VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 10

DRY SWALES

VERSION 1.9
March 1, 2011

SECTION 1: DESCRIPTION

Dry 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 dry swale is a soil filter system that temporarily stores and then filters the desired Treatment Volume (T_v). Dry 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. In most cases, however, 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. Dry 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 stormwater functions of the dry swale are summarized in **Table 10.1**.

Table 10.1. Summary of Stormwater Functions Provided by Dry Swales

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	40%	60%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	20%	40%
Total Phosphorus (TP) Mass Load Removal	52%	76%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	25%	35%
Total Nitrogen (TN) Mass Load Removal	55%	74%
Channel Protection	Use the RRM Design Spreadsheet to calculate the Cover Number (CN) Adjustment ***OR*** Design for extra storage (optional; as needed) on the surface, in the engineered soil matrix, and in the stone/underdrain layer to accommodate a larger storm, and use NRCS TR-55 Runoff Equations [2] to compute the CN Adjustment.	
Flood Mitigation	Partial. Reduced Curve Numbers and Time of Concentration	

[1] Change in the event mean concentration (EMC) through the practice. The actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).

[2] NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events, based on the retention storage provided by the practice(s).

Sources: CWP and CSN (2008), CWP, 2007

SECTION 3: DESIGN TABLE

A ***Dry Conveyance Swale*** is a linear adaptation of the bioretention basin that is aligned along a contributing impervious cover such as a roadway or parking lot. The length of the swale is generally equivalent to that of the contributing impervious area. The runoff enters the dry conveyance swale as lateral sheet flow and the total contributing drainage area cumulatively increases along the length of the swale. The treatment component of the swale can extend to a greater length for additional or storage.

A ***Dry Treatment Swale*** is located to accept runoff as concentrated flow or sheet flow from non-linear drainage areas at one or more locations and, due to site constraints or other issues, is configured as a linear practice (as opposed to a bioretention configuration). A dry treatment swale can also be used to convey stormwater from the contributing drainage area to a discharge point; however, the cumulative drainage area does not necessarily increase along the linear dimension.

Both the *Dry Conveyance Swale* and the *Dry Treatment Swale* can be configured as a Level 1 or Level 2 design (see **Table 10.2**). The difference is that the typical contributing drainage area of a *Dry Conveyance Swale* is impervious, with an adjacent grass filter strip (or other acceptable measure as described in **Section 6.4**) providing pre-treatment.

Table 10.2. Dry Swale Design Criteria

<table>
<tr><th>Level 1 Design (RR:40; TP:20; TN:25)</th><th>Level 2 Design (RR:60; TP:40; TN: 35)</th></tr>
<tr><td><u>Sizing (Sec. 5.1):</u>
Surface Area (sq. ft.) = (T_V– the volume reduced by an upstream BMP) / Storage depth [1]</td><td><u>Sizing (Sec. 5.1):</u>
Surface Area sq. ft.) = {(1.1)(T_V) – the volume reduced by an upstream BMP } / Storage Depth [1]</td></tr>
<tr><td>Effective swale slope ≤ 2%</td><td>Effective swale slope ≤ 1%</td></tr>
<tr><td><u>Media Depth</u>: minimum = 18 inches;
Recommended maximum = 36 inches</td><td><u>Media Depth</u> minimum = 24 inches
Recommended maximum = 36 inches</td></tr>
<tr><td><u>Sub-soil testing (Section 6.2)</u>: not needed if an underdrain is used; min. infiltration rate must be > 1/2 inch/hour to remove the underdrain requirement;</td><td><u>Sub-soil testing (Section 6.2)</u>: one per 200 linear feet of filter surface; min. infiltration rate must be > 1/2 inch/hour to remove the underdrain requirement</td></tr>
<tr><td><u>Underdrain (Section 6.7)</u>: Schedule 40 PVC with clean-outs</td><td><u>Underdrain and Underground Storage Layer (Section 6.7)</u>: Schedule 40 PVC with clean outs, and a minimum 12-inch stone sump below the invert; OR
none if the soil infiltration requirements are met (see <u>Section 6.2</u>)</td></tr>
<tr><td colspan="2"><u>Media (Section 6.6)</u>: supplied by the vendor; tested for an acceptable phosphorus index:
P-Index between 10 and 30; OR Between 7 and 23 mg/kg of P in the soil media [2]</td></tr>
<tr><td colspan="2"><u>Inflow</u>: sheet or concentrated flow with appropriate pre-treatment</td></tr>
<tr><td colspan="2"><u>Pre-Treatment (Section 6.4):</u> a pretreatment cell, grass filter strip, gravel diaphragm, gravel flow spreader, or another approved (manufactured) pre-treatment structure.</td></tr>
<tr><td>On-line design</td><td>Off-line design or multiple treatment cells</td></tr>
<tr><td>Turf cover</td><td>Turf cover, with trees and shrubs</td></tr>
<tr><td colspan="2">All Designs: acceptable media mix tested for phosphorus index (see Section 6.6)</td></tr>
<tr><td colspan="2">1 The storage depth is the sum of the Void Ratio (V_r) 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 Stormwater Design Specification No. 9: Bioretention for soil specifications</td></tr>
</table>

Figure 10.1. Typical Dry Swale in commercial/office setting

SECTION 4: TYPICAL DETAILS

Figures 10.2 through 10.6 below provide typical schematics for dry swales.

