Grassed Swales (GS), Infiltration Swales (IS), and Wet Swales (WS)

Infiltration Swale at Auburn Research Park; Auburn, AL

Site Selection

Quantity Control	---
Drainage Area	small
Space Required	small

Works with:

Steep Slopes	✔
Shallow Water Table	✔
Poorly Drained Soils	✔

General Significance

Construction Cost	low
Maintenance	low
Community Acceptance	high
Habitat	low
Sun / Shade	either

Synonyms: Vegetated swale, bioswale, wetland channel, dry swale, wet swale, conveyance channel, reinforced swale, grassy swales, biofilter

A water quality swale is a shallow, open-channel stabilized with grass or other herbaceous vegetation designed to filter pollutants and convey stormwater. Swales are applicable along roadsides, in parking lots, residential subdivisions, commercial developments, and are well suited to single-family residential and campus-type developments. Water quality swales presented in this handbook are designed to meet velocity targets for the water quality design storm, may be characterized as wet or dry swales, may contain amended soils to infiltrate stormwater runoff, and are generally planted with turfgrass or other herbaceous vegetation.

Site Selection

Swales can reduce infrastructure costs by eliminating the need for curb and gutter and traditional stormwater piping. Swales are applicable along roadsides, in parking lots, residential subdivisions, or commercial developments, and are well suited to single-family residential and campus-type development. Any type of swale design can be paired with other structural Low Impact Development (LID) stormwater control measures (SCMs) to increase pollutant load reductions and to capture excess stormwater leaving the swale. Swales are typically paired with level spreaders, filter strips, bioretention cells, constructed stormwater wetlands, or permeable pavement to meet treatment needs. However, swales are also used as a stand-alone practice in many applications and work well as retrofits.

Drainage Area: Swales are designed as conveyance channels that capture and treat stormwater runoff in smaller drainage areas. Swales are recommended for drainage areas of 5 acres or less and should capture runoff from approximately 10-20% of the contributing impervious surface area.

Evaluating Soils: Use the USDA Web Soil Survey to identify soil map units and to make initial interpretations for potential uses and limitations of a site. However, since most soil map units have inclusions of other soils that may be quite different, detailed evaluations should be made at the proposed site by a professional soil scientist or soil classifier. On-site evaluations should properly identify a soil or the hydrologic soil group (HSG) and the final decision for use should be made based on the detailed determination of soil series or HSG. For a detailed list of HSG properties, see Table A.3 in Appendix A on Stormwater Hydrology.

In-Situ Soil: The topography and in-situ soil characteristics, particularly the soil texture and hydrologic soil group (HSG), will determine the applicability of a wet or dry swale design. An infiltration test should be performed to determine

Table 4.4.1
Site Selection: Constraints & Limitations for Swales

Slope	Locations with less than 5% slopes where possible
Utilities	Call Alabama 811 before construction to locate utilities (for more information, visit: www.al1call.com)
Limited Volume Control	If storage volume is a primary objective - may need to use another SCM
High Sediment Loads	Swale location should not experience high sediment loads that may clog system; when sediment is introduced there is a risk of possible sediment re-suspension
Continuous Flow	Locations that will not experience continuous flow and are allowed to drain are recommended for dry swales
Not Regional Stormwater Control	If regional stormwater control is desired, use another SCM
Lower Pollutant Removal Rates	An infiltration swale is recommended for highest pollutant removal; increase media/fill material depth for temperature reductions
Undersized Swale, Site Size Constrained	If the site will not support swale size required for design storm treatment, use another SCM or use in conjunction with another SCM, an undersized swale will not adequately reduce total suspended solids

infiltration rates (for more information on an infiltration test, see Chapter 5.1 on Rain Gardens). Dry swales (grassed swales and infiltration swales) are appropriate for HSG A and B that are well-drained to moderately well-drained, respectively (see Table A.3 in Appendix A on Stormwater Hydrology for more information on HSG properties). A dry swale should have an infiltration rate greater than 0/5"/hr and may require that soils be amended to achieve the desired infiltration rate. Infiltration swales may require that soils be amended to achieve desired infiltration rates. Wet swales are conducive to HSG C or in areas where the water table is close to the soil surface.

USDA's online Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm) can be used as a guide to determine the needed soil information for the site, such as the hydrologic soil group (HSG) and depth to water table.

Depth to Groundwater: The seasonally high water table should be a minimum of 1' below the bottom of any type of swale and the swale should never intercept groundwater. However, if an aquifer or "hotspot" is present, there should be a minimum of 2' between the bottom of the channel and the seasonally high water table. Hotspots are defined as commercial, industrial, or other operations that produce higher levels of stormwater pollutants and/or have concentrated pollutants.

Slope: Swales should be sited so that they have a mild entrance slope to avoid high velocity flows, and channel dimensions that allow for non-erosive velocities (less than 4' per second or fps). The longitudinal slope should not exceed 5% where possible. Longitudinal slope is important to create conveyance, but should not increase the velocity of the system greater than 1 fps for a 10 - year design storm.

Flow Regime: The designer should evaluate grade transitions to consider the flow regime and range of discharges up to the design flow rate. Hydraulic jumps caused by changes in flow regime should be avoided due to potential erosion and scouring that may occur at locations of undulating flow. Grading to ensure a uniform slope and surface will minimize erosion, sediment re-suspension, and additional maintenance.

Turf Reinforced Matting: Velocities greater than 4 fps may result in eroded grassed swales, and a turf reinforced matting (TRM) under the sod can be used to hold turfgrass in place during high flows.

Common Swale Design Variations

Dry Swales: Dry swales consist of grassed swales and infiltration swales. Dry swales are designed to convey or infiltrate only the "first flush" (water quality volume) or to handle the peak flow volume. See Appendix A on Stormwater Hydrology for more information on first flush. Dry swales may have underdrains that convey stormwater into an outlet, use an overflow device, or a combination of these. Dry swales are designed to have standing water for a maximum of 48 hours, however, 24 hours is preferred. Depending on the type of dry swale, these designs may have shallow,

Table 4.4.2

Types of Swales

Swale Type	Soil/Media	Comments
Grassed Swale	Well-drained in-situ soil or a 50/50 sand/soil mix	Dry swale planted with turfgrass sod
Infiltration Swale	50/50 sand/soil mix or bioretention media mix	Dry swale planted with flood and drought tolerant vegetation; when a bioretention media is used, a layer of gravel is typically placed below the media and an underdrain may be utilized
Wet Swale	Native poorly drained soils	Wetland vegetation

open-channels over a fill material of well-drained in-situ soils, a 50/50 sand/soil mix, or a bioretention media mix.

Grassed Swales: Grassed Swales are dry swales planted with turfgrass and are often used along roadsides where mowing is the primary form of maintenance. Grassed swales are typically used for conveyance, but when placed over well-drained soils (or amended soils), these may provide infiltration of runoff and water quality improvement. In-situ soil can be amended with a 50/50 sand/soil mix to enhance infiltration.

Infiltration Swales: Infiltration swales typically have at least 30" of amended soil (50/50 sand/soil mix or bioretention media mix) beneath the bottom of the swale to aid in infiltrating runoff. See Chapter 4.1 on Bioretention for more information on the recommended media recipe for targeted pollutant removal. Infiltration swales that use a bioretention media mix typically have a layer of gravel beneath the media and an underdrain may or may not be utilized. Infiltration Swales are dry swales that are planted with native grasses, herbaceous perennials, and small shrubs. Infiltration swales are easily integrated into the landscape and can be attractive and aesthetically pleasing in residential and commercial developments, parking lot islands, and medians. Small woody shrubs can be planted in swale channels when their mature height and width does not exceed landscape requirements of the site.

