Technical Reclamation Memorandum

TRM # 10

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Division of Reclamation Services

Kentucky Department for Surface Mining Reclamation and Enforcement

Subject: Sediment Pond Design Guideline-Procedures for Hand Calculators

Attached is the department's <u>Sediment Pond Design Guideline-Procedures for Hand Calculators</u>. This design guideline employs simple equations and graphical relationships to enable an engineer with the aid of a hand calculator to design a sediment pond to meet the settleable solids effluent limitation and to size an emergency spillway to control storm runoff. Worksheets covering all essential steps in the sediment pond design process have been included to provide a convenient means of organizing computations. An example sediment pond design has been provided to illustrate use of the procedures and worksheets.

The principal spillway routing and settleable solids prediction relationships have been programmed for a Hewlett-Packard HP-41CV hand calculator. This program can provide a significant reduction in the time required to perform the iterative calculations associated with locating and sizing a principal spillway.

This guideline is the result of an intensive effort by the department to provide engineers serving the coal mining industry with procedures for designing sediment ponds which do not require a computer. Questions concerning the contents of this guideline should be directed to Richard Rohlf or John Drake at (502) 564-2356.

Because of the department's commitment to release a simplified approach at the earliest possible date, it has not been possible to include "dugout ponds" and a wider variety of spillway configurations in this guideline. However, the department considers this guideline an important first step in the development of a comprehensive handbook of sediment control practices for surface coal mining operations. The department hopes to complete the comprehensive handbook within the next few months. The procedures contained in this guideline will continue to be acceptable under the handbook.

SEDIMENT POND DESIGN GUIDELINE - PROCEDURES FOR HAND CALCULATORS

COMMONWEALTH OF KENTUCKY

NATURAL RESOURCES AND ENVIRONMENTAL PROTECTION CABINET

Department for Surface Mining Reclamation and Enforcement

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Introduction

The Kentucky Permanent Program Regulations require (1) that sediment ponds provide sufficient sediment storage volume and detention time so that discharges from the pond will meet applicable effluent limitations, and (2) that an appropriate combination of principal and emergency spillways be provided to handle a 25-year or 100-year, 24 hour precipitation event (405 KAR 16:090 and 18:090; Sections 2, 3, and 5). This design guideline employs simple equations and graphical relationships to enable an engineer with the aid of a hand calculator to design a sediment pond to meet the settleable solids effluent limitation and to size an emergency spillway to control storm runoff. This guideline addresses only pond sizing requirements for meeting the settleable solids effluent limitation and for controlling storm runoff and does not consider other design requirements contained in 405 KAR 16:090 or 18:090.

Most of the material contained in this guideline has been adapted from existing hydrologic and pond design procedures. The guideline assumes that the user is basically familiar with the fields of hydrology and hydraulics as they pertain to sediment pond design. Those desiring additional explanation beyond that contained in this guideline may consult <u>Applied Hydrology and Sedimentology for Disturbed Areas</u> by Barfield, Warner, and Haan or other references cited in the guideline.

The department has attempted to make this guideline as flexible as possible while providing procedures which can be used with a hand calculator. In some cases, procedures contained in this guideline can be eliminated without significantly affecting the size or predicted performance of the sediment pond. Applicable short-cut procedures are discussed in subsequent sections.

Application of these design procedures should be limited to embankment sediment ponds with (1) a conduit and riser or trickle tube principal spillway and (2) a maximum embankment height of 20 feet (measured from the upstream toe to the crest of the emergency spillway). These design procedures are not applicable to dugouts with open spillways. Specific technical limitations associated with procedures used in this guideline are discussed in appropriate sections.

Steps contained in the sediment pond design process include (1) selection of sub-watersheds, (2) determination of peak discharge and runoff volume, (3) determination of sediment load, (4) principal spillway design, and (5) emergency spillway design. The following sections contain a more detailed description of each of the design steps.

Design Step 1 - Selection of Sub-watersheds

Due to the non-linear nature of rainfall-runoff and erosion relationships, watersheds which exhibit a wide range in watershed characteristics should be divided into sub-watersheds having uniform runoff and erosion characteristics. The selection of sub-watersheds should be based primarily on (1) land slope; (2) subsurface soil conditions (disturbed, undisturbed, soil type); and (3) surface cover (bare, partially vegetated, fully vegetated). For the prediction of peak discharge, soil type and surface cover conditions are measured by the SCS runoff curve number (CN). For the calculation of sediment load, soil type and surface cover conditions are measured by the Universal Soil Loss Equation soil erodibility (K) and control practice (CP) factors. The determination of peak discharge and sediment load are described in the next two sections. The user should be familiar with range of soil type and surface cover conditions described by the CN, K, and CP parameters to have an adequate background for selecting sub-watersheds.

Watershed characteristics (CN and CP factors) representative of a "worst-case"condition should be assumed in selecting sub-watersheds for designing a sediment pond. A "worst-case" condition is one which produces a maximum amount of runoff and erosion. Depending on the mining and reclamation schedule, a "worst-case" condition may contain several different surface conditions including areas which have been (1) cleared and grubbed, (2) mined, (3) backfilled and graded, (4) seeded and mulched, or (5) in some stage of vegetation. Dividing the sediment pond drainage area into sub-watersheds allows the design engineer to evaluate the effects of timely reclamation, diversions, terraces, and other runoff and erosion control practices which can reduce the size of the sediment pond.

Design Step 2 - Determination of Peak Discharge and Runoff Volume (Worksheets 1 and 2)

Peak discharges are first calculated for each sub-watershed and then combined to produce a peak inflow for the pond. Peak discharge can be expressed as a function of time of concentration, travel time, rainfall excess, and drainage area. For steep slope watersheds with a drainage area less than 40 acres, time of concentration and travel time generally have an insignificant effect, and the peak discharge can be expressed as a function of rainfall excess and drainage area only. In steep slope areas where the watershed drainage area is larger than 40 acres, it will generally be necessary to include time of concentration in calculating the sub-watershed peak discharge and to calculate the watershed peak discharge by combining sub-watershed discharges using the graphical routing procedures discussed in this section. As the slope of the watershed decreases, time of concentration and travel time will increase for a given drainage area and, thus, become more significant factors in computing peak discharge. Time of concentration and travel time will generally be insignificant factors in computing peak discharge and settleable solids for any watershed in which the maximum combined time of concentration and travel time is less than 0.150 hours. The design engineers should evaluate the range of time of concentration and travel time values which will occur for a particular watershed configuration and determine if it is necessary to use these parameters in computing peak discharge. A maximum sub-watershed combined time of concentration and travel time less than 0.150 hours may be used as a criterion for not including these parameters.

Peak sub-watershed discharge

The peak sub-watershed discharge for steep slope watersheds with a drainage area greater than 40 acres (any watershed with a maximum sub-watershed combined time of concentration and travel time greater than 0.150 hours) can be calculated from (Soil Conservation Service, 1975):

$$Q_p = (q_u Q A)/640 \qquad (1)$$

where Q_p is the peak discharge in cubic feet per second, q_u is the sub-watershed unit discharge per square mile of drainage area per inch of runoff (cfs/mi^2/in), Q is the runoff in inches, and A is the sub-watershed area in acres.

The unit peak discharge, q_u, is a function of the sub-watershed time of concentration and can be determined from Figure 1. Time of concentration is the time required for runoff to travel from the most remote part of the sub-watershed to the watershed outlet. The time of concentration can be determined by dividing the flow path or hydraulic length into segments of uniform surface condition (bare, grass, channel, etc.), determining the overland flow velocity and travel time for each of the segments, and summing the individual segment travel times to produce the time of concentration for the sub-watershed. The following equation can be used to calculate time of concentration (Barfield, Warner, and Haan, 1981):

$$T_c = \left(\sum_{j=1}^{n} L_{h,j}/V_j\right)/3600 \qquad (2)$$

where T_c is time of concentration in hours, $L_{h,j}$ is the segment length in feet, V_j is the segment overland flow velocity in feet per second and n is the number of segments in the flow path. The overland flow velocity is a function of the segment slope and surface condition and can be obtained from Figure 2.

In steep slope areas where the watershed drainage area is less than 40 acres (any watershed with a maximum sub-watershed combined time of concentration and travel time less than 0.150 hours), the sub-watershed peak discharge can be calculated with the equations:

$$Q_p = 1.05QA \tag{3}$$

for disturbed areas,

$$Q_p = 0.875QA \tag{4}$$

for revegetated or agricultural areas, and

$$Q_p = 0.594QA \tag{5}$$

for forested areas.

The sub-watershed runoff volume, Q, is determined by the U.S. Soil Conservation Service (SCS) curve number rainfall-runoff relationship (Soil Conservation Services, 1975). This relationship is presented in Figure 3 and expresses the runoff volume as a function of total storm rainfall, P, and the curve number, CN. Table 1 contains average curve numbers for selected vegetative and soil conditions which can be used in lieu of site specific data collection (Department for Surface Mining Reclamation and Enforcement, 1982). Professionals who feel that the average values contained in Table 1 are not representative of their particular situation may perform site specific data collection and analysis to determine alternative curve numbers. Table 2 contains 10-year and 25-year, 24 hour rainfall amounts for each county in Kentucky (Division of Water Resources, 1979) which can be used with Figure 2 to calculate the runoff volume. After the unit peak discharge and runoff volume have been determined for the sub-watershed, the peak discharge can be calculated with equation 1 or where time of concentration is not included, with equations 3, 4, or 5.

Peak watershed discharge

To calculate a peak watershed discharge (peak inflow to the sediment pond) for steep slope watersheds larger than 40 acres (any watershed with a maximum sub-watershed combined time of concentration and travel time greater than 0.150 hours), discharges from sub-watersheds are combined taking into account the time of concentration and travel time from the sub-watershed outlet to the sediment pond. Travel time from the sub-watershed outlet to the sediment pond is used to account for the effects of channel storage and other factors on the sub-watershed peak discharge and to estimate the relative time of arrival of the sub-watershed peak discharge at the sediment pond.

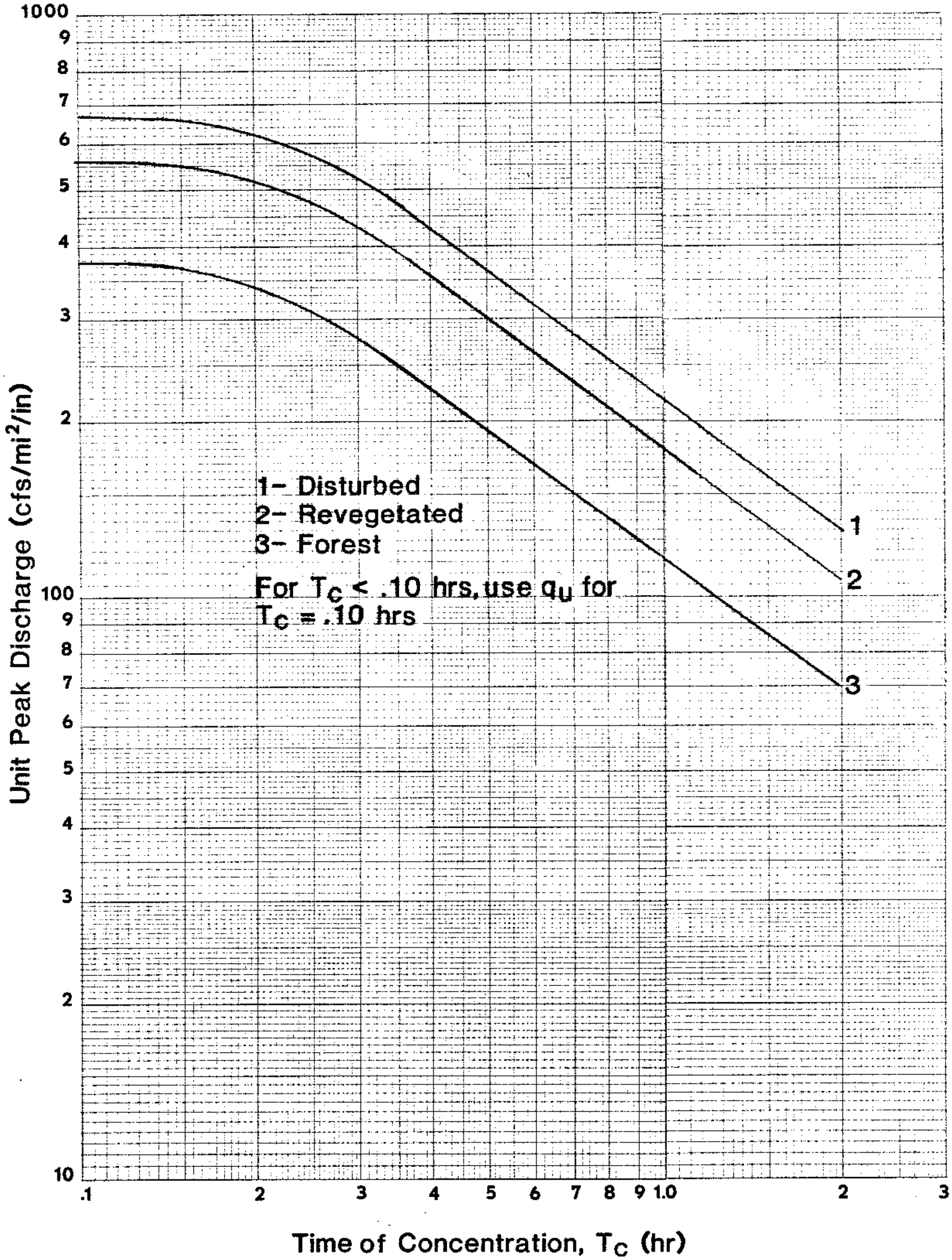


Figure 1 Unit peak discharge (after Soil Conservation Service, 1975).

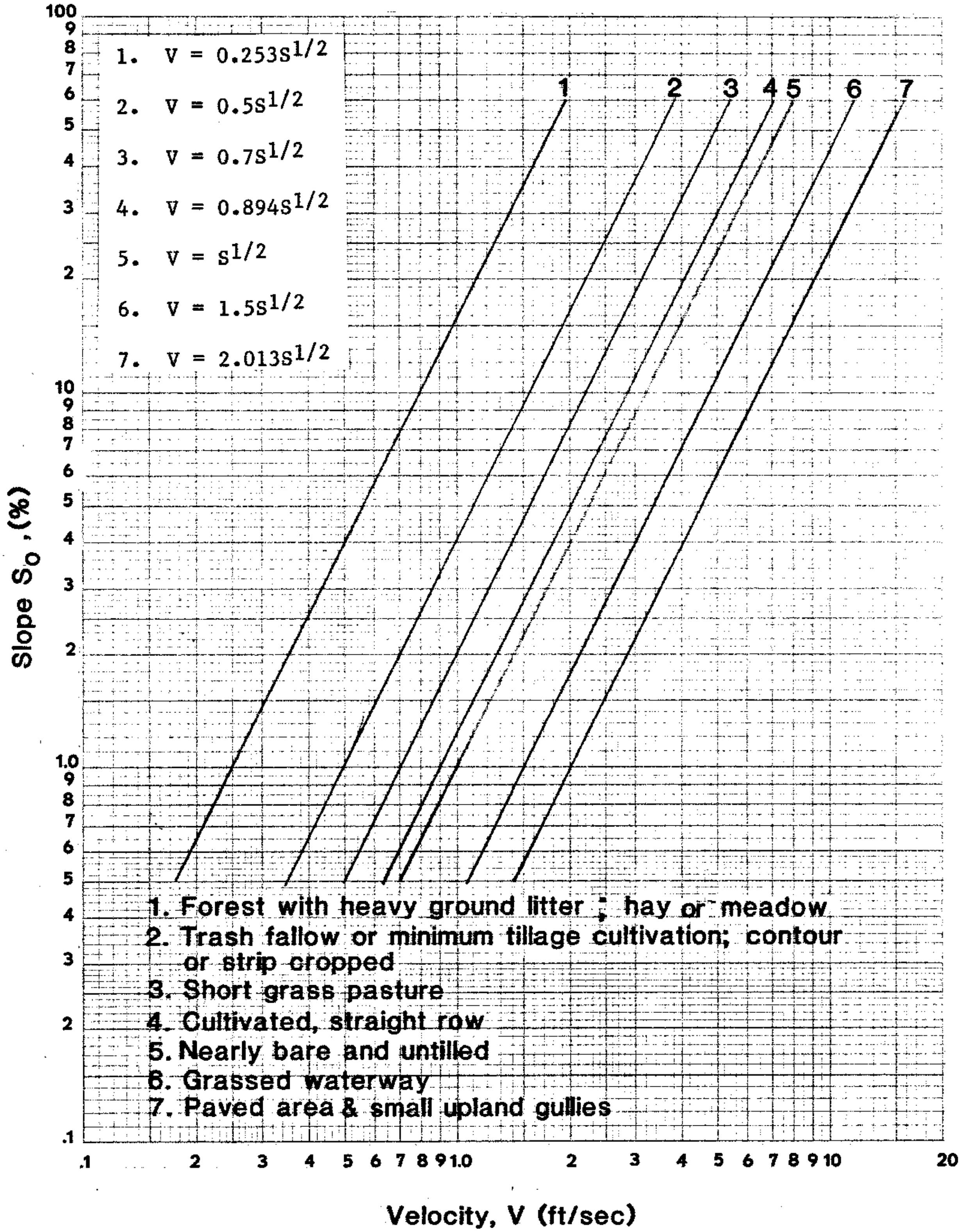


Figure 2 Overland and channel flow velocities (Soil Conservation Service, 1971).

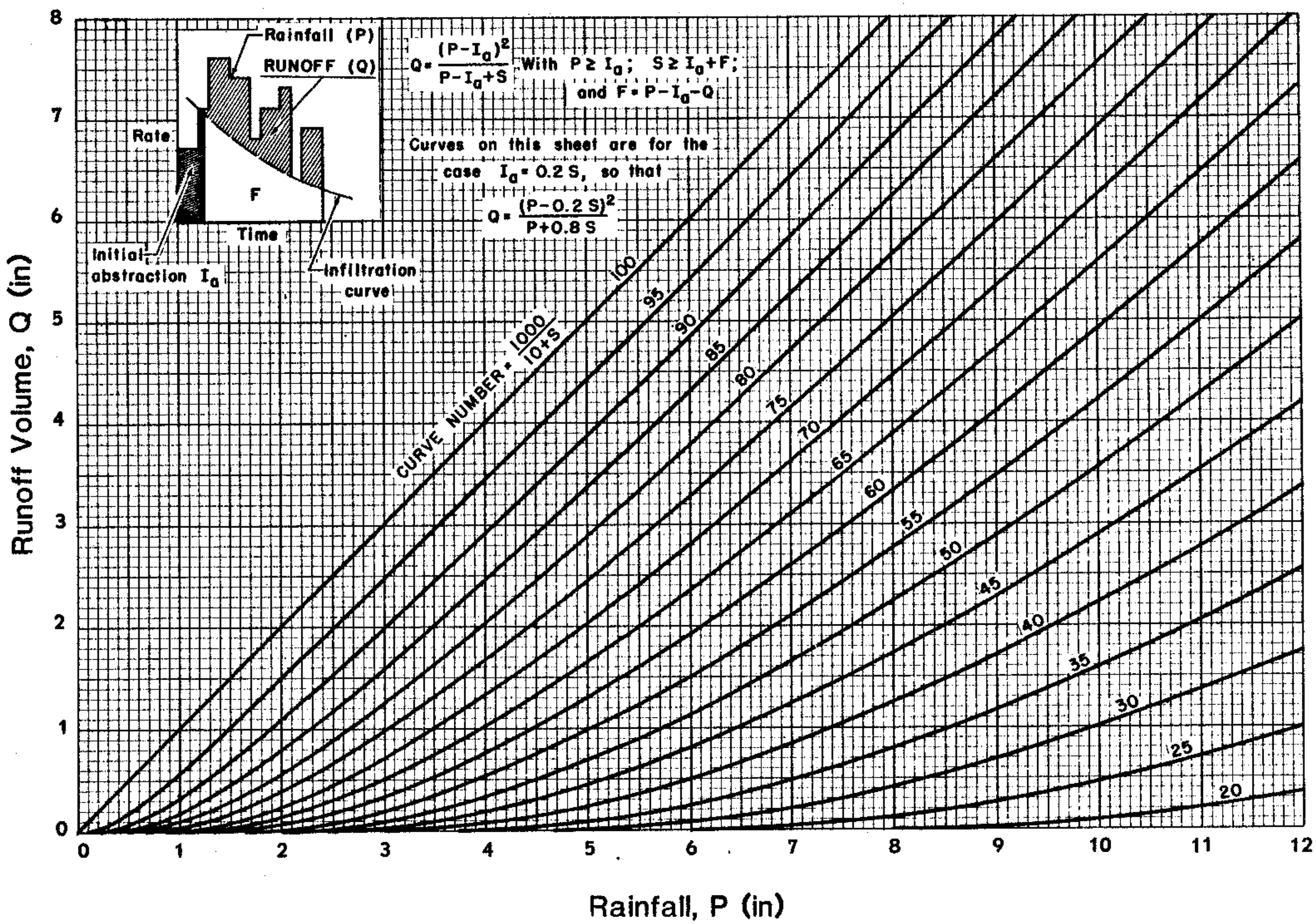


Figure 3 SCS curve number rainfall runoff relationship (Soil Conservation Service, 1971).

TABLE 1

Soil Conservation Service Curve Numbers

Surface Condition	Hydrologic Soil Condition: Subsurface(*) Disturbed (Mine Spoil)	Hydrologic Soil Condition: Subsurface(**) Undisturbed (Natural Soil)
Cleared and grubbed; bare	-	88
Active mining, pit	86	-
Spoil, spoil with topsoil; graded, bare . .	86	-
Grass, legumes; seeded and mulched 0-2 months after seeding.	79	86
2-12 months after seeding	74	82
Hay, pasture, grassland; fully established, fair hydrologic condition	69	79
Forest, woods; fair hydrologic condition. .	60	73
Roads; dirt, gravel	95	95
Roads; paved	98	98

(*) Subsurface soils or rock strata which have been fragmented by surface mining or other similar disturbance. Curve numbers for disturbed subsurface soils were based on the Soil Conservation Service hydrologic soil group "B."

(**) Subsurface soils or rock strata which exist in a natural undisturbed condition. Curve numbers for natural undisturbed soils were based on the Soil Conservation Service hydrologic soil group "C."

