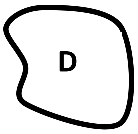
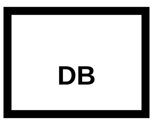
3.4 Post Construction Stormwater Control Fact Sheets (PTP)

Post Construction Stormwater Control Practices	**PTP-08 Dry Detention/Dry ED Ponds**



Symbol



TSS Reduction: 60%

Description

KEY CONSIDERATIONS

- Applicable for drainage areas up to 75 acres
- Typically less costly than stormwater (wet) ponds for equivalent flood storage, as less excavation is required
- Often used in conjunction with water quality structural control
- Recreational and other open space opportunities between storm runoff events
- Typical BMP used in residential landuse

Dry detention and dry extended detention (ED) ponds are surface facilities intended to provide for the temporary storage of stormwater runoff to reduce downstream water quantity impacts. These facilities temporarily detain stormwater runoff, releasing the flow over a period of time. They are designed to completely drain following a storm event and are normally dry between rain events. Dry detention ponds are intended to provide overbank flood protection (peak flow reduction of the 25-year storm, Q_{p25}) and can be designed to control the extreme flood (100-year, Q_{p100}) storm event. Dry ED ponds provide Q_{p25} and Q_{p100} control. Both dry detention and dry ED ponds provide limited pollutant removal benefits and are not intended for water quality treatment. Detention-only facilities must be used in a treatment train approach with other structural controls the 80% TSS reduction goal. Compatible multi-objective use of dry detention facilities in strongly encouraged.

Applications

BMP Suitability

- Used for residential, commercial and industrial sites
- Large space requirement
- Not well-suited for sites with
  - Low relief
  - High water table
  - Near-surface bedrock
- Safety concerns should be considered in deciding BMP use
- Extended detention ponds can be sized to treat WQ_v.
- Cannot be used alone to meet the 80% TSS reduction goal. Must be used in a treatment train.
- Suitable for a secondary or end-of-pipe BMP at the downstream end of a treatment train.
- This BMP is prone to sediment re-suspension since the pond does not have a permanent pool
- This BMP's performance may be enhanced by using multiple treatment cells in succession.
- Use of upstream BMPs may also reduce the required detention pond size and outflow regulation requirements.

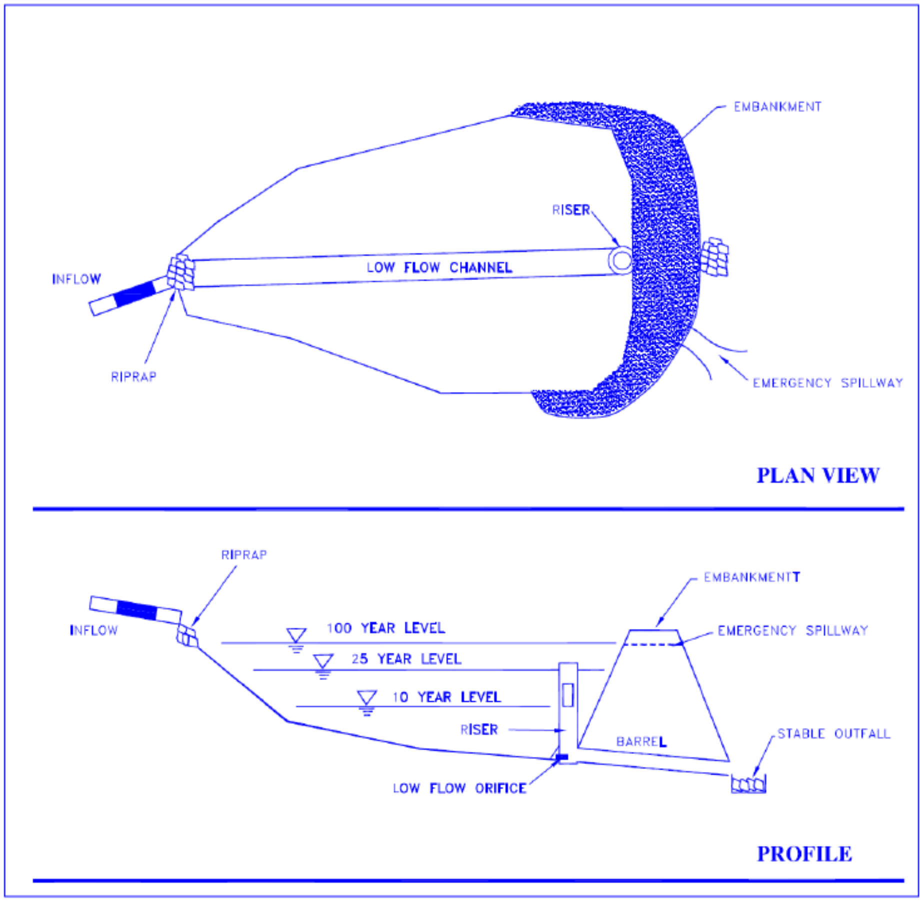


Figure PTP-08- 1 Detention Pond
Source, Center for Watershed Protection

Maintenance

A site-specific maintenance plan describing maintenance responsibilities must be developed. that addresses the following items:

- Maintenance access for appropriate equipment, vehicles, and personnel
- Vegetation maintenance schedule that includes mowing multiple times per year
- Inspection checklist
- Maintenance agreement between the facility owner and the City with these items:
  - Sediment removal from the forebay and/or pond when sediment depth is ½ of the total depth to the outlet, or is greater than 1.5 feet (whichever is less)
  - Clean and/or repair outlet devices if drawdown times exceed 48 hours
  - Trash and debris should be removed as necessary
- Grass cover filters should be mowed as needed (maximum grass height of 12 inches)
- Properly dispose of any material generated during maintenance activities.

Maintenance

Monthly to Quarterly or After Major Storms (>1")

Check that the maintenance access is free and clear.

- Inspect low flow orifices and all pipes for clogging.
- Check the pond area for debris, bare soil areas and undesirable vegetation.
    - The minimum mowing requirements will be a spring mowing and a fall mowing.
    - Remove debris.
    - Repair undercut, eroded and bare soil areas.
- Look for damaged safety measures or other dangerous items.

Semi-Annual to Annual

- Ensure that the pond's mechanical components (if any) are functional. Repair broken mechanical components if needed.

1-3 Years

- Inspect riser, barrel and embankment for damage. Make any needed repairs.
- Inspect all pipes.
- Monitor sediment deposition in the pond and in the forebay. Remove sediment from the forebay and the pond when needed.

5-25 Years

- Use remote television inspection of the reverse slope pipes, underdrains or other hard-to-access piping. If needed, replace or repair pipes.

Embankment

The pond embankment and/or riser will require inspection by a qualified professional (e.g., structural engineer, geotechnical engineer, etc.) who has experience in the construction, inspection and repair of these features.

Inspection Checklist

All appropriate items should be checked on the inspection checklist. If an applicable item does not meet the condition on the checklist, maintenance and/or repair should be planned.

Monthly

- ❑ Maintenance access is free and clear
- ❑ Low flow orifice(s) and pipes are free from clogging.
- ❑ Pond areas are free of debris.
- ❑ Pond area is stabilized with no evidence of erosion.
- ❑ Pond areas do not include any undesirable vegetation (i.e., woody vegetation near the embankment, etc.).
- ❑ Pond vegetation is mown with grass height no greater than 12 inches.
- ❑ There are no damaged safety measures or other dangerous items at the pond.

