5.4.3 Vegetated Swale (Water Quality Swale)

Description: Designed to manage runoff primarily by reducing its velocity for increased treatment efficiency by a downstream practice, vegetated surfaces provide water quality pretreatment through filtering, biological uptake mechanisms, and subsoil cation exchange capacity. Subsoil can also provide a relatively small amount of runoff volume reduction especially when check dams are used. These attributes, in addition to low installation and maintenance costs, make the vegetated swale preferable to the traditional system of curb and gutter, storm drains, and pipes for managing stormwater runoff.

Figure 1: Roadside channel in Spokane, WA.

Site Constraints:
- **Depth to water table:** variable
- **Steep slopes:** longitudinal slope ≤ 4%
- **Soils:** C/D may require compost
- **Hotspots:** typically OK
- **Karst**

Key Design Criteria:
- Contributing drainage area ≤ 5 acres
- Longitudinal slope ≤ 4%
- Side slopes 3:1 (H:V) or flatter
- Bottom width of channel should be between 4 and 8 ft wide
- Flow velocities in channel must be:
  - less than 1 fps during a 1” storm event, and
  - non-erosive during the 2-year and 10-year design storm events.
- 10-year design flow must be contained within the channel which must have a 6” minimum freeboard.
- Dense vegetation capable of withstanding relatively high flow velocities and alternating dry and wet periods
- Check dams and compost material can be added to maximize pollutant capture and stormwater infiltration, respectively.

Maintenance:
- Monitor sediment accumulation and remove as necessary
- Inspect channel and repair any eroding surfaces or damaged vegetation
- Ensure vegetation is well established
- Remove debris from any inlet and outlet structures

Advantages:
- Provides pretreatment when used as part of runoff conveyance system
- Provides partial infiltration of runoff in pervious soils
- Less expensive than typical curb and gutter
- Wildlife habitat potential
- Reduces thermal effects of impervious surfaces

Disadvantages:
- Minimal runoff volume and pollutant reduction
- May allow sediment re-suspension
- Poor design may lead to standing water and mosquito problems

Design Checklist:
- ❑ Identify management goal(s)
- ❑ Review site constraints
- ❑ Review design criteria
- ❑ Protect site resources
- ❑ Size channel for site conditions
- ❑ Submit plans for review

1. Design

1.1 Suggested Applications

Vegetated swales are well suited as pretreatment structures for a volume reducing BMP such as upstream of an infiltration trench or bioretention area. They can also be used to convey water downstream from an SCM. The linear form factor of *vegetated swales* makes them well-suited to treat highway runoff or to be placed in road and highway shoulders and medians. However, *vegetated swales* can also be used in residential, commercial, or institutional developments along parking lot edges or islands, around buildings, or along driveways. *Vegetated swales* should be applied in linear configurations parallel to the contributing impervious cover, such as roads and small parking areas to allow for level spreading and not concentrating flow at one inlet and similarly to prevent a bottleneck or clogging at said single inlet. *Vegetated swales* are not recommended when residential density exceeds more than 4 dwelling units per acre due to lack of available land, the frequency of driveway crossings along the channel, and in order to avoid safety hazards and nuisance conditions.

Standard vegetated swales may or may not have storage capacity, depending on design needs and the use of internal check dams or other structures. Water quality swales are differentiated from standard swales with the use of layered media below the vegetation, which acts like a bioretention cell to filter and infiltrate water. Water quality swale design must include design details on internal baffles or check dams. Sizing of water quality swales follows the protocol for bioretention (see section 5.4.6). As storage in water quality swales fills, overflow occurs along the swale. Sizing of swale dimensions above the storage layers follows in water quality swales follows that of standard vegetated swales. Adequate overflow and spillway design must be in place to protect the surface and vegetation in water quality swales.

1.2 Site Constraints

Contributing Drainage Area: The development density of the contributing drainage area (CDA) affects peak runoff rates and the amount of land available for the footprint of the practice. Also note that the CDA for a single *Vegetated swale* must be 5 acres or less to reduce the occurrence of channel failure due to erosive velocities. When *vegetated swales* treat and convey runoff from drainage areas greater than 5 acres, the velocity and flow depth through the channel become too great to treat runoff or prevent channel erosion.

Note: The footprint required will likely be greater than that of a typical conveyance channel (TDOT or equivalent). However the benefit of the runoff reduction may reduce the footprint requirements for stormwater management elsewhere onsite.

Slopes: *Vegetated swales* are most effective on grades less than 5%. *Vegetated swales* should be designed on areas allowing for longitudinal slopes less than 4%. Slopes greater than 4% create rapid runoff velocities that can cause erosion and do not allow enough contact time for filtering or infiltration unless check dams are used. However, terracing a series of *Vegetated swale* cells may work on slopes from 5% to 10%. The drop in elevation between check dams should be limited to 18 inches in these cases, and the check dams should be armored on the downslope side with properly sized stone to prevent erosion.

Longitudinal slopes less than 2% are ideal and may eliminate the need for check dams. Channels having longitudinal slopes less than 1% must be monitored carefully during construction to ensure a continuous grade to avoid flat areas holding pockets of standing water, i.e. mosquitos.

