
APPENDIX D BMP DESIGN EXAMPLES

| | |
|---|------|
| Bioretention Worksheet..... | D-2 |
| Bioretention Design Example..... | D-4 |
| Vegetated Swale Filter Worksheet..... | D-7 |
| Vegetated Swale Filter Design Example..... | D-12 |
| Vegetated Filter Strip Worksheet | D-16 |
| Vegetated Filter Strip Design Example..... | D-18 |
| Sand Filter Worksheet | D-20 |
| Sand Filter Design Example..... | D-23 |
| Infiltration BMP Worksheet..... | D-27 |
| Infiltration BMP Design Example..... | D-29 |
| Permeable Pavement Worksheet..... | D-32 |
| Permeable Pavement Design Example..... | D-35 |
| Constructed Treatment Wetland Worksheet..... | D-38 |
| Constructed Treatment Wetland Design Example..... | D-43 |
| Wet Retention Basin Worksheet..... | D-48 |
| Wet Retention Basin Design Example..... | D-52 |
| Dry Extended Detention Basin Worksheet..... | D-57 |
| Dry Extended Detention Basin Design Example.... | D-60 |

Bioretention Worksheet

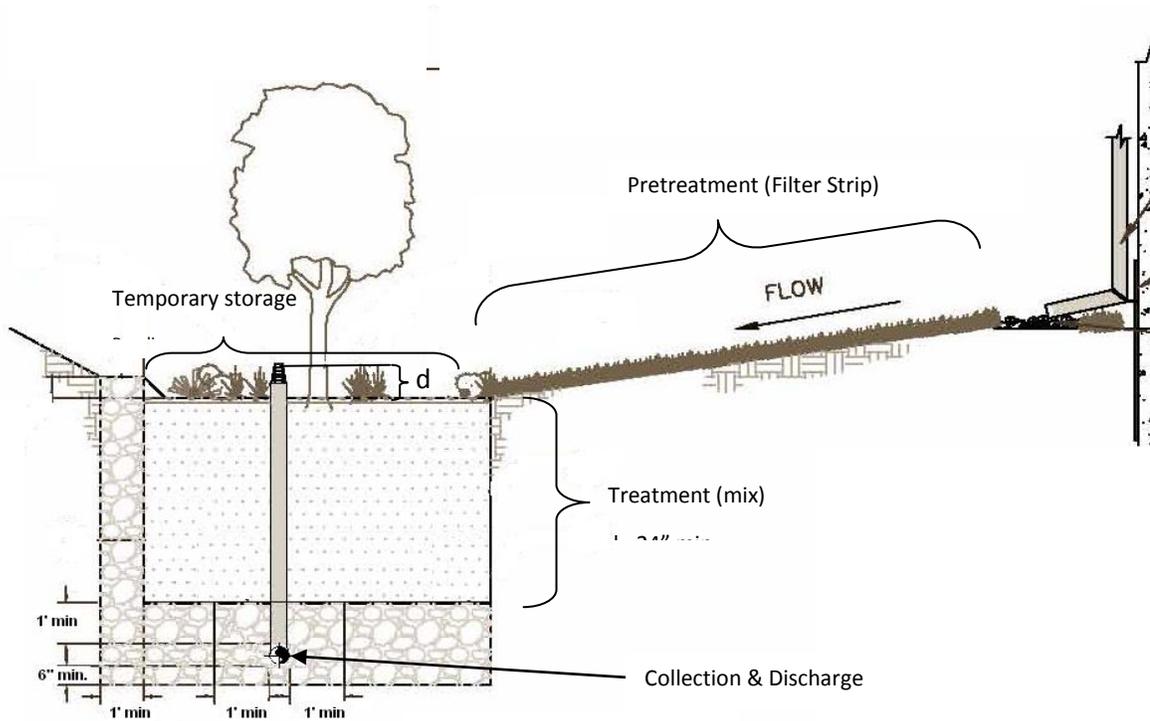


Figure D-1: Bioretention Area Cross-Section

Refer to Figure D-1 and Figure 6-2 for the description of the geometric variables.

| Step 1: Determine design volume reduction, $V_{\text{reduction}}$ | |
|--|--|
| 1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25} , calculated using SBUH method, Appendix C | $V_{25} =$ _____ ft^3 |
| 1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{\text{one-inch}}$, calculated using SBUH method, Appendix C | $V_{\text{one-inch}} =$ _____ ft^3 |
| 1-3. Determine design volume reduction which is the larger of V_{25} and $V_{\text{one-inch}}$ and is the volume to be retained on-site | $V_{\text{reduction}} =$ _____ ft^3 |
| Step 2: Determine storm water quality design volume, V_{wq} | |
| 2-1. Determine the water quality design volume, V_{wq} , using SBUH method, Appendix C (<u>Note</u> : V_{wq} is always equal to $V_{\text{one-inch}}$) | $V_{\text{wq}} =$ _____ ft^3 |

| | |
|--|---|
| Step 3: Determine design volume, V_{design} (for sizing) | |
| 3-1. If underdrain system is used, $V_{\text{design}} = V_{\text{wq}}$ If there is no underdrain system, $V_{\text{design}} =$ the larger of $V_{\text{reduction}}$ and V_{wq} | $V_{\text{design}} =$ _____ ft^3 |
| Step 4: Pretreatment | |
| 4-1. If pretreatment is required please go the vegetated filter strip worksheet, Appendix C | |
| Step 5: Calculate bioretention area | |
| 5-1. Enter thickness of planting mix (min. 24"), l | $l =$ _____ in |
| 5-2. Enter storage depth (12" max.) above the filter, d | $d =$ _____ in |
| 5-3. Enter infiltration rate, k_{design} (Note: infiltration rate of planting soil. If no underdrain, infiltration rate of native subsoil or fill). If no underdrains, see Step 4 of the Infiltration BMP Worksheet, Appendix D to calculate k_{design}). | $k_{\text{design}} =$ _____ in/hr |
| 5-4. Enter drawdown time, t | $t =$ _____ hr |
| 5-5. Calculate bioretention area, $A_{\text{sf}} = (V_{\text{design}} \bullet l) / [(t \bullet k_{\text{design}} / 12) \bullet (l + d)]$ | $A_{\text{sf}} =$ _____ ft^2 |
| Step 6: Calculate underdrain system flow rate (if an underdrain is provided) | |
| 6-1. Calculate filtered flow rate to be conveyed by the longitudinal drain pipe, $Q_f = k_{\text{design}} \bullet A_{\text{sf}} / 43200$ (Note: for this example, step 6-1 is equivalent to step 5-1 of the Sand Filter Worksheet, Appendix D). | $Q_f =$ _____ cfs |
| 6-2. Please follow steps 5-2 through 5-7 of the Sand Filter Worksheet, Appendix D to calculate the underdrain system capacity. | |
| Step 7: Provide Conveyance Capacity for Flows Higher than Q_{wq} | |
| 7-1. An emergency overflow must be provided if the bioretention area is placed online or in the event the surface area becomes clogged. | |

Bioretention Design Example

Bioretention areas have several components that allow the pretreatment, spreading, filtration, collection and discharge of the incoming flows.

Step 1: Determine Storm Water Quality Design Volume Reduction, $V_{\text{reduction}}$

| Step 1: Determine design volume reduction, $V_{\text{reduction}}$ | |
|--|---|
| 1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25} , calculated using SBUH method, Appendix C | $V_{25} = \frac{20}{\quad} \text{ft}^3$ |
| 1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{\text{one-inch}}$, calculated using SBUH method, Appendix C | $V_{\text{one-inch}} = \frac{25,700}{\quad} \text{ft}^3$ |
| 1-3. Determine design volume reduction which is the larger of V_{25} and $V_{\text{one-inch}}$ and is the volume to be retained on-site | $V_{\text{reduction}} = \frac{25,700}{\quad} \text{ft}^3$ |

Step 2: Determine Storm Water Quality Design Volume, V_{wq}

| Step 2: Determine storm water quality design volume, V_{wq} | |
|--|--|
| 2-1. Determine the water quality design volume, V_{wq} , using SBUH method, Appendix C (<u>Note</u> : V_{wq} is always equal to $V_{\text{one-inch}}$) | $V_{\text{wq}} = \frac{25,700}{\quad} \text{ft}^3$ |

Step 3: Determine Design Volume, V_{design}

| Step 3: Determine design volume, V_{design} (for sizing) | |
|---|--|
| 3-1. If underdrain system is used, $V_{\text{design}} = V_{\text{wq}}$. If there is no underdrain system, $V_{\text{design}} =$ the larger of $V_{\text{reduction}}$ and V_{wq} | $V_{\text{design}} = \frac{25,700}{\quad} \text{ft}^3$ |

Step 4: Pretreatment

| Step 4: Pretreatment | |
|---|--|
| 4-1. If pretreatment is required please go the vegetated filter strip worksheet, Appendix C | |

The bioretention areas that collect runoff from residential roofs, sidewalks, driveways, or other “cleaner” surfaces do not require pretreatment. If the runoff originates from locations other than “clean” surfaces, then pretreatment is required. Please refer to Vegetated Filter Strip Worksheet (Appendix D) for detailed calculations.

Step 5: Determine bioretention area footprint area

A bioretention area is designed with two components: (1) temporary storage reservoir to store runoff, and (2) a planting soil bed (planting soil mixed with sand content = 70%) through which the stored runoff must percolate to obtain treatment.

The simple sizing method does not route flows through the planting soil which would allow a more accurate sizing of the facility. The area of the planting soil bed is determined based on the simple assumption that inflow is immediately discharged through the filter at a rate which is equivalent to drawing down the maximum 12” storage depth and the planting soil depth (min. depth 24”) over 48 hours. If the planting soil bed depth is 24”, the minimum infiltration rate would be (12” + 24”)/48 hr = 0.875 in/hr. Infiltration rates for bioretention area planting soil mixes are often in the range of 1 in/hr to 6 in/hr depending on the pollutants of concern to be targeted for removal.

| Step 5: Calculate bioretention area | |
|--|----------------------------------|
| 5-1. Enter thickness of planting mix (min. 24”), l | l = 24 in |
| 5-2. Enter storage depth (12" max.) above the filter, d | d = 12 in |
| 5-3. Enter infiltration rate, k_{design} (Note: infiltration rate of planting soil. If no underdrain, infiltration rate of native subsoil or fill). If no underdrains, see Step 4 of the Infiltration BMP Worksheet, Appendix D to calculate k_{design}). | $k_{design} = 1.5$ in/hr |
| 5-4. Enter drawdown time, t | t = 48 hr |
| 5-5. Calculate bioretention area, $A_{sf} = (V_{design} \cdot l) / [(t \cdot k_{design} / 12) \cdot (l + d)]$ | $A_{sf} = 2,856$ ft ² |

Step 6: Calculate Underdrain System

If an underdrain is required, please see the Sand Filter underdrain calculation, Appendix D. All underdrain pipes must be 6 inches or greater to facilitate cleaning.

| Step 6: Calculate underdrain system flow rate (if an underdrain is provided) | | |
|--|---------|-------------------------------------|
| 6-1. Calculate filtered flow rate to be conveyed by the longitudinal drain pipe, $Q_f = k \cdot A_{sf} / 43200$ (Note: for this example, step 6-1 is equivalent to step 5-1 of the Sand Filter Worksheet, Appendix D). | $Q_f =$ | $\frac{0.099}{\quad\quad\quad}$ cfs |
| 6-2. Please follow steps 5-2 through 5-7 of the Sand Filter Worksheet, Appendix D to calculate the underdrain system capacity. | | |

Step 7: Provide Conveyance Capacity for Flows Higher than Q_{wq}

Provide conveyance capacity for flows higher than Q_{wq} , water quality design flow rate, to bypass the bioretention area. An emergency overflow must also be provided in the event that the surface area becomes clogged or the bioretention area is placed online.

Vegetated Swale Filter Worksheet

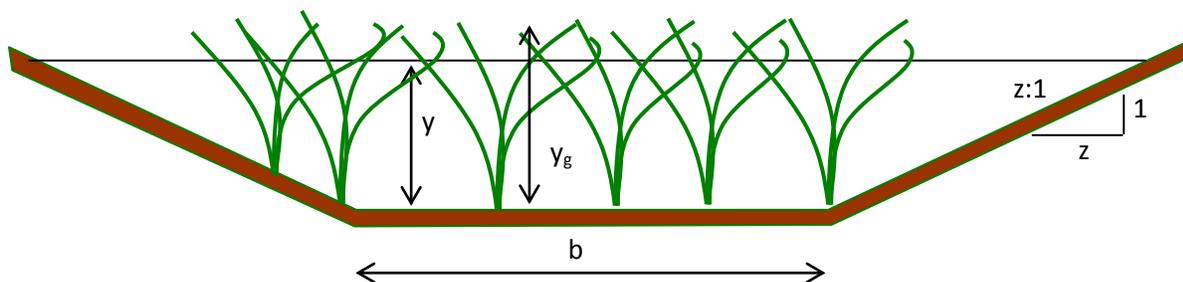


Figure D-2: Vegetated swale filter cross-section

Refer to Figure D-2, Figure 6-5, and Figure 6-6 for a diagrammatic description of the geometric variables.

| Step 1: Determine design volume reduction, $V_{\text{reduction}}$ (if applicable) | |
|--|--|
| 1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25} , calculated using SBUH method, Appendix C | $V_{25} =$ _____ ft^3 |
| 1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{\text{one-inch}}$, calculated using SBUH method, Appendix C | $V_{\text{one-inch}} =$ _____ ft^3 |
| 1-3. Determine the design volume reduction, $V_{\text{reduction}}$, which is the larger of V_{25} and $V_{\text{one-inch}}$ and is the volume to be retained on-site | $V_{\text{reduction}} =$ _____ ft^3 |
| Note: Volume reduction credit is only provided for vegetated swale filters that include a gravel drainage layer to encourage infiltration. | |
| - | |
| Step 2: Determine storm water quality design flow rate, Q_{wq} | |
| 2-1. Enter drainage area, A | A = _____ acres |
| 2-2. Enter impervious fraction, Imp | Imp = _____ |
| 2-3. Calculate runoff coefficient, $C = (0.9 \cdot \text{Imp} + 0.05)$ | C = _____ |
| 2-4. Calculate the water quality design flow rate, Q_{wq} , based on a constant rainfall intensity of 0.25 in/hr, Appendix C | $Q_{\text{wq}} =$ _____ cfs |

