Chapter 8: Stormwater Management Design Examples

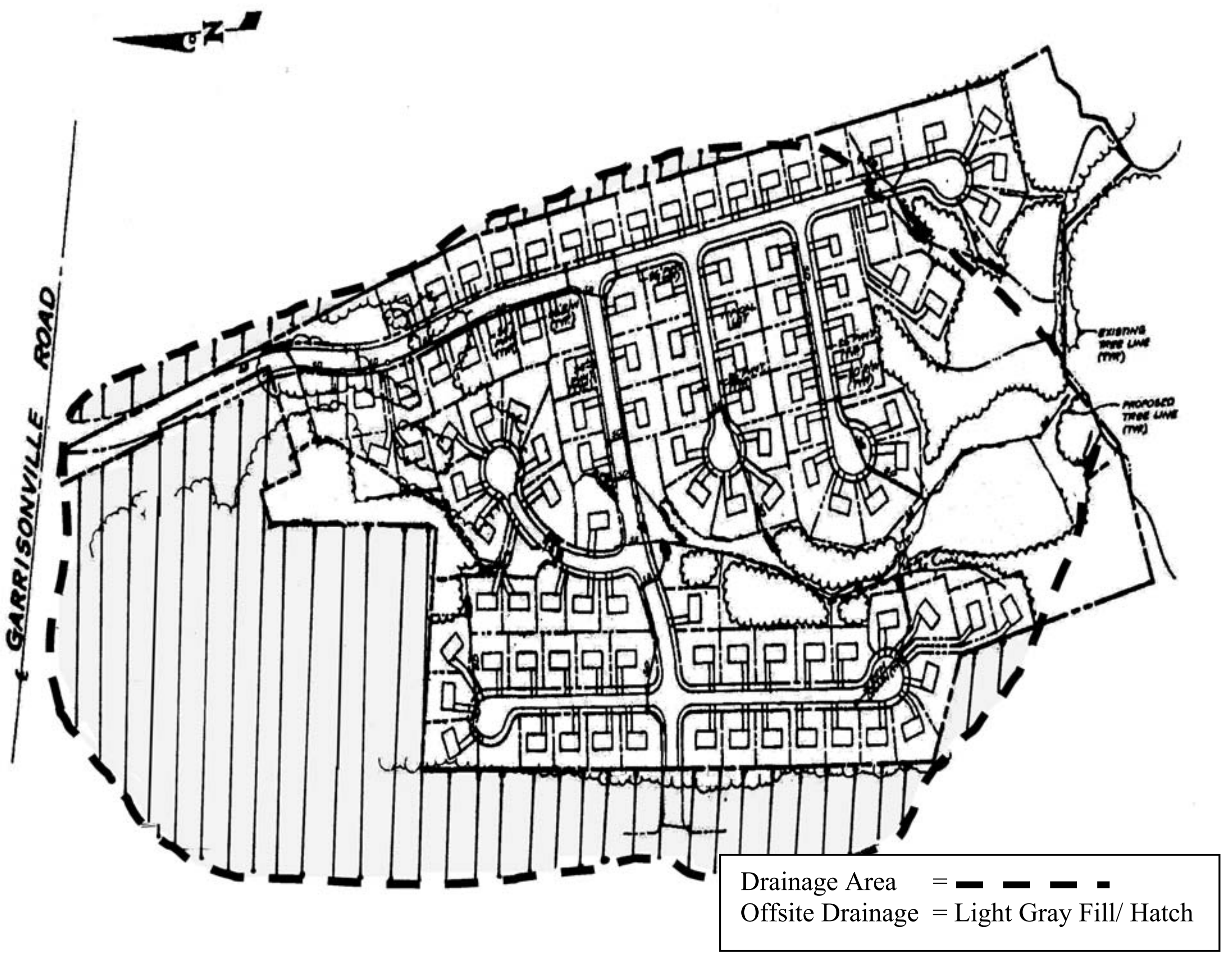
This chapter presents design examples for two hypothetical development sites in the State of New York. The first site, "Stone Hill Estates," is a residential development near Ithaca. The second is a commercial site in Albany. The chapter is divided into five sections, each of which focuses on a particular element of stormwater management design.

- Section 8.1 provides an example of detailed hydrology calculations at the residential site.
- Section 8.2 presents a pond design example based on the hydrology calculated in Section 8.1. This design example demonstrates the hydrologic and hydraulic computations to achieve water quality and water quantity control for stormwater management. Other specific dam design criteria such as soil compaction, structural appurtenances, embankment drainage, outlet design, gates, reservoir drawdown requirements, etc. are stated in Guidelines For Design of Dams.
- This design example in Section 8.2 requires an Article 15 Permit from NYS-DEC since the dam is 15 feet high measured from the top of dam to the low elevation at the downstream outlet, and the storage measured behind the structure to the top of the dam is 2.2 MG.
- Sections 8.3 through 8.5 present design examples for three practices on the commercial site: a sand filter, infiltration trench, and bioretention practice.

Section 8.1 Sizing Example - Stone Hill Estates

Following is a sizing example for the hypothetical "Stone Hill Estates," a 45-acre residential development in Ithaca, New York (Figure 8.1). The site also drains approximately 20 acres of off-site drainage, which is currently in a meadow condition. The site is on mostly C soils with some D soils.

Figure 8.1 Stone Hill Site Plan



Base Data
Location: Ithaca, NY
Site Area = 45.1 ac; Offsite Area = 20.0 ac (meadow)
Total Drainage Area (A) = 65.1
Measured Impervious Area=12.0 ac;
Site Soils Types: 78% "C", 22% "D"
Offsite Soil Type: 100% "C"
Zoning: Residential (½ acre lots)
Hazard Class: Low "A", Dam Size small per table #1 Appendix A.

Hydrologic Data

	Pre	Post	Ult.
CN	72	78	82
t_c (hr)	.46	.35	.35

Computation of Preliminary Stormwater Storage Volumes and Peak Discharges

The layout of the Stone Hill subdivision is shown on the previous page.

Water Quality Volume, WQ_v

- Compute Impervious Cover

  Use both on-site and off-site drainage:

  $$I = 12.0 \text{ acres}/65.1 \text{ acres} = 18.4\%$$

- Compute Runoff Coefficient, R_v

  $$R_v = 0.05 + (I)(0.009) = 0.05 + (18.4)(0.009) = 0.22$$

- Compute WQ_v (Includes both on-site and off-site drainage)

Use the 90% capture rule with 0.9” of rainfall. (From Figure 4.1)

$$WQ_v = (0.9")(R_v)(A) = (0.9")(0.22)(65.1 \text{ ac})(1\text{ft}/12\text{in}) = 1.07 \text{ ac-ft}$$

Establish Hydrologic Input Parameters and Develop Site Hydrology (see Figures 8.2, 8.3, and 8.4)

Condition	**Area**	**CN**	**Tc**
	Ac		*hrs*
Pre-developed	65.1	72	0.46
Post-developed	65.1	78	0.35
Ultimate buildout*	65.1	82	0.35

*Zoned land use in the drainage area.

