Water Quality Swale

Description: Vegetated open channels designed to capture and infiltrate stormwater runoff within a dry storage layer beneath the base of the channel.

Components:
- Open trapezoidal or parabolic channel to store entire treatment volume, which is ultimately infiltrated
- Filter bed of permeable, engineered soils
- Underdrain system for impermeable soils
- Level spreaders every 50 feet, if length exceeds 100 feet

Advantages/Benefits:
- Stormwater treatment combined with conveyance
- Less expensive than curb and gutter
- Reduces runoff velocity
- Promotes infiltration

Disadvantages/Limitations:
- Higher maintenance than curb and gutter
- Cannot be used on steep slopes
- High land requirement
- Requires 3 feet of head

Design considerations:
- Longitudinal slopes ideally less than 2%
- Bottom channel width of 2 to 8 feet
- Underdrain required for subsoil infiltration rates less than 0.5 inches/hour
- Side slopes of 3:1 or flatter; 4:1 recommended
- Must convey the 10-year storm event with a minimum of 6 inches of freeboard

Selection Criteria:

Level 1 – 40% Runoff Reduction Credit

Level 2 – 60% Runoff Reduction Credit

Land Use Considerations:

X **Residential**

X **Commercial**

X **Industrial** (with MWS approval)

Maintenance:
- Maintain grass height (if turf)
- Remove sediment from forebay and channel
- Remove accumulated trash and debris
- Re-establish plants as needed

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

SECTION 1: DESCRIPTION

Water quality swales are essentially bioretention cells that are shallower, configured as linear channels, and covered with turf or other surface material (other than mulch and ornamental plants). The water quality swale is a soil filter system that temporarily stores and then filters the desired Treatment Volume (T_v). Water quality swales rely on a pre-mixed soil media filter below the channel that is similar to that used for bioretention. If soils are extremely permeable, runoff infiltrates into underlying soils. Otherwise, the runoff treated by the soil media flows into an underdrain, which conveys treated runoff back to the conveyance system further downstream. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale, beneath the filter media. Water quality swales may appear as simple grass channels with the same shape and turf cover, while others may have more elaborate landscaping. Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover or trees.

SECTION 2: PERFORMANCE

The primary pollutant removal mechanisms operating in swales are settling, filtering infiltration and plant uptake. The overall runoff reduction capabilities of water quality swales are summarized in **Table 5.1**.

Table 5.1. Runoff Volume Reduction Provided by Water Quality Swales

Stormwater Function	Level 1 Design	Level 2 Design
Runoff Volume Reduction (RR)	40%	60%

Sources: CSN (2008), CWP (2007)

SECTION 3: DESIGN TABLE

Swales can be oriented to accept runoff from a single discharge point, or to accept runoff as lateral sheet flow along the swale's length.

Table 5.2. Water Quality Swale Design Criteria	
Level 1 Design (RR:40)	**Level 2 Design (RR:60)**
Sizing: See **Section 6.1**	Sizing: See **Section 6.1**
Surface Area (sq. ft.) = (Tv– the volume reduced by an upstream BMP) / Storage depth[1]	Surface Area sq. ft.) = {(1.1)(Tv) – the volume reduced by an upstream BMP } / Storage Depth[1]
Effective swale slope ≤ 2%	Effective swale slope ≤ 1 %
Media Depth: minimum = 18 inches;	Media Depth minimum = 24 inches
Recommended maximum = 36 inches	Recommended maximum = 36 inches
Sub-soil testing (**Section 6.2**): one per 50 linear feet, 2 minimum; not needed if an underdrain is used; min. infiltration rate must be > 0.5 inch/hour to remove the underdrain requirement;	
Underdrain (**Section 6.7**): Schedule 40 PVC or HDPE with clean-outs	Underdrain and Underground Storage Layer (**Section 6.7**): Schedule 40 PVC or HDPE with clean outs, and a minimum 12-inch stone sump below the invert; OR none if the soil infiltration requirements are met (see **Section 6.2**)
Media (**Section 6.6**): supplied by the vendor or mixed onsite[2]	
Inflow: sheet or concentrated flow with appropriate pre-treatment	
Pre-Treatment (**Section 6.4**): a pretreatment cell, spreader, or another approved (manufactured) grass filter strip, gravel diaphragm, or gravel flow pre-treatment structure.	
On-line design	Off-line design or multiple treatment cells
Planting Plan: turf grass, tall meadow grasses, decorative herbaceous cover, or trees	

[1] The storage depth is the sum of the porosity (n) of the soil media and gravel layers multiplied by their respective depths, plus the surface ponding depth (Refer to **Section 6.1**)

[2] Refer to **GIP 01: Bioretention** for soil specifications

Figure 5.1. Turf Grass Water Quality Swale in commercial/office setting (source: VADCR, 2011)

Figure 5.2. Water Quality Swale w/ tall meadow grasses & herbaceous plants along trail receiving runoff from parking area (source: National Transportation Enhancements Clearinghouse / www.enhancements.org)

SECTION 4: TYPICAL DETAILS

Figures 5.3 through 5.7 below provide typical schematics for water quality swales.