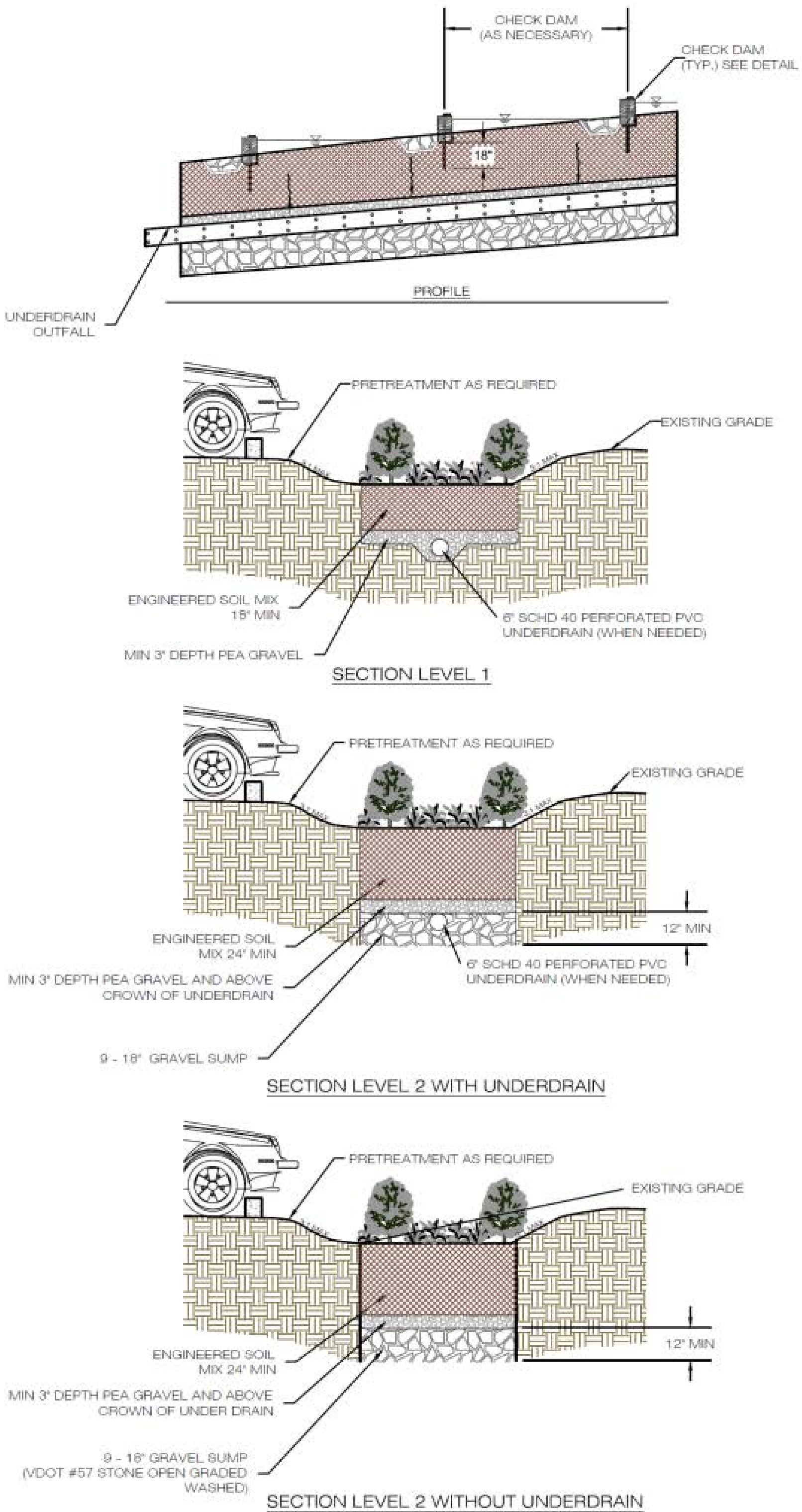
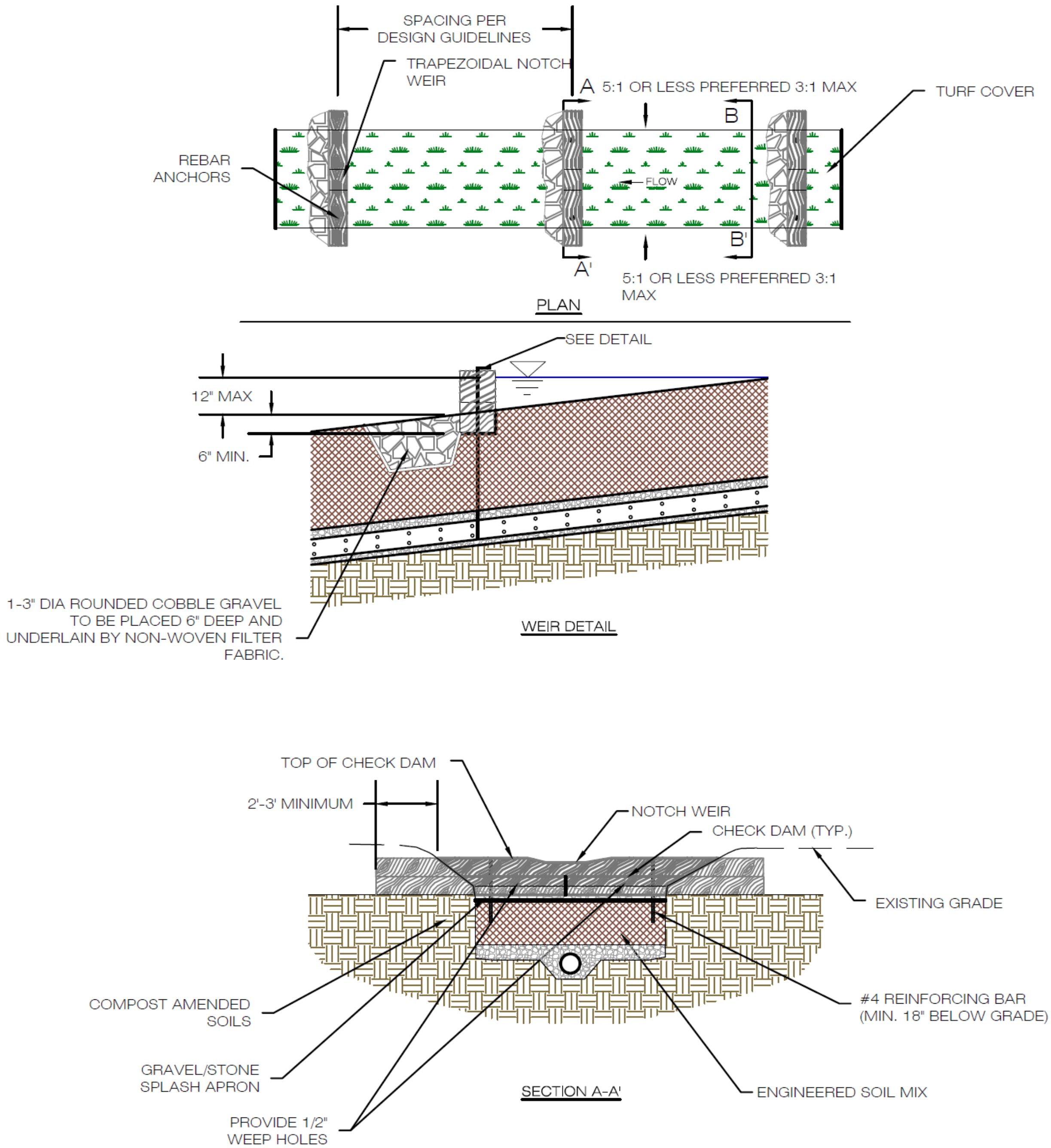
