

## 2I-3 Dry and Wet Swales



Source: Georgia Stormwater Manual

BENEFITS			
	Low = <30%	Medium = 30-65%	High = 65-100%
	Low	Med	High
Suspended Solids			■
Nitrogen	■	■	
Phosphorous	■		
Metals			■
Bacteriological	*	*	*
Hydrocarbons	*	*	*

\* Insufficient Data

**Description:** Dry swales (also called bio-swales) are a type of open vegetated channel used to treat and attenuate the WQv of stormwater runoff. The swale also serves as a conveyance to move excess stormwater to a downstream discharge point. In dry swales, the entire WQv is temporarily retained in a pool or series of pools created by permanent check dams. The holding time provides an opportunity for sedimentation of particulates and facilitates infiltration of runoff. The wet swale is a vegetated channel designed to retain water or marshy conditions that support wetland vegetation. A high water table or poorly-drained soil is necessary to retain water.

**Typical uses:**

- Manage runoff from residential sites, parking areas, and along perimeter of paved roadways.
- Located in a drainage easement at the rear of side of residential parcels.
- Road shoulder rights-of-way; used adjacent to paved roadways in place of curb and gutter, or used as a conveyance channel on the back side of curb-cut openings.

**Advantages/benefits:**

- Mitigate runoff from impervious surfaces.
- Remove sediment and pollutants to improve water quality.
- Reduce runoff rate and volume in highly impervious areas; reduce runoff velocity.
- Provide for groundwater recharge if design and site soils provide sufficient infiltration.
- Good option for small area retrofits – replacing existing drainage ditches.
- Good retrofit opportunities for residential or institutional areas of low to moderate density.
- Linear configuration works well with highway or residential street applications.

**Disadvantages/limitations:**

- Sediment/pollutant removal sensitive to proper design of slope and maintaining sufficient vegetation density.
- Limited to small areas (<5 acres); cannot be used on steep slopes (>6%).
- Higher maintenance than curb and gutter systems.
- Possible re-suspension of sediment.

**Maintenance requirements:**

- Need routine landscape maintenance; maintain grass height of approximately 4-6 inches.
- Inspect annually for erosion problems; remove accumulated trash and debris.
- Remove sediment from forebay and channel (if necessary).

## A. Description

Dry and wet swales (also referred to as vegetated open channels, water quality swales, or enhanced swales) are conveyance channels engineered to capture and treat the water quality volume for a drainage area. They differ from a normal drainage channel or swale through the incorporation of specific features that enhance stormwater pollutant removal effectiveness. Dry and wet 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 and infiltration. Brief descriptions of these two designs are listed below (Claytor and Schuler, 1996):

1. **Dry swale.** The dry swale consists of an open channel capable of temporarily storing the water quality treatment volume, and a filtering medium consisting of a soil bed with an underdrain system. The dry swale uses volume-based sizing criteria. The dry swale is designed to drain down between storm events within approximately one day. The water quality treatment mechanisms are similar to bioretention practices, except that the pollutant uptake is likely to be more limited since only a grass cover crop is available for nutrient uptake. Dry swales are sized to allow the entire WQv to be filtered or infiltrated through the bottom of the swale. Because they are dry most of the time, they are often the preferred option in residential settings. Figure 3 illustrates the configuration and design components of the dry swale.

**Figure 1:** Dry swale



Source: Georgia Stormwater Manual, 2001

2. **Wet swale (wetland channel).** The wet swale also consists of a broad open channel capable of temporarily storing the WQv (also a volume-based sizing criteria), but does not have an underlying filtering bed. The wet swale is constructed directly within existing soils and may or may not intercept the water table. Like the dry swale, the WQv within the wet swale should be stored for approximately 24 hours. The wet swale has water quality treatment mechanisms similar to stormwater wetlands, which rely primarily on settling of suspended solids, adsorption, and uptake of pollutants by vegetative root systems. Figure 4 illustrates the configuration and design components of the wet swale.

