
Chapter 7. STORM WATER DETENTION DESIGN AND DOWNSTREAM ANALYSIS

This chapter provides policies and technical procedures for analyzing storm water facilities required for land disturbance activities in Greenville County. The design methods and criteria outlined in this chapter shall be used in the design and evaluation of detention systems utilized for storm water quantity control.

7.1. Hydrologic and Hydraulic Design Criteria

All designs of detention systems utilized for storm water quantity control shall be submitted with a design summary report when applying for a Storm Water Management Permit. The following design criteria shall be implemented for water quantity control unless a waiver is granted on a case-by-case basis.

- Post-development discharge rates from the entire development area shall not exceed pre-development discharge rates for the 2-, 10- and 25-year frequency 24-hour duration storm events.
 - ◆ Multi-stage control structures may be required to control the 2-, 10- and 25-year storm events.
 - ◆ The same hydrologic procedures shall be used in determining both the pre-development and post-development peak flow rates.
- Post-development discharge velocities in receiving channels shall be non-erosive flow velocities or shall be equal to or less than the pre-development 10-year, 24-hour storm event flow velocities.
- Emergency spillways shall be designed to safely pass the post-development 100-year 24-hour storm event without overtopping any dam structures.
- All dry detention basin volumes shall be drained from the structures from 48 to 72 hours.
- Watersheds that have well documented water quantity problems may have more stringent or modified design criteria as determined from master plan studies by Greenville County including but are not limited to:
 - ◆ Post-development discharge rates from the entire development area not exceeding pre-development discharge rates for storm frequencies greater than the 25-year frequency 24-hour duration storm event.
 - ◆ Post-development discharge volumes from the entire development area not exceeding pre-development discharge volumes.
 - ◆ Reduction of peak flow rates from pre-development to post-development.
 - ◆ Reduction of total volume released from pre-development to post-development.
 - ◆ Downstream channel, culvert or property improvements.
- A project may be eligible for a waiver from the storm water management requirements for water quantity control if the applicant can justly verify that:
 - ◆ The proposed project will not create any significant adverse effects on the receiving natural waterway downstream of the property.
 - ◆ The imposition of peak flow rate control for storm water management would create, aggravate, or accelerate downstream flooding.

7.1.1 Accepted Detention Structural Controls

Detention structural controls are used for providing water quantity control and are typically used downstream of other minor structural controls. These structures are designed to provide channel protection, overbank flood protection, and any adverse downstream impacts that are related to the increase in peak flow rates and flow volumes from development. Detention structural storm water controls can be classified into several categories as shown in Table 7-1.

Table 7-1. Detention Structural Controls

General Structural Control	Description
Dry Detention/Dry Extended Basins	Dry detention basins and dry extended detention basins are surface storage facilities intended to provide temporary storage of storm water runoff and releasing it at a designed flow rate to reduce downstream water quantity impacts. These structures are designed to completely drain to a dry condition within 72 hours.
Wet Storm Water Detention Basins  Wet Pond  Wet Extended Detention Pond  Micropool Extended Detention Pond  Multiple Pond System	Wet detention basins are constructed storm water basins that have a permanent pool or micropool of water. Runoff from each rain event is detained above the permanent pool and released at a designed flow rate to reduce downstream water quantity impacts.
Multi-purpose Detention Areas	Multi-purpose detention areas are used for one or more specific activities such as parking areas and rooftops. These areas are used to provide temporary storage of runoff. Some of the multi-purpose area such as infiltration trenches or bio-retention areas may also be used for water quality purposes.
Underground Detention	Underground detention is used as an alternative to surface dry-detention basins. They are used in areas that are space-limited where there is not enough adequate land to provide the required detention volume. The underground storage utilizes tanks, vaults, and buried pipes to supply the required storage volume.

7.2. Design Procedures

This section provides the general design procedures for the design of storm water quantity structures. The following items shall be required for the design of these structures, and routing flows through them.

-  Compute the inflow hydrograph for the structure.
-  Compute a stage-storage relationship for the proposed structure. A stage storage-curve defines the relationship between the depth of water and storage volume within the detention facility.
-  Compute stage-discharge relationship of the outlet control structures.
-  Perform routing calculations for the 2-, 10-, 25- and 100-year 24-hour storm events. These may be done by hand, or may be done by using a storage routing computer model.

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- Evaluate the control structure outlet flow velocity and provide velocity control or channel stabilization if needed.