Soils: *Vegetated swales* can be used in all hydrologic soil groups, but soil amendments may be required to enhance performance in C or D soils. *Vegetated swales* should not be used on soils with infiltration rates less than or equal to 0.5” per hour if infiltration of small runoff flows is intended. In these cases, *vegetated swales* situated on HSG C or D soils will require compost amendments to facilitate acceptable performance conditions.

In areas of fill, soil slips can result from saturating sections of different soil types. While *Vegetated swales* are not necessarily designed to infiltrate runoff, they can attenuate flows so as to encourage infiltration where soils allow. *Vegetated swales* can be used in cut or fill. However, a clear note should address proper fill material preparation in order to minimize any differential soil conditions. *Vegetated swales* depend on dense vegetation to promote filtering and abstraction. Construction of *vegetated swales* in fill material or in a disturbed soil profile may require soil amendments in order to establish vegetation to achieve basic performance. A soil test should be done to evaluate the organic content and fertilization requirements.

Depth to Water Table: Vegetated swale bottoms should lie completely above the water table above an elevation that allows for infiltration of the target reduction volume. This is modeled using soil input data in the TNRRAT. Otherwise, soil texture infiltration must be justified to account for volume reduction.

Utilities and Setbacks: Tennessee One Call (811) must be contacted before onsite digging begins. Typically, utilities can cross vegetated swales if they are protected (e.g. double casing) or located below the channel invert, but designers should consult their local utility provider(s) for guidance concerning the horizontal and vertical clearances between utilities and channels.

As a general rule vegetated swales should be at least 10 feet down-gradient from building foundations, 50 feet from septic system fields, and 100 feet from private wells. Vegetated swales should also be located outside the limits of the mapped 100 year flood plain unless a waiver is obtained from the local authority. However, consult local ordinances and design criteria to determine minimum setbacks from property lines, structures, utilities and wells.

Hotspots: Vegetated swales can typically be used to convey runoff from stormwater hotspots. Vegetated swales are not recommended to treat stormwater hotspots due to the potential for the infiltration of hydrocarbons, trace metals, and other toxic pollutants into groundwater.

1.3 Design Criteria and Calculations

Section 1.3 provides a comprehensive process for designing vegetated swales including recommended calculations, relevant site constraints, and required design objectives. Alternative methods may be used so long as no constraints are violated and all goals are achieved.

Design Constraint:

- ❍ The Contributing Drainage Area to a single channel must be ≤ 5 ac.

1.3.1 Runoff Volume

Swales provide both runoff reduction and pollutant removal. Sizing these practices as part of a stormwater management system of SCMs is accomplished using the TNRRAT. If alternative sizing methods are used, then it is up to the designer to justify the appropriate use of the selected method and provide adequate design calculations to support runoff reduction and pollutant removal.

Water quality swale sizing is efficiently accomplished in the TNRRAT as well. See Section 5.4.6 (Bioretention) for detailed design specifications.

1.3.2 Practice Dimensions

Design Flow Rate: The primary design criterion for Vegetated swales is flow rate. For relatively steeper slopes (2% - 4%), check dams may be necessary in order to meet the allowable max flow velocities. Vegetated swales should generally be aligned adjacent to and the same length (minimum) as the adjacent edge of the contributing drainage area. The minimum length may be achieved with multiple channel segments connected by culverts with energy dissipaters.

Channel Dimensions: The dimensions of a Vegetated swale must convey the required flow at a velocity that is non-erosive. A channel should be sized to convey the 10-yr 24-hr storm (or 10-yr peak runoff if using the rational method) for channel sizing unless an alternate path for high flows is available. It is recommended that the velocity not exceed 1 fps unless supporting calculations are provided to demonstrate that erosive conditions will not occur through the use of turf reinforcement matts (TRMs) or other methods.

Design Constraints:

- ❍ Longitudinal slope ≤ 4% (≤ 10% if terracing is used)
- ❍ Side slopes 3:1 (H:V) or flatter
- ❍ Flow velocities in channel must be less than 1 fps during a 1” storm event and non-erosive during the 2-year and 10-year design storm events.
- ❍ 10-year design flow must be contained within the channel which must have a 6” minimum freeboard.

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

$$Q = 1.49 / n\ A\ R^{1.67}\ S^{0.5}$$

where

Q = flow rate cfs

n = Manning's roughness coefficient (unitless: assume 0.15 for grass, 0.20 for dense vegetation)

A = cross sectional area of flow (sf)

R = hydraulic radius (ft) = area / wetted perimeter

S = longitudinal slope (ft/ft).

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

$$B = Q\ n / 1.49\ y^{1.67}\ s^{0.5}$$

where

B = bottom width of channel (ft)

Q = design flow rate (cfs)

n = Manning's roughness coefficient (unitless: assume 0.15 for grass, 0.20 for dense vegetation)

y = design flow depth (ft)

s = slope (ft/ft)

If the bottom width is less than 2 ft, adjust the flow depth. If the bottom width is more than 10 ft (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 ft and 10 ft, the second step is to determine the flow velocity:

$$V = Q / A$$

where

V = design flow velocity (fps)

Q = design flow rate (cfs)

A = cross sectional area (ft^2) determined by:

A = by + zy

where

b = bottom width of channel (ft)

y = design flow depth (ft)

z = side slope (ft/ft)

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

Channels must have a min of 4 inches of freeboard without creating erosive velocities.

