Chapter 7 – Vegetated Filter Strip

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7.1 Overview of Practice

A vegetated filter strip is a densely vegetated strip of land, similar to a grassed swale, but engineered to accept runoff from upstream development only as *overland sheet flow* (Yu, 2004). The type of vegetation selected may range from native species, to grass meadow, to forest. In addition to serving as a primary water quality improvement practice, vegetated filters strips function extremely well as pre-treatment measures for other BMPs whose function may be compromised if sediment loading is excessive.

Vegetated filter strips are water quality improvement practices, and cannot be considered effective flood control strategies.

7.2 Site Constraints and Siting of the Facility

A number of site constraints must be considered in addition to the contributing drainage area's impervious cover when the implementation of a vegetated filter strip is proposed. These constraints are discussed as follows.

7.2.1 Minimum Drainage Area

The minimum drainage area contributing to a vegetated filter strip is not restricted. Vegetated filter strips are particularly well suited to small drainage areas.

7.2.2 Maximum Drainage Area

The water quality improvement function of a vegetated filter strip is predicated on its ability to maintain sheet flow across the strip. When flow on the strip becomes concentrated, forming channels, the hydraulic residence time on the strip is reduced to ineffective levels. As contributing drainage area increases, so does the difficulty in ensuring that the volume of runoff generated from the area can remain as sheet flow across the strip. The contributing area to a filter strip should never exceed five acres. Regardless of the strip's contributing drainage area, flow entering onto the strip must never be concentrated. If sheet flow cannot be maintained upstream of the filter strip, a level spreader should be employed to convert concentrated flows back to sheet flow prior to their entrance onto the strip.

7.2.3 Site Slopes

Sites upon which a vegetated filter strip is proposed should exhibit relatively flat topography. Alternative BMPs should be considered when site topography is such that slopes exceed five percent.

7.2.4 Site Soils

The implementation of a vegetated filter strip is restricted to those soils having an infiltration rate of at least 0.52 inches per hour. A permeability test is required for this BMP. This data should be provided to the Materials Division early in the project planning stages to determine if a vegetated filter strip is feasible on native site soils. In addition to infiltration rate restrictions, the soil must be capable of sustaining a dense stand of vegetation with minimal fertilization.

7.2.5 Depth to Water Table

The presence of a shallow water table in the vicinity of a proposed filter strip may hinder the infiltration function of the strip. The lowest elevation of the filter strip should be a minimum of two feet above the local seasonally high water table.

7.2.6 Existing Utilities

Filter strips often can be constructed over existing easements, provided permission to construct the strip over these easements is obtained from the utility owner *prior* to design of the strip.

7.2.7 Wetlands

When the construction of a vegetated filter strip is planned in the vicinity of known wetlands, the designer must coordinate with the appropriate local, state, and federal agencies to identify wetlands boundaries, their protected status, and the feasibility of BMP implementation in their vicinity.

7.3 General Design Guidelines

The following presents a collection of broad design issues to be considered when designing a vegetated swale for improvement of water quality.

7.3.1 Length

Ultimately, the required length of a filter strip (in the direction of flow) is a function of the target hydraulic residence time for flows entering onto the strip. A 9 minute hydraulic residence time is recommended with five minutes being the absolute minimum for water quality improvement (FHWA, 1996). Generally, for strips exhibiting a longitudinal slope of less than two percent, the *minimum* strip length that should be considered is 25 feet. For any one percent increase in slope, the filter length should increase by at least four feet. These values, however, are only estimates and computational procedures (discussed later in this chapter) must be used to ensure target hydraulic residence times are met. Optimal filter strip lengths will range from 80 to 100 feet. Flow over pervious surfaces tends to become concentrated when the flow path exceeds 150 feet (CWP, 1996). Therefore, strips of excessive length are discouraged.

7.3.2 Width

Ideally, the width of the filter strip (perpendicular to the flow direction) should, if at all possible, be equal to the width of the area contributing runoff to the strip. When this is not possible, a level spreader may be used to distribute flow evenly onto the strip. The *minimum* width of the filter strip should be the greater of the two values:

0.2 x Filter Length

or

8 feet

7.3.3 Slope

The filter strip slope should be as flat as practically possible while still providing positive drainage across the strip. Excessive ponding of runoff is undesirable as this will lead to saturation of the strip's underlying soil, resulting in difficulty maintaining a dense stand of vegetation on the strip. The slope of a vegetated filter strip is not restricted to any specific maximum value. However, as the strips slope is increased the flow velocity on the strip increases. The increase in velocity will necessarily require lengthening of the strip to attain an effective hydraulic residence time. As filter strip length increases so does the likelihood of the flow becoming concentrated. Filter strips function best on slopes of five percent or less (Yu, 2004). Table 7.1 presents maximum recommended filter strip slopes as a function of Hydrologic Soil Group and vegetative cover.