Step 3: Determine design volume for sizing gravel drainage layer, if applicable

3-1. $V_{\text{design}} = V_{\text{reduction}}$

$V_{\text{design}} = \underline{\hspace{2cm}} \text{ ft}^3$

3-2. Please follow Steps 3 through 5 of the Permeable Pavement Worksheet, Appendix D to calculate the size of the gravel drainage layer

| Step 4: Calculate flow depth, d, and swale bottom width, b | |
|--|---------------------------|
| 4-1. Enter Manning's roughness coefficient for shallow flow conditions (0.2 typical), n | n = _____ |
| 4-2. Enter expected vegetation height, y_v | y_v = _____ in |
| 4-3. Calculate design flow depth (0.33 ft max), $d = y_v/18$ | d = _____ ft |
| 4-4. Enter longitudinal slope (along direction of flow), s | s = _____ ft/ft |
| 4-5. Enter side slope length per unit height (e.g. 3 if side slope are 3H :1V), Z | Z = _____ |
| 4-6. Calculate bottom width of swale assuming a trapezoidal channel shape, $b = Q_{wq}n_{wq}/1.49y^{1.67}s^{0.5}$ | b = _____ ft |
| 4-7. Calculate $AR^{2/3}$, using $Q_{wq}n/1.49s^{0.5}$ (Equation 6-5) | $AR^{2/3}$ = _____ |
| 4-8. Calculate the wetted area, A | A = _____ ft ² |
| 4-9. Calculate the wetted perimeter, P | P = _____ ft |
| 4-10. Calculate the hydraulic radius, R | R = _____ ft |
| 4-11. Re-calculate $AR^{2/3}$, using the A and R calculated in steps 4-8 and 4-10. Change b until the $AR^{2/3}$ calculated in this step is equal to $AR^{2/3}$ calculated in 4-7. | $AR^{2/3}$ = _____ |
| 4-12. If b is between 2 and 10 feet, go to Step 5 | |
| 4-13. If $b < 2$ ft, set $b = 2$ ft and go to Step 4-4 and decrease swale slope (0.015 ft/ft max.). If slope cannot be changed due to site constraints, go to Step 4-14. | |
| 4-14. If $b < 2$ ft and slope is maximized, set $b = 2$ ft and go to Step 4-2 and decrease vegetation height | |
| 4-15. If b is greater than 10 ft, one of the following design adjustments must be made: 1) increase the longitudinal slope to a maximum of 0.06 ft/ft, and repeat steps 4-7 to 4-11 above. 2) include a flow splitter longitudinally along the swale bottom (Figure 6-6 and Appendix F) at least three-quarters of the swale length (beginning at the inlet) | |
| Step 5: Determine design flow velocity | |
| 5-1. Calculate design flow velocity, $v_{wq} = Q_{wq}/A$ | v_{wq} = _____ ft/s |
| 5-2. If the design flow velocity is higher than 1ft/s go to Step 4-4 and decrease the slope, if possible | |

| Step 6: Calculate swale length | | |
|--|------------|-----------------------|
| 6-1. Enter target residence time (7 minutes minimum), t_{HR} | $t_{HR} =$ | _____ min |
| 6-2. Calculate swale length, $L = v_{wq} \cdot 60 \cdot t_{HR}$ | $L =$ | _____ ft |
| 6-3. If L is too long for the site, proceed to step 5 to adjust the swale layout | | |
| Step 7: Adjust swale layout to fit within site constraints | | |
| 7-1. Choose a reduced swale length, L_f | $L_f =$ | _____ ft |
| 7-2. Recalculate flow velocity, $v_{wq} = L_f / (t_{HR} \cdot 60)$ | $v_{wq} =$ | _____ ft/s |
| 7-3. Recalculate cross-sectional area, $A_{wq} = Q_{wq} / v_{wq}$ | $A_{wq} =$ | _____ ft ² |
| 7-4. Calculate an increased bottom width, $b_f = (A_{wq} - Zy^2) / y$ | $b_f =$ | _____ ft |
| 7-5. Recalculate longitudinal slope assuming a rectangular channel shape, $s_f = [Q_{wq} n_{wq} / (1.49 A_{wq} y^{0.67})]^2$ | $s_f =$ | _____ ft/ft |
| 7-6. If s_f is between 1.5% and 6%, the swale design is acceptable for water quality, proceed to Step 6 | | |
| 7-7. If s_f is between 1% and 1.5%, the swale design is acceptable for water quality with underdrains (see design requirements). Proceed to Step 6. | | |
| 7-8. If s_f is <1%, the swale design is unacceptable. Consider subdividing drainage area and repeat all above steps, or choose a different BMP for the site. | | |

Step 8: Provide conveyance capacity for flows higher than Q_{wq}

8-1. If the swale already includes a high-flow bypass to convey flows higher than the water quality design flow rate, skip this step and verify that all parameters meet design requirements to complete sizing.

8-2. If swale does not include a high-flow bypass, check the swale size for the peak discharge rate that will be conveyed in the swale. If online, the peak discharge rate is the 100-yr, 24-hr design storm calculated using the SBUH method (See Appendix C). Calculate the peak discharge velocity, $V_{peak} = Q_{peak}/A_{swale}$, where Q_{peak} = the peak discharge rate (cfs) and A_{swale} = the cross-sectional area of the swale including freeboard (ft²)

$$V_{peak} = \underline{\hspace{2cm}} \text{ ft/s}$$

8-3. If $V_{peak} > 3.0$ feet per second, return to Step 2 and increase the bottom width or flatten the longitudinal slope as necessary to reduce the peak discharge flow velocity to 3.0 feet per second or less. If the longitudinal slope is flattened, the swale bottom width must be recalculated (Step 2) and must meet all design criteria.

Vegetated Swale Filter Design Example

Step 1: Determine Storm Water Quality Design Volume Reduction, $V_{\text{reduction}}$

| Step 1: Determine design volume reduction, $V_{\text{reduction}}$ (if applicable) | |
|--|--|
| 1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25} , calculated using SBUH method, Appendix C | $V_{25} = \underline{\quad 20 \quad} \text{ ft}^3$ |
| 1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{\text{one-inch}}$, calculated using SBUH method, Appendix C | $V_{\text{one-inch}} = \underline{\quad 25,700 \quad} \text{ ft}^3$ |
| 1-3. Determine the design volume reduction, $V_{\text{reduction}}$, which is the larger of V_{25} and $V_{\text{one-inch}}$ and is the volume to be retained on-site, | $V_{\text{reduction}} = \underline{\quad 25,700 \quad} \text{ ft}^3$ |
| <p>Note: Volume reduction credit is only provided for vegetated swale filters that include a gravel drainage layer to encourage infiltration.</p> <p style="margin-left: 20px;">-</p> | |

Step 2: Determine Storm Water Quality Design Flow

For this design example, a 10-acre residential development with a 60% total impervious area is considered. Flow-based sizing as described in Appendix C is assumed. Therefore, the design intensity is 0.25 in/hr.

| Step 2: Determine storm water quality design flow rate, Q_{wq} | |
|---|--|
| 2-1. Enter drainage area, A | $A = \underline{\quad 10 \quad} \text{ acres}$ |
| 2-2. Enter impervious fraction, Imp | $\text{Imp} = \underline{\quad 0.60 \quad}$ |
| 2-3. Calculate runoff coefficient, $C = (0.9 \cdot \text{Imp} + 0.05)$ | $C = \underline{\quad 0.59 \quad}$ |
| 2-4. Calculate the water quality design flow rate, Q_{wq} , based on a constant rainfall intensity of 0.25 in/hr, Appendix C | $Q_{\text{wq}} = \underline{\quad 1.48 \quad} \text{ cfs}$ |

Step 3: Determine design volume for sizing gravel drainage layer

| Step 3: Determine design volume for sizing gravel drainage layer | |
|---|---|
| 3-1. $V_{\text{design}} = V_{\text{reduction}}$ | $V_{\text{design}} = \underline{\quad 25,700 \quad} \text{ ft}^3$ |
| 3-2. Please follow Steps 3 through 5 of the Permeable Pavement Worksheet, Appendix D to calculate the gravel drainage layer | |

Step 4: Calculate flow depth, d, and swale bottom width

The swale bottom width is calculated based on Manning's equation. The grass height in the swale will be maintained at 6-inches. Therefore, the design flow depth is assumed to be 2/3 of 4 inches, or 4 inches (0.33 ft). The default Manning's roughness coefficient is assumed appropriate for expected vegetation density and design depth.

| Step 4: Calculate flow depth, d, and swale bottom width, b | |
|--|------------------------------------|
| 4-1. Enter Manning's roughness coefficient for shallow flow conditions (0.2 typical), n | n = 0.2 |
| 4-2. Enter expected vegetation height, y _v | y _v = $\frac{6}{12}$ in |
| 4-3. Calculate design flow depth (0.33 ft max), d = y _v /18 | d = $\frac{0.33}{12}$ ft |
| 4-4. Enter longitudinal slope (along direction of flow), s | s = $\frac{0.04}{100}$ ft/ft |
| 4-5. Enter side slope length per unit height (e.g. 3 if side slope are 3H :1V), Z | Z = 3 |
| 4-6. Calculate bottom width of swale assuming a trapezoidal channel shape, b = Q _{wq} n _{wq} /1.49y ^{1.67} s ^{0.5} | b = 9.0 ft |
| 4-7. Calculate AR ^{2/3} , using Q _{wq} n /1.49s ^{0.5} (Equation 6-5) | AR ^{2/3} = 1.0 |
| 4-8. Calculate the wetted area, A | A = 3.3 ft ² |
| 4-9. Calculate the wetted perimeter, P | P = 11.1 ft |
| 4-10. Calculate the hydraulic radius, R | R = 0.3 ft |
| 4-11. Re-calculate AR ^{2/3} , using the A and R calculated in steps 4-8 and 4-10. Change b until the AR ^{2/3} calculated in this step is equal to AR ^{2/3} calculated in 4-7. | AR ^{2/3} = 1.0 |
| 4-12. If b is between 2 and 10 feet, go to Step 5 | |
| 4-13. If b < 2 ft, set b = 2 ft and go to Step 4-4 and decrease swale slope (0.015 ft/ft max.). If slope cannot be changed due to site constraints, go to Step 4-14. | |
| 4-14. If b < 2 ft and slope is maximized, set b= 2 ft and go to Step 4-2 and decrease vegetation height | |
| 4-15. If b is greater than 10 ft, one of the following design adjustments must be made: | |
| 1) increase the longitudinal slope to a maximum of 0.06 ft/ft, and repeat steps 4- to 4-11 above. | |
| 2) include a flow splitter longitudinally along the swale bottom (Figure 6-6 and Appendix F) at least three-quarters of the swale length (beginning at the inlet) | |

Step 5: Determine Design Flow Velocity

| Step 5: Determine design flow velocity | |
|---|---|
| 5-1. Calculate design flow velocity, $v_{wq} = Q_{wq}/A$ | $v_{wq} = \frac{0.4}{\quad} \text{ ft/s}$ |
| 5-2. If the design flow velocity is higher than 1 ft/s go to Step 4-4 and decrease the slope, if possible | |

Step 6: Calculate Swale Length

Using the design flow velocity and a minimum residence time of 7 minutes, the length of the swale is calculated as follows. The swale length must be a minimum of 100 ft.

| Step 6: Calculate swale length | |
|--|---|
| 6-1. Enter target residence time (7 minutes minimum), t_{HR} | $t_{HR} = \frac{10}{\quad} \text{ min}$ |
| 6-2. Calculate swale length, $L = v_{wq} \cdot 60 \cdot t_{HR}$ | $L = \frac{266}{\quad} \text{ ft}$ |
| 6-3. If L is too long for the site, proceed to step 5 to adjust the swale layout | |

Site constraints only allow a swale length of 200 feet. Reduce the target residence time or proceed to Step 4 to adjust the swale cross-sectional area, A, to shorten the swale length.

Step 7: Adjust Swale Layout to Fit Within Site Constraints

To adjust swale length to 200 feet, the bottom width needs to be increased (up to a maximum of 16 ft).

| Step 7: Adjust swale layout to fit within site constraints | | |
|--|------------|---------------------|
| 7-1. Choose a reduced swale length, L_f | $L_f =$ | 250 ft |
| 7-2. Recalculate flow velocity, $v_{wq} = L_f / (t_{HR} \bullet 60)$ | $v_{wq} =$ | 0.42 ft/s |
| 7-3. Recalculate cross-sectional area, $A_{wq} = Q_{wq} / v_{wq}$ | $A_{wq} =$ | 3.5 ft ² |
| 7-4. Calculate an increased bottom width, $b_f = (A_{wq} - Zy^2) / y$ | $b_f =$ | 9.6 ft |
| 7-5. Recalculate longitudinal slope assuming a rectangular channel shape, $s_f = [Q_{wq} n_{wq} / (1.49 A_{wq} y^{0.67})]^2$ | $s_f =$ | 0.016 ft/ft |
| 7-6. If s_f is between 1.5% and 6%, the swale design is acceptable for water quality, proceed to Step 6 | | |
| 7-7. If s_f is between 1% and 1.5%, the swale design is acceptable for water quality with underdrains (see design requirements). Proceed to Step 6. | | |
| 7-8. If s_f is <1%, the swale design is unacceptable. Consider subdividing drainage area and repeat all above steps, or choose a different BMP for the site. | | |

Since width > 10 feet, the swale design is acceptable if a swale divider is included.

Step 8: Provide Conveyance Capacity for Flows Higher than Q_{wq}

The swale will be offline such that all flows greater than Q_{wq} will be bypassed.