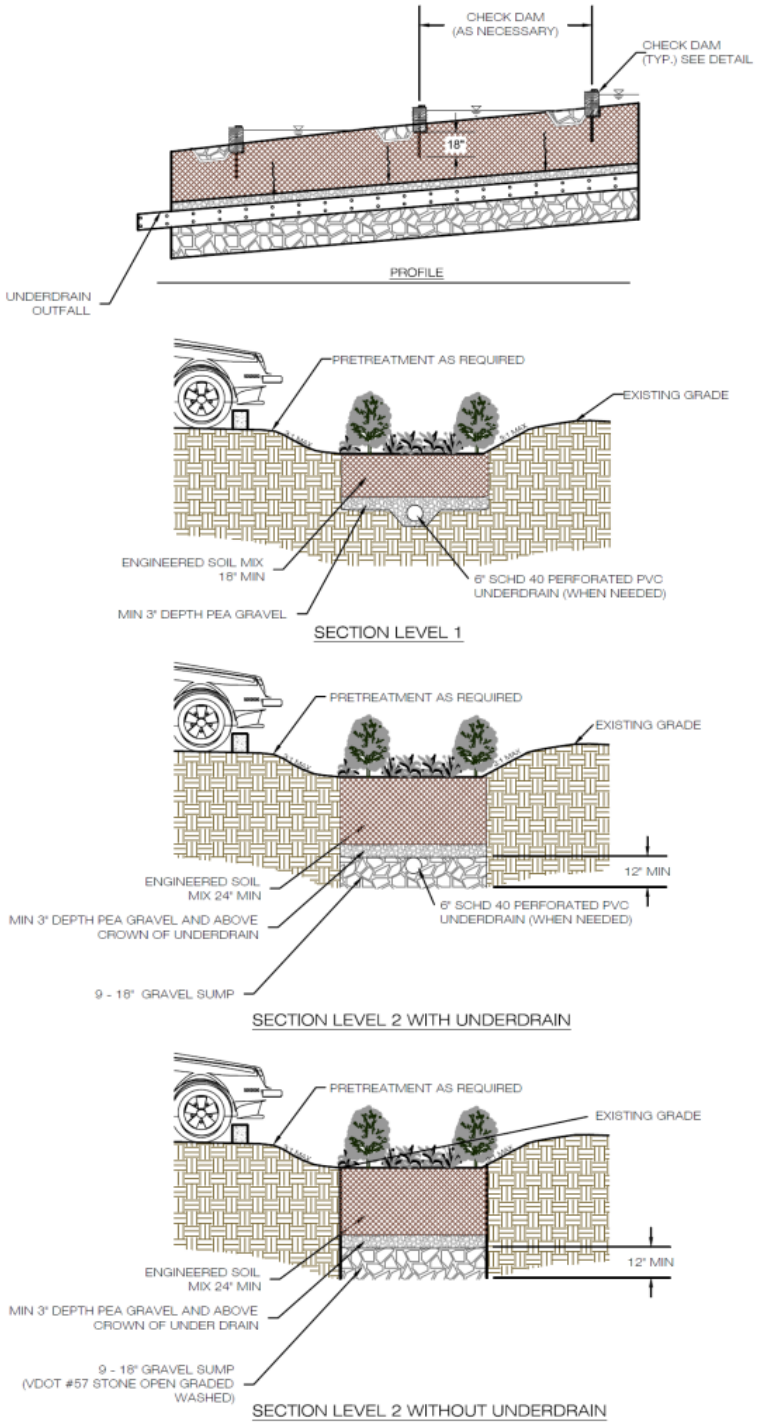


Figure 5.3. Typical Details for Level 1 and 2 Water Quality Swales (source: VADCR, 2011)

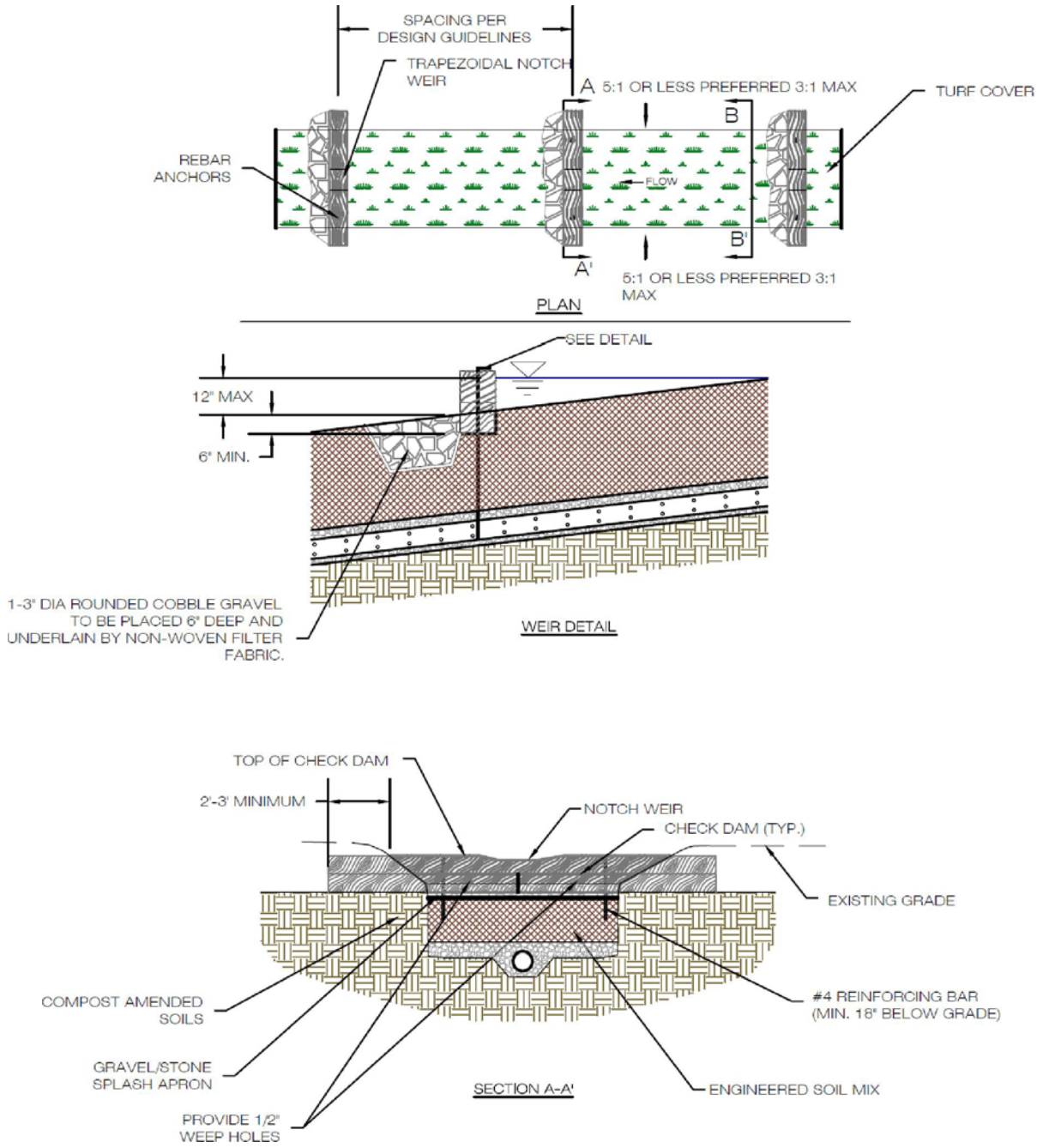
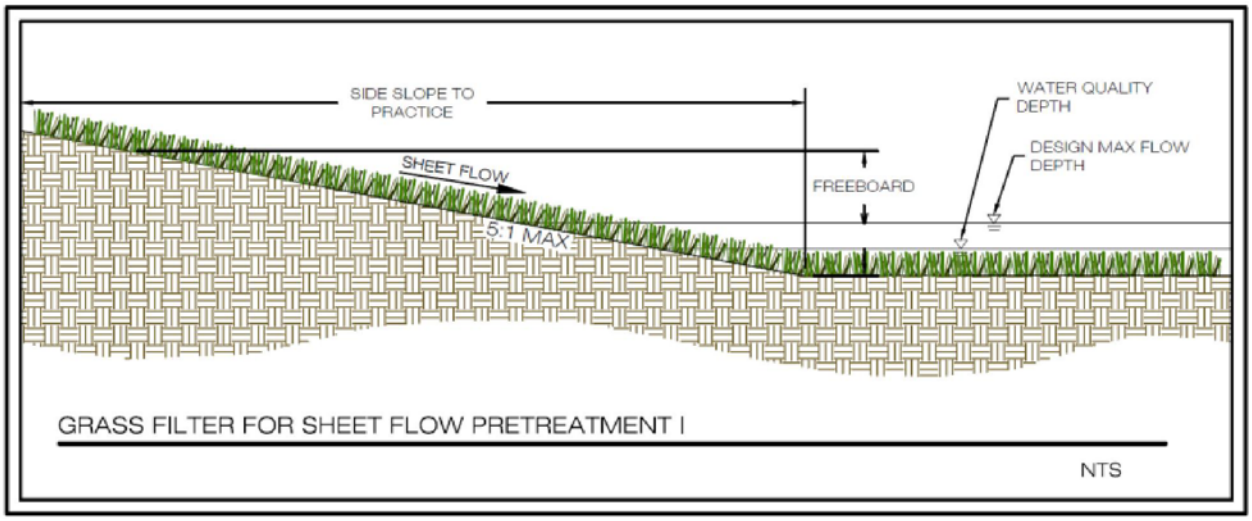


