4.4 Enhanced Grassed Swale BMP Summary Fact Sheets

Description: Enhanced grassed swales (also called vegetated open channels, water quality swales or engineered swales) are vegetated open channels that are explicitly designed and constructed to capture and treat storm water runoff by limiting the slope in the direction of flow or within dry cells formed by check dams or other means. Swale pollution removal effectiveness is provided by sedimentation, biologic activity, and infiltration. Swales can also be designed without check dams or engineered media as grass channels but with greatly reduced pollution removal rates.

IMPORTANT CONSIDERATIONS

DESIGN REQUIREMENTS:

- Must have dense grass coverage or vegetation with permanent reinforcement to reduce erosion potential. Three different plant types must be included in the design.
- Maximum depth of flow for the 1-inch, 6-hour storm event is 4inches.
- Have a trapezoidal cross-sectional shape with slide slopes flatter than 3:1 (h:v) and a minimum bottom width of 2 feet.
- Must be designed to pass the 10-yr, 25-yr and 100-yr storm event without causing erosion or flood damage problems.
- A permeable filter media and underdrain system must be provided.
- Maximum ponding duration is 48 hours and minimum ponding duration is 30 minutes.
- The slope of the swale must be 2% or less with an underdrain. Check dams may be used to produce an effective slope of 2% or less.
- Drainage area must be a maximum of 20 acres with no dry weather flow.
- The minimum length in the direction of flow must be 100 feet.

ADVANTAGES/BENEFITS:

- Swales can be designed to combine storm water treatment with a runoff conveyance system.
- Less expensive than curb and gutter.
- Reduces runoff velocity and erosion problems.
- Infiltration and internal water storage layer are allowed

DISADVANTAGES/LIMITATIONS:

- Higher maintenance than curb and gutter systems.
- Cannot be used on steep slopes.
- Possible re-suspension of sediment.
- Concerns with aesthetics if not adequately maintained.

MAINTENANCE CONSIDERATIONS:

- Maintain grass heights of 3 to 6 inches.
- Remove sediment from forebay and channels or swales.
- Invasive species must not be allowed to encroach within the swale.

STORMWATER MANAGEMENT SUITABILITY

L = Low **M** = Moderate **H** = High

M **1-inch, 6-hr Water Quality Control**

L **1-yr, 24-hr Channel Protection Volume**

L **Peak Attenuation Control for 10-yr, 6-hr Storm**

L **Peak Attenuation Control for 25-yr, 6-hr storm**

IMPLEMENTATION CONSIDERATIONS

L **Land Requirements**

L **Capital Cost**

M **Maintenance Cost**

M **Maintenance Considerations**

PRIMARY POLLUTANT REMOVAL PROCESSES

- Filtration

POLLUTANT REMOVAL RATES

Effective.	Length	Depth	Slope	Pollutant Removal Rates
Optimal	100 feet	4 inches	2%	45% TSS 30% TP

4.4 Enhanced Grassed Swales

4.4.1 General Description

Enhanced grassed swales (also referred to as vegetated open channels or water quality swales) are conveyance channels engineered to capture and treat water quality volume (WQ_v) for a drainage area. They differ from a normal drainage channel or swale through the incorporation of specific features such as underdrains and filtration media that enhance storm water pollutant removal effectiveness.

Enhanced grassed swales are designed with limited longitudinal slopes to force the flow to be slow and shallow, thus allowing for particulates to settle and limiting the effects of erosion. Berms and/or check dams installed perpendicular to the flow path promote settling, infiltration and lower the effective slope of the swale.

The enhanced grassed swale is a vegetated open conveyance channel designed to include a filter bed of prepared soil that overlays an underdrain system. Flow passes through the channel where it is filtered through the soil bed and vegetation. Runoff is collected and conveyed by a perforated pipe and gravel underdrain system to the outlet. Enhanced grassed swales are sized to allow the entire WQ_v to be filtered through the vegetation or infiltrated through the filter media at bottom of the swale. Because they are dry most of the time, they are often a preferred water quality control option in residential settings.

Enhanced grass swales can be used in a variety of development types; however, they are primarily applicable to areas of low to moderate density where the impervious cover in the contributing drainage area is relatively small. Thus, enhanced grass swales are mainly used in moderate to large lot residential developments, small impervious areas (parking lots and rooftops), along roads and highways, and in commercial developments as part of a landscaped area. Because of their relatively large land requirement, enhanced grassed swales are generally not used in higher density areas. Enhanced grass swales can be designed and constructed outside of public right-of-ways.

The topography and soils of a site will determine the applicability of the use of enhanced grass swale designs. Overall, the topography should allow for the design of a swale with relatively flat slopes and sufficient cross-sectional area to maintain nonerosive velocities.

Figure 4.4.1 shows typical local enhanced grassed swales and Figure 4.4.2 shows a schematic of a typical enhanced grassed swale.

Enhanced grass swales should not be confused with a filter-strip/wooded buffer strip or grass channel. Ordinary grass channels are not engineered to provide the same treatment capability as a well-designed enhanced grass swale with filter media. Filter strips are designed to accommodate overland flow rather than channelized flow and can be used to help reduce the total water quality treatment volume for a site. Both of these practices may be used for pretreatment or included in a treatment train approach.

