APPENDIX B
BIOFILTRATION FACILITIES

1.0 Introduction

This appendix provides information for the design of biofiltration facilities such as swales and filter strips. Biofiltration facilities are intended to maximize the amount of stormwater that flows through dense vegetation, compost or soil, and to increase the potential for infiltration as compared to standard conveyance systems.

2.0 Biofiltration Swales

Biofiltration swales are open channels engineered to treat stormwater. Figures 1A and 1B are general configurations of a biofiltration swale. They are designed with gentle slopes, shallow flows, and lined with grass. Biofiltration swales are very popular because of their low construction and maintenance cost, few design limitations, and ability to be located in median strips, along the shoulders of roadways, and parking lots.

Applications

- Retrofit existing drainage channel characteristics such as the slope and shape or incorporate a soil amendment to maintain or improve treatment opportunities (low impact approach)
- Place prior to the outfall when runoff is consolidated using curbing, inlets, and storm drain piping
- Place along median strips, roadway shoulders, and parking lots

Trapezoidal channel cross-sections are used for biofiltration swales because they are easy to construct and are hydraulically efficient cross-sectional shapes. These flat-bottomed open channels minimize flow depth and therefore maximize the amount of runoff flowing through the vegetation. This is turn increases pollutant removal by trapping and sedimentation. Also, the wide and flat-bottom cross section increases the amount of water that comes in contact with soil/organics which increases the removal of dissolves and increases the potential for infiltration.

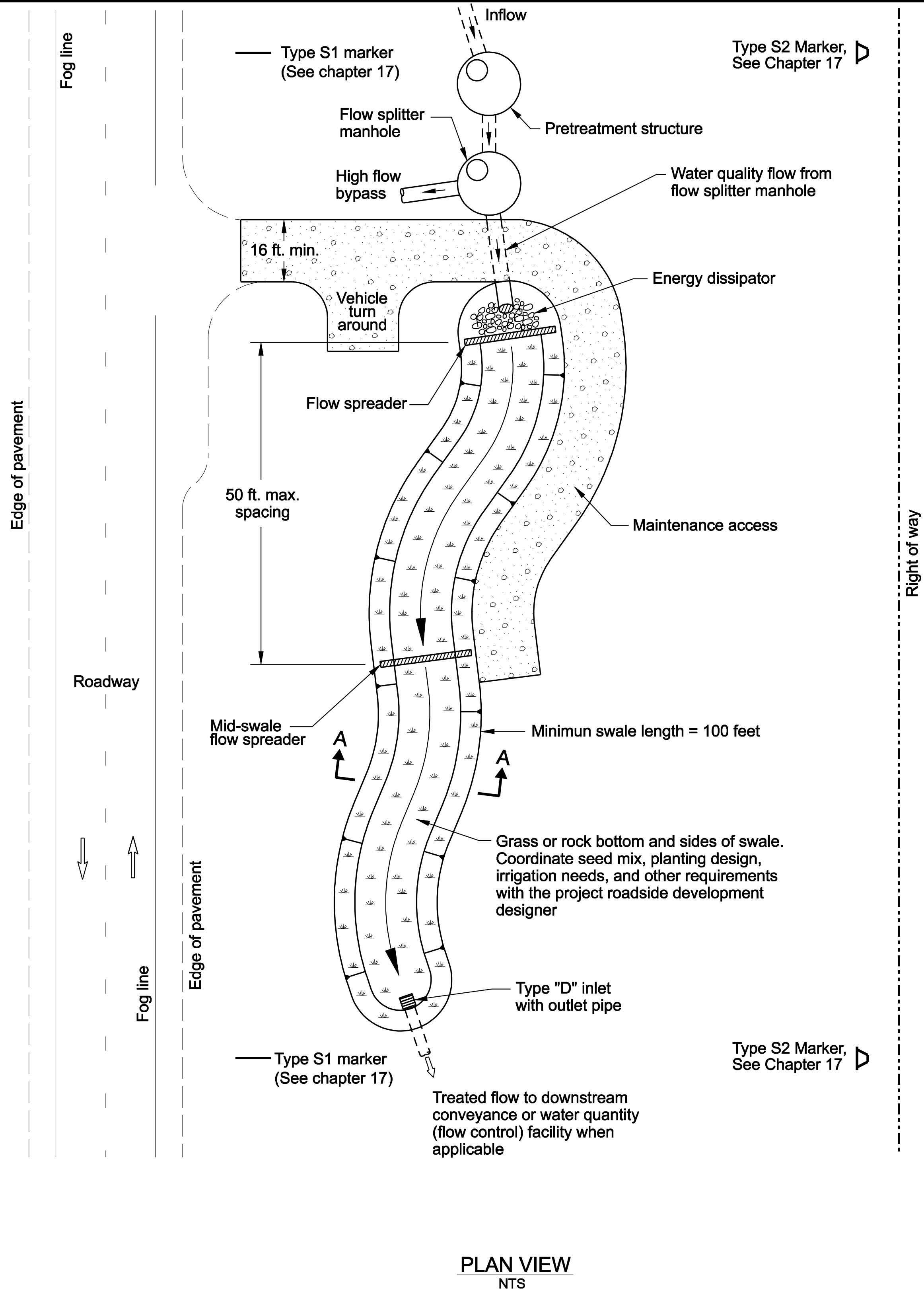
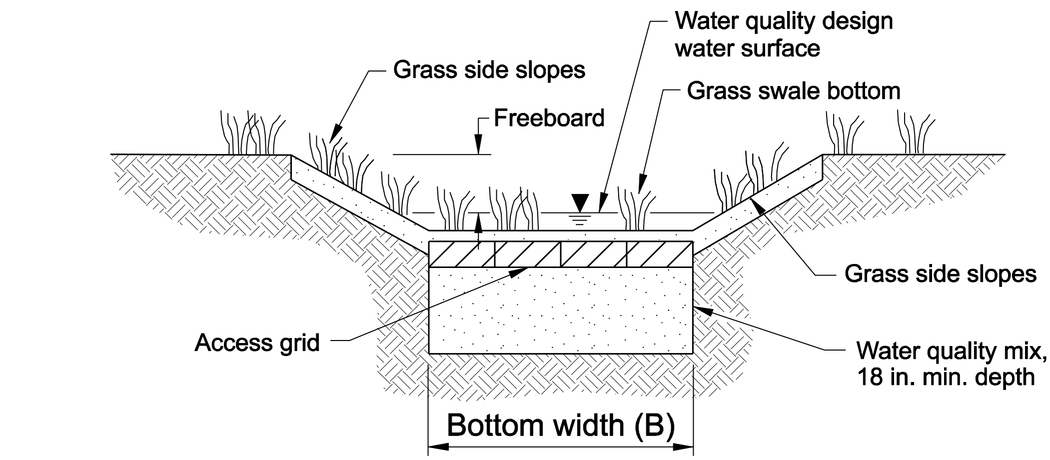


