8.0 Stormwater Management Practices

8.1 Overview

Stormwater management practices (also known as *structural stormwater controls*, *structural stormwater best management practices* or *structural stormwater BMPs*) are engineered facilities designed to *intercept and manage* post-construction stormwater runoff rates, volumes and pollutant loads. Together with *green infrastructure practices*, which can be used to help *prevent* increases in post-construction stormwater runoff rates, volumes and pollutant loads, *stormwater management practices* can be used to help control and minimize the negative impacts of land development and nonpoint source pollution. Stormwater management practices can be used whenever green infrastructure practices cannot, on their own, be used to completely satisfy the post-construction stormwater management criteria (SWM Criteria) presented in this Coastal Stormwater Supplement (CSS):

- Stormwater Runoff Reduction (SWM Criteria #1): Reduce the stormwater runoff volume generated by the 85th percentile storm event (and the "first flush" of the stormwater runoff volume generated by all larger storm events) on a development site through the use of appropriate green infrastructure practices. In coastal Georgia, this equates to reducing the stormwater runoff volume generated by the 1.2 inch rainfall event (and the stormwater runoff generated by the first 1.2 inches of all larger rainfall events).

- Water Quality Protection (SWM Criteria #2): Adequately treat post-construction stormwater runoff before it is discharged from a development site. In coastal Georgia, this criteria can be met simply by satisfying the stormwater runoff reduction criteria (SWM Criteria #1). However, if any of the stormwater runoff generated by the 1.2 inch storm event (and the first 1.2 inches of all larger rainfall events), cannot be r*educed* on a development site, due to site characteristics or constraints, it should be *intercepted and treated* in one or more stormwater management practices that: (1) provide for at least an 80 percent reduction in TSS loads; and (2) reduce nitrogen and bacteria loads to the *maximum extent practical*.

- Aquatic Resource Protection (SWM Criteria #3): Protect coastal Georgia's valuable aquatic resources from several other negative impacts of the land development process (e.g., complete loss or destruction, stream channel enlargement, increased salinity fluctuations) by: (1) protecting them from the direct impacts of the land development process through the use of better site planning techniques; (2) establishing a minimum 25-foot wide aquatic buffer around them (although a 75-foot wide aquatic buffer is preferred); (3) providing 24 hours of extended detention for the stormwater runoff volume generated by the 1-year, 24-hour storm event before it is discharged from a development site; and (4) providing velocity control and energy dissipation measures at all new and existing stormwater outfalls.

- Overbank Flood Protection (SWM Criteria #4): Prevent an increase in the duration, frequency and magnitude of damaging overbank flooding by controlling (attenuating) the peak discharge generated by the 25-year, 24-hour storm event under post-development conditions.

- Extreme Flood Protection (SWM Criteria #5): Prevent an increase in the duration, frequency and magnitude of dangerous extreme flooding by controlling (attenuating) the peak discharge generated by the 100-year, 24-hour storm event under post-development conditions.

This Section provides additional information about using *stormwater management practices* to help satisfy these SWM Criteria.

8.2 Recommended Stormwater Management Practices

The stormwater management practices *recommended* for use in coastal Georgia have been divided into two groups: (1) general application practices (also known as *general application controls*); and (2) limited application practices (also known as *limited application controls* or *detention controls*). Each of these groups is briefly described below.

8.2.1 General Application Practices

General application practices can be used to *treat* stormwater runoff and *manage* the post-construction stormwater runoff rates and volumes generated by larger, less frequent rainfall events (e.g., 1-year, 24-hour event, 25-year, 24-hour event). Several of these practices, namely bioretention areas, infiltration practices and dry swales, can also be used to reduce post-construction stormwater runoff volumes and, consequently, are also classified as runoff reducing low impact development practices (Section 7.8).

Since they can be used to both *treat* and *manage* post-construction stormwater runoff, it is *recommended* that general application practices be used whenever green infrastructure practices cannot, on their own, be used to completely satisfy the stormwater runoff reduction (SWM Criteria #1), stormwater quality protection (SWM Criteria #2), aquatic resource protection (SWM Criteria #3), overbank flood protection (SWM Criteria #4) and extreme flood protection (SWM Criteria #5) criteria presented in this CSS. The general application practices *recommended* for use in coastal Georgia include:

Figure 8.1: Stormwater Pond
(Source: Atlanta Regional Commission, 2001)

Stormwater Ponds

Stormwater ponds (Figure 8.1) are stormwater detention basins that have a permanent pool of water. Post-construction stormwater runoff is conveyed into the pool, where it is both detained and treated over an extended period of time. The types of stormwater ponds that are *recommended* for use in coastal Georgia include:

- Wet Ponds
- Wet Extended Detention Ponds
- Micropool Extended Detention Ponds
- Multiple Pond Systems

Figure 8.2: Stormwater Wetland
(Source: Merrill et al., 2006)

Stormwater Wetlands

Stormwater wetlands (Figure 8.2) are constructed wetland systems built for stormwater management purposes. Stormwater wetlands typically consist of a combination of open water, shallow marsh and semi-wet areas, and can be used to both detain and treat post-construction stormwater runoff. The types of stormwater wetlands that are *recommended* for use in coastal Georgia include:

- Shallow Wetlands
- Extended Detention Shallow Wetlands
- Pond/Wetland Systems
- Pocket Wetlands

Bioretention Areas

Bioretention areas (Figure 8.3), which may also be classified as a low impact development practice (Section 7.8.13), are shallow depressional areas that use an engineered soil mix and vegetation to intercept and treat post-construction stormwater runoff. After passing through a bioretention area, stormwater runoff may be returned to the stormwater conveyance system through an underdrain, or may be allowed to fully or partially infiltrate into the surrounding soils.

Figure 8.3: Bioretention Area
(Source: Center for Watershed Protection)

Filtration Practices

Filtration practices are multi-chamber structures designed to treat post-construction stormwater runoff using the physical processes of screening and filtration. Sand is typically used as the filter media. After passing through a filtration practice, stormwater runoff is typically returned to the conveyance system through an underdrain. The filtration practices that are *recommended* for use in coastal Georgia include:

- Surface Sand Filter
- Perimeter Sand Filter

Infiltration Practices

Infiltration practices (Figure 8.4), which may also be classified as a runoff reducing low impact development practice (Section 7.8.14), are shallow excavations, typically filled with stone or an engineered soil mix, that are designed to intercept and temporarily store post-construction stormwater runoff until it infiltrates into the surrounding soils. The infiltration practices that are *recommended* for use in coastal Georgia include:

- Infiltration Trench
- Infiltration Basin

Figure 8.4: Infiltration Trench
(Source: Center for Watershed Protection)

Swales

Swales (Figure 8.5) are vegetated open channels that are designed to manage post-construction stormwater runoff within wet or dry cells formed by check dams or other control structures (e.g., culverts). The two types of swales that are *recommended* for use in coastal Georgia include:

- Dry Swale
- Wet Swale

Figure 8.5: Wet Swale
(Source: Center for Watershed Protection)

Because of their ability to reduce annual stormwater runoff volumes and pollutant loads, dry swales may also be classified as a low impact development practice (Section 7.8.15).

8.2.2 Limited Application Practices

There are two groups of limited application stormwater management practices that can be used in coastal Georgia, each of which is briefly described below:

Water Quantity Management Practices

Water quantity management practices (Figure 8.6) can only be used to *manage* the post-construction stormwater runoff rates and volumes generated by larger, less frequent rainfall events (e.g., 1-year, 24-hour event, 25-year, 24-hour event). They provide little, if any, stormwater runoff reduction or stormwater treatment. Consequently, it is *recommended* that they be used only on a limited basis, and only when green infrastructure practices and general application stormwater management practices cannot be used to completely satisfy the aquatic resource protection (SWM Criteria #3), overbank flood protection (SWM Criteria #4) and extreme flood protection (SWM Criteria #5) criteria presented in this CSS. The water quantity management practices that may be used in coastal Georgia include:

- Dry Detention Basins
- Dry Extended Detention Basins
- Multi-Purpose Detention Areas
- Underground Detention Systems

Figure 8.6: Dry Detention Basin Used to Provide Water Quantity Management
(Source: Center for Watershed Protection)

Water Quality Management Practices

Water quality management practices can only be used to *treat* post-construction stormwater runoff. They typically have high or special maintenance requirements, provide little, if any, stormwater runoff reduction, and cannot be used to *manage* the post-construction stormwater runoff rates and volumes generated by larger, less frequent rainfall events (e.g., 1-year, 24-hour event, 25-year, 24-hour event). Consequently, it is *recommended* that they be used only on a limited basis, and only when green infrastructure practices and general stormwater management application practices cannot be used to completely satisfy the stormwater runoff reduction (SWM Criteria #1) and stormwater quality protection criteria (SWM Criteria #2) presented in this CSS. The water quality management practices that may be used in coastal Georgia include:

- Organic Filters
- Underground Filters
- Submerged Gravel Wetlands
- Gravity (Oil-Grit) Separators
- Alum Treatment Systems
- Proprietary Systems

8.3 Other Stormwater Management Practices

8.3.1 Not Recommended Stormwater Management Practices

Proprietary catch basin inserts and media filter systems are not recommended for use in coastal Georgia. These proprietary devices tend to clog very easily and typically carry a very high long-term maintenance burden. Although they are not recommended for use on new development and redevelopment sites, these proprietary devices may be used in retrofit applications where surface space is at a premium.

8.3.2 New and Innovative Stormwater Management Practices

The use of new and innovative stormwater management practices is encouraged in coastal Georgia, provided that their ability to satisfy the stormwater management and site planning and design criteria presented in this CSS has been sufficiently documented. At its discretion, a local development review authority may allow for the use of a stormwater management practice that is not discussed in this CSS. However, local development review authorities are encouraged not to do so until they are provided with reliable information about practice performance and information about practice design and maintenance requirements.

New and innovative stormwater management practices will not be added to this CSS until reliable, independently derived performance monitoring data confirm their ability to satisfy the stormwater management and site planning and design criteria presented in this CSS. Appendix C outlines a stormwater management monitoring protocol that can be used to help document the performance of new and innovative stormwater management practices in coastal Georgia.

8.4 Applying Stormwater Management Practices During the Site Planning & Design Process

A procedure that can be used to apply stormwater management practices to a development site during the site planning and design process is illustrated in Figure 8.7 and briefly outlined below.

8.4.1 Step 4.6: Apply Stormwater Management Practices

After low impact development practices have been distributed across the development site, and it has been determined that the SWM Criteria that apply to the development site cannot be satisfied exclusively through the use of green infrastructure practices, a site planning and design team should be able to begin applying stormwater management practices to the site to further *manage* post-construction stormwater runoff rates, volumes and pollutant loads. Stormwater management practices should be placed downstream of any previously applied green infrastructure practices to form what are known as “stormwater management trains” (Figure 8.8).

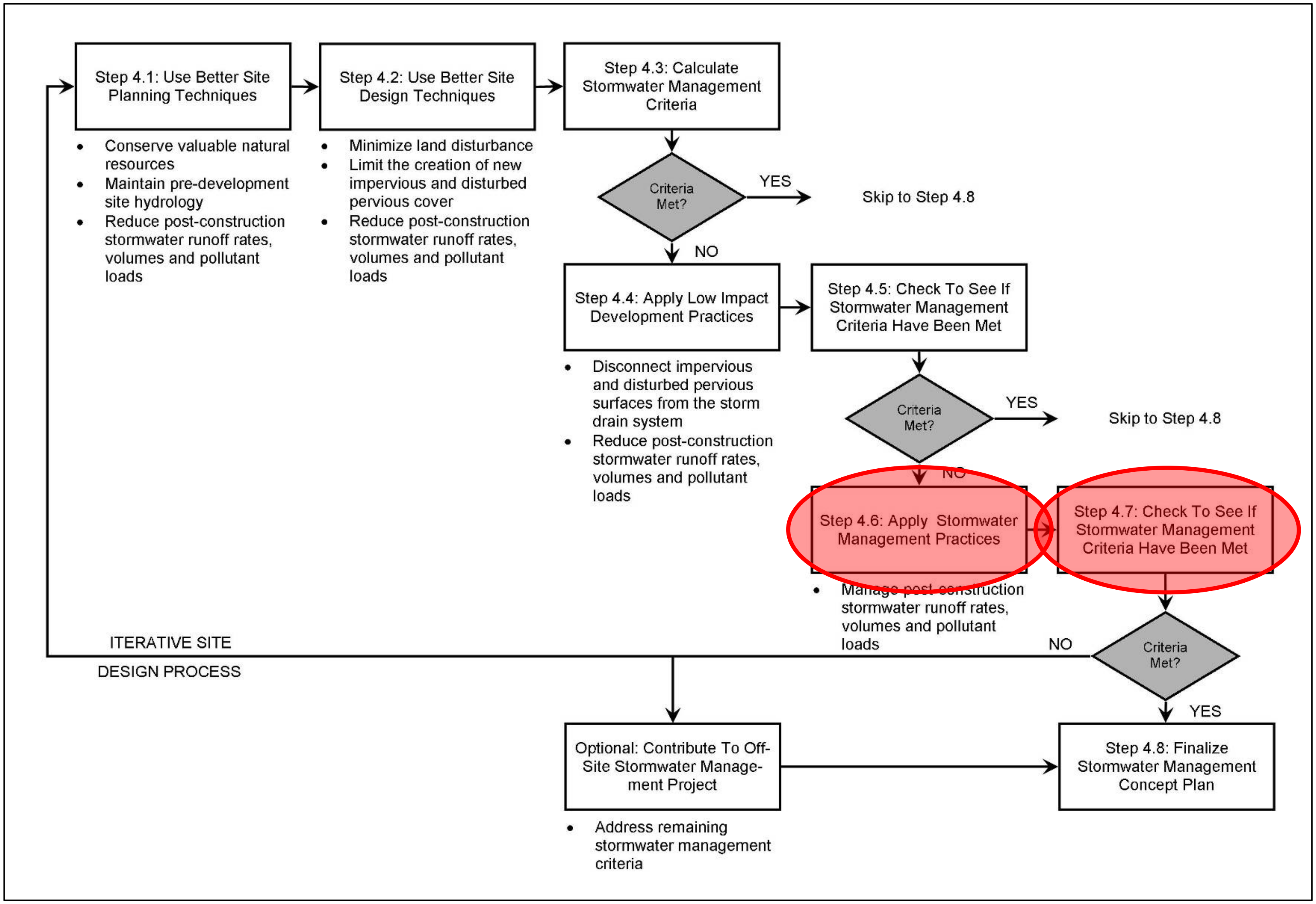

Figure 8.7: Using Stormwater Management Practices During the Creation of a Stormwater Management Concept Plan
(Source: Center for Watershed Protection)

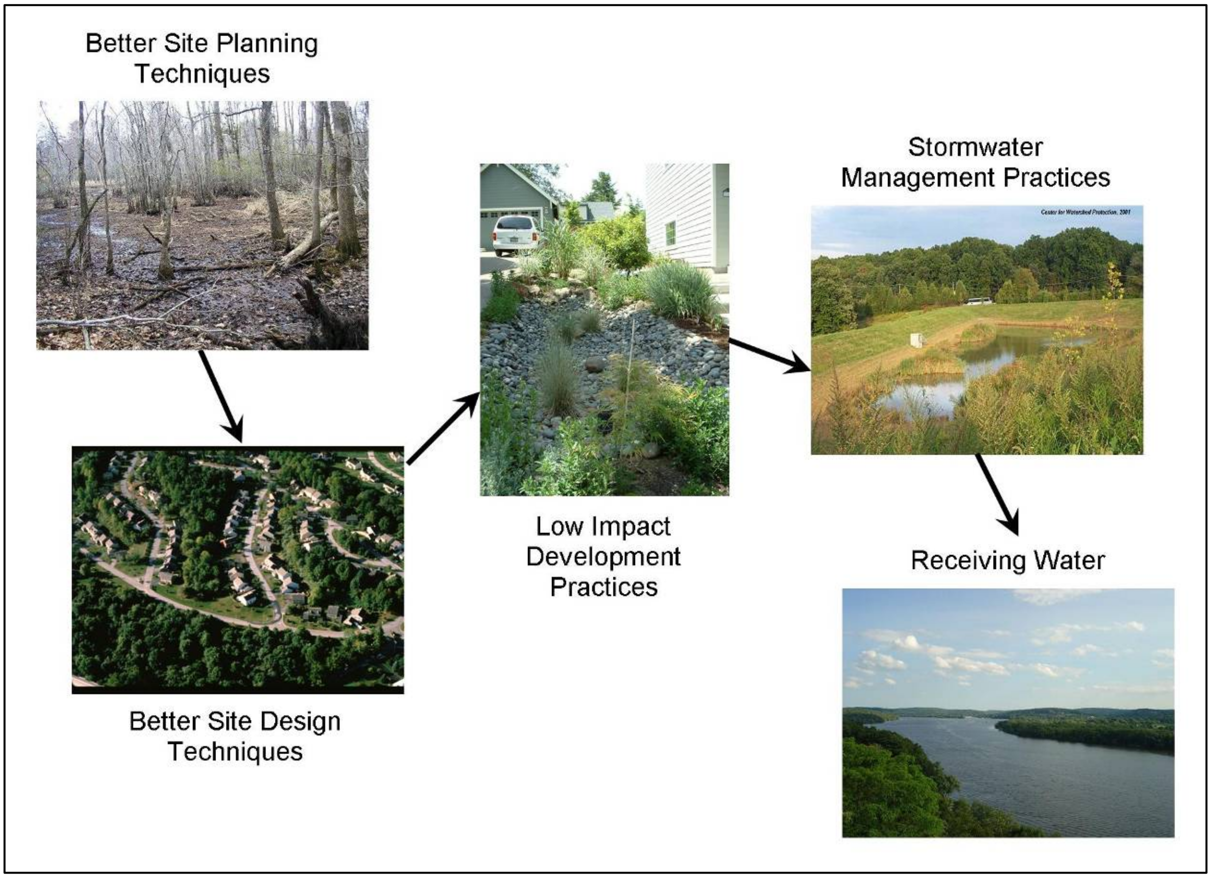

Figure 8.8: Stormwater Management Train
(Source: Center for Watershed Protection)

It is important to note that the structure of the "stormwater management train" illustrated in Figure 8.8 mirrors the step-wise process of developing a stormwater management concept plan for a development site. The position of stormwater management practices within the "stormwater management train" reflects the notion that they should not be used on a development site until it has been determined that the SWM Criteria presented in this CSS cannot be satisfied exclusively through the use of green infrastructure practices.

