VI. DIVERSION AND CONVEYANCE SYSTEMS

6.1 General

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

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

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

6.2 Procedural Guide

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

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

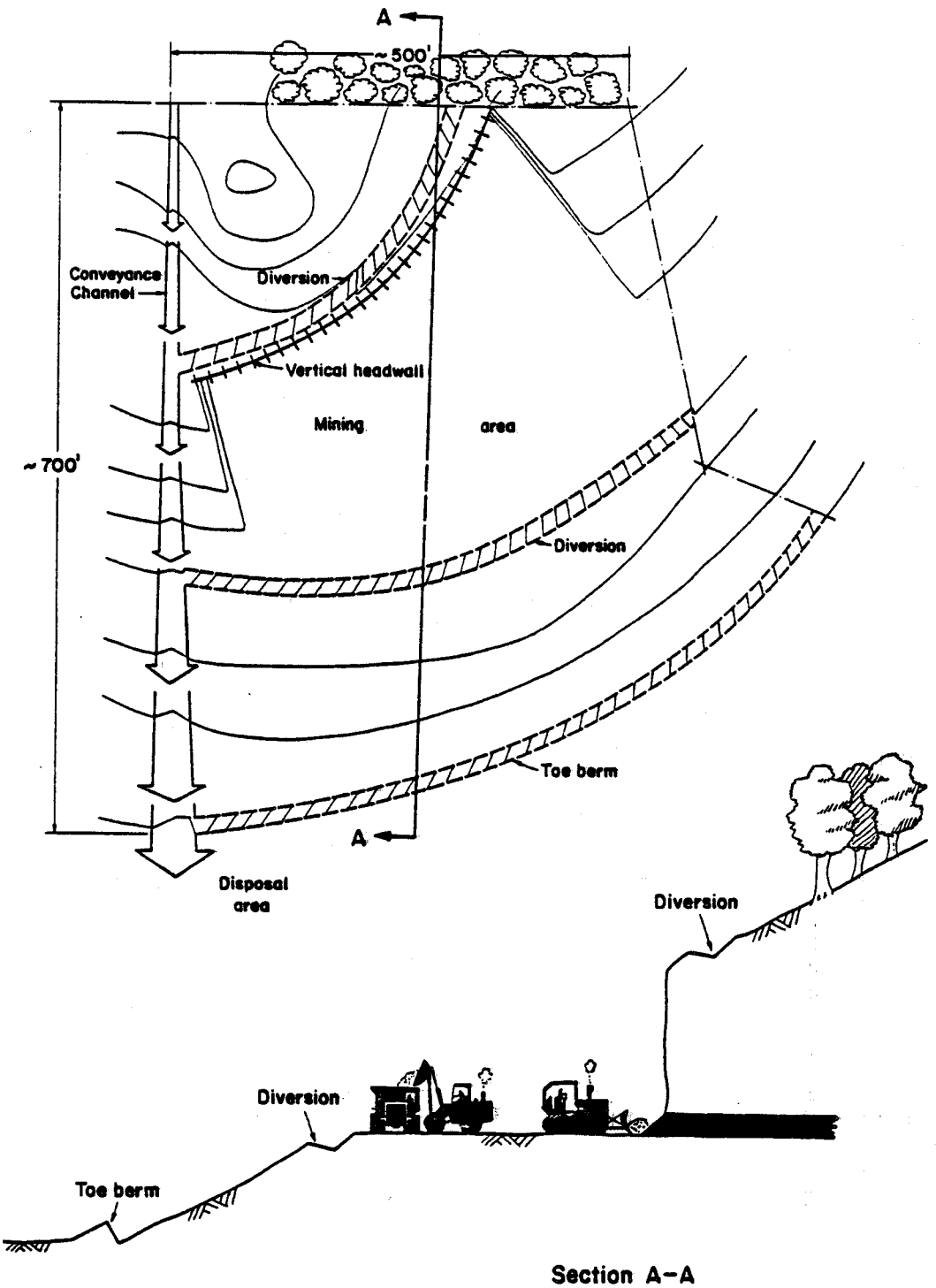


Figure 6.1. Typical mine site.

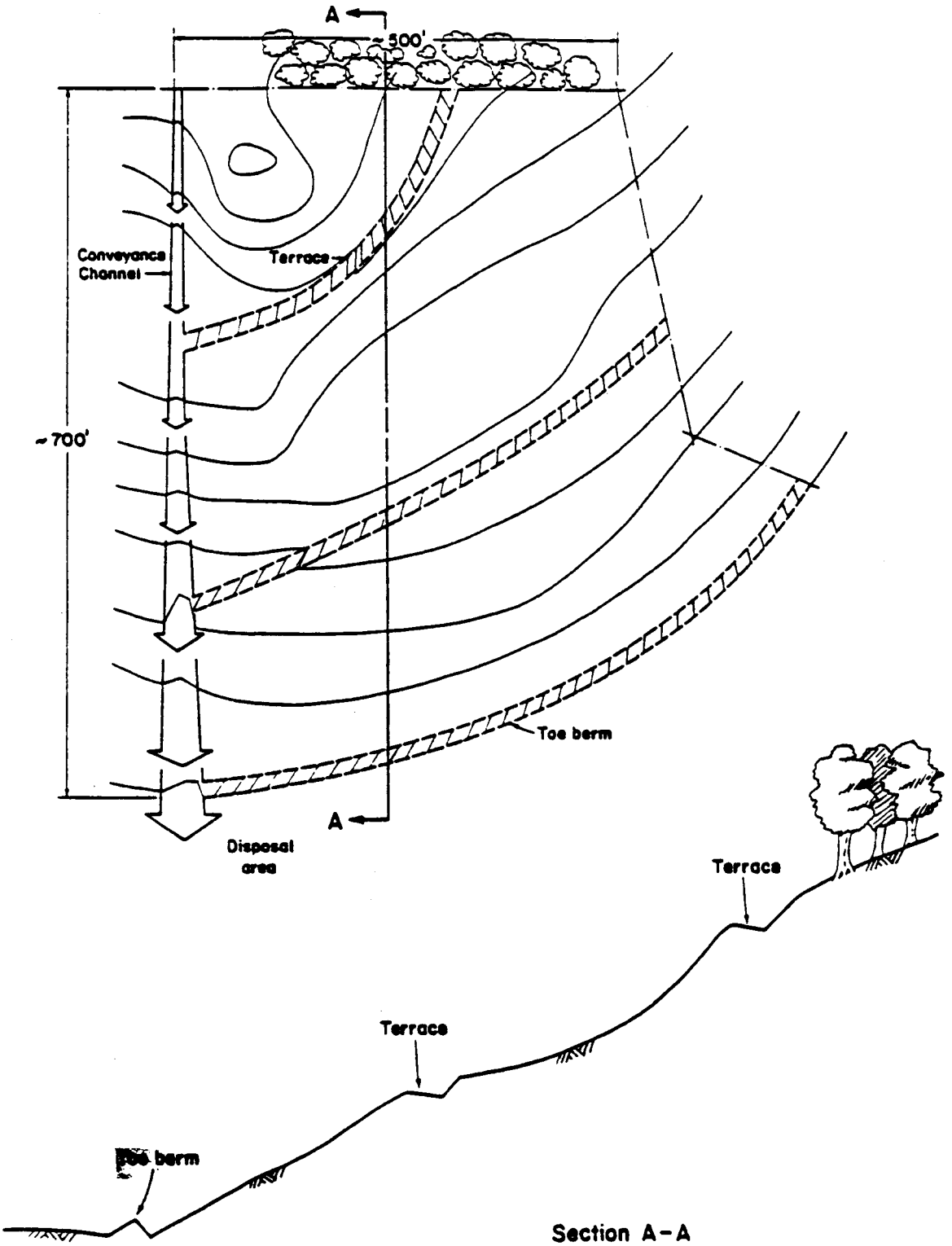


Figure 6.2. Typical reclaimed mine site.