Semi-Annual to Annual

- ❑ The pond's mechanical components (if any) are functional.

1-3 Years

- ❑ The riser, barrel and embankment were inspected for damage and do not require repairs.
- ❑ All pipes were inspected and do not require repairs or replacement.
- ❑ The sediment deposition in the pond and in the forebay was checked, and, if needed, sediment was removed from these areas.

5-25 Years

- ❑ Use remote television inspection of the reverse slope pipes, underdrains or other hard-to-access piping. If needed, replace or repair pipes.

Design Criteria

Location and Layout

- As dry detention and dry ED ponds provide limited water quality benefits, they are to be located downstream of other structural stormwater controls providing treatment of the water quality volume (WQ_v) to meet the 80% TSS reduction goal.
- The maximum contributing drainage area to be served by a single dry detention or dry ED pond is 75 acres.
- A minimum separation distance between the pond and the groundwater table and/or an impervious liner may be required for ponds where source water protection is required or for contributing drainage areas designated with “hot spot” landuses.

General Design

- Dry detention ponds are sized to temporarily store the volume of runoff required to provide Q_{p25} protection (i.e., reduce the post-development peak flow of the 25-year storm event to the pre-development rate), and control the 100-year storm (Q_{p100}) if required. The dry detention pond should be sized to release the WQ_v over 24 to 36 hours.

  Dry ED ponds are sized to provide extended detention of the water quality volume over 24 hours and can also provide additional storage volume for normal detention (peak flow reduction). Routing calculations must be used to demonstrate that the storage volume is adequate for peak flow attenuation (see Appendix B).
- The dry pond or ED pond must be installed in series with other water quality BMPs to achieve the 80% TSS reduction goal.
- The maximum depth of the pond should not exceed 10 feet.
- Areas above the normal high water elevations of the detention facility should be sloped toward the pond to allow drainage and to prevent standing water. Careful finish grading is required to avoid creation of upland surface depressions that may retain runoff. The bottom area of storage facilities should be graded toward the outlet to prevent standing water conditions. A low flow or pilot channel across the facility bottom from the inlet to the outlet (often constructed with concrete) is recommended to convey low flows and prevent standing water conditions.
- For karst areas, it is recommended that ponds use an impermeable liner and include a minimum three foot separation from the high water table.
- A landscaping plan must address how the pond and the surrounding areas will be stabilized and how vegetation will be established. This plan should include maintenance actions and schedules for the vegetation.
- Pre-treatment measures such as other water quality BMPs and/or forebay(s) are desirable. For areas receiving drainage from potential “hot spot” landuse areas, the pre-treatment measures may need an impermeable liner and/or other separation to keep stormwater separated from groundwater.

Design Criteria

- Direct vehicle/equipment access should be required for forebays to allow for sediment removal and maintenance.
- The bottom of the forebay may be hardened using concrete, asphalt or grouted riprap to make sediment removal easier.

Inlet and Outlet Structures

- Inflow channels are to be stabilized with flared riprap aprons, or the equivalent.
- Pond outlets must be designed to prevent discharge of floating debris.
- Burying all pipes below the frost line can prevent frost heave and pipe freezing.
- A riser or an alternative method may be used for the pond's principal spillway. This riser must include a low flow orifice to allow the pond to fully dewater for a dry pond.
- The outflow riser should be located so that short-circuiting between inflow points and riser does not occur.
- Riprap, plunge pools or pads, or other energy dissipators are to be placed at the end of the outlet to prevent scouring and erosion.

Embankment

- Vegetated embankments shall be less than 20 feet in height and shall have side slopes no steeper than 2:1 (horizontal to vertical) although 3:1 is preferred. Riprap-protected embankments shall be no steeper than 2:1. Geotechnical slope stability analysis is recommended for embankments greater than 10 feet in height and is mandatory for embankment slopes steeper than those given above. All embankments must be designed to State of Kentucky guidelines for dam safety.
- Seepage control or anti-seep collars should be provided for all outlet pipes.
- A minimum of 1 foot of freeboard above the elevation corresponding with the Q_{p100} must be provided for earthen embankments. For dug ponds, the freeboard must be provided and identified in the area of inundation.

Maintenance and Safety

- Adequate maintenance access must be provided for all dry detention and dry ED ponds. One approach for this is to incorporate an access bench (a shallow slope area adjacent to the pond) that will be used for equipment access.
- The forebay of the pond should include a fixed vertical sediment depth marker securely installed in the forebay. This marker will be used as an indicator for when sediment removal is needed in the forebay. Sediment removal should occur for forebay areas when 50% of the total forebay storage capacity is filled with sediment.
- The riser configuration should be planned for future maintenance, lessening the clogging potential, planning access for inspections and maintenance, and safety from improper access by children and/or vandals.

Design Criteria

- Public safety must be considered in every aspect of the pond design.
- Dam safety regulations must be strictly followed in pond design and maintenance to ensure that downstream property and structures are adequately protected.
- OSHA safety procedures must be followed for maintenance activities in enclosed areas, such as outlet structures.

Design Components

Pre-Treatment

- A sediment forebay sized to 0.1 inches per impervious acre of contributing drainage should be provided for dry detention and dry ED ponds that are in a treatment train with off-line water quality treatment structural controls. This forebay may be a small pool separated from the pond area by barriers such as earthen berms, concrete weirs or gabion baskets.

Inlet and Outlet Structures

- Where the outlet structure is connected to an improved sinkhole, zero drawdown through the sinkhole must be assumed.
- For a dry ED pond, a low flow orifice capable of releasing the water quality volume over 24 hours must be provided. The water quality protection orifice should have a minimum diameter of 3 inches and should be adequately protected from clogging by an acceptable external trash rack. The orifice diameter may be reduced to 1 inch if internal orifice protection is used (e.g., an over perforated vertical stand pipe with 0.5-inch orifices or slots that are protected by wire cloth and a stone filtering jacket). Adjustable gate valves can also be used to achieve this equivalent diameter.
- For a dry detention pond, the outlet structure shall be sized according to the detention requirements found in Warren County Government's Subdivision Regulations, Appendix B, and can consist of a weir, orifice, outlet pipe, combination outlet, or other acceptable control structure. Small outlets that will be subject to clogging or are difficult to maintain are not acceptable.
- An emergency spillway is to be included in the stormwater pond design to safely pass the extreme flood flow. The spillway prevents pond water levels from overtopping the embankment and causing structural damage. The emergency spillway must be designed to State of Kentucky guidelines for dam safety and must be located so that downstream structures will not be impacted by spillway discharges.
- A riser or an alternative method may be used for the pond's principal spillway. This riser must include a low flow orifice to allow the pond the fully dewater for a dry pond.
    - For perforated risers, the minimum opening diameter should be ½ inch and the minimum pipe diameter is 8 inches.
    - The low flow orifice for the riser must be adequately protected from clogging. This protection may be an acceptable external trash rack (recommended minimum orifice diameter of 3 inches) or a smaller orifice diameter may be used along with internal orifice protection (recommended minimum diameter of 1 inch).
    - One example alternative method would be to use a broad crested, rectangular, V-notch or proportional weir, protected by a half-round CMP.