Vegetated Filter Strip Worksheet

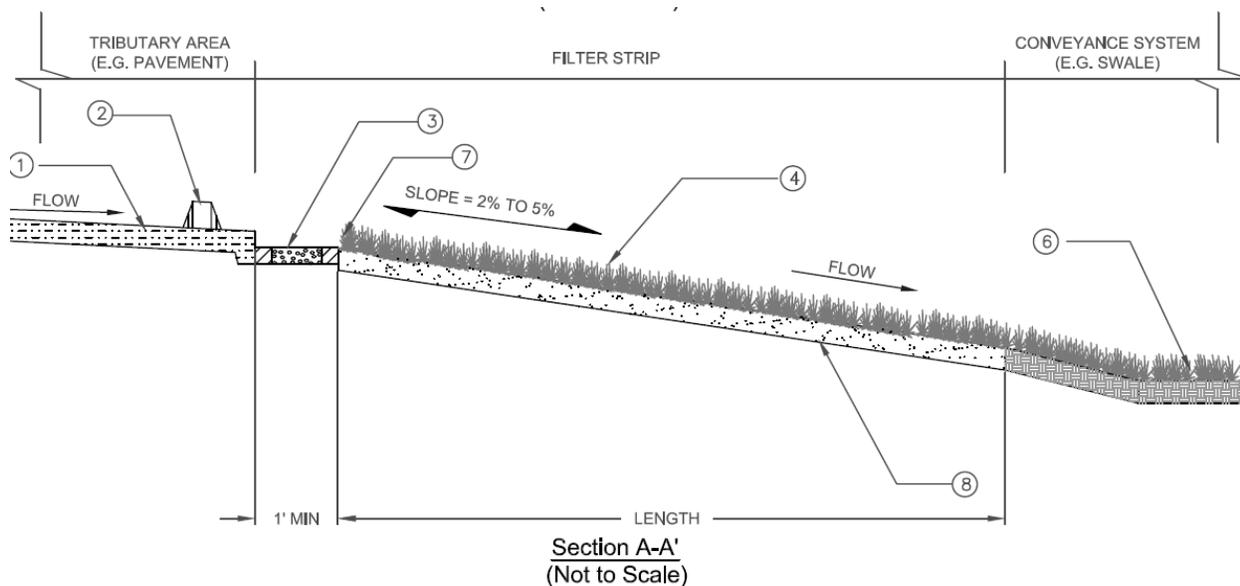


Figure D-3: Vegetated filter strip cross-section

Refer to Figure D-3 and Figure 6-8 for the description of the geometric variables.

| Step 1: Calculate the design flow | | |
|--|------------------|-------|
| 1-1. Enter drainage area, A | A = _____ | acres |
| 1-2. Enter impervious fraction, Imp | Imp = _____ | |
| 1-3. Calculate runoff coefficient, $C = (0.9 \cdot \text{Imp} + 0.05)$ | C = _____ | |
| 1-4. Calculate the water quality design flow rate, Q_{wq} , based on a constant rainfall intensity of 0.25 in/hr, Appendix C | $Q_{wq} =$ _____ | cfs |

| Step 2: Calculate the design flow depth | |
|---|-----------------------|
| 2-1. Enter strip filter slope (in direction of flow), s | s = _____ |
| 2-2. Enter Manning roughness coefficient (0.25-.3), n_{wq} | n_{wq} = _____ |
| 2-3. Enter width of impervious surface contributing area, W | W = _____ ft |
| 2-4. Calculate average depth of water using Manning eq, $d_f = \frac{12[Q_{wq}n_{wq}/1.49Ws^{0.5}]^{0.6}}{}$ | d_f = _____ in |
| 2-5. If $d_f > 1"$, go Step 2-1 and decrease the slope | |
| 2-6. If the slope cannot be changed due to construction constraints, go Step 2-3 and increase the width perpendicular to flow | |
| 2-7. If $d_f > 1"$ and neither the slope nor the width can be changed adequately, choose an alternate BMP for the site | |
| Step 3: Calculate the design velocity | |
| 3-1. Calculate design flow velocity, $V_{wq} = Q_{wq}/d_fW$ | V_{wq} = _____ ft/s |
| 3-2. If the design flow velocity is higher than 1ft/s go to step 2-1 and decrease the slope | |
| Step 4: Calculate the length of the filter strip | |
| 4-1. Enter residence time (10 minutes, min.), t | t = _____ min |
| 4-2. Calculate length of the filter strip, $L = 60tV_{wq}$ | L = _____ ft |
| 4-3. If $L < 4$ ft (pre-treatment) or less $L < 15$ ft (treatment), go to step 2-1 and increase the slope | |

Vegetated Filter Strip Design Example

Step 1: Calculate the Design Flow

For this design example, a 10-acre residential development with a 60% total impervious area is considered. Flow-based sizing, as described in Appendix C, is assumed. Therefore, the design rainfall intensity is assumed to be 0.25 in/hr.

| Step 1: Calculate the design flow | | |
|--|------------|----------|
| 1-1. Enter drainage area, A | A = | 10 acres |
| 1-2. Enter impervious fraction, Imp | Imp = | 0.60 |
| 1-3. Calculate runoff coefficient, $C = (0.9 \cdot \text{Imp} + 0.05)$ | C = | 0.59 |
| 1-4. Calculate the water quality design flow rate, Q_{wq} , based on a constant rainfall intensity of 0.25 in/hr, Appendix C | $Q_{wq} =$ | 1.48 cfs |

Step 2: Calculate the Design Flow Depth

Based on the site constraints we choose the width of the filter strip 150 ft and the filter strip longitudinal slope as 3%. The design water depth should not exceed 1 inch.

| Step 2: Calculate the design flow depth | | |
|---|------------|---------|
| 2-1. Enter strip filter slope (in direction of flow), s | s = | 0.03 |
| 2-2. Enter Manning roughness coefficient (0.25-.3), n_{wq} | $n_{wq} =$ | 0.27 |
| 2-3. Enter width of impervious surface contributing area, W | W = | 150 ft |
| 2-4. Calculate average depth of water using Manning eq, $d_f = 12[Q_{wq}n_{wq}/1.49Ws^{0.5}]^{0.6}$ | $d_f =$ | 0.77 in |
| 2-5. If $d_f > 1"$, go Step 2-1 and decrease the slope | | |
| 2-6. If the slope cannot be changed due to construction constraints, go Step 2-3 and increase the width perpendicular to flow | | |
| 2-7. If $d_f > 1"$ and neither the slope nor the width can be changed adequately, choose an alternate BMP for the site | | |

Step 3: Calculate the Design Velocity

The designed flow velocity should not exceed 1 foot/second across the filter strip.

| Step 3: Calculate the design velocity | |
|---|---|
| 3-1. Calculate design flow velocity, $V_{wq} = Q_{wq}/d_f W$ | $V_{wq} = \quad 0.1532 \quad \text{ft/s}$ |
| 3-2. If the design flow velocity is higher than 1ft/s go to step 2-1 and decrease the slope | <hr style="width: 100px; margin-left: auto; margin-right: 0;"/> |

Step 4: Calculate the Length of the Filter Strip

The filter strip should be at least 4 feet long (in the direction of flow) and accommodate a minimum residence time of 10 minutes to provide adequate water quality treatment.

| Step 4: Calculate the length of the filter strip | |
|---|---|
| 4-1. Enter residence time (10 minutes, min.), t | t = <u>10</u> min |
| 4-2. Calculate length of the filter strip, $L = 60tV_{wq}$ | L = <u>91.9</u> ft |
| 4-3. If $L < 4$ ft (pre-treatment) or less $L < 15$ ft (treatment), go to step 2-1 and increase the slope | <hr style="width: 100px; margin-left: auto; margin-right: 0;"/> |

Sand Filter Worksheet

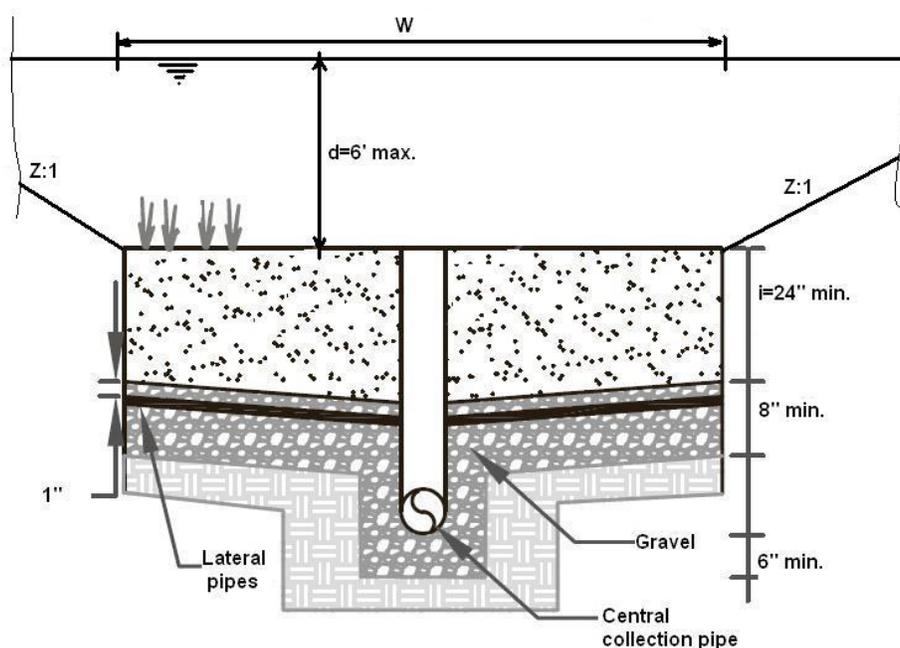


Figure D-4: Sand filter cross-section

Refer to Figure D-4 and Figure 6-10 for a diagrammatic description of the geometric variables.

| Step 1: Determine storm water quality design volume, V_{wq} | |
|---|--|
| 1-1. Determine the water quality design volume, V_{wq} , using SBUH method, Appendix C (<u>Note</u> : V_{wq} is always equal to $V_{one-inch}$) | $V_{wq} = \underline{\quad 25,700 \quad} \text{ ft}^3$ |

| Step 2: Calculate sand filter area | | |
|---|-------------|--------------------------|
| 2-1. Enter thickness of sand filter (min. 24" or 2'), l | l = | 2 ft |
| 2-2. Enter maximum storage depth (6 feet) above the filter, d | d = | 6 ft |
| 2-3. Enter routing adjustment factor, R | R = | 0.7 |
| 2-4. Calculate average depth of water above the filter, $h = d/2$ | h = | 3 ft |
| 2-5. Enter hydraulic conductivity (1"/hr), K_i | $K_i =$ | 1 in/hr |
| 2-6. Calculate hydraulic conductivity (ft/day), $K_{day} = 2K_i$ | $K_{day} =$ | 2 ft/day |
| 2-7. Calculate hydraulic gradient, $i = (h+l)/l$ | i = | 2.5 ft/ft |
| 2-8. Enter drawdown time, t | t = | 2 day |
| 2-9. Calculate sand filter area, $A_{sf} = (V_{wq}RI)/(K_{day}t(h+l))$ | $A_{sf} =$ | 1,799 ft ² |
| Step 3: Determine filter dimensions | | |
| 3-1. Sand filter area, A_{sf} | $A_{sf} =$ | 1,799 ft ² |
| 3-2. Enter geometric configuration, $L_R:W$ ratio (2:1), L_R | $L_R =$ | 2 |
| 3-3. Calculate the width of the sand filter, W | W = | 30.0 ft |
| 3-4. Calculate the length of the sand filter, L | L = | 60.0 ft |
| 3-5. Calculate rate of filtration, $r_{wq} = K_{day}i$ | $r_{wq} =$ | 5.0 ft/d/ft ² |
| Step 4: Calculate storage volume | | |
| 4-1. Enter interior side slopes, 3H:1V (max), Z | Z = | 3 |
| 4-2. Calculate top length, $L_t = L + 2Zd$ | $L_t =$ | 96.0 ft |
| 4-3. Calculate top width, $W_t = W + 2Zd$ | $W_t =$ | 66.0 ft |
| 4-4. Calculate filter storage volume, $V_s = 1/3 \cdot d(A_{sf} + A_t + (A_{sf}A_t)^{0.5})$ where $A_t = L_t \cdot W_t$ | $V_s =$ | 23,018 ft ³ |

| Step 5: Calculate underdrain system | | |
|--|-------------|-----------------|
| 5-1. Calculated filtered flow rate, $Q_f = (r_{wq}A_{sf})/86400$ | $Q_f =$ | <u>0.10</u> cfs |
| 5-2. Enter minimum slope for energy gradient, S_e | $S_e =$ | <u>0.005</u> |
| 5-3. Enter Hazen-Williams coefficient for plastic, C | $C =$ | <u>140</u> |
| 5-4. Enter pipe diameter, D | $D =$ | <u>6</u> in |
| 5-5. Calculate pipe hydraulic radius, $R_h = D/48$ | $R_h =$ | <u>0.13</u> |
| 5-6. Calculate velocity at the outlet of the pipe, $V_p = 1.318CR_h^{0.63}S_e^{0.54}$ | $V_p =$ | <u>2.8</u> ft/s |
| 5-7. Calculate pipe capacity, $Q_{cap} = 0.25\pi(D/12)^2V_p$ | $Q_{cap} =$ | <u>0.6</u> cfs |
| Step 6: Provide conveyance capacity for filter clogging | | |
| 6-1. The sand filters should be placed off-line, but an emergency overflow must still be provided in the event the filter becomes clogged and verify that all parameters meet design requirements to complete sizing. | | |

Sand Filter Design Example

Step 1: Calculate the Design Flow

For this design example, a 10-acre residential development with a 60% total impervious area is considered. Flow-based sizing, as described in Appendix C, is assumed. Therefore, the design rainfall intensity is assumed to be 0.25 in/hr.

| Step 1: Calculate the design flow | | |
|--|------------|----------|
| 1-1. Enter drainage area, A | A = | 10 acres |
| 1-2. Enter impervious fraction, Imp | Imp = | 0.60 |
| 1-3. Calculate runoff coefficient, $C = (0.9 \cdot \text{Imp} + 0.05)$ | C = | 0.59 |
| 1-4. Calculate the water quality design flow rate, Q_{wq} , based on a constant rainfall intensity of 0.25 in/hr, Appendix C | Q_{wq} = | 1.48 cfs |

Step 2: Calculate Sand Filter Area

A sand filter is designed with two components: (1) temporary storage reservoir to store runoff, and (2) a sand filter bed through which the stored runoff must percolate getting treatment.

The simple sizing method does not route flows through the filter. The size of the filter is determined based on the simple assumption that inflow is immediately discharged through the filter. The adjustment factor, R, is applied to compensate for the greater filter size resulting from this method.

| Step 2: Calculate sand filter area | | | |
|--|-------------|-------|-----------------|
| 2-1. Enter thickness of sand filter (min. 24" or 2'), l | l = | 2 | ft |
| 2-2. Enter maximum storage depth (6 feet) above the filter, d | d = | 6 | ft |
| 2-3. Enter routing adjustment factor, R | R = | 0.7 | |
| 2-4. Calculate average depth of water above the filter, $h = d/2$ | h = | 3 | ft |
| 2-5. Enter hydraulic conductivity (1"/hr), K_i | $K_i =$ | 1 | in/hr |
| 2-6. Calculate hydraulic conductivity (ft/day), $K_{day} = 2K_i$ | $K_{day} =$ | 2 | ft/day |
| 2-7. Calculate hydraulic gradient, $i = (h+l)/l$ | i = | 2.5 | ft/ft |
| 2-8. Enter drawdown time, t | t = | 2 | day |
| 2-9. Calculate sand filter area, $A_{sf} = (V_{wq}RI)/(K_{day}t(h+l))$ | $A_{sf} =$ | 1,799 | ft ² |

Step 3: Determine Filter Dimensions

| Step 3: Determine filter dimensions | | |
|--|------------|---------------------------------|
| 3-1. Sand filter area, A_{sf} | $A_{sf} =$ | <u>1,799</u> ft ² |
| 3-2. Enter geometric configuration, $L_R:W$ ratio (2:1), L_R | $L_R =$ | <u>2</u> |
| 3-3. Calculate the width of the sand filter, W | $W =$ | <u>30.0</u> ft |
| 3-4. Calculate the length of the sand filter, L | $L =$ | <u>60.0</u> ft |
| 3-5. Calculate rate of filtration, $r_{wq} = K_{day}i$ | $r_{wq} =$ | <u>5.0</u> ft/d/ft ² |

Step 4: Calculate Storage Volume

The side slopes are will be designed as 3H:1V, so $Z = 3$.

| Step 4: Calculate storage volume | | |
|---|---------|-------------------------------|
| 4-1. Enter interior side slopes, 3H:1V (max), Z | $Z =$ | <u>3</u> |
| 4-2. Calculate top length, $L_t = L + 2Zd$ | $L_t =$ | <u>96.0</u> ft |
| 4-3. Calculate top width, $W_t = W + 2Zd$ | $W_t =$ | <u>66.0</u> ft |
| 4-4. Calculate filter storage volume, $V_s = 1/3 \cdot d(A_{sf} + A_t + (A_{sf}A_t)^{0.5})$ where $A_t = L_t \cdot W_t$ | $V_s =$ | <u>23,018</u> ft ³ |

Step 5: Calculate Underdrain System

All underdrain pipes must be 6 inches or greater to facilitate cleaning.

| Step 5: Calculate underdrain system | | | |
|---|-------------|-------|------|
| 5-1. Calculated filtered flow rate, $Q_f = (r_{wq}A_{sf})/86400$ | $Q_f =$ | 0.10 | cfs |
| 5-2. Enter minimum slope for energy gradient, S_e | $S_e =$ | 0.005 | |
| 5-3. Enter Hazen-Williams coefficient for plastic, C | C = | 140 | |
| 5-4. Enter pipe diameter, D | D = | 6 | in |
| 5-5. Calculate pipe hydraulic radius, $R_h = D/48$ | $R_h =$ | 0.13 | |
| 5-6. Calculate velocity at the outlet of the pipe, $V_p = 1.318CR_h^{0.63}S_e^{0.54}$ | $V_p =$ | 2.8 | ft/s |
| 5-7. Calculate pipe capacity, $Q_{cap} = 0.25\pi(D/12)^2V_p$ | $Q_{cap} =$ | 0.6 | cfs |

Step 6: Provide Conveyance Capacity for Filter Clogging

The sand filters should be placed off-line, but an emergency overflow must still be provided in the event the filter becomes clogged and **verify that all parameters meet design requirements** to complete sizing.