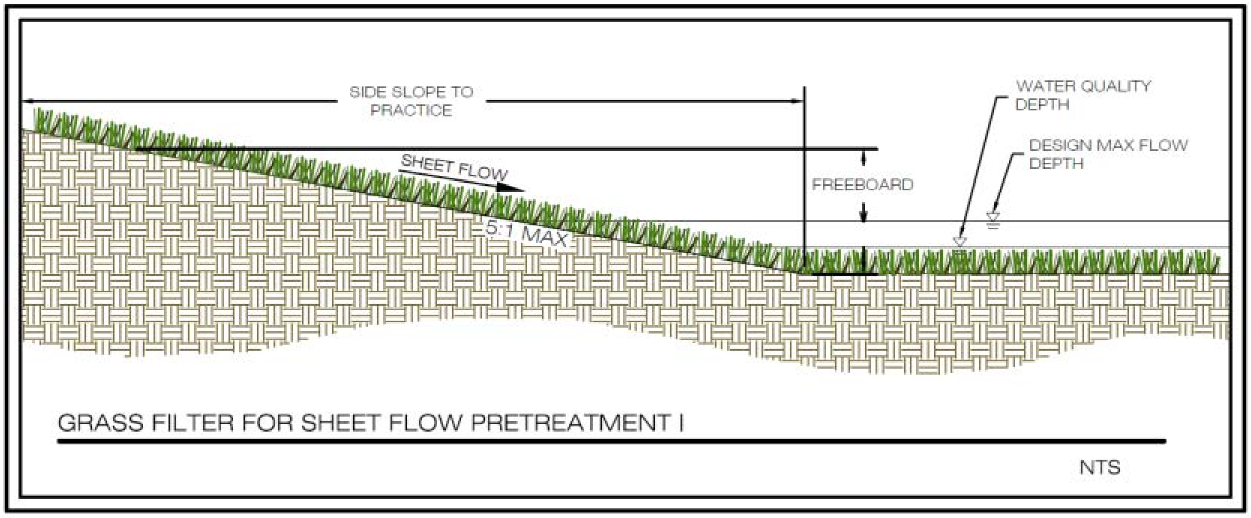