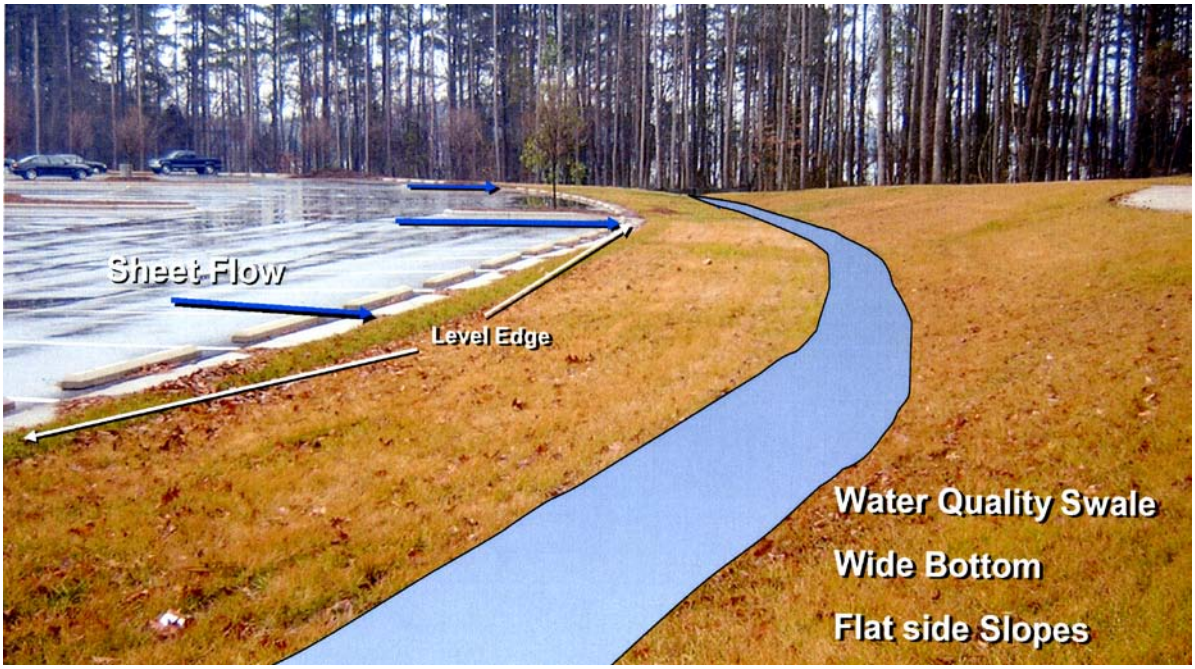
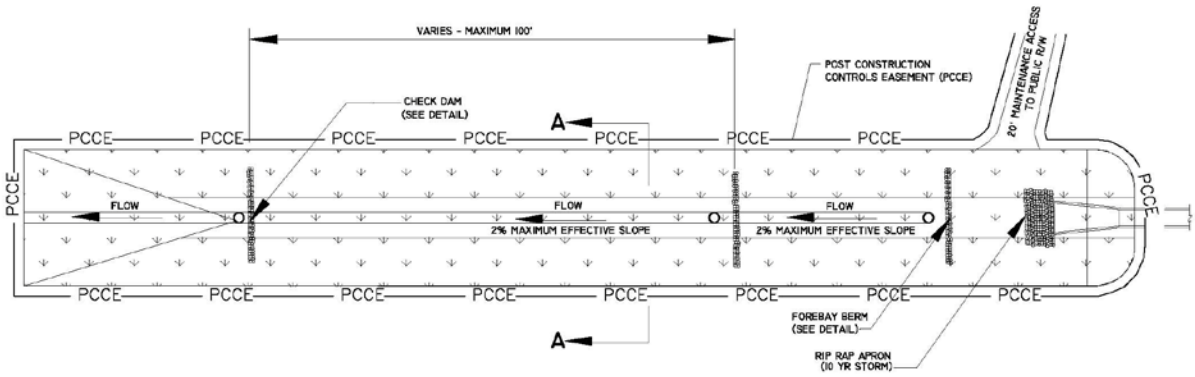
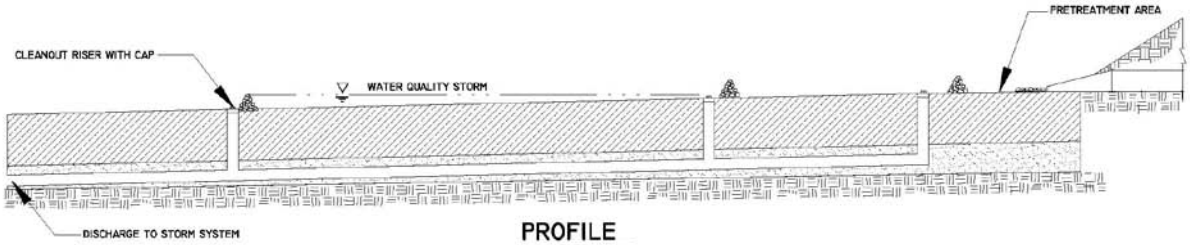


Figure 4.4.1 Enhanced Grassed Swale Examples



PLAN VIEW
NOT TO SCALE



PROFILE
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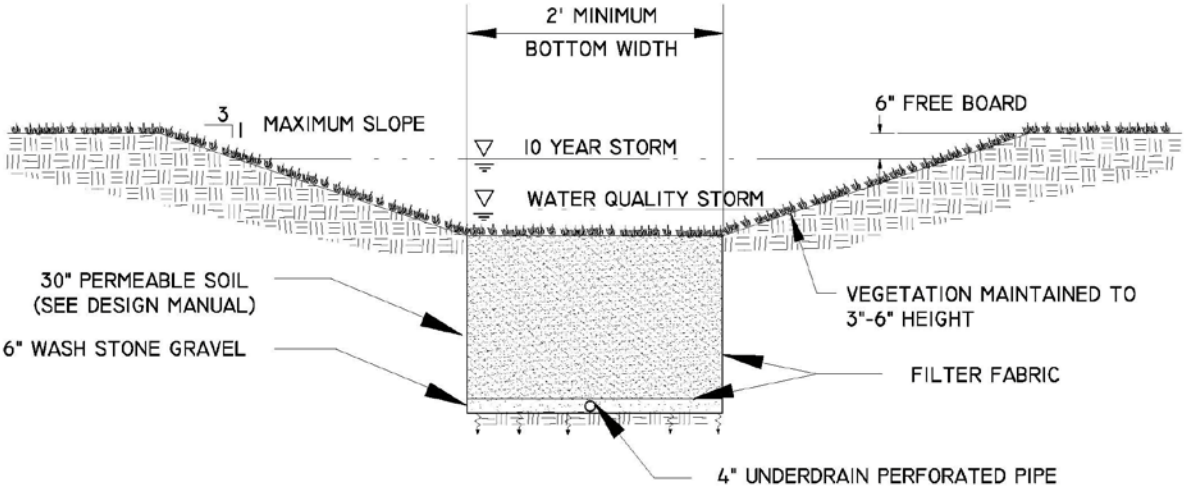

SECTION A-A
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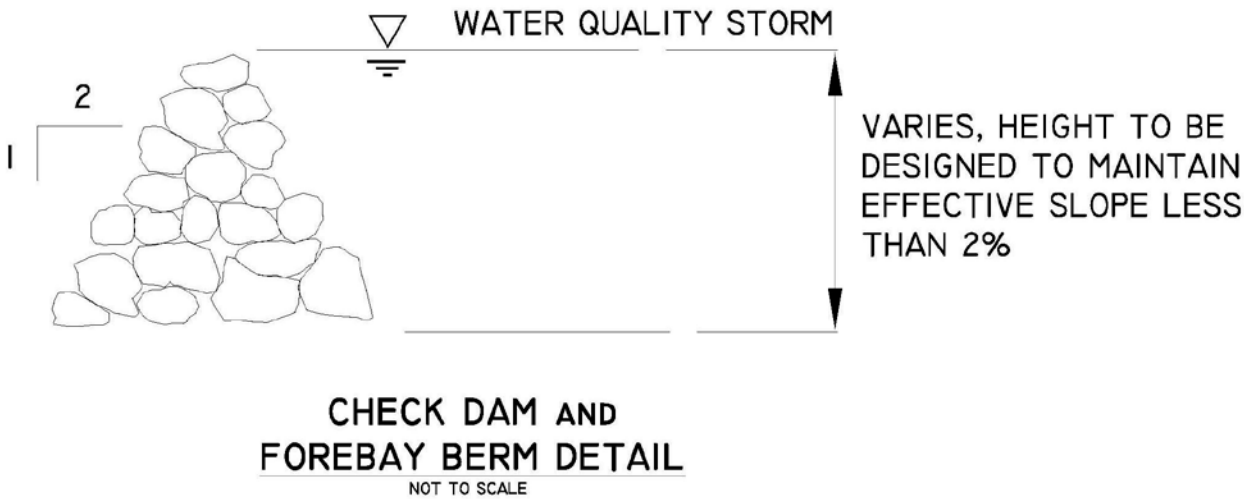

Figure 4.4.2 Schematic of Enhanced Grass Swale

4.4.2 Storm Water Management Suitability

Enhanced grass swale systems are designed primarily for storm water quality and have only a limited ability to provide channel protection volume (CP_v) control. They can be used to convey higher flows to other BMP controls.