Infiltration BMP Worksheet

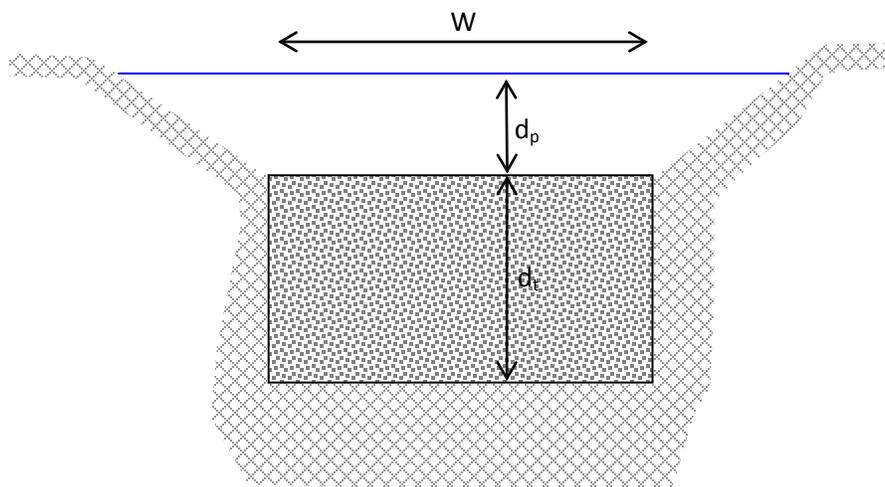


Figure D-5: Infiltration BMP cross-section

Refer to Figures D-5, 6-12, 6-13 and 6-14 for a diagrammatic description of the geometric variables.

| Step 1: Determine design volume reduction, $V_{\text{reduction}}$ | |
|--|--|
| 1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25} , calculated using SBUH method, Appendix C | $V_{25} =$ _____ ft^3 |
| 1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{\text{one-inch}}$, calculated using SBUH method, Appendix C | $V_{\text{one-inch}} =$ _____ ft^3 |
| 1-3. Determine design volume reduction which is the larger of V_{25} and $V_{\text{one-inch}}$ and is the volume to be retained on-site | $V_{\text{reduction}} =$ _____ ft^3 |
| Step 2: Determine storm water quality design volume, V_{wq} | |
| 2-1. Determine the water quality design volume, V_{wq} , using SBUH method, Appendix C (<u>Note</u> : V_{wq} is always equal to $V_{\text{one-inch}}$) | $V_{\text{wq}} =$ _____ ft^3 |
| Step 3: Determine design volume, V_{design} (for sizing) | |
| 3-1. $V_{\text{design}} =$ the larger of $V_{\text{reduction}}$ and V_{wq} | $V_{\text{design}} =$ _____ ft^3 |

| Step 4: Calculate design infiltration rate | |
|---|---|
| 4-1. Enter soil infiltration rate (0.5 in/hr min.), k_{measured} | $k_{\text{measured}} =$ _____ in/hr |
| 4-2. Enter correction factor for testing (0.3 small scale, 0.5 large scale), F_t | $F_t =$ _____ ft |
| 4-3. Enter correction factor for plugging, (0.7 loams-sandy loams, 0.8 fine-loamy sands, 0.9 medium sands, 1.0 coarse sands-cobbles, F_p | $F_p =$ _____ |
| 4-4. Enter the depth from the bottom of the facility to the maximum wet-season water table or nearest impervious layer, whichever is less. D | $D =$ _____ ft |
| 4-5. Enter the estimated width of the facility | $W =$ _____ ft |
| 4-6. Calculate the correction factor of geometry (0.25 min, 1.0 max), $F_g = 4 \cdot D/W + 0.05$ | $F_g =$ _____ |
| 4-7. Calculate the design infiltration rate, $k_{\text{design}} = k_{\text{measured}} F_t F_p F_g$ | $k_{\text{design}} =$ _____ in/hr |
| Step 5: Determine facility size | |
| 5-1. Enter drawdown time(72 hrs max.), t_d | $t_d =$ _____ hrs |
| 5-2. Calculate max.depth of runoff that can be infiltrated within the t_d , $d_{\text{max}} = k_{\text{design}} t_d / 12$ | $d_{\text{max}} =$ _____ ft |
| 5-3. Enter trench fill aggregate porosity, n_t | $n_t =$ _____ |
| 5-4. Enter depth of trench fill, d_t | $d_t =$ _____ in |
| 5-5. Enter max ponding depth, or max. $d_p = d_{\text{max}} - n_t d_t$ | $d_p =$ _____ ft |
| Step 6: Determine infiltrating surface area (filter bottom area) | |
| 6-1. Enter the time to fill infiltration basin or trench with water (Use 2 hours for most designs), T | $T =$ _____ hrs |
| 6-2. Calculate infiltrating surface area for infiltration basin: $A_b = V_{\text{design}} / ((T k_{\text{design}} / 12) + d_p)$ | $A_b =$ _____ ft ² |
| 6-3. Calculate infiltrating surface area for infiltration trenches: $A_t = V_{\text{design}} / ((T k_{\text{design}} / 12) + n_t d_t + d_p)$ | $A_t =$ _____ ft ² |
| 6-4. Calculate infiltrating surface area for dry wells: $A_{\text{dw}} = V_{\text{design}} / ((T k_{\text{design}} / 12) + n_t d_t)$ | $A_{\text{dw}} =$ _____ ft ³ |
| Step 7: Provide conveyance capacity for filter clogging | |
| 7-1. The infiltration facility should be placed off-line, but an emergency overflow must still be provided in the event the filter becomes clogged. | |

Infiltration BMP Design Example

Step 1: Determine Storm Water Quality Design Volume Reduction, $V_{\text{reduction}}$

| Step 1: Determine design volume reduction, $V_{\text{reduction}}$ | |
|--|---|
| 1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25} , calculated using SBUH method, Appendix C | $V_{25} = \underline{\quad 20 \quad} \text{ft}^3$ |
| 1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{\text{one-inch}}$, calculated using SBUH method, Appendix C | $V_{\text{one-inch}} = \underline{\quad 25,700 \quad} \text{ft}^3$ |
| 1-3. Determine design volume reduction which is the larger of V_{25} and $V_{\text{one-inch}}$ and is the volume to be retained on-site | $V_{\text{reduction}} = \underline{\quad 25,700 \quad} \text{ft}^3$ |

Step 2: Determine Storm Water Quality Design Volume, V_{wq}

| Step 2: Determine storm water quality design volume, V_{wq} | |
|--|--|
| 2-1. Determine the water quality design volume, V_{wq} , using SBUH method, Appendix C (<u>Note</u> : V_{wq} is always equal to $V_{\text{one-inch}}$) | $V_{\text{wq}} = \underline{\quad 25,700 \quad} \text{ft}^3$ |

Step 3: Determine Design Volume, V_{design}

| Step 3: Determine design volume, V_{design} (for sizing) | |
|---|--|
| 3-1. $V_{\text{design}} =$ the larger of $V_{\text{reduction}}$ and V_{wq} | $V_{\text{design}} = \underline{\quad 25,700 \quad} \text{ft}^3$ |

Step 4: Calculate Design Infiltration Rate

Infiltration facilities require a minimum soil infiltration rate of 0.5 in/hr. If the rate exceeds 2.4 in/hr, then the runoff should be fully treated in an upstream BMP prior to infiltration to protect the groundwater quality.

The factors applied to in-situ measured infiltration rate take into account uncertainty in measures, depth of water, geometry and long term reductions in permeability due to biofouling and fines accumulation. A small scale testing factor has been assigned to this example. Since the soils in the residential development have been designated as loamy sands, a plugging factor of 0.8 should be used. If the depth from the bottom of the site to the maximum water table is 10 ft and there is space to create the infiltration facility at roughly 60 ft wide, then the correction factor of geometry can be calculated as 0.72.

| Step 4: Calculate design infiltration rate | | |
|--|-------------------------|------------|
| 4-1. Enter soil infiltration rate (0.5 in/hr min.), k_{measured} | $k_{\text{measured}} =$ | 4 in/hr |
| 4-2. Enter correction factor for testing (0.3 small scale, 0.5 large scale), F_t | $F_t =$ | 0.3 |
| 4-3. Enter correction factor for plugging, (0.7 loams-sandy loams, 0.8 fine-loamy sands, 0.9 medium sands, 1.0 coarse sands-cobbles, F_p | $F_p =$ | 0.8 |
| 4-4. Enter the depth from the bottom of the facility to the maximum wet-season water table or nearest impervious layer, whichever is less. D | D = | 10 ft |
| 4-5. Enter the estimated width of the facility | W = | 60 ft |
| 4-6. Calculate the correction factor of geometry (0.25 min, 1.0 max), $F_g = 4 \cdot D/W + 0.05$ | $F_g =$ | 0.72 |
| 4-7. Calculate the design infiltration rate, $k_{\text{design}} = k_{\text{measured}} F_t F_p F_g$ | $k_{\text{design}} =$ | 0.69 in/hr |

Step 5: Determine Facility Size

The simple sizing method requires that the water quality volume must be completely infiltrated within 72 hours. The size of the filter is determined based on the simple assumption that inflow is immediately discharged through the filter.

| Step 5: Determine facility size | | | |
|---|-------------|------|-----|
| 5-1. Enter drawdown time(72 hrs max.), t_d | $t_d =$ | 72 | hrs |
| 5-2. Calculate max.depth of runoff that can be infiltrated within the t_d , $d_{max}=k_{design}t_d/12$ | $d_{max} =$ | 4.13 | ft |
| 5-3. Enter trench fill aggregate porosity, n_t | $n_t =$ | 0.35 | |
| 5-4. Enter depth of trench fill, d_t | $d_t =$ | 48 | in |
| 5-5. Enter max ponding depth, or max. $d_p=d_{max}-n_t d_t$ | $d_p =$ | 2.73 | ft |

Step 6: Determine Infiltrating Surface Area

The size of the infiltrating surface is determined by assuming the water quality design volume will fill the available ponding depth plus the void spaces of the computed porosity (usually about 32%) of the filter media.

| Step 6: Determine infiltrating surface area (filter bottom area) | | | |
|--|------------|-------|-----------------|
| 6-1. Enter the time to fill infiltration basin or trench with water (Use 2 hours for most designs), T | T = | 2 | hrs |
| 6-2. Calculate infiltrating surface area for infiltration basin: $A_b=V_{design}/((Tk_{design}/12)+d_p)$ | $A_b =$ | 9,041 | ft ² |
| 6-3. Calculate infiltrating surface area for infiltration trenches: $A_t=V_{design}/((Tk_{design}/12)+n_t d_t+d_p)$ | $A_t =$ | 1,308 | ft ² |
| 6-4. Calculate infiltrating surface area for dry wells: $A_{dw}=V_{design}/((Tk_{design}/12)+n_t d_t)$ | $A_{dw} =$ | 1,519 | ft ³ |

Step 7: Provide Conveyance Capacity for Flows Higher than Q_{wq}

The infiltration facility should be placed off-line, but an emergency overflow for flows greater than the water quality peak flow rate, Q_{wq} , must still be provided in the event the filter becomes clogged.

Permeable Pavement Worksheet

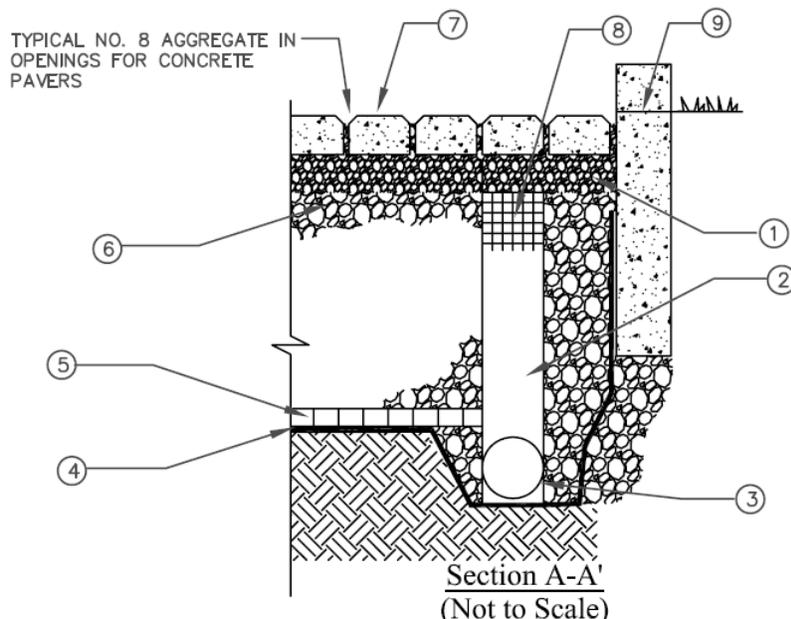


Figure D-6: Permeable Pavement cross-section

Refer to Figures D-6 and Figure 6-16 for a diagrammatic description of the geometric variables.