Figure 10.2. Typical Details for Level 1 and 2 Dry Swales



NOTE: CHECK DAM CONSTRUCTED OF RAILROAD TIES OR PRESSURE TREATED LOGS OR TIMBERS CHECK DAM SPANS ENTIRE WIDTH OF SWALE AND IS ANCHORED INTO THE SWALE A MINIMUM OF 2 FEET ON EACH SIDE. CHECK DAM IS KEYED INTO THE GROUND AT A 2-3 INCH DEPTH AND UNDERLAIN BY FILTER FABRIC PER STD & SPEC 3.19: RIP RAP VESCH, 1992 SMALL GRAVEL SPLASH PAD PROVIDED AT DOWNSTREAM SIDE OF CHECK DAMS

Figure 10.3. Typical Detail for Dry Swale Check Dam



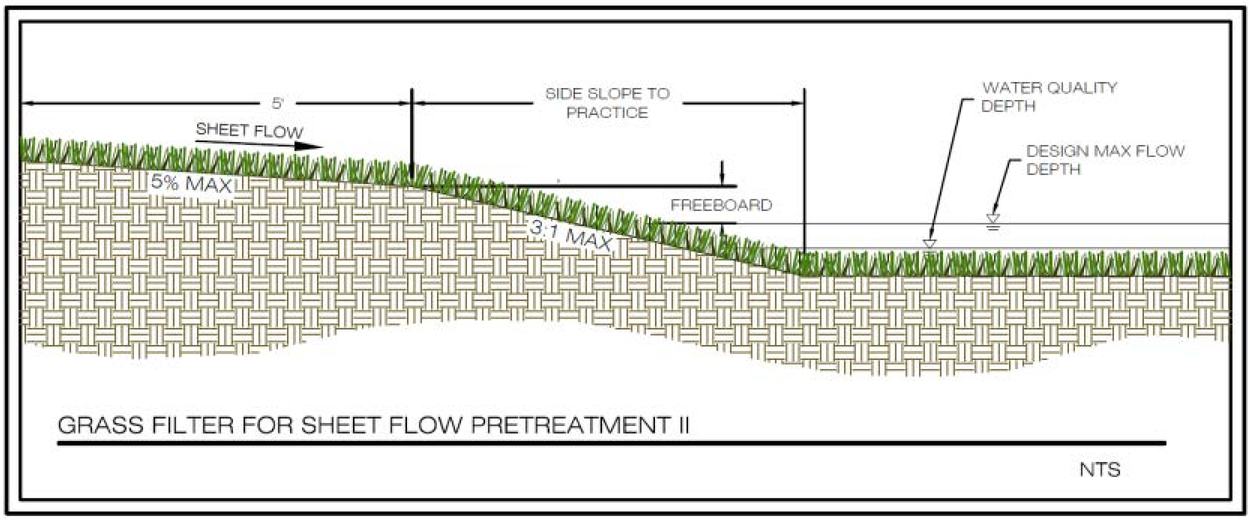


Figure 10.4: Pretreatment I and II - Grass Filter for Sheet Flow

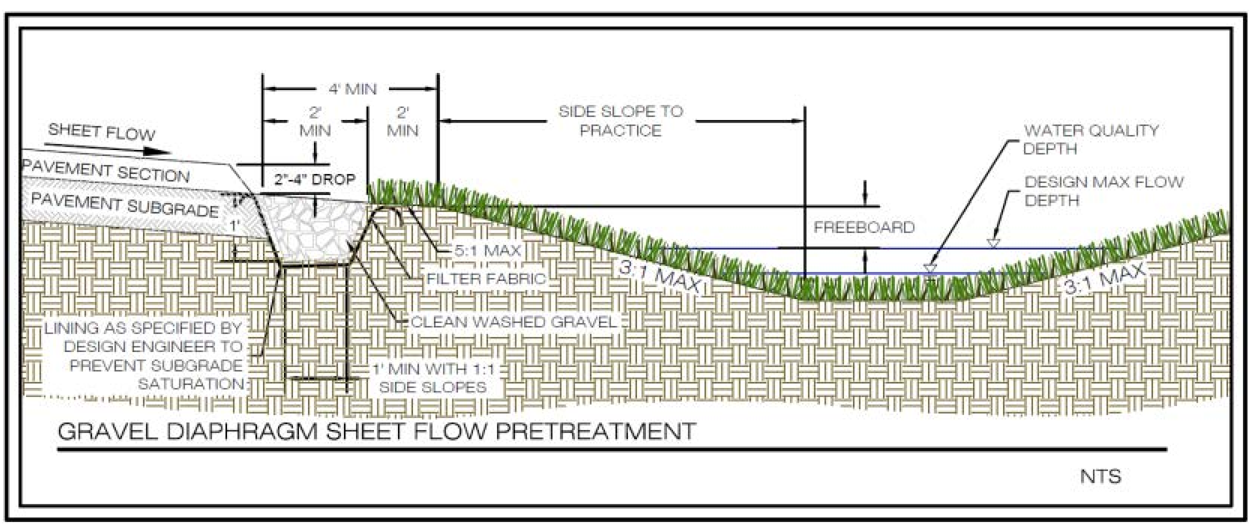