Hydrologic Calculations

Condition	**Q_{1-yr}**	**Q_{1-yr}**	**Q_{10-yr}**	Q_{100-yr}
Runoff	*inches*	*cfs*	*cfs*	*cfs*
Pre-developed	0.4	19	72	141
Post-developed	0.7	38	112	202
Ultimate buildout	NA	NA	NA	227

PEAK DISCHARGE SUMMARY				
JOB:	STONE HILL			EWB
DRAINAGE AREA NAME:	PRE DEVELOPMENT			21-Jan-97
COVER DESCRIPTION	**SOIL NAME**	**GROUP A,B,C,D**	**Curve Number**	**AREA (In acres)**
MEADOW		C	71	20.25 Ac.
MEADOW		D	78	7.95 Ac.
WOOD		C	70	15.09 Ac.
WOOD		D	77	1.81 Ac.
OFF-SITE MEADOW		C	71	20.00 Ac.
			AREA SUBTOTALS:	**65.10 Ac.**
Time of Concentration 2-Yr 24 Hr Rainfall = 2.7 In	**Surface Cover Cross Section**	**Manning 'n' Wetted Per**	**Flow Length Avg Velocity**	**Slope Tt (Hrs)**
Sheet Flow	dense grass	'n'=0.24	150 Ft.	3.80% 0.28 Hrs
Shallow Flow	UNPAVED		1300 Ft. 2.65 F.P.S.	2.70% 0.14 Hrs.
Channel Flow Hydraulic Radius =1.26	22.0 SqFt	'n'=0.040 17.5 Ft.	1100 Ft. 7.14 F.P.S.	2.70% 0.04 Hrs.
Total Area in Acres =	65.10 Ac.	Total Sheet Flow= 0.28 Hrs.	Total Shallow Flow= 0.14 Hrs.	Total Channel Flow = 0.04 Hrs.
Weighted CN =	72			
Time Of Concentration =	0.46 Hrs.			
Pond Factor =	1	RAINFALL TYPE II		
STORM	*Precipitation (P) inches*	*Runoff (Q)in*	Qp, PEAK DISCHARGE	TOTAL STORM Volumes
1 Year	2.3 In.	0.428	18.6 CFS	101,195 Cu. Ft.
2 Year	2.7 In.	0.635	30.2 CFS	150,257 Cu. Ft.
10 Year	3.9 In.	1.39	72 CFS	328,570 Cu. Ft.
100 Year	5.5 In.	2.59	141 CFS	611,958 Cu. Ft.

Figure 8.2 Stone Hill Pre-Development Conditions

PEAK DISCHARGE SUMMARY				
JOB:	STONE HILL			EWB
DRAINAGE AREA NAME:	POST DEVELOPMENT			21-Jan-97
COVER DESCRIPTION	SOIL NAME	GROUP A,B,C,D	Curve Number	AREA (In acres)
MEADOW		C	71	0.16 Ac.
MEADOW		D	78	0.14 Ac.
WOOD		C	70	3.09 Ac.
WOOD		D	77	1.81 Ac.
IMPERVIOUS			98	12.00 Ac.
GRASS		C	74	20.09 Ac.
GRASS		D	80	7.81 Ac.
OFFSITE MEADOW		C	71	20.00 Ac.
			AREA SUBTOTALS:	65.10 Ac.
Time of Concentration 2-Yr 24 Hr Rainfall = 2.7 In	Surface Cover Cross Section	Manning 'n' Wetted Per	Flow Length Avg Velocity	Slope Tt (Hrs)
Sheet Flow	dense grass	'n'=0.24	100 Ft.	3.80% 0.20 Hrs
Shallow Flow (a)	UNPAVED		100 Ft. 1.98 F.P.S.	1.50% 0.01 Hrs.
(b)	PAVED		400 Ft. 2.03 F.P.S.	1.00% 0.05 Hrs.
Channel Flow (a) Hydraulic Radius =0.50	1.6 SqFt	'n'=0.013 3.2 Ft.	1550 Ft. 7.22 F.P.S.	1.00% 0.06 Hrs.
(b) Hydraulic Radius =1.42	12.0 SqFt	'n'=0.030 8.5 Ft.	350 Ft. 13.01 F.P.S.	4.30% 0.01 Hrs.
(c) Hydraulic Radius =1.26	22.0 SqFt	'n'=0.040 8.5 Ft.	300 Ft. 7.89 F.P.S.	3.30% 0.01 Hrs.
Total Area in Acres =	65.10 Ac.	Total Sheet Flow=	Total Shallow Flow=	Total Channel Flow =
Weighted CN =	78			
Time Of Concentration =	0.35 Hrs.	0.20 Hrs.	0.07 Hrs.	0.08 Hrs.
Pond Factor =	1	RAINFALL TYPE II		
STORM	*Precipitation* (P) inches	*Runoff* (Q)in	Qp, PEAK DISCHARGE	TOTAL STORM Volumes
1 Year	2.3 In.	0.66 In.	37.6 CFS	156,283 Cu. Ft.
2 Year	2.7 In.	0.92 In.	54.0 CFS	217,511 Cu. Ft.
10 Year	3.9 In.	1.8 In.	112 CFS	427,155 Cu. Ft.
100 Year	5.5 In.	3.14 In.	202 CFS	742,265 Cu. Ft.