Wet Swales: A wet swale design consists of a shallow, open channel that is placed over poorly drained soils or in areas with a high water table. Amended soil media is not necessary for wet swales. Wet swales are retention structures that are designed to handle the peak flow event and retain all or a portion of the water quality volume. By retaining stormwater, wet swales use increased residence time to provide water quality benefits. They are planted with wetland plants to facilitate pollutant removal.

Pretreament Swales: When used as pretreatment for other SCMs, the swale should be at least 20' in length.

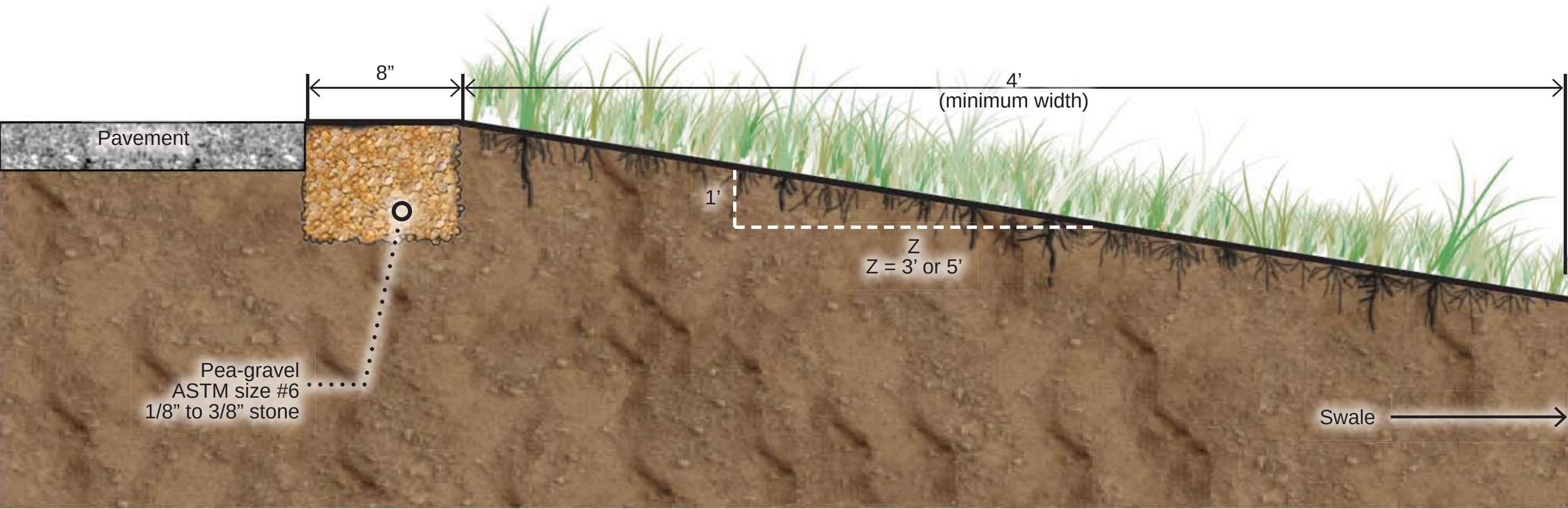
Design

All swale designs consist of three primary components: pretreatment, swale, and overflow. The size of each of these components is based on the volume or design storm to be treated. Swale location should be based on site topography to allow for the integration of natural drainage patterns within the swale drainage way.

Components

Pretreatment: A forebay, grassed filter strip, or grassed inlet is used as a pretreatment device for swales.

Forebay: The forebay is a pool located at the inlet of a system. It is deepest at the point of runoff entry and shallowest at the exit point. This design dissipates energy throughout the forebay and provides diffuse flow into the swale. A forebay



is recommended when there is a single, concentrated flow entering the swale. It serves as a sediment sink for runoff entering the system to prevent clogging of the swale channel and subsequent damage to vegetation.

The forebay should be 18 - 30” deep and is designed to be 0.2% of the watershed drainage area. If standing water is a concern, a grassed filter strip may be used as a pretreatment device. Wet swales typically have a forebay for pretreatment and stormwater is released into the wet channel.

Grassed Filter Strip: A minimum width of 3’ of a grassed filter strip is recommended for the entire length of the swale. See Chapter 4.5 on Level Spreaders and Grassed Filter Strips for more information.

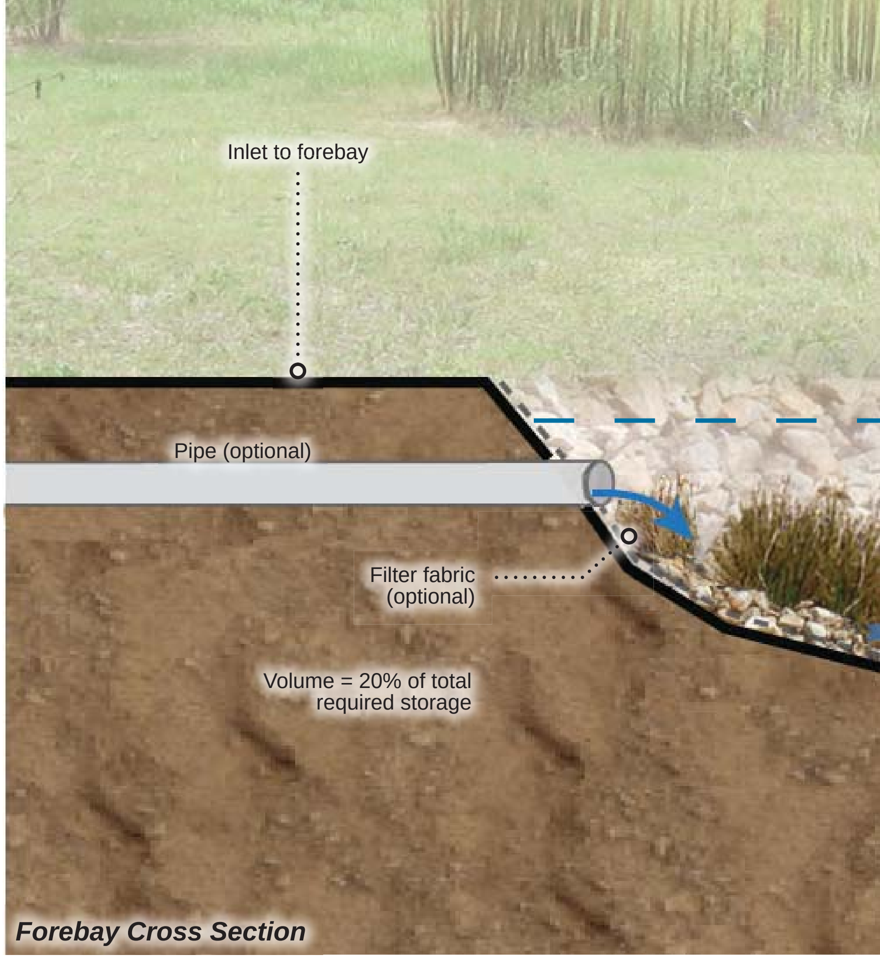
Grassed Inlet: A grassed inlet uses the side slopes of the swale as pretreatment. Grassed inlets are planted with dense turfgrass and have a gentle slope (3:1 or greater, 5:1 is recommended) to prevent erosion. A grassed inlet allows water to enter the system from all sides of the swale, which slows stormwater velocity, and serves as a sediment trap for larger particles.

Swale: The swale is designed to be triangular or trapezoidal in shape, with a minimum of 3:1 side slopes (5:1 is recommended), and a length that does not exceed 100’. Whether the swale is designed to be wet or dry, it is ultimately designed as an infiltration, filtration, and conveyance structure.

Additional Components

Underdrain: Infiltration swales may include the use of underdrains to drain the swale within 48 hours and minimize standing water conditions. Underdrains are corrugated or smooth wall perforated pipe and should be configured to tie in with the overflow or discharge into the stormwater conveyance network. Underdrains are not used in wet swale designs.