Figure 1A Biofiltration Swale – off-line (Plan View)



Cross Section A-A
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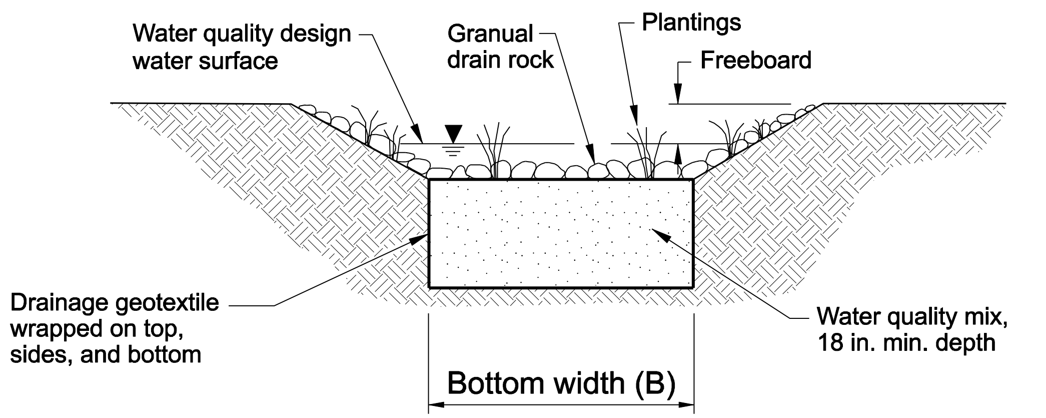
(Typical cross-section in Oregon climate zones 1, 2, 3, and 4)



Cross Section A-A
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(Typical cross-section in Oregon climate zones 5, 6, 7, 8, and 9)

Figure 1B Biofiltration Swale (Cross Sections)

Biofiltration swales can be designed to provide water quality control only. These types of facilities are:

- Constructed offline, thereby requiring a flow splitter structure upstream.
- Constructed channels with regular geometric cross-sections.
- Dry between storms otherwise vegetation would die off.
- Designed for storm drain pipe to direct roadway runoff into the upstream end of the swale. The runoff drains along the swale and outlets into an appropriate outfall.

Combination biofiltration swales are designed to provide water quality control and high flow conveyance. These types of facilities are:

- Constructed online, thereby not requiring an upstream flow splitter structure.
- Constructed channels with regular geometric cross-sections.