Design Components

- The pond must include an emergency spillway to pass storm events in excess of the pond's hydraulic design. The emergency spillway must be stabilized to prevent erosion, must comply with state dam safety requirements and must be located so that downstream structures will not be impacted by spillway discharges. If the emergency spillway crosses the maintenance access for the pond, materials meeting the appropriate load requirements must be selected.
- Riprap, plunge pools or pads, or other energy dissipators are to be placed at the end of the outlet to prevent scouring and erosion. If the pond discharges to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance.
- For outlets, it is recommended that a stilling pond or outlet protection be used to reduce outflow velocities to non-erosive velocities and sheer stresses.

Pond

As dry detention and dry ED ponds provide limited water quality benefits (60% TSS reduction), they are to be located downstream of other structural stormwater controls providing treatment of the water quality volume (WQ_v) to provide the full 80% TSS reduction.

- Adequate maintenance access must be provided for all dry detention and dry ED ponds. One approach for this is to incorporate an access bench (a shallow slope area adjacent to the pond) that will be used for equipment access.
  - The recommended access bench width is 10 feet (minimum 8 feet).
  - The maximum access bench cross-slope should be 0.06:1 (V:H) or 6%.
  - Use a maximum bench slope of 0.15:1 (V:H).
  - The bench should be appropriately stabilized for vehicle and equipment access.
  - This bench may also consider extending to other areas such as forebays, inlet and outlet, and should also consider the need for vehicle turn around space.
  - Access benches are not needed for ponds with side slopes that are 1:4 (V:H) or flatter.
  - The recommended maintenance access will connect with a maintenance right-of-way or easement (if needed) that will extend from the pond to a public or a private road.
- The maximum contributing drainage area to be served by a single dry detention or dry ED pond is 75 acres.
- The minimum length to width ratio for the pond is 1.5:1.
- It is recommended that the pond's footprint cover approximately 1-3% of the contributing drainage area.

Design Components

- A minimum separation distance between the pond and the groundwater table and/or an impervious liner may be required for ponds where source water protection is required or for contributing drainage areas designated as "hot spots".
- Side slopes should not exceed 1V:3H.
- The slopes immediately adjacent to the pond should be less than 25% but greater than 0.5-1% to maintain positive drainage toward the pond.
- For karst areas, it is recommended that ponds use an impermeable liner and include a minimum three foot separation from the barotic rock layer. Liner options include a layer of 6-12 inches of clay soil including bentonite (minimum 15% passing the #200 sieve and a maximum permeability of 1X 10^{-5} cm/sec), a 30 mL polyliner or another approved engineering design.
- A landscaping plan must address how the pond and the surrounding areas will be stabilized and how vegetation will be established. This plan should include maintenance actions and schedules for the vegetation.
- Inspections during construction are needed to confirm that the pond is being built according to the approved design standards and specifications. A detailed construction inspection checklist should be developed that will include sign-offs by qualified individuals at critical construction stages to ensure that the contractor's interpretation of the plan is acceptable to the project's professional designer. As-built inspection documentation is required.

Embankment

- Vegetated embankments shall be less than 20 feet in height and shall have side slopes no steeper than 2:1 (horizontal to vertical) although 3:1 is preferred. Riprap-protected embankments shall be no steeper than 2:1. Geotechnical slope stability analysis is recommended for embankments greater than 10 feet in height and is mandatory for embankment slopes steeper than those given above. All embankments must be designed to State of Kentucky guidelines for dam safety.
- Seepage control or anti-seep collars should be provided for all outlet pipes.
- A minimum of 1 foot of freeboard must be provided, measured from the top of the water surface elevation for the extreme flood, to the lowest point of the dam embankment not counting the emergency spillway.
- For earthen embankments, suitable soils must be used to construct the embankment.
- Woody vegetation should not be planted or allowed to grow within 15 feet of the embankment toe and within 25 feet of the inlet and outlet structures.

Design Procedure

Step 1 – Make a preliminary judgment as to whether site conditions are appropriate for the use of a dry pond or dry ED pond, and identify the function of the pond in the overall treatment system. This includes performing an initial suitability screening for the site.

- Consider basic issues for initial suitability screening, including:
  - Site drainage area
  - Site topography and slopes
  - Soil characteristics
  - Depth to water table and bedrock
  - Presence of active karst features and/or wetlands
  - Post-development landuse (Is it a potential "hot spot" landuse?)
- Determine how the dry pond or dry ED pond will fit into the overall stormwater treatment system.
  - Keep in mind that other water quality BMPs are needed upslope of the pond for impervious area drainage, and that the pond cannot be a primary water quality BMP.
  - Decide where on the site the pond is most likely to be located.
- Determine how the dry pond or dry ED pond will fit into the overall stormwater treatment system.

Step 2 – Confirm design criteria, site constraints and applicability.

- Determine the design criteria that will be used.
  - Local construction and stormwater requirements
  - State stream construction permitting (if in a floodplain area)
  - State dam safety guidance (for ponds with embankments)
  - Any other criteria or restrictions that apply
- Determine any constraints the site will place on the pond such as:
  - Limited amount of space and surface area available for treatment
  - High water table
  - Active karst areas
- Determine the TSS reduction provided, using the equations below for weighted TSS reduction, $TSS_{weighted}$, and TSS treatment train, TSS_{train}. The minimum TSS reduction required for the site is 80% and can be weighted for the site.

$$\%TSS_{\text{weighted}} = \frac{\sum_n^1 (TSS_1 A_1 + TSS_2 A_2 + ... + TSS_n A_n)}{\sum_n^1 (A_1 + A_2 + ... + A_n)}$$

Where runoff is treated by two or more BMPs in series, the TSS reduction provided is calculated with the following equation for a treatment train:

Design Procedure

$$TSS_{train} = A + B - \frac{(A \times B)}{100}$$

Where A is the TSS reduction provided by the first BMP and B is the TSS reduction provided by the next BMP.

Step 3 –Confirm site suitability, including field verification of site suitability.

- The field verification should be conducted by a qualified geotechnical professional.
- The recommended minimum is one soil boring per acre with a minimum of three soil borings or pits dug at the same location as the proposed pond. The borings or pits will be used to verify soil types and to determine the depth to groundwater and bedrock.
- The recommended minimum depth of the soil borings or pits is five feet below the bottom elevation of the proposed pond.

Step 4 – Compute runoff control volumes and peak flows. Refer to Chapter 2 and Appendix B for more information on these values. Note that this design is only for water quality treatment, not *quantity* control. Therefore, only TSS reduction and WQ_v design is included.

- Calculate the Water Quality Volume (WQ_V).

  $$WQ_v = [P\ Rv)(A)]/12$$

  Where:

  P = is the average rainfall, (inches)

  R_V = 0.05 + 0.009(I), where I is the percent impervious cover

  A = the area of imperviousness, (acres)

- Calculate the peak flow for the Water Quality Volume (Q_{wq}).

  $$Q_{wq} = C \times I_{WQ} \times A$$

  Where:

  Q_{wq} = the water quality volume peak flow, (cfs)

  C = the runoff coefficient

  I_{WQ} = the rainfall intensity, (in/hr)

  A = the area of imperviousness, (acres)

- Calculate the volume for the Peak Flow attenuation. See appendix B for more information on detention requirements.