Figure 10.5: Pretreatment – Gravel Diaphragm for Sheet Flow from Impervious or Pervious

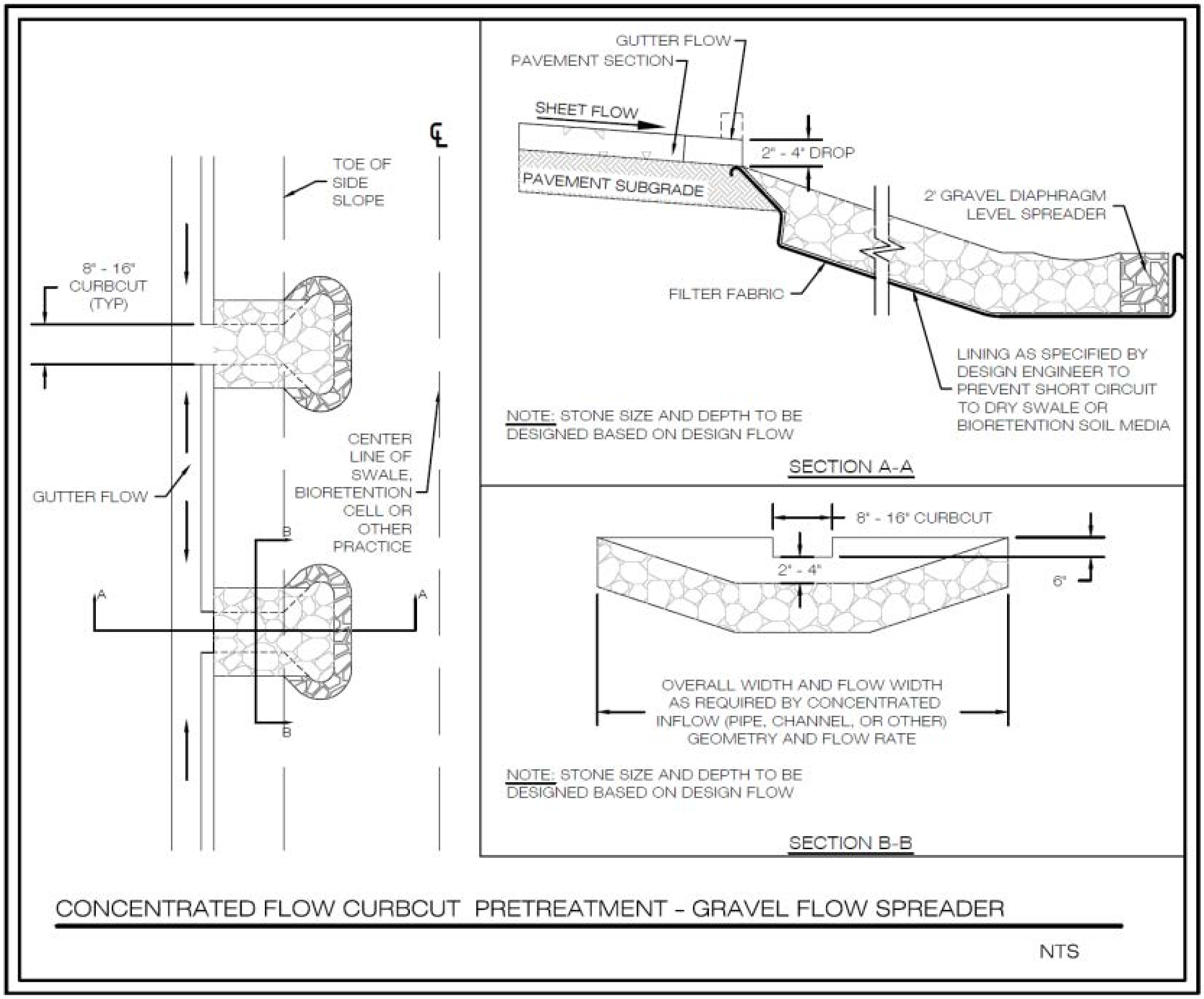


Figure 10.6: Pre-Treatment – Gravel Flow Spreader for Concentrated Flow

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

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

Contributing Drainage Area. The maximum contributing drainage area to a dry swale should be 5 acres, but preferably less. When dry 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 dry swale. An alternative is to provide a series of inlets or diversions that convey the treated water to an outlet location.

