Advanced Design Workshops: Wet Detention Pond Design

Note: This course is available as online training on ELMS: https://learning.dot.ga.gov

Always check the current edition of the GDOT Drainage Design for Highways Manual for current policies.

This presentation shall not supersede any policies in the GDOT Drainage Design for Highways Manual (current edition) or any other GDOT policy publications.

Why Are We Here?

…to discuss wet detention ponds and how they are used to meet GDOT’s post-construction BMP requirements

GDOT's Approved Post-Construction BMPs

- Filter Strip
- Grass Channel
- Enhanced Swale
- Infiltration Trench
- Bioslope
- Sand Filter

- Bioretention Basin
- Dry Detention Pond
- Wet Detention Pond
- Stormwater Wetland
- Open Graded Friction Course (OGFC)

Included in the designer's "tool box" to meet MS4 and other stormwater requirements.

Points of Discussion

Wet Detention Pond

- Function and Components
- Design Considerations
- Advantages and Disadvantages
- Sizing and Design Methodology

Wet Detention Pond

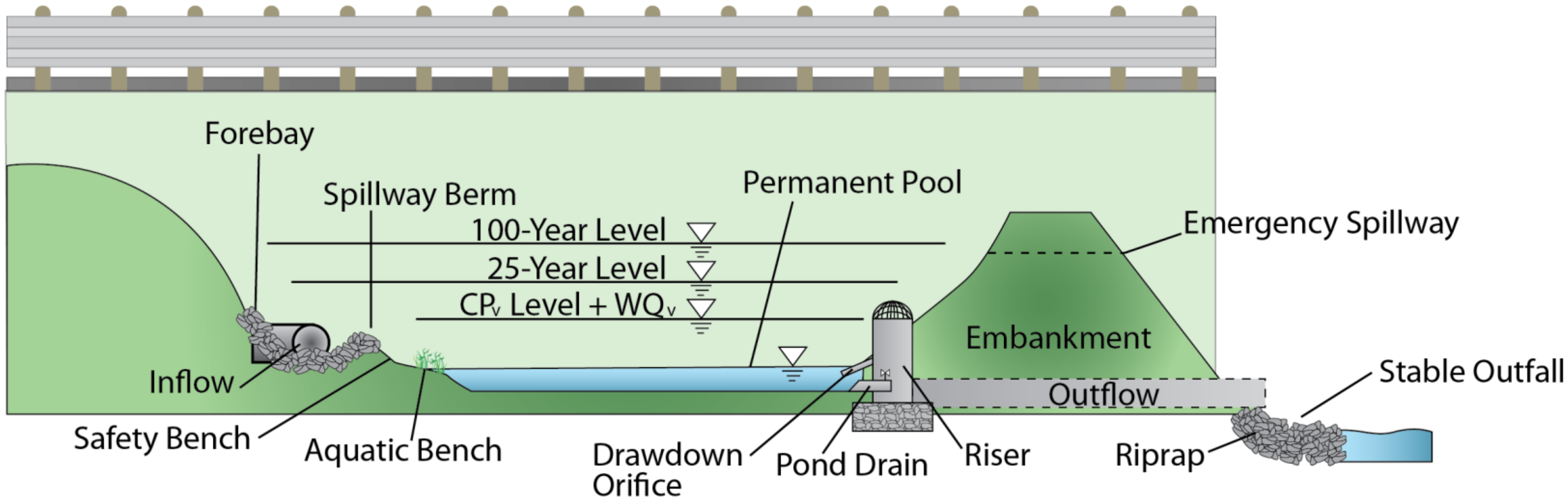
What is it?

An earthen pond with a permanent pool and temporary storage for attenuating stormwater flows

Wet Detention Pond

What are its critical components?

- Forebay
- Permanent Pool
- Aquatic Bench (wetland plantings)
- Safety Bench
- Detention Storage
- Outlet Control Structure
- Emergency Spillway



Wet Detention Pond

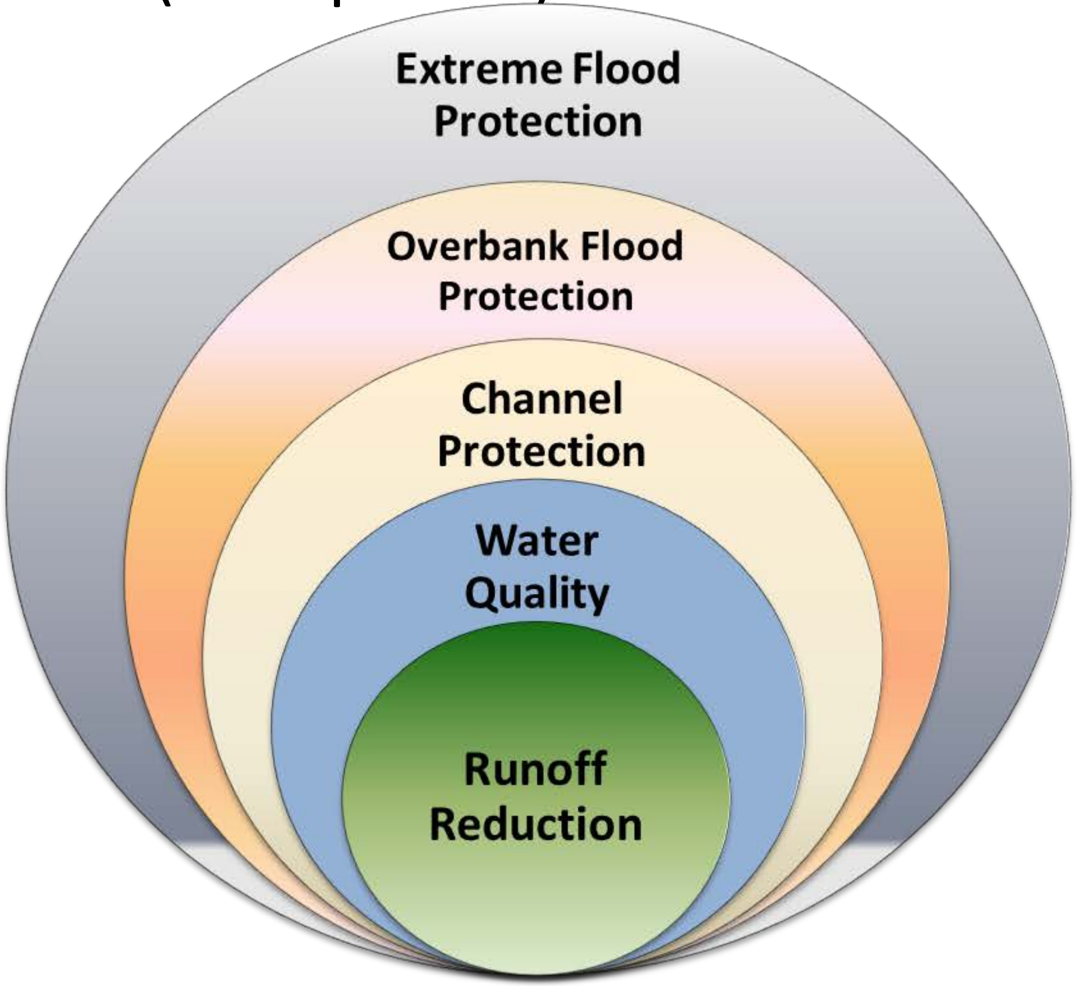
What is its purpose?

- Provide detention and attenuate peak flows
- Can be designed to meet all unified sizing criteria (water quality, channel protection, overbank flood protection and extreme flood protection)
- Reduce TSS and other pollutants

- ✗ Vegetative Conveyance
- ✗ Filtration
- ✓ Settling
- ✗ Infiltration
- ✓ TSS Removal = 80%
- ✓ Detention

Wet Detention Pond

Five major Post-Construction Stormwater Management Requirements (MS4 permit):



Wet Detention Pond

Advantages

- Meets 80% TSS removal requirement
- Effective in treating other contaminants (fecal coliform, nitrogen, phosphorus, heavy metals)

Wet Detention Pond

Disadvantages

- Large footprint
- Difficult to maintain permanent pool
- Additional maintenance issues over dry pond
- Safety concerns associated with a permanent pool

Wet Detention Pond

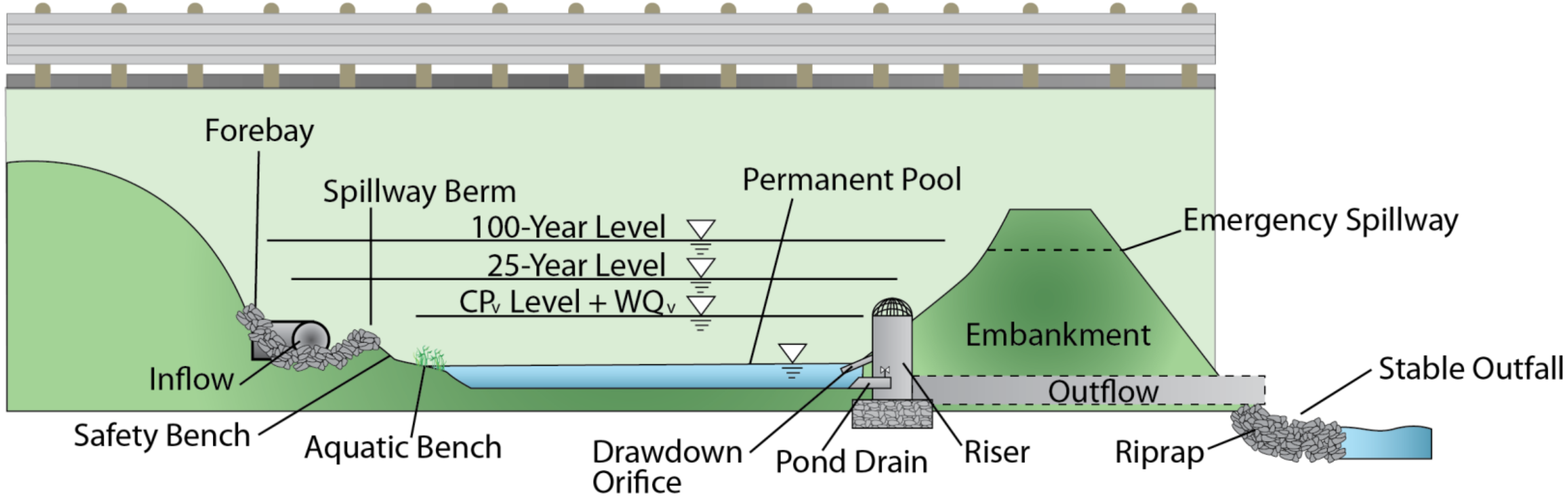
How does it compare to other BMPs?

BMP	TSS	Total Phosphorus	Total Nitrogen	Fecal Coliform	Metals
Filter Strip	60 %	20 %	20 %	----------	40 %
Grass Channel	50 %	25 %	20 %	----------	30 %
Enhanced Dry Swale	80 %	50 %	50 %	----------	40 %
Enhanced Wet Swale	80 %	25 %	40 %	----------	20 %
Infiltration Trench	80 %	60 %	60 %	90 %	90 %
Sand Filter	80 %	50 %	25 %	40 %	50 %
Dry Detention Basin	65 %	10 %	10 %	----------	50 %
Wet Detention Pond	80 %	50 %	30 %	70 %	50 %
Stormwater Wetland – Level I	80 %	40 %	30 %	70 %	50 %
Stormwater Wetland – Level II	85 %	75 %	55 %	85 %	60 %
Bioslope	95 %	80 %	25 %	60 %	85 %
OGFC	50 %	----------	----------	----------	----------
Bioretention	85 %	80 %	60 %	90 %	95 %

Wet Detention Pond

Design of Critical Components

- Forebay
- Permanent Pool
- Aquatic bench (wetland plantings)
- Safety Bench
- Detention Storage
- Outlet Control Structure
- Emergency Spillway

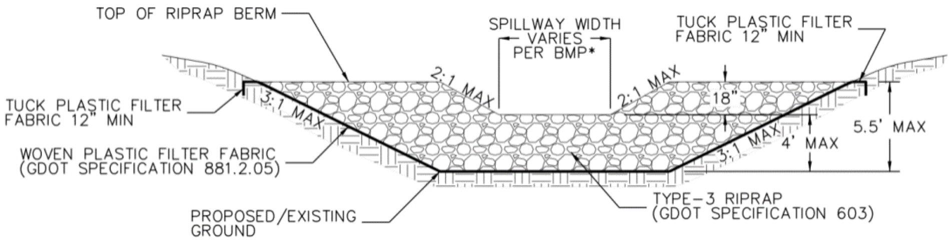


Wet Detention Pond

Forebay

Purpose: Dissipates inflow and reduces large particulates

Sizing: Capacity of 0.1 inch runoff/impervious acre



Wet Detention Pond

Permanent Pool

Purpose: Provides for settling and water quality treatment

Sizing: Capacity of 0.1 inch runoff/impervious acre or WQ_v for larger drainage areas

Design Considerations:

- Requires 3’ to 8’ depth (6’ max is preferred for safety)
- Ensure permanent pool can be maintained with water balance calculation
- Bottom of pond should be minimum 2 ft above seasonably high water table if over a water supply aquifer

Wet Detention Pond

Outlet Control Structure

Purpose: Establishes permanent pool level, Outflow hydrographs

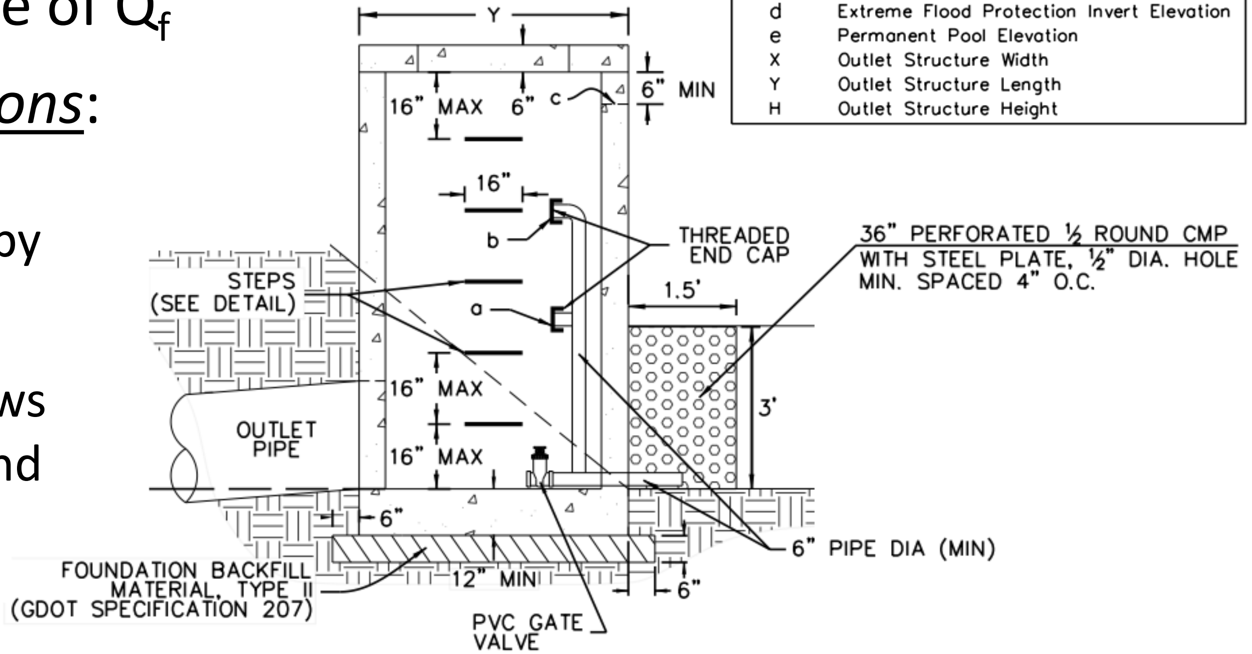
Sizing: Size WQ_V orifice and CP_V orifice to draw down in 24 hours

$Q_{p25POST} \leq Q_{p25\ PRE}$

Safe passage of Q_f

Design Considerations:

- Ensure design prevents clogging by floating debris
- Ensure design allows access to drain pond for maintenance



SYMBOL	DEFINITION
a	Water Quality Orifice Invert Elevation
b	Channel Protection Orifice Invert Elevation
c	Overbank Flood Protection Invert Elevation
d	Extreme Flood Protection Invert Elevation
e	Permanent Pool Elevation
X	Outlet Structure Width
Y	Outlet Structure Length
H	Outlet Structure Height

Wet Detention Pond

Detention Storage

Purpose: Detain and attenuate peak flows for larger storms

Sizing: Contain all Unified Sizing Criteria volumes (WQ_v, CP_v, Q_{p25}, Q_f)

Design Considerations:

- Drainage area between 10 and 75 acres
- Detention storage is located above (and does not include) permanent pool volume

Wet Detention Pond

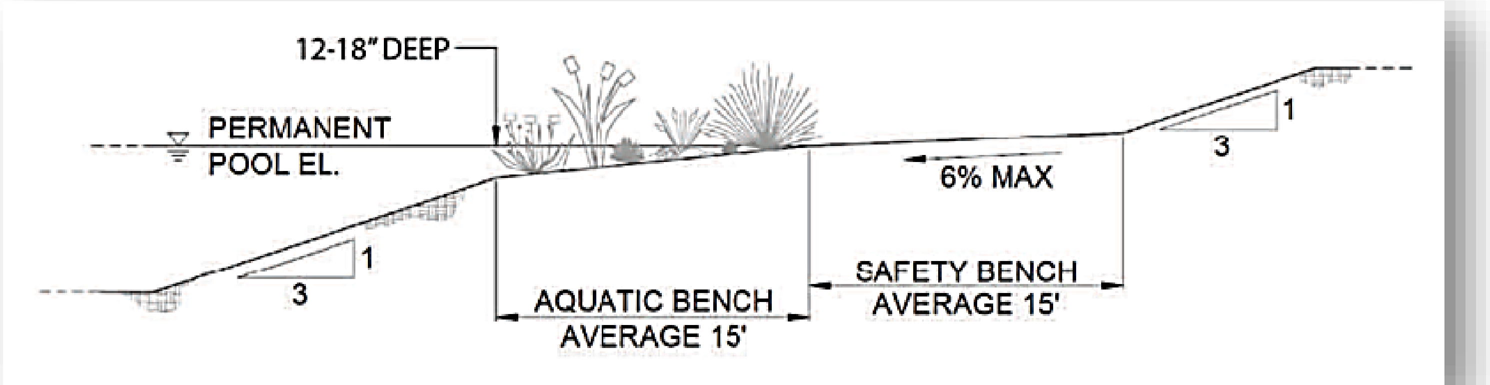
Embankment

Purpose: Provide aquatic and safety bench, maintenance access

Sizing: Bench/embankments to allow plantings and maintenance

Design Considerations:

- 2:1 maximum embankment side slope, but 3:1 is preferred
- 15’ (average) aquatic bench with 12-18” depth below permanent pool
- 15’ safety bench with maximum 6% slope (not required if embankment slope 4:1 or less)

