5.3.5 Vegetated Swales

Description

A vegetated swale is a landscaped channel, often broad and shallow with trapezoidal or parabolic geometry and a slight longitudinal slope, used to convey and treat stormwater runoff. Vegetated swales are densely planted with grasses, shrubs, and often trees, and can be used to improve water quality and reduce flow rates (see Figure 5.3.5-1). Vegetated swales are a commonly used first BMP in a “treatment train” approach to improve water quality. Depending on design, vegetated swales can also reduce volume. Specifically, if the swale includes berms or check dams such that water is retained and allowed to infiltrate, a vegetated swale can provide volume management.

Figure 5.3.5-1. This vegetated swale in a residential area is broad and shallow. Curb cuts allow street runoff to enter the swale.

BMP Functions Table

BMP	Applicability	Volume Reduction	Water Quality	Peak Rate Reduction	Recharge	Runoff Temperature Mitigation	Heat Island	Habitat Creation	Maintenance Burden	Cost
Vegetated Swales	U/S/R	H	H	M	M	M	M	M	L	L

KEY: U = Urban; S = Suburban; R = Rural; H = High; M = Medium; L = Low

Key Design Features

- Minimum flat bottom width of 2 feet (see Figure 5.3.5-2).
- Maximum bottom width of 10 feet.
- Side slopes at 3:1 maximum, 4:1 adjacent to pedestrian areas.
- Longitudinal slope at 2 percent maximum; up to 8 percent with check dams.
- Average recommended flow depth of 4 inches.
- Maximum ponding depth of 12 inches behind check dams.
- Minimum freeboard of 4 inches.
- Overall depth from top of sidewalls to bottom is generally not less than 10 inches or more than 24 inches.
- Planted in grasses and shrubs, and may include trees.
- Bioretention soil criteria apply.
- Minimum vegetation height of 4 inches is recommended.
- Trapezoidal or parabolic in shape (equations provided may be used for either).
- Entrance and conveyance flow conditions must be controlled to minimize erosion.
- Recommended maximum flow rate at entrance is 2 feet per second. Higher flow rates may be accepted with use of turf reinforcement mats or other materials to prevent erosion.
- Curb cuts and pipes may be used to direct runoff into the swale; however, the designer must demonstrate that entrance conditions will not be erosive. Splash blocks and other measures should be used at entrance locations as needed.
- Must convey 10-year/24-hour storm flow rate at non-erosive velocities. Alternatively, the swale may be designed to limit the flow rate of water entering the swale to maintain non-erosive conditions.
- The surface area, size, and slope are a function of the flow rates from the contributing drainage area.
- Erosive conditions must be prevented during germination and establishment of vegetation.
- The use of temporary or permanent stabilization fabrics or materials is recommended.

- May be designed to intentionally lengthen time of concentration and corresponding peak flow rate.
- Vegetated swales may include berms and check dams to facilitate shallow ponding of water (surface storage) that is limited in depth and duration. Standing water does not remain visible for more than a few hours after rainfall has ceased. Vegetated swales that include berms or check dams can provide volume reduction.
- Earthen check dams function best when constructed by excavation. Swales constructed of fill may be prone to failure.

Applications

- Pretreatment for a volume-reducing BMP (such as upstream of an infiltration trench or bioretention area)
- Road and highway shoulders and medians
- Parking islands and edges
- To convey water to or from a BMP, and to connect BMPs
- As an alternative to a curb and gutter system

Advantages

- Improves water quality and reduces flow velocities.
- Integrates stormwater into landscape.
- Improves aesthetics.
- Flexible dimensions to fit conditions.
- Reduces temperature impacts from impervious surfaces.
- Excellent retrofit capability.
- Cost-effective.
- May be designed to manage SOV.

Disadvantages

- Can create erosion problems if not properly designed, constructed, and maintained.
- Limited flow velocities permitted.
- Should not convey large drainage areas. Multiple swales (in segments) may be required.
- Not appropriate for project sites where spills may occur.
- Vegetation and soils must be protected from damage and compaction.
- Salt use may impact vegetation and soils.