Swale with an access grid using porous pavers

Figure 2 Biofiltration Swale with an access grid using porous pavers

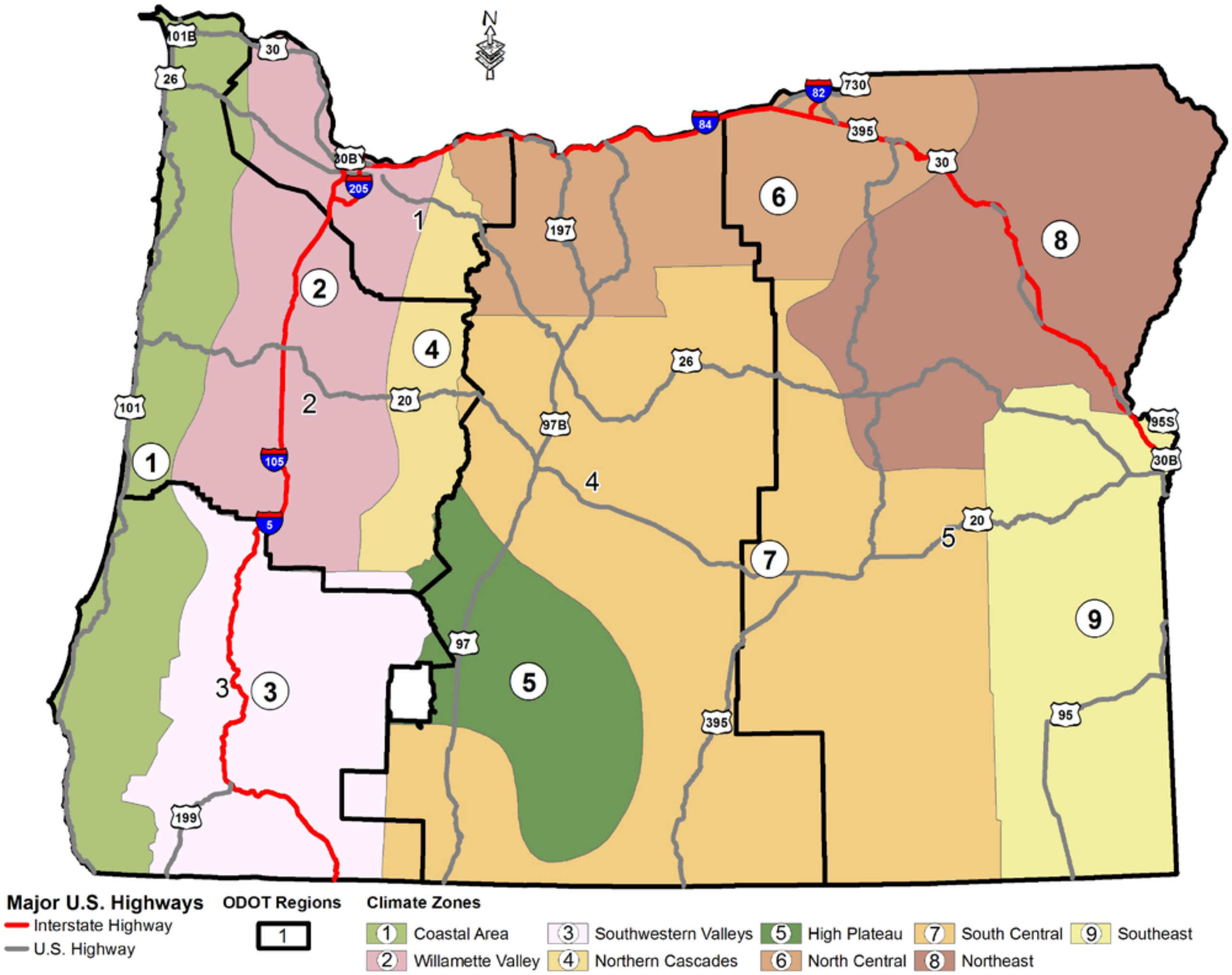


Figure 3 Oregon Climate Zones

2.1 Design Criteria

The design goal is to provide a uniform shallow flow depth over and through densely grassed area and long hydraulic residence time because this provides the most favorable opportunity for pollutant removal. The design criteria for grassed swales that achieve this goal are summarized below. Also apply the general requirements discussed in Section 14.10.

Site Selection

1. General siting requirements are discussed in Section 14.9. Additional siting criteria that apply specifically to swales include:

   a) The site must be of sufficient size to accommodate the swale and maintenance access.
   b) Do not place swales in shady areas. Daily sunlight is needed to maintain adequate vegetation cover.
   c) Climate conditions that affect the condition of grass and plantings as discussed in Section 14.9.

Groundwater

1. Maintain a minimum distance of 3 feet from the bottom or invert of a facility to bedrock or seasonally high water table.

Pretreatment

1. A pretreatment facility component is required to be installed upstream of the proposed swale. Design a pretreatment facility component according to guidance provided in Appendix E. Swales that are adjacent and parallel to the highway may receive pretreatment by sheet flow along vegetated side slopes. The minimum width of the vegetated side slope is 3 feet.

Swale Geometry

1. The **minimum bottom width** is 4 feet. The final width must be wide enough to convey the peak water quality design flow (see Design Water Depth below), and allow for maintenance. Therefore, the final design requires concurrence by the Maintenance District responsible for maintaining the facility.

2. The **longitudinal slope** (along the direction of flow) of the bottom of these facilities must be sloped toward the outlet.

   a) The minimum bottom grade is 0.5 percent.
   b) The maximum bottom grade is 6 percent.

3. The swale shall have a flat cross section (perpendicular to the flow direction) to allow for even flow across the entire width of the swale.

4. The swale cross-section shall be trapezoidal with 1V:4H maximum side slopes. Side slopes may be steeper if approved by the project design team and the maintenance district.

5. The swale **depth** must be adequate to convey the peak water quality design flow for off-line designs. The swale **depth** must be adequate to convey the peak water quality design and high flow for on-line designs.

6. The swale **freeboard** depth is 1 foot minimum measured between the design storm water elevation to the top of side slope.

7. The flow **length** between the swale inlet and outlet must be equal to or greater than 100 feet. There is no maximum length guideline. The total treatment length does not include the energy dissipator footprint. For example, assume a treatment length of 125 feet is required and a 3-foot-long by 4-foot-wide inlet energy dissipator is proposed. Therefore, the total bottom treatment length should be 128 feet long (125 feet + 3 feet).

8. Swales with horizontal curves are encouraged, but the curves must be mild to prevent bottom and side slope erosion and allow for equipment access to perform maintenance activities.