TABLE 2

10-Year and 25-Year, 24 Hour Rainfall Amounts

County	Frequency (Years) 10	Frequency (Years) 25
Adair	4.6	5.4
Allen	4.8	5.6
Anderson	4.4	5.2
Ballard	5.1	5.8
Barren	4.7	5.5
Bath	4.2	4.9
Bell	4.5	5.2
Boone	4.2	4.9
Bourbon	4.3	5.0
Boyd	4.0	4.6
Boyle	4.5	5.2
Bracken	4.2	4.9
Breathitt	4.3	4.9
Breckinridge	4.6	5.4
Bullitt	4.5	5.2
Butler	4.8	5.5
Caldwell	4.9	5.6
Calloway	5.0	5.8
Campbell	4.2	4.9
Carlisle	5.1	5.8
Carroll	4.3	5.1
Carter	4.0	4.7
Casey	4.5	5.3
Christian	4.9	5.7
Clark	4.3	5.0
Clay	4.4	5.1
Clinton	4.7	5.5
Crittenden	4.9	5.6
Cumberland	4.7	5.5
Daviess	4.7	5.5
Edmonson	4.7	5.5
Elliott	4.1	4.7
Estill	4.3	5.0
Fayette	4.3	5.1
Fleming	4.1	4.8
Floyd	4.2	4.8
Franklin	4.4	5.1
Fulton	5.2	5.9
Gallatin	4.3	5.0
Garrard	4.4	5.2
Grant	4.2	5.0
Graves	5.1	5.8
Grayson	4.7	5.5
Green	4.6	5.4
Greenup	4.0	4.6
Hancock	4.7	5.4
Hardin	4.6	5.3
Harlan	4.4	5.1
Harrison	4.2	5.0
Hart	4.6	5.4
Henderson	4.8	5.5
Henry	4.4	5.1
Hickman	5.2	5.9
Hopkins	4.8	5.5
Jackson	4.4	5.1
Jefferson	4.5	5.2
Jessamine	4.4	5.1
Johnson	4.1	4.7
Kenton	4.2	4.9
Knott	4.3	4.9
Knox	4.5	5.2
Larue	4.6	5.3
Laurel	4.5	5.2
Lawrence	4.0	4.7
Lee	4.3	5.0
Leslie	4.4	5.0
Letcher	4.3	4.9
Lewis	4.0	4.7
Lincoln	4.5	5.2
Livingston	4.9	5.7
Logan	4.8	5.6
Lyon	4.9	5.7
McCracken	5.0	5.8
McCreary	4.6	5.3
McLean	4.8	5.5
Madison	4.3	5.1
Magoffin	4.2	4.8
Marion	4.5	5.3
Marshall	5.0	5.7
Martin	4.1	4.7
Mason	4.1	4.8
Meade	4.6	5.3

Table 2 (continued)

County	Frequency (Years) 10	25	County	Frequency (Years) 10	25
Menifee	4.2	4.9	Rockcastle	4.4	5.2
Mercer	4.4	5.2	Rowan	4.1	4.8
Metcalfe	4.7	5.5	Russell	4.6	5.4
Monroe	4.7	5.6	Scott	4.3	5.1
Montgomery	4.2	5.0	Shelby	4.4	5.2
Morgan	4.1	4.8	Simpson	4.8	5.6
Muhlenberg	4.8	5.5	Spencer	4.5	5.2
Nelson	4.5	5.3	Taylor	4.6	5.3
Nicholas	4.2	4.9	Todd	4.9	5.6
Ohio	4.7	5.5	Trigg	5.0	5.7
Oldham	4.4	5.2	Trimble	4.4	5.1
Owen	4.3	5.1	Union	4.8	5.5
Owsley	4.3	5.0	Warren	4.8	5.5
Pendleton	4.2	4.9	Washington	4.5	5.2
Perry	4.3	5.0	Wayne	4.6	5.4
Pike	4.2	4.8	Webster	4.8	5.5
Powell	4.3	5.0	Whitley	4.5	5.3
Pulaski	4.5	5.3	Wolfe	4.2	4.9
Robertson	4.2	4.9	Woodford	4.4	5.1

Travel time from the sub-watershed outlet to the sediment pond is calculated in a manner similar to time of concentration (Barfield, Warner, and Haan, 1981):

$$T_t = \left(\sum_{j=1}^{n} L_{h,j}/V_j\right)/3600 \qquad (6)$$

where T_t is the travel time in hours, $L_{h,j}$ is the segment hydraulic length in feet, V_j is the segment velocity in feet per second, and n is the number of segments. As in the calculation of time concentration, segments of uniform surface condition should be selected. In most situations, travel from the sub-watershed outlet to the sediment pond will occur through existing natural channels or diversion ditches. Velocities for each segment can be obtained from Figure 2.

With the travel time from the sub-watershed to the sediment pond determined, an adjusted unit peak discharge can be calculated using the travel time reduction factor obtained from Figure 4. The adjusted unit peak discharge is given by:

$$q_t = F_t q_u \qquad (7)$$

where q_t is the sub-watershed unit peak discharge adjusted for travel time from the sub-watershed outlet to the sediment pond, and F_t is the unit peak discharge travel time reduction factor from Figure 4.

Next, the adjusted sub-watershed peak discharge can be determined from:

$$Q_{pt} = F_t Q_p \tag{8}$$

where Q_{pt} is the sub-watershed peak discharge in cubic feet per second adjusted for travel time from the sub-watershed outlet to the sediment pond.

With q_t and Q_{pt} known, the peak discharge for the watershed (peak inflow to the sediment pond) can be calculated from:

$$Q_{pi} = \max\left(\sum_{j=1}^{n} F_{h,k\Delta t}\, Q_{pt,j}\right) \tag{9}$$

where Q_{pi} is the peak watershed discharge in cubic feet per second, F_h is the peak discharge to hydrograph conversion factor obtained from Figures 5 and 6, Δt is the time increment used for computing the peak discharge, k is the number of Δt increments on either side of the sub-watershed peak discharge, and n is the number of sub-watersheds. Application of equation 9 is best understood by using the worksheets provided in Appendix A. Use of the worksheets is discussed in the following paragraphs.

The computation of the sub-watershed and watershed peak discharges with equations (1) and (2) and (6)-(9) can be accomplished by using worksheets 1 and 2 contained in Appendix A. Worksheet 1 is designed for calculation of sub-watershed time of concentration, T_c, and travel time, T_t, and worksheet 2 is designed for calculation of sub-watershed peak discharge, Q_p; adjusted peak discharge, Q_{pt}; and watershed peak discharge, Q_{pi}. Appendix B contains a sediment pond design example which illustrates use of worksheets 1 and 2 for equations (1) and (2) and (6)-(9). Use of the worksheets for equations (1) and (2) and (6)-(8) is straightforward and the user should be able to obtain an understanding of the calculation procedure from the above explanation and example in Appendix B. Use of worksheet 2 in calculating the watershed peak discharge is somewhat more involved and will be discussed in greater detail.

The relative time of arrival of sub-watershed hydrograph peaks at the sediment pond can be obtained by adding the time concentration, T_c, and travel time, T_t. Column 9 on worksheet 1 has been provided for recording the combined T_c and T_t. To allow computations to occur at convenient times, the combined time should be rounded to the nearest 0.05 or 0.10 hour. The time increment selected for rounding (0.05 or 0.10 hr) is dependent on the variation between $T_c + T_t$ for the sub-watersheds. For sub-watersheds with a small range in $T_c + T_t$ (0.10 to 0.30 hr), round off to the nearest 0.05 hour will probably be necessary. For a greater range in $T_c + T_t$ values, round off to the nearest 0.1 hour should be adequate. The rounded $T_c + T_t$ values should be recorded in column 12 of worksheet 2.

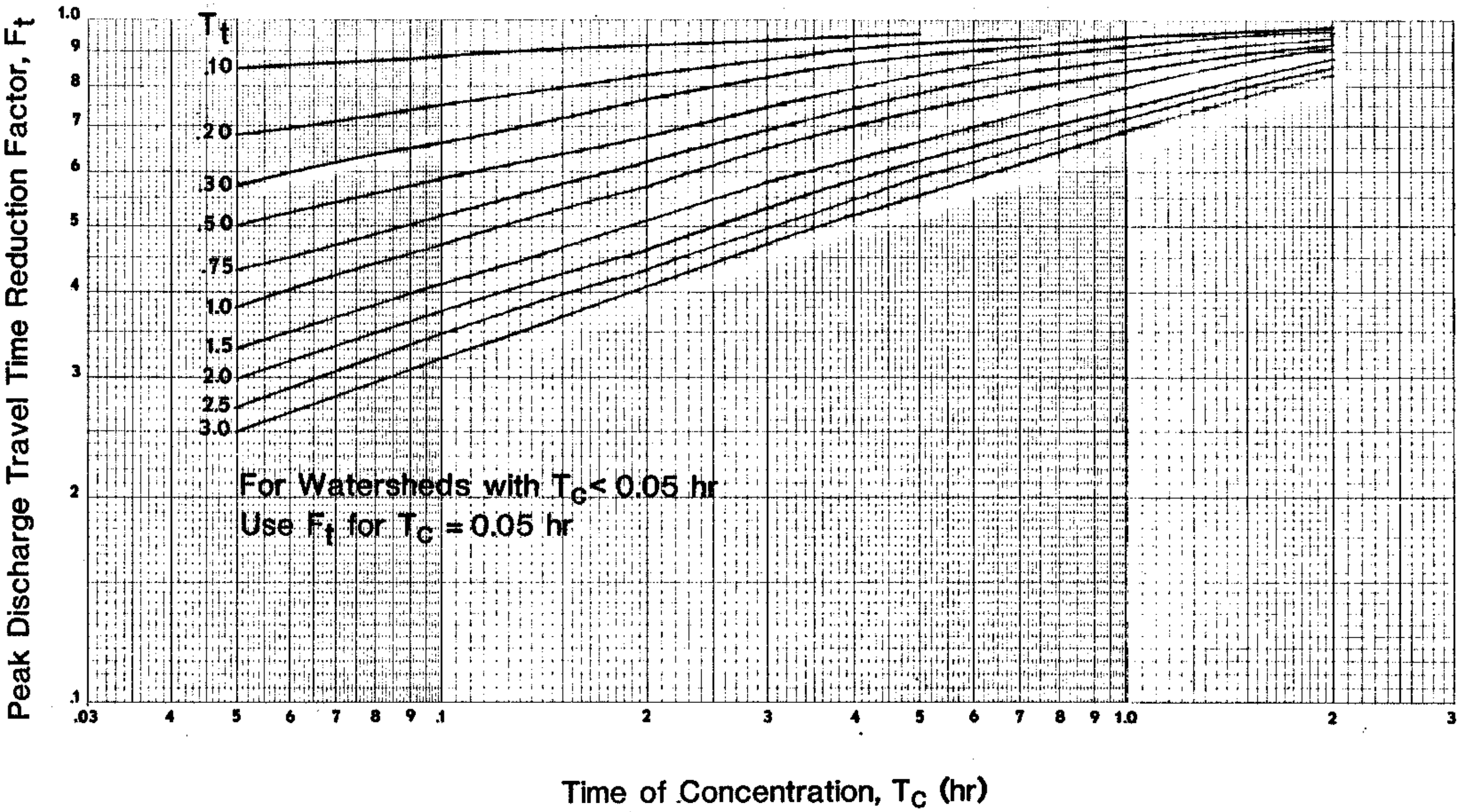


Figure 4 Unit peak discharge travel time reduction factor (After Soil Conservation Service, 1975).

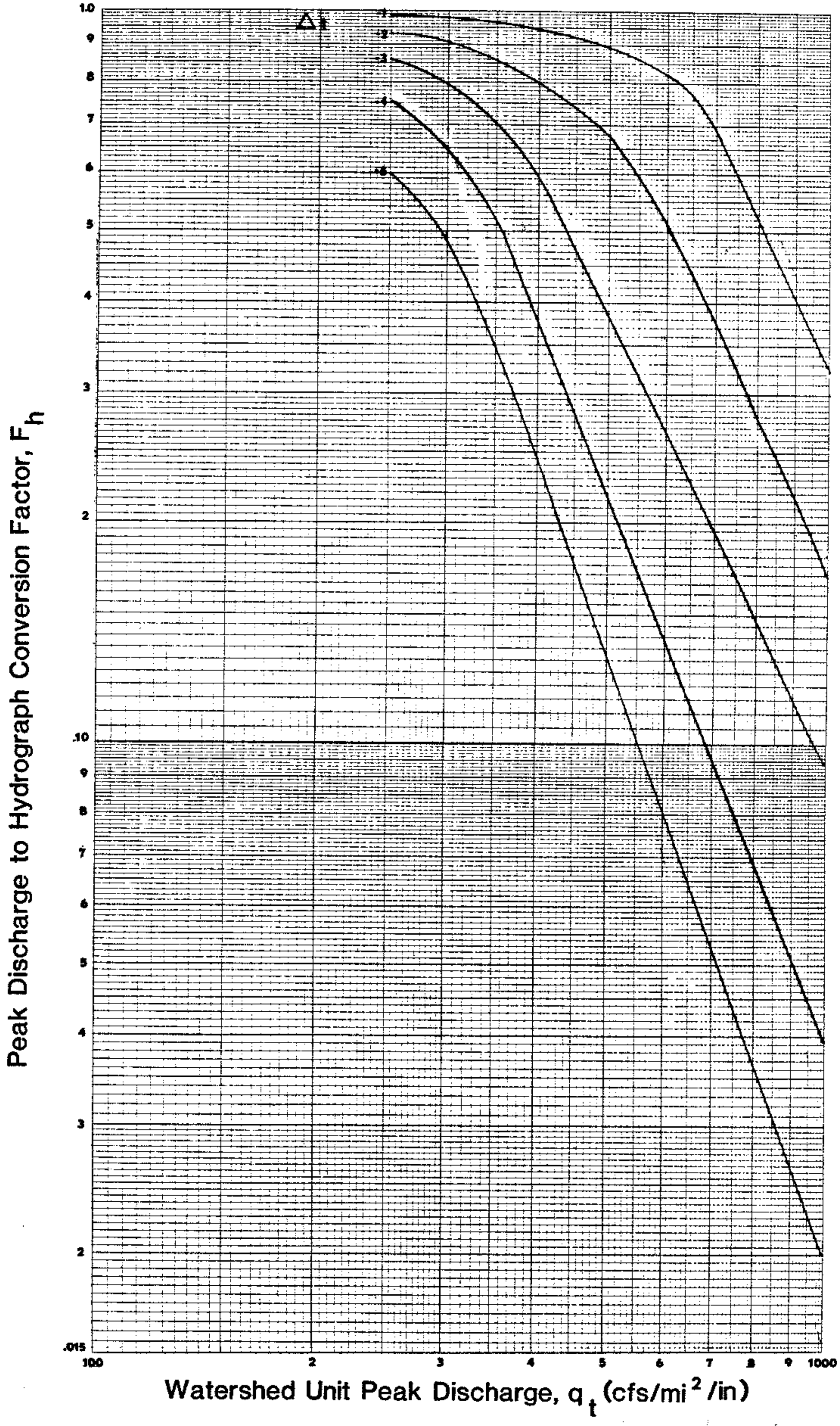


Figure 5 Peak discharge to hydrograph conversion factor for the rising limb (After Soil Conservation Service, 1975).

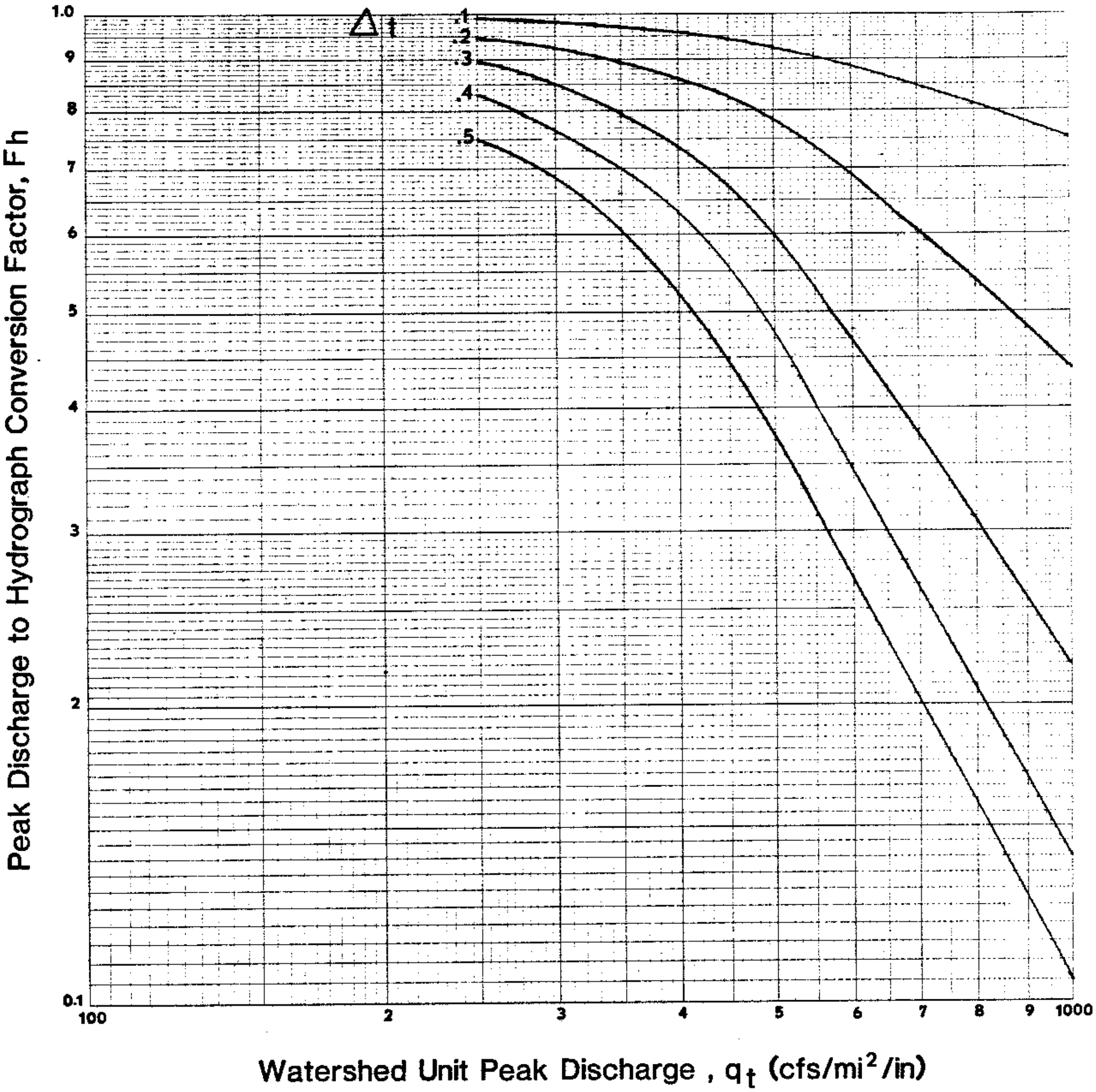


Figure 6 Peak discharge to hydrograph conversion factor for the falling limb (After Soil Conservation Service, 1975).

Column 13 of worksheet 2 is for recording the peak discharge to hydrograph conversion factors, F_h, and is divided into a positive section and a negative section to indicate time before (negative) or after (positive) the sub-watershed peak discharge. In the first row of column 13, record incremental Δt values corresponding to the roundoff used for the $T_c + T_t$ values (Δt increments of 0.05 for roundoff to the nearest 0.05 hr and 0.10 for roundoff to the nearest 0.10 hr). If a Δt increment of 0.05 is used, the negative side of column 13 would read -0.25, -0.20, -0.15, -0.10, -0.05 for the five spaces provided. The positive side of column 13 would be similarly labeled +0.05, +0.10, +0.15, +0.20, +0.25.

In column 16 of worksheet 2, record the range of rounded $T_c + T_t$ values, in the same time increments used for column 13. Corresponding with the appropriate watershed and rounded $T_c + T_t$ values also record the adjusted peak sub-watershed discharges, Q_{pt}, in column 16. Obtain values of F_t for the appropriate time increments from Figures 5 and 6 and record these values in column 13. Multiply the Q_{pt} values by the corresponding F_t values as indicated in equation 9 to generate hydrograph ordinates surrounding the peak discharge. An inspection of the timing of the peak discharges in column 16 will allow the user to narrow the time range over which the peak discharge will likely occur and probably allow the computation to be confined to two or three $T_c + T_t$ values in column 16.

The peak watershed discharge, Q_{pi}, is obtained by summing the discharges in column 16 for selected $T_c + T_t$ values and picking the maximum discharge. The example in Appendix B provides additional information for using worksheet 2 for equation 9.

For steep slope watersheds with a drainage area less than 40 acres (any watershed with a maximum sub-watershed combined time of concentration and travel time less than 0.150 hours), the watershed peak discharge can be calculated by simply summing the sub-watershed peak discharge:

$$Q_{pi} = \sum_{j=1}^{n} Q_{p,j} \tag{10}$$

where Q_{pi} is the watershed peak discharge, Q_p is the sub-watershed peak discharge, and n is the number of sub-watersheds. Column 9 of worksheet 2 may be used to record the sub-watershed and watershed peak discharges.

Runoff volume

The sub-watershed runoff volume is given by:

$$Q_v = (QA)/12 \tag{11}$$

where Q_v is the sub-watershed runoff volume in acre-feet.

The total watershed runoff volume is obtained by summing the contributions from the sub-watersheds:

$$Q_{vi} = \sum_{j=1}^{n} Q_{v,j} \tag{12}$$

where Q_{vi} is the watershed runoff volume in acre-feet and n is the number of sub-watersheds. Columns 6-8 of worksheet 2 are provided for the calculation of Q_v and Q_{vi}.

Design Step 3 - Determination of Sediment Load (worksheet 3)

The sub-watershed sediment load can be calculated with the Modified Universal Soil Loss Equation (Barfield, Warner, and Haan, 1981):

$$Y = 95\ (Q_v Q_p)^{0.56}\ KLSCP \tag{13}$$

where Y is the sub-watershed sediment load in tons, K is the soil erodibility factor, LS is the length slope factor, and CP is the control practice factor. Q_p and Q_v are calculated from equations (1), (3), (4) or (5) and (11), respectively.

Average values of K and CP which the department will accept in lieu of values determined by site specific data collection are contained in Table 3 (Department for Surface Mining Reclamation and Enforcement, 1982). As noted previously in relation to SCS curve numbers, professionals who feel that the average K and CP values provided by the department are not representative of their particular situation may perform site specific data collection and analysis to determine alternate input parameters.