**Figure 2:** Wet swale

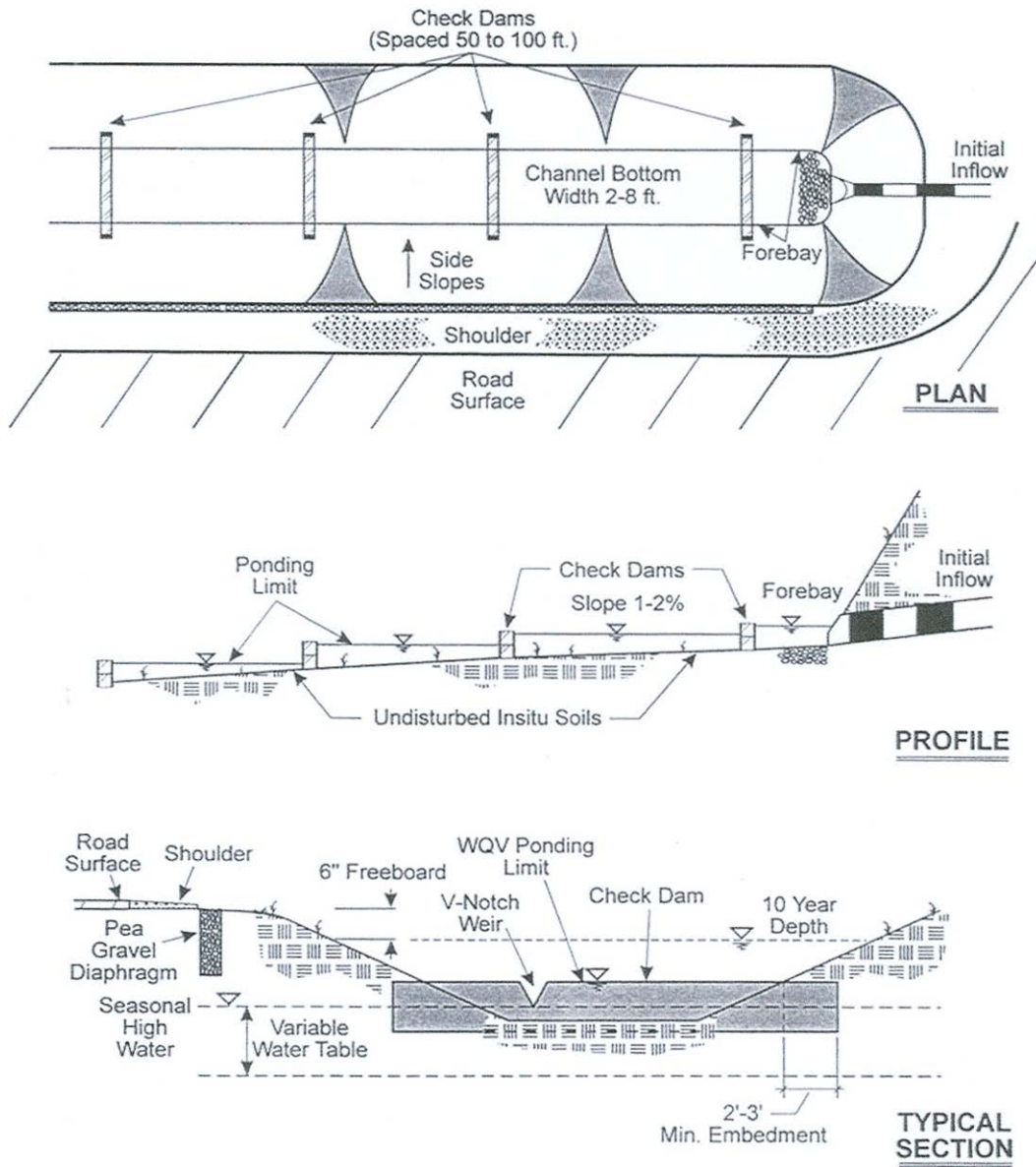


Source: Georgia Stormwater Manual, 2001

Dry and wet swales are not to be confused with a filter strip or grass swale, which are limited-application structural controls, and not considered acceptable for meeting the TSS removal performance goal when used alone. Ordinary grass swales are not engineered to provide the same treatment capability as a well-designed dry swale with filter media. Filter strips are designed to accommodate overland flow rather than channelized flow, and can be used as stormwater credits to help reduce the total water quality treatment volume for a site. Both of these practices may be used for pre-treatment or included in a treatment train approach where redundant treatment is provided. For a further discussion of these limited application structural controls, see Sections 2I-2 and 2I-4.



**Figure 4:** Configuration and design components of a wet swale BMP



Source: Claytor and Schuler, 1996

## B. Stormwater management suitability

Dry and wet swale systems are designed primarily for stormwater quality and have only a limited ability to provide channel protection or to convey higher flows to other controls.

1. **Water quality.** Dry swale systems rely primarily on filtration through an engineered media to provide removal of stormwater contaminants. Wet swales achieve pollutant removal both from sediment accumulation and biological removal. Section 2I-1 provides median pollutant removal efficiencies that can be used for planning and design purposes.
2. **Channel protection.** Generally only the WQv is treated by a dry or wet swale, and another structural control must be used to provide Cpv extended detention. However, for some smaller sites, a swale may be designed to capture and detain the full Cpv.
3. **Overbank flood protection.** Enhanced swales must provide flow diversion and/or be designed to safely pass overbank flood flows. Another structural control must be used in conjunction with an enhanced swale system to reduce the post-development peak flow of the 25-year storm (Qp25) to pre-development levels (detention).
4. **Extreme flood protection.** Enhanced swales must provide flow diversion and/or be designed to safely pass extreme storm flows. Another structural control must be used in conjunction with an enhanced swale system to reduce the post-development peak flow of the 100-year storm (Qf) if necessary.

## C. Pollutant removal capabilities

Both the dry and wet enhanced swale are presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Undersized or poorly-designed swales can reduce TSS removal performance. The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. 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.

- Total suspended solids – 80%
- Total phosphorus – dry swale 50%, wet swale 25%
- Total nitrogen – dry swale 50%, wet swale 40%
- Fecal coliform – insufficient data
- Heavy metals – dry swale 40%, wet swale 20%

For additional information and data on pollutant removal capabilities for enhanced dry and wet swales, see the National Pollutant Removal Performance Database (2nd Edition) available at [www.cwp.org](http://www.cwp.org) and the International Stormwater Best Management Practices (BMP) Database at [www.bmpdatabase.org](http://www.bmpdatabase.org).

## D. Application and feasibility

Dry and wet swales can be used in a variety of development types; however, they are primarily applicable to residential and institutional areas of low to moderate density where the impervious cover in the contributing drainage area is relatively small, and along roads and highways. Dry swales are mainly used in moderate- to large-lot residential developments, small impervious areas (parking lots and rooftops), and along rural highways. Wet swales tend to be used for highway runoff applications, small parking areas, and in commercial developments as part of a landscaped area.

Because of their relatively large land requirements, enhanced swales are generally not used in higher-density areas. In addition, wet swales may not be desirable for some residential applications, due to the presence of standing and stagnant water, which may create nuisance odor or mosquito problems.

The topography and soils of a site will determine the applicability of the use of one of the two swale designs. Overall, the topography should allow for the design of a swale with sufficient slope and cross sectional area to maintain non-erosive velocities. The following criteria should be evaluated to ensure the suitability of a stormwater pond for meeting stormwater management objectives on a site or development.

### 1. General feasibility.

- a. Suitable for residential subdivision usage – yes
- b. Suitable for high-density/ultra urban areas – no
- c. Regional stormwater control – no

### 2. Physical feasibility – physical constraints at project site.

- a. **Drainage area.** 5 acres maximum
- b. **Space required.** Approximately 10-20% of the tributary impervious area
- c. **Site slope.** Typically no more than 4% channel slope
- d. **Minimum head.** Elevation difference needed at a site from the inflow to the outflow: 3-5 feet for dry swale; 1 foot for wet swale
- e. **Minimum depth to water table.** 2 feet required between the bottom of a dry swale and the elevation of the seasonally high water table if an aquifer or treating a hotspot; wet swale is below water table or placed in poorly drained soils.
- f. **Soils.** Engineered media for dry swale
- g. The WQv for high-density residential, commercial, and industrial land uses will most likely be too great to be accommodated with most swale designs. However, swales may be appropriate for pre-treatment in association with other practices for these higher-density land uses, or may be acceptable solutions for watershed retrofit projects.

### 3. Other constraints/considerations. Aquifer protection: exfiltration should not be allowed for hotspots.

## E. Planning and design criteria

The following criteria are considered minimum criteria for the design of dry and wet swale system.

### 1. Location and siting.

- a. A dry or wet swale should be sited such that the topography allows for the design of a channel with sufficiently mild slope (unless small drop structures are used) and cross sectional area to maintain non-erosive velocities.
- b. Dry and wet swale systems should have a contributing drainage area of 5 acres or less.
- c. Swale siting should also 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.
- d. A wet swale can be used where the water table is at or near the soil surface, or where there is a sufficient water balance in poorly drained soils to support a wetland plant community.