Water Quality Control (WQ_v)

Enhanced grass swale systems rely on filtration through an engineered media and through the vegetation to provide removal of storm water contaminants. A small amount of water quality benefit occurs through exfiltration to the underlying soils.

Channel Protection Volume (CP_v)

Generally, only WQ_v is treated by an enhanced grass swale, and another structural control must be used to control the channel protection volume (CP_v). However, for some smaller sites, a swale may be designed to capture and detain the full channel protection volume (CP_v) through the design and construction of check dams or other structural devices that provide controlled outflow.

Peak Attenuation Control (Q_p)

The design of enhanced grass swales must include flow diversion and/or be designed to safely pass flood flows. Another structural control may be required in conjunction with an enhanced swale system to reduce the post-development peak flows. The channel lining must be designed to withstand erosion for all storm events up to the 10-year, 6-hour storm event.

4.4.3 Pollutant Removal Capabilities

One enhanced grass swale design has been developed for application in the Mecklenburg County area. The optimal efficiency design has the capability to remove 45% of the total suspended solids and 30% of the total phosphorus load. The design assumes urban post-development runoff conditions that have been observed in the Mecklenburg County area and that the facilities are sized, designed, constructed,

and maintained in accordance with the recommended specifications in this manual. The design pollutant removal rate is derived from sampling data and computations completed for the development of this manual. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach. See Section 4.4.4 for a discussion of design values and appropriate pollutant removal rates.

4.4.4 Planning and Design Criteria

The following criteria are to be considered minimum standards for the design of an enhanced grassed swale. Items listed in Section 4.1.4.A through 4.1.4.I. are requirements and must be addressed in the design. Items listed in Section 4.1.4.J. are recommendations and are optional.

A. Design Requirements

Following is a list of design requirements that must be followed in the design of enhanced grassed swales:

- Following are the design values that are required for the enhanced grass channel design that is available for application in Mecklenburg County. The appropriate minimum design values and associated pollutant removal rates for the design are given in Table 4.4.1.

Table 4.4.1 Design Values and Pollution Removal Rates

Effectiveness	Length	Depth	Slope	Pollutant Removal Rates
Optimal	**100 feet**	**4 inches**	**2%**	**45% TSS 30% TP**

- A gravel and perforated pipe underdrain system is required to collect runoff that has filtered through the bottom of the enhanced grass swale. The underdrain system must be designed so that runoff exits the system within 48 hours. The underdrain system must be designed assuming that 50 percent of the capacity is lost due to clogging. The underdrain system must maintain a positive flow condition (minimum of 2.5 foot per second flow velocity) to a storm drainage system.

- Enhanced grass swales must have dense grass coverage or vegetation with permanent reinforcement to reduce erosion potential. Several different plant types must be included in the design.

- Maximum depth of flow for water quality purposes must be 4.0 inches.

- Enhanced grass swales must have a minimum bottom width of 2 to 8 feet to ensure adequate filtration. Wider channels can be designed, but must contain berms, walls, or a multi-level cross section to prevent channel braiding or uncontrolled sub-channel formation.

- Enhanced grass swales must have a trapezoidal cross-sectional shape and must be designed with moderate side slopes no greater than 3:1 (h:v) for ease of maintenance and side inflow by sheet flow (4:1 or flatter is recommended).

- Must be designed to pass the 10-year and 25-year and 100-year storm events without causing erosion problems or damages from large floods.

- Underdrain system must be provided to prevent ponding longer than 48 hours which must be designed to exceed total infiltration treatment capacity. An internal water storage (IWS) system is allowed, provided that the filter media and underdrain system are designed per requirements, specifications and calculations for infiltration provided in Chapter 18 of the NCDENR Stormwater BMP Manual. If IWS is used, the WQv should infiltrate the soil within 48 hours.

- The slope of the swale must be 2% or less. Check dams may be used to produce an effective slope of 2% or less for facilities up to 5% slope.

- Maximum ponding duration is 48 hours and minimum ponding duration is 30 minutes.

- Drainage area must be a maximum 20 acres with no dry weather flow.

- The minimum length in the direction of flow must be 100 feet.

B. Physical Specifications/Geometry

Channel slopes of 2% or less are recommended unless topography necessitates a steeper slope with a maximum of 5%, in which case drop structures can be placed to limit the hydraulic gradeline slope to within the recommended 2% range. Energy dissipation may be required below the drops. Spacing between the drops must not be closer than 50 feet and greater than 100 feet. Depth of the WQ_v at the downstream end must not exceed 4 inches during the 1-inch storm event.

The 2% hydraulic gradeline slope requirement is met by ensuring that the slope is less than 2% using the critical depth elevation at each drop structure or by setting the top elevation of the lower drop structure equal or higher than the toe elevation of the higher drop structure.

The peak velocity for the 10-year storm must be nonerosive for the soil and vegetative cover provided. If the system is on-line, channels must be sized to convey runoff from a flood event safely with a minimum of 6 inches of freeboard and without damage to adjacent property.

The bed of the enhanced grass swale consists of a permeable soil layer of at least 30 inches in depth, above a 4-inch diameter perforated PCV pipe (AASHTO M 252) longitudinal underdrain in a 6-inch gravel layer. The soil media must have an infiltration rate of at least 1 foot per day (1.5 feet per day maximum) and contain a high level of organic material to facilitate pollutant removal. A permeable filter fabric is placed between the gravel layer and the overlying soil.

The swale and underdrain excavation must be limited to the width and depth specified in the design. The bottom of the excavated trench must not be loaded in a way that causes soil compaction and scarified prior to placement of gravel and permeable soil. The sides of the swale must be trimmed of all large roots. The sidewalls must be uniform with no voids and scarified prior to backfilling.

C. Pretreatment/Inlets

Inlet considerations are presented below:

- Inlets to enhanced grass swales must be provided with energy dissipators such as riprap.

- Pretreatment of runoff to an enhanced grass swale system is typically provided by a sediment forebay located at the inlet. The pretreatment volume should be equal to 0.2 inches for impervious acre. This storage is usually obtained by providing check dams at pipe inlets and/or driveway crossings.

- Enhanced grass swale systems that receive direct concentrated runoff may have a 6-inch drop to a pea gravel diaphragm flow spreader at the upstream end of the control.

- A pea gravel diaphragm and gentle side slope must be provided along the top of swales to provide pretreatment for lateral sheet flows.

D. Outlet Structures

The underdrain system must discharge to the storm drainage infrastructure or a stable outfall.

E. Emergency Spillway

Enhanced grass swales must be adequately designed to safely pass flows that exceed the design storm flows.