Figure 5.4. Typical Detail for Water Quality Swale Check Dam (source: VADCR, 2011)



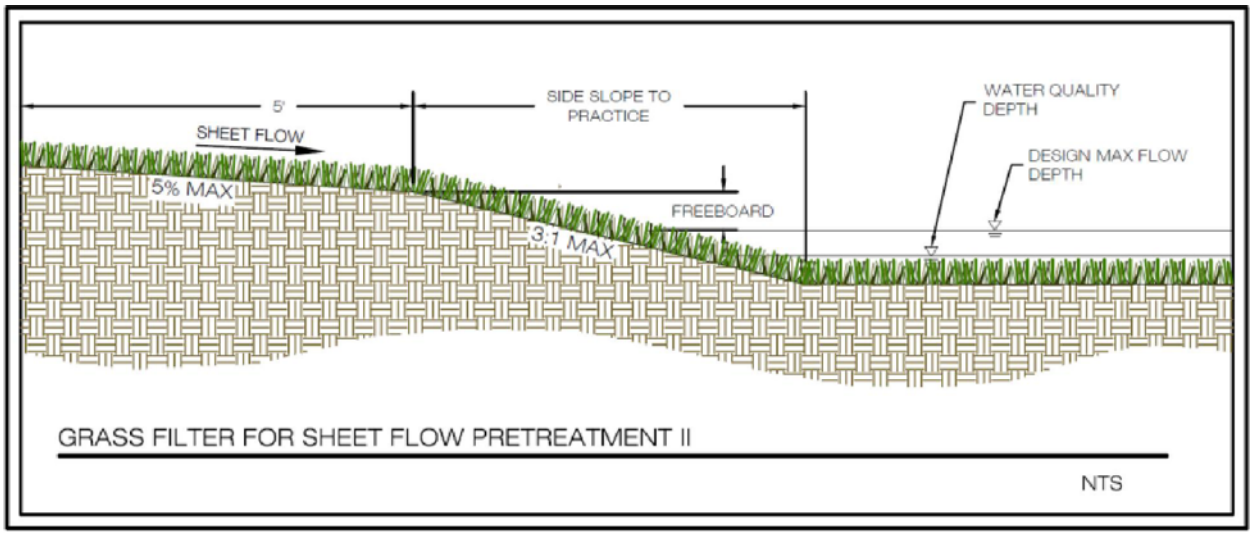


Figure 5.5: Pretreatment I and II - Grass Filter for Sheet Flow (source: VADCR, 2011)

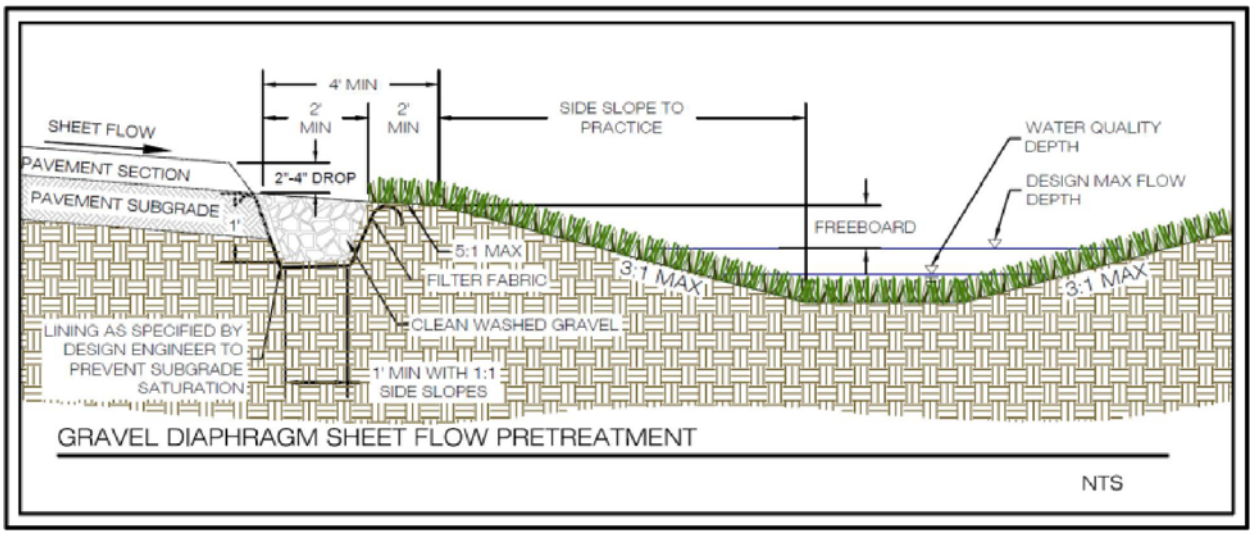


Figure 5.6: Pretreatment – Gravel Diaphragm for Sheet Flow from Impervious or Pervious (source: VADCR, 2011)