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

Design Steps for Diversion and Conveyance Channels

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

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

Step 1: Determine Water and Sediment Delivery to Channel

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

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

Step 2: Estimate Required Channel Slope

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

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

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

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

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

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

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

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

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

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

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

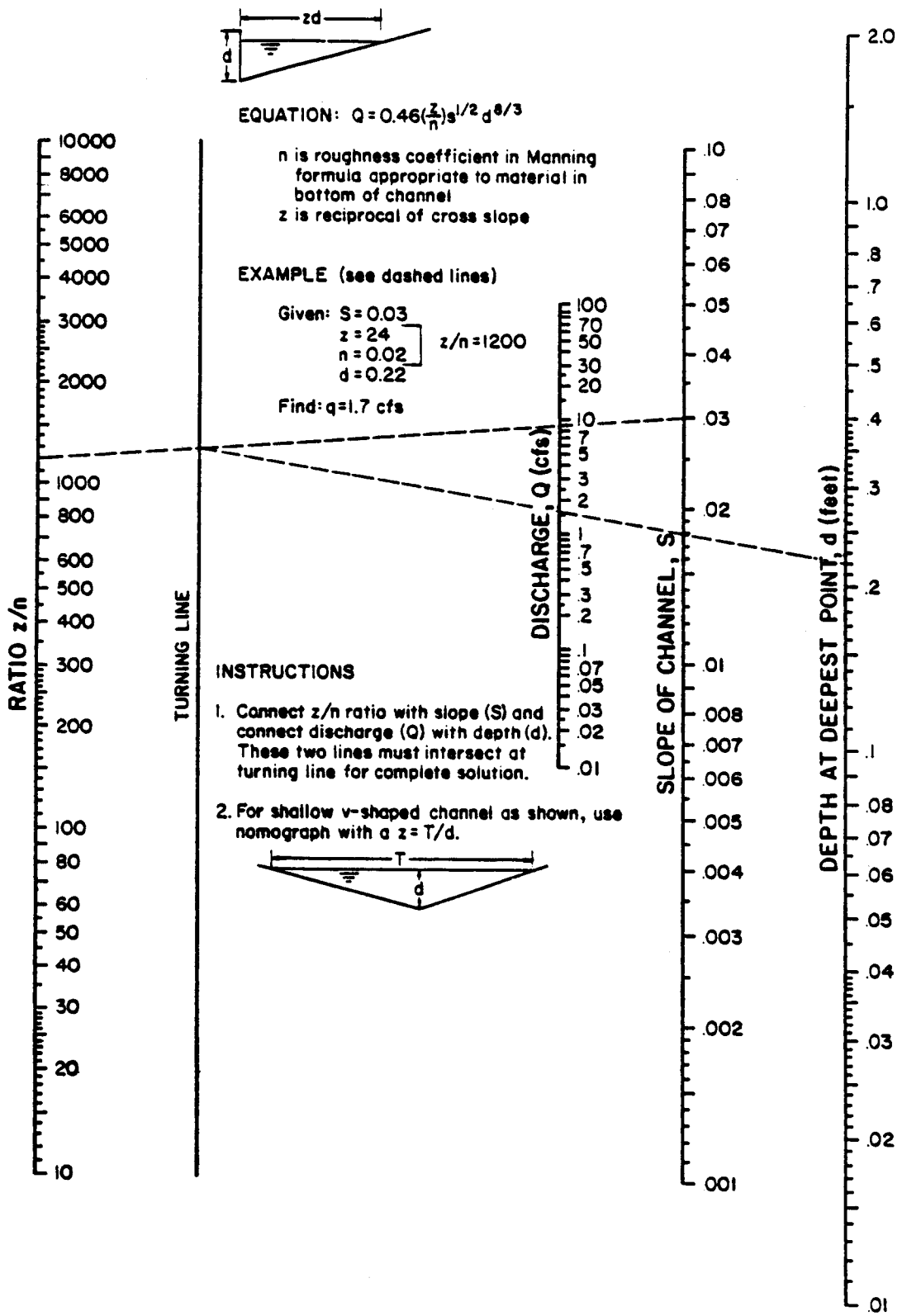
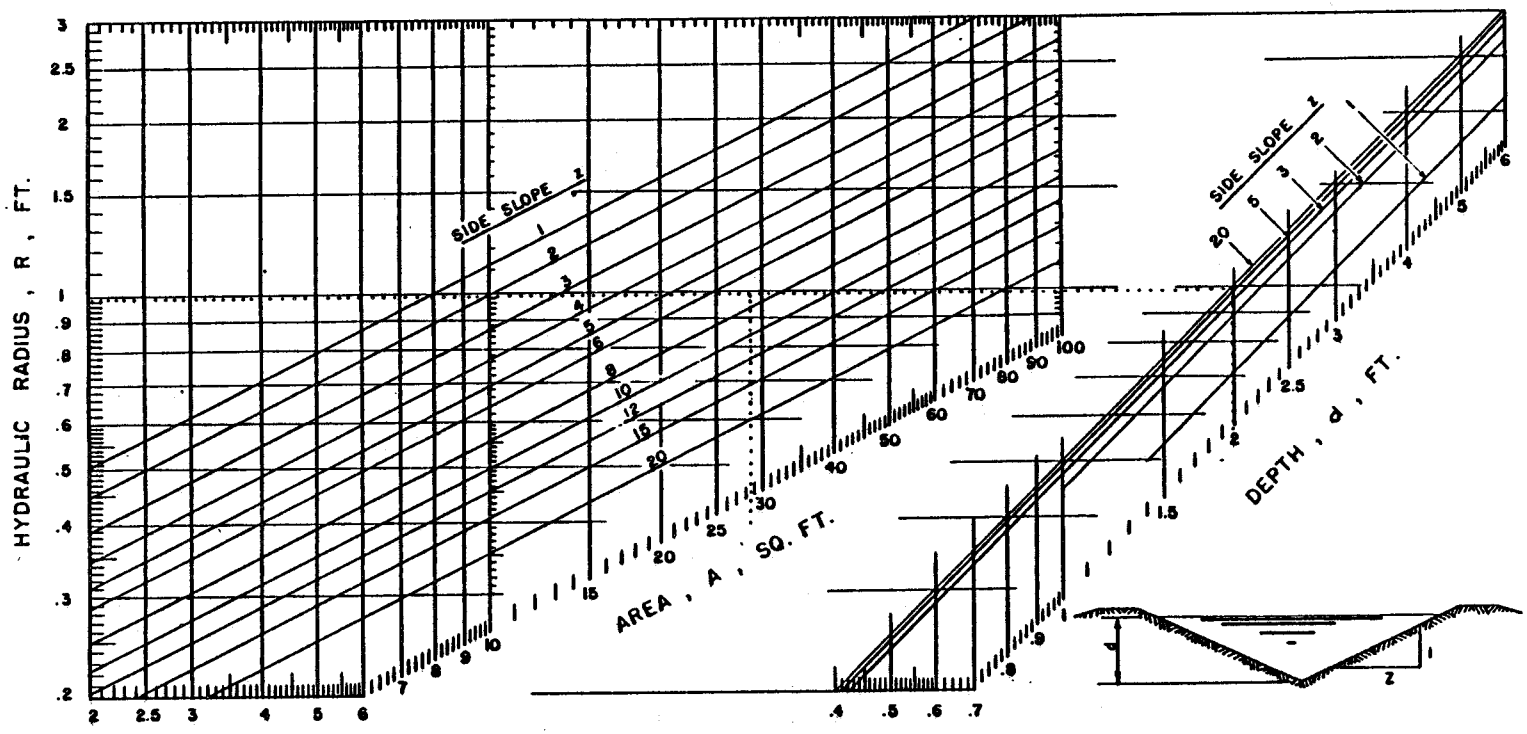


Figure 6.3. Nomograph for flow in triangular channels (from Simons, Li & Associates, Inc., 1982).



where: $A = zd^2$

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

$T = 2dz$

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

Table 6.1. Manning Roughness Coefficients, n.

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

Table 6.1. (continued)

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

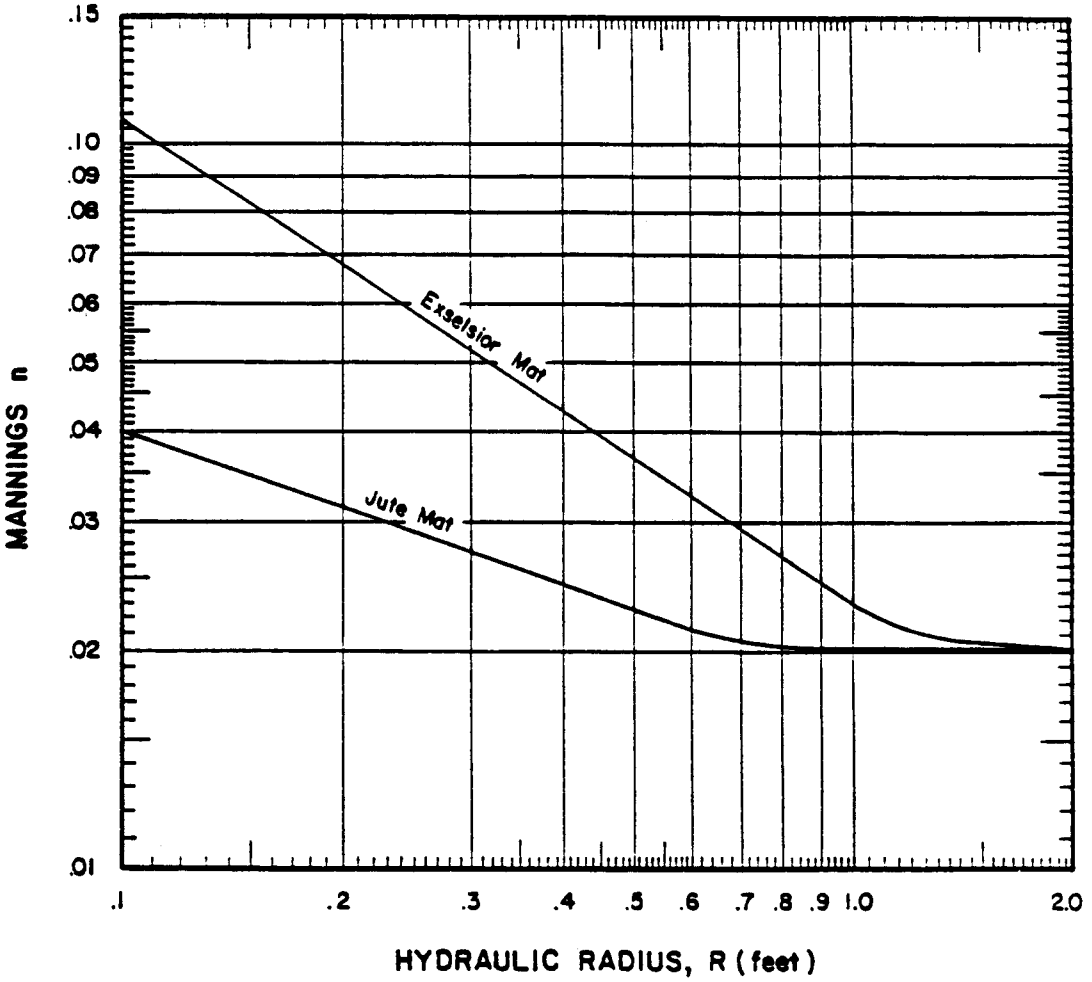


Figure 6.5. Manning's roughness coefficient versus hydraulic radius for manufactured channel linings (from Simons, Li & Associates, Inc., 1982).