When applying stormwater management practices to a development site, they should be placed in drainage or maintenance easements and included in all stormwater management system inspection and maintenance plans (SP&D Criteria #6). Additional information about the use of stormwater management practices, including information about their proper application and design, can be found in Sections 8.6-8.7.

8.4.2 Step 4.7: Check to See If Stormwater Management Criteria Have Been Met

Once stormwater management practices have been applied to a development site, site planning and design teams should check to make sure that all of the SWM Criteria that apply to the site have been completely satisfied. If they have not, they will need to go back to the development plan and apply additional low impact development and stormwater management practices to further *reduce* and *manage* post-construction stormwater runoff rates, volumes and pollutant loads on the development site.

On many development sites, the process of putting together a development plan will be an iterative process. When compliance with the SWM Criteria presented in the CSS is not achieved on the first try, site planning and design teams should return to earlier steps in the process to explore alternative site layouts and different combinations of green infrastructure and stormwater management practices.

If the SWM Criteria presented in this CSS cannot, due to site characteristics or constraints, be satisfied through the use of *on-site* green infrastructure and stormwater management practices, developers may be able to achieve compliance by implementing or contributing to an *off-site* stormwater management project. Off-site projects can be an extremely attractive compliance option on redevelopment sites where space for on-site green infrastructure and stormwater management practices is extremely limited. If a developer is interested in using an off-site stormwater management project to help satisfy the SWM Criteria presented in this CSS, they are encouraged to consult with the local development review authority.

8.5 Stormwater Management Practice Selection

A screening process that can be used to help decide what stormwater management practices can be used on a development site is outlined below. This process is intended to assist site planning and design teams in selecting the most appropriate stormwater management practices for use on a development site.

In general, the following information should be considered when deciding what stormwater management practices can be used on a development site:

- Ability to Help Satisfy the Stormwater Management Criteria
- Overall Feasibility
- Site Applicability

In addition, site planning and design teams should consider how the following site characteristics and constraints, which are commonly encountered in coastal Georgia, will influence the use of stormwater management practices on a development site:

- Poorly drained soils, such as hydrologic soil group C and D soils
- Well drained soils, such as hydrologic soil group A and B soils
- Flat terrain
- Shallow water table
- Tidally-influenced drainage

Additional information on a step-wise process that can be used to decide what stormwater management practices can be used on a development site is provided below. The process uses three screening matrices to evaluate the feasibility and applicability of the various stormwater management practices recommended for use in coastal Georgia.

8.5.1 Step 1: Evaluate Ability to Help Satisfy the Stormwater Management Criteria

Through the use of the first screening matrix (Table 8.1), site planning and design teams can evaluate how each of the stormwater management practices can be used to help satisfy the post-construction stormwater management criteria that apply to a development site. Additional information about each of the screening categories included in the matrix is provided below.

- Stormwater Runoff Reduction: This column indicates the stormwater management "credit" that can be applied toward the stormwater runoff reduction criteria (SWM Criteria #1) if the stormwater management practice is used on the development site.

- Water Quality Protection: This column indicates the stormwater management "credit" that can be applied toward the water quality protection criteria (SWM Criteria #2) if the stormwater management practice is used on the development site.

- Aquatic Resource Protection: This column indicates the stormwater management "credit" that can be applied toward the aquatic resource protection criteria (SWM Criteria #3) if the stormwater management practice is used on the development site.

- Overbank Flood Protection: This column indicates the stormwater management "credit" that can be applied toward the overbank flood protection criteria (SWM Criteria #4) if the stormwater management practice is used on the development site.

- Extreme Flood Protection: This column indicates the stormwater management "credit" that can be applied toward the extreme flood protection criteria (SWM Criteria #5) if the stormwater management practice is used on the development site.

Table 8.1: How Stormwater Management Practices Can Be Used to Help Satisfy the Stormwater Management Criteria					
Stormwater Management Practice	**Stormwater Runoff Reduction**	**Water Quality Protection**	**Aquatic Resource Protection**	**Overbank Flood Protection**	**Extreme Flood Protection**
General Application Practices					
Stormwater Ponds	**"Credit":** None	**"Credit":** Assume that a *stormwater pond* provides an 80% reduction in TSS loads[1], a 30% reduction in TN loads[2] and a 70% reduction in bacteria loads[1].	**"Credit":** A *stormwater pond* can be designed to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).	**"Credit":** A *stormwater pond* can be designed to attenuate the overbank peak discharge (Q_{p25}) on a development site.	**"Credit":** A *stormwater pond* can be designed to attenuate the extreme peak discharge (Q_{p100}) on a development site.
Stormwater Wetlands	**"Credit":** None	**"Credit":** Assume that a *stormwater wetland* provides an 80% reduction in TSS loads[1], a 30% reduction in TN loads[2] and an 80% reduction in bacteria loads[1].	**"Credit":** A *stormwater wetland* can be designed to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).	**"Credit":** A *stormwater wetland* can be designed to attenuate the overbank peak discharge (Q_{p25}) on a development site.	**"Credit":** A *stormwater wetland* can be designed to attenuate the extreme peak discharge (Q_{p100}) on a development site.
Bioretention Areas, No Underdrain	**"Credit":** Subtract 100% of the storage volume provided by a non-underdrained *bioretention area* from the runoff reduction volume (RR_v) conveyed through the *bioretention area*.	**"Credit":** Assume that a *bioretention area* provides an 80% reduction in TSS loads[1], a 60% reduction in TN loads[2] and an 80% reduction in bacteria loads[#].	**"Credit":** Although uncommon, on some development sites, a *bioretention area* can be designed to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).	**"Credit":** Although relatively rare, on some development sites, a *bioretention area* can be designed to attenuate the overbank peak discharge (Q_{p25}).	**"Credit":** Although relatively rare, on some development sites, a *bioretention area* can be designed to attenuate the extreme peak discharge (Q_{p100}).
Bioretention Areas, Underdrain	**"Credit":** Subtract 50% of the storage volume provided by an underdrained *bioretention area* from the runoff reduction volume (RR_v) conveyed through the *bioretention area*.				
Filtration Practices	**"Credit":** None	**"Credit":** Assume that a *filtration practice* provides an 80% reduction in TSS loads[1], a 30% reduction in TN loads[2] and a 40% reduction in bacteria loads[1].	**"Credit":** Although uncommon, on some development sites, a *filtration practice* can be designed to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).	**"Credit":** Although relatively rare, on some development sites, a *filtration practice* can be designed to attenuate the overbank peak discharge (Q_{p25}).	**"Credit":** Although relatively rare, on some development sites, a *filtration practice* can be designed to attenuate the extreme peak discharge (Q_{p100}).

Table 8.1: How Stormwater Management Practices Can Be Used to Help Satisfy the Stormwater Management Criteria

Stormwater Management Practice	Stormwater Runoff Reduction	Water Quality Protection	Aquatic Resource Protection	Overbank Flood Protection	Extreme Flood Protection
Infiltration Practices	**"Credit":** Subtract 100% of the storage volume provided by an *infiltration practice* from the runoff reduction volume (RR_v) conveyed through the *infiltration practice*.	**"Credit":** Assume that an *infiltration practice* provides an 80% reduction in TSS loads[1], an 60% reduction in TN loads[2] and an 80% reduction in bacteria loads[#].	**"Credit":** Although uncommon, on some development sites, an *infiltration practice* can be designed to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).	**"Credit":** Although relatively rare, on some development sites, an *infiltration practice* can be designed to attenuate the overbank peak discharge (Q_{p25}).	**"Credit":** Although relatively rare, on some development sites, an *infiltration practice* can be designed to attenuate the extreme peak discharge (Q_{p100}).
Dry Swales, No Underdrain	**"Credit":** Subtract 100% of the storage volume provided by a non-underdrained *dry swale* from the runoff reduction volume (RR_v) conveyed through the *dry swale*.	**"Credit":** Assume that a *dry swale* provides an 80% reduction in TSS loads[1], a 50% reduction in TN loads[2] and a 60% reduction in bacteria loads[#].	**"Credit":** Although uncommon, on some development sites, a *dry swale* can be designed to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).	**"Credit":** Although relatively rare, on some development sites, a *dry swale* can be designed to attenuate the overbank peak discharge (Q_{p25}).	**"Credit":** Although relatively rare, on some development sites, a *dry swale* can be designed to attenuate the extreme peak discharge (Q_{p100}).
Dry Swales, Underdrain	**"Credit":** Subtract 50% of the storage volume provided by an underdrained *dry swale* from the runoff reduction volume (RR_v) conveyed through the *dry swale*.				
Wet Swales	**"Credit":** None	**"Credit":** Assume that a *wet swale* provides an 80% reduction in TSS loads[1], a 25% reduction in TN loads[2] and a 40% reduction in bacteria loads[#].	**"Credit":** Although uncommon, on some development sites, a *wet swale* can be designed to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).	**"Credit":** Although uncommon, on some development sites, a *wet swale* can be designed to attenuate the overbank peak discharge (Q_{p25}).	**"Credit":** Although uncommon, on some development sites, a *wet swale* can be designed to attenuate the extreme peak discharge (Q_{p100}).
Limited Application Practices					
Water Quantity Management Practices					
Dry Detention Basins	**"Credit":** None	**"Credit":** None	**"Credit":** None	**"Credit":** A *dry detention basin* can be used to attenuate the overbank peak discharge (Q_{p25}) on a development site.	**"Credit":** A *dry detention basin* can be used to attenuate the extreme peak discharge (Q_{p100}) on a development site.

Table 8.1: How Stormwater Management Practices Can Be Used to Help Satisfy the Stormwater Management Criteria					
Stormwater Management Practice	**Stormwater Runoff Reduction**	**Water Quality Protection**	**Aquatic Resource Protection**	**Overbank Flood Protection**	**Extreme Flood Protection**
Dry Extended Detention Basins	**"Credit":** None	**"Credit":** Assume that a *dry extended detention basin* provides a 40% reduction in TSS loads[1], a 10% reduction in TN loads[2] and a 20% reduction in bacteria loads[#].	**"Credit":** A *dry extended detention basin* can be used to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).	**"Credit":** A *dry extended detention basin* can be used to attenuate the overbank peak discharge (Q_{p25}) on a development site.	**"Credit":** A *dry extended detention basin* can be used to attenuate the extreme peak discharge (Q_{p100}) on a development site.
Multi-Purpose Detention Areas	**"Credit":** None	**"Credit":** None	**"Credit":** None	**"Credit":** A *multi-purpose detention area* can be used to attenuate the overbank peak discharge (Q_{p25}) on a development site.	**"Credit":** A *multi-purpose detention area* can be used to attenuate the overbank peak discharge (Q_{p25}) on a development site.
Underground Detention Systems	**"Credit":** None	**"Credit":** None	**"Credit":** An *underground detention system* can be used to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).	**"Credit":** An *underground detention system* can be used to attenuate the overbank peak discharge (Q_{p25}) on a development site.	**"Credit":** An *underground detention system* can be used to attenuate the extreme peak discharge (Q_{p100}) on a development site.
Water Quality Management Practices					
Organic Filters	**"Credit":** None	**"Credit":** Assume that an *organic filter* provides an 80% reduction in TSS loads[3], a 40% reduction in TN loads[3] and a 40% reduction in bacteria loads[1].	**"Credit":** None	**"Credit":** None	**"Credit":** None
Underground Filters	**"Credit":** None	**"Credit":** Assume that an *underground filter* provides an 80% reduction in TSS loads[1], a 30% reduction in TN loads[1] and a 40% reduction in bacteria loads[1].	**"Credit":** None	**"Credit":** None	**"Credit":** None

Table 8.1: How Stormwater Management Practices Can Be Used to Help Satisfy the Stormwater Management Criteria					
Stormwater Management Practice	**Stormwater Runoff Reduction**	**Water Quality Protection**	**Aquatic Resource Protection**	**Overbank Flood Protection**	**Extreme Flood Protection**
Submerged Gravel Wetlands	**"Credit":** None	**"Credit":** Assume that a *submerged gravel wetland* provides an 80% reduction in TSS loads[3], a 20% reduction in TN loads[3] and a 40% reduction in bacteria loads[#].	**"Credit":** None	**"Credit":** None	**"Credit":** None
Gravity (Oil-Grit) Separators	**"Credit":** None	**"Credit":** Assume that a *gravity (oil-grit) separator* provides a 40% reduction in TSS loads[#], a 10% reduction in TN loads[#] and a 20% reduction in bacteria loads[#].	**"Credit":** None	**"Credit":** None	**"Credit":** None
Alum Treatment Systems	**"Credit":** None	**"Credit":** Assume that an *alum treatment system* provides a 90% reduction in TSS loads[4], a 60% reduction in TN loads[4] and a 90% reduction in bacteria loads[4].	**"Credit":** None	**"Credit":** None	**"Credit":** None
Proprietary Systems	**"Credit":** TBD*	**"Credit":** TBD*	**"Credit":** TBD*	**"Credit":** TBD*	**"Credit":** TBD*
Notes: 1 National Pollutant Removal Database, Version 3.0 (Fraley-McNeal et al., 2007) 2 Runoff Reduction Technical Memorandum (Hirschman et al., 2008) 3 National Pollutant Removal Database, Version 2.0 (Winer, 2000) 4 Georgia Stormwater Management Manual, Volume 2 (ARC, 2001) # Load reduction estimates are based on a very limited amount of data and should be considered to be provisional estimates. * Information about how specific proprietary devices and systems can be used to help satisfy the stormwater management criteria must be provided by the manufacturer and should be verified using independently-reviewed performance monitoring data and calculations. See Appendix D for more information about monitoring the performance of individual stormwater management practices.					

8.5.2 Step 2: Evaluate Overall Feasibility

Through the use of the second screening matrix (Table 8.2), site planning and design teams can evaluate the overall feasibility of applying each of the stormwater management practices on a development site. Additional information about each of the screening categories included in the matrix is provided below.

- Drainage Area: This column describes how large of a contributing drainage area each stormwater management practice can realistically handle. It indicates the maximum size of the contributing drainage area that each stormwater management practice should be designed to “receive” stormwater runoff from.

- Area Required: This column indicates how much space the stormwater management practice typically consumes on a development site.

- Slope: This column describes the influence that site slope can have on the performance of the stormwater management practice. It indicates the maximum or minimum slope on which the stormwater management practice can be installed.

- Minimum Head: This column provides an estimate of the minimum amount of elevation difference needed within the stormwater management practice, from the inflow to the outflow, to allow for gravity operation.

- Minimum Depth to Water Table: This column indicates the minimum distance that should be provided between the bottom of the stormwater management practice and the top of the water table.

- Soils: This column describes the influence that the underlying soils (i.e., hydrologic soil groups) can have on the performance of the stormwater management practice.

