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VI. DESIGN PROCEDURES AND EXAMPLE

6.1 Design Procedure

Step 1. Site selection (Section 3.1)

The sedimentation pond loction is selected considering the factors presented in Section 3.1.

Step 2. Hydrology (Section 3.2.1)

The peak inflow rate and runoff volume for the design storm event are determined.

Step 3. Influent sediment size distribution (Section 3.2.2.1)

The size distribution of the inflowing sediment is required. Where existing information from the mine site or nearby mine sites is available, it should be used. When there is no existing data, a size distribution can be developed using information from soil surveys.

Step 4. Sediment yield (Section 3.2.2.2)

Determine the annual sediment yield and the storm sediment yield.

Step 5. Inflow suspended solids concentration (Section 3.2.3)

Using the storm sediment yield and the storm runoff volume, determine the average influent suspended solids concentration.

Step 6. Settleable solids concentration (Section 3.5)

Develop the settleable sediment size distribution (particles > 0.001 mm) from the influent sediment size distribution. Select a particle size to be removed in the pond. Determine the trapping efficiency from the settleable sediment size distribution. Determine the average effluent suspended solids concentration using the trapping efficiency, sediment yield, and runoff volume (Equation 3.6). Calculate the settleable solids concentration (SS) from Equation 3.5. If $SS > 0.5$ ml/l, select a smaller size particle and repeat procedure. If $SS \cong 0.5$ ml/l, go to Step 7 and design pond to remove selected particle size. If $SS < 0.5$ ml/l, select a larger size particle and repeat procedure.

<u>Step 7</u>. Available storage volume (Section 3.7)

Develop stage-storage curve for sedimentation pond location. Determine the required sediment storage volume and the corresponding depth. Determine the available detention storage depth by

D = embankment height - (embankment settlement + required

freeboard + emergency spillway depth + sediment

storage depth)

Determine the available detention storage volume above the sediment storage depth from the stage-storage curve.

<u>Step 8</u>. Required storage volume (Section 3.6)

Assume a detention storage depth and determine the required detention time for the design particle size from Figure 3.10. Calculate the time base of the inflow hydrograph. Determine the required storage volume from Figure 3.7. Determine the required outflow rate from Figure 3.8. Compare the required storage volume to the available storage volume. If the available storage volume is less than the required storage volume, either

(a) Increase the embankment height and determine the new available storage volume. Repeat Step 8.

(b) Excavate the pond side slopes and a develop new stage-storage curve. Repeat Step 8.

(c) Construct a pond downstream and return to Step 1.

If the available storage volume is larger than the required storage volume, check the required surface area (Section 3.8.3.1). If the measured surface area is less than the required surface area, (1) excavate pond side slopes or (2) raise principal spillway crest. If the measured surface area is greater than the required surface area, check length-width ratio (Section 3.8.2.2) and calculate required length to settle design particle size (Section 3.8.1). If the length is not large enough, increase the flow length (Section 4.2). If the length criteria is met, check scouring (Section 3.8.3.4). If the scouring velocity is smaller than the horizontal velocity, increase the depth and return to Step 7. If the scouring velocity is greater than the horizontal velocity, go to Step 9.

<u>Step 9</u>. Principal spillways (Section 3.9.1)

Select principal spillway type and design for the peak outflow rate and the corresponding head.

Step 10. Emergency spillway (Section 3.9.4)

Select emergency spillway type and design the spillway system to pass the peak discharge from the 25-year, 24-hour runoff event.

Step 11. Erosion control below the spillways (Section 3.9.5)

Size the riprap below the principal spillway.

Step 12. Check base flow conditions after pond is operational.

6.2 Design Example

The design example is to illustrate the procedures of sizing a detention pond to meet the effluent standard. Design of principal spillway (Step 9), emergency spillway (Step 10), erosion control below the spillway (Step 11), and base flow condition (Step 12) are not included because methodologies can be found in various texts and references.

Step 1. Considerations for sedimentation pond selection have been presented in Section 3.1. In this design example, a site is preselected and presented in Figure 6.1.

Step 2. Hydrology

Design Event	Q_I (cfs)	V (acre-feet)
10-year, 24-hour	77	2.31
25-year, 24-hour	91.5	3.35

Step 3. Sediment size distribution

For the purpose of illustrating the methodology, develop influent size distribution from Soil Surveys (Table 6.1).

55 percent of area is sand
40 percent of area is sandy clay
5 percent of area is silty clay

Figure 6.2 presents the influent size distribution. The distribution is extended with a straight line to a particle size of 0.001 mm.