Filter Strip Soil Type	Hydrologic Soil Group	Maximum Filter Strip Slope (Percent)	
		Turf Grass, Native Grasses, and Meadows	Planted and Indigenous Woods
Sand	A	7	5
Sandy Loam	B	8	7
Loam, Silt Loam	B	8	8
Sandy Clay Loam	C	8	8
Clay Loam, Silty Clay, Clay	D	8	8

Table 7.1. Recommended Maximum Filter Strip Slopes

Source: Pennsylvania Department of Environmental Protection. Stormwater Best Management Practices Manual. 2006.

7.3.4 Pervious Berm

When soil infiltration rates, site groundwater depths, and/or slopes do not adhere to the guidelines previously described, the filter strip may be equipped with a berm at its downstream end. Such a berm will effectively force ponding on the surface of the strip, thus increasing the hydraulic residence time of the entering flows. The berm should be constructed of moderately permeable soils as approved by the Materials Division. Generally acceptable soils are ASTM *ML, SM,* or *SC* or soils meeting USDA sandy loam or loamy sand texture with a minimum of 10 – 25% clay. The berm must be equipped with an armored overflow section to permit safe passage of large flows which would otherwise overtop the berm. The maximum depth of ponding behind the berm should not exceed one foot. The use of a berm should only be considered as a last resort, as the forced ponding of runoff on the strip will hinder the establishment of a dense stand of vegetation.

7.3.5 Discharge Flows

When a grassed swale empties into an existing swale or other surface conveyance system, the receiving channel must be evaluated for adequacy as defined by Regulation MS-19 in the Virginia Erosion and Sediment Control Handbook, (DCR, 1992). Existing natural channels conveying pre-development flows may be considered receiving channels if they satisfactorily meet the standards outlined in the VESCH MS-19. Unless unique site conditions mandate otherwise, receiving channels should be analyzed for overtopping during conveyance of the 10-year runoff producing event and for erosive potential under the 2-year event.

7.4 Design Process

This section presents the steps in the design process applicable to vegetated filter strips serving as water quality BMPs. The pre and post-development runoff characteristics are intended to replicate stormwater management needs routinely encountered during linear development projects. The hydrologic calculations and assumptions presented in this section serve only as input data for the detailed BMP design steps. Full hydrologic discussion is beyond the scope of this report, and the user is referred to Chapter 4 of the Virginia Stormwater Management Handbook (DCR, 1999) for expanded hydrologic methodology.

The following filter strip design will provide the technology-based water quality requirements arising from a linear development scenario similar to that described in *Chapter Six – Vegetated Swale*. The new scenario entails the construction of approximately 1,300 linear feet of secondary subdivision roadway in the City of Hampton. Topography is such that runoff from the road is collected in roadside ditches and conveyed to a low point near the mid station of the road. The concentrated runoff is discharged into a level spreader from which it then enters onto the proposed filter strip as overland sheet flow. The total project site, including right-of-way and all permanent easements, consists of 4.6 acres. Pre and post-development land cover characteristics and peak rates of runoff are summarized below in Tables 7.2 and 7.3. The project site exhibits topography typical of the coastal region of Virginia, with slopes generally less than two percent. Site soils are categorized as a sandy loam (Hydrologic Soil Group B).