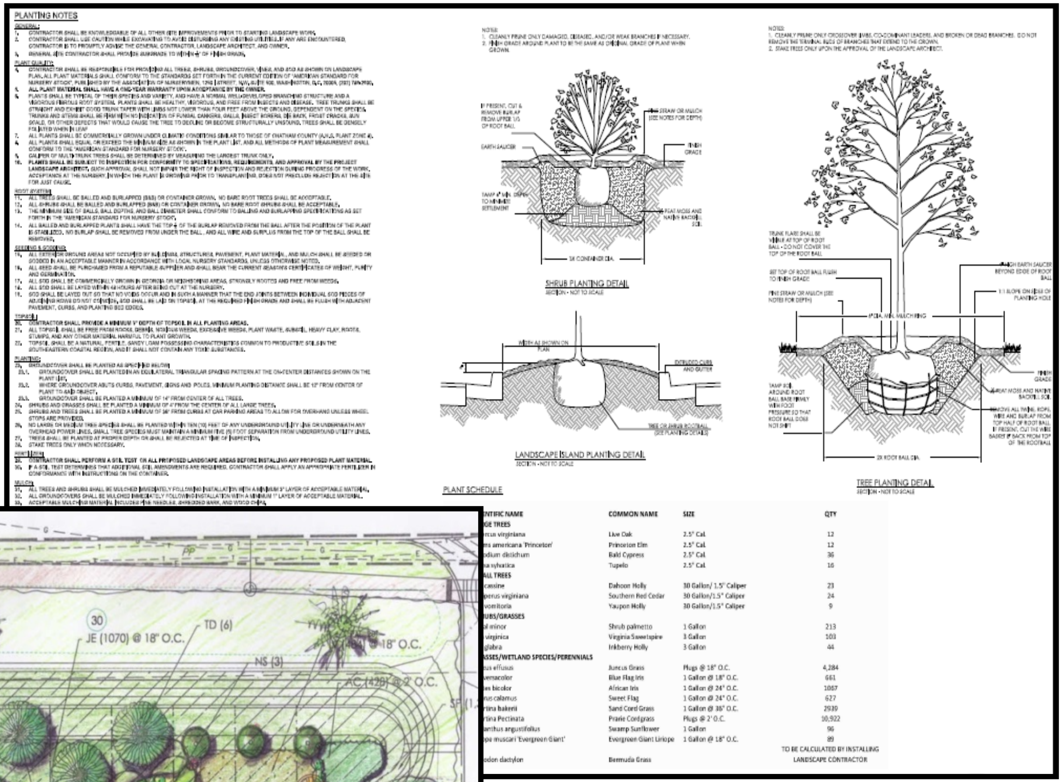


Wet Detention Pond

Embankment

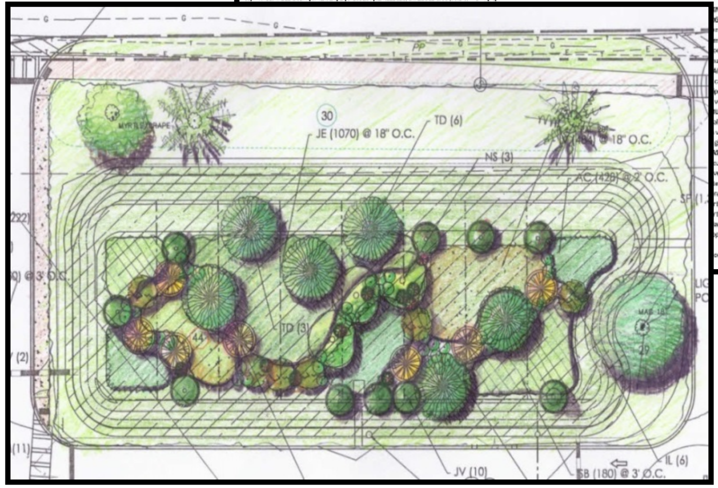
Design Considerations:

- Aquatic plantings as detailed in landscape plan
- Woody vegetation should not be planted on dam



Source: Mandel Design

Source: NCDOT



Wet Detention Pond

Emergency Spillway

Purpose: Provide emergency overflow relief for protection of pond structural integrity and downstream flood prevention during extreme events

Sizing: Size to safely pass the 100-yr peak flow

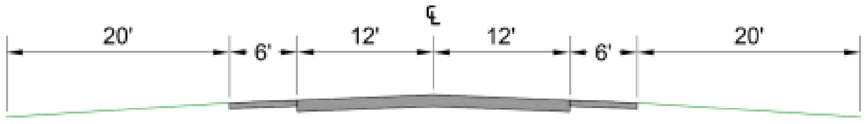
Design Considerations:

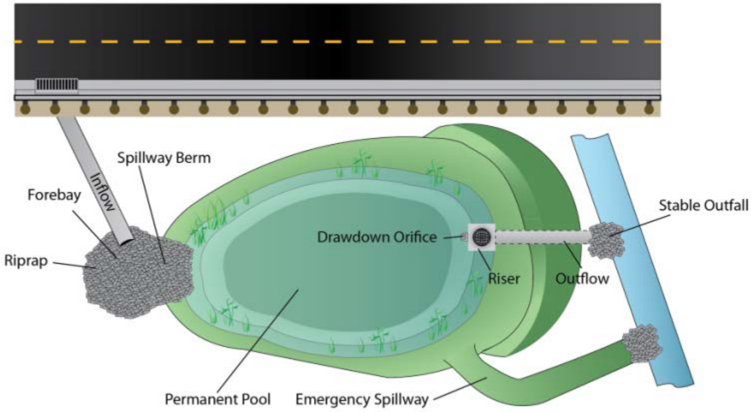
- Protect and armor spillway weir and embankment tie-ins with concrete or riprap
- Proper sizing and protection of conveyance connection to stable outfall

Design Example

Given:

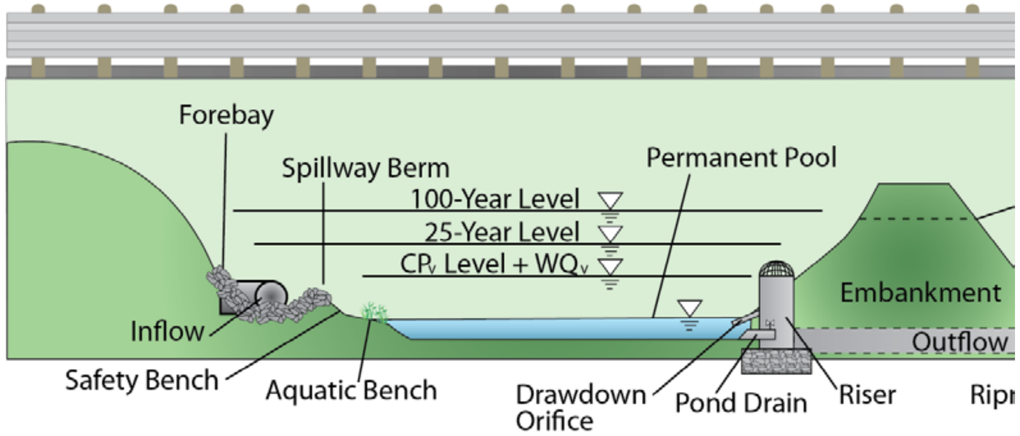
- New alignment roadway project in Paulding County (District 6)
- Total drainage area of 10.23 acres discharging into a wet detention pond comprised of:
  - 3,000 linear feet of roadway:
    - two 12-ft lanes
    - two 6-ft paved shoulders
    - 20-ft grassed areas (both sides of road) draining via sheet flow
  - 5 acres off-site drainage area (no existing impervious area)
  - Pre developed Tc = 45 minutes
  - Post developed Tc = 25 minutes





Steps to Design Wet Detention Pond

1. Calculate forebay volume
2. Calculate permanent pool volume and min depth
3. Calculate water quality volume and design orifice
4. Calculate channel protection volume and design orifice
5. Design pond and outlet to maintain 25-yr pre-development peak flow
6. Design spillway to safely convey 100-yr post-development peak flow



Steps to Design Wet Detention Pond

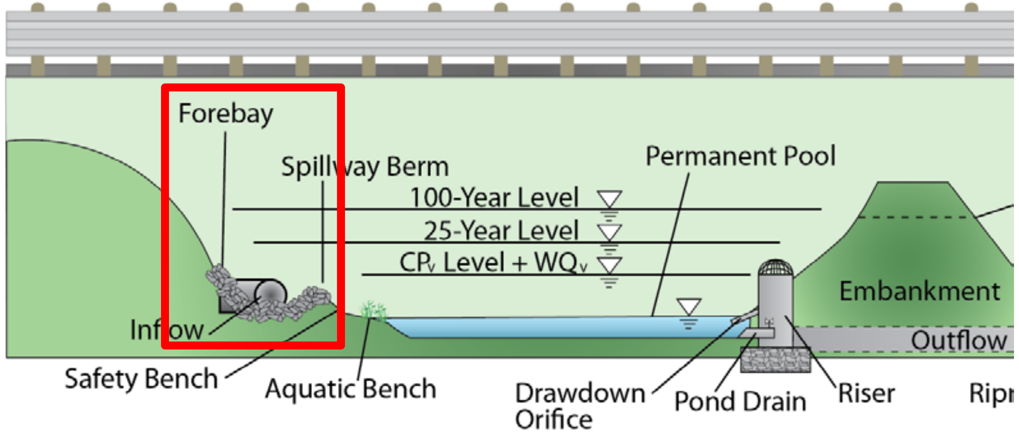
1 Calculate Forebay Volume

<u>Minimum forebay size: 0.1 inch per impervious acre (ImpAc)</u>

ImpAc = (3000')*(24'+12') = 108,000 ft^2 = 2.48 acres

$V_{Forebay}$ = (0.1 inch/acre)*(2.48 acre) = .248 acre-inch

= 900 ft^3 (actual forebay volume = 1,046 ft^3)



Conversions:
1 acre = 43,560 ft^2
1 acre-inch = 3,630 ft^3

Steps to Design Wet Detention Pond

1. Calculate forebay volume
2. Calculate permanent pool volume and verify pond can maintain
3. Calculate water quality volume and design orifice
4. Calculate channel protection volume and design orifice
5. Design pond and outlet to maintain 25-yr pre-development peak flow
6. Design spillway to safely convey 100-yr post-development peak flow

$V_{forebay}$ = 1,046 ft^3

Steps to Design Wet Detention Pond

2 Calculate permanent pool volume

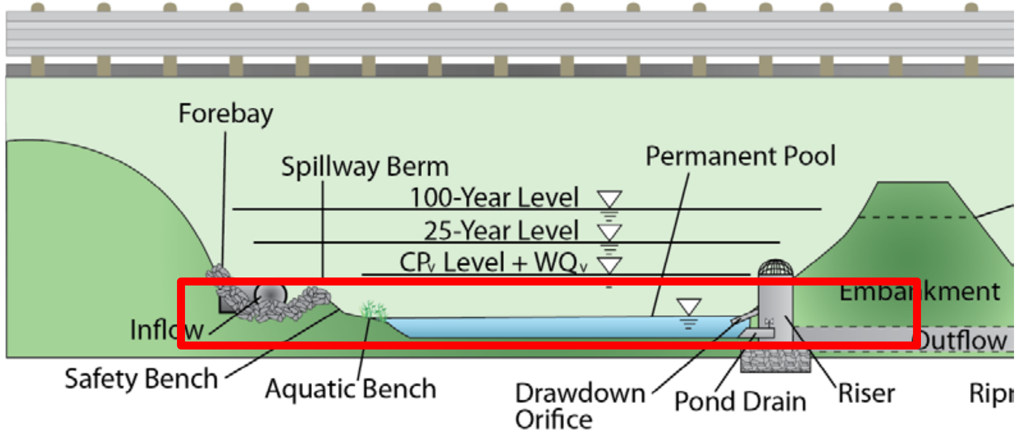
Minimum permanent pool (PP) size: 0.1 inch per impervious acre

ImpAc = (3000')*(24'+12') = 108,000 ft^2 = 2.48 acres

V_{PP} = (0.1 inch/acre)*(2.48 acre) = .248 acre-inch

= 900 ft^3 (actual permanent pool = 1,422 ft^3)

Conversions:
1 acre = 43,560 ft2
1 acre-inch = 3,630 ft^3

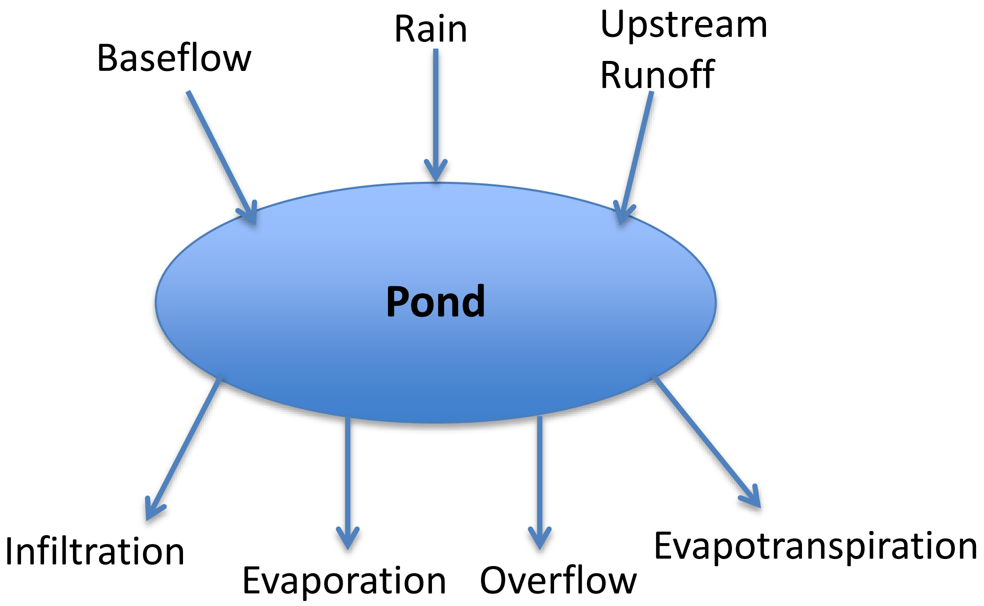


Water Balance Calculations

2 Verify perm pool can be maintained

$$\Delta V = \Sigma\, inflow \; - \; \Sigma\, outflow$$ Eq 10.2-1

$$\Delta V = P + Ro + Bf - I - E - Et - Of$$ Eq 10.2-2



P = precipitation (ft)
Ro = runoff (ac-ft)
Bf = baseflow (ac-ft)
I = infiltration (ft)
E = evaporation (ft)
Et = evapotranspiration (ft)
Of = overflow (ac-ft)

*For this example, assume no baseflow and no evapotranspiration. Overflow is not a concern for average values of precipitation.

Water Balance Calculation Steps

1. Calculate the volume of precipitation that falls on the permanent pool
2. Calculate the volume of runoff from the contributing drainage area

SUM INFLOWS

3. Calculate the volume of evaporation that occurs over the permanent pool
4. Calculate infiltration

SUM OUTFLOWS

5. Calculate the difference between the inflows and outflows

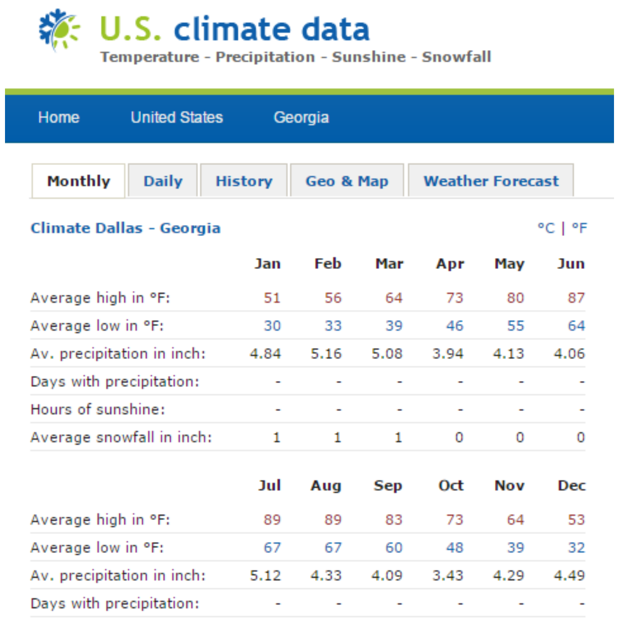
VERIFY PERM POOL CAN BE MAINTAINED

Water Balance Calculations

1 Calculate the volume of precipitation that falls on the permanent pool

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Precip (in)	4.84	5.16	5.08	3.94	4.13	4.06	5.12	4.33	4.09	3.43	4.29	4.49

http://www.usclimatedata.com/climate/dallas/georgia/united-states/usga0157



U.S. climate data
Temperature - Precipitation - Sunshine - Snowfall

Home United States Georgia

Monthly Daily History Geo & Map Weather Forecast

Climate Dallas - Georgia °C | °F

	Jan	Feb	Mar	Apr	May	Jun
Average high in °F:	51	56	64	73	80	87
Average low in °F:	30	33	39	46	55	64
Av. precipitation in inch:	4.84	5.16	5.08	3.94	4.13	4.06
Days with precipitation:	-	-	-	-	-	-
Hours of sunshine:	-	-	-	-	-	-
Average snowfall in inch:	1	1	1	0	0	0

	Jul	Aug	Sep	Oct	Nov	Dec
Average high in °F:	89	89	83	73	64	53
Average low in °F:	67	67	60	48	39	32
Av. precipitation in inch:	5.12	4.33	4.09	3.43	4.29	4.49
Days with precipitation:	-	-	-	-	-	-

Water Balance Calculations

1 Calculate the volume of precipitation that falls on the permanent pool

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Precip (in)	4.84	5.16	5.08	3.94	4.13	4.06	5.12	4.33	4.09	3.43	4.29	4.49
P (pool) (ac-ft)	0.008	0.009	0.008	0.007	0.007	0.007	0.009	0.007	0.007	0.006	0.007	0.007

Precipitation volume directly into pond (P) equals precipitation depth (inches) times permanent pool surface area (**0.02 acre**) divided by 12 to convert to acre-feet

Water Balance Calculations

2 Calculate the volume of runoff from the contributing drainage area

$$Ro = \frac{QA}{12}$$ Eq 10.2-5

$$Q = (0.9R_v)P$$ Eq 10.2-4

$$\boldsymbol{Ro = \frac{(0.9R_v) * P * A}{12}}$$

Q = runoff depth (in)
Ro = runoff volume (ac-ft)
A = site area minus permanent pool area (acres)
P = precipitation (in)
R_v = volumetric runoff coefficient

Values needed to calculate Ro:

Rv = ?
P = determined in previous step
A = ?