Routing of hydrographs is critical to the proper design of storm water quantity control structures. Storage design procedures have been formulated without using routing, but the use of these methods in designing storm water quantity structures has not produced acceptable results for the Southeastern United States.

Hand calculations are available for routing hydrographs through detention structures, however they are time consuming and inefficient when multiple designs are required to be evaluated. For this chapter, it is assumed that the design professional will be using one of the many computer software packages available to perform storage routing calculations. Input parameters typically required for computer software packages include:

- Hydrological parameters of the development site
 - Area
 - Curve Numbers
 - Time of concentration
- Hydraulic parameters of detention structures
 - Stage-storage relationship
 - Stage-discharge relationship

7.2.1 Stage-Storage Calculations

A stage storage curve defines the relationship between the depth of water and storage volume within the detention facility. The stage storage relationship is calculated by utilizing known surface area values at known elevations within the basin. The areas used for this calculation are obtained by either field survey data or using known geometric relationships within the basin. Two of the most common methods of calculating stage storage relationships are the double end area method, and the pyramid frustum method.

7.2.1.1 Double End Area Method

The double end area method is expressed as:

$$V_{1,2} = \left[\frac{(A_1 + A_2)}{2} \right] d$$

Where:

- $V_{1,2}$ = Storage volume (ft³) between elevation 1 and 2.
- A_1 = Surface area (ft²), at elevation 1.
- A_2 = Surface area (ft²), at elevation 2.
- D = Change in elevation between stations 1 and 2.

7.2.1.2 Pyramid Frustum Method

The pyramid frustum method is expressed as:

$$V = \frac{d}{3} \left[\frac{(A_1 + A_2)^{0.5} + A_1 + A_2}{3} \right]$$

Where:

- $V_{1,2}$ = Volume of frustum of a pyramid (ft³) between elevation 1 and 2.
- d = Change in elevation between stations 1 and 2.
- A_1 = Surface area (ft²), at elevation 1.
- A_2 = Surface area (ft²), at elevation 2.

7.2.2 Stage-Discharge Calculations

A stage discharge curve defines the relationship between the depth of water within a storage structure and the outflow from the structure. This relationship shall be determined by utilizing the flow equation from Section 6.2.

7.2.3 Detention Structure Design Parameters

The construction of detention structures usually requires excavation or the placement of earthen embankments to obtain a required storage volume. This section discusses the design criteria of detention structures to ensure the long term function of the structure while minimizing the maintenance responsibilities.

7.2.3.1 General Design Criteria

1. Basins on Slopes: When basins are created by cutting and filling a slope, care should be taken that the seasonal groundwater table on the slope above the basin is not exposed, thus creating a seasonal spring. Controlling the groundwater flow or spring flow into a basin may be accomplished by the proper installation of a subsurface interceptor drainage system. To prevent destabilization from groundwater seepage, riprap may be needed.
2. Inlet and Outlet Locations: The inlets and outlet should be as far apart as possible, with a minimum of a 2:1 ratio of length to width between inlet and outlet. Runoff should have to travel the longest distance possible thorough the basin before being discharged. The shallow and narrow end of the basin should be located near the inlet and the deeper and wider end near the outlet.
3. Inlet Design: The inlet must be designed with riprap or other energy dissipater, such as a baffle below the inflow structure to reduce erosive forces and pretreatment to remove sediment. Sediment fore bays will be required on all ponds for post construction water quality and shall be designed with a minimum length to width ratio of 2:1.
4. Relationship to Groundwater: The basin bottom should be located above the seasonal high groundwater table to avoid standing water in the basin.
5. Scour: Prevention of scour at the inlet is necessary to reduce maintenance problems and prevent damage to basin floor vegetation. The velocities of flow through the inlet sediment control structure and basin should not exceed 2.5 feet per second. Energy dissipation should be provided at the inlet and outlet to prevent scour and reduce the velocity of storm water.

6. Access:

- Maintenance access shall be planted with grass and at least 10 feet wide with a maximum slope of 15% and a maximum cross slope of 3%. Sufficient land areas for equipment access for the basin maintenance should be provided. This access shall extend to the fore bay, micropool and outlet structure. It should never cross the emergency spillway, unless the spillway has been designed for that purpose and to the extent feasible, be designed to allow for vehicle turnaround. An easement may be required.
 - Provide a flat maintenance shelf/berm with a minimum width of 10-foot around the perimeter of the basin. The pond berm must provide load bearing capability for industrial maintenance mowers.
7. Outlet Protection: Outflow from the basin must be directed to a stable channel.
8. Minimum Buffer/ Setback: Minimum buffer/setback for the detention structure shall be 25 feet from the basin easement to any dwelling
9. Safety Fence: A safety fence or vegetative barrier is required where a detention structures interior side slopes are steeper than 3H:1V or when the impoundment is a wall greater than 24 inches in height. If the wall is adjacent to a walkway or street a railing may be required instead of a fence.