Step 4. Sediment yield (use USLE for annual sediment yield and MUSLE for storm sediment yield)

Annual sediment yield = 115 tons
Storm sediment yield = 50 tons (10-year, 24-hour storm)

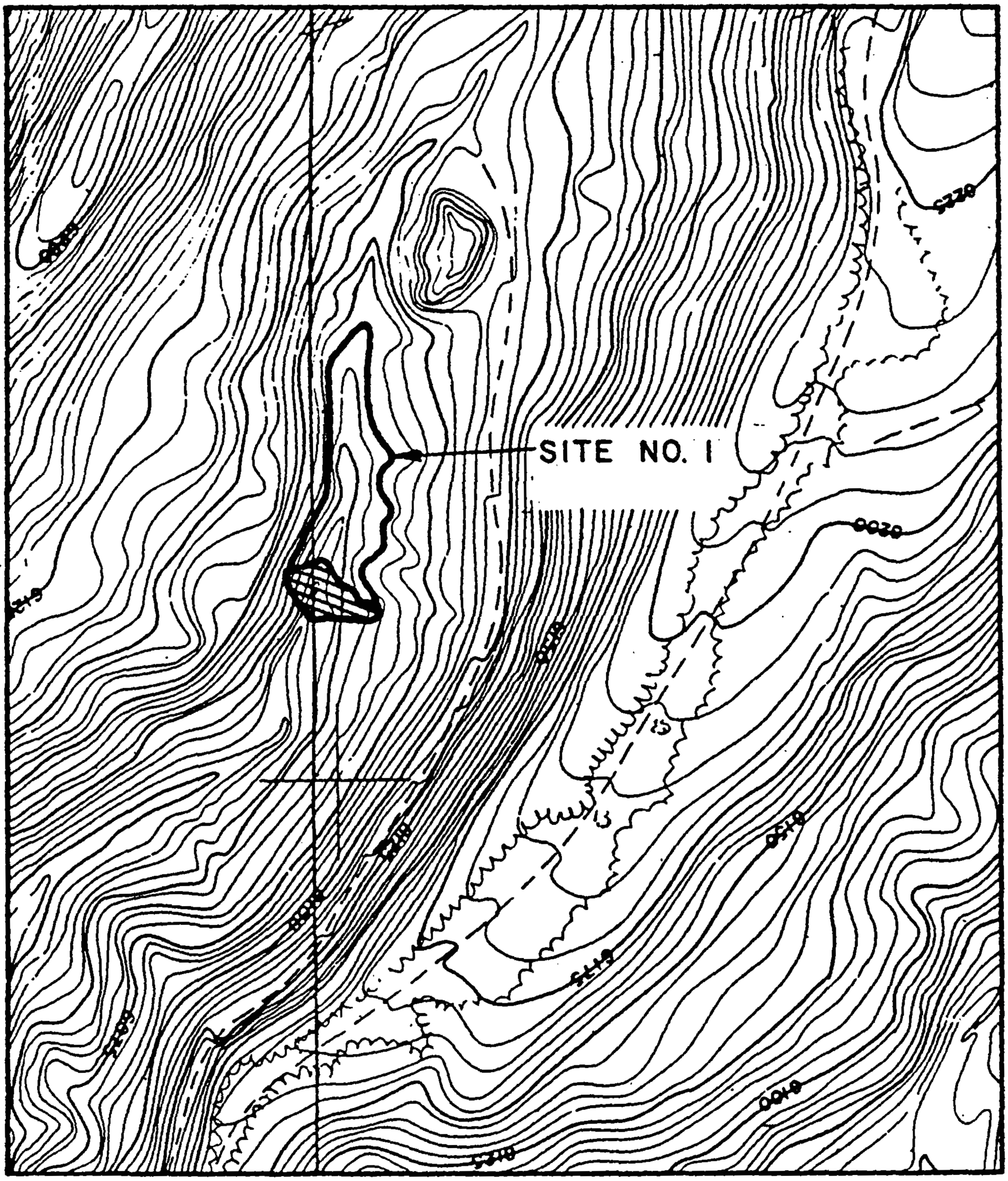

FIGURE 6.I SEDIMENTATION POND SITE

Table 6.1. Development of Influent Size Distribution.

Particle Size Range (mm) (1)	Mean Particle Size (mm) (2)	Sand: From Table 3.1 (% finer) (3)	Sand: Col. 3 x 0.55 (% finer) (4)	Sandy Clay: From Table 3.1 (% finer) (5)	Sandy Clay: Col. 5 x 0.40 (% finer) (6)	Silty Clay: From Table 3.1 (% finer) (7)	Silty Clay: Col. 7 x 0.05 (% finer) (8)	Col. 4 + Col. 6 + Col. 8 (9)	Influent Size Distribution Σ Col. 9 (% finer) (10)
< 0.002	0.002	2	1.1	55	22.0	45	2.2	25.3	25.3
0.002-0.05	0.010	10	5.5	5	2.0	45	2.2	9.7	35.0
0.05-0.10	0.070	15	8.3	5	2.0	5	0.3	10.6	45.6
0.10-1.0	0.316	35	19.2	10	4.0	5	0.3	23.5	69.1
1.0-2.0	1.414	38	20.9	25	10.0	--	---	30.9	100.0