Table 8.2: Factors to Consider When Evaluating the Overall Feasibility of Stormwater Management Practices

Stormwater Management Practice	Drainage Area	Area Required	Slope	Minimum Head	Minimum Depth to Water Table	Soils
General Application Practices						
Stormwater Ponds	No restrictions, although a contributing drainage area of between 10 to 25 acres or a shallow water table is typically needed to maintain a permanent pool	2-3% of contributing drainage area	15%	6 to 8 feet	No restrictions	No restrictions
Stormwater Wetlands	No restrictions, although a contributing drainage area of between 5 to 25 acres or a shallow water table is typically needed to maintain a permanent water surface	3-5% of contributing drainage area	15%	2 to 5 feet	No restrictions	No restrictions
Bioretention Areas	5 acres	5-10% of contributing drainage area	6%	42 to 48 inches[1]	2 feet	Should drain within 48 hours of end of rainfall event
Filtration Practices	2 to 10 acres	3-5% of contributing drainage area	6%	2 to 5 feet	2 feet	Should drain within 36 hours of end of rainfall event
Infiltration Practices	2 to 5 acres	5% of contributing drainage area	6%	42 to 48 inches[1]	2 feet	Should drain within 48 hours of end of rainfall event
Dry Swales	5 acres	5-10% of contributing drainage area	0.5% to 4%, although 1% to 2% is recommended	36 to 48 inches[1]	2 feet	Should drain within 48 hours of end of rainfall event
Wet Swales	5 acres	10-20% of contributing drainage area	0.5% to 4%, although 1% to 2% is recommended	1 to 2 feet	No restrictions	No restrictions
Limited Application Practices						
Water Quantity Management Practices						
Dry Detention Basins	No restrictions	1-3% of contributing drainage area	15%	4 to 8 feet	2 feet	No restrictions
Dry Extended Detention Basins	No restrictions	1-3% of contributing drainage area	15%	4 to 8 feet	2 feet	No restrictions

Table 8.2: Factors to Consider When Evaluating the Overall Feasibility of Stormwater Management Practices						
Stormwater Management Practice	**Drainage Area**	**Area Required**	**Slope**	**Minimum Head**	**Minimum Depth to Water Table**	**Soils**
Multi-Purpose Detention Areas	No restrictions	1-3% of contributing drainage area	15%	4 to 8 feet	2 feet	No restrictions
Underground Detention Systems	No restrictions	N/A	15%	4 to 8 feet	2 feet	No restrictions
Water Quality Management Practices						
Organic Filters	10 acres	3-5% of contributing drainage area	6%	2 to 5 feet	2 feet	Should drain within 36 hours of end of rainfall event
Underground Filters	10 acres	N/A	6%	2 to 5 feet	2 feet	Should drain within 36 hours of end of rainfall event
Submerged Gravel Wetlands	5 acres	3-5% of contributing drainage area	0.5% to 4%, although 1% to 2% is recommended	2 to 5 feet	No restrictions	No restrictions
Gravity (Oil-Grit) Separators	5 acres	N/A	6%	4 feet	2 feet	No restrictions
Alum Treatment Systems	No restrictions, although a contributing drainage area of between 10 to 25 acres or a shallow water table is typically needed to construct a stormwater pond	N/A	N/A	6 to 8 feet typically needed to construct a stormwater pond	N/A	N/A
Proprietary Systems	TBD*	TBD*	TBD*	TBD*	TBD*	TBD*

Notes:
1 Criteria may be relaxed on development sites that have a shallow water table. See profile sheets provided in Sections 8.6-8.7 for additional information.
* Information about the factors to consider when evaluating the overall feasibility of specific proprietary devices and systems can be obtained directly from the manufacturer.

8.5.3 Step 3: Evaluate Site Applicability

Through the use of the third screening matrix (Table 8.3), site planning and design teams can evaluate the applicability of each of the stormwater management practices on a particular development site. Additional information about each of the screening categories included in the matrix is provided below.

- Rural Use: This column indicates whether or not the stormwater management practice is suitable for use in rural areas and on low-density development sites.

- Suburban Use: This column indicates whether or not the stormwater management practice is suitable for use in suburban areas and on medium-density development sites.

- Urban Use: This column identifies the stormwater management practices that are suitable for use in urban and ultra-urban areas where space is at a premium.

- Construction Cost: This column assesses the relative construction cost of each of the stormwater management practices.

- Maintenance: This column assesses the relative maintenance burden associated with each stormwater management practice. It is important to note that *all* stormwater management practices require some kind of routine inspection and maintenance.

Table 8.3: Factors to Consider When Evaluating the Applicability of Stormwater Management Practices on a Development Site					
Stormwater Management Practice	**Rural Use**	**Suburban Use**	**Urban Use**	**Construction Cost**	**Maintenance**
General Application Practices					
Stormwater Ponds	✓	✓		Low	Low
Stormwater Wetlands	✓	✓		Low	Medium
Bioretention Areas	✓	✓	✓	Medium	Medium
Filtration Practices	✱	✓	✓	High	High
Infiltration Practices	✓	✓	✓	Medium	High
Dry Swales	✓	✓	✱	Medium	Medium
Wet Swales	✓	✓	✱	Medium	Medium
Limited Application Practices					
Water Quantity Practices					
Dry Detention Basins	✓	✓		Low	Low
Dry Extended Detention Basins	✓	✓		Low	Low
Multi-Purpose Detention Areas	✱	✓	✓	Low	Low
Underground Detention Systems			✓	High	Medium
Water Quality Practices					
Organic Filters	✱	✱	✓	High	High
Underground Filters			✓	High	High
Submerged Gravel Wetlands	✱	✱	✓	High	High
Gravity (Oil-Grit) Separators	✱	✱	✓	High	High
Alum Treatment Systems	✓	✓		High	High
Proprietary Systems	✱	✱	✓	TBD*	TBD*

Notes:
✓ = Suitable for use on development sites located in these areas.
✱ = Under certain situations, can be used on development sites located in these areas.
* Information about the factors to consider when evaluating the applicability of specific proprietary devices and systems can be obtained directly from the manufacturer.

8.6 General Application Stormwater Management Practice Profile Sheets

This Section contains profile sheets that provide information about the general application stormwater management practices that are *recommended* for use in coastal Georgia. The profile sheets describe each of the stormwater management practices, discuss how to properly apply and design them on development sites and provide information about how they can be used to help satisfy the SWM Criteria presented in this CSS. The stormwater management practices profiled in this Section include:

<u>General Application Practices</u>

- 8.6.1 Stormwater Ponds
- 8.6.2 Stormwater Wetlands
- 8.6.3 Bioretention Areas
- 8.6.4 Filtration Practices
- 8.6.5 Infiltration Practices
- 8.6.6 Swales

NOTE: Much of the information presented in the following profile sheets can also be found in Section 3.2 of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001). It is has been updated with new design guidance and new information about the stormwater management "credits" associated with each of these stormwater management practices. The information is presented here to prevent the reader from having to leave the CSS during the site planning and design process.

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8.6.1 Stormwater Ponds

Description

Stormwater ponds are stormwater detention basins that have a permanent pool of water. Post-construction stormwater runoff is conveyed into the pool, where it is detained and treated over an extended period of time, primarily through gravitational settling and biological uptake, until it is displaced by stormwater runoff from the next rain event. Temporary storage (i.e., live storage) can be provided above the permanent pool for stormwater quantity control. This allows stormwater ponds to both *treat* stormwater runoff and *manage* the stormwater runoff rates and volumes generated by larger, less frequent rainfall events on development sites.

(Source: Atlanta Regional Commission, 2001)

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Contributing drainage area of 25 acres or more typically needed for wet and wet extended detention ponds; 10 acres or more typically needed for micropool extended detention pond
- A sediment forebay (or equivalent pretreatment) should be provided upstream of all ponds
- Permanent pools should be designed to be between 3 and 8 feet deep
- Length to width ratio should be at least 1.5:1 (L:W), although a length to width ratio of 3:1 (L:W) or greater is preferred
- Side slopes should not exceed 3:1 (H:V)

BENEFITS:

- Provides moderate to high removal of many of the pollutants of concern contained in post-construction stormwater runoff
- Can be attractively integrated into a development site and designed to provide some wildlife habitat

LIMITATIONS:

- Provides minimal reduction of post-construction stormwater runoff volumes
- Stormwater pond design can be challenging in flat terrain

SITE APPLICABILITY

☑ Rural Use	L Construction Cost
☑ Suburban Use	L Maintenance
Urban Use	H Area Required

STORMWATER MANAGEMENT "CREDITS"

Runoff Reduction
☑ Water Quality Protection
☑ Aquatic Resource Protection
☑ Overbank Flood Protection
☑ Extreme Flood Protection

☑ = practice has been assigned quantifiable stormwater management "credits" that can be used to address this SWM Criteria

STORMWATER MANAGEMENT PRACTICE PERFORMANCE

Runoff Reduction
0% - Annual Runoff Volume
0% - Runoff Reduction Volume

Pollutant Removal[1]
80% - Total Suspended Solids
50% - Total Phosphorus
30% - Total Nitrogen
50% - Metals
70% - Pathogens

1 = expected annual pollutant load removal

Discussion

Stormwater ponds (also known as *retention ponds*, *wet ponds*, or *wet extended detention ponds*) are stormwater detention basins that are designed to have a permanent pool of water (i.e., dead storage) throughout the year. Post-construction stormwater runoff is conveyed into the pool, where it is detained and treated over an extended period of time, primarily through gravitational settling and biological uptake, until it is displaced by stormwater runoff from the next rain event. The permanent pool also helps protect deposited sediments from resuspension. Above the permanent pool, temporary storage (i.e., live storage) can be provided for stormwater quantity control.

Stormwater ponds treat post-construction stormwater runoff through a combination of physical, chemical and biological processes. The primary pollutant removal mechanism at work is gravitational settling, which works to remove particulate matter, organic matter, metals and bacteria as stormwater runoff is conveyed through the permanent pool. Another primary pollutant removal mechanism at work in stormwater ponds is biological uptake of nutrients by algae and wetland vegetation. Volatilization and other chemical processes also work to break down and eliminate a number of other stormwater pollutants (e.g., hydrocarbons) in stormwater ponds.

Stormwater ponds are among the most common stormwater management practices used in coastal Georgia and the rest of the United States. They are typically created by excavating a depressional area to create "dead storage" below the water surface elevation of the receiving storm drain system, stream or other aquatic resource. A well-designed pond can be attractively integrated into a development site as a landscaping feature and, if appropriately designed, sited and landscaped, can provide some wildlife habitat. However, site planning and design teams should use caution when siting a stormwater pond. They should use the results of the natural resources inventory (Section 6.3.3), to ensure that the pond will not negatively impact any existing primary conservation areas on the development site (e.g., freshwater wetlands, bottomland hardwood forests). Site planning and design teams should also consider the other potential drawbacks associated with stormwater ponds, including their potential to become a source of mosquitoes and harmful algal blooms.

There are several variations of stormwater ponds that can be used to manage post-construction stormwater runoff on development sites, the most common of which include wet ponds, wet extended detention ponds and micropool extended detention ponds (Figure 8.9). In addition, multiple stormwater ponds can be placed in series or parallel to increase storage capacity or address specific site characteristics or constraints (e.g., flat terrain). A brief description of each of these design variants is provided below:

- Wet Ponds: Wet ponds (Figure 8.10) are stormwater detention basins that are designed to have a permanent pool that provides enough storage for the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event). Stormwater runoff is conveyed into the pool, where it is detained and treated over an extended period of time, primarily through gravitational settling and biological uptake, until it is displaced by stormwater runoff from the next rain event. Additional temporary storage (i.e., live storage) can be provided above the permanent pool for stormwater quantity control.

- Wet Extended Detention (ED) Ponds: Wet extended detention ponds (Figure 8.11) are wet ponds that are designed to have a permanent pool that provides enough storage for approximately 50% of the stormwater runoff volume generated by the target runoff

Wet Pond

Wet Extended Detention Pond

Micropool Extended Detention Pond

Wet Pond

Figure 8.9: Various Stormwater Ponds

reduction rainfall event (e.g., 85th percentile rainfall event). The remainder of the stormwater runoff volume generated by the target runoff reduction rainfall event is managed in an extended detention zone provided immediately above the permanent pool. During wet weather, stormwater runoff is detained in the extended detention zone and released over a 24-hour period.

- <u>Micropool Extended Detention (ED) Ponds</u>: Micropool extended detention ponds (Figure 8.12) are a variation of the standard wet extended detention pond that have only a small permanent pool (i.e., micropool). The "micropool" provides enough storage for approximately 10% of the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event). The remainder of the stormwater runoff volume generated by the target runoff reduction rainfall event is managed in an extended detention zone provided immediately above the "micropool" and released over an extended 24-hour period.

- <u>Multiple Pond Systems</u>: Multiple pond systems (Figure 8.13) consist of a series of two or more wet ponds, wet extended detention ponds or micropool extended detention ponds. The additional cells can increase the storage capacity provided on a development or redevelopment site.

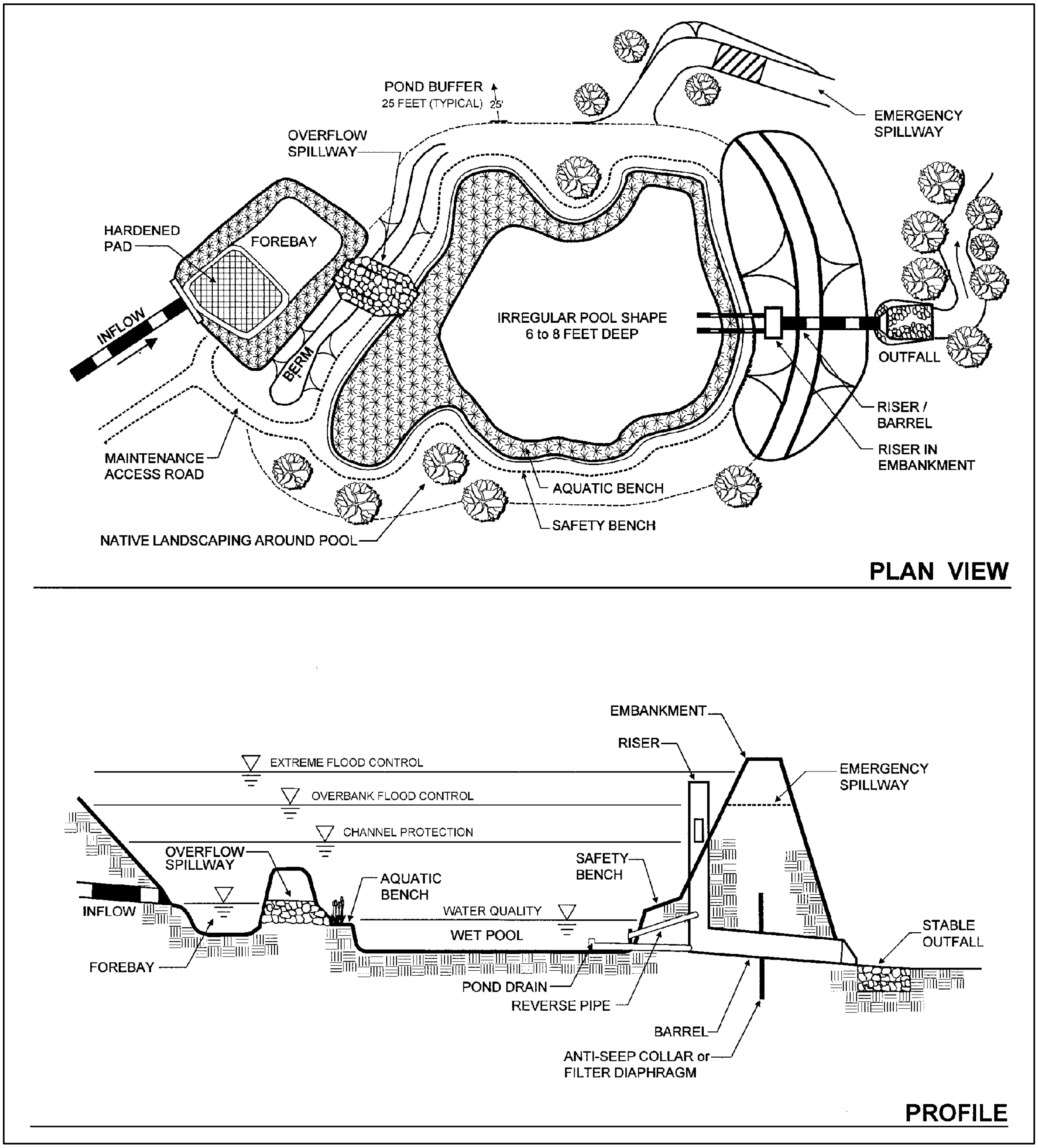

Figure 8.10: Schematic of a Typical Wet Pond
(Source: Center for Watershed Protection)