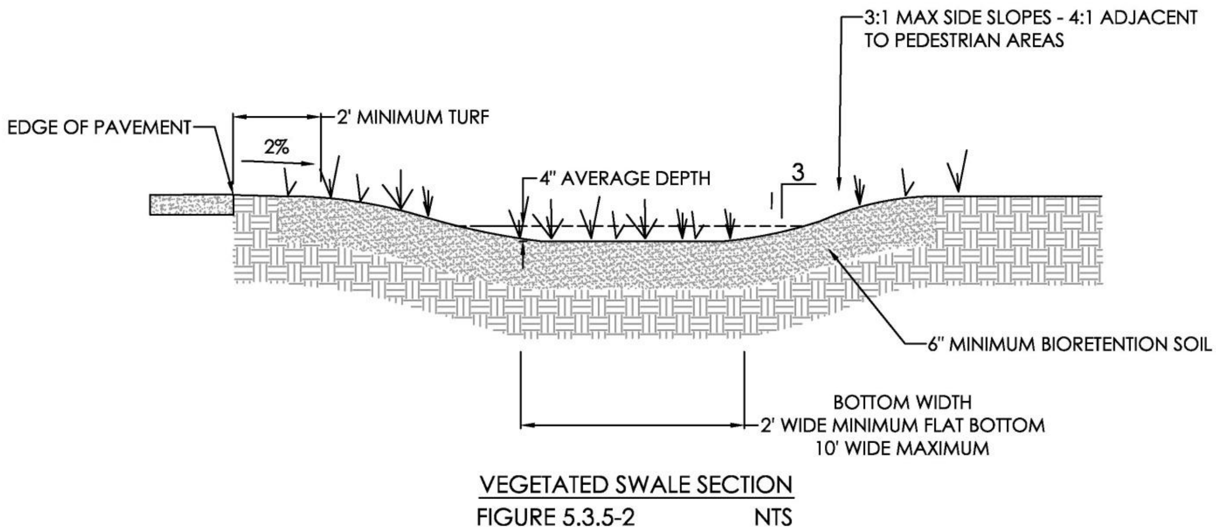


Figure 5.3.5-2. Cross-section of a vegetated swale.

Applications

Industrial Vegetated Swales

Figure 5.3.5-3. This manufacturing facility includes vegetated swales between parking areas to manage runoff.

Swales with Check Dams on Slopes

Figure 5.3.5-4. This vegetated swale on a slope includes stone check dams to slow runoff and earthen check dams to retain runoff.

Residential Vegetated Swales

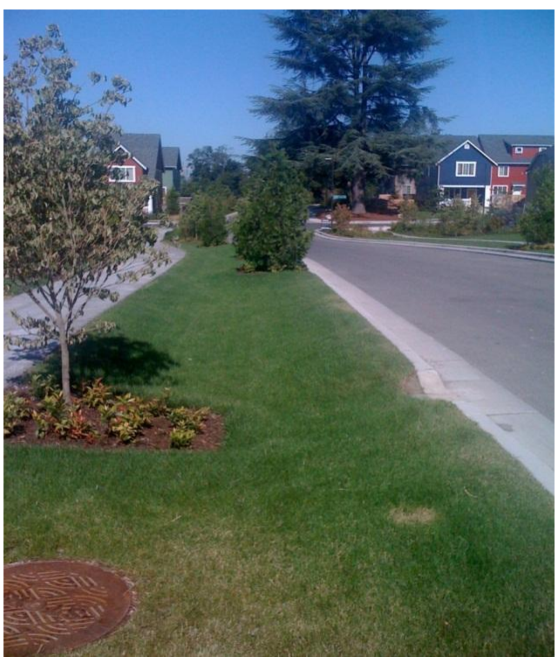


Figure 5.3.5-5. Curb cuts allow street runoff into a vegetated swale in a residential neighborhood.

Commercial Vegetated Swales

Figure 5.3.5-6. The parking lot vegetated swale at this commercial center is designed for pedestrian crossings.