Note: Locate the treatment section along the downstream end of combination swales or online designs. Provide a minimum 5 foot wide filter strip between the combination swale and roadway pavement along the treatment section.

Water Quality Design Water Depth

1. A swale that will have a gradient of 0.5 percent to 4 percent shall have a maximum depth of 0.33 feet (4 inches) for the water quality design storm

2. A swale that will have a gradient of greater than 4 percent to 6 percent shall have a maximum depth of 0.25 feet (3 inches) for the water quality design storm.

Manning Coefficient

1. The flow resistance coefficient (Manning's n) is 0.24.

Hydraulic Residence Time

1. The **minimum residence time** is 9 minutes to allow the opportunity for pollutant removal from stormwater entering the swale.

Flow Velocity, Flow Spreading, Energy Dissipation

1. The **maximum flow velocity** is 3 feet per second during the 25-year design flow.

2. A **flow spreader** must be used at the inlet of a swale (off-line designs) to dissipate energy and evenly spread runoff as sheet flow over the swale bottom. An inlet flow spreader is not

required for swales that are parallel and adjacent to the road (on-line designs). Provide additional flow spreaders at 50-foot intervals. Design flow spreaders according to guidance provided in Appendix E.

3. An **energy dissipator** must be provided when the swale outlet pipe discharges into an outfall channel or sloped bank. Energy dissipator design guidance is provided in Appendix E.

Sub Surface Drain

A typical sub surface drain pipe system is shown in Figure 5. A sub surface drain pipe system is required to prevent standing water conditions when the subsoil classification is Natural Resources Conservation Service (NRCS) Hydrologic soil groups C or D and the bottom slopes less than 1.5 percent. A sub surface drain pipe may not be needed for NRCS Hydrologic subsoil groups A and B.

Subsurface drains must meet the following criteria:

1. The sub surface drain pipe must be a perforated pipe, laid parallel to the swale bottom, centered beneath the swale, and backfilled and bedded as shown in Figure 5.

2. The sub surface drain pipe must be 6 inches or greater in diameter.

3. The granular drain backfill material must be wrapped with drainage geotextile.

4. The sub surface drain pipe must drain freely to an existing discharge point or outfall.

Bottom Marker

1. A **bottom marker** made of porous pavers, are installed along the swale bottom to indicate the bottom elevation. Pavers are required in Oregon climate zones 1, 2, 3, and 4 (See Figure 3). Pavers are not required in Oregon climate zones 5, 6, 7, 8, and 9 (See Figure 3). Select a porous paver from the Qualified Products List. The porous paver must provide a minimum 80 percent bottom area opening for grass growth. Spaced solid paver blocks are not allowed. Pavers can also function as the access grid to support maintenance equipment. See maintenance access section below.

2. Note the following in the facility’s operation and maintenance manual:

   - the use of porous pavers to mark the bottom elevation of the swale
   - use sediment removal techniques that will not damage porous pavers

Maintenance Access

3. An **access road** shall be provided along one side of the swale when constructed away from the highway. The proposed access road must be able to support heavy equipment such as a vactor truck, dump truck, track hoe, or large mower.

4. Access road must be 16 feet in **width**.

5. The access road **maximum longitudinal slope** must be:

   a) 2 percent (edge of pavement to a longitudinal distance of 20 feet)
   b) 10 percent (20 feet from edge of pavement to end of access road)

6. The access road **maximum cross slope** is 4 percent.

7. An **access grid** made of porous pavers must be installed along the swale bottom for maintenance vehicle and mowing equipment access. Select a porous paver from the Qualified Products List. The porous paver must provide a minimum 80 percent bottom area opening for grass growth. Spaced solid paver blocks are not allowed. Pavers are required in Oregon climate zones 1, 2, 3, and 4 (See Figure 3). Pavers are not required in Oregon climate zones 5, 6, 7, 8, and 9 (See Figure 3).

8. **Manhole lids** for access to inlet and outflow pipe that are located in non-traffic areas such as grassed areas or behind guardrail must be set 1 foot above finish ground so that manhole location is visible for locating and for maintenance. This should be coordinated with the maintenance districts, lids may be placed flush with the finished grade at the request of the serving maintenance district. Lid elevations must match proposed finish grade in traffic areas. No manholes should be placed in biofiltration swales.

Retaining Walls

1. Retaining walls are not to be located within the active treatment channel.

Water Quality Mix

There are three design options to establish a "Water Quality Mix" that meets criteria for organic content, long term hydraulic conductivity and other soil characteristics. See Appendix E.

Planting Requirements

1. Grass shall be established along the sides and bottom of swale prior to facility operation.

2. Permanent seeding is best performed as follows:

- West of the Cascades – March 1 through May 15 and September 1 through October 31 if grass areas are watered regularly during the establishment period.
- East of the Cascades – October 1 through February 1 or March 1 through October 1 if grass areas are watered regularly during the establishment period.

3. Sod can be used if the sod is grown from a seed mix suitable for the wet conditions of a swale.

4. Grass seeding is not required, but should be considered for Oregon climate zones 5, 6, 7, 8, and 9 (See Figure 4). Coordinate herbaceous plants and shrubs planting plan with the project roadside development designer or landscape architect when grass is not an appropriate option.

Field Markers

1. Field Markers are required to be installed at the start and end of a facility's maintenance area. Marking guidance is provided in Chapter 17.