Figure 8.3 Stone Hill Post-Development Conditions

PEAK DISCHARGE SUMMARY				
JOB:	STONE HILL			EWB
DRAINAGE AREA NAME:	ULTIMATE BUILDOUT			21-Jan-97
COVER DESCRIPTION	SOIL NAME	GROUP A,B,C,D	Curve Number	AREA (In acres)
MEADOW		C	71	0.16 Ac.
MEADOW		D	78	0.14 Ac.
WOOD		C	70	3.09 Ac.
WOOD		D	77	1.81 Ac.
IMPERVIOUS			98	12.00 Ac.
GRASS		C	74	20.09 Ac.
GRASS		D	80	7.81 Ac.
OFFSITE ULTIMATE				
SF RES (0.25 AC LOTS)		C	83	20.00 Ac.
			AREA SUBTOTALS:	65.10 Ac.
Time of Concentration 2-Yr 24 Hr Rainfall = 2.7 In	Surface Cover Cross Section	Manning 'n' Wetted Per	Flow Length Avg Velocity	Slope Tt (Hrs)
Sheet Flow	dense grass	'n'=0.24	100 Ft.	3.80% 0.20 Hrs
Shallow Flow (a)	UNPAVED		100 Ft. 1.98 F.P.S.	1.50% 0.01 Hrs.
(b)	PAVED		400 Ft. 2.03 F.P.S.	1.00% 0.05 Hrs.
Channel Flow (a) Hydraulic Radius =0.50	1.6 SqFt	'n'=0.013 3.2 Ft.	1550 Ft. 7.22 F.P.S.	1.00% 0.06 Hrs.
(b) Hydraulic Radius =1.42	12.0 SqFt	'n'=0.030 8.5 Ft.	350 Ft. 13.01 F.P.S.	4.30% 0.01 Hrs.
(c) Hydraulic Radius =1.26	22.0 SqFt	'n'=0.040 8.5 Ft.	300 Ft. 7.89 F.P.S.	3.30% 0.01 Hrs.
Total Area in Acres =	65.10 Ac.	Total Sheet	Total Shallow	Total Channel
Weighted CN =	82	Flow=	Flow=	Flow =
Time Of Concentration =	0.35 Hrs.	0.20 Hrs.	0.07 Hrs.	0.08 Hrs.
Pond Factor =	1	RAINFALL TYPE II		
STORM	Precipitation (P) Inches	Runoff (Q)	Qp, PEAK DISCHARGE	TOTAL STORM Volumes
1 Year	2.3 In.	0.85 In.	50.9 CFS	201,772 Cu. Ft.
2 Year	2.7 In.	1.15 In.	70.0 CFS	271,097 Cu. Ft.
10 Year	3.9 In.	2.12 In.	135 CFS	500,458 Cu. Ft.
100 Year	5.5 In.	3.52 In.	227 CFS	834,167 Cu. Ft.

Figure 8.4 Stone Hill Ultimate Buildout Conditions

Compute Stream Channel Protection Volume, (Cp_v) (see Section 4.3 and Appendix B)

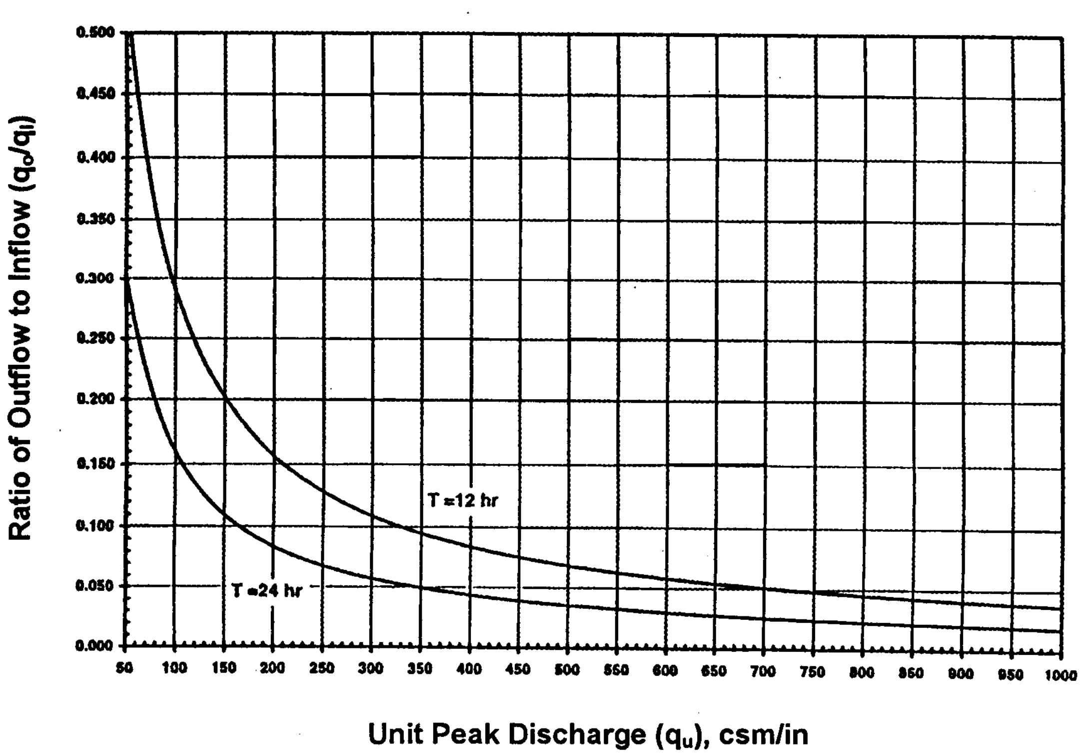
For stream channel protection, provide 24 hours of extended detention (T) for the one-year event.

<u>Compute Channel Protection Storage Volume</u>

First, determine the value of the unit peak discharge (q_u) using TR-55 and Type II Rainfall Distribution

- Initial abstraction (Ia) for CN of 78 is 0.564: [Ia = (200/CN - 2)]
- Ia/P = (0.564)/ 2.3 inches = 0.245
- T_c = 0.35 hours
- Using the above data and Exhibit 4-II from TR-55 (NRCS, 1986), q_u = 570 csm/in (cubic feet per second per square mile per year)

Figure 8.5 Detention Time vs. Discharge Ratios (Source: MDE, 2000)



- Knowing q_u and T = 24 hours, find q_o/q_i using Figure 8.5 (also see methodology in Appendix B)
- Peak outflow discharge/peak inflow discharge (q_o/q_i) = 0.035
- $Vs/Vr = 0.683 - 1.43(q_o/q_i) + 1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3$ (from Appendix B)

  Where Vs equals channel protection storage (Cp_v) and Vr equals the volume of runoff in inches.
- Vs/Vr = 0.63 and, from figure 8.3, Q = 0.7"
- Solving for V_s

  $Vs = Cp_v = 0.63(0.7")(1/12)(65.1\text{ ac}) = 2.4\text{ ac-ft}$ (104,214 cubic feet)

Define the Average Release Rate

- The above volume, 2.4 ac-ft, is to be released over 24 hours
- $(2.4\text{ ac-ft} \times 43{,}560\text{ ft}^2/\text{ac}) / (24\text{ hrs} \times 3{,}600\text{ sec/hr}) = 1.2\text{ cfs}$

Compute Overbank Flood Protection Volume, (Qp_{10}) (see Section 4.4)