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

Site Topography. Dry 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 dry swales, measured as the elevation difference in elevation between the inflow point and the downstream storm drain invert. Dry swales typically require 3 to 5 feet of hydraulic head since they have both a filter bed and underdrain.

Hydraulic Capacity. Dry swales are an on-line practice and must be designed with enough capacity to (1) convey runoff from the 2-year and 10-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 *Dry Conveyance Swales* within existing rights-of-way (e.g., constrained by sidewalks).

Depth to Water Table. Designers should ensure that the bottom of the dry 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 dry swales, although they normally determine whether an underdrain is needed. Low-permeability soils with an infiltration rate of less than 1/2 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 8-A of Stormwater Design Specification No. 8 (Infiltration), 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 dry swales.

Avoidance of Irrigation or Baseflow. Dry swales should be located to 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, dry 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 dry 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. Dry 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. If dry swales are installed on private lots, homeowners will need to be educated on their routine maintenance needs, must understand the long-term maintenance plan, and may be subject to a legally binding maintenance agreement (see **Section 8**). The short ponding time of 6 hours is much less than the time required for one mosquito breeding cycle, so well-maintained dry swales should not create mosquito problems or be difficult to mow. The local government my require that dry swales be placed in a drainage or maintenance easement in order to ensure long term maintenance.

The linear nature of dry swales makes them well-suited to treat highway or low- and medium-density residential road runoff, if there is ~~an~~ adequate right-of-way width and distance between driveways. Typical applications of *Dry Conveyance Swales* include the following:

- Within a roadway right-of-way
- Along the margins of small parking lots
- Oriented from the roof (downspout discharge) to the street
- Disconnecting small impervious areas

SECTION 6: DESIGN CRITERIA

6.1. Sizing of Dry Conveyance and Dry Treatment Swales

Sizing of the surface area (SA) for Dry 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 void ratio.

The accepted Void Ratios (V_r) are:

Dry Swale Soil Media V_r = 0.25
Gravel V_r = 0.40
Surface Storage behind check dams V_r = 1.0

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

(1) (1.5 ft. x 0.25) + (0.25 ft. x 0.40) = 0.5 ft.

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

(2) (2.0 ft. x 0.25) + (1.0 ft. x 0.40) = 0.9 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 dry swale that includes surface ponding (with check dams), the storage depth calculation (Equation 1 or 2) should be adjusted accordingly.

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

(3) SA (sq. ft.) = { T_v – the volume reduced by an upstream BMP } / 0.5 ft.

And the Level 2 Dry Swale SA is computed as:

(4) SA (sq. ft.) = [(1.1 $\ast$ T_v) – the volume reduced an by upstream BMP] / 0.9 ft.

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

Where:

SA = Minimum surface area of Dry Swale (sq. ft.)

T_v = Treatment Volume (cu. ft.) = [(1 inch)(R_v)(A)] / 12

The final Dry 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.

Sizing for Stormwater Quantity

In order to accommodate a greater stormwater quantity credit for channel protection or flood control, designers may be able to create additional surface storage by expanding the surface ponding behind the check dams by either increasing the number of check dams, or by expanding the swale width at selected areas. However, the expanded surface storage footprint is limited to the ponding area directly behind the check dams and is also limited to twice the channel bottom width. Care must be taken to ensure that (1) the check dams are properly entrenched into the side slopes of the swale, and (2) adequate overflow capacity is provided over the weir.

6.2. Soil Infiltration Rate Testing

The second key sizing decision is to measure the infiltration rate of subsoils below the dry swale area to determine if an underdrain will be needed. The infiltration rate of the subsoil must exceed 1/2 inch per hour to avoid installation of an underdrain. The acceptable methods for on-site soil infiltration rate testing are outlined in Appendix 8-A of Bay-wide Stormwater Design Specification No. 8 (Infiltration). A soil test should be conducted for every 200 linear feet of dry swale.

6.3. Dry Swale Geometry

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

Shape. A parabolic shape is preferred for dry 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 dry 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 4 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. A Dry Swale designed with a longitudinal slope less than 1% may be restricted by the locality. The minimum recommended slope for an on-line Dry Swale is 0.5%. An off-line dry swale may be designed with a longitudinal slope of less than 0.5% and function similar to a bioretention practice, although this option may be limited by the locality. Refer to **Table 10.3** for check dam spacing based on the swale longitudinal slope.