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

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

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

Table 6.2. (Continued)

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

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

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

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

Step 4: Determine Sediment Transport Capacity

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

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

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

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

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

Step 5: Determine Sediment Yield

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

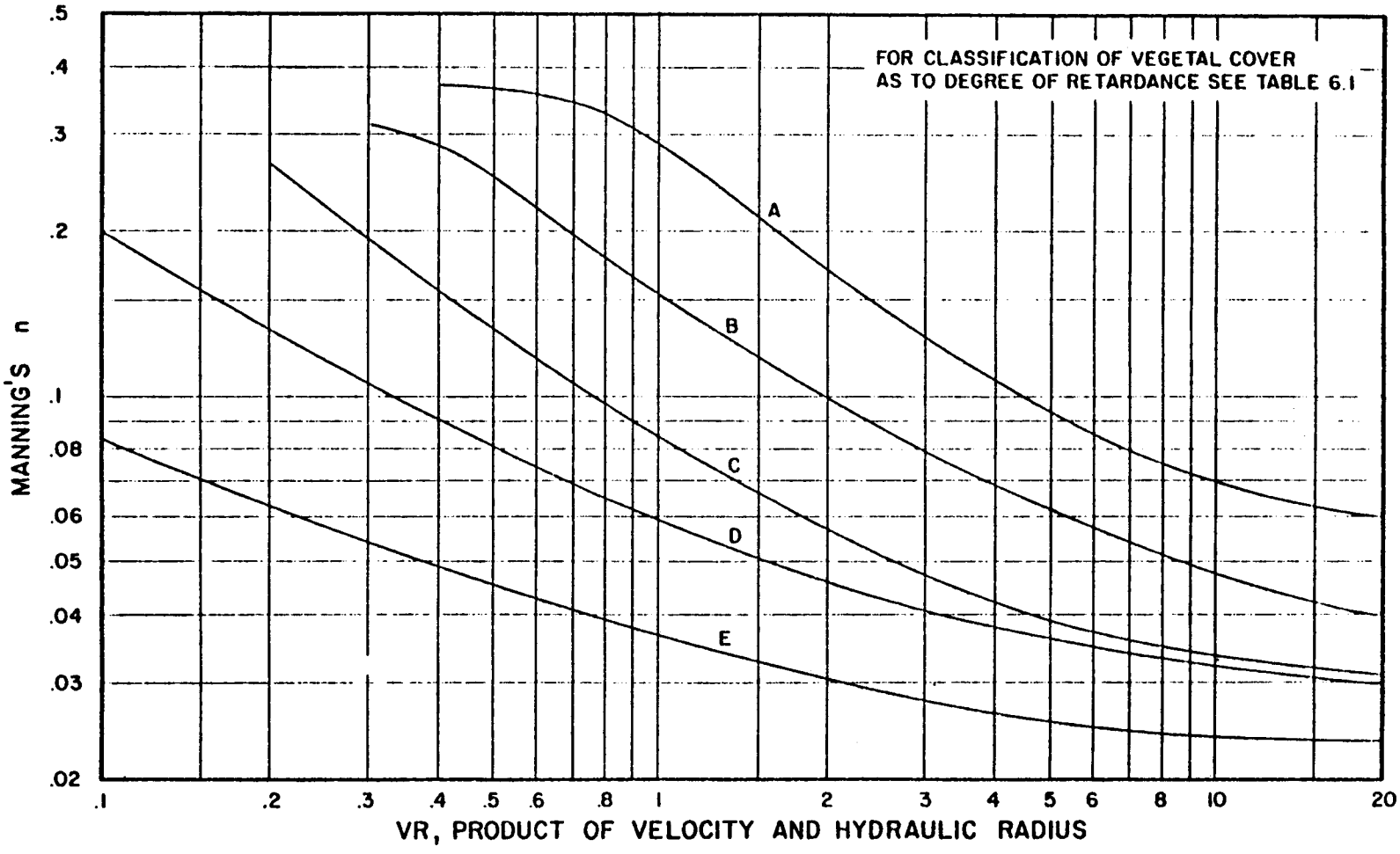


Figure 6.6. Manning's n for vegetal-lined channels (from handbook of channel design for soil and water conservation SCS-TP-61 revised June 1964).

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

Worksheet 6.1. Step Three worksheet.

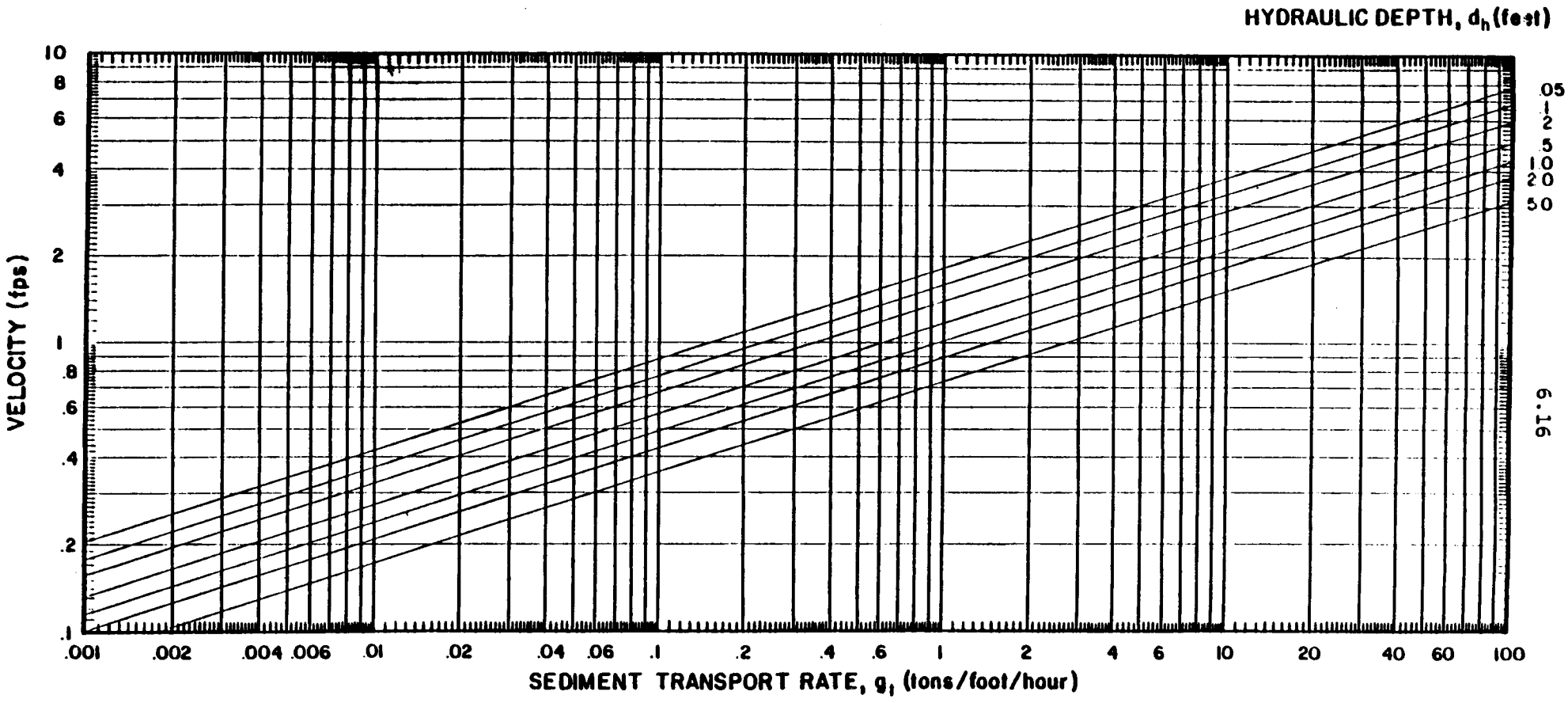


Figure 6.7. Sediment transport capacity for silt (0.002 mm - 0.05 mm) (from Simons, Li & Associates, Inc., 1982).