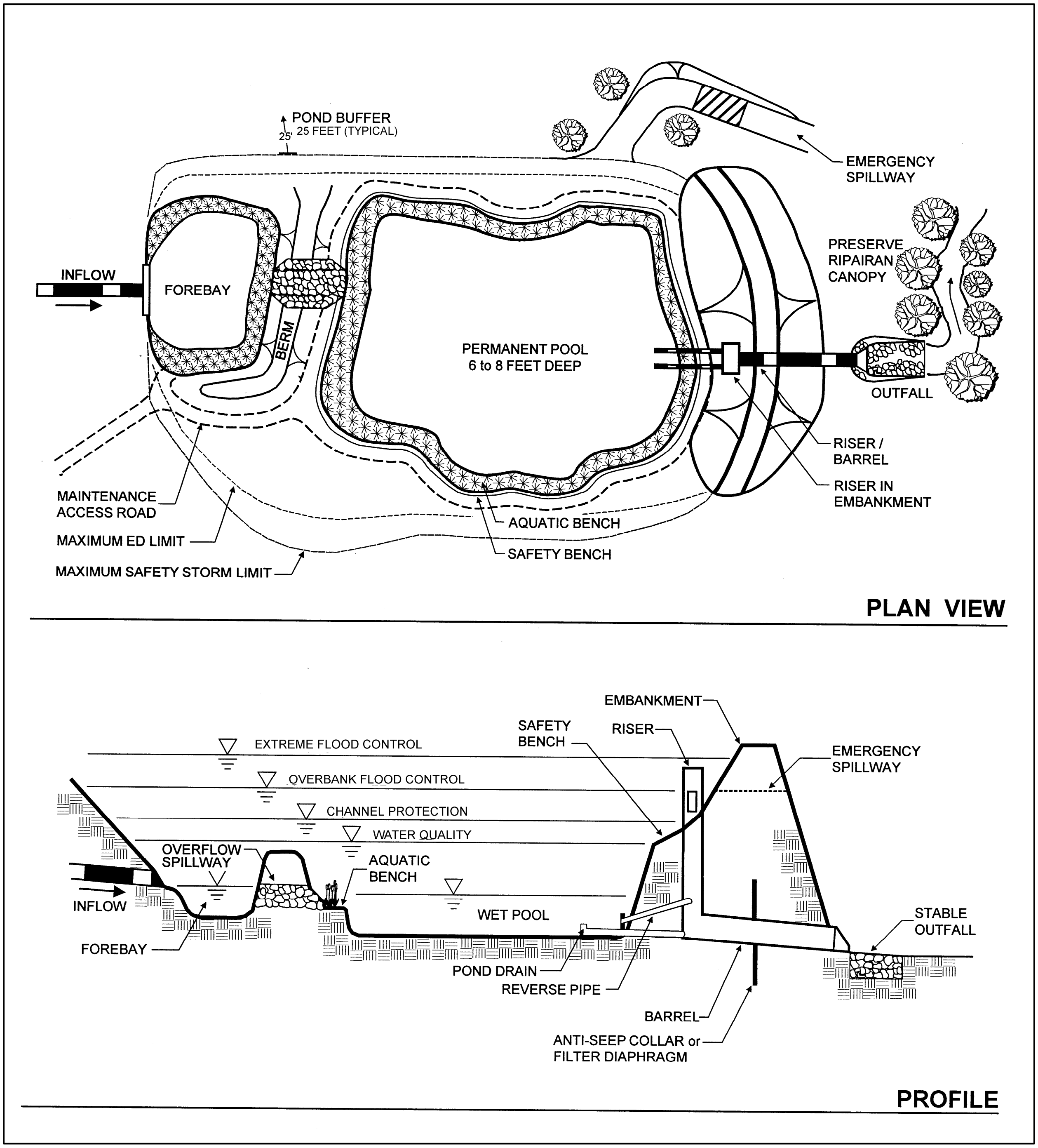

Figure 8.11: Schematic of a Typical Wet Extended Detention Pond
(Source: Center for Watershed Protection)

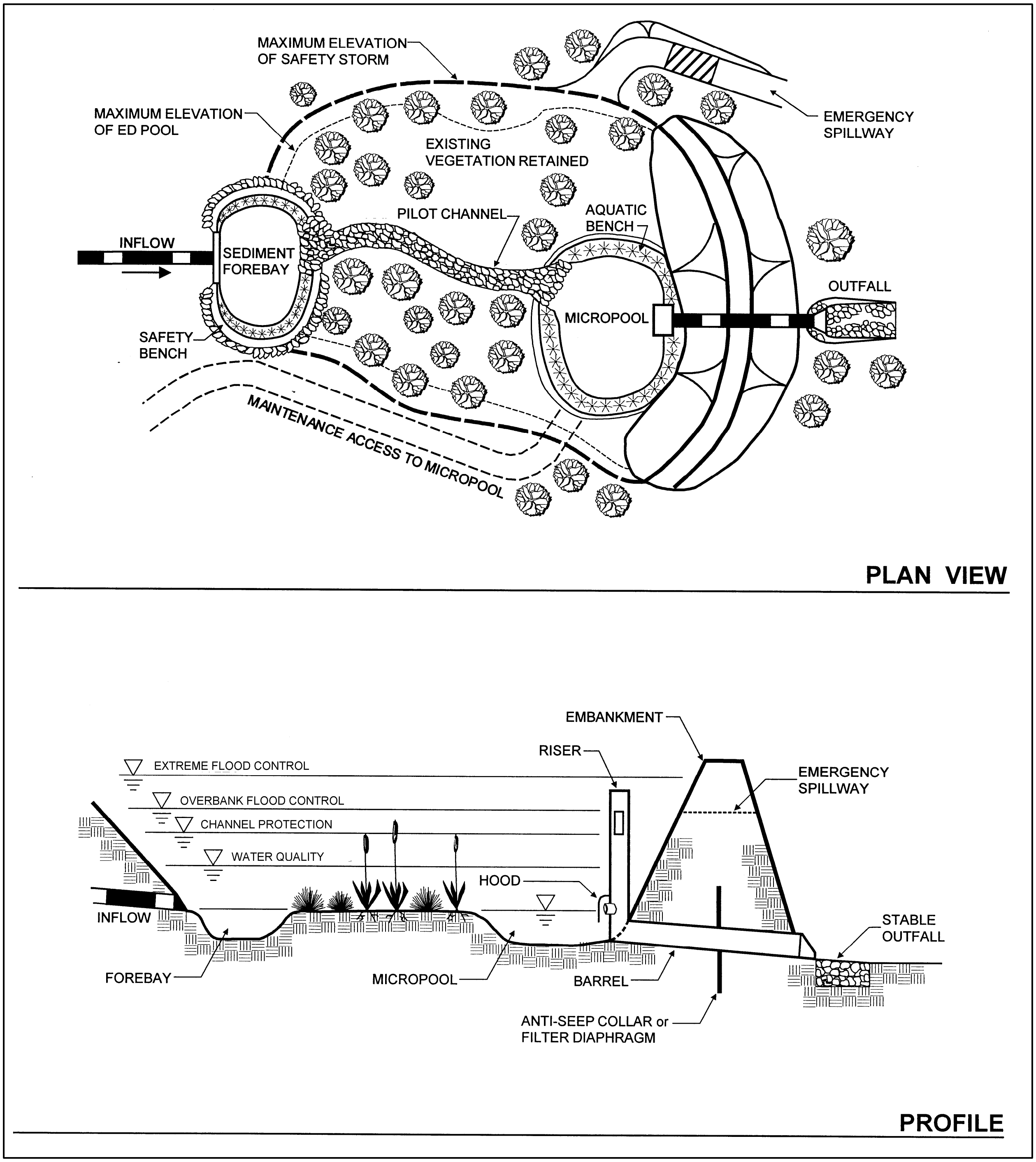

Figure 8.12: Schematic of a Typical Micropool Extended Detention Pond
(Source: Center for Watershed Protection)

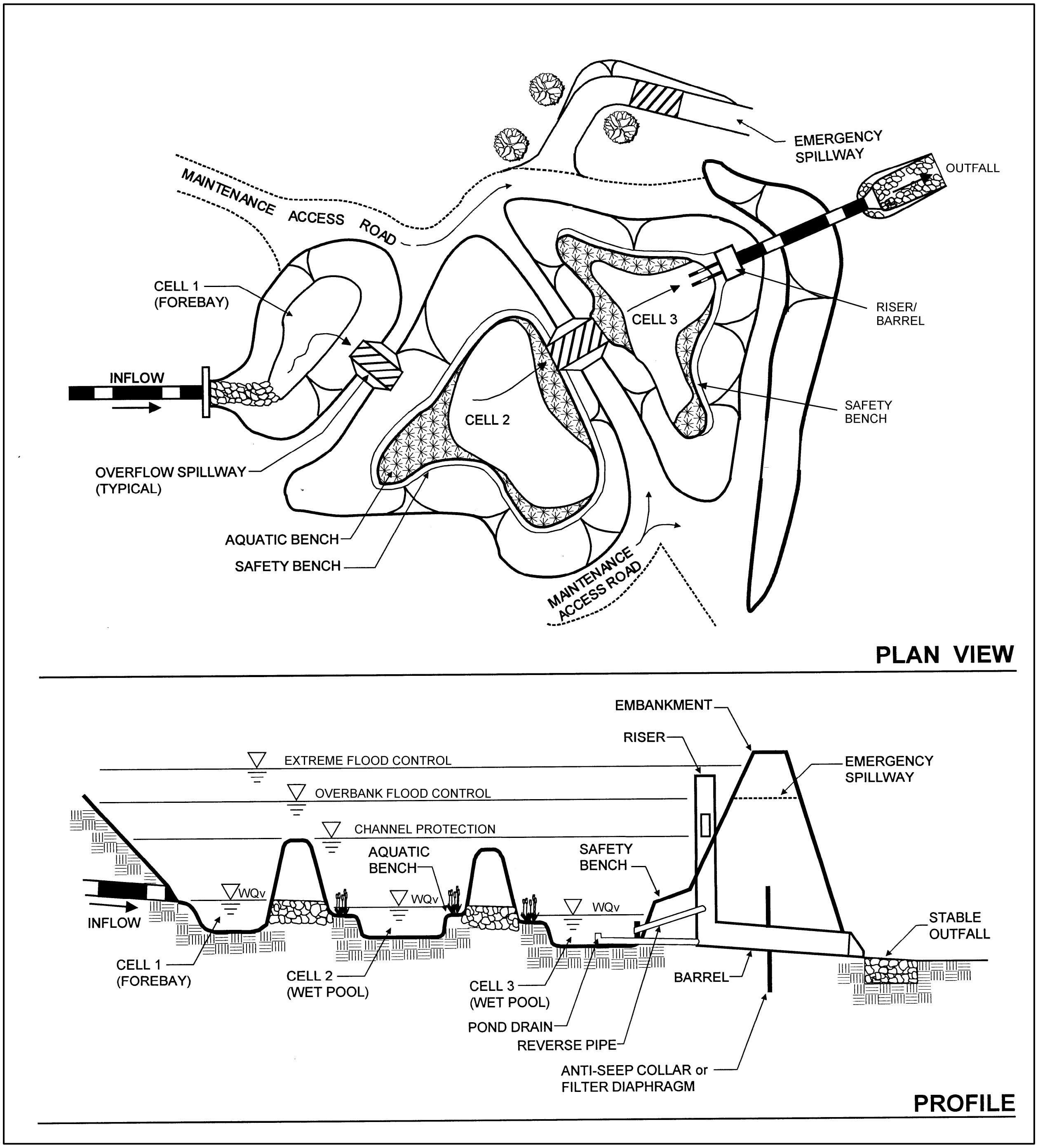

Figure 8.13: Schematic of a Typical Multiple Pond System
(Source: Center for Watershed Protection)

Stormwater Management "Credits"

Stormwater ponds have been assigned quantifiable stormwater management "credits" that can be used to help satisfy the SWM Criteria presented in this CSS:

- Stormwater Runoff Reduction: None. Although stormwater ponds provide moderate to high removal of many of the pollutants of concern typically contained in post-construction stormwater runoff, recent research shows that they provide little, if any, reduction of post-construction stormwater runoff volumes (Hirschman et al., 2008, Strecker et al., 2004). Although stand-alone stormwater ponds cannot be used to help satisfy the stormwater runoff reduction criteria (SWM Criteria #1), stormwater ponds may be used as "cisterns" in large-scale rainwater harvesting systems (Section 7.8.12), which help reduce post-construction stormwater runoff volumes on a development site.

- Water Quality Protection: Assume that a *stormwater pond* provides an 80% reduction in TSS loads, a 30% reduction in TN loads and a 70% reduction in bacteria loads.

- Aquatic Resource Protection: A *stormwater pond* can be designed to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).

- Overbank Flood Protection: A *stormwater pond* can be designed to attenuate the overbank peak discharge (Q_{p25}) on a development site.

- Extreme Flood Protection: A *stormwater pond* can be designed to attenuate the extreme peak discharge (Q_{p100}) on a development site.

In order to manage post-construction stormwater runoff and be eligible for these "credits," it is *recommended* that stormwater ponds satisfy the planning and design criteria outlined below.

Overall Feasibility

The criteria listed in Table 8.4 should be evaluated to determine whether or not a stormwater pond is appropriate for use on a development site.

Table 8.4: Factors to Consider When Evaluating the Overall Feasibility Of Using a Stormwater Pond on a Development Site

Site Characteristic	Criteria
Drainage Area	As a general rule of thumb, a contributing drainage area of 25 acres or more is typically needed to maintain a permanent pool in wet and wet extended detention ponds. A contributing drainage area of 10 acres or more is typically needed to maintain a permanent pool in micropool extended detention ponds. Water balance calculations should be completed to confirm that the contributing drainage area will be large enough or that there will be enough baseflow (e.g., groundwater) to maintain a permanent pool.
Area Required	In general, stormwater ponds require about 2-3% of the size of their contributing drainage areas.
Slope	Although stormwater ponds may be used on development sites with slopes of up to 15%, ponds constructed on development sites with steeper slopes typically require less excavation to create.
Minimum Head	6 to 8 feet

Table 8.4: Factors to Consider When Evaluating the Overall Feasibility Of Using a Stormwater Pond on a Development Site	
Site Characteristic	**Criteria**
Minimum Depth to Water Table	No restrictions, although 2 feet of separation is recommended at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers.
Soils	No restrictions, although poorly drained soils (i.e., hydrologic soil group C or D soils) are usually adequate to maintain a permanent pool in a stormwater pond. Stormwater ponds constructed on development sites with permeable soils (i.e., hydrologic soil group A or B soils) may require a pond liner.

<u>Feasibility in Coastal Georgia</u>

Several site characteristics commonly encountered in coastal Georgia may present challenges to site planning and design teams that are interested in using stormwater ponds to manage post-construction stormwater runoff on a development site. Table 8.5 identifies these common site characteristics and describes how they influence the use of stormwater ponds on development sites. The table also provides site planning and design teams with some ideas about how they can work around these potential constraints.

Table 8.5: Challenges Associated with Using Stormwater Ponds in Coastal Georgia		
Site Characteristic	**How it Influences the Use of Stormwater Ponds**	**Potential Solutions**
• *Poorly drained soils*, such as hydrologic soil group C and D soils	• Since they are designed to have a permanent pool of water, the presence of poorly drained soils does not influence the use of ponds on development sites. In fact, the presence of poorly drained soils may help maintain a permanent pool of water within a stormwater pond.	
• *Well drained soils*, such as hydrologic soil group A and B soils	• May be difficult to maintain a permanent pool of water within a stormwater pond. • May allow stormwater pollutants to reach groundwater aquifers with greater ease.	• Install a pond liner to maintain a permanent pool of water. • At stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers, install a pond liner to prevent pollutants from reaching groundwater aquifers. • In areas that are not considered to be stormwater hotspots and areas that do not provide groundwater recharge to water supply aquifers, use non-underdrained bioretention areas (Section 8.6.3) and infiltration practices (Section 8.6.5) to significantly reduce stormwater runoff rates, volumes and pollutant loads.

