New York City Stormwater Manual

Appendix G
DETENTION IN SERIES WORKBOOK AND EXAMPLES

NYC Environmental Protection

Detention in Series Example

A site in Queens consists of a multistory office building and a parking lot for its tenants. The site was proposed to connect to a 15 in. combined sewer. The building owner intends to use a blue roof and detention tank in series to meet the stormwater management requirement. The total roof area will be used for detention. Design a blue roof and a downstream detention system that treats runoff from the roof and the parking lot, given the following:

Total Contributing Area = 40,000 sf
Roof (sloped 1/8 in per ft) = 20,000 sf @ 0.95 runoff coefficient.
Paved = 20,000 sf @ 0.85 runoff coefficient

Use the Detention In Series Workbook provided in Appendix I.

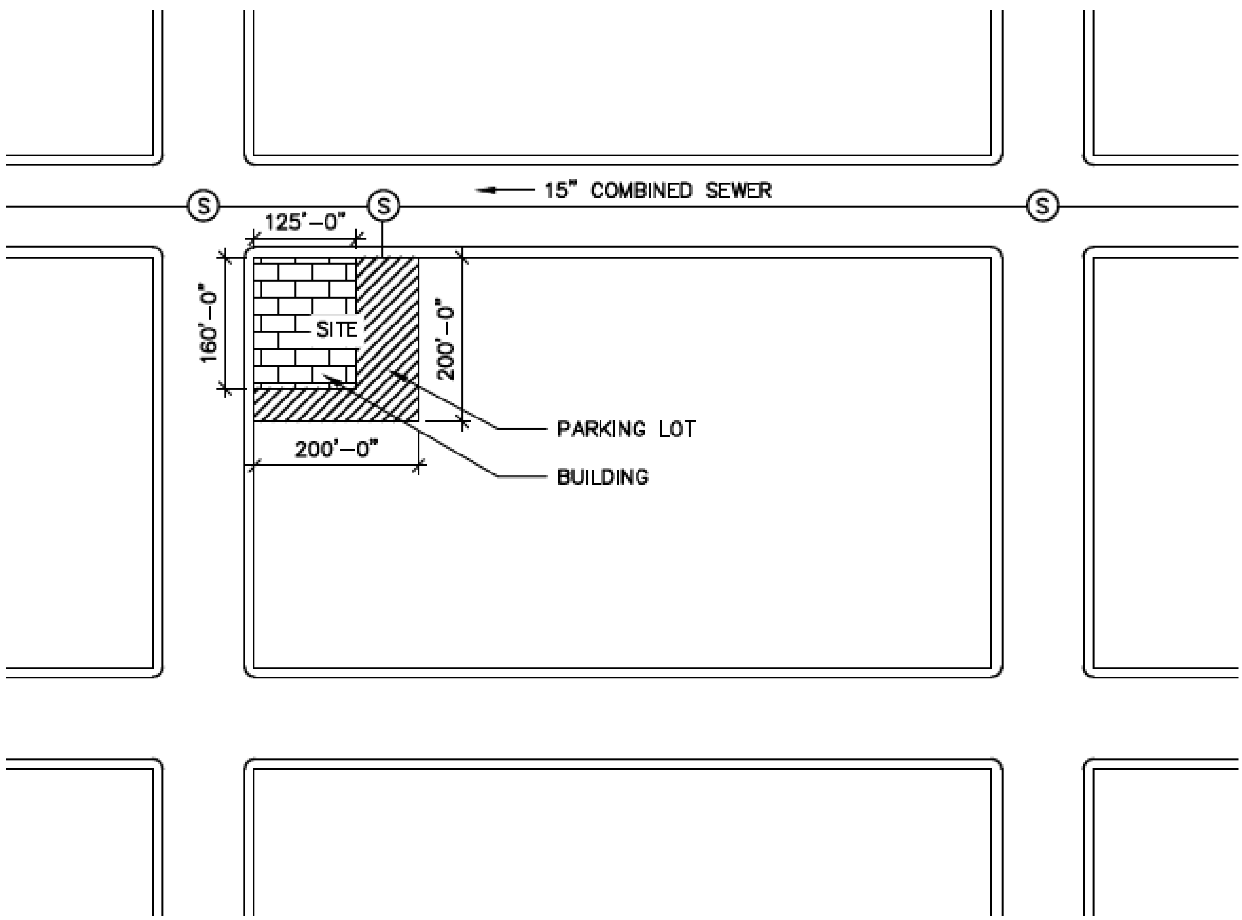

Figure I.1. Schematic of Example 1 (Not to Scale)

Step 1: Input the properties of the blue roof that will drain into the downstream detention system.