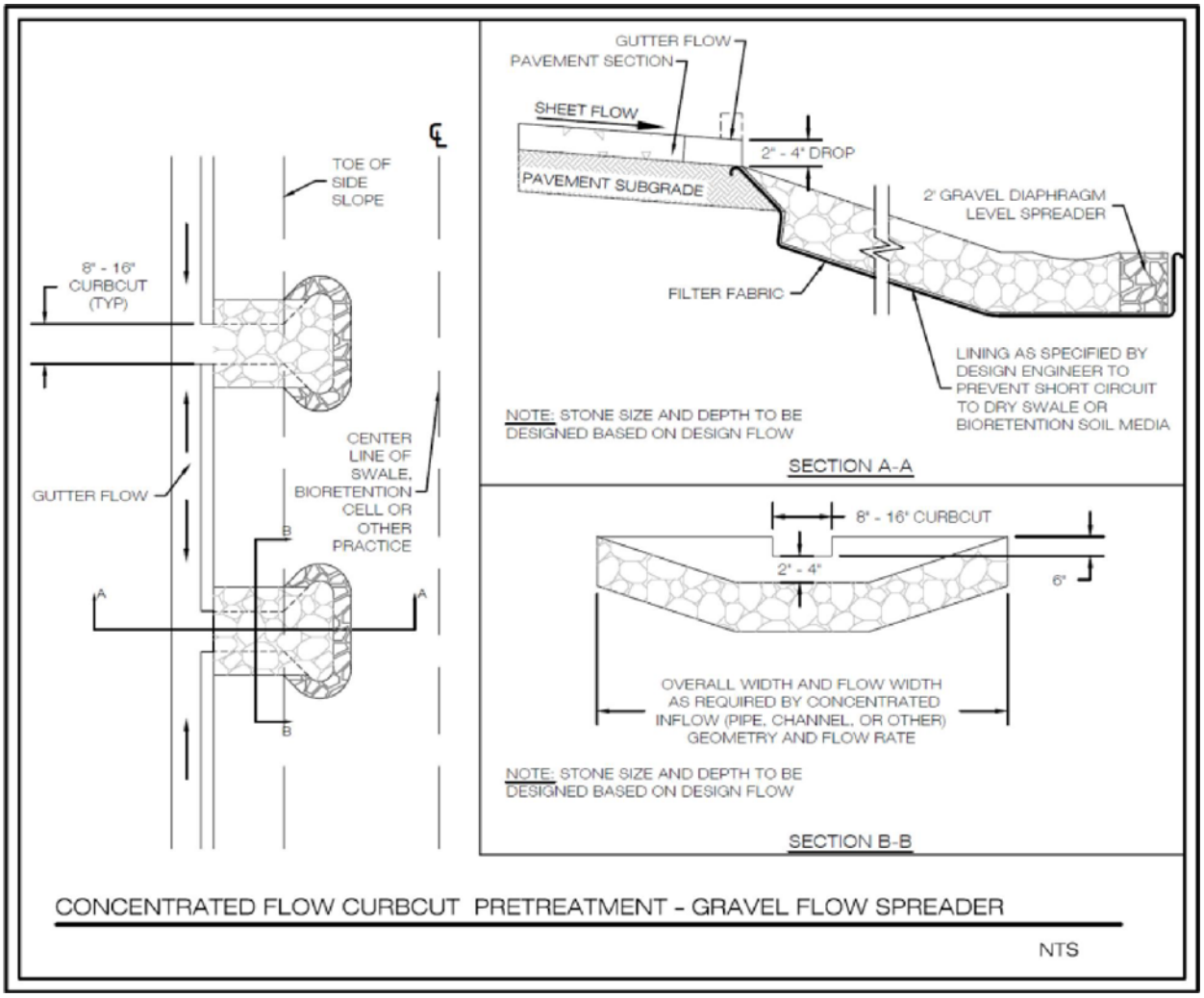


Figure 5.7: Pre-Treatment – Gravel Flow Spreader for Concentrated Flow (source: VADCR, 2011)

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Water quality swales can be implemented on a variety of development sites where density and topography permit their application. Some key feasibility issues for water quality swales include the following:

Contributing Drainage Area. The maximum impervious contributing drainage area to a water quality swale should be 2.5 acres. When water quality swales treat larger drainage areas, the velocity of flow through the surface channel often becomes too great to treat runoff or prevent erosion in the channel. Similarly, the longitudinal flow of runoff through the soil, stone, and underdrain may cause hydraulic overloading at the downstream sections of the water quality swale. An alternative is to provide a series of inlets or diversions that convey the treated water to an outlet location.

Available Space. Water quality swale footprints can fit into relatively narrow corridors between utilities, roads, parking areas, or other site constraints. Water quality swales should be approximately 3% to 10% of the size of the contributing drainage area, depending on the amount of impervious cover.

Site Topography. Water quality swales should be used on sites with longitudinal slopes of less than 4%, but preferably less than 2%. Check dams can be used to reduce the effective slope of the swale and lengthen the contact time to enhance filtering and/or infiltration. Steeper slopes adjacent to the swale may generate rapid runoff velocities into the swale that may carry a high sediment loading (refer to pre-treatment criteria in **Section 6.4**).

Available Hydraulic Head. A minimum amount of hydraulic head is needed to implement water quality swales, measured as the difference in elevation between the inflow point and the downstream storm drain invert. Water quality swales typically require 3 feet of hydraulic head.