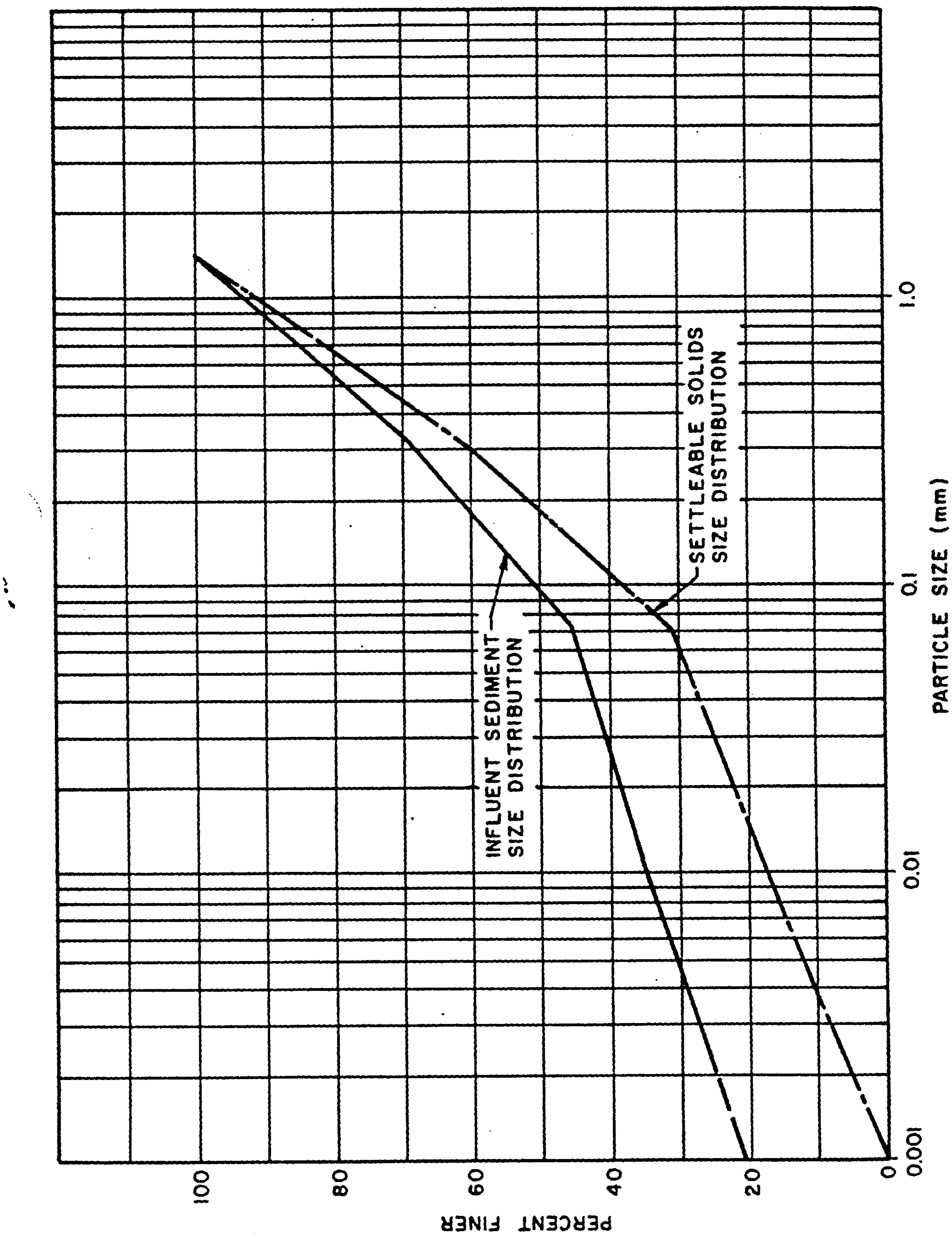

FIGURE 6.2 SEDIMENT SIZE DISTRIBUTION

Step 5. Average inflow suspended solids concentration

$$C_I = \frac{50 \text{ tons x } 2000 \text{ lb/ton x } 10^6}{2.31 \text{ ac-ft x } 43{,}560 \text{ ft}^2\text{/ac x } 62.4 \text{ lb/ft}^3} = 15{,}926 \text{ mg/l}$$

Step 6. Settleable solids concentration

From Figure 6.2, 21 percent of the influent size distribution is non-settleable (< 0.001 mm). The redistributed settleable size distribution is also presented in Figure 6.2.

Start with d = 0.011 mm.

From Figure 6.2, trapping efficiency E = 0.82 and fraction of settleable solids K = 0.79, using Equation 3.6.

$$C_o^* = \frac{(1.0 - 0.82) \text{ x } 0.79 \text{ x } 50 \text{ tons x } 2000 \text{ lb/ton}}{2.31 \text{ ac-ft x } 43{,}560 \text{ ft}^2\text{/ac x } 62.4 \text{ lb/ft}^3}$$

$$\text{x } 10^6 = 2265 \text{ mg/l}$$

The settleable solids concentration is determined as follows:

Particle Size Range	Mean Size (di)	Influent ΔX_i	Effluent ΔX_i	$(d_i/0.011)^6$ x ΔX_i
0.001 -0.002	0.0014	0.05	0.28	1.19×10^{-6}
0.002 -0.0038	0.0028	0.05	0.28	7.62×10^{-5}
0.0038-0.0072	0.0052	0.05	0.28	3.12×10^{-3}
0.0072-0.011	0.0089	0.03	0.16	4.49×10^{-2}
		0.18	1.0	0.048

From Equation 3.5, settleble solids concentration can be calculated as

$$SS = \frac{2265 \text{ mg/l}}{1120 \text{ mg/ml}} [(1.0 - 1.0) + 0.048] = 0.10 \text{ ml/l} < 0.5 \text{ ml/l}$$