Water Balance Calculations

2 Calculate the volume of runoff from the contributing drainage area

$$R_v = 0.05 + 0.009(I)$$ Eq 10.2-3

I = percent imperviousness of drainage basin (percent)

$$I = \frac{2.48\ ac}{10.23\ ac} = 24.2\%$$

$$R_v = 0.05 + 0.009(24.2) = 0.27$$

Water Balance Calculations

2 Calculate the volume of runoff from the contributing drainage area

$$\text{Permanent Pool Area} = 857\ \text{ft}^2 = 0.02\ \text{acre}$$

$$\text{Basin Area} = 10.23\ \text{acres}$$

$$A = 10.23 - 0.02 = 10.21\ \text{acres}$$

$$\boldsymbol{Ro = \frac{(0.9 * 0.27) * P * (10.21\ ac)}{12\ \left(\frac{in}{ft}\right)}}$$

Conversions:
1 acre = 43,560 ft2

Water Balance Calculations

2 Calculate the volume of runoff from the contributing drainage area

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Precip (in)	4.84	5.16	5.08	3.94	4.13	4.06	5.12	4.33	4.09	3.43	4.29	4.49
P (pool) (ac-ft)	0.008	0.009	0.008	0.007	0.007	0.007	0.009	0.007	0.007	0.006	0.007	0.007
Ro (ac-ft)	1.00	1.07	1.05	0.81	0.85	0.84	1.06	0.90	0.85	0.71	0.89	0.93

Water Balance Calculations

Total the inflow to the Wet Pond

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
P (pool) (ac-ft)	0.008	0.009	0.008	0.007	0.007	0.007	0.009	0.007	0.007	0.006	0.007	0.007
Ro (ac-ft)	1.00	1.07	1.05	0.81	0.85	0.84	1.06	0.90	0.85	0.71	0.89	0.93
Inflow (ac-ft)	1.008	1.079	1.058	0.817	0.857	0.847	1.069	0.907	0.857	0.716	0.897	0.937

Sum the monthly precipitation and runoff inflows to get total monthly inflow to the pond

Water Balance Calculations

3 Calculate the volume of evaporation that occurs over the permanent pool

- Obtain monthly evaporation distribution

Table 10.2-2 Evaporation Monthly Distribution (10-11)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
3.2%	4.4%	7.4%	10.3%	12.3%	12.9%	13.4%	11.8%	9.3%	7.0%	4.7%	3.2%

- Determine the annual free water surface evaporation value

= 37.5 inches

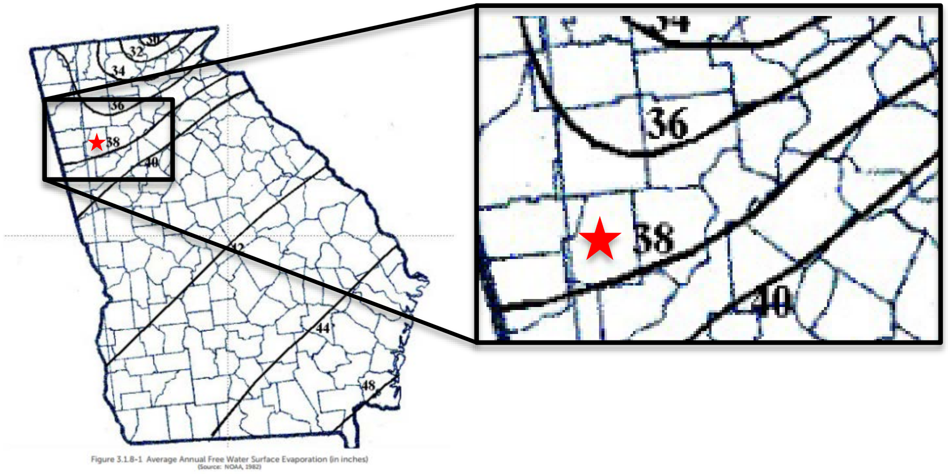


Fig 10.2-4

Water Balance Calculations

3 Calculate the volume of evaporation that occurs over the permanent pool

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Evap. Dist.	3.2%	4.4%	7.4%	10.3%	12.3%	12.9%	13.4%	11.8%	9.3%	7.0%	4.7%	3.2%
E (inch)	1.2	1.7	2.8	3.9	4.6	4.8	5.0	4.4	3.5	2.6	1.8	1.2
E (ac-ft)	0.002	0.003	0.005	0.006	0.008	0.008	0.008	0.007	0.006	0.004	0.003	0.002

Evaporation equals monthly percent of 37.5 inches multiplied by the surface area of the permanent pool (*calculated earlier as .02 acre*) and converted to acre-feet

Water Balance Calculations

4 Calculate the volume of infiltration that occurs in the wet pond

Estimate the hydraulic conductivity of your soils using Table 10.2-1

For this example, assume sandy clay loam soil

Table 10.2-1 Saturated Hydraulic Conductivity (10-11)

Material	Hydraulic Conductivity	
	in/hr	ft/day
ASTM Crushed Stone No. 3	50,000	100,000
ASTM Crushed Stone No. 4	40,000	80,000
ASTM Crushed Stone No. 5	25,000	50,000
ASTM Crushed Stone No. 6	15,000	30,000
Sand	8.27	16.54
Loamy sand	2.41	4.82
Sandy loam	1.02	2.04
Loam	0.52	1.04
Silt loam	0.27	0.54
Sandy clay loam	0.17	0.34
Clay loam	0.09	0.18
Silty clay loam	0.06	0.12
Sandy clay	0.05	0.1
Silty clay	0.04	0.08
Clay	0.02	0.04

Water Balance Calculations

4 Calculate the volume of infiltration that occurs in the wet pond

$$I = Ak_hG_h$$ Eq 10.2-6

I = infiltration (ac-ft/day)
A = cross sectional area through which water infiltrates (ac).
k_h = saturated hydraulic conductivity or infiltration rate (ft/day)
G_h = hydraulic gradient = pressure head/distance

In this example, we have a total surface area of 0.02 acres (A_{total}) in our permanent pool.

Typical values of G_h are 1.0 for pond bottom and 0.5 for pond sides steeper than 4:1

$A_{total} = A_{bottom} + A_{sides} = 0.016 + 0.004$

$$I = [(0.004\,ac)(1) + (0.016\,ac)(0.5)]\left(0.34\,\frac{ft}{day}\right)$$
$$= 0.004\,ac - ft/day$$

Georgia Department of Transportation

Water Balance Calculations

4 Calculate the volume of infiltration that occurs in the wet pond

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Days/ Mo	31	28	31	30	31	30	31	31	30	31	30	31
Evap. Dist.	3.2%	4.4%	7.4%	10.3%	12.3%	12.9%	13.4%	11.8%	9.3%	7.0%	4.7%	3.2%
E (inch)	1.2	1.7	2.8	3.9	4.6	4.8	5.0	4.4	3.5	2.6	1.8	1.2
E (ac-ft)	0.002	0.003	0.005	0.006	0.008	0.008	0.008	0.007	0.006	0.004	0.003	0.002
I (ac-ft)	0.105	0.095	0.105	0.102	0.105	0.102	0.105	0.105	0.102	0.105	0.102	0.105

Infiltration equals daily infiltration rate of .004 ac-ft per day multiplied by the number of days in each month

Water Balance Calculations

Total the outflow from the Wet Pond

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
E (ac-ft)	0.002	0.003	0.005	0.006	0.008	0.008	0.008	0.007	0.006	0.004	0.003	0.002
I (ac-ft)	0.105	0.095	0.105	0.102	0.105	0.102	0.105	0.105	0.102	0.105	0.102	0.105
Outflow (ac-ft)	0.107	0.098	0.110	0.108	0.113	0.110	0.114	0.113	0.108	0.110	0.105	0.107

Sum the monthly evaporation and infiltration outflows to get total monthly outflow from the pond

Water Balance Calculations

5 Calculate the difference between the inflows and outflows

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Inflow (ac-ft)	1.008	1.079	1.058	0.817	0.857	0.847	1.069	0.907	0.857	0.716	0.897	0.937
Outflow (ac-ft)	0.107	0.098	0.110	0.108	0.113	0.110	0.114	0.113	0.108	0.110	0.105	0.107
Balance (ac-ft)	0.901	0.981	0.948	0.709	0.744	0.737	0.955	0.794	0.749	0.606	0.792	0.83
Balance (ft^3)	39,248	42,732	41,295	30,884	32,409	32,104	41,600	34,587	32,626	26,397	34,500	36,155

Subtract the outflows from the inflows to get the monthly balance of the wet pond and convert to cubic feet for comparison with perm pool volume

The water balance is greater than the permanent pool volume (1,422 ft^3) every month: **the pond can maintain the permanent pool**

Steps to Design Wet Detention Pond

1. Calculate forebay volume
2. Calculate permanent pool volume and verify pond can maintain
3. Calculate water quality volume and design orifice
4. Calculate channel protection volume and design orifice
5. Design pond and outlet to maintain 25-yr pre-development peak flow
6. Design spillway to safely convey 100-yr post-development peak flow

$V_{forebay}$ = 1,046 ft^3

$V_{permpool}$ = 1,422 ft^3, $Depth_{min}$ = 3.0 ft

Steps to Design Wet Detention Pond

3 Calculate water quality volume (WQ_V)

WQv based on basin area and new impervious area percentage

Eq 10.4-5 WQ_V (ft³) = 1.2(in) * R_V * A(acres) * 43,560(acres/ft²)/12(in/ft)

= (1.2) * (0.47) * (5.23) * (43,560) / 12

= **10,707 ft³**

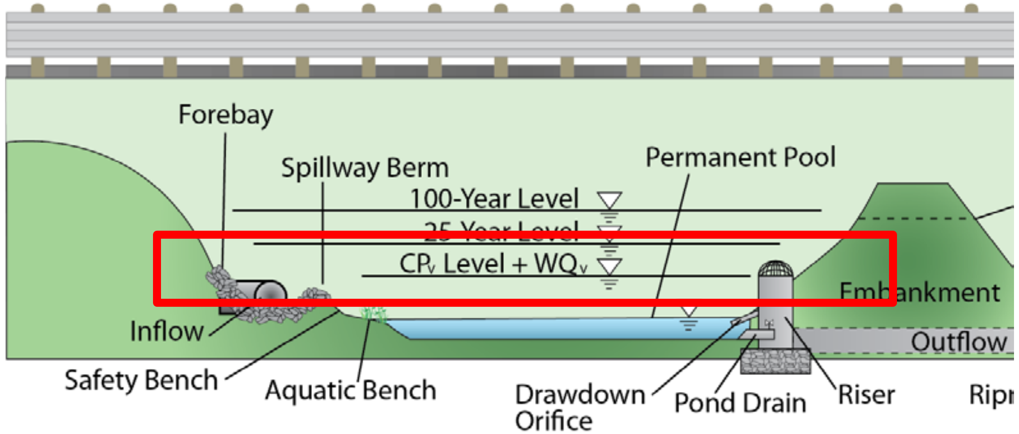
R_v = volumetric runoff coefficient
*= 0.05+0.009*I*
= 0.05+0.009(47) = 0.47*

I = impervious area (%)

Remember the permanent pool volume is included in WQv, so:

WQ_V (ft³) = 10,707 ft³ – (1,046 ft³ + 1,422 ft³)

= 8,239 ft³



Steps to Design Wet Detention Pond

3 Design water quality (WQ_V) orifice

Orifice sized to release WQv over 24 hours

Orifice Equation:

$$Q_{WQv}\ (cfs) = C_D * A\ (ft^2) * \sqrt{(2g)\Delta H_{max}\ (ft)}$$

Eq 10.6.3-3

$$(.095\ cfs) = (0.6) * (A) * \sqrt{2 * (32.2 ft/s^2) * (1 ft)}$$

$$A = .020\ ft^2$$

$$D = \sqrt{4 * (.020\ ft^2) / \pi}$$

$D = 0.16$ ft $= 1.9$ in **(use 2.0 inches for constructability)**

Q_{WQv} (orifice flow rate) = 8,239 ft^3 /24 hr = 0.095 cfs
C_D (orifice coefficient) = 0.6
A = orifice area (ft)
ΔH_{max} (max depth at WQv stage) = 1.0 ft

WQ_v orifice: 2" diameter at top of permanent pool

Steps to Design Wet Detention Pond

1. Calculate forebay volume

2. Calculate permanent pool volume and verify pond can maintain

3. Calculate water quality volume and design orifice

4. Calculate channel protection volume and design orifice

5. Design pond and outlet to maintain 25-yr pre-development peak flow

6. Design spillway to safely convey 100-yr post-development peak flow

$V_{forebay}$ = 1,046 ft^3

$V_{permpool}$ = 1,422 ft^3, $Depth_{min}$ = 3.0 ft

WQ_v = 8,239 ft^3, D_{orif} = 2" , $Elev_{orif}$ = perm pool elevation

Channel Protection Volume (CP_V) Calculation Steps

1. Determine runoff depth(Q-inches) for 1-year 24-hour storm event

2. Determine the unit peak discharge rate (q_u) for the 1-year 24-hour storm event

3. Compute the channel protection volume

Channel Protection Volume (CP_V) Calculation Steps

1 Determine direct runoff depth for 1-year 24-hour storm event

Calculate direct runoff:

P = 1-year 24-hour rainfall depth (inches)

S = ultimate abstraction (inches)

$$Q_{1,24} = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Eq 10.4-10

S = 4.29 inches
P = ?

To calculate S, we use the following formula:

Eq 10.4-11

$$\mathbf{S} = \frac{1000}{\mathrm{CN}} - 10$$

We need to know the basin CN to perform this calculation

Channel Protection Volume (CP_V) Calculation Steps

1 Determine direct runoff depth for 1-year 24-hour storm event

Calculate composite CN number for the project basin:

Impervious Area (*calculated earlier*) = 2.48 ac (CN=98)
Pervious Area (*10.23 total acres – 2.48 acres*) = 7.75 ac (CN=61)

$$\text{CN} = \frac{(2.48*98)+(7.75*61)}{10.23} = 70$$

Now we can calculate ultimate abstraction:

$$\mathbf{S} = \frac{1000}{\text{CN}} - 10 = 1000/70 - 10 = \mathbf{4.29\ inches}$$

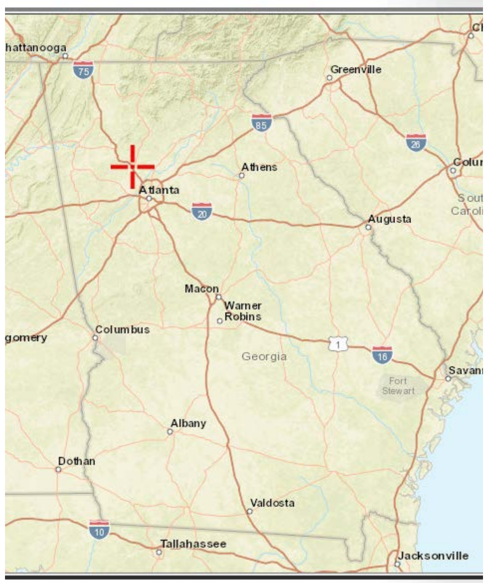
S = 4.29 inches
P = ?

Channel Protection Volume (CP_V) Calculation Steps

1 Determine direct runoff depth for 1-year 24-hour storm event

Obtain 1-year 24-hour rainfall depth for project location from NOAA website:
http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ga

S = 4.29 inches
P = 3.41 inches



PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)								
	1	2	5	10	25	50	100	200	500
5-min	0.410 (0.351-0.483)	0.470 (0.402-0.555)	0.576 (0.490-0.680)	0.669 (0.565-0.793)	0.806 (0.660-0.987)	0.919 (0.731-1.13)	1.04 (0.794-1.30)	1.17 (0.850-1.49)	1.34 (0.937-1.75)
10-min	0.601 (0.513-0.708)	0.689 (0.588-0.812)	0.843 (0.717-0.996)	0.979 (0.828-1.16)	1.18 (0.966-1.45)	1.35 (1.07-1.66)	1.52 (1.16-1.91)	1.71 (1.24-2.19)	1.97 (1.37-2.57)
15-min	0.732 (0.626-0.863)	0.840 (0.717-0.991)	1.03 (0.874-1.21)	1.19 (1.01-1.42)	1.44 (1.18-1.76)	1.64 (1.31-2.03)	1.85 (1.42-2.33)	2.08 (1.52-2.66)	2.40 (1.67-3.13)
30-min	1.04 (0.889-1.23)	1.19 (1.02-1.41)	1.46 (1.24-1.72)	1.69 (1.43-2.01)	2.05 (1.67-2.51)	2.33 (1.86-2.88)	2.64 (2.02-3.32)	2.97 (2.17-3.80)	3.43 (2.39-4.48)
60-min	1.35 (1.15-1.59)	1.54 (1.32-1.82)	1.89 (1.61-2.23)	2.19 (1.85-2.60)	2.65 (2.17-3.24)	3.02 (2.40-3.73)	3.42 (2.61-4.29)	3.84 (2.80-4.92)	4.44 (3.10-5.80)
2-hr	1.66 (1.42-1.94)	1.90 (1.63-2.22)	2.32 (1.98-2.72)	2.69 (2.29-3.17)	3.25 (2.68-3.95)	3.71 (2.98-4.54)	4.19 (3.24-5.23)	4.72 (3.48-5.99)	5.45 (3.86-7.05)
3-hr	1.86 (1.61-2.17)	2.13 (1.83-2.48)	2.60 (2.23-3.03)	3.01 (2.57-3.53)	3.62 (3.00-4.38)	4.13 (3.33-5.03)	4.66 (3.62-5.78)	5.23 (3.89-6.60)	6.03 (4.30-7.76)
6-hr	2.30 (1.99-2.66)	2.61 (2.26-3.03)	3.16 (2.72-3.66)	3.63 (3.12-4.23)	4.33 (3.62-5.19)	4.91 (3.99-5.92)	5.51 (4.33-6.76)	6.15 (4.63-7.69)	7.04 (5.10-8.97)
12-hr	2.85 (2.48-3.27)	3.22 (2.80-3.70)	3.85 (3.34-4.44)	4.40 (3.80-5.08)	5.19 (4.35-6.15)	5.82 (4.77-6.95)	6.48 (5.14-7.87)	7.17 (5.47-8.86)	8.12 (5.96-10.2)
24-hr	3.41 (2.99-3.89)	3.88 (3.40-4.43)	4.66 (4.06-5.33)	5.31 (4.61-6.09)	6.23 (5.25-7.29)	6.94 (5.73-8.20)	7.67 (6.14-9.21)	8.41 (6.49-10.3)	9.41 (7.01-11.7)
2-day	3.93 (3.46-4.45)	4.52 (3.97-5.12)	5.47 (4.80-6.21)	6.26 (5.47-7.13)	7.35 (6.23-8.52)	8.18 (6.81-9.58)	9.02 (7.29-10.7)	9.86 (7.70-11.9)	11.0 (8.30-13.5)

Channel Protection Volume (CP_V) Calculation Steps

1 Determine direct runoff depth for 1-year 24-hour storm event

Now we have values for S and P:

Calculate direct runoff:

P = 1-year 24-hour rainfall depth (inches)

S = ultimate abstraction (inches)

$$Q_{1,24} = \frac{(P-0.2S)^2}{(P+0.8S)}$$

Eq 10.4-10

S = 4.29 inches
P = 3.41 inches

$$= \frac{(3.41-0.2*4.29)^2}{(3.41+0.8*4.29)}$$

= 0.95 inches

Channel Protection Volume (CP_V) Calculation Steps

2 Determine the unit peak discharge rate (q_u) for the 1-year 24-hour storm event

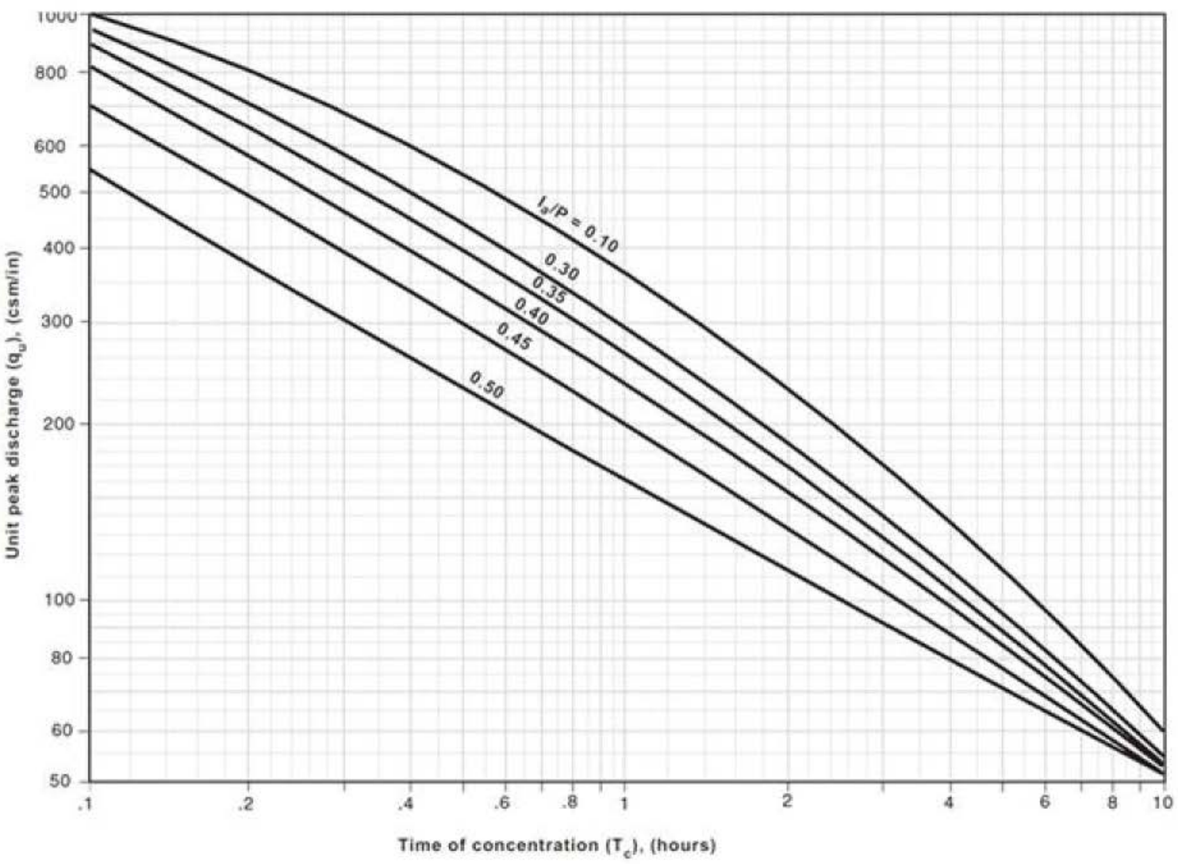
Determine q_u:

Fig 10.4-3

Ia = ?
P = 3.41 inches
Tc = 25 minutes (*given*)

Ia = 0.2 * S
= 0.2 * 4.29 inches
= 0.858 inches

Figure 10.2-8 - Unit peak discharge (qu) for SCS Type II rainfall distribution (10-33)



Channel Protection Volume (CP_V) Calculation Steps

2 Determine the unit peak discharge rate (q_u) for the 1-year 24-hour storm event

Determine q_u:

Fig 10.4-3

Ia = 0.858
P = 3.41 inches
Tc = 25 minutes (*given*)

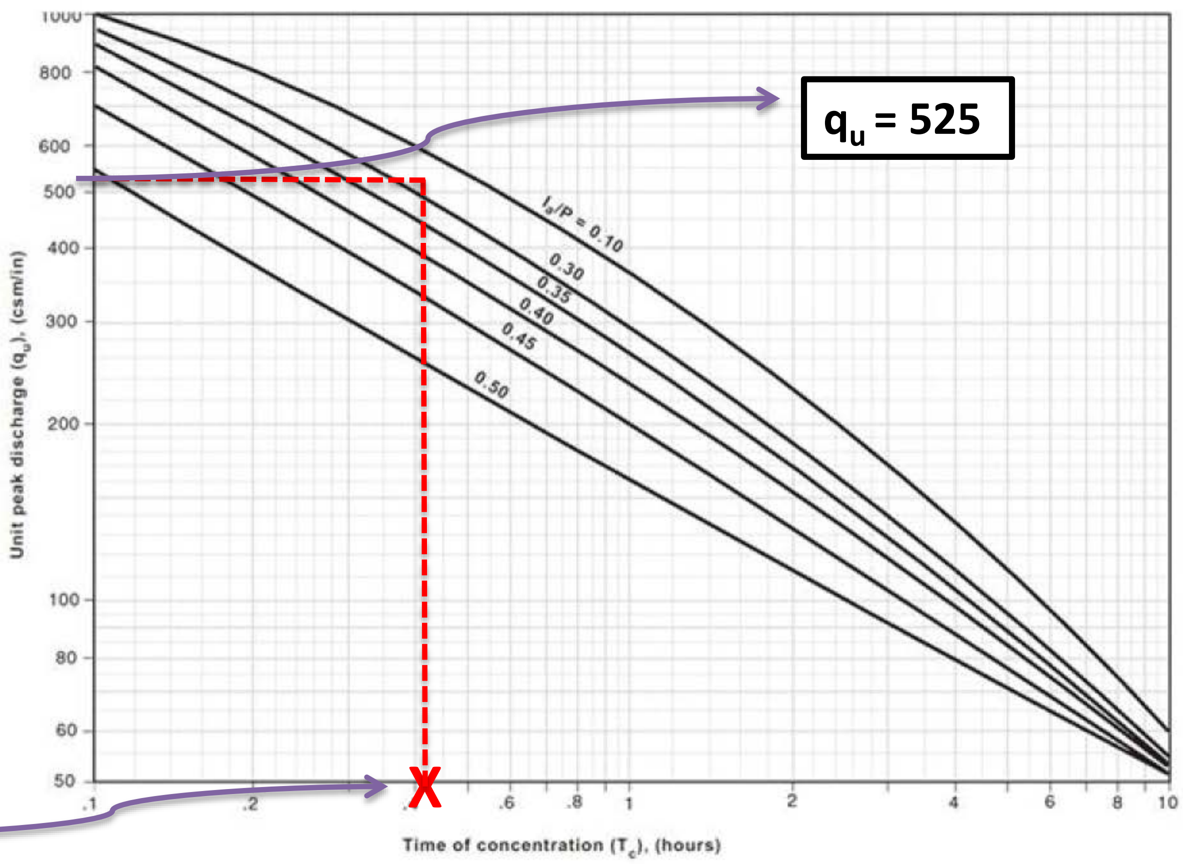
Ia/P = 0.858/3.41

= 0.25

Tc = 25 minutes

= 0.42 hour

Figure 10.2-8 - Unit peak discharge (qu) for SCS Type II rainfall distribution (10-33)



q_u = 525

Channel Protection Volume (CP_V) Calculation Steps

3 Compute the channel protection volume

Calculate Vs (storage volume required):

Eq 10.4-15

$$V_S = \left(\frac{V_S}{V_R}\right) * Q"1{,}24 * A * 3630$$

We need to know V_S/V_R to perform this calculation…..

Eq 10.4-14

$$\frac{V_S}{V_R} = 0.682 - 1.43\left(\frac{q_o}{q_i}\right) + 1.64\left(\frac{q_o}{q_i}\right)^2 - 0.804\left(\frac{q_o}{q_i}\right)^3$$

We need to know q_o/q_i to perform this calculation…..

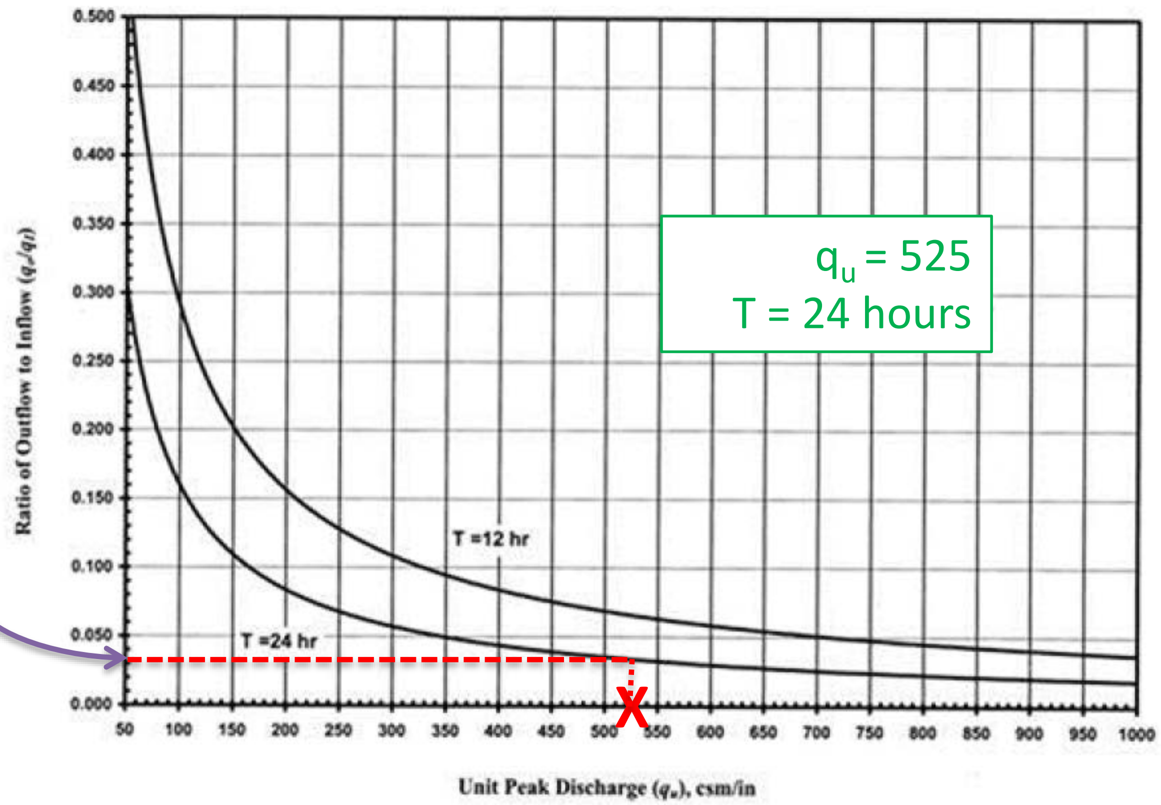
Channel Protection Volume (CP_V) Calculation Steps

3 Compute the channel protection volume

Determine q_o/q_i:

Fig 10.4-6

Figure 10.2-6 - SCS ratio of outflow to inflow curves (10-23)



q_o/q_i = .035

Channel Protection Volume (CP_V) Calculation Steps

3 Compute the channel protection volume

Now we can calculate V_S/V_R:

Eq 10.4-14

$$\frac{V_S}{V_R} = 0.682 - 1.43\left(\frac{q_o}{q_i}\right) + 1.64\left(\frac{q_o}{q_i}\right)^2 - 0.804\left(\frac{q_o}{q_i}\right)^3$$

$q_o/q_i = .035$

$= 0.682 - 1.43\ (.035) + 1.64\ (.035)^2 - 0.804\ (.035)^3$

$= 0.63$

Now we can calculate V_S:

Eq 10.4-15

$$V_S = \left(\frac{V_s}{V_R}\right) * Q"1{,}24 * A * 3630$$

$= (0.63) * (0.95\ \text{inch}) * (\ 10.23\ \text{acre}) * (3{,}630\ \text{ft}^3/\text{inch-acre})$

$= 22{,}225\ \text{ft}^3$

Steps to Design Wet Detention Pond

4 Design channel protection (CP_V) orifice

Orifice sized to release CPv over 24 hours

Orifice Equation:

$$Q_{CPv}\ (cfs) = C_D * A\ (ft^2) * \sqrt{(2g)\Delta H_{max}\ (ft)}$$

Eq 10.6.3-3

$$(.257\ cfs) = (0.6) * (A) * \sqrt{2 * (32.2 ft/s^2) * (1.28 ft)}$$

$$A = 0.047\ ft^2$$

$$D = \sqrt{4 * (0.047\ ft^2) / \pi}$$

D = 0.25 ft = 2.9 in **(use 3 inches for constructability)**

Q_{WQv} (orifice flow rate) = 22,225 ft^3 /24 hr = .257 cfs

C_D (orifice coefficient) = 0.6

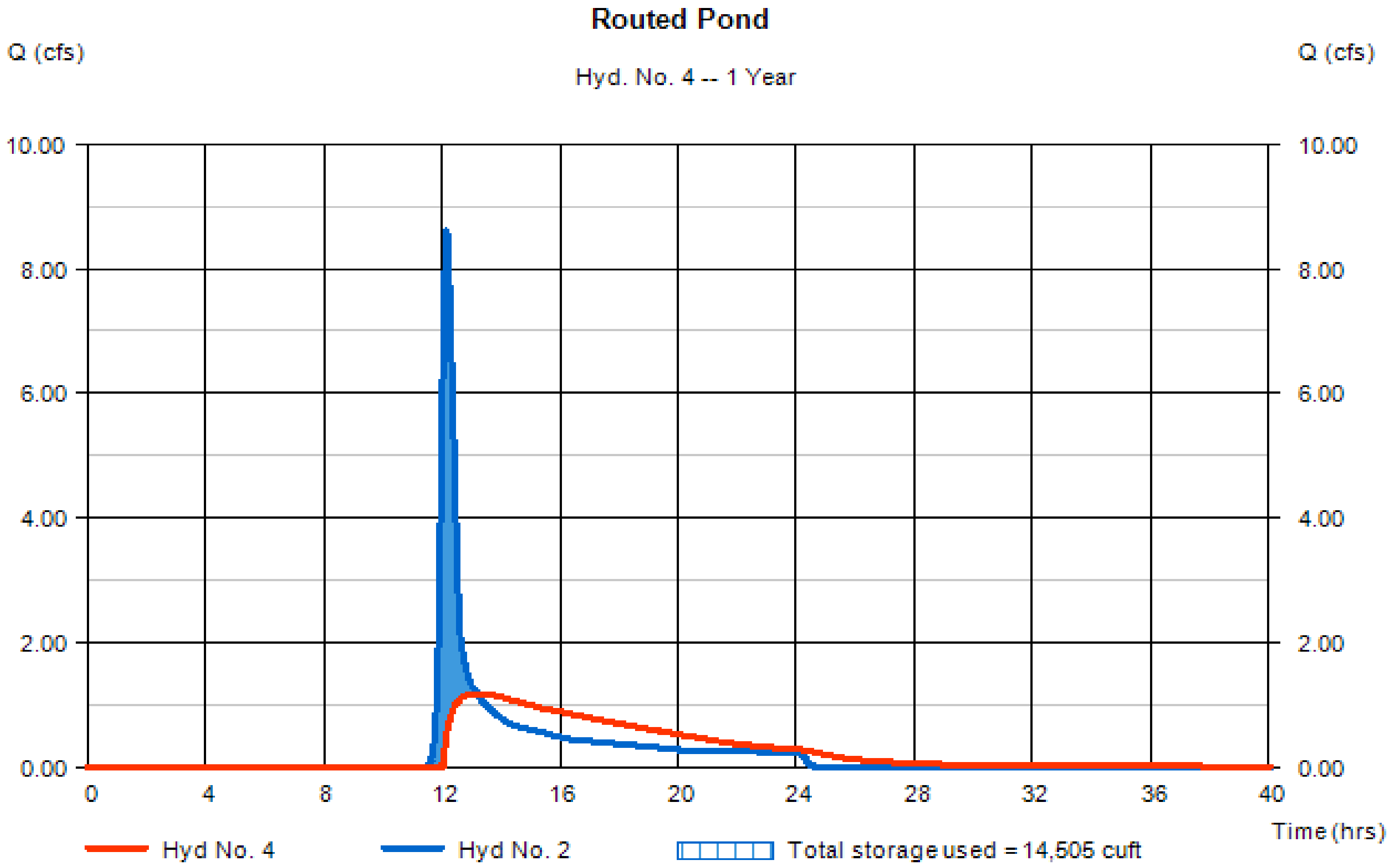
A = orifice area (ft)

ΔH_{max} (max depth at CPv stage) = 1.28 ft

CP_v orifice: 3” diameter at top of water quality volume

Steps to Design Wet Detention Pond

4 Design channel protection (CP_V) orifice



Steps to Design Wet Detention Pond

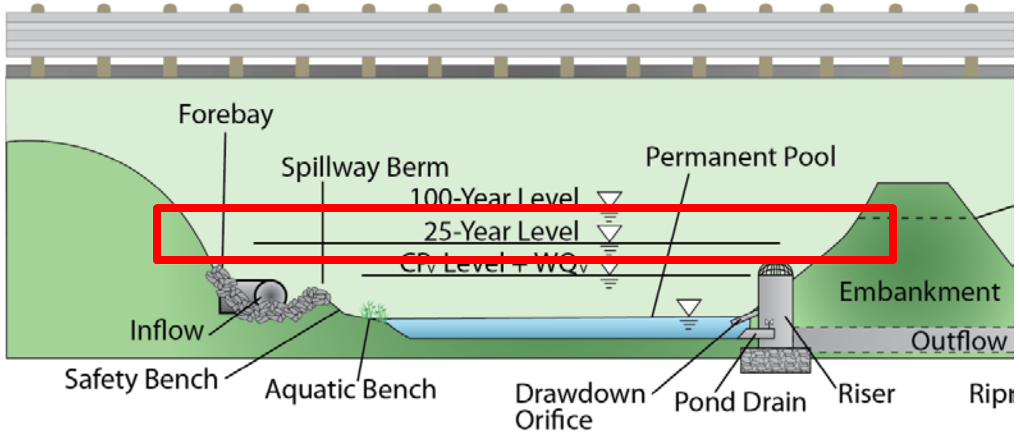
1	Calculate forebay volume	V_{fbay} = 900 ft^3
2	Calculate permanent pool volume and verify pond can maintain	V_{pool} = 900 ft^3, $Depth_{min}$ = 1.5 ft
3	Calculate water quality volume and design orifice	WQ_v = 9,059 ft^3, D_{orif} = 2", $Elev_{orif}$ = perm pool elevation
4	Calculate channel protection volume and design orifice	CP_v = 22,225 ft^3, D_{orif} = 3", $Elev_{orif}$ = water quality elevation
5	Design pond and outlet to maintain 25-yr pre-development peak flow	Q_{25pre} =
6	Design spillway to safely convey 100-yr post-development peak flow	Q_{fpre} =

Steps to Design Wet Detention Pond

5 Maintain pre-development peak flows (Q_{P25})

Multi-step process to calculate Q_{P25} using NRCS TR-55 Methodology

- *Compute pre-development peak flow*
- *Compute post-development peak flow*
- *Calculate estimated storage volume*
- *Design outlet control structure for $Q_{25post} \leq Q_{25pre}$*



Overbank Flooding Protection Volume (Q_V) Calculation Steps

1. Determine runoff depth(Q-inches) for 25-year 24-hour storm event
2. Determine the unit peak discharge rate (q_u) for the 25-year 24-hour storm event
3. Compute the overbank flooding protection volume
4. Estimate the peak flow rates

Overbank Flooding Protection Volume (Q_V) Calculation Steps

1. Determine runoff depth(Q-inches) for 25-year 24-hour storm event
2. Determine the unit peak discharge rate (q_u) for the 25-year 24-hour storm event
3. Compute the overbank flooding protection volume
4. Estimate the peak flow rates

Calculate direct runoff: $Q''_{25,24} = \frac{(P-0.2S)^2}{(P+0.8S)}$

Eq 10.4-10

$$\mathbf{S} = \frac{1000}{\text{CN}} - 10$$

$CN_{exist} = 61$

$CN_{prop} = 70$

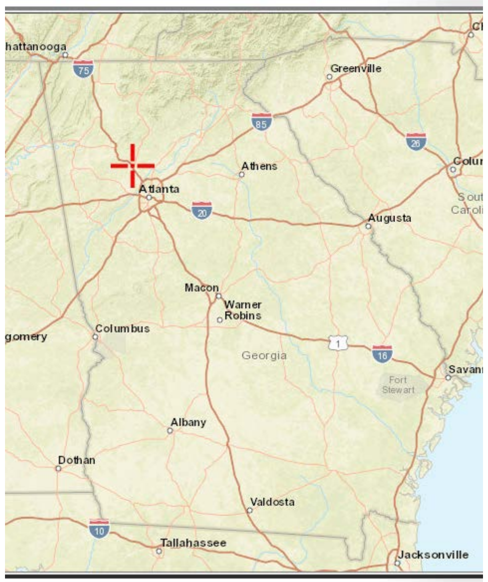
$S_{pre} = 6.4$

$S_{post} = 4.3$

$P_{25,24} = ?$

Overbank Flooding Protection Volume (Q_V) Calculation Steps

Obtain 25-year 24-hour rainfall depth for project location from NOAA website:
http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ga



PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)								
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5-min	0.410 (0.351-0.483)	0.470 (0.402-0.555)	0.576 (0.490-0.680)	0.669 (0.565-0.793)	0.806 (0.660-0.987)	0.919 (0.731-1.13)	1.04 (0.794-1.30)	1.17 (0.850-1.49)	1.34 (0.937-1.75)
10-min	0.601 (0.513-0.708)	0.689 (0.588-0.812)	0.843 (0.717-0.996)	0.979 (0.828-1.16)	1.18 (0.966-1.45)	1.35 (1.07-1.66)	1.52 (1.16-1.91)	1.71 (1.24-2.19)	1.97 (1.37-2.57)
15-min	0.732 (0.626-0.863)	0.840 (0.717-0.991)	1.03 (0.874-1.21)	1.19 (1.01-1.42)	1.44 (1.18-1.76)	1.64 (1.31-2.03)	1.85 (1.42-2.33)	2.08 (1.52-2.66)	2.40 (1.67-3.13)
30-min	1.04 (0.889-1.23)	1.19 (1.02-1.41)	1.46 (1.24-1.72)	1.69 (1.43-2.01)	2.05 (1.67-2.51)	2.33 (1.86-2.88)	2.64 (2.02-3.32)	2.97 (2.17-3.80)	3.43 (2.39-4.48)
60-min	1.35 (1.15-1.59)	1.54 (1.32-1.82)	1.89 (1.61-2.23)	2.19 (1.85-2.60)	2.65 (2.17-3.24)	3.02 (2.40-3.73)	3.42 (2.61-4.29)	3.84 (2.80-4.92)	4.44 (3.10-5.80)
2-hr	1.66 (1.42-1.94)	1.90 (1.63-2.22)	2.32 (1.98-2.72)	2.69 (2.29-3.17)	3.25 (2.68-3.95)	3.71 (2.98-4.54)	4.19 (3.24-5.23)	4.72 (3.48-5.99)	5.45 (3.86-7.05)
3-hr	1.86 (1.61-2.17)	2.13 (1.83-2.48)	2.60 (2.23-3.03)	3.01 (2.57-3.53)	3.62 (3.00-4.38)	4.13 (3.33-5.03)	4.66 (3.62-5.78)	5.23 (3.89-6.60)	6.03 (4.30-7.76)
6-hr	2.30 (1.99-2.66)	2.61 (2.26-3.03)	3.16 (2.72-3.66)	3.63 (3.12-4.23)	4.33 (3.62-5.19)	4.91 (3.99-5.92)	5.51 (4.33-6.76)	6.15 (4.63-7.69)	7.04 (5.10-8.97)
12-hr	2.85 (2.48-3.27)	3.22 (2.80-3.70)	3.85 (3.34-4.44)	4.40 (3.80-5.08)	5.19 (4.35-6.15)	5.82 (4.77-6.95)	6.48 (5.14-7.87)	7.17 (5.47-8.86)	8.12 (5.96-10.2)
24-hr	3.41 (2.99-3.89)	3.88 (3.40-4.43)	4.66 (4.06-5.33)	5.31 (4.61-6.09)	6.23 (5.25-7.29)	6.94 (5.73-8.20)	7.67 (6.14-9.21)	8.41 (6.49-10.3)	9.41 (7.01-11.7)
2-day	3.93 (3.46-4.45)	4.52 (3.97-5.12)	5.47 (4.80-6.21)	6.26 (5.47-7.13)	7.35 (6.23-8.52)	8.18 (6.81-9.58)	9.02 (7.29-10.7)	9.86 (7.70-11.9)	11.0 (8.30-13.5)

Overbank Flooding Protection Volume (Q_V) Calculation Steps

1. Determine runoff depth(Q-inches) for 25-year 24-hour storm event
2. Determine the unit peak discharge rate (q_u) for the 25-year 24-hour storm event
3. Compute the overbank flooding protection volume
4. Estimate the peak flow rates

Calculate direct runoff: $Q''_{25,24} = \frac{(P-0.2S)^2}{(P+0.8S)}$ Eq 10.4-10

$$\mathbf{S} = \frac{1000}{CN} - 10$$

$CN_{exist} = 61$ $S_{pre} = 6.4$ $P_{25,24} = 6.23$ inches

$CN_{prop} = 70$ $S_{post} = 4.3$

$Q_{25,24\ pre} =$ 2.15 inches $Q_{25,24\ post} =$ 2.98 inches

$\mathbf{Q_{25,24\ NET}} =$ **0.83 inches**

Overbank Flooding Protection Volume (Q_V) Calculation Steps

1 Determine runoff depth(Q-inches) for 25-year 24-hour storm event

2 Determine the unit peak discharge rate (q_u) for the 25-year 24-hour storm event

3 Compute the overbank flooding protection volume

4 Estimate the peak flow rates

Calculate direct runoff: $Q''_{25,24} = \frac{(P-0.2S)^2}{(P+0.8S)}$ Eq 10.4-10

$$S = \frac{1000}{CN} - 10$$

$CN_{exist} = 61$ $S_{pre} = 6.4$ $P_{25,24} = 6.23$ inches

$CN_{prop} = 70$ $S_{post} = 4.3$

$Q_{25,24\ pre} =$ 2.15 inches $Q_{25,24\ post} =$ 2.98 inches

$Q_{25,24\ NET} =$ 0.83 inches

Determine q_u using Figure 10.4-3

Overbank Flooding Protection Volume (Q_V) Calculation Steps

Determine q_u:

Fig 10.4-3

$Ia_{pre} = 0.2 * S_{pre} = 1.28$

$Ia_{post} = 0.2 * S_{post} = 0.86$

P = 6.23 inches

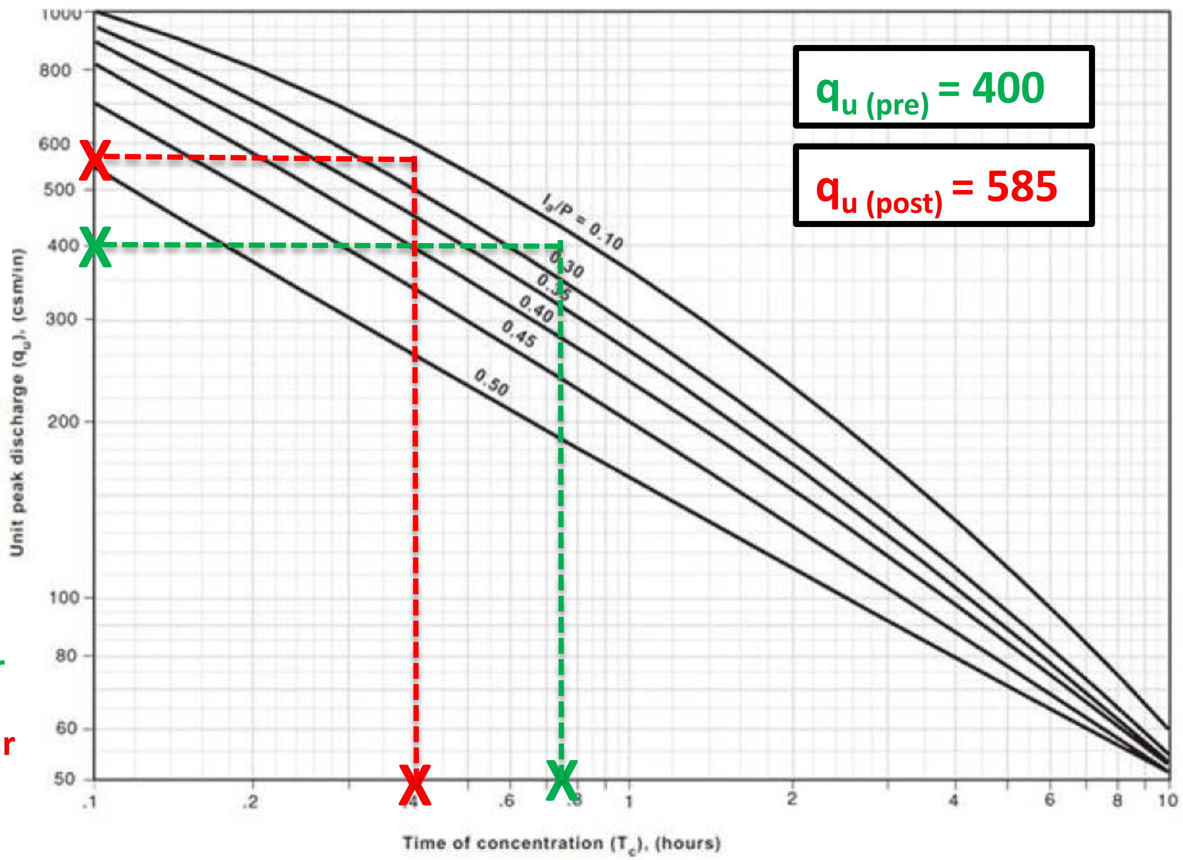
$Ia/P_{(pre)} = 1.28/6.23 = 0.20$

$Ia/P_{(post)} = 0.868/6.23 = 0.14$

$Tc_{(pre)}$ = 45 minutes = 0.75 hour

$Tc_{(post)}$ = 25 minutes = 0.40 hour

Figure 10.2-8 - Unit peak discharge (qu) for SCS Type II rainfall distribution (10-33)



$q_{u\ (pre)}$ = 400

$q_{u\ (post)}$ = 585

Overbank Flooding Protection Volume (Q_V) Calculation Steps

1 Determine runoff depth(Q-inches) for 25-year 24-hour storm event

2 Determine the unit peak discharge rate (q_u) for the 25-year 24-hour storm event

3 Compute the overbank flooding protection volume

4 Estimate the peak flow rates

Calculate direct runoff: $Q''_{25,24} = \frac{(P-0.2S)^2}{(P+0.8S)}$ Eq 10.4-10

$$\mathbf{S} = \frac{1000}{\text{CN}} - 10$$

$CN_{exist} = 61$ $S_{pre} = 6.4$ $P_{25,24} = 6.23$ inches

$CN_{prop} = 70$ $S_{post} = 4.3$

$Q_{25,24\ pre} =$ 2.15 inches $Q_{25,24\ post} =$ 2.98 inches

$\mathbf{Q_{25,24\ NET}} =$ **0.83 inches**

Determine q_u using Figure 10.4-3

$q_{u\ 25,24\ pre} =$ **400** $q_{u\ 25,24\ post} =$ **585**

Overbank Flooding Protection Volume (Q_V) Calculation Steps

1 Determine runoff depth(Q-inches) for 25-year 24-hour storm event

2 Determine the unit peak discharge rate (q_u) for the 25-year 24-hour storm event

3 Compute the overbank flooding protection volume

4 Estimate the peak flow rates

Calculate direct runoff: $Q''_{25,24} = \frac{(P-0.2S)^2}{(P+0.8S)}$ Eq 10.4-10

$$\mathbf{S} = \frac{1000}{\mathrm{CN}} - 10$$

$CN_{exist} = 61$ $S_{pre} = 6.4$ $P_{25,24} = 6.23$ inches

$CN_{prop} = 70$ $S_{post} = 4.3$

$Q_{25,24\ pre} =$ 2.15 inches $Q_{25,24\ post} =$ 2.98 inches

$Q_{25,24\ NET} =$ 0.83 inches

Determine q_u using Figure 10.4-3

$q_{u\ 25,24\ pre} =$ 400 **$q_{u\ 25,24\ post} =$ 585**

Eq 10.4-15

Calculate Vs (storage volume required): $V_S = \left(\frac{V_S}{V_R}\right) * Q''25{,}24 * A * 3{,}630$

Overbank Flooding Protection Volume (Q_V) Calculation Steps

1. Determine runoff depth(Q-inches) for 25-year 24-hour storm event
2. Determine the unit peak discharge rate (q_u) for the 25-year 24-hour storm event
3. Compute the overbank flooding protection volume
4. Estimate the peak flow rates

Calculate direct runoff: $Q''_{25,24} = \frac{(P-0.2S)^2}{(P+0.8S)}$ Eq 10.4-10

$\mathbf{S} = \frac{1000}{CN} - 10$

$CN_{exist} = 61$ $S_{pre} = 6.4$ $P_{25,24} = 6.23$ inches

$CN_{prop} = 70$ $S_{post} = 4.3$

$Q_{25,24\ pre} =$ 2.15 inches $Q_{25,24\ post} =$ 2.98 inches

$\mathbf{Q_{25,24\ NET}} =$ **0.83 inches**

Determine q_u using Figure 10.4-3

$q_{u\ 25,24\ pre} =$ **400** $q_{u\ 25,24\ post} =$ **585**

Eq 10.4-15

Calculate Vs (storage volume required): $V_S = \left(\frac{V_S}{V_R}\right) * Q''25{,}24 * A * 3{,}630$

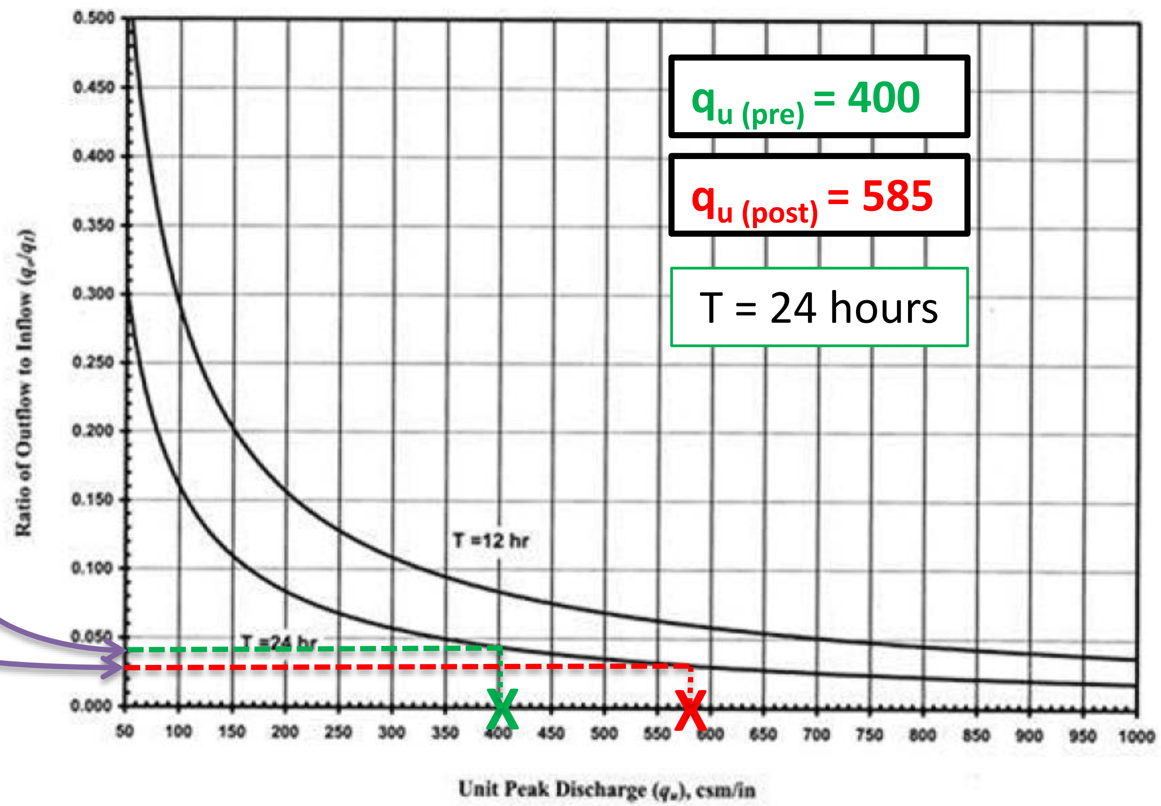
Determine q_o/q_i from Figure 10.4-6

Overbank Flooding Protection Volume (Q_V) Calculation Steps

Determine q_o/q_i:

Fig 10.4-6

Figure 10.2-6 - SCS ratio of outflow to inflow curves (10-23)



$q_o/q_{i\,(pre)}$ = .040

$q_o/q_{i\,(post)}$ = .028

Overbank Flooding Protection Volume (Q_V) Calculation Steps

1. Determine runoff depth(Q-inches) for 25-year 24-hour storm event
2. Determine the unit peak discharge rate (q_u) for the 25-year 24-hour storm event
3. Compute the overbank flooding protection volume
4. Estimate the peak flow rates

Calculate direct runoff: $Q''_{25,24} = \frac{(P-0.2S)^2}{(P+0.8S)}$ Eq 10.4-10

$S = \frac{1000}{CN} - 10$

$CN_{exist} = 61$ $S_{pre} = 6.4$ $P_{25,24} = 6.23$ inches

$CN_{prop} = 70$ $S_{post} = 4.3$

$Q_{25,24\ pre}=$ 2.15 inches $Q_{25,24\ post}=$ 2.98 inches

$Q_{25,24\ NET}=$ 0.83 inches

Determine q_u using Figure 10.4-3

$q_{u\ 25,24\ pre}=$ 400 **$q_{u\ 25,24\ post}=$ 585**

Eq 10.4-15

Calculate Vs (storage volume required): $V_S = \left(\frac{V_S}{V_R}\right) * Q''25{,}24 * A * 3{,}630$

Determine q_o/q_i from Figure 10.4.6

$q_o/q_{i\ 25,24\ pre}=$ 0.040 $q_o/q_{i\ 25,24\ post}=$ 0.028

Overbank Flooding Protection Volume (Q_V) Calculation Steps

1. Determine runoff depth(Q-inches) for 25-year 24-hour storm event
2. Determine the unit peak discharge rate (q_u) for the 25-year 24-hour storm event
3. **Compute the overbank flooding protection volume**
4. Estimate the peak flow rates

Calculate direct runoff: $Q''_{25,24} = \frac{(P-0.2S)^2}{(P+0.8S)}$ Eq 10.4-10

$$S = \frac{1000}{CN} - 10$$

$CN_{exist} = 61$ $S_{pre} = 6.4$ $P_{25,24} = 6.23$ inches

$CN_{prop} = 70$ $S_{post} = 4.3$

$Q_{25,24\ pre} =$ 2.15 inches $Q_{25,24\ post} =$ 2.98 inches

$Q_{25,24\ NET} =$ 0.83 inches

Determine q_u using Figure 10.4.3

$q_{u\ 25,24\ pre} =$ 400 $q_{u\ 25,24\ post} =$ 585

Eq 10.4-15

Calculate Vs (storage volume required): $V_S = \left(\frac{V_S}{V_R}\right) * Q''25{,}24 * A * 3{,}630$

Determine q_o/q_i from Figure 10.4.6

$q_o/q_{i\ 25,24\ pre} =$ 0.040 $q_o/q_{i\ 25,24\ post} =$ 0.028

Determine V_S/V_R from Equation 10.4-14: Eq 10.4-14

$$\frac{V_S}{V_R} = 0.682 - 1.43\left(\frac{q_o}{q_i}\right) + 1.64\left(\frac{q_o}{q_i}\right)^2 - 0.804\left(\frac{q_o}{q_i}\right)^3$$

$V_S/V_{R\ pre} =$ 0.627 $V_S/V_{R\ post} =$ 0.643

Overbank Flooding Protection Volume (Q_V) Calculation Steps

1. Determine runoff depth(Q-inches) for 25-year 24-hour storm event
2. Determine the unit peak discharge rate (q_u) for the 25-year 24-hour storm event
3. **Compute the overbank flooding protection volume**
4. Estimate the peak flow rates