  If the pond will be used as the only BMP for rate control for larger storms, the pond should be designed to treat the entirety of each of these runoff control volumes. If other BMPs will be used to control portions of these runoff control volumes, the portion handled by other BMPs may be subtracted from the appropriate volumes to determine the volumes to be controlled in the pond.

Design Procedure

Note: Steps 5 – 12 may be iterative to achieve a pond design that meets the required performance and the site constraints.

Step 5 – Determine the pond location and preliminary geometry.

- Use the following steps to develop the preliminary grading plan for the pond.
  - Locate the pond at the site's lowest elevation area that is not in a jurisdictional wetland or active karst area. Provide space around the pond for maintenance access (minimum width of 8 feet, recommended minimum width of 10 feet).
  - Provide storage based on the water quality volume (WQ_V), volume for the Q_{p25} and Q_{p100}. .
  - Considering the desired pond footprint during the WQ_V, allocate storage volume above the riser bottom orifice for WQ_V. Flow attenuation must be provided for the Q_{p25} and Q_{p100}. While developing the grading plan, consider the desired (or required) length to width ratio and side slopes based on the Design Criteria and Design Components information.
  - Once the preliminary grading plan has been developed, determine the associated stage-storage relationship for water surface elevations through the maximum expected levels.
- Use the average end area method (or other equivalent method) to calculate the approximate storage at a given stage (elevation). The area within each of the closed contour lines on the pond's grading plan is measured. The average area is calculated between two adjacent contours. The average areas are then multiplied by the elevation difference to calculate the approximate volume between the two contours.

$$\boldsymbol{V_{1-2} = \frac{A_1 + A_2}{2} \times (E_2 - E_1)}$$

Where:

V_{1-2} = the volume between contour 1 and contour 2 (acre-feet)

A_1 and A_2 = the areas within closed contours 1 and 2, respectively (acres)

E_1 and E_2 = the elevations of contours 1 and 2, respectively (feet)

The cumulative pond volume above the bottom of the pond can be calculated by adding the incremental volumes. The stages (elevations) and the corresponding storages can be used to develop a stage-storage-discharge table as the outlet structures are designed. This is an iterative process that may require revising the preliminary grading plan and recalculating the stage-storage relationship until all of the items in Design Criteria and Design Components are satisfied.

STEP 6 – Determine the pre-treatment volume for the sediment forebay.

- Where there are no adequate upstream treatment BMPs, a sediment forebay or a similarly performing treatment system is recommended at each inlet to the pond that conveys 10% or more of the total design inflow.

Design Procedure

- The recommended forebay volume is 10% of the WQ_v with a depth of 4-6 feet. More shallow depths increase the potential for sediment re-suspension in the forebay.
- Both the storage volume of the forebay and the storage volumes for other water quality BMPs upstream in the treatment train count toward the required water quality volume, and may be subtracted from the total water quality volume required.

STEP 7 – Size and design the outlet structures.

- The pond must include the following outlet stages in the pond design. It is possible to design one device to meet all required stages.
- The assumed water quality volume (low flow) outlet is an orifice at the bottom of the riser designed to release WQ_v with an average detention time of 24 hours. After designing the low flow orifice, the design should be checked to verify that the release rate is no greater than 5.66 cfs/acre of pond surface area.
- The pond must also be designed to meet the requirements of Warren County Government's Subdivision Regulations, Appendix B.
- The following outlet equations are based on assumptions about the outlet structure type that will be used to control flows at various stages. If a different structure type is selected, the designer must use specific equations for structure type to determine the stage-discharge relationships. However, the general design approach will remain the same even if a different outlet structure type is used for the pond calculations.
- The average release rate of WQ_v (Q_{WQ_avg}) is calculated using the following equation: Hydrologic software can be used for determining the release rate and stage-storage table.

$$Q_{WQ\_avg} = \frac{WQ_v}{t_{WQ}}$$

Where:

Q_{WQ_avg} = average release rate of WQ_v (cfs)

t_{WQ} = the intended WQ_v detention time (seconds)

WQ_v = water quality volume (cubic feet)

- From the stage-storage table, find the elevation associated with WQ_v. Calculate the approximate average head (in feet) on the water quality outlet (h_{wq_avg}) using the following equation:

$$h_{wq\_avg} = \frac{E_{WQ} - E_{PermPool}}{2}$$

Where:

h_{wq_avg} = average head on the water quality outlet (feet)

E_{WQ} = the WQ_v pool elevation (feet)

$E_{PermPool}$ = the permanent pool elevation (feet) at the invert of the water quality orifice. For a dry pond, this elevation is at the bottom of the pond.

Design Procedure

- Using the determined opening and spillway information, incorporate the outlet structures into the pond design. Keep in mind that the spillway design must also consider using measures such as removable trash racks to prevent the discharge of floating debris.

STEP 8 – Design the spillways and embankments.

- All spillway and embankment design must meet any applicable state and/or local criteria.
- The emergency spillway must be stabilized.
- The embankments must be overfilled by at least 5% to allow for settling.
- The minimum embankment with is 6 feet. A wider embankment width may be preferred for maintenance access.
- All embankments must be adequately stabilized with appropriate non-woody vegetation or other measures.
- The embankment and spillway side slopes should be no steeper than 1:3 (V:H).
- Using the determined opening and spillway information, incorporate the outlet structures into the pond design. Keep in mind that the spillway design must also consider using measures such as removable trash racks to prevent the discharge of floating debris.

STEP 9 – Design the inlets.

- If inflow inlet pipes are used, it is recommended that the pipes be buried below the frost line.
- Inlet design should consider preventing or reducing scour by including riprap or flow diffusion devices such as plunge pools or berms.

STEP 10 – Design the sediment forebay.

- The sediment forebay size was determined in Step 6.
- The bottom of the forebay may be hardened using concrete, asphalt or grouted riprap to make sediment removal easier.
- The forebay outlets should include non-erosive conditions as flows move from the forebay to the pond.
- The forebay of the pond should include a fixed vertical sediment depth marker securely installed in the forebay. This marker will be used as an indicator for when sediment removal is needed in the forebay. Sediment removal should occur for forebay areas when 50% of the total forebay storage capacity is filled with sediment.

STEP 11 – Design the maintenance access and safety features.

- Maintenance access and safety features should meet the requirements included in the Design Criteria and Design Component sections.
- Any additional safety features or signage should be added as appropriate.

