# 4.0 Structural Storm Water Controls

## 4.0.1 Introduction

Structural storm water controls are engineered facilities intended to treat storm water runoff from urbanization and/or mitigate the effects of increased storm water runoff peak rates from developed sites. This chapter provides an overview and detailed specifications of structural storm water controls (BMPs) that are to be used to address the minimum storm water management policies as outlined in the Post-Construction Control Ordinances within the Charlotte-Mecklenburg area. Additionally, the detailed BMP designs and specifications are to be used to address the minimum storm water management requirements and policies of BMPs required by watershed protection overlay ordinances, detention ordinances, rezoning notes, and BMPs required by State 401 water quality certifications constructed within the Charlotte-Mecklenburg area.

In terms of meeting the policies as outlined in the Post-Construction Control Ordinances in the Mecklenburg County area, a structural storm water control or set of structural controls must:

- Water Quality: Remove pollutants in storm water runoff to protect water quality by removing 85 percent of TSS in all watershed districts, removing 70 percent of TP in all watershed districts except the Central Catawba from the 1-inch, 6-hour storm, and removing fecal coliform to the maximum extent practicable in the Goose Creek watershed district;
- Channel Protection: Regulate discharge from the development site by controlling the 1-year, 24-hour storm for 24 hours (48 hours in Charlotte) to minimize downstream bank and channel erosion; and
- Flood Control: Control conveyance of storm runoff within and from the development site to minimize flood risk to people and properties for the 10-year, 6-hour storm, and 25-year, 6-hour storm, if necessary.
- Long Term Maintenance: Maintenance agreements and plans must be recorded to ensure maintenance of BMPs in perpetuity.
- Promote Infiltration: In the Goose Creek watershed district, BMPs that promote infiltration and flows of groundwater recharge must be used when practical for the purposes of maintaining stream base flow.

## 4.0.2 Approved Structural Management Measures

Nine (9) BMPs have been approved for use in the Charlotte-Mecklenburg area for demonstrating compliance with Phase I and Phase II post-construction storm water ordinances, watershed protection overlay ordinances, detention ordinances, rezoning notes, and BMPs required by State 401 Water Quality Certifications. The nine BMPs are presented in the following list.

- Bioretention
- Wet Pond
- Wetland
- Enhanced Grass Swale
- Grassed Channel
- Infiltration Trench
- Filter Strip/Wooded Buffer
- Sand Filter
- Extended Dry Detention

In addition to the nine (9) BMP's that have been approved, the use of "bioengineering techniques" is presented as an appropriate treatment option in the post-construction ordinance. The design methods, specifications, etc. presented in the NCDENR North Carolina Department of Environment and Natural

Resources (NCDENR) – *Manual of Stormwater Best Management Practices* should be implemented for "bioengineering techniques".

Additional BMPs may be added in later versions of this Manual. Alternative BMPs that are not currently described in the Manual will be considered, reviewed, and approved on case-by-case basis. The review and approval process will consider BMP documentation, pollutant removal efficiency, long-term maintenance ease, etc.

To ensure long-term maintenance of BMPs designed according to this manual, maintenance agreements and plans are required to be prepared, approved by each jurisdiction's staff, and recorded with the Register of Deeds for each BMP.

### 4.0.3 Selection of Structural Management Measures

#### 4.0.3.1 Introduction

Any BMP has both unique capabilities and persistent limitations. Additionally each site imposes limitations and each overall watershed location requires consideration of the storm water and other management objectives for that watershed. Selection of BMPs is always a balance between competing needs, physical limitations, sociological or institutional constraints, financial constraints, and pollution removal needs.

No single BMP option can be applied to all development situations and all BMPs options require careful site assessment prior to design. For example, pond options are applicable to the widest range of development situations, but typically require a minimum contributing drainage area to remain hydrated. On the other hand, infiltration trenches often have more limited applications, and require field verification of soils, water tables, slope and other factors.

Several BMPs can have significant secondary environmental impacts, although the extent and nature of these impacts is uncertain and site-specific. Pond systems, which can offer reliable pollutant removal and longevity, tend to be associated with the greatest number and strongest degree of secondary environmental impacts. Careful site assessment and design are often required to prevent stream warming, natural wetland destruction and riparian habitat modification.