	Pre-Development	Post-Development
Project Area (acres)	4.6	4.6
Land Cover	Unimproved Grass Cover	0.75 acres impervious cover
Impervious Percentage	0	16.3

Table 7.2. Land Cover Characteristics of Example Project Site

		York County - 10 Year				
Acreage	**Rational C**	**A Constant**	**B Constant**	**t_c (min)**	**i_{10} (iph)**	**Q_{10} (cfs)**
0.75	0.9	186.78	21.22	8	6.39	4.3

Table 7.3. Peak 10-Year Runoff from Example Project Site

Step 1. Compute the Required Water Quality Volume

The project site water quality volume is a function of the developed impervious area. This basic water quality volume is computed as follows:

$$WQ_V = \frac{IA \times \frac{1}{2} in}{12 \frac{in}{ft}}$$

IA = Impervious Area (ft^2)

The project site is comprised of a total drainage area of 4.6 acres. With impervious area within the project site of 0.75 acres, the water quality volume is computed as:

$$WQ_V = \frac{0.75ac \times \frac{1}{2} in \times \frac{43{,}560\, ft^2}{ac}}{12 \frac{in}{ft}} = 1{,}361\, ft^3$$

The vegetated filter strip should be sized to provide a minimum hydraulic residence time of five minutes for the computed water quality volume.

Step 2. Estimate the Required Strip Length

The next step is to estimate the strip's required length. Making an initial estimate of the required length will assist in evaluating the feasibility of the practice for the given site conditions. The following nomographs, Figures 7.1 – 7.5 (obtained from the Pennsylvania Department of Environmental Protection Stormwater Best Management Practices Manual, 2006), provide a means by which to estimate the required filter strip length as a function of the underlying Hydrologic Soil Group (HSG), strip slope, and type of vegetative cover. As stated previously, the proposed strip's underlying soil is a sandy loam of HSG *B*. At this point in the design, the vegetative cover is assumed to be native grasses. Figure 7.2 reflects the site-specific conditions.

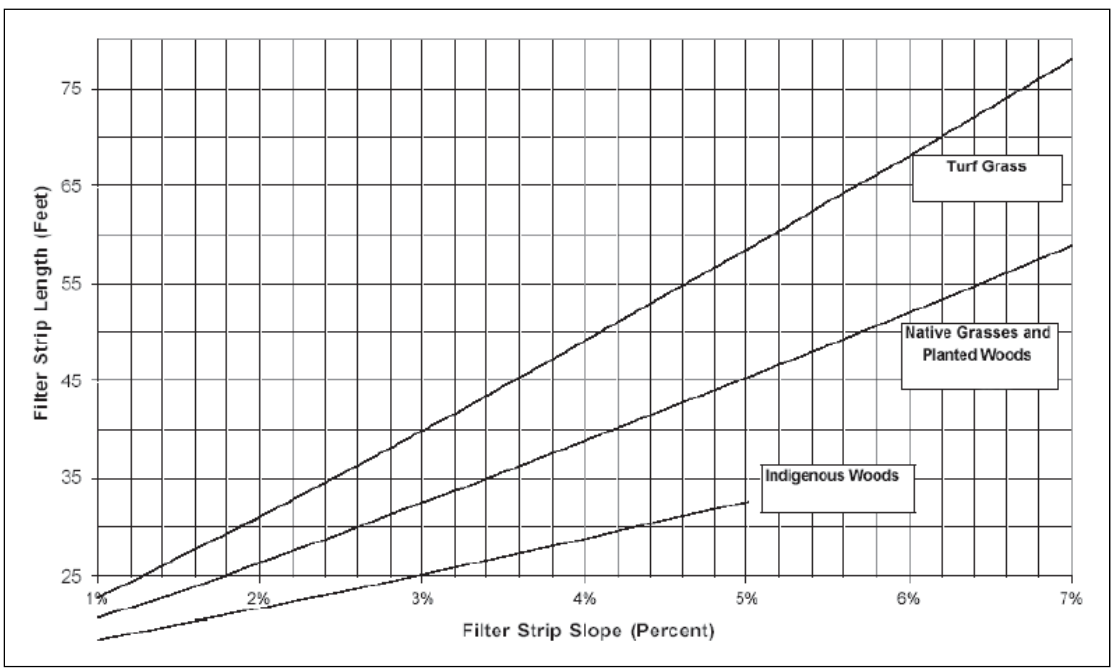

Figure 7.1. Filter Strip Length – Sand, HSG A (PADEP, 2006)