The first upstream area that drains to the downstream detention system is the 20,000 sf blue roof.

UPSTREAM SYSTEM

INPUTS					OUTPUTS	
TDA ID	TDA Area	C-value	Detention System Type	Maximum Release Rate	Required Detention Volume	Effective C-value
name	sf	#	name	cfs	cf	#
1	20000	0.95	Blue Roof			

Figure I.2. Inputs for the Blue Roof Properties

Step 2: Design the maximum release rate to be maintained by the blue roof.

Identify a controlled-flow roof drain by an approved manufacturer. In this case, the designer has selected a controlled-flow roof drain that restricts flow to 10 gpm/in.

The roof has an area of 20,000 sf. According to the 2014 Plumbing Code by the NYC Department of Buildings, not less than four roof drains shall be installed in roofs over 10,000 sf in area. In this case, the designer has chosen to install four roof drains.

Ponding depths should not exceed 4 inches above the low point (or as specified in the current Construction Codes). The designer has chosen to use a ponding depth of 2 inches.

$$Q_{ROOF} = \frac{Q_i N_{RD} d_{max}}{449}$$

where:

Q_{ROOF} = maximum release rate from rooftop detention (cfs)

Q_i = maximum release rate from each drain (gpm/in) = 10 gpm/in

N_{RD} = number of roof drains = 4

d_R = the roof drain depth of flow (in) = 2 in

$$Q_{ROOF} = \frac{10\frac{gpm}{in} * 4 * 2\ in}{449}$$

$$Q_{ROOF} = 0.18\ cfs$$

The blue roof can maintain a maximum release rate of approximately 0.2 cfs. Input this maximum release rate into the workbook.

UPSTREAM SYSTEM

INPUTS					OUTPUTS	
TDA ID	TDA Area	C-value	Detention System Type	Maximum Release Rate	Required Detention Volume	Effective C-value
name	sf	#	name	cfs	cf	#
1	20000	0.95	Blue Roof	0.2		

Figure I.3. Input for the Maximum Release Rate Maintained by the Blue Roof

Step 3: Based on the inputs from Steps 1 and 2, the workbook will automatically calculate the duration of a storm (min) with a 10-year return frequency. This calculation is shown below.

The total roof area will be used for detention. Therefore, the available area is the entire 20,000 sf.

$$t_V = 0.27(\frac{C_{WT}A_t}{Q_{DRR}})^{0.5} - 15$$

where:

t_V = the duration of the storm with a 10 yr. return frequency requiring the maximum detention volume with a variable outflow (min)

C_{WT} = the weighted runoff coefficient for the contributing area = 0.95

A_t = contributing area (sf) = 20,000 sf

Q_{DRR} = maximum release rate for the site (cfs) = 0.2 cfs

$$t_V = 0.27(\frac{0.95 * 20{,}000\ sf}{0.2\ cfs})^{0.5} - 15$$

$$t_V = 68.2\ min$$

Step 4: Based on the inputs from Steps 1 and 2, the workbook will automatically calculate the required detention volume through the blue roof. This calculation is shown below.

$$V_V = (\frac{0.19C_{WT}A_t}{t_V + 15} - 40Q_{DRR})t_V$$

where:

V_v = the maximum required detention volume (cf)

C_{WT} = the weighted runoff coefficient for the contributing area = 0.95

A_t = contributing area (sf) = 20,000 sf

t_V = the duration of the storm with a 10 yr. return frequency requiring the maximum detention volume with a variable outflow (min) = 68.2 min

Q_{DRR} = maximum release rate for the site (cfs) = 0.2 cfs

$$V_V = [\frac{0.19 * 0.95 * 20{,}000\ sf}{68.2\ min + 15} - (40 * 0.2\ cfs)](68.2\ min)$$

$$V_V = 2{,}414\ cf$$

UPSTREAM SYSTEM

INPUTS					OUTPUTS	
TDA ID	TDA Area	C-value	Detention System Type	Maximum Release Rate	Required Detention Volume	Effective C-value
name	sf	#	name	cfs	cf	#
1	20000	0.95	Blue Roof	0.2	2414	

Figure I.4. Output for the Required Detention Volume Through the Blue Roof

Step 5: Check that the available storage volume of the roof is greater than the required detention volume.