Applicable Protocols and Specifications

The following protocols and specifications (see Appendices A through F) are applicable to vegetated swales and must be addressed:

- Protocol 1 Setbacks from Structures
- Protocol 2 Coordination with Other Utilities
- Protocol 3 Site Evaluation and Infiltration Testing (for swales intended to infiltrate)
- Protocol 4 Infiltration System Design and Construction Guidelines (for swales intended to infiltrate)
- Protocol 5 Planting and Mulching Guidelines
- Appendix F Bioretention Soil Specifications
- Stormwater System Specifications

– Aggregates and Drainage Layers
– Pipes
– Control Structures
– Geotextiles
– Impervious Liners and Waterproofing

Design Considerations for Vegetated Swales

1. Location and Capture Area

- Vegetated swales may be subject to erosion and channelization if flow velocities create erosive conditions. Depending on slope and available space for a vegetated swale, it may be necessary to limit the drainage area directed to the swale.
- If necessary, a series of swales separated by berms or check dams may limit velocity (see Figure 5.3.5-7). Berms can also provide locations for pedestrian crossings.
- When located adjacent to pedestrian areas, the side slopes of the swale are recommended to be 4:1.
- When located adjacent to parking areas, a recommended setback width of 2 feet (minimum) of lawn or level area adjacent to the swale allows passengers to exit vehicles without stepping into the swale.
- Areas where side slopes or berms would need to be constructed with fill should be avoided. Such slopes are prone to erosion and/or structural damage.
- Pedestrian passage and maintenance access should be provided for, if necessary. This will prevent unintended damage to soils and vegetation.

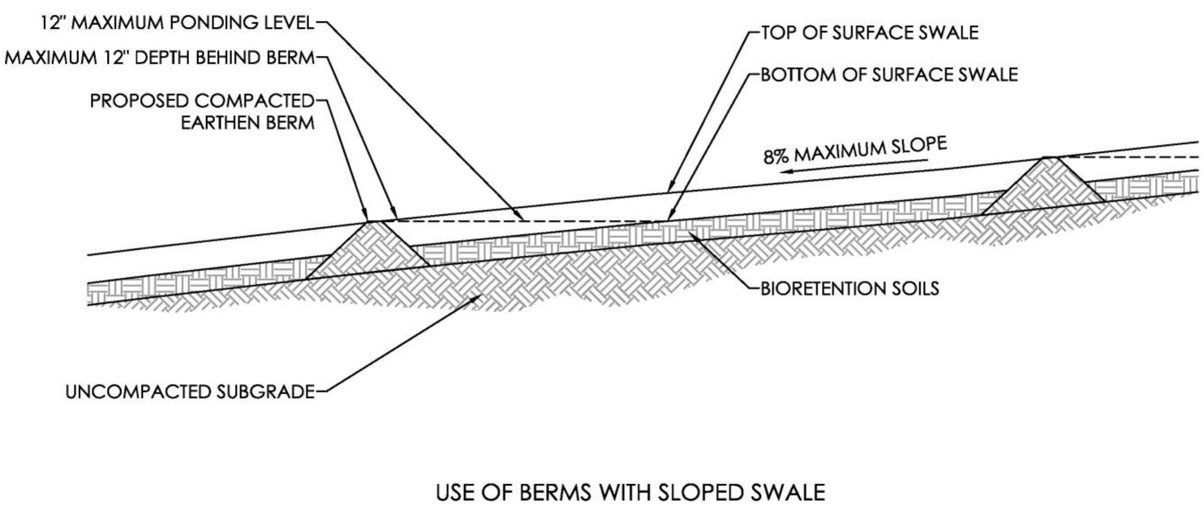


Figure 5.3.5-7. Longitudinal section of a swale with berms.

2. Entrance/Flow Conditions

It is important that entrance conditions or distributed flow into a vegetated swale be non-erosive.

