Section 7
Drainage Criteria Manual Review

7.1 Background

As discussed in Section 6, urbanization increases impervious areas, which reduces the amount of rainfall that infiltrates into the ground. As a result, more rainfall is directly converted to stormwater runoff. This causes an increase in stormwater runoff flow rate, volume, and velocity, which increases erosion and sediment deposition.

Altering the magnitude, frequency, and duration of stormwater runoff and sediment loads to streams causes impacts to water quality, stream stability, and loss of aquatic life and habitat through a wide variety of geomorphic mechanisms. These mechanisms include changes in channel bed material, increased suspended sediment loads and loss of riparian habitat due to streambank erosion. In addition, the aquatic environment and habitat are also affected by pollutants transported by stormwater runoff. However, as shown in Section 6, if predevelopment hydrologic conditions can be replicated using stormwater facilities, the impacts to water quality, stream stability, and aquatic habitat can be minimized.

Given the variability of rainfall and the resulting stormwater runoff volumes and discharge rates, the statistical probabilities of runoff events must be considered in the sizing of storm-water facilities to meet both water quality and water quantity goals. However, conventional stormwater facilities are typically sized to achieve flood control objectives for the rare storm events (i.e., 10- and 100-year return periods). Therefore, stormwater facilities must be designed for the full range of hydrologic events, from the relatively frequent small storms for water quality control and stream stability to the rare large storms for flood control.

Chapters 6 and 8 of the City's Drainage Criteria Manual revised May 10, 2004, address regulatory requirements and design principles for stormwater detention facilities and stormwater BMPs. The Drainage Criteria Manual requires adequate detention volume to attenuate the post development peak discharge rates to predevelopment discharge rates for the 2-, 10-, and 100-year return intervals. The Drainage Criteria Manual encourages the use of BMPs on a voluntary basis, and recommends a design WQCV of 0.5 inches with a 24-hour drawdown time. The WQCV is calculated by multiplying the inches of runoff by the contributing drainage area and dividing by 12.

The key issues described in the following paragraphs include:

- Design features that integrate water quantity and quality into a single integrated facility
- Outlet control structure design guidance to achieve the required release rate
- Design guidance in determining the appropriate WQCV and release rates
- Alternative design approaches
- Guidance on necessary maintenance activities, ordinances, agreements, and inspection reports
- Conservation culvert design approach

7.2 Integrating Stormwater Detention with Structural BMPs

The benefits of integrating water quality features with flood control facilities is discussed in Section 8.3.3 of the City's Drainage Criteria Manual:

> *For many BMPs, combining the water quality facility with a flood control facility is practical and cost effective. Specifically, the water quality control volume (WQCV) that is recommended for control is the first half inch (0.5 inches) of runoff from the basin tributary to the BMP. For facilities that combine water quality control with flood control, the runoff from the design storms for the flood control criteria should be "stacked" on top of the water quality control volume. The water quality control volume should be detained over at least a 24-hour period, and preferably for longer.*

The purpose of this section is to provide design guidance to integrate structural BMPs with the City's current stormwater detention basin control requirements to provide both water quantity and quality benefits. This integrated approach offers a cost-effective method towards preserving water quality, maintaining the stability of natural streams, and achieving flood control objectives.

The City's current detention policy (Section 6 of the Drainage Criteria Manual) focuses on controlling the 2-, 10-, and 100-year design storms to predevelopment conditions. The more frequent rainstorms (e.g., less than 2-year return interval) carry the majority of pollutants and generally cause the greatest amount of erosion and sediment deposition, which directly impacts the aquatic and riparian habitat. As noted in Section 6, recent research and application in urban hydrology and geomorphology indicate the key to providing long-term stream sustainability is to control the full range of hydrologic conditions. Among the conclusions from the biological assessment and stream sustainability analysis:

- Stormwater detention basins should be designed to control the full range of hydrologic conditions, including the WQCV and the 2-, 10-, and 100-year design storms to maintain predevelopment hydrologic conditions.
- By controlling the WQCV using a 40-hour drain time, the cumulative excess shear stress applied to the natural streams can be properly managed to provide long-term stream stability.

For the purposes of this report, the following terms are defined:

- Extended dry detention basin: An extended dry detention basin provides flood control and water quality treatment and is a dry storage facility. The term "extended" means the entire WQCV is treated by slowly releasing the runoff over a specified period of time until the facility completely drains. The primary pollutant removal mechanism is sedimentation, which is achieved through an appropriate detention time.
- Extended wet detention basin: An extended wet detention basin provides flood control and water quality treatment and contains a permanent pool. The term "extended" means the entire WQCV is treated above the permanent pool by slowly releasing it over a specified period of time. The permanent pool provides a mixing

volume for the settling of solids and the removal of dissolved pollutants (e.g., nutrients). Section 8.3.4.2 of the Drainage Criteria Manual refers to these basins as "Retention (Wet) Ponds."

Table 7-1 summarizes the key design criteria for the two types of stormwater facilities. For extended wet detention basins, the permanent pool provides a holding volume for continued settling of particulate pollutants and uptake of dissolved pollutants by aquatic plants, with a residence time between 2 and 4 weeks. The permanent pool represents the portion of the basin that normally holds water (i.e., between the normal water level and the pond bottom). For extended dry detention basins, the micropool is an optional, relatively shallow impoundment intended to reduce the potential for resuspension during runoff events.

Table 7-1
Design Criteria for Stormwater Basins

Type of Basin	Permanent Pool Volume	Storage Volume	
		Water Quality	Flood Control
Extended Dry Detention	Micropool (optional)	WQCV (40-hr drawdown)	Predevelopment 2-, 10-, 100-yr release rate
Extended Wet Detention	1 to 2*WQCV (2-4 week residence time)	WQCV (40-hr drawdown)	Predevelopment 2-, 10-, 100-yr release rate

The volume required for extended detention basins (both dry and wet) is a function of the basin geometry and outlet control structure. As mentioned above, controlling the WQCV with a 40-hour drawdown time provides both water quality treatment and long-term stream stability.

The following paragraphs provide a summary of key design features, outlet control recommendations, and other issues that should be considered when designing extended dry and wet detention basin facilities. This discussion is followed by various approaches to calculate the WQCV.

7.2.1 Extended Dry Detention Basin

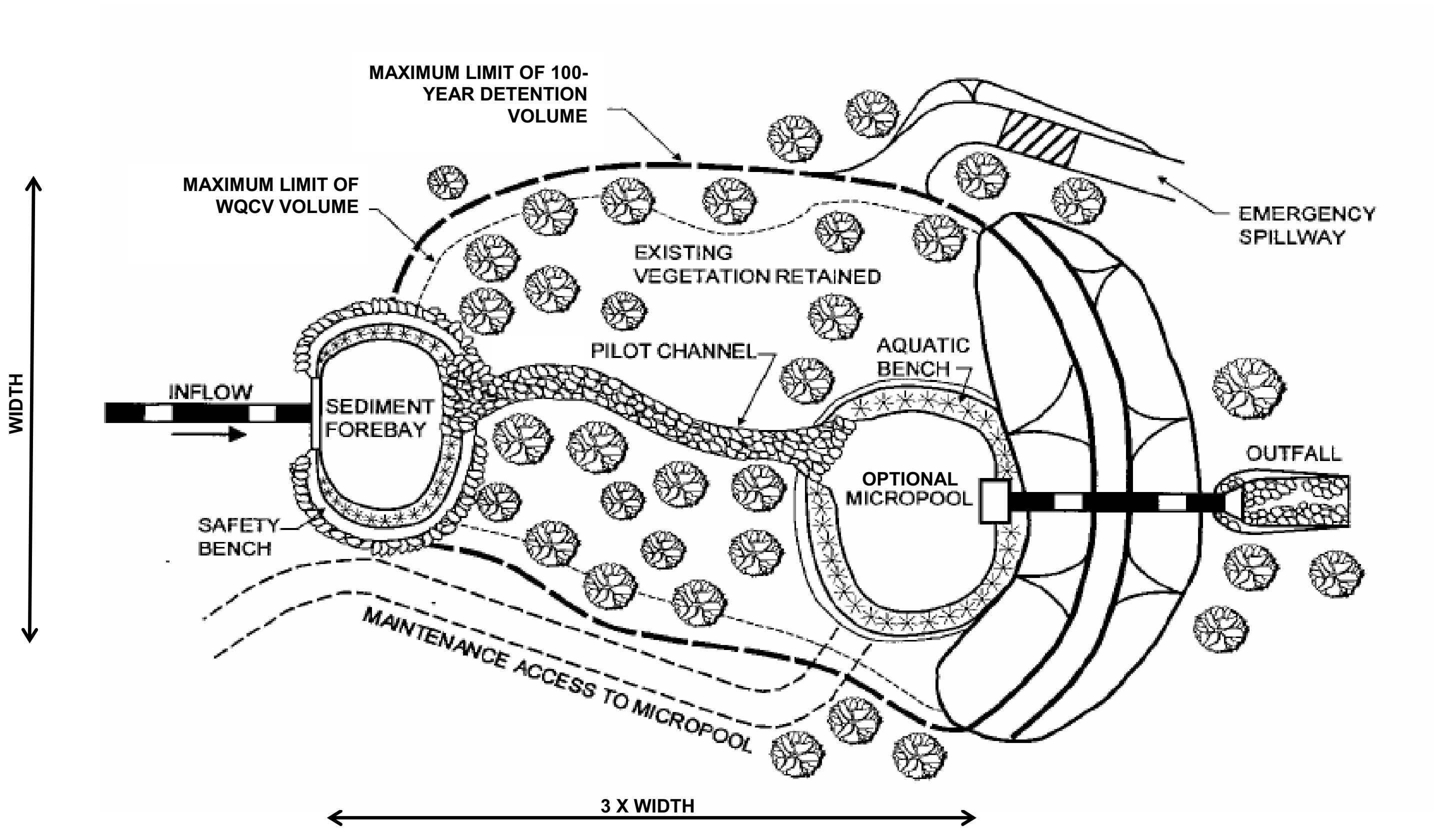
Figure 7-1 shows a schematic plan and profile view of an extended dry detention basin with a micropool (adapted from Figure 3-1 of the *Maryland Stormwater Design Manual*, Maryland Dept of the Environment, 2000). The profile view shows the various volume components listed in Table 7-1, including the water levels corresponding to the WQCV, 2-, 10-, and 100-year design storm events.

The advantages of extended dry versus extended wet detention basins include:

- Algae growth problems are not a concern, unless design includes a micropool.
- Recreational amenities (e.g., athletic fields) can be accommodated.

The disadvantages of extended dry versus extended wet detention basins include:

- Less aesthetically pleasing if amenities are not included due to dry, bare areas.
- Little pollutant removal for nutrients and soluble pollutants.
- Resuspension of settled material is more likely.
- Debris and silt buildup are seen.