An underdrain system is used in channels 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 channel quickly enough, the system will backup and flood adjacent properties. It is not recommended that surface water remain visible in residential areas for more than 24 hrs. All underdrain systems must discharge the water quality volume between 48 and 72 hrs. Underdrain systems must be included in the design if native soils infiltration is less than 0.1 inch per hour.

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

Design Checklist:

- ✔ Velocity less than 1 fps for 1 in event and non-erosive for 10-yr event
- ✔ Freeboard of at least 4 in for 10-yr event
- ✔ Check dams sized to handle flow-through velocity

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 can be calculated using the following equation:

$$q = h^{1.5} / (L / D + 2.5 + L2)^{0.5}$$

where

q = flow rate exiting check dam (cfs/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 channel 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:

$$L = (ss) \times (2d - h)$$

where

s = check dam side slope (max 3:1) (side slope is entered as rise over run so 3:1 is entered as 3)

d = height of dam (ft)

h = flow depth (ft).

When channel 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 principal spillway 6icnches 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 is recommended for ease of construction. However two or more stone sizes may be sued provided a larger stone 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.

1.4 Typical Details

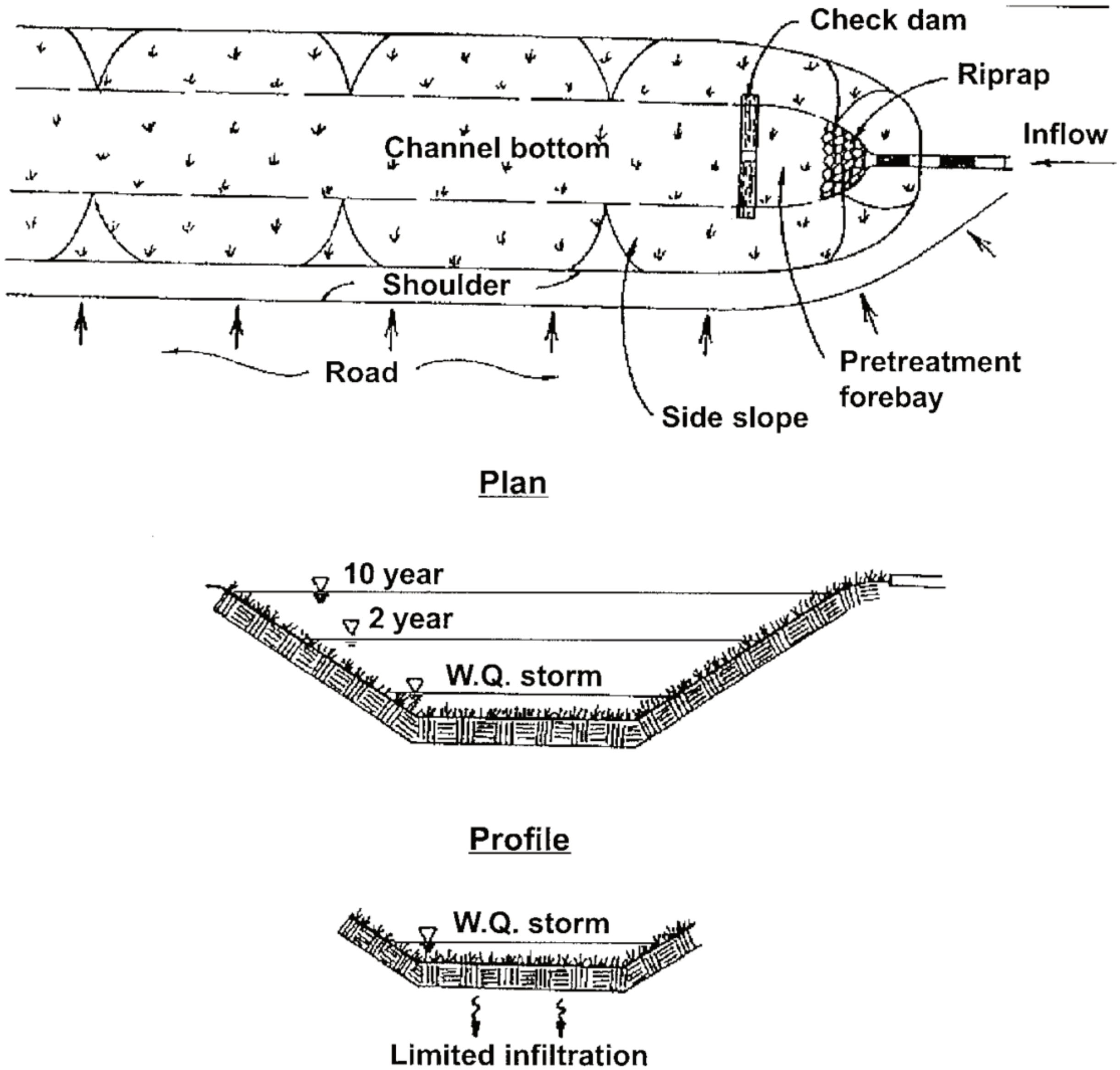

Figure 2: Grass channel – Typical plan, profile, and section (Source: Virginia).