F. Maintenance Access

Adequate access must be provided for all enhanced grass swale systems for inspection and maintenance.

G. Safety Features

Ponding depths for durations longer than 6 hours for all storm events must be limited to a maximum of 18 inches.

H. Landscaping

Landscape design must specify proper grass species and other plants based on specific site, soils, and hydric conditions present along the swale. See Chapter 6 – Vegetation and Landscaping. Figure 4.4.3 presents the planting zones that should be considered when developing a landscaping plan for an enhanced grassed swale.

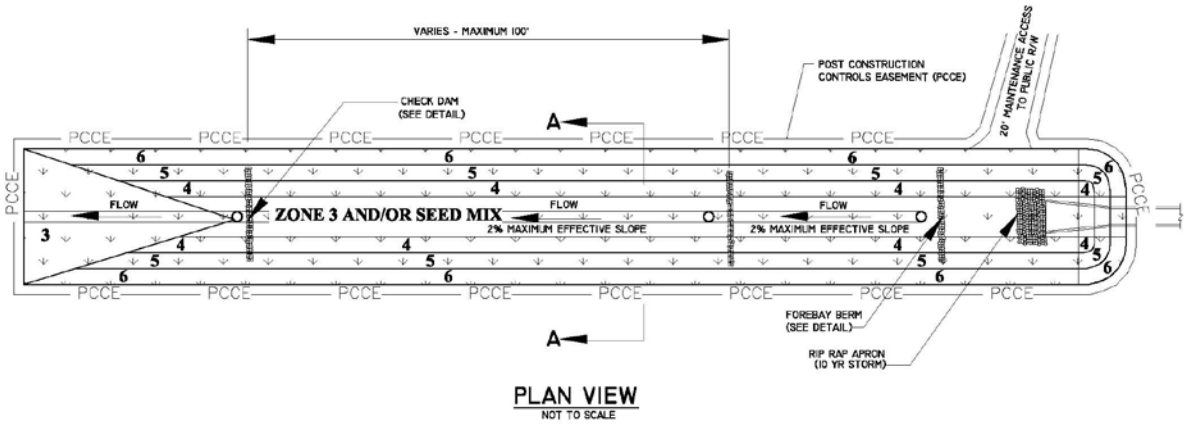

Figure 4.4.3 Planting Zones for Enhanced Grassed Swale

I. Materials

Following are some detailed specifications/recommendations for materials that could be used in the construction of a bioretention facility.

No. 57 Aggregate	NCDOT Section 1005
No. 7 Aggregate	NCDOT Section 1005
Underdrain Pipe, Polyethylene Plastic Pipe Schedule 40	NCDOT Section 1044
Geotextile	NCDOT Section 1056
Plant Materials	NCDOT Section 1670

The enhanced grassed swale soil mix should be developed by amending the existing soil or removing the existing soil and replacing it with the new planting mix. The material must be uniform in composition throughout. It should also be free of stones, lumps, live plants and their roots, weed seeds, sticks, and other extraneous material. The enhanced grass swale soil mixture must meet the following criteria:

PARAMETER	ACCEPTABLE VALUES		TESTING REQUIRED *	TEST METHODS
Sand Content (ASTM C-144 recommended)	80%		No	-
Organic Material (compost, sandy loam and loamy sand)	20%		No	TMECC 05.07-A
Clay Content	Less than 6%		No	-
Phosphorus Index (total Phosphorus)	10 to 30 (12 to 36 ppm on a dry basis)		**Yes**	Mehlich 3 Extraction, Mehlich 2 Extraction (Mehlich 1 Extraction is acceptable but result must be multiplied by 1.7 for comparison)
pH	5.5 to 7.0		No	TMECC 04.11-A
Permeability	1 to 4 in/hr		No	ASTM D2434 (compacted to 20%)
Particle Size Analysis	Acceptable % Passing by Weight		**Yes**	ASTM D422
	Lower	Upper		
Sieve 2 inch (50 mm)	100	100		
Sieve No. 4 (4.75 mm)	98	100		
Sieve No. 8 (2.36 mm)	95	100		
Sieve No. 10 (2.0 mm)	86	100		
Sieve No. 16 (1.18 mm)	70	100		
Sieve No. 30 (600 um)	40	75		
Sieve No. 50 (300 um)	10	35		
Sieve No. 100 (150 um)	2	15		
Sieve No. 200 (75 um)	0	10		

* Even though testing is not required for all parameters, the inspector reserves the right to test suspect material and disapprove it for use if results show that parameters do not meet the acceptable values.

All enhanced grassed swale areas must have a minimum of one test for soil mixture composition. A composite soil test is required to be performed on the soil planting media after it has been mixed and prior to its installation into the bioretention area to determine that the soil constituents meet the acceptable values in the table above.

If the test results are outside of the acceptable limits, then the soil mixture must be removed and replaced with an acceptable soil mixture. Should the pH fall out of the acceptable range, it may be modified with lime or iron sulfate plus sulfur.

The enhanced grassed swale soil mixture must be a uniform mix, free of stones, stumps, roots or other similar objects larger than two inches. No other materials or substances must be mixed or dumped within the bioretention area that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations. The soil must be free of noxious weeds such as Bermuda grass, Quackgrass,

Johnson grass, Mugwort, Nutsedge, Poison Ivy, Canadian Thistle, and/or Teathumb. The soil, mulch, and sand must be uniformly mixed and graded.

J. Design Recommendations

In addition to the design requirements, following are some design recommendations that should be considered for enhanced grass swale design.

- Enhanced grass swale siting should take into account the location and use of other site features, such as buffers and undisturbed natural areas, and should attempt to aesthetically "fit" the facility into the landscape.

- Enhanced grass swales are designed to treat the WQ_v and to safely pass larger storm flows. Flows can enter the swale through a pretreatment forebay. Runoff can also enter along the sides of the swale as sheet flow through the use of a pea gravel flow spreader trench along the top of the bank.

4.4.5 Design Procedures

Following are the steps to be used for the design of enhanced grassed swales.

Step 1 - Using the BMP Site Selection Matrix presented at the beginning of Chapter 4 determine if the development site and conditions are appropriate for the use of an enhanced grass swale system.

Step 2 - Consider any special site-specific design conditions.

Step 3 – Compute site hydrologic parameters using the SCS procedures and/or computer models that use the SCS procedure.

Step 4 Calculate the Water Quality Volume (WQ_v), Channel Protection Volume (CP_v), and Flood Control Q_{10} and Q_{25} and Q_{100} flood hydrographs.

Step 5 - Determine pretreatment volume if included in the design. The forebay should be sized to contain 0.2 inches per impervious acre of contributing drainage.

Step 6 - Determine swale dimensions.

Size bottom width, depth, length, and slope necessary to store WQ_v with a design depth of 4.0 inches or less.

- Slope cannot exceed 2% (5% if check dams are used).
- Bottom width must range from 2 to 8 feet.
- Ensure that side slopes are no greater than 3:1 (4:1 recommended).

Step 7 - Compute number of check dams (or similar structures) required to produce a hydraulic grade line slope of 1% or less and to detain the WQ_v.

