B.13 VEGETATIVE SWALE

DESCRIPTION

Vegetated swales are shallow vegetated channels to convey stormwater where pollutants are removed by filtration through grass and infiltration through soil. They look similar to, but are wider than, a ditch that is sized only to transport flow. They require shallow slopes and soils that drain well. Grassed swale designs have achieved mixed performance in pollutant removal efficiency. Moderate removal rates have been reported for suspended solids and metals associated with particulates such as lead and zinc. Runoff waters are typically not detained long enough to effectively remove very fine suspended solids, and swales are generally unable to remove significant amounts of dissolved nutrients. Pollutant removal capability is related to channel dimensions, longitudinal slope, and type of vegetation. Optimum design of these components will increase contact time of runoff through the swale and improve pollutant removal rates.

Vegetated swales are primarily stormwater conveyance systems. They can provide sufficient control under light to moderate runoff conditions, but their ability to control large storms is limited. Therefore, they are most applicable in low to moderate sloped areas as an alternative to ditches and curb and gutter drainage. Their performance diminishes sharply in highly urbanized settings. Vegetated swales are often used as a pretreatment measure for other downstream BMPs, particularly infiltration devices. Enhanced vegetative swales utilize check dams and wide depressions to increase runoff storage and promote greater settling of pollutants.

ADVANTAGES

1. Relatively easy to design, install and maintain.
2. Vegetated areas that would normally be included in the site layout, if designed for appropriate flow patterns, may be used as a vegetated swale.
3. Relatively inexpensive.
4. Vegetation is usually pleasing to residents.

LIMITATIONS

1. Irrigation may be necessary to maintain vegetative cover.
2. Potential for mosquito breeding areas.
3. Possibility of erosion and channelization over time.
4. Requires dry soils with good drainage and high infiltration rates for better pollutant removal.

5. Not appropriate for pollutants toxic to vegetation.
6. Large area requirements may make this BMP infeasible for some sites.
7. Used to serve sites less than 10 acres in size, with slopes no greater than 5 percent.
8. The seasonal high water table should be at least 2 feet below the surface.
9. Buildings should be at least 10 feet from the site.

DESIGN CRITERIA

Several criteria should be kept in mind when beginning swale design. These provisions, presented in Table 1, have been developed through a series of evaluative research conducted on swale performance.

Table 1. Criteria for optimum swale performance (Horner, 1993).

Parameter	***Optimal Criteria***	***Minimum Criteria****
Hydraulic Residence Time	9 min	$ 5 min
Average Flow Velocity	# 0.9 ft/s	
Swale Width	8 ft	2 ft
Swale Length	200 ft	100 ft
Swale Slope	- 2 - 6%	- 1%
Side Slope Ratio (horizontal:vertical)	4 : 1	2 : 1

* Criteria at or below minimum values can be used when compensatory adjustments are made to the standard design. Specific guidance on implementing these adjustments will be discussed in the design section.

The procedures described below were set forth by Horner, and unless otherwise cited, are set forth in *Biofiltration for Stormwater Runoff Quality Control*, published in 1993. The following steps are recommended to be conducted in order to complete a swale design:

(1) Determine the flow rate to the system.
(2) Determine the slope of the system.
(3) Select a swale shape (skip if filter strip design).
(4) Determine required channel width.
(5) Calculate the cross-sectional area of flow for the channel.
(6) Calculate the velocity of channel flow.
(7) Calculate swale length.
(8) Select swale location based on the design parameters.
(9) Select a vegetation cover for the swale.
(10) Check for swale stability.

Recommended procedures for each task are discussed in detail below.