Table 10.3. Typical Check Dam (CD) Spacing to Achieve Effective Swale Slope

Swale Longitudinal Slope	**LEVEL 1** **Spacing [1] of 12-inch High (max.) Check Dams [3, 4] to Create an Effective Slope of 2%**	**LEVEL 2** **Spacing [1] of 12-inch High (max.) Check Dams [3, 4] 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.
4.5% [2]	40 ft.	20 ft. to 30 ft.
5.0% [2]	40 ft.	20 ft. to 30 ft.

Notes:

[1] The spacing dimension is half of the above distances if a 6-inch check dam is used.

[2] *Dry Conveyance Swales* and *Treatment Swales* with slopes greater than 4% require special design considerations, such as drop structures to accommodate greater than 12-inch high check dams (and therefore a flatter effective slope), in order to ensure non-erosive flows.

[3] A Check dams requires a stone energy dissipater at its downstream toe.

[4] Check dams require weep holes at the channel invert. Swales with slopes less than 2% will require multiple weep holes (at least 3) in each check dam.

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 Dry Swale's filter bed surface, through a centrally located depressed 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 10.3**). Check dams should be constructed of wood or stone.

Soil Plugs. Soil plugs serve to help minimize the potential for blow-out of the soil media underneath the check dams, due to hydrostatic pressure from the upstream ponding. Soil plugs are appropriate for Dry Swales (1) on slopes of 4% or greater, or (2) with 12-inch high check dams.

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. Dry swales should be designed so that the desired Treatment Volume is completely filtered within 6 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 dry swales to ensure that they drain properly after storms. The underdrain should have a minimum diameter of 6 inches and be encased in a 12-inch deep gravel bed. Two layers of stone should be used. A choker stone layer, consisting of #8 or #78 stone at least 3 inches deep, should be installed immediately below the filter media. Below the choker stone layer, the main underdrain layer should be at least 12 inches deep and composed on 1-inch double washed stone. The underdrain pipe should be set at least 4 inches above the bottom of the stone layer.

6.4. Pre-treatment

Pre-treatment for a *Dry Conveyance Swale* is in the form of a grass filter strip (minimum 10 ft. wide) along the length of the contributing impervious cover. Pre-treatment for a *Dry Treatment Swale* is required at the inflow points along the length of the Dry Swale, to trap coarse sediment particles before they reach the filter bed to prevent premature clogging. Several pre-treatment measures are feasible, depending on whether the specific location in the Dry 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 dry 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 Dry 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 dry 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 dry swale. (**See Figure 10.4**)
- ***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 10.5**)
- ***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 10.6**)

6.5. Conveyance and Overflow

The bottom width and slope of a Dry Swale should be designed such that ~~a~~ 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 velocity (refer to Stormwater Design Specification No. 3: Grass Swale, for additional guidance on channel design). Check dams should be spaced based on channel slope and ponding requirements, consistent with the criteria in **Table 10.3**.

The swale should also convey the locally required design storms (usually the 2- and 10-year storms) at non-erosive velocities with at least 3 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. Refer to Stormwater Design Specifcation No. 3: Grass Channels, for design criteria pertaining to maximum velocities and depth of flow.

A Dry Swales may be designed as an off-line system, 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

Dry 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 Dry Swale. At least 18 inches of soil media should be added above the choker stone layer to create an acceptable filter. The recipe for the soil media is identical to that used for bioretention and is provided in **Table 10.4** below (refer to Stormwater Design Specification No. 9: Bioretention, for additional soil media specifications). The soil media should be obtained from an approved vendor to create a consistent, homogeneous fill media. One design adaptation is to use 100% sand for the first 18 inches of the filter and add a combination of topsoil and leaf compost for the top 4 inches, where turf cover will be maintained.

6.7. Underdrain and Underground Storage Layer

Some Level 2 Dry Swale designs will not use an underdrain (where soil infiltration rates meet minimum standards (see **Section 6.2** and the design table in **Section 3**). 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, channel protection, and/or flood protection criteria. However, the bottom of the storage layer must be at least 2 feet above the seasonally high groundwater table. The storage layer should consist of clean, washed #57 stone or an approved infiltration module.

A Dry 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 Dry Swales located along roads. 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. To find a list of plant species suitable for use in Dry Swales, consult the Virginia Erosion and Sediment Control Handbook.