Curb Cuts: Curb cuts can be used to direct flows into the swale and are easy retrofits to traditional curb and gutter. Curb cuts do not treat stormwater runoff, but can function as the inlet to a swale system while minimizing erosion (for more information, see Chapter 5.2 on Curb Cuts).



Forebay Cross Section

EQN 4.4.1

$$T_c = \frac{\left(\frac{L^3}{H}\right)^{0.385}}{128}$$

L = Longest length of water path in drainage area (ft)
H = Change in Elevation throughout drainage area or watershed (ft)
T_c = Time of Concentration (minutes)

EQN 4.4.2

$$Q_p = CiA$$

C = Rational coefficient (dimensionless) *See Table A.2 in Stormwater Hydrology Appendix A*
i = Rainfall intensity (in/hr)
A = Watershed area (ac)
Q_p = Peak flow (ft^3/s)

Overflow Structure: Overflow structures should be designed to safely pass runoff from rainfall events greater than the peak flow event.

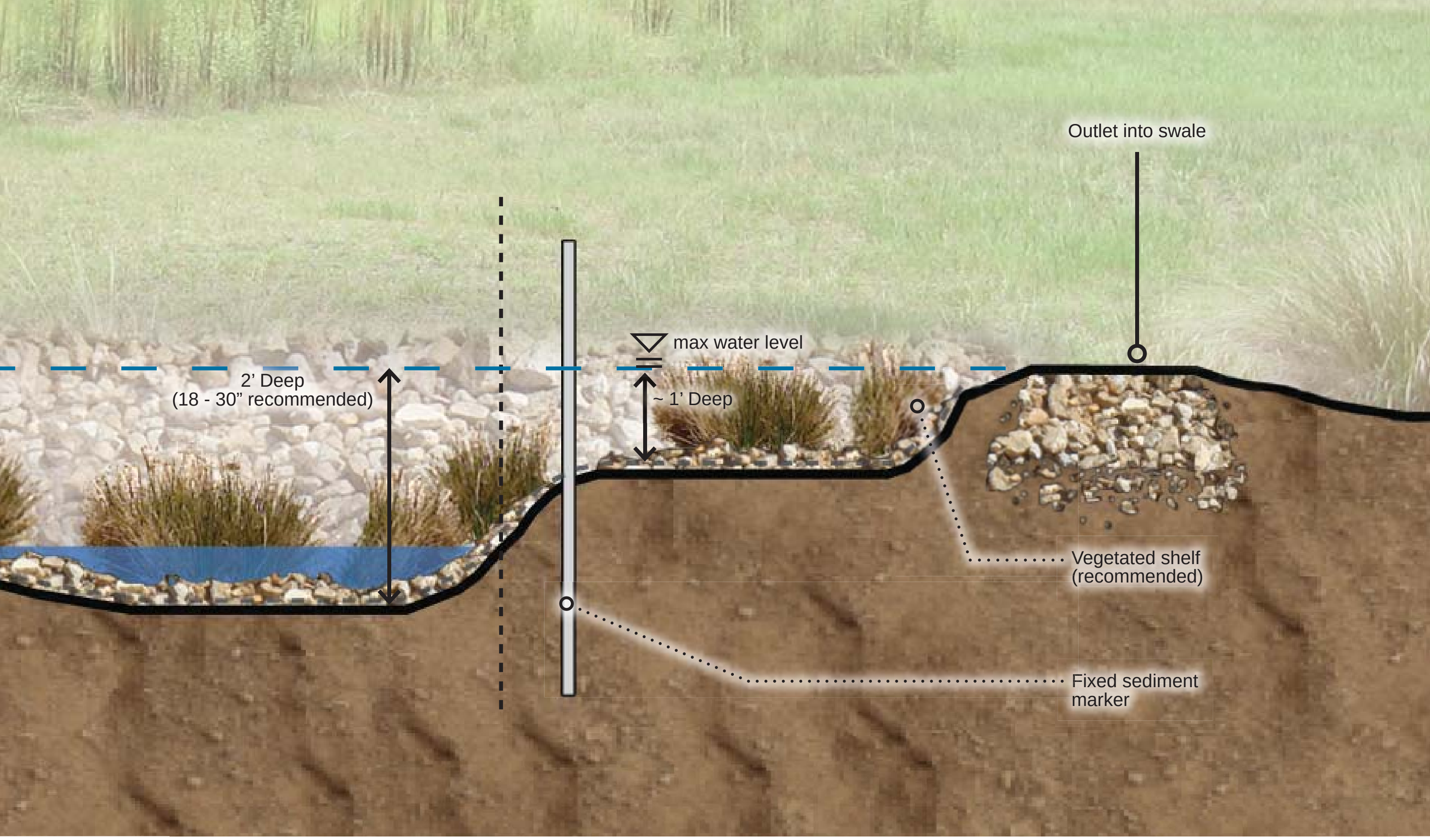
Design Guidance

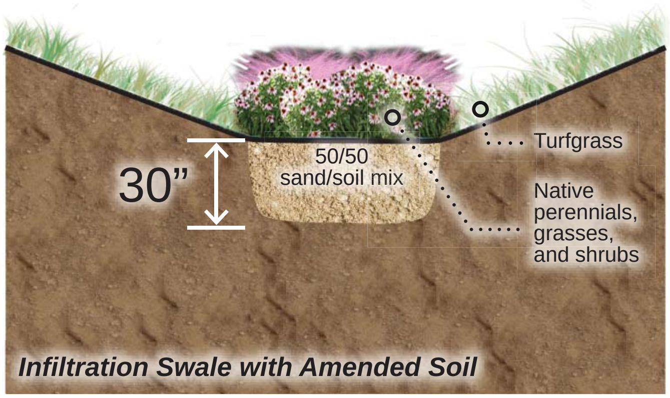
Information should be collected for watershed size, soil texture, HSG, slope, and depth to water table. The design layout or swale location is specific to the site. When determining the best location for the swale, site constraints, retrofit opportunities, aesthetics, and maintenance should be considered. Swales may be designed to be trapezoidal or triangular, see Design Guidance for more information.

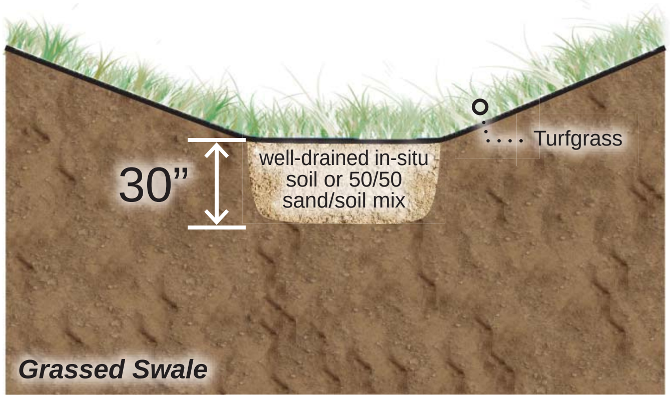
1. **Determine Treatment Volume or Peak Flow**

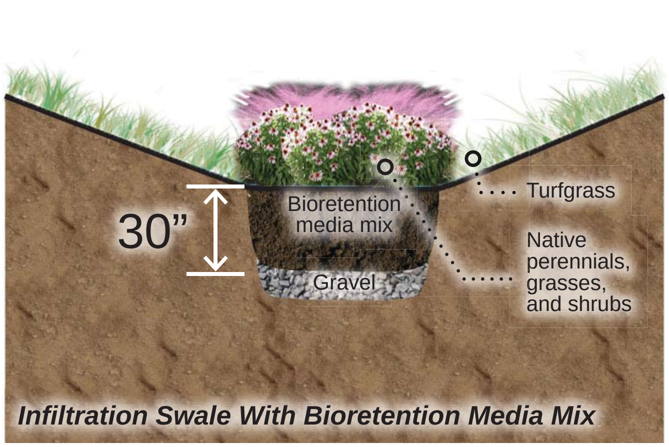
   Swales are designed to treat the first flush volume and control peak flow. The peak flow event is runoff from the primary design storm and is used because it is often the greater of the two.