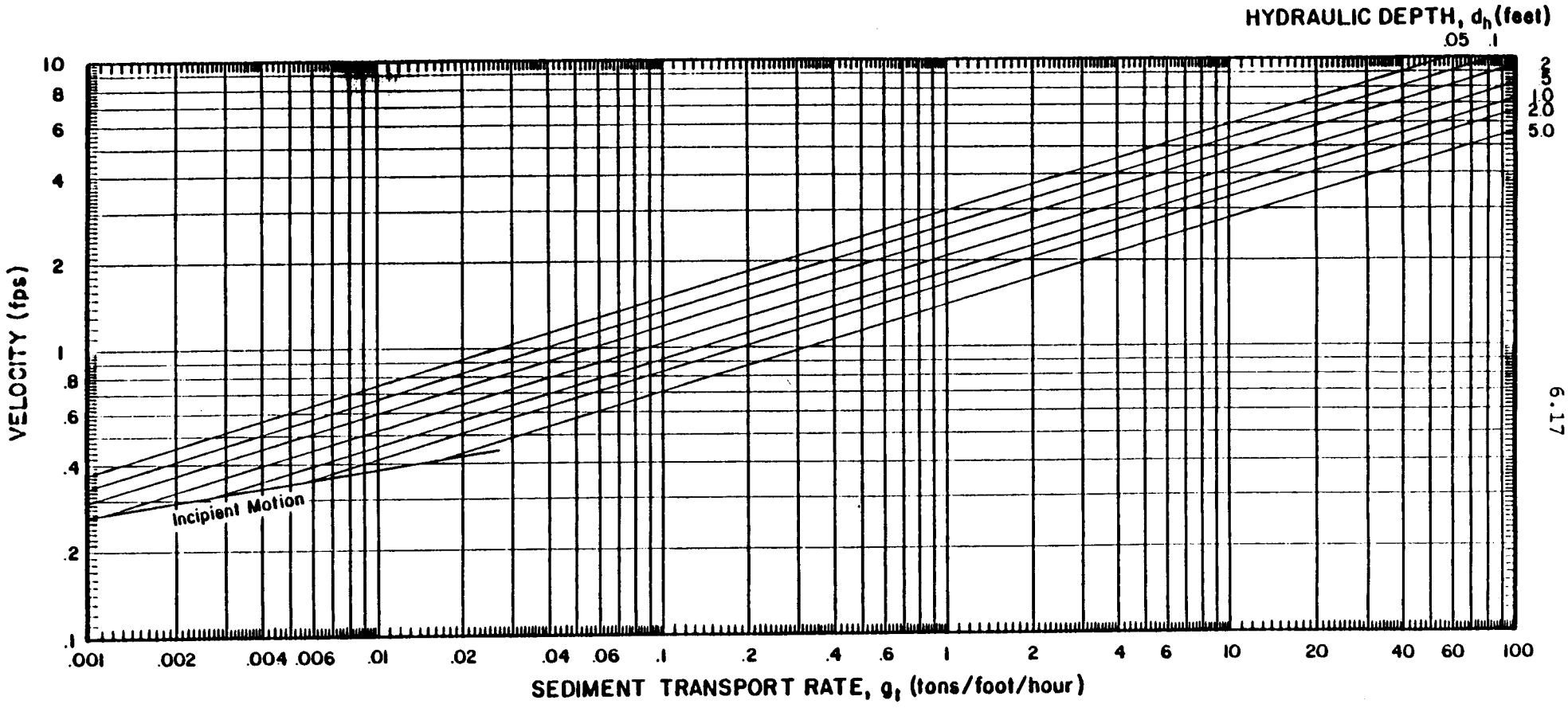


Figure 6.8. Sediment transport capacity for very fine sand (0.05 mm - 0.1 mm) (from Simons, Li & Associates, Inc., 1982).

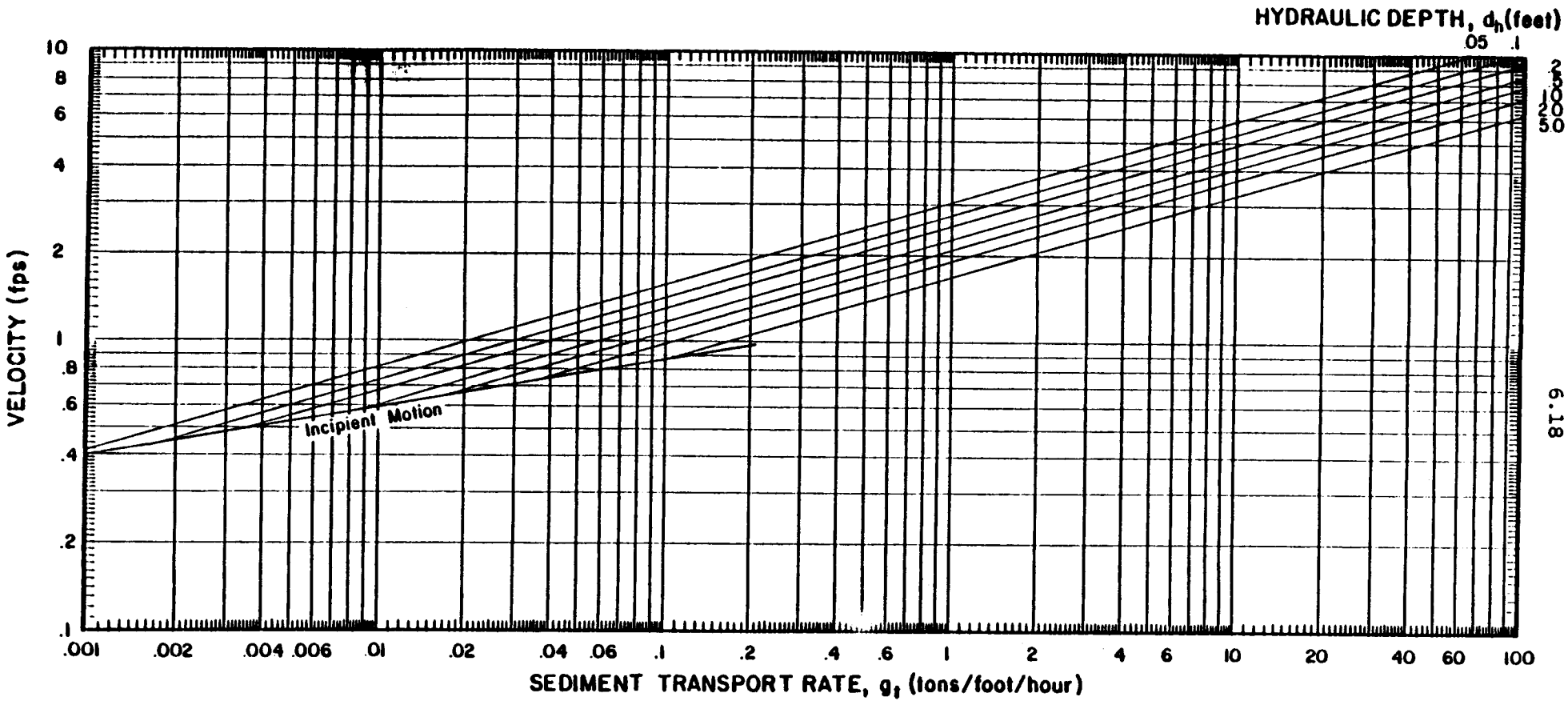


Figure 6.9. Sediment transport capacity for fine, medium and coarse sand (0.1 mm - 1.0 mm)(from Simons, Li & Associates, Inc., 1982).

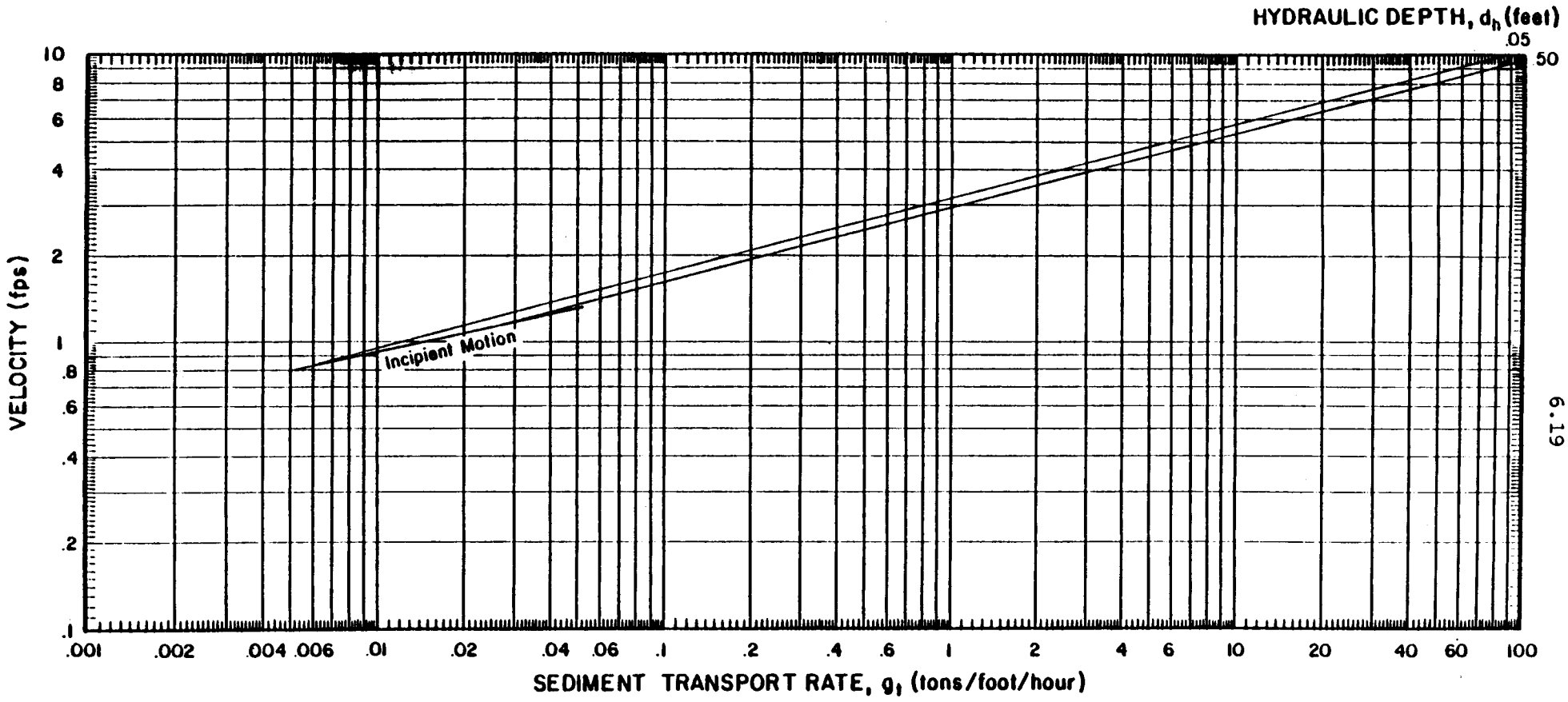


Figure 6.10. Sediment transport capacity for very coarse sand (1.0 mm - 2.0 mm)(from Simons, Li & Associates, Inc., 1982).