#### 4.0.3.2 Basic Structural BMP Types

Structural BMPs can be classified by the predominant removal mechanism into the four major categories of: detention basins, filtration devices, vegetative filtration, and special devices.

- Detention/retention basins, as the term implies, hold runoff for a period of time allowing for settling of the solid pollutants. Other removal mechanisms, which are generally of lesser importance, include filtration through vegetation, infiltration, evapotranspiration, and biological and chemical transformation. Basic types include extended detention, retention ponds, and constructed wetlands.
- Filtration devices remove pollutants through the natural filtering process of soil and reduction in runoff volume. Infiltration devices generally transport runoff to groundwater. Filtration (often called exfiltration) devices filter water through an engineered layer of soil and then discharge it to the drainage system. Specific devices include bioretention areas, infiltration trenches, and sand filters.
- Vegetative filtration devices operate through the contact of runoff with vegetation. They tend to be used for on-site controls. Pollutant removal mechanisms include sedimentation and filtration, infiltration, evapotranspiration and biological uptake. Devices include filter strips and wooded buffers with flow spreaders, grassed swales (with or without check dams), and other devices.

### 4.0.3.3 BMPs for the Goose Creek Watershed

The Goose Creek Watershed district is subject to additional storm water treatment requirements in accordance with 15A NCAC 2B.0600Site Specific Water Quality Management Plan for the Goose Creek Watershed (as implemented in Mint Hill's Post-Construction Ordinance) and the Goose Creek Water Quality Recovery Plan. The additional water quality treatment requirements of these ordinances include:

- Promotion of storm water infiltration and groundwater recharge for the purposes of maintaining base flow; and
- Reduction of fecal coliform to the maximum extent practicable.

To accomplish the provisions above, the following BMPs have been approved for use within the Goose Creek Watershed:

- Infiltration Trench
- Bioretention Garden
- Grassed Channel
- Enhanced Grass Swale
- Wetland
- Wet Pond
- Sand Filter

However, if the soil infiltration rate of site soils is 0.52 in/hr or greater, structural BMPs that promote infiltration must be used. The following BMPs must be used (individually or in combination with other allowable BMPs) to meet the storm water treatment requirements:

- Infiltration Trench
- Bioretention Garden
- Enhanced Grass Swale

The soil infiltration rate (hydraulic conductivity) can be initially determined from NRCS soil texture classification, but must be determined using field geotechnical tests. A minimum of three tests per acre is required to determine soil suitability and location of infiltration BMPs.

### 4.0.3.4 Combined Measures

Although the management measures mentioned here can be used individually to remove pollutants, it may be desirable to consider combining two or more of these measures. Combining two or more management measures can often have advantages such as the following.

- increase the operational life of a given BMP,
- increase pollutant removal effectiveness, or
- overcome any site limiting factors.

Wet detention ponds can be used in combination with vegetative filters to provide sediment removal before the runoff can enter an infiltration system or wetland. Wetlands should only be used in combination with vegetative filters and/or detention, not with infiltration. Typically, wetlands should receive inflow from vegetated conveyance facilities and/or a wet detention pond.

Any planned discharge from a wetland should be into a vegetated conveyance facility. Wetlands should not precede an infiltration trench as accumulated sediment and/or decaying matter may clog the infiltration mechanism. It must be recognized that conditions favorable to wetlands (high water table, impervious soils, etc.) are unfavorable for infiltration trenches.

Many types of structural BMPs also provide, or can be designed to provide, flood control capabilities. Wet ponds, extended detention, and infiltration channels are of particular benefit for flood control at least for the more frequent nuisance floods.

In addition, structural BMPs can provide channel protection by storing a design volume of runoff for an extended time before discharging into the receiving drainage system. The result has been stabilization of downstream streambanks providing protection for the system as storm runoff travels downstream.

### 4.0.3.5 Structural BMP Screening

Outlined below is a screening process for structural storm water controls. This process is intended to assist the site designer and design engineer in the selection of the most appropriate structural controls for a development site, and provides guidance on factors to consider in their location.

