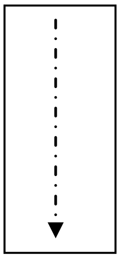
3.4 Post Construction Stormwater Control Fact Sheets (PTP)

Post Construction Stormwater Control Practices	3.4.2 **Open Channel Systems**

Symbol



TSS Reduction
Wet Swale: 75%
Dry Swale: 90%

Description Open channel systems are vegetated swales that are designed to capture, treat, and release stormwater runoff. Open channel systems consist of treatment via dry or wet cells created through the installation of check dams or berms. Wet swales (shown above) and dry swales are two types of open channel systems. Dry swales typically utilize a permeable soil layer, and wet swales typically have wetland plants. Open channel systems treat stormwater while also acting as a stormwater runoff conveyance system. They incorporate water quality features that typical drainage channels do not offer. Installation costs are less expensive than a curb and gutter system, although maintenance costs are typically higher.

Open channel systems must be designed with limited longitudinal slopes to reduce runoff velocities and allow particulates to settle. Berms or check dams placed perpendicular to the flow path also aid in reducing velocities and promoting infiltration.

Inlets to open channel systems can be enhanced through the use of the following options:

- Riprap or other energy dissipaters
- Pretreatment through a sediment forebay
- Flow spreader for situations of direct and concentrated flow

Applications

Open channel systems are designed to manage stormwater runoff for water quality purposes. Open channel systems are typically suitable in the following applications:

- Residential subdivisions of low to moderate density (dry swales)
- Small impervious area in the contributing drainage area
- Along roads and highways (off right-of-way)
- Adjacent to parking lots
- Small drainage areas (less than 5 acres)
- Landscaped commercial areas (wet swales)
- As a pretreatment practice to other BMPs

Open Channel Variations

Figure PTP-02- 1 Dry Swale
Source, Stormwater Managers Resource Center

- **Dry Swales**

Dry swales are open channel systems that convey stormwater runoff through vegetation and a filter bed. Sizing for dry swales should allow the entire water quality volume to be filtered or infiltrated through the swale, such that there is no standing water between rain events. Dry swales are the preferred option in residential areas.

Dry swales are made up of an open conveyance channel with a filter bed of prepared soil that overlays an underdrain system. Flow is conveyed into the main channel of the swale where it is filtered by the soil bed. Runoff is then collected and passes into a perforated pipe and gravel underdrain system to the outlet.

Open Channel Variations

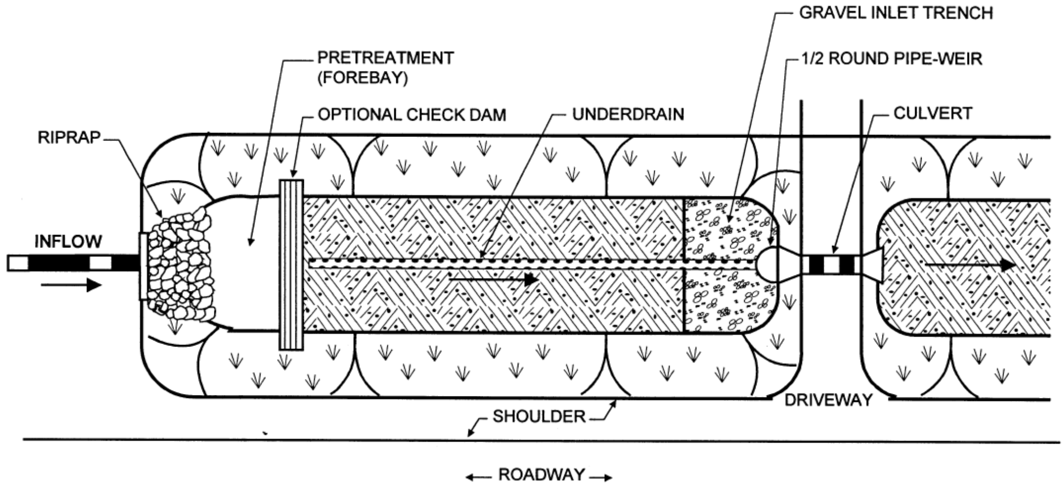


Figure PTP-02- 2 Dry Swale, Plan View
Source, Georgia Stormwater Management Manual