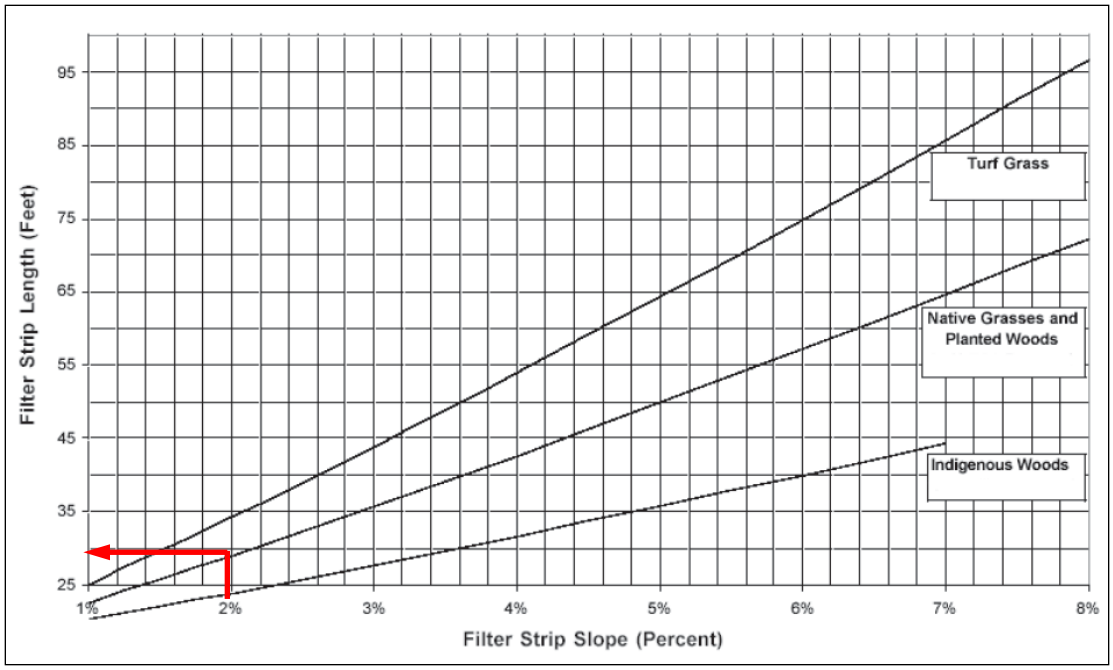

Figure 7.2. Filter Strip Length – Sandy Loam, HSG B (PADEP, 2006)

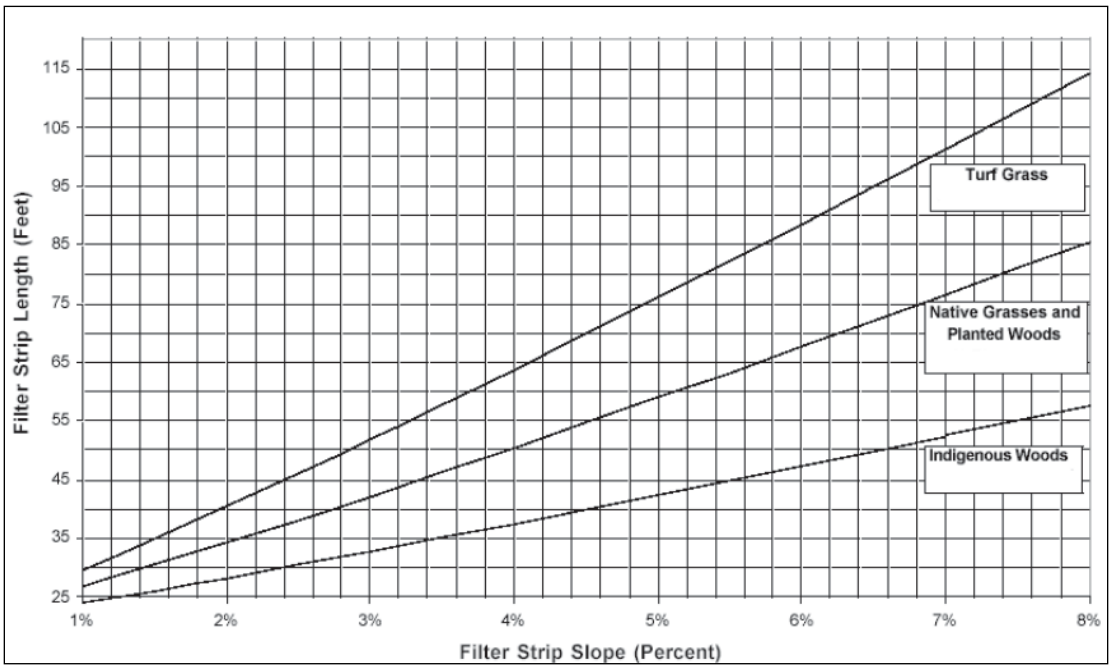

Figure 7.3. Filter Strip Length – Loam / Silt Loam, HSG B (PADEP, 2006)