Hydraulic Capacity. Level 1 water quality swales are an on-line practice and must be designed with enough capacity to (1) convey runoff from the 100-year design storms at non-erosive velocities, and (2) contain the 10-year flow within the banks of the swale. This means that the swale's surface dimensions are more often determined by the need to pass the 10-year storm events, which can be a constraint in the siting of water quality swales within existing right of way (e.g., constrained by sidewalks).

Depth to Water Table. Designers should ensure that the bottom of the water quality swale is at least 2 feet above the seasonally high groundwater table, to ensure that groundwater does not intersect the filter bed, since this could lead to groundwater contamination or practice failure.

Soils. Soil conditions do not constrain the use of water quality swales, although they normally determine whether an underdrain is needed. Low-permeability soils with an infiltration rate of less than or equal to 0.5 inch per hour, such as those classified in Hydrologic Soil Groups (HSG) C and D, will require an underdrain. Designers must verify site-specific soil permeability at the proposed location using the methods for on-site soil investigation presented in **Appendix 5-A** in order to eliminate the requirements for an underdrain.

Utilities. Designers should consult local utility design guidance for the horizontal and vertical clearance between utilities and the swale configuration. Utilities can cross linear swales if they are specially protected (e.g., double-casing). Water and sewer lines generally need to be placed under road pavements to enable the use of water quality swales.

Avoidance of Irrigation or Baseflow. Water quality swales should be located so as to avoid inputs of springs, irrigation systems, chlorinated wash-water, or other dry weather flows.

Setbacks from Building and Roads. Given their landscape position, water quality swales are not subject to normal building setbacks. The bottom elevation of swales should be at least 1 foot below the invert of an adjacent road bed.

Hotspot Land Use. Runoff from hotspot land uses should not be treated with infiltrating water quality swales. An impermeable liner should be used for filtration of hotspot runoff.

Community Acceptance. The main concerns of adjacent residents are perceptions that swales will create nuisance conditions or will be hard to maintain. Common concerns include the continued ability to mow grass, landscape preferences, weeds, standing water, and mosquitoes. Water quality swales are actually a positive stormwater management alternative, because all these concerns can be fully addressed through the design process and proper on-going operation and routine maintenance. The ponding time is less than the time required for one mosquito breeding cycle, so well-maintained water quality swales should not create mosquito problems or be difficult to mow.

SECTION 6: DESIGN CRITERIA

6.1 Sizing of Water Quality Conveyance and Water Quality Treatment Swales

Sizing of the surface area (SA) for water quality swales is based on the computed Treatment Volume (T_v) of the contributing drainage area and the storage provided within the swale media and gravel layers and behind check dams. The required surface area (in square feet) is computed as the Treatment Volume (in cubic feet) divided by the equivalent storage depth (in feet). The equivalent storage depth is computed as the depth of the soil media, the gravel, and surface ponding (in feet) multiplied by the accepted porosity.

The accepted porosities are:

Water Quality Swale Soil Media n	=	0.40
Gravel n	=	0.40
Surface Storage behind check dams n	=	1.0

The equivalent storage depth for the Level 1 design (without considering surface ponding) is therefore computed as:

Equation 5.1. Equivalent Storage Depth – Level 1

$$\text{Equivalent Storage Depth} = D_E = n_1(D_1) + n_2(D_2) + \cdots$$

$$D_E = (1.5 \text{ ft. x } 0.40) + (0.25 \text{ ft. x } 0.40) = 0.7\text{ft.}$$

And the equivalent storage depth for the Level 2 design (without considering surface ponding) is computed as:

Equation 5.2. Equivalent Storage Depth – Level 2

$$D_E = (2.0 \text{ ft. x } 0.40) + (1.0 \text{ ft. x } 0.40) = 1.2 \text{ ft}$$

The effective storage depths will vary according to the actual design depths of the soil media and gravel layer.

Note: When using Equations 3 or 4 below to calculate the required surface area of a water quality swale that includes surface ponding (with check dams), the storage depth calculation (Equation 1 or 2) should be adjusted accordingly.

The Level 1 Water Quality Swale Surface Area (SA) is computed as:

Equation 5.3. Surface Area – Level 1

$$\text{SA (sq. ft.)} = (T_v - \text{the volume reduced by an upstream GIP})/D_E \text{ ft.}$$

And the Level 2 Water Quality Swale SA is computed as:

Equation 5.4. Surface Area – Level 2

$$\text{SA (sq. ft.)} = [(1.1 * T_v) - \text{the volume reduced by an upstream GIP}]/D_E$$

NOTE: The volume reduced by upstream PTPs is supplemented with the anticipated volume of storage created by check dams along the swale length.

Where:

SA	=	Minimum surface area of Water Quality Swale (sq. ft.)
T_v	=	Treatment Volume (cu. ft.) = [(1 inch)(R_v)(A)]*3630 , A= Area in acres

The final water quality swale design geometry will be determined by dividing the SA by the swale length to compute the required width; or by dividing the SA by the desired width to compute the required length.

6.2 Soil Infiltration Rate Testing

The second key sizing decision is to measure the infiltration rate of subsoils below the water quality swale area to determine if an underdrain will be needed. The infiltration rate of the subsoil must exceed 0.5 inches per hour to avoid installation of an underdrain. The acceptable methods for on-site soil infiltration rate testing are outlined in **Appendix 5-A**. A soil test should be conducted for every 50 linear feet of water quality swale, with a minimum of two tests per swale.

6.3 Water Quality Swale Geometry

Design guidance regarding the geometry and layout of water quality swales is provided below.

Shape. A parabolic shape is preferred for water quality swales for aesthetic, maintenance and hydraulic reasons. However, the design may be simplified with a trapezoidal cross-section, as long as the soil filter bed boundaries lay in the flat bottom areas.

Side Slopes. The side slopes of water quality swales should be no steeper than 3H:1V for maintenance considerations (i.e., mowing). Flatter slopes are encouraged where adequate space is available, to enhance pre-treatment of sheet flows entering the swale. Swales should have a bottom width of from 2 to 8 feet to ensure that an adequate surface area exists along the bottom of the swale for filtering. If a swale will be wider than 8 feet, the designer should incorporate berms, check dams, level spreaders or multi-level cross-sections to prevent braiding and erosion of the swale bottom.