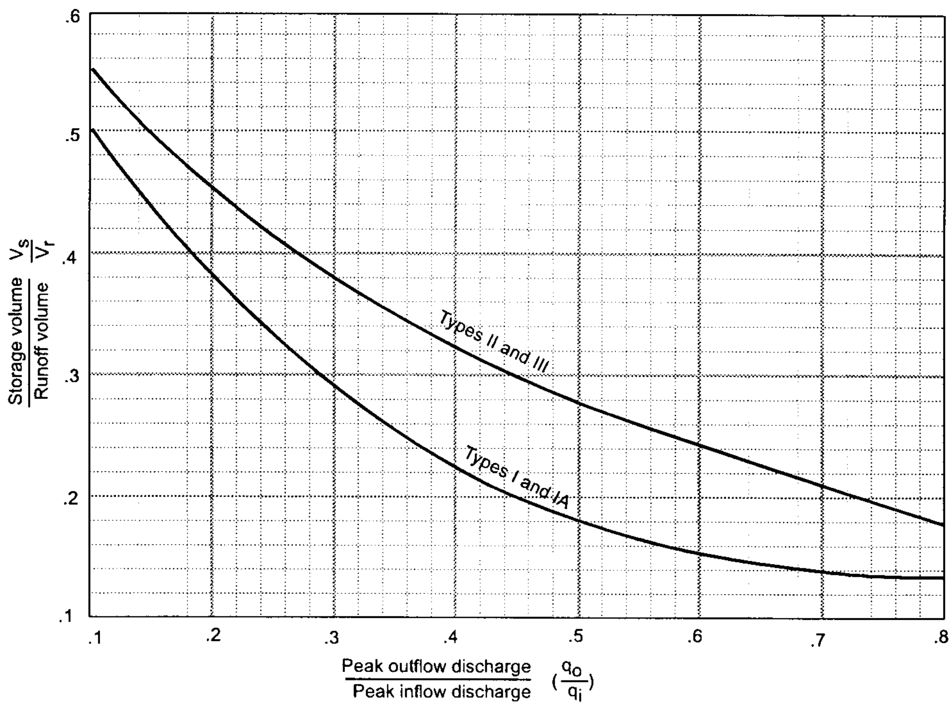
For both the overbank flood protection volume and the extreme flood protection volume, size is determined using the TR-55 "Short-Cut Method," which relates the storage volume to the required reduction in peak flow and storm inflow volume (Figure 8.6).

- For a q_i of of 112 cfs (post-developed), and an allowable q_o of 72 cfs (pre-developed), the value of $(q_o)/(q_i)$ is 0.64
- Using figure 8.6, and a post-developed curve number of 78, Vs/Vr = 0.23
- Using a total storm runoff volume of 427,155 cubic feet (9.8 acre-feet), the required storage (Vs) is:

  $V_s = Qp_v = 0.23(427{,}155)/43{,}560 = 2.26$ acre-feet

Figure 8.6 Approximate Detention Basin Routing for Rainfall Types I, IA, II, and III

Source: TR-55, 1986



While the TR-55 short-cut method reports to incorporate multiple stage structures, experience has shown that an additional 10-15% storage is required when multiple levels of extended detention are provided inclusive with the 10-year storm. So, for preliminary sizing purposes, add 15% to the required volume for the 10-year storm. $Q_{p-10} = 2.23 \times 1.15 = 2.59$ ac-ft.

Compute Extreme Flood Protection Volume, (Q_f)

Extreme flood protection is calculated using the same methodology as overbank protection.

- For a Q_{in} of, and an allowable Q_{out} of, and a runoff volume of the Vs necessary for 100-year control is, under a developed CN of 78. Note that 5.5 inches of rain fall during this event, with approximately 3.1 inches of runoff.
- While the TR-55 short-cut method reports to incorporate multiple stage structures, experience has shown that an additional 10-15% storage is required when multiple levels of extended detention are provided inclusive with the 100-year storm. So, for preliminary sizing purposes add 15% to the required volume for the 100-year storm. $Q_{f-100} = 3.53 \times 1.15 = 4.06$ ac-ft.

Analyze Safe Passage of 100-Year Design Storm (Qf)

If peak discharge control of the 100-year storm is not required, it is still necessary to provide safe passage for the 100-year event under ultimate buildout conditions (Q_{ult} = 227 cfs). See table 4-1 appendix A for low and moderate hazard dam design storm.

Section 8.2 Pond Design Example

Following is a step-by-step design example for an extended detention pond (P-3) applied to Stone Hill Estates, which is described in detail in Section 8.1 along with design treatment volumes. This example continues with the design to develop actual design parameters for the constructed facility.

Step 1. Compute preliminary runoff control volumes.

The volume requirements were determined in Section 8.1. Table 8.1 provides a summary of the storage requirements.

Table 8.1. Summary of General Storage Requirements for Stone Hill Estates

Symbol	*Category*	Volume Required (ac- ft)	*Notes*
WQ_v	Water Quality Volume	1.07	
Cp_v	Stream Protection	2.4	Average ED release rate is 1.2 cfs over 24 hours
Q_p	Peak Control	2.6	10-year, in this case
Q_f	Flood Control	4.1	

Step 2. Determine if the development site and conditions are appropriate for the use of a stormwater pond.

The drainage area to the pond is 65.1 acres. Existing ground at the proposed pond outlet is 619 MSL. Soil boring observations reveal that the seasonally high water table is at elevation 618. The underlying soils are SC (sandy clay) and are suitable for earthen embankments and to support a wet pond without a liner. The stream invert at the adjacent stream is at elevation 616.

Step 2A. Determine Hazardous Class of Dam.

The height of the dam, its maximum impoundment capacity, the physical characteristics of the dam site and the effect that a failure of the dam would have upon human life, residences, buildings, roads, highways, utilities and other facilities should be assessed to determine whether a low (A), moderate (B) or high (C) hazard classification is appropriate for designing the dam. Refer to Section 3.0 of the "Guidelines for the Design of Dams" for additional information regarding hazard class and Table 1 of those guidelines for the appropriate hydrologic design criteria for new dams based on the assigned hazard class and size.

Step 3. Confirm local design criteria and applicability.

There are no additional requirements for this site.

Step 4. Determine pretreatment volume.

Size wet forebay to treat 10% of the WQ_v. (10%)(1.07 ac-ft) = **0.1 ac-ft**

(forebay volume is included in WQ_v

curve is prepared using the average area method for computing volumes. See Figure 8.7 for pond location on site, Figure 8.8 for grading and Figure 8.9 for Elevation-Storage Data.