Table 8.5: Challenges Associated with Using Stormwater Ponds in Coastal Georgia

Site Characteristic	How it Influences the Use of Stormwater Ponds	Potential Solutions
• *Flat terrain*	• Reduces the amount of storage volume that can be provided within a stormwater pond. • Makes it difficult, if not impossible, to provide a pond drain at the bottom of a stormwater pond.	• Design stormwater ponds that have shallower permanent pools, with depths of 4 feet or less (e.g., dugouts). • Eliminate the use of pond drains, if necessary. • Consider stormwater wetlands (Section 8.6.2) as an alternative stormwater management practice in areas with flat terrain and a shallow water table.
• *Shallow water table*	• Makes it easier to maintain a permanent pool within a stormwater pond, but may allow stormwater pollutants to reach groundwater aquifers with greater ease.	• Excavation below the water table to create a stormwater pond is acceptable, but any storage volume found below the water table should not be counted when determining the total storage volume provided by the stormwater pond. • At stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers, install a pond liner to prevent pollutants from reaching underlying groundwater aquifers. • Use bioretention areas (Section 8.6.3) and filtration practices (Section 8.6.4) with liners and underdrains to intercept and treat stormwater runoff at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers.

Table 8.5: Challenges Associated with Using Stormwater Ponds in Coastal Georgia		
Site Characteristic	**How it Influences the Use of Stormwater Ponds**	**Potential Solutions**
• *Tidally-influenced drainage system*	• May occasionally prevent stormwater runoff from being conveyed through a stormwater pond, particularly during high tide. • May increase the amount of pollution that is transferred from stormwater ponds to adjacent estuarine resources.	• Maximize the use of low impact development practices (Section 7.8) in these areas to reduce stormwater runoff rates, volumes and pollutant loads. • Provide enlarged aquatic benches (e.g., up to 30 feet wide) that have been planted with dense wetland vegetation to increase pollutant removal. • Consider the use of bubbler aeration and proper fish stocking to maintain nutrient cycling and healthy oxygen levels in stormwater ponds located in these areas. • Consider stormwater wetlands (Section 8.6.2) as an alternative stormwater management practice in these areas.

Site Applicability

Although it may be difficult to use them to manage post-construction stormwater runoff in urban areas, due to space constraints, stormwater ponds can be used to manage stormwater runoff on a wide variety of development sites, including residential, commercial, industrial and institutional development sites in rural and suburban areas. When compared with other stormwater management practices, stormwater ponds have a relatively low construction cost, a relatively low maintenance burden and require a relatively large amount of surface area.

Planning and Design Criteria

It is *recommended* that stormwater ponds meet all of the planning and design criteria provided in Section 3.2.1 of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001) to be eligible for the stormwater management "credits" described above.

Construction Considerations

To help ensure that stormwater ponds are successfully installed on a development site, site planning and design teams should consider the following recommendations:

- Because stormwater ponds are typically installed early in the construction phase, they may accumulate a significant amount of sediment during construction. Any accumulated sediment should be removed from stormwater ponds near the end of the construction phase.
- To help prevent excessive sediment accumulation, stormwater runoff may be diverted around the stormwater pond until the contributing drainage area has become stabilized.
- Sediment markers should be installed in forebays and permanent pools to help determine when sediment removal is needed.

Maintenance Requirements

Maintenance is very important for stormwater ponds, particularly in terms of ensuring that they continue to provide measurable stormwater management benefits over time. Consequently, a legally binding inspection and maintenance agreement and plan should be created to help ensure that they are properly maintained after construction is complete. Table 8.6 provides a list of the routine maintenance activities typically associated with stormwater ponds.

Table 8.6: Routine Maintenance Activities Typically Associated with Stormwater Ponds

Activity	Schedule
• Water side slopes and buffers to promote plant growth and survival. • Inspect side slopes and buffers following rainfall events. Plant replacement vegetation in any eroded areas.	As Needed (Following Construction)
• Remove any accumulated sediment and debris from inlet and outlet structures.	Monthly
• Inspect side slopes and buffers for erosion. Plant replacement vegetation in any eroded areas. • Inspect side slopes and buffers for dead or dying vegetation. Plant replacement vegetation as needed. • Inspect side slopes and buffers for invasive vegetation and remove as needed. • If applicable, monitor wetland vegetation and perform replacement planting as necessary.	Annually (Semi-Annually During First Year)
• Inspect for damage, paying particular attention to the control structure and side slopes. Repair as necessary. • Inspect side slopes for erosion and undercutting and repair as needed. • Check for signs of eutrophic conditions (e.g., excessive algal growth). • Check for signs of hydrocarbon accumulation and remove appropriately. • Monitor sediment markers for sediment accumulation in forebays and permanent pools. • Examine to ensure that inlet and outlet devices are free of sediment and debris and are operational. • Check all control gates, valves and other mechanical devices.	Annually
• Remove sediment from forebay.	5 to 7 years or after 50% of the total forebay storage capacity has been lost
• Monitor sediment markers for sediment accumulation and remove sediment when the permanent pool volume has become reduced significantly, or when the pond becomes eutrophic.	10 to 20 years or after 25% of the permanent pool volume has been lost

It should be noted that sediments excavated from stormwater ponds that do not receive stormwater runoff from stormwater hotspots are typically not considered to be toxic and can be safely disposed through either land application or landfilling. Check with the local development review authority to identify any additional constraints on the disposal of sediments excavated from stormwater ponds.

Additional Resources

Atlanta Regional Commission (ARC). 2001. “Stormwater Ponds.” *Georgia Stormwater Management Manual*. Volume 2. Technical Handbook. Section 3.2.1. Atlanta Regional Commission. Atlanta, GA. Available Online: http://www.georgia stormwater.com/.

Minnesota Pollution Control Agency (MPCA). 2006. “Stormwater Ponds.” *Minnesota Stormwater Manual*. Chapter 12. Minnesota Pollution Control Agency. Available Online: http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html.

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8.6.2 Stormwater Wetlands

Description

Stormwater wetlands are constructed wetland systems built for stormwater management purposes. They typically consist of a combination of open water, shallow marsh and semi-wet areas that are located just above the permanent water surface. As stormwater runoff flows through a wetland, it is treated, primarily through gravitational settling and biological uptake. Temporary storage (i.e., live storage) can be provided above the permanent water surface for stormwater quantity control. This allows wetlands to both *treat* stormwater runoff and *manage* the stormwater runoff rates and volumes generated by larger rainfall events.

(Source: Merrill et al., 2006)

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Contributing drainage area of 25 acres or more typically needed for shallow and shallow extended detention wetlands; 10 acres or more typically needed for pocket wetlands
- A sediment forebay (or equivalent pretreatment) should be provided upstream of all wetlands
- Minimum of 35% of wetland surface area should have a depth of 6 inches or less; 10% to 20% of surface area should have a depth of between 1.5 and 6 feet
- Length to width ratio should be at least 2:1 (L:W), although a length to width ratio of 3:1 (L:W) or greater is preferred
- Side slopes should not exceed 3:1 (H:V)

BENEFITS:

- Provides moderate to high removal of many of the pollutants of concern typically contained in post-construction stormwater runoff
- Ideal for use in flat terrain and in areas with high groundwater

LIMITATIONS:

- Provides minimal reduction of post-construction stormwater runoff volumes
- Requires relatively large amount of land

SITE APPLICABILITY

☑ Rural Use	L	Construction Cost
☑ Suburban Use	M	Maintenance
Urban Use	H	Area Required

STORMWATER MANAGEMENT "CREDITS"

Runoff Reduction
☑ Water Quality Protection
☑ Aquatic Resource Protection
☑ Overbank Flood Protection
☑ Extreme Flood Protection

☑ = practice has been assigned quantifiable stormwater management "credits" that can be used to address this SWM Criteria

STORMWATER MANAGEMENT PRACTICE PERFORMANCE

Runoff Reduction
0% - Annual Runoff Volume
0% - Runoff Reduction Volume

Pollutant Removal[1]
80% - Total Suspended Solids
50% - Total Phosphorus
30% - Total Nitrogen
50% - Metals
70% - Pathogens

1 = expected annual pollutant load removal

Discussion

Stormwater wetlands (also known as *constructed wetlands*) are constructed wetland systems built for stormwater management purposes. They typically consist of a combination of open water, shallow marsh and semi-wet areas that are located just above the permanent water surface. As stormwater runoff flows through a wetland, it is treated, primarily through gravitational settling and biological uptake. Temporary storage (i.e., live storage) can be provided above the permanent water surface for stormwater quantity control. This allows wetlands to both *treat* stormwater runoff and *manage* the stormwater runoff rates and volumes generated by larger rainfall events.

Stormwater wetlands treat post-construction stormwater runoff through a combination of physical, chemical and biological processes. The primary pollutant removal mechanisms at work in stormwater wetlands are biological uptake, physical screening and gravitational settling. Other pollutant removal mechanisms at work in stormwater wetlands include volatilization and other biological and chemical processes.

Stormwater wetlands are among the most effective stormwater management practices that can be used coastal Georgia and the rest of the United States. They are typically created by excavating a depressional area to create "dead storage" below the water surface elevation of the receiving storm drain system, stream or other aquatic resource. A well-designed stormwater wetland can be attractively integrated into a development site as a landscaping feature and, if appropriately designed, sited and landscaped, can provide valuable wildlife habitat. Stormwater wetlands differ from natural wetland systems in that they are engineered facilities designed specifically for the purpose of managing post-construction stormwater runoff. They typically have less biodiversity than natural wetlands in terms of both plant and animal life but, like natural wetlands, require continuous base flow or a high water table to maintain a permanent water surface and support the growth of aquatic vegetation.

There are several variations of stormwater wetlands that can be used to manage post-construction stormwater runoff on development sites, including shallow wetlands, shallow extended detention wetlands and pocket wetlands. In addition, stormwater wetlands can be used in combination with stormwater ponds to increase storage capacity or address specific site characteristics or constraints (e.g., flat terrain). A brief description of each of these design variants is provided below:

- Shallow Wetlands: In a shallow wetland (Figure 8.15), most of the storage volume provided by the wetland is contained in some relatively shallow high marsh and low marsh areas. The only deep water areas found within a shallow wetland are the forebay, which is located at the entrance to the wetland, and the "micropool," which is located at the outlet. One disadvantage to the shallow wetland design is that, since most of the storage volume is provided in the relatively shallow high marsh and low marsh areas, a large amount of land may be needed to provide enough storage for the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85^{th} percentile rainfall event).

- Shallow Extended Detention (ED) Wetlands: A shallow extended detention wetland (Figure 8.16) is essentially the same as a shallow wetland, except that approximately 50% of the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85^{th} percentile rainfall event) is managed in an extended detention zone provided immediately above the permanent water surface. During wet weather, stormwater runoff is detained in the extended detention zone and released over a 24-hour period. Although this design variant requires less land than the shallow wetland design variant, it

Shallow Wetland

Shallow Extended Detention Wetland

Shallow Wetland

Pocket Wetland

Figure 8.14: Various Stormwater Wetlands

can be difficult to establish vegetation within the extended detention zone due to the fluctuating water surface elevations found within.

- Pond/Wetland Systems: A pond/wetland system (Figure 8.17) has two separate cells, one of which is a wet pond and the other of which is a shallow wetland. The wet pond cell is used to trap sediment and reduce stormwater runoff velocities upstream of the shallow wetland cell. Less land is typically required for pond/wetland systems than for shallow wetlands or shallow extended detention wetlands.

- Pocket Wetlands: Pocket wetlands (Figure 8.18) can be used to intercept and manage stormwater runoff from relatively small drainage areas of up to about 10 acres in size. In order to ensure that they have a permanent water surface throughout the year, they are typically designed to interact with the groundwater table.

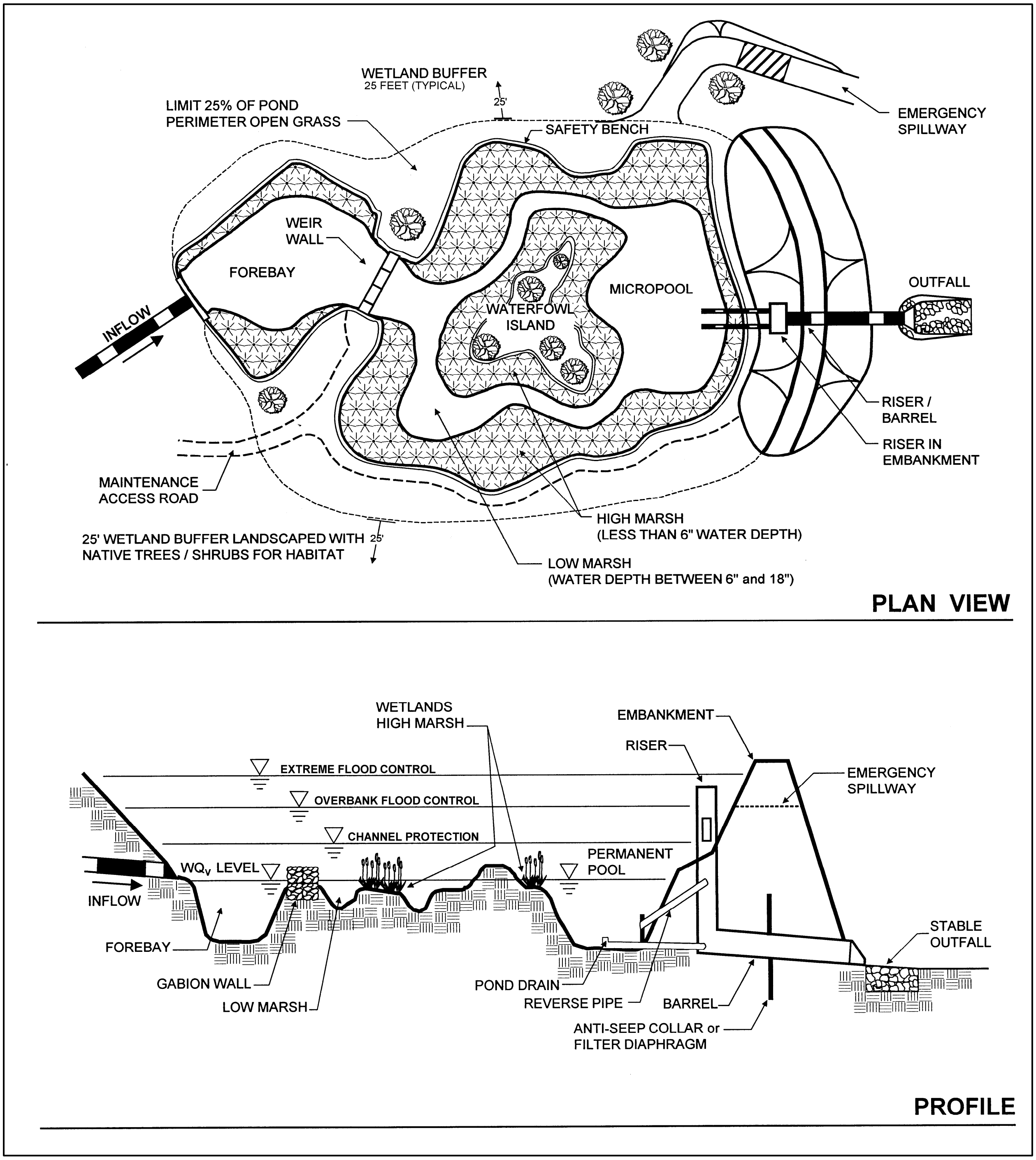

Figure 8.15: Schematic of a Typical Shallow Wetland
(Source: Center for Watershed Protection)