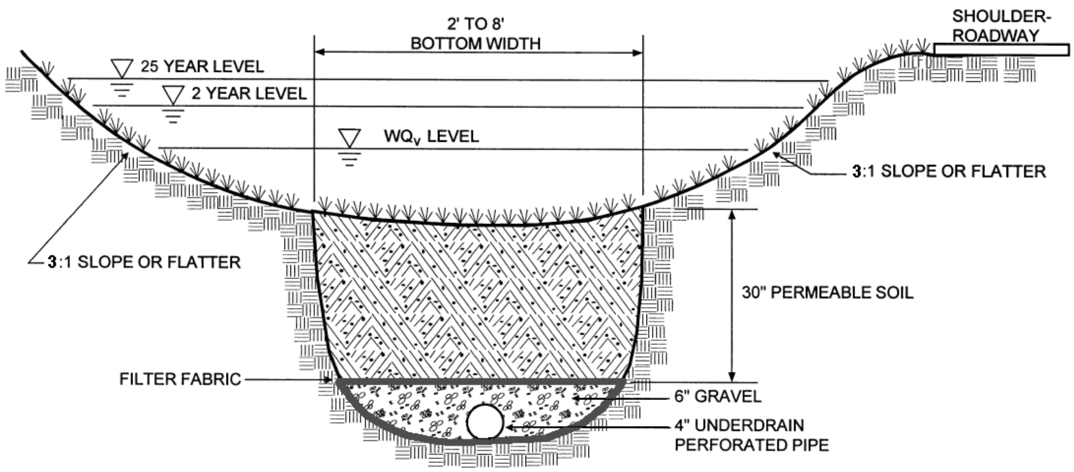


Figure PTP-02- 3 Dry Swale, Cross Sectional View
Source, Georgia Stormwater Management Manual

Open Channel Variations

Figure PTP-02- 4 Wet Swale
Source, Stormwater Managers Resource Center

- **Wet Swales**

Wet swales are also referred to as wetland channels. Like the dry swale, wet swales are vegetated channels that treat stormwater runoff. They differ in that wet swales are designed to retain water, imitating marshy conditions and supporting wetland vegetation. A high water table or soils that retain water are necessary to retain water in the system. In these regards, a wet swale is much like a wetland, with a shallow and linear design.

Wet swales are constructed by excavating the channel to the water table or to poorly drained soils. Check dams are installed to create wetland “cells”. These cells contain the runoff similar to a shallow wetland.

Open Channel Variations

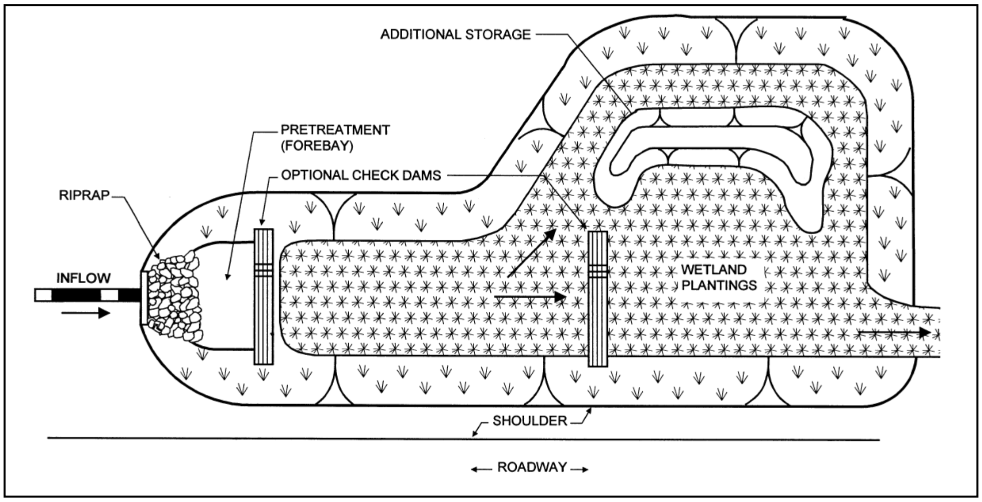


Figure PTP-02- 5 Wet Swale Plan View
Source, Georgia Stormwater Management Manual