Figure 8.7 Pond Location on Site

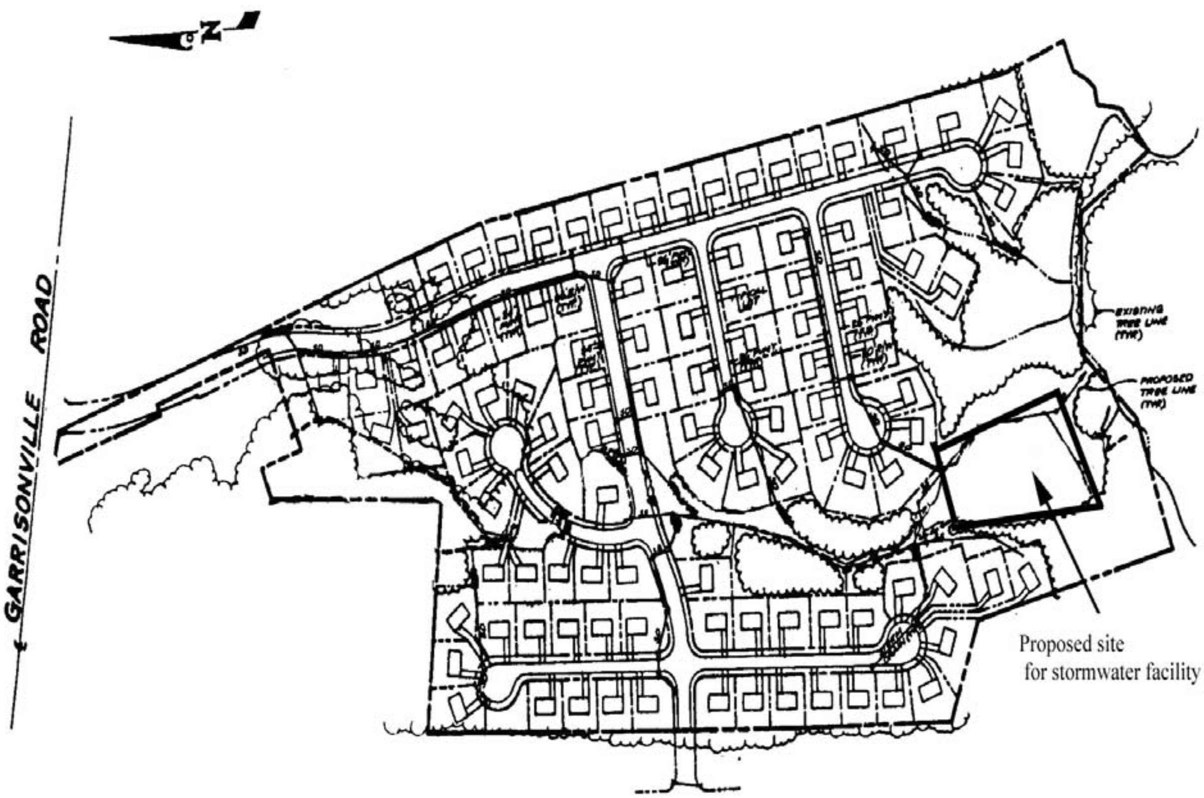


Figure 8.8 Plan View of Pond Grading (Not to Scale)

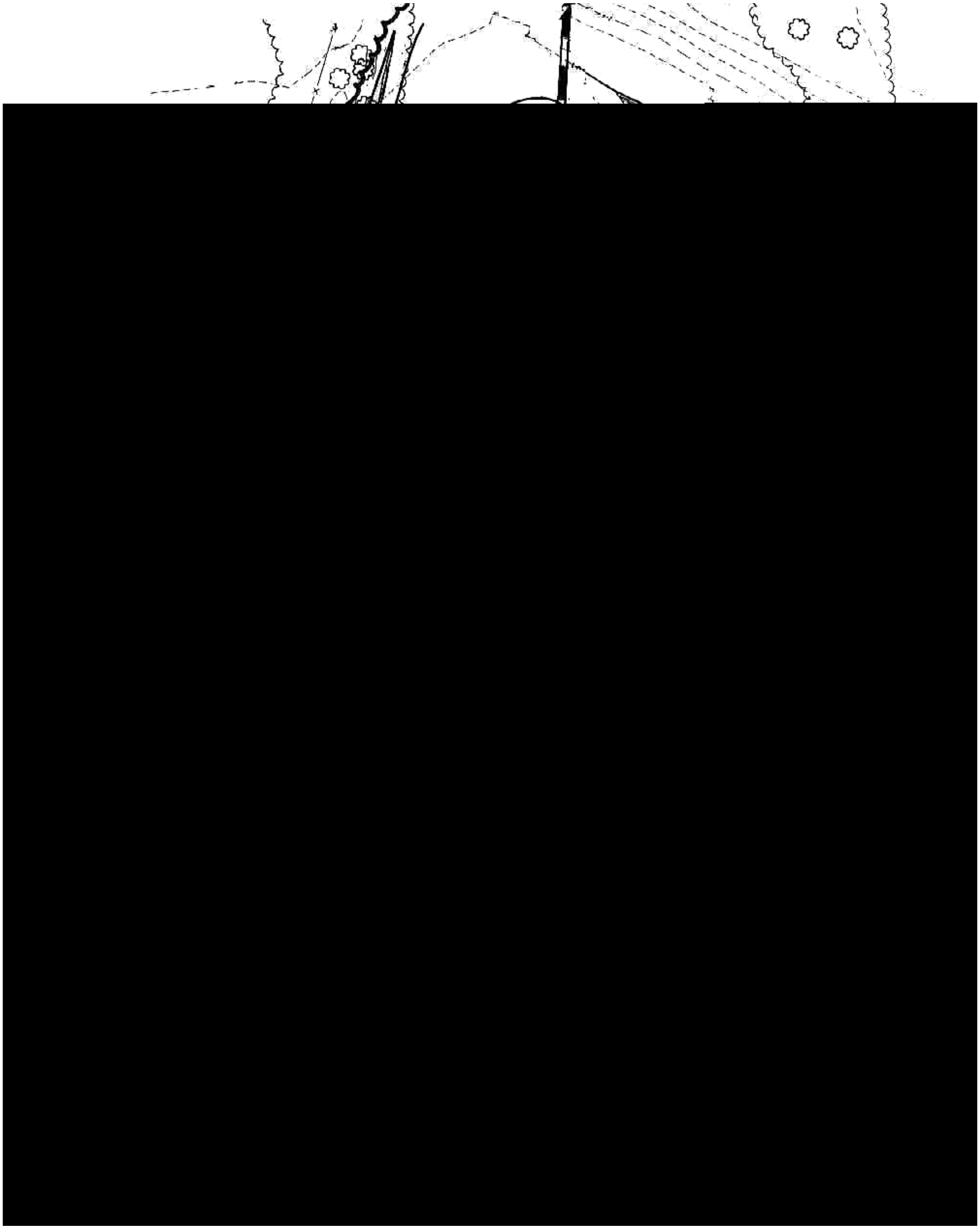
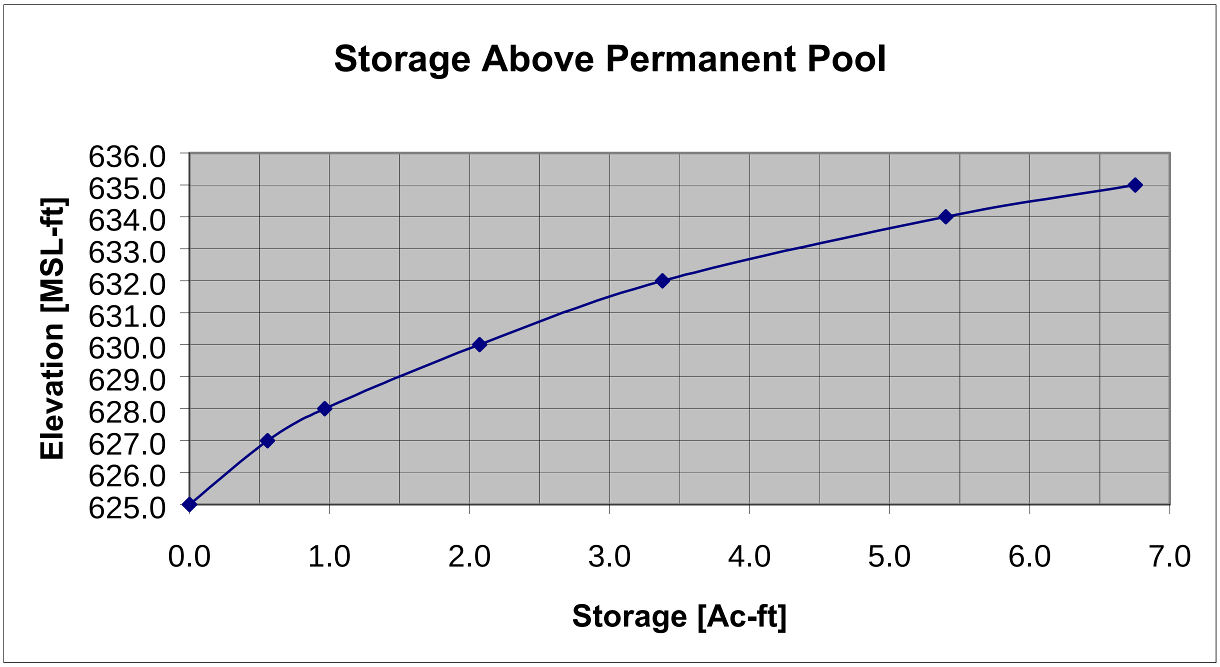