The total roof area will be used for detention. Therefore, the available area is the entire 20,000 sf.

The designer has considered two different roof configurations: 1) a uni-directionally sloped roof, as shown in Figure I.5 and 2) a multi-directionally sloped roof, as shown in Figure I.6.

Uni-directionally Sloped Roof:

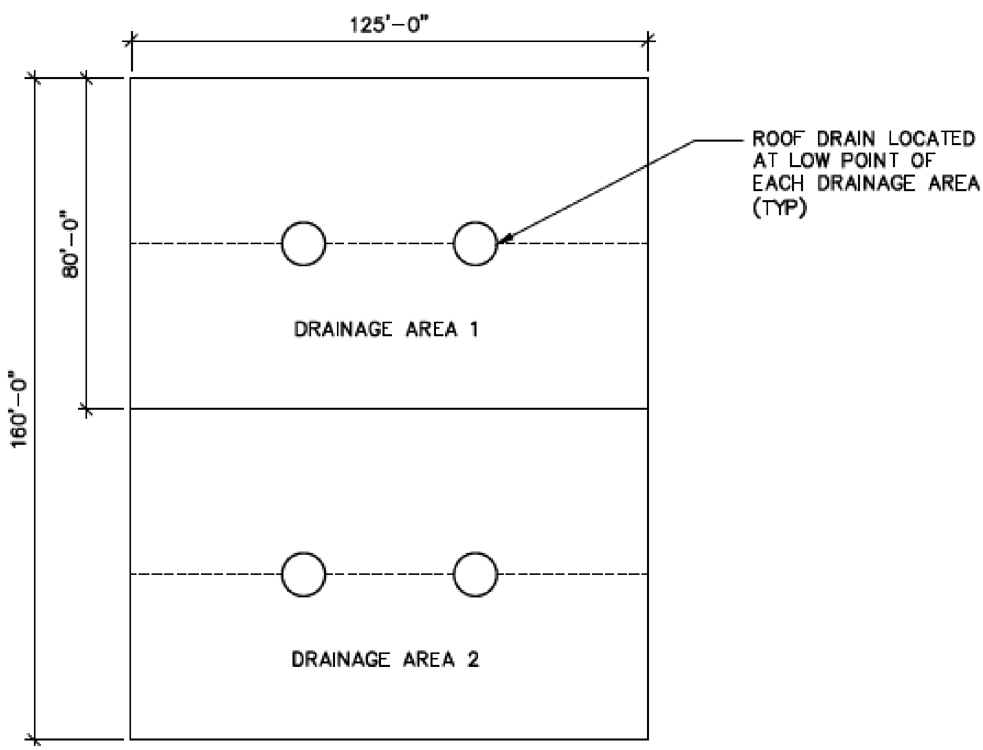

Figure I.5. Plan View of Uni-Directionally Sloped Blue Roof

The lengths and widths of each drainage area are as follows:

Drainage Area 1: 125'L x 80'W
Drainage Area 2: 125'L x 80'W

If the roof is sloped 1/8 in per ft, the height difference between the high and low points of each drainage area is 5 inches. The ponding depth is 2 inches. Therefore, the high point of each drainage area will not be inundated.

Calculate the available storage volume of each drainage area, using the volume of a triangular prism.

$$V_A = \frac{1}{2} LW * \frac{d_R}{12}$$

where:

V_A = the available storage volume of each drainage area (cf)

L = the length of each drainage area (ft) = 125 ft

W = the width of each drainage area (ft = 80 ft

d_R = the roof drain depth of flow (in) = 2 in

$$V_A = \frac{1}{2} * 125\ ft * 80\ ft * \frac{2\ in}{12}$$

$$V_A = 833\ cf$$

The total available storage volume is:

$$V_T = V_1 + V_2$$

where:

V_T = the total available storage volume (cf)

V_1 = the available storage volume of Drainage Area 1 (cf) = 833 cf

V_2 = the available storage volume of Drainage Area 2 (cf) = 833 cf

$$V_T = 833\ cf + 833\ cf$$

$$V_T = 1{,}666\ cf \leq V_V = 2{,}414\ cf \qquad \boldsymbol{NOT\ MET}$$

Since the required detention volume is greater than the available storage volume, select a different controlled-flow roof drain or design depth of flow and re-run Steps 2-4.