<u>Try with a larger size of settleable solids, d = 0.020 mm.</u>

$$X_o = \frac{\text{\% of settleable size distribution smaller than 0.011 mm}}{\text{\% of settleable size distribution smaller than 0.020 mm}}$$

$$= \frac{0.18}{0.22} = 0.818$$

From Figure 6.2, E = 0.78 and K = 0.79

$$C_o^{\bullet} = \frac{(1.0 - 0.78) \times 0.79 \times 50 \text{ tons} \times 2000 \text{ lb/ton}}{2.31 \text{ ac-ft} \times 43{,}560 \text{ ft}^2/\text{ac} \times 62.4 \text{ lb/ft}^3}$$

$$\times 10^6 = 2768 \text{ mg/l}$$

$$SS = \frac{2768 \text{ mg/l}}{1120 \text{ mg/ml}} [(1.0 - 0.818) + (0.818 \times 0.048)]$$

$$= 0.55 \text{ ml/l} > 0.5 \text{ ml/l}$$

<u>Try with a smaller size of settleable solids, d = 0.018 mm.</u>

$$X_o = \frac{\text{\% of settleable size distribution smaller than 0.011 mm}}{\text{\% of settleable size distribution smaller than 0.018 mm}}$$

$$= \frac{0.18}{0.215} = 0.837$$

From Figure 6.2, E = 0.785 and K = 0.79

$$C_o^{\bullet} = \frac{(1.0 - 0.785) \times 0.79 \times 50 \text{ tons} \times 2000 \text{ lb/ton}}{2.31 \text{ ac-ft} \times 43{,}560 \text{ ft}^2/\text{ac} \times 62.4 \text{ lb/ft}^3}$$

$$\times 10^6 = 2705 \text{ mg/l}$$

$$SS = \frac{2705 \text{ mg/l}}{1120 \text{ mg/ml}} [(1.0 - 0.837) + (0.837 \times 0.048)]$$

$$= 0.49 \text{ ml/l} \cong 0.5 \text{ ml/l}$$

In order to meet the 0.5 ml/l standard, the pond is designed to remove all particles equal to and larger than 0.018 mm.

<u>Step 7.</u> Available storage volume

Based on the selected site (Figure 6.1), the stage-storage curve is obtained using the methodology described in Section 3.7 and is presented in Figure 6.3. The sediment storage volume should provide for three times the annual sediment yield

$$V_s = \frac{3\ yr \times 115\ ton/yr \times 2000\ lb/ton}{70\ lb/ft^3 \times 43{,}560\ ft^2/ac} = 0.23\ ac\text{-}ft$$

From Figure 6.3, depth of sediment = 4.2 ft

Total maximum embankment height (assumed)	=	16 ft
Allow 5 percent settlement (0.5 x 16)	=	0.80 ft
Required freeboard	=	1.0 ft
Allow 2.5 ft for emergency spillway	=	2.5 ft
Maximum depth of sediment storage	=	4.2 ft
Available detention storage depth (D_1) 16 - (0.80 + 1.0 + 2.5 + 4.2)	=	7.5 ft
Stage at maximum detention storage depth 7.5 + 4.2	=	11.7 ft

The available storage volume is described by taking the difference between the storage volume at the stage of the maximum detention storage depth and the storage volume at the elevation of the principal spillway.

From Figure 6.3, available detention storage volume 1.71 - 0.23	=	1.48 ac-ft

Step 8. Required storage volume

The total depth (D_T) of the pond is used in the following computations and is equal to the sum of the sediment storage depth, detention storage depth, and the permanent pool depth (if used).

Time base of inflow hydrograph

$$T_b = \frac{2V}{Q_I} = \frac{2 \times 2.31\ ac\text{-}ft \times 43{,}560\ ft^2/ac}{77\ ft^3/sec \times 3600\ sec/hr} = 0.73\ hours$$

For $d = 0.018$ mm and $D_T = 11.70$ ft,

$T_D = 4.50$ hours (From Figure 3.10)