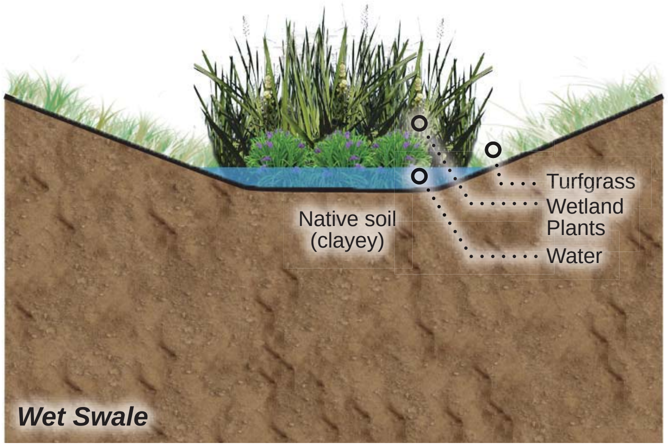
   The Kirpich Equation and Rational Method are used to determine peak flow and swale geometry is calculated to provide sizing recommendations and determine flow equations. The Kirpich Equation shown in EQN 4.4.1,


Outlet into swale
max water level
2' Deep
(18 - 30" recommended)
~ 1' Deep
Vegetated shelf
(recommended)
Fixed sediment
marker


30"
50/50
sand/soil mix
Turfgrass
Native
perennials,
grasses,
and shrubs
Infiltration Swale with Amended Soil


30"
well-drained in-situ
soil or 50/50
sand/soil mix
Turfgrass
Grassed Swale


30"
Bioretention
media mix
Gravel
Turfgrass
Native
perennials,
grasses,
and shrubs
Infiltration Swale With Bioretention Media Mix


Native soil
(clayey)
Turfgrass
Wetland
Plants
Water
Wet Swale

uses the **Longest Length in the Watershed (L)** and the **Change in Elevation (H)** to calculate the **Time of Concentration (T_c)**.

Intensity (i) is derived using the **Time of Concentration** and a selected design storm. **Peak Flow (Q_p)** is calculated using the Rational Method, EQN 4.4.2.

EQN 4.4.3

$$Q_p = \left(\frac{1.486}{n}\right) * A * R^{0.667} * S^{0.5}$$

n = Manning's n (dimensionless) – *see in Stormwater Hydrology Appendix A.*
A = Swale channel cross sectional area (ft^2), based on swale geometry
R= Hydraulic radius (ft)
S = Swale channel slope (ft/ft)

2. **Determine Swale Geometry**

Calculating swale geometry may require several design iterations using Manning's Equation, EQN 4.4.3. It should first be determined whether the swale will be trapezoidal or triangular; if vegetation other than turfgrass is to be used, a trapezoidal channel is recommended.

Swale geometry affects the **Swale Channel Cross Sectional Area (A)**, therefore affecting the **Hydraulic Radius (R)**; both of which are used to calculate the **Swale Depth (D)**. Next, the **steepness of the side slope (S)** should be specified. A 5:1 slope is recommended when side slopes are used to optimize pollutant removal as pretreatment filter strips or when mowing is used to maintain vegetation. Side slopes, which are not the same as swale channel slope, are also used in the calculation of swale channel geometry.

Depth (D) is determined using Peak Flow (Q_p) calculated from EQN 4.4.2. in Manning's Equation, EQN 4.4.3.

Triangular Channels: A modified Manning's Equation for a triangular channel with 3:1 and 5:1 side slopes is shown in EQNs 4.4.4 and Y.5.

Trapezoidal Channels: Once **D** is calculated, side slopes and channel geometry can be altered to calculate the swale width. This iterative process is especially useful when a fixed dimension is necessary.

3. **Check Channel Velocity**

The Continuity Equation, EQN 4.4.6, can be used to validate the velocity within the swale and determine if there is a need for turf reinforced matting (TRM) or additional vegetation to prevent erosion and scour within the swale channel. If velocity exceeds 4 fps, TRM is necessary.

4. **Determine Number and Size of Underdrains**

To calculate the number and size of underdrains, EQNs 4.4.9 – Y.12 found in Chapter 4.1 on Bioretention can be used.

Swale Geometry

(illustrations are exaggerated)

for triangular swale geometry:

Area, $A = 0.5(b*h)$

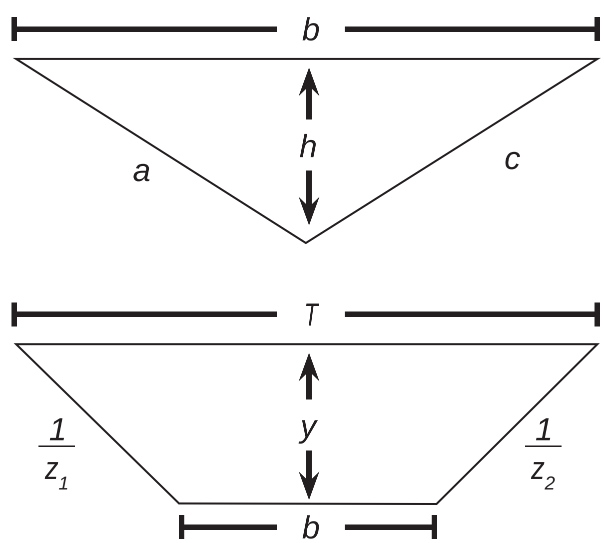
Wetted Perimiter, $P = a + b + c$

for trapezoidal swale geometry:

Top Width, $T = b + y(z_1+z_2)$

$$A = \frac{y}{2}(b + T)$$

$$P = b + y\left(\sqrt{1 + z_1^2} + \sqrt{1 + z_2^2}\right)$$



Note: typically $z_1 = z_2$

EQN 4.4.4 *for 3:1 side slopes*

$$Q_p=\left(\frac{2.71}{n}\right)*D^{2.67}*S^{0.50}$$

-or-

$$D=\left(\frac{Q_p*n}{2.71*S^{0.5}}\right)^{\frac{1}{2.67}}$$

EQN 4.4.5 *for 5:1 side slopes*

$$Q_p=\left(\frac{4.62}{n}\right)*D^{2.67}*S^{0.50}$$

n = Manning's n
D = Depth (ft)
S = Swale channel slope (ft/ft)
Q_p = Peak flow (ft^3/s)

EQN 4.4.6

$$Q = V*A$$

Q = Flow (ft^3/s)
V = Average velocity in channel (ft/s)
A = swale channel cross sectional area (ft^2), based on swale geometry

Design Example

A site in south central Alabama was chosen for an infiltration swale design. This site has a watershed area of **2.5 acres**, with a Kinston soil series, and HSG B. Most of the site is impervious with **2.0 acres in concrete and pavement. Only the impervious portion of the site is to be treated by the swale (2.0 acres)**.

1. Determine Peak Flow

The swale is designed for the peak flow event, using the Kirpich Equation.

EQN 4.4.1

$$T_c=\frac{\left(\frac{L^3}{H}\right)^{0.385}}{128}$$

The length (l), width (w), and longest length of water path in the drainage area (L) are 480', 180', and 512', respectively. The **Longest Length** of water path in the drainage area, **L is 512**' and **Change of Elevation, H, is 8'**.