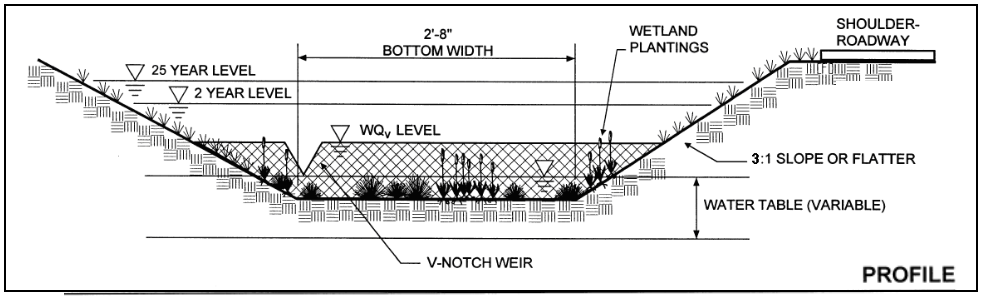


Figure PTP-02- 6 Wet Swale Profile
Source, Georgia Stormwater Management Manual

Design Criteria

Design Criteria

- Limit the contributing drainage to a maximum of 5 acres. One-half (0.5) to two (2) acre drainage areas are preferred.
- Size assuming no losses to infiltration.
- Size channels to store the entire water quality volume with less than 18 inches of ponding.
- Design dry swales to dewater in 24 to 48 hours (24-hours preferred).
- Channel excavation should not result in soil compaction.
- Outlet structures for open channel systems should discharge into the storm drainage system or a stable outfall. For wet swales, incorporate outlet protection to prevent scour and downstream erosion.
- Integrate open channels into the site planning process, and design then to fit aesthetically into the design as attractive green spaces.
- Dry swales require 30 inches of permeable bed material.
- The bottom of dry swales should be at least three feet above the seasonably high water table. For wet swales the seasonably high water table may inundate the swale.
- Dry swales require an underdrain system.
- For wet swales, incorporate check dams and wetland plantings into the channel to form wetland cells. Flow direction can be achieved through the use of V-notch weirs in the check dams.
- The longitudinal slope must be between 1-4% with a channel bottom width of 2'-8'.
- Side slopes must be 3:1 or flatter.
- The channel must be designed to safely and non-erosively convey the 10-year storm event with a minimum of 6 inches of freeboard.

Design Components

- Pretreatment
    - Level Spreader – at locations where lateral flow enters to allow coarse sediment to settle and to evenly distribute flow across the full width of the open channel.
    - Forebay – at locations where concentrated flow enters to allow coarse sediment to settle. The forebay should be sized to contain 10% of the WQ_V.
    - Filter Strip – reduces velocity of runoff and filters particles in the stormwater. The length of the filter strip depends on the drainage area, imperviousness, and the buffer strip slope.
    - Street/Parking Lot Sweeping – may be used as pretreatment where spatial limitations make structural pretreatment measures infeasible.

- Treatment
    - Channel - the bottom width, depth, length, and slope should be sized to store WQ_V with less than 18 inches of ponding at the downstream end.
        - Longitudinal slopes must be between 1% and 4% (1-2% preferred). Slopes steeper than 2% may require 6- to 12-inch drop structures to limit the energy to within the recommended 1 to 2% slope range. Spacing between drops should not be closer than 50 feet. Energy dissipation is required below the drops.
        - Bottom width should range from 2 to 8 feet.
        - Side slopes should be no greater than 3:1 (4:1 recommended)
        - Must convey the 10-yr storm with 6 inches of freeboard

Design Components

- Soil Layer (dry swale) –
  - The channel bed shall consist of a 30 inch permeable soil layer.
  - Soil media should have an infiltration rate of at least 0.5 feet per day (fpd) with a maximum of 1.5 fpd.
  - Soil media should have a high organic content to allow pollutant removal
- Underdrain System (dry swale) –
  - Underdrain should consist of an 8 inch diameter perforated PVC pipe, installed longitudinally in a 12 inch gravel layer.
  - Permeable filter fabric must be installed that encompasses the stone underdrain
  - Designed to draw down the WQv in 24-48 hours

Maintenance

Adequate access shall be provided to allow for inspection and maintenance.

- Grass heights should be maintained at heights of approximately 4 to 6 inches for dry swales
- Sediment should be removed from forebay and channel regularly and disposed of properly
- Measure shall be located in a drainage easement.

Design Procedures

Step 1 – Make a preliminary judgment as to whether site conditions are appropriate for the use of an Open Channel System, and identify the function of open channels in the overall treatment system.

- Consider basic issues for initial suitability screening, including:
  - Site drainage area
  - Site topography and slopes
  - Local depth to ground water and bedrock
  - Site location/minimum setbacks
  - Presence of active karst features
- Determine how the open channel system will fit into the overall stormwater treatment system.
  - Decide whether the open channel system is the only BMP to be employed, or if there are other BMPs addressing some of the treatment requirements.
  - Decide where on the site the open channel system is most likely to be located.