Swale Longitudinal Slope. The longitudinal slope of the swale should be moderately flat to permit the temporary ponding of the Treatment Volume within the channel. The recommended swale slope is less than or equal to 2% for a Level 1 design and less than or equal to 1% for a Level 2 design, though slopes up to 4% are acceptable if check dams are used. The minimum recommended slope for an on-line water quality swale is 0.5%. Refer to **Table 5.3** for check dam spacing based on the swale longitudinal slope.

Table 5.3. Typical Check Dam (CD) Spacing to Achieve Effective Swale Slope		
Swale Longitudinal Slope	LEVEL 1	LEVEL 2
	Spacing[1] of 12-inch High (max.) Check Dams[2] to Create an Effective Slope of 2%	Spacing[1] of 12-inch High (max.) Check Dams[2] to Create an Effective Slope of 0 to 1%
0.5%	–	200 ft. to –
1.0%	–	100 ft. to –
1.5%	–	67 ft. to 200 ft.
2.0%	–	50 ft. to 100 ft.
2.5%	200 ft.	40 ft. to 67 ft.
3.0%	100 ft.	33 ft. to 50 ft.
3.5%	67 ft.	30 ft. to 40 ft.
4.0%	50 ft.	25 ft. to 33 ft.

[1] The spacing dimension is half of the above distances if a 6-inch check dam is used.
[2] Check dams require a stone energy dissipater at the downstream toe.

Check dams. Check dams must be firmly anchored into the side-slopes to prevent outflanking and be stable during the 10 year storm design event. The height of the check dam relative to the normal channel elevation should not exceed 12 inches. Each check dam should have a minimum of one weep hole or a similar drainage feature so it can dewater after storms. Armoring may be needed behind the check dam to prevent erosion. The check dam must be designed to spread runoff evenly over the water quality swale's filter bed surface, through a centrally located depression with a length equal to the filter bed width. In the center of the check dam, the depressed weir length should be checked for the depth of flow, sized for the appropriate design storm (see **Figure 5.4**). Check dams should be constructed of wood, stone, or concrete.

Ponding Depth. Drop structures or check dams can be used to create ponding cells along the length of the swale. The maximum ponding depth in a swale should not exceed 12 inches at the most downstream point.

Drawdown. Water quality swales should be designed so that the desired Treatment Volume is completely filtered within 24 hours or less. This drawdown time can be achieved by using the soil media mix specified in **Section 6.6** and an underdrain along the bottom of the swale, or native soils with adequate permeability, as verified through testing (see **Section 6.2**).

Underdrain. Underdrains are provided in water quality swales to ensure that they drain properly after storms (see **Section 6.7**). The underdrain should be constructed of 6-inch diameter perforated HDPE or PVC, which is placed on either a 3-inch layer of double-washed gravel (TDOT #57) for Level 1 or directly on a 12-inch sump layer of 1-inch stone for Level 2. The underdrain should be encased in a gravel layer extending at least 3 inches above the surface of the pipe. This gravel layer should be covered with a 3-inch layer of choker stone (TDOT #8 or #89), which is then covered with a permeable geotextile.

6.4 Pre-treatment

Several pre-treatment measures are feasible, depending on whether the specific location in the water quality swale system will be receiving sheet flow, shallow concentrated flow, or fully concentrated flow:

- ***Initial Sediment Forebay*** (channel flow). This grass cell is located at the upper end of the water quality swale segment with a 2:1 length to width ratio and a storage volume equivalent to at least 15% of the total Treatment Volume.
- ***Check dams*** (channel flow). These energy dissipation devices are acceptable as pre-treatment on small swales with drainage areas of less than 1 acre.

- ***Tree Check dams*** (channel flow). These are street tree mounds that are placed within the bottom of a water quality swale up to an elevation of 9 to 12 inches above the channel invert. One side has a gravel or river stone bypass to allow storm runoff to percolate through.
- ***Grass Filter Strip*** (sheet flow). Grass filter strips extend from the edge of the pavement to the bottom of the water quality swale at a 5:1 slope or flatter. Alternatively, provide a combined 5 feet of grass filter strip at a maximum 5% (20:1) slope and 3:1 or flatter side slopes on the water quality swale. (**See Figure 5.5**)
- ***Gravel Diaphragm*** (sheet flow). A gravel diaphragm located at the edge of the pavement should be oriented perpendicular to the flow path to pre-treat lateral runoff, with a 2 to 4 inch drop. The stone must be sized according to the expected rate of discharge. (**See Figure 5.6**)
- ***Pea Gravel Flow Spreader*** (concentrated flow). The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2 to 4 inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the swale. (**See Figure 5.7**)

6.5 Conveyance and Overflow

The bottom width and slope of a water quality swale should be designed such that the velocity of flow from a 1-inch rainfall will not exceed 3 feet per second. Check dams may be used to achieve the needed runoff reduction volume, as well as to reduce the flow. Check dams should be spaced based on channel slope and ponding requirements, consistent with the criteria in **Table 5.3**.

The swale should also convey the 2- and 10-year storms at non-erosive velocities with at least 6 inches of freeboard. The analysis should evaluate the flow profile through the channel at normal depth, as well as the flow depth over top of the check dams.

Water quality swales may be designed as off-line systems, with a flow splitter or diversion to divert runoff in excess of the design capacity to an adjacent conveyance system. Or, strategically placed overflow inlets may be placed along the length of the swale to periodically pick up water and reduce the hydraulic loading at the downstream limits.

6.6 Filter Media

Water quality swales require replacement of native soils with a prepared soil media. The soil media provides adequate drainage, supports plant growth, and facilitates pollutant removal within the water quality swale. At least 18 inches of soil media should be added above the choker stone layer to create an acceptable filter. The mixture for the soil media is identical to that used for bioretention and is provided in **Table 5.4** (refer to GIP-01: Bioretention, for additional soil media specifications).

6.7 Underdrain and Underground Storage Layer

Some Level 2 water quality swale designs will not use an underdrain [(where soil infiltration rates meet minimum standards (see **Section 6.2** and **Table 5.2**)]. For Level 2 designs with an underdrain, an underground storage layer, consisting of a minimum 12 inches of stone, should be incorporated below the invert of the underdrain. The depth of the storage layer will depend on the target treatment and storage volumes needed to meet water quality criteria. However, the bottom of the storage layer must be at least 2 feet above the seasonally high groundwater table and bedrock. The storage layer should consist of clean, washed #57 stone or an approved infiltration module.