Therefore the **Time of Concentration** is $T_c=\frac{\left(\frac{512^3}{8}\right)^{0.385}}{128}=\frac{605}{128}=4.7\ min$

T_c is 4.7 minutes and will be rounded to the nearest whole number, 5 minutes.

The T_c is used to calculate rainfall **Intensity (i)** in the Rational Method. The design storm or rainfall intensity is determined using the 10 - year flow event and closest estimate of the T_c, 5 minutes. The lowest calculated T_c is 5 minutes so the **10 – year, 5 - minute Intensity (i) is used**. For more detail on how to determine storm intensity using Intensity-Duration-Frequency (IDF) curve refer to Appendix A on Stormwater Hydrology.

The Rational Method, EQN 2, is used to determine **Peak Flow (Q_p)** from the 10 - year, 5 - minute event.

EQN 4.4.2 $Q_p = CiA$

A **Rational Coefficient (C)** of **0.95 for parking lot runoff (impervious), Intensity (i) of 7.36 in/hr** (from appropriate IDF curve, determined using the 10 - year, 5 - minute event), and an **Area (A) of 2.0 acres** for the impervious surface is used for this equation.

$$Q_p = 0.95*7.36in/hr*2.0ac$$

Converting the intensity, I, 7.36 in/hr to ft/s $7.36in/hr\left|\frac{1ft}{12\ in}\right|=0.613\ ft/hr\left|\frac{1hr}{3600s}\right|=0.00017037\ ft/s$

Converting 2 acres into square feet $2ac\left|\frac{43560ft^2}{1ac}\right|=87120ft^2$ Therefore

The swale should be able to handle **peak flows of 14 cubic feet per second (cfs)**.

$$Q_p = 0.95*0.00017037*87120 = 14\ ft^3/s$$

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2. Determine Swale Geometry

A trapezoidal geometry for the swale is desired for maintenance. Calculating the geometry for a trapezoidal swale is often an iterative process; however, in some instances, site constraints limit the dimensions.

For this example, the **Swale Channel Bottom Width (b)**, needs to be a **minimum of 4'** to accommodate the desired herbaceous vegetation. A 5:1 side slope is desired; however, site constraints limit the side slopes to 3:1. These site constraints create limited swale geometry. Using the equations to calculate **Top Width (T), Area (A)**, and **wetted perimeter (P)**, the variables in the modified Manning's Equation, EQN 4.4.3 can be used to confirm $\mathbf{Q_p}$.

$$\textbf{EQN 4.4.3} \qquad Q_p = \left(\frac{1.486}{n}\right) * A * R^{0.667} * S^{0.5}$$

For the trapezoidal geometry: $T = b + y(z_1+z_2)$, **where b is 4' and z is 3' and a depth of 1' is assumed.**

$$T = 4ft + 1ft(3ft+3ft) = 10\ ft$$

The **top width (T) of 10'** is then used to calculate cross sectional area. The following equation is used.

$A = \frac{y}{2}(b + T)$, where y is an assumed depth of 1', b is 4', and T is the calculated 10'.

$$A = \frac{1}{2}(4ft + 10ft) = 7\ ft^2$$

In order to calculate peak flow using EQN 4.4.3, **Hydraulic Radius (R)** must also be calculated. **Hydraulic Radius (R)** is defined as the **Cross Sectional Area (A)** divided by the **Wetted Perimeter (P)**.

$$R = \frac{A}{P}$$

Wetted Perimeter (P) is first determined. For a trapezoidal channel, **P** is calculated as:

$P = b + y\left(\sqrt{1 + z_1^2} + \sqrt{1 + z_2^2}\right)$, where b is 4', y is assumed to be 1', and $z_1=z_2=3$.

$P = 4ft + 1ft\left(\sqrt{1 + 3ft^2} + \sqrt{1 + 3ft^2}\right) = 10.3ft$ Therefore, $R = \frac{7.0ft}{10.3ft} = 0.68ft$

From the channel geometry calculation, the trapezoidal channel variables of **Area (A) and Hydraulic Radius (R) are 7ft² and 0.68', respectively.**

Additionally, Manning's Equation requires a **Manning's n** and **Swale Channel Slope (S)**. Herbaceous vegetation has an estimated Manning's n value of **0.04** and the **Channel Slope** of the design example is 0.005 ft/ft.

Using EQN 4.4.3 and the calculated variables, peak flow is calculated as follows:

$$Q_p = \left(\frac{1.486}{0.04}\right) * 7 * 0.068^{0.667} * 0.005^{0.5}$$

$$Q_p = 14.2\ ft^3/s$$

The calculated Q_p using the Manning's Equation is compared to the Peak Flow (Q_p) determined by the Rational Method Equation. If the peak flow determined by the Manning's Equation is equal to or greater than the peak flow calculated in the Rational Method, the swale geometry is sufficient for peak flow. However, if peak flow calculated in the Manning's Equation is less, then the swale geometry is insufficient and swale dimensions need to be altered. In this example, due to site constraints, the only available dimension for alteration would be the swale depth.

3. Check Channel Velocity

The Continuity Equation (EQN 4.4.6) can be used to verify that the velocity in the swale channel does not exceed what the vegetation can sustain without resulting in erosion. $Q = VA$, where $\mathbf{Q_p}$ is used to determine the maximum velocity within the designed channel.

The peak flow for the designed system is $\mathbf{Q_p}$ determined using the Manning's Equation, **14.2 ft³/s**.

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Transposed to solve for the maximum velocity:

EQN 4.4.6 $Q = V*A \quad Q_p = V_{max}*A \quad \frac{Q_p}{A} = V_{max}$

$$V_{max} = \frac{14.2\ ft^3/s}{7\ ft^2} = 2.03\ ft/s$$

Since $\mathbf{V_{max}}$ is less than 4 fps, turf reinforced matting (TRM) is not necessary.

This design example is for an infiltration swale. The soil was amended with a 50/50 sand and existing soil mix to a depth of 3' below the swale bottom and was planted using vegetation described in the Vegetation Design Example. Additionally, a wet swale vegetation plan is shown in the Vegetation Design Example; however, like the vegetation, the SCM engineering and design would change based on channel geometry and site constraints.

Construction

Compaction: Heavy equipment used to excavate the swale should not be operated within the swale channel to minimize compaction. The bottom of the swale should be scarified, chiseled, or ripped prior to placing any media or soil mix to further enhance infiltration especially when native, well-drained soils are used. If constructed properly, post construction infiltration rates should be similar to pre-construction infiltration rates.

Erosion and Sediment Control: Erosion control blankets should be used if the swale will receive runoff before vegetation has become established. (Refer to the *Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas* for guidance on erosion matting.)

Vegetation: To prevent scour, vegetation should be established prior to diverting runoff into the swale.

Underdrains: If underdrains are desired, a gravel layer should be considered. The gravel layer is comprised of #57 stone at a depth of 2" greater than the diameter of the underdrain pipe.

Bioretention Media: Infiltration swales that use a bioretention media should have a minimum infiltration rate of 0.5"/hr. To achieve this, the bioretention media uses 85-88% washed sand, 8 - 12% fines, and 3-5% aged organics. For more information on targeted pollutant removal using this mix, see Chapter 4.1 on Bioretention.

Mulch: Infiltration swales have a 3" layer of double- or triple-shredded hardwood mulch. Hardwood mulch is recommended, but other mulches such as pine bark or pine straw have been successfully used although they may require more frequent replacement. All mulches float, however, coarser textured mulches such as pine bark are more likely to float throughout the swale and can clog the overflow device. Mulch should be aged at least 6 months.

Retrofits: Swales used during construction as components of a site's erosion and sediment control plan can be retrofitted to function as a water quality swale. Regrading of the channel and slope may be necessary as well as complete sediment removal within the channel and the establishment of the proper vegetation.

Vegetation

Channel vegetation is dependent on the type of swale design (i.e. grassed, infiltration, or wet swale).