Figure 4 Biofiltration Swale (Southbound I-205 ramp onto Southbound I-5)

2.2 Design Procedure

The procedure for designing an off-line or on-line swale is presented below.

Step 1 – **New or relocated designs:** Identify facility locations according to the site suitability requirements noted in Section 2.1.

Existing vegetated roadside drainage channels: Identify existing channels with the following characteristics:

- receives sheet flow from adjacent roadside pavement
- channel length is equal to the adjacent roadside pavement length
- has a maximum longitudinal slope of 6 percent
- is within the project limits and will not be eliminated or impacted by proposed improvements, or
- has a trapezoidal shape or can be modified to the desired shape within existing or purchased right-of-way limits

Note: Additional right-of-way may be required for construction of new, relocated, or modified swales.

Step 2 – Determine water quality design storm. Highway runoff from impervious areas needs to address the most stringent standards or reference ODOT's requirements summarized in Section 14.10.2.

Step 2a – Determine the Contributing Impervious Area for the facility. See Section 14.10.1.

Step 3 – Determine the water quality peak flow. Use hydrology guidance in Chapter 7 and the design recurrence interval from step 2.

Step 4 – Select what appears to be the best longitudinal slope based on site-specific conditions.

Step 5 – Assume an initial water quality depth. The maximum treatment depth allowed is 3 inches or 4 inches. See design water depth section (Section 2.1).

Note: The removal rate of stormwater pollutants through a swale should increase as the water depth decreases.

Step 6 – Calculate swale bottom width (B).

B = Bottom width of the trapezoidal swale (feet)

$$B = \frac{nQ}{1.49y^{1.67}s^{0.5}}$$

Where:

n	=	Manning's Roughness Coefficient = 0.24 (dimensionless)
Q	=	peak water quality design flow (cubic feet per second)
y	=	design water depth (feet)
s	=	swale slope (feet per feet)
Z	=	side slope (dimensionless); for example, 1V:4H slope; Z = 4

Step 7 – Calculate the cross-sectional area (A).

A = Cross sectional area of the swale (square feet)

$$A = By + Zy^2$$

Note: Variables are defined in Step 5.

Step 8 – Calculate the average velocity (V).

V = Average velocity (feet per second)

$$V = \frac{Q}{A}$$

Note: Variables are defined in Steps 5 and 6.

Step 9 – Calculate the swale length (L).

L = Swale flow path length (feet)

L = Vt (60 seconds per minute)

Where:

V	=	average velocity (feet per second) from Step 6
t	=	hydraulic residence time in swale (minutes)

The minimum hydraulic residence time is 9 minutes. Substituting 9 minutes into the above equation results in the following:

L = 540V

Note: Length of swale is never less than 100 feet long. Use (L) calculated in this step or 100 feet; whichever is greater.

Step 10 – Calculate the swale top width (T) using the water depth in Step 3.

T = Swale top width at the water quality depth (feet)

$T = B + 2yZ$

Note: Variables are defined in Step 5.

Step 11– **Off-line designs** (new installations or modifying an existing channel/swale)**:** Adjust swale cross-section design to include freeboard using the bottom and top width calculated in Steps 6 and 10.

OR

On-line designs (new installations or modifying an existing channel/swale): Adjust swale cross-section design to include freeboard and high flow conveyance using the bottom and top width calculated in Steps 6 and 10. Follow these steps to design for high flow conveyance:

11.1 Compute the 25-year design discharge using hydrology guidelines in Chapter 7.

11.2 Calculate the average velocity using the design discharge calculated in step 11.1. Check adequacy of lining if average velocity is greater than 3 feet per second during the 25 year design discharge using guidance on shear stresses on channel linings that are presented in Chapter 8. Compare maximum to permissible shear stress. Reduce maximum shear stress by one or more of the following if maximum shear stress is greater than allowed:

- widening the channel, or
- Decreasing the channel slope
- Flattening the bank side slope, or
- Increasing the radius of curvature if the swale channel has bends.

11.3 Re-check water quality control design.

Step 12 – Coordinate the following field testing with the project geologist for the areas of interest:

- Determine the soil type(s). Take at least three samples (one at each end and mid-point of the channel.
- Determine the organic matter content

Step 13 – Evaluate the soils tests for gradation and organic matter content for each facility site. Go to Appendix E, Section 2 regarding Water Quality Mix. One of the following options is met to achieve treatment performance:

- the existing soil gradation and organic matter content criteria is met, or
- add compost to the topsoil or subsoil in-place, or
- excavate and place imported or stockpiled soil that meets the gradation and organic matter content criteria