The LS factor is a function of the erosion slope length, L_e, and the slope steepness and can be determined from Figure 7. Measurement of the erosion slope length should be done in a manner compatible with the data base and procedures used in the development of the Universal Soil Loss Equation. Erosion slope lengths should be measured along the gradient of the slope (water flow path) and terminate at the point where the flow path enters a stabilized channel or at a point where the slope decreases sufficiently to cause deposition. For sub-watersheds which are irregular in shape and have corresponding varying erosion slope lengths, an area weighted average slope length can be used. The example in Appendix B contains additional information on the calculation of LS factors.

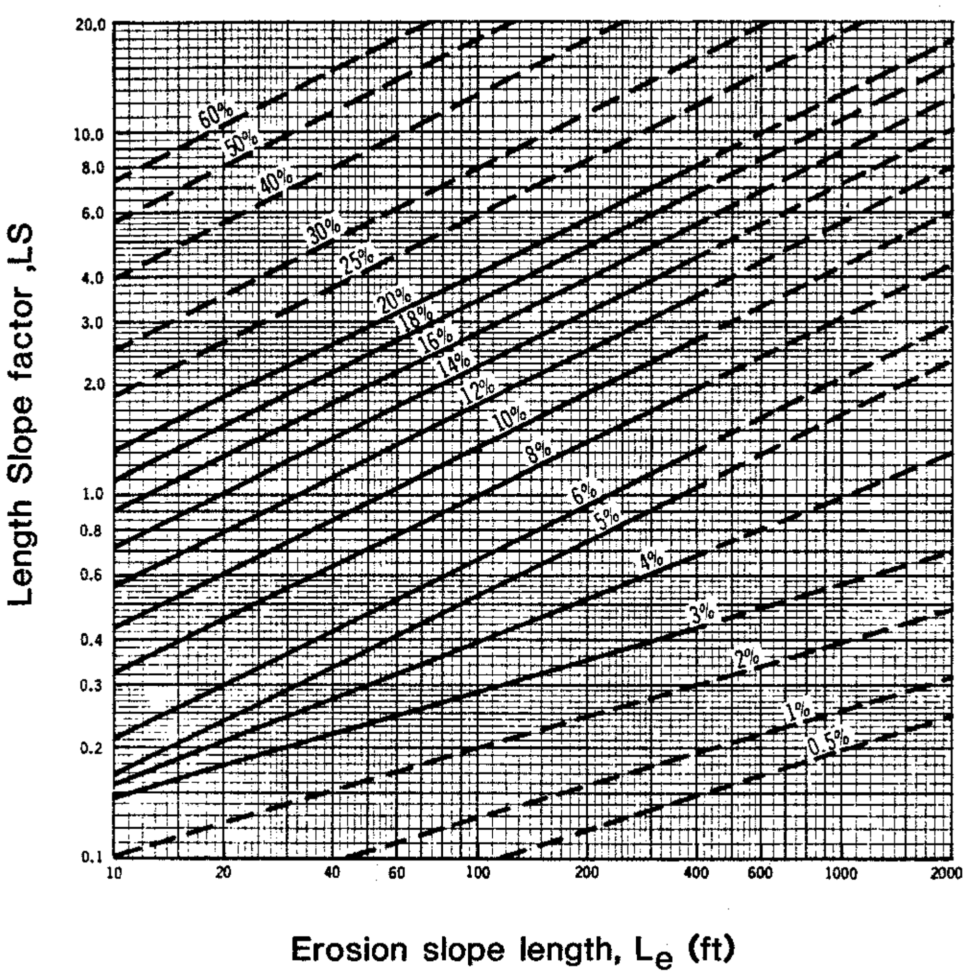
TABLE 3

Control Practice and Soil Erodibility Factors

Surface Condition	CP Factor
Cleared and grubbed; bare	1.00
Active mining, pit	0.80
Spoil, spoil with topsoil; graded, bare	0.90
Grass, legumes; seeded and mulched(*)	
0-2 months after seeding	0.14
2-12 months after seeding	0.05
Hay, pasture, grassland; fully established	0.01
Forest, woods	0.003
Roads; dirt, gravel	1.20
Roads; paved	0.0

	K Factor
Disturbed area	0.22
Undisturbed area	0.17

(*) Straw mulch at 1.5 ton per acre



*The dashed lines represent estimates for slope dimensions beyond the range of lengths and steepnesses for which data are available. The curves were derived by the formula:

$$LS = \left(\frac{\lambda}{72.6}\right)^m \left(\frac{430x^2 + 30x + 0.43}{6.613}\right)$$

where λ = field slope length in feet and m = 0.5 if s = 5% or greater, 0.4 if s = 4%, and 0.3 if s = 3% or less; and x = sin θ. θ is the angle of slope in degrees.

Figure 7 Universal Soil Loss Equation LS factor (Barfield, Warner, and Haan, 1981).

The total watershed sediment yield can be obtained by simply summing the contribution from each sub-watershed:

$$Yi = \sum_{j=i}^{n} Y_j \tag{14}$$

where Yi is the sediment pond inflow sediment load in tons and n is the number of sub-watersheds. Worksheet 3 in Appendix A can be used with equations (13) and (14) to compute the sub-watershed and watershed sediment loads.

Design Step 4 - Principal Spillway Design (worksheets 4 and 5)

The principal spillway should be sized and placed at an elevation which will meet the settleable solids effluent limitation of 0.5 ml/l while keeping the routed 10-year, 24 hour storm maximum water surface elevation as low as possible.

In addition to the input parameters calculated with equations (1)-(14), sediment pond stage-area and stage-volume curves are required for design of the principal spillway. The principal spillway design process can be divided into the following general steps:

(1) Determine the amount of sediment storage required and incremental stage needed for the sediment pool,

(2) Select a spillway type and size and locate the crest or invert of the spillway at some point above the sediment pool elevation (the final crest or invert elevation must be located at an elevation above the sediment pool which is at least 40% of the elevation difference between the sediment pool and the maximum 10-year storm water surface),

(3) Determine the routed 10-year, 24 hour storm peak discharge and corresponding water surface elevation (check to see that the above 40% depth criterion is satisfied and raise the spillway if the crest or invert elevation is less than 40% of the maximum stage),

(4) Calculate the settleable solids concentration for the selected spillway size and location, and

(5) Repeat steps (2)-(4) if the settleable solids concentration is greater than 0.5 ml/l or is sufficiently below 0.5 ml/l to indicate that a more cost-effective pond can be designed.

The following material will provide a more detailed discussion of the above general steps.

Sediment storage volume

An appropriate sediment storage volume should be provided consistent with the sediment load expected over the life of the mining operation and a reasonable pond cleanout schedule. The Universal Soil Loss Equation may be used to predict average annual sediment production and to determine an approximate pond cleanout schedule. As an alternative to using the Universal Soil Loss Equation, engineers may determine the sediment pond cleanout elevation by sizing the sediment storage volume to contain 0.075 acre-foot per acre of disturbed area. At a minimum, the sediment pond cleanout elevation should be located at an elevation which will store 1.5 times the 10-year, 24 hour storm sediment volume. The 10-year, 24 hour storm sediment load in tons can be calculated with the Modified Universal Soil Loss Equation as discussed in the previous section.

Assuming a specific gravity of 1.25 for deposited sediment, the sediment storage volume can be calculated from

$$V_s = 8.83 \times 10^{-4} Y_i \tag{15}$$

where V_s is the sediment storage volume in acre-feet for the 10-year, 24-hour storm and Y_i is the inflow sediment load in tons for the 10-year, 24 hour storm.

The design engineer should be aware that a relatively small sediment storage volume may commit the mining operation to a frequent pond cleanout schedule.

Selection of a principal spillway type and size

These design procedures are applicable to conduit and riser and trickle tube principal spillways. The conduit and riser design incorporates a 3 inch diameter dewatering orifice in the riser pipe at a stage of one-half the distance between the sediment pool and the crest of the riser. Due to the dewatering orifice, conduit and riser principal spillways will generally produce smaller ponds than trickle tube principal spillways.

To prevent bottom scour and to satisfy the assumption of uniform withdrawal under which the settleable solids prediction equation was developed, the crest or invert of the principal spillway must be located at an elevation above the sediment pool which is at least 40% of the elevation difference between the sediment pool and the maximum 10-year storm water surface. This minimum stage requirement for the principal spillway can be expressed by the following relationship:

$$P_f = \frac{\Delta E_{sp}}{\Delta E_{sp} + \Delta E_{pm}} \geq 0.40 \tag{16}$$

where P_f is the principal spillway fractional depth, ΔE_{sp} is the incremental elevation between the sediment pool and the principal spillway crest, and ΔE_{pm} is the incremental elevation between the principal spillway crest or invert and the maximum water surface elevation. Since the maximum water surface elevation is initially unknown, the initial principal spillway elevation must be estimated.

Since the sediment pond design process is a trial and error procedure, the user must make an initial selection of a principal spillway configuration and then check to see that the selection was adequate. If the initial spillway size is too large, the pond will not provide sufficient detention time to meet the settleable solids limitation. If the spillway is too small, the pond may produce a settleable solids concentration significantly below 0.5 ml/l, and the resulting water surface elevation will likely be excessive.

Calculation of a Routed 10-year, 24 hour peak discharge

The peak outflow from the sediment pond for the 10-year, 24 hour storm for conduit and riser or trickle tube principal spillways can be determined by using the routing functions contained in Figure 8 or Figure 9 in combination with the stage discharge curves contained in Figures 10 and 11. The routing functions contained in Figures 8 and 9 were based on procedures developed by the U.S. Soil Conservation Service and provide a relationship between the dimensionless ratios of peak outflow from the sediment pond to peak inflow, and the sediment pond maximum storage volume to inflow volume. To reduce the time required for performing the iterative calculations for determining peak outflow, two volume relationships were used (after Soil Conservation Service, 1975):

$$V_{rv} = \frac{\Delta V_{pm}}{Q_{vi} - \Delta V_{op}} \tag{17}$$

and

$$V_{rs} = \frac{A_p \, \Delta E_{pm}}{Q_{vi} - \Delta V_{op}} \tag{18}$$

where V_{rv} is a dimensionless volume ratio based on the incremental sediment pond volume between the principal spillway and maximum water surface elevation, V_{rs} is a dimensionless volume ratio based on the sediment pond area at the principal spillway and the incremental stage between the principal spillway and the maximum water surface elevation, ΔV_{pm} is the incremental volume between the principal spillway elevation and the maximum water surface in acre-feet, A_p is the sediment pond area at the principal spillway in acres, ΔE_{pm} is the incremental elevation between the principal spillway elevation and the maximum water surface in feet, Q_{vi} is the sediment pond inflow volume in acre-feet, and ΔV_{op} is the incremental volume between the riser dewatering orifice elevation and the principal spillway crest in acre-feet. Since the trickle tube design procedures contained in this guideline do not incorporate a dewatering orifice, ΔV_{op} is equal to zero (0) for trickle tube principal spillways.

As explained in more detail in the following paragraphs, the use of equation 18 allows an approximate routing to be performed without using the sediment pond stage-storage curve to determine the water-surface elevation. As a final check, the routing can be performed using equation 17 which requires that stage values be obtained from the stage-storage curve.

The peak outflow to peak inflow ratio used in Figures 8 and 9 is represented by (Soil Conservation Service, 1975):

$$Q_r = \frac{Q_{po}}{Q_{pi}} \tag{19}$$

where Q_r is a dimensionless discharge ratio, Q_{po} is the peak sediment pond outflow in cubic feet per second, and Q_{pi} is the peak sediment pond inflow in cubic feet per second.

The routing functions contained in Figures 8 and 9 are applicable to full pipe flow only. Consequently, the head above the riser or above the trickle tube invert must be greater than certain minimum values to insure that weir flow does not occur for risers and partial pipe flow does not occur for trickle tubes. The minimum allowable heads are contained in Table 4.

TABLE 4

Minimum Allowable Heads for Full Pipe Flow

Conduit and Riser		Trickle Tube	
Diameter(1) (in)	H_r(2) (ft)	Diameter (in)	H_t(3) (ft)
12 R - 18 C	0.6	12	1.4
15 R - 24 C	0.7	15	2.0
18 R - 30 C	0.8	18	2.5
24 R - 36 C	1.1	24	3.1
30 R - 42 C	1.6	30	4.0

(1) 12 C - 18 R - 12" conduit and 18" riser
(2) H_r - Head above the riser crest, (ft.)
(3) H_t - Head above the trickle tube invert, (ft.)

The conduit and riser stage-discharge curves contained in Figure 10 were developed using the default energy loss coefficients contained in TRM #6 (Department for Surface Mining Reclamation and Enforcement, 1982) and a conduit length of 140 feet. Discharge correction factors for lengths other than 140 feet can be obtained from Figure 12. The stage-discharge curves are applicable to standard corrugated metal pipe risers and conduits. The head used in Figure 10 is total head and is computed as

$$H_T = \Delta H + H_r \tag{20}$$

where H_T is the total head in feet, ΔH is the incremental elevation between the conduit invert and the riser crest in feet, and H_r is the head above the riser crest in feet. As previously noted, H_r must be greater than the minimum head for full pipe flow as contained in Table 4, for the stage discharge curves to be applicable.

The stage-discharge curves for trickle tubes were developed with procedures published by the U.S. Geological Survey (Bodhaine, 1968) for a corrugated metal pipe culvert with a length of 70 feet. Discharge correction factors for lengths other than 70 feet can be obtained from Figure 13. Due to the complex nature of culvert flow, it was necessary to use a constant slope of 5 percent for trickle tube principal spillways. Use of a 5 percent slope for the pipe diameters and lengths normally encountered in the design of sediment ponds confined the flow types to (1) inlet control (critical depth at the inlet) where H_t is less than or equal to 1.5 times the pipe diameter, and (2) full pipe flow where H_t is greater than 1.5 times the pipe diameter. Use of trickle tube slopes greater than 5 percent could result in rapid flow at the inlet (partial pipe flow) for relatively short pipes and large diameters where H_t is greater than 1.5 times the pipe diameter.

The following steps can be used with Figures 8 and 9, and Figures 10 and 11 to compute a routed peak discharge. Worksheet 4 in Appendix A has been provided to facilitate the computation.

(1) Assume an initial value for H_r (compute H_T from H_r) or H_t (the assumed head must be greater than the minimum values contained in Table 4) and enter the value in column 2 of worksheet 4.

(2) Enter Figure 10 or 11 with H_r or H_t to determine a discharge, Q_{po}, and multiply the discharge by the pipe length correction factor from Figure 12 or Figure 13. Record the corrected Q_{po} in column 3 of worksheet 4.

(3) Calculate the discharge ratio $Q_r = Q_{po}/Q_{pi}$ and enter it in column 4.

(4) Enter the appropriate routing function in Figure 8 or 9 and obtain a value of V_{rs}. Record V_{rs} in column 5.

(5) Multiply V_{rs} by $(Q_{vi}-\Delta V_{op})/A_p$ (column 6) to determine ΔE_{pm} (ΔE_{pm} is equal to H_r for riser and conduit principal spillways or H_t for trickle tube principal spillways) and record ΔE_{pm} in column 7.

(6) Compare the value of H_r or H_t determined in step 5 (column 7) with the previous value of H_r or H_t (column 2) and repeat steps 2 through 5 if the difference between the two heads is greater than 0.2 feet. Step 6 completes the first phase of the pond routing and provides an initial estimate of H_r or H_t and Q_{po}. Steps 7-14 provide an improved estimate of H_r or H_t and Q_{po} using V_{rv}.

(7) Using the previous value of H_r or H_t (column 7 for the first iteration or column 19 for subsequent iterations) and Figure 10 or 11, determine Q_{po}. Multiply the discharge by the pipe length correction factor from Figure 12 or 13 and record H_r or H_t and the corrected value of Q_{po} in columns 9 and 10, respectively.

(8) Calculate the discharge ratio $Q_r = Q_{po}/Q_{pi}$ and enter Q_r in column 11.

(9) Enter Figure 8 or 9 with Q_r and obtain V_{rv}. Record V_{rv} in column 12.

(10) Multiply V_{rv} by $Q_{vi}-\Delta V_{op}$ (column 13) to determine ΔV_{pm}. Enter ΔV_{pm} in column 14.

(11) Calculate the sediment pond volume at the maximum 10-year water surface elevation, V_m, by adding ΔV_{pm} to the pond volume at the principal spillway, V_p (column 15). Record V_m in column 16.

(12) Enter the sediment pond stage-volume curve with V_m and obtain the maximum 10-year water surface elevation, E_m. Enter E_m in column 17.

(13) Calculate H_r or H_t by subtracting the elevation at the principal spillway, E_p, (column 18) from the maximum water surface elevation (H_r or $H_t = E_m - E_p$). Record H_r or H_t in column 19.

(14) Compare the value of H_r or H_t determined in step 13 (column 19) with the previous value of H_r or H_t (column 9).

(15) If the difference in head values is greater than 0.2 feet, repeat steps 7 through 13.

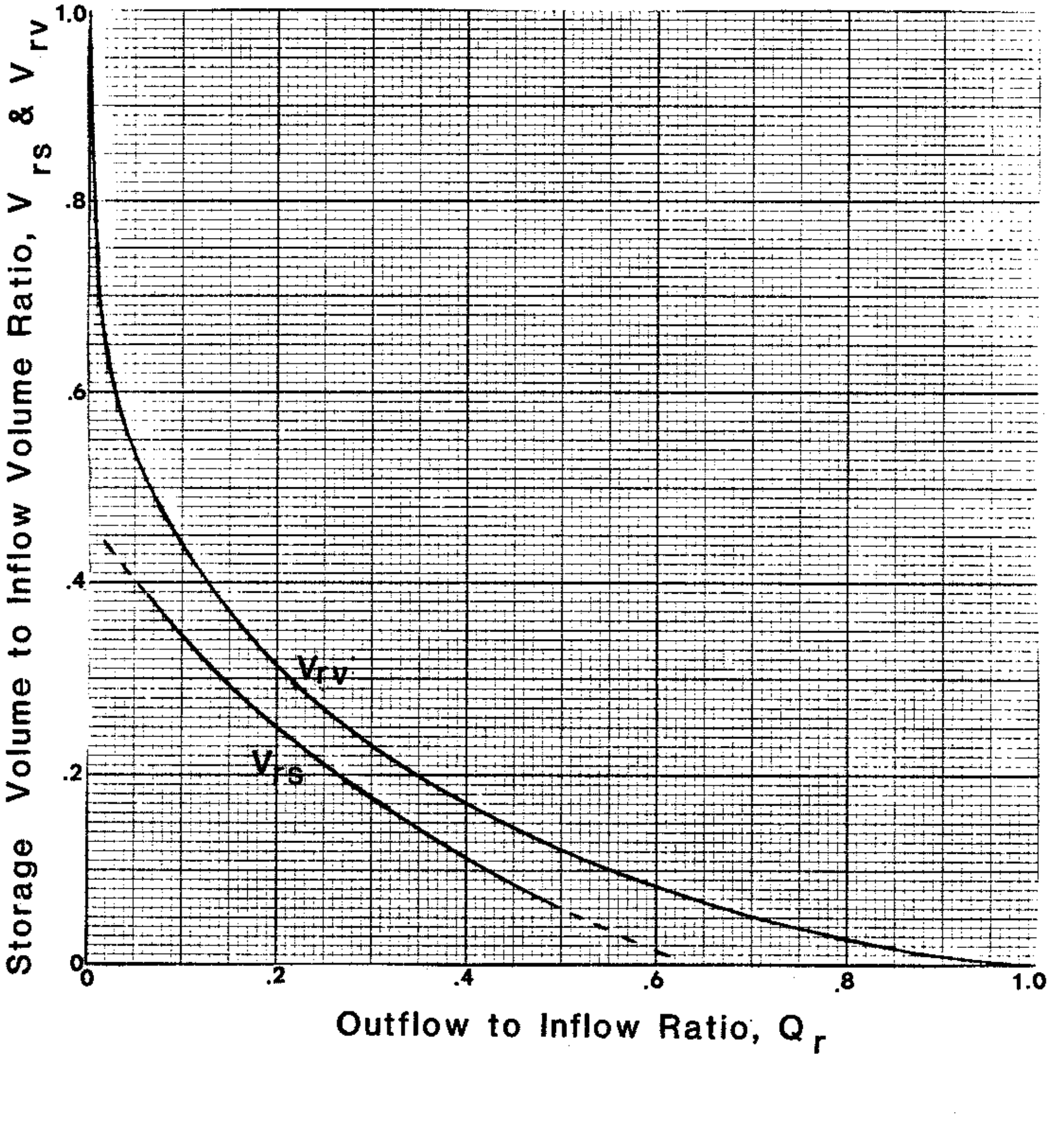


Figure 8 Routed peak discharge for conduit and riser principal spillways (After Soil Conservation Service, 1975).