Grassed Swales: Grassed swales using sod are less likely to encounter establishment issues as sod provides a quick and dense cover.

Infiltration Swales: Infiltration swales support drought tolerant plants that thrive under brief flooding during and after a rainfall event. Most of these plants have a facultative (FAC) wetland indicator status.

Wet Swales: Wet swales utilize wetland plants in the channel and may have turfgrass or native grasses planted on the side slopes. Wet swale channel plants usually have a facultative wet (FACW) or obligate (OBL) wetland indicator status since the channels of wet swales have standing water present the majority of the time. (For more information on wetland indicator status, see Vegetation in Appendix D.)

Seeding: The side slopes can be seeded with native grass if stormwater will be conveyed into the swale channel from a forebay pretreatment device or if runoff is diverted until seeds are established. Depending on time of year, temporary seeding of the side slopes may be necessary. Seeding the swale channel or any part of the swale that will receive stormwater is not recommended unless paired with an erosion control blanket (see the *Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas* for details regarding erosion control blankets and seeding recommendations).

Plant Sizes: Most native grasses, herbaceous perennials, and shrubs can be purchased as containerized plants ranging in sizes from plugs or liners (~ 2 - 4” pots) up to 3-gallons. Using containers provides quick cover since containers establish more quickly than seeds. Wet swale plants can be harvested locally or ordered from wetland plant nurseries as plugs or 1-gallon containers.

Harvesting Plants: Harvesting locally is labor intensive and may require a permit to ensure legality. To harvest, wetland plants are divided and tubers or rootballs are transplanted on site. While harvested plants are beneficial because of quick establishment and prior adaptation to local climate conditions, invasive plant species can be introduced.

Plant Height: Plants for swale channels should never be completely submerged, thus plant height in the channel should be no less than the maximum ponding depth. When plants are fully submerged or bend to accommodate high flows, swale channel roughness is reduced resulting in higher flow velocities and reduced filtering contact of plants.

Plant Establishment: Infiltration swale vegetation can be installed any time of the year when using containerized plants. However, installing plants during the summer requires more frequent irrigation until plant establishment regardless of the size plant used. High temperatures and decreased rainfall during summer months reduce the chance for survival of plants. Fall installations are also appropriate as this is the ideal time of year for division or transplant of most perennial plants and a milder climate is experienced during this season. Wet swale plants should be installed from April to October.

Turf Establishment: For June to September installation, newly planted turf should be irrigated at planting so that the surface does not dry out. Sod should be watered daily for the first one to two weeks to keep it evenly moist. As the sod begins to grow new roots, irrigation frequency can be decreased, but a larger volume of water should be applied at each watering. Rainfall should be supplemented so that turfgrass receives about 1 – 1.5” per week from all irrigation sources. Turfgrass sod planted during dormancy will require less irrigation for establishment. In some cases, a dormant planting will not need any supplemental irrigation because rainfall during these months is sufficient for turf to establish. However, dormant plantings may benefit from irrigation during spring months when sod begins to produce new growth.

Table 4.4.3
Infiltration Swale Plant List

Botanical Name	Common Name	Habit	Prefers	Comments
Asclepias tuberosa	butterfly weed	herbaceous perennial	sun	Used as host and nectar source for Monarch butterfly
Baptisia alba	white false indigo	herbaceous perennial	sun to part shade	
Clethra alnifolia	summersweet clethra	deciduous shrub	sun to part shade	‘Sixteen Candles’ is a good dwarf
Conoclinium coelestinum	mistflower	herbaceous perennial	sun to part shade	‘Wayside Form’ is a good compact growth cultivar
Echinacea purpurea	purple coneflower	herbaceous perennial	sun to part shade	Long bloom season
Eragrostis spectabilis	purple love grass	native grass	sun	Compact native grass
Gaillardia pulchella	firewheel	herbaceous perennial	sun	Very heat and drought tolerant
Fothergilla gardenii	dwarf witch alder	deciduous shrub	sun to part shade	Not tolerant of extended flooding
Hypericum densiflorum	bushy St. John’s wort	deciduous shrub	sun	‘Creel’s Gold’ is a good dwarf
Ilex glabra	inkberry holly	evergreen shrub	part shade	‘Shamrock’ is a good dwarf

Botanical Name	Common Name	Habit	Prefers	Comments
Ilex verticillata	winterberry	deciduous shrub	sun to part shade	'Red Sprite' is a good dwarf
Ilex vomitoria	dwarf yaupon holly	evergreen shrub	sun to part shade	'Stoke's Dwarf' or 'Schillings' are good dwarfs
Itea virginica	sweetspire	deciduous shrub	sun to part shade	'Little Henry' is a good dwarf
Liatris spicata	gayfeather	herbaceous perennial	sun to part shade	Narrow form
Lindera benzoin	spicebush	deciduous shrub	sun to part shade	
Morella cerifera	wax myrtle	evergreen shrub	sun to part shade	'Tom's Dwarf' is a good dwarf
Muhlenbergia capillaris	muhly grass	native grass	sun to part shade	Very drought tolerant
Panicum virgatum	switchgrass	native grass	sun to part shade	Flood and drought tolerant
Physostegia virginiana	obedient plant	herbaceous perennial	sun to shade	Can be aggressive
Rudbeckia fulgida	orange coneflower	herbaceous perennial	sun to part shade	Long bloom season
Schizachryium scoparium	little bluestem	native grass	sun to part shade	
Sorghastrum nutans	indian grass	native grass	sun to part shade	
Stokesia laevis	Stoke's aster	herbaceous perennial	sun to part shade	Long bloom season
Tradescantia virginiana	spiderwort	herbaceous perennial	sun to shade	
Vernonia gigantea	giant ironweed	herbaceous perennial	sun	
Vernonia novenboracensis	New York ironweed	herbaceous perennial	sun	
Viburnum dentatum	arrowwood	deciduous shrub	sun to part shade	
Viburnum nudum	possumhaw	deciduous shrub	sun to part shade	

Table 4.4.4
Wet Swale Plant

Botanical Name	Common Name	Habit	Prefers	Comments
Carex crinita	fringed sedge	Grass like, evergreen	part shade	Can be divided
Hibiscus moscheutos	rose mallow	herbaceous perennial	sun to part shade	Attracts birds, hummingbirds, and ducks
Iris virginica	Southern blue flag iris	herbaceous perennial	sun	Do not plant the nonnative invasive yellow flag iris (*I. pseudacorus*); *I. versilcolor* is the Northern blue flag iris
Juncus effusus	common rush	Grass like, evergreen	sun to part shade	Can be divided
Lobelia cardinalis	cardinal flower	herbaceous perennial	Sun to shade	Butterfly and hummingbird attractant; self sows
Peltandra virginica	arrow arum	herbaceous perennial	part shade	Attracts birds
Pontederia cordata	pickerelweed	herbaceous perennial	sun to part shade	Attracts dragonflies
Sagittaria latifolia	duck potato	herbaceous perennial	sun to part shade	Starchy rhizomes attract ducks and snapping turtles; colonizing
Saururus cernuus	lizard tail	herbaceous perennial	part shade to shade	Colonizing; dominates during drought
Sisyrichium angustifolium	blue eyed grass	herbaceous perennial	sun to part shade	If allowed to dry out, will decline
Sparganium americanum	bur-reed	herbaceous perennial	sun to part shade	Tolerates flowing water

Table 4.4.5
Turfgrass List for Grassed Swales, Swales Side Slopes, and Grassed Inlets

Name	Prefers	Drought Tolerance	Comments
Bermudagrass	Sun	Excellent	Tolerates foot traffic, spreads above and below ground, fast growth rate, use statewide
Centipedegrass	Sun to Part Shade	Good	Slow growing, sensitive to some herbicides (check label), may be susceptible to cold injury in North AL
St. Augustinegrass	Sun to Shade	Good	Adapted better to the bottom third of the state, spreads above ground, fast growing, can be sensitive to herbicides, most shade tolerant turf, used in Central and South AL
Zoysiagrass	Part Shade	Excellent	Used statewide, most cold tolerant of warm season turfgrasses, slow growing

*Adapted from Han and Huckabay, 2008

Vegetation Design Guidelines

- Swales are long and linear and because of this, it can be helpful to sketch channel vegetation in 10' or 20' sections.
- Low growing perennials, grasses, and shrubs are planted in the channel if not grassed.
- Swale side slopes are planted with turfgrass or native grass.
- Low maintenance native grasses are sometimes used because mowing is needed only once per year.
- Non-turfgrass swale vegetation should have varied seasonal interest and growth patterns.
- Dwarf cultivars are suitable for smaller channel widths.