Figure 8.9 Storage-Elevation Table/Curve

Elevation MSL	Area ft^2	Average Area ft^2	Depth ft	Volume ft^3	Cumulative Volume ft^3	Cumulative Volume ac-ft	Volume Above Permanent Pool ac-ft
621.0	3150						
624.0	8325	5738	3	17213	17213	0.40	
625.0	10400	9363	1	9363	26575	0.61	0
627.0	13850	12125	2	24250	50825	1.17	0.56
628.0	21850	17850	1	17850	68675	1.58	0.97
630.0	26350	24100	2	48200	116875	2.68	2.07
632.0	30475	28413	2	56825	173700	3.99	3.38
634.0	57685	44080	2	88160	261860	6.01	5.40
635.0	60125	58905	1	58905	320765	7.36	6.75



Set basic elevations for pond structures

- The pond bottom is set at elevation 621.0
- Provide gravity flow to allow for pond drain, set riser invert at 620.5
- Set barrel outlet elevation at 620.0

Set water surface and other elevations

- Required permanent pool volume = 50% of WQv = 0.54 ac-ft. From the elevation-storage table, read elevation 625.0 (0.61 ac-ft > 0.54 ac-ft) site can accommodate it and it allows a small safety factor for fine sediment accumulation – OK

Set permanent pool wsel = 625.0

- Forebay volume provided in single pool with volume = 0.1 ac-ft - OK
- Required extended detention volume (WQ_v-ED)= 0.54 ac-ft. From the elevation-storage table (volume above permanent pool), read elevation 627.0 (0.56 ac-ft > 0.54 ac-ft) OK. Set ED wsel = 627.0

Note: Total storage at elevation 627.0 = 1.17 ac-ft (greater than required WQ_v of 1.07 ac-ft)

Compute the required WQ_v-ED orifice diameter to release 0.54 ac-ft over 24 hours

- Avg. ED release rate = (0.54 ac-ft)(43,560 ft^2/ac)/(24 hr)(3600 sec/hr) = 0.27 cfs
- Invert of orifice set at wsel = 625.0
- Average head = (627.0 - 625.0)/ 2 = 1.0'
- Use orifice equation to compute cross-sectional area and diameter

  $Q = CA(2gh)^{0.5}$, for Q=0.27 cfs h = 1.0 ft; C = 0.6 = discharge coefficient. Solve for A

  $A = 0.27 \text{ cfs} / [(0.6)((2)32.2 \text{ ft/s}^2)(1.0 \text{ ft}))^{0.5}]$ $A = 0.057 \text{ ft}^2$, $A = \pi d^2 / 4$;

  dia. = 0.26 ft = 3.2", say 3.0 inches

  Use 4" pipe with 4" gate valve to achieve equivalent diameter

Compute the stage-discharge equation for the 3.0" dia. WQv orifice

- $Q_{WQv\text{-}ED} = CA(2gh)^{0.5} = (0.6)\ (0.052 \text{ ft}^2)\ [((2)(32.2 \text{ ft/s}^2))^{0.5}]\ (h^{0.5})$,
- $Q_{WQv\text{-}ED} = (0.25)\ h^{0.5}$, where: h = wsel - 625.125

  (Note: Account for one half of orifice diameter when calculating head)

Step 7. Compute ED orifice size, and compute release rate for Cpv-ED control and establish Cpv elevation.

Set the Cp_v pool elevation

- Required Cp_v storage = 2.4 ac-ft (see Table 1).
- From the elevation-storage table, read elevation 630.6 (this includes the WQ_v).
- Set Cp_v wsel = 630.6

Size Cp_v orifice

- Size to release average of 1.2 cfs.
- Set invert of orifice at wsel = 627.0
- Average WQ_v-ED orifice release rate is 0.41 cfs, based on average head of 2.74' ((630.6 – 625.125)/2)
- Cp_v-ED orifice release = 1.2 -0.41 = 0.79 cfs
- Head = (630.6 - 627.0)/2 = 1.8'

Use orifice equation to compute cross-sectional area and diameter

- $Q = CA(2gh)^{0.5}$, for h = 1.8'
  - $A = 0.79\text{ cfs} / [(0.6)((2)(32.2'/s^2)(1.8'))^{0.5}]$
  - $A = 0.12\text{ ft}^2$, $A = \pi d^2 / 4$;
  - dia. = 0.39 ft = 4.7"
  - Use 6" pipe with 6" gate valve to achieve equivalent diameter

Compute the stage-discharge equation for the 4.7" dia. Cp_v orifice

- $Q_{Cpv\text{-}ED} = CA(2gh)^{0.5} = (0.6)\ (0.12\text{ ft}^2)\ [((2)\ (32.2'/s^2))^{0.5}]\ (h^{0.5})$,
- $Q_{Cpv\text{-}ED} = (0.58)\ (h^{0.5})$, where: h = wsel – 627.2

(Note: Account for one half of orifice diameter when calculating head)

Step 8. Calculate Qp_{10} (10 year storm) release rate and water surface elevation.

In order to calculate the 10 year release rate and water surface elevation, the designer must set up a stage-storage-discharge relationship for the control structure for each of the low flow release pipes (WQ_v-ED and Cp_v-ED) plus the 10 year storm.