### 2. General design.

- a. Both dry and wet swales are designed to treat the WQv through a volume-based design and to safely pass larger storm flows. Flow enters the channel through a pre-treatment forebay. Runoff can also enter along the sides of the channel as sheet flow through the use of a pea gravel flow spreader trench along the top of the bank.
- b. **Dry swale.** A dry swale system consists of an open conveyance channel with a filter bed of permeable soil overlaying a perforated pipe underdrain system. Flow passes into and is detained in the main portion of the channel, where it is filtered through the soil bed. Runoff is collected and conveyed by a perforated pipe and gravel underdrain system to the outlet. Figure 3 provides a plan view and profile schematic for the design of a dry swale system.
- c. **Wet swale.** A wet swale or wetland channel consists of an open conveyance channel which has been excavated to the water table or to poorly drained soils. Check dams are used to create multiple wetland cells, which act as miniature shallow marshes. Figure 4 provides a plan view and profile schematic for the design of a wet swale system.

### 3. Physical specifications and geometry.

- a. Channel slopes between 1-2% are recommended unless topography necessitates a steeper slope, in which case 6- to 12-inch drop structures can be placed to limit the energy slope to within the recommended 1-2% range. Energy dissipation will be required below the drops. Spacing between the drops should not be closer than 50 feet. Depth of the WQv at the downstream end should not exceed 18 inches.
- b. Dry and wet swales should have a bottom width of 2-8 feet to ensure adequate filtration. Wider channels can be designed but should contain berms, walls, or a multi-level cross section to prevent channel braiding or uncontrolled sub-channel formation.
- c. Dry and wet swales are parabolic or trapezoidal in cross section, and are typically designed with moderate side slopes no greater than 2:1 for ease of maintenance and side inflow by

sheet flow (4:1 or flatter recommended).

- d. Dry and wet swales should maintain a maximum WQv ponding depth of 18 inches at the end point of the channel. A 12-inch average depth should be maintained.
- e. The peak velocity for the 2-year storm must be nonerosive for the soil and vegetative cover provided.
- f. If the system is on-line, channels should be sized to convey runoff from the overbank flood event (Qp25) safely with a minimum of 6 inches of freeboard and without damage to adjacent property.

#### **4. Dry swale.**

- a. Dry swale channels are sized to store and infiltrate the entire WQv with less than 18 inches of ponding, and allow for full filtering through the permeable soil layer. The maximum ponding time is 48 hours, though a 24-hour ponding time is more desirable.
- b. The bed of the dry swale consists of a permeable soil layer of at least 30 inches in depth, above a 4-inch diameter perforated PVC pipe (AASHTO M 252) longitudinal underdrain in a 6-inch gravel layer. The soil media should 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.
- c. The channel and underdrain excavation should be limited to the width and depth specified in the design. The bottom of the excavated trench shall not be loaded in a way that causes soil compaction, and scarified prior to placement of gravel and permeable soil. The sides of the channel shall be trimmed of all large roots. The sidewalls shall be uniform with no voids and scarified prior to backfilling.

#### **5. Wet swale.**

- a. Wet swale channels are sized to retain the entire WQv with less than 18 inches of ponding at the maximum depth point.
- b. For wet swales, the WQv volume is still retained for 24 hours, but ponding may continue indefinitely depending on the depth and elevation to the water table.
- c. Check dams can be used to achieve multiple wetland cells. V-notch weirs in the check dams can be utilized to direct low-flow volumes.

#### **6. Pre-treatment inlets.**

- a. Inlets to dry and wet swales must be provided with energy dissipators such as riprap or rock-lines stilling basins.
- b. Pre-treatment of runoff in both a dry and wet swale system is typically provided by a sediment forebay located at the inlet. The pre-treatment volume should be equal to 0.1 inches per impervious acre. This storage is typically obtained by providing check dams at pipe inlets and/or driveway crossings.
- c. Dry and wet swale systems that receive direct concentrated runoff have a 6-inch drop to a pea gravel diaphragm flow spreader at the upstream end of the control.

- d. A pea gravel diaphragm and gentle side slope is provided along the top of channels to provide pre-treatment for lateral sheet flows.
7. **Outlet structures.**
- a. **Dry swale.** The underdrain system should discharge to the storm drainage infrastructure or a stable outfall.
  - b. **Wet swale.** Outlet protection must be used at any discharge point from a wet swale to prevent scour and downstream erosion.
8. **Emergency spillway/overflow.** Dry and wet swales must be adequately designed to safely pass flows that exceed the design storm flows.
9. **Maintenance access.** Adequate access is to be provided for all dry and wet swale systems for inspection and maintenance.
10. **Safety features.** Ponding depths should be limited to a maximum of 18 inches.
11. **Landscaping.** Landscape design should specify proper grass species and wetland plants based on specific site, soils, and hydric conditions present along the channel. Below is some specific guidance for dry and wet swales:
- a. **Dry swale.** Information on appropriate turf grass species for Iowa can be found in the SUDAS Specifications Manual Section 9010.
  - b. **Wet swale.**
    - 1) Emergent vegetation should be planted or wetland soils may be spread on the swale bottom for seed stock.
    - 2) Information on establishing wetland vegetation and appropriate wetland species for Iowa can be found in the SUDAS Specifications Manual, Section 9010.
    - 3) Where wet swales do not intercept the groundwater table, a water balance calculation should be performed to ensure an adequate water budget to support the specified wetland species. See Section 2C-10 for guidance on water balance calculations.
12. **Additional site-specific design criteria and issues.**
- a. **Physiographic factors (local terrain design constraints).**
    - 1) Low relief: reduced need for use of check dams.
    - 2) High relief: often infeasible if slopes are greater than 4%.
    - 3) Karst: no exfiltration of hotspot runoff from dry swales; use impermeable liner.
  - b. **Soils.** No additional criteria.
  - c. **Special downstream watershed considerations.** Aquifer protection: no exfiltration of hotspot runoff from dry swales; use impermeable liner.