In general the following four criteria should be evaluated in order to select the appropriate structural control(s) or group of controls for a development:

- Storm Water Treatment Suitability
- Water Quality Performance
- Site Applicability
- Implementation Considerations

In addition, for a given site, the following factors should be considered and any specific design criteria or restrictions need to be evaluated:

- Physiographic Factors
- Soils
- Special Watershed or Stream Considerations

**No utilities (sewer lines, power lines, water lines, etc.) shall be located within or under the storm water BMP facility.**

Finally, environmental regulations that may influence the location of a structural control on site, or may require a permit, need to be considered.

Table 4.0.1 can be used to list the results of the selection analysis using the Fact Sheet for each individual BMP (see section 4.0.4 in this chapter).

**Table 4.0.1 Sample Structural Control Selection Matrix**

| Structural Control BMP Alternatives | Storm water Treatment Suitability | Site Applicability | Implementation Considerations | Physiographic Factors/Soils | Special Watershed Considerations | Other Issues |
|---|---|---|---|---|---|---|
| Bioretention | | | | | | |
| Wet Pond | | | | | | |
| Wetlands | | | | | | |
| Enhanced Grass Swale | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Grassed Swales | | | | | | |
| Infiltration Trench | | | | | | |
| Filter Strip/Wooded Buffer | | | | | | |
| Sand Filter | | | | | | |
| Extended Dry Detention | | | | | | |

### 4.0.3.6 Storm Water Treatment Trains

Using several BMPs to control storm water quantity and quality is an integrated planning and design approach whose components work together to limit the adverse impacts of urban development on downstream waters and riparian areas. This approach is sometimes called a storm water "treatment train". When considered comprehensively, a treatment train consists of all the design concepts and nonstructural and structural controls that work to attain water quality and quantity goals. This is illustrated below.


**Generalized Storm Water Treatment Train**

Runoff and Load Generation – The initial part of the "train" is typically located at the source of runoff and pollutant load generation, and consists of any techniques that can be used to reduce runoff and storm water pollutants.

Pretreatment – The next step in the treatment train consists of pretreatment measures. These measures typically do not provide sufficient pollutant removal to meet pollution reduction goals, but do provide calculable water quality benefits that may be applied towards meeting the water quality volume treatment requirement. These measures include:

- Pretreatment facilities such as sediment forebays and vegetated areas before the use of structural control BMPs.
- The use of structural BMPs that do not provide the required pollutant removal rates but do remove a portion of TSS and TP.

Primary Treatment and/or Quantity Control – The last step is primary water quality treatment and/or quantity (channel protection, overbank flood protection, and/or extreme flood protection) control. This may be achieved through the use of combinations of structural controls in series.

The combinations of structural storm water controls are limited only by the need to employ measures of proven effectiveness and meet regulatory and physical site requirements.

Twenty-four (24) BMP treatment trains were selected as being the most common for application in the Mecklenburg County area. Detailed water quality modeling was performed on those twenty-four BMP combinations to determine the combined pollutant removal capability. Table 4.0.2 presents the results of the detailed water quality modeling. These pollutant removal efficiencies must be used when these treatment trains are used. The following abbreviations are used.

- BRH – bioretention – optimal design threshold
- BRL – bioretention – standard design threshold
- TWH – treatment wetland – optimal design threshold
- TWL – treatment wetland – standard design threshold
- GS – grassed swale
- SFH – sand filter – optimal design threshold
- BS – buffer strip
- EDD – extended dry detention
- WPH – wetpond – optimal design threshold
- WPL – wetpond – standard design threshold
- IT – infiltration trench
- EGS – enhanced grassed swale