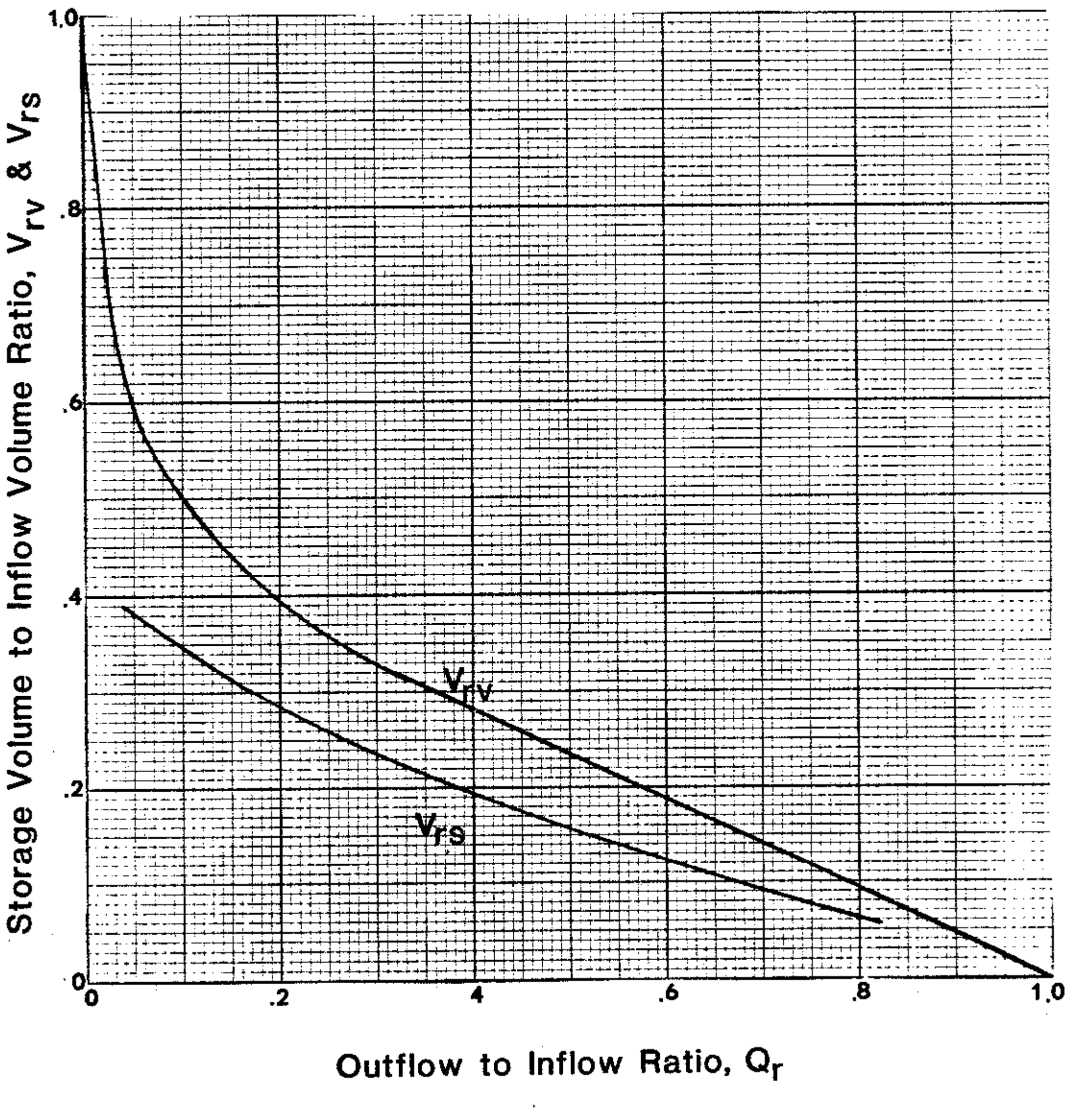


Figure 9 Routed peak discharge for trickle tube principal spillways (After Soil Conservation Service, 1975).

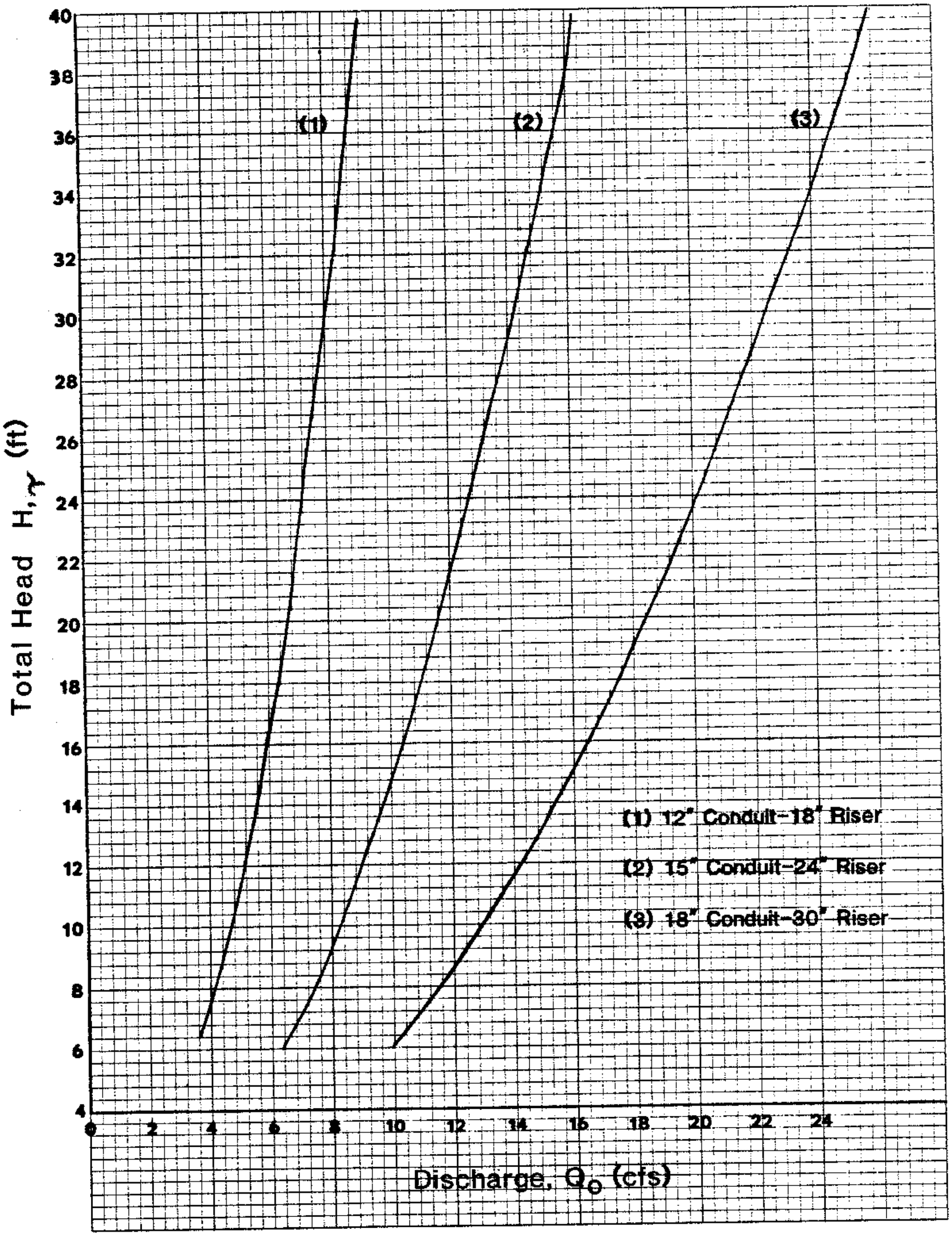


Figure 10 Stage discharge relationships for selected conduit and riser principal spillways (Wilson, Barfield, and Moore, 1982).

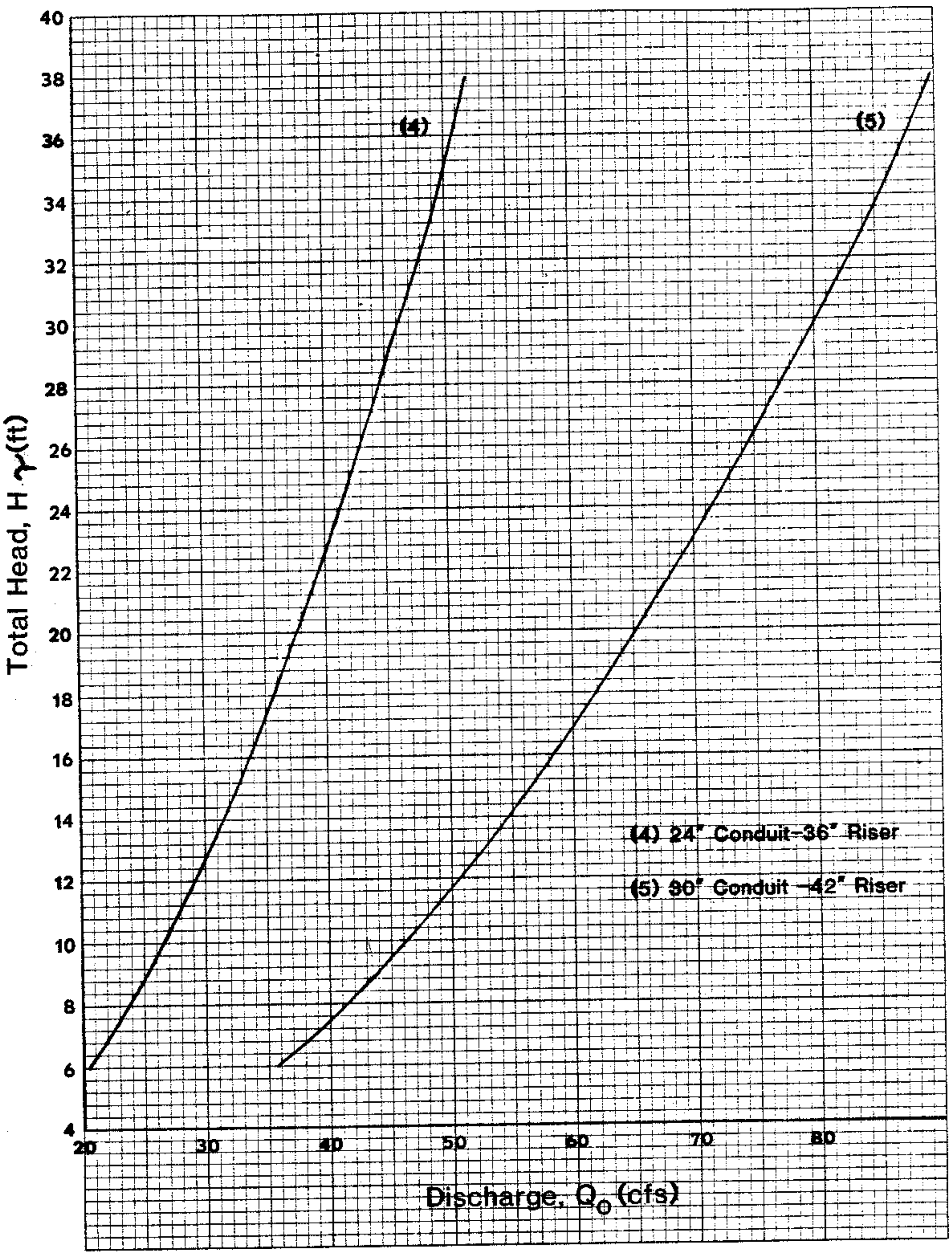


Figure 10 Stage discharge relationships for selected conduit and riser principal spillways (Wilson, Barfield, and Moore, 1982).

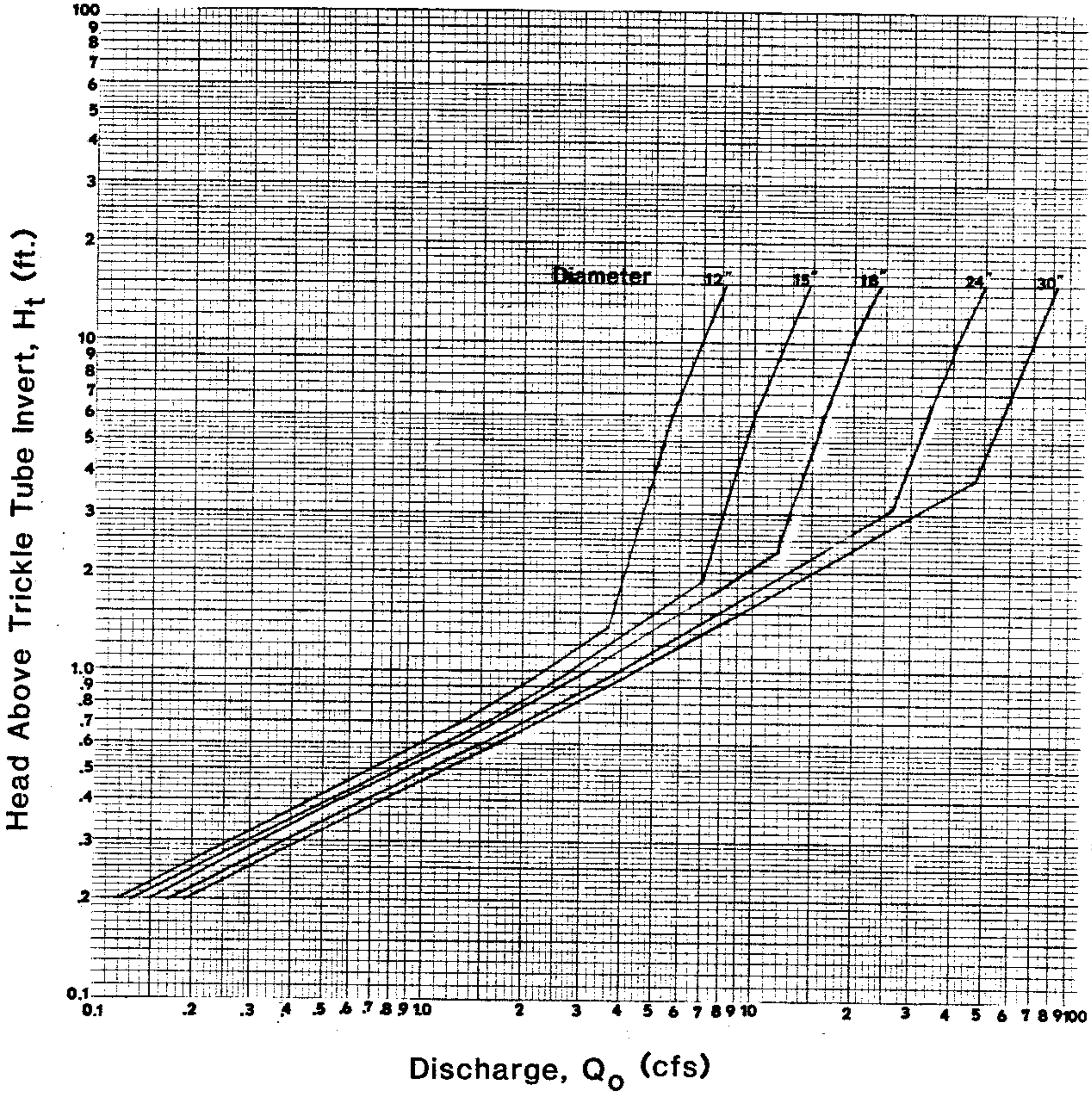


Figure 11 Stage discharge relationship for selected trickle tube principal spillways (After Bodhaine, 1968).

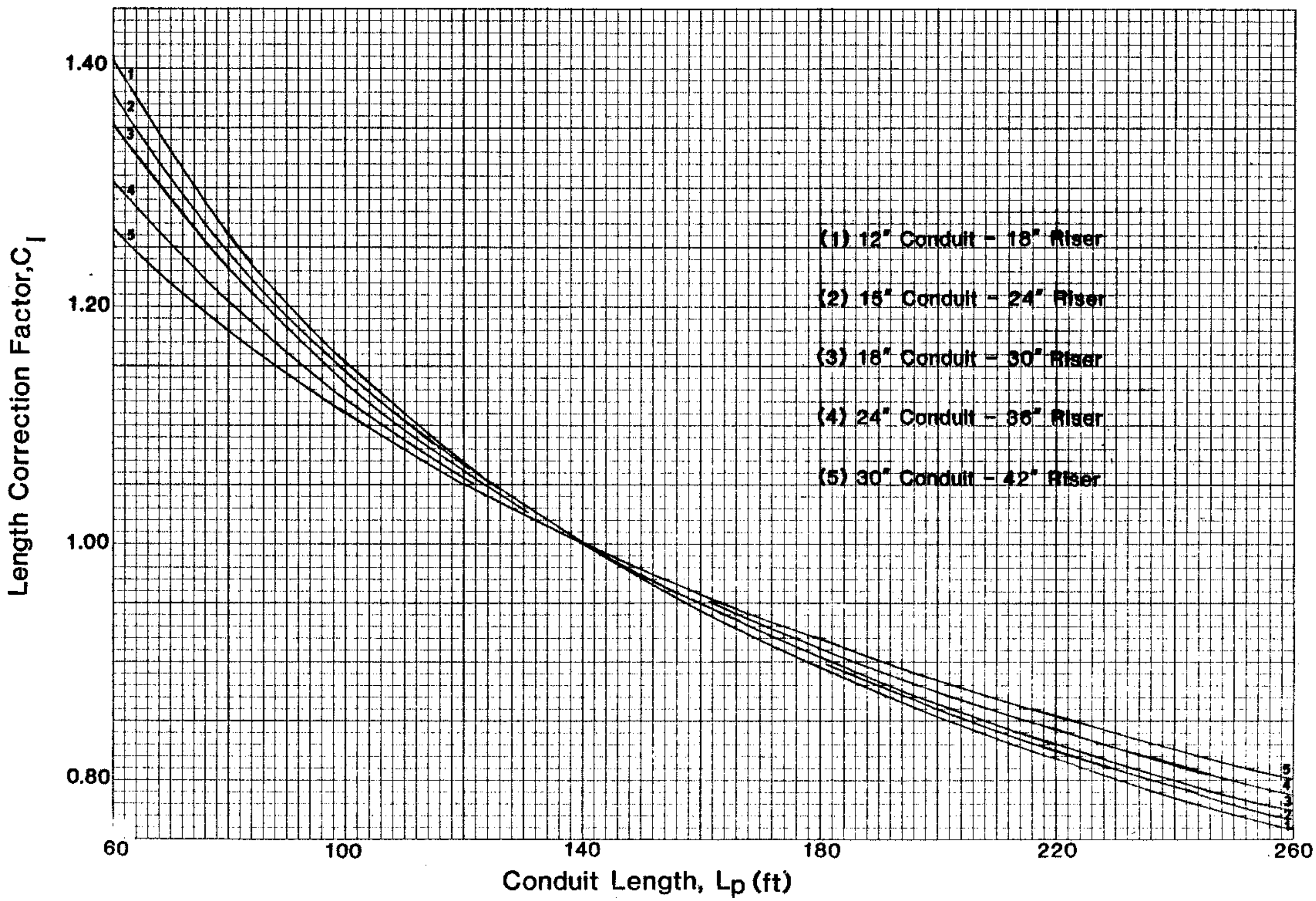


Figure 12 Conduit length discharge correction factors for riser and conduit princ' l spillways.

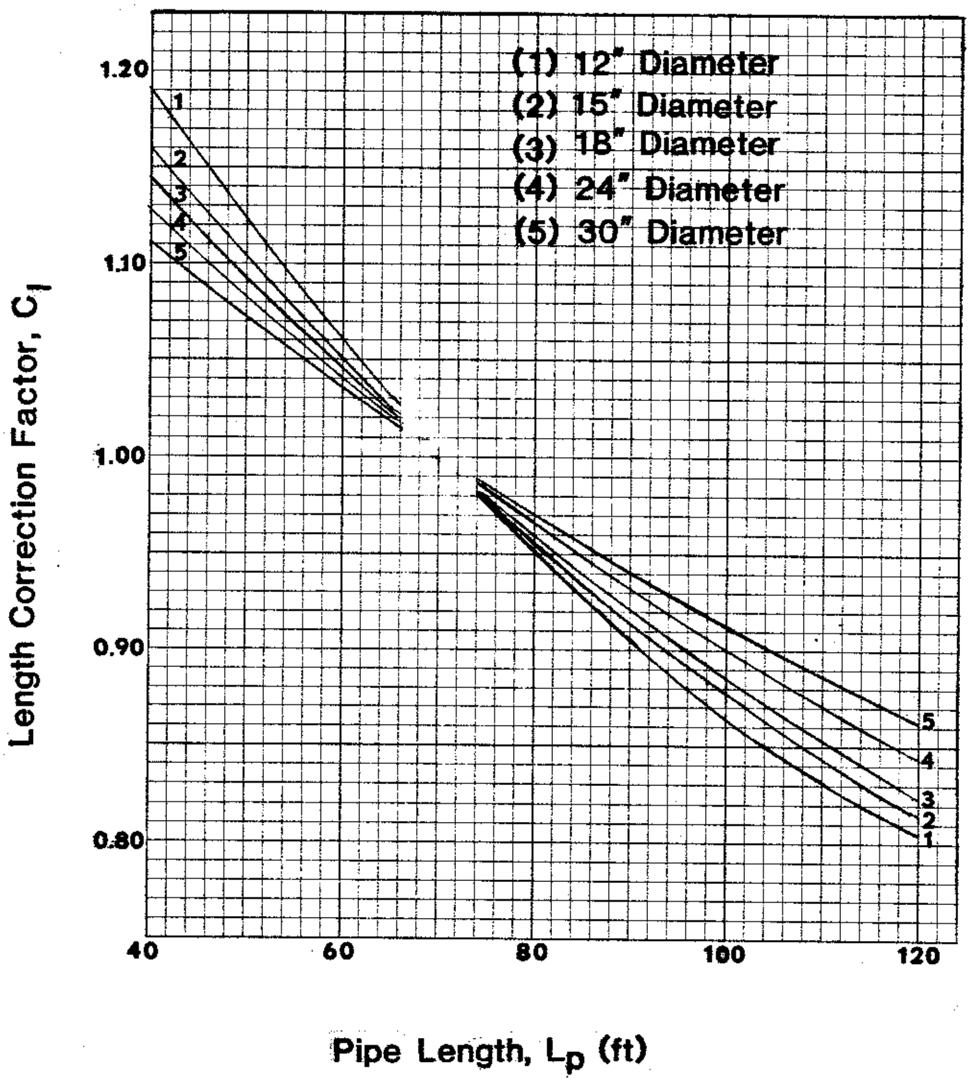


Figure 13 Pipe length discharge correction factors for trickle tube principal spillways.

Calculation of settleable solids concentration

The maximum settleable solids concentration for conduit and riser principal spillways is given by:

$$C_{se} = \frac{6.871 \times 10^{-7}}{1250} D^{2.694} \frac{Q_{vi}^{\;2.000}}{\Delta V_{sp}^{\;1.189}} \left(\frac{Q_{po}}{Q_{pi}}\right)^{2.399} C_{su}^{\;0.9396} \qquad (21)$$

and for trickle tube principal spillways by:

$$C_{se} = \frac{1.738 \times 10^{-4}}{1250} D^{\;1.222} \frac{Q_{vi}^{\;2.796}}{\Delta V_{sp}^{\;1.541}} \left(\frac{Q_{po}}{Q_{pi}}\right)^{2.076} C_{su}^{\;0.9587} \qquad (22)$$

where C_{se} is the settleable solids concentration in ml/l, D is the pond depth in feet measured from the sediment pool elevation to the maximum water surface elevation, Q_{vi} is the watershed runoff volume in acre-feet, ΔV_{sp} is the pond storage volume in acre-feet at the principal spillway crest or invert (incremental volume between the sediment pool and principal spillway), Q_{po} is the peak outflow in cubic feet per second, Q_{pi} is the peak watershed inflow in cubic feet per second, and C_{su} is the average inflow suspended solids concentration in mg/l.