7.2.3.2 Surface Detention Basin Criteria

1. Basin Side Slopes: Vegetated embankments shall be less than 15-feet in height and shall have side slopes no steeper than 3H:1V. Embankments protected with Erosion Control Blankets or Turf Reinforcement Matting shall be no steeper than 2H:1V. In this case, at a minimum, one interior side slope must be 3H:1V to provide easier access into the basin. Geotechnical slope stability analysis is required for slopes greater than 10-feet in height and embankments that have steeper slope than those indicated above
2. Basin Shape: Provide a long and narrow basin shape, with a minimum length to width ration of 2:1, 3:1 is best. Length to width ratio can be increased by designing an irregularly shaped basin or by using baffles to create a longer path of flow. The allowable dead storage space of a basin is limited to a maximum of 20%.
3. Dry Detention Bottom Slopes: The bottom of detention structures shall be graded towards the outlet structure to prevent standing water conditions and be stabilized to prevent scour. A low flow or pilot channel constructed across the facility bottom from the inlet to the outlet is required to prevent standing water conditions when the pond bottom may be subject to non-storm flow from groundwater, footing drainage, storm sewer acting as under drain and sump discharge. A minimum 2 percent bottom slope is recommended for both cross slope and longitudinal slope.
4. Under Drains: If the 2% grade can not be obtained an acceptable alternative is to install an under drain. The under drain shall be constructed in the following manner:
 - The under drain shall be one of the last items to be installed to eliminate any sediment build-up that would cause the under drain to not function properly.
 - A non-woven geotextile fabric shall be laid in the excavated trench first.
 - The perforated drainpipe shall be covered with washed stone.
 - Both stone and drain shall then be wrapped with the non-woven geotextile and backfilled with sandy porous material.

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5. **Permanent Pool Detention:** The maximum depth of permanent storage facilities shall be determined by site conditions, design constraints, and environmental needs. The facility should provide a permanent pool of water with a depth sufficient to discourage weed growth without creating undue potential for anaerobic bottom conditions. A depth of 6 to 8 feet is reasonable unless fishery requirements dictate otherwise. Aerating may be required for permanent pools to prevent anaerobic conditions. Wildlife experts shall be contacted where aquatic habitat is required.
 6. **Emergency Spillways:** Emergency spillways shall be designed to convey the routed runoff of the 100-year 24-hour design storm while maintaining at least one foot of freeboard between the high water elevation and the top of the embankment crest. Overflow must discharge to a stable channel or established wetland area.
 - **Location:** Emergency spillways must be located on undisturbed, non-fill soil wherever possible. If the spillway must be located on fill soils, then it must be horizontally offset at least 20 feet from the principal outlet and be designed with some type of lining (i.e.: riprap, reinforced turf, or non-flexible lining).
 - **Exit channel grade:** The maximum grade of the spillway's exit channel may not exceed 20% unless a non-flexible lining is used to control erosion with the channel. All linings must be evaluated for stability at the channel grade chosen (Flexible linings include vegetation, reinforced turf, riprap and modular blocks).
 7. **Safe Dams Act:** A dam is defined as being an artificial barrier that impounds water to a depth of 15-feet or greater and has a maximum storage volume of 10-acre-feet or greater; therefore, impoundment depths greater than 15-feet are subject to the requirements of the Safe Dams Act unless the facility is excavated. Several exemptions are allowed from the Safe Dams Act and any questions concerning specific design application should be addressed by SCDHEC.
 8. **Principal Spillways:**
 - **Trash Racks:** All basin outlets must have a trash rack to control clogging by debris and to provide safety to the public. The surface area of each rack must be at least four times the outlet opening it is protecting. The spaces between rack bars must be no more than six inches or one-half the dimension of the smallest outlet opening behind it, whichever is less. Trash racks should be inclined to be self-cleaning.
 - **Seepage Control:** All pipes that extend through an embankment should have anti-seep collars or filter diaphragms to control the migration of soil materials and, so prevent potential embankment failure from "piping" within the backfill soil along the conduit. All smooth outlet pipes greater than eight inches and all corrugated outlet pipes greater than 12 inch must have seepage controls to prevent the migration of soil along the outside of the pipe.
 - **Anti-floatation:** All outlets employing a riser structure must be designed to prevent the riser floating.