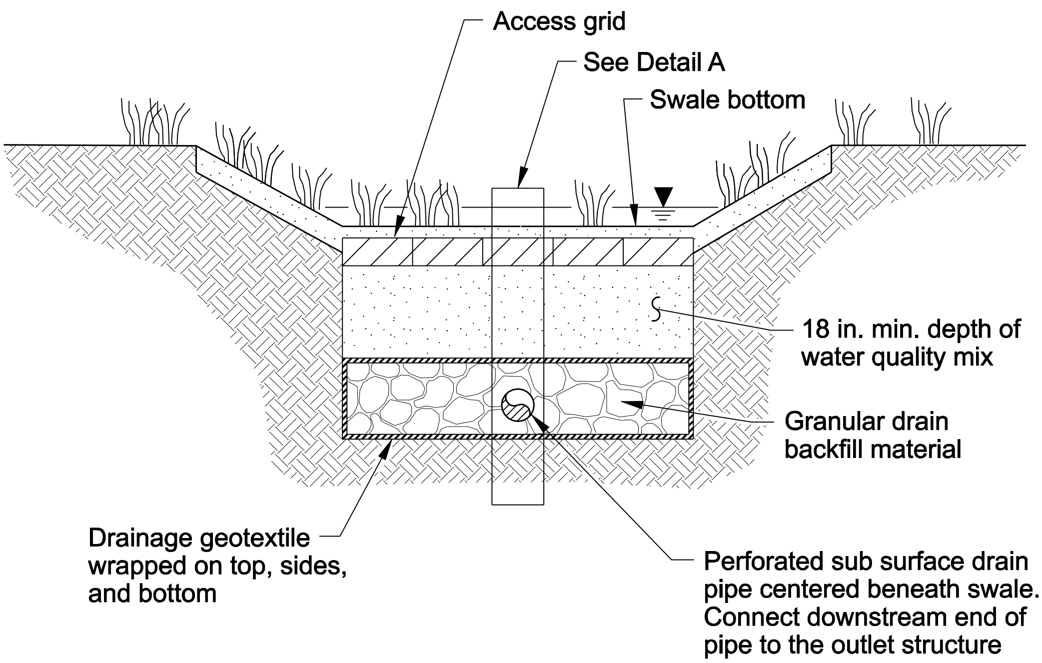
Step 14– Design a sub surface drain pipe system for bottom slopes less than 1.5 percent or when the subsoil classification is Natural Resources Conservation Service Hydrologic soil groups C or D. See Sub Surface Drain Section (Section 2.1).

Step 15– Design or coordinate the following facility components using the guidelines included in Appendix E:

- Pretreatment
- Flow splitter manhole
- Inlet energy dissipation
- Flow spreaders
- Storm drain piping
- Outfall
- Energy dissipation
- Coordinate soil preparation, seed mix, planting requirements, irrigation needs, and other requirements with the project roadside development designer.
- Coordinate temporary and/or permanent erosion control measures with the project erosion control designer

Step 16– Prepare the Stormwater Design Report and Operations and Maintenance Manual as discussed in Section 14.10.15 and 14.11.

Step 17 – Coordinate the installation field markers at the start and end of a facility's maintenance area. Marking guidance is provided in Chapter 17.



Cross Section A-A
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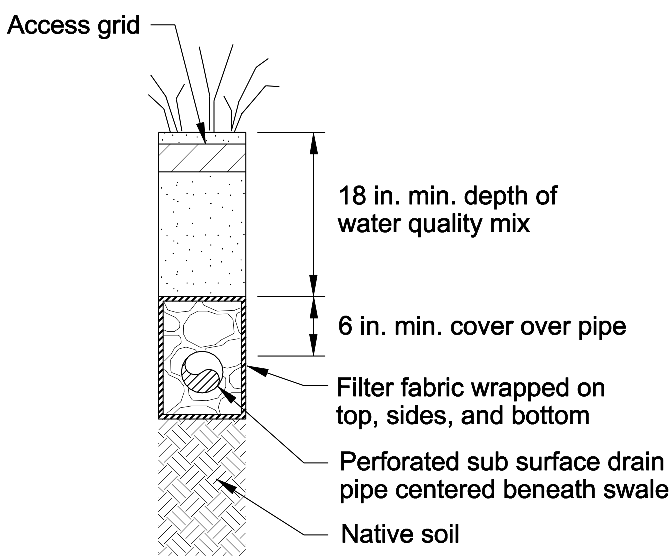

DETAIL A
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Figure 5 Biofiltration Swale with Sub Surface Drain

3.0 Filter Strips (Dispersion)

Dispersion is a simple and common method of treating stormwater runoff. It relies on maintaining sheet flow across vegetated and permeable ground which maximizes stormwater contact with soil and vegetation. In arid areas, aggregate may be used instead of vegetation where the soil supports infiltration.

Filter strips are the most common form of dispersion for highways, and can be used as either the sole BMP or as part of a treatment train. They consist of the right-of-way parallel to the road, with a relatively flat cross slope to maintain sheet flow of stormwater runoff over the entire width of the strip. Dispersion areas away from the highway receive collected runoff and use flow spreaders to create shallow, dispersed flow over vegetated slopes. The discussion here will focus on filter strips. Elements particular to other dispersion areas will be specifically called out.

A filter strip removes pollutants from pavement runoff by means of filtration through vegetation, media filtration and infiltration. Treatment mechanisms include physical trapping of particles, density separation (settling) in hydraulic dead zones and absorption, and to a lesser extent biological uptake and decomposition. Factors affecting the ability of filter strips to treat stormwater include vegetation density, slope and soil characteristics.

A filter strip (Figures 6 and 7) is a grassed sloped area located or placed between pavement and a downslope conveyance system. In cases where site conditions are not appropriate for a filter strip, stormwater can be collected and conveyed to a dispersion area.

The low impact approach is to preserve or enhance existing filter strip characteristics by modifying the side slope or incorporating a soil amendment to maintain or improve infiltration or media filtration.