The average inflow suspended solids concentration is given by:

$$C_{su} = 735 \frac{Y_i}{Q_{vi} + 2.94 \times 10^{-4}\; Y_i} \qquad (23)$$

where Y_i is the pond inflow sediment mass in tons and Q_{vi} is the inflow runoff volume in acre-feet. All other terms in equations 21 and 22 are given by previous equations and figures or can be obtained from the stage-area or stage-storage relationships for the sediment pond.

Equations 21 and 22 were developed by a regression analysis of data generated for watershed drainage areas which ranged from 23 acres to 101 acres, average inflow suspended solids concentrations which ranged from 2,800 mg/l to 574,000 mg/l, and effluent settleable solids which ranged from approximately 0.019 ml/l to 2.8 ml/l. The R^2 values for equations 21 and 22 were 0.65 and 0.62, respectively. The standard errors ranged from 0.30 ml/l to 0.82 ml/l for equation 21 and 0.27 ml/l to 0.91 ml/l for equation 22 (the standard error ranges are based on a settleable solids concentration of 0.5 ml/l).

To assist in obtaining an initial estimate of the permanent pool storage volume and discharge reduction required to meet a settleable solids concentration of 0.5 ml/1 a second set of regression equations was developed by eliminating D from equations 20 and 21. The discharge ratio prediction equations are:

$$\frac{Q_{po}}{Q_{pi}} = \left(\frac{1250}{0.5132} \; \frac{C_{se}}{C_{su}} \; 0.4116 \quad \frac{\Delta V_{sp}}{Q_{vi}} \; \frac{0.6167}{1.954} \right)^{1.066} \qquad (24)$$

for conduit and risers and

$$\frac{Q_{po}}{Q_{pi}} = \left(\frac{1250}{0.007311} \; \frac{C_{se}}{C_{su}} \; 0.8327 \quad \frac{\Delta V_{sp}}{Q_{vi}} \; \frac{1.179}{2.703} \right)^{0.5405} \qquad (25)$$

for trickle tubes.

The above equations can be used in conjunction with equations 21 and 22 and the sediment pond routing procedures previously discussed to produce a sediment pond design. Worksheet 5 has been provided for calculating settleable solids.

(1) Determine the sediment pool elevation, E_s, sediment pool volume, V_s, sediment pond inflow volume, Q_{vi}, and inflow suspended solids, C_{su}, and record these parameters at the top of worksheet 5.

(2) Estimate an initial principal spillway elevation, E_p, needed to meet the settleable solids effluent limitation and obtain the corresponding volume, V_p, from the sediment pond stage-volume curve. Record E_p and V_p in columns 4 and 5 of worksheet 5.

(3) For a conduit and riser principal spillway, calculate the elevation of the dewatering orifice E_o [$E_o = E_s + (E_p - E_s)/2$] and obtain the corresponding volume, V_o. Record E_o and V_o in columns 2 and 3.

(4) Obtain the sediment pond surface area, A_p, at the principal spillway from the stage-area relationship and record A_p in column 6.

(5) Calculate ΔV_{op} ($\Delta V_{op} = V_p - V_o$) and record ΔV_{op} in column 7. ΔV_{op} is zero for trickle tube principal spillways.

(6) Calculate $Q_{vi} - \Delta V_{op}$ and record the value in column 8 (for conduit and riser principal spillways only).

(7) Using the principal spillway incremental storage volume, ΔV_{sp}, ($\Delta V_{sp}=V_p-V_s$) calculate the required discharge reduction ratio, Q_r, with equation 24 or 25. Record ΔV_{sp} in column 9 and Q_r in column 10 of worksheet 5.

(8) Enter Figure 8 or 9 with the discharge reduction ratio determined in step 7 and obtain V_{rs}. Record V_{rs} in column 11.

(9) Multiply V_{rs} by $(Q_{vi}-\Delta V_{op})/A_p$ to determine ΔE_{pm} ($\Delta E_{pm} = H_r$ or H_t for conduit and riser or trickle tube principal spillways, respectively). Enter H_r or H_t in column 12.

(10) Use equation 15 to determine if the principal spillway fractional depth, P_f, is greater than 0.40.

(11) If P_f is less than 0.40, increase the principal spillway elevation and repeat steps 2-10.

(12) Select a principal spillway size and use H_r or H_t determined in step 9, to complete steps 1-5 of the sediment pond routing procedure discussed in the previous section. Record the routed H_r or H_t in column 14.

(13) If H_r or H_t determined in step 5 of the sediment pond routing procedure (column 14) is less than H_r or H_t determined in step 9 above (column 12), the principal spillway size may need to be reduced to meet the 0.5 ml/l effluent limitation.

(14) If H_r or H_t determined in step 5 of the sediment pond routing procedure is approximately equal to or greater than H_r or H_t determined in step 9 above, complete steps 7-15 of the sediment pond routing procedure. Record the final H_r or H_t in column 15 of worksheet 5.

(15) After the routing has been completed, use equation 15 to make a final check on the principal spillway fractional depth and enter the fractional depth in column 16.

(16) Calculate D ($D = E_p + \Delta E_{pm} - E_s$) and enter D in column 17.

(17) Record the indicated parameters in columns 18-22 and calculate the settleable solids concentration using equation 21 or 22. Record the settleable solids in column 23.

(18) If the settleable solids concentration does not meet the effluent limitation or is significantly below the effluent limitation, repeat steps 2-17 with an adjusted principal spillway elevation or spillway size.

Design Step 5 - Emergency Spillway Design (worksheet 6)

To satisfy cumulative impact assessment flood control criteria for new structures, the combined principal spillway and emergency spillway peak overflow must be equal to or less than the pre-mining peak inflow to the sediment pond (Department for Surface Mining Reclamation and Enforcement, 1982). Consequently, in designing the emergency spillway (1) the runoff volume and peak inflow to the sediment pond must be determined for the 25-year, 24-hour storm, and (2) the 25-year storm must be routed through the sediment pond to determine the peak outflow. The following paragraphs describe a graphical routing procedure which can be used to design an emergency spillway to handle the 25-year, 24-hour storm. The graphical routing procedure assumes that the emergency spillway crest elevation is set at the maximum water surface elevation for the 10-year, 24-hour storm. Worksheet 6 in Appendix A has been provided for use with the graphical routing procedure.

The 25-year, 24-hour peak discharge for the pre-mining condition (Department for Surface Mining Reclamation and Enforcement, 1981) can be determined using the procedures outlined in design steps 1 and 2 and worksheets 1 and 2. The 25-year discharge should be entered in column 11 of worksheet 6. The following material provides a step-by-step procedure for designing the emergency spillway.

(1) Determine the difference between the 25-year and the 10-year storm inflow volumes and peak inflows as indicated at the top of worksheet 6.

(2) Assume an emergency spillway crest elevation, (E_e), equal to the routed 10-year, 24-hour storm maximum water surface elevation, E_m, and enter the elevation in column 1 of worksheet 6.

(3) From the sediment pond stage-volume curve read the volume, V_e, at the emergency spillway crest elevation, E_e, and record V_e in column 2.

(4) Assume an emergency spillway head, H_e, for the routed 25-year, 24-hour storm and calculate the maximum water elevation E_{me} ($E_{me} = E_e + H_e$). Enter H_e in column 3.

(5) From the stage-volume curve read the maximum storage, V_{me}, at the maximum water surface elevation, E_{me}, and record V_{me} in column 4.

(6) Subtract V_e (column 2) from V_{me} (column 4) to determine the incremental volume ΔV_{em}. Enter ΔV_{em} in column 5.

(7) Divide ΔV_{em} by ΔQ_{vi} and enter the result in column 6.

(8) Enter Figure 14 with $\Delta V_{em}/ \Delta Q_{vi}$ and obtain the outflow to inflow ratio ($Q_{eo}/ \Delta Q_{pi}$). Record the outflow to inflow ratio in column 7.

(9) Multiply ($Q_{eo}/ \Delta Q_{pi}$) by ΔQ_{pi} to determine Q_{eo} and record Q_{eo} in column 8.

(10) Determine the peak discharge for the principal spillway, Q_{po}, from Figure 10 or 11 using H_{τ} or H_t, where $H_{\tau} = E_{em} - E_p + \Delta H$ and $H_t = E_{em} - E_p$. Enter Q_{po} in column 9.

(11) Sum Q_{eo} and Q_{po} to determine the total routed peak outflow, Q_{pe}, for the principal and emergency spillways and record the peak outflow in column 10.

(12) Compare Q_{pe} (column 10) with the 25-year, 24-hour pre-mining peak outflow, Q_{pm} (column 11). If Q_{pe} is greater than Q_{pm}, repeat steps 4-11 with a higher assumed H_e.

(13) If Q_{pe} is significantly less than Q_{pm}, the remaining steps will produce a conservative design and it may be desirable to repeat steps 4-11 with a lower assumed H_e.

(14) If Q_{pe} is equal to or slightly less than Q_{pm}, perform steps 15-19.

(15) Choose a side slope ratio (H:V) to insure stability of the spillway cut and enter the side slope in column 12.

(16) Using the emergency spillway head, H_e, obtain a discharge, Q_{tr}, for the triangular portion of the emergency spillway cross-section from Figure 15. Record Q_{tr} in column 13.

(17) From Figure 16 read the peak discharge, Q_b, for the rectangular portion of the emergency spillway cross-section. Q_b has units of discharge per unit foot of width. Enter Q_b in column 14.

(18) The emergency spillway bottom width, BW, is determined by the equation:

$$BW = (Q_{eo} - Q_t)/Q_b$$

(19) Round the bottom width to the nearest 1 foot and record in column 15.

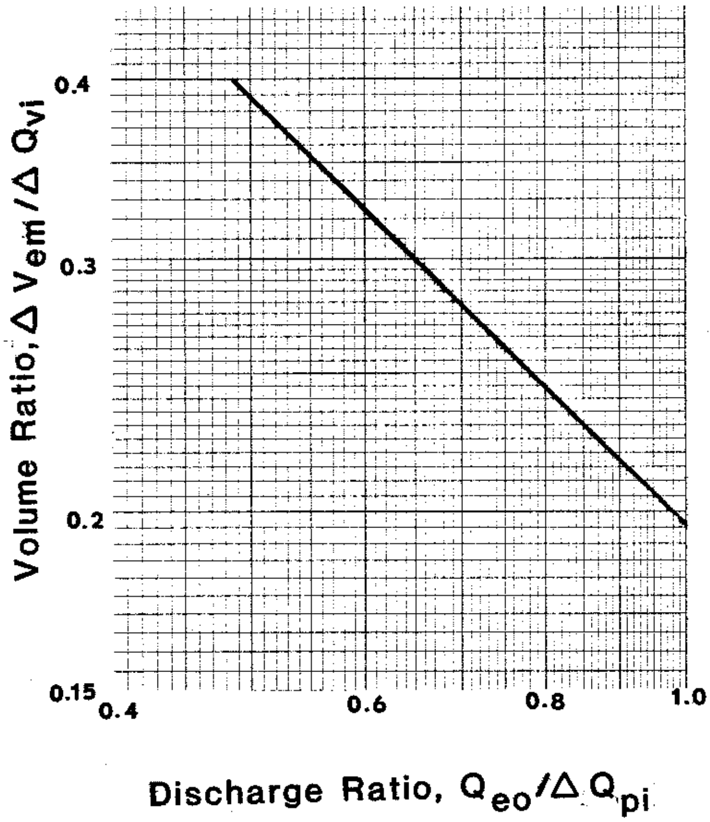


Figure 14 Routed peak discharge for the emergency spillway (After Soil Conservation Service, 1975).

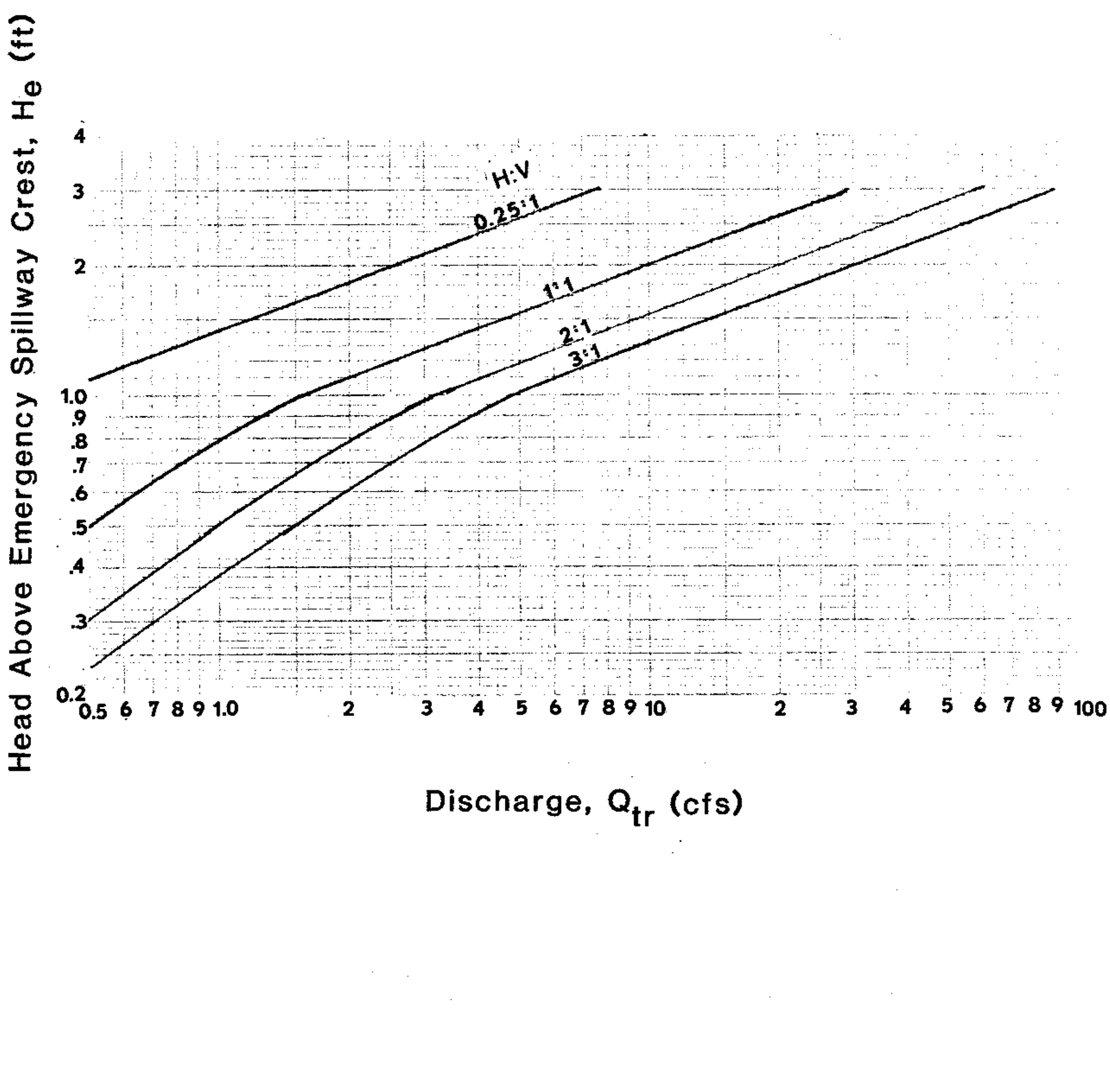


Figure 15 Stage discharge relationship for the triangular portion of a trapezoidal emergency spillway.

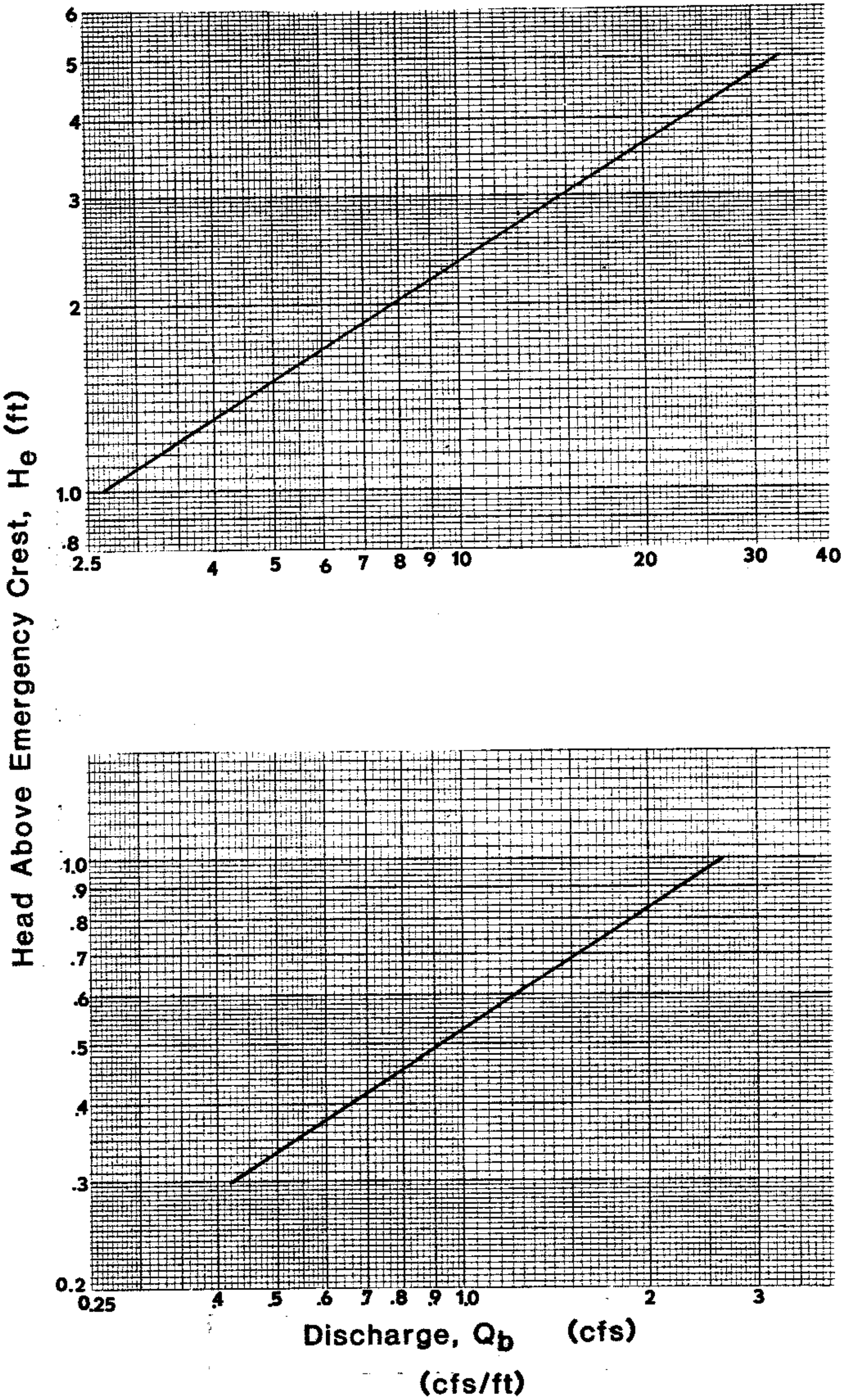


Figure 16 Stage discharge relationship for the rectangular portion of a trapezoidal emergency spillway.

APPENDIX A

WORKSHEETS

CONTENTS

WORKSHEET 1

Design Step 2 - Calculation of Time of Concentration and Travel Time

(1) Watershed and Segment	(2) Surface Condition	(3) Hydraulic Length (ft)	(4) Average Slope (%)	(5) Velocity (ft/sec)	(6) Segment T_c or T_t (hr)	(7) Watershed T_c (hr)	(8) Watershed T_t (hr)	(9) $T_c + T_t$ (hr)

WORKSHEET 2

Design Step 2 - Determination of Peak Discharge and Runoff Volume

(1) Watershed	(2) T_c (hr)	(3) T_t (hr)	(4) CN	(5) q_{u_2} (cfs/mi^2/in)	(6) Q (in)	(7) A (ac)	(8) Q_v (ac-ft)	(9) Q_p (cfs)	(10) F_t	(11) q_{t_2} (cfs/mi^2/in)	(12) Rounded $T_c + T_t$ (hr)

(1) Sub-watershed identification.
(2) From column 7 worksheet 1.
(3) From column 8 worksheet 1.
(4) From Table 1.
(5) From Figure 1.
(6) From Figure 3.
(8) (6) X (7)/12.
(9) (5) X (6) X (7)/640.
(10) From Figure 4.
(11) (5) X (10).

WORKSHEET 2 (CONTINUED)

Design Step 2 - Determination of Peak Discharge and Runoff Volume

(13) F_h − +										(14) Water-shed	(15) q_t (cfs/ mi^2/in)	(16) Q_t(cfs)									

(13) From Figure 5 and Figure 6.
(14) Sub-watershed identification.
(15) From column 11.
(16) (13) X Q_p.

WORKSHEET 3

Design Step 3 -Determination of Sediment Load

Watershed	(1) Q_v (ac-ft)	(2) Q_p (cfs)	(3) L_e (ft)	(4) S_o (%)	(5) LS	(6) K	(7) CP	(8) Y (tons)

(1) From column 8 worksheet 2
(2) From column 9 worksheet 2.
(5) From Figure 7.
(6) From Table 3.
(7) From Table 3.
(8) From equation 13.

WORKSHEET 4

Determination of Routed Peak Discharge for the 10-Year, 24 Hour Storm

Q_{pi} ____________ (cfs) C_1 ____________

Initial Routing Using V_{rs}						
(1) Principal size (in)	(2) H_r/H_t (ft)	(3) Q_{po} (cfs)	(4) Q_r	(5) V_{rs}	(6) $\frac{Q_{vi}-\Delta V_{op}}{A_p}$ (ft)	(7) ΔE_{pm} (ft)

(1) Selected principal size.
(2) Initial estimated value of H_r/H_t from worksheet 5 column 12.
(3) From Figure 10 or 11 multiplied by the length correction factor from Figure 12 or 13.
(4) (3)/Q_{pi}.
(5) From Figure 8 or 9.
(6) Worksheet 5 (8)/(6).
(7) (5) x (6).