6.9. Dry Swale Material Specifications

Table 10.4 outlines the standard material specifications for constructing Dry Swales**.**

Table 10.4. Dry Swale Material Specifications

Material	Specification	Notes
Filter Media Composition	Filter Media to contain: • 85-88% sand • 8-12% soil fines • 3-5% organic matter in form of leaf compost	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	P-Index range = 10-30; Cation Exchange Capacity (CEC) greater than 10. Mix on-site or procure from an approved media vendor (refer to Stormwater Design Spec No. 9: Bioretention, for additional soil media information.	
Surface Cover	Turf or river stone.	
Top Soil	4 inch surface depth of loamy sand or sandy loam texture, with less than 5% clay content, a corrected pH of 6 to 7, and at least 2% organic matter.	
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 underdrain only.] For hotspots and certain karst sites only, use an appropriate liner on the bottom.	
Choking Layer	A 2 to 4 inch layer of sand over a 2 inch layer of choker stone (typically #8 or # 89 washed gravel) laid above the underdrain stone.	
Stone and/or Storage Layer	A 9 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 rigid schedule 40 PVC pipe, with 3/8-inch perforations. Use Corrugated HDPE for Rain Gardens.	Install perforated pipe for the full length of the Dry Swale cell. Use non-perforated pipe, as needed, to connect with the storm drain system.
Vegetation	Plant species as 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 (EC2) that are durable enough to last at least 2 growing seasons.	

SECTION 7: REGIONAL AND SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

Shallow Dry Swales are an acceptable practice in the karst regions of the Ridge and Valley province. To prevent sinkhole formation and possible groundwater contamination, Dry Swales should use impermeable liners and underdrains. Therefore, Level 2 Dry Swale designs that rely on infiltration are not recommended in any area with a moderate or high risk of sinkhole formation (Hyland, 2005).

If a dry swale facility is located in an area of sinkhole formation, standard setbacks to buildings should be increased.

7.2. Coastal Plain

The flat terrain, low head and high water table of many coastal plain sites can constrain the application of Dry Swales (particularly Level 2 designs). Swales perform poorly in extremely flat terrain because they lack enough grade to create storage cells, and they lack sufficient hydraulic head to drive the system. In these situations, the following design adaptations apply:

- The minimum depth to the seasonally high groundwater table can be 1 foot, as long as the Dry Swale is equipped with an underdrain.
- A minimum underdrain slope of 0.5% must be maintained to ensure positive drainage.
- The underdrain should be tied into the drainage ditch system.

While these design criteria permit Dry Swales to be used on a wider range of coastal plain sites, it is important to avoid installing Dry Swales on marginal sites. Other stormwater practices, such as Wet Swales, ditch wetland restoration, and smaller linear wetlands are preferred alternatives for coastal plain sites.

7.3. Steep Terrain

In areas of steep terrain, Dry 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 Dry 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.

7.4. Cold Climate and Winter Performance

Dry swales can store snow and treat snowmelt runoff when they serve road or parking lot drainage. If roadway salt is applied within the CDA, Dry Swales should be planted with salt-tolerant non-woody plant species. Consult the Minnesota Stormwater Manual for a list of salt-tolerant grass species (MSSC, 2005). The underdrain pipe should also extend below the frost line and be oversized by one pipe size to reduce the chances of freezing.

7.5. Linear Highway Sites

Dry swales are a preferred stormwater practice for linear highway sites.

SECTION 8: CONSTRUCTION

8.1. Construction Sequence

Construction Stage ESC Controls**.** Dry 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, Dry Swale areas should remain *outside* the limits of disturbance during construction to prevent soil compaction by heavy equipment.

Dry 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 E&S Control 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 Dry 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 Dry Swale, although the steps may be modified to adapt to different site conditions.

Step 1: Protection during Site Construction**.** As noted above, Dry 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 E&S controls 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. Dry 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 may only 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 E&S controls may be needed during swale construction, particularly to divert stormwater from the Dry 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 Dry 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 Dry Swale area.

Step 4. The bottom of the Dry 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 dry 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 pea gravel as a filter layer.

Step 6. Add the soil media in 12-inch lifts until the desired top elevation of the Dry 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 punchlist for facility acceptance.

8.3. Construction Inspection

Inspections are needed during construction to ensure that the Dry Swale practice 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. An example construction phase inspection checklist for Dry Swales can be accessed at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of dry 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 Dry Swale occurs after its first big storm. The post-storm inspection should focus on whether the desired sheetflow, shallow concentrated flows or fully concentrated flows assumed in the plan actually occur in the field. Also, inspectors should check that the Dry Swale drains completely within minimum 6 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 Agreements

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

If a Dry Swale is located on a residential lot, the existence and purpose of the Dry Swale must be noted on the deed of record. Homeowners will need to be provided a simple document that explains their purpose and routine maintenance needs. A deed restriction, drainage easement or other mechanism enforceable by the qualifying local program must be in place to help ensure that dry swales are maintained. The mechanism should, if possible, grant authority for local agencies to access the property for inspection or corrective action. In addition, the GPS coordinates should be logged for all Dry Swales, upon facility acceptance, and submitted for entry into the local BMP maintenance tracking database.

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 any salt-killed vegetation.
- Remove any accumulated sand or sediment deposits on the filter bed surface or in pre-treatment 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. Example maintenance inspection checklists for Dry Swales can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010) or at CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

9.3 Routine Maintenance and Operation

Once established, Dry 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: REFERENCES

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