Calculate direct runoff: $Q''_{25,24} = \frac{(P-0.2S)^2}{(P+0.8S)}$ Eq 10.4-10

$S = \frac{1000}{CN} - 10$

$CN_{exist} = 61$ $S_{pre} = 6.4$ $P_{25,24} = 6.23$ inches

$CN_{prop} = 70$ $S_{post} = 4.3$

$Q_{25,24\ pre} =$ 2.15 inches $Q_{25,24\ post} =$ 2.98 inches

$Q_{25,24\ NET} =$ 0.83 inches

Determine q_u using Figure 10.4.3

$q_{u\ 25,24\ pre} =$ 400 **$q_{u\ 25,24\ post} =$ 585**

Eq 10.4-15

Calculate Vs (storage volume required): $V_S = \left(\frac{V_S}{V_R}\right) * Q''25{,}24 * A * 3{,}630$

Determine q_o/q_i from Figure 10.4.6

$q_o/q_{i\ 25,24\ pre} =$ 0.040 $q_o/q_{i\ 25,24\ post} =$ 0.028

Determine V_S/V_R from Equation 10.4-14: Eq 10.4-14

$$\frac{V_S}{V_R} = 0.682 - 1.43\left(\frac{q_o}{q_i}\right) + 1.64\left(\frac{q_o}{q_i}\right)^2 - 0.804\left(\frac{q_o}{q_i}\right)^3$$

$V_S/V_{R\ pre} =$ 0.627 $V_S/V_{R\ post} =$ 0.643

$V_{S\ pre} = 50{,}059\ ft^3$ $V_{S\ post} = 71{,}181\ ft^3$

Overbank Flooding Protection Volume (Q_V) Calculation Steps

1. Determine runoff depth(Q-inches) for 25-year 24-hour storm event
2. Determine the unit peak discharge rate (q_u) for the 25-year 24-hour storm event
3. Compute the overbank flooding protection volume
4. Estimate the peak flow rates

Calculate direct runoff: $Q''_{25,24} = \frac{(P-0.2S)^2}{(P+0.8S)}$ Eq 10.4-10

$$\mathbf{S} = \frac{1000}{CN} - 10$$

$CN_{exist} = 61$ $S_{pre} = 6.4$ $P_{25,24} = 6.23$ inches

$CN_{prop} = 70$ $S_{post} = 4.3$

$Q_{25,24\ pre} =$ 2.15 inches $Q_{25,24\ post} =$ 2.98 inches

$Q_{25,24\ NET} =$ 0.83 inches

Determine q_u using Figure 10.4-3

$q_{u\ 25,24\ pre} =$ 400 **$q_{u\ 25,24\ post} =$ 585**

Eq 10.4-15

Calculate Vs (storage volume required): $V_S = \left(\frac{V_S}{V_R}\right) * Q''25{,}24 * A * 3{,}630$

Determine q_o/q_i from Figure 10.4.6

$q_o/q_{i\ 25,24\ pre} =$ 0.040 $q_o/q_{i\ 25,24\ post} =$ 0.028

Determine V_S/V_R from Equation 10.4-14:

$$\frac{V_S}{V_R} = 0.682 - 1.43\left(\frac{q_o}{q_i}\right) + 1.64\left(\frac{q_o}{q_i}\right)^2 - 0.804\left(\frac{q_o}{q_i}\right)^3$$

$V_S/V_{R\ pre} =$ 0.627 $V_S/V_{R\ post} =$ 0.643

$V_{S\ pre} =$ 50,059 ft^3 $V_{S\ post} =$ 71,181 ft^3

$V_{S\ NET} =$ 71,181 – 50,059 = 21,122 ft^3

Estimate the peak flow rate using Equation 10.4-16:

Q_{25} (pre) = q_u*A*Q"*F_p = 400*10.23 acres/640 acre/mi^2*2.15 inches*1 = 13.7 cfs

Q_{25} (post) = q_u*A*Q"*F_p = 585*10.23 acres/640 acre/mi^2*2.98 inches*1 = 27.9 cfs

Georgia Department of Transportation

Extreme Flooding Protection Volume ($Q_{f\text{-}100yr}$) Calculation Steps

1. Determine runoff depth(Q-inches) for 100-year 24-hour storm event
2. Determine the unit peak discharge rate (q_u) for the 100-year 24-hour storm event
3. Compute the overbank flooding protection volume
4. Estimate the peak flow rates

Calculate direct runoff: $Q''_{100,24} = \frac{(P-0.2S)^2}{(P+0.8S)}$ Eq 10.4-10

$S = \frac{1000}{CN} - 10$

$CN_{exist} = 61$ $S_{pre} = 6.4$ $P_{100,24} = 7.67$ inches

$CN_{prop} = 70$ $S_{post} = 4.3$

$Q_{100,24\ pre} =$ 3.19 inches $Q_{100,24\ post} =$ 4.17 inches

Determine q_u using Figure 10.4.3

$q_{u\ 100,24\ pre} =$ **405** $q_{u\ 100,24\ post} =$ **590**

Eq 10.4-15

Calculate Vs (storage volume required): $V_S = \left(\frac{V_S}{V_R}\right) * Q''25{,}24 * A * 3{,}630$

Determine q_o/q_i from Figure 10.4.6

$q_o/q_{i\ 100,24\ pre} = 0.037$ $q_o/q_{i\ 100,24\ post} = 0.025$

Determine V_S/V_R from Equation 10.4-14:

$$\frac{V_S}{V_R} = 0.682 - 1.43\left(\frac{q_o}{q_i}\right) + 1.64\left(\frac{q_o}{q_i}\right)^2 - 0.804\left(\frac{q_o}{q_i}\right)^3$$

$V_S/V_{R\ pre} = 0.631$ $V_S/V_{R\ post} = 0.647$

$V_{S\ pre} = 74{,}748\ ft^3$ $V_{S\ post} = 100{,}190\ ft^3$

Estimate the peak flow rate using Equation 10.4-16:

Q_{100} (pre) = q_u*A*Q"*F_p = 405*10.23 acres/640 acre/mi^2*3.19 inches*1 = 20.7 cfs

Q_{100} (post) = q_u*A*Q"*F_p = 590*10.23 acres/640 acre/mi^2*4.17 inches*1 = 39.3 cfs

Steps to Design Wet Detention Pond

1. Calculate forebay volume — V_{fbay} = 900 ft^3
2. Calculate permanent pool volume and verify pond can maintain — V_{pool} = 900 ft^3, $Depth_{min}$ = 1.5 ft
3. Calculate water quality volume and design orifice — WQ_v = 9,059 ft^3, D_{orif} = 2”, $Elev_{orif}$ = perm pool elevation
4. Calculate channel protection volume and design orifice — CP_v = 22,225 ft^3, D_{orif} = 3”, $Elev_{orif}$ = water quality elevation
5. Design pond and outlet to maintain 25-yr pre-development peak flow — Q_{25pre} =
6. Design spillway to safely convey 100-yr post-development peak flow — Q_{fpre} =

Storage Volume Estimation Steps

25-year Storm

1. Calculate ratio of post ($Q_{P25post}$) to pre-development (Q_{P25pre}) discharge:
2. Calculate the inflow volume of runoff (V_R)
3. Find the ratio of V_S/V_R using Figure 10.7-3
4. Calculate V_S

Storage Volume Estimation Steps

25-year Storm

1 Calculate ratio of post ($Q_{P25post}$) to pre-development (Q_{P25pre}) discharge:

2 Calculate the inflow volume of runoff (V_R)

3 Find the ratio of V_S/V_R using Figure 10.7-3

4 Calculate V_S

Calculate $Q_{P25(pre)}$ / $Q_{P25(post)}$:

$$\frac{Q_{P25\,(pre)}}{Q_{P25\,(post)}} = \left(\frac{13.7\ cfs}{27.9\ cfs}\right) = 0.49$$

Storage Volume Estimation Steps

25-year Storm

1. Calculate ratio of post ($Q_{P25post}$) to pre-development (Q_{P25pre}) discharge:
2. Calculate the inflow volume of runoff (V_R)
3. Find the ratio of V_S/V_R using Figure 10.7-3
4. Calculate V_S

Calculate $Q_{P25(pre)}$ / $Q_{P25(post)}$:

$$\frac{Q_{P25\,(pre)}}{Q_{P25\,(post)}} = \left(\frac{13.7\ cfs}{27.9\ cfs}\right) = 0.49$$

V_R = volume of runoff (ft^3)
K_R = conversion from in-mi^2 to acre-ft
Q_D = $Q_{25,24}$ = 25-yr, 24-hr runoff depth (in)
A_M = basin area (mi^2)

Calculate V_R:

$V_R = K_R * Q_D * A_M$

= (53.33)*(2.98 in)*(10.23 ac) * (mi^2/640 acre)

= 2.55 ac-ft = 111,026 ft^3

Storage Volume Estimation Steps

25-year Storm

1. Calculate ratio of post ($Q_{P25post}$) to pre-development (Q_{P25pre}) discharge:
2. Calculate the inflow volume of runoff (V_R)
3. Find the ratio of V_S/V_R using Figure 10.7-3
4. Calculate V_S

Calculate $Q_{P25(pre)}$ / $Q_{P25(post)}$:

$$\frac{Q_{P25\,(pre)}}{Q_{P25\,(post)}} = \left(\frac{13.7\,cfs}{27.9\,cfs}\right) = 0.49$$

V_R = volume of runoff (ft^3)
K_R = conversion from in-mi^2 to acre-ft
Q_D = $Q_{1,24}$ = 1-yr, 24-hr runoff depth (in)
A_M = basin area (mi^2)

Calculate V_R:

$V_R = K_R * Q_D * A_M$

= (53.33)*(2.99 in)*(10.23 ac) * (mi^2/640 acre)

= 2.55 ac-ft = 111,026 ft^3

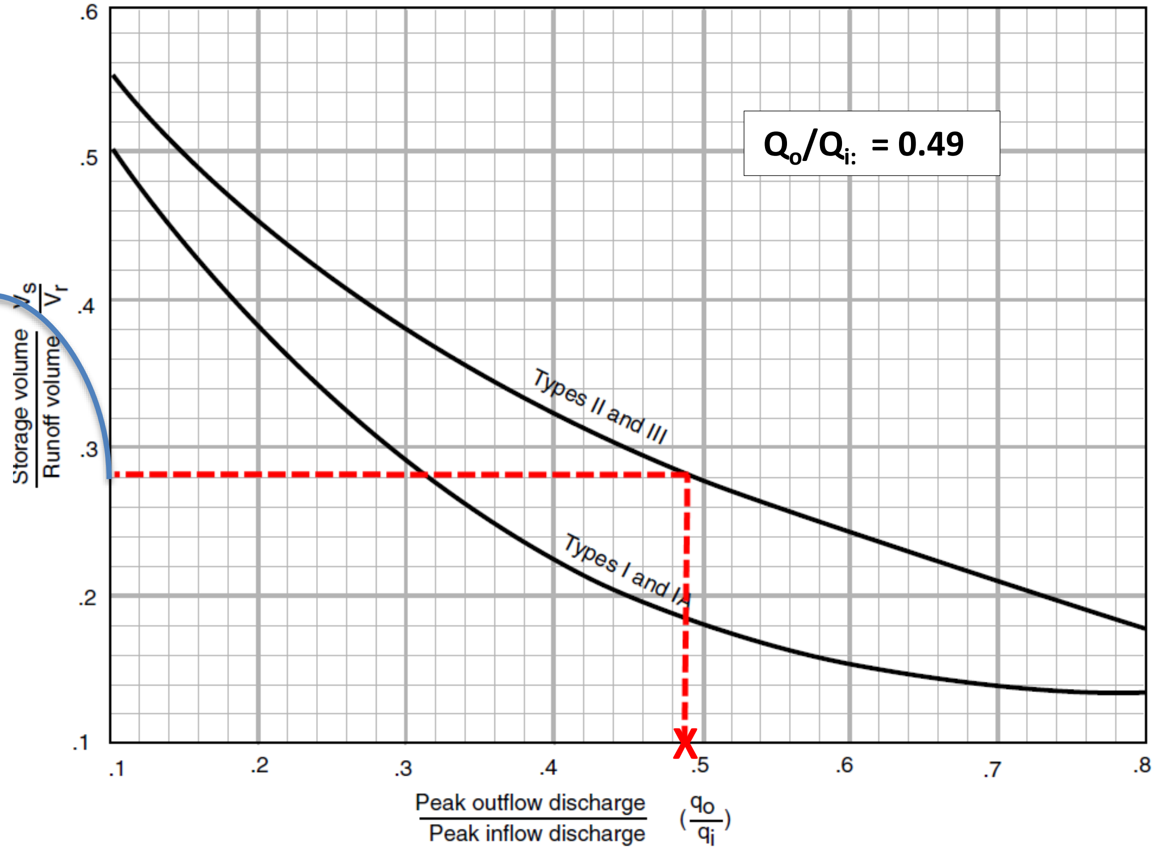
Find V_S/V_R :using Figure 10.7-3:

Steps to Design Wet Detention Pond

5 Maintain pre-development peak flows (Q_{P25})

- **Find the ratio of V_S/V_R using Figure 10.7-3**

V_S/V_R (*25-yr*) = 0.28



Storage Volume Estimation Steps

25-year Storm

1. Calculate ratio of post (Q_{post}) to pre-development (Q_{pre}) discharge:
2. Calculate the inflow volume of runoff (V_R)
3. Find the ratio of V_S/V_R using Figure 10.7-3
4. Calculate V_S

Calculate $Q_{P25(pre)}$ / $Q_{P25(post)}$:

$$\frac{Q_{P25\,(pre)}}{Q_{P25\,(post)}} = \left(\frac{13.7\ cfs}{27.9\ cfs}\right) = 0.49$$

V_R = volume of runoff (ft^3)
K_R = conversion from in-mi^2 to acre-ft
Q_D = $Q_{1,24}$ = 1-yr, 24-hr runoff depth (in)
A_M = basin area (mi^2)

Calculate V_R:

$V_R = K_R * Q_D * A_M$

= (53.33)*(2.99 in)*(10.23 ac) * (mi^2/640 acre)

= 2.55 ac-ft = 111,026 ft^3

Find V_S/V_R :using Figure 10.7-3:

V_S/V_R (*25-yr*) = 0.28

Storage Volume Estimation Steps

25-year Storm

1. Calculate ratio of post (Q_{post}) to pre-development (Q_{pre}) discharge:

Calculate $Q_{P25(pre)}$ / $Q_{P25(post)}$:

$$\frac{Q_{P25\,(pre)}}{Q_{P25\,(post)}} = \left(\frac{13.7\ cfs}{27.9\ cfs}\right) = 0.49$$

V_R = volume of runoff (ft^3)
K_R = conversion from in-mi^2 to acre-ft
Q_D = $Q_{1,24}$ = 1-yr, 24-hr runoff depth (in)
A_M = basin area (mi^2)

2. Calculate the inflow volume of runoff (V_R)

Calculate V_R:

$V_R = K_R * Q_D * A_M$

$= (53.33)*(2.99\ in)*(10.23\ ac) * (mi^2/640\ acre)$

$= 2.55$ ac-ft $= 111{,}026\ ft^3$

3. Find the ratio of V_S/V_R using Figure 10.7-3

Find V_S/V_R :using Figure 10.7-3:

V_S/V_R (*25-yr*) = 0.28

4. Calculate V_S

Calculate V_S :

$V_S = V_R * V_S/V_R$

$= (111{,}026\ ft^3) * (0.28)$

$= 31{,}087\ ft^3$

Steps to Design Wet Detention Pond

Step	Task	Result
1	Calculate forebay volume	V_{fbay} = 900 ft^3
2	Calculate permanent pool volume and verify pond can maintain	V_{pool} = 900 ft^3, $Depth_{min}$ = 1.5 ft
3	Calculate water quality volume and design orifice	WQ_v = 9,059 ft^3, D_{orif} = 2", $Elev_{orif}$ = perm pool elevation
4	Calculate channel protection volume and design orifice	CP_v = 22,225 ft^3, D_{orif} = 3", $Elev_{orif}$ = water quality elevation
5	Design pond and outlet to maintain 25-yr pre-development peak flow	Q_{25} = 31,087 ft^3
6	Design spillway to safely convey 100-yr post-development peak flow	

Storage Volume Estimation Steps

100-year Storm

1. Calculate ratio of post ($Qf_{100post}$) to pre-development (Q_{100pre}) discharge:

Calculate $Q_{f100(pre)}$ / $Q_{f100(post)}$:

$$\frac{Q_{P100\ (pre)}}{Q_{100\ (post}} = \left(\frac{20.7\ cfs}{39.3\ cfs}\right) = 0.53$$

2. Calculate the inflow volume of runoff (V_R)

Calculate V_R:

$V_R = K_R * Q_D * A_M$

$= (53.33)*(4.17 \text{ in})*(10.23 \text{ ac}) * (mi^2/640 \text{ acre})$

$= 3.55$ ac-ft = **154,843 ft³**

V_R = volume of runoff (ft^3)
K_R = conversion from in-mi^2 to acre-ft
Q_D = $Q_{1,24}$ = 100-yr, 24-hr runoff depth (in)
A_M = basin area (mi^2)

3. Find the ratio of V_S/V_R using Figure 10.7-3

Find V_S/V_R :using Figure 10.7-3:

V_S/V_R (100-*yr*) = 0.26

4. Calculate V_S

Calculate V_S :

$V_S = V_R * V_S/V_R$

$= (154{,}843\ ft^3) * (0.26)$

= **40,259 ft³**

Design Example

Caution: Manual calculations are approximate and can result in storage volumes larger than necessary. Route using software that bases calculations on entire hydrograph rather than just peak flow, for more accurate storage design

Steps to Design Wet Detention Pond

1. Calculate forebay volume — V_{fbay} = 900 ft^3
2. Calculate permanent pool volume and verify pond can maintain — V_{pool} = 900 ft^3, $Depth_{min}$ = 1.5 ft
3. Calculate water quality volume and design orifice — WQ_v = 9,059 ft^3, D_{orif} = 2", $Elev_{orif}$ = perm pool elevation
4. Calculate channel protection volume and design orifice — CP_v = 22,225 ft^3, D_{orif} = 3", $Elev_{orif}$ = water quality elevation
5. Design pond and outlet to maintain 25-yr pre-development peak flow — Q_{P25} = 31,087 ft^3
6. Design spillway to safely convey 100-yr post-development peak flow — Q_f =40,259 ft^3