- Dispersed surface flow (sheet flow) along a depressed curb, lawn area, or edge of pavement with careful grading will prevent concentrated flow points and potential erosion.
- Concentrated discharge velocities into vegetated swales (i.e., through a trench drain, outlet pipe, or curb cut) should not exceed 2 feet per second unless the entrance is designed with erosion prevention measures such as cobble splash blocks, level spreaders, and/or turf reinforcement materials.
- A turf reinforcement mat (TRM) or other stabilization fabric is recommended on slopes greater than 6 percent or when flows into the vegetated swale exceed 2 feet per second and are not slowed by other measures.
- Supporting entrance flow velocity calculations are required for all concentrated discharges into vegetated swales to demonstrate non-erosive conditions.

Figure 5.3.5-8. A series of splash blocks prevents erosion on the side of this vegetated swale as runoff enters from a parking lot via a trench drain.

3. Management of Sediment, Trash, and Debris

In areas of high sediment load, vegetated swales must include measures to prevent the movement of material into the swale. Sediment can clog a vegetated swale and limit its functional lifespan.

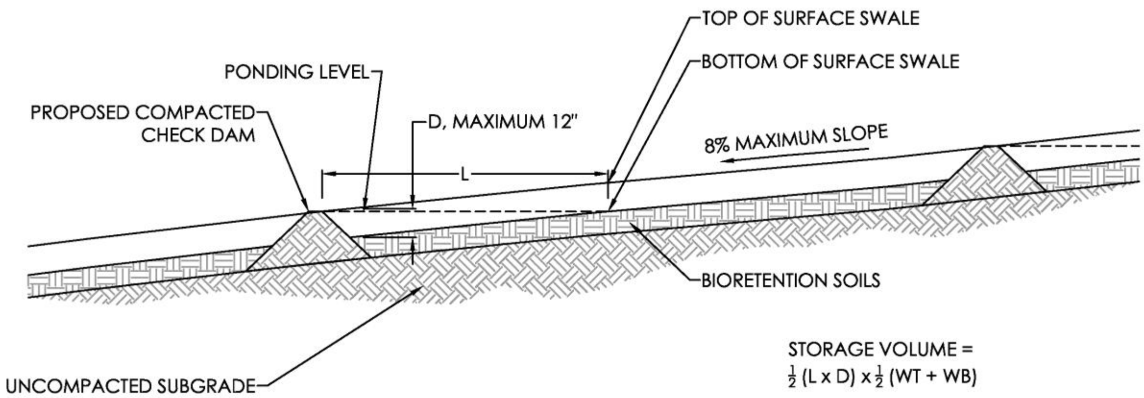
- Trench drains, curb cuts, and visible surface entrances require maintenance. Maintenance is more likely to occur if clogging conditions are visible. In areas of high trash or with specific concerns such as plastic shopping bags, entrance conditions may include a screen to prevent material from entering the vegetated swale. The designer must consider the site-specific conditions and adjacent land uses in each application.
- Site conditions should be considered when choosing vegetation. In areas of high debris, avoid plantings that will trap materials such as trash and paper bags.

4. Storage and Stay-on-Volume

A vegetated swale is generally a conveyance and water quality BMP. However, swales with check dams may be designed to capture SOV behind the check dam.

- Water depth behind a check dam should not exceed 12 inches.
- Both surface storage and bioretention soil storage can be considered. The expected void ratio for bioretention soils is 0.20.
- The designer must consider the slope of the swale and the depth of water storage at the check dam when calculating SOV.

  Storage Volume = ½ (Length of Swale Impoundment Area (L) x Depth of Check Dam (D)) x ½ (Top Width of Check Dam (WT) + Bottom Width (WB) of Check Dam)