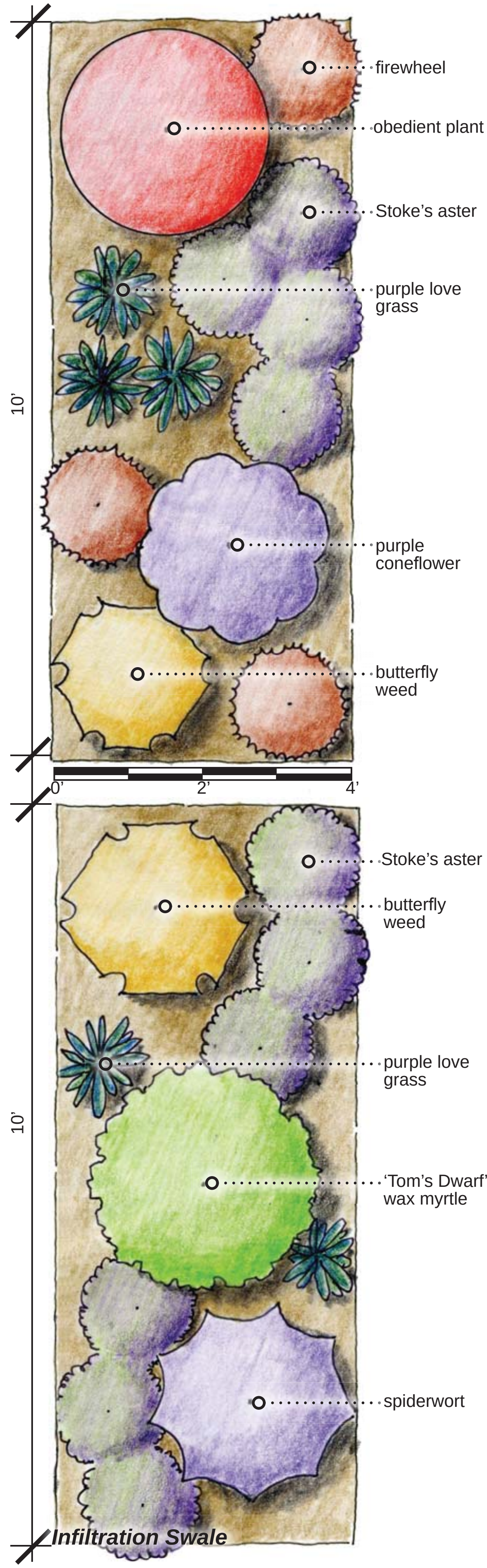
Infiltration Swale Design Example

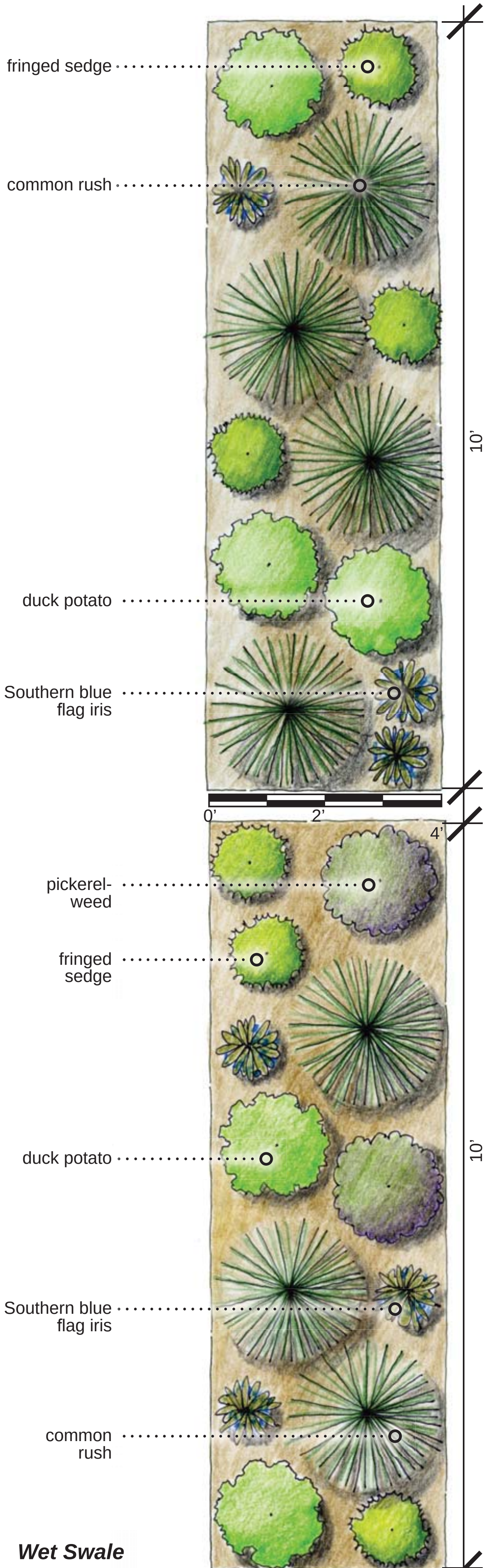
An infiltration swale is designed to capture runoff from the backside of a parking lot. In this example, the channel is 4' wide. Visibility from the road and parking lot may limit the use of taller growing vegetation in the channel. This vegetation plan can be used for an infiltration swale using a 50/50 sand/soil mix or a bioretention media mix.

This design was sketched using a circle template and drawn to scale to reflect mature plant sizes. Woody shrubs used are dwarf cultivars with a maximum width of 4'. For more information on cultivars, see Appendix D on Vegetation. The length of the infiltration swale is 50' and because of this, it is helpful to only draw a vegetation plan for a couple of 10' sections that can be repeated throughout the length of the swale. The side slopes can be planted with bermudagrass to be used as pretreatment into the swale.