**Table 1:** Summary design criteria for dry and wet swale systems

Parameter	Swale Design Criteria
Pre-treatment volume	0.05-0.10 inches per impervious acre at initial inflow point
Preferred shape	Trapezoidal or parabolic
Bottom width	2-foot minimum, 8-foot maximum widths; up to 16-foot width if a dividing berm is installed to reduce concentrated flow channels.
Side slopes	2:1 maximum; 4:1 is optimum
Longitudinal slope	1-2% without check dams. On greater slopes, check dams added to achieve ponding of the WQv.
Sizing criteria	Length, width, depth, and slope needed to provide surface storage for WQv. Outlet structures sized to release WQv over 24 hours.
Hydraulic residence time	Minimum: 5 minutes; Optimum: 10-minutes
Average flow velocity	0.9 fps
Length	Minimum: 100 feet; Optimum: 200 feet
Underlying soil bed	Equal to swale width <i>Dry swale:</i> Moderately-permeable soils (USC ML, SM, or SC); soil mix 30 inches deep with gravel/pipe underdrain. <i>Wet swale:</i> Undisturbed soils, no underdrain system
Depth and capacity	Surface storage of WQv with a maximum depth of 18-inches for water quality treatment (12-inch average depth); safely convey 2-yr storm peak discharge with non-erosive velocity (4-5 fps); adequate conveyance capacity for the 10-yr storm peak discharge with 6 inches of freeboard.

Source: Adapted from Claytor and Schuler, 1996

## F. Design procedure

1. **Step 1.** Compute runoff control volumes from the unified stormwater sizing criteria. Calculate the WQv, Cpv, Qp, and the Qf. (See Part 2B).
2. **Step 2.** Determine if the development site and conditions are appropriate for the use of a dry or wet swale system. Consider the application and site feasibility criteria, location, and siting guidelines.
3. **Step 3.** Confirm local design criteria and applicability.
  - a. Consider any special site-specific design conditions/criteria from Section 2D-1.
  - b. Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.
4. **Step 4.** Determine pre-treatment volume.
  - a. The forebay should be sized to contain 0.1 inches per impervious acre of contributing drainage.
  - b. The forebay storage volume counts toward the total WQv requirement, and should be subtracted from the WQv for subsequent calculations.
5. **Step 5.** Determine swale dimensions.

- a. Size bottom width, depth, length, and slope necessary to store WQv with less than 18 inches of ponding at the downstream end.
  - b. Slope cannot exceed 4% (1-2% recommended).
  - c. Bottom width should range from 2-8 feet.
  - d. Ensure that side slopes are no greater than 2:1 (4:1 recommended).
6. **Step 6.** Compute the number of check dams (or similar structures) required to detain WQv.
7. **Step 7.** Calculate draw-down time.
- a. **Dry swale.** Planting soil should pass a maximum rate of 1.5 feet in 24 hours, and must completely filter WQv within 48 hours.
  - b. **Wet swale.** Must hold the WQv.
8. **Step 8.** Check 2-year and 25-year velocity erosion potential and freeboard.
- a. Use NRCS WINTR55 to compute estimates of the peak flow rates for the 2-yr through 100-yr storm events.
  - b. Check for erosive velocities and modify design as appropriate.
  - c. Provide a minimum of 6 inches freeboard for the 10-year discharge.
  - d. Check stability for larger storm events and overland flow pathways for the larger storms.
9. **Step 9.** Design low-flow orifice at downstream headwalls and check dams. Design orifice to pass WQv in 6 hours, using orifice equation.
10. **Step 10.** Design inlets, sediment forebay(s), and underdrain system (dry swale).
11. **Step 11.** Prepare vegetation and landscaping plan. A landscaping plan for a dry or wet swale should be prepared to indicate how the dry or wet swale system will be stabilized and established with vegetation.

## **G. Design example**

### **Dry swale.**

1. **Site description.** Bucketsville, IA Recreation Center (Story County, IA).
  - a. Site area = total drainage area (A) = 3.4 acres
  - b. Total impervious area (building, parking, and driveway) = 1.9 acres I = 56%
  - c. Soils: HSG – C
  - d. Pre-development: meadow in good condition

**Table 2:** Data for Story County example

<b>Rainfall Data for Story County Example</b>	
(24-hr duration)	
Return period	Rainfall, P (inches)
0.3-yr (WQ event)	1.25
1-yr	2.38
2-yr	2.91
5-yr	3.64
10-yr	4.27
25-yr	5.15
100-yr	6.61

Hydrologic Data		
	Pre	Post
CN	71	87
$t_c$	0.34	0.22

<b>WINTR55 Storm Summary – Pre-development</b>				
Storm	P (inches)	Runoff $Q_a$ (inches)	$Q_p$ , Peak Discharge, cfs	Total Runoff Volume (ft <sup>3</sup> )
1	2.38	0.38	1.27	4,690
2	2.91	0.71	2.34	8,763
5	3.64	1.15	4.05	14,193
10	4.27	1.58	5.70	19,500
25	5.15	2.22	8.18	27,399
100	6.61	3.39	12.57	41,839
<b>WINTR55 Storm Summary – Post-development</b>				
Storm	P (inches)	Runoff $Q_a$ (inches)	$Q_p$ , Peak Discharge, cfs	Total Runoff Volume (ft <sup>3</sup> )
WQ storm	1.25	0.79	3.7	9,750
1	2.38	1.20	5.32	14,810
2	2.91	1.65	7.27	20,364
5	3.64	2.29	10.04	28,263
10	4.27	2.87	12.46	35,422
25	5.15	3.70	15.85	45,665
100	6.61	5.09	21.48	62,870

This example focuses on the design of a dry swale (with media) to meet the water quality treatment requirements of the site. Channel protection and overbank flood control is not addressed in this example other than quantification of preliminary storage volume and peak discharge requirements. In general, the primary function of dry swales is to provide water quality treatment and groundwater recharge, and not large storm attenuation. Flows in excess of the WQv are typically routed to bypass the facility. Where quantity control is required, the bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults).