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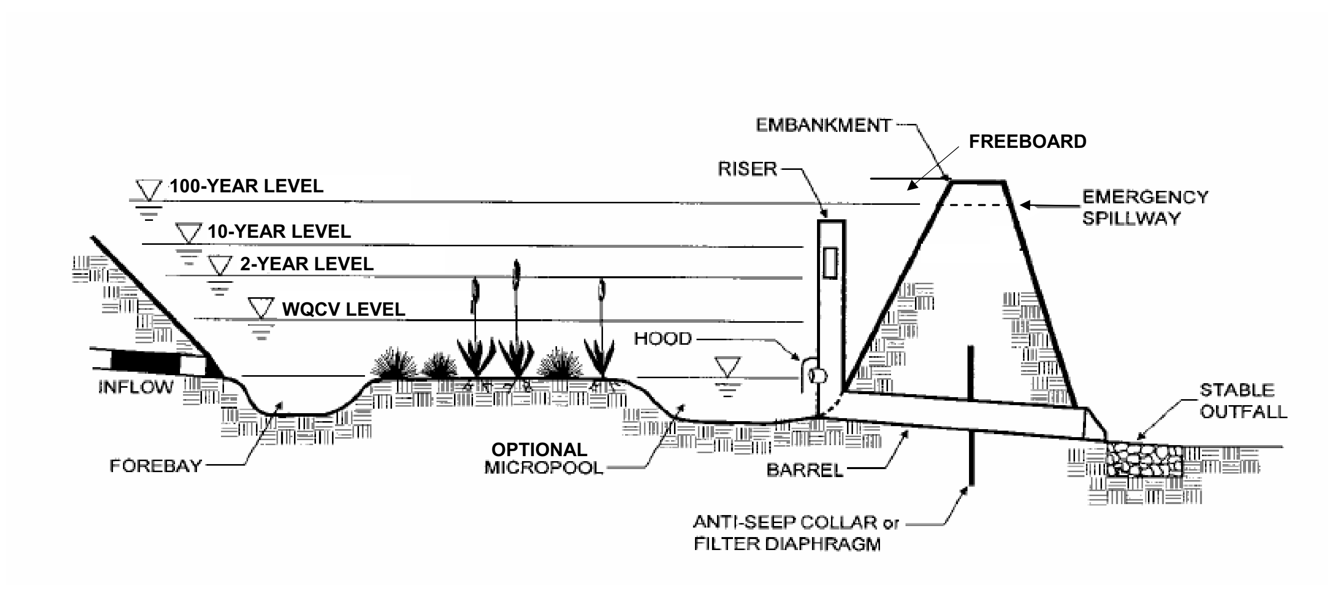

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Figure 7-1
Schematic of an Extended Dry Detention Basin
(Adapted from Maryland Department of Environment, 2000)

Design Features

The performance of extended dry detention basins can be maximized by addressing key design features including sediment forebay, length-to-width ratio, recommended side and bottom slopes, micropool design, storage volume, and vegetation.

Sediment Forebay

A sediment forebay is a pretreatment feature that can increase the pollutant removal efficiency of the facility by trapping sediment and trash at all basin inlets. Generally it is recommended that the forebay represent at least 10 percent of the WQCV to be effective. The forebay can also facilitate maintenance by concentrating sediment in an accessible location. The forebay consists of a separate cell, formed by an acceptable barrier such as a vegetated earthen weir.

To make sediment removal easier, the bottom and side slopes of the forebay are generally lined with concrete. This area should be designed to minimize aesthetic problems associated with sediment and debris accumulation and saturated soils in this portion of the basin. Additional design inlet considerations should include energy dissipaters to reduce inflow velocity, scour potential, and the turbulence and mixing currents that disturb sedimentation.

Length-to-Width Ratio

Increasing the length-to-width ratio of the facility increases the water quality treatment potential by providing additional detention time for settling, infiltration, and possibly biological uptake. As a result, a 3:1 length-to-width ratio or greater is generally recommended. Basins should be wedge-shaped, narrowest at the inlet and widest at the outlet. Greater flow lengths can be accommodated by relocating the basin inlet or outlet where possible, or by installing berms or baffles within the basin to the full depth of the WQCV to avoid short circuiting and increase travel time to the outlet.

Side and Bottom Slopes

Side slopes for extended wet detention facilities should be no steeper than 4:1 (horizontal to vertical). A bottom slope of 2 percent is required to prevent ponding and prolonged standing water.

Micropool

The micropool is an optional feature for extended dry detention basins; a relatively shallow impoundment intended to concentrate sediment and reduce the potential for resuspension during runoff events. Vegetation in the micropool can help stabilize the trapped sediment. A micropool also helps prevent clogging of the outlet.

Storage Volume

The storage volume for an extended dry detention facility includes the WQCV and flood control volume to control the 2-, 10-, and 100-year peak flow rates. Chapter 6 of the City's Drainage Criteria Manual describes the calculations required to determine the storage needed for the flood control volume. Section 7.2.3 of this report describes the methodology for calculating the WQCV. A portion of the WQCV can be included in the sediment forebay.

Based on the results of the stream sustainability analysis that is described in Section 6 of this report, it is not recommended that the flood control volumes be "stacked" on top of the WQCV. Stacking the volumes is overly conservative and reduces peak flows below predevelopment levels.

To account for sediment deposition, an additional volume equal to 20 percent of the WQCV should be included in the overall storage volume for the entire facility. This sediment storage volume is generally located near the outlet control structure of the basin. Similar to the forebay, the bottom and side slopes near the outlet structure are generally lined with concrete to make sediment removal easier. This area should be designed to minimize aesthetic and other impacts associated with sediment and debris accumulation and saturated soils in this portion of the basin.

Vegetation

The type of vegetation appropriate for extended dry detention facilities is greatly dependent upon where the facility will be used for recreational purposes. Vegetation in the basin bottom must be able to withstand prolonged periods of standing water during the WQCV drawdown. Native grasses increase infiltration capacities when planted at the bottom of the basin. If the facility is designed to provide recreational amenities, a conventional turf grass may be desired.

Embankments should be planted with native grasses and wildflowers to provide aesthetic benefits. Native grasses typically have a more robust root structure than turf grasses and reduce erosion along the banks. Trees or shrubs should not be planted along the embankment to avoid long-term maintenance problems.

Outlet Control Structure

The outlet control structure for an extended dry detention basin includes both water quality and water quantity controls. The outlet should be configured such that the WQCV is released over 40 hours and that peak discharge rates for post development conditions do not exceed predevelopment peak runoff rates for the 2-, 10-, and 100-year discharges. Determination of the WQCV drawdown period is addressed in Section 7.2.3.

Figure 7-2 shows a sample outlet structure detail of an extended dry detention basin without a micropool. The water quality and water quantity controls are included in the same structure located in the basin embankment. The WQCV is controlled by a v-notch weir located at the bottom of the detention basin. The weir top corresponds to the WQCV level shown on Figure 7-2. The 2-year peak flow rate is controlled by the v-notch weir and transverse weir that extends on each side of the v-notch weir. The 10-year peak flow rate is controlled by the overflow grate in the same structure. This grate should be designed to be removable and normally kept locked. The 100-year peak flow rate is controlled by the spillway in the basin embankment. Outlet control structures are generally located in the embankment for ease of access, maintenance, and aesthetic reasons.

Maintenance considerations for outlet structure design are described in Section 8.3.4.1 of the Drainage Criteria Manual. The following recommendations are provided to reduce the potential for clogging:

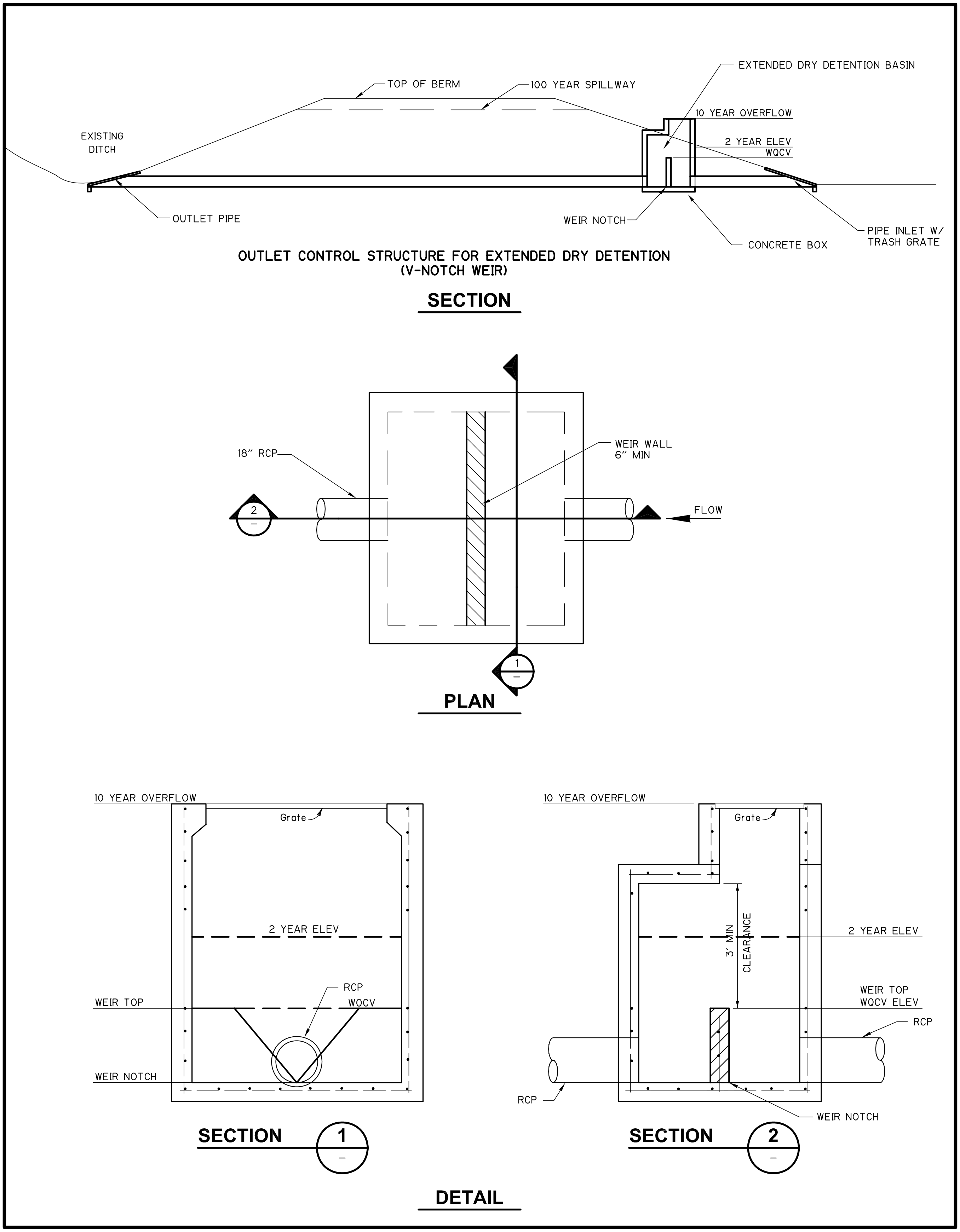


Figure 7-2
Outlet Structure Details
Extended Dry Detention Basin

- Single orifice outlets should not have an equivalent diameter less than 4 inches.
- As stated in Section 6.4.5 of the Drainage Criteria Manual, slotted riser pipes are discouraged due to clogging problems. If slotted riser pipes are used for the WQCV (Figure 8-2 of the Drainage Criteria Manual), a filter fabric is recommended rather than packed sand and gravel.
- V-notch weir outlets should not have a weir angle less than 15 degrees.
- A trash rack or other acceptable means should be incorporated to protect the outlet structure.