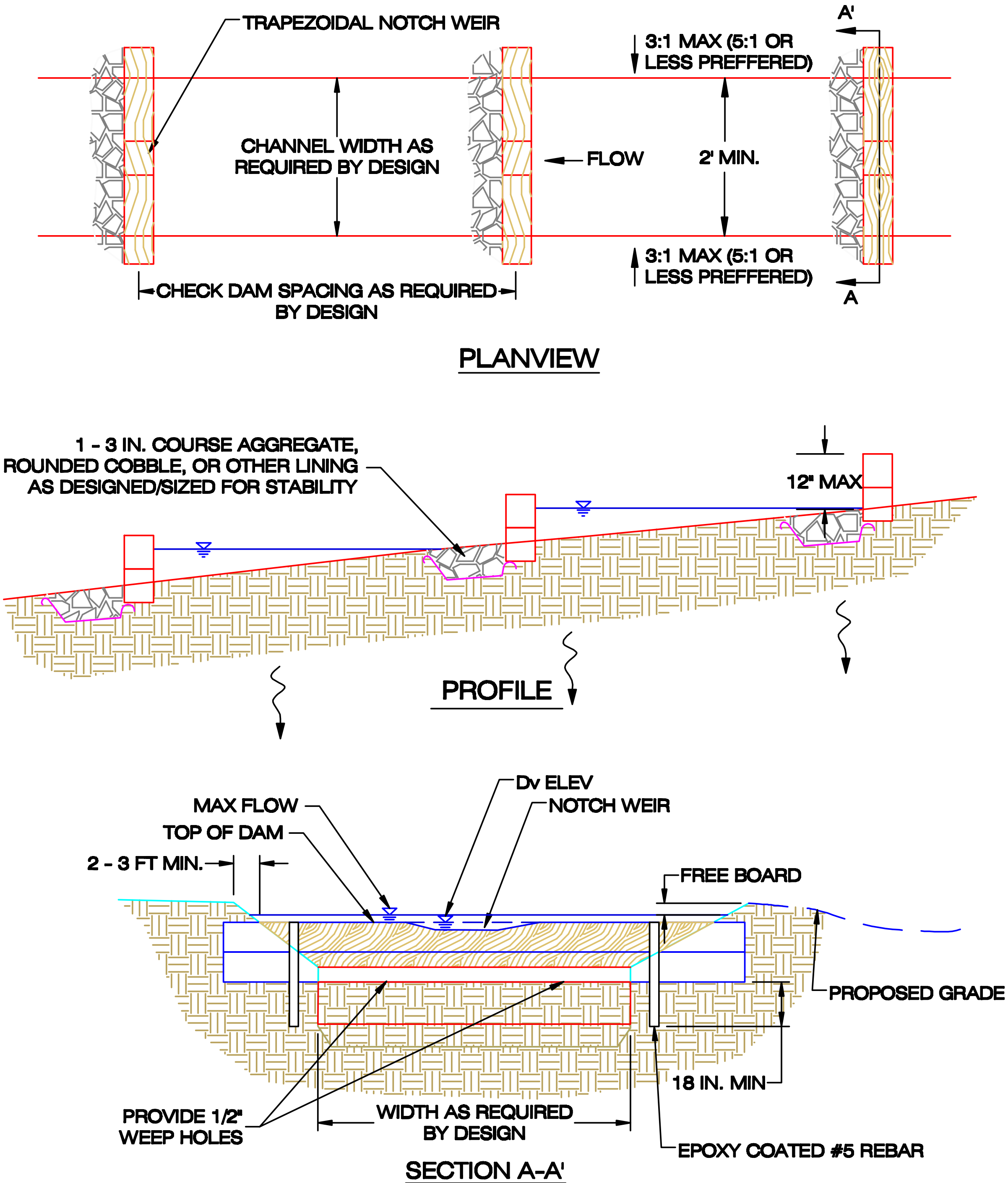

Figure 3: Grass swale with check dams – typical plan, profile, and section (Source: West Virginia).