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

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

Worksheet 6.2. Step Four worksheet.

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

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

and

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

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

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

G_y = sediment yield from the channel, tons.

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

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

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

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

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

where: L_d = structure length, feet

V = flow velocity, ft/sec

d_h = hydraulic depth, feet

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

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

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

p_s (see Figure 6.11)

Worksheet 6.3. Step Five worksheet.

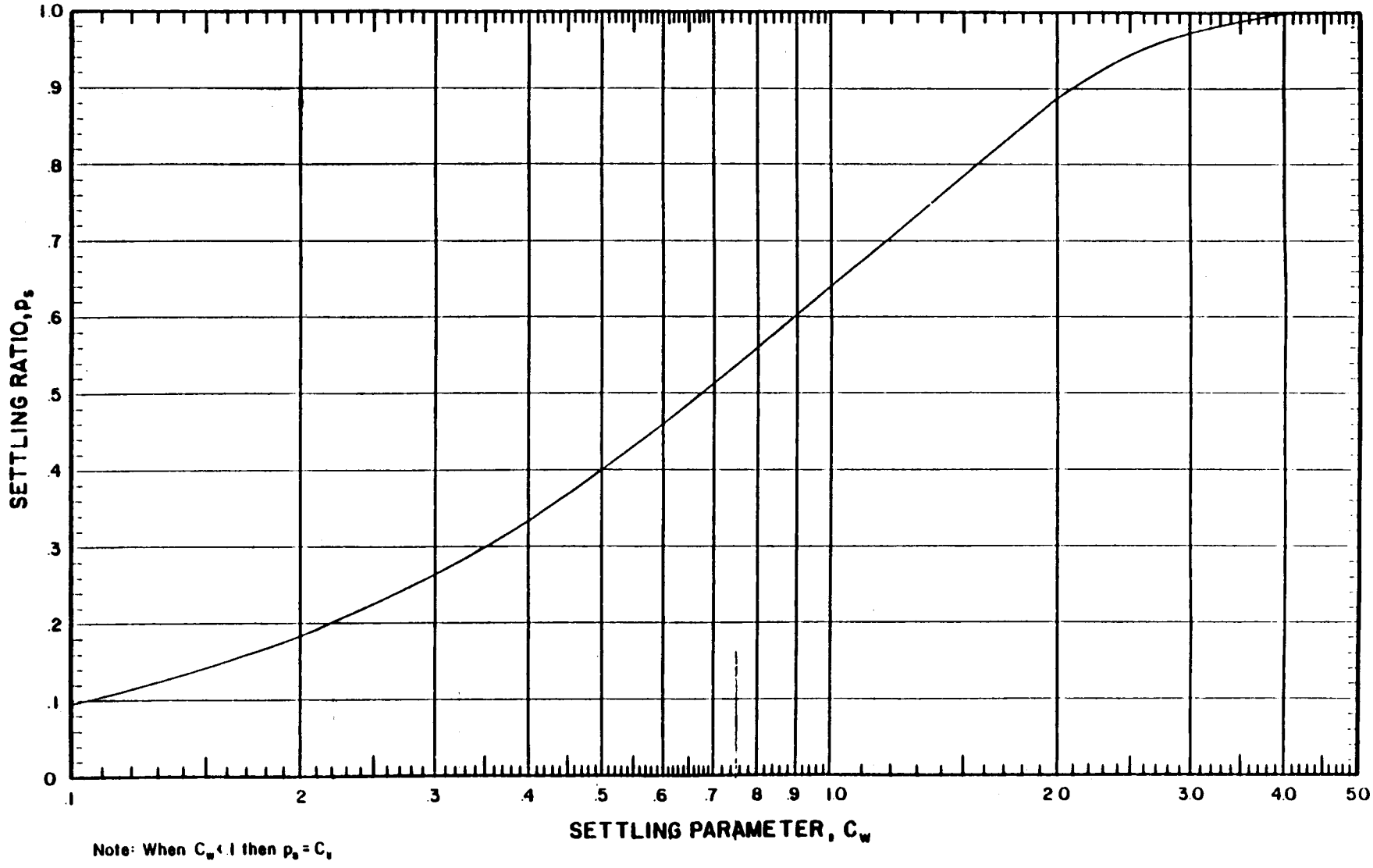


Figure 6.11. Settling ratio versus settling parameter (from Simons, Li & Associates, Inc., 1982).

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

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

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

Step 6: Compute the Deposition Depth

The volume of deposition can be determined by the relation:

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

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

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

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

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

Step 7: Size the Channel

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

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

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

Stable Channel Design

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

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

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

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

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

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

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

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

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

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

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

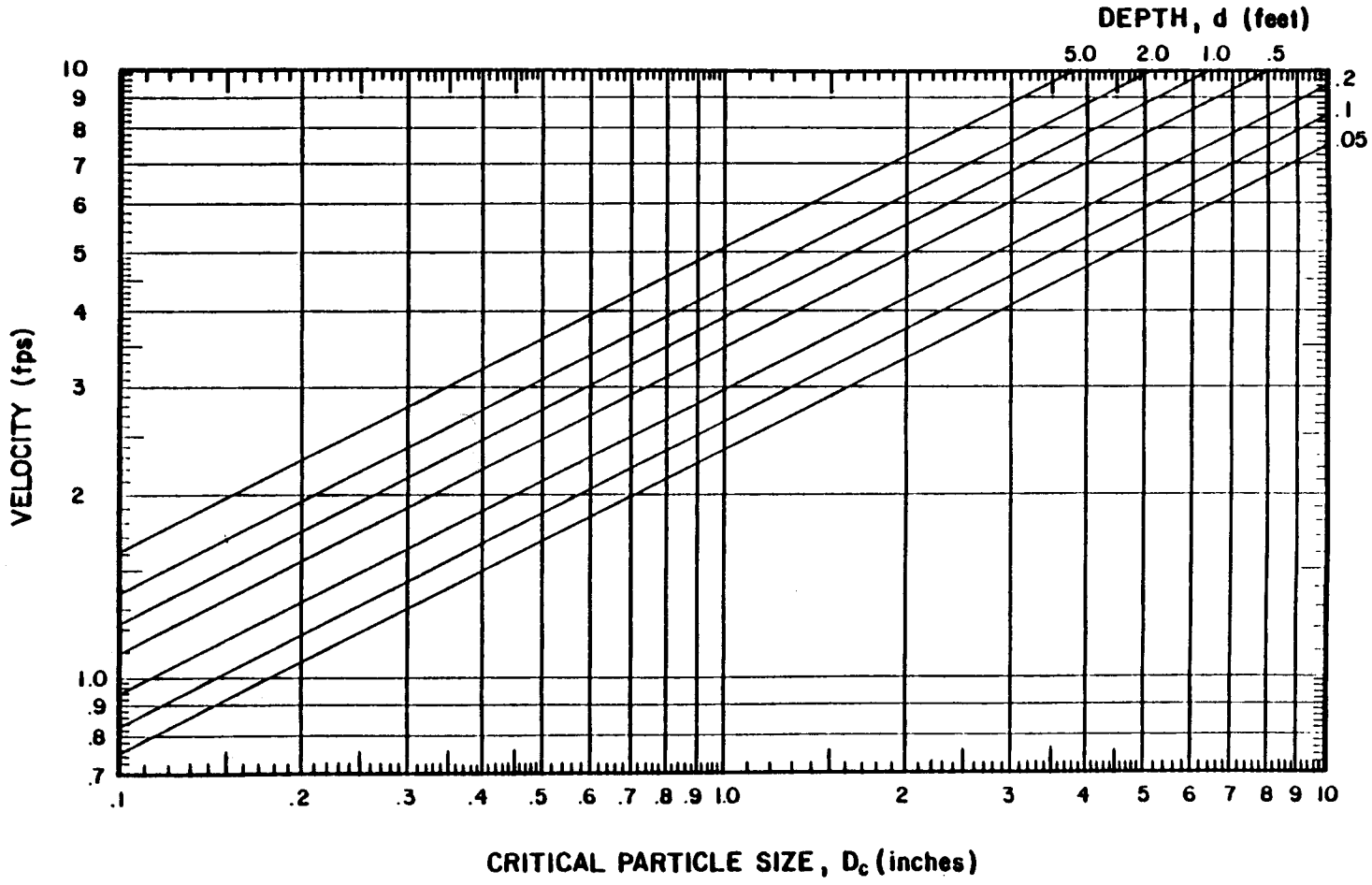


Figure 6.12. Critical particle size versus velocity and depth (from Simons, Li & Associates, Inc., 1982).

Table 6.3. Coarse Aggregate Gradation Table.

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

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

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

6.3 Planning and Design Information

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

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

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

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

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

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

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

Diversions

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

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

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

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

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

Conveyance Channel

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

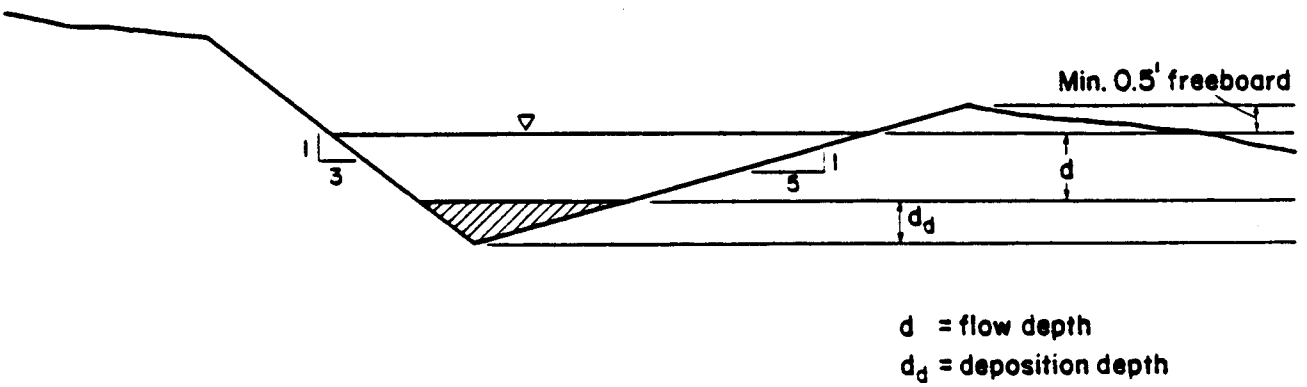


Figure 6.13. Typical diversion channel.

this application.