1. *Determine Flow Rate to the System.* Calculate the flow rate of stormwater to be mitigated by the vegetated swale using the Los Angeles County Department of Public Works *Method for Calculating Standard Urban Stormwater Mitigation Plan (SUSMP) Flow Rates and Volumes Based on 0.75-inches of Rainfall*. Runoff from larger events should be designed to bypass the swale, consideration must be given to the control of channel erosion and destruction of vegetation. A stability analysis for larger flows (up to the 100-yr 24-hour) must be performed. If the flow rate approaches or exceeds 1 ft^3/s, one or more of the design criteria in Table 1 may be violated, and the swale system may not function correctly (Washington State Department of Transportation, 1995). Alternative measures to lower the design flow should be investigated. Possibilities include dividing the flow among several swales, installing detention to control release rate upstream, and reducing developed surface area to reduce runoff coefficient value and gain space for biofiltration (Horner, 1993).
2. *Determine the Slope of the System.* The slope of the swale will be somewhat dependent on where the swale is placed, but should be between the stated criteria of one and six percent.
3. *Select a Swale Shape.* Normally, swales are designed and constructed in a trapezoidal shape, although alternative designs can be parabolic, rectangular, and triangular. Trapezoidal cross-sections are preferred because of relatively wider vegetative areas and ease of maintenance (Khan, 1993). They also avoid the sharp corners present in V-shaped and rectangular swales, and offer better stability than the vertical walls of rectangular swales.
4. *Determine Required Channel Width.* Estimates for channel width for the selected shape can be obtained by applying Manning's:

$$Q = \frac{1.486 A R_h^{0.667} S^{0.5}}{n} \qquad (1)$$

Where:

Q	=	Flow (ft^3/s).
A	=	Cross-sectional area of flow (ft^2).
R_h	=	Hydraulic radius of flow cross section (ft).
S	=	Longitudinal slope of biofilter (ft/ft).
n	=	Manning's roughness coefficient.

A Manning's n value of 0.02 is used for routine swales that will be mowed with some regularity. For swales that are infrequently mowed, use a Manning's n value of 0.024. A higher n value can be selected if it is known that vegetation will be very dense (Khan, 1993). Figure 1 presents channel geometry and equations for a trapezoidal swale, the most frequently used shape.

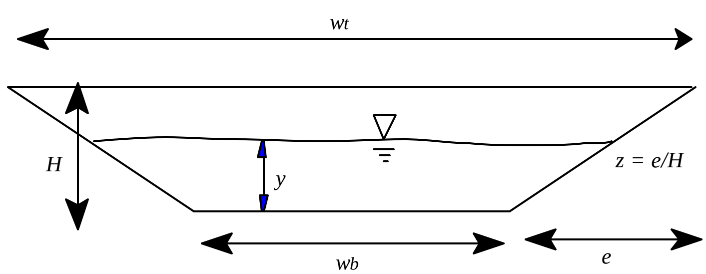

Figure 1. Channel geometry for a trapezoid swale.

$$Cross\ Sectional\ Area(A_x) = by + zy^2$$

$$Width(w) = b + 2yz$$

$$Hydraulic\ Radius(R_h) = \frac{by + zy^2}{by + 2y\sqrt{z^2 + 1}}$$

Substituting the geometric equations presented in Figure 1 into Manning’s equation, the bottom width (w_b) and the top width (w_t) for the trapezoid swale can be computed using the following equations:

$$w_b = \frac{Qn}{y^{1.67} s^{0.5}} - zH \qquad (2)$$

$$w_t = w_b + 2zH \qquad (3)$$

Where:

Q	=	Flow rate in ft^3/s.
n	=	Manning's roughness coefficient.
y	=	Depth of flow.
H	=	The side slope in the form of z:1.

For trapezoidal and the limited case of V-shapes, the side slope (z) used should be at least 3:1 (horizontal:vertical). V-shaped swales should be double checked after computation of w_t to make sure that $z = 2w_t$ is at least 3. If a slope steeper than 2:1 must be used, additional stabilization measures (i.e., lining the swale with riprap) may be needed.