| Step 1: Determine design volume reduction, $V_{\text{reduction}}$ | |
|--|---|
| 1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25} , calculated using SBUH method, Appendix C | $V_{25} = \underline{\quad 32,000 \quad} \text{ft}^3$ |
| 1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{\text{one-inch}}$, calculated using SBUH method, Appendix C | $V_{\text{one-inch}} = \underline{\quad 25,700 \quad} \text{ft}^3$ |
| 1-3. Determine design volume reduction which is the larger of V_{25} and $V_{\text{one-inch}}$ and is the volume to be retained on-site | $V_{\text{reduction}} = \underline{\quad 32,000 \quad} \text{ft}^3$ |
| Step 2: Determine storm water quality design volume, V_{wq} | |
| 2-1. Determine the water quality design volume, V_{wq} , using SBUH method, Appendix C (<u>Note</u> : V_{wq} is always equal to $V_{\text{one-inch}}$) | $V_{\text{wq}} = \underline{\quad 25,700 \quad} \text{ft}^3$ |

| Step 3: Determine design volume, V_{design} (for sizing) | |
|--|---|
| 3-1. If no infiltration (i.e., impermeable liner w/ underdrains), $V_{\text{design}} = V_{\text{wq}}$. | $V_{\text{design}} = \underline{\quad 25,700 \quad} \text{ ft}^3$ |
| 3-2. If partial infiltration (i.e., permeable liner w/underdrains), $V_{\text{design}} = V_{\text{wq}} + 0.2V_{\text{wq}}$ | $V_{\text{design}} = \underline{\quad 30,840 \quad} \text{ ft}^3$ |
| 3-3. If full infiltration (i.e., permeable liner w/ no underdrains), $V_{\text{design}} = V_{\text{reduction}}$ | $V_{\text{design}} = \underline{\quad 32,000 \quad} \text{ ft}^3$ |
| Step 4: Calculate design infiltration rate (assume full infiltration, $V_{\text{design}} = V_{\text{reduction}}$) | |
| 4-1. Enter soil infiltration rate (0.5 in/hr min.), k_{measured} | $k_{\text{measured}} = \underline{\quad 3 \quad} \text{ in/hr}$ |
| 4-2. Enter correction factor for testing (0.3 small scale, 0.5 large scale), F_t | $F_t = \underline{\quad 0.3 \quad} \text{ ft}$ |
| 4-3. Enter correction factor for plugging, (0.7 loams-sandy loams, 0.8 fine-loamy sands, 0.9 medium sands, 1.0 coarse sands-cobbles, F_p | $F_p = \underline{\quad 0.8 \quad}$ |
| 4-4. Enter the depth from the bottom of the facility to the maximum wet-season water table or nearest impervious layer, whichever is less. D | $D = \underline{\quad 10 \quad} \text{ ft}$ |
| 4-5. Enter the estimated width of the facility | $W = \underline{\quad 60 \quad} \text{ ft}$ |
| 4-6. Calculate the correction factor of geometry (0.25 min, 1.0 max), $F_g = 4 \cdot D/W + 0.05$ | $F_g = \underline{\quad 0.72 \quad}$ |
| 4-7. Calculate the design infiltration rate, $k_{\text{design}} = k_{\text{measured}} F_t F_p F_g$ | $k_{\text{design}} = \underline{\quad 0.52 \quad} \text{ in/hr}$ |
| Step 5: Determine maximum depth that can be infiltrated | |
| 5-1. Enter drawdown time (72 hrs max.), t | $t = \underline{\quad 72 \quad} \text{ hrs}$ |
| 5-2. Calculate max.depth of runoff that can be infiltrated within the t , $d_{\text{max}} = k_{\text{design}} t / 12$ | $d_{\text{max}} = \underline{\quad 3.10 \quad} \text{ ft}$ |
| Step 6: Determine infiltrating surface area (gravel drainage area) | |
| 6-1. Enter gravel drainage layer porosity, n | $n = \underline{\quad 0.32 \quad}$ |
| 6-2. Enter depth of gravel drainage layer, l | $l = \underline{\quad 48.00 \quad} \text{ in}$ |
| 6-3. Enter the time to fill the gravel drainage layer with water (Use 2 hours for most designs), T | $T = \underline{\quad 2 \quad} \text{ hrs}$ |
| 6-4. Calculate infiltrating surface area for dry wells: $A = V_{\text{design}} / (T k_{\text{design}} / 12 + n \cdot l)$ | $A = \underline{\quad 2,072 \quad} \text{ ft}^3$ |

Step 7: Provide conveyance capacity for filter clogging

7-1. The permeable pavement must have an emergency overflow for storm events greater than the design and in the event the permeable pavement becomes clogged.

Permeable Pavement Design Example

Step 1: Determine Storm Water Quality Design Volume Reduction, $V_{\text{reduction}}$

| Step 1: Determine design volume reduction, $V_{\text{reduction}}$ | |
|--|---|
| 1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25} , calculated using SBUH method, Appendix C | $V_{25} = \underline{\quad 20 \quad} \text{ft}^3$ |
| 1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{\text{one-inch}}$, calculated using SBUH method, Appendix C | $V_{\text{one-inch}} = \underline{\quad 25,700 \quad} \text{ft}^3$ |
| 1-3. Determine design volume reduction which is the larger of V_{25} and $V_{\text{one-inch}}$ and is the volume to be retained on-site | $V_{\text{reduction}} = \underline{\quad 25,700 \quad} \text{ft}^3$ |

Step 2: Determine Storm Water Quality Design Volume, V_{wq}

| Step 2: Determine storm water quality design volume, V_{wq} | |
|--|--|
| 2-1. Determine the water quality design volume, V_{wq} , using SBUH method, Appendix C (<u>Note</u> : V_{wq} is always equal to $V_{\text{one-inch}}$) | $V_{\text{wq}} = \underline{\quad 25,700 \quad} \text{ft}^3$ |

Step 3: Determine Design Volume, V_{design}

| Step 3: Determine design volume, V_{design} (for sizing) | |
|--|--|
| 3-1. If no infiltration (i.e., impermeable liner w/ underdrains), $V_{\text{design}} = V_{\text{wq}}$. | $V_{\text{design}} = \underline{\hspace{2cm}} \text{ft}^3$ |
| 3-2. If partial infiltration (i.e., permeable liner w/underdrains), $V_{\text{design}} = V_{\text{wq}} + 0.2V_{\text{wq}}$ | $V_{\text{design}} = \underline{\hspace{2cm}} \text{ft}^3$ |
| 3-3. If full infiltration (i.e., permeable liner w/ no underdrains), $V_{\text{design}} = V_{\text{reduction}}$ | $V_{\text{design}} = \underline{\hspace{2cm}} \text{ft}^3$ |

Step 4: Calculate Design Infiltration Rate (assuming full infiltration)

Permeable pavement with no underdrain requires a minimum soil infiltration rate of 0.5 in/hr.

The factors applied to in-situ measured infiltration rate take into account uncertainty in measures, depth of water, geometry and long term reductions in permeability due to biofouling and fines accumulation. A small scale testing factor has been assigned to this example. Since the soils in the residential development have been designated as loamy sands, a plugging factor of 0.8 should be used. If the depth from the bottom of the site to the maximum water table is 10 ft and there is space to create the infiltration facility at roughly 60 ft wide, then the correction factor of geometry can be calculated as 0.72.

| Step 4: Calculate design infiltration rate (assume full infiltration, $V_{\text{design}} = V_{\text{reduction}}$) | |
|--|--|
| 4-1. Enter soil infiltration rate (0.5 in/hr min.), k_{measured} | $k_{\text{measured}} = 3 \text{ in/hr}$ |
| 4-2. Enter correction factor for testing (0.3 small scale, 0.5 large scale), F_t | $F_t = 0.3$ |
| 4-3. Enter correction factor for plugging, (0.7 loams-sandy loams, 0.8 fine-loamy sands, 0.9 medium sands, 1.0 coarse sands-cobbles), F_p | $F_p = 0.8$ |
| 4-4. Enter the depth from the bottom of the facility to the maximum wet-season water table or nearest impervious layer, whichever is less. D | $D = 10 \text{ ft}$ |
| 4-5. Enter the estimated width of the facility | $W = 60 \text{ ft}$ |
| 4-6. Calculate the correction factor of geometry (0.25 min, 1.0 max), $F_g = 4 \cdot D/W + 0.05$ | $F_g = 0.72$ |
| 4-7. Calculate the design infiltration rate, $k_{\text{design}} = k_{\text{measured}} F_t F_p F_g$ | $k_{\text{design}} = 0.52 \text{ in/hr}$ |

Step 5: Determine maximum depth that can be infiltrated

| Step 5: Determine maximum depth that can be infiltrated | |
|--|------------------------------------|
| 5-1. Enter drawdown time (72 hrs max.), t | $t = 72 \text{ hrs}$ |
| 5-2. Calculate max.depth of runoff that can be infiltrated within the t, $d_{\text{max}} = k_{\text{design}} t / 12$ | $d_{\text{max}} = 3.10 \text{ ft}$ |

Step 6: Determine the infiltrating surface area (gravel drainage area)

| Step 6: Determine infiltrating surface area (gravel drainage area) | | |
|---|-----|------------------------------|
| 6-1. Enter gravel drainage layer porosity, n | n = | 0.32 |
| 6-2. Enter depth of gravel drainage layer, l | l = | <u>48.00</u> in |
| 6-3. Enter the time to fill the gravel drainage layer with water (Use 2 hours for most designs), T | T = | <u>2</u> hrs |
| 6-4. Calculate infiltrating surface area for dry wells: $A = V_{\text{design}} / ((T k_{\text{design}} / 12) + n * l)$ | A = | <u>2,072</u> ft ³ |

Step 7: Determine maximum depth that can be infiltrated

| Step 7: Provide conveyance capacity for filter clogging |
|---|
| 7-1. The permeable pavement must have an emergency overflow for storm events greater than the design and in the event the permeable pavement becomes clogged. |

Constructed Treatment Wetland Worksheet

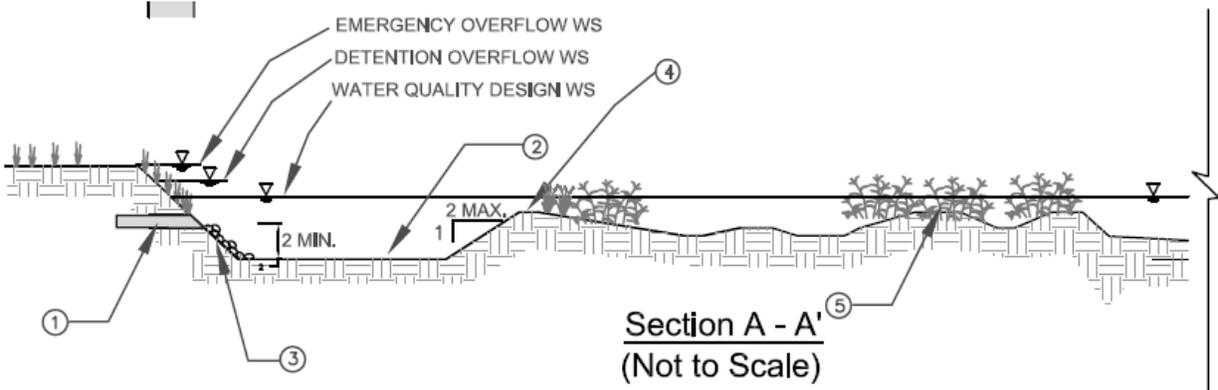


Figure D-7: Constructed treatment wetland cross-section

Refer to Figures D-7 and 6-22 for a diagrammatic description of the geometric variables.

| | |
|---|-------------------------|
| Step 1: Determine storm water quality design volume, V_{wq} | |
| 1-1. Determine the water quality design volume, V_{wq} , using SBUH method, Appendix C (<u>Note</u> : V_{wq} is always equal to $V_{one-inch}$) | $V_{wq} =$ _____ ft^3 |

Step 2: Determine Wetland Location, Wetland Type and Preliminary Geometry Based on Site Constraints

2-1. Based on site constraints, determine the wetland geometry and the storage available by developing an elevation-storage relationship for the wetland. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2. The wetland does not have extended detention.

2-2. Enter the total surface area of the wetland footprint based on site constraints, A_{tot}

$$A_{tot} = \underline{\hspace{2cm}} \text{ ft}^2$$

2-3. Enter the length of the wetland footprint based on site constraints, L_{tot}

$$L_{tot} = \underline{\hspace{2cm}} \text{ ft}$$

2-4. Calculate the width of the wetland footprint, $W_{tot} = A_{tot} / L_{tot}$

$$W_{tot} = \underline{\hspace{2cm}} \text{ ft}$$

2-5. Enter interior side slope as length per unit height (min = 3), Z

$$Z = \underline{\hspace{2cm}}$$

2-6. Enter desired freeboard depth, d_{fb}

$$d_{fb} = \underline{\hspace{2cm}} \text{ ft}$$

2-7. Calculate the length of the water quality surface area including the internal berm but excluding freeboard, $L_{wq-tot} = L_{tot} - 2Zd_{fb}$

$$L_{wq-tot} = \underline{\hspace{2cm}} \text{ ft}$$

2-8. Calculate the width of the water quality surface area including the internal berm but excluding freeboard, $W_{wq-tot} = W_{tot} - 2Zd_{fb}$

$$W_{wq-tot} = \underline{\hspace{2cm}} \text{ ft}$$

2-9. Calculate the total water quality surface area including the internal berm and excluding freeboard, $A_{wq-tot} = L_{wq-tot} \cdot W_{wq-tot}$

$$A_{wq-tot} = \underline{\hspace{2cm}} \text{ ft}^2$$

2-10. Enter the width of the internal berm (6 ft min), W_{berm}

$$W_{berm} = \underline{\hspace{2cm}} \text{ ft}$$

2-11. Enter the length of the internal berm, $L_{berm} = W_{wq-tot}$

$$L_{berm} = \underline{\hspace{2cm}} \text{ ft}$$

2-12. Calculate the area of the berm, $A_{berm} = W_{berm} \cdot L_{berm}$

$$A_{berm} = \underline{\hspace{2cm}} \text{ ft}^2$$

2-13. Calculate the active volume surface area excluding the internal berm and freeboard, $A_{wq} = A_{wq-tot} - A_{berm}$

$$A_{wq} = \underline{\hspace{2cm}} \text{ ft}^2$$

| Step 3: Determine Dimensions of Cell 1 | | |
|--|-----------|---------------------|
| 3-1. Enter the percent of V_{wq} in Cell 1 (10-20% required), $\%V_1$ | $\%V_1 =$ | _____ % |
| 3-2. Calculate the active volume of Cell 1 (including sediment storage), $V_1 = (V_{wq} \cdot \%V_1)/100$ | $V_1 =$ | _____ ft^3 |
| 3-3. Enter desired average depth of Cell 1 (5-9 ft including sediment storage of 1 ft), d_1 | $d_1 =$ | _____ ft |
| 3-4. Calculate the surface area for the water quality volume of Cell 1, $A_1 = V_1 / d_1$ | $A_1 =$ | _____ ft^2 |
| 3-5. Enter the width of Cell 1, $W_1 = W_{av-tot} = L_{berm}$ | $W_1 =$ | _____ ft |
| 3-6. Calculate the length of Cell 1 (<u>Note</u> : inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W_1$ | $L_1 =$ | _____ ft |