Develop basic data and information

- The 10 year pre-developed peak discharge = 72 cfs,
- The post developed inflow = 112 cfs, from Table 1,
- From previous estimate Q_{p-10} = 2.26 ac-ft. Adding 15% to account for ED storage yields a preliminary volume of 2.56 ac-ft.
- From elevation-storage table (Figure 8.9), read elevation 631.0.
- Size 10 year slot to release 72 cfs at elevation 631.0.

@ wsel 631.0:

- WQ_v-ED orifice releases 0.61 cfs,
- Cp_v-ED orifice releases 1.13 cfs, therefore;
- Allowable Q_{p-10} = 72 cfs - (.61 + 1.13) = 70.26 cfs, say 70.3 cfs.
- Set weir crest elevation at wsel = 630.6
- Max head = (631.0 – 630.6) = 0.4'

Use weir equation to compute slot length

- $Q = CLh^{3/2}$
- $L = 70.3 \text{ cfs} / (3.1) (0.4^{3/2}) = 89.6 \text{ ft}$
- This weir length is impractical, so adjust max head (and therefore slot height) to 1.5' and recalculate weir length.
- $L = 70.3 \text{ cfs} / (3.1) (1.5^{3/2}) = 12.3 \text{ ft}$
- Use three 5ft x 1.5 ft slots for 10-year release (opening should be slightly larger than needed so as to have the barrel control before slot goes from weir flow to orifice flow).
- Maximum $Q = (3.1)(15)(1.5)^{3/2} = 85.4$ cfs

Check orifice equation using cross-sectional area of opening

- $Q = CA(2gh)^{0.5}$, for h = 0.75' (For orifice equation, h is from midpoint of slot)
- A = 3 (5.0') (1.5') = 22.5ft^2
- $Q = 0.6 (22.5\text{ft}^2) [(64.4)(0.75)]^{0.5} = 93.8$ cfs > 85.4 cfs, so use weir equation

$$Q_{10} = (3.1)(15')\, h^{3/2}, \quad \underline{Q_{10} = (46.5)\, h^{3/2}, \text{ where } h = \text{wsel} - 630.6}$$

- Size barrel to release approximately 70.3 cfs at elevation 632.1 (630.6 + 1.5)
- Check inlet condition: (use FHWA culvert charts)

H_w = 632.1-620.5 = 11.6 ft

- Try 27" diameter RCP, Using FHWA Chart ("Headwater Depth for Concrete Pipe Culverts with Inlet Control") with entrance condition 1
- H_w / D = 11.6/2.25 = 5.15, Discharge = 69 cfs
- Check outlet condition (use NRCS pipe flow equation from NEH Section 5 ES-42):
- $Q = a\ [(2gh)/(1+k_m+k_pL)]^{0.5}$

where:

where:	Q	=	discharge in cfs
	a	=	pipe cross sectional area in ft^2
	g	=	acceleration of gravity in ft/sec^2
	h	=	head differential (wsel - downstream centerline of pipe or tailwater elev.)
	k_m	=	coefficient of minor losses (use 1.0)
	k_p	=	pipe friction loss coef. (= $5087n^2/d^{4/3}$, d in inches, n is Manning's n)
	L	=	pipe length in ft

h = 632.1 - (620.0 + 1.125) = 10.98'
for 27" RCP, approximately 70 feet long:
$Q = 4.0\ [(64.4)\ (10.98) / (1+1+(0.0106)\ (70))]^{0.5} = 64.2$ cfs
64.2 cfs < 69 cfs, so barrel is outlet controlled and use outlet equation
$Q = 19.4\ (h)^{0.5}$, where h = wsel – 621.125

Note: pipe will control flow before high stage inlet reaches max head.

Complete stage-storage-discharge summary (Figure 8.10) up to preliminary 10-year wsel (632.1) and route 10 year post-developed condition inflow using computer software (e.g., TR-20). Pond routing computes 10-year wsel at 632.5 with discharge = 65.4 cfs < 72 cfs, OK (see Figure 8.10).

Figure 8.10 Stage-Storage-Discharge Summary

Elevation MSL	Storage ac-ft	Low Flow WQv-ED 3.0" eq dia		Riser						27" Barrel				Emergency Spillway 26' earthen 3:1		Total Discharge
				Cpv-ED 4.7" eq. dia		High Stage Slot				Inlet		Pipe				
						Orifice		Weir								
		H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	Q cfs
625.0	0.00	0	0													0.00
625.5	0.14	0.4	0.15													0.15
626.0	0.28	0.9	0.23													0.23
626.5	0.42	1.4	0.29													0.29
627.0	0.56	1.9	0.34	0.0	0.00											0.34
627.5	0.77	2.4	0.39	0.3	0.32											0.70
628.0	0.97	2.9	0.42	0.8	0.52											0.94
629.0	1.52	3.9	0.49	1.8	0.78											1.27
629.5	1.80	4.4	0.52	2.3	0.88											1.40
630.0	2.07	4.9	0.55	2.8	0.97											1.52
630.6	2.40	5.5	0.58	3.4	1.07	-	-	0.0	0.0							1.65
631.0	2.73	5.9	0.61	3.8	1.13	-	-	0.4	11.8							13.5
632.1	3.45	7.0	0.66	4.9	1.28	0.75	94	1.5	85.4	11.6	69.0	11.0	64.2			64.2
632.5	3.80	7.4	0.68	5.3	1.34	0.95	106	-	-	12.0	70.0	11.4	65.4			65.4
632.7	4.10	7.6	0.69	5.5	1.36	1.05	111	-	-	12.2	71.0	11.6	66.0	0.0	0.0	66.0
633.3	4.70	-	-	-	-	-	-	-	-	12.8	72.0	12.2	67.6	0.6	26.0	93.6
634.0	5.40	-	-	-	-	-	-	-	-	13.5	73.0	12.9	69.6	1.3	95.0	164.6
635.0	6.75	-	-	-	-	-	-	-	-	14.5	86.0	13.9	72.2	2.3	251.0	323.2

Note: Adequate outfall protection must be provided in the form of a riprap channel, plunge pool, or combination to ensure non-erosive velocities.

Step 9. Calculate spillway design flood release rate and water surface elevation (wsel), size emergency spillway, calculate spillway design flood wsel.

For a Hazard Class "A" dam, in order to calculate the 100-year release rate and water surface elevation, the designer must continue with the stage-storage-discharge relationship (Figure 8.10) for the control riser and emergency spillway.

Develop basic data and information

- The 100 year pre-developed peak discharge = 141 cfs,
- The post developed inflow = 202 cfs, from Table 1,
- From previous estimate Q_{p-100} = 3.53 ac-ft. Adding 15% to account for ED storage yields a preliminary volume of 4.06 ac-ft.
- From elevation-storage table (Figure 8.10), read elevation 632.8, say 633.0.