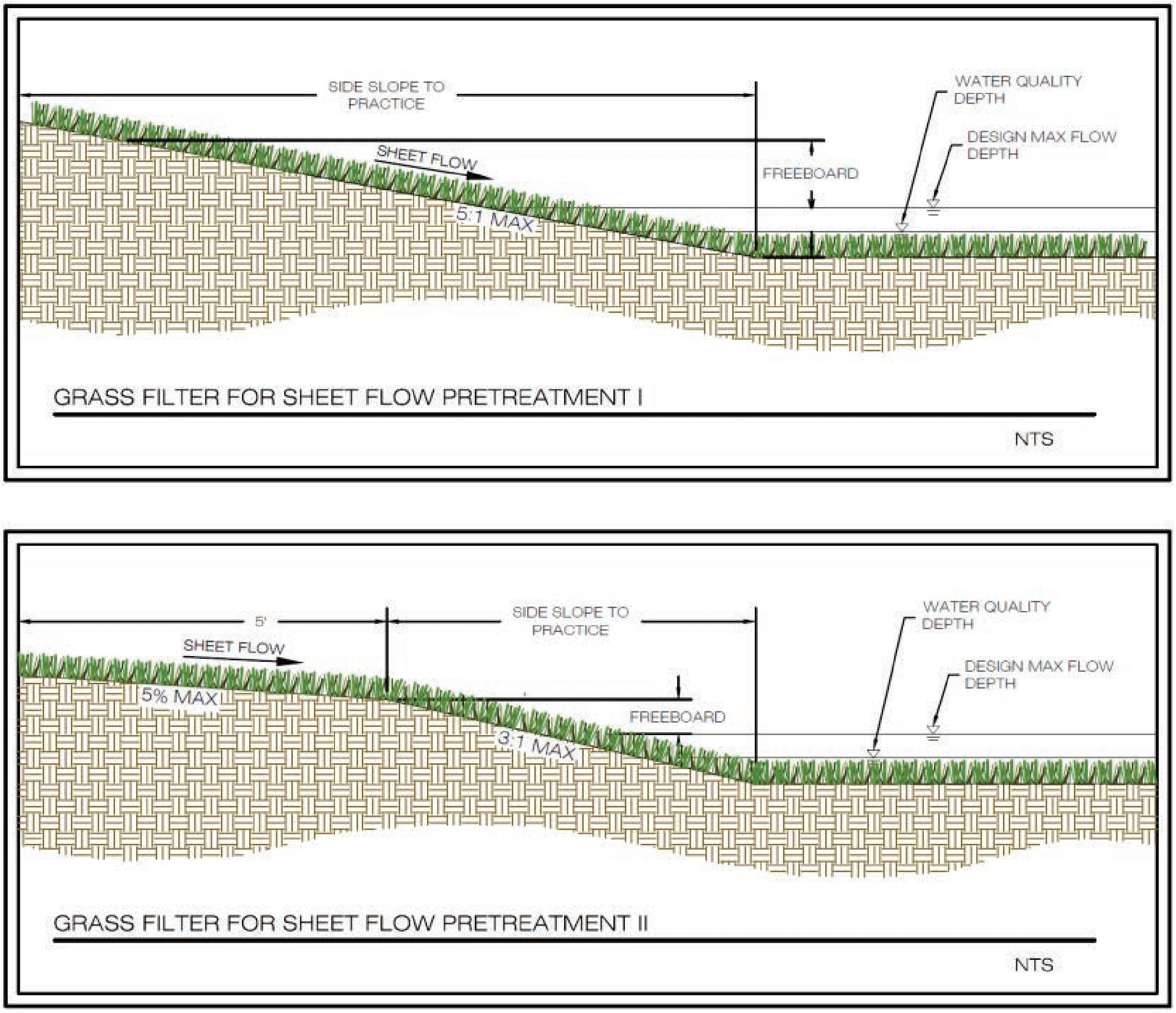

Figure 4: Pretreatment I and II – Grass filter for sheet flow (Source: West Virginia).

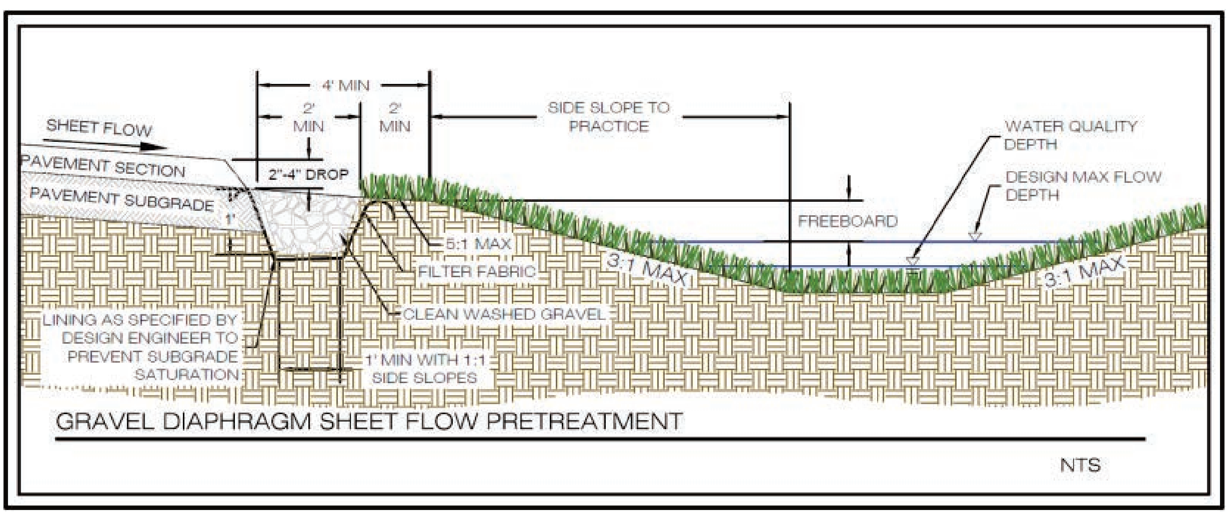

Figure 5: Pretreatment – gravel diaphragm for sheet from impervious or pervious surface (Source: West Virginia).