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

Grade control

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

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

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

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

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

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

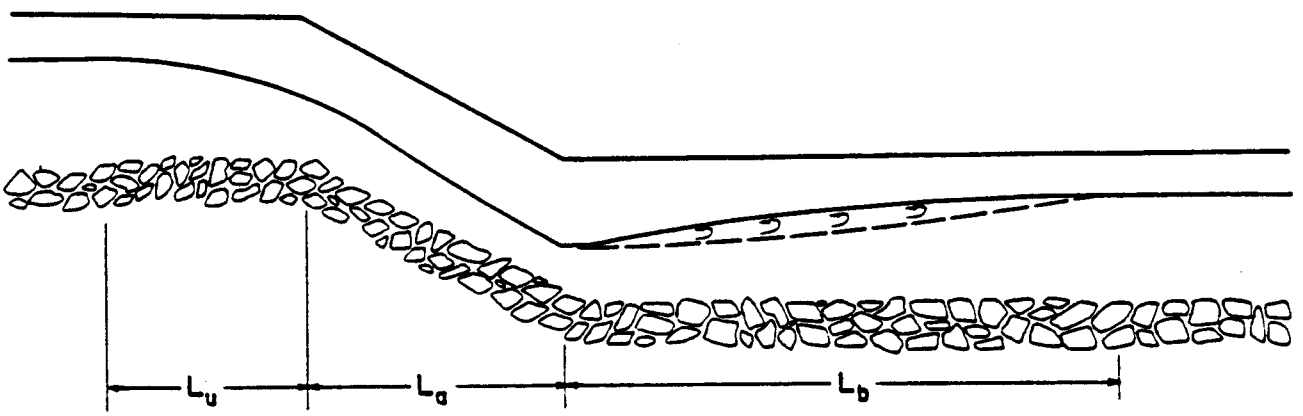


Figure 6.14. Definition sketch for a riprap drop structure.

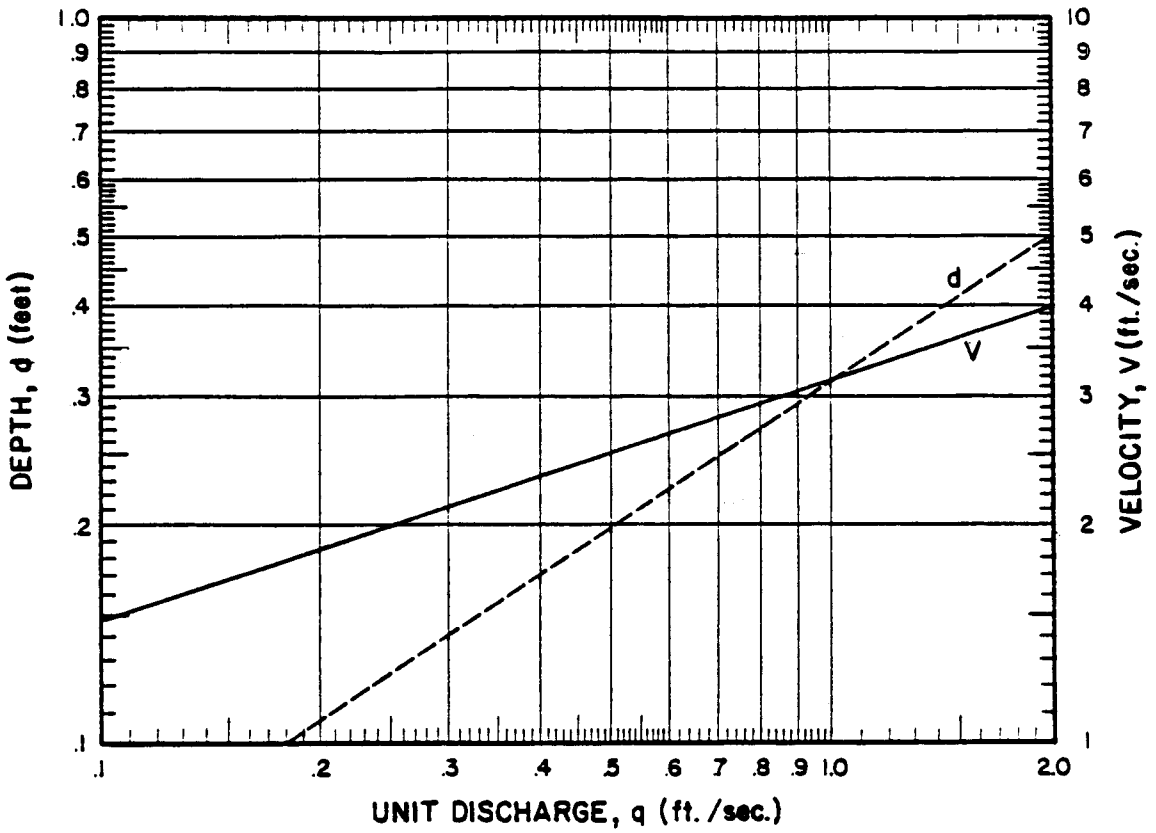
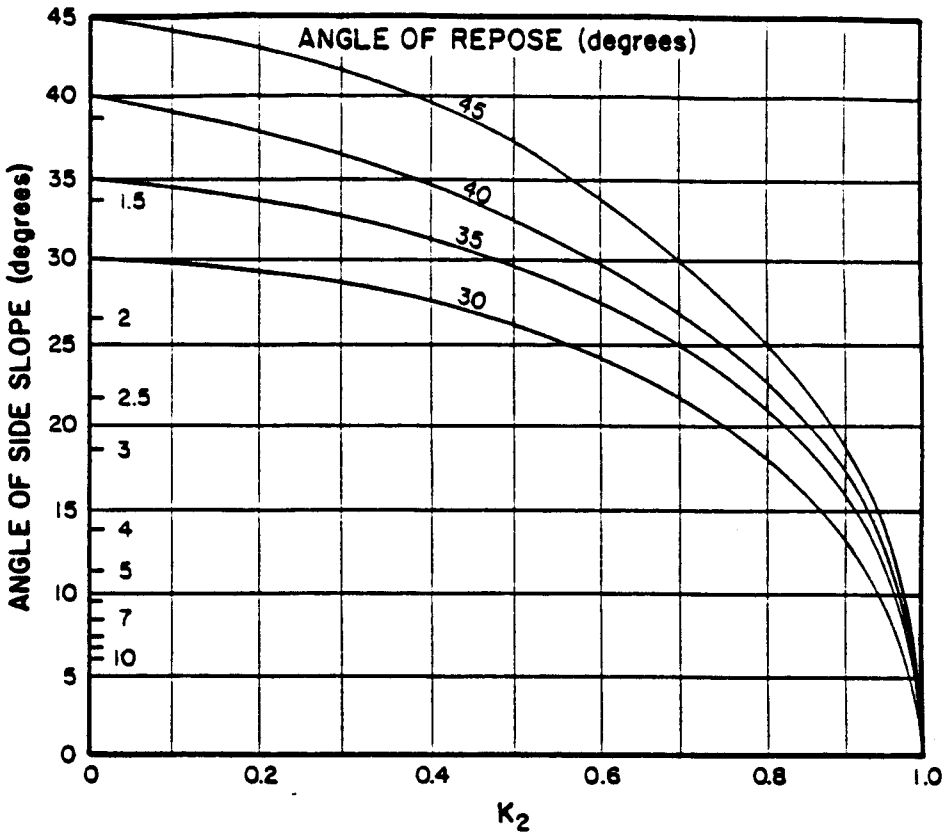


Figure 6.15. Critical flow (from Simons, Li & Associates, Inc., 1982).



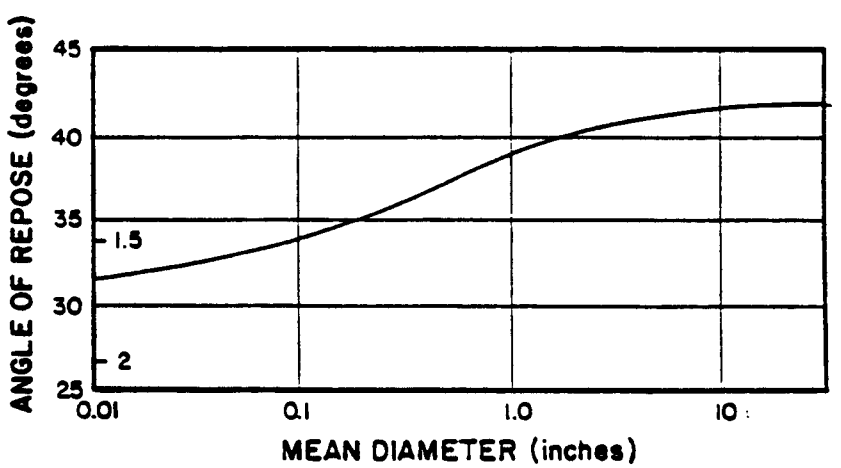


Figure 6.16. Graphs of angle of repose for riprap stones and ratio of critical shear on sides to critical shear (after Simons, 1957).