| Step 4: Determine Dimensions of Cell 2 | | |
|--|--------------|-----------------------|
| 4-1. Calculate the active volume of Cell 2, $V_2 = V_{wq} - V_1$ | $V_2 =$ | _____ ft ³ |
| 4-2. Calculate surface area of Cell 2, $A_2 = A_{wq} - A_1$ | $A_2 =$ | _____ ft ² |
| 4-3. Enter width of Cell 2, $W_2 = W_1 = W_{wq-tot} = L_{berm}$ | $W_2 =$ | _____ ft |
| 4-4. Calculate top length of Cell 2, $L_2 = A_2 / W_2$ | $L_2 =$ | _____ ft |
| 4-5. Verify that the length-to-width ratio of Cell 2 is at least 3:1 with $\geq 4:1$ preferred. If the length-to-width ratio is less than 3:1, modify input parameters until a ratio of at least 3:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen, $LW_2 = L_2 / W_2$ | $LW_2 =$ | _____ |
| 4-6. Enter percent of surface area of very shallow zone, % A_{vs} | % $A_{vs} =$ | _____ ft ² |
| 4-7. Calculate very shallow zone surface area, $A_{vs} = (A_2 \cdot \%A_{vs})/100$ | $A_{vs} =$ | _____ ft ² |
| 4-8. Enter average depth of very shallow zone (0.1 - 1 ft), d_{vs} | $d_{vs} =$ | _____ ft |
| 4-9. Calculate volume of very shallow zone, $V_{vs} = A_{vs} \cdot d_{vs}$ | $V_{vs} =$ | _____ ft ³ |
| 4-10. Enter width of very shallow zone, $W_{vs} = W_2$ | $W_{vs} =$ | _____ ft |
| 4-11. Calculate length of very shallow zone, $L_{vs} = A_{vs} / W_{vs}$ | $L_{vs} =$ | _____ ft |
| 4-12. Enter percent of surface area of shallow zone, % A_s | % $A_s =$ | _____ |
| 4-13. Calculate surface area of shallow zone, $A_s = (A_2 \cdot \%A_s)/100$ | $A_s =$ | _____ ft ² |
| 4-14. Enter average depth of shallow zone (1 - 3 ft), d_s | $d_s =$ | _____ ft |
| 4-15. Calculate volume of shallow zone, $V_s = A_s \cdot d_s$ | $V_s =$ | _____ ft ³ |
| 4-16. Enter width of shallow zone, $W_s = W_2$ | $W_s =$ | _____ ft |
| 4-17. Calculate length of shallow zone, $L_s = A_s / W_s$ | $L_s =$ | _____ ft |
| 4-18. Calculate surface area of deep zone, $A_{deep} = A_2 - A_{vs} - A_s$ | $A_{deep} =$ | _____ ft ² |
| 4-19. Calculate volume of deep zone, $V_{deep} = V_2 - V_{vs} - V_s$ | $V_{deep} =$ | _____ ft ³ |
| 4-20. Calculate average depth of deep zone (3 - 5 ft), $d_{deep} = V_{deep} / A_{deep}$ | $d_{deep} =$ | _____ ft |
| 4-21. Enter width of deep zone, $W_{deep} = W_2$ | $W_{deep} =$ | _____ ft |
| 4-22. Calculate length of deep zone, $L_{deep} = A_{deep} / W_{deep}$ | $L_{deep} =$ | _____ ft |
| Step 5: Ensure Design Requirements and Site Constraints are Achieved | | |
| 5-1. Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the wetland is inadequate to meet the design requirements, choose a new location for the wetland. | | |

Step 6: Size Outlet Structure

6-1. Please refer to Appendix D for outlet structure sizing methodologies and examples. The wetland outlet pipe shall be sized, at a minimum, to pass flows greater than the water quality design peak flow for off-line basins or flow from the capital storm for on-line basins.

Step 7: Determine Emergency Spillway Requirements

7-1. For online basins, an emergency overflow spillway should be sized to pass the capital design storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Constructed Treatment Wetland Design Example

Wetland siting requires the following considerations prior to construction: (1) availability of base flow – storm water wetlands require a regular source of water to support wetland biota, (2) slope stability – storm water wetlands are not permitted near steep slope hazard areas, (3) surface space availability – large footprint area is required, and (4) compatibility with flood control – basins must not interfere with flood control functions of existing conveyance and detention structures.

The wetland in this example does not have extended detention. An internal berm separates the forebay (Cell 1) and the main basin (Cell 2). The berm is at the elevation of the active volume design surface which is also the permanent wetpool elevation.

Step 1: Determine Water Quality Design Volume

For this design example, a 10-acre residential development with a 60% total impervious area is considered.

| Step 1: Determine storm water quality design volume, V_{wq} | |
|--|--|
| 1-1. Determine the water quality design volume, V_{wq} , using SBUH method, Appendix C (Note: V_{wq} is always equal to $V_{one-inch}$) | $V_{wq} = \underline{\quad 27,500 \quad} \text{ ft}^3$ |

Step 2: Determine Pond Location and Preliminary Geometry Based on Site Constraints

A total footprint area and total length available for the wetland is provided. This step calculates the total active volume surface area which is equivalent to the permanent wetpool surface area. This step also calculates the dimensions of the internal berm.

| Step 2: Determine Wetland Location, Wetland Type and Preliminary Geometry Based on Site Constraints | | |
|---|----------------|------------------------|
| 2-1. Based on site constraints, determine the wetland geometry and the storage available by developing an elevation-storage relationship for the wetland. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2. The wetland does not have extended detention. | | |
| 2-2. Enter the total surface area of the wetland footprint based on site constraints, A_{tot} | $A_{tot} =$ | 11,000 ft ² |
| 2-3. Enter the length of the wetland footprint based on site constraints, L_{tot} | $L_{tot} =$ | 200 ft |
| 2-4. Calculate the width of the wetland footprint, $W_{tot} = A_{tot} / L_{tot}$ | $W_{tot} =$ | 55 ft |
| 2-5. Enter interior side slope as length per unit height (min = 3), Z | $Z =$ | 3 |
| 2-6. Enter desired freeboard depth, d_{fb} | $d_{fb} =$ | 2 ft |
| 2-7. Calculate the length of the water quality surface area including the internal berm but excluding freeboard, $L_{wq-tot} = L_{tot} - 2Zd_{fb}$ | $L_{wq-tot} =$ | 188 ft |
| 2-8. Calculate the width of the water quality surface area including the internal berm but excluding freeboard, $W_{wq-tot} = W_{tot} - 2Zd_{fb}$ | $W_{wq-tot} =$ | 43 ft |
| 2-9. Calculate the total water quality surface area including the internal berm and excluding freeboard, $A_{wq-tot} = L_{wq-tot} \cdot W_{wq-tot}$ | $A_{wq-tot} =$ | 8,084 ft ² |
| 2-10. Enter the width of the internal berm (6 ft min), W_{berm} | $W_{berm} =$ | 6 ft |
| 2-11. Enter the length of the internal berm, $L_{berm} = W_{wq-tot}$ | $L_{berm} =$ | 43 ft |
| 2-12. Calculate the area of the berm, $A_{berm} = W_{berm} \cdot L_{berm}$ | $A_{berm} =$ | 258 ft ² |
| 2-13. Calculate the active volume surface area excluding the internal berm and freeboard, $A_{wq} = A_{wq-tot} - A_{berm}$ | $A_{wq} =$ | 7,826 ft ² |

Step 3: Determine Dimensions of Cell 1

It should be assumed that cell 1 (the forebay) should be 15% of the water quality design volume, V_{wq} .

| Step 3: Determine Dimensions of Cell 1 | | | |
|---|-----------|-------|-----------------|
| 3-1. Enter the percent of V_{wq} in Cell 1 (10-20% required), $\%V_1$ | $\%V_1 =$ | 15 | % |
| 3-2. Calculate the active volume of Cell 1 (including sediment storage), $V_1 = (V_{wq} \cdot \%V_1)/100$ | $V_1 =$ | 4,125 | ft ³ |
| 3-3. Enter desired average depth of Cell 1 (5-9 ft including sediment storage of 1 ft), d_1 | $d_1 =$ | 5 | ft |
| 3-4. Calculate the surface area for the water quality volume of Cell 1, $A_1 = V_1 / d_1$ | $A_1 =$ | 825 | ft ² |
| 3-5. Enter the width of Cell 1, $W_1 = W_{av-tot} = L_{berm}$ | $W_1 =$ | 43 | ft |
| 3-6. Calculate the length of Cell 1 (<u>Note:</u> inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W_1$ | $L_1 =$ | 19 | ft |

Step 4: Determine Dimensions of Cell 2

Verify that the surface area and length-to-width ratio of Cell 2 meet the design criteria. Calculate volumes, depths, and surface areas for the very shallow, shallow and deep zones.

| Step 4: Determine Dimensions of Cell 2 | | | |
|--|--------------|--------|-----------------|
| 4-1. Calculate the active volume of Cell 2, $V_2 = V_{wq} - V_1$ | $V_2 =$ | 23,375 | ft ³ |
| 4-2. Calculate surface area of Cell 2, $A_2 = A_{wq} - A_1$ | $A_2 =$ | 7,001 | ft ² |
| 4-3. Enter width of Cell 2, $W_2 = W_1 = W_{wq-tot} = L_{berm}$ | $W_2 =$ | 43 | ft |
| 4-4. Calculate top length of Cell 2, $L_2 = A_2 / W_2$ | $L_2 =$ | 163 | ft |
| 4-5. Verify that the length-to-width ratio of Cell 2 is at least 3:1 with $\geq 4:1$ preferred. If the length-to-width ratio is less than 3:1, modify input parameters until a ratio of at least 3:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen, $LW_2 = L_2 / W_2$ | | | |
| 4-6. Enter percent of surface area of very shallow zone, $\%A_{vs}$ | $\%A_{vs} =$ | 15 | ft ² |
| 4-7. Calculate very shallow zone surface area, $A_{vs} = (A_2 \cdot \%A_{vs})/100$ | $A_{vs} =$ | 1,050 | ft ² |
| 4-8. Enter average depth of very shallow zone (0.1 - 1 ft), d_{vs} | $d_{vs} =$ | 1 | ft |
| 4-9. Calculate volume of very shallow zone, $V_{vs} = A_{vs} \cdot d_{vs}$ | $V_{vs} =$ | 1,050 | ft ³ |
| 4-10. Enter width of very shallow zone, $W_{vs} = W_2$ | $W_{vs} =$ | 43 | ft |
| 4-11. Calculate length of very shallow zone, $L_{vs} = A_{vs} / W_{vs}$ | $L_{vs} =$ | 24 | ft |
| 4-12. Enter percent of surface area of shallow zone, $\%A_s$ | $\%A_s =$ | 55 | |
| 4-13. Calculate surface area of shallow zone, $A_s = (A_2 \cdot \%A_s)/100$ | $A_s =$ | 3,851 | ft ² |
| 4-14. Enter average depth of shallow zone (1 - 3 ft), d_s | $d_s =$ | 3 | ft |
| 4-15. Calculate volume of shallow zone, $V_s = A_s \cdot d_s$ | $V_s =$ | 11,552 | ft ³ |
| 4-16. Enter width of shallow zone, $W_s = W_2$ | $W_s =$ | 43 | ft |
| 4-17. Calculate length of shallow zone, $L_s = A_s / W_s$ | $L_s =$ | 90 | ft |
| 4-18. Calculate surface area of deep zone, $A_{deep} = A_2 - A_{vs} - A_s$ | $A_{deep} =$ | 2,100 | ft ² |
| 4-19. Calculate volume of deep zone, $V_{deep} = V_2 - V_{vs} - V_s$ | $V_{deep} =$ | 10,773 | ft ³ |
| 4-20. Calculate average depth of deep zone (3 - 5 ft), $d_{deep} = V_{deep} / A_{deep}$ | $d_{deep} =$ | 5 | ft |
| 4-21. Enter width of deep zone, $W_{deep} = W_2$ | $W_{deep} =$ | 43 | ft |
| 4-22. Calculate length of deep zone, $L_{deep} = A_{deep} / W_{deep}$ | $L_{deep} =$ | 49 | ft |

Step 5: Ensure Design Requirements and Site Conditions are Achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the wetland is inadequate to meet the design requirements, choose a new location for the wetland.

Step 6: Size Outlet Structure

Please refer to Appendix E for wetland outlet structure sizing methodologies and examples. The wetland outlet pipe shall be sized, at a minimum, to pass flows greater than the water quality design peak flow for off-line basins or flow from the capital storm for on-line basins.

Step 7: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass the capital design storm to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Wet Retention Basin Worksheet

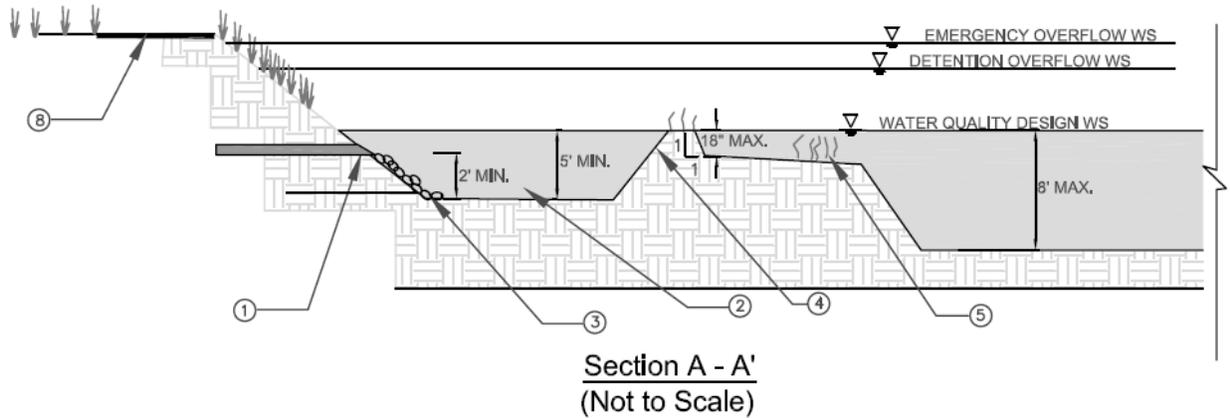


Figure D-8: Wet Retention Basin cross-section

Refer to Figure D-8 and Figure 6-24 for a diagrammatic description of the geometric variables.