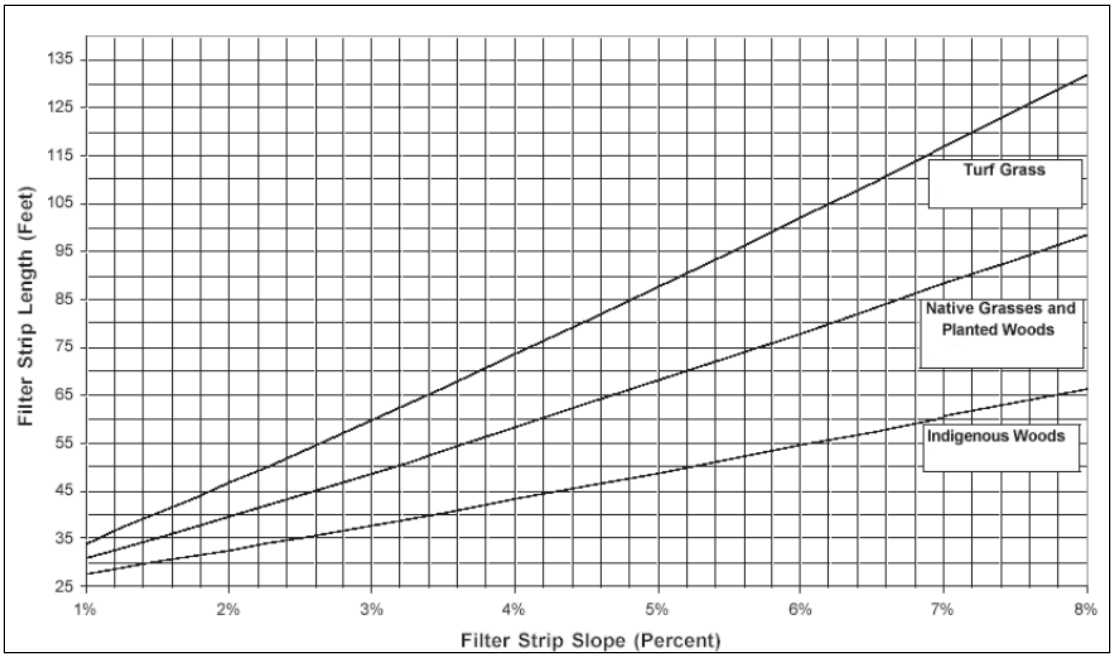

Figure 7.4. Filter Strip Length – Sandy Clay Loam, HSG C (PADEP, 2006)