**Table 3:** WINTR-55 current data description

User: SEJ Date: 12/10/2006  
 Project: Bucketsville Rec Center Units: English  
 SubTitle: Dry Swale (**pre-development**) Area Units: Acres  
 State: Iowa County: Story  
 Filename: C:\Documents and Settings\Stephen\Application Data\WinTR-55\Dry Swale\_pre.w55

--- Sub-Area Data ---

Name	Description	Reach	Area(ac)	RCN	Tc
DA-1		Outlet	3.4	71	.341
			Total area: 3.40 (ac)		

-----Storm Data-----

Rainfall Depth by Rainfall Return Period

0.3-yr (in)	1-Yr (in)	2-Yr (in)	5-Yr (in)	10-Yr (in)	25-Yr (in)	100-Yr (in)
1.25	2.38	2.91	3.64	4.27	5.15	6.61

Storm Data Source: User-provided custom storm data (MRA – Bulletin 71)  
 Rainfall Distribution Type: Type II  
 Dimensionless Unit Hydrograph: <standard>

-----Sub-Area Land Use and Curve Number Details-----

Sub-Area Identifier	Land Use	Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
DA-1	Meadow -cont. grass (non grazed)	C	3.4	71
Total Area / Weighted Curve Number			3.4	71

-----Sub-Area Time of Concentration Details-----

Sub-Area Identifier/	Flow Length (ft)	Mannings's Slope (ft/ft)	End n	Wetted Area (sq ft)	Perimeter (ft)	Velocity (ft/sec)	Travel Time (hr)
DA-1 SHEET	100	0.0150	0.240				0.280
SHALLOW	500	0.0200	0.050				0.061
<b>Time of Concentration</b>							<b>.341</b>

-----Hydrograph Peak/Peak Time Table-----

Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period					
	1-Yr (cfs)	2-Yr (cfs)	5-Yr (cfs)	10-Yr (cfs)	25-Yr (cfs)	100-Yr (cfs)
	(hr)	(hr)	(hr)	(hr)	(hr)	(hr)
SUBAREAS						
DA-1	1.27	2.34	4.05	5.70	8.18	12.57
	12.13	12.13	12.12	12.11	12.10	12.10
OUTLET	1.27	2.34	4.05	5.70	8.18	12.57

--- Identification Data ---

User: SEJ Date: 12/10/2006  
 Project: Bucketsville Rec Center Units: English  
 SubTitle: Dry Swale (post-development) Area Units: Acres  
 State: Iowa County: Story  
 Filename: C:\Documents and Settings\Stephen\Application Data\WinTR-55\Dry Swale\_post.w55

--- Sub-Area Data ---

Name	Description	Reach	Area (ac)	RCN	Tc
DA-1		Outlet	3.4	87	0.222
			Total area: 3.40 (ac)		

-----Sub-Area Land Use and Curve Number Details-----

Sub-Area Identifier	Land Use	Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
DA-1	Open space; grass cover > 75% (good)	C	1.5	74
	Paved parking lots, roofs, driveways	C	1.9	98
Total Area / Weighted Curve Number			<b>3.4</b>	<b>87</b>

-----Sub-Area Time of Concentration Details-----

Sub-Area Identifier/	Flow Length (ft)	Slope (ft/ft)	Mannings's n	End Area (sq ft)	Wetted Perimeter (ft)	Velocity (ft/sec)	Travel Time (hr)
DA-1							
SHEET	50	0.0150	0.240				0.161
SHALLOW	600	0.0200	2.91				0.058
CHANNEL	50	0.0200	0.024	4.50	10.30	4.630	0.003
<b>Time of Concentration</b>							<b>.222</b>

-----Hydrograph Peak/Peak Time Table-----

Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period						
	0.3-Yr (cfs)	1-Yr (cfs)	2-Yr (cfs)	5-Yr (cfs)	10-Yr (cfs)	25-Yr (cfs)	100-Yr (cfs)

SUBAREAS

DA-1	1.55	5.32	7.27	10.04	12.46	15.85	21.48
	12.05	12.03	12.02	12.02	12.02	12.02	12.02

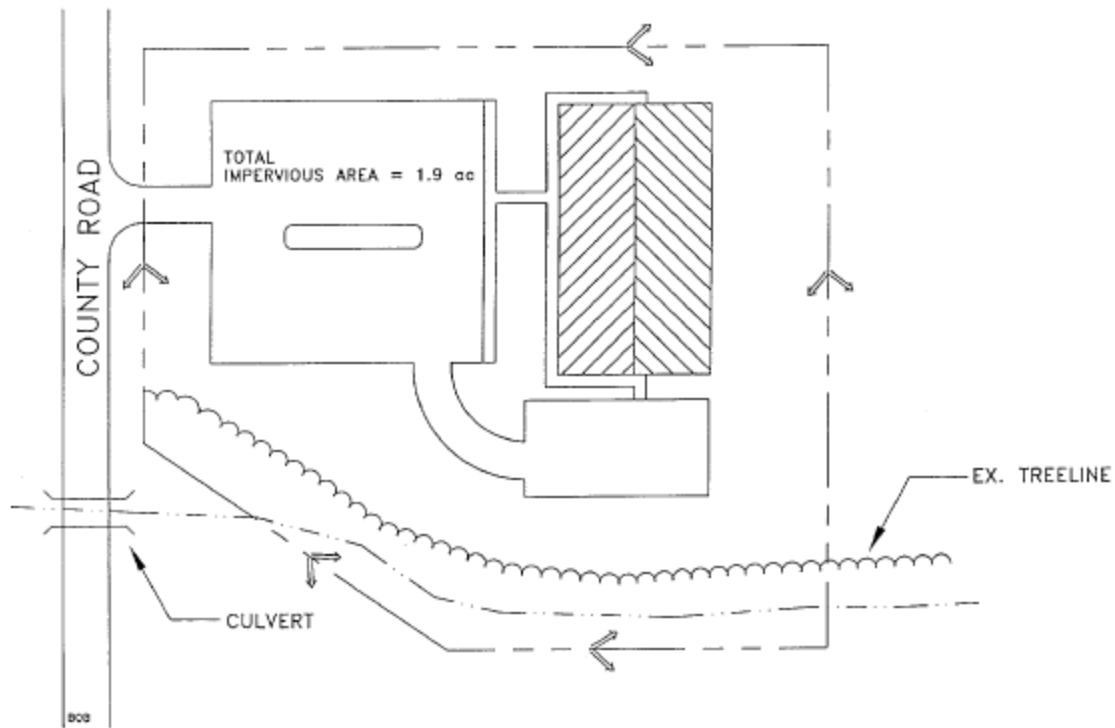
REACHES

<b>OUTLET</b>	<b>1.55</b>	<b>5.32</b>	<b>7.27</b>	<b>10.04</b>	<b>12.46</b>	<b>15.85</b>	<b>21.48</b>
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WINTR20 summary data for the 1-yr post-development scenario (From WINTR55 analysis)

Area or Reach Identifier	Drainage Area (sq mi)	Rain Gage ID or Location	<u>STORM 1-Yr</u> Runoff		Peak Flow			
			Amount (in)	Elevation (ft)	Time (hr)	Rate (cfs)	Rate (csm)	
DA-1		0.005		1.200		12.03	5.32	1002.36