The 10-year wsel is at 632.5. Set the emergency spillway at elevation at 632.7 (this allows for some additional storage above the 10-yr wsel) and use design information and criteria for Earth Spillways (not included in this manual).

- Size 100 year spillway to release 141 cfs at elevation 633.0.

- @ wsel 633.0:
- Outflow from riser structure is controlled by barrel (under outlet control), from Figure 8.10, read Q = 67.6 cfs at wsel = 633.3. Assume Q = 67 cfs at wsel = 633.0.
- Set spillway invert at wsel = 632.7
- Try 26' wide vegetated emergency spillway with 3:1 side slopes.
- Finalize stage-storage-discharge relationships and perform pond routing

Pond routing (TR-20) computes 100-year wsel at 633.76 with discharge = 140.95 cfs < 141 cfs, OK (see Figure 8.11).

Note: this process of sizing the emergency spillway and storage volume determination is usually iterative. This example reflects previous iterations at arriving at an acceptable design solution.

Step 10. Check for safe passage of Qp_{100} under current build-out conditions and set top of embankment elevation.

The safety design of the pond embankment requires that the 100-year discharge, based on ultimate buildout conditions be able to pass safely through the emergency spillway with sufficient freeboard (one foot). This criteria does not mean that the ultimate buildout peak discharge be attenuated to pre-development rates.

From previous hydrologic modeling we know that:

- The 100 year ultimate buildout peak discharge = 227 cfs,
- The ultimate buildout composite curve number is 82.

Using TR-20 or equivalent routing model, determine peak wsel. Pond routing computes 100-year wsel at 634.0 with discharge = 192 cfs (Figure 8.12).

Therefore, with one foot of freeboard, the minimum embankment elevation is 635.0. Table 8.2 provides a summary of the storage, stage, and discharge relationships determined for this design example. See Figure 8.13 for a schematic of the riser.

Table 8.2 Summary of Controls Provided					
Control Element	**Type/Size of Control**	**Storage Provided**	**Elevation**	**Discharge**	**Remarks**
Units		Acre-feet	MSL	cfs	
Permanent Pool		0.61	625.0	0	part of WQ_v
Forebay	submerged berm	0.1	625.0	0	included in permanent pool vol.
Extended Detention (WQ_v-ED)	4" pipe, sized to 3.0" equivalent diameter	0.56	627.0	0.25	part of $WQ_{V.}$, vol. above perm. pool, discharge is average release rate over 24 hours
Channel Protection (Cp_v-ED)	6" pipe sized to 4.7" equivalent diameter	2.4	630.6	1.2	volume above perm. pool, discharge is average release rate over 24 hours
Overbank Protection (Q_{p-10})	Three 5' x 1.5' slots on a 6' x 6' riser, 27"barrel.	2.5	632.5	65.4	volume above perm. pool
Extreme Storm (Q_{f-100})	26' wide earth spillway	4.0	633.8	140.9	volume above perm. pool
Extreme Storm Ultimate Buildout	26' wide earth spillway	NA	634	192.0	Set minimum embankment height at 635.0

Figure 8.11 TR-20 Model Input and Output

```
*****************80-80 LIST OF INPUT DATA FOR TR-20 HYDROLOGY*****************


JOB TR-20                    FULLPRINT                        NOPLOTS
TITLE      New York Manual Wet ED Example 1/01          EWB
TITLE      Post Developed Conditions Routing for 1, 10, and 100
 3 STRUCT       1
 8                      625.0        0.0          0.0
 8                      625.5        0.15         0.14
 8                      626.0        0.23         0.28
 8                      626.5        0.29         0.42
 8                      627.0        0.34         0.56
 8                      627.5        0.70         0.77
 8                      628.0        0.94         0.97
 8                      629.0        1.27         1.52
 8                      629.5        1.40         1.80
 8                      630.0        1.52         2.07
 8                      630.6        1.65         2.40
 8                      631.0        13.50        2.73
 8                      632.1        64.20        3.45
 8                      632.7        66.00        4.10
 8                      633.3        93.60        4.70
 8                      634.0        165.0        5.40
 8                      635.0        35230        6.75
 9 ENDTBL
 6 RUNOFF 1     1     2 0.102        78.0         0.35         1 1   0 0 1
 6 RESVOR 2     1 2   3 625.0                                  1 1       1
   ENDATA
 7 INCREM 6           0.1
 7 COMPUT 7     1     1 0.0          2.3          1.0          2 2   1  01
   ENDCMP 1
 7 COMPUT 7     1     1 0.0          3.9          1.0          2 2   1  10
   ENDCMP 1
 7 COMPUT 7     1     1 0.0          5.5          1.0          2 2   1  99
   ENDCMP 1
   ENDJOB 2

*******************************END OF 80-80 LIST********************************
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TR20 XEQ 1/22/** New York Manual Wet ED Example 1/01 EWB JOB 1 SUMMARY
REV 09/01/83 Post Developed Conditions Routing for 1, 10, and 100 PAGE 8

SUMMARY TABLE 1 - SELECTED RESULTS OF STANDARD AND EXECUTIVE CONTROL INSTRUCTIONS IN THE ORDER PERFORMED
(A STAR(*) AFTER THE PEAK DISCHARGE TIME AND RATE (CFS) VALUES INDICATES A FLAT TOP HYDROGRAPH
A QUESTION MARK(?) INDICATES A HYDROGRAPH WITH PEAK AS LAST POINT.)

SECTION/ STRUCTURE ID	STANDARD CONTROL OPERATION	DRAINAGE AREA (SQ MI)	RAIN TABLE #	ANTEC MOIST COND	MAIN TIME INCREM (HR)	PRECIPITATION BEGIN (HR)	PRECIPITATION AMOUNT (IN)	PRECIPITATION DURATION (HR)	RUNOFF AMOUNT (IN)	PEAK DISCHARGE ELEVATION (FT)	PEAK DISCHARGE TIME (HR)	PEAK DISCHARGE RATE (CFS)	PEAK DISCHARGE RATE CSM)
ALTERNATE 1 STORM 1													
STRUCTURE 1	RUNOFF	.10	2	2	.10	.0	2.30	24.00	.66	---	12.13	40.62	398.2
STRUCTURE 1	RESVOR	.10	2	2	.10	.0	2.30	24.00	.40	630.31	18.00?	1.59?	15.6
ALTERNATE 1 STORM 10													
STRUCTURE 1	RUNOFF	.10	2	2	.10	.0	3.90	24.00	1.81	---	12.11	118.47	161.5
STRUCTURE 1	RESVOR	.10	2	2	.10	.0	3.90	24.00	1.49	632.51	12.34	65.43	41.5
ALTERNATE 1 STORM 99													
STRUCTURE 1	RUNOFF	.10	2	2	.10	.0	5.50	24.00	3.14	---	12.11	206.59	025.4
STRUCTURE 1	RESVOR	.10	2	2	.10	.0	5.50	24.00	2.80	633.76	12.29	140.95	381.9