Step 2 – Confirm design criteria, site constraints, and applicability.

- Determine the design criteria that will be used.
- Determine any constraints the site will place on the open channel system.
- Ensure that stormwater runoff from impervious surfaces is being treated to the 80%TSS reduction standard.
  - The equation for determining the weighted TSS reduction for a site with multiple outlet points is below.

$$\%TSS = \frac{\sum_n^1 (TSS_1 A_1 + TSS_2 A_2 + \ldots + TSS_n A_n)}{\sum_n^1 (A_1 + A_2 + \ldots + A_n)}$$

Where:

TSS_1 = TSS reduction by BMP providing treatment for A_1
A_1 = area 1, (acres)
TSS_2 = TSS reduction by BMP providing treatment for A_2
A_2 = area 2, (acres)

  - Where one BMP discharges into another, the treatment train TSS reduction can be found by the following equation:

$$TSS_{train} = A + B - \frac{(A \times B)}{100}$$

Where:

TSS_{train} = total TSS reduction through successive BMPs
A = TSS reduction through first BMP
B = TSS reduction through second BMP

Design Procedures

Step 3 – Calculate WQ_v.

- Calculate the Water Quality Volume (WQ_V). Channel practices are not designed for stormwater quantity design.
  - The required water quality treatment volume is 1.1 inches of runoff from the new impervious surfaces created by the project.
  - Determine Water Quality Volume (WQ_V).

$$WQv = [P\ Rv)(A)]/12$$

Where:

P = is the average rainfall, (inches)
R_V = 0.05 + 0.009(I), where I is the percent impervious cover
A = the area of imperviousness, (acres)

Step 4 – Determine pretreatment method.

- Level Spreader,
- Forebay,
- Filter Strip, or
- Street/Parking Lot Sweeping

Storage volume created for pre-treatment counts toward the total WQ_v requirement, and can be subtracted from the WQ_v for subsequent calculations.

Step 5 – Determine open channel dimensions.

Size bottom width, depth, length, and slope necessary to store WQ_v with less than 18 inches of ponding.

- Longitudinal slope cannot exceed 4% (1 to 2% recommended) or be flatter than 1%
- Bottom width should range from 2 to 8 feet
- Ensure that side slopes are no greater than 3:1 (4:1 recommended)

See Design Criteria for more details.

Step 6 – Compute number of check dams (or similar structures) required to detain WQ_v.

See Design Criteria for more details.

Step 7 – Calculate draw-down time.

- Dry swale channels are sized to store and filter the entire WQ_v and allow for full filtering through the permeable soil layer. The underdrain system in dry swales must be designed to draw down the WQv within 24-48 hrs.
- When designing the underdrain, infiltration of the in situ soils should not be considered. Zero drawdown through the in situ soils should be assumed. The underdrain system must be sized to drain the entire water quality volume (WQ_v) within 48hrs

Design Procedures

- The open channel surface area is computed using the following equation, for those systems that are designed with an underdrain:

$$A_f = (WQ_V \times d_f) / [k \times (h_f + d_f) \times t_f]$$

Where:

A_f = surface area of the dray swale system, (ft^2)
WQ_V = water quality volume, (ft^3)
d_f = filter bed depth, (ft)
k = coefficient of permeability of filter media, (ft/day) (0.5 ft/day is the recommended k for the permeable soil layer. This value is conservative to account for clogging associated with accumulated sediment.)
h_f = average height of water above filter bed, (ft)
t_f = design filter bed drain time, (days) (24- 48 hours is the required drawdown time, t_f, for dry swales)

- Wet swale channels are sized to store the WQ_v.

Step 8 – Design inlets, sediment forebay(s), and underdrain system (dry swale). See Design criteria for more details.