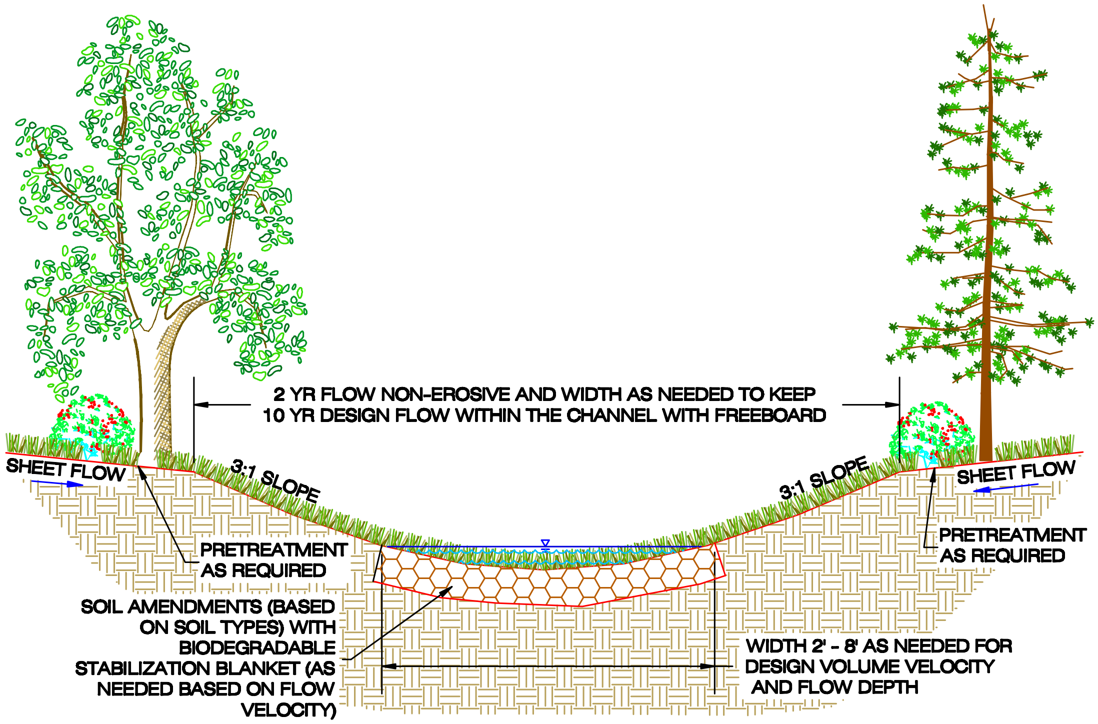

Figure 6: Grass swale with compost amendments – sections (Source: West Virginia).

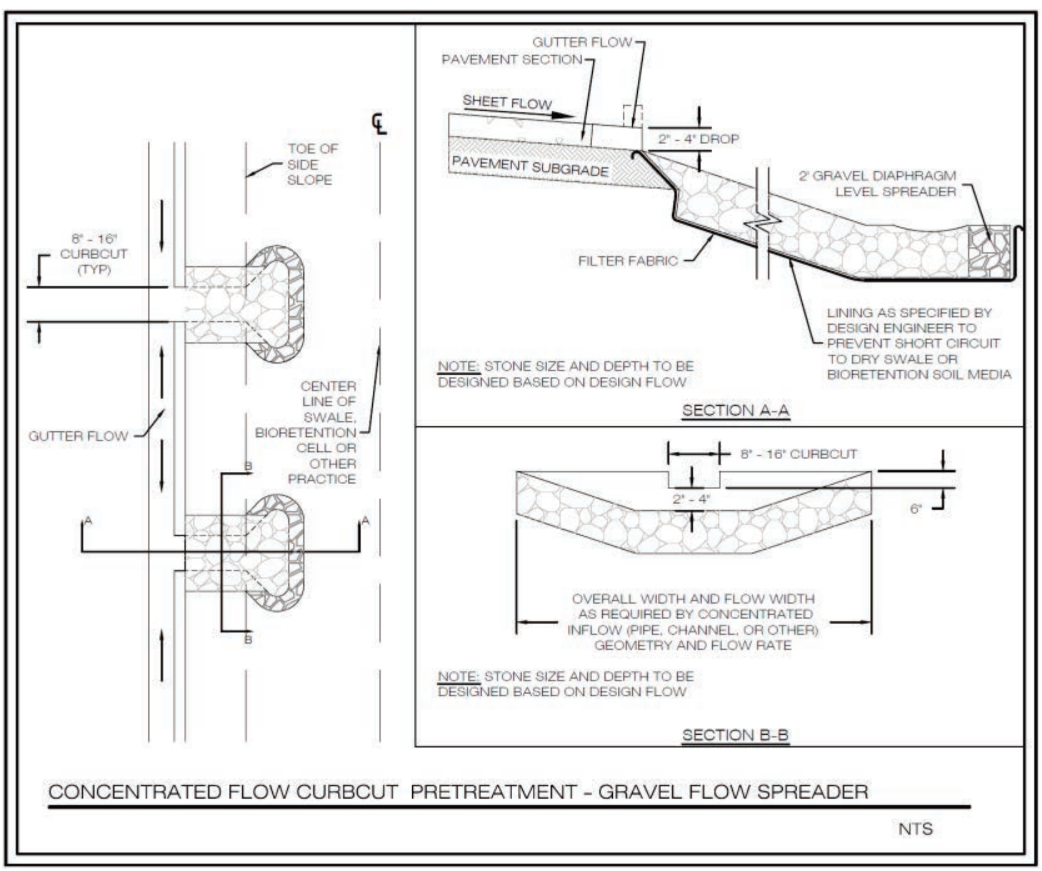

Figure 7: Pretreatment – Gravel from spreader for concentrated flow (Source: Virginia).