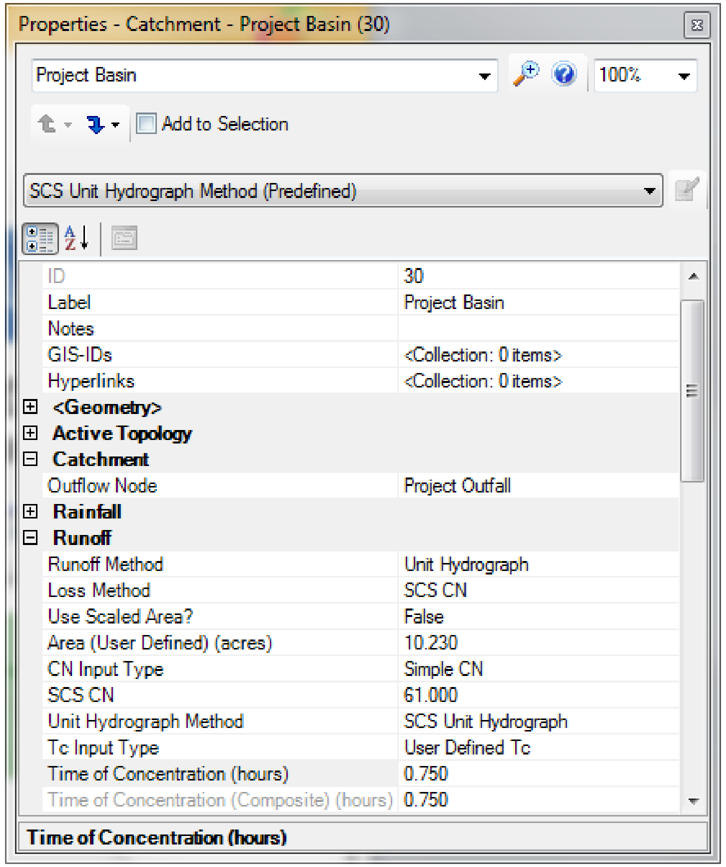
Steps to Design Wet Detention Pond

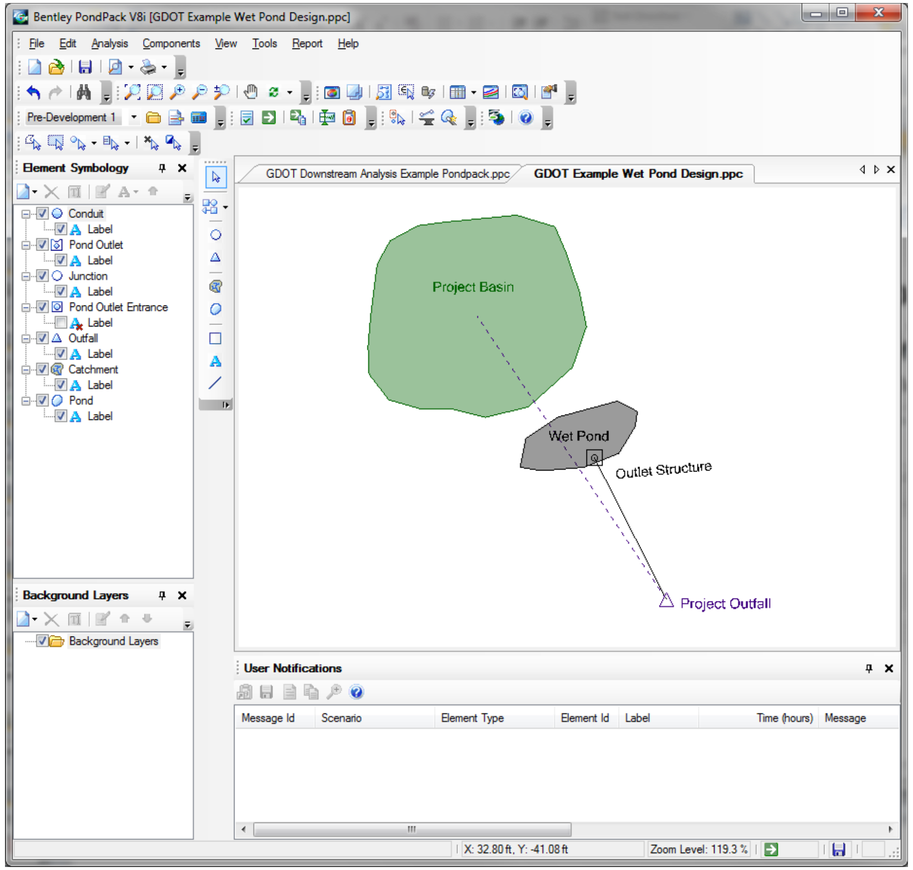
5 Maintain pre-development peak flows (Q_{P25})

Calculate Storage Volume Required using NRCS Method

Pre-Project Conditions

CN = 61
Tc = 45 min





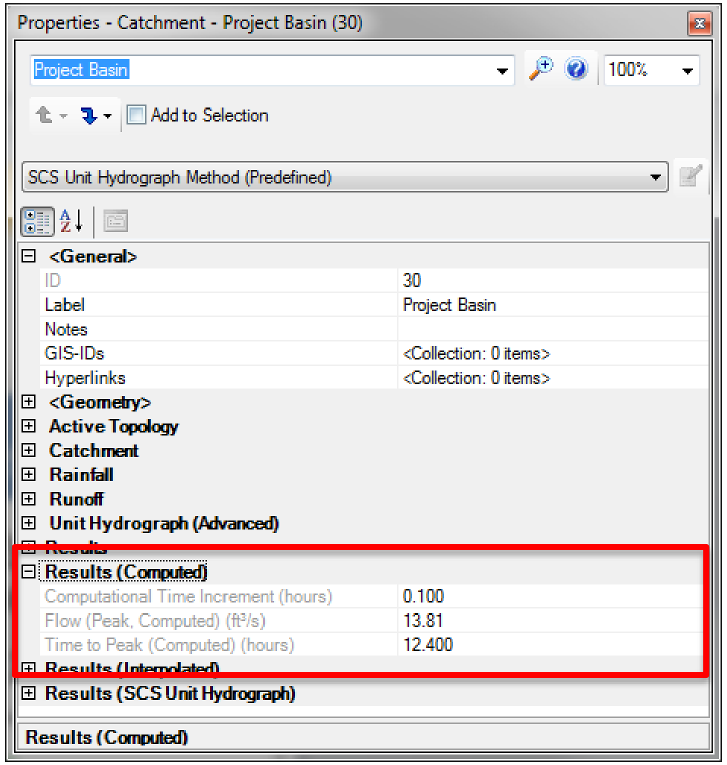
Steps to Design Wet Detention Pond

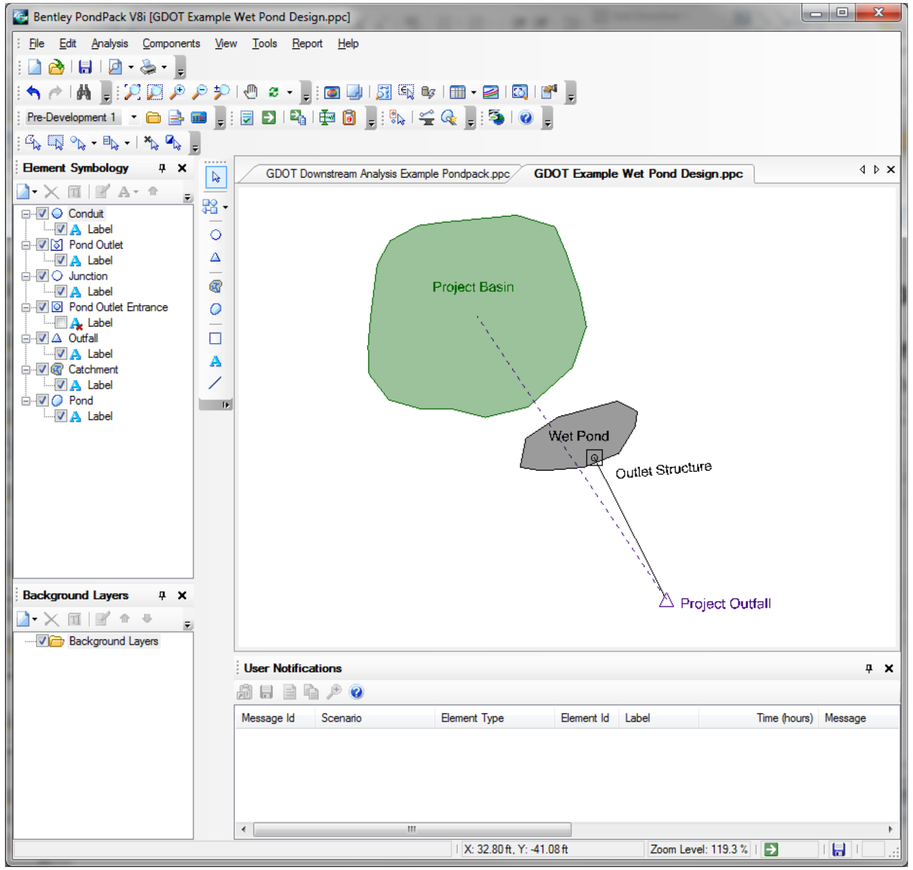
5 Maintain pre-development peak flows (Q_{P25})

Calculate Storage Volume Required using NRCS Method

Pre-Project Conditions

CN = 61
Tc = 45 min





Steps to Design Wet Detention Pond

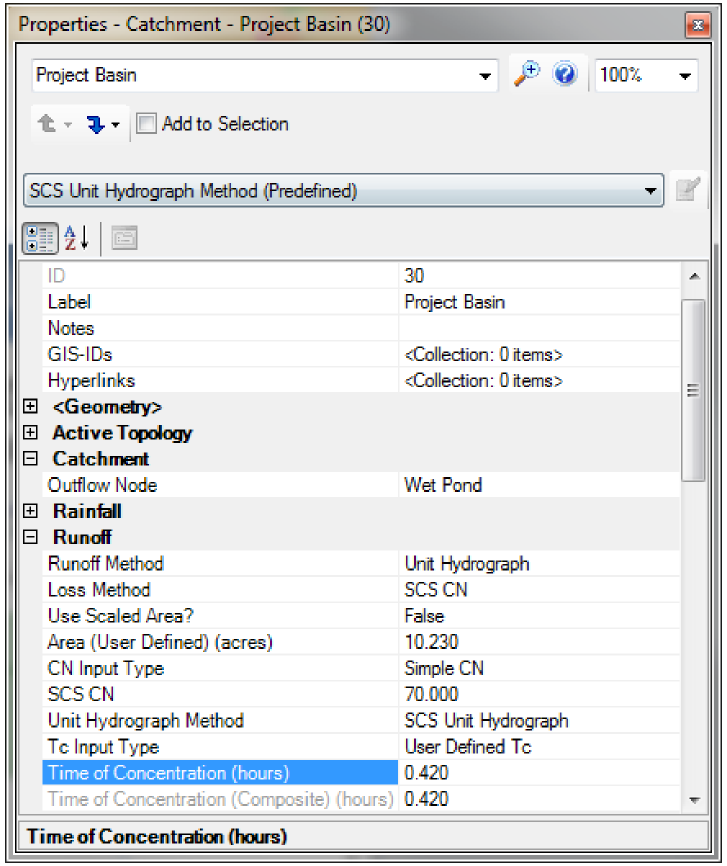
5 Maintain pre-development peak flows (Q_{P25})

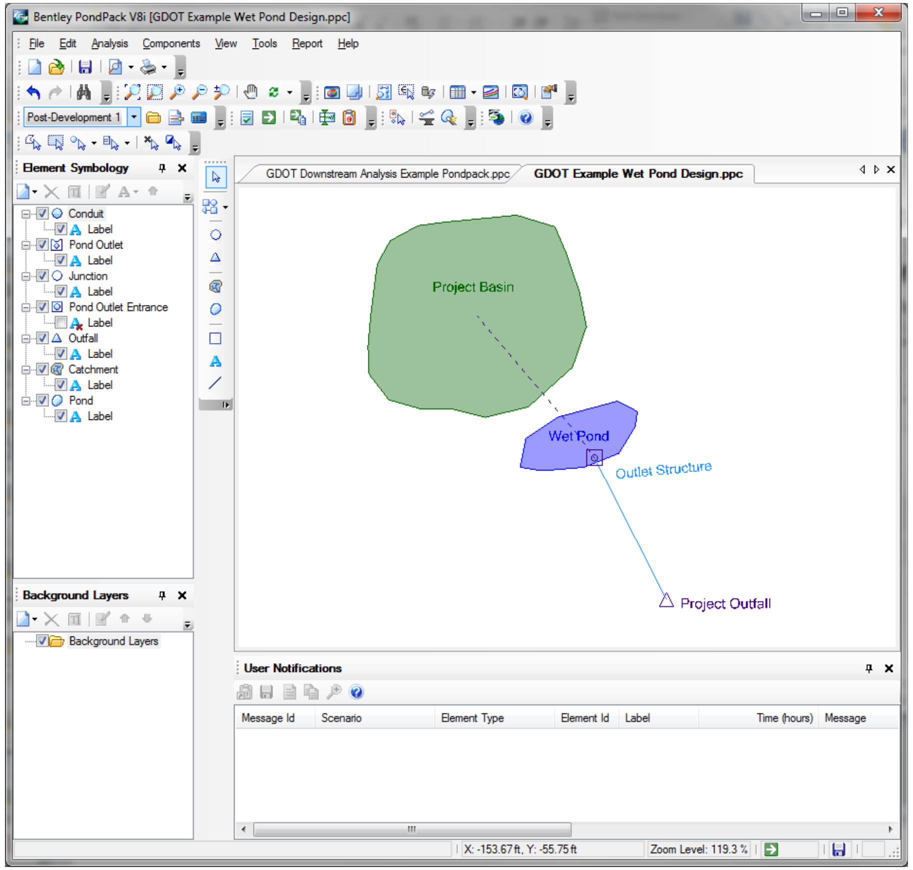
Calculate Storage Volume Required using NRCS Method

Post-Project Conditions

Roadway Impervious Area Added

CN = 70
Tc = 25 min





Steps to Design Wet Detention Pond

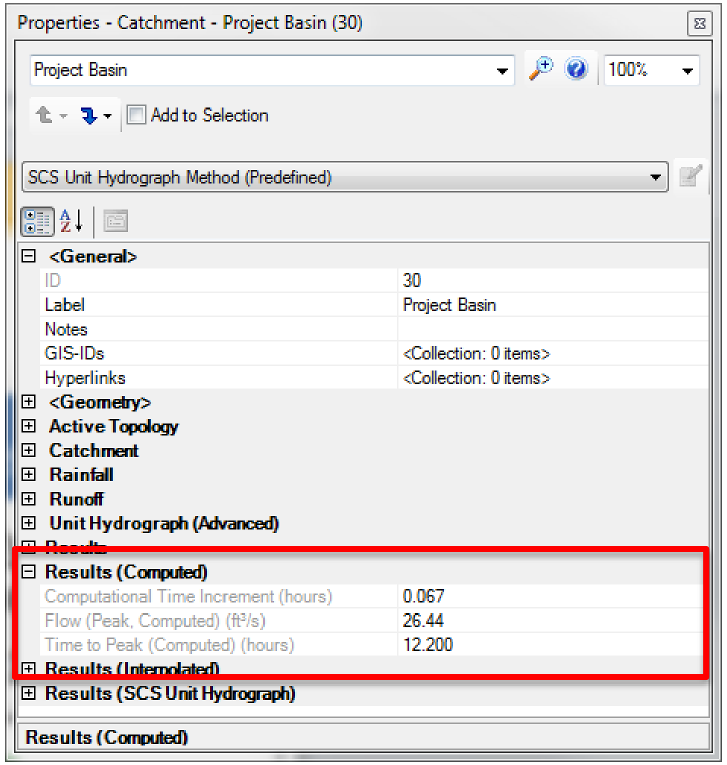
5 Maintain pre-development peak flows (Q_{P25})

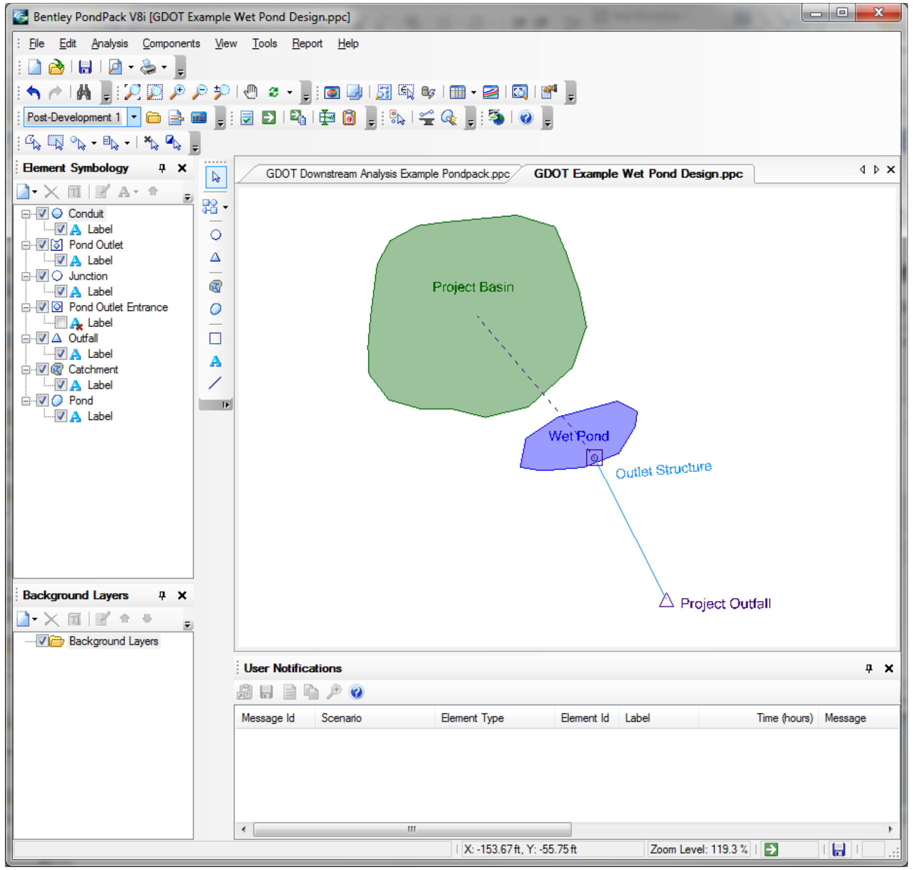
Calculate Storage Volume Required using NRCS Method

Post-Project Conditions

Roadway Impervious Area Added

CN = 70
Tc = 25 min





Steps to Design Wet Detention Pond

5 Maintain pre-development peak flows (Q_{P25})

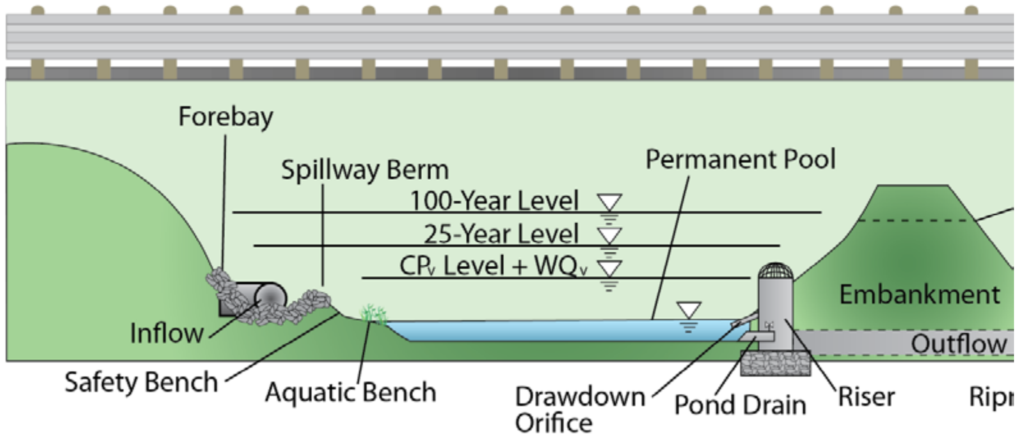
Comparison of peak flows calculated with software:

Scenario	Peak Flow (cfs)		
	1-yr	25-yr	100-yr
Pre-development	2.47	13.95	21.34
Post-development	8.61	29.52	41.62
Difference	6.14	15.57	16.11
Percent Increase	248%	112%	95%