7.2.3.3 Subsurface Detention Basin Criteria

1. **Emergency Spillways:** Overflow must discharge to a stable channel.
2. **Pretreatment:** All subsurface systems must include pretreatment for the removal of sediments prior to entering the detention structure.
3. **Observation Wells:** Subsurface detention systems must have an observation port for monitoring sediment and debris levels and determining when rehabilitation is necessary. This should be installed to the bottom of the system.

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4. Access Port: Access to the subsurface system must be provided to allow for the removal of accumulated sediment and debris.

7.2.3.4 Landscaping Criteria

In order to ensure that the ponds' engineering function is protected the following criteria for a landscaping plan near storm water ponds has been established:

1. Do not place landscaping within 10 feet of inlet or outlet pipes or other manmade structures such as spillways.
2. Do not place trees on berms that impound water, only shrubs that have fibrous roots may be planted on berms.
3. Do not plant trees on steep slopes or berms in order to prevent damage from blowdowns that can lead to failure of the dam/berm.
4. Side slopes and berms should be built no steeper than 3H:1V so that standard riding mowers can be used to maintain them.
5. Ensure that there is enough space between plantings and structures to allow room for an industrial mower to maneuver (a minimum of six foot is needed for the mower).
6. Use drought tolerant species or assure watering from the HOA if non-drought tolerant perennials, trees, shrubs or vines are a part of the design.
7. Plant in clumps or "landscaping islands" rather than rows. Clustering allows for mowing around clusters but not necessarily within them.
8. Avoid planting perennials where committed care is not guaranteed. Perennials may look like meadow weeds and be accidentally mowed if not cared for.
9. Provide ongoing maintenance to keep weeds at bay until any ground cover or cluster planting become well established.
10. Avoid planting berms with thick, shrubby ground cover which could mask rodent activity that could weaken the berm, piping of water along living or dead roots that lead to dam failure.
11. Plant on cut slopes which pose little threat in blowdown or piping conditions.
12. Use good soil by amending native soil with at least 2" of compost tilled into the subgrade to a depth of at least six inches to ensure the plants succeed.
13. Trees or shrubs with a mature height over 4 feet tall may not be planted on the embankment or allowed to grow within 15 feet of the toe of the embankment and 24 feet from the principal spillway structure of wet ponds.
14. On wet ponds side slopes along the shoreline of the pond should be three to one (3H:1V) or flatter to facilitate maintenance and to reduce public risk of slipping and falling into the water.
15. A shallow water bench, which is home to most of the aquatic plant life, should be established around the perimeter of the permanent pool to promote the growth of emergent vegetation along the shoreline and deter individuals from wading.

7.3. Simplified Detention

7.3.1 Purpose

The purpose of the Simplified Urban Drainage System (SUDS) model is to emulate a more complex model, such as HEC-1, for use on smaller watershed such as those in Greenville County. It will also reduce most of the trial and error work done by designers and yield more uniform designs.

A simplified design procedure, as used in this context, is a design procedure for small catchments where hydrologic computational procedures can be greatly simplified using regionalized constants. The computations should be based on selected simple parameters such as watershed area and percent impervious. The design that results will be right sized in some cases and conservative in all others.

Simplified detention design procedures are desirable for a number of reasons. First computations are simple, making for a reduced design time. Second, there will be more uniformity in design which should make the review process simpler, less time consuming and more consistent across reviewers. Third, very little data is required for more simplified design procedures. Finally, designs are right sized in some cases and conservative in most cases. Thus, if a developer is willing to use a conservative design, he or she can trade engineering design cost for construction cost. In all cases, the option of using a more complex model such as HEC-1 for design should be available.

The main difference with the SUDS model is that a triangular hydrograph is being assumed. This is something that was not previously allowed in the IDEAL model.

7.3.2 Benefits of Simplified Detention

The Simplified Detention Design Aid design procedure is defined as a design procedure for small catchments where hydrologic computational procedures can be greatly simplified using regionalized constants. The computations are based on selected simple parameters such as watershed area and percent impervious. The resulting detention designs are correctly sized in some cases and conservative in all others. The SUDS model is available on the Greenville County Website along with documentation.

Simplified detention design procedures are desirable for a number of reasons:

1. They result in reduced design time,
2. Designs will be more uniform in general which makes the review process simpler, less time consuming, and more consistent across reviewers,
3. Very little data is required for some simplified design procedures, and
4. Designs are right sized in some cases and conservative in most cases.