Typically, the depth of flow in the channel (H) is set at 3 to 4 inches. Flow depth can also be determined by subtracting 2 inches from the expected grass height, if the grass type and the height it will be maintained is known. Values lower than 3 to 4 inches can be used, but doing so will increase the computed width (w_t or w_b) of the swale (Washington State Department of Transportation, 1995).

Swale width computed should be between 2 to 8 feet. Relatively wide swales (those wider than 8 feet are more susceptible to flow channelization and are less likely to have uniform sheet flow across the swale bottom for the entire swale length. The maximum widths for swales is on the order of 10 feet, however widths greater than 8 feet should be evaluated to consider the effectiveness of the flow spreading design used and the likelihood of maintaining evenness in the swale bottom. Since length may be used to compensate for width reduction (and vice versa) so that area is maintained, the swale width can be arbitrarily set to 8 feet to continue with the analysis. If b is less than 2 feet, set b = 2 feet and continue. Narrower widths can be used if space is very constrained. Sometimes when the flow rate is very low, the equation above can generate a negative value for w_b. Since this is not possible, the bottom width should be set to 1 feet when this occurs.

5. *Calculate Cross-Sectional Area.* Compute the cross-sectional area (A) for the swale, using the following equation:

$$A_x = (w_b + 2zH)yH \qquad (4)$$

6. *Calculate the Velocity of the Channel Flow.* Channel flow velocity (U) can be computed using the continuity equation:

$$U = \frac{Q}{A_x} \quad (5)$$

This velocity should be less than 0.9 ft/s, a velocity that was found to cause grasses to be flattened, reducing filtration. A velocity lower than this maximum value is recommended to achieve the 9-minute hydraulic residence time criterion, particularly in shorter swales (at U = 0.9 ft/s, a 485-ft swale is needed for a 9-min residence time and a 269-ft swale for a 5-min residence time).

If the value of U suggests that a longer swale will be needed than space permits, investigate how the design flow Q can be reduced, or increase flow depth (H) and/or swale width (w_t) up to the maximum allowable values and repeat the analysis.

7. *Calculate Swale Length.* Compute the swale length (L) using the following equation:

$$L = U t_r \, (60 \; s/\text{min}) \quad (6)$$

Where:

t_r = Hydraulic residence time (in minutes).

Use t_r = 9 min for this calculation.

If a swale length greater than the space will permit results, investigate how the design flow Q can be reduced. Increase flow depth (H) and/or swale width (w_b) up to the maximum allowable values and repeat the analysis. If all of these possibilities are checked and space is still insufficient, t can be reduced, but to no less than 5 minutes. If the computation results in L less than 100 ft, set L = 100 ft and investigate possibilities in width reduction. This is possible through recalculating U at the 100-ft length, recomputing cross-sectional area, and ultimately adjusting the swale width w_b using the appropriate equation.

8. *Select Swale Location.* Swale geometry should be maximized by the designer, using the above equations, and given the area to be utilized. If the location has not yet been chosen, it is advantageous to compute the required swale dimensions and then select a location where the calculated width and length will fit. If locations available cannot accommodate a linear swale, a wide-radius curved path can be used to gain length. Sharp bends should be avoided to reduce erosion potential. Regardless of when and

how site selection is performed, consideration should be given to the following site criteria:

Soil Type. Soil characteristics in the swale bottom should be conducive to grass growth. Soils that contain large amounts of clay cause relatively low permeability and result in standing water, and may cause grass to die. Where the potential for leaching into groundwater exists, the swale bottom may need to be sealed with clay to protect from infiltration into the resource. Compacted soils will need to be tilled before seeding or planting. If topsoil is required to facilitate grass seeding and growth, use 6 inches of the following recommended topsoil mix: 50 to 80 percent sandy loam, 10 to 20 percent clay, and 10 to 20 percent composted organic matter (exclude animal waste).