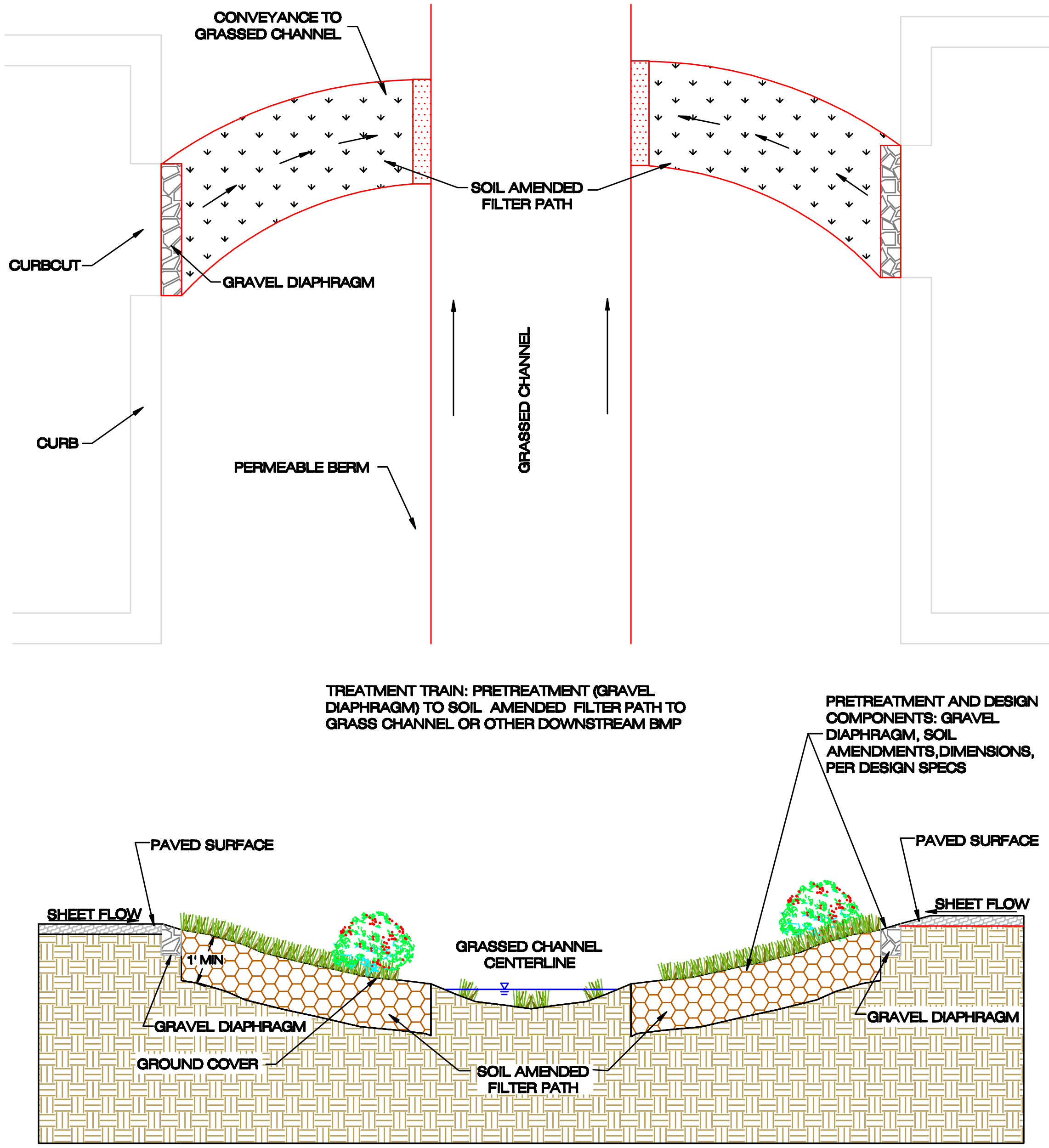

Figure 8: Filter path to grass channel (Source: Virginia).

2. Construction

The following is a typical construction sequence to properly install a grass channel, although steps may be modified to reflect different site conditions. Grass channels should be installed at a time of year that is best to establish turf cover without irrigation.

2.1 Pre-Construction

Site Assessment: Determine whether any site characteristics conflict with the feasibility requirements for successfully implementing the vegetated swale(s) listed below (and discussed in Section 1.1):

- Contributing Drainage Area
- Slopes
- Soils

- Depth to Water Table
- Utilities and Setbacks
- Hotspots

If there are any conflicts, revise the site plan or select another practice.