Filter strips may be appropriate where:

- The road is elevated above the landscape on at least one side
- Impervious drainage area longitudinal slope is 4 percent or less
- Lateral slope of the highway (impervious surface) is 5 percent or less
- At least 6 feet of width from the edge of the shoulder is available
- Slope of the filter strip would be 15 percent or less (6:1 or flatter)

Sites that do not meet all of these criteria may still be used as filter strips. Modifications such as soil amendments may compensate for some shortfalls, or the strip may be part of a treatment train. For example, a too narrow filter strip may function as pre-treatment for a biofiltration swale.

Figure 6 Filter Strip

Filter strips would not be effective and should not be considered when:

- Sheet flow cannot be maintained
- Steep slopes are proposed
- Impervious drainage area longitudinal slope is steeper than 4 percent, or
- Longitudinal slope of filter strip area is greater than 2 percent.
- Impervious drainage area lateral slope is steeper than 5 percent.
- Climate conditions adversely affect the condition of grass and plantings as discussed in Section 14.9.6.3.
- Site conditions affect the condition of grass such as heavily shaded areas. Filter strips require sunlight exposure and moisture to ensure vigorous grass growth

Figure 7 is a typical grassed filter strip configuration. Filter strip width is measured perpendicular to the pavement and filter strip length is measured parallel to the pavement. In addition, the figure defines the longitudinal and lateral slopes.

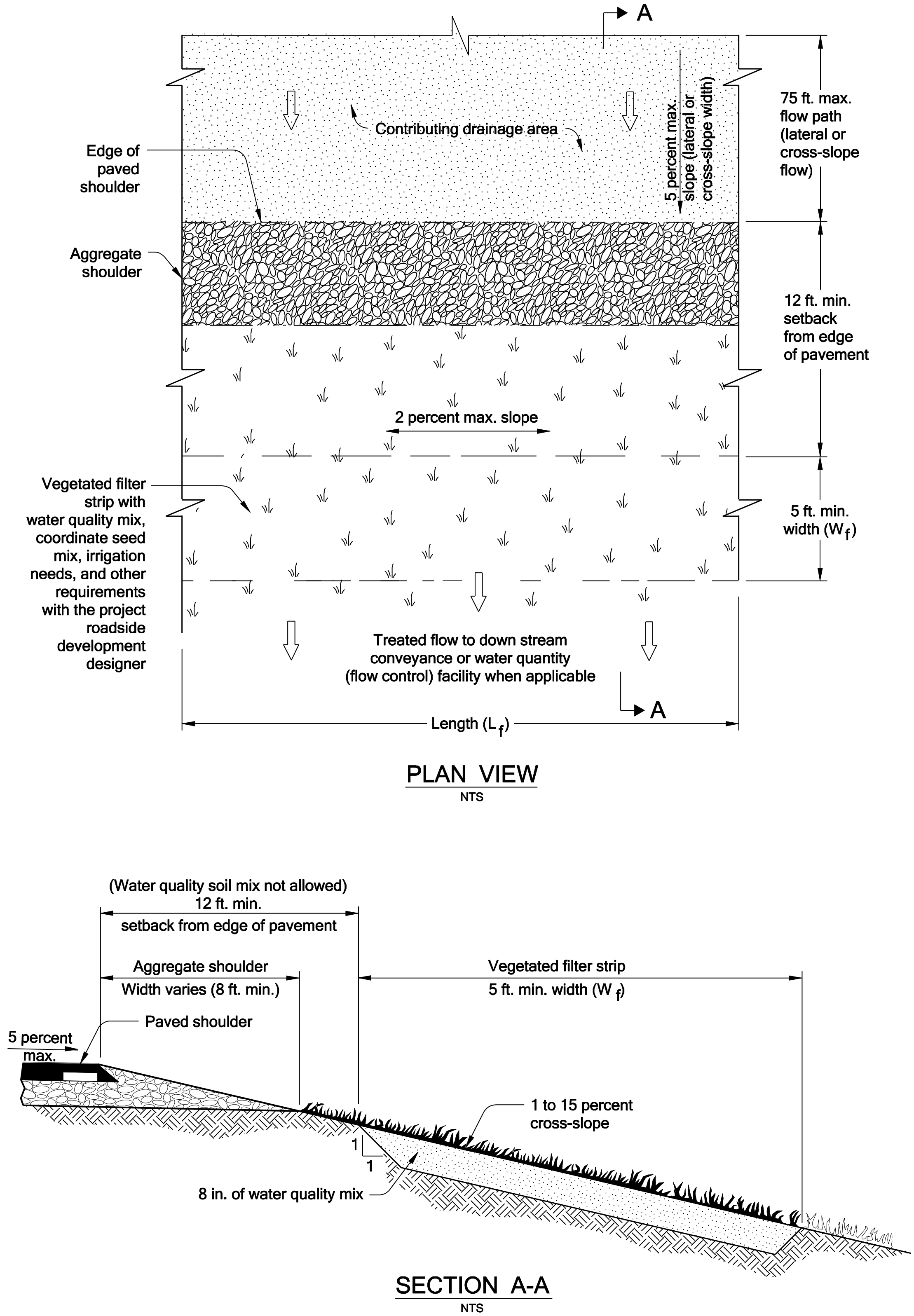

Figure 7 Grassed Filter Strip

3.1 Design Criteria

The design criteria for vegetated filter strips are presented in this section. Also apply the general requirements discussed in Section 14.10.