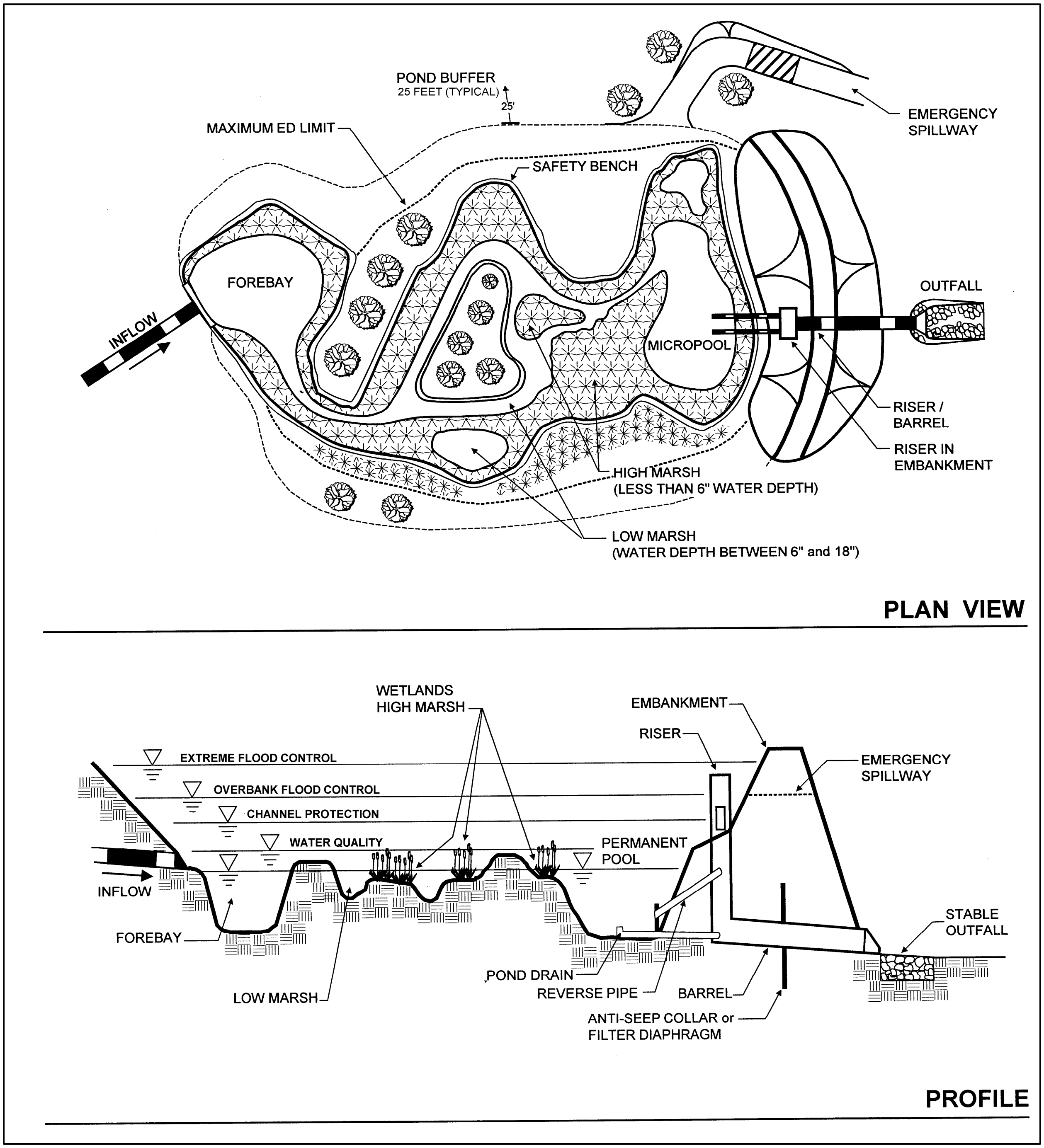

Figure 8.16: Schematic of a Typical Shallow Extended Detention Wetland
(Source: Center for Watershed Protection)

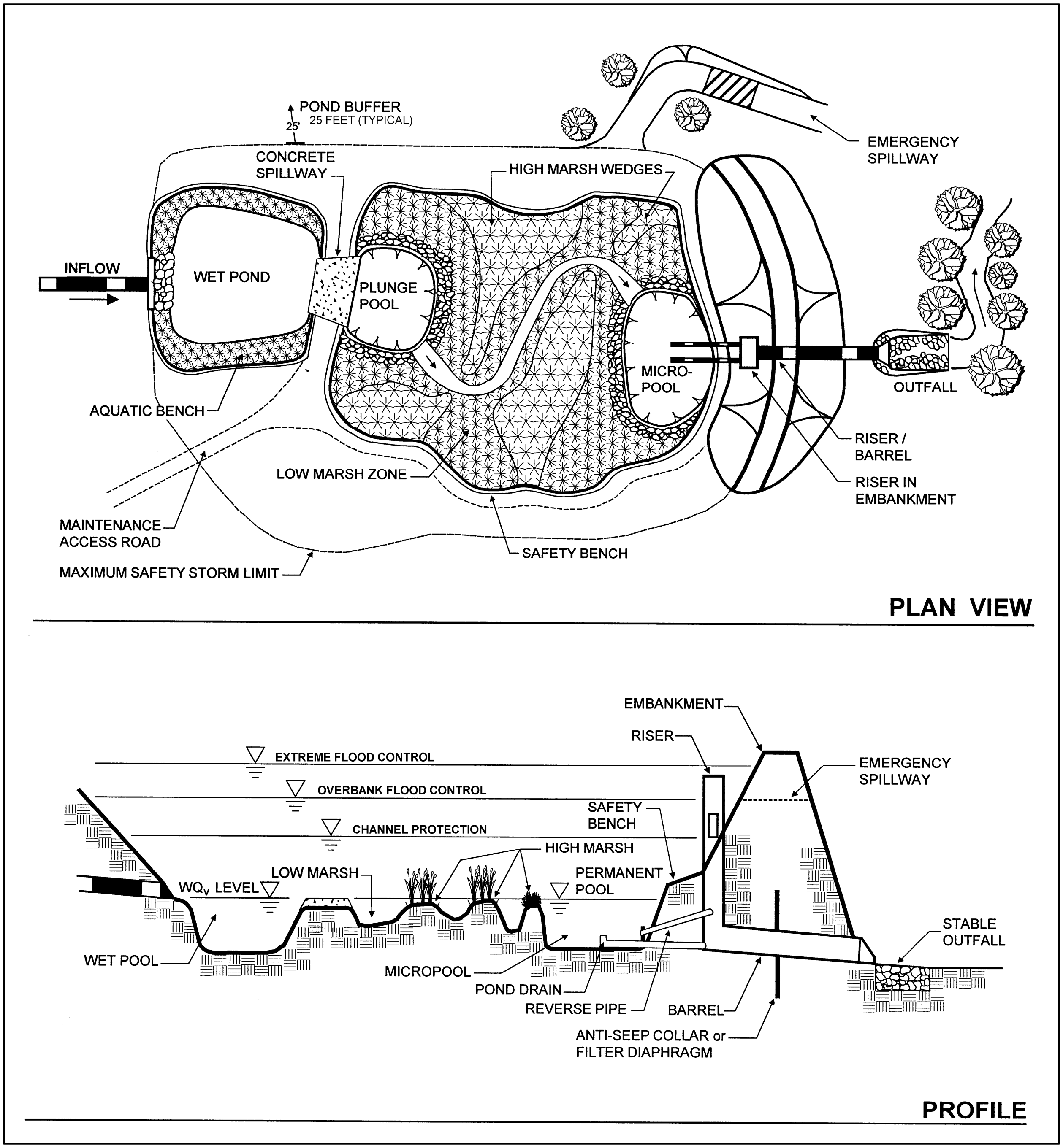

Figure 8.17: Schematic of a Typical Pond/Wetland System
(Source: Center for Watershed Protection)

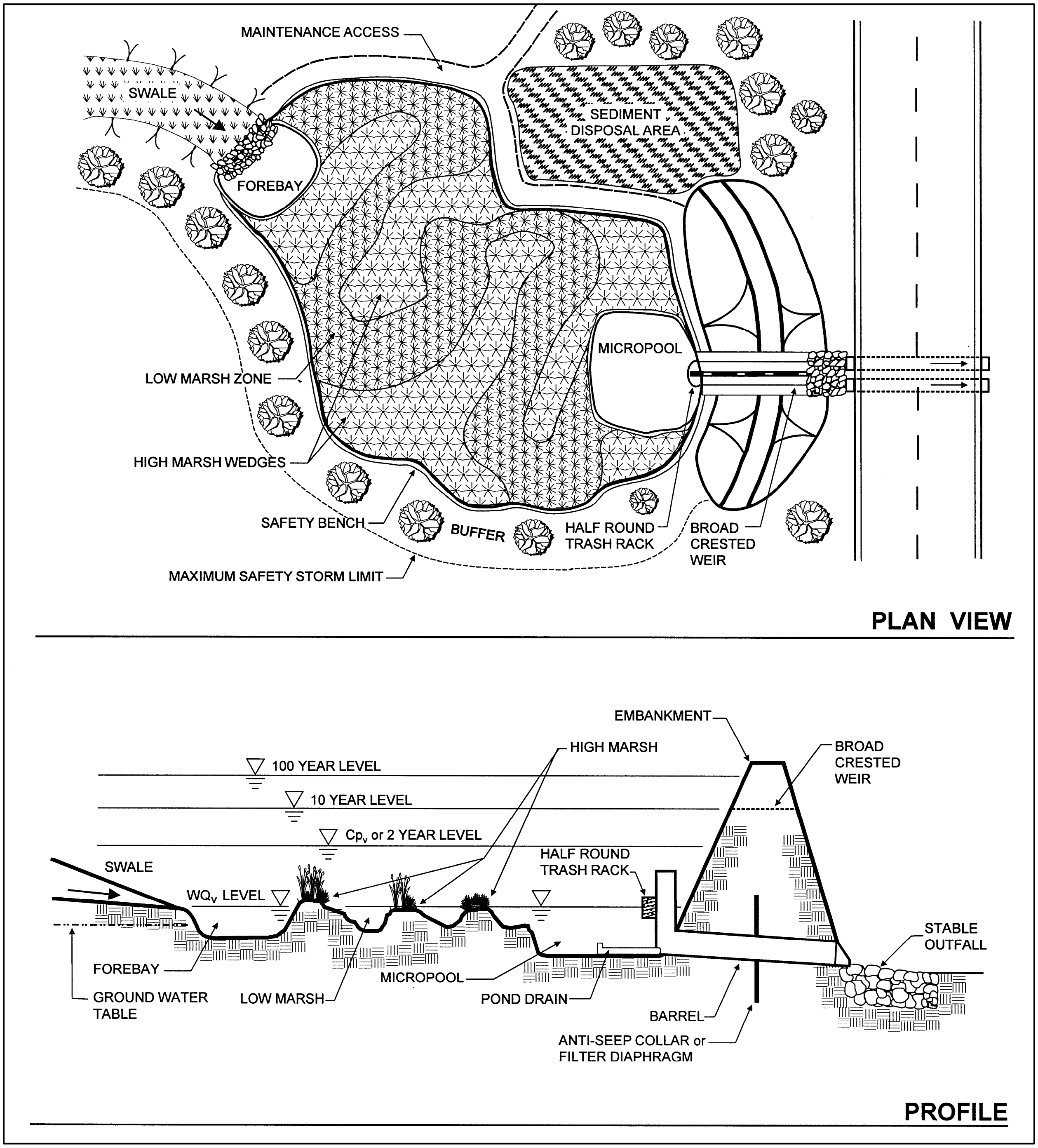

Figure 8.18: Schematic of a Typical Pocket Wetland
(Source: Center for Watershed Protection)

Stormwater Management "Credits"

Stormwater wetlands have been assigned quantifiable stormwater management "credits" that can be used to help satisfy the SWM Criteria presented in this CSS:

- Stormwater Runoff Reduction: None. Although stormwater wetlands provide moderate to high removal of many of the pollutants of concern typically contained in post-construction stormwater runoff, recent research shows that they provide little, if any, reduction of post-construction stormwater runoff volumes (Hirschman et al., 2008, Strecker et al., 2004).

- Water Quality Protection: Assume that a *stormwater wetland* provides an 80% reduction in TSS loads, a 30% reduction in TN loads and an 80% reduction in bacteria loads.

- Aquatic Resource Protection: A *stormwater wetland* can be designed to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v). Site planning and design teams are encouraged to store this volume in as shallow an area as possible to minimize the magnitude of the water surface elevation fluctuations that take place within the wetland.

- Overbank Flood Protection: A *stormwater wetland* can be designed to attenuate the overbank peak discharge (Q_{p25}) on a development site.

- Extreme Flood Protection: A *stormwater wetland* can be designed to attenuate the extreme peak discharge (Q_{p100}) on a development site.

In order to manage post-construction stormwater runoff and be eligible for these "credits," it is *recommended* that stormwater wetlands satisfy the planning and design criteria outlined below.

Overall Feasibility

The criteria listed in Table 8.7 should be evaluated to determine whether or not a stormwater wetland is appropriate for use on a development site.

Table 8.7: Factors to Consider When Evaluating the Overall Feasibility Of Using a Stormwater Wetland on a Development Site

Site Characteristic	Criteria
Drainage Area	As a general rule of thumb, a contributing drainage area of 25 acres or more is typically needed to maintain a permanent water surface in shallow wetlands, shallow ED wetlands and pond/wetland systems. A contributing drainage area of 5 acres or more is typically needed to maintain a permanent water surface in pocket wetlands. Water balance calculations should be completed to confirm that the contributing drainage area will be large enough or that there will be enough baseflow (e.g., groundwater) to maintain a permanent water surface.
Area Required	In general, stormwater wetlands require about 3-5% of the size of their contributing drainage areas.
Slope	Although stormwater wetlands may be used on development sites with slopes of up to 15%, wetlands constructed on development sites with steeper slopes typically require less excavation to create.
Minimum Head	2 to 5 feet

Table 8.7: Factors to Consider When Evaluating the Overall Feasibility Of Using a Stormwater Wetland on a Development Site	
Site Characteristic	**Criteria**
Minimum Depth to Water Table	No restrictions, although 2 feet of separation is recommended at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers.
Soils	No restrictions, although poorly drained soils (i.e., hydrologic soil group C or D soils) are usually adequate to maintain a permanent water surface in a stormwater wetland. Stormwater wetlands constructed on development sites with permeable soils (i.e., hydrologic soil group A or B soils) may require a liner.

Feasibility in Coastal Georgia

Several site characteristics commonly encountered in coastal Georgia may present challenges to site planning and design teams that are interested in using stormwater wetlands to manage post-construction stormwater runoff on a development site. Table 8.8 identifies these common site characteristics and describes how they influence the use of stormwater wetlands on development sites. The table also provides site planning and design teams with some ideas about how they can work around these potential constraints.

Table 8.8: Challenges Associated with Using Stormwater Wetlands in Coastal Georgia		
Site Characteristic	**How it Influences the Use of Stormwater Wetlands**	**Potential Solutions**
• *Poorly drained soils*, such as hydrologic soil group C and D soils	• Since they are designed to have a permanent water surface, the presence of poorly drained soils does not influence the use of stormwater wetlands on development sites. In fact, the presence of poorly drained soils may help maintain a permanent water surface within a stormwater wetland.	
• *Well drained soils*, such as hydrologic soil group A and B soils	• May be difficult to maintain a permanent water surface within a stormwater wetland. • May allow stormwater pollutants to reach groundwater aquifers with greater ease.	• Install a liner to maintain a permanent water surface. • At stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers, install a liner to prevent pollutants from reaching underlying groundwater aquifers. • In areas that are not considered to be stormwater hotspots and areas that do not provide groundwater recharge to water supply aquifers, use non-underdrained bioretention areas (Section 8.6.3) and infiltration practices (Section 8.6.5) to significantly reduce stormwater runoff volumes.

Table 8.8: Challenges Associated with Using Stormwater Wetlands in Coastal Georgia

Site Characteristic	How it Influences the Use of Stormwater Wetlands	Potential Solutions
• *Flat terrain*	• Makes it difficult, if not impossible, to provide a drain at the bottom of a stormwater wetland.	• Eliminate the use of drains, if necessary.
• *Shallow water table*	• Makes it easier to maintain a permanent water surface within a stormwater wetland, but may allow stormwater pollutants to reach groundwater aquifers with greater ease.	• Excavation below the water table to create a stormwater wetland is acceptable, but any storage volume found below the water table should not be counted when determining the total storage volume provided by the stormwater wetland. • At stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers, install a liner to prevent pollutants from reaching underlying groundwater aquifers. • Use bioretention areas (Section 8.6.3) and filtration practices (Section 8.6.4) with liners and underdrains to intercept and treat stormwater runoff at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers.
• *Tidally-influenced drainage system*	• May occasionally prevent stormwater runoff from being conveyed through a stormwater wetland, particularly during high tide.	• Maximize the use of low impact development practices (Section 7.8) in these areas to reduce stormwater runoff rates, volumes and pollutant loads. • Consider the use of bubbler aeration and proper fish stocking to maintain nutrient cycling and healthy oxygen levels in stormwater wetlands located in these areas.

Site Applicability

Although it may be difficult to use them to manage post-construction stormwater runoff in urban areas, due to space constraints, stormwater wetlands can be used to manage stormwater runoff on a wide variety of development sites, including residential, commercial, industrial and institutional development sites in rural and suburban areas. When compared with other stormwater management practices, stormwater wetlands have a relatively low construction cost, a moderate maintenance burden and require a relatively large amount of surface area.

Planning and Design Criteria
It is *recommended* that stormwater wetlands meet all of the planning and design criteria provided in Section 3.2.2 of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001) to be eligible for the stormwater management "credits" described above.

Construction Considerations
To help ensure that stormwater wetlands are successfully installed on a development site, site planning and design teams should consider the following recommendations:

- While the earthwork for a stormwater wetland can be completed early in the construction phase, stormwater wetlands should not be landscaped until the end of the construction phase, when the contributing drainage area has been stabilized.
- Because stormwater wetlands are typically installed early in the construction phase, they may accumulate a significant amount of sediment during construction. Any accumulated sediment should be removed from stormwater wetlands near the end of the construction phase.
- To help prevent excessive sediment accumulation, stormwater runoff may be diverted around the stormwater wetland until the contributing drainage area has become stabilized.
- Sediment markers should be installed in forebays and permanent pools to help determine when sediment removal is needed.