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

6. Maximum drop height should not exceed 2 feet.

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

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

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

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

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

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

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

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

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

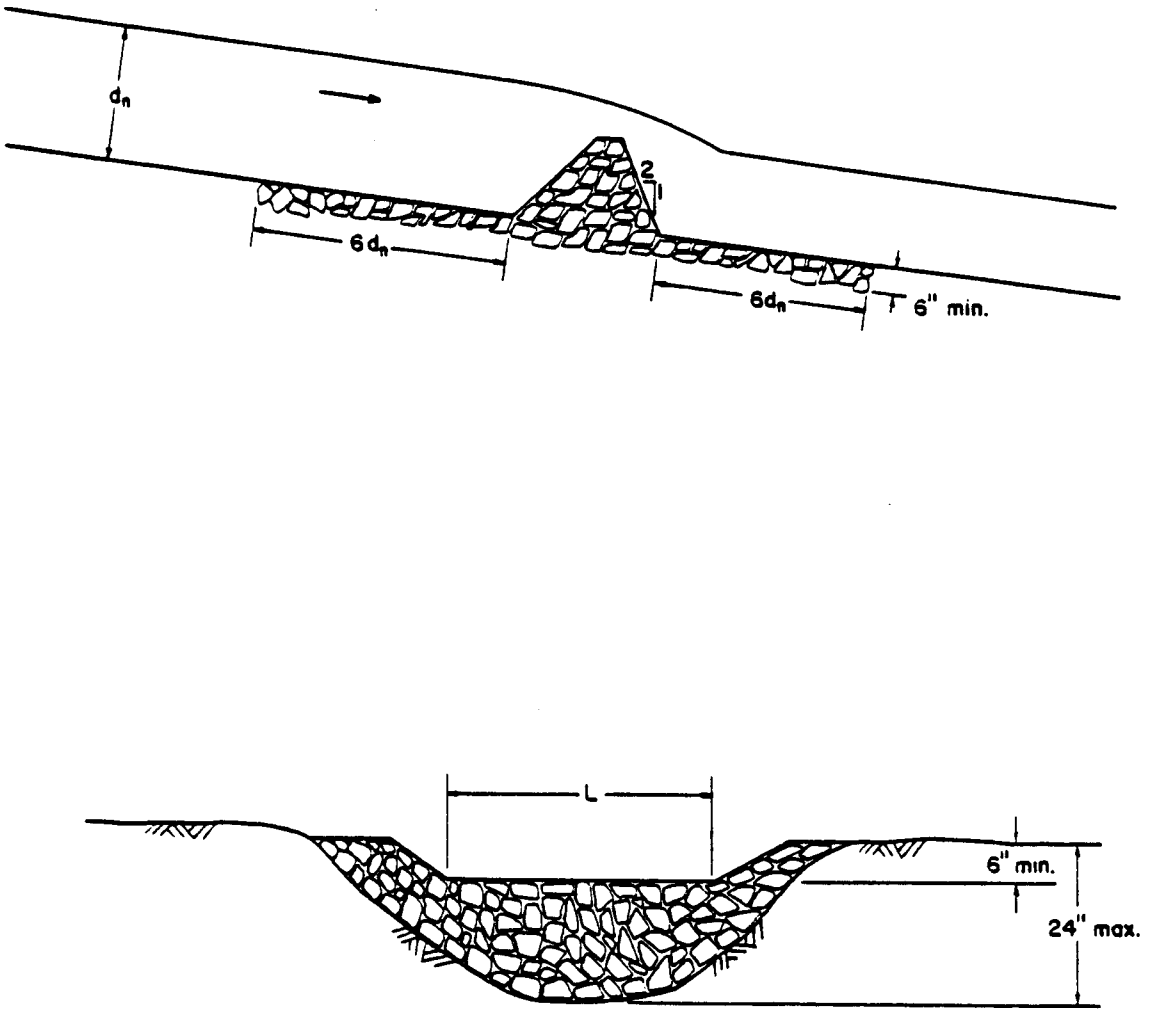


Figure 6.17. Rock check dam definition sketch.

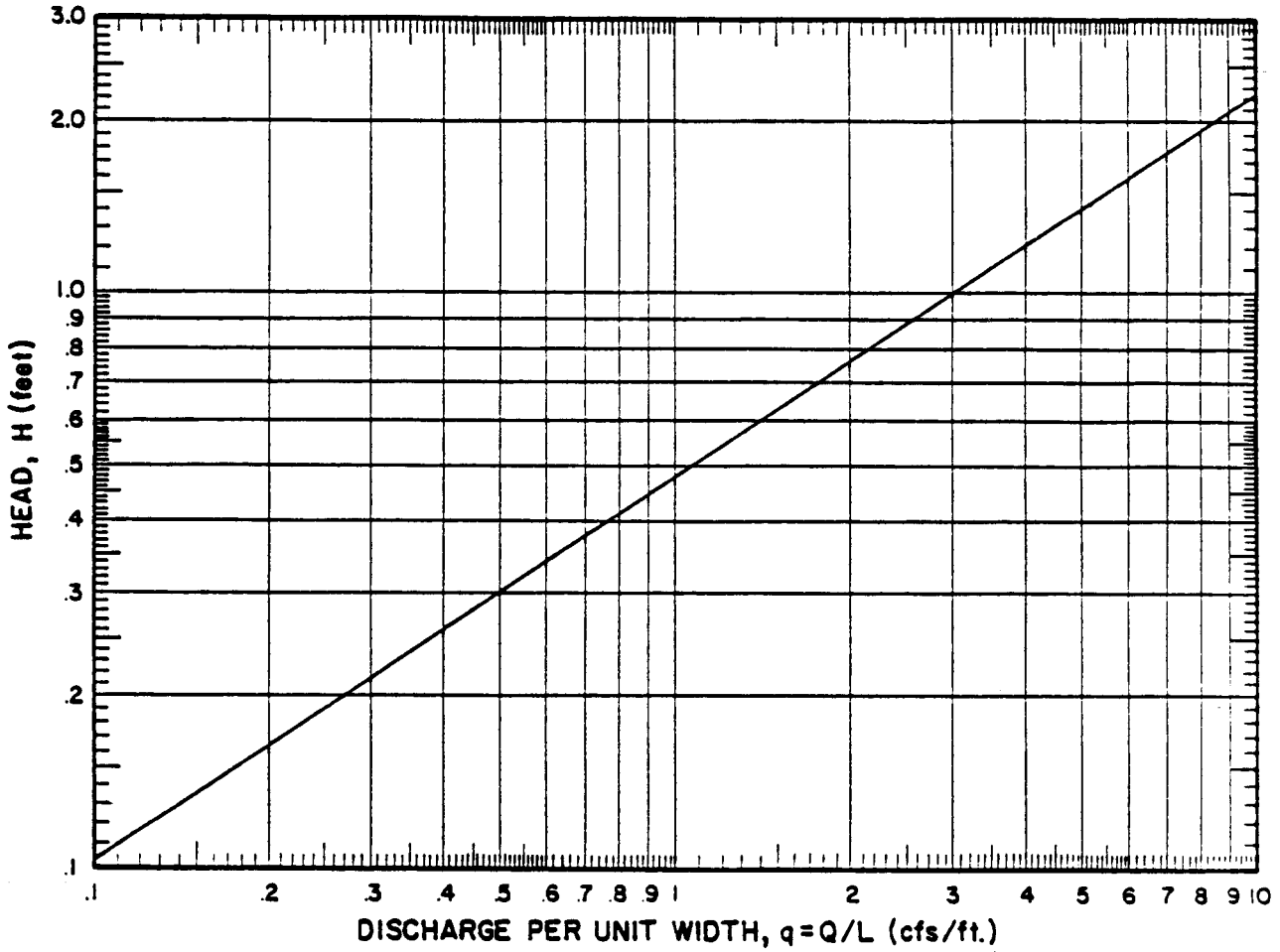


Figure 6.18. Plot of weir equation $Q/L = CH^{2/3}$ where C = 3.0 (from Equation 6.6) (from Simons, Li & Associates, Inc., 1982).

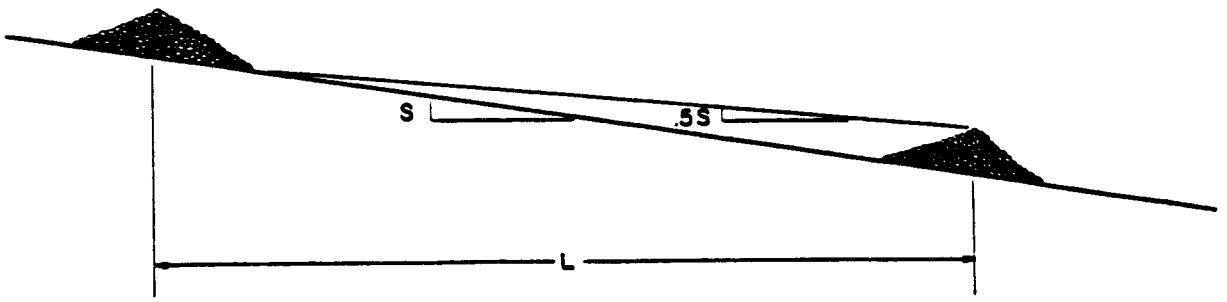


Figure 6.19. Spacing between check dams.