WORKSHEET 4 (CONTINUED)

Determination of Routed Peak Discharge for the 10-Year, 24 Hour Storm

Final Routing Using V_{rv}											
(8) Principal size (in)	(9) H_r/H_t (ft)	(10) Q_{po} (cfs)	(11) Q_r	(12) V_{rv}	(13) $Q_{vi}-\Delta V_{op}$ (ac-ft)	(14) ΔV_{pm} (ac-ft)	(15) V_p (ac-ft)	(16) V_m (ac-ft)	(17) E_m (ft)	(18) E_p (ft)	(19) H_r/H_t (ft)

(8) Selected principal size.
(9) From (7) for first trial or (19) for subsequent trials.
(10) From Figure 10 or 11 multiplied by the length correction factor from Figure 12 or 13.
(11) (10)/Q_{pi}.
(12) From Figure 8 or 9.
(13) From column 8 worksheet 5.
(14) (12) X (13)
(15) From column 5 worksheet 5.
(16) (14) + (15).
(17) From sediment pond stage-volume relationship for V_m.
(18) Selected principal spillway elevation from worksheet 5 column 4.
(19) (17) - (18).

WORKSHEET 5

Calculation of Settleable Solids

E_s ________ (ft) V_s ________ (ac-ft) Q_{vi} ________ (ac-ft) C_{su} ________ (mg/l)

(1) Principal size (in)	(2) E_o (ft)	(3) V_o (cfs)	(4) E_p (ft)	(5) V_p (ac-ft)	(6) A_p (ac)	(7) ΔV_{op} (ac-ft)	(8) $Q_{vi}-\Delta V_{op}$ (ac-ft)	(9) ΔV_{sp} (ac-ft)	(10) Q_r	(11) V_{rs}	(12) H_r/H_t (ft)

(1) Selected principal size.
(2) Elevation at the dewatering orifice. $E_o = E_s + (E_p - E_s)/2$.
(3) From sediment pond stage-volume relationship.
(4) Selected principal spillway elevation.
(5) From sediment pond stage-volume relationship.
(6) From sediment pond stage-area relationship.
(7) (5) - (3).
(8) Q_{vi} - (7).
(9) (5) - V_s.
(10) From equation 24 or 25.
(11) From Figure 8 or 9.
(12) (11) X (8)/(6).

WORKSHEET 5 (CONTINUED)

Calculation of Settleable Solids

(13) Principal size (in)	(14) H_r/H_t (ft)	(15) H_r/H_t (ft)	(16) P_f (ft)	(17) D (ft)	(18) Q_{vi} (ac-ft)	(19) ΔV_{sp} (ac-ft)	(20) Q_{po} (cfs)	(21) Q_{pi} (cfs)	(22) C_{su} (mg/l)	(23) C_{se} (ml/l)

(13) Selected principal size.
(14) From column 7 worksheet 4.
(15) From column 19 worksheet 4.
(16) From equation 16.
(17) (4) + (15) - E_s.
(18) From equation 12.
(19) From column 9.
(20) From column 10 worksheet 4.
(21) From equation 9 or 10.
(22) From equation 23.
(23) From equation 21 or 22.

WORKSHEET 6

Determination of Emergency Spillway Routed Peak
Discharge for the 25-Year, 24-Hour Storm

ΔQ_{vi} = Q_{vi} (25-yr)________ac-ft - Q_{vi} (10-yr)________ac-ft =_______ac-ft.

ΔQ_{pi} = Q_{pi} (25-yr)__________cfs - Q_{pi} (10-yr)__________cfs = _______cfs.

(1) E_e (ft)	(2) V_e (ac-ft)	(3) H_e (ft)	(4) V_{me} (ac-ft)	(5) ΔV_{em} (ac-ft)	(6) $\frac{\Delta V_{em}}{\Delta Q_{vi}}$	(7) $\frac{Q_{eo}}{\Delta Q_{pi}}$

(8) Q_{eo} (cfs)	(9) Q_{po} (cfs)	(10) Q_{pe} (cfs)	(11) Q_{pm} (cfs)	(12) Side slope (H:V)	(13) Q_{tr} (cfs)	(14) Q_b (cfs/ft)	(15) BW (ft)

Emergency Spillway Crest____________ft. Peak Stage___________ft.

Bottom Width___________ft. Side slopes___________(H:V).

Pre-mining Discharge___________cfs. Pond Routed Discharge__________cfs.

(1) From column 17 worksheet 4.
(2) From sediment pond stage-volume relationship for E_e.
(3) Assumed emergency spillway head.
(4) From sediment pond stage-volume. relationship for E_{me}. ($E_{me} = E_e + H_e$).
(5) (4) - (2).
(6) (5)/ΔQ_{vi}.
(7) From Figure 14.
(8) (7) x Q_{pi}.
(9) From Figure 10 or 11.
(10) (8) + (9).
(11) Pre-mining peak discharge.
(12) Selected side slope.
(13) From Figure 15.
(14) From Figure 16.
(15) ((C8) - (C13))/C14).

APPENDIX B

EXAMPLE

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Example 1 - Mountaintop Removal Operation

A mountaintop removal operation is proposed for the watershed presented in Figure B-1. The operation will generate 15.2 acres of disturbance as a result of coal extraction and produce an additional 3.6 acres of disturbance through the construction of two valley fills. The remaining portion of the watershed (12.3 ac) will be kept in the original forested condition. The proposed sediment pond location is at a drainage area of 31.1 acres.

Selection of Sub-watersheds

The 31.1 acre total watershed was divided into seven sub-watersheds (Figure B-1) for the purpose of calculating peak discharge and sediment load. A summary of sub-watershed information representative of a "worst case" condition is presented in Table B-1. Parameter values from TRM #6 were used for all sub-watersheds. Even though the watershed has a drainage area less than 40 acres, travel time and time of concentration were used in determining peak discharge to illustrate the calculation procedure.

Determination of Peak Discharge and Runoff Volume

Time of concentration, T_c, values were calculated first for each of the sub-watersheds according to the following steps:

(1) Hydraulic segment lengths and slopes for each sub-watershed were determined and entered in columns 3 and 4 of worksheet 1 (Figure B-2), respectively.

(2) The overland flow velocity for each of the segments was determined using Figure 2 and the results were entered in column 5 of worksheet 1 (Figure B-2).

(3) The segment length was divided by the velocity, according to equation 2, to determine the segment travel time and the results were recorded in column 6 of worksheet 1 (Figure B-2).

(4) When all segments within a particular sub-watershed were completed, the individual segment T_c values were summed and entered in column 7 of worksheet 1 (eq. 2).

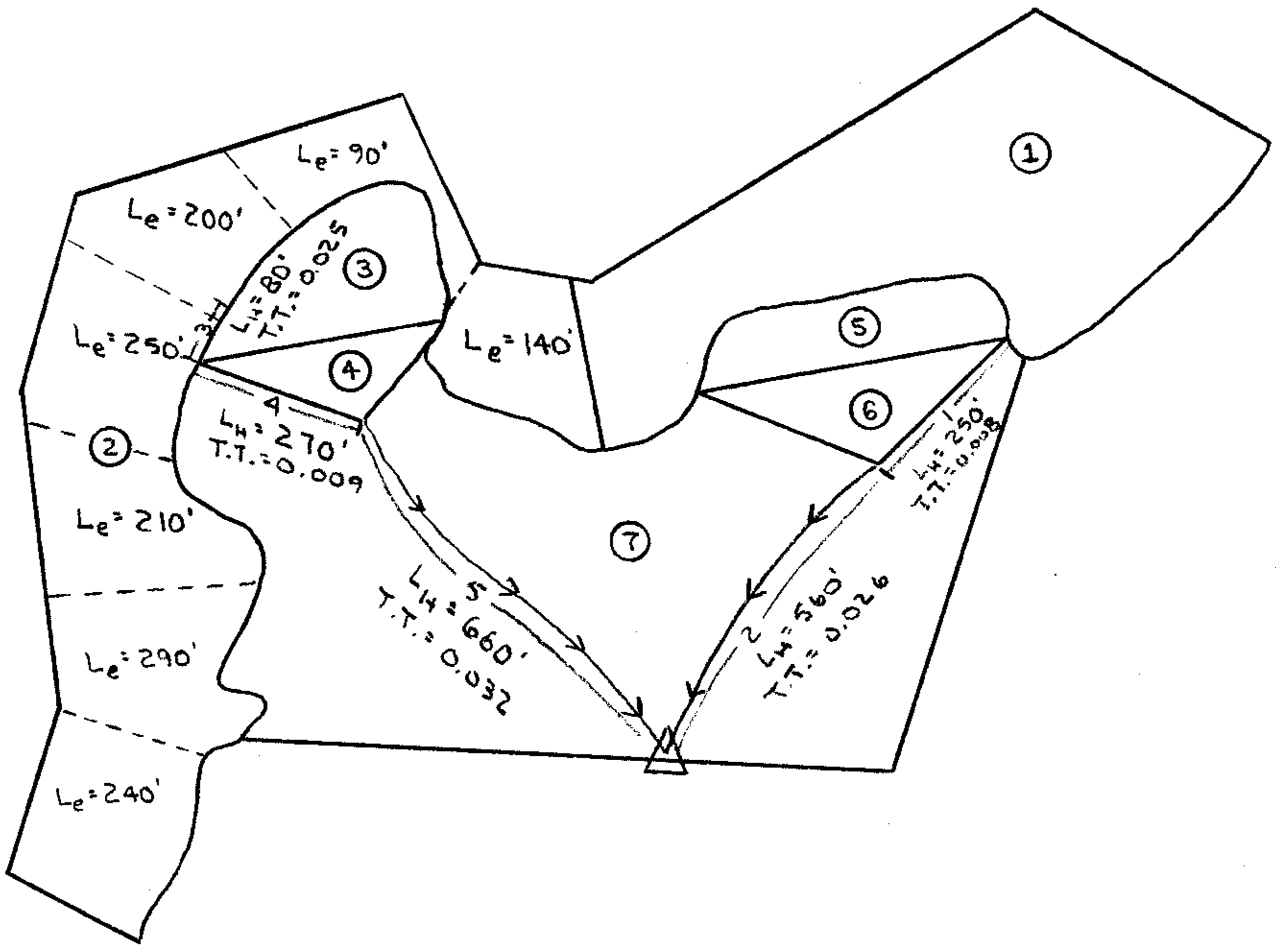


Figure B-1 Location map.

TABLE B-1

Summary of Sub-watershed Surface Conditions

Watershed	Surface Condition	Area (ac)	CN	K	CP
1	Reclaimed; 0-2 months vegetation	6.5	79	.22	.14
2	Backfilled & graded; bare	8.7	86	.22	.90
3	Valley fill; graded, bare	1.1	86	.22	.90
4	Valley fill; graded, bare	0.7	86	.22	.90
5	Valley fill; 0-2 months vegetation	1.0	79	.22	.14
6	Valley fill; 0-2 months vegetation	0.8	79	.22	.14
7	Undisturbed forest	12.3	73	.17	.003

In calculating the travel time, T_t, for each sub-watershed, the channel reaches downstream from each sub-watershed were numbered (see Figure B-1) and the reach numbers were entered in column 1 of worksheet 1 (Table B-3). The travel time for each reach was calculated in a manner similar to the above procedure for calculating time of concentration. The individual reach travel times were written on the map in Figure B-1 next to the reach numbers to facilitate computation of the travel time, T_t, for each sub-watershed.

The sub-watershed travel time was calculated by summing the appropriate reach travel times contained on Figure 1. The results were entered in column 8 of worksheet 1 (Table B-2) for each sub-watershed.

The time of concentration and travel time values were then added and entered in column 9 on worksheet 1 (Table B-2) and the T_c + T_t values were rounded to the nearest 0.05 hr. and entered in column 12 of worksheet 2 (Table B-4).

With T_c and T_t determined, the peak discharge, Q_p, and runoff volume, Q_v, were calculated according to the following steps:

(1) The unit peak discharge was determined from Figure 1 and entered in column 5 of worksheet 2 (Table B-4).

(2) A 10-year, 24-hour rainfall of 4.0 inches (Carter County) was selected from Table 2.

(3) The runoff volume, Q, was determined from Figure 3 and entered in column 6 of worksheet 2 (table B-4).

(4) The runoff volume in acre-feet, Q_v, was determined (eq. 7) and entered in column 8 of worksheet 2 (Table B-4).

(5) The peak sub-watershed discharge, Q_p, was calculated (eq. 1) and entered in column 9 of worksheet 2 (Table B-4).

The sub-watershed unit peak discharge was adjusted for travel time from the sub-watershed outlet to the sediment pond by obtaining travel time reduction factors, F_t, from Figure 4 and multiplying the unit peak discharge, q_u, (column 5) by the reduction factor (column 10). The adjusted peak discharge was entered in column 11 of worksheet 2 (Table B-4).

The sub-watershed peak discharge, Q_p, was also adjusted for travel time from the sub-watershed outlet to the sediment pond (eq. 5) and the adjusted discharge, Q_{pt}, was entered in column 16 at the appropriate rounded T_c + T_t values (the top line of column 16 was labeled according to the range of rounded T_c + T_t values; .05, .10, .15).

Inspection of column 16 of worksheet 2 revealed that the largest sub-watershed peak discharges occurred at $T_c + T_t$ values of 0.10 and 0.15 hours. Consequently, it was only necessary to calculate hydrograph ordinates for $T_c + T_t$ values of 0.10 and 0.15 hours.

Peak discharge to hydrograph conversion factors, F_h, were obtained from Figures 5 and 6 for the corresponding sub-watershed adjusted unit discharge, q_t, (column 15) and at time increments of 0.05 hour on either side of the peak discharge and entered in column 13 of worksheet 2. For example, the peak discharge for sub-watershed 1 occurred at a $T_c + T_t$ time of 0.15 hours and a hydrograph ordinate value was needed at .05 hours before the peak ($T_c + T_t$ = 0.10 hr.). A value of F_h was obtained from Figure 5 at - .05 hours (rising limb of hydrograph or time prior to the peak discharge) and placed in the corresponding section of column 13, worksheet 2. The conversion factor, F_h, (0.93) was then multiplied with the peak discharge for sub-watershed 1 (10.4 cfs) and the result entered under a $T_c + T_t$ time of 0.10 hour (-0.05 hr. prior to the peak) in column 16. Other hydrograph ordinates in column 16 were determined in a similar manner.

After all hydrograph ordinates were calculated, the peak discharge for the watershed (inflow to the sediment pond) was determined by summing the hydrograph ordinates for $T_c + T_t$ equal to 0.10 and 0.15 hours and selecting the maximum discharge (eq. 6).

Determination of Sediment Load

Worksheet 3 (Table B-5) was used with equation 8 to calculate the sediment load for each sub-watershed. The sub-watershed sediment loads were summed to generate the pond inflow sediment load.

Area weighted erosion slope lengths, L_e, were determined for each sub-watershed by visually dividing the sub-watershed into approximately equal areas and averaging the slope lengths for all areas in the sub-watershed. The LS factors were obtained from Figure 7 and entered in column 5 of worksheet 3 (Table B-5). Soil erodibility, K, and control practice, CP, factors were obtained from Table 3 and entered in columns 6 and 7, respectively. Sediment loads were determined with equation 8 and entered in column 8 of worksheet 3.

Principal Spillway Design

The required sediment pool storage volume was determined first and then worksheets 4 and 5 were used to design the principal spillway.

Sediment Storage Volume

As previously noted, the example operation has a disturbed area of 18.8 acres. Providing a sediment pool volume of 0.075 acre-feet per acre disturbed would yield a sediment pool storage volume of 1.41 acre-feet. However, the 10-year, 24-hour storm sediment load is 1990 tons which converts to a sediment volume (equation 15) of 1.76 acre-feet. Using a minimum sediment storage volume of 1.5 times the 10-year, 24-hour storm sediment volume produces a sediment storage of 2.63 acre-feet and a corresponding sediment pool elevation of 15.0 feet (Figure B-2). For this design example the sediment pool elevation was increased 0.5 feet above the minimum to an elevation of 15.5 feet.

Selection of a principal spillway size and type

Worksheet 5 (Table B-7) was used to begin the principal spillway design process. An initial principal spillway elevation of 17.5 feet was assumed for a 12"-18" conduit-riser spillway (2.0 feet above the sediment pool) and basic information concerning the pond was entered at the top of worksheet 5 and in columns 1-9. Equation 24 was used to calculate the discharge ratio, Q_r, needed to meet the settleable solids effluent limitation of 0.5 ml/l. The discharge ratio of .300 (column 10) was used with Figure 8 to produce a volume ratio, V_{rs}, of 0.183 (column 11) and an H_r of 1.33 feet (column 12). The H_r value in column 12 is the estimated head needed to meet the effluent limitation as determined from equation 24. An H_r of 1.33 yields a fractional depth, P_f, of .60. The initial H_r was entered in column 2 of worksheet 4 (Figure B-6) to perform the routing using the V_{rs} routing function. Two iterations produced a E_{pm} (H_r) of 2.23 feet and a P_f 0.47. The final routing using the V_{rv} routing function produced an H_r of 2.62 feet (column 9-14) and a peak discharge of 6.2 cfs. The routing settleable solids concentration was 0.01ml/l (column 23 of worksheet 5), well below the effluent limitation. The maximum water surface elevation (pond height) was 20.1 feet (column 17 of worksheet 4).

Since the settleable solids concentration produced in the first trial indicated that a smaller pond could possibly meet the effluent limitation, a 18"-30" conduit-riser spillway at an elevation of 16.5 feet was analyzed. The resulting settleable solids concentration was 0.35 ml/l, (column 23, worksheet 5) the maximum water surface was 18.0 feet (column 27, worksheet 4) and the peak outflow was 16.8 cfs (column 10 worksheet 4).

Emergency spillway design

Procedures summarized in worksheet 6 were used to design the emergency spillway to control the total sediment pond outflow for the 25-year, 24-hour storm such that the pre-mining 25-year, 24-hour peak discharge was not exceeded. The pre-mining 25-hour peak discharge (37.8 cfs) was calculated for a forested condition with equation 1 and worksheets 1 and 2 (Tables B-8 and B-9). The resulting discharge was entered in column 11 of worksheet 6 (Table B-10). The during mining 25-year, 24-hour storm peak discharge was calculated using worksheet 2 (Table B-9). The same time of concentration and travel time values initially used with the 10-year storm were used with the 25-year storm. The maximum routed 25-year discharge, (T_c and T_t used in calculations) was 66.7 cfs (column 16, worksheet 2, Table B-9) while the peak discharge calculated without considering the effects of travel time and time of concentration (equations 3-5) was 68.3 cfs, only 2 percent higher (column 9, worksheet 2, Table B-9). The 25-year, 24-hour during mining runoff and peak discharge were used to calculate ΔQ_{vi} and ΔQ_{pi} (top of worksheet 6, Table B-10). Following the calculation procedures summarized in worksheet 6, an initial head above the emergency spillway crest of 0.75 feet produced a peak outflow (principal plus emergency) of 29.1 cfs for an emergency spillway with a bottom width of 5.8 feet and 2:1 side slopes. Since the maximum outflow was well below the pre-mining discharge of 37.8 cfs, a lower water surface elevation, H_e, of 0.60 feet was assumed. A lower water surface means that less water is stored and a higher discharge will result due to a wider spillway bottom width. The resulting discharge was 31.9 cfs, still well below the pre-mining peak discharge of 37.8 cfs, and the spillway bottom width was 10.7 feet.

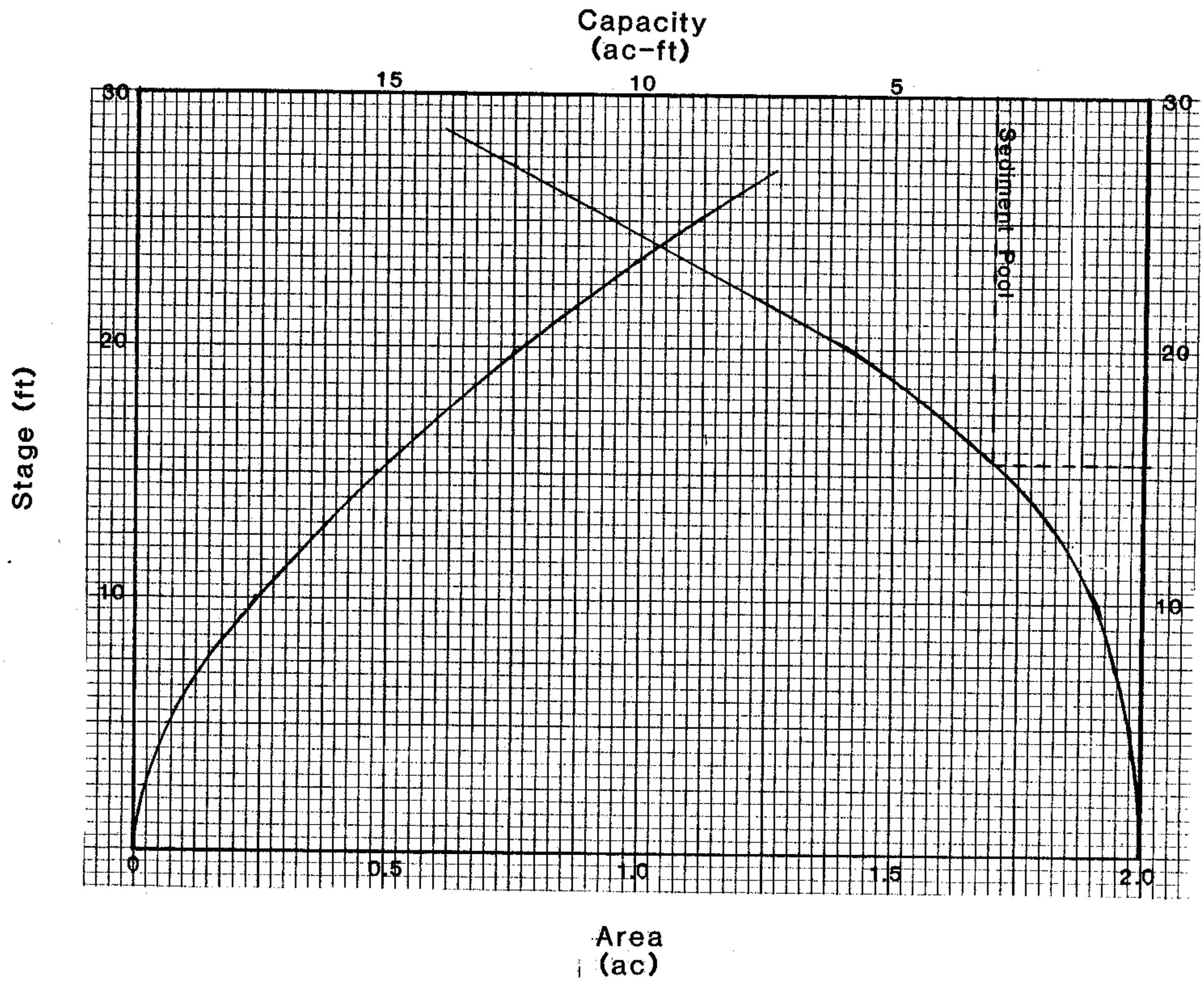


Figure B-2 Sediment pond area-capacity curves.