LONGITUDINAL SECTION

USE OF CHECK DAMS WITH SLOPED SWALE
FIGURE 5.3.5-9a NTS

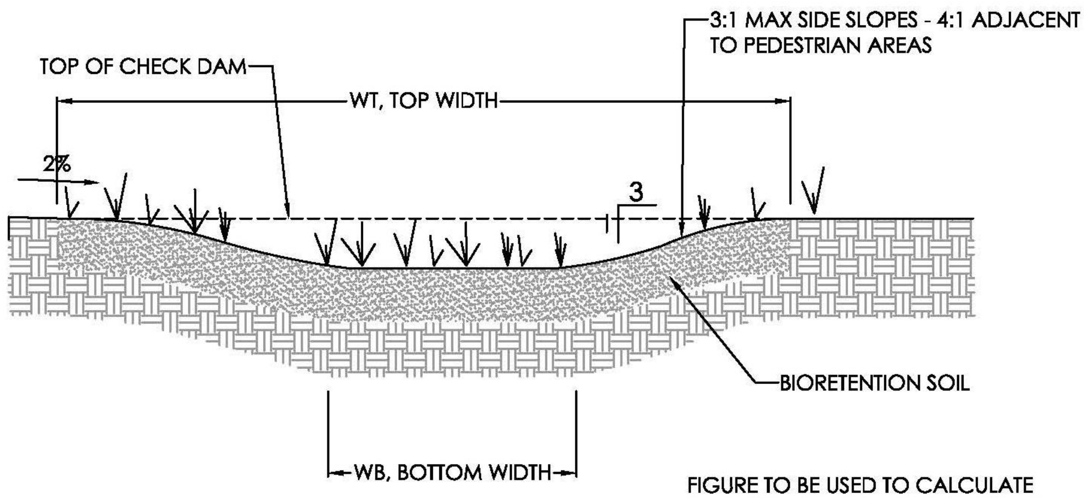


FIGURE TO BE USED TO CALCULATE STORAGE VOLUME. OTHER DETAILS AND DIMENSIONS ARE GIVEN IN FIGURE 5.3.5-2.

CROSS SECTION

USE OF CHECK DAMS WITH SLOPED SWALE
FIGURE 5.3.5-9b NTS

Figures 5.3.5-9a and b. Section of a vegetated swale with check dams.

Figures 5.3.5-10. A simple level spreader of perforated pipe can direct flow into a vegetated swale and prevent erosive conditions at the entrance.

5. Swale Dimensions

The dimensions of a vegetated swale must convey the required flow rate at a velocity that is non-erosive. A swale should be sized to convey the 10-year/24-hour storm (or 10 year peak runoff if using the Rational Method) for swale sizing)unless an alternate conveyance path for high flows is available. It is recommended that the velocity not exceed 1 foot per second unless supporting calculations are provided to demonstrate that erosive conditions will not occur through the use of TRMs or other measures.

Determining swale dimensions can be an iterative process. The flow capacity of a vegetated swale is a function of the longitudinal slope, resistance to flow (Manning's n), and cross-sectional area. The flow depth should not exceed 4 inches. The swale bottom width is calculated based on Manning's equation for open channel flow:

$$Q = 1.49 / n\ A\ R^{0.67}\ S^{0.5}$$

Where:

Q = flow rate (cubic feet per second)

n = Manning's roughness coefficient (unitless; assume 0.15 for grass, 0.20 for dense vegetation)
A = cross-sectional area of flow (ft^2)
R = hydraulic radius (ft) = area/wetted perimeter
S = longitudinal slope (ft/ft)

The first step is to estimate the swale bottom width. For shallow flow depths in swales, channel side slopes are ignored and the swale bottom width is estimated as:

$$b = Q\ n/1.49\ y^{0.67}\ s^{0.5}$$

Where:
b = bottom width of swale (ft)
Q = design flow rate (cubic feet per second)
n = Manning's roughness coefficient (unitless; assume 0.15 for grass, 0.20 for dense vegetation)
y = design depth (ft)
s = slope (ft/ft)

If the bottom width is less than 2 feet, adjust the flow depth. If the bottom width is more than 10 feet (or allowable width per site conditions), it may be necessary to limit the flow rate or adjust the slope (if feasible).

If the bottom width is between 2 feet and 10 feet, the second step is to determine the flow velocity:

$$V = Q / A$$

Where:
V = design flow velocity (feet per second)
Q = design flow rate (cubic feet per second)
A = cross-sectional area determined by:

A = by + zy where
z = side slope (ft/ft)
y = design depth (ft)
b = bottom width of swale (ft)

If the velocity exceeds 2 feet per second, or the channel bottom width is less than 2 feet or more than 10 feet, the designer must modify the proposed dimensions until the design criteria are met.