Figure 5: Site plan for dry swale design example



2. Compute water quality volume (WQv) and WQv peak discharge ( $Q_{wq}$ ).

- a.  $R_v = 0.05 + (0.009)(56) = 0.55$
- b.  $P = 1.25$  inches (WQv design storm)
- c.  $WQ_v = 0.55 \times 1.25$  inches = 0.69 inches (Q)
- d.  $WQ_v = 0.69$  inches  $\times$  3.4 acres  $\times$   $1/12 \times 43,560$   $ft^2/ac = 8,516$   $ft^3$

3. Compute  $Q_{wq}$ .

- a. Compute modified CN for 1.25-inch rainfall ( $P=1.25$ ) (see Section 2C-6):

$$\begin{aligned}
 CN &= 1000/[10+5P+10Q-10(Q^2+1.25QP)^{0.5}] \\
 &= 1000/[10+(5)(1.25)+(10)(0.69)-10((0.74)^2+(1.25)(0.69)(1.25))^{0.5}] \\
 &= 96.15 \text{ (Use CN = 96)}
 \end{aligned}$$

- b. For CN = 94 and an estimated time of concentration ( $t_c$ ) of 13 minutes (0.22 hours) compute the  $Q_{wq}$  for the 1.25-inch storm. Results from WINTR55 are:

$$Q_{wq} = 3.7 \text{ ft}^3/\text{sec}$$

4. **Compute channel protection volume (CPv).** The criteria for stream channel protection, (Part 2B), is 24-hour extended detention for the 1-year, 24-hour event. The Cpv is calculated here even though it will be provided downstream of the dry swale. The methodology for calculating the CPv is summarized in Section 2C-6. The WINTR-55 analysis performed above for the pre/post development scenarios provides data for this analysis.

a. For the post-development scenario, CN = 87 and  $t_c = 0.22$  hour, the peak discharge,  $q_p$ , for the 1-year storm event is 5.32 cfs, or 1002.36 csm (See WINTR-55 result summary).

$$q_p = q_u A_m QF$$

b. The unit peak rate,  $q_u$ , is 835.3 csm/in (1002.26 csm/1.2 inches).

c. Using  $q_u$  and extended detention time, T, of 24 hours, find  $q_o/q_i$  for a Type II rainfall distribution. (See Section 2C-6).

$$q_o/q_i = 0.03$$

d. For Type II rainfall distribution:

$$V_s/V_r = 0.683 - 1.43(q_o/q_i) + 1.64 (q_o/q_i)^2 - 0.804 (q_o/q_i)^3 \quad \text{Equation 1}$$

$$V_s/V_r = 0.64$$

$$CPv = V_s = (V_s/V_r)V_r = (V_s/V_r)(Q_a)(A)/12$$

Note:  $V_r = Q_a$  (runoff in inches for developed 1-year storm from WINTR-55 analysis)

$$CPv = (0.64)(1.2 \text{ in})(3.4 \text{ ac})/12 = 0.218 \text{ ac-ft} = 9,479 \text{ ft}^3$$

5. **Determine overbank flood protection volume ( $Q_{25}$ ).** For this site, the post-developed  $Q_{25}$  (15.85 cfs) must be controlled to the pre-development rate for the 5-year storm,  $Q_{5\text{-pre}}$  (4.05 cfs).

From WINTR55 analysis:

Area or Reach Identifier	-----STORM 25-Yr-----		Runoff Amount (in)	Elevation (ft)	Time (hr)	----- Peak Flow -----	
	Drainage Area (sq mi)	Rain Gage ID or Location				Rate (cfs)	Rate (csm)
DA-1	0.005		3.697		12.02	15.85	2985.75

$$q_u = 807.6 \text{ csm/in} \quad q_o = 4.05 \text{ cfs} \quad q_i = 15.85 \text{ cfs} \quad q_o/q_i = 0.26$$

From Section 2C-6 and a Type II rainfall distribution:

$$V_s/V_r = 0.405$$

$$V_s = (0.405)(3.697 \text{ in})(3.40 \text{ ac})/12 = 0.424 \text{ ac-ft} = 18,480 \text{ ft}^3$$

Note: The channel protection volume (CPv) and the detention storage for larger storm peak flow control will be provided by separate downstream detention storage for this site; no additional design details will be provided in this example.

6. **Determine if the development site and conditions are appropriate for the use of dry swale system.** Existing ground elevation at the facility location is 984 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 976 feet, and underlying soils are silt loams (ML). Adjacent creek invert is at 972 feet.
7. **Confirm local design criteria and applicability.** There is a local requirement that the 25-year storm is contained within the top of banks of all channels, including the dry swale BMP controls. No additional local criteria are applicable.
8. **Determine pretreatment volume.** For this site, we will use two dry swale systems (DS-1 and DS-2) indicated in Figure 6. Provide two shallow forebays at the head of the swales equal to 0.05 inches per impervious acre of drainage (each). Note: total recommended pre-treatment requirement is 0.1 inches per impervious acre. For this site, the impervious area is 1.9 acres.

$$(0.05 \text{ in}) (1 \text{ ft}/12 \text{ in}) (43,560 \text{ ft}^2/\text{ac})(1.9 \text{ ac}) = 345 \text{ ft}^3$$

Use a 2-foot deep pea gravel drain at the head of the swale to provide erosion protection, and to act as a level spreader to distribute the inflow. Any side flow at this site will be minimal, and will enter the swales as sheet flow.

9. **Determine swale dimensions.** Required: bottom width, depth, length, and slope necessary to store WQv with less than 18 inches of ponding. Use a trapezoidal channel with a measured maximum WQv depth of 18 inches. A shallow concrete wall configured with a low-flow orifice, with an integral trash rack will provide outlet flow control (see Figure 6 for location). A schematic of the outlet is illustrated in Figure 7.

The total swale length of 1500 feet will be divided into two branches, as shown in Figure 6.

Dry swale #1: 1000 feet  
Dry swale #2: 500 feet

The outlet structure will be set at the existing invert minus 3 feet at (984 – 3 = 981 feet). The existing upstream invert for dry swale #1 is 992 (length of 1000 feet), and the existing invert for dry swale #2 is 988 (length of 500 feet).