Step 8 - Calculate draw-down time.

Planting soil must pass a maximum rate of 1.5 feet in 24 hours and must completely filter WQ_v within 48 hours.

Step 9 - Check low flow and design event velocity, erosion potential, and freeboard. Provide 6 inches of freeboard.

Step 10 - Design low flow orifice at downstream headwalls and check dams. Design orifice to pass WQ_v in 6 hours.

Step 11 - Design inlets, sediment forebay(s), and underdrain system.

Step 12 - Prepare Vegetation and Landscaping Plan.

A landscaping plan for the enhanced grass swales must be prepared to indicate how the enhanced swale system will be stabilized and established with vegetation. Plan must also include an invasive species prevention plan. Vegetation and landscaping plan must include plans for the first year of operation and full maturity (i.e. 3-year duration).

4.4.6 Inspection and Maintenance Requirements

Specific maintenance inspections and requirements are contained in Chapter 7 of the Administrative Manual.

4.4.7 Design Form

Design Procedure Form: Enhanced Grassed Swales

ENHANCED GRASS SWALE FEASIBILITY	**NOTES:**
1. Is the use of an enhanced grass swale appropriate?	
2. Confirm design criteria and applicability.	
PRELIMINARY HYDROLOGIC CALCULATIONS	
3. Compute, WQ_v volume requirements Compute Runoff Coefficient, R_v Compute WQ_v volume requirements	 R_v = _____ WQ_v = _____ acre-ft
4. Compute site hydrologic input parameters Development Conditions Area CN Adjusted CN Time of concentration	 Pre-developed Post-developed _____acres _____acres _____ _____ s _____ _____ s _____hours _____ hours
Compute CP_v Compute Q_{10} Compute Q_{25} Compute Q_{100}	CP_v = _____ cfs Q_{p10} = _____ cfs Q_{p25} = _____ cfs Q_{100} = _____ cfs
ENHANCED SWALE DESIGN	
5. Pretreatment volume (if included in design) Vol_{pre} = Acres of Impervious Area(0.2")(1'/12")	WQ_{pre} = _____ acre-ft
6. Determine swale dimensions Assume trapezoidal channel with max depth of 4.0 inches	Length = _____ ft Width = _____ft Side Slopes = _____ Area = _____ft^2
7. Computer number of check dams (or similar structures) required to detain WQ_v	Slope = _____ft/ft Depth = _____ft Distance = _____ft Number = _____each
8. Calculate drawn-down time	t = _____hr

Require k = 1.5 ft per day	
9. Check low flow and design storm velocity erosion potential and freeboard	V_{min} = _____fps
Requires separate computer analysis for velocity	
Overflow weir (use weir equation) Use weir equation for slot length ($Q = CLH^{3/2}$)	Weir Length = ____ft
10. Design low flow orifice at headwall Area of orifice from orifice equation $Q = CA(2gh)^{0.5}$	Area = ____ft^2 Diam. = ____inch
11. Design inlets, sediment forebays, underdrain system	
12. Attached vegetation and landscaping plan including an invasive species prevention plan.	

Notes: _____

_____

4.4.8 Design Example

The following design example is for an enhanced grassed swale designed to control the 1-inch, 6-hour for water quality purposes, and safely pass the 1-year, 24-hour, and 10-year and 25-year, 6-hour storm events following the design procedures given in section 4.4. Figure 4.4.4 shows the site plan for the development and base and hydrologic data that will be used in the design example. The site provides an area where an enhanced grassed swale 250 feet long, a slope of 4.0 percent, and side slopes of 3:1 horizontal to vertical can be installed.

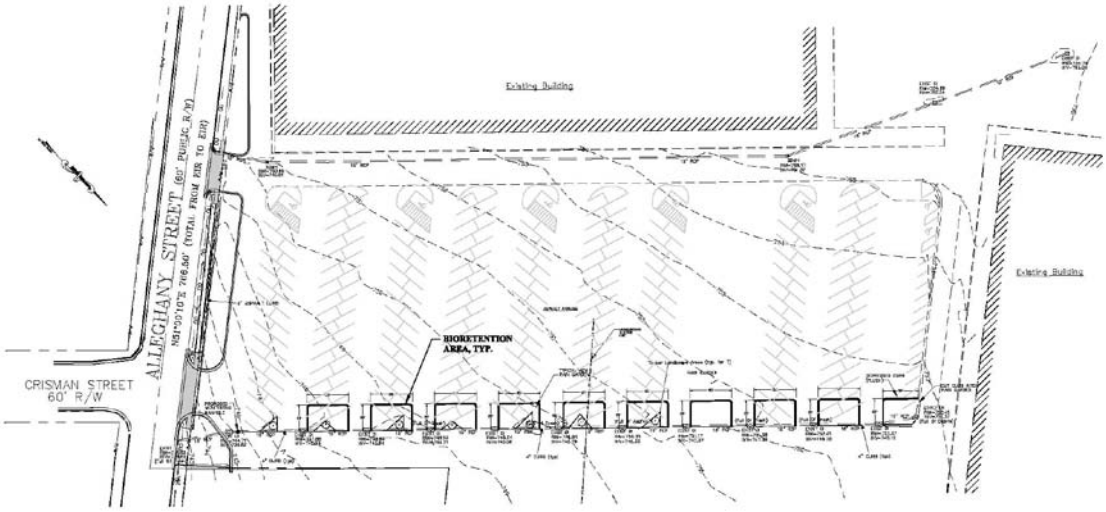

Figure 4.4.4 Example Site Plan for Enhanced Grass Swale Design

The following steps illustrate how to use the design procedures given in section 4.4 to design a grass channel that will be acceptable for the design criteria given in this manual.

Step 1 Compute Site Hydrologic Input Parameters

Using the methods presented in the Charlotte-Mecklenburg Storm Water Design Manual, the following data can be determined for the example development site.

Hydrologic Input Data

Condition	Area (acres)	CN	CN (adjusted) for 1-inch storm	t_c (hours)
Pre-developed	1.0	65	N/A	0.323
Post-developed	1.0	93.4	98.3	0.133

Step 2 Compute Water Quality Volume (WQ_v)

- Compute Runoff Coefficient, R_v, using (Schueler's Method) Equation 3.1

  $R_v = 0.05 + 0.009(I) = 0.05 + (85.0)(0.009) = 0.82$

- Compute Water Quality Volume, WQ_v, using Equation 3.2

  $WQ_v = 1.0R_vA/12 = (1.0 \text{ inches})(0.82)(1.0 \text{ acre})(1\text{foot}/12 \text{ inches}) = 0.07 \text{ ac-ft}$

- Convert Water Quality Volume, WQ_v to inches of runoff using Equation 3.3

  $WQ_v = 1.0(R_v) = 1.0(0.82) = 0.82$ inches

Step 3 Compute Water Quality Peak Flow (WQ_p)

- Compute modified SCS curve number, CN, using Equation 3.4

  $CN = 1000/[10 + 5P + 10WQ_v - 10(WQ_v^2 + 1.25\ WQ_vP)^{0.5}]$
  $CN = 1000/[10 + 5(1.0) + 10(0.82) - 10\{(0.82^2 + 1.25(0.82 \times 1.0)\}^{0.5}] = 98.3$

- Compute WQ_p using SCS the hydrograph procedure documented in the CMSWDM and the HEC-1 model or similar hydrologic model as approved by the review engineer. A 1-inch, 6-hour balanced storm event is required.