In this case, the designer has chosen 3 inches as the new design depth of flow. The new ponding depth results in a maximum release rate of 0.27 cfs, a required detention volume of 2,242 cf, and a total available storage volume of 2,500 cf.

Multi-directionally Sloped Roof:

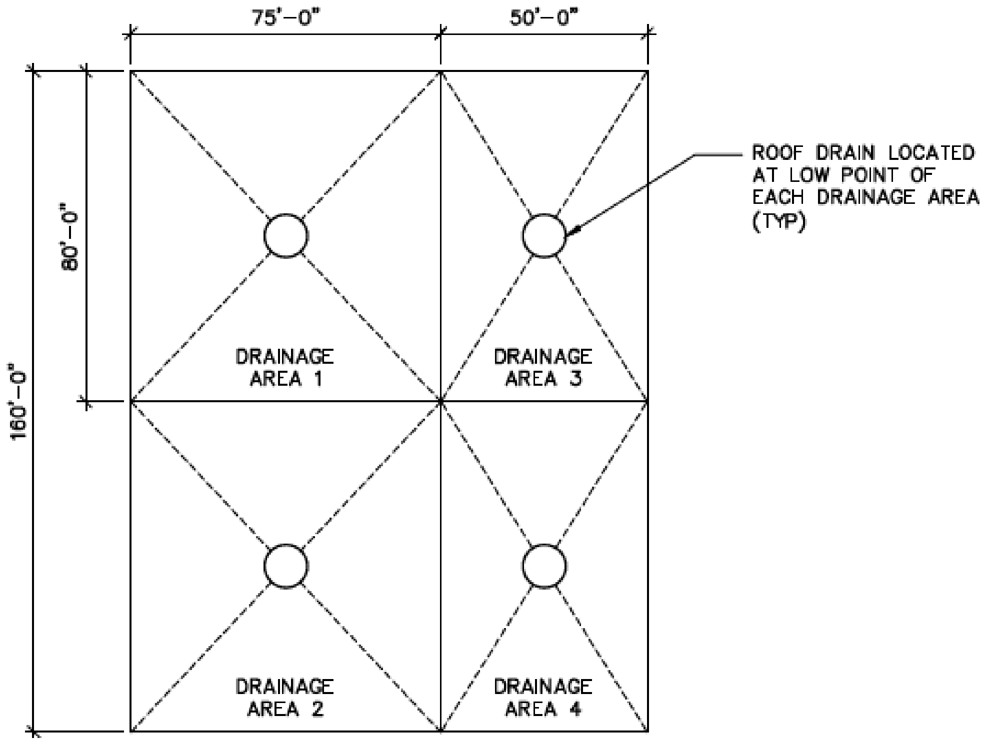

Figure I.6. Plan View of Multi-Directionally Sloped Blue Roof

The lengths and widths of each drainage area are as follows:

Drainage Area 1: 75'L x 80'W
Drainage Area 2: 75'L x 80'W
Drainage Area 3: 50'L x 80'W
Drainage Area 4: 50'L x 80'W

If the roof is sloped 1/8 in per ft, the height difference between the high and low points is 6.9 inches for drainage areas 1 and 2, and 5.9 inches for drainage areas 3 and 4. The ponding depth is 2 inches. Therefore, the high point of each drainage area will not be inundated.

Calculate the available storage volume of each drainage area, using the volume of a pyramid.