Integration of Recreational Amenities

The preferred design of an extended dry detention basin incorporates amenities that include landscaped features with native vegetation and/or recreational amenities (e.g., athletic fields). Passive recreation features include walking and biking trails, benches, and picnic areas. Surrounding land uses and facility access should be considered when choosing the type of recreational facility. Walking trails with benches and picnic tables work well in office park settings, while athletic fields are well suited in residential areas that can be safely accessed by children.

7.2.2 Extended Wet Detention Basin

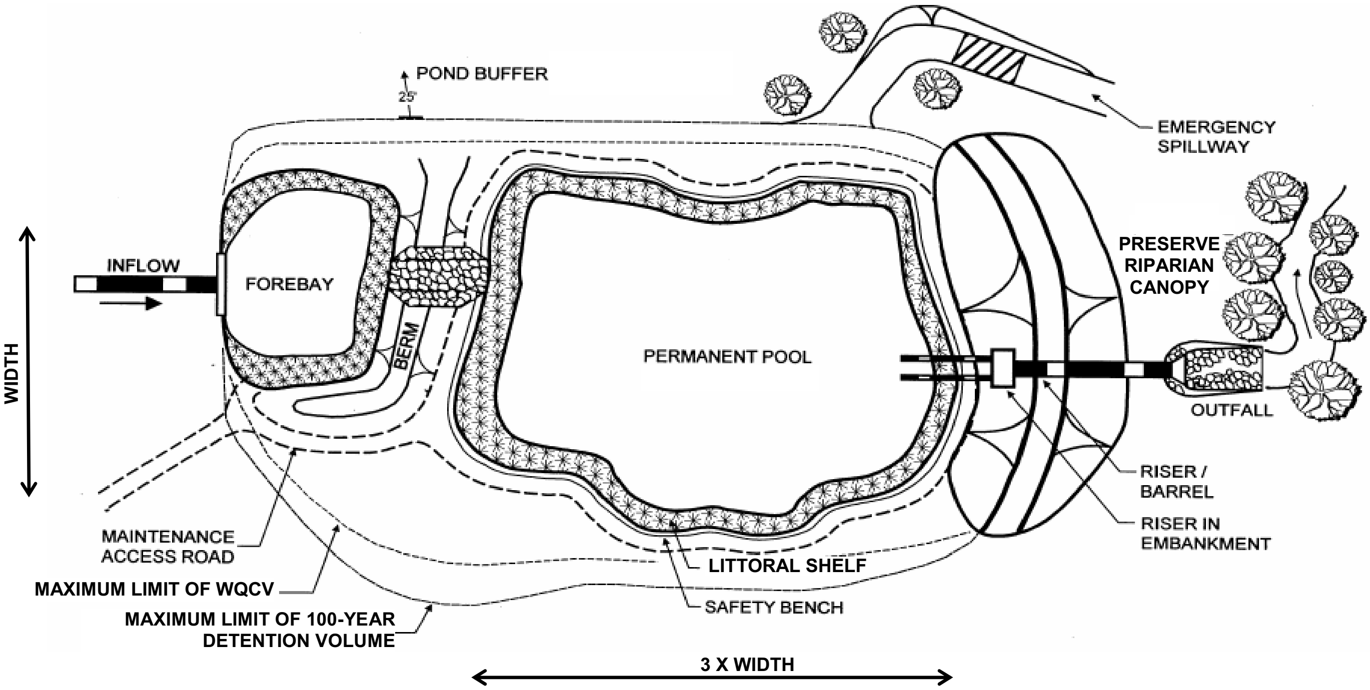
Figure 7-3 shows a schematic plan and profile view of an extended wet detention basin (adapted from Figure 3-3 of the *Maryland Stormwater Design Manual*, Maryland Dept of the Environment, 2000). The profile view shows the various volume components listed in Table 7-1 including the water levels corresponding to the WQCV, 2-, 10-, and 100-year design storm events.

The advantages of extended wet versus extended dry detention basins include:

- Generally they are more aesthetically pleasing and considered more of an amenity, as well as providing more opportunities for wildlife and aquatic habitats.
- Higher pollutant removal efficiency through enhanced sedimentation, filtration, and biological uptake.
- Resuspension of settled material is less likely.

The disadvantages of extended wet versus extended dry detention basins include:

- Although they are more attractive since sediment and debris accumulation are generally hidden from public view within the permanent pool, maintaining the permanent pool and controlling algae growth can result in higher maintenance.
- Higher potential safety risks due to open impoundments.
- Recreational amenities such as athletic fields are better suited for dry basins.



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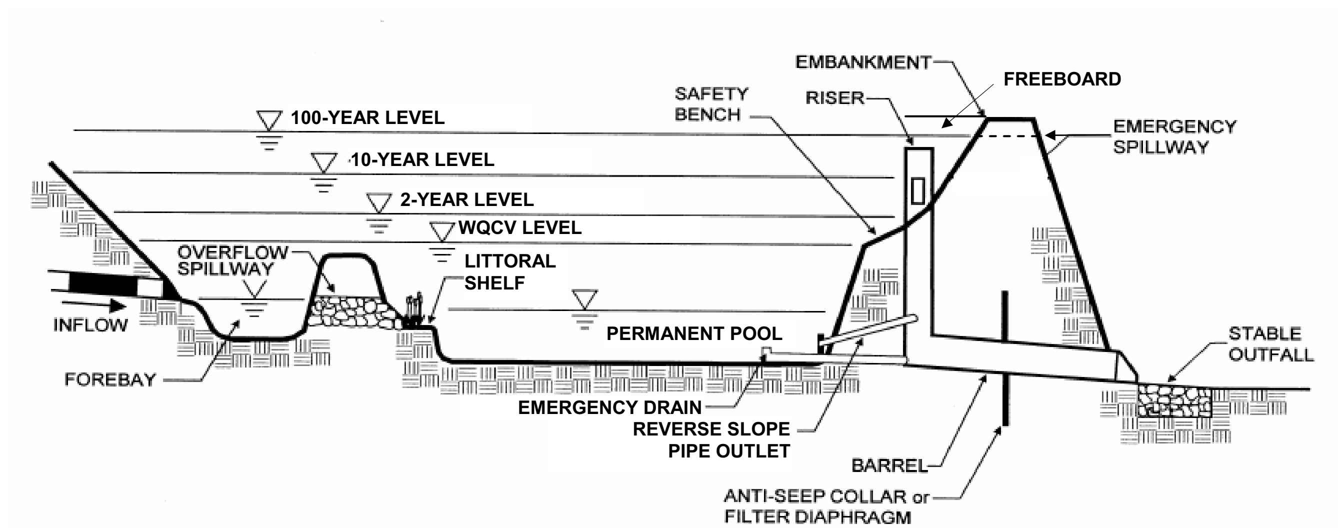

Profile

Figure 7-3
Schematic of an Extended Wet Detention Basin
(Adapted from Maryland Department of Environment, 2000)

Design Features

The performance of extended wet detention basins can be maximized by addressing key design features including the sediment forebay, length-to-width ratio, permanent pool, littoral zone, and storage volume.

Sediment Forebay

Section 7.2.1 describes sediment forebay design considerations for extended dry detention basins. The same considerations apply for forebays in extended wet detention. For wet basins, the forebay helps to reduce the frequency of dredging the larger permanent pool.

Length-to-Width Ratio

Similar to extended dry detention basins, increasing the length-to-width ratio for wet facilities will increase the water quality treatment by providing additional detention time for settling, infiltration, and biological uptake. The minimum length-to-width ratio of 3:1 specified in the City's Drainage Criteria Manual is appropriate, though it should be noted that higher ratios are preferred for extended wet detention basins. Section 7.2.1 provides recommendations on ways to increase the length-to-width ratio.

Side Slopes

Side slopes above the permanent pool should be 6:1, and can be 4:1 below the littoral zone to maximize permanent pool volumes where needed. Slopes steeper than 3:1 will be susceptible to erosion.

Permanent Pool

The permanent pool provides a holding volume between runoff events for continued settling of particulate contaminants and nutrient uptake by aquatic plants. As discussed in Section 6.11.2 of the City's Drainage Criteria Manual, water budget calculations are required for all permanent pool stormwater facilities to demonstrate that a permanent pool will be achieved given the average annual site hydrologic conditions. If the permanent pool cannot be maintained under normal conditions, infiltration losses in the permanent pool can be minimized using various methods, including compaction, incorporating clay into the base materials, and installing an impermeable liner.

There are a variety of methods for determining the design volume of the permanent pool. Sizing criteria have been developed based on solids settling and nutrient removal mechanisms. Due to limited empirical evidence to support these designs, a simplified method of three to five times the WQCV is suggested (Table 7-1). The permanent pool depth should be between 5 to 10 feet, which is consistent with City's Drainage Criteria Manual guidance.

Littoral Zone

An aquatic and safety bench around the perimeter of the basin is called the littoral zone. Incorporating rooted vegetation in this bench serves several functions, including:

- Enhanced removal of dissolved pollutants
- Bank erosion protection
- Reduced formation of floating algal mats

- Reduced drowning hazard
- Enhanced habitat for insects, aquatic life, and wetland wildlife

The littoral zone should be gently sloped (i.e., maximum 6 (horizontal):1 (vertical) side slopes) below the permanent pool elevation to provide a littoral shelf and safety bench around the perimeter of the basin. The littoral zone should extend 2 feet below the permanent pool elevation, which equates to a 12-foot wide littoral shelf around the perimeter of the facility. In general, the littoral zone vegetation should occupy 20 to 30 percent of the permanent pool surface.

Storage Volume

The storage volume for an extended wet detention facility includes the WQCV and flood control volume to control the 2-, 10-, and 100-year peak flow rates. The storage volume is provided above the permanent pool elevation. Chapter 6 of the City's Drainage Criteria Manual describes the calculations required to determine the storage required for the flood control volume. Section 7.2.3 of this report describes various approaches for calculating the WQCV. A portion of the WQCV can be included in the sediment forebay.

As is the case with extended dry detention, stacking of the flood control volume on top of the WQCV is not recommended. However, an additional volume equal to 20 percent of the WQCV should be included in the overall storage volume for the entire facility to account for sediment deposition. In addition, the WQCV level should generally not exceed 18 inches above the permanent pool unless the littoral zone vegetation is sufficiently hardy to withstand prolonged inundation.

Vegetation

Wetland vegetation should be planted or seeded along the littoral zone. Plant species should vary along the side slopes according to the expected flooding duration between the normal water level and the maximum elevation associated with the WQCV.