TABLE B-2

WORKSHEET 1

Design Step 2 - Calculation of Time of Concentration and Travel Time

(1) Watershed and Segment	(2) Surface Condition	(3) Hydraulic Length (ft)	(4) Average Slope (%)	(5) Velocity (ft/sec)	(6) Segment T_c or T_t (hr)	(7) Watershed T_c (hr)	(8) Watershed T_t (hr)	(9) $T_c + T_t$ (hr)
1-a	(3) RECLAIMED	400	19	3.0	0.037			
1-b	(7) DIVERSION	530	1	2.0	0.074	0.111	0.034	0.145
2-a	(4) DISTURBED	240	31	5.0	0.014	0.014	0.066	0.082
3-a	(4) DISTURBED	110	1	0.9	0.034			
3-b	(7) DIVERSION	190	1	2.0	0.026	0.060	0.041	0.101
4-a	(4) DISTURBED	140	36	5.4	0.007	0.007	0.032	0.039
5-a	(3) RECLAIMED	190	1	0.7	0.075			
5-b	(7) DIVERSION	110	1	2.0	0.015	0.090	0.034	0.124
6-a	(3) RECLAIMED	140	36	4.2	0.009	0.009	0.026	0.035
7-a	(1) FORREST	400	15	1.0	0.111			
7-b	(7) CHANNEL	500	8	5.7	0.024	0.135	0	0.135

TABLE B-3

WORKSHEET 1

Design Step 2 - Calculation of Time of Concentration and Travel Time

(1) Watershed and Segment	(2) Surface Condition	(3) Hydraulic Length (ft)	(4) Average Slope (%)	(5) Velocity (ft/sec)	(6) Segment T_c or T_t (hr)	(7) Watershed T_c (hr)	(8) Watershed T_t (hr)	(9) $T_c + T_t$ (hr)
1	(7) DIVERSION	250	20	9.0	0.008			
2	(7) CHANNEL	260	9	6.0	0.026			
3	(7) DIVERSION	80	1	2.7	0.025			
4	(7) DIVERSION	270	18	8.5	0.009			
5	(7) CHANNEL	660	8	5.7	0.032			

TABLE B-4

WORKSHEET 2

Design Step 2 - Determination of Peak Discharge and Runoff Volume

(1) Watershed	(2) T_c (hr)	(3) T_t (hr)	(4) CN	(5) q_{u_2} (cfs/mi^2/in)	(6) Q (in)	(7) A (ac)	(8) Q_v (ac-ft)	(9) Q_p (cfs)	(10) F_t	(11) q_{t_2} (cfs/mi^2/in)	(12) Rounded $T_c + T_t$ (hr)
1	0.111	0.034	79	560	1.9	6.5	1.029	10.8	0.96	540	0.15
2	0.014	0.066	86	670	2.6	8.7	1.885	23.7	0.92	620	0.10
3	0.060	0.041	86	670	2.6	1.1	0.238	3.0	0.95	640	0.10
4	0.007	0.032	86	670	2.6	0.7	0.152	1.9	0.96	640	0.05
5	0.090	0.034	79	560	1.9	1.0	0.158	1.7	0.97	540	0.10
6	0.009	0.026	79	560	1.9	0.8	0.127	1.3	0.98	550	0.05
7	0.135	0.	73	370	1.5	12.3	1.538	10.7	1.00	370	0.15

(1) Sub-watershed identification.
(2) From column 7 worksheet 1.
(3) From column 8 worksheet 1.
(4) From Table 1.
(5) From Figure 1.
(6) From Figure 3.
(8) (6) X (7)/12.
(9) (5) X (6) X (7)/640.
(10) From Figure 4.
(11) (5) X (10).

TABLE B-4 (CONTINUED)

WORKSHEET 2 (CONTINUED)

Design Step 2 - Determination of Peak Discharge and Runoff Volume

(13) F_h -									+	(14) Water-shed	(15) q_t (cfs/mi²/in)	(16) Q_t(cfs)									
				0.05	0.05	0.10						0	0.05	0.10	0.15						
				0.93						1	540			9.7	10.4						
					0.94					2	620			21.8	20.5						
					0.93					3	640			2.9	2.7						
					0.93	0.87				4	640		1.8	1.7	1.6						
					0.95					5	540			1.6	1.5						
					0.94	0.91				6	550		1.3	1.2	1.2						
				0.98						7	370			10.5	10.7						
													Σ	49.4	48.6						

(13) From Figure 5 and Figure 6.
(14) Sub-watershed identification.
(15) From column 11.
(16) (13) X Q_p.

TABLE B-5

WORKSHEET 3

Design Step 3 -Determination of Sediment Load

Watershed	(1) Q_v (ac-ft)	(2) Q_p (cfs)	(3) L_e (ft)	(4) S_o (%)	(5) LS	(6) K	(7) CP	(8) Y (tons)
1	1.029	10.8	250	19	6.00	0.22	0.14	67.6
2	1.885	23.7	200	31	11.60	0.22	0.90	1831.8
3	0.238	3.0	120	1	0.14	0.22	0.90	2.1
4	0.152	1.9	60	36	8.19	0.22	0.90	76.8
5	0.158	1.7	110	1	0.13	0.22	0.14	0.2
6	0.127	1.3	60	36	8.19	0.22	0.14	8.7
7	1.538	10.7	180	15	3.43	0.17	0.003	0.8
							ΣY	1988.0

(1) From column 8 worksheet 2
(2) From column 9 worksheet 2.
(5) From Figure 7.
(6) From Table 3.
(7) From Table 3.
(8) From equation 13.

TABLE B-6

WORKSHEET 4

Determination of Routed Peak Discharge for the 10-Year, 24 Hour Storm
Q_{pi} 49.4 (cfs) C_1 1.00

Initial Routing Using V_{rs}						
(1) Principal size (in)	(2) H_r/H_t (ft)	(3) Q_{po} (cfs)	(4) Q_r	(5) V_{rs}	(6) $\frac{Q_{vi}-\Delta V_{op}}{A_p}$ (ft)	(7) ΔE_{pm} (ft)
12-18	1.33	6.0	0.121	0.312	7.23	2.25
	2.25	6.1	0.124	0.309	7.23	2.23
NOTE: ΔE_{pm} IS MUCH > 1.33, SPILLWAY TOO SMALL, CALC. CONTINUE.						
18-30	2.32	17.2	0.348	0.155	8.66	1.34
	1.34	16.7	0.339	0.160	8.66	1.39

(1) Selected principal size.
(2) Initial estimated value of H_r/H_t from worksheet 5 column 12.
(3) From Figure 10 or 11 multiplied by the length correction factor from Figure 12 or 13.
(4) $(3)/Q_{pi}$.
(5) From Figure 8 or 9.
(6) Worksheet 5 (8)/(6).
(7) (5) x (6).

TABLE B-6 (CONTINUED)

WORKSHEET 4 (CONTINUED)

Determination of Routed Peak Discharge for the 10-Year, 24 Hour Storm

Final Routing Using V_{rv}											
(8) Principal size (in)	(9) H_r/H_t (ft)	(10) Q_{po} (cfs)	(11) Q_r	(12) V_{rv}	(13) $Q_{vi}-\Delta V_{op}$ (ac-ft)	(14) ΔV_{pm} (ac-ft)	(15) V_p (ac-ft)	(16) V_m (ac-ft)	(17) E_m (ft)	(18) E_p (ft)	(19) H_r/H_t (ft)
12-18	2.73	6.1	0.124	0.410	4.48	1.84	4.18	6.02	20.1	17.5	2.63
	2.63	6.2	0.125	0.409	4.48	1.83	4.18	6.01	20.1	17.5	2.62
18-30	1.39	16.8	0.339	0.202	4.85	0.978	3.53	4.51	18.0	16.5	1.50
	1.50	16.8	0.340	0.201	4.85	0.977	3.53	4.51	18.0	16.5	1.50

(8) Selected principal size.
(9) From (7) for first trial or (19) for subsequent trials.
(10) From Figure 10 or 11 multiplied by the length correction factor from Figure 12 or 13.
(11) (10)/Q_{pi}.
(12) From Figure 8 or 9.
(13) From column 8 worksheet 5.
(14) (12) X (13)
(15) From column 5 worksheet 5.
(16) (14) + (15).
(17) From sediment pond stage-volume relationship for V_m.
(18) Selected principal spillway elevation from worksheet 5 column 4.
(19) (17) - (18).

TABLE B-7

WORKSHEET 5

Calculation of Settleable Solids

E_s 15.5 (ft) V_s 3.03 (ac-ft) Q_{vi} 5.13 (ac-ft) C_{su} 256,000 (mg/l)

(1) Principal size (in)	(2) E_o (ft)	(3) V_o (cfs)	(4) E_p (ft)	(5) V_p (ac-ft)	(6) A_p (ac)	(7) ΔV_{op} (ac-ft)	(8) $Q_{vi}-\Delta V_{op}$ (ac-ft)	(9) ΔV_{sp} (ac-ft)	(10) Q_r	(11) V_{rs}	(12) H_r/H_t (ft)
12-18	16.5	3.53	17.5	4.18	0.62	0.65	4.48	1.15	0.300	0.183	1.33
18-30	16.0	3.25	16.5	3.53	0.56	0.28	4.85	0.50	0.174	0.268	2.32

(1) Selected principal size.
(2) Elevation at the dewatering orifice. $E_o = E_s + (E_p - E_s)/2$.
(3) From sediment pond stage-volume relationship.
(4) Selected principal spillway elevation.
(5) From sediment pond stage-volume relationship.
(6) From sediment pond stage-area relationship.
(7) (5) - (3).
(8) Q_{vi} - (7).
(9) (5) - V_s.
(10) From equation 24 or 25.
(11) From Figure 8 or 9.
(12) (11) X (8)/(6).

TABLE B-7 (CONTINUED)

WORKSHEET 5 (CONTINUED)

Calculation of Settleable Solids

(13) Principal size (in)	(14) H_r/H_t (ft)	(15) H_r/H_t (ft)	(16) P_f (ft)	(17) D (ft)	(18) Q_{vi} (ac-ft)	(19) ΔV_{sp} (ac-ft)	(20) Q_{po} (cfs)	(21) Q_{pi} (cfs)	(22) C_{su} (mg/l)	(23) C_{se} (ml/l)
12-18	2.23	2.62	0.43	4.6	5.13	1.15	6.2	49.4	256,000	0.01
NOTE: C_{se} IS MUCH < 0.5, SPILLWAY IS TOO SMALL.										
18-30	1.39	1.50	0.40	2.5	5.13	0.50	16.8	49.4	256,000	0.35

(13) Selected principal size.
(14) From column 7 worksheet 4.
(15) From column 19 worksheet 4.
(16) From equation 16.
(17) (4) + (15) - E_s.
(18) From equation 12.
(19) From column 9.
(20) From column 10 worksheet 4.
(21) From equation 9 or 10.
(22) From equation 23.
(23) From equation 21 or 22.

TABLE B-8

WORKSHEET 1

Design Step 2 - Calculation of Time of Concentration and Travel Time

(1) Watershed and Segment	(2) Surface Condition	(3) Hydraulic Length (ft)	(4) Average Slope (%)	(5) Velocity (ft/sec)	(6) Segment T_c or T_t (hr)	(7) Watershed T_c (hr)	(8) Watershed T_t (hr)	(9) $T_c + T_t$ (hr)
	25-	YEAR,	24-HOUR	PRE-	MINING			
1-a	(1) FORREST	400	15	1.0	0.111			
1-b	(7) CHANNEL	500	8	5.7	0.024	0.135	0.	0.135

TABLE B-9

WORKSHEET 2

Design Step 2 - Determination of Peak Discharge and Runoff Volume

(1) Watershed	(2) T_c (hr)	(3) T_t (hr)	(4) CN	(5) q_{u_2} (cfs/mi^2/in)	(6) Q (in)	(7) A (ac)	(8) Q_v (ac-ft)	(9) Q_p (cfs)	(10) F_t	(11) q_{t_2} (cfs/mi^2/in)	(12) Rounded $T_c + T_t$ (hr)
		25-YEAR, 24-HOUR PRE-MINING									
1	0.135	0	73	370	2.1	31.1	5.443	37.8	1.0	370	0.15
		25-YEAR, 24-HOUR DURING MINING									
1	0.111	0.034	79	560	2.5	6.5	1.354	14.2	0.96	540	0.15
2	0.014	0.066	86	670	3.2	8.7	2.320	29.2	0.92	620	0.10
3	0.060	0.041	86	670	3.2	1.1	0.293	3.7	0.95	640	0.10
4	0.007	0.032	86	670	3.2	0.7	0.187	2.3	0.96	640	0.05
5	0.090	0.034	79	560	2.5	1.0	0.208	2.2	0.97	540	0.10
6	0.009	0.026	79	560	2.5	0.8	0.167	1.8	0.98	550	0.05
7	0.135	0.	73	370	2.1	12.3	2.153	14.9	1.00	370	0.15
						Σ	6.68	68.3			

(1) Sub-watershed identification.
(2) From column 7 worksheet 1.
(3) From column 8 worksheet 1.
(4) From Table 1.
(5) From Figure 1.
(6) From Figure 3.
(8) (6) X (7)/12.
(9) (5) X (6) X (7)/640.
(10) From Figure 4.
(11) (5) X (10).

TABLE B-9 (CONTINUED)

WORKSHEET 2 (contd.)

Calculation of Peak Discharge

(13) F_h −							+			(14) Water-shed	(15) q_t (cfs/mi/in)	(16) Q_t (cfs)									
				0.05	0.05	0.10						0	0.05	0.10	0.15						
				0.93						1	540			13.2	14.2						
					0.94					2	620			29.2	27.5						
					0.93					3	640			3.7	3.4						
					0.93	0.97				4	640		2.3	2.1	2.0						
					0.95					5	540			2.2	2.1						
					0.94	0.91				6	550		1.8	1.7	1.6						
				0.93						7	370			14.6	14.9						
													Σ	66.7	65.7						

TABLE B-10

WORKSHEET 6

Determination of Emergency Spillway Routed Peak Discharge for the 25-Year, 24-Hour Storm

ΔQ_{vi} = Q_{vi} (25-yr) 6.63 ac-ft - Q_{vi} (10-yr) 5.13 ac-ft = 1.55 ac-ft.

ΔQ_{pi} = Q_{pi} (25-yr) 68.3 cfs - Q_{pi} (10-yr) 49.4 cfs = 18.9 cfs.

(1) E_e (ft)	(2) V_e (ac-ft)	(3) H_e (ft)	(4) V_{me} (ac-ft)	(5) ΔV_{em} (ac-ft)	(6) $\frac{\Delta V_{em}}{\Delta Q_{vi}}$	(7) $\frac{Q_{eo}}{\Delta Q_{pi}}$
18.0	4.51	0.75	5.00	0.49	0.316	0.62
18.0	4.51	0.60	4.83	0.32	0.207	0.94

(8) Q_{eo} (cfs)	(9) Q_{po} (cfs)	(10) Q_{pe} (cfs)	(11) Q_{pm} (cfs)	(12) Side slope (H:V)	(13) Q_{tr} (cfs)	(14) Q_b (cfs/ft)	(15) BW (ft)
11.7	17.4	29.1	37.8	2:1	1.8	1.71	5.8
14.6	17.3	31.9	37.8	2:1	1.3	1.24	10.7

Emergency Spillway Crest 18.0 ft. Peak Stage 18.6 ft.

Bottom Width 11 ft. Side slopes 2:1 (H:V).

Pre-mining Discharge 37.8 cfs. Pond Routed Discharge 31.9 cfs.

(1) From column 17 worksheet 4.
(2) From sediment pond stage-volume relationship for E_e.
(3) Assumed emergency spillway head.
(4) From sediment pond stage-volume. relationship for E_{me}. ($E_{me} = E_e + H_e$).
(5) (4) - (2).
(6) (5)/ΔQ_{vi}.
(7) From Figure 14.
(8) (7) x Q_{pi}.
(9) From Figure 10 or 11.
(10) (8) + (9).
(11) Pre-mining peak discharge.
(12) Selected side slope.
(13) From Figure 15.
(14) From Figure 16.
(15) ((C8) - (C13))/C14).

APPENDIX C

Hand Calculator Program for Routing and Settleable Solids Prediction

CONTENTS

LIST OF TABLES

Introduction

The graphical routing procedures and settleable solids prediction equations contained in design step 4 have been programmed for a Hewlett-Packard HP-41CV hand calculator. A listing of the program (GRASP - Graphical Routing and Solids Prediction) including all data registers which contain constants is presented in Table 1. GRASP is composed of three main programs and several subroutines. A listing of the abbreviated catalog program names and full program names is contained in Table 2. In developing the program, it was necessary to fit functions to the routing and stage-discharge relationships. A summary of these functions is contained in Table 3. The following material provides instructions for loading and using GRASP.

Loading GRASP

The program including the contents of registers 31-106 and 110-115 should be loaded exactly as contained in Table 1. Two subprograms (LDRG and VWRG) have been provided to facilitate loading registers 31-106 and for checking the contents of all registers.

Instructions for using LDRG (Load Registers)

(1) Enter 31 into register 30.
(2) Execute (XEQ) LDRG.
(3) Key in the constant (0.5132) to be loaded into register 31 and key R/S. LDRG will load 0.5132 into register 31.
(4) Key in the constant (0.4116) to be loaded into register 32 and key R/S.
(5) Repeat the above process until registers 31-106 have been loaded.

Instructions for loading error messages

Registers 110-115 contain error messages 1-6 and need to be loaded indirectly using the ALPHA register and ASTO (alpha store) command.

Instructions for using VWRG (View Registers)

After all registers have been loaded, the register contents should be checked using VWRG.

(1) Enter 31 into register 30.
(2) Execute (XEQ) VWRG.
(3) The constant in register 31 will be displayed.
(4) Key R/S and the contents of register 32 will be displayed.
(5) Repeat the above process until the contents of all the registers have been checked.

Executing GRASP

GRASP has three main programs which follow the same basic principal spillway design procedures contained in design step 4. CSE1 (calculate Settleable Solids 1) calculates the discharge ratio, Q_r, and initial water surface elevation needed to meet the settleable solids effluent limitation for a given principal spillway storage, ΔV_{sp} and performs the pond routing using the V_{rs} routing function (equation 18). ROUTE2 (Route 2) performs the final routing using the routing function V_{rv} (equation 17). CSE2 (calculate Settleable Solids 2) calculates the final settleable solids concentration. To facilitate execution, the user should assign the three main programs (CSE1, ROUTE2, CSE2) to appropriate keys using the ASN function. The following information provides more detailed instructions for using GRASP.

(1) Load program input data into registers 00-12. A description of the contents of registers 01-12 is contained in Table 4. Register 00 contains a code for the spillway type and size. A complete listing of principal spillways which the program will handle is contained in Table 5. The principal spillway code is of the form

x.y

where x is a spillway type designation (1 for conduit and riser spillways and 2 for trickle tubes) and y is a size designation (1-5 for the sizes contained in Table 5).

(2) Execute (XEQ) CSE1.

(3) On the first iteration output from CSE1 includes:
   (a) The initial stage (H_r or H_t) needed to meet the settleable solids limitation of 0.5 ml/l.
   (b) Key R/S and the principal spillway fractional depth, P_f, for the initial stage will be calculated and displayed.

(4) Key R/S, and on the second and following iterations CSE1 will perform the initial routing using the V_{rs} routing relationship. Output for each iteration includes:
   (a) The routed peak stage (H_r or H_t)for the 10-year storm.
   (b) Key R/S and the principal spillway fractional depth, P_f, will be calculated and displayed.

(5) Key R/S after the fractional depth is displayed to provide another routing iteration.

(6) The routing iteration should be continued until successive stages are within 0.1 feet of each other.

(7) Using the final stage (ΔE_{pm}) determined in Step 6 compute E_m ($E_m = E_p + \Delta E_{pm}$) and obtain elevations and corresponding storage values from the stage-storage curve at approximately 1 foot below and 1 foot above E_m. The stage-storage relationship should be linear over this approximate 2 foot range. Enter the elevation and storage values into registers 13-16 as indicated in Table 4.

(8) Execute (XEQ) ROUTE2 to produce the final routing using the routing relationship V_{rv}.

(9) Output from ROUTE2 includes:
   (a) The routed peak stage (H_r or H_t) for the 10-year storm.
   (b) Key R/S And the principal spillway fractional depth, P_f, will be calculated and displayed.

(10) Key R/S to initiate another routing iteration.

(11) The routing iteration should be continued until successive stages are within 0.1 feet of each other.

(12) Execute (XEQ) CSE2 to calculate the final settleable solids concentration.

Error Messages

GRASP checks for selected error conditions and generates the following messages:

Error 1 - Q_r less than minimum allowable value (RTFN).

Error 2 - Maximum volume, V_m, is less than V_1 contained in register 14. The program is unable to interpolate to determine E_m (ROUTE2).

Error 3 - The calculated maximum volume V_m, is greater than V_2 contained in register 16. The program is unable to interpolate to determine E_m (ROUTE2).

Error 4 - H_T is less than 6.0 feet (CRSQ).

Error 5 - H_t is less than the minimum allowable for full pipe flow (TTSQ).

Error 6 - Calculated outflow, Q_{po}, is greater than inflow, Q_{pi}.

Example

An example sediment pond evaluation is included to illustrate the use of GRASP. The example calculations are for a 12 inch trickle tube principal spillway set at an elevation of 14.5 feet. Additional information on this example is contained in Appendix B. The contents of registers 00 - 16 are:

Register	Variable	Contents	Register	Variable	Contents
00	I_s	2.1	09	E_s	11.5
01	Q_{vi}	5.13	10	V_s	1.35
02	$Q_{vi}-\Delta V_{op}$	5.13	11	E_p	14.5
03	Q_{pi}	49.4	12	V_p	2.43
04	C_{su}	256,000	13	E_1	17.0
05	C_{se}	0.5	14	V_1	3.85
06	A_p	0.46	15	E_2	19.0
07	ΔH	0	16	V_2	5.10
08	C_1	1.0			

Executing GRASP with the above data produces the following results.