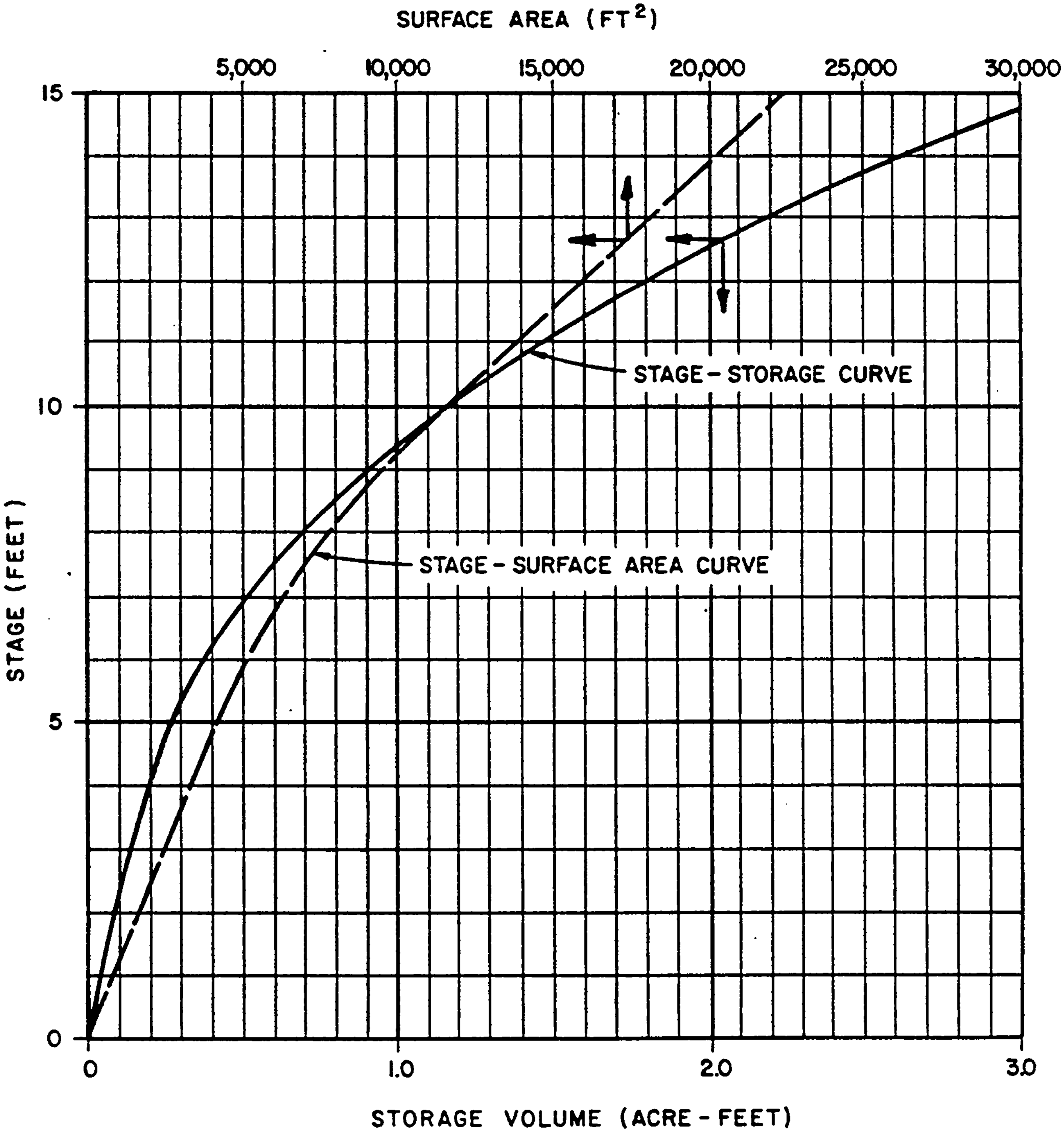

FIGURE 6.3 STAGE - SURFACE AREA AND STAGE - STORAGE CURVES OF POND SITE NO. 1

For T_b = 0.73 hours and T_D = 4.50 hours,

$$\frac{S}{V} = 0.950 \quad \text{(From Figure 3.7)}$$

$$\frac{Q_o}{Q_I} = 0.05 \quad \text{(From Figure 3.8)}$$

$$S = 0.950 \times 2.31 \text{ ac-ft} = 2.19 \text{ ac-ft} > 1.48 \text{ ac-ft}$$

Since the pond location with an assumed 16 ft embankment height cannot provide the required storage volume, the designer has three alternatives.

(a) Increase the detention storage depth and return to Step 7 and determine the new available storage.

(b) Excavate the pond side slopes no steeper than 2 horizontal to 1 vertical and return to Step 7 and develop new stage-storage curve.

(c) Construct another pond downstream.

For purposes of illustrating multiple pond design, alternative (c) is chosen.

Step 8c. Determine the sediment removal in the upstream pond

$$\frac{S}{V} = \frac{1.48 \text{ ac-ft}}{2.31 \text{ ac-ft}} = 0.64$$

For $\frac{S}{V}$ = 0.64 and T_b = 0.73 hours,

$$T_D = 0.4 \text{ hours} \quad \text{(Figure 3.7)}$$

$$\frac{Q_o}{Q_I} = 0.360 \quad \text{(Figure 3.8)}$$

For T_D = 0.4 hours and D_T = 11.70 ft,

$$2.254\ d^2 = \frac{D_T}{3600\ T_D} \quad \text{(Equation 3.10)}$$

$$d = \sqrt{\frac{D_T}{2.254 \times 3600\ T_D}} = \sqrt{\frac{11.7\ \text{ft}}{2.254 \times 0.4\ \text{hrs} \times 3600\ \text{sec/hr}}}$$

$$= 0.060\ \text{mm}$$

Therefore, only particles larger than 0.060 mm can be removed in the first pond based upon ideal settling.

Check surface area

A (measured at depth = 4.2 ft) = 3490 ft^2

Q_o = 0.360 x 77 cfs = 27.7 cfs

From Equation 3.14, required surface area

$$A_{req} = 1.2 \times \frac{27.7\ \text{ft}^3/\text{sec}}{2.254 \times (0.060)^2} = 4096\ \text{ft}^2 > 3490\ \text{ft}^2$$

Due to nonideal settling conditions, the smallest particle which will be removed using the available surface area is

$$d = \sqrt{\frac{1.2 \times Q_o}{2.254 \times A}} = \sqrt{\frac{1.2 \times 27.7}{2.254 \times 3490}} = 0.065\ \text{mm}$$