Embankment areas above the WQCV elevation should be planted with native grasses and wildflowers to provide aesthetic benefits. Native grasses typically have a more robust root structure than turf grasses and reduce erosion along the banks. Trees or shrubs should not be planted along the embankment.

Outlet Control Structure

The outlet structure for the extended wet detention basin includes both water quality and water quantity controls. The release rate requirements for the 2-, 10-, and 100-year return intervals are described in Section 6.4.2 of the City's Drainage Criteria Manual, while the WQCV release rate is discussed in Section 7.2.3. The main types of outlet structures include:

- Single orifice. In extended wet detention basins, the orifice can be located at the permanent pool elevation. The drawdown example in Section 7.2.3 uses a single orifice.
- Riser with perforated holes. This allows a relatively uniform bleed down and should be designed according to the criteria in Section 8.4.3.2 of the Drainage Criteria Manual.
- V-notch weir. The v-notch weir equation is given in Section 6.7.4 of the Drainage Criteria Manual.

Figure 7-4 shows a sample outlet structure detail of an extended wet detention basin. The water quality and water quantity controls are included in the same structure located in the basin embankment. The WQCV is controlled by a v-notch weir located at the permanent pool elevation. The weir top corresponds to the WQCV level shown on Figure 7-4. The 2-year design water level is located above this and is controlled by the v-notch weir and the transverse weir that extends on each side of the v-notch weir. The 10-year peak flow rate is controlled by the overflow grate in the same structure. This grate should be designed to be removable and normally kept locked. The 100-year peak flow rate is controlled by the spillway in the basin embankment.

Many of the maintenance considerations for extended wet detention design are the same as those for extended dry detention as described in Section 7.2.1. Other maintenance considerations include:

- A manually operated valve can be added to the outlet structure to prevent basin discharge in case of an accidental spill upstream.
- A manually operated emergency drain can be added to the outlet structure to allow for the drawdown of the permanent pool for dredging, harvesting of the vegetation, maintenance if the primary outlet becomes clogged, and for cold weather operations (i.e., empty or reduced permanent pool elevation during winter).
- A submerged, reverse-slope pipe water quality control structure can be designed to reduce clogging potential. Such outlets draw water from below the permanent pool elevation and are therefore less likely to be clogged by floating debris.

Mosquito Control Design Considerations

Mosquito populations associated with stormwater facilities can be controlled using the proper design concepts.

- **Basin Geometry** - Using the proper basin geometry as previously discussed, flow through systems will be provided to encourage distributed flow with no standing water, which will prevent stagnant zones that are susceptible to mosquito breeding.
- **Promote Desirable Biology** - Incorporating the proper littoral zone width will provide habitat for mosquito predators. In addition, the littoral shelf provides a shallow depth that surrounds the basin making the facility safer for children. If the permanent pool is large enough, carp or macroinvertebrate population can be stocked to assist in consuming the mosquito larvae.
- **Perimeter Lining** - A concrete or brick curb lining along the perimeter of the pond will eliminate the soggy zone near the pond's edge, which will eliminate potential breeding areas for mosquitoes. In addition, the curb lining will minimize erosion along the edge of the pond.

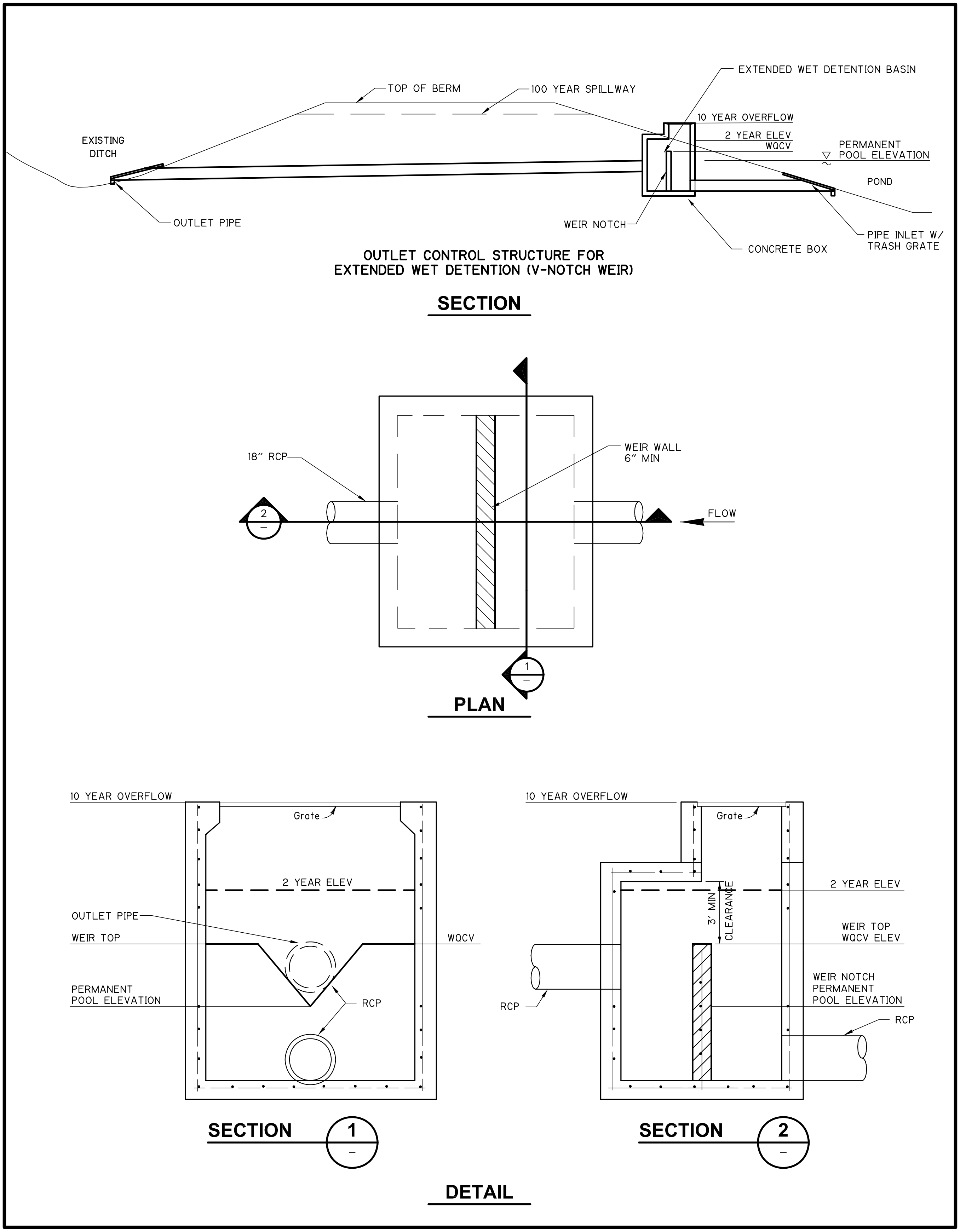

Figure 7-4
Outlet Structure Details
Extended Wet Detention Basin

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7.2.3 Water Quality Control Volume

There are a variety of methods for determining the WQCV storage requirements. The WQCV is generally defined as the volume of water that is retained and slowly released to remove pollutants and reduce erosion. The optimum methods consider the local long-term rainfall characteristics as well as the land use characteristics of the contributing drainage area to the facility.

The City's Drainage Criteria Manual Section 8.1.1 references the first flush approach for estimating the WQCV storage requirements. However, recent research suggests that the first flush concept does not sufficiently address the control of pollutants over the long term (WEF/ASCE 1998). Using a percent capture approach better addresses long-term pollutant loading and stream stability since it considers the full range of runoff events, including those that are smaller than and greater than the first flush runoff volume. In addition, percent capture approaches account for the increase in runoff volume from developments with high impervious areas. By designing for the 90-percent capture volume, the majority of runoff volume and pollutants will be captured, and long-term stream stability will be achieved. This section compares three commonly used methods, including:

- First flush approach (City Drainage Criteria Manual)
- Percentage capture approach
- Percentage capture with drawdown and interevent times

These three approaches are discussed in detail below.

Approach 1 - First Flush

The first flush approach is based on the assumption that the majority of pollutants that have accumulated between rain events are washed off during the first 0.5 inches of runoff. This approach applies to all development sites regardless of the type of land use. Thus, if a facility is designed using this approach, particularly in areas with high impervious surfaces, it will not adequately treat for water quality or protect streams from erosion.

This approach to calculating the WQCV is easily used by developers to determine the volume of the water quality control portion of the stormwater pond. The WQCV is determined by multiplying 0.5 inches by the tributary area to determine a volume. The 0.5 inches is applied broadly over the entire tributary area regardless of percent imperviousness. This approach does not require a larger volume of runoff to be treated for high density developments, nor does it provide incentives to developers to construct low impact developments with open spaces. In addition, this approach does not account for basin drawdown times or small interevent times. The interevent time is the period of no precipitation between rainstorms.

Using Approach 1, the WQCV for a 100-acre development would be calculated as follows:

WQCV = 0.5 in x 100 acres x 1 foot/12 inches = **4.2 acre-feet**

Because this method does not account for the percentage of impervious area, the WQCV for a 100-acre residential, commercial, or industrial site would all equal 4.2 acre-feet.

Approach 2 - Percentage Capture
The percent capture approach is based on capturing a certain percentage (90 percent recommended) of the average annual runoff volume. For example, using a 90 percent capture criteria, the WQCV is equal to the storage required to capture and treat approximately 90 percent of the average annual stormwater runoff volume. To determine the WQCV, the 90 percent storm event is based on all 24-hour storms on an annual basis using historical precipitation records. Using the 20 years of precipitation data available at the Havelock USGS rain gauge, the 90 percent rainfall depth was determined to be 1.3 inches.

Once the 90 percent rainfall is estimated, the resulting runoff volume is calculated based on the percent imperviousness of the contributing area to the stormwater facility. The equation below is used to calculate the WQCV using the 90 percent storm event.

WQCV = P* Rv (Clayton and Schueler 1996)

P = 90 percent storm event (1.3 inches for Lincoln, Nebraska)

Rv = Volumetric Runoff Coefficient (0.05+0.009*I)

I = Percent Imperviousness

The advantage to this approach is that the basin size relates directly to the amount of impervious area in the contributing drainage area. This provides an incentive for developers to reduce imperviousness and provide green space. However, it does not account for loss of basin storage volume due to long draindown times coupled with short interevent times. For example, if the average interevent time is less than or equal to the WQCV drawdown time, then the basin is not allowed to empty before the next storm occurs. Therefore, in geographic areas where this commonly occurs, the drawdown and interevent time should be considered when calculating the WQCV.