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 *           VERSION 4.1                *
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*    U.S. ARMY CORPS OF ENGINEERS      *
*    HYDROLOGIC ENGINEERING CENTER     *
*          609 SECOND STREET           *
*       DAVIS, CALIFORNIA 95616        *
*           (916) 756-1104             *
*                                      *
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THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM
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1                                                HEC-1 INPUT                                                PAGE  1

          LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

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             2          ID       ANALYZED BY ABC ENGINEERING
             3          ID       DATE: OCTOBER 2006
                        *  ******************************************************************************
                        *
                        *     TIME SPECIFICATION CARD
             4          IT       1       0       0     365
                        *  DIAGRAM
                        *     TIME INTERVAL CARD
             5          IN       5       0       0
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                        * **************** 1-INCH, 6 HOUR STORM EVENT ********************************
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             8          PI    .000    .003    .003    .003    .003    .003    .003    .004    .004    .004
             9          PI    .004    .004    .004    .004    .004    .005    .005    .005    .005    .006
            10          PI    .007    .007    .007    .008    .008    .009    .009    .010    .011    .012
            11          PI    .013    .019    .022    .025    .039    .050    .108    .188    .075    .043
            12          PI    .028    .023    .020    .014    .012    .011    .010    .009    .009    .008
            13          PI    .008    .007    .007    .007    .006    .005    .005    .005    .005    .005
            14          PI    .004    .004    .004    .004    .004    .004    .004    .004    .003    .003
            15          PI    .003    .003    .003    .000
                        * ******************************************************************************
            16          KM   1-ACRE PRE-DEVELOPED CONDITIONS
            17          KO       5       0       0       0      21
            18          BA   .0016
            19          LS       0    65.0       0
            20          UD   0.194

            21          KK   POST1
            22          KM   1-ACRE POST-DEVELOPED CONDITIONS - ADJUSTED CURVE NUMBER
            23          KO       1       0       0       0      21
            24          BA   .0016
            25          LS       0    98.3       0
            26          UD   0.080
            27          ZZ
1****************************************                                                  ***************************************
*                                      *                                                  *                                     *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *                                                  *    U.S. ARMY CORPS OF ENGINEERS     *
*              JUN   1998              *                                                  *    HYDROLOGIC ENGINEERING CENTER    *
*            VERSION 4.1               *                                                  *          609 SECOND STREET          *
*                                      *                                                  *       DAVIS, CALIFORNIA 95616       *
*  RUN DATE   12APR07  TIME  18:40:19  *                                                  *           (916) 756-1104            *
*                                      *                                                  *                                     *
****************************************                                                  ***************************************


                                MECKELNBURG COUNTY BMP DESIGN MANUAL
                                ANALYZED BY ABC ENGINEERING
                                DATE: OCTOBER 2006


             **************
             *            *
   21 KK     *     POST1  *
             *            *
             **************


 ************************************************************************************************************************

     TOTAL RAINFALL =    1.00, TOTAL LOSS =     .18, TOTAL EXCESS =     .82

  PEAK FLOW     TIME                        MAXIMUM AVERAGE FLOW
                                     6-HR       24-HR       72-HR      6.07-HR
+   (CFS)       (HR)
                          (CFS)
+       2.      3.20                 0.          0.          0.           0.
                       (INCHES)     .812        .812        .812         .812
                        (AC-FT)      0.          0.          0.           0.

                       CUMULATIVE AREA =     .00 SQ MI

1
                                                     RUNOFF SUMMARY
                                                FLOW IN CUBIC FEET PER SECOND
                                              TIME IN HOURS,  AREA IN SQUARE MILES

                                     PEAK   TIME OF     AVERAGE FLOW FOR MAXIMUM PERIOD      BASIN     MAXIMUM     TIME OF
          OPERATION       STATION    FLOW    PEAK                                           AREA      STAGE     MAX STAGE
+                                                        6-HOUR     24-HOUR     72-HOUR