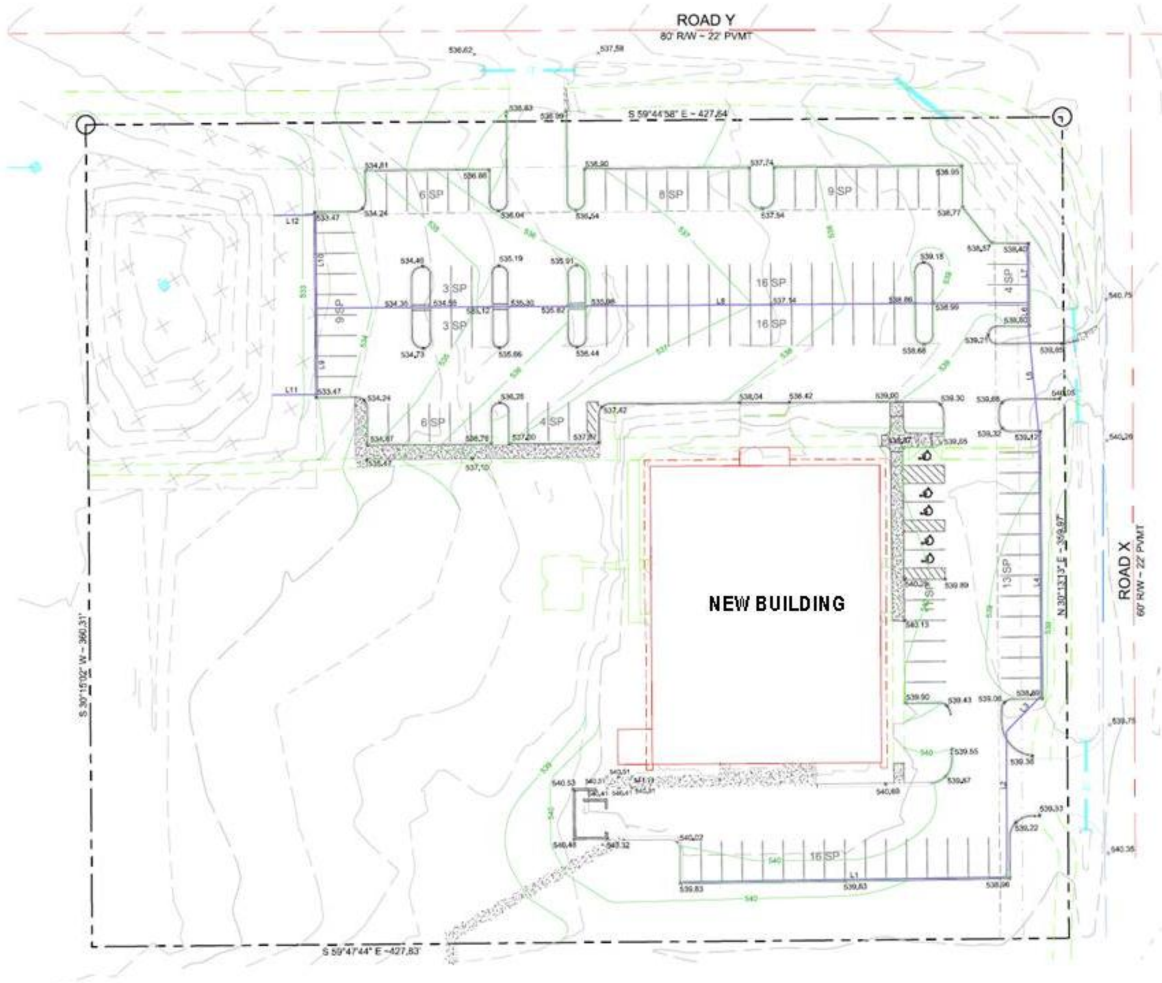
Step 9 – Prepare Vegetation and Landscaping Plan.

A landscaping plan for a dry or wet swale should be prepared to indicate how the enhanced swale system will be stabilized and established with vegetation. The appropriate grass species and wetland plants should be chosen based on the site location, soil type, and hydric conditions.

Step 10 – Complete the Design Summary Table.

Design Parameter	Required Size	Actual Size
Open Channel Type		
WQ_v		
Channel Dimensions (WxL)		
Slope		
Check Dams or other		

Example Design



Proposed development of an undeveloped site into an office building and associated parking.

Base Data	**Hydrologic Data**
Total Drainage Area = 5 ac Site Area = 3.54 ac Soils Type "C"	Pre Post CN 71 89
	WQ_v Depth = 1.1 in
Pre-Development Impervious Area = 0 ac; or I = 0% Meadow (CN = 71)	**Precipitation** I_{WQ} 2.45 in/hr
Post-Development Impervious Area = 1.72 ac; or I = 1.72/3.54 = 49% Open Space, Fair (CN = 79) Paved parking lots, roofs, driveways, etc. (CN =98)	2yr, 24hr 3.54 in 25yr, 24hr 5.88 in 100yr, 24hr 7.43 in

Example Design

This example focuses on the design of a dry swale to meet the water quality treatment requirements of the site. Stormwater quantity design is not addressed in this example. In general the primary function of dry swales is to provide water quality treatment and not large storm attenuation. As such, flows in excess of the water quality volume 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).