Step	Key	Output	Description
1	XEQ CSE1	3.36	H_t
2	R/S	0.47	P_f
3	R/S	3.80	H_t
4	R/S	0.44	P_f
5	R/S	3.77	H_t
6	R/S	0.44	P_f

The difference between H_t in step 3 and H_t in step 5 is less than 0.1 ft (actually 0.03 ft) and the initial routing using V_{rs} is complete. Also note that P_f is greater than 0.40 and H_t in step 5 is greater than the initial H_t (step 1) required to meet 0.5 ml/1.

Step	Key	Output	Description
7	XEQ ROUTE2	4.27	H_t
8	R/S	0.41	P_f
9	R/S	4.23	H_t
10	R/S	0.41	P_f

The difference between H_t in step 7 and H_t in step 9 is less than 0.1 ft (actually .04 ft) and the final routing using V_{rv} is completed. Note that only two iterations were required for the initial routing and only two iterations were required for the final routing.

Step	Key	Output	Description
11	XEQ CSE2	0.19	C_{se}

The predicted settleable solids concentration is 0.19 ml/1.

TABLE 1
GRASP Program Listing

```
                   CAT 1
LBL'CSE1
END          41 BYTES
LBL'CRQR
LBL'TTQR
LBL'R
LBL'QR
LBL'ROUTE1
LBL'CRSQ
LBL'TTSQ
LBL'CRRF1
LBL'TTRF1
LBL'RTFN
LBL'PFRACT
LBL'DIA
END          419 BYTES
LBL'ROUTE2
END          125 BYTES
LBL'CRRF2
LBL'TTRF2
LBL'CRR12
LBL'CRR22
LBL'TTR12
LBL'TTR22
END          163 BYTES
LBL'CSE2
END          29 BYTES
LBL'CRSS
LBL'TTSS
LBL'SLSOLID
END          117 BYTES
LBL'ER1
LBL'ER2
LBL'ER3
LBL'ER4
LBL'ER5
LBL'ER6
END          102 BYTES
LBL'LDRG
END          30 BYTES
LBL'VWRG
END          29 BYTES
.END.        09 BYTES
```

```
01♦LBL "CSE1"
02 RCL 00
03 INT
04 1
05 -
06 STO 24
07 X=0?
08 XEQ "CRQR"
09 RCL 24
10 X>0?
11 XEQ "TTQR"
12 XEQ "ROUTE1"
13 END

01♦LBL "CRQR"
02 XEQ "R"
03 31
04 ST+ 30
05 XEQ "QR"
06 RTN
07♦LBL "TTQR"
08 XEQ "R"
09 36
10 ST+ 30
11 XEQ "QR"
12 RTN
13♦LBL "R"
14 .99901
15 STO 30
16 RTN
17♦LBL "QR"
18 RCL 05
19 1250
20 *
21 RCL IND 30
22 /
23 RCL 04
24 ISG 30
25 RCL IND 30
26 Y↑X
27 /
28 RCL 01
29 ISG 30
30 RCL IND 30
31 Y↑X
32 /
33 RCL 12
34 RCL 10
35 -
36 ISG 30
37 RCL IND 30
38 Y↑X
39 *
40 ISG 30
41 RCL IND 30
42 Y↑X
43 RCL 03
44 *
45 STO 17
46 RTN
47♦LBL "ROUTE1"
48 GTO 01
49♦LBL 02
50 RCL 24
51 X=0?
52 XEQ "CRSQ"
53 RCL 24
54 X>0?
55 XEQ "TTSQ"
56♦LBL 01
57 RCL 17
58 RCL 03
59 /
60 STO 18
61 1
62 -
63 X>0?
64 XEQ "ER6"
65 RCL 24
66 X=0?
67 XEQ "CRRF1"
68 RCL 24
69 X>0?
70 XEQ "TTRF1"
71 RCL 19
72 RCL 02
73 *
74 RCL 06
75 /
76 STO 20
77 STOP
78 XEQ "PFRACT"
79 GTO 02
80♦LBL "CRSQ"
81 XEQ "R"
82 XEQ "DIA"
83 20
84 *
85 39
86 +
87 ST+ 30
88 RCL 20
89 RCL 07
90 +
```

```
91 6
92 -
93 X<0?
94 XEQ "ER4"
95 .726
96 Y↑X
97 RCL IND 30
98 *
99 ISG 30
100 RCL IND 30
101 +
102 RCL 08
103 *
104 STO 17
105 RTN
106♦LBL "TTSQ"
107 XEQ "R"
108 XEQ "DIA"
109 40
110 *
111 47
112 +
113 ST+ 30
114 RCL 20
115 RCL IND 30
116 -
117 X<0?
118 XEQ "ER5"
119 ISG 30
120 RCL IND 30
121 Y↑X
122 ISG 30
123 RCL IND 30
124 *
125 ISG 30
126 RCL IND 30
127 +
128 RCL 08
129 *
130 STO 17
131 RTN
132♦LBL "CRRF1"
133 XEQ "R"
134 71
135 ST+ 30
136 XEQ "RTFN"
137 RTN
138♦LBL "TTRF1"
139 XEQ "R"
140 75
141 ST+ 30
142 XEQ "RTFN"
143 RTN
144♦LBL "RTFN"
145 RCL 18
146 RCL IND 30
147 -
148 X<0?
149 XEQ "ER1"
150 ISG 30
151 RCL IND 30
152 Y↑X
153 ISG 30
154 RCL IND 30
155 *
156 ISG 30
157 RCL IND 30
158 X<>Y
159 -
160 STO 19
161 RTN
162♦LBL "PFRACT"
163 RCL 11
164 RCL 09
165 -
166 STO 25
167 RCL 20
168 +
169 RCL 25
170 X<>Y
171 /
172 STO 25
173 STOP
174 RTN
175♦LBL "DIA"
176 RCL 00
177 FRC
178 RTN
179 END

01♦LBL "ROUTE2"
02 RCL 24
03 X=0?
04 XEQ "CRSQ"
05 RCL 24
06 X>0?
07 XEQ "TTSQ"
08 RCL 17
09 RCL 03
10 /
11 STO 18
12 RCL 24
13 X=0?
14 XEQ "CRRF2"
15 RCL 24
16 X>0?
17 XEQ "TTRF2"
18 RCL 19
19 RCL 02
20 *
21 STO 21
22 RCL 14
23 RCL 12
24 -
25 STO 22
26 X>Y?
27 XEQ "ER2"
28 RDN
29 RCL 16
30 RCL 12
31 -
32 STO 23
33 X<Y?
34 XEQ "ER3"
35 RCL 21
36 RCL 22
37 -
38 RCL 23
39 RCL 22
40 -
41 /
42 RCL 15
43 RCL 13
44 -
45 *
46 RCL 13
47 +
48 RCL 11
49 -
50 STO 20
51 STOP
52 XEQ "PFRACT"
53 GTO "ROUTE2"
54 END

01♦LBL "CRRF2"
02 .3
03 RCL 18
04 X<=Y?
05 XEQ "CRR12"
06 .3
07 RCL 18
08 X>Y?
09 XEQ "CRR22"
10 RTN
```

```
11♦LBL "TTRF2"
12 .3
13 RCL 18
14 X<=Y?
15 XEQ "TTR12"
16 .3
17 RCL 18
18 X>Y?
19 XEQ "TTR22"
20 RTN
21♦LBL "CRR12"
22 XEQ "R"
23 79
24 ST+ 30
25 XEQ "RTFN"
26 RTN
27♦LBL "CRR22"
28 XEQ "R"
29 83
30 ST+ 30
31 XEQ "RTFN"
32 RTN
33♦LBL "TTR12"
34 XEQ "R"
35 87
36 ST+ 30
37 XEQ "RTFN"
38 RTN
39♦LBL "TTR22"
40 XEQ "R"
41 91
42 ST+ 30
43 XEQ "RTFN"
44 RTN
45 END

01♦LBL "CSE2"
02 RCL 24
03 X=0?
04 XEQ "CRSS"
05 RCL 24
06 X>0?
07 XEQ "TTSS"
08 END

01♦LBL "CRSS"
02 XEQ "R"
03 95
04 ST+ 30
05 XEQ "SLSOLID"
06 RTN
07♦LBL "TTSS"
08 XEQ "R"
09 101
10 ST+ 30
11 XEQ "SLSOLID"
12 RTN
13♦LBL "SLSOLID"
14 RCL 11
15 RCL 09
16 -
17 RCL 20
18 +
19 RCL IND 30
20 Y↑X
21 RCL 01
22 ISG 30
23 RCL IND 30
24 Y↑X
25 *
26 RCL 12
27 RCL 10
28 -
29 ISG 30
30 RCL IND 30
31 Y↑X
32 /
33 RCL 18
34 ISG 30
35 RCL IND 30
36 Y↑X
37 *
38 RCL 04
39 ISG 30
40 RCL IND 30
41 Y↑X
42 *
43 ISG 30
44 RCL IND 30
45 *
46 1250
47 /
48 STOP
49 RTN
50 END

01♦LBL "ER1"
02 110
03 STO 29
04 VIEW IND 29
05 STOP
06 0
07 RTN
08♦LBL "ER2"
09 111
10 STO 29
11 VIEW IND 29
12 STOP
13 RTN
14♦LBL "ER3"
15 112
16 STO 29
17 VIEW IND 29
18 STOP
19 RTN
20♦LBL "ER4"
21 113
22 STO 29
23 VIEW IND 29
24 STOP
25 0
26 RTN
27♦LBL "ER5"
28 114
29 STO 29
30 VIEW IND 29
31 0
32 STOP
33 RTN
34♦LBL "ER6"
35 115
36 STO 29
37 VIEW IND 29
38 STOP
39 RTN
40 END

01♦LBL "LDRG"
02 .99901
03 ST+ 30
04♦LBL 01
05 STOP
06 STO IND 30
07 ISG 30
08 GTO 01
09 END

01♦LBL "VWRG"
02 .99901
03 ST+ 30
04♦LBL 01
05 STOP
06 VIEW IND 30
07 ISG 30
08 GTO 01
09 END
```

R31= 5.132-01
R32= 4.116-01
R33= 1.954+00
R34= 6.167-01
R35= 1.066+00
R36= 7.311-03
R37= 8.327-01
R38= 2.703+00
R39= 1.179+00
R40= 5.405-01
R41= 4.380-01
R42= 3.570+00
R43= 7.740-01
R44= 6.330+00
R45= 1.227+00
R46= 1.005+01
R47= 2.525+00
R48= 2.066+01
R49= 4.368+00
R50= 3.577+01
R51= 1.500+00
R52= 7.380-01
R53= 6.330-01
R54= 3.770+00
R55= 2.000+00
R56= 7.940-01
R57= 9.210-01
R58= 7.210+00
R59= 2.500+00
R60= 7.790-01
R61= 1.568+00
R62= 1.200+01
R63= 3.000+00
R64= 8.160-01
R65= 2.917+00
R66= 2.612+01
R67= 4.000+00
R68= 8.200-01
R69= 4.797+00
R70= 4.768+01
R71= 5.000-02
R72= 6.760-01
R73= 5.710-01
R74= 4.070-01
R75= 5.000-02
R76= 7.000-01
R77= 3.880-01
R78= 3.860-01
R79= 5.000-02
R80= 6.660-01
R81= 7.880-01
R82= 5.490-01
R83= 3.000-01
R84= 7.160-01
R85= 3.450-01
R86= 2.360-01
R87= 5.000-02
R88= 4.540-01
R89= 5.660-01
R90= 6.380-01
R91= 4.000-01
R92= 9.550-01
R93= 4.510-01
R94= 2.870-01
R95= 2.694+00
R96= 2.000+00
R97= 1.189+00
R98= 2.399+00
R99= 9.396-01
R100= 6.871-05
R101= 1.222+00
R102= 2.796+00
R103= 1.541+00
R104= 2.076+00
R105= 9.587-01
R106= 1.738-04
R107= 0.000+00
R108= 0.000+00
R109= 0.000+00
R110= "ERROR1"
R111= "ERROR2"
R112= "ERROR3"
R113= "ERROR4"
R114= "ERROR5"
R115= "ERROR6"

TABLE 2

Summary of Abbreviated Program and Subroutine Names

CSE1	-	Calculate Settleable Solids 1
CRQR	-	Conduit and Riser Discharge Ratio, Q_r
TTQR	-	Trickle Tube Discharge Ratio, Q_r
R	-	Indirect Register Constant
QR	-	Discharge Ratio, Q_r
ROUTE1	-	Initial Routing Using V_{rs}
CRSQ	-	Conduit and Riser Stage-Discharge
TTSQ	-	Trickle Tube Stage-Discharge
CRRF1	-	Conduit and Riser Routing Function 1
TTRF1	-	Trickle Tube Routing Function 1
RTFN	-	Routing Function
PFRACT	-	Principal Spillway Fractional Depth, P_f
DIA	-	Spillway Diameter
ROUTE2	-	Final Routing Using V_{rv}
CRRF2	-	Conduit and Riser Routing Function 2
TTRF2	-	Trickle Tube Routing Function 2
CRR12	-	Conduit and Riser Routing Function 1, 2
CRR22	-	Conduit and Riser Routing Function 2, 2
TTR12	-	Trickle Tube Routing Function 1, 2
TTR22	-	Trickle Tube Routing Function 2, 2
CSE2	-	Calculate Settleable Solids 2
CRSS	-	Conduit and Riser Settleable Solids
TTSS	-	Trickle Tube Settleable Solids
SLSOLID	-	Settleable Solids Calculation

TABLE 2 (continued)

ER1	-	Error 1
ER2	-	Error 2
ER3	-	Error 3
ER4	-	Error 4
ER5	-	Error 5
ER6	-	Error 6
LDRG	-	Load Register
VWRG	-	View Registers

TABLE 3

Routing and Stage Discharge Functions

Conduit and Riser Routing Functions

$V_{rs} = 0.407 - 0.571\ (Q_r - .050)^{0.676}$ (1)

$V_{rv} = 0.549 - 0.788\ (Q_r - .050)^{0.666}$ $0.050 \leq Q_r \leq 0.300$ (2)

$V_{rv} = 0.236 - 0.345\ (Q_r - .300)^{0.716}$ $0.300 < Q_r \leq 0.700$ (3)

Conduit and Riser Stage-Discharge Relationships

$Q_o = 3.57 + 0.438\ (H_T - 6.00)^{0.726}$ 12"C - 18"R* (4)

$Q_o = 6.33 + 0.774\ (H_T - 6.00)^{0.726}$ 15"C - 24"R (5)

$Q_o = 10.05 + 1.227\ (H_T - 6.00)^{0.726}$ 18"C - 30"R (6)

$Q_o = 20.66 + 2.525\ (H_T - 6.00)^{0.726}$ 24"C - 36"R (7)

$Q_o = 35.77 + 4.368\ (H_T - 6.00)^{0.726}$ 30"C - 42"R (8)

Trickle Tube Routing Functions

$V_{rs} = 0.386 - 0.388\ (Q_r - 0.050)^{0.700}$ (9)

$V_{rv} = 0.638 - 0.566\ (Q_r - 0.050)^{0.454}$ $0.050 \leq Q_r \leq 0.400$ (10)

$V_{rv} = 0.287 - 0.451\ (Q_r - 0.400)^{0.955}$ $0.400 < Q_r \leq 0.800$ (11)

Trickle Tube Stage Discharge Relationships

$Q_o = 3.77 + 0.633\ (H_t - 1.5)^{0.738}$ $H_t > 1.5$; 12" ** (12)

$Q_o = 7.21 + 0.921\ (H_t - 2.0)^{0.794}$ $H_t > 2.0$; 15" (13)

$Q_o = 12.00 + 1.568\ (H_t - 2.5)^{0.779}$ $H_t > 2.5$; 18" (14)

$Q_o = 26.12 + 2.917\ (H_t - 3.0)^{0.816}$ $H_t > 3.0$; 24" (15)

$Q_o = 47.68 + 4.797\ (H_t - 4.0)^{0.820}$ $H_t > 4.0$ ' 30" (16)

*12"C - 18"R - 12" Conduit and 18" riser
**12" - 12" diameter trickle tube

TABLE 4

Contents of Registers 00 - 30

Register Number	Contents	Number	Contents
00	Spillway type and size (See Table 5)	16	V_2
01	Q_{vi}	17	Q_{po}
02	$Q_{vi} - \Delta V_{op}$	18	Q_r
03	Q_{pi}	19	V_{rs}, V_{rv}
04	C_{su}	20	ΔE_{pm}
05	C_{se}	21	ΔV_{pm}
06	A_p	22	ΔV_{p1}
07	ΔH	23	ΔV_{p2}
08	C_1	24	ST
09	E_s	25	P_f
10	V_s	26	
11	E_p	27	
12	V_p	28	
13	E_1	29	Indirect Address Register
		30	Indirect Address Register

TABLE 5

Spillway Codes

Spillway Designation	Spillway Type	Spillway Size (in)
1.1	Conduit and Riser	12 C - 18 R*
1.2	Conduit and Riser	15 C - 24 R
1.3	Conduit and Riser	18 C - 30 R
1.4	Conduit and Riser	24 C - 36 R
1.5	Conduit and Riser	30 C - 42 R
2.1	Trickle Tube	12**
2.2	Trickle Tube	15
2.3	Trickle Tube	18
2.4	Trickle Tube	24
2.5	Trickle Tube	30

* 12"C - 18"R - 12" conduit and 18" riser
** 12" - 12" diameter trickle tube

APPENDIX D

LIST OF SYMBOLS

SYMBOLS

A	-	Watershed area, (ac).
A_p	-	Sediment pond area at the principal spillway, (ac).
C_1	-	Pipe length discharge correction factor.
BW	-	Emergency spillway bottom width, (ft).
CN	-	SCS runoff curve number.
CP	-	USLE control practice factor.
C_{se}	-	Settleable solids concentration, (ml/l).
C_{su}	-	Inflow average suspended solids concentration, (mg/l).
E_e	-	Emergency spillway crest elevation, (ft).
E_m	-	Sediment pond maximum water surface elevation for the 10-year storm, (ft).
D	-	Sediment pond depth measured from the sediment pool elevation to the maximum water surface, (ft).
E_p	-	Sediment pond principal spillway elevation, (ft).
E_{pp}	-	Sediment pond permanent pool elevation, (ft).
E_s	-	Sediment pond sediment pool elevation, (ft).
E_1	-	Elevation on stage-volume curve at a point less than E_m, (ft).
E_2	-	Elevation on the stage-storage curve at a point greater than E_m, (ft).
F_h	-	Peak discharge to hydrograph conversion factor.
F_t	-	Unit peak discharge travel time reduction factor.
H_e	-	Head above emergency spillway crest, (ft).
H_r	-	Head above riser crest, (ft).
H_t	-	Head above trickle tube invert, (ft).
H_T	-	Total head, (ft).

I_s - Principal spillway type and size index.

K - USLE soil erodibility factor.

L_e - Erosion slope length, (ft).

L_h - Hydraulic length of a watershed or flow path, (ft).

LS - USLE length slope factor.

P - Rainfall, (in).

P_f - Principal spillway fractional depth.

q_t - Sub-watershed unit peak discharge adjusted for travel time ($cfs/mi^2/in$).

q_u - Sub-watershed unit peak discharge, ($cfs/mi^2/in$).

Q - Storm runoff volume, (in).

Q_b - Emergency spillway discharge for the rectangular portion of a trapezordal cross-section, (cfs/ft).

Q_{eo} - Emergency spillway peak discharge, (cfs).

Q_o - Principal or emergency spillway discharge, (cfs).

Q_p - Sub-watershed peak discharge, (cfs).

Q_{pi} - Peak sediment pond inflow, (cfs).

Q_{po} - Principal spillway peak discharge.

Q_{pe} - Combined principal and emergency spillway peak discharge, (cfs).

Q_{pm} - Pre-mining 25-year, 24-hour peak discharge, (cfs).

Q_{pt} - Sub-watershed peak discharge adjusted for travel time, (cfs).

Q_t - Hydrograph ordinate, (cfs).

Q_{tr} - Emergency spillway discharge for the triangular portion of a trapezoidal cross-section, (cfs).

Q_v - Sub-watershed storm runoff volume, (ac-ft).

Q_{vi} - Sediment pond inflow storm runoff volume, (ac-ft).

S_o	-	Slope of flow path, (%).
ST	-	Principal spillway type index.
T_c	-	Sub-watershed time of concentration, (hr).
T_t	-	Travel time from the sub-watershed outlet to the sediment pond, (hr).
V	-	Overland flow or channel velocity (ft/sec).
V_e	-	Sediment pond storage volume at the emergency spillway crest, (ac-ft).
V_m	-	Sediment pond maximum volume for the 10-year storm, (ac-ft).
V_{me}	-	Sediment pond maximum volume for the 25-year, 24-hour storm, (ac-ft).
V_p	-	Sediment pond volume at the principal spillway, (ac-ft).
V_{pp}	-	Sediment pond volume at the permanent pool, (ac-ft).
V_{rs}	-	Sediment pond storage to inflow volume ratio based on A_p and ΔE_{pm}.
V_{rv}	-	Sediment pond storage to inflow volume ratio based on ΔV_{pm}.
V_s	-	Sediment pond volume at the sediment pool, (ac-ft).
V_1	-	Sediment pond volume at E_1, (ac-ft).
V_2	-	Sediment pond volume at E_2, (ac-ft).
Y	-	Sub-watershed sediment yield, (tons).
Y_i	-	Sediment load inflow to the sediment pond, (tons).
ΔE_{pm}	-	Incremental elevation between the principal spillway and maximum water surface. Same as H_r or H_t (ft).
ΔH	-	Elevation difference between the riser crest and the conduit invert, (ft).
ΔQ_{pi}	-	Difference between the 25-year, 24-hour storm peak discharge and the 10-year, 24-hour storm peak discharge, (cfs).

ΔQ_{vi} - Difference between the 25-year, 24-hour storm runoff volume and the 10-year, 24-hour storm runoff volume, (ac-ft).

ΔV_{em} - Incremental sediment pond storage volume between the emergency spillway and maximum water surface elevation, (ac-ft).

ΔV_{op} - Incremental sediment pond storage volume between the dewatering orifice and the principal spillway.

ΔV_{pm} - Incremental sediment pond storage between the principal spillway and the maximum water surface, (ac-ft).

ΔV_{p1} - Incremental sediment pool volume between the permanent pool and E_1, (ac-ft).

ΔV_{p2} - Incremental sediment pool volume between the permanent pool and E_2, (ft).

ΔE_{sp} - Incremental elevation between the sediment pool and the principal spillway.

Δt - Time interval between hydrograph ordinates, (hr).