Maintenance Requirements
Maintenance is very important for stormwater wetlands, particularly in terms of ensuring that they continue to provide measurable stormwater management benefits over time. Consequently, a legally binding inspection and maintenance agreement and plan should be created to help ensure that they are properly maintained after construction is complete. Table 8.9 provides a list of the routine maintenance activities typically associated with stormwater wetlands.

Table 8.9: Routine Maintenance Activities Typically Associated with Stormwater Wetlands

Activity	Schedule
• Water side slopes and buffers to promote plant growth and survival. • Inspect wetland, side slopes and buffers following rainfall events. Plant replacement vegetation in any eroded areas.	As Needed (Following Construction)
• Remove any accumulated sediment and debris from inlet and outlet structures.	Monthly
• Inspect wetland, side slopes and buffers for erosion. Plant replacement vegetation in any eroded areas. • Inspect wetland, side slopes and buffers for dead or dying vegetation. Plant replacement vegetation as needed. • Inspect wetland, side slopes and buffers for invasive vegetation and remove as needed. • Monitor wetland vegetation and perform replacement planting as necessary. • Harvest wetland plants that have been "choked out" by sediment build-up.	Semi-Annually (Quarterly During First Year)

Table 8.9: Routine Maintenance Activities Typically Associated with Stormwater Wetlands	
Activity	**Schedule**
• Inspect wetland vegetation and replace vegetation, as necessary, to maintain at least 75% surface area coverage after the end of the first growing season.	One-Time Activity
• Inspect for damage, paying particular attention to the control structure and side slopes. Repair as necessary. • Examine stability of the original depth zones and microtopographical features. • Inspect side slopes for erosion and undercutting and repair as needed. • Check for signs of eutrophic conditions (e.g., excessive algal growth). • Check for signs of hydrocarbon accumulation and remove appropriately. • Monitor sediment markers for sediment accumulation in forebays and permanent pools. • Examine to ensure that inlet and outlet devices are free of sediment and debris and are operational. • Check all control gates, valves and other mechanical devices.	Annually
• Remove sediment from forebay.	5 to 7 years or after 50% of the total forebay storage capacity has been lost
• Monitor sediment markers for sediment accumulation and remove sediment when the permanent pool volume has become reduced significantly, plants are "choked" with sediment, or the wetland becomes eutrophic.	10 to 20 years or after 25% of the wetland storage volume has been lost

It is important to note that maintenance requirements for stormwater wetlands are particularly high during the first few years following installation and vegetation establishment. Regular inspection and maintenance during these first few years is crucial to the success of the wetland as an effective stormwater management practice.

It is also important to note that sediments excavated from stormwater wetlands that do not receive stormwater runoff from stormwater hotspots are typically not considered to be toxic and can be safely disposed through either land application or landfilling. Check with the local development review authority to identify any additional constraints on the disposal of sediments excavated from stormwater wetlands.

Additional Resources

Atlanta Regional Commission (ARC). 2001. "Stormwater Wetlands." *Georgia Stormwater Management Manual*. Volume 2. Technical Handbook. Section 3.2.2. Atlanta Regional Commission. Atlanta, GA. Available Online: http://www.georgia stormwater.com/.

Minnesota Pollution Control Agency (MPCA). 2006. "Stormwater Wetlands." *Minnesota Stormwater Manual*. Chapter 12. Minnesota Pollution Control Agency. Available Online: http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html.

8.6.3 Bioretention Areas

Description

Bioretention areas, which may also be classified as a low impact development practice (Section 7.8.13), are shallow depressional areas that are filled with an engineered soil mix and are planted with trees, shrubs and other herbaceous vegetation. They are designed to capture and temporarily store stormwater runoff in the engineered soil mix, where it is subjected to the hydrologic processes of evaporation and transpiration, before being conveyed back into the storm drain system through an underdrain or allowed to infiltrate into the surrounding soils. This allows them to provide measurable reductions in post-construction stormwater runoff rates, volumes and pollutant loads on development sites.

(Source: Center for Watershed Protection)

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Bioretention areas should be designed to completely drain within 48 hours of the end of a rainfall event
- A maximum ponding depth of 9 inches is recommended within bioretention areas to help prevent the formation of nuisance ponding conditions
- Unless a shallow water table is found on the development site, bioretention area planting beds should be at least 3 feet deep

BENEFITS:

- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates, volumes and pollutant loads
- Can be integrated into development plans as attractive landscaping features

LIMITATIONS:

- Can only be used to manage runoff from relatively small drainage areas of 5 acres in size

SITE APPLICABILITY

☑ Rural Use	M Construction Cost
☑ Suburban Use	M Maintenance
☑ Urban Use	L Area Required

STORMWATER MANAGEMENT "CREDITS"

☑ Runoff Reduction
☑ Water Quality Protection
☑ Aquatic Resource Protection
☑ Overbank Flood Protection
☑ Extreme Flood Protection

☑ = practice has been assigned quantifiable stormwater management "credits" that can be used to address this SWM Criteria

STORMWATER MANAGEMENT PRACTICE PERFORMANCE

Runoff Reduction
40%/80% - Annual Runoff Volume
Varies[1] - Runoff Reduction Volume

Pollutant Removal[2]
80% - Total Suspended Solids
60% - Total Phosphorus
60% - Total Nitrogen
N/A - Metals
80% - Pathogens

1 = varies according to storage capacity of the bioretention area
2 = expected annual pollutant load removal

Discussion
Bioretention areas (also known as *bioretention filters* and *biofilters*), which may also be classified as a low impact development practice (Section 7.8.13), are shallow depressional areas that are filled with an engineered soil mix and are planted with trees, shrubs and other herbaceous vegetation. They are designed to capture and temporarily store stormwater runoff in the engineered soil mix, where it is subjected to the hydrologic processes of evaporation and transpiration, before being conveyed back into the storm drain system through an underdrain or allowed to infiltrate into the surrounding soils. This allows them to provide measurable reductions in post-construction stormwater runoff rates, volumes and pollutant loads on development sites.

Bioretention areas (Figure 8.19) are one of the most effective stormwater management practices that can be used in coastal Georgia to reduce post-construction stormwater runoff rates, volumes and pollutant loads. They also provide a number of other benefits, including improved aesthetics, wildlife habitat, urban heat island mitigation and improved air quality. Bioretention areas differ from rain gardens (Section 7.8.9), in that they are designed to receive stormwater runoff from larger drainage areas and may be equipped with an underdrain (Figure 8.20).

Figure 8.19: Various Bioretention Areas

Stormwater Management "Credits"
Bioretention areas have been assigned quantifiable stormwater management "credits" that can be used to help satisfy the SWM Criteria presented in this CSS:

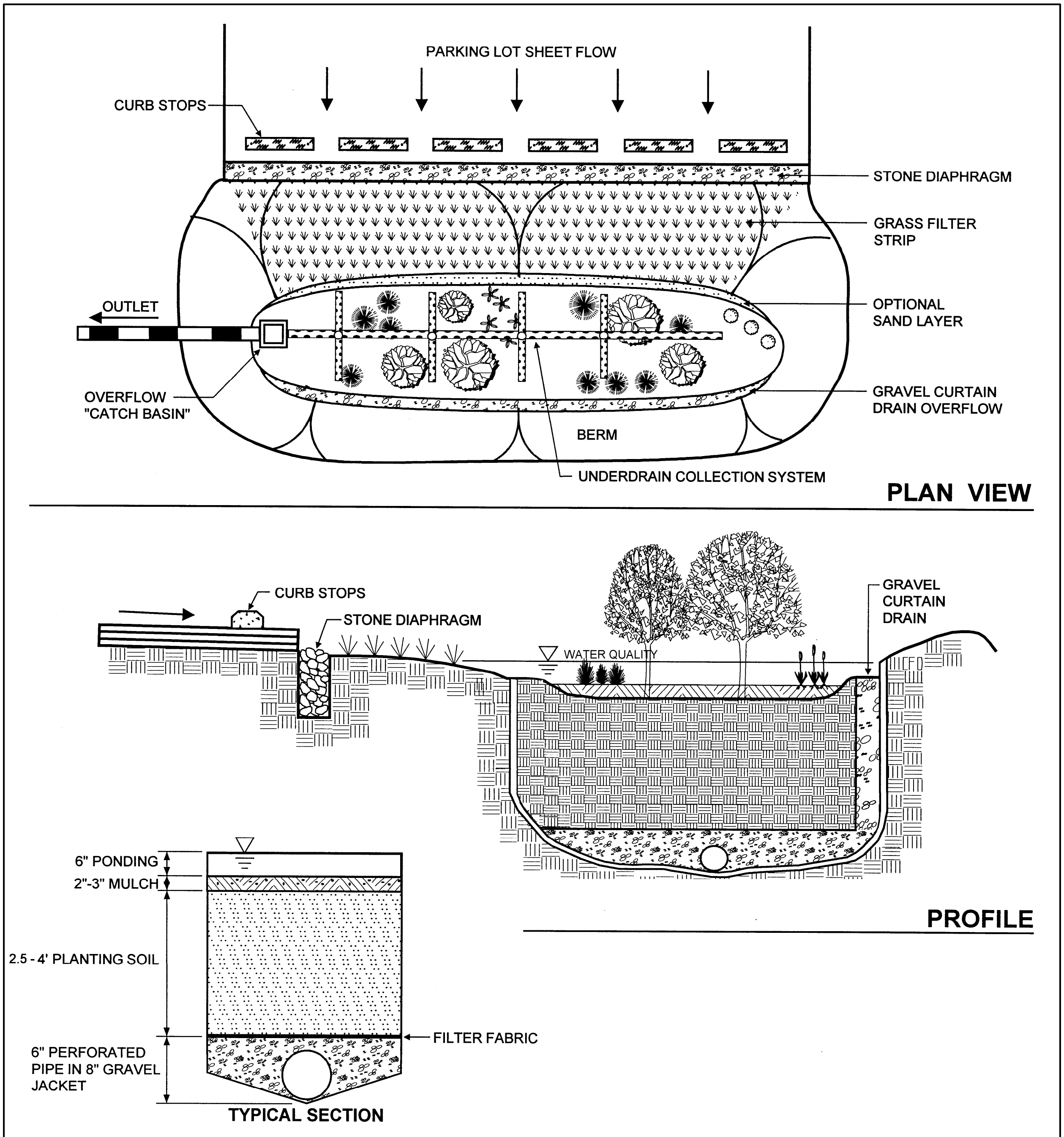

Figure 8.20: Schematic of a Typical Bioretention Area
(Source: Center for Watershed Protection)

- Stormwater Runoff Reduction: Subtract 100% of the storage volume provided by a non-underdrained *bioretention area* from the runoff reduction volume (RR_v) conveyed through the *bioretention area*. Subtract 50% of the storage volume provided by an underdrained *bioretention area* from the runoff reduction volume (RR_v) conveyed through the *bioretention area*.

- Water Quality Protection: Assume that a *bioretention area* provides an 80% reduction in TSS loads, a 60% reduction in TN loads and an 80% reduction in bacteria loads.

- Aquatic Resource Protection: Although uncommon, on some development sites, a *bioretention area* can be designed to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).

- Overbank Flood Protection: Although relatively rare, on some development sites, a *bioretention area* can be designed to attenuate the overbank peak discharge (Q_{p25}).

- Extreme Flood Protection: Although relatively rare, on some development sites, a *bioretention area* can be designed to attenuate the extreme peak discharge (Q_{p100}).

The storage volume provided by a bioretention area can be determined using the following equation:

Storage Volume = Surface Area x [Ponding Depth + (Depth of Planting Bed x Void Ratio)]

A void ratio (i.e., void space/total volume) of 0.32 should be used in all storage volume calculations, unless more specific planting bed void ratio data are available.

In order to manage post-construction stormwater runoff and be eligible for these "credits," it is *recommended* that bioretention areas satisfy the planning and design criteria outlined below.

Overall Feasibility

The criteria listed in Table 8.10 should be evaluated to determine whether or not a bioretention area is appropriate for use on a development site.

Table 8.10: Factors to Consider When Evaluating the Overall Feasibility of Using a Bioretention Area on a Development Site

Site Characteristic	Criteria
Drainage Area	Although bioretention areas can be used to manage stormwater runoff from contributing drainage areas as large as 5 acres in size, contributing drainage areas of between 2,500 square feet and 2 acres are preferred.
Area Required	Bioretention area surface area requirements vary according to the size of the contributing drainage area and the infiltration rate of the soils on which the bioretention area will be located. In general, bioretention areas require about 5-10% of the size of their contributing drainage areas.
Slope	Although bioretention areas may be used on development sites with slopes of up to 6%, they should be designed with slopes that are as close to flat as possible to help ensure that stormwater runoff is evenly distributed over the planting bed.
Minimum Head	Bioretention areas may be designed with a maximum ponding depth of 12 inches, although a ponding depth of 9 inches is recommended to help prevent the formation of nuisance ponding conditions. Unless a shallow water table is found on the development site, all bioretention area planting beds should be at least 36 inches deep.
Minimum Depth to Water Table	2 feet

Table 8.10: Factors to Consider When Evaluating the Overall Feasibility of Using a Bioretention Area on a Development Site	
Site Characteristic	**Criteria**
Soils	Bioretention areas should be designed to completely drain within 48 hours of the end of a rainfall event. Consequently, non-underdrained bioretention areas generally should not be used on development sites that have soils with infiltration rates of less than 0.25 inches per hour (i.e., hydrologic soil group C and D soils). Underdrained bioretention areas may be used to manage stormwater runoff on development sites that have soils with infiltration rates of less than 0.25 inches per hour.

<u>Feasibility in Coastal Georgia</u>

Several site characteristics commonly encountered in coastal Georgia may present challenges to site planning and design teams that are interested in using bioretention areas to manage post-construction stormwater runoff on a development site. Table 8.11 identifies these common site characteristics and describes how they influence the use of bioretention areas on development sites. The table also provides site planning and design teams with some ideas about how they can work around these potential constraints.

Table 8.11: Challenges Associated with Using Bioretention Areas in Coastal Georgia		
Site Characteristic	**How it Influences the Use of Bioretention Areas**	**Potential Solutions**
• *Poorly drained soils*, such as hydrologic soil group C and D soils	• Reduces the ability of bioretention areas to reduce stormwater runoff rates, volumes and pollutant loads.	• Use underdrained bioretention areas to manage post-construction stormwater runoff in these areas. • Use additional low impact development and stormwater management practices to supplement the stormwater management benefits provided by bioretention areas in these areas. • Use rainwater harvesting (Section 7.8.12), small stormwater wetlands (i.e., pocket wetlands) (Section 8.6.2) or wet swales (Section 8.6.6), instead of bioretention areas to intercept and treat stormwater runoff in these areas.

Table 8.11: Challenges Associated with Using Bioretention Areas in Coastal Georgia		
Site Characteristic	**How it Influences the Use of Bioretention Areas**	**Potential Solutions**
• *Well drained soils*, such as hydrologic soil group A and B soils	• Enhances the ability of bioretention areas to reduce stormwater runoff rates, volumes and pollutant loads, but may allow stormwater pollutants to reach groundwater aquifers with greater ease.	• Avoid the use of infiltration-based stormwater management practices, including non-underdrained bioretention areas, at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers, unless adequate pretreatment is provided upstream of them. • Use bioretention areas and dry swales (Section 8.6.6) with liners and underdrains at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers.
• *Flat terrain*	• May be difficult to provide adequate drainage and may cause stormwater runoff to pond in the bioretention area for extended periods of time.	• Ensure that the underlying native soils will allow the bioretention area to drain completely within 48 hours of the end of a rainfall event to prevent the formation of nuisance ponding conditions.
• *Shallow water table*	• May be difficult to provide 2 feet of clearance between the bottom of the bioretention area and the top of the water table. • May occasionally cause stormwater runoff to pond in the bioretention area.	• Ensure that the distance from the bottom of the bioretention area to the top of the water table is at least 2 feet. • Reduce the depth of the planting bed to 18 inches. • Use stormwater ponds (Section 8.6.1), stormwater wetlands (Section 8.6.2) and wet swales (Section 8.6.6), instead of bioretention areas to intercept and treat stormwater runoff in these areas.
• *Tidally-influenced drainage system*	• May occasionally prevent stormwater runoff from being conveyed through a bioretention area, particularly during high tide.	• Investigate the use of other low impact development and stormwater management practices, such as rainwater harvesting (Section 7.8.12) to manage post-construction stormwater runoff in these areas.