Problem: Design a water quality treatment plan for this site. A dry detention pond will be constructed to meet the required detention standards and will provide 60% TSS reduction for the site (note that this design example does not address the design of the detention structure). The total drainage area to the pond is 5 ac. Try designing a dry swale to convey the stormwater from the parking area to the dry pond.

Step 1 Make a preliminary judgment as to whether site conditions are appropriate for the use of an Open Channel System, and identify the function of open channels in the overall treatment system.

- Consider basic issues for initial suitability screening, including:
  - The site has type "C" soils
  - There are no minimum setbacks
  - A sinkhole is located on the property where the dry detention facility will be constructed. The dry swale will not be located close to the sinkhole.
- Determine how the open channel system will fit into the overall stormwater treatment system.
  - A dry swale will be constructed in combination with a dry detention pond for water quality and quantity control on the site. Design of the dry detention pond can be found in Section 4.8.
  - See the figure further in the example for site layout. The site has 2 drainage basins, DA1 and DA2. DA1 drains to the dry swale and then discharges into the dry pond. DA2 flows only into the dry detention pond for treatment.
  - The WQ_V treated by the dry swale will be collected by an underdrain and routed to the dry pond located in the northwest corner of the site for water quantity control. Flows greater than the water quality volume will bypass the dry swale and be routed to the dry pond for water quantity control and final polishing prior to discharging.

Step 2 – Confirm design criteria, site constraints, and applicability.

- Determine the design criteria that will be used.
  - Maximum 6 in ponding depth
  - Maximum 48hr drain time from peak water level
  - Minimum 8 in underdrain enveloped in a 12 in gravel layer
  - Minimum 3 ft separation from bottom to seasonally saturated soils
  - 2% longitudinal slope
- Determine any constraints the site will place on the open channel system such as:
  - The dry swale will not be place near an active sinkhole.
  - Due to topography and layout of the parking area only a portion of the WQ_V can be treated by the dry swale. The other portion of the WQ_V will enter the dry pond directly from the parking area.

Example Design

- Ensure that stormwater runoff from impervious surfaces is being treated to the 80% TSS reduction standard.
  - DA1 = 1.03 acres and will discharge into the dry swale and dry pond.
  - Determine the treatment train TSS reduction for DA1.
    After the water quality volume for 1.03 acres of the impervious area is treated by a dry swale it is then treated in the dry pond before leaving the site. Dry Swales have a 90% TSS reduction. Dry ponds have a 60% TSS reduction.

$$TSS_{train} = A + B - \frac{(A \times B)}{100}$$

$$TSS_{train} = 90 + 60 - \frac{(90 \times 60)}{100}$$

$$TSS_{train} = 96\%$$

  - Dry swale and dry pond treatment train has a 96% TSS reduction ≥ 80 % TSS reduction ✓
  - DA2 = 0.69 acres and will only be treated by the dry pond. Dry ponds have a 60% TSS reduction.
  - Determine the weighted TSS reduction for the site.

$$\%TSS = \frac{\sum_n^1 (TSS_1 A_1 + TSS_2 A_2 + \ldots + TSS_n A_n)}{\sum_n^1 (A_1 + A_2 + \ldots + A_n)}$$

$$\%TSS = \frac{\sum_2^1 (96x1.03 + 60x0.69)}{\sum_n^1 (1.03 + 0.69)}$$

  - $\%TSS = 81.5$ ≥ 80 % TSS reduction ✓

Step 3 – Compute runoff control volumes.

- Calculate the Water Quality Volume (WQv).