Drainage Areas 1 and 2:

$$V_A = \frac{1}{3}LW * \frac{d_R}{12}$$

where:

V_A = the available storage volume of each drainage area (cf)

L = the length of each drainage area (ft) = 75 ft

W = the width of each drainage area (ft = 80 ft

d_R = the roof drain depth of flow (in) = 2 in

$$V_A = \frac{1}{3} * 75\ ft * 80\ ft * \frac{2\ in}{12}$$

$$V_A = 333\ cf$$

Drainage Areas 3 and 4:

$$V_A = \frac{1}{3} LW * \frac{d_R}{12}$$

where:
V_A = the available storage volume of each drainage area (cf)
L = the length of each drainage area (ft) = 50 ft
W = the width of each drainage area (ft = 80 ft
d_R = the roof drain depth of flow (in) = 2 in

$$V_A = \frac{1}{3} * 50\ ft * 80\ ft * \frac{2\ in}{12}$$

$$V_A = 222\ cf$$

The total available storage volume is:

$$V_T = V_1 + V_2 + V_3 + V_4$$

where:
V_T = the total available storage volume (cf)
V_1 = the available storage volume of Drainage Area 1 (cf) = 333 cf
V_2 = the available storage volume of Drainage Area 2 (cf) = 333 cf
V_3 = the available storage volume of Drainage Area 3 (cf) = 222 cf
V_4 = the available storage volume of Drainage Area 4 (cf) = 222 cf

$$V_T = 333\ cf + 333\ cf + 222\ cf + 222\ cf$$

$$V_T = 1{,}110\ cf \leq V_V = 2{,}414\ cf \qquad \boldsymbol{NOT\ MET}$$

Since the required detention volume is greater than the available storage volume, select a different controlled-flow roof drain or design depth of flow and re-run Steps 2-4.

In this case, the designer has chosen 3 inches as the new design depth of flow. The new ponding depth results in a maximum release rate of 0.27 cfs, a required detention volume of 2,242 cf, and a total available storage volume of 1,666 cf.

A uni-directionally sloped roof provides sufficient storage volume for a ponding depth of 3 inches. The multi-directionally sloped roof does not provide enough storage volume for the same depth. Therefore, the designer has chosen to use a uni-directionally sloped roof, with a ponding depth of 3 inches.

The inputs have been updated, and the workbook automatically outputs the new required detention volume of 2,242 cf.

UPSTREAM SYSTEM

INPUTS					OUTPUTS	
TDA ID	TDA Area	C-value	Detention System Type	Maximum Release Rate	Required Detention Volume	Effective C-value
name	sf	#	name	cfs	cf	#
1	20000	0.95	Blue Roof	0.27	2242	

Figure I.7. Inputs and Output for the Required Detention Volume Through the Blue Roof, Using a Ponding Depth of 3"

Step 6: Based on the inputs from Steps 1 and 2, the workbook will automatically calculate the effective weighted runoff coefficient for the blue roof. This calculation is shown below.

$$C_{WE} = \frac{311 Q_{DRR}(t_V + 15)}{A_t}$$

where:

C_{WE} = the effective weighted runoff coefficient for the roof with runoff restricted by controlled-flow roof drains

Q_{DRR} = maximum release rate for the site (cfs) = 0.27 cfs

t_V = the duration of the storm with a 10 yr. return frequency requiring the maximum detention volume with a variable outflow (min) = 56.6 min

A_t = contributing area (sf) = 20,000 sf

$$C_{WE} = \frac{311 * 0.27\, cfs * (56.6\, min + 15)}{20{,}000\, sf}$$

$$C_{WE} = 0.301$$

UPSTREAM SYSTEM

INPUTS					OUTPUTS	
TDA ID	TDA Area	C-value	Detention System Type	Maximum Release Rate	Required Detention Volume	Effective C-value
name	sf	#	name	cfs	cf	#
1	20000	0.95	Blue Roof	0.27	2242	0.301

Figure I.8. Output for the Effective C-Value of the Blue Roof

Step 7: Input the properties of the parking lot that will drain into the downstream detention system.

The second upstream area that drains to the downstream detention system is the 20,000 sf parking lot. Since there is no detention system specifically for the parking lot, the effective weighted runoff coefficient remains as 0.85. The workbook will automatically output this value.

UPSTREAM SYSTEM

INPUTS					OUTPUTS	
TDA ID	TDA Area	C-value	Detention System Type	Maximum Release Rate	Required Detention Volume	Effective C-value
name	sf	#	name	cfs	cf	#
1	20000	0.95	Blue Roof	0.27	2242	0.301
2	20000	0.85	None			0.850

Figure I.9. Inputs and Output for the Parking Lot

Step 8: Calculate the release rate to be maintained by the controlled-flow orifice for the downstream detention system. Use the maximum release rate per acre (q) shown in Table 2.9, Chapter 2.