Slope. The natural slope of the potential location will determine the nature and amount of regrading, or if additional measures to reduce erosion and/or increase pollutant removal are required. Swales should be graded carefully to attain uniform longitudinal and lateral slopes and to eliminate high and low spots. If needed, grade control checks should be provided to maintain the computed longitudinal slope and limit maximum flow velocity (Urbonas, 1992).

Natural Vegetation. The presence and composition of existing vegetation can provide valuable information on soil and hydrology. If wetland vegetation is present, inundated conditions may exist at the site. The presence of larger plants, trees and shrubs, may provide additional stabilization along the swale slopes, but also may shade any grass cover established. Most grasses grow best in full sunlight, and prolonged shading should be avoided. It is preferable that vegetation species be native to the region of application, where establishment and survival have been demonstrated.

9. *Select Vegetative Cover.* A dense planting of grass provides the filtering mechanism responsible for water quality treatment in swales. In addition, grass has the ability to grow through thin deposits of sediment and sand, stabilizing the deposited sediment and preventing it from being resuspended in runoff waters. Few other herbaceous plant species provide the same density and surface per unit area. Grass is by far the most effective choice of plant material in swales, however not all grass species provide optimum vegetative cover for use in swale systems. Dense turf grasses are best for vegetative cover. Table 2 lists several turf grasses, and their suitability in terms of cold tolerance, heat tolerance, mowing height adaptation, drought tolerance, and maintenance cost and effort.

In areas of poor drainage, wetlands species can be planted for increased vegetative cover. Use wetland species that are finely divided like grass and relatively resilient. Invasive species, such as cattails, should be avoided to eliminate proliferation in the swale and downstream.

Woody or shrubby plantings can be used for landscaping on the edge of side slopes, but not in the swale treatment area. Trees and shrubs can provide some additional stabilization, but also mature and shade the grass. In addition, leaf or needle drop can contribute unwanted nutrients, create debris jams, or interfere with waterflow through the system. If landscape plantings are to be used, selection and planting processes should be carefully planned and carried out to avoid these potential problems.

	Cold Tolerance	Heat Tolerance	Mowing Height	Drought Tolerance	Maintenance
High	Creeping bentgrass Kentucky bluegrass Red fescue Colonial bentgrass Highland bentgrass	Zoysia grass Hybrid bermuda grass Common bermuda grass St Augustine grass Kikuyu grass	Tall fescue	Hybrid bermuda grass Zoysia grass Common bermuda grass	Creeping bentgrass Dichondra
			Red fescue Kentucky bluegrass Perennial ryegrass Weeping alkali grass	St Augustine grass Kikuyu grass	Hybrid bermuda grass
		Tall fescue Dichondra Creeping bentgrass			
		Kentucky bluegrass	St. Augustinegrass Common bermudagrass		Kentucky bluegrass Colonial bentgrass Perennial ryegrass
	Tall fescue Weeping alkali grass	Highland bentgrass Perennial ryegrass Colonial bentgrass	Dichondra Kikuyugrass Colonial bentgrass Highland bentgrass Zoysiagrass	Tall fescue Red fescue	St. Augustine grass Highland bentgrass Zoysia grass
			Hybrid bermudagrass		
Low	Dichondra Zoysia grass Common bermuda grass Hybrid bermuda grass Kikuyu grass St. Augustine grass	Weeping alkaligrass Red fescue	Creeping bentgrass	Kentucky bluegrass Perennial ryegrass Highland bentgrass Creeping bentgrass Colonial bentgrass Weeping alkaligrass Dichondra	Tall fescue Common bermuda grass Kikuyu grass

Table 2. Criteria for turf grass cover
(Camp, Dresser and McKee, 1993.)

10. *Check Swale Stability.* The stability check is performed for the combination of highest expected flow and least vegetation coverage and height. Stability is normally checked for flow rate (Q) for the 100-yr, 24-h storm unless runoff from larger such events will bypass the swale. Q can be determined using the same methods mentioned for the initial design storm computation. The maximum velocity (U_{max}) in ft/s, that is permissible for the vegetation type, slope, and soil conditions should be obtained. Table 3 provides maximum velocity data for a variety of vegetative covers and slopes.