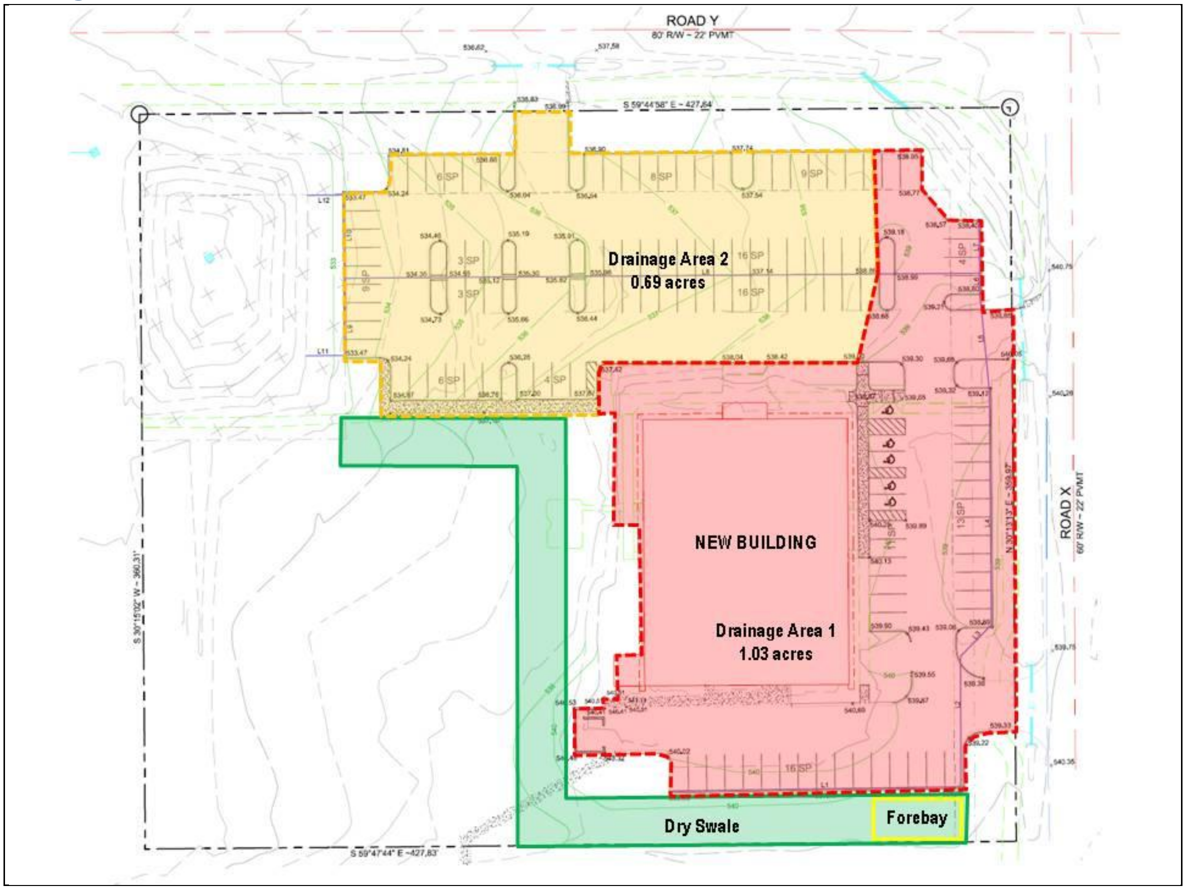
Water Quality Volume Treated By Dry Swale:

WQv = [*P* R_v)(*A*)]/12

Where:
P = 1.1 inches
R_v = 0.05 + 0.009(I)
I = 49
R_v = 0.05 + 0.009(49) = 0.491
A = 1.03 acres

WQv = (1.1in x 0.491 x 1.03ac)/12 = 0.046 acre-ft = **2004 ft³**

Example Design



Step 4 – Determine pretreatment method.

- A forebay will be used as pretreatment for the WQ_V.

  Forebay Volume = 0.10 (2004 ft^3) = **200 ft^3**

- Use a 2 foot deep pea gravel drain at the head of the dry swale to provide erosion protection and to assist in the distribution of the inflow.

- Stormwater will be collected in the parking area and conveyed to the forebay of the dry swale. There will be no significant inflow to the dry swales along its length.

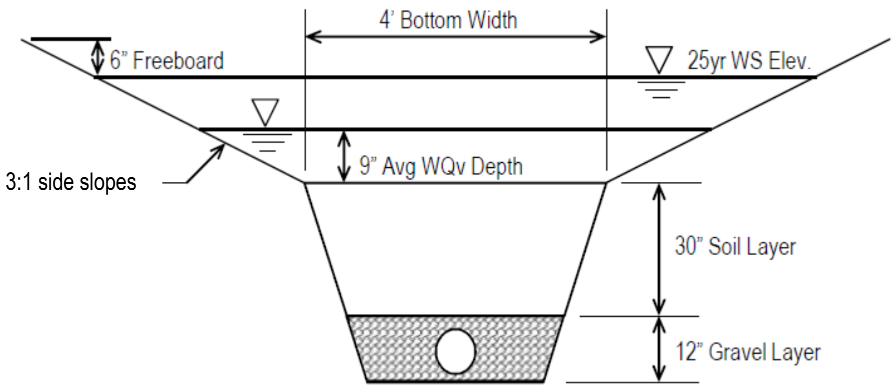
Step 5 – Determine open channel dimensions.