          HYDROGRAPH AT
+                           PRE1       0.     .00          0.          0.          0.        .00

          HYDROGRAPH AT
+                          POST1       2.    3.20          0.          0.          0.        .00


 *** NORMAL END OF HEC-1 ***
```

Note that the previous HEC-1 model output using the SCS method indicates that the runoff volume is 0.82 inches which matches the Schueler method runoff volume results using Equation 3-2. The peak discharge for the 1-inch, 6-hour storm event is shown to be 1.67 cfs.

Step 4 Compute CP_v, $Q_{10\text{-year}}$, and $Q_{25\text{-year}}$ Peak Flow

Using the SCS hydrologic procedures, HEC-1 computer model, or other suitable hydrologic model and the site data computed in Step 2, peak discharges and runoff hydrographs are computed. The following table summarizes the results of the hydrologic modeling.

Results of Hydrologic Calculations
(From Computer Model Results Using SCS Hydrologic Procedures)

Condition	$Q_{1\text{-inch}}$	$Q_{1\text{-year}}$	$Q_{10\text{-year}}$	$Q_{25\text{-year}}$	$Q_{50\text{-year}}$
Runoff	cfs	cfs	cfs	cfs	cfs
Pre-developed	0.00	0.24	1.09	1.64	2.09
Post-developed	1.67	2.65	5.43	6.43	7.18

Step 5 Compute Pretreatment System Requirements

One of the pretreatment requirements for an enhanced grass swale is a forebay that contains 0.2 inches/impervious acre for each inflow location. The example channel has one inflow point at which runoff from the entire watershed enters the BMP. Therefore, the following computation is performed.

Forebay volume = (0.85 acres of impervious area)(0.2 inch)((1 ft/12 in)
= 0.014 ac-ft
= 617 cubic feet

Step 6 Compute Enhanced Grassed Swale Bottom Width and Depth to Control the WQ_v

The design requirements for an enhanced grass swale to provided 45 percent TSS and 30 percent TP removal is that the effective slope must be less than or equal to 2 percent and the depth of flow for the WQ_v must be less than 4 inches. The design process is iterative and uses Mannings formula to derive an enhanced grass swale bottom width that meets the design requirements of flow depth.

$$Q = (1.49/n)A(A/P)^{2/3}S^{1/2}$$

where:

Q = discharge for the 1-inch, 6-hour storm event (cfs) = 1.69 cfs
n = Mannings "n" value for dense grasses with flow through the vegetation = 0.24
A = area of flow (sq ft) = function of depth (0.33 feet), bottom width, and side slope
P = wetted perimeter (ft) = function of depth 90.33 feet), bottom width, and side slope
S = channel slope = 0.04 ft/ft

Note that two of the design parameters are slightly different than standard Manning equations applications. The Mannings n value for the WQ_v design is assuming that the flow depth is less than the vegetation height and therefore is based on sheet flow values. Typical values that should be used are 0.15 for short grasses, 0.24 for dense grasses, and 0.40 for Bermuda-type grasses. The slope used is the actual channel slope (0.04 ft/ft), even though the effective channel slope is less (0.02 ft/ft) due to the installation of rock check dams. The actual slope should be used for the WQ_v design because the benefit/impact of the rock check dams is negligible for the smaller storm events. The effective slope should be used for flood control design because the benefit/impact of the rock check dams is significant.

Based on the Mannings formula shown above, the required bottom width is 8.3 feet. The maximum channel bottom width is 8 feet, so a berm must be installed for the enhanced grass swale to reduce the opportunity for braided flow. The flow velocity of the water quality control storm event (WQv) is 0.55 ft/sec which is less than the allowable stable flow velocity of grass (5.5 foot/second for Kentucky bluegrass per the *North Carolina Erosion and Sediment Control Planning and Design Manual*).

Step 7 Design Enhanced Grassed Swale To Pass Appropriate Flood Events - Q_{10}

The standard design target listed in the Charlotte-Mecklenburg Storm Water Design Manual for channels is the 10-year storm event. The same design process is used to assess the Q_{10} that was used to size the channel bottom width to treat the WQ_v with three exceptions:

- Mannings n value is the standard n value for flow over vegetation and not the roughness used for flow through vegetation.
- The channel slope is the effective slope and not the actual slope.
- The equation is solved for flow depth, as the channel bottom width was designed in the previous step.

The design process is iterative and uses Mannings formula to derive an enhanced grass swale flow depth that meets the design requirements.

$$Q = (1.49/n)A(A/P)^{2/3}S^{1/2}$$

where:

Q = discharge for the 10-year, 6-hour storm event (cfs) = 5.43 cfs
n = Mannings "n" value for dense grasses with flow over the vegetation = 0.045
A = area of flow (sq ft) = function of depth, bottom width (8.3 feet), and side slope
P = wetted perimeter (ft) = function of depth, bottom width (8.3 feet), and side slope
S = effective slope = 0.02 ft/ft

Based on the Mannings formula shown above, the flow depth is 0.30 feet. An additional 0.5 feet of freeboard should be provided. The flow velocity of the 10-year, 6-hour storm event (Q_{10}) is 1.96 ft/sec which is less than the allowable stable flow velocity of grass (5.5 foot/second for Kentucky bluegrass per the *North Carolina Erosion and Sediment Control Planning and Design Manual*).

Step 8 Compute Number and Height of Check Dams (or similar structures)