Check length-to-width ratio

L (measured at depth = 4.2 ft) = 130 ft

$$W = \frac{A}{L} = \frac{3490\ \text{ft}^2}{130\ \text{ft}} = 26.8\ \text{ft}$$

$$\frac{L}{W} = \frac{130}{26.8\ \text{ft}} = 4.9 > 2.0$$

Check Scouring

$$V_H = \frac{Q_o}{WD} = \frac{27.7\ ft^3/sec}{26.8\ ft \times 7.5\ ft} = 0.14\ fps\ \text{(Equation 3.18)}$$

$$V_{sc} = 1.67\ d^{1/2} = 1.67 \times (0.065)^{1/2} = 0.43\ fps\ \text{(Equation 3.17)}$$

$$V_H < V_{sc}$$

The smallest particle which will be removed in the first pond is 0.065 mm which corresponds to a removal efficiency of 69.5 percent (Figure 6.2).

Design of Downstream Pond (repeat Steps 1 through 8)

Step 1. Site selection (Figure 6.4). Select a second pond just downstream of the first pond.

Step 2. Hydrology (10-year, 24-hour design event)

10-year, 24-hour design event	Q (cfs)	V (acre-feet)
First pond (Q_O)	27.7	2.31
Additional contributing area (Q_I)	22.0	0.39
Design parameter (Q_I second pond)	49.7	2.70

25-year, 24-hour design event	Q (cfs)	V (acre-feet)
First pond (Q_O)	91.5	3.35
Additional contributing area (Q_S)	26.1	0.56
Design parameter	117.6	3.91

Notes: 1. The design inflow peak flow for second pond should be determined by reservoir routing and added to the hydrograph of the additional contributing area. For illustration of sedimentation pond design, the peak outflow from the first pond is added directly to the peak flow of the additional contributing area.

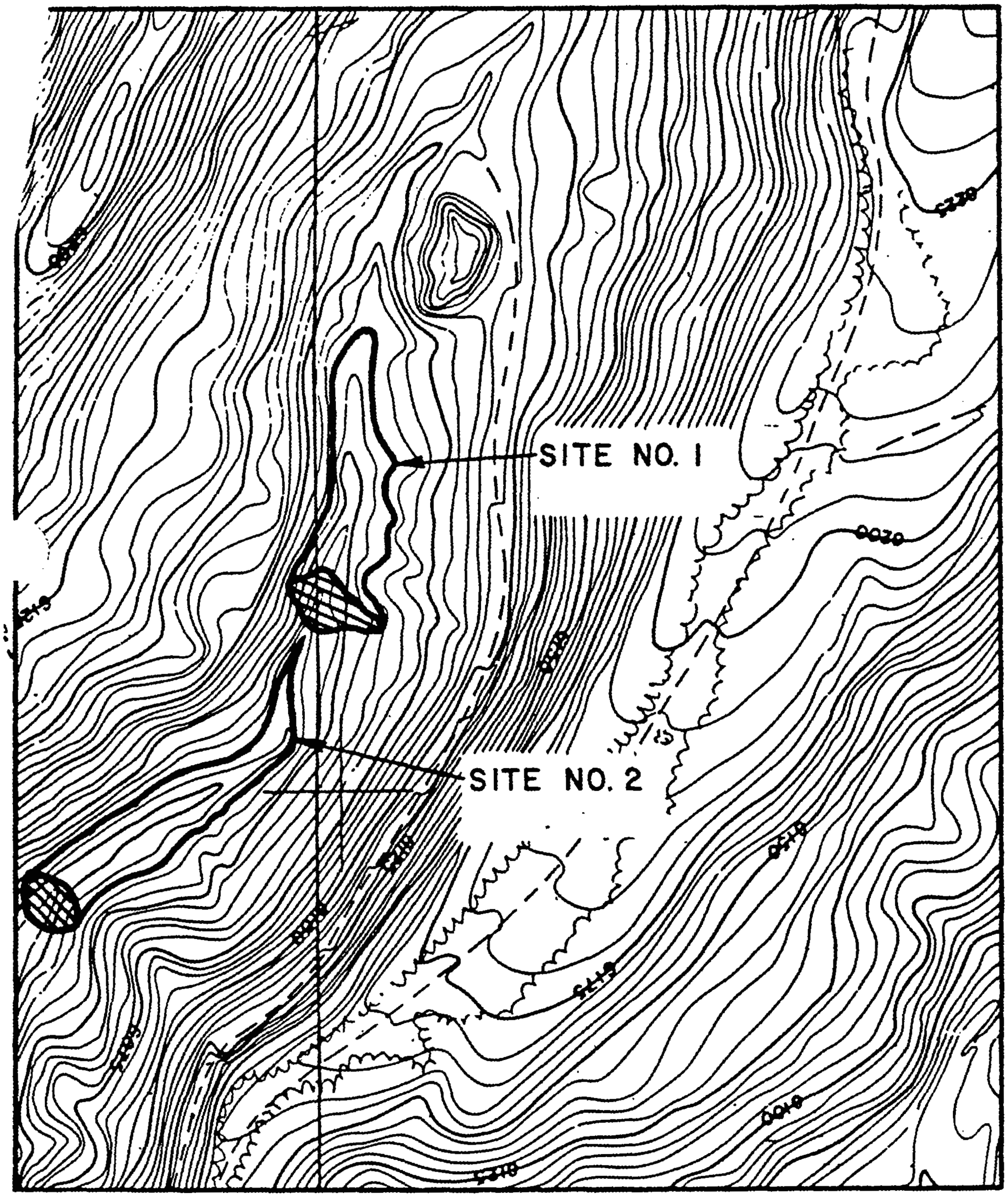

FIGURE 6.4 SEDIMENTATION POND SITE NO. 2

2. If there is any permanent pool storage in the first pond, the stored volume should be subtracted from the total volume for designing the second pond.