- Assume a trapezoidal channel with a maximum WQ_V depth of 18 inches (9 inch average depth).
- The dry swale has a length of 475 ft, and a slope of 1.1%.
- Assume 4 foot bottom width and 3:1 side slopes.

Cross-sectional area = 0.5 x 0.75 ft x (4 ft + 7 ft) = 4.125 ft^2

Volume of Dry Swale = 4.125 ft^2 x 475 ft = 1959 ft^3 > 2004 ft^3– 200 ft^3= 1804 ft^3 ✓ The WQ_V is reduced by the volume of the pretreatment forebay.

Example Design



Step 6 – Compute number of check dams (or similar structures) required to detain WQ_V.

- The slope of the dry swale is 1.1% and the maximum depth of is 18 inches.
  Maximum check dam spacing = 1.5 ft / 1.1% = 136 ft
- Place 4 check dams spaced at 118 ft.

Step 7 – Calculate draw-down time.

Check channel geometry to ensure sizing for full drawdown through 8" underdrain.

$$A_f = (WQ_V \times d_f) / [k \times (h_f + d_f) \times t_f]$$

Where:

A_f = surface area of the dry swale system, (ft^2)
WQ_V = available water quality volume, (ft^3)
d_f = filter bed depth, (ft)
k = coefficient of permeability of filter media, (ft/day) (0.5 ft/day is the recommended k for the permeable soil layer. This value is conservative to account for clogging associated with accumulated sediment.)
h_f = average height of water above filter bed, (ft)
t_f = design filter bed drain time, (days)
(24- 48 hours is the required drawdown time, t_f, for dry swales)

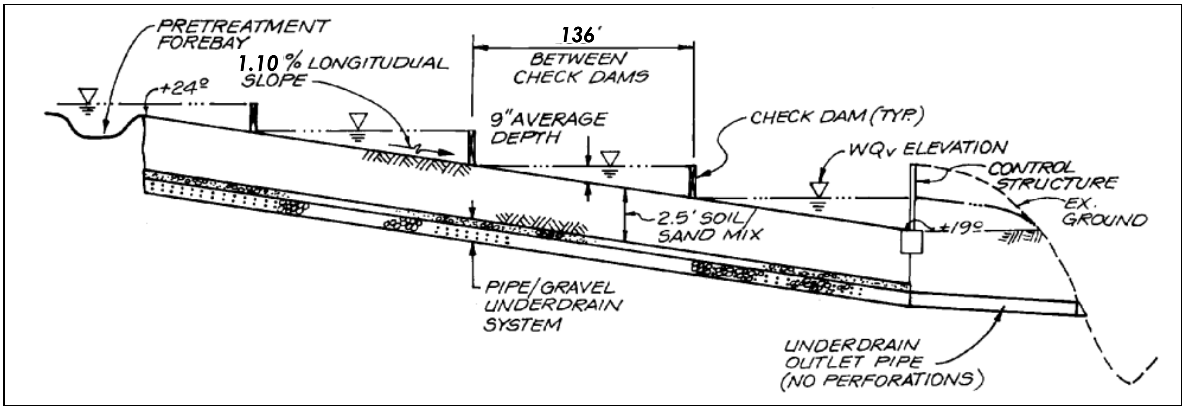
$A_f = (1959ft^3 \times 2.5ft) / [0.5ft/day \times (0.75ft + 2.5ft) \times 2days]$

A_f = **1506.9** ft^2

Surface area available = 475' x 4' = **1900**ft^2 ✓

Example Design

Step 8 – Design inlets, sediment forebay(s), and underdrain system (dry swale).



Step 9 – Prepare Vegetation and Landscaping Plan.

- Prepare vegetation and landscaping management plan based on the guidance given in the Landscaping Section.

Step 10 – Complete the Design Summary Table.

Design Parameter	Required Size	Actual Size
Open Channel Type	Dry Swale	
WQ_v	2004 ft^3	Forebay- 200 ft^3; Swale - 1959 ft^3 = 2159 ft^3
Channel Dimensions (WxL)	1506.9 ft^3	1900 ft^3 (475' x 4')
Slope	1.1%	1.1%
Check Dams or other	4 @ 118ft	4 @ 118ft