Design Procedure

- Calculate the required orifice cross-sectional area indirectly by using the orifice equation.

$$Q_{WQ\_avg} = CA_{WQ}\sqrt{2gh_{wq\_avg}}$$

Where:

C = the orifice coefficient (0.6 is typically used, but not apply for all cases)

A_{WQ} = the orifice area (square feet)

g = gravitational acceleration (32.2 feet/s^2)

- Calculate the orifice diameter using the following equation:

$$d_{WQ} = 2\sqrt{\frac{A_{WQ}}{\pi}}$$

Where:

d_{WQ} = the orifice diameter (feet)

- The rate of discharge for the orifice for any head value at the water quality orifice (h_{WQ}) can be calculated using:

$$Q_{WQ} = CA_{WQ}\sqrt{2gh_{WQ}}$$

Where:

Q_{WQ} = the orifice discharge rate at head h_{WQ} (cfs)

h_{WQ} = the head value above the water quality orifice (feet)

- Calculate the control for the 25-year, 24-hour runoff peak flow (Q_{P25}). The calculation procedures will be similar to those used for the low flow orifice except that any higher outflow openings (i.e., perforated riser openings, weir, orifices, etc.) would be included as well. The combined outflow from all openings must be such that the post-development Q_{P25} does not exceed the pre-development Q_{P25}.
- The combined outflow from the low flow orifice and any higher outflow openings is calculated by adding together the discharges from each structures associated with a given head value and a specified pond water surface elevation.
- Calculate the required control for the 100-year storm peak flow (Q_{p100}). If required, the post-development Q_{p100} must be no greater than the pre-development Q_{p100}. At minimum, Q_{p100} must be able to be safely passed through the pond with 1-2 feet of freeboard below the top of the embankment. Check with local officials and/or state dam safety personnel to determine whether Q_{p100} may be passed using only a principal spillway, or if a combination of a principal spillway and emergency spillway will be required. If an emergency spillway is required, the spillway type is often a broad-crested weir or similar structure that is not easily obstructed. The combined outflow through all spillway openings is calculated by adding together the discharges for each opening associated with a given head value and a specified water surface elevation.

Design Procedure

- Dam safety regulations must be strictly followed in pond design and maintenance to ensure that downstream property and structures are adequately protected.

- OSHA safety procedures must be followed for maintenance activities in enclosed areas, such as outlet structures.

STEP 12 – Check the expected pond performance against regulatory requirements.

- The pond design should be re-checked to confirm that the pond meets the flow control requirements.
- The average detention time for WQ_v is 12 hours. The release rate for WQ_v should not exceed 5.66 cfs per acre of pond area.
- Post-development Q_{P25} is no more than the pre-development Q_{P25}.
- If required, post-development Q_{p100} is no greater than the pre-development Q_{p100}.
- If required, the post-development Q_{p100} must be able to be safely passed through the pond while maintaining 1-2 feet of freeboard below the top of the embankment.
- The % TSS removal for the treatment train (upstream water quality BMPs and pond) must be 80% or greater.

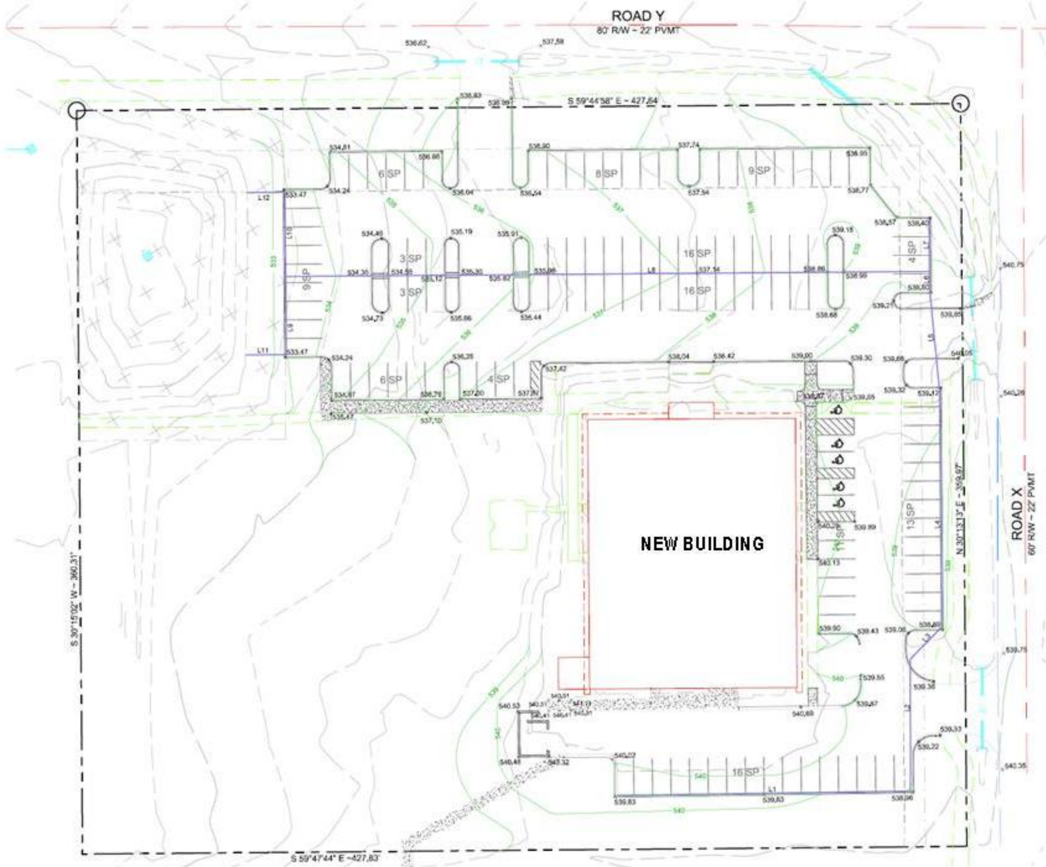
STEP 13 – Prepare the vegetation and landscaping plan.

The vegetation and landscaping plan should include soil preparation information, vegetation type and vegetation maintenance. The plan should include information about where woody vegetation is not appropriate (i.e., embankment areas, near spillways where access may be affected, etc.). The plan should also include information about reapplying stabilization measures to areas where vegetation growth is sparse.

STEP 14 – Prepare the operation and maintenance plan.

The operation and maintenance plan should include maintenance information and inspection checklists similar to those discussed in this practice's fact sheet.

Example Design



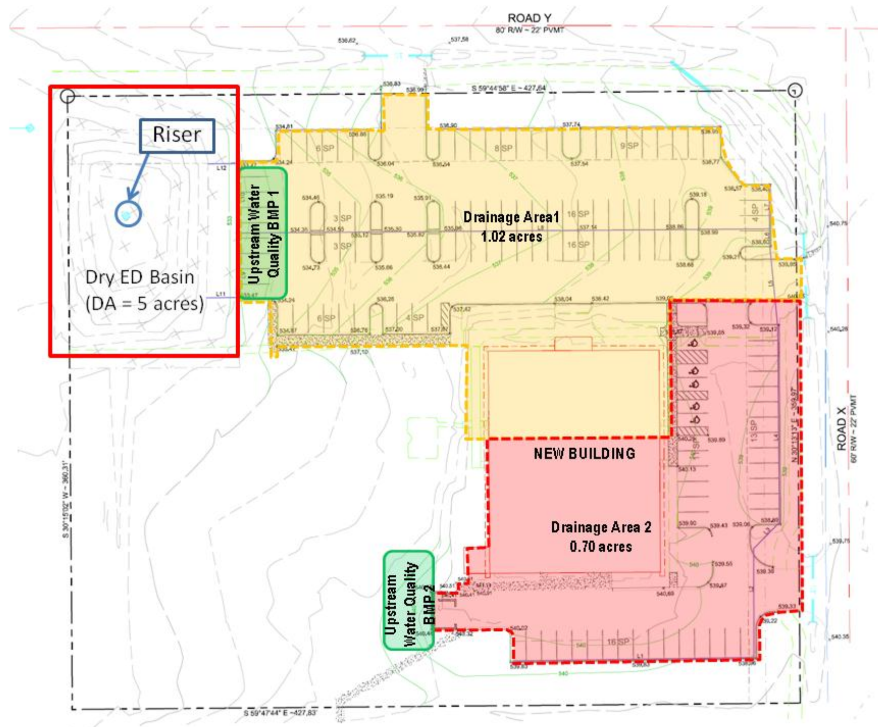
Proposed development of an undeveloped site into an office building and associated parking.