A water quality swale should include observation wells with cleanout pipes along the length of the swale, if the contributing drainage area exceeds 1 acre. The wells should be tied into any T's or Y's in the underdrain system, and should extend upwards to be flush with surface, with a vented cap.

6.8 Landscaping and Planting Plan

Designers should choose grasses, herbaceous plants or trees that can withstand both wet and dry periods and relatively high velocity flows for planting within the channel. Salt tolerant grass species should be chosen for water quality swales receiving drainage from areas treated for ice in winter. Taller and denser grasses are preferable, although the species is less important than good stabilization and dense vegetative cover. Grass species should have the following characteristics: a deep root system to resist scouring; a high stem density with well-branched top growth; water-tolerance; resistance to being flattened by runoff; and an ability to recover growth following inundation. A qualified landscape designer should be consulted for selection of appropriate plantings.

6.9 Water Quality Swale Material Specifications

Table 5.4 outlines the standard material specifications for constructing water quality swales**.**

Table 5.4. Water Quality Swale Material Specifications

Material	Specification	Notes
Filter Media Composition	Filter Media to contain (by volume): 30-70% sand < 40% silt 5-10% organic matter < 20% clay	The volume of filter media is based on 110% of the product of the surface area and the media depth, to account for settling.
Filter Media Testing	Mix on-site or procure from an approved media vendor (refer to **GIP-01: Bioretention**, for additional soil media information).	
Filter Fabric	A non-woven polyprene geotextile with a flow rate of > 110 gal./min./sq. ft. (e.g., Geotex 351 or equivalent); Apply immediately above the choker stone.	
Choking Layer	A 3- inch layer of choker stone (typically #8 or # 89 washed gravel) laid above the underdrain stone.	
Stone and/or Storage Layer	A 12 to 18 inch layer (depending on the desired depth of the storage layer) of #57 stone should be double-washed and clean and free of all soil and fines.	
Underdrains, Cleanouts, and Observation Wells	6-inch PVC or HDPE pipe, with 3/8-inch perforations.	If needed, install perforated pipe for the full length of the water quality swale. Use non-perforated pipe, as needed, to connect with the storm drain system.
Vegetation	Plant species as specified on the landscaping plan	
Check Dams	Use non-erosive material such as wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric, and include weep holes. Wood used for check dams should consist of pressure-treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.	
Erosion Control Fabric	Where flow velocities dictate, use woven biodegradable erosion control fabric or mats that are durable enough to last at least 2 growing seasons.	

SECTION 7: SPECIAL CASE DESIGN ADAPTATIONS

7.1 Steep Terrain

In areas of steep terrain, water quality swales can be implemented with contributing slopes of up to 20% gradient, as long as a multiple cell design is used to dissipate erosive energy prior to filtering. This can be accomplished by terracing a series of water quality swale cells to manage runoff across or down a slope. The drop in elevation between cells should be limited to 1 foot and armored with river stone or a suitable equivalent. A greater emphasis on properly engineered energy dissipaters and/or drop structures is warranted.

SECTION 8: CONSTRUCTION

8.1 Construction Erosion Prevention and Sediment Control

Construction Stage EPSC Controls. Water quality swales should be fully protected by silt fence or construction fencing, particularly if they will provide an infiltration function (i.e., have no underdrains). Ideally, water quality swale areas should remain *outside* the limits of disturbance during construction to prevent soil compaction by heavy equipment.

Water quality swale locations may be used for small sediment traps or basins during construction. However, these must be accompanied by notes and graphic details on the EPSC plan specifying that the maximum excavation depth of the sediment trap/basin at the construction stage must (1) be at least 1 foot above the depth of the post-construction water quality swale installation, (2) contain an underdrain, and (3) specify the use of proper procedures for conversion from a temporary practice to a permanent one, including de-watering, cleanout and stabilization.

8.2 Construction Sequence

The following is a typical construction sequence to properly install a water quality swale, although the steps may be modified to adapt to different site conditions.

Step 1: Protection during Site Construction. As noted above, water quality swales should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical given that swales are a key part of the drainage system at most sites. In these cases, temporary EPSC such as dikes, silt fences and other similar measures should be integrated into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, erosion control fabric should be used to protect the channel, and excavation should be no deeper than 2 feet above the proposed invert of the bottom of the planned underdrain. Water quality swales that lack underdrains (and rely on filtration) must be fully protected by silt fence or construction fencing to prevent compaction by heavy equipment during construction.

Step 2. Installation should begin after the entire contributing drainage area has been stabilized by vegetation. The designer should check the boundaries of the contributing drainage area to ensure it conforms to original design. Additional EPSC may be needed during swale construction, particularly to divert stormwater from the water quality swale until the filter bed and side slopes are fully stabilized. Pre-treatment cells should be excavated first to trap sediments before they reach the planned filter beds.

Step 3. Excavators or backhoes should work from the sides to excavate the water quality swale area to the appropriate design depth and dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the water quality swale area.

Step 4. The bottom of the water quality swale should be ripped, roto-tilled or otherwise scarified to promote greater infiltration.

Step 5. Place an acceptable filter fabric on the underground (excavated) sides of the water quality swale with a minimum 6 inch overlap. Place the stone needed for storage layer over the filter bed. Perforate the underdrain pipe and check its slope. Add the remaining stone jacket, and then pack #57 stone to 3 inches above the top of the underdrain, and then add 3 inches of choker stone as a filter layer.

Step 6. Add the soil media in 12-inch lifts until the desired top elevation of the water quality swale is achieved. Wait a few days to check for settlement, and add additional media as needed.

Step 7. Install check dams, driveway culverts and internal pre-treatment features, as specified in the plan.

Step 8. Prepare planting holes for specified trees and shrubs, install erosion control fabric where needed, spread seed or lay sod, and install any temporary irrigation.

Step 9. Plant landscaping materials as shown in the landscaping plan, and water them weekly during the first 2 months. The construction contract should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.

Step 10. Conduct a final construction inspection and develop a punch list for facility acceptance.

8.3 Construction Inspection

Inspections are needed during construction to ensure that the water quality swale is built in accordance with these specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intent. Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of water quality swale installation.