**Table 4.0.2 Treatment Train Pollutant Removal Efficiencies**

| Treatment Train | TSS | TP |
|---|---|---|
| BRL:TWH | 96 | 80 |
| GS:SFH | 93 | 78 |
| GS:BRH | 85 | 87 |
| GS:BRL:BS | 73 | 80 |
| GS:BRL:EDD | 72 | 72 |
| GS:TWH | 91 | 72 |
| GS:TWH:EDD | 91 | 71 |
| GS:TWH:WPL | 96 | 79 |
| GS:TWL:WPH | 88 | 78 |
| GS:WPH:TWL | 90 | 78 |
| GS:WPL:TWL | 86 | 77 |
| IT:TWH | 95 | 80 |
| IT:WPH:TWL | 94 | 83 |
| IT:WPL:TWH | 96 | 82 |
| EGS:TWL:WPL | 60 | 72 |
| BS:BRL | 73 | 80 |
| BS:IT:WPL | 64 | 71 |
| BS:TWH | 91 | 76 |
| BS:TWH:EDD | 91 | 75 |
| BS:TWH:WPL | 96 | 80 |
| BS:TWL:WPH | 85 | 78 |
| TWH:EDD | 95 | 77 |
| WPH:TWH | 98 | 82 |
| WPL:TWH | 94 | 78 |

Detailed modeling of other combinations of BMPs was preformed to assess general trends of pollutant removals based on different types of BMP combinations. In general, the following three observations were made.

- Treatment trains with three BMP's had pollutant removal efficiencies that were less than expected.
- Treatment trains with two *complementary* BMP's had pollutant removal efficiencies that were within acceptable expected ranges
- Treatment trains with two *non-complementary* BMP's had pollutant removal efficiencies that were less than expected.

The term complementary and non-complementary BMP's used in the previous bullets refer to that each BMP relies on primary and secondary pollutant removal processes. There are three key pollutant removal processes that are considered; infiltration, biological uptake; and settling. A complementary BMP treatment train is one that includes a series of BMP's that use each of the three primary processes. A non-complementary BMP treatment train is one that includes a series of BMP's that do not use all of the three primary processes. Table 4.0.3 presents the primary process that can be used for assessing BMP treatment trains. This same list of primary processes is presented on each BMP Fact Sheet.

**Table 4.0.3 Primary BMP Pollutant Removal Processes**

| Pollutant | Bioreten. | Treat. Wetland | Grassed Swale | Sand Filter | Buffer Strip | Extended Dry Detention | Wet Pond | Infiltrat. Trench | Enh. Grass Channel |
|---|---|---|---|---|---|---|---|---|---|
| Settling - sedimentation | | X | | | | X | X | | |
| Filtration | X | | X | X | X | | | X | X |
| Biological treatment | X | X | | | | | | | |

For treatment trains that are not included in Table 4.0.2, the designer can use the following formulas to estimate the total pollutant removal efficiencies.

For treatment trains with three BMP's and/or two non-complementary BMPs:

$$E = 0.95 \times [AB + C - \{(AB \times C)/100\}]$$
$$AB = A + B - \{(A \times B)/100\}$$

For treatment trains with two complementary BMP's:

$$E = A + B - \{(A \times B)/100\}$$

where:
E = total efficiency
A = efficiency of first or upstream BMP
B = efficiency of second BMP
C = efficiency of third or downstream BMP

## 4.0.4 BMP Fact Sheets

For each of the nine BMPs included in this chapter, a summary fact sheet is given at the beginning followed by a detailed general description and specifications. Following is a brief discussion of the different sections included in the fact sheets.

Design Criteria – This section gives a summary list of the design requirements that must be used in the design of each BMP.

Advantages/Benefits – Some of the advantages or benefits for a particular BMP is given to assist the designer in determining if this BMP is appropriate for a particular application.

Disadvantages/Limitations – All BMPs will have some disadvantages or limitations which should be considered for application of a particular BMP which should be considered by the designer.

Maintenance Requirements – A few of the major maintenance requirements are listed which may affect the decision to use a particular BMP. To ensure long-term maintenance of BMPs designed according to this manual, maintenance agreements and plans are required to be prepared, approved by each jurisdiction's staff, and recorded with the Register of Deeds for each BMP.