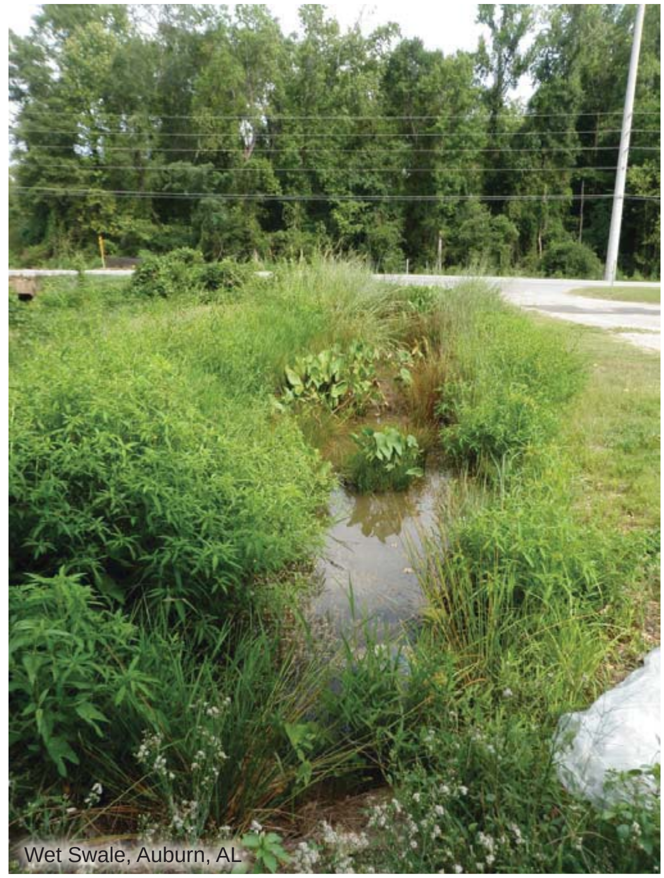
Wet Swale Design Example

For this example, a wet swale is located downslope of a trash compactor site. A forebay is utilized as pretreatment. The channel width is 3' and the swale is 50' in length. Wetland vegetation is planted in the channel with some herbaceous and semi-evergreen species. *Panicum virgatum* (switchgrass) is planted on the side slopes since the site is mowed only once per year. Due to the site location at a trash compactor site, weekly trash cleanup is needed to remove stray trash and large items from the forebay and channel.





Wet Swale


Wet Swale, Auburn, AL

Maintenance

Long-term functionality of swales is directly equivalent to the frequency in which maintenance is performed. Although maintenance of infiltration swales can be more frequent, over its life cycle it is still considered less expensive compared to traditional curb and gutter maintenance.

Trash and Litter: Swales in commercial or industrial settings tend to collect more litter and may need monthly or even weekly trash removal for aesthetics and to avoid clogging.

Sediment Removal: Accumulated sediment can form sandbars that inhibit flow patterns and have the potential to be re-suspended, transported throughout the swale, and eventually transported off site. Excess sediment can also smother swale vegetation. For small channel widths, sediment is best removed by hand using a flat shovel and metal rake. If excessive sediment clogs the swale often, check upslope for loose or bare soil areas that need to be stabilized.

Plant Maintenance: Where plant aesthetics are important, more frequent plant maintenance will be required. Wet swales and infiltration swales using a mixture of native grasses, small shrubs, and herbaceous perennials should not be mowed or cut back more than once a year. Vegetation should be maintained at the maximum height appropriate to the plant and site requirements, striving for a dense cover. Additional plants should be installed when plant replacement is needed.

Mowing: Grassed swales with turfgrass require mowing during the growing season and clippings should be removed from the swale to minimize clogging and nutrient release. Turfgrass should be maintained at a height no lower than 5" or the design depth. At lower mowing heights, velocities are not adequately slowed in the swale channel and plants may become completely submerged causing damage and possibly mortality.

Pickerelweed can be planted to attract dragonflies; Phenix City, AL

Nuisance Species: Unwanted plants, or weeds, should be removed from the swale channel and side slopes. In wet swales, cattails (*Typha latifolia*) can become a nuisance as they quickly displace other native plant species to form dense monocultures. Moreover, cattails promote mosquito infestation and have high mosquito counts. Herbaceous plants that attract mosquito predators such as dragonflies should be used in wet swale applications to minimize mosquito populations.

Table 4.4.6
Maintenance Schedule

Task	How Often	Comments
Erosion Inspection	During and after major storm events for first 2 years, annually thereafter	Ruts, holes, or gullies should be repaired with soil and vegetation cover
Inspection	After 0.5" or greater rainfall event	Visually inspect all components including any pretreatment device, channel, overflow structure, and vegetation for damage.
Trash Removal	At least annually, twice a year is better	Trash removal frequency is dependent on location of the swale
Sediment Removal from the Channel	When it reaches 4"	Sediment should be removed from the channel when it reaches a depth of 4" or when vegetation is covered
Sediment Removal from the Forebay	Site dependent	Sediment and other debris should be removed from the forebay when the storage volume is greatly decreased or when the forebay is half full
Mowing of Turfgrass	Every other week in growing season	Mowing should be done more often during the growing season; dense, low growing vegetation is best to maintain diffuse flow. Maintain at a height no lower than 5" or the design depth.
Mowing of Native Grasses	Annually	Most native grasses should be mowed before new growth appears in Spring.
Herbaceous and Woody Vegetation Pruning	Annually	Leaves dropped from deciduous shrubs and herbaceous plants should be collected to decrease clogging of mulch or any damming that might occur in the channel. Woody shrubs should be pruned based on the May Rule (see Appendix D on Vegetation)
Removal of Invasive Plants	Twice a year	Weeds or other invasive plants should be removed as they crowd and rob native plants of water, sunlight, and nutrients
Mulch Replacement	Every 2 years	Infiltration swales and vegetated swales will require mulch removal and replacement. Replenish bare areas as they occur
Irrigation	During plant establishment	Channel vegetation will require irrigation during plant establishment. The frequency is largely dependent on the time of year of plant installation and precipitation. Plants should not require any irrigation beyond establishment
Plant Replacement	When dead plants are noted	Sod or other plants should be replaced when they are choked out by sediment. Replant as needed to maintain dense cover

Pollutant Removal

Table 4.4.7
Pollutant Removal Table

	Sediment	Nutrients		Metals	Pathogens
		N	P		
Grassed Swale	a. 35%	20%	20%		Low
	b. 80%	50%	50%	40%	No Data
Enhanced Swale	c. 80%	50%	50%	40%	No Data
	c. 80%*	40%*	25%*	20%*	
	d. 50%	20%	25%	30%	Insufficient Data

* Represents data for a wet swale. All others are for dry swales.
Sources:
a. North Carolina Department of Environment and Natural Resources, 2007
b. City of Auburn, 2011
c. Georgia Manual, 2011
d. Iowa State University, 2008

Swales are most effective when channels are broad, slopes are not steep or flat, and when vegetation is dense. The ability of swales to reduce runoff volumes is largely dependent on the drainage area size, surrounding land use, slope, underlying soil, and vegetation density and type. Swales remove pollutants primarily through sedimentation but also through infiltration, filtration, and biofiltration. As with most LID practices, increased removal efficiencies are dependent on their design, soils, vegetation, and maintenance.

Enhancing Pollutant Removal: Dense vegetation increases the pollutant removal capabilities by increasing runoff contact time; coupled with small storm events and well-drained soils, the pollutant removal efficiency may be increased even more.

Check Dams: Check dams or other depressional storage areas within the channel can aid in enhancing pollutant removal by improving storage and slowing runoff from steep longitudinal slopes on site.

In-Situ Soil: Infiltration swales with a bioretention media mix typically have higher pollutant removal capabilities due to the specialized soil media designed to filter pollutants. Function and treatment capabilities are increased when in-situ soils are well-drained. Additionally, it has been reported that alkaline soils may facilitate the retention of metals in the swale.

Phosphorus: A soil media with a low phosphorus concentration and high phosphorus sorption is recommended so that phosphorus is not exported from the system.

Wet Swales: Standing water conditions in wet swales foster higher pollutant removal than typical dry grassed swales. In the channel, native wetland plants are used to uptake nutrients and promote biological processes that filter excess nutrients and other pollutants. Wet swales function similarly to a small, shallow constructed stormwater wetland. These linear “wetland areas” foster anaerobic conditions favorable to nutrient cycling processes such as denitrification.

Seasonal Variations: Seasonal pollutant removal efficiency variations can be expected in swales due to winter dormancy of vegetation. It should be noted that plant die back and subsequent reduced plant cover can result in increased erosive forces during wet weather associated with winter months, which can lead to downstream sedimentation.

Vegetation: For increased pollutant removal efficiency, a mix of herbaceous, deciduous, and evergreen vegetation is recommended for all types of swales; however, each project site may have different aesthetic value and needs associated with it.

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