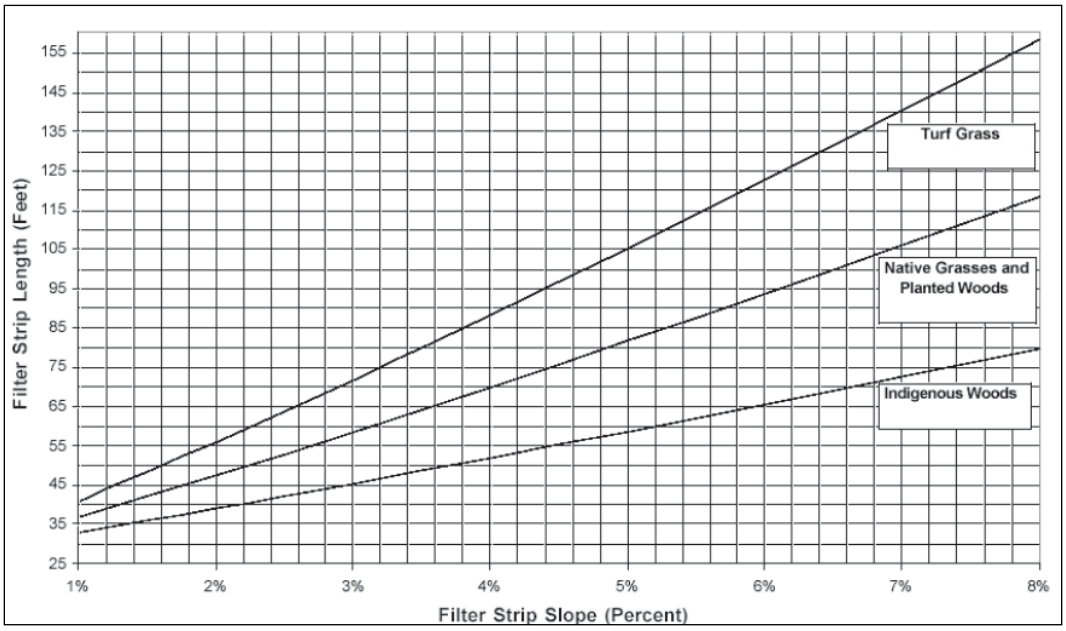

Figure 7.5. Filter Strip Length – Clay Loam / Silty Clay / Clay, HSG D (PADEP, 2006)

Figure 7.2 provides an estimated filter strip length of 29 feet. It should be noted that this is a short strip, whose estimated length is largely a function of the relatively high permeability rates exhibited by sandy loams categorized as HSG *B*. While the filter strip may be able to infiltrate a large portion of its received runoff under ideal conditions, conservative design practice will size the strip to provide effective hydraulic residence times even when antecedent moisture conditions are such that the underlying soils are in a near-saturated condition. This sizing procedure is discussed in the next steps. The estimated strip length of 29 feet is the absolute minimum length that should be considered for this example.

Step 3. Estimate the Peak Rate of Runoff Corresponding to the Water Quality Volume

A detailed filter strip design requires that the design discharge onto the strip be known. The length of the strip can then be sized to accommodate this discharge while providing the desired hydraulic residence time. The site's water quality volume was computed previously as 1,361 ft^3. The peak volumetric rate of discharge which generates this runoff volume can be estimated by examining the basic Rational Method hydrograph shape shown in Figure 7.6.

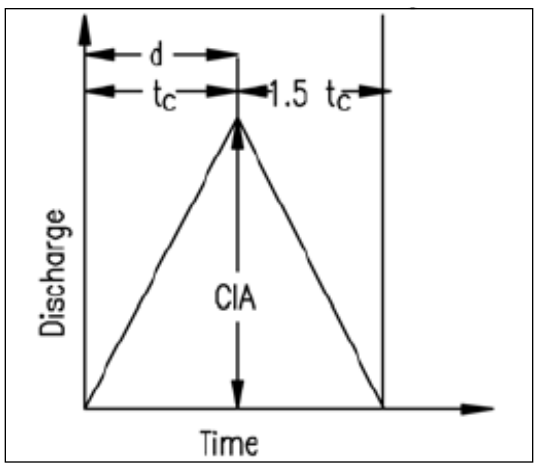

Figure 7.6. Basic Rational Hydrograph Shape
Virginia Stormwater Management Handbook, (DCR, 1999)

The time of concentration is known to be 8 minutes. Therefore, the "base" of the triangular shaped hydrograph is 20 minutes (1,200 seconds). The total area under the hydrograph is the water quality volume (1,361 ft^3). Therefore, employing the area relationship of a triangle, the lone unknown, Q, is computed as follows:

$$A = \left(\frac{1}{2}\right) \times b \times h$$

$$h = \frac{2A}{b}$$

$$Q = \frac{(2)(1{,}361\,ft^3)}{1{,}200s} = 2.3cfs$$

The water quality volume from the 0.75 acre impervious development generates an estimated peak discharge of 2.3 cfs. This value is now used to size the strip.

Step 4. Compute the Strip Length (Flow Direction)

Runoff will enter onto the strip from a level spreader. The size of the level spreader is a function of the 10-year flow from the contributing drainage area. The required level spreader dimensions are shown in Table 7.4.

Q10 (cfs)	Depth (ft)	Width of Lower Side Slope of Spreader (ft)	Length (ft)
0-10	0.5	6	10
20-10	0.6	6	20

Table 7.4. Minimum Level Spreader Dimensions
Virginia Erosion and Sediment Control Handbook (DCR, 1992)

The 10-year peak rate of runoff from the roadway is 4.3 cfs. Therefore, the minimum level spreader "lip" length that will discharge runoff onto the strip is 10 feet.

In order to assure that the minimum five minute hydraulic residence time is achieved, the length of the strip (in the direction of flow) must be sized as a function of the anticipated flow velocity on the strip.