Storm Water Management Suitability – The purpose of this section is to give the designer some idea whether a particular BMP will meet the storm water quantity and quality requirements. The four criteria included are the 1-inch, 6-hour storm (water quality), 1-year, 24-hour storm (channel protection), and the 10-year and 25-year, 6-hour storms (for peak attenuation control). Each criteria is given a Low (L), Moderate (M), or high (H) rankings giving some idea if a BMP can be designed to accomplish the design criteria. Thus a high rating indicates it should be relatively easy to design the BMP for the criteria while a low rating indicates it may be difficult or not feasible to use this BMP for that particular criteria.

Implementation Considerations – Four criteria are given in this section – land requirements, capital cost, maintenance cost, and clogging issues. A high rating means that the costs or requirements will be significant and should be considered in selecting this BMP. This section also gives additional information on whether this BMP is appropriate for residential subdivisions, is appropriate for high density land uses, can be used to accept runoff from hotspots, is subject to any soil restrictions, and/or protects the water table. Although most of these are self explanatory the following definition was used to determine if a development or site should be considered a hot spot.

Storm water hotspots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in urban storm water runoff or with types of pollutants that re not typically treated with standard BMPs. Examples of potential hotspots include gas stations, convenience stores, public works storage areas, vehicle service and maintenance areas, auto recycling or salvage yards, material storage sites, garbage transfer facilities, commercial nurseries, vehicle washing/steam cleaning areas, landfills, industrial sites, and industrial rooftops.

Primary Pollutant Removal Processes – Each BMP uses many different processes to remove pollution from storm water runoff. Typically, only one or two process is used primarily by each BMP, and the other processes are used secondarily. The primary processes are the processes that can be included when evaluating the effectiveness of a treatment train, because the secondary processes are not considered substantial enough to benefit the pollutant removal mechanisms. Each fact sheet lists the approved primary processes that can be included in the treatment train analysis.

Pollutant Removal Rates – This section gives the pollutant removal rates for TSS and TP for the different design values that are acceptable for this BMP. If more than one design is given, a table of design parameters and various effectiveness levels (optimal, standard, TSS-only, etc.) that must be used for the BMP design to produce the given pollutant removal rate is provided.

### 4.0.5 Detailed General Description and Specifications

Following the fact sheet, a detailed general description and specifications are given for each of the nine BMPs included in this chapter. This section is divided into several topics including the following, if appropriate for the particular BMP.

- General Description
- Storm Water Management Suitability
- Pollutant Removal Capabilities
- Planning and Design Criteria
    - Design Requirements
    - Physical Specifications/Geometry
    - Pretreatment/Inlets
    - Outlet Structures
    - Emergency Spillway
    - Maintenance Access
    - Safety Features
    - Landscaping

- Design Recommendations
- Design Procedures
- Design Example
- Inspection and Maintenance Requirements
- Design Forms

Fact sheets and a detailed general description and specifications are given for the following BMPs.

- Bioretention
- Wet Pond
- Wetland
- Enhanced Grass Swale
- Grassed Channel
- Infiltration Trench
- Filter Strip/Wooded Buffer
- Sand Filter
- Extended Dry Detention

### 4.0.6 Embankment Requirements

The following embankment specifications apply to all BMPs with embankments that are designed to hold water, even if the embankment is designed to hold water only during a storm event.

#### 4.0.6.1 Embankment Fill Materials

The following parameters apply to materials used to construct embankments:

- Borrow material shall be classified as ML, MH, SC, SM, CL or CH soils according to the Unified Soil Classification System (ASTM D2487) or any mixture of these soils.

- Borrow materials shall have a liquid limit (LL) between 40 and 60 and a plasticity index (PI) between 15 and 30 (ASTM D4318).

- Materials shall be free of topsoil, organic material, roots, stumps, brush, rocks larger than 3 inches, subsoil, debris, vegetation, and other foreign matter.

- All material clods will be broken down with tillers and/or discs to provide a homogeneous soil that is free of clay clods greater than 3 inches in diameter.

#### 4.0.6.2 Embankment Construction

The following steps apply to construction of an embankment:

Step 1: Subgrade Preparation:

- Compact subgrade to density requirements for subsequent fill materials.

- Cut out soft areas of subgrade not capable of compaction in place.