Using Approach 2, the WQCV for a 100-acre residential development with 38 percent imperviousness would be calculated as follows:

Rv = 0.05+0.009*38 = 0.392

WQCV (inches) = P*Rv = 1.3*0.392 = 0.51 inches

WQCV (acre-feet) = 0.51 in x 100 acres x 1 foot/12 inches = **4.2 acre-feet**

Using this same approach for a 100-acre commercial development with 79 percent imperviousness, the WQCVs would be calculated as follows:

Rv = 0.05+0.009*79 = 0.761

WQCV (inches) = P*Rv = 1.3*0.761 = 0.99 inches

WQCV (acre-feet) = 0.99 in x 100 acres x 1 foot/12 inches = **8.3 acre-feet**

Approach 3 - Percentage Capture with Drawdown and Interevent Times
Incorporating the drawdown time and interevent time into the WQCV calculation provides the most comprehensive approach to determining the necessary WQCV. One of the easiest ways to do this is to use modeling software to produce WQCV look-up curves.

WQCV look up curves are generated using historical precipitation data, tributary area percent imperviousness or runoff coefficient, an estimated WQCV, and required drawdown time. Figure 7-5 shows WQCV look up curves that were generated for the City of Lincoln using software developed by CDM called NetSTORM and historical precipitation data from the Havelock USGS gauge. NetSTORM incorporates the calculation procedures that are included in the USACE's STORM program. The curves were developed for a 40-hour drawdown. The look-up curves provide a simple method of determining the WQCV based on projected land use.

Using Approach 3, the WQCV for a 100-acre residential development with a C value of 0.4 would be calculated as follows:

WQCV (inches) for 90 percent capture from Figure 7-5 = 0.50 inches

WQCV (acre-feet) = 0.50 in x 100 acres x 1 foot/12 inches = **4.2 acre-feet**

Using this same approach, the WQCV for a 100-acre commercial development with C value of 0.80 would be calculated as follows:

WQCV (inches) for 90 percent capture from Figure 7-5 = 0.98 inches

WQCV (acre-feet) = 0.98 in x 100 acres x 1 foot/12 inches = **8.2 acre-feet**

Approach Comparison and Recommendation
In summary, Table 7-2 compares the WQCV calculated using the three approaches for residential and commercial development sites. For residential developments, the results provide the same answers. However, WQCVs increase significantly for higher density developments (commercial) when using a 90 percent capture calculation (Approach 2 and 3) compared to the first flush approach. Comparing the results from Approach 2 and 3 shows that the interevent time did not reduce annual storage capacity of basins with a drawdown of 40 hours.

Table 7-2
Comparison of WQCV Calculation Approaches

Approach	WQCV (acre-feet)	
	Residential	Commercial
Approach 1 - First Flush	4.2	4.2
Approach 2 - 90 Percent Capture	4.2	8.3
Approach 3 - 90 Percent Capture w/40-hr Drawdown	4.2	8.2

The project team recommends the City adopt Approach 2 for calculating the WQCV for structural BMPs. This approach can be easily implemented by developers and City staff. In addition, it provides incentive for developers to limit impervious area.

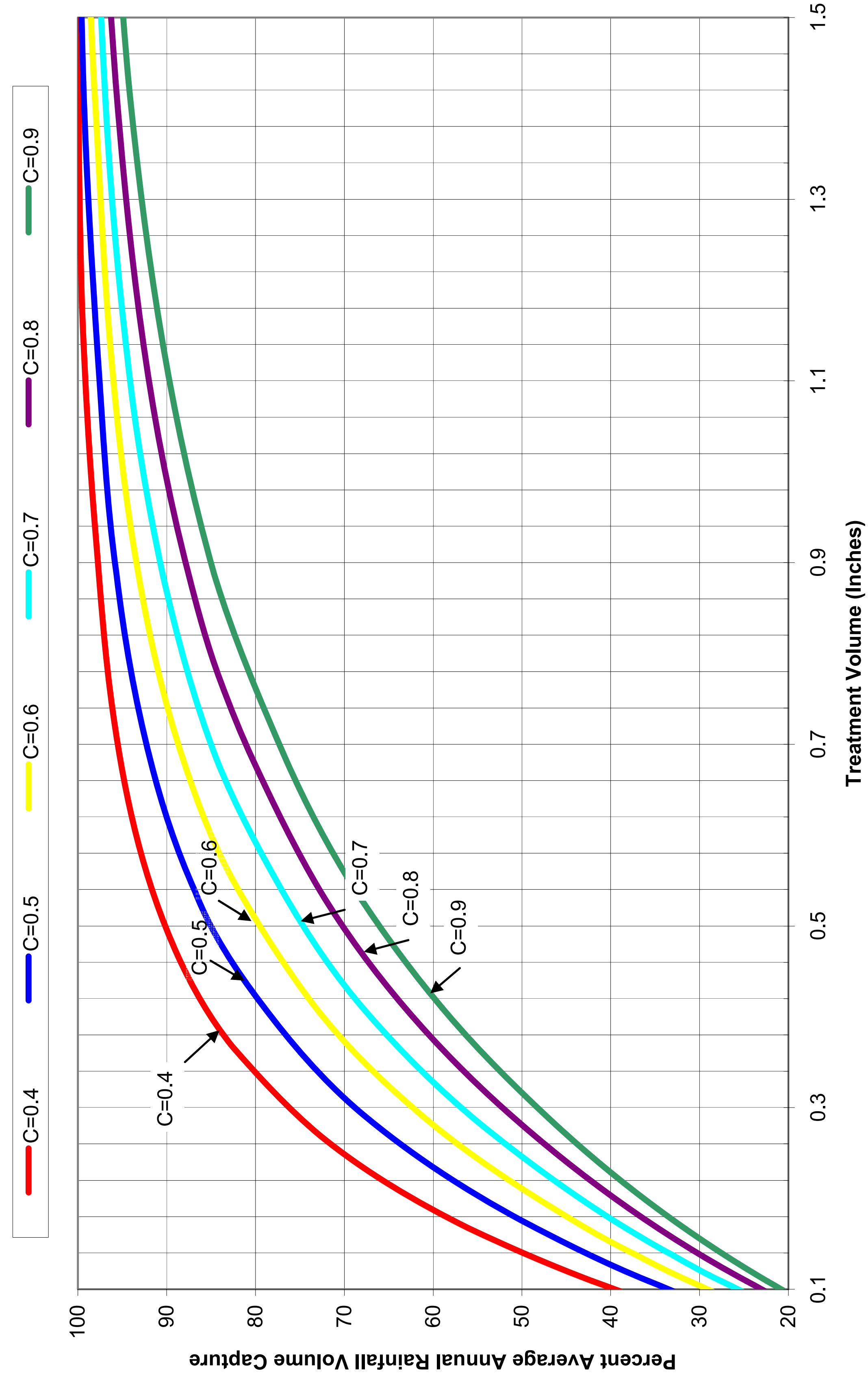

Figure 7-5
Lincoln, Nebraska
Average Annual Rainfall Volume Capture

Drawdown Calculations

Section 6.1.4 of the Drainage Criteria Manual requires all storage facilities to be analyzed using reservoir routing calculations, either performed manually or using HEC-HMS. Section 6.9 of the Drainage Criteria Manual provides a procedure and examples of storage routing calculations for 2- and 10-year storm events. To incorporate the water quality benefits in storage facility design, a 40-hour drawdown of the WQCV should be provided. Below are examples of calculating the drawdown time for a depth of water equal to the WQCV using an orifice outlet structure. Both a manual calculation and HEC-HMS example are provided.

Manual Calculations of the WQCV Drawdown

The first step in calculating the drawdown for the WQCV is determining the depth in the basin at which the WQCV is satisfied (or the WQC depth). This WQC depth can be determined by estimating storage volume in the basin at incremental depths using topographic maps and preliminary grading plans, and interpolating the depth associated with the WQCV. Once the WQC depth is determined, the procedure outlined in Drainage Criteria Manual Section 6.9 can be used to determine the drawdown time.

Step 1 - Choose an appropriate routing time step (the example uses 0.1 hours).

Step 2 - Set up the stage-storage-discharge table. The discharge column (Q) should be calculated using the appropriate equation for the hydraulic control of the WQCV.

Step 3 - Set up the storage routing table for the WQCV. The inflow hydrograph is 0 cfs for all time steps, and the starting depth is the WQC depth.

Step 4 - Continue with routing calculations until Q=0. The time step associated with Q=0 is the drawdown time.

Step 5 - Modify the outlet structure (Q column in the stage-storage-discharge table) or the storage volume and WQC depth until the time step at which Q=0 is 40 hours.

Appendix G located in Volume II of this report provides example calculations to determine WQCV drawdown using the method above.

HEC-HMS Calculations for WQCV Drawdown

The following steps can be used to determine WQCV drawdown in HEC-HMS. The same basin parameters as used in the manual routing example are used for this example.

Step 1 - Set up a new basin model that contains only one reservoir element. Do NOT include a Subbasin in the same basin model.

Step 2 - Populate the reservoir element with stage-storage-discharge data or stage-storage data and an outlet structure. Set the initial elevation equal to the WQC depth.

Step 3 - Set up a new meteorological model and choose the “No Precipitation” method.

Step 4 - Set up new control specifications and make certain the runtime extends beyond 40 hours.

Summary
Figure 7-6 shows that the results from the HEC-HMS model and the manual calculations closely match. The manual calculations are greatly simplified by the use of a spreadsheet.

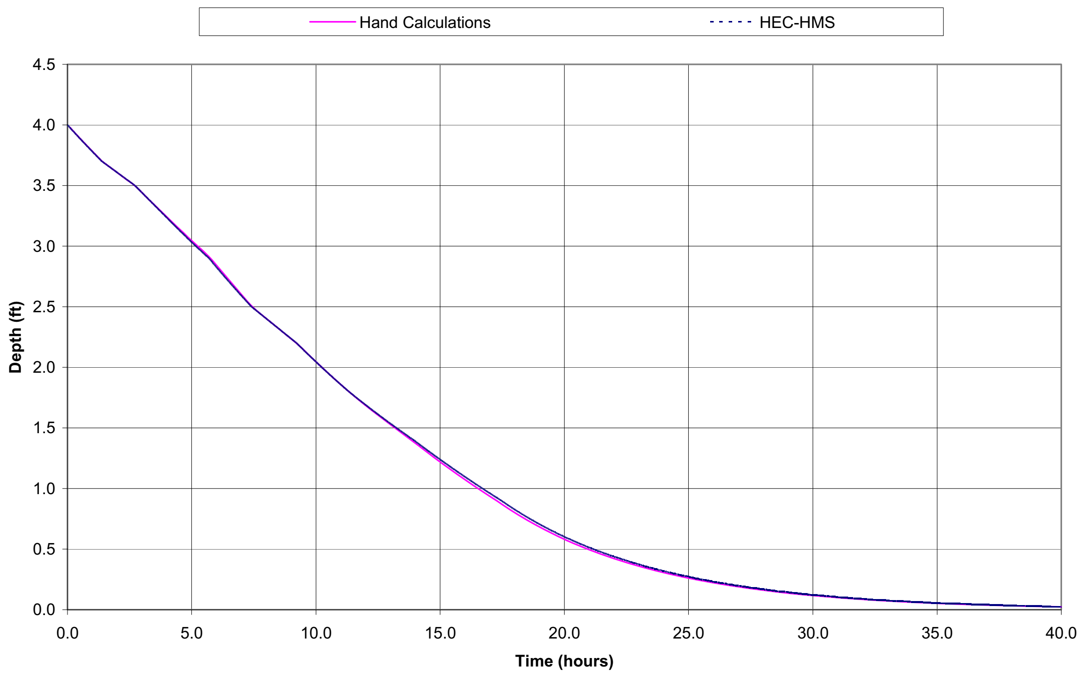

Figure 7-6
Example WQCVs Drawdown

7.3 Alternative Design Approaches

The design approach described above combines the water quantity (2-, 10-, and 100-year controls) requirements with the water quality component (structural BMP) into a single integrated facility. This integrated approach is one of many design concepts that can be employed to achieve the desired results. When revised design standards are drafted, all low cost options providing the same or greater water quality benefits should be considered and included as options for the developer. The following paragraphs provide other alternative design approaches that can be implemented to achieve the same overall goals and objectives.