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

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

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

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

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

6.4 In-Service Performance

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

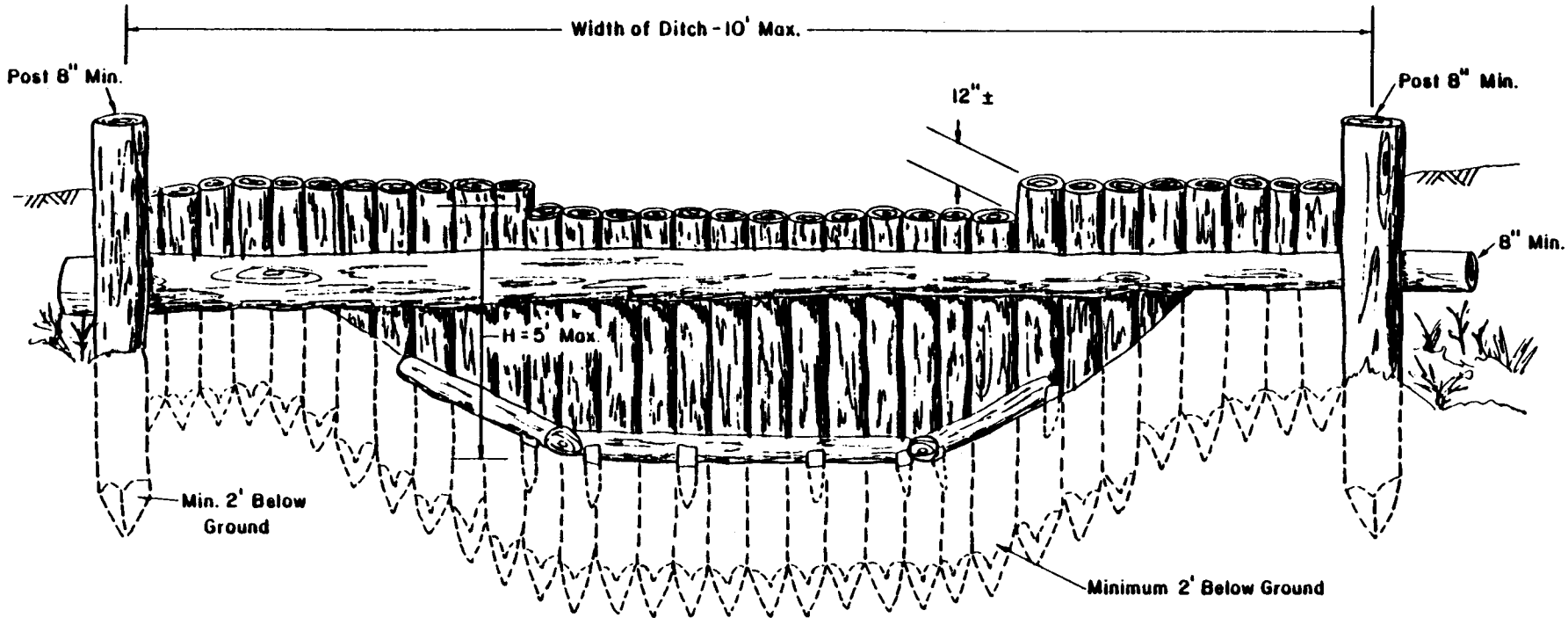


Figure 6.20. Log and brush check dam.

6.5 Example Problems

Example 6.1

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

Required input data for the terrace design are summarized below.

Particle Size Distribtuion

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

Area of mine site: 10 acres.

Solution:

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

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

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

Storm hydrograph:

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

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

Sediment supply to terrace from overland flow:

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

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

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

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

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

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

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

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

Example Problem 6.1. Step Three Worksheet.

Step Four: Determine the Sediment Transport Capacity.

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

Step Five: Determine the Sediment Yield.

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

The average sediment concentration is:

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

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

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

INFLOW HYDROGRAPH TO EACH TERRACE

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

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

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

Example Problem 6.1, Step Four Worksheet.

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

Example Problem 6.1. Step Five Worksheet.

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

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

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

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

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

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

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

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

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

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

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

Step Six: Compute the Deposition Depth

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

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

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

The deposition depth is

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

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

Step Seven: Channel Size.

The design depth of the terrace cross section is

$$d_c = 0.95 + 0.56 + 0.5$$

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

Use 2.0 feet as the design depth for the terrace.

Discussion of Example Problem 6.1

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

Example Problem 6.2

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

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

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

INFLOW HYDROGRAPH

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

SEDIMENT INFLOW

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

Step Two: Estimate Channel Slope.

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

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

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

Step Four: Determine the Sediment Transport Capacity.

See Step Four Worksheet.

Step Five: Determine the Sediment Yield.

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

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

Stable Channel Design

Step One: Compute Velocity and Depth for Maximum Discharge.

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

$V = 4.73$ ft

$d = 0.79$ ft

Step Two: Determine the Critical Particle Size.

From Figure 6.12,

$D_c = 1.6$ inches

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

Example Problem 6.2. Step Three Worksheet.

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

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

Example Problem 6.2. Step Four Worksheet.

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

Example Problem 6.2. Step Five Worksheet.

Step Three: Select an Available Coarse Aggregate.

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

Step Four: Determine the Required Thickness of the Lining.

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

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

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

$$= 4.64 \text{ inches}$$

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

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

Step Six: Compute the Deposition Depth.

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

Step Seven: Channel Size.

The design depth of the conveyance channel is

$$d_c = 0.79 + 0.0 + 0.5$$

$$= 1.29 \text{ ft}$$

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

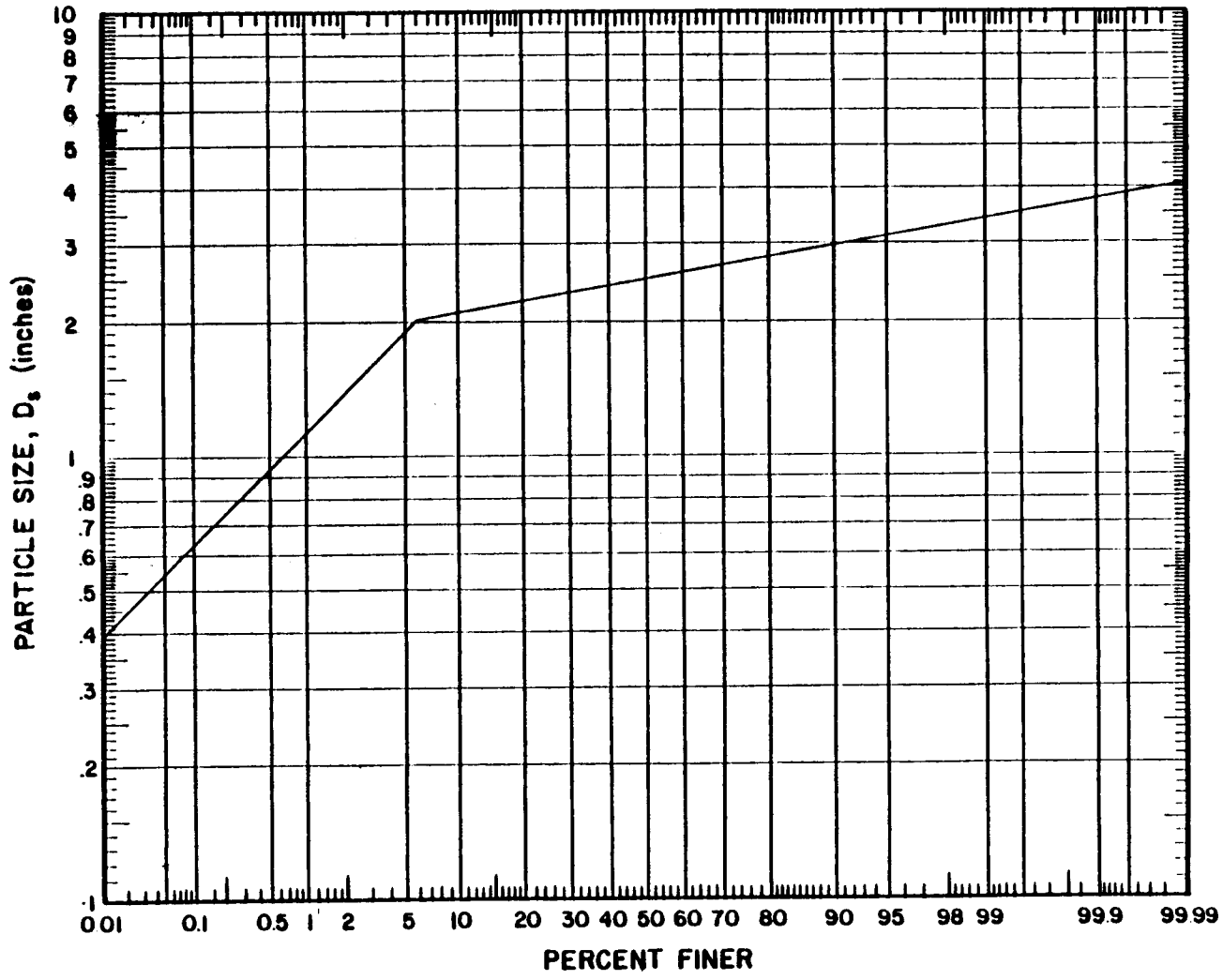


Figure 6.21. Aggregate mix particle size distribution.

6.6 Specifications

Specifications - Aggregate Channel Lining

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

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

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

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

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

Payment will be made under:

PAY ITEM	PAY UNIT
Aggregate Channel Lining	Ton

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

Specifications - Excavation and Embankment for Channels

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

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

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

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

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

Payment will be made under:

PAY ITEM	PAY UNIT
Excavation	Cubic Yard
Embankment	Cubic Yard

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

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

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

Specifications - Haul

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

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

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

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

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

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

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

6.7 References

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