| | |
|--|-------------------------|
| Step 1: Determine storm water quality design volume, V_{wq} | |
| 1-1. Determine the water quality design volume, V_{wq} , using SBUH method, Appendix C (Note: V_{wq} is always equal to $V_{one-inch}$) | $V_{wq} =$ _____ ft^3 |
| Step 2: Determine Active Design Volume for the Wet Pond without Extended Detention | |
| 2-1. Calculate the active design volume (without extended detention), $V_a = 1.05V_{wq}$ | $V_a =$ _____ ft^3 |

| Step 3: Determine Pond Location and Preliminary Geometry Based on Site Constraints | | |
|---|----------------------|-----------------|
| 3-1. Based on site constraints, determine the pond geometry and the storage available by developing an elevation-storage relationship for the pond. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2. | | |
| 3-2. Enter the total surface area of the pond footprint based on site constraints, A_{tot} | $A_{tot} =$ _____ | ft ² |
| 3-3. Enter the length of the pond footprint based on site constraints, L_{tot} | $L_{tot} =$ _____ | ft |
| 3-4. Calculate the width of the pond footprint, $W_{tot} = A_{tot} / L_{tot}$ | $W_{tot} =$ _____ | ft |
| 3-5. Enter interior side slope as length per unit height (min = 3), Z | $Z =$ _____ | |
| 3-6. Enter desired freeboard depth, d_{fb} | $d_{fb} =$ _____ | ft |
| 3-7. Calculate the length of the active volume surface area including the internal berm but excluding freeboard, $L_{av-tot} = L_{tot} - 2Zd_{fb}$ | $L_{av-tot} =$ _____ | ft |
| 3-8. Calculate the width of the active volume surface area including the internal berm but excluding freeboard, $W_{av-tot} = W_{tot} - 2Zd_{fb}$ | $W_{av-tot} =$ _____ | ft |
| 3-9. Calculate the total water quality surface area including the internal berm and excluding freeboard, $A_{av-tot} = L_{av-tot} \cdot W_{av-tot}$ | $A_{av-tot} =$ _____ | ft ² |
| 3-10. Enter the width of the internal berm (6 ft min), W_{berm} | $W_{berm} =$ _____ | ft |
| 3-11. Enter the length of the internal berm, $L_{berm} = W_{av-tot}$ | $L_{berm} =$ _____ | ft |
| 3-12. Calculate the area of the berm, $A_{berm} = W_{berm} \cdot L_{berm}$ | $A_{berm} =$ _____ | ft ² |
| 3-13. Calculate the active volume surface area excluding the internal berm and freeboard, $A_{av} = A_{av-tot} - A_{berm}$ | $A_{av} =$ _____ | ft ² |
| Step 4: Determine Dimensions of Cell 1 | | |
| 4-1. Enter the percent of V_a in Cell 1, $\%V_1$ | $\%V_1 =$ _____ | % |
| 4-2. Calculate the active volume of Cell 1 (including sediment storage), $V_1 = (V_a \cdot \%V_1)/100$ | $V_1 =$ _____ | ft ³ |
| 4-3. Enter desired average depth of Cell 1 (5-9 ft including sediment storage of 1 ft), d_1 | $d_1 =$ _____ | ft |
| 4-4. Calculate the surface area for the active volume of Cell 1, $A_1 = V_1 / d_1$ | $A_1 =$ _____ | ft ² |
| 4-5. Enter the width of Cell 1, $W_1 = W_{av-tot} = L_{berm}$ | $W_1 =$ _____ | ft |
| 4-6. Calculate the length of Cell 1 (<u>Note</u> : inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W_1$ | $L_1 =$ _____ | ft |

| Step 5: Determine Dimensions of Cell 2 | |
|--|---|
| 5-1. Calculate the active volume of Cell 2, $V_2 = V_a - V_1$ | $V_2 =$ _____ ft^3 |
| 5-2. Determine <u>minimum</u> wetpool surface area, $A_{\text{min}2} = V_2 \cdot 0.3$ | $A_{\text{min}2} =$ _____ ft^2 |
| 5-3. Determine actual wetpool surface area, $A_2 = A_{\text{av}} - A_1$ | $A_2 =$ _____ ft^2 |
| 5-4. If A_2 is greater than $A_{\text{min}2}$ then move on to step 5-5. If A_2 is less than $A_{\text{min}2}$, then modify input parameters to increase A_2 until it is greater than $A_{\text{min}2}$. If site constraints limit this criterion, then another site for the pond should be chosen. | |
| 5-5. Enter width of Cell 2, $W_2 = W_1 = W_{\text{av-tot}} = L_{\text{berm}}$ | $W_2 =$ _____ ft |
| 5-6. Calculate top length of Cell 2, $L_2 = A_2 / W_2$ | $L_2 =$ _____ ft |
| 5-7. Verify that the length-to-width ratio of Cell 2 is at least 1.5:1 with $\geq 2:1$ preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen, $LW_2 = L_2 / W_2$ | |
| | $LW_2 =$ _____ |
| 5-8. Enter percent of surface area that will be planted with emergent vegetation (25-75%), $\%A_{\text{ev}}$ | $\%A_{\text{ev}} =$ _____ $\%$ |
| 5-9. Calculate emergent vegetation surface area, $A_{\text{ev}} = (A_2 \cdot \%A_{\text{ev}}) / 100$ | $A_{\text{ev}} =$ _____ ft^2 |
| 5-10. Enter average depth of emergent vegetation shallow zone (1.5 - 3 ft), d_{ev} | $d_{\text{ev}} =$ _____ ft |
| 5-11. Calculate volume of emergent vegetation shallow zone (1.5 - 3 ft), $V_{\text{ev}} = A_{\text{ev}} \cdot d_{\text{ev}}$ | $V_{\text{ev}} =$ _____ ft^3 |
| 5-12. Enter width of emergent vegetation shallow zone, $W_{\text{ev}} = W_2$ | $W_{\text{ev}} =$ _____ ft |
| 5-13. Calculate length of emergent vegetation shallow zone, $L_{\text{ev}} = A_{\text{ev}} / W_{\text{ev}}$ | $L_{\text{ev}} =$ _____ ft |
| 5-14. Calculate volume in deep zone, $V_{\text{deep}} = V_2 - V_{\text{ev}}$ | $V_{\text{deep}} =$ _____ ft^3 |
| 5-15. Calculate surface area of deep (>3 ft) zone, $A_{\text{deep}} = A_2 - A_{\text{ev}}$ | $A_{\text{deep}} =$ _____ ft^2 |
| 5-16. Calculate the average depth in deep zone (4-8 ft), $d_{\text{deep}} = V_{\text{deep}} / A_{\text{deep}}$ | $d_{\text{deep}} =$ _____ ft |
| 5-17. Enter width of deep zone, $W_{\text{deep}} = W_2$ | $W_{\text{deep}} =$ _____ ft |
| 5-18. Calculate length of deep zone, $L_{\text{deep}} = A_{\text{deep}} / W_{\text{deep}}$ | $L_{\text{deep}} =$ _____ ft |
| Step 6: Ensure Design Requirements and Site Constraints are Achieved | |
| 6-1. Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the pond is inadequate to meet the design requirements, choose a new location for the pond. | |

Step 7: Size Outlet Structure

7-1. Please refer to Appendix D for pond outlet structure sizing methodologies and examples. The pond outlet pipe shall be sized, at a minimum, to pass flows greater than the water quality design peak flow for off-line basins or flow from the capital storm for on-line basins.

Step 8: Determine Emergency Spillway Requirements

8-1. For online basins, an emergency overflow spillway should be sized to pass the capital design storm to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Wet Retention Basin Design Example

Wet retention basin siting requires the following considerations prior to construction: (1) availability of base flow – wet retention basins require a regular source of water if water level is to be maintained, (2) surface space availability – large footprint area is required, and (3) compatibility with flood control – basins must not interfere with flood control functions of existing conveyance and detention structures.

The wet retention basin in this example does not have extended detention. An internal berm separates the forebay (Cell 1) and the main basin (Cell 2). The berm is at the elevation of the active volume design surface which is also the permanent wetpool elevation.

Step 1: Determine Water Quality Design Volume

For this design example, a 10-acre residential development with a 60% total impervious area is considered.

| Step 1: Determine storm water quality design volume, V_{wq} | |
|---|--|
| 1-1. Determine the water quality design volume, V_{wq} , using SBUH method, Appendix C (<u>Note</u> : V_{wq} is always equal to $V_{one-inch}$) | $V_{wq} = \underline{\hspace{2cm} 25,700 \hspace{1cm}} \text{ ft}^3$ |

Step 2: Determine Active Design Volume for a Wet Retention Basin without Extended Detention

If there is no extended detention provided, wet retention basins shall be sized to provide a minimum wet pool volume equal to the water quality design volume plus an additional 5% for sediment accumulation.

| Step 2: Determine Active Design Volume for the Wet Pond without Extended Detention | |
|---|---|
| 2-1. Calculate the active design volume (without extended detention), $V_a = 1.05V_{wq}$ | $V_a = \underline{\hspace{2cm} 26,985 \hspace{1cm}} \text{ ft}^3$ |

Step 3: Determine Retention Basin Location and Preliminary Geometry Based on Site Constraints

A total footprint area and total length available for the basin is provided. This step calculates the total active volume surface area which is equivalent to the permanent wetpool surface area. This step also calculates the dimensions of the internal berm.

| Step 3: Determine Pond Location and Preliminary Geometry Based on Site Constraints | | |
|---|----------------|-------------------------------|
| 3-1. Based on site constraints, determine the pond geometry and the storage available by developing an elevation-storage relationship for the pond. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2. | | |
| 3-2. Enter the total surface area of the pond footprint based on site constraints, A_{tot} | $A_{tot} =$ | <u>11,000</u> ft ² |
| 3-3. Enter the length of the pond footprint based on site constraints, L_{tot} | $L_{tot} =$ | <u>200</u> ft |
| 3-4. Calculate the width of the pond footprint, $W_{tot} = A_{tot} / L_{tot}$ | $W_{tot} =$ | <u>55</u> ft |
| 3-5. Enter interior side slope as length per unit height (min = 3), Z | $Z =$ | <u>3</u> |
| 3-6. Enter desired freeboard depth, d_{fb} | $d_{fb} =$ | <u>2</u> ft |
| 3-7. Calculate the length of the active volume surface area including the internal berm but excluding freeboard, $L_{av-tot} = L_{tot} - 2Zd_{fb}$ | $L_{av-tot} =$ | <u>188</u> ft |
| 3-8. Calculate the width of the active volume surface area including the internal berm but excluding freeboard, $W_{av-tot} = W_{tot} - 2Zd_{fb}$ | $W_{av-tot} =$ | <u>43</u> ft |
| 3-9. Calculate the total water quality surface area including the internal berm and excluding freeboard, $A_{av-tot} = L_{av-tot} \cdot W_{av-tot}$ | $A_{av-tot} =$ | <u>8,084</u> ft ² |
| 3-10. Enter the width of the internal berm (6 ft min), W_{berm} | $W_{berm} =$ | <u>6</u> ft |
| 3-11. Enter the length of the internal berm, $L_{berm} = W_{av-tot}$ | $L_{berm} =$ | <u>43</u> ft |
| 3-12. Calculate the area of the berm, $A_{berm} = W_{berm} \cdot L_{berm}$ | $A_{berm} =$ | <u>258</u> ft ² |
| 3-13. Calculate the active volume surface area excluding the internal berm and freeboard, $A_{av} = A_{av-tot} - A_{berm}$ | $A_{av} =$ | <u>7,826</u> ft ² |

Step 4: Determine Dimensions of Cell 1

It should be assumed that Cell 1 (the forebay) should be 20% of the total active design volume, V_a .

| Step 4: Determine Dimensions of Cell 1 | | | |
|--|-----------|-------|-----------------|
| 4-1. Enter the percent of V_a in Cell 1, $\%V_1$ | $\%V_1 =$ | 20 | % |
| 4-2. Calculate the active volume of Cell 1 (including sediment storage), $V_1 = (V_a \cdot \%V_1)/100$ | $V_1 =$ | 5,397 | ft ³ |
| 4-3. Enter desired average depth of Cell 1 (5-9 ft including sediment storage of 1 ft), d_1 | $d_1 =$ | 5 | ft |
| 4-4. Calculate the surface area for the active volume of Cell 1, $A_1 = V_1 / d_1$ | $A_1 =$ | 1,079 | ft ² |
| 4-5. Enter the width of Cell 1, $W_1 = W_{av-tot} = L_{berm}$ | $W_1 =$ | 43 | ft |
| 4-6. Calculate the length of Cell 1 (<u>Note</u> : inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W_1$ | $L_1 =$ | 25 | ft |

Step 5: Determine Dimensions of Cell 2

Verify that the surface area and length-to-width ratio of Cell 2 meet the design criteria. Calculate volumes, depths and surface areas for the emergent vegetation shallow zone and the deep zone.

| Step 5: Determine Dimensions of Cell 2 | | | |
|--|--------------|--------|-----------------|
| 5-1. Calculate the active volume of Cell 2, $V_2 = V_a - V_1$ | $V_2 =$ | 21,588 | ft ³ |
| 5-2. Determine <u>minimum</u> wetpool surface area, $A_{min2} = V_2 \cdot 0.3$ | $A_{min2} =$ | 6,476 | ft ² |
| 5-3. Determine actual wetpool surface area, $A_2 = A_{av} - A_1$ | $A_2 =$ | 6,747 | ft ² |
| 5-4. If A_2 is greater than A_{min2} then move on to step 5-5. If A_2 is less than A_{min2} , then modify input parameters to increase A_2 until it is greater than A_{min2} . If site constraints limit this criterion, then another site for the pond should be chosen. | | | |
| 5-5. Enter width of Cell 2, $W_2 = W_1 = W_{av-tot} = L_{berm}$ | $W_2 =$ | 43 | ft |
| 5-6. Calculate top length of Cell 2, $L_2 = A_2 / W_2$ | $L_2 =$ | 157 | ft |
| 5-7. Verify that the length-to-width ratio of Cell 2 is at least 1.5:1 with $\geq 2:1$ preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen, $LW_2 = L_2 / W_2$ | | | |
| | $LW_2 =$ | 4 | |

| Step 5: Determine Dimensions of Cell 2 | | |
|--|---------------------|------------------------|
| 5-8. Enter percent of surface area that will be planted with emergent vegetation (25-75%), %A _{ev} | %A _{ev} = | 25 % |
| 5-9. Calculate emergent vegetation surface area, A _{ev} = (A ₂ • %A _{ev})/100 | A _{ev} = | 1,687 ft ² |
| 5-10. Enter average depth of emergent vegetation shallow zone (1.5 - 3 ft), d _{ev} | d _{ev} = | 2 ft |
| 5-11. Calculate volume of emergent vegetation shallow zone (1.5 - 3 ft), V _{ev} = A _{ev} • d _{ev} | V _{ev} = | 3,373 ft ³ |
| 5-12. Enter width of emergent vegetation shallow zone, W _{ev} = W ₂ | W _{ev} = | 43 ft |
| 5-13. Calculate length of emergent vegetation shallow zone, L _{ev} = A _{ev} / W _{ev} | L _{ev} = | 39 ft |
| 5-14. Calculate volume in deep zone, V _{deep} = V ₂ - V _{ev} | V _{deep} = | 18,215 ft ³ |
| 5-15. Calculate surface area of deep (>3 ft) zone, A _{deep} = A ₂ - A _{ev} | A _{deep} = | 5,060 ft ² |
| 5-16. Calculate the average depth in deep zone (4-8 ft), d _{deep} = V _{deep} / A _{deep} | d _{deep} = | 4 ft |
| 5-17. Enter width of deep zone, W _{deep} = W ₂ | W _{deep} = | 43 ft |
| 5-18. Calculate length of deep zone, L _{deep} = A _{deep} / W _{deep} | L _{deep} = | 118 ft |

Step 6: Ensure Design Requirements and Site Conditions are Achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location for the basin.

Step 7: Size Outlet Structure

Please refer to Appendix F for basin outlet structure sizing methodologies and examples. The basin outlet pipe shall be sized, at a minimum, to pass flows greater than the water quality design peak flow for off-line basins or flow from the capital storm for on-line basins.

Step 8: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass the capital design storm to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Footnotes

Wetpool volumes less than or equal to 4,000 cubic feet (or 0.0918 acre-feet) may be single celled.