Step 3. Sediment size distribution

Use the same sediment size distribution as the first pond.

Step 4. Sediment yield (use USLE for annual sediment yield and MUSLE for storm sediment yield)

From additional contributing drainage area (10 acres)

Annual sediment yield = 19 tons
Storm sediment yield = 8.3 tons

Step 5. Inflow suspended solids concentration

Since the design is to remove all particles larger than 0.018 mm, calculation of the inflow suspended solids concentration is not required.

Step 6. Settleable solids concentration

Must remove all particles larger than 0.018 mm.

Step 7. Available storage volume

The stage-storage curve is presented in Figure 6.5. Since the first pond has a trapping efficiency of 69.5 percent, the sediment storage volume required in the second pond is equal to 30.5 percent of the upstream sediment yield plus the sediment yield from the additional contributing drainage area.

$$V_s = \frac{[(115 \text{ ton/yr} \times 0.305) + 19 \text{ ton/yr}] \times 3 \text{ yr} \times 2000 \text{ lb/ton}}{70 \text{ lb/ft}^3 \times 43{,}560 \text{ ft}^2\text{/ac}}$$

$$= 0.11 \text{ ac-ft}$$

From Figure 6.5, depth of sediment = 1.3 ft

Using the same embankment settlement, required freeboard, and emergency spillway depth as the first pond, the available detention storage depth is