Base Data	Hydrologic Data		
Total drainage area = 5 ac		Pre	Post
Site Area = 3.54 ac	CN	71	89
Soils Type "C"			
	WQ_v Depth = 1.1 in		
Pre-Development			
Impervious Area = 0 ac; or I = 0%	**Precipitation**		
Meadow (CN = 71)	I_{WQ}	2.45 in/hr	
Post-Development	2yr, 24hr	3.54 in	
Impervious Area = 1.72 ac; or I = 1.72/3.54 = 49%	25yr, 24hr	5.88 in	
Open Space, Fair (CN = 79)	100yr, 24hr	7.43 in	
Paved parking lots, roofs, driveways, etc. (CN =98)			

This example focuses on the design of dry extended detention (ED) pond to meet the water quantity control requirements and to also be a part of the treatment train for the site's water quality treatment requirements. This example design focuses on water quality volume (WQ_v) control only. However, similar design procedures would be used to design for the other water quantity control requirements. In general, the primary function of the dry ED pond is to provide large storm attenuation rather than to provide water quality treatment.

Example Design

Problem: Design a post-construction stormwater water quantity dry extended detention (ED) pond for this site. The dry ED pond will be constructed to meet the required detention standards and will provide 60% TSS reduction for the site. Sand filters are to be installed upstream of the dry ED pond so that the % TSS removed by the treatment train is over 80%. The total drainage area to the pond is 5 acres. Try designing the dry ED pond for this site.



Step 1 – Make a preliminary judgment as to whether site conditions are appropriate for the use of a dry pond or dry ED pond, and identify the function of the pond in the overall treatment system. This includes performing an initial suitability screening for the site.

- Consider basic issues for initial suitability screening, including:
  - The total drainage area to the pond is 5 acres.
  - The site's topography and slopes show that the northwest corner of the site is the preferred pond location.
  - The site has type "C" soils
  - The depth to the water table and bedrock show that the northwest corner of the site is a suitable location for a dry ED pond.
  - There are active karst areas on the site.
  - The proposed development is a commercial office building with associated parking.

Example Design

- Determine how the dry pond or dry ED pond will fit into the overall stormwater treatment system.
    - The proposed dry ED pond will be a downstream component of a treatment train for TSS removal. Two separate sand filters will be designed and installed upgradient (identified as Upstream Water Quality BMP 1 and 2).
    - The northwest corner of the site is the best candidate location for the dry ED pond.
    - The treated WQ_v from the two sand filters will be conveyed through pipes or other stabilized conveyances into the dry ED pond. All pervious site areas as well as all contributing pervious off-site drainage areas will be well-stabilized with vegetative cover. Therefore, the dry ED pond design will not require a separate sediment forebay at the dry ED pond. If a forebay were to be used for the design, one could be located at the south end of the pond.

Step 2 – Confirm design criteria, site constraints and applicability.

- The following minimum criteria will be used in the design.
    - The dry ED pond must meet the following criteria:
        - The WQ_v must have an average detention time of 12 hours.
        - The post-development 25-year peak flow (Q_{P25}) discharged from the pond must be no greater than the pre-development 25-year peak flows (Q_{P25}).
        - For this location, the City is not requiring that the 100-year peak flow to be controlled by the dry ED pond, but is requiring the pond to be able to safely pass the 100-year peak flow through the principal spillway.
        - The dry ED pond is a part of a water quality treatment train that will meet the City's requirement for % TSS removal.
    - The site is not within a floodplain area.
    - The pond is bounded on two sides by existing streets, and will not require an embankment (i.e., the pond is excavated). Therefore, no state dam safety approvals are needed.
    - The outlet structure will be an improved sinkhole. Improved sinkholes must be inventoried, with specific information provided to US EPS. The inventory form can be found at www.bgky.org under the Stormwater Section page.
- The following items are the site constraints related to the pond:
    - The proposed pond location is bounded on two sides (north and west) by existing streets. The design for high flow conditions must consider street flooding potential.
    - The proposed pond's principal spillway discharge will not impact roads or buildings downstream (and also off-site).

Example Design

- Determine the TSS reduction provided, using the equations below for weighted TSS reduction, $TSS_{weighted}$, and TSS treatment train, TSS_{train}. The two upstream water quality BMPs are sand filters with 80% TSS removal. The dry ED pond has 60% TSS removal. All runoff from impervious surfaces goes to the sand filters and dry ED pond.

$$\%TSS_{train} = 80 + 60 - \frac{80 * 60}{100} = 92\%$$

Step 3 –Confirm site suitability, including field verification of site suitability.

- The site geotechnical investigation showed that proposed pond location was suitable for installing a dry ED pond and that the sinkhole can be improved to serve as the primary spillway.
- The soil borings indicated that the underlying soils in the vicinity of the proposed dry ED pond had limited infiltration capacity and that the high water elevation allowed a minimum 3-foot separation between the bottom of the pond and the high water elevation.
- No impermeable layers/lenses or bedrock was encountered during the geotechnical field evaluation of the site.

Step 4 – Compute runoff control volumes and peak flows. Refer to Appendix B for more information on peak flow attenuation for Q_{p25} and Q_{p100}.

- Calculate the Water Quality Volume (WQ_V).

Total Site WQ_v:

$$WQ_v = [(P\ R_v)(A)]/12$$

Where:

P = 1.1 inches

$R_v = 0.05 + 0.009(I)$

I = 49

$R_v = 0.05 + 0.009(49) = 0.491$

A = 1.72 acres

$$WQ_v = (1.1\text{in} \times 0.491 \times 1.72\text{ac})/12 = 0.077 \text{ acre-ft} = 3373 \text{ ft}^3$$

Example Design

- Calculate the peak flow for the Water Quality Volume (Q_{wq}). The equation below is based on the Rational Method. The Rational Method equation is an empirical equation, and the input units do not match up with the output units.

$$Q_{wq} = C \times I_{WQ} \times A$$

Where:

Q_{wq} = the water quality volume peak flow, (cfs)

C = the runoff coefficient (0.90 for impervious areas)

I_{WQ} = 2.45 in/hr

A = 1.72 acres

$$Q_{wq} = 0.90 \times 2.45 \times 1.72 = 3.79 \text{ cfs}$$

- Calculate the Q_{p25} and Q_{p100}. The NRCS hydrograph method is recommended for these calculations.

For the Example Design, the focus will be on sizing the pond based on WQ_v. Therefore, higher flow event calculations are not included.

Note: Steps 5 – 12 may be iterative to achieve a pond design that meets the required performance and the site constraints.

First Iteration

Step 5 – Determine the pond location and preliminary geometry.