Since the project is 20,000 sf or more, and consists of a multistory office building, this project requires a site connection permit (SCP). In addition, the site is connecting to a 15 in. combined sewer.

Table 2.9. Maximum release rate per acre (cfs/acre) by sewershed type.

q (cfs/acre)	Description
1.0	MS4 areas
0.1	CSS areas

According to Table 2.9, $q = 0.1 \frac{cfs}{acre}$.

$$Q_{DRR} = \frac{q * A}{43560} \text{ or } 0.046 \ [\text{whichever is greater}]$$

where:

Q_{DRR} = maximum release rate for the site (cfs)

q = maximum release rate per acre (cfs/acre) = 0.1 cfs/acre

A = contributing area (sf) = 40,000 sf

$$Q_{DRR} = \frac{0.1 \frac{cfs}{acre} * 40{,}000 \ sf}{43560} \text{ or } 0.046 \ [\text{whichever is greater}]$$

$$Q_{DRR} = 0.092 \ cfs > 0.046 \ cfs$$

The maximum release rate is 0.092 cfs.

Step 9: Input the properties of the downstream detention system. Use the maximum release rate from Step 8.

Since the project is 20,000 sf or more, and consists of a multistory office building, this project requires a site connection permit (SCP). The site has a total contributing area of 40,000 sf.

DOWNSTREAM SYSTEM

INPUTS			OUTPUTS	
Permit Type	Total Contributing Area	Maximum Release Rate	Required Detention Volume	Effective C-value
name	sf	cfs	cf	#
CSS - SCP	40000	0.092		

Figure I.10. Inputs for the Downstream Detention System

Step 10: Based on the inputs from Step 9, the workbook will automatically calculate the effective weighted runoff coefficient for the downstream detention system. This calculation is shown below.

$$C_W = \frac{(C_1A_1 + C_2A_2 + \cdots etc.)}{A_t}$$

where:

C_W = weighted runoff coefficient relating peak rate of rainfall and runoff

C_1 = the effective weighted runoff coefficient for the area classified as roof = 0.30

A_1 = the area classified as roof (sf) = 20,000 sf

C_2 = the effective weighted runoff coefficient for the area classified as paved = 0.85

A_2 = the area classified as paved (sf) = 20,000 sf

A_t = contributing area (sf) = 40,000 sf

$$C_W = \frac{(0.30 * 20{,}000\ sf) + (0.85 * 20{,}000\ sf)}{40{,}000\ sf}$$

$$C_W = 0.575$$

DOWNSTREAM SYSTEM

INPUTS			OUTPUTS	
Permit Type	Total Contributing Area	Maximum Release Rate	Required Detention Volume	Effective C-value
name	sf	cfs	cf	#
CSS - SCP	40000	0.092		0.575

Figure I.11. Output for the Effective C-Value of the Downstream Detention System

Step 11: Identify the rainfall depth (R_D) based on the sewershed type and connection proposal type for the project. Use Table 2.7 in Chapter 2.

Since the project is 20,000 sf or more, and consists of a multistory office building, this project requires a site connection permit (SCP). In addition, the site is connecting to a 15 in. combined sewer.

Table 2.7. Applied rainfall depth by sewershed type and connection proposal type.

R_D	Description
1.85	CSS areas with SCP
1.50	CSS areas with HCP
1.50	MS4 areas wiith SCP
1.10	MS4 areas with HCP

According to Table 2.7, $R_D = 1.85\ in.$

Step 12: Based on the inputs from Step 9, the workbook will automatically calculate the required detention volume through the detention tank. This calculation is shown below.

$$V_V = \frac{R_D}{12} * A * C_W$$

where:

V_V = the maximum required detention volume (or sewer operations volume) (cf)

R_D = rainfall depth (in) = 1.85 in

A = contributing area (sf) = 40,000 sf

C_W = weighted runoff coefficient relating peak rate of rainfall and runoff = 0.575

$$V_V = \frac{1.85\ in}{12} * 40{,}000\ sf * 0.575$$

$$V_V = 3{,}548\ cf$$

DOWNSTREAM SYSTEM

INPUTS			OUTPUTS	
Permit Type	Total Contributing Area	Maximum Release Rate	Required Detention Volume	Effective C-value
name	sf	cfs	cf	#
CSS - SCP	40000	0.092	3548	0.575

Figure I.12. Output for the Required Detention Volume Through the Downstream Detention System

Step 13: Use the controlled-flow orifice equation to determine an appropriate orifice area for the detention tank, by assuming the active storage depth.