$$D_1 = 16 - (0.80 + 1.0 + 2.5 + 1.3) = 10.4 \text{ ft}$$

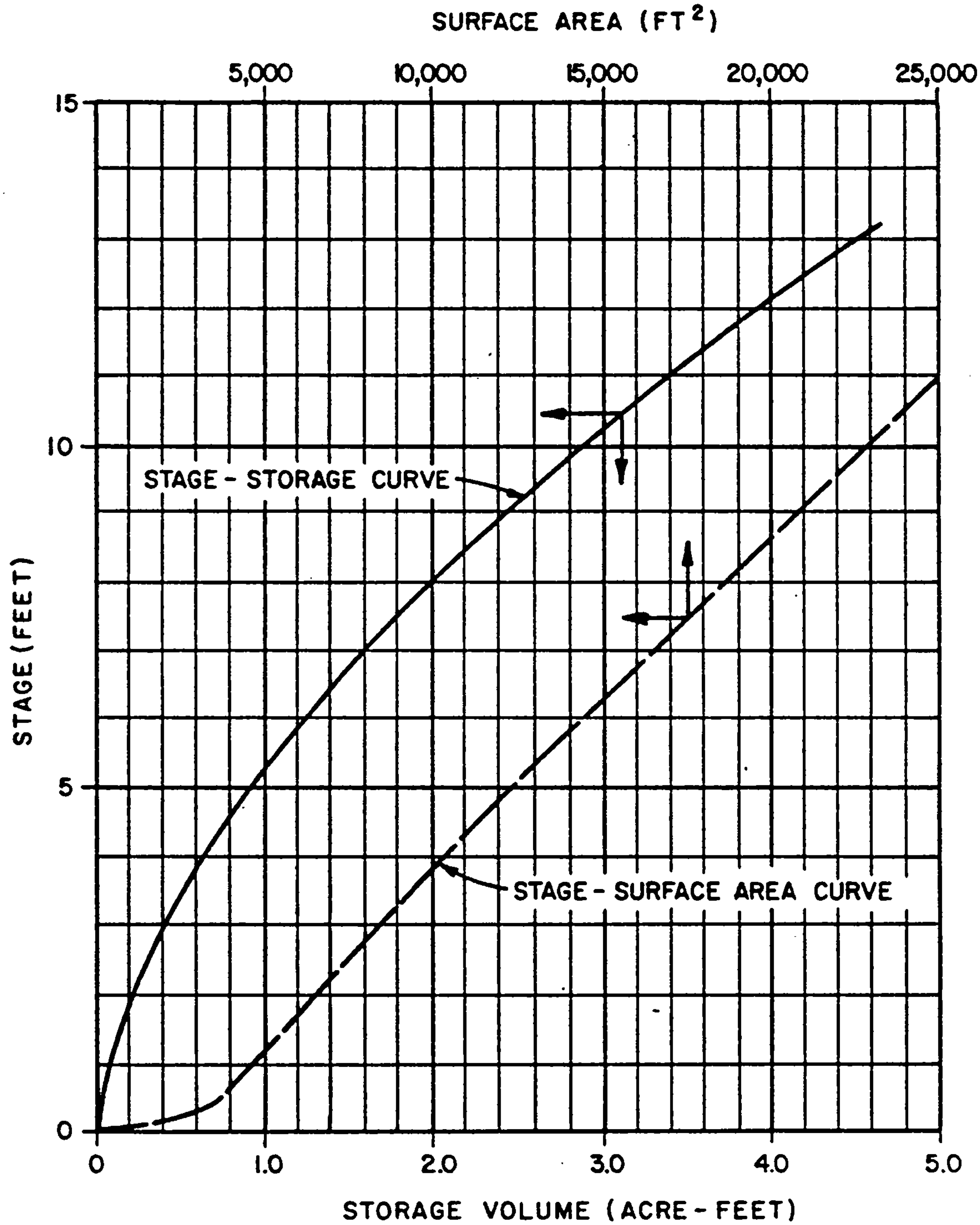

FIGURE 6.5 STAGE - SURFACE AREA AND STAGE - STORAGE CURVES OF SITE NO. 2

Stage at maximum detention stage depth

$$10.4 + 1.3 = 11.7$$

From Figure 6.5, available storage volume is

$$3.75 - 0.11 = 3.64 \text{ ac-ft}$$

Step 8. Required storage volume

Time base of inflow hydrograph

$$T_b = \frac{2V}{Q_I} = \frac{2 \times 2.70 \text{ ac-ft} \times 43{,}560 \text{ ft}^2/\text{ac}}{49.7 \text{ ft}^3/\text{sec} \times 3600 \text{ sec/hr}} = 1.31 \text{ hours}$$

For $d = 0.018$ mm and $D_T = 11.7$ ft,

$$T_D = 4.5 \text{ hours}$$

For $T_b = 1.31$ hours and $T_D = 4.5$ hours,

$$\frac{S}{V} = 0.930, \quad S = 0.930 \times 2.70 \text{ ac-ft} = 2.51 \text{ ac-ft} < 3.64 \text{ ac-ft}$$

$$\frac{Q_o}{Q_I} = 0.070, \quad Q_o = 0.070 \times 49.7 = 3.48 \text{ cfs}$$

Since the required storage volume is less than the available storage volume, decrease the depth and repeat Step 8.

Assume $D_1 = 8.5$ ft

From Figure 6.5, stage at maximum detention depth

$$8.5 + 1.3 = 9.8 \text{ ft}$$

Available storage = 2.80 - 0.11 = 2.69 ac-ft

For $d = 0.018$ mm and $D_T = 9.8$ ft

$$T_D = 3.9 \text{ hours}$$

For $T_b = 1.31$ hours and $T_D = 3.9$ hours

$$\frac{S}{V} = 0.910, \quad S = 0.910 \times 2.70 = 2.46 \text{ ac-ft} < 2.69 \text{ ac-ft}$$

$$\frac{Q_o}{Q_I} = 0.09, \quad Q_o = 0.09 \times 49.7 = 4.47 \text{ cfs}$$

Check surface area

A (measured at depth = 1.3 ft) = 5300 ft^2

$$A_{req} = 1.2 \times \frac{4.47}{2.254 \times (0.018)^2} = 6120 \text{ ft}^2 > 5300 \text{ ft}^2$$

The pond must be excavated to meet the surface area requirement or raise the principal spillway crest to elevation 2.0 ft. This will provide more sediment storage than is required. A permanent pool will exist if a dewatering device is not provided.

A (measured at depth = 2.0 ft) = 6500 ft^2

Check available storage volume

Available storage = 3.20 - 0.25 = 2.95 ac-ft > 2.46 ac-ft

Check length-to-width ratio

L (measured at depth = 2.0) = 250 ft

$$W = \frac{A}{L} = \frac{6500}{250} = 26 \text{ ft}$$

$$\frac{L}{W} = \frac{250}{26} = 9.6 > 2.0$$

Check scouring

$$V_H = \frac{Q_o}{WD_1} = \frac{4.47 \text{ ft}^3/\text{sec}}{26 \text{ ft} \times 8.5 \text{ ft}} = 0.02 \text{ fps}$$

$$V_s = 1.67\, d^{1/2} = 1.67 \times (0.018)^{1/2} = 0.22 \text{ fps}$$

$$V_H < V_s$$

A summary of the design is presented in Table 6.2.

Table 6.2. Summary of Sedimentation Pond Design.

	Description	Pond No. 1	Pond No. 2
1.	Design inflow (Q_I), cfs	77	49.7
2.	Design runoff volume (V), ac-ft	2.31	2.7
3.	Annual sediment yield, tons	115	54
4.	Storm sediment yield, tons (10-year, 24-hour storm)	50	---
5.	Inflow suspended solids concentration, mg/l	15,926	---
6.	Minimum size of particle settled, mm	0.065	0.018
7.	Detention time, hours	0.4	4.5
8.	Principal spillay elevation, ft	4.2	2.0
9.	Sediment storage required, ac-ft	0.23	0.11
10.	Sediment storage provided, ac-ft	0.23	0.25
11.	Runoff detention depth provided, ft	7.5	8.5
12.	Runoff detention volume provided, ac-ft	1.48	2.95
13.	Surface area required, ft^2	3490	6120
14.	Surface area provided, ft^2	3490	6500
15.	Length-to-width ratio	4.9	9.6
16.	Scour velocity (V_{sc}), fps	0.43	0.22
17.	Flow-through velocity (V_H), fps	0.14	0.02
18.	10-year, 24-hour design outflow, cfs	27.7	4.47
19.	25-year, 24-hour design outflow, cfs	63.8	113.13