Wet Detention Pond Design

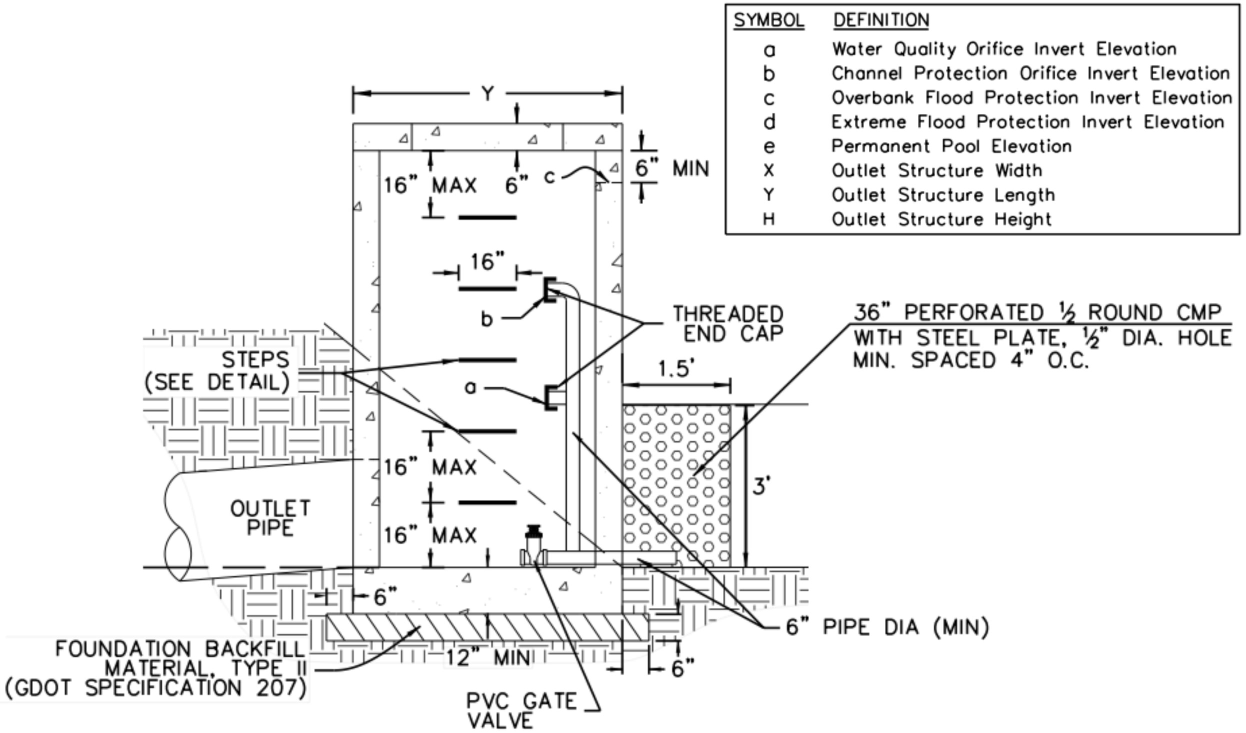
<u>Estimate dimensions of wet detention basin:</u>

- Use software OR manual calculation
- Dimensions will need adjustment to include:
  - Permanent Pool
  - Safety bench
  - Aquatic Bench



Wet Detention Pond Design

- Design emergency spillway to provide safe passage of the 100-yr, 24-hr event

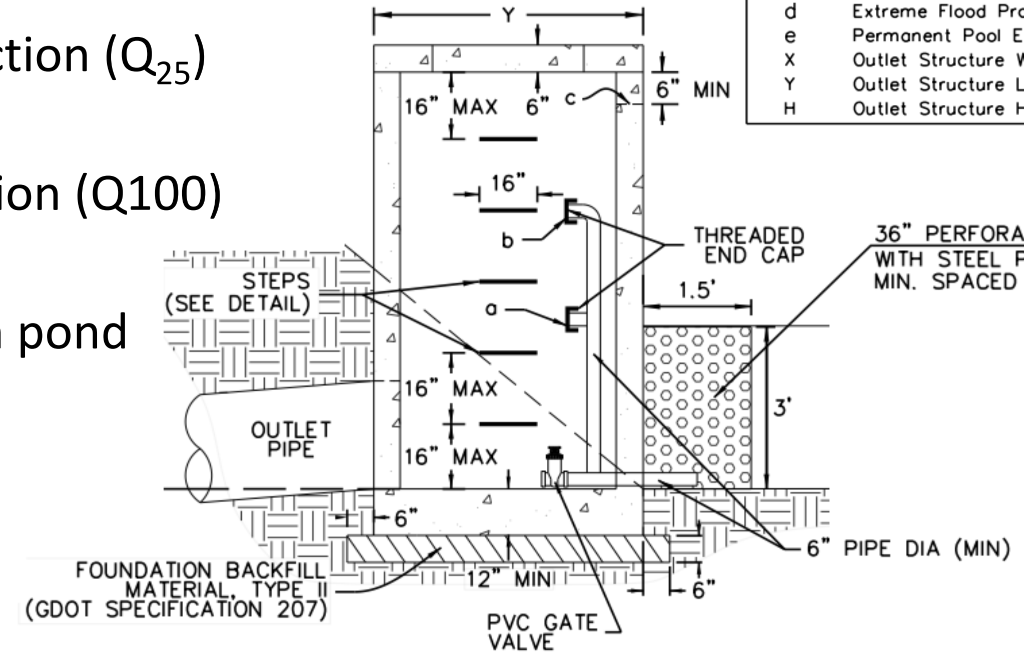


Detailed Wet Pond Design

Outlet Structure Configuration

Configure Outlet Structure According to Calculations:

- Outlet pipe
- Water Quality Orifice
- Channel Protection Orifice
- Overbank Flood Protection (Q_{25}) Weir/Orifice
- Extreme Flood Protection (Q100) Weir/Orifice
- Emergency Spillway (in pond embankment)



SYMBOL	DEFINITION
a	Water Quality Orifice Invert Elevation
b	Channel Protection Orifice Invert Elevation
c	Overbank Flood Protection Invert Elevation
d	Extreme Flood Protection Invert Elevation
e	Permanent Pool Elevation
X	Outlet Structure Width
Y	Outlet Structure Length
H	Outlet Structure Height

Detailed Wet Pond Design

Pond Design

Routed pond outflows must maintain or be less than the 25-year pre-developed peak flow rate

1-Yr 2-Yr 3-Yr 5-Yr 10-Yr 25-Yr 50-Yr 100-Yr

Hyd. No.	Hydrograph type	Peak flow	Time interval	Time of conc. Tc	Time to peak	Volume	Inflow hyd(s)	Maximum Elevation	Maximum Storage	Hydrograph description
	(origin)	(cfs)	(min)	(min)	(min)	(cuft)		(ft)	(cuft)	
1	SCS Runoff	13.95	2	45.00	742.00	79,530				Pre-dev
2	SCS Runoff	29.52	2	25.00	728.00	109,255				Post-dev
3										
4	Reservoir	13.88	2		746.00	107,790	2	105.73	41,826	Routed Pond

Detailed Wet Pond Design

Pond Design

Must provide 1' (minimum) of freeboard for 100-yr event:

- 100-yr pond elevation = 106.24 + 1.00 (freeboard)

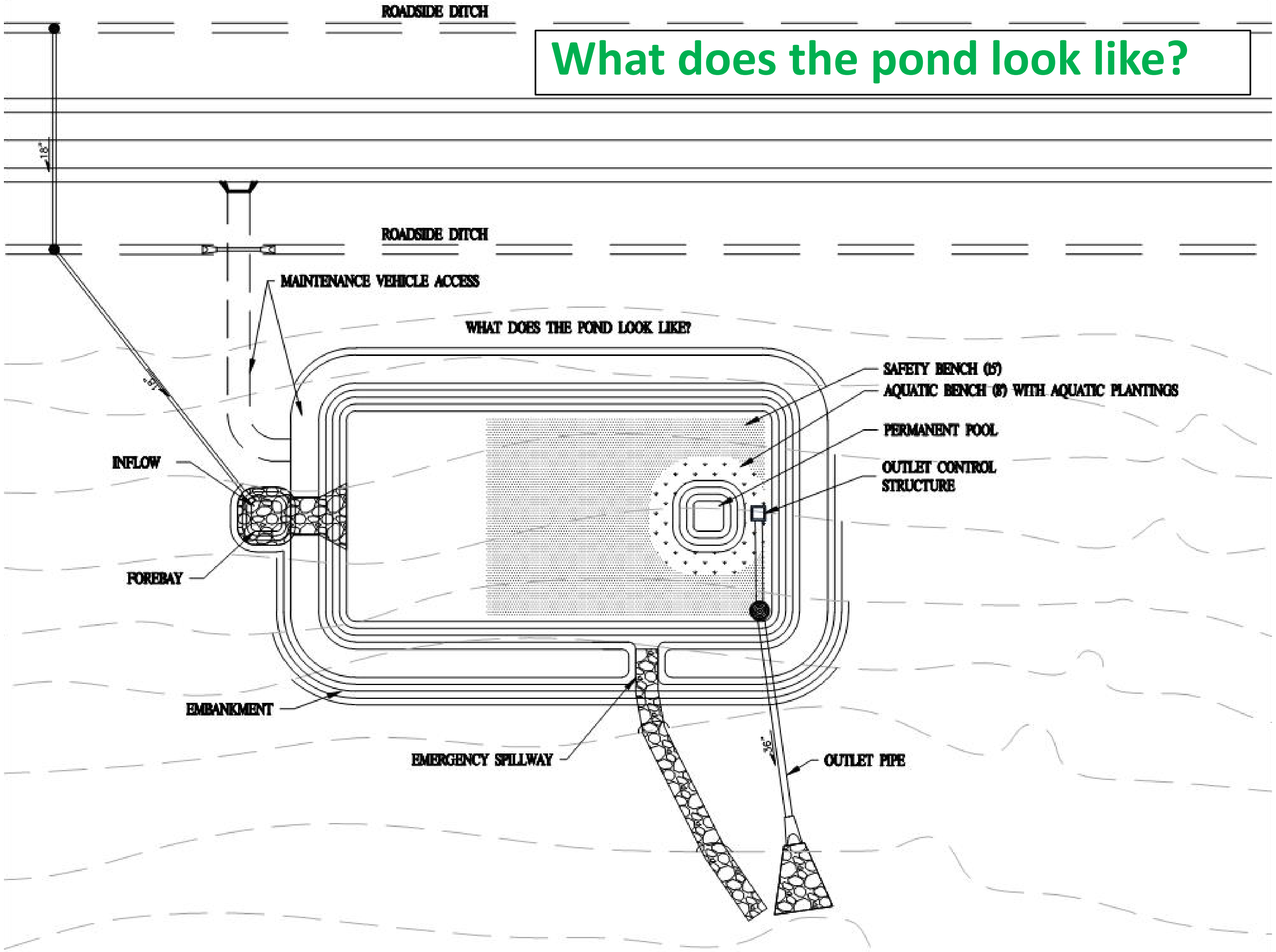
  = 107.24

- **Set top of pond embankment at 108.00 for constructability**

1-Yr 2-Yr 3-Yr 5-Yr 10-Yr 25-Yr 50-Yr 100-Yr

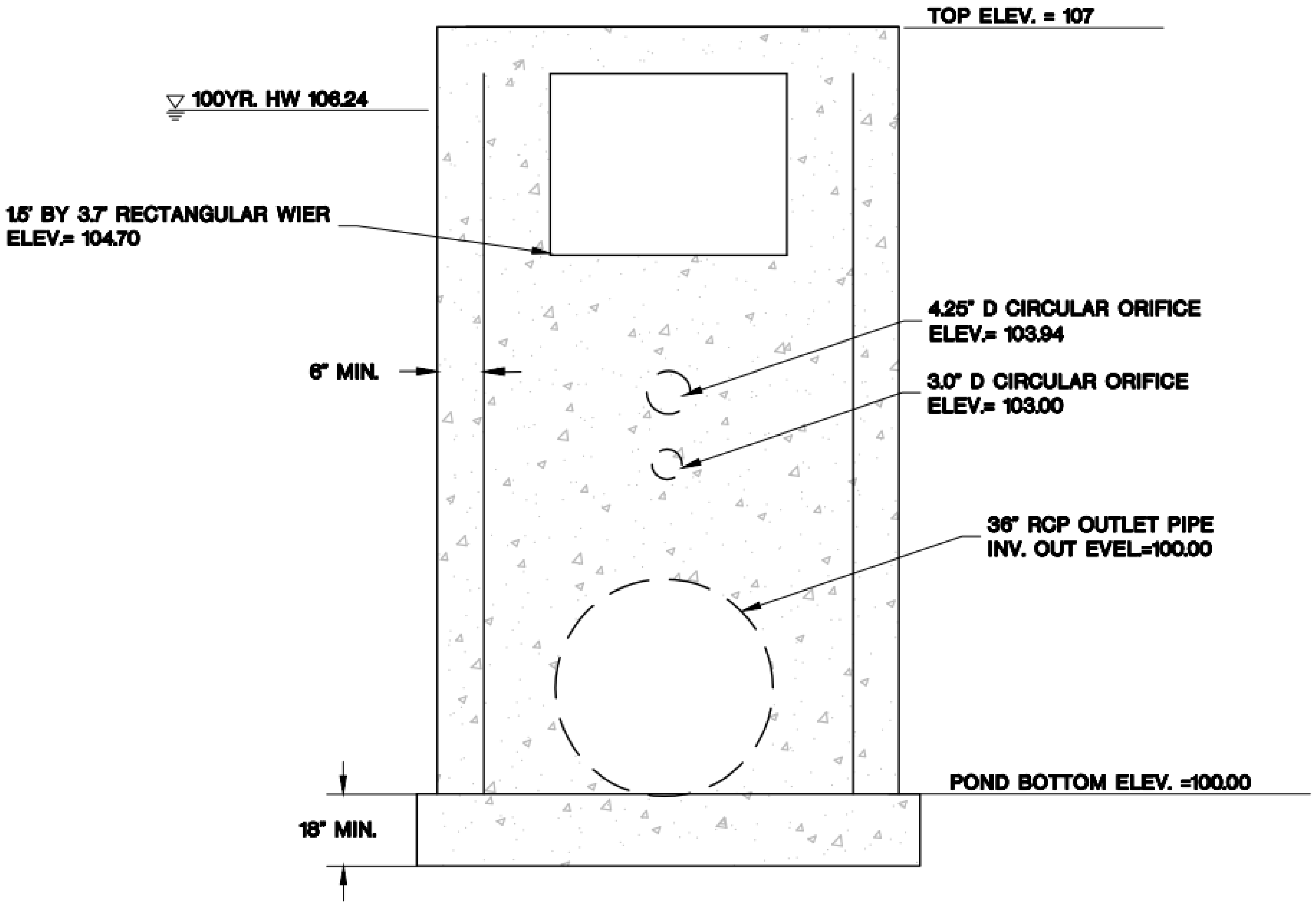
Hyd. No.	Hydrograph type	Peak flow	Time interval	Time of conc. Tc	Time to peak	Volume	Inflow hyd(s)	Maximum Elevation	Maximum Storage	Hydrograph description
	(origin)	(cfs)	(min)	(min)	(min)	(cuft)		(ft)	(cuft)	
1	SCS Runoff	21.34	2	45.00	742.00	117,591				Pre-dev
2	SCS Runoff	41.62	2	25.00	728.00	152,874				Post-dev
3										
4	Reservoir	24.84	2		742.00	151,409	2	106.24	52,126	Routed Pond

Detailed Wet Pond Design



Detailed Wet Pond Design

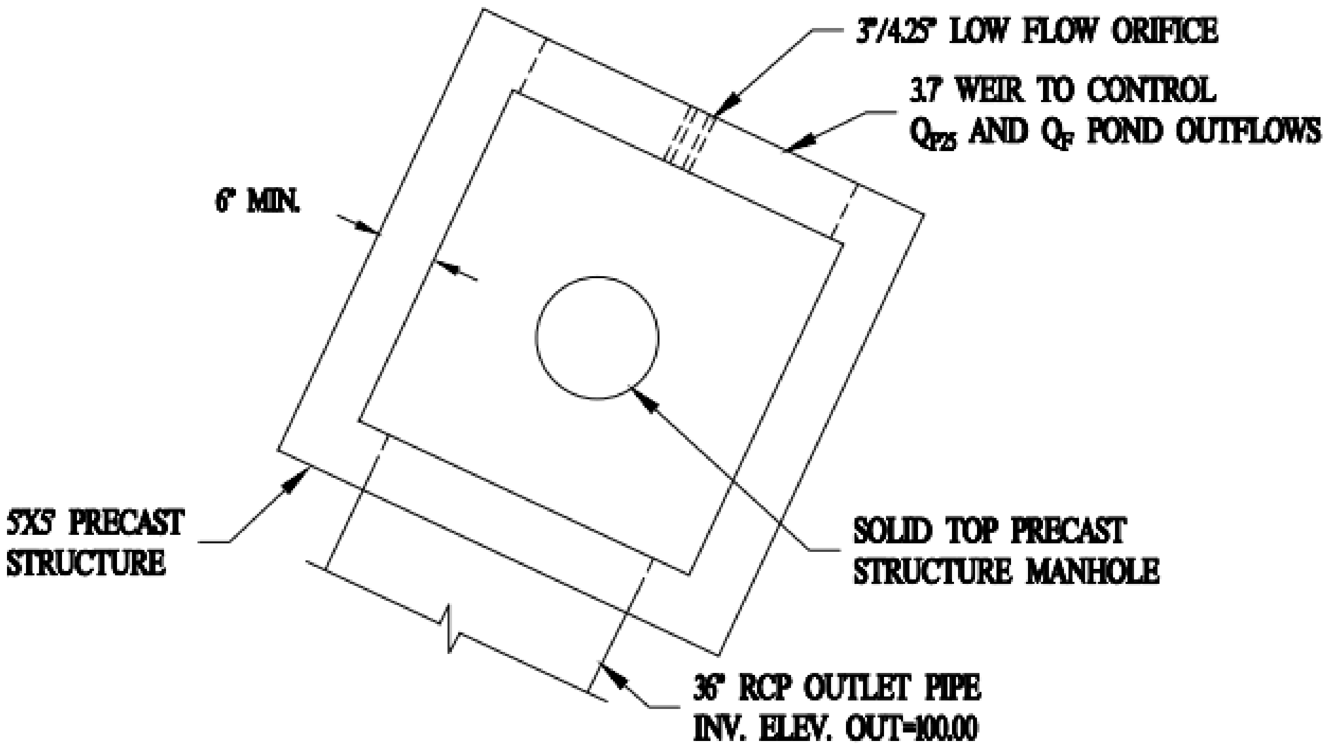
What does the OCS look like?



OUTLET CONTROL STRUCTURE
N.T.S

Detailed Wet Pond Design

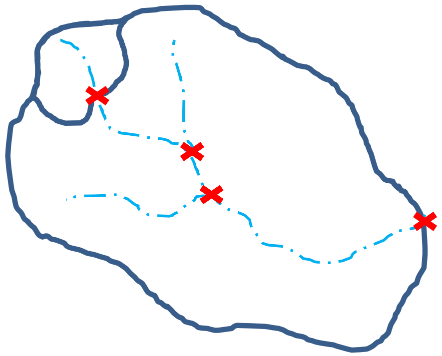
What does the OCS look like?



PLAN
N.T.S

Design Example - Other Considerations

- Finally, perform cost analysis $$$
  - May be infeasible due to cost
- Perform a downstream analysis
  - Remember detention is required if downstream analysis shows adverse impacts due to increased flows, even if it is determined infeasible based on MS4 infeasibility criteria
- Other considerations:
  - OCS buoyancy calculation
  - Construction detailing
  - Construction notes
  - Special provisions



Questions

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