Check dams are required to reduce the actual channel slope from 0.04 foot/foot to an effective slope of 0.02 foot/foot. The grassed swale design specifications state that the minimum check dam spacing is 50 feet and the maximum check dam spacing is 100 feet. The designer has two options to design the height and spacing of the check dams.

The first option is to assume that the hydraulic gradeline slope is equal to the depth of flow over each check dam. Therefore, the designer should compute the critical depth at each check dam, set those elevations as the hydraulic gradeline elevation, and set the height and spacing of the check dam system so that effective hydraulic gradeline slope is less than 0.02 foot/foot.

The second option, and the option used for this design example, is based on the assumption that the effective hydraulic gradeline slope is less than 0.02 foot/foot if the top elevation the downstream check dam is equal or greater than the toe elevation of the upstream check dam. For a channel with a slope of 0.04 foot/foot, 2 foot tall check dams spaced at 50 foot intervals will meet that requirement.

Step 9 Determine Check Dam Drawdown Method

The check dam specifications require that erosion at the check dam toe does not occur and that the water quality runoff volume (WQv) draws down within 24 hours. An orifice/pipe system through the check dam is used to ensure that the appropriate draw down duration is met. The orifice/pipe system is sized using the following computational procedures.

Allowable discharge = (0.07 acre-feet)(43,560ft^2/acre)/[(24 hours)(3,600 sec/hour)]
= 0.035 cfs

Size opening based on orifice equation:
Area = (0.035 cfs)/ [(0.6)((2)(32.2 ft^2/sec)(1.0 ft))$^{0.5}$]
= 0.0072 sq ft, diameter = 0.096 feet = 1.1 inch orifice

Step 10 Compute Underdrain System Requirements

The underdrain must be sized to flow full with a minimum velocity of 2.5 feet per second. The capacity of the underdrain must exceed the discharge for the 1-inch, 6-hour storm event assuming that 50 percent of the pipe capacity is lost due to clogging. In addition, the number and size of perforations must pass the 1-inch, 6-hour storm event assuming that 50 percent of the perforation capacity is lost due to clogging.

The first step is to determine underdrain size and slope to meet full flow minimum velocity requirements. The design process is iterative and uses Mannings formula to derive the full flow velocity that meets the design requirements. The following computations present the results of the iterative process. Intermediate steps are not presented.

$$V = (1.49/n)(A/P)^{2/3}S^{1/2}$$

where:

V = flow velocity
n = Mannings "n" value for underdrain pipe = 0.012
A = area of flow (sq ft) based on full flow conditions = 0.349 ft^2 for 8-inch pipe
P = wetted perimeter (ft) based on full flow conditions = 2.094 ft for 8-inch pipe
S = slope of underdrain system = 0.02 ft/ft

therefore:

Full flow velocity = 1.90 fps which meets the design requirement of 1.0 fps

The second step is to compute the capacity of the underdrain system to ensure that the 1-inch, 6-hour storm event peak discharge can pass assuming 50 percent of the system is lost due to clogging. The design process uses Mannings formula to derive the flow depth that meets the design requirements.

$$Q = (1.49/n)A(A/P)^{2/3}S^{1/2}$$

where:

Q = discharge capacity that must be greater than the 1-inch, 6-hour storm event (cfs) = 1.67 cfs
n = Mannings "n" value for underdrain pipe = 0.012
A = area of flow (sq ft) based on full flow conditions = 0.349 ft^2 for 8-inch pipe
P = wetted perimeter (ft) based on full flow conditions = 2.094 ft for 8-inch pipe
S = slope of underdrain system = 0.02 ft/ft

therefore:

Full flow capacity = 1.85 cfs which is greater than the 1-inch, 6-hour storm event discharge. However, <u>two</u> 8-inch perforated pipes must be installed in order to meets the design requirement that 50 percent of capacity is lost due to clogging.

The third and final step is to the number and size of perforations that are needed to pass the 1-inch, 6-hour peak discharge, assuming that 50 percent of the perforation capacity is lost due to clogging. The design process uses the orifice formula to derive the perforation capacity.

$Q = CA(2gh)^{0.5}$ where: Q = 1.67 cfs
h = 1.00 feet (assumed head on perforations)
C = discharge coefficient = 0.6

Solve for Area (assuming 50 percent clogging)

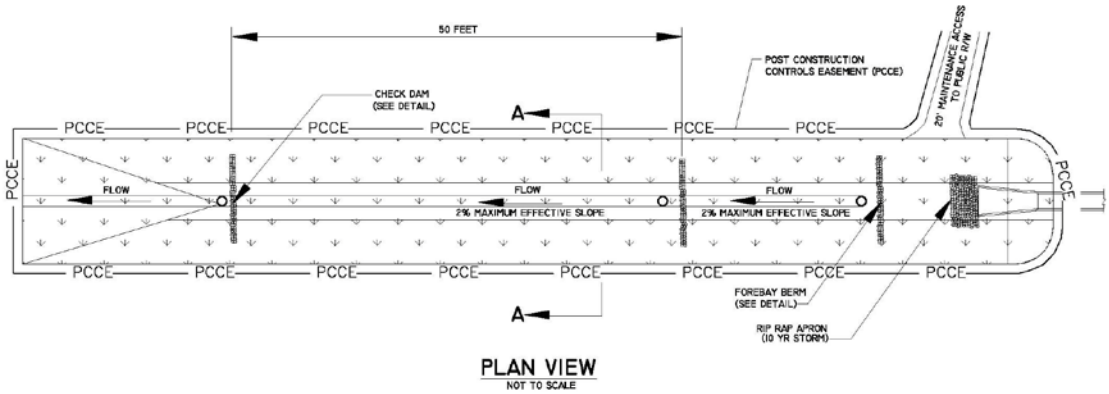
$A = 1.67 \text{ cfs} / [0.6((2)(32.2 \text{ ft/s}^2)(1.00))^{0.5}] = 0.347 \text{ ft}^2$ times 2 = 0.694 ft^2

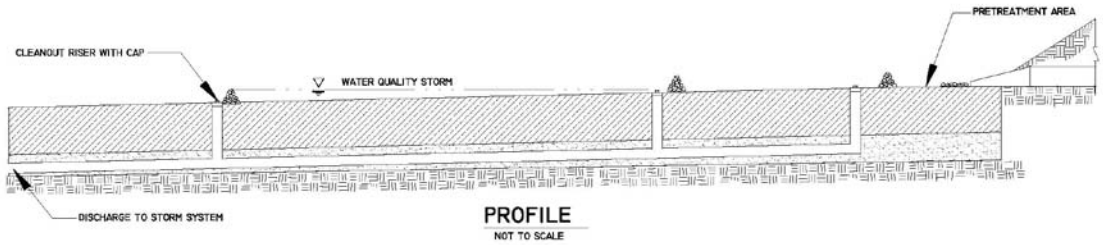
Compute the number of ½ inch perforations to provide 0.694 ft^2 of opening

$A = \pi d^2/4$
d = 0.042 ft
A = 0.0014 ft^2

Use 496 perforations (0.694/0.0014)

The design results are presented in Figure 4.4.5 below.





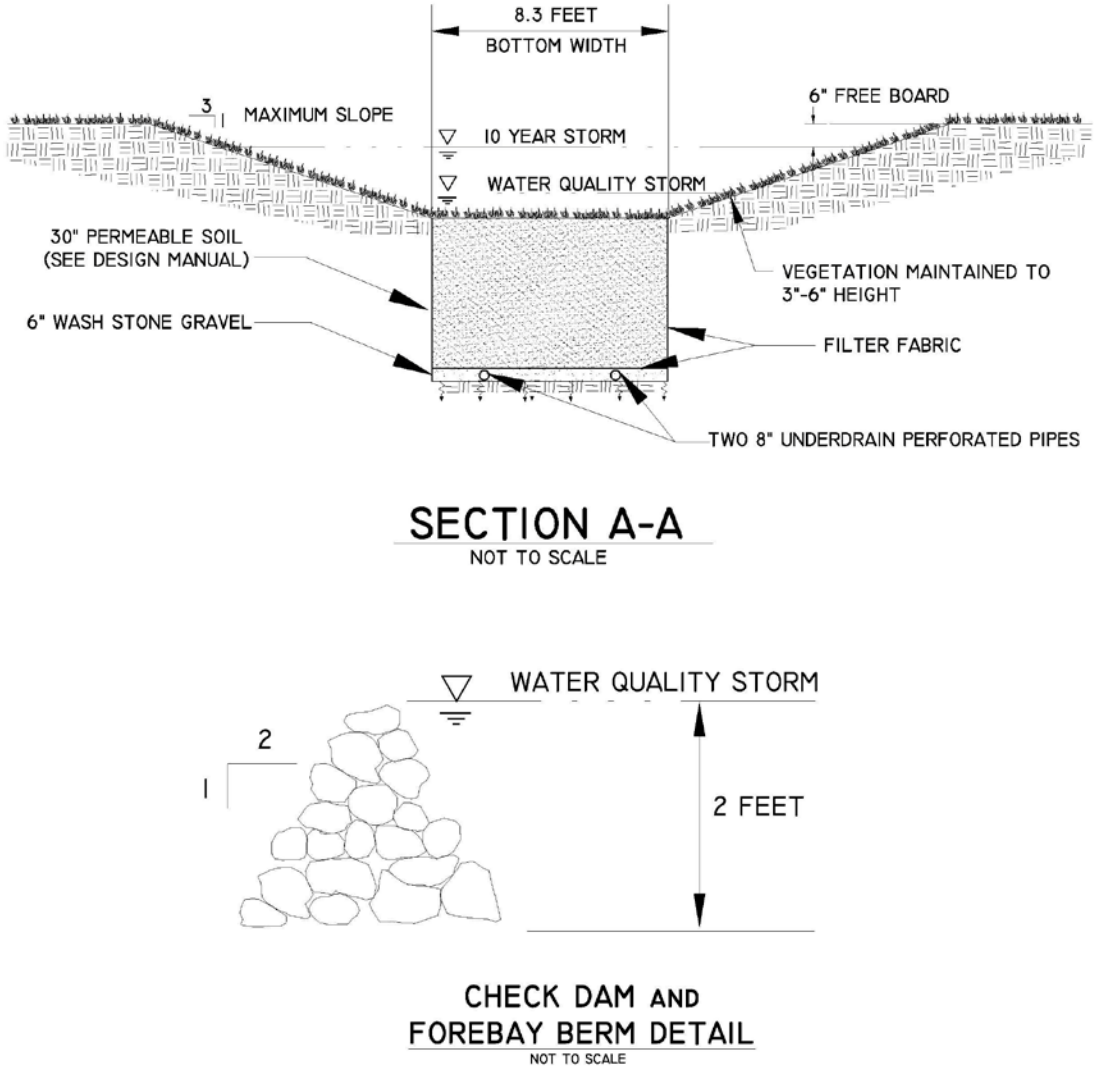


Figure 4.4.5 – Enhanced Grass Swale Design Results

<u>Step 11 Assess Maintenance Access and Safety Features</u>

A 12-foot wide stable maintenance access route must be provided. The access route must be contained within a 20-foot wide maintenance access easement from the BMP facility to public right-of-way.

<u>Step 12 Prepare Vegetation and Landscaping Plan</u>

A landscaping plan for the enhanced grass swale must be prepared to indicate how the enhanced grass swale will be stabilized and established with vegetation. Plan must also include an invasive species prevention plan. Vegetation and landscaping plan must include plans for the first year of operation and full maturity (i.e. 3-year duration).