Flow velocity is computed by the Manning's equation. A Manning roughness coefficient of 0.20 is typically used in grass filter strip flow calculations. If the filter strip is mowed infrequently, a roughness coefficient of 0.24 may be used. (FHWA, 1996, pg 325; also, Horner, 1993). This Manning roughness coefficient is derived from employing the anticipated flow velocity and flow depth on the filter strip. Manning's n values for various categories of vegetative ground covers are presented in Table 7.5.

Surface	Recommended Value	Range of Values
Range (natural)	0.13	0.01-0.32
Range (clipped)	0.08	0.02-0.24
Grass (bluegrass sod)	0.45	0.39-0.63
Short Grass Prairie	0.15	0.10-0.20
Dense Grass	0.24	0.17-0.30
Bermuda Grass	0.41	0.30-0.48

Table 7.5. Recommended Manning's n Values for Overland Flow

Source: Mays, Larry W. Water Resources Engineering. John Wiley & Sons, Inc. New York, NY, 2001.

By the principal of continuity, flow on the strip can be expressed as:

$$Q = V \times W \times h$$

Q = volumetric flow rate (cfs)
V = average flow velocity on the strip (fps)
W = strip width (ft)
H = flow depth on the strip (ft)

For shallow overland flow, the anticipated flow depth is assumed equal to the hydraulic radius. Expressing flow in terms of the Manning's equation, the previous expression becomes:

$$Q = \frac{1.49}{n} \times h^{\frac{2}{3}} \times S^{\frac{1}{2}} \times (W \times h)$$

n = Manning roughness coefficient
S = filter strip slope (ft/ft)
Other terms as previously defined

This equation can then be rearranged to isolate the desired unknown, *h.*

$$\frac{Q}{W} = \frac{1.49}{n} \times h^{\frac{5}{3}} \times S^{\frac{1}{2}}$$

At this stage in the design, the filter strip width is unknown. Therefore, an assumption must be made and its adequacy later verified. We will assume a filter strip width of 25 feet. Then, solving for h:

$$\frac{2.3}{25} = \frac{1.49}{0.20} \times h^{\frac{5}{3}} \times 0.02^{\frac{1}{2}}$$

$$h = 0.23 \text{ ft}$$

Employing the previously established parameters, flow velocity on the strip is computed as follows:

$$V = \frac{1.49}{n} R_h^{\frac{2}{3}} S^{\frac{1}{2}}$$

V = velocity (fps)
N = Manning roughness coefficient
R_h = hydraulic radius (ft, equal to flow depth for shallow overland flow)
S = filter strip slope (ft/ft)

$$V = \frac{1.49}{0.20}(0.23)^{\frac{2}{3}}(0.02)^{\frac{1}{2}} = 0.395\frac{ft}{s}$$

Next, the filter strip length can be computed as a function of this flow velocity and the target hydraulic residence time. First, the minimum residence time of five minutes is considered:

$$L = t \times V$$

L = filter strip length (ft)
t = target hydraulic residence time (sec)
V = flow velocity (fps)

$$L = 5\min \times \frac{60\sec}{\min} \times 0.395\frac{ft}{\sec} = 119\,ft$$

It is again noted that this approach does not consider that a portion of the water quality volume will infiltrate into the strip's subsoil. Additionally, the accumulation of flow depth and subsequent decrease in velocity is not considered. Therefore, the computed length of 119 feet reflects a conservative design which can reasonably be assumed to provide a hydraulic residence time in excess of the minimum value of five minutes.

Step 5. Verify Adequacy of the Assumed Strip Width (Perpendicular to Flow Direction)

The *minimum* width of the filter strip should be the greater of the two values:

0.2 x Filter Length

or

8 feet

Therefore, the minimum strip width is computed as follows:

$$0.2 \times 119\,ft = 23.8\,ft$$

The assumed strip width of 25 feet is therefore adequate.

Ideally, the filter strip width will equal the width of the contributing drainage area. When a level spreader is used, as in this example, the lip of the spreader must extend to within *a minimum* of 10 feet of the filter strip on each end (Virginia Stormwater Management Handbook*, (DCR, 1999)*. The proposed level spreader lip is 10 feet in length. Therefore the spreader extends to within 7.5 feet of the filter edges (see calculation below):

$$\frac{25\,ft - 10\,ft}{2} = 7.5\,ft$$

If this value was found to exceed 10 feet the level spreader length would need to be increased.