Figure 5.3.5-11. Vegetated swales may be planted in grasses or denser vegetation.

6. Freeboard

Vegetated swales must contain a minimum of 4 inches of freeboard without creating erosive velocities.

7. Underdrain

An underdrain system is used in swales with check dams to ensure that water moves through the system when the native soil infiltration rate is not high enough to empty excess ponded water, or if infiltration is not feasible. If water does not exit the swale quickly enough, the system will back up and flood adjacent properties. It is not recommended that surface water remain visible in residential areas for more than

24 hours. All underdrain systems must discharge the water quality volume (WQv) between 48 and 72 hours. See Chapter 7 for more information on WQv.

Underdrain systems must be included in the design if native soil infiltration is less than 0.1 inch per hour. See Protocol 3 for the infiltration testing procedure and Protocol 4 for infiltration system guidelines.

8. Check Dams

Check dams are used to create shallow pools of water that reduce the velocity of runoff through the swale while also promoting infiltration. Check dams may measure 4 to 12 inches in height and extend the full width of the swale. Quantity and placement of check dams depend on the slope and required volume storage. Earthen check dams created by excavation, rather than by placement of fill, are recommended. For constructed check dams, stone is recommended.

Flows through a stone check dam vary based on stone size, flow depth, flow width, and flow path length through the dam. Flow through a stone check dam shall be calculated using the following equation:

$$q = h^{1.5} / (L / D + 2.5 + L^2)^{0.5}$$

Where:

q = flow rate exiting check dam (cubic feet per second/ft)
h = flow depth (ft)
L = length of flow (ft)
D = average stone diameter (ft) (more uniform gradations are preferred)

For low flows, check-dam geometry and swale width are actually more influential on flow than stone size. The average flow length through a check dam as a function of flow depth can be determined by the following equation:

$$L = (ss) \times (2\, d – h)$$

Where:

ss = check dam side slope (maximum 3:1)
(side slope is entered into the equation as rise over run, so a maximum 3:1 side slope would be entered as 3)
d = height of dam (ft)
h = flow depth (ft)

When swale flows overwhelm the flow-through capacity of a stone check dam, the top of the dam should act as a standard weir (use standard weir equation, although a principal spillway, 6 inches below the height of the dam, may also be required depending on flow conditions). If the check dam is designed to be overtopped, appropriate selection of aggregate will ensure stability during flooding events. In general, one stone size for a dam is recommended for ease of construction. However, two or more stone sizes may be used, provided a larger stone (e.g., R-4) is placed on the downstream side, since flows are concentrated at the exit channel of the weir. Several feet of smaller stone (e.g., AASHTO #57) can then be placed on the upstream side. Smaller stone may also be more appropriate at the base of the dam for constructability purposes.

9. Waterproofing

Infiltration from vegetated swales, in certain applications, may raise concerns about the impact on nearby structures, such as basements, or adjacent paved surfaces. In all vegetated swale designs, the designer must appraise the effect of the design on adjacent structures and utilities. See Protocol 1, Setbacks from Structures and Protocol 2, Coordination with Other Utilities for further guidelines. If an impervious liner is incorporated into the design, the liner must meet the criteria provided in the Stormwater Specifications.

10. Water Quality/Total Suspended Solids

Vegetated swales designed to capture and manage the required SOV through infiltration are considered to meet all water quality requirements.

Construction Considerations

For the best success, vegetated swales should not be installed until site construction is complete and site stabilization has occurred. Vegetated swales completed before site stabilization **must** be protected from receiving sediment-laden runoff. Runoff should be directed around the completed vegetated swale until site stabilization has occurred. Sediment-laden water should not be allowed to enter swales.