- Check the filter media to confirm that it meets specifications and is installed to the correct depth.
- Check elevations such as the invert of the underdrain, inverts for the inflow and outflow points, and the ponding depth provided between the surface of the filter bed and the overflow structure.
- Ensure that caps are placed on the upstream (but not the downstream) ends of the underdrains.
- Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the filter beds and their contributing side-slopes.
- Inspect check dams and pre-treatment structures to make sure they are properly installed and working effectively.
- Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.

The real test of a water quality swale occurs after its first big storm. The post-storm inspection should focus on whether the desired sheet flow, shallow concentrated flows or fully concentrated flows assumed in the plan actually occur in the field. Also, inspectors should check that the water quality swale drains completely within 24 hour drawdown period. Minor adjustments are normally needed as a result of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets or outfalls, and check dam realignment.

SECTION 9: MAINTENANCE

9.1 Maintenance Document

The requirements for the Maintenance Document are in Appendix C of Volume 1 of the Manual. They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities.

9.2. Maintenance Inspections

Annual inspections are used to trigger maintenance operations such as sediment removal, spot revegetation and inlet stabilization. The following is a list of several key maintenance inspection points:

- Add reinforcement planting to maintain 95% turf cover or vegetation density. Reseed or replant any dead vegetation.
- Remove any accumulated sand or sediment deposits on the filter bed surface or in pretreatment cells.
- Inspect upstream and downstream of check dams for evidence of undercutting or erosion, and remove trash or blockages at weepholes.
- Examine filter beds for evidence of braiding, erosion, excessive ponding or dead grass.
- Check inflow points for clogging, and remove any sediment.
- Inspect side slopes and grass filter strips for evidence of any rill or gully erosion, and repair as needed.
- Look for any bare soil or sediment sources in the contributing drainage area, and stabilize immediately.

Ideally, inspections should be conducted in the spring of each year.

9.3 Routine Maintenance and Operation

Once established, water quality swales have minimal maintenance needs outside of the spring clean-up, regular mowing, and pruning and management of trees and shrubs. The surface of the filter bed can become clogged with fine sediment over time, but this can be alleviated through core aeration or deep tilling of the filter bed. Additional effort may be needed to repair check dams, stabilize inlet points and remove deposited sediment from pre-treatment cells.

SECTION 10: AS-BUILTS

After the water quality swale has been constructed, the developer must have an as-built certification of the swale prepared by a registered Professional Engineer and submit this to Metro. The as-built certification verifies that the BMP was installed as designed and approved.

The following components must be addressed in the as-built certification:

1. Appropriate underdrain system for water quality swales.
2. Correctly sized treatment volume.
3. Appropriate filter media and stone installed.
4. Adequate vegetation in place. Landscape plan must be provided.
5. Correct ponding depths and infiltration rates verified.
6. Overflow system in place for high flows.

SECTION 11: REFERENCES

Chesapeake Stormwater Network (CSN). 2008. *Technical Bulletin 1: Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed.* Version 1.0. Baltimore, MD. Available online at: http://www.chesapeakestormwater.net/all-things-stormwater/stormwater-guidance-for-karst-terrain-in-the-chesapeake-bay.html

CWP. 2007. *National Pollutant Removal Performance Database, Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Claytor, R. and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection. Ellicott City, MD.

Hirschman, D. and J. Kosco. 2008. *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program*. EPA Publication 833-R-08-001, Tetra-Tech, Inc. and the Center for Watershed Protection. Ellicott City, MD.

Maryland Department of Environment (MDE). 2000. *Maryland Stormwater Design Manual*. Baltimore, MD. Available online at:

http:/www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater design/index.asp

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban stormwater retrofit practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

Virginia Department of Conservation and Recreation (VADCR). 1999. *Virginia Stormwater Management Handbook. Volumes 1 and 2*. Division of Soil and Water Conservation. Richmond, VA.

Virginia Department of Conservation and Recreation (VADCR). 2011. *Stormwater Design Specification No. 10: Dry Swales. Version 1.9*. Division of Soil and Water Conservation. Richmond, VA.

APPENDIX 5-A

INFILTRATION SOIL TESTING PROCEDURES

I. Test Pit/Boring Procedures

1. One test pit or standard soil boring should be provided for every 50 linear feet of the proposed infiltration area, with a minimum of two per swale.

2. The location of each test pit or standard soil boring should correspond to the location of the proposed infiltration area.

3. Excavate each test pit or penetrate each standard soil boring to a depth at least 2 feet below the bottom of the proposed infiltration area.

4. If the groundwater table is located within 2 feet of the bottom of the proposed facility, determine the depth to the groundwater table immediately upon excavation and again 24 hours after excavation is completed.

5. Determine the USDA or Unified Soil Classification system textures at the bottom of the proposed infiltration area and at a depth that is 2 feet below the bottom. All soil horizons should be classified and described.

6. If bedrock is located within 2 feet of the bottom of the proposed infiltration area, determine the depth to the bedrock layer.

7. Test pit/soil boring stakes should be left in the field to identify where soil investigations were performed.

II. Infiltration Testing Procedures

1. One infiltration test should be conducted for every 50 linear feet of surface area for the infiltration area, with a minimum two per swale.

2. The location of each infiltration test should correspond to the location of the proposed infiltration area.

3. Install a test casing (e.g., a rigid, 4 to 6 inch diameter pipe) to a depth 2 feet below the bottom of the proposed infiltration area.

4. Remove all loose material from the sides of the test casing and any smeared soil material from the bottom of the test casing to provide a natural soil interface into which water may percolate. If desired, a 2-inch layer of coarse sand or fine gravel may be placed at the bottom of the test casing to prevent clogging and scouring of the underlying soils. Fill the test casing with clean water to a depth of 2 feet, and allow the underlying soils to presoak for 24 hours.

5. After 24 hours, refill the test casing with another 2 feet of clean water and measure the drop in water level within the test casing after one hour. Repeat the procedure three (3) additional times by filling the test casing with clean water and measuring the drop in water level after one hour. A total of four (4) observations must be completed. The infiltration rate of the underlying soils may be reported either as the average of all four observations or the value of the last observation. The infiltration rate should be

reported in terms of inches per hour.

6. Infiltration testing may be performed within an open test pit or a standard soil boring. After infiltration testing is completed, the test casing should be removed and the test pit or soil boring should be backfilled and restored.