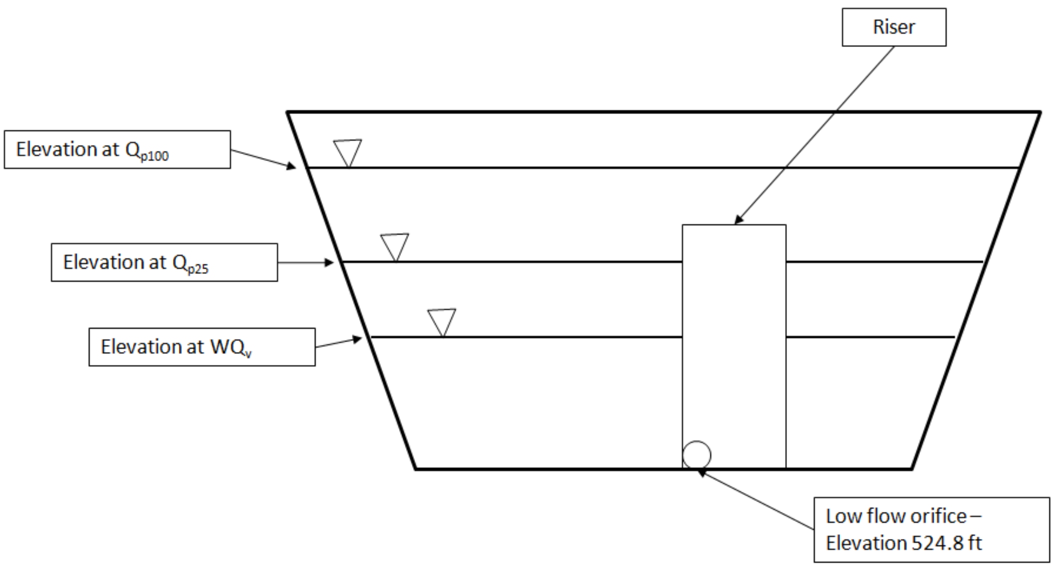
- These items were used to develop the preliminary grading plan for the pond.
  - The pond's lowest elevation is not in a jurisdictional wetland. The maintenance access for the pond will be on the eastern side of the pond near the parking area. Additionally, the pond side slopes here are approximately 1.4% or 7:1 (H:V)
  - The pond bottom elevation is at 524.80 feet. This elevation will also be the invert for the low flow orifice control WQ_v.
  - The pond is assumed to have sufficient storage for all required controlled discharges.
  - The outlet riser is centrally located in the pond, and cannot be moved farther away from the pond inlets due to the existing roadways nearby. The central riser location helps maximize the available length to width ratio.

Example Design

STEP 6 – Determine the pre-treatment volume for the sediment forebay.

- This design example does not include a sediment forebay as discussed earlier.
- If a forebay were used, it would be designed to hold 10% of WQ_v, or about 338 ft^3.

STEP 7 – Size and design the outlet structures.



- The assumed outlet structure will be an improved sinkhole throat with a principal spillway riser that has a low flow orifice for controlling WQ_v, perforations in the riser for controlling Q_{P25}, and a top riser opening for passing Q_{p100}. The example design will not include outlet calculations for the higher flow events.
- The assumed water quality volume (low flow) outlet is an orifice at the bottom of the riser designed to release WQ_v with an average detention time of 24 hours.
- The average release rate of the WQ_v (Q_{WQ_avg}) is calculated using the following equation:

$$Q_{WQ\_avg} = \frac{WQ_v}{t_{WQ}}$$

Where:

t_{WQ} = the intended WQ_v detention time = 24 hours = 86,400 seconds

WQ_v = 3373 ft^3

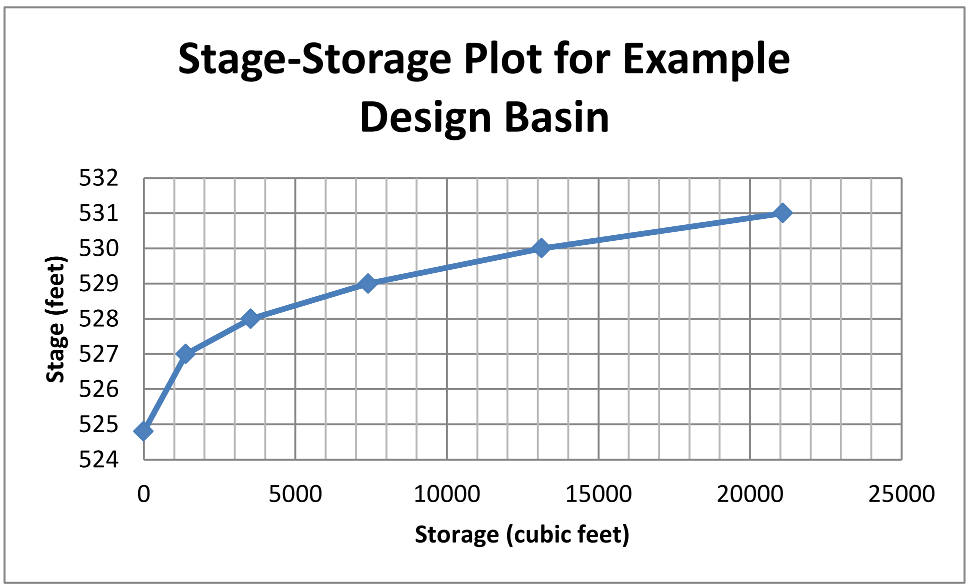
Q_{WQ_avg} = average release rate of WQ_v (cfs)

$$Q_{WQ\_avg} = \frac{3373 ft^3}{86400\ seconds} = 0.039\ cfs$$

Example Design

- The proposed stage-storage relationships for the pond are summarized in the table and chart shown below:

Elevation E (ft)	Area A (square feet)	Average Area between Elevations	Average Area (ft²)	Depth (Elevation Difference)	Incremental Volume (ft³)	Cumulative Volume (ft³)
524.8	0	NA – pond bottom	NA – pond bottom	NA – pond bottom	0	0
527	1266	524.8 ft & 527 ft	633	2.2	1392.6	1392.6
528	3024	527 ft & 528 ft	2145	1	2145	3537.6
529	4709	528 ft & 529 ft	3866.5	1	3866.5	7404.1
530	6744	529 ft & 530 ft	5726.5	1	5726.5	13130.6
531	9169	530 ft & 531 ft	7956.5	1	7956.5	21087.1



- The proposed pond's storage volume is sufficient to hold the WQ_v, and is assumed to be sufficient for the other required peak flow controls.

STEP 7 – Determine the pre-treatment volume for the sediment forebay.

- This design example does not include a sediment forebay as discussed earlier.
- If a forebay were used, it would be designed to hold 10% of WQ_v, or about 338 ft³.