As discussed above, the purpose of the structural BMP is to treat the WQCV using a 40-hour release time. To accomplish this goal, the structural BMP can be designed to take many different forms, including grass swales and bioretention filters. Figure 7-7 depicts a typical development site that contains a structural BMP separated from the detention basin. In this example, the parking lot and buildings are drained by typical stormwater conveyance components (curb/surface grates/pipeline), which discharge to the grass swale adjacent to the parking lot. For the smaller rainstorms, the stormwater runoff is treated and detained within the grass swale, and slowly released offsite using an outlet structure, such as a v-notch weir, designed to release the WQCV over a 40-hour period. For rainstorms that exceed the WQCV, the stormwater spills into the detention basin via the overflow spillway.

Figure 7-8 illustrates another alternative design using the same site layout. In this example, bioretention filters (landscape swales) are used within the parking lot to provide water quality benefits. For the smaller rainstorms, the runoff infiltrates into a natural soil media, and eventually drains into a perforated pipeline system. The pipeline transports the runoff to a flow splitter box that contains two outlet pipes. The pipeline that drains directly to the stream is sized only to convey the WQCV. All excess flow is diverted to the detention basin. For the rainstorms that exceed the WQCV, standpipes located within the bioretention filters act as overflow structures that transport the larger rainstorms to the pipeline system. The flow splitter box then directs the higher flows to the detention basin.

There are numerous other variations to the concepts presented on Figures 7-7 and 7-8, which allows the site designer the flexibility for achieving both water quantity and water quality benefits. In considering other alternatives, the following two key design concepts need to be followed: The structural BMP must be placed upstream of the detention basin to properly regulate the smaller rainstorms and provide water quality treatment. Outlet control structures need to be designed for both the structural BMP and the detention basin.

One of the key advantages of separating the structural BMP from the detention basin is the ability to enhance the usability of the facility. Using the approaches described above, the detention basin bottom only becomes saturated for storms greater than the water quality storm, which equates to a rainfall depth of approximately 1.3 inches. This allows the basin to be dry for prolonged periods of time, allowing the facility to be used for passive recreation and doubling as a parkland dedication area in some cases. In addition, the structural BMPs can be designed with landscape features, especially within bioretention filers, adding aesthetic value to the site.

7.4 Facility Ownership and Maintenance

Stormwater facilities, including both structural BMPs and storage facilities, must be regularly inspected and properly maintained to meet their expected level of performance. In addition to achieving their design functions, the proper maintenance of facilities can extend their design life and possibly reduce the costs of repairs and rehabilitation in the future.

The clear identification of ownership responsibility is critical for ensuring proper maintenance. Section 6.1.6 of the Drainage Criteria Manual describes ownership and maintenance requirements of storage facilities:

> *Storage facilities proposed in a development, along with all inlet and outlet structures and/or channels, are to be owned and maintained by the developer or a property-owners' association unless a different ownership/maintenance arrangement has been approved by the Director of Public Works and Utilities. Because the downstream storm sewer system will be designed assuming detention storage upstream, a storage facility in the storm sewer system shall remain functional as a storage facility site permanently. Provisions shall be made in the approval of development by the Planning Commission and City Council for the permanence of the storage facilities and ongoing maintenance of the storage facilities.*

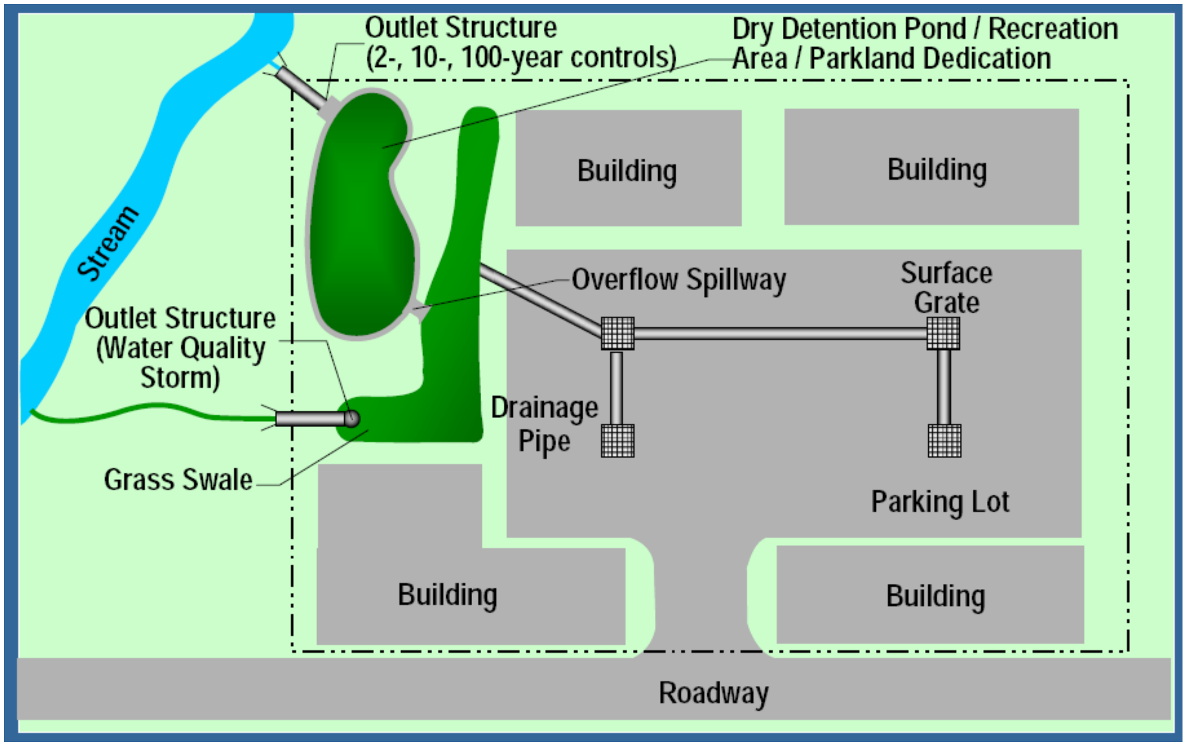

Figure 7-7
Design Alternative No. 1 - Incorporating Structural BMPs and Detention Basins

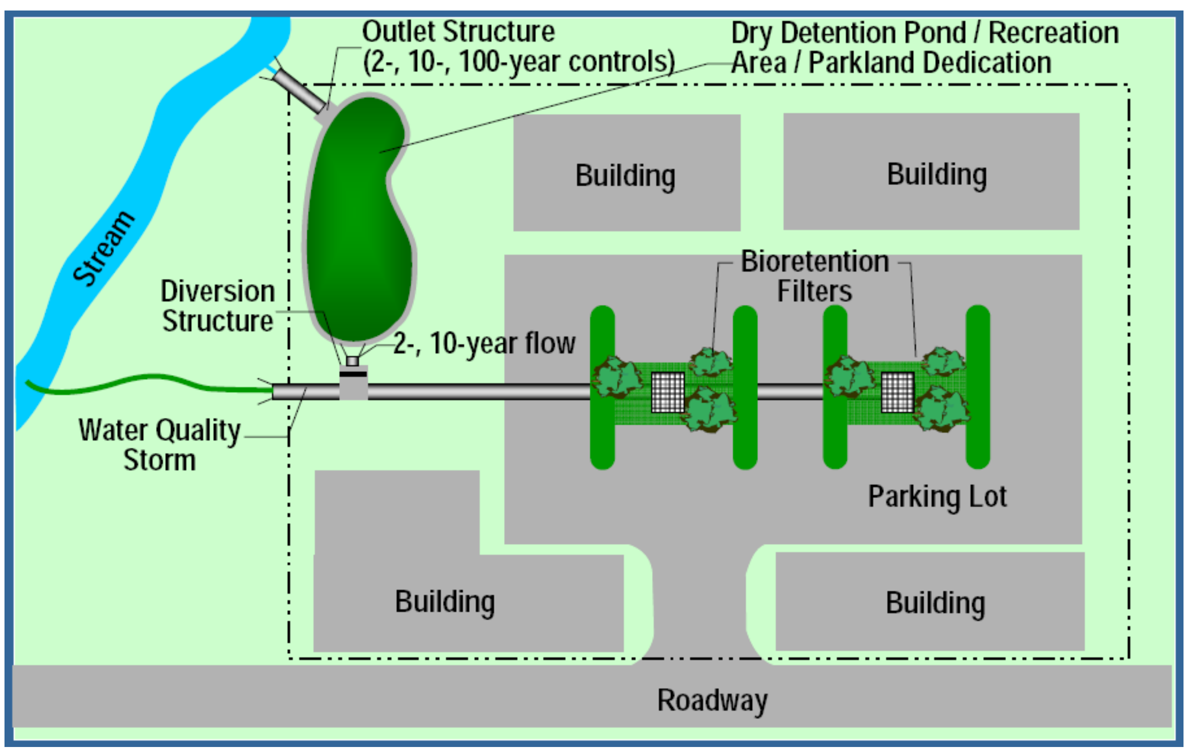

Figure 7-8
Design Alternative No. 2 - Incorporating Structural BMPs and Detention Basins

In addition, the City's NPDES Stormwater Permit, effective September 1, 2002, requires the City to "ensure adequate long-term operation and maintenance of BMPs," which is discussed in Chapter 9 of the Drainage Criteria Manual.

While the Drainage Criteria Manual provides useful information on some of the inspection and maintenance activities required of stormwater facilities, there are areas of the manual that can be strengthened to ensure that the facilities function as designed. For example, maintenance ordinances and formal maintenance agreements with the facility owner would enforce maintenance activities. In addition, a maintenance plan that outlines specific work activities should be submitted as part of the approval process. The maintenance plan would also include inspection and maintenance checklists to assist the owner in implementing the maintenance plan.

This section discusses maintenance ordinances and agreements, outlines key components of an effective maintenance plan, and recommends updates to the Drainage Criteria Manual. Design considerations for stormwater facilities that include maintenance are addressed in Section 7.2. Appendix H located in Volume II of this report includes a model maintenance ordinance, example maintenance agreement, and example inspection and maintenance checklists.