Table 3. Guide for selecting maximum permissible swale velocities for stability (adapted from Chow [1959], Livingston, et al., [1984], and Goldman, et al., [1986] from Horner [1993]).

		Maximum Velocity (ft/s)	
Cover Type	***Slope (%)***	***Erosion-resistant soils***	***Easily eroded soils***
Kentucky bluegrass Tall fescue	0 - 5	6	5
Kentucky bluegrass Ryegrasses Western wheat-grass	5 - 10	5	4
Grass-legume Mixture	0 - 5 5 - 10	5 4	4 3
Red fescue	0 - 5	3	2.5

The estimated degree of retardance for different grass coverage ("good" or "fair") should be obtained for the selected vegetation height. Estimation should be based on coverage and height will first receive flow, or whenever coverage and height are at their lowest. Table 4 provides qualitative degree of retardance for coverage and grass height.

Table 4. Grass coverage, height, and degree of retardance (Horner, 1993).

Average Grass Height (mm [inches])	***Degree of Retardance***	
Coverage = "Good"		
> 760 (30)	A.	Very high
280 - 610 (11 -24)	B.	High
150 - 270 (6 - 10)	C.	Moderate
50 - 150 (2 - 6)	D.	Low
> 50 (>2)	E.	Very low
Coverage = "Fair"		
> 760 (30)	B.	High

Table 4. Grass coverage, height, and degree of retardance (Horner, 1993).

Average Grass Height (mm [inches])	***Degree of Retardance***
280 - 610 (11 -24)	C. Moderate
150 - 270 (6 - 10)	D. Low
50 - 150 (2 - 6)	D. Low
> 50 (>2)	E. Very low

Select a trial Manning's n value for poor vegetation cover and low height. A good initial choice is n = 0.04. Using the alphabetic code assigned for the degree of retardance and the chosen n value, consult the following graph to obtain a first approximation for UR_h (velocity x hydraulic radius).

The graph in Figure 2 was derived based on English units. Compute the hydraulic radius, using the U_{max} determined for vegetation type and slope, by applying the following equation:

$$UR_h = \frac{UR_h}{U_{\max}} \tag{7}$$

Use Manning's equation to solve for the actual UR_h:

$$VR = \frac{1}{n} R^{1.67} s^{0.5} \tag{8}$$

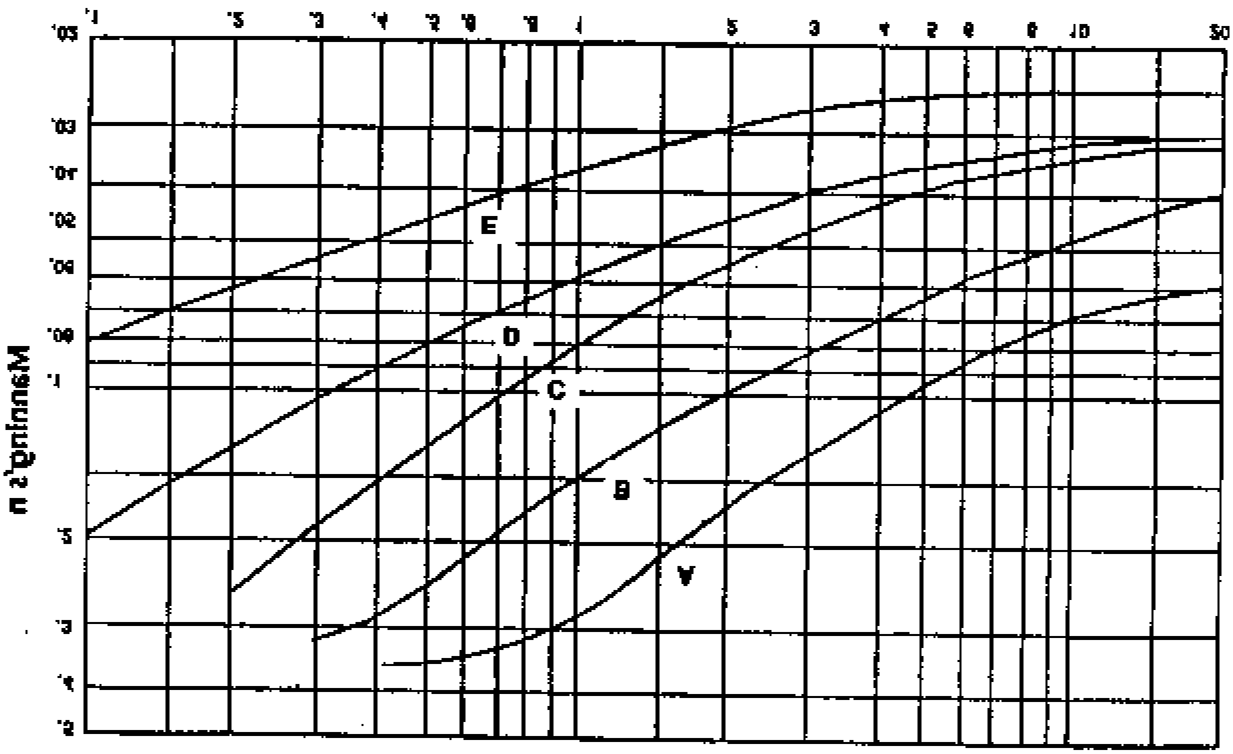

Figure 2. Relationship of Manning's n with UR_h for various degrees of flow retardance.

Once the actual UR_h is determined, compare this value with the first approximation for UR_h obtained through Figure 2. If they do not agree within five percent, adjust Manning's n value and repeat the process until acceptable agreement is reached. If n < 0.033 is needed to get agreement, set n = 0.033, solve UR_h again using Manning's equation above, and proceed.

The actual velocity for the final design conditions should be computed using the following equation:

$$U = \frac{UR_h}{R_h} \quad (9)$$

The actual velocity U should be less than the U_{max} value obtained from Table 3.

The area (A_x) required for stability should be computed from the following equation:

$$A_x = \frac{Q}{U} \tag{10}$$

The area value obtained in this procedure should be compared with the area (A_x) value obtained in the capacity analysis. If less area is required for stability than is provided for capacity, the design is acceptable. If more area is required for stability, use the area (A_x) value obtained in the stability analysis to recalculate channel dimensions.

The depth of flow at the stability check design flow rate then needs to be computed for the final dimensions of the swale by solving for y in the area equations provided on Figure 2. Compare this flow depth to the depth used in the capacity design. The larger of the two values should be used, plus 1 ft of freeboard, to obtain the total depth of the swale. The top width for the full depth of the swale should than be recalculated.

As a final check for capacity should be performed based on the stability check design storm, maximum vegetation height and cover to ensure that capacity is adequate if the largest expected event coincides with the greatest retardance. Using Manning's equation, the Manning's n value used for capacity design, and the calculated channel dimension (including freeboard) to compute the flow capacity of the channel. If the flow capacity is less than the stability check design storm flow rate, increase the channel cross-sectional area as needed for this conveyance, and specify the new channel dimensions.

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The following is a list of known locations where a Vegetated Swale was installed. The design of the installed swale in each location may vary from what is recommended in this SUSMP due to its specific circumstances. Los Angeles County does not endorse nor warranty any design used in the locations herein. Each individual case may require that the design be tailored to perform properly.

Installed Location (City/Address)	**Brand/Manufacturer**	**Owner/Client**
Cerritos Maintenance Station	N/A	Caltrans
I-605/Del Amo Ave.	N/A	Caltrans