Slope of dry swale #1:  $(992 - 981)/1000 \text{ feet} = 0.011 = 1.1\%$   
Slope of dry swale #2:  $(988 - 981)/500 \text{ feet} = 0.014 = 1.4\%$

Minimum slope is 1% (OK)

For a trapezoidal cross section with a bottom width of 6 feet, a WQv average depth of 9 inches, 3:1 side slopes, compute the cross-sectional area:

$$\text{Area} = (6 \text{ ft})(0.75 \text{ ft}) + (0.75 \text{ ft})(2.25 \text{ ft}) = 6.2 \text{ ft}^2 \quad (\text{See Figure 8})$$

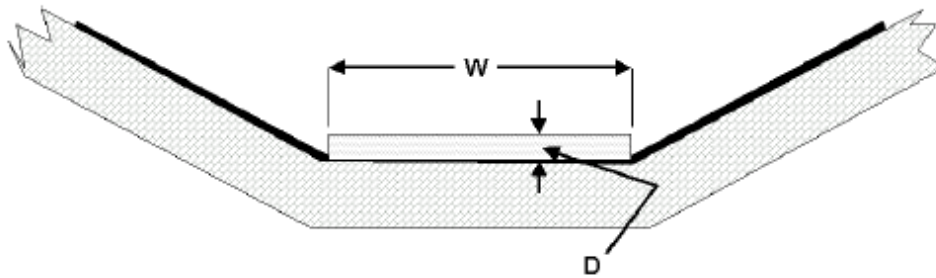
Calculate volume provided:

$$\text{Swale volume} = (6.2 \text{ ft}^2)(1500 \text{ ft}) = 9300 \text{ ft}^3 \quad [9.300 \text{ ft}^3 > \text{WQv of } 8,516 \text{ ft}^3] \quad (\text{OK})$$

10. **Determine the number of check dams to be installed along the length of the swale to detain WQv (See Figure 9).** For dry swale #1, 1000 feet @ 1/1% slope and maximum depth of 18 inches, set check dams at spacing of  $1.5 \text{ ft}/0.011 = 136 \text{ ft}$ ; place at 135 ft ---- > 8 required.

For dry swale #2, 500 feet @ 1.4% slope and maximum depth at 18 inches, set check dams at spacing of  $1.5 \text{ ft}/0.014 = 107 \text{ ft}$ ; place at 107-ft ----> 5 required.

11. **Determine the drain-down time.** To ensure the swales will drain down within the 24-hour criteria, the planting media will need to pass a maximum rate of 1.5 ft (18 in) in 24 hours ( $k = 1.5 \text{ ft/day}$ ). Provide a 6-inch perforated subdrain pipe and gravel system below the soil bed (see Figure 8).
12. **Check 2-year and 25-year flow for velocity erosion potential and freeboard.** Plan to provide 6 inches of freeboard above the 25-year discharge water level. The 25-year peak discharge is 15.9 cfs; assume 70% (11.13 cfs) is routed through swale #1 and 30% (4.77 cfs) through swale #2.



From Manning's equation and trapezoidal channel: (for swale #1)  
 $Q = VA = 1.49/n D^{5/3} S^{1/2} W$

Use  $n = 0.08$  for swale surface condition (See Section 2I-2):

$$D = [(Q * n)/(1.49 * S^{1/2} * W)]^{3/5}$$

$$= [(11.13 \text{ cfs}) * 0.08]/(1.49 * (0.011)^{1/2} * (6 \text{ ft}))^{3/5} = 0.97 \text{ ft (depth @ } q_{p25})$$

$$V = Q/WD = 11.13 \text{ cfs}/(6 \text{ ft} * 0.97 \text{ ft}) = 1.91 \text{ fps}$$

Add 0.5 feet of freeboard above the top of the check dams, and add 25-year flow depth to determine the total swale depth:

$$1.5 \text{ ft (berm)} + 0.5 \text{ ft (freeboard)} + 0.97 \text{ ft (25-year flow depth)} = 2.97 \text{ ft (total depth of swale)}$$

Use 3 feet total depth.

Determine required 25-year overflow weir length:

$$Q = CLH^{3/2} \quad C = 3.1 \quad Q_{25} = 15.9 \text{ cfs} \quad H = 0.97 \text{ ft} + 0.5 \text{ ft} = 1.47 \text{ ft}$$

$$L = (15.0 \text{ cfs})/[(3.1)(1.47)^{1.5}] = 2.88 \text{ ft (use 3 feet)}.$$

13. **Design low-flow orifice at downstream headwall and checkdam (See Figure 7).** Design orifice to pass 8,516 cfs ( $WQ_v$ ) in 6 hours:

$$(8416 \text{ ft}^3)/(6 \text{ hr})(3600 \text{ sec/hr}) = 0.39 \text{ cfs} = 4 \text{ cfs}$$

$$\text{Use orifice equation: } Q = CA(2gh)^{1/2}$$

Assume  $H = 1.5$  ft (18 inches)

$$A = (0.4 \text{ cfs}) / [(0.6)((2)(32.2 \text{ ft/sec}^2)(1.5 \text{ ft})^{0.5})] = 0.068 \text{ ft}^2$$

$$\text{Diameter} = [(0.068 \text{ ft}^2) / 0.785]^{0.5} = 0.29 \text{ ft} = 3.5 \text{ inches}; \text{ use 4-inch orifice.}$$

Provide a 3-inch V-notch slot in each check dam.

14. **Design inlets, sediment forebay, and subdrain piping.** Use minimum 4-inch Schedule 40 PVC perforated pipe (see Figure 9).
15. **Prepare vegetation, seeding, and landscaping plan.**