7.4.1 Maintenance Requirements

One way to ensure adequate operation and maintenance of stormwater facilities is to adopt higher standards for the design, maintenance, and inspection of facilities. Design standards referenced in the subdivision ordinance can specify inspection frequency, maintenance responsibilities, and recordkeeping procedures to be followed by facility owners. At a minimum, maintenance standards should include the following:

- Identification of the facility owner responsible for long-term maintenance and inspection of the facility
- An inspection and maintenance plan that outlines specific work activities for each type of facility
- Inclusion of the maintenance plan in the subdivision agreement
- Penalties for noncompliance

A model maintenance ordinance from the Stormwater Manager's Resource Center is provided in Appendix H.

7.4.2 Maintenance Agreement

The City currently requires a subdivision agreement between the City and the owner. Through this agreement, the owner (or his successor) is required to maintain the private improvements. Language requiring a stormwater facility maintenance plan should be added to the subdivision agreement to clearly identify who is responsible for proper installation and maintenance of the stormwater facility.

The City should obtain legally binding agreements with property owners stating that the stormwater facilities for the site will not be altered and will be maintained as needed to achieve their original design intent. Example maintenance agreements from various communities are included in Appendix H.

7.4.3 Maintenance Plan

Maintenance plans for stormwater facilities on private residential, commercial, or industrial development sites should be developed by the facility owner and submitted to the City during the project design approval phase.

The maintenance plan should outline activities to maintain the facility's hydraulic storage and discharge release capacity, vegetative cover, and other connected structural components such as inlets, outlets, and tile lines that are tied to the same stormwater management system. In addition, the facility owners should be held responsible for damage to downstream or nearby property as a result of poorly designed or maintained facilities.

The key items to consider in a maintenance plan include:

- Identification of the facility owner responsible for long-term maintenance and inspection of the facility
- Definition of the specific maintenance and inspection activities to be performed
- Maintenance and inspection checklists and schedules
- Annual report to the City from the facility owner

The paragraphs below identify each of the key components of an effective maintenance plan for various types of stormwater facilities.

Maintenance and Inspection Activities

Maintenance and inspection activities can be divided into routine and as-needed activities. Examples of routine and as-needed activities are discussed in more detail below.

Routine Maintenance and Inspection
Routine or preventative maintenance is performed on a regular basis and includes mowing, debris removal, minor silt/sediment removal, erosion repair, nuisance control, and clearing of vegetation around the outlet control structures to prevent clogging.

At a minimum, routine inspection should be performed on an annual basis with additional inspections of problematic areas following large storm events (e.g., rainfall greater than one inch). Routine inspections can be performed in a systematic manner using the checklists described in this section. For inspections following a major storm, the inspector should visit the site within 2 days after the specified drawdown period to ensure that the outlet control structures are performing properly.

In some cases, inspection and maintenance activities can be combined, such that inspections are arranged to coincide with scheduled maintenance visits to minimize site visits and to ascertain that maintenance activities are performed satisfactorily. At the time of all site inspections, the inspector should check the accumulation of debris and sediment. If applicable, the weir or controlling structure and side slopes of the facility should be checked to ensure that they do not show signs of erosion, settlement, slope failure, or vehicular damage. Vegetated littoral zones should be inspected to ensure that water level elevations are appropriate to enhance vegetative growth, support desirable aquatic habitats, maintain acceptable survival rates for planted species, and to confirm that vegetative cover is acceptable.

Standing water or soggy conditions within a "dry" stormwater facility can create nuisance conditions for nearby residents. Odors, mosquitoes, weeds, and litter can all be potential problems in stormwater facilities. However, wetland plants established in wet extended detention ponds can harbor birds and predacious insects and fish that serve as a natural check on mosquitoes, and regular maintenance to remove debris and ensure control structure functionality will help control these potential problems.

As-Needed Maintenance
As-needed maintenance includes major silt/sediment removal on a 5- to 10-year cycle, control structure replacement, removal of log jams, or a major harvesting of aquatic vegetation.

Sediment removal is a very important maintenance activity for extended detention ponds because these facilities are designed to primarily remove pollutants by sedimentation. Sediments collect at the bottom of the basin, reducing storage volume and increasing the likelihood of clogging the outlet structure. Sediment deposition should be regularly monitored in the routine inspections, and dry ponds may have to be cleaned out more frequently than wet ponds for aesthetic reasons. The detention facility will generally need sediment removal if greater than 10 percent of the storage is filled with silt. The typical frequency of sediment removal is 5 to 10 years, sometimes even longer if a forebay is incorporated into the design.

Floatables and trash should be cleaned from the sediment forebay on an as-needed basis. Yearly inspections should be performed to determine if sediment needs to be removed from the forebay. The typical frequency of sediment removal is 5-10 years.

Sediments removed from detention ponds, especially in highly urbanized areas, may contain high levels of toxins (e.g., heavy metals and organics). In addition to monitoring sediment deposition rates, core samples from detention ponds every few years could be used to monitor the buildup of pollutants. If bottom sediment concentrations approach levels that would restrict disposal onsite or in local landfills, clean out may be required on a more frequent basis.

Side slopes, emergency spillways, and embankments all may periodically suffer from slumping and erosion. This should not occur often if the soils are properly compacted and vegetated during construction. Regrading and revegetation may be required to correct problems that develop. Areas of erosion and slope failure should be filled and compacted, if necessary, and reseeded (or sodded) as soon as possible. Eroded areas near the inlet or outlet should be revegetated and, if necessary, be filled, compacted, and revegetated or lined with riprap. Damaged side slopes and embankments should be repaired using fill with adequate permeability. Major damage to outlet structures (e.g., cracks, leaks, or failure) should be repaired as soon as possible.

Control structures will eventually deteriorate and must be replaced. Control structures should be inspected at least annually. In the case of exfiltration/infiltration trenches, sand filters, and porous pavement, part or all of the facility may need replacement when the trench, filter, or pavement becomes clogged.

Tables 7-3 through 7-8 provide suggested maintenance activities and frequency for various BMPs to be used by developers and homeowners for maintaining BMPs. These maintenance activities are typically used by the City/NRD during inspections.

Tables 7-3 through 7-5 show suggested maintenance activities and schedules for extended dry detention basins, extended wet detention basins, and constructed wetlands. These types of stormwater facilities can be used for water quality protection and flood control.

Table 7-3
Suggested Maintenance Activities for Extended Dry Detention Basins

Activity	*Schedule*
▪ Note erosion of pond banks or bottom.	Semiannual inspection
▪ Inspect for damage to the embankment. ▪ Monitor for sediment accumulation in the facility and forebay. ▪ Examine to ensure that inlet and outlet/overflow spillway devices are free of debris and are operational. ▪ Inspect fences/accessways for needed repair. ▪ Check for standing water within 72 hours of major storm; remove standing water as necessary to control mosquito populations. Remove and replace any existing media filters that have been exposed to standing water for longer than 72 hours.	Annual inspection and after major storms
▪ Repair undercut or eroded areas. ▪ Manage pesticide and nutrients. ▪ Mow side slopes (frequency is dependent on type of vegetation). ▪ Check for both adequate and undesirable vegetation growth. ▪ Remove litter, debris, and floatables from the sediment forebay. ▪ Inspect for and repair any depressions on the pond bottom.	Monthly
▪ Monitor for presence of mosquito larvae populations.	Weekly during peak seasons
▪ Seed or sod to restore dead or damaged ground cover.	Annual maintenance (as needed)
▪ Remove sediment from the forebay.	5- to 10-year maintenance
▪ Monitor sediment accumulations in the pond, remove sediment when pond volume has been reduced by 10 percent (as determined by depth compared to design depth).	25- to 50-year maintenance

Adapted from: WMI 1997

Table 7-4
Suggested Maintenance Activities for Extended Wet Detention Basins

Activity	Schedule
▪ Note erosion of pond banks or bottom ▪ If wetland components are included, inspect for invasive vegetation and remove where possible	Semiannual inspection
▪ Inspect for damage to the embankment ▪ Monitor for sediment accumulation in the facility and forebay ▪ Examine to ensure that inlet and outlet devices are free of debris and are operational ▪ Inspect fences/accessways for needed repair ▪ Inspect principal and emergency spillways	Annual inspection and after major storms
▪ Repair undercut or eroded areas	Maintenance as needed
▪ Manage pesticide and nutrients ▪ Remove debris from inlet, outlet structures ▪ Mow side slopes (frequency is dependent on type of vegetation) ▪ Monitor undesirable vegetative growth ▪ Remove litter, debris, and floatables from the sediment forebay	Monthly maintenance
▪ Monitor for presence of mosquito larvae populations	Weekly during peak seasons
▪ Seed or sod to restore dead or damaged ground cover on upland areas ▪ Manage and harvest wetland plants	Annual maintenance (if needed)
▪ Remove sediment from the forebay	5- to 10-year maintenance
▪ Remove sediment when the pool volume has become reduced significantly or the pond becomes eutrophic	20- to 50-year maintenance

Adapted from: WMI 1997

Table 7-5
Suggested Maintenance Activities for Constructed Wetlands

Activity	Schedule
▪ Replace vegetation to maintain 50 percent surface area coverage in wetland plants	One time after the second growing season
▪ Inspect for invasive vegetation and remove where possible	Semiannual inspection
▪ Inspect for, repair damage to embankment and inlet/outlet structures ▪ Monitor for sediment accumulation in the facility and forebay ▪ Examine to ensure that inlet and outlet devices are free of debris and are operational	Annual inspection and after major storms
▪ Repair undercut or eroded areas	Maintenance as needed
▪ Remove debris from inlet, outlet structures ▪ Mow side slopes (frequency is dependent on type of vegetation)	Frequent (3 to 4 times/year) maintenance
▪ Monitor for presence of mosquito larvae population	Weekly during peak seasons
▪ Manage and harvest wetland plants	Annual maintenance (if needed)
▪ Remove sediment from the forebay	5- to 7-year maintenance
▪ Remove sediment when the pool volume has become reduced significantly or the pond becomes eutrophic	20- to 50-year maintenance

Adapted from: WMI 1997

Tables 7-6 through Table 7-8 show suggested maintenance activities and schedules for bioretention areas, vegetated swales, and open channels. These types of stormwater facilities are typically used to provide only water quality benefits.