Construction Sequence Example

Step 1 Excavate Swale

a. Do **not** compact or subject existing subgrade in vegetated swale locations to excessive construction equipment traffic. Protect areas from vehicle traffic during construction with construction fence, silt fence, or compost sock.
b. Rough grade the vegetated swale. Excavating equipment should operate from the side of the swale and never on the bottom. If excavation leads to substantial compaction of the subgrade (where an

infiltration trench is not proposed), 18 inches shall be removed and replaced with a blend of topsoil and sand to promote infiltration and biological growth. At the very least, topsoil shall be thoroughly deep-plowed into the subgrade in order to penetrate the compacted zone and promote aeration and the formation of macropores. Following this, the area should be disked prior to final grading of topsoil.

c. Halt excavation and notify the engineer immediately if evidence of sinkhole activity, unanticipated bedrock or groundwater, or other site conditions are encountered that may affect infiltration bed design or performance.

Step 2 Install Overflow Structure and Other Stormwater Structures

a. Close and secure all inlets, pipes, trench drains, and other structures to prevent runoff from entering the vegetated swale before completion and site stabilization.
b. Maintain drainage overflow pathways during construction, while the vegetated swale is closed, to provide for drainage during storm events.

Step 3 Install Vegetated Swale and Check Dams

a. Construct check dams, if required.
b. Grade vegetated swale to line, grade, and elevations indicated. Accurate grading is essential for swales. Even the smallest non-conformities may compromise flow conditions. Fill and lightly regrade any areas damaged by erosion, ponding, or traffic compaction. Bioretention soil shall be placed immediately after approval of subgrade preparation.
c. Remove any accumulation of debris or sediment that takes place after approval of subgrade prior to installation of planting soil at no extra cost to the owner.
d. Install bioretention soil in 8-inch maximum lifts and lightly compact (tamp with backhoe bucket). Keep equipment movement over planting soil to a minimum – do not over compact. Install planting soil to grades indicated on the drawings.
e. Seed and vegetate according to plans, and stabilize bioretention soil. Plant the swale at a time of the year when successful establishment without irrigation is most likely. Temporary irrigation may be needed in periods of little rain or drought. Vegetation should be established as soon as possible to prevent erosion and scour.
f. Stabilize freshly seeded swales with appropriate temporary or permanent soil stabilization methods, such as erosion control matting or blankets. Erosion control for seeded swales shall be required for at least the first 75 days following the first storm event of the season. If runoff velocities are high, consider sodding the swale or diverting runoff until vegetation is fully established.
g. Protect the vegetated swale from sediment at all times during construction. Hay bales, diversion berms, and/or other appropriate measures shall be used at the toe of slopes adjacent to the vegetated swale to prevent sediment from washing into these areas during site development.

h. Notify engineer when the site is fully vegetated and the soil mantle stabilized. The engineer shall inspect the vegetated swale drainage area at his/her discretion before the area is brought online and sediment control devices are removed.

   If a vegetated swale is used for runoff conveyance during construction, regrade and reseed immediately after construction and stabilization have occurred. Any damaged areas must be fully restored to ensure future functionality of the swale.

Figure 5.3.5-12. This vegetated swale is stabilized with a temporary turf reinforcement mat until vegetation is established. Careful erosion control is maintained through erosion control materials on the other portions of the site.

Operations and Maintenance

A properly designed and installed vegetated swale requires relatively minimal maintenance.

- While vegetation is being established, pruning and weeding may be required.
- Detritus may also need to be removed approximately twice per year. Perennial grasses can be cut down or mowed at the end of the growing season.

- Inspect vegetated swales annually for sediment buildup, erosion, vegetative conditions, etc.
- Inspect for pools of standing water; dewater and discharge to a sanitary sewer at an approved location.
- Mow and trim vegetation according to maintenance schedule to ensure safety, aesthetics, and proper swale operation, or to suppress weeds and invasive species; dispose of cuttings in a local composting facility.
- Mow only when swale is dry to avoid rutting.
- Inspect for uniformity in cross-section and longitudinal slope, and correct as needed.
- Inspect swale inlet (curb cuts, pipes, etc.) and outlet for signs of erosion or blockage, and correct as needed.

The following should be done only as needed:

- Plant alternate grass species in the event of unsuccessful establishment.
- Reseed bare areas and install appropriate erosion control measures when native soil is exposed or erosion is observed.
- Rototill and replant swale if drawdown time is less than 48 hours.
- Inspect and correct check dams when signs of altered water flow (channelization, obstructions, etc.) are identified.