Example Design

- From the stage-storage table, find the elevation associated with WQ_v. The table indicates that WQ_v = 3373 ft^3 is between elevations 527 ft and 528 ft. The stage-storage relationship plot may be used to estimate the elevation associated with WQ_v, or the elevation may be obtained by linear interpolation between the table values. The elevation associated with WQ_v is estimated at 527.92 feet.
- Calculate the approximate average head (in feet) on the water quality outlet (h_{wq_avg}) using the following equation:

$$h_{wq\_avg} = \frac{E_{WQ} - E_{PermPool}}{2}$$

Where:

E_{WQ} = 527.92 feet

$E_{PermPool}$ = bottom elevation of the pond = 524.80 feet.

$$h_{wq\_avg} = \frac{3.12\,feet}{2} = 1.56\,feet$$

- Calculate the required orifice cross-sectional area indirectly by using the orifice equation.

$$Q_{WQ\_avg} = CA_{WQ}\sqrt{2gh_{wq\_avg}}$$

Where:

Q_{WQ} = 0.039 cfs

C = the orifice coefficient (0.6 is typically used, but not apply for all cases)

A_{WQ} = the orifice area (square feet)

g = gravitational acceleration (32.2 feet/s^2)

First, rearrange the orifice equation to solve for A_{WQ}.

$$A_{WQ} = \frac{Q_{wq\_avg}}{C\sqrt{2gh_{wq\_avg}}}$$

$$A_{WQ} = \frac{0.039\,cfs}{0.6\sqrt{2\left(32.2\frac{ft}{s^2}\right)(1.56\,feet)}} = 0.0065\,feet^2$$

$$A_{WQ} = 0.0065\,feet^2$$

Example Design

- Calculate the orifice diameter using the following equation:

$$d_{WQ} = 2\sqrt{\frac{A_{WQ}}{\pi}}$$

Where:

d_{WQ} = the orifice diameter (feet)

$$d_{WQ} = 2\sqrt{\frac{0.0065 feet^2}{3.14}} = 0.09\ feet$$

$$d_{WQ} = 0.09\ feet = 1.10\ inches \approx 1\ inch$$

For the Example Design, the minimum allowed orifice diameter (1 inch) will be used. This device will require internal orifice protection.

- The rate of discharge for the orifice for any head value at the water quality orifice (h_{WQ}) can be calculated using:

$$Q_{WQ} = CA_{WQ}\sqrt{2gh_{WQ}}$$

Where:

Q_{WQ} = the orifice discharge rate at head h_{WQ} (cfs)

h_{WQ} = the head value above the water quality orifice (feet)

Using the range of values for h_{WQ} based on the elevations (E) up to E_{WQ} used in the pond's stage-storage relationship, the Q_{WQ} values are calculated for each corresponding value of h_{WQ}.

Elevation E (ft)	h_{WQ} (feet)	Q_{WQ} (cfs)
524.8	0	0
527	2.2	0.0390
527.92	3.12	0.0464

Example Design

- The combined outflow from the low flow orifice and any higher outflow openings is calculated by adding together the discharges from each structures associated with a given head value and a specified pond water surface elevation.

  The combined outflow would be calculated for all of the outflow openings to check that the pond meets the requirements for controlling the post-development Q_{P25}.

- Calculate the required control for the 100-year storm peak flow (Q_{p100}). If required, the post-development Q_{p100} must be no greater than the pre-development Q_{p100}. At minimum, Q_{p100} must be able to be safely passed through the pond with 1-2 feet of freeboard below the top of the embankment. Check with local officials and/or state dam safety personnel to determine whether Q_{p100} may be passed using only a principal spillway, or if an emergency spillway will be required. If an emergency spillway is required, the spillway type is often a broad-crested weir or similar structure that is not susceptible to obstruction. For calculating the combined outflow through all spillway openings, the combined outflow may be calculated by adding together the discharges for each opening associated with a given head value and a specified water surface elevation.

  For this Example Design, the pond's ability to control Q_{p100} will not be calculated. The Example Design pond is an excavated pond that does not include an embankment other than the two existing roadbeds north and west of the site. However, the pond would still need to be checked to determine if the pond could safely pass Q_{p100} while maintaining the required freeboard of 1-2 feet above the elevation associated with the Q_{p100}.

- Using the determined opening and spillway information, incorporate the outlet structures into the pond design. Keep in mind that the spillway design must also consider using measures such as removable trash racks to prevent the discharge of floating debris.

  The outlet openings and spillways are then added into the pond design. Other measures such as removable trash racks are also added to the design.

STEP 8 – Design the spillways and embankments.

- The Example Design pond will target passing all required flows through the principal spillway, and will not be required to include an emergency spillway.

STEP 9 – Design the inlets.

- The Example Design pond uses inflow inlet pipes from the upstream water quality BMPs to the pond. These inflow inlet pipes are designed to be buried below the frost line. Additionally, this pond is a dry pond (no permanent pool). This means that the inlet pipes should be sloped to fully drain as the water levels in the pond drop.

STEP 10 – Design the sediment forebay.

- The sediment forebay size was determined in Step 6. For the Example Design pond, a sediment forebay will not be used because (1) the upstream water quality BMPs will reduce the sediment load to the pond and (2) all pervious areas draining to the pond will be well-stabilized to not provide significant sediment load to the dry ED pond.

Example Design

STEP 11 – Design the maintenance access and safety features.

- All maintenance access and safety features are designed in this step. The removable trash racks on the spillway riser will also function to prevent unauthorized access to the riser. The riser's pipe diameter will include bars across the pipe outlet to prevent unauthorized access if the pipe diameter is over 3 feet.

STEP 12 – Check the expected pond performance against regulatory requirements.

- The pond design should be re-checked to confirm that the pond meets the flow control requirements.
- The release rate for WQ_v should not exceed 5.66 cfs per acre of pond surface area. Calculate the flow rate and pond surface area associated with each available elevation and head value up to E_{WQ}. The maximum release rate for WQ_v will then be calculated using the pond surface area at each given elevation and head value, and the actual release rate will be compared with the maximum release rate.

Elevation E (ft)	h_{WQ} (feet)	Q_{WQ} (cfs)	Pond Surface Area at E (sq ft)	Pond Surface Area at E (acres)	Release rate (based on Q_{WQ} per acre of surface area) (cfs/acre)
524.8	0	0.000	0	0	0
527	2.2	0.039	1266	0.0291	1.34
527.92	3.12	0.046	3373	0.0774	0.60

See last column in above table. All values are below the target value of 5.66 cfs per acre.

- The expected average detention time for WQ_v is 24 hours. Calculate the average release rate for the pond (Q_{WQ_avg}). Use WQ_v and Q_{WQ_avg} to calculate the actual average detention time for the pond. The required target detention time for WQ_v is 24 hours.

$$Q_{WQ\_avg} = \frac{0+0.039+0.046}{3} = 0.028 \text{ cfs}$$

$$t_{WQ} = \frac{WQ_v}{Q_{WQ\_avg}} = \frac{3373ft^3}{0.028cfs} = 118574 \text{ seconds} = 32.9 \text{ hours}$$

The actual value of t_{WQ} is greater than the required 24 hours. The 1-inch diameter orifice used for the pond design is smaller than the calculated orifice size (diameter of 1.10 inches) from earlier in the Design Procedure. The smaller orifice gives a conservative design with a higher detention time for WQ_v.

Example Design

Second Iteration

If required or desired, a second iteration may be performed to attempt to adjust the pond configuration to try to get the detention time closer to 24 hours or to fit other site constraints. Another modification that could affect the pond's detention time would be to include a forebay that would store a portion of WQ_v.

The Example Design will not include the final three design steps (Steps 13-15), but these steps would be incorporated into a full pond design.

STEP 13 – Prepare the vegetation and landscaping plan.

STEP 14 – Prepare the operation and maintenance plan.