Table 7-6
Suggested Maintenance Activities for Bioretention Filters

Activity	Schedule
▪ Remulch void areas ▪ Treat diseased trees and shrubs ▪ Mow turf areas	As needed/Monthly
▪ Water plants daily for 2 weeks	At project completion
▪ Inspect soil and repair eroded areas ▪ Remove litter and debris ▪ Check dewater rate after storm	Monthly and after major storms
▪ Remove and replace dead and diseased vegetation	Semiannually
▪ Add mulch ▪ Replace tree stakes and wires ▪ Inspect dams, energy dissipators, sumps, outlets and overflow spillways ▪ Remove sediment when the structure's design depth has been reduced by 20 percent	Annually and after major storms

Source: ETA & Biohabitats 1993 and WMI 1997

Table 7-7
Suggested Maintenance Activities for Vegetated Swales

Activity	Schedule
▪ Inspect pea gravel diaphragm (if applicable) for clogging, correct problem. ▪ Inspect, repair erosion in grass along side slopes and bed. Inspect outlets/overflow spillways (if applicable). Check dams or energy dissipators.	Annual (twice the first year) and after major storms
▪ Rototill or cultivate the surface of the sand/soil bed of dry swales if the swale does not draw down within 48 hours. ▪ Remove sediment buildup within the bottom of the swale once it has accumulated to 25 percent of the original design volume (as determined by design depth). ▪ Debris cleanout.	Monthly or as needed (may be infrequent)
▪ Mow grass to maintain a height of 3 to 4 inches.	As needed (frequent, seasonally)

Source: WMI 1997

Table 7-8
Suggested Maintenance Activities for Open Channels

Activity	Schedule
▪ Mow grass so as not to exceed minimum depth	As needed/Monthly
▪ Remove litter and debris ▪ Inspect, repair areas of erosion ▪ Check for dewatering rate after storms	Monthly and after major storms
▪ Check dams, energy dissipators, outlets, and overflow spillways ▪ Check for areas of excessive sediment deposition	Annually and after major storms

Source: New York State Stormwater Management Design Manual, August 2003

Maintenance and Inspection Checklists

Many communities track routine maintenance and inspections in a systematic manner using checklists. An example inspection and maintenance checklist from the *New York State Stormwater Management Design Manual* is provided in Appendix H of this report. Some communities have found it beneficial to track maintenance activities using an electronic database.

Annual Report from the Facility Owner

Many communities require the facility owner to submit an annual report detailing inspection and maintenance activities of their stormwater facilities. The annual report should include completed inspection and maintenance checklists, scheduled maintenance activities, and future inspection and maintenance schedules.

7.5 Conservation Culvert Design

The installation of new drainage structures should take into account the natural channel configuration at the location of the improvement. Long-term observations of stream channels and structures have shown that natural channels once modified will return to their original size and shape without routine maintenance. Therefore, by accounting for this natural tendency during design, long-term maintenance cost can be reduced.

Typically, natural channels have a two-stage configuration. The first stage handles flows up to the 1.5- to 2-year flood. This stage is typically referred to as the primary channel or flow-way. The second stage handles flows from larger flood events and is better known as the floodway.

Accounting for the natural channel configuration in the design of improvements translates to the construction of nonsymmetrical structures. Using the traditional approach, a culvert designed with three parallel box culverts would be designed around all three culverts being constructed with the same invert, requiring the channel bed to be artificially widened to match the new opening width. Figure 7-9 shows an example of a typical traditional installation. Typically, structures constructed with this approach have siltation problems that either require a significant amount of maintenance and/or significantly reduce the flow capacity of the structure.

This problem can be avoided by accounting for the natural channel configuration in the design. Through this approach, the inverts and shape of parallel culverts would be adjusted to match the shape of the natural channel. The primary culvert would be set at the natural channel invert and any secondary culverts would be set at a higher elevation, matching the flow line of the flood channel. This type of configuration is referred to as a conservation culvert design, which is shown on Figure 7-10. Through applying this design concept, flood flow capacity of the structure can be maintained while reducing the amount of routine maintenance (i.e., pipe cleaning). However, when applying this approach, the engineer should be careful to verify that the flow capacity of the modified design is contained below the peak flood elevation.

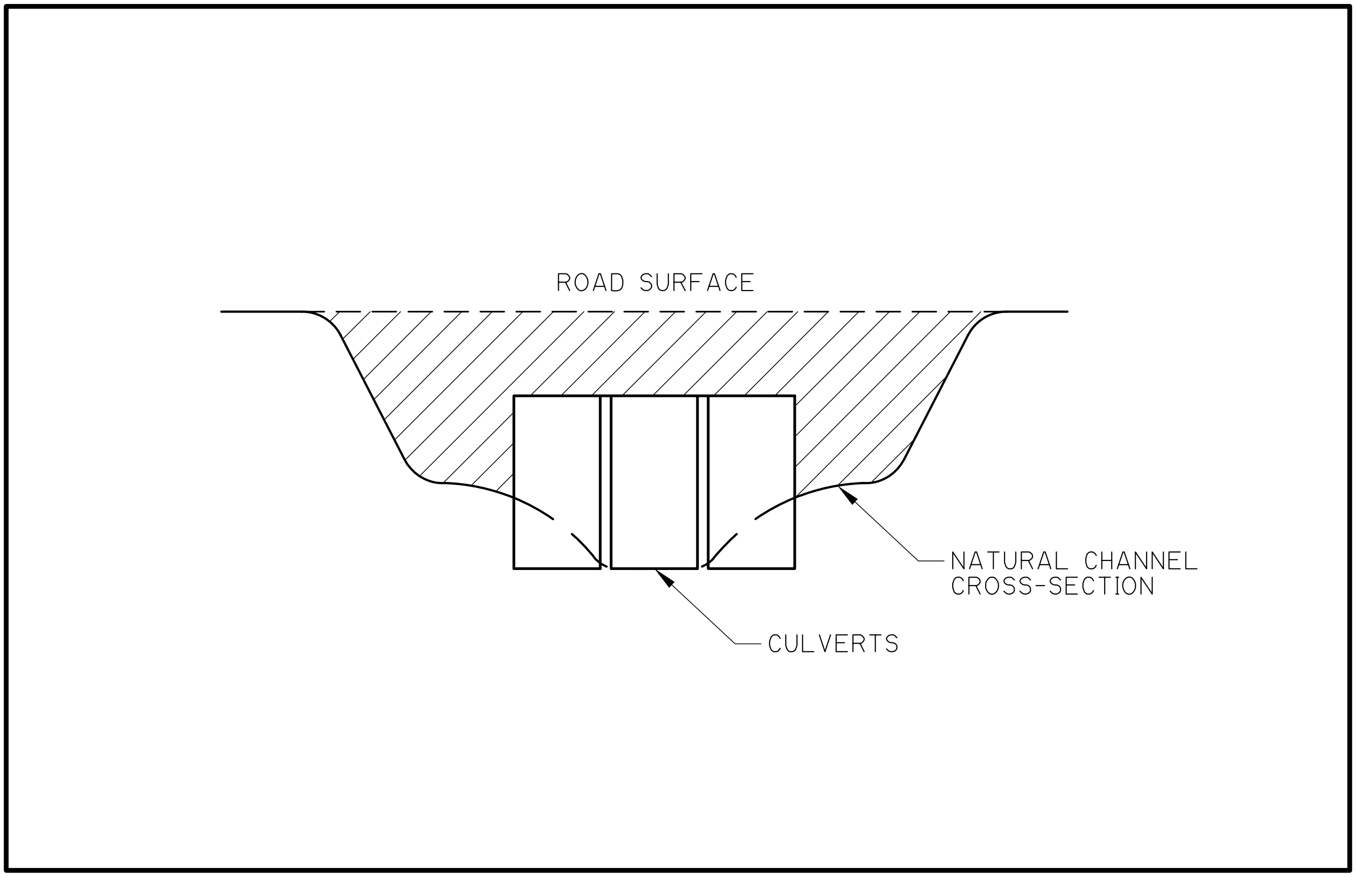

Figure 7-9
Traditional Culvert

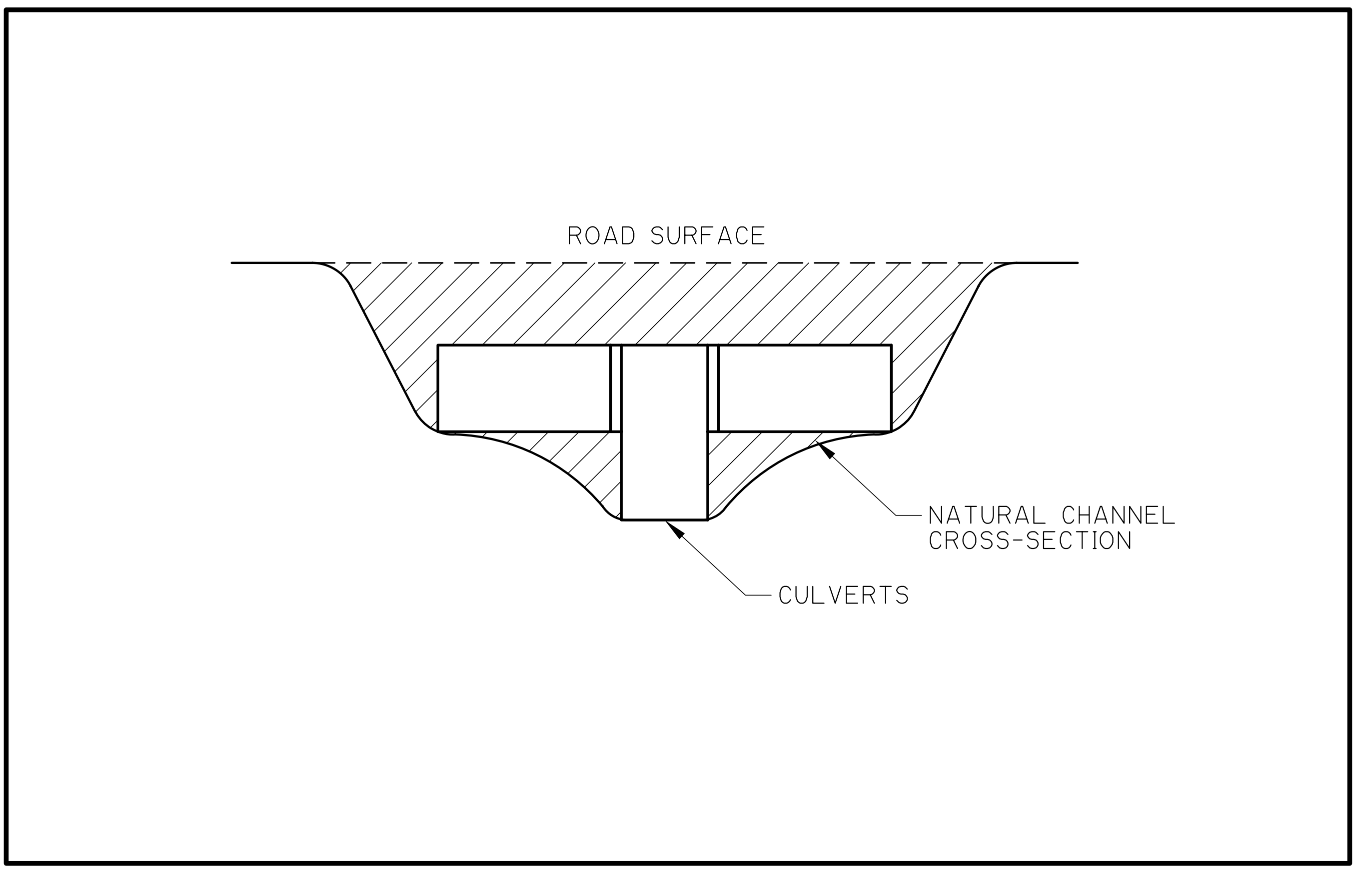

Figure 7-10
Modified Culvert

CDM