Protect Resources: Set aside undisturbed portions of the site or areas conducive to vegetated swale installation before construction begins. Place restorative practices onsite (conceptually or physically) to determine the availability of land for the vegetated swale(s).

Ideally, vegetated swales should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical, given that the channels are a key part of the drainage system at most sites. In these cases, temporary EPSC such as dikes, silt fences and other erosion control measures should be integrated into the channel design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, and erosion control fabric should be used to protect the channel.

Stabilize Contributing Drainage Area: Vegetated swale installation may only begin after the entire contributing drainage area has been stabilized with vegetation. Any accumulation of sediments that does occur within the channel must be removed during the final stages of grading to achieve the design cross-section. EPSC for construction of the vegetated swale should be installed as specified in the erosion and sediment control plan. Stormwater flows must not be permitted into the vegetated swale until the bottom and side slopes are fully stabilized.

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

2.2 Construction

Grade Channel: Grade the vegetated swale to the final dimensions shown on the plan. Do not compact or subject existing subgrade in vegetated channels to excessive construction equipment traffic. Protect areas from vehicle traffic during construction with construction fence, silt fence, or compost sock. Rough grade the vegetated channel. Excavating equipment should operate from the side of the channel 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. 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.

Install Necessary Treatment Structures: Install check dams, driveway culverts, and internal pre-treatment features as shown on the plan. Fill material used to construct check dams should be placed in 8- to 12-inch lifts and compacted to prevent settlement. The top of each check dam should be constructed level at the design elevation.

Install overflow structure and other stormwater structures: close and secure all inlets, pipes, trench drains, and other structures to prevent runoff from entering the vegetated channel prior to completion and site stabilization. Maintain drainage overflow pathways during construction while the vegetated channel is closed to provide for drainage during storm events.

Add Necessary Soil Amendments: Till the bottom of the channel to a depth of 1 foot and incorporate compost amendments as needed.

Vegetate Channel: Hydro-seed the bottom and banks of the grass channel, and peg in erosion control fabric or blanket where needed. After initial planting, a biodegradable erosion control fabric should be used, conforming to soil stabilization blanket and matting requirements found in MA–1 of the Tennessee Erosion and Sediment Control Handbook. Prepare planting holes for any trees and shrubs, then plant materials as shown in the landscaping plan and water them weekly in the first two months. The construction contract should include a 'Care and Replacement Warranty' to ensure vegetation is properly established and survives during the first growing season following construction.

2.3 Inspections

Notify the engineer when the site is fully vegetated and the soil mantle is stabilized. The engineer shall inspect the vegetated channel drainage area at his / her discretion before the area is brought online and sediment control devices are removed. Conduct the final construction inspection and develop a punch list for facility acceptance.

During Construction

Inspections during construction are needed to ensure that the grass channel is built in accordance with these specifications. Some common pitfalls can be avoided by careful post-storm inspection of the grass channel:

- Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the channel beds and their contributing side-slopes.
- Inspect check dams and pre-treatment structures to make sure they are at correct elevations, are properly installed, and are working effectively.
- Make sure outfall protection/energy dissipation at concentrated inflows are stable.

The real test of a grass channel occurs after its first big storm. Minor adjustments are normally needed as part of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets or realignment of outfalls and check dams).

As-Built

Conduct as-built inspection to determine success of installation and installed channel characteristics. After the grass channel has been constructed, an as-built certification of the grass channel should be prepared by a registered Professional Engineer and submitted to the local stormwater program. The as-built certification verifies that the SCM was installed as designed and approved. The following components should be addressed in the as-built certification:

1. The channel must be adequately vegetated.
2. The water quality channel flow velocity must not exceed 1.0 foot per second.
3. A mechanism for overflow for large storm events must be provided.

3. Maintenance

3.1 Agreements

The requirements for the maintenance may include the execution and recording of an inspection and maintenance agreement, a declaration of restrictions and covenants, and the development of a long term maintenance plan by the design engineer (See Appendix F for examples).

3.2 Schedules

A properly designed and installed vegetated channel will require relatively little 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 channels 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 channel operation or to suppress weeds and invasive species. Dispose of cuttings in a local composting facility. Mow only when channel is dry to avoid rutting. Inspect for uniformity in cross section and longitudinal slope and correct as needed. The following should only be done 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 channel if drawdown time is less than 48 hours. Inspect and correct check dams when signs of altered water flow (channelization, obstructions, etc.) are identified.

Once established, vegetated swales have minimal maintenance needs outside of the spring cleanup, regular mowing, repair of check dams and other measures to maintain the hydraulic efficiency of the channel and a dense, healthy grass cover. Maintenance requirements for vegetated swales include the following:

1. Maintain grass height of 3 to 4 inches.
2. Remove sediment build up in channel bottom when it accumulates to 25% of original total channel volume.
3. Ensure that rills and gullies have not formed on side slopes. Correct if necessary.
4. Remove trash and debris build up.
5. Replant areas where vegetation has not been successfully established.

All vegetated swales must be covered by a drainage easement to allow inspection and maintenance. If a vegetated swale is located in a residential private lot, the existence and purpose of the vegetated swale shall be noted on the deed of record.

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