7.4. Downstream Analysis

Downstream analysis shall be required for all development sites unless a waiver or variance is granted from this analysis. When water quantity controls are implemented, an off-site analysis waiver may not be required, provided that all required design criteria of the Design Manual are met.

In some cases the design professional may verify that storm water quantity controls may adversely impact downstream conditions. Therefore, downstream analysis shall be performed prior to sizing storm water quantity control structures to determine the extent of the controls to be implemented. Downstream analysis may show that more stringent controls need to be implemented to effectively prevent any adverse downstream impacts.

A downstream peak flow analysis which includes the assumptions, results and supporting calculations to show safe passage of post-development design flows downstream. The analysis of downstream conditions in the report shall address each and every point or area along the project site's boundaries at which runoff will exit the property. The analysis shall focus on the portion of the drainage channel or watercourse immediately downstream from the project. This area shall extend downstream from the project to a point in the drainage basin where the total area of the development comprises ten percent (10%) of the total

basin area. In calculating runoff volumes and discharge rates, consideration may need to be given to any planned future upstream land use changes.

7.4.1 Downstream Analysis Limits

Hydrologic and hydraulic engineering analysis shall be implemented to determine the downstream effects from any development activity. This analysis shall extend downstream to a specific point of concern. The point of concern may be identified by the Director in certain situations. The following are typical points of concern:

- The point where the development represents less than 10 percent of the total drainage of the watershed to that point. This is the minimum set by the ordinance.
- The first downstream road crossing
- Downstream residential lots.
- Location of known existing flooding, drainage, or erosion problems.
- Any point as directed by Greenville County.

The primary areas of analysis shall be done for:

- The development area,
- All drainage exit points from the property,
- The receiving channel at the exit points, and
- Each component of the downstream system including:
 - ◆ Channels
 - ◆ Pipes
 - ◆ Culverts
 - ◆ Bridges
 - ◆ Overbank areas
 - ◆ Overbank structures

7.4.2 Downstream Analysis Design Storm Events

All downstream analysis studies shall be done using the 2, 10, 25, and 100-year 24-hour storm events.

7.4.3 Downstream Analysis Criteria

The downstream analysis shall determine whether the design storm events of interest cause or increase flooding, drainage, or erosion impacts to downstream properties or road crossings. The analysis criteria shall include but is not limited to:

- Existing land use curve numbers shall be used for developed areas upstream. Where areas upstream are known to be developed the Director may require these areas to be considered developed in a future land use condition.

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- The weighted curve number for the proposed development site shall be used for all undeveloped upstream areas.
 - Existing land use for downstream areas of interest may be used, but future land use, when applicable, is recommended for conservative results.
 - Routing of flows using an accepted hydrologic and hydraulic method from Chapters 5, and 6.
 - Hydraulic step-backwater calculations (Corps of Engineer's HEC-2 or HEC-RAS models or equivalent) shall be performed to determine flood elevations of any downstream impacted areas.
 - The effects of any upstream and proposed storm water quantity or quality structures.

7.4.4 Improvement Options

If the downstream analysis determines that the development of a particular site does contribute to flooding, drainage, or erosion problems, then at least one the following improvements shall be implemented:

- On-site Water Quantity Control
- Off-site Water Quantity Control
- Improvements to the Downstream Storm Water Conveyance System

7.4.4.1 On-Site Water Quantity Control

The design professional may select to implement on site water quantity control structures designed according to the criteria in Section 7.1. These structures may consist of nonstructural controls such as swales, natural drainageways, wetlands, and low areas within the site terrain. These structures may also consist of structural approaches such as engineered detention facilities.

7.4.4.2 Off-Site Water Quantity Control

The design professional may use an off-site publicly or privately owned facility to prevent adverse downstream impacts. The use of off-site facilities must meet the following requirements:

- The facility to be used must be functional,
- The owner/entity has agreed to accept runoff from the proposed development site,
- The owner has an implemented maintenance agreement for the facility,
- The facility is sized to effectively handle increased flow rates and flow volumes, and
- There are no significant adverse impacts between the outlet from the proposed development site and the inlet to the off-site facility.

7.4.4.3 Improvements to the Downstream Storm Water Conveyance System

The design professional may perform and provide supporting calculations that indicate that the best solution is to upgrade the downstream system. This option may be implemented under the following

requirements,

- The downstream property owner of the facilities to be improved has granted temporary construction easements,
- The downstream improvements are economically feasible, and
- The improvement will not cause any other significant problems downstream.