- Scarify subgrade surface to depth of 6 inches.

- Proof roll subgrade to identify soft spots; fill and compact to density equal to or greater than requirements for subsequent fill material.

Step 2: Seepage Key Placement

- Seepage key trench will be located between embankment abutments.

- Seepage key shall extend to a minimum depth of 4 feet or as required through geotechnical seepage analysis. A minimum bottom trench width shall be 10 feet and the trench sidewalls shall be sloped or benched to promote stability and bonding between the sidewall soils and seepage key fill.

Step 3: Embankment Fill Placement

- Embankment fill shall be constructed at 3(horizontal):1(vertical) or as shown on the drawings. Demonstration of appropriate safety factors against failure through geotechnical analysis shall be required for slopes steeper than 3(horizontal):1(vertical).

- Fill soils shall be placed in loose lifts not to exceed 8 inches in thickness and be compacted to a minimum of 95 percent of the soils Standard Proctor (ASTM D698) maximum dry density, or as specified on the Drawings.

- Compacted moisture content shall be between 3 percent below and 3 percent above the optimum moisture content for all fill placed, or as otherwise approved by Engineer.

- Fill soils should be placed in continuous, horizontal layers from abutment to abutment. Existing slopes greater than 4(horizontal):1(vertical) shall be benched to promote bonding of newly placed fill with existing soils. Benching shall be performed at maximum of 2 feet vertical intervals and shall extend a minimum of 4 feet horizontally or as specified on Drawings.

- Within the upper 12 inches of embankment, fill soils should be compacted to 100% of its Standard Proctor (ASTM D698) maximum dry density.

- Fill against supported structures. Do not fill against unsupported structures.

- Place fill simultaneously on each side of unsupported structures until supports are in place.

- Place a minimum of six inches of topsoil across dam embankment to promote vegetative growth.

Step 4: Outlet Pipe Fill Placement

- Fill of the culverts shall be placed and compacted in 6-inch thick loose lifts around the drop inlets and up to 2 feet above the culverts.

- Compaction shall be performed by hand tampers or small hand operated compactors.

- Compaction shall be at a minimum 95 percent of the Standard Proctor (ASTM D698) maximum dry density. Compacted moisture content shall be between 3 percent below and 3 percent above the optimum moisture content for all fill placed, or as otherwise approved by Engineer.

- Additional compaction of lifts 2 feet or greater above culverts shall conform to the

Embankment Fill Placement section of this specification.

Step 5: Field Quality Control

- Laboratory Testing

  - Perform laboratory material tests in accordance with ASTM D422, ASTM D698, ASTM D2216, and ASTM D4318.
  - Test at a frequency of every 500 cubic yards of embankment fill material placed, when materials using for embankment fill change, and/or as directed by the Engineer.
  - Sample size shall be 50-lb.

- In Place Compaction and Natural Moisture Content Tests

  - Perform in place compaction tests in accordance with ASTM D1556, ASTM D2922, or ASTM D2937 and natural moisture content test in accordance with ASTM D2216.
  - Frequency of compaction/natural moisture content tests:
  - Embankment Fill: Each lift at a minimum frequency of 1 per 2,500 sq. ft.
  - Pipe Installation: Each lift at a minimum frequency of 1 per 30 lf of pipe.

- When tests indicate Work does not meet specified requirements, remove Work, replace and retest.

### 4.0.6.3 Allowable Variances

Embankment specifications may be modified based on site-specific geotechnical investigation and engineering design.

### 4.0.6.4 References


- ASTM D422 - Standard test Method for Particle-Size Analysis of Soils (Grain Size with Hydrometer.

- ASTM D698 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft$^3$).

- ASTM D1556 – Standard Test Method for Density of Soil In Place by the Sand-Cone Method.

- ASTM D2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.

- ASTM D2922 - Standard Test Method for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth).

- ASTM D2487 – Standard Practices for Classification of Soil for Engineering Purposes (Unified Soil Classification System)

- ASTM D2937 - Standard Test Method for Density of Soil in place by the Drive-Cylinder Method Test.

- ASTM D4318 - Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.