**Figure 6:** Site plan for dry swales

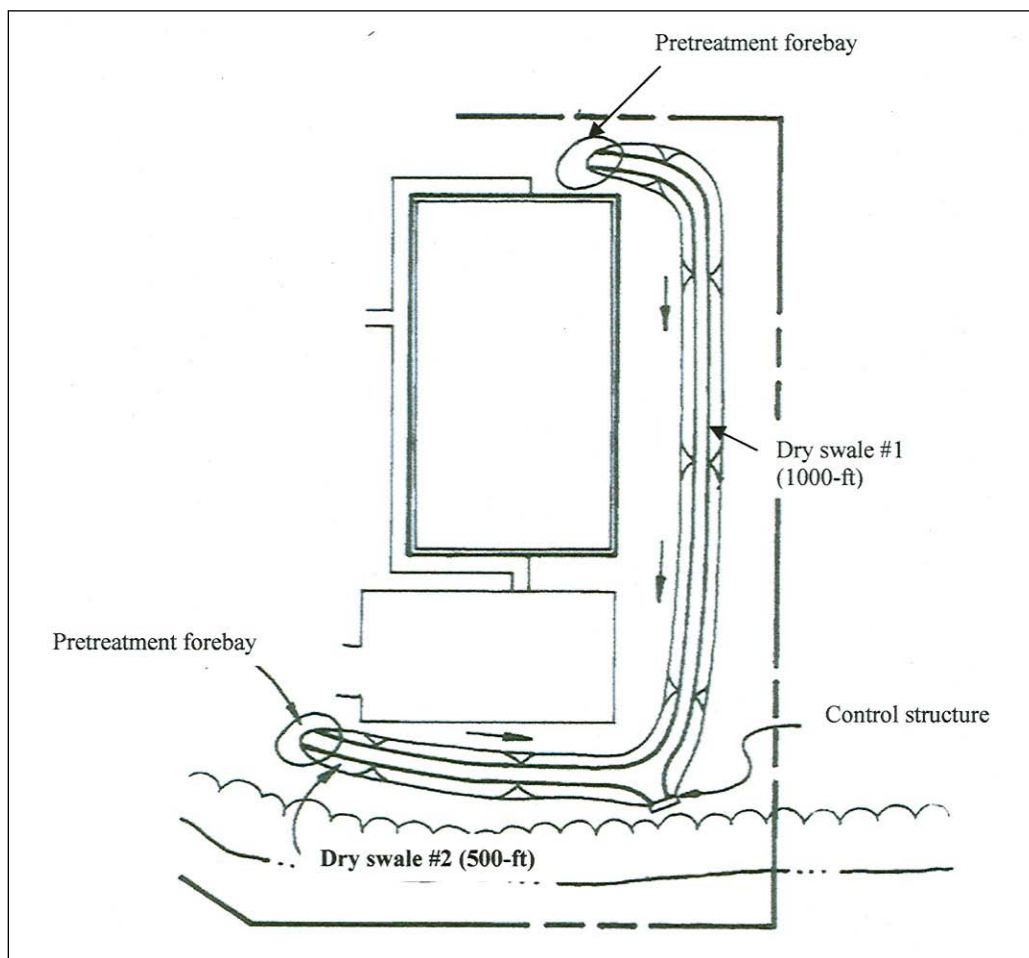


Figure 7: Control structure at swale outlet

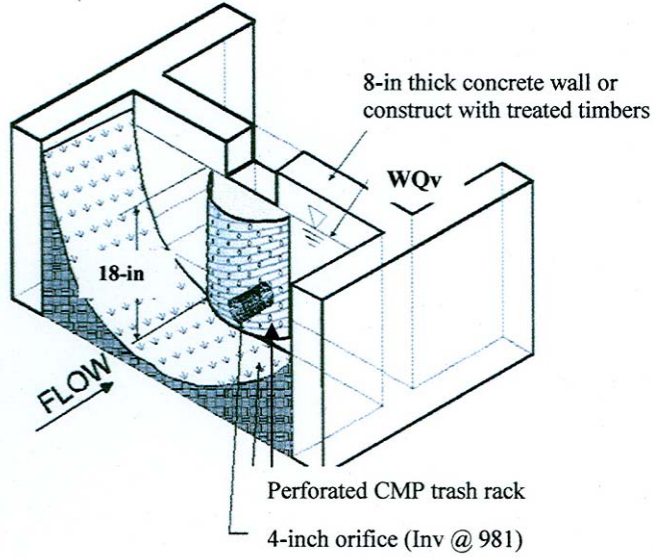
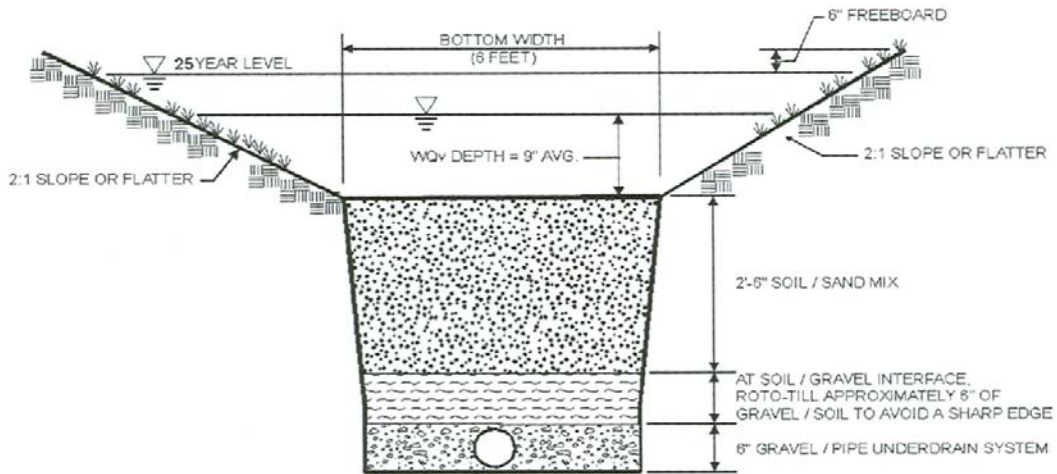
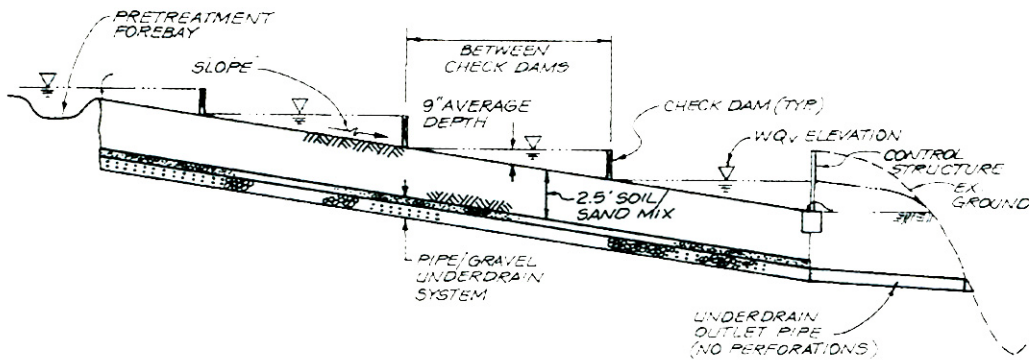


Figure 8: Trapezoidal dry swale section



Source: Adapted from Claytor and Schuler

Figure 9: Dry swale #1 profile



Source: Adapted from Claytor and Schuler