In order to minimize the area required for the detention tank, choose the maximum depth that is still feasible according to site limitations and use a re-entrant orifice. In this case, the designer has chosen an active storage depth of 4 ft.

$$Q_O = C_D * A_o * \sqrt{2gH}$$

where:

Q_O = maximum release rate of orifice (cfs) = 0.092 cfs

C_D = coefficient of discharge, 0.52 for re-entrant orifice

A_O = area of orifice (sf)

g = acceleration due to gravity, 32.2 (ft/s^2)

H = maximum hydraulic head above the centerline of the orifice (ft) = 4 ft

$$0.092\ cfs = 0.52 * A_o * \sqrt{2 * 32.2\left(\frac{ft}{s^2}\right) * 4\ ft}$$

$$A_o = 0.011\ sf$$

Step 14: Translate the area of the controlled-flow orifice (A_O) into a diameter and check that it is greater than the minimum diameter of 1 in.

$$A_o = \frac{\left[\pi * \left(\frac{D_o}{2}\right)^2\right]}{144}$$

where:

A_O = area of orifice (sf) = 0.011 sf

D_O = diameter of orifice (in)

$$0.011\ sf = \frac{\left[\pi * \left(\frac{D_O}{2}\right)^2\right]}{144}$$

$$D_O = 1.42\ in > 1\ in \qquad OK$$

Set the orifice diameter to the nearest 0.25-inch interval rounding down, with a minimum orifice diameter of one-inch. In this case, use an orifice diameter of 1.25 inches.

Step 15: Confirm the orifice area of the selected orifice diameter from Step 14.

$$A_o = \frac{\left[\pi * \left(\frac{D_o}{2}\right)^2\right]}{144}$$

where:

A_O = area of orifice (sf)

D_O = diameter of orifice (in) = 1.25 inches

$$A_O = \frac{\left[\pi * \left(\frac{1.25\ in}{2}\right)^2\right]}{144}$$

$$A_O = 0.009\ sf$$

Step 16: Confirm the required active storage depth in the tank using the orifice area from Step 15.

$$Q_O = C_D * A_o * \sqrt{2gH}$$

where:

Q_O = maximum release rate of orifice (cfs) = 0.092 cfs

C_D = coefficient of discharge, 0.52 for re-entrant orifice

A_O = area of orifice (sf) = 0.009 sf

g = acceleration due to gravity, 32.2 (ft/s^2)

H = maximum hydraulic head above the centerline of the orifice (ft)

$$0.092\ cfs = 0.52 * 0.009\ sf * \sqrt{2 * 32.2\ \left(\frac{ft}{s^2}\right) * H}$$

$$H = 6.0\ ft$$

If the active storage depth is too high, then increase the orifice size by 0.25 inches and re-run Steps 13-14 until a suitable depth is identified. If the active storage depth is too low, then decrease the orifice size by 0.25 inches (but not less than 1 inch) and re-run Steps 13-14. Alternatively, the designer can choose a different orifice configuration as needed to modify the active storage depth.

In this case, the depth is too high to drain via gravity connection to the storm sewer. Using a flush orifice, which has a coefficient of discharge of 0.61, results in an active storage depth of 4.4 ft.

Step 17: Set the dimensions of the detention tank's active storage zone.

Based on the active storage depth of 4.4 ft and the V_V of 3,548 cf, set the interior detention tank dimensions to L: 28.5 ft and W: 28.5 ft. The resulting detention tank has an active storage volume of 3,574 cf. Note that the exterior dimensions of the detention tank will be larger than the dimensions of the active storage zone (28.5'L x 28.5'W x 4.4'D) to accommodate wall thickness, bypass structures, and/or other internal features.