Dry Extended Detention Basin Worksheet

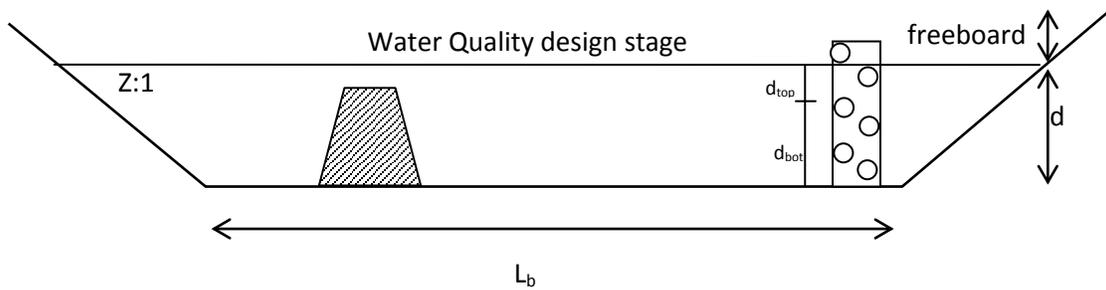


Figure D-9: Extended detention basin longitudinal profile

Refer to Figure D-9 and Figure 6-28 for a diagrammatic description of the geometric variables.

| Step 1: Determine design volume reduction, $V_{reduction}$ | |
|--|--------------------------------|
| 1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25} , calculated using SBUH method, Appendix C | $V_{25} =$ _____ ft^3 |
| 1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{one-inch}$, calculated using SBUH method, Appendix C | $V_{one-inch} =$ _____ ft^3 |
| 1-3. Determine design volume reduction which is the larger of V_{25} and $V_{one-inch}$ and is the volume to be retained on-site | $V_{reduction} =$ _____ ft^3 |
| Step 2: Determine storm water quality design volume, V_{wq} | |
| 2-1. Determine the water quality design volume, V_{wq} , using SBUH method, Appendix C (<u>Note</u> : V_{wq} is always equal to $V_{one-inch}$) | $V_{wq} =$ _____ ft^3 |
| Step 3: Determine design volume, V_{design} (for sizing) | |
| 3-1. $V_{design} =$ the larger of $V_{reduction}$ and V_{wq} | $V_{design} =$ _____ ft^3 |
| Step 4: Calculate the volume of the active basin | |
| 4-1. Calculate basin active volume, $V_a = 1.05V_{wq}$ | $V_a =$ _____ ft^3 |

Step 5: Determine Detention Basin Location and Preliminary Geometry Based on Site Constraints

5-1. Based on site constraints, determine the basin geometry and the storage available by developing an elevation-storage relationship for the basin. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2.

5-2. Enter the total surface area of the basin footprint based on site constraints, A_{tot}

$A_{tot} =$ _____ ft^2

5-3. Enter the length of the basin footprint based on site constraints, L_{tot}

$L_{tot} =$ _____ ft

5-4. Calculate the width of the basin footprint, $W_{tot} = A_{tot} / L_{tot}$

$W_{tot} =$ _____ ft

5-5. Enter interior side slope as length per unit height (min = 3), Z

$Z =$ _____

5-6. Enter desired freeboard depth, d_{fb}

$d_{fb} =$ _____ ft

5-7. Calculate the length of the active volume surface area including the internal berm but excluding freeboard, $L_{av-tot} = L_{tot} - 2Zd_{fb}$

$L_{av-tot} =$ _____ ft

5-8. Calculate the width of the active volume surface area including the internal berm but excluding freeboard, $W_{av-tot} = W_{tot} - 2Zd_{fb}$

$W_{av-tot} =$ _____ ft

5-9. Calculate the total active volume surface area including the internal berm and excluding freeboard, $A_{av-tot} = L_{av-tot} \cdot W_{av-tot}$

$A_{av-tot} =$ _____ ft^2

5-10. Enter the width of the internal berm (6 ft min), W_{berm}

$W_{berm} =$ _____ ft

5-11. Enter the length of the internal berm, $L_{berm} = W_{av-tot}$

$L_{berm} =$ _____ ft

5-12. Calculate the area of the berm, $A_{berm} = W_{berm} \cdot L_{berm}$

$A_{berm} =$ _____ ft^2

5-13. Calculate the water quality surface area excluding the internal berm and freeboard, $A_{av} = A_{av-tot} - A_{berm}$

$A_{av} =$ _____ ft^2

Step 6: Determine Dimensions of Cell 1

6-1. Enter the percent of V_a in Cell 1 (25% required), $\%V_1$

$\%V_1 =$ _____ $\%$

6-2. Calculate the active volume of Cell 1 (including sediment storage), $V_1 = (V_a \cdot \%V_1) / 100$

$V_1 =$ _____ ft^3

6-3. Enter a desired average depth for the active volume of Cell 1, d_1

$d_1 =$ _____ ft

6-4. Calculate the surface area for the active volume of Cell 1, $A_1 = V_1 / d_1$

$A_1 =$ _____ ft^2

6-5. Enter the width of Cell 1, $W_1 = W_{av-tot} = L_{berm}$

$W_1 =$ _____ ft

6-6. Calculate the length of Cell 1 (Note: inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W_1$

$L_1 =$ _____ ft

| Step 7: Determine Dimensions of Cell 2 | |
|--|--------------------------------|
| 7-1. Calculate the active volume of Cell 2, $V_2 = V_a - V_1$ | $V_2 =$ _____ ft^3 |
| 7-2. Calculate the surface area of the active volume of Cell 2, $A_2 = A_{av} - A_1$ | $A_2 =$ _____ ft^2 |
| 7-3. Calculate the average depth of the active volume of Cell 2, $d_2 = V_2 / A_2$ | $d_2 =$ _____ ft |
| 7-4. Enter the width of Cell 2, $W_2 = W_1 = W_{av-tot} = L_{berm}$ | $W_2 =$ _____ ft |
| 7-5. Calculate the length of Cell 2, $L_2 = A_2 / W_2$ | $L_2 =$ _____ ft |
| 7-6. Calculate the width of Cell 2 at half of d_2 , $W_{mid2} = W_2 - Zd_2$ | $W_{mid2} =$ _____ ft |
| 7-7. Calculate the length of Cell 2 at half of d_2 , $L_{mid2} = W_2 - Zd_2$ | $L_{mid2} =$ _____ ft |
| 7-8. Verify that the length-to-width ratio of Cell 2 at half of d_2 is at least 1.5:1 with $\geq 2:1$ preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the basin should be chosen, $LW_{mid2} = L_{mid2} / W_{mid2}$ | $LW_{mid2} =$ _____ |
| Step 8: Ensure Design Requirements and Site Constraints are Achieved | |
| 8-1. Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location. | |
| Step 9: Size Outlet Structure | |
| 9-1. Refer to Appendix F for basin outlet structure sizing methodologies and examples. The total drawdown time for the basin should be 48 hours. The outlet structure shall be designed to release the bottom 50% of the detention volume (half-full to empty) over 32 hours, and the top half (full to half-full) in 16 hours. A primary overflow should be sized to pass the peak flow rate from the developed capital design storm. | |
| Step 10: Determine Emergency Spillway Requirements | |
| 10-1. For online basins, an emergency overflow spillway should be sized to pass the capital design storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided. | |

Dry Extended Detention Basin Design Example

Step 1: Determine Storm Water Quality Design Volume Reduction, $V_{\text{reduction}}$

| Step 1: Determine design volume reduction, $V_{\text{reduction}}$ | | |
|--|--------------------------|------------------------|
| 1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25} , calculated using SBUH method, Appendix C | $V_{25} =$ | 20 ft ³ |
| 1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{\text{one-inch}}$, calculated using SBUH method, Appendix C | $V_{\text{one-inch}} =$ | 25,700 ft ³ |
| 1-3. Determine design volume reduction which is the larger of V_{25} and $V_{\text{one-inch}}$ and is the volume to be retained on-site, if practical and feasible | $V_{\text{reduction}} =$ | 25,700 ft ³ |

Step 2: Determine Storm Water Quality Design Volume, V_{wq}

| Step 2: Determine storm water quality design volume, V_{wq} | | |
|--|-------------------|------------------------|
| 2-1. Determine the water quality design volume, V_{wq} , using SBUH method, Appendix C (<u>Note</u> : V_{wq} is always equal to $V_{\text{one-inch}}$) | $V_{\text{wq}} =$ | 25,700 ft ³ |

Step 3: Determine Design Volume, V_{design}

| Step 3: Determine design volume, V_{design} (for sizing) | | |
|---|-----------------------|------------------------|
| 3-1. $V_{\text{design}} =$ the larger of $V_{\text{reduction}}$ and V_{wq} | $V_{\text{design}} =$ | 25,700 ft ³ |

Step 4: Calculate Volume of the Active Basin and the Forebay Basin

| Step 4: Calculate the volume of the active basin | | |
|---|---------|------------------------|
| 4-1. Calculate basin active volume, $V_a = 1.05V_{\text{wq}}$ | $V_a =$ | 26,985 ft ³ |

Step 5: Determine Detention Basin Location and Preliminary Geometry Based on Site Constraints

The detention basin in this example has an internal berm separating the forebay (Cell 1) and the main basin (Cell 2). The internal berm elevation is equivalent to the elevation of the active design volume. The berm length is equal to the width of the basin when filled to the active design volume.

| Step 5: Determine Detention Basin Location and Preliminary Geometry Based on Site Constraints | | |
|---|----------------|------------------------|
| 5-1. Based on site constraints, determine the basin geometry and the storage available by developing an elevation-storage relationship for the basin. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2. | | |
| 5-2. Enter the total surface area of the basin footprint based on site constraints, A_{tot} | $A_{tot} =$ | 11,000 ft ² |
| 5-3. Enter the length of the basin footprint based on site constraints, L_{tot} | $L_{tot} =$ | 200 ft |
| 5-4. Calculate the width of the basin footprint, $W_{tot} = A_{tot} / L_{tot}$ | $W_{tot} =$ | 55 ft |
| 5-5. Enter interior side slope as length per unit height (min = 3), Z | $Z =$ | 3 |
| 5-6. Enter desired freeboard depth, d_{fb} | $d_{fb} =$ | 2 ft |
| 5-7. Calculate the length of the active volume surface area including the internal berm but excluding freeboard, $L_{av-tot} = L_{tot} - 2Zd_{fb}$ | $L_{av-tot} =$ | 188 ft |
| 5-8. Calculate the width of the active volume surface area including the internal berm but excluding freeboard, $W_{av-tot} = W_{tot} - 2Zd_{fb}$ | $W_{av-tot} =$ | 43 ft |
| 5-9. Calculate the total active volume surface area including the internal berm and excluding freeboard, $A_{av-tot} = L_{av-tot} \cdot W_{av-tot}$ | $A_{av-tot} =$ | 8,084 ft ² |
| 5-10. Enter the width of the internal berm (6 ft min), W_{berm} | $W_{berm} =$ | 6 ft |
| 5-11. Enter the length of the internal berm, $L_{berm} = W_{av-tot}$ | $L_{berm} =$ | 43 ft |
| 5-12. Calculate the area of the berm, $A_{berm} = W_{berm} \cdot L_{berm}$ | $A_{berm} =$ | 258 ft ² |
| 5-13. Calculate the water quality surface area excluding the internal berm and freeboard, $A_{av} = A_{av-tot} - A_{berm}$ | $A_{av} =$ | 7,826 ft ² |

Step 6: Calculate Dimensions of Cell 1

Calculate the dimensions of the forebay (Cell 1) based on the active design volume for Cell 1 (25% of V_a) and a desired average depth, d_1 . The width of the forebay, W_1 , is equivalent to the length of the berm, L_{berm} , and the width of Cell 2, W_2 .

| Step 6: Determine Dimensions of Cell 1 | | | |
|--|-----------|-------|---------------|
| 6-1. Enter the percent of V_a in Cell 1 (25% required), $\%V_1$ | $\%V_1 =$ | 25 | % |
| 6-2. Calculate the active volume of Cell 1 (including sediment storage), $V_1 = (V_a \cdot \%V_1)/100$ | $V_1 =$ | 6,746 | ft^3 |
| 6-3. Enter a desired average depth for the active volume of Cell 1, d_1 | $d_1 =$ | 5 | ft |
| 6-4. Calculate the surface area for the active volume of Cell 1, $A_1 = V_1 / d_1$ | $A_1 =$ | 1,349 | ft^2 |
| 6-5. Enter the width of Cell 1, $W_1 = W_{\text{av-tot}} = L_{\text{berm}}$ | $W_1 =$ | 43 | ft |
| 6-6. Calculate the length of Cell 1 (<u>Note</u> : inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W_1$ | $L_1 =$ | 31 | ft |

Step 7: Calculate the Dimensions of Cell 2

Calculate the dimensions of the main basin (Cell 2) based on the active design volume for Cell 2 and a desired average depth, d_2 . A calculation of the length, L_{mid2} , and width, W_{mid2} , at half basin depth, d_2 , is conducted in order to verify that the length-to-width ratio at half d_2 is greater than 1.5:1.

| Step 7: Determine Dimensions of Cell 2 | | | |
|---|---------------|--------|-----------------|
| 7-1. Calculate the active volume of Cell 2, $V_2 = V_a - V_1$ | $V_2 =$ | 20,239 | ft ³ |
| 7-2. Calculate the surface area of the active volume of Cell 2, $A_2 = A_{av} - A_1$ | $A_2 =$ | 6,477 | ft ² |
| 7-3. Calculate the average depth of the active volume of Cell 2, $d_2 = V_2 / A_2$ | $d_2 =$ | 3 | ft |
| 7-4. Enter the width of Cell 2, $W_2 = W_1 = W_{av-tot} = L_{berm}$ | $W_2 =$ | 43 | ft |
| 7-5. Calculate the length of Cell 2, $L_2 = A_2 / W_2$ | $L_2 =$ | 151 | ft |
| 7-6. Calculate the width of Cell 2 at half of d_2 , $W_{mid2} = W_2 - Zd_2$ | $W_{mid2} =$ | 34 | ft |
| 7-7. Calculate the length of Cell 2 at half of d_2 , $L_{mid2} = W_2 - Zd_2$ | $L_{mid2} =$ | 52 | ft |
| 7-8. Verify that the length-to-width ratio of Cell 2 at half of d_2 is at least 1.5:1 with $\geq 2:1$ preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the basin should be chosen, $LW_{mid2} = L_{mid2} / W_{mid2}$ | $LW_{mid2} =$ | 1.6 | |

Step 8: Ensure Design Requirements and Site Constraints are Achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location.

Step 9: Size Outlet Structure

Refer to Appendix F for basin outlet structure sizing methodologies and examples. The total drawdown time for the basin should be 48 hours. The outlet structure shall be designed to release the bottom 50% of the detention volume (half-full to empty) over 32 hours, and the top half (full to half-full) in 16 hours. A primary overflow should be sized to pass the peak flow rate from the developed capital design storm.

Step 10: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass the capital design storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.