Site Selection

1. General siting requirements are discussed in Section 14.9. Additional siting criteria that apply specifically to filter strips include:

    a) The site must be of sufficient size to accommodate filter strips.
    b) Do not place a filter strip in shady areas. Daily sunlight is needed to maintain adequate vegetation cover.
    c) Climate conditions that affect the condition of grass and plantings as discussed in Section 14.9.6.3.

Contributing Impervious Area Restrictions

1. The **maximum flow path** across the contributing impervious area to the filter strip must not exceed 75 feet.

2. The **lateral slope of the contributing impervious area** shall be 5 percent or less.

3. The **longitudinal slope of the contributing impervious area** shall be 4 percent or less.

Groundwater

1. Maintain a minimum distance of 3 feet from lowest point of the filter strip to bedrock or seasonally high water table.

Filter Strip Geometry

1. The **flow width** of the filter strip must be equal to or greater than 5 feet.

2. The **length** of filter strips placed parallel to the road must be equal to the length of the contributing impervious or pavement area. The **length** of dispersion areas away from the highway must be the length needed to create a dispersed flow condition equal to the design water depth noted below

3. The **lateral or cross-section** of the filter strip must be equal to or greater than 1 percent and to not exceed 15 percent.

4. The **maximum longitudinal slope** of the filter strip is 2 percent.

5. The flow resistance coefficient is 0.24.

Design Water Depth

1. Shallow non-concentrated flow is the goal. The maximum water depth is 1-inch.

Sizing

1. The **flow width or filter strip width** must be determined using the ratios or table provided below:

   - 2% sloped filter strip to treat 4 feet of pavement for every 1 foot of filter strip
   - 5% sloped filter strip to treat 3 feet of pavement for every 1 foot of filter strip
   - 10% sloped filter strip to treat 2 feet of pavement for every 1 foot of filter strip
   - 15% sloped filter strip to treat 1.5 feet of pavement for every 1 foot of filter strip

filter strip slope (%)	filter strip width for 20 ft pavement width	filter strip width for 30 ft pavement width	filter strip width for 40 ft pavement width	filter strip width for 50 ft pavement width	filter strip width for 60 ft pavement width
2	5	8	10	13	15
5	7	10	14	17	20
10	10	15	20	25	30
15	14	20	27	33	40

Table 1 Filter Strip Sizing

Flow Spreader

A **flow spreader** must be used between the roadway pavement and filter strip to ensure runoff is evenly distributed across the filter strip. This function is usually performed by the gravel shoulder.

A **flow spreader** must be used to create a dispersed flow condition equal to the design water depth at the inlet of dispersion areas placed away from the highway.

Water Quality Mix

There are three design options to establish a “Water Quality Mix” that meets criteria for organic content, long term hydraulic conductivity and other soil characteristics. See Appendix E.

Planting Requirements

1. Grass shall be established along the entire treatment area of the filter strip. In arid areas, aggregate may be used instead of vegetation where the soil supports infiltration.

2. Permanent seeding is best performed as follows:

    - West of the Cascades – March 1 through May 15 and September 1 through October 31 if grass areas are watered regularly during the establishment period.
    - East of the Cascades – October 1 through February 1 or March 1 through October 1 if grass areas are watered regularly during the establishment period.

Field Markers

1. Field Markers are required to be installed at the start and end of a facility's maintenance area. Marking guidance is provided in Chapter 17.

3.2 Design Procedure (low impact development approach or new installation)

The following design procedure is for new installation or for determining if an existing vegetated area meets dispersion requirements to treat stormwater runoff.

Step 1 – Identify areas within the project limits that will not be paved or gravelled. Areas of interest are vegetated areas or areas that can be modified with vegetation, slopes less than 15 percent, and minimum flow path widths of 5 feet (see site criteria in Section 3.1).

Step 2 – Determine the lateral or cross-sectional width of the impervious surface.

Step 3 – Determine the average lateral or cross-sectional slope. Use 2 percent for sizing treatment area if the slope is less than 2 percent.

Step 4 – Using the sizing table provided in Section 3.1 determine the minimum filter strip width using the information obtained in Steps 2 and 3. Coordinate with the Project Leader and Right-of-Way if additional right-of-way is necessary.

Step 5 – Coordinate the following field testing with the project geologist for the areas of interest identified in Step 1:

- Determine the soil type(s). Take at least three samples (one at each end and mid-point of the dispersion area(s).
- Determine the depth of the seasonally high water table and bedrock is at least 3 feet below existing ground for the entire limits of the dispersion area(s).

Step 6 – Evaluate the soils tests for gradation and organic matter content for each vegetated area identified in Step 1. Go to Appendix E, Section 2 regarding Water Quality Mix. A vegetated area(s) can be utilized as a dispersion area when the soil gradation and organic matter content is met. Alternate option for areas with soils meeting gradation requirements but not meeting the necessary percentage of organic matter is to add compost.

Step 7 - Coordinate seed mix, seed establishment irrigation needs, and other requirements with the project roadside development designer or landscape architect. Coordinate temporary and/or permanent erosion control measures with the project erosion control designer.

Step 8 – Prepare the Stormwater Design Report and Operations and Maintenance Manual as discussed in Section 14.10.15 and 14.11.

Step 9 – Coordinate the installation field markers at the start and end of a facility's maintenance area. Marking guidance is provided in Chapter 17.