Step 6. Selection of Vegetation

Filter strips must be constructed of dense, soil-binding deep rooted water-resistant plants. If a grass filter strip is to be employed, a dense turf is necessary to achieve desirable pollutant removal percentages while avoiding erosion. If turf grass is used, the height shall be maintained between two and four inches. The specific species of vegetation should be appropriate for the climatic conditions and expected maintenance.

Filter strips should be planted with a minimum of two of the following vegetation types, per the Virginia Stormwater Management Handbook (DCR, 1999):

- deep-rooted grasses, ground covers, or vines
- deciduous and evergreen shrubs
- under-and over-story trees

The choice of planting species should be largely based on the project site's physiographic zone classification. Additionally, the selection of plant species should match the native plant species as closely as possible. Surveying a project site's native vegetation will reveal which plants have adapted to the prevailing hydrology, climate, soil, and other geographically-determined factors. Figure 3.05-4 of the Virginia Stormwater Management Handbook provides guidance in plant selection based on project location.

All chosen plant species should conform to the American Standard for Nursery Stock, current issue, and be suited for USDA Plant Hardiness Zones 6 or 7, see Figure 7.7 on the following page.

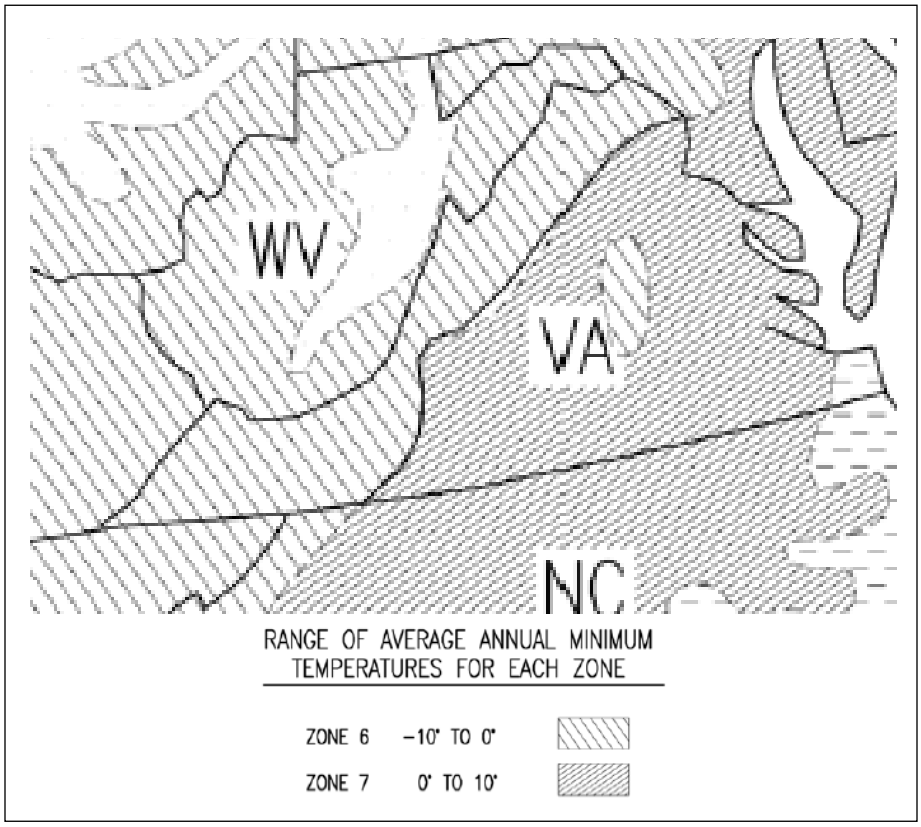

Figure 7.7. USDA Plant Hardiness Zones

The presences of trees, shrubs, and other woody vegetation can further increase the water quality performance of vegetated filter strips. In addition to intercepting a portion of stormwater before it even reaches the ground, trees and shrubs increase the infiltration and retention present in the filter strip. However, when trees are incorporated into the filter strip design, one must be aware that the overall density of vegetation is decreased. Consequently, while filter strips with trees and other woody vegetation can demonstrate higher pollutant removal efficiencies than their strictly grass counterparts, they require that the filter strip be longer in length to account for the reduced vegetation density. Additionally, tree and shrub trunks have the potential to support the development of gullies and channels in the strip. To offset this phenomenon, filter strips equipped with trees and shrubs should be designed with flatter slopes than those employing only grass.