Site Applicability

Bioretention areas can be used to manage post-construction stormwater runoff on a wide variety of development sites, including residential, commercial and institutional development sites in rural, suburban and urban areas. They are well suited to "receive" stormwater runoff from nearly all small impervious and pervious drainage areas, including local streets and roadways, highways, driveways, small parking areas and disturbed pervious areas (e.g., lawns, parks, community open spaces). When compared with other stormwater management practices, bioretention areas have a moderate construction cost, a moderate maintenance burden and require a relatively small amount of surface area.

Planning and Design Criteria

It is *recommended* that bioretention areas meet all of the following criteria to be eligible for the stormwater management "credits" described above:

General Planning and Design

- Although bioretention areas can be used to manage post-construction stormwater runoff from contributing drainage areas as large as 5 acres in size, contributing drainage areas of between 2,500 square feet and 2 acres are preferred. Multiple bioretention areas can be used to manage stormwater runoff from larger contributing drainage areas.
- Although bioretention areas may be used on development sites with slopes of up to 6%, they should be designed with slopes that are as close to flat as possible to help ensure that stormwater runoff is evenly distributed over the planting bed.
- Bioretention areas can be designed without an underdrain on development sites that have underlying soils with an infiltration rate of 0.25 inches per hour (in/hr) or greater, as determined by NRCS soil survey data and subsequent field testing. Field infiltration test protocol, such as that provided by the City of Portland, OR (Portland, OR, 2008) on the following website: http://www.portlandonline.com/shared/cfm/image.cfm?id= 202911, can be used to conduct field testing, but should be approved by the local development review authority prior to use.
- Although the number of infiltration tests needed on a development site will ultimately be determined by the local development review authority, at least one infiltration test is recommended for each bioretention area that will be used on the development site. If the infiltration rate of the underlying soils on the development site is not 0.25 inches per hour (in/hr) or greater, an underdrain should be included in the bioretention area design.
- Since clay lenses or any other restrictive layers located below the bottom of a bioretention area will reduce soil infiltration rates, infiltration testing should be conducted within any confining layers that are found within 4 feet of the bottom of a proposed bioretention area.
- Bioretention areas should be designed to provide enough storage for the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event). The required dimensions of an underdrained bioretention area can be determined using the following equation, which is based on Darcy's Law:

$$A_{bio} = (RR_v)(d_{bio}) \div [(k_{bio})(h_{bio} + d_{bio})(t_{drain})]$$

Where:

A_{bio} = surface area of bioretention area (ft^2)

RR_v = stormwater runoff volume generated by target runoff reduction rainfall event (ft^3) (e.g., 85th percentile rainfall event)

d_{bio} = depth of bioretention area planting bed (ft) (use 36 inches or more, unless a shallow water table is found on the development site)

k_{bio} = coefficient of permeability of bioretention area planting bed (ft/day) (use k_{bio} = 0.5 ft/day for engineered soil mix specified below)
h_{bio} = average height of ponded water above bioretention area (ft) (use 50% of maximum ponding depth)
t_{drain} = design bioretention area drain time (days) (use 48 hours or less)

The required dimensions of a non-underdrained bioretention area can be determined using the following equation, which is also based on Darcy's Law:

$$A_{bio} = (RR_v)(d_{bio}) \div [(i_{soil})(h_{bio} + d_{bio})(t_{drain})]$$

Where:
A_{bio} = surface area of bioretention area (ft^2)
RR_v = stormwater runoff volume generated by target runoff reduction rainfall event (ft^3) (e.g., 85th percentile rainfall event)
d_{bio} = depth of bioretention area planting bed (ft) (use 36 inches or more, unless a shallow water table is found on the development site)
i_{soil} = infiltration rate of underlying native soils (ft/day) or coefficient of permeability of bioretention area planting bed (ft/day) (use k_{bio} = 0.5 ft/day for engineered soil mix specified below), whichever is less
h_{bio} = average height of ponded water above bioretention area (ft) (use 50% of maximum ponding depth)
t_{drain} = design bioretention area drain time (days) (use 48 hours or less)

- Bioretention areas should be designed to completely drain within 48 hours of the end of a rainfall event. Where site characteristics allow, it is preferable to design bioretention areas to drain within 24 hours of the end of a rainfall event to help prevent the formation of nuisance ponding conditions.
- Unless a shallow water table is found on the development site, all bioretention area planting beds should be at least 36 inches deep. If a shallow water table is found on the development site, the depth of the planting bed may be reduced to 18 inches.
- The soils used within bioretention area planting beds should be an engineered soil mix that meets the following specifications:
  - Texture: Sandy loam or loamy sand.
  - Sand Content: Soils should contain 85%-88% clean, washed sand.
  - Topsoil Content: Soils should contain 8%-12% topsoil.
  - Organic Matter Content: Soils should contain 3%-5% organic matter.
  - Infiltration Rate: Soils should have an infiltration rate of at least 0.25 inches per hour (in/hr), although an infiltration rate of between 1 and 2 in/hr is preferred.
  - Phosphorus Index (P-Index): Soils should have a P-Index of less than 30.
  - Exchange Capacity (CEC): Soils should have a CEC that exceeds 10 milliequivalents (meq) per 100 grams of dry weight.
  - pH: Soils should have a pH of 6-8.
- The organic matter used within a bioretention area planting bed should be a well-aged compost that meets the specifications outlined in Section 7.8.1.
- Bioretention areas should be preceded by a pea gravel (i.e., ASTM D 448 Size No. 8, 3/8" to 1/8") diaphragm or equivalent level spreader device (e.g., concrete sills, curb stops, curbs with "sawteeth" cut into them) and appropriate pretreatment device, such as a vegetated filter strip (Section 7.8.6) or sediment forebay.
- If no underdrain is required, underlying native soils should be separated from the planting bed by a thin, 2 to 4 inch layer of choker stone (i.e., ASTM D 448 size No. 8, 3/8" to 1/8" or

ASTM D 448 size No. 89, 3/8" to 1/16"). The choker stone should be placed between the planting bed and the underlying native soils.

- If an underdrain is required, it should be placed beneath the planting bed. The underdrain should consist of a 4 to 6 inch perforated PVC (AASHTO M 252) pipe bedded in an 8 inch layer of clean, washed stone. The pipe should have 3/8 inch perforations, spaced 6 inches on center, and should have a minimum slope of 0.5%. The clean, washed stone should be ASTM D448 size No. 57 stone (i.e., 1-1/2 to 1/2 inches in size) and should be separated from the planting bed by a thin, 2 to 4 inch layer of choker stone (i.e., ASTM D 448 size No. 8, 3/8" to 1/8" or ASTM D 448 size No. 89, 3/8" to 1/16").
- Bioretention areas should be designed with side slopes of 3:1 (H:V) or flatter.
- The depth from the bottom of a bioretention area to the top of the water table should be at least 2 feet to help prevent ponding and ensure proper operation of the bioretention area. On development sites with high water tables, small stormwater wetlands (i.e., pocket wetlands) (Section 8.6.2) should be used to intercept and treat post-construction stormwater runoff.
- To prevent damage to building foundations and contamination of groundwater aquifers, bioretention areas, unless equipped with a waterproof liner (e.g., 30 mil (0.030 inch) polyvinylchloride (PVC) or equivalent), should be located at least:
  - 10 feet from building foundations
  - 10 feet from property lines
  - 100 feet from private water supply wells
  - 1,200 feet from public water supply wells
  - 100 feet from septic systems
  - 100 feet from surface waters
  - 400 feet from public water supply surface waters
- Consideration should be given to the stormwater runoff rates and volumes generated by larger storm events (e.g., 25-year, 24-hour storm event) to help ensure that these larger storm events are able to safely bypass the bioretention area. An overflow system should be designed to convey the stormwater runoff generated by these larger storm events safely out of the bioretention area. Methods that can be used to accommodate the stormwater runoff rates and volumes generated by these larger storm events include:
  - Using yard drains or storm drain inlets set at the maximum ponding depth to collect excess stormwater runoff.
  - Placing a vertical gravel curtain drain at the downstream end of the bioretention area (Figure 8.20) to provide additional conveyance of stormwater runoff into the underdrain after the planting bed has been filled.
  - Placing a perforated pipe (e.g., underdrain) near the top of the planting bed to provide additional conveyance of stormwater runoff after the planting bed has been filled.

<u>Landscaping</u>

- A landscaping plan should be prepared for all bioretention areas. The landscaping plan should be reviewed and approved by the local development review authority prior to construction.
- Vegetation commonly planted in bioretention areas includes native trees, shrubs and other herbaceous vegetation. When developing a landscaping plan, site planning and design teams should choose vegetation that will be able to stabilize soils and tolerate the stormwater runoff rates and volumes that will pass through the bioretention area. Vegetation used in bioretention areas should also be able to tolerate both wet and dry conditions. See Appendix F of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001) for a list of grasses and other plants that are appropriate for use in bioretention areas installed in the state of Georgia.

- A mulch layer, consisting of 2-4 inches of fine shredded hardwood mulch or shredded hardwood chips, should be included on the surface of the bioretention area.
- Methods used to establish vegetative cover within a bioretention area should achieve at least 75 percent vegetative cover one year after installation.
- To help prevent soil erosion and sediment loss, landscaping should be provided immediately after the bioretention area has been installed. Temporary irrigation may be needed to quickly establish vegetative cover within a bioretention area.

Construction Considerations

To help ensure that bioretention areas are successfully installed on a development site, site planning and design teams should consider the following recommendations:

- To prevent practice failure due to sediment accumulation and pore clogging, bioretention areas should only be installed after their contributing drainage areas have been completely stabilized. To help prevent practice failure, stormwater runoff may be diverted around the bioretention area until the contributing drainage area has become stabilized.
- Simple erosion and sediment control measures, such as temporary seeding and erosion control mats, should be used within the bioretention area. Appropriate measures should be taken (e.g., temporary diversion) to divert post-construction stormwater runoff around a bioretention area until vegetative cover has been established.
- To help prevent soil compaction, heavy vehicular and foot traffic should be kept out of bioretention areas before, during and after construction. This can typically be accomplished by clearly delineating bioretention areas on all development plans and, if necessary, protecting them with temporary construction fencing.
- The native soils along the bottom of the bioretention area should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the underdrain and/or engineered soil mix.
- Construction contracts should contain a replacement warranty that covers at least three growing seasons to help ensure adequate growth and survival of the vegetation planted within a bioretention area.

Maintenance Requirements

Maintenance is very important for bioretention areas, particularly in terms of ensuring that they continue to provide measurable stormwater management benefits over time. Consequently, a legally binding inspection and maintenance agreement and plan should be created to help ensure that they are properly maintained after construction is complete. Table 8.12 provides a list of the routine maintenance activities typically associated with bioretention areas.

Table 8.12: Routine Maintenance Activities Typically Associated with Bioretention Areas

Activity	Schedule
• Water to promote plant growth and survival. • Inspect bioretention area following rainfall events. Plant replacement vegetation in any eroded areas.	As Needed (Following Construction)
• Prune and weed bioretention area to maintain appearance. • Remove accumulated trash and debris. • Replace mulch as needed.	Regularly (Monthly)

Table 8.12: Routine Maintenance Activities Typically Associated with Bioretention Areas	
Activity	**Schedule**
• Inspect inflow area for sediment accumulation. Remove any accumulated sediment or debris. • Inspect bioretention area for erosion and the formation of rills and gullies. Plant replacement vegetation in any eroded areas. • Inspect bioretention area for dead or dying vegetation. Plant replacement vegetation as needed. • Test planting bed for pH. If the pH is below 5.2, limestone should be applied. If the pH is above 8.0, iron sulfate and sulfur should be applied.	Annually (Semi-Annually During First Year)
• Replace mulch. • Replace pea gravel diaphragm, if necessary	Every 2 to 3 Years

It should be noted that sediments removed from bioretention areas that do not receive stormwater runoff from stormwater hotspots are typically not considered to be toxic and can be safely disposed through either land application or landfilling. Check with the local development review authority to identify any additional constraints on the disposal of sediments removed from bioretention areas.

Additional Resources

Atlanta Regional Commission (ARC). 2001. "Bioretention Areas." *Georgia Stormwater Management Manual*. Volume 2. Technical Handbook. Section 3.2.3. Atlanta Regional Commission. Atlanta, GA. Available Online: http://www.georgia stormwater.com/.

Hunt, W.F. and W.G. Lord. 2006. "Bioretention Performance, Design, Construction and Maintenance." *North Carolina Cooperative Extension Service Bulletin.* Urban Waterways Series. AG-588-5. North Carolina State University. Raleigh, NC. Available Online: http://www.bae.ncsu.edu/stormwater/PublicationFiles/Bioretention2006.pdf.

Biohabitats, Inc. 2005. *Bioretention Guidance*. Prepared for: Lake County, OH. Stormwater Management Department. Available Online: http://www2.lakecountyohio.org/smd/Forms.htm.

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8.6.4 Filtration Practices

Description

Filtration practices are multi-chamber structures designed to treat stormwater runoff using the physical processes of screening and filtration. After passing through the filter media (e.g., sand), stormwater runoff is typically returned to the conveyance system through an underdrain. Because they have very few site constraints beyond head requirements (i.e., vertical distance between inlet and outlet), filtration practices can often be used on development sites where other stormwater management practices, such as stormwater ponds (Section 8.6.1) and infiltration practices (Section 8.6.5), can not.

(Source: Atlanta Regional Commission, 2001)

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Maximum contributing drainage area of 10 acres for surface filters; maximum contributing drainage area of 2 acres for perimeter filters
- Filtration practices should be designed to completely drain within 36 hours of the end of a rainfall event
- A maximum ponding depth of 12 inches is recommended to help prevent the formation of nuisance ponding conditions
- Typically require 3 to 6 feet of head, although perimeter filters may be designed to function on development sites with as little as 2 feet of head

BENEFITS:

- Provides moderate to high removal of many of the pollutants of concern typically contained in post-construction stormwater runoff
- Ideal for intercepting and treating stormwater runoff from small, highly impervious areas, including stormwater hotspots

LIMITATIONS:

- Relatively high construction and maintenance costs
- Should not be used to "receive" stormwater runoff that contains high sediment loads

SITE APPLICABILITY

✱ Rural Use	H Construction Cost
☑ Suburban Use	H Maintenance
☑ Urban Use	L Area Required

STORMWATER MANAGEMENT "CREDITS"

Runoff Reduction
☑ Water Quality Protection
☑ Aquatic Resource Protection
☑ Overbank Flood Protection
☑ Extreme Flood Protection

☑ = practice has been assigned quantifiable stormwater management "credits" that can be used to address this SWM Criteria

STORMWATER MANAGEMENT PRACTICE PERFORMANCE

Runoff Reduction
0% - Annual Runoff Volume
0% - Runoff Reduction Volume

Pollutant Removal[1]
80%- Total Suspended Solids
60% - Total Phosphorus
40% - Total Nitrogen
50% - Metals
40% - Pathogens

1 = expected annual pollutant load removal

Description

Filtration practices are multi-chamber structures designed to treat stormwater runoff using the physical processes of screening and filtration. Most filtration practices are two-chamber structures. The first chamber is a sediment forebay or sedimentation chamber, which works to remove trash, debris and larger sediment particles. The second chamber is a filtration chamber, which removes additional stormwater pollutants by conveying stormwater runoff through a filter media. After passing through the filter media (e.g., sand), stormwater runoff is typically returned to the conveyance system through an underdrain. Because they have very few site constraints beyond head requirements (i.e., vertical distance between inlet and outlet), filtration practices can often be used on development sites where other stormwater management practices, such as stormwater ponds (Section 8.6.1) and infiltration practices (Section 8.6.5), can not.

Filtration practices treat stormwater runoff primarily through a combination of the physical processes of gravitational settling, physical screening, filtration, absorption and adsorption. The filtration process effectively removes suspended solids, particulate matter, heavy metals and fecal coliform bacteria and other pathogens from stormwater runoff. Surface filters that are designed with vegetative cover provide additional opportunities for biological uptake of nutrients by the vegetation and for biological decomposition of other stormwater pollutants, such as hydrocarbons.

There are several variations of filtration practices that can be used to manage post-construction stormwater runoff on development sites, the most common of which include surface sand filters and perimeter sand filters (Figure 8.21). A brief description of each of these design variants is provided below:

- Surface Sand Filters: Surface sand filters (Figure 8.22) are ground-level, open air practices that consist of a pretreatment forebay and a filter bed chamber. Surface sand filters can treat stormwater runoff from contributing drainage areas as large as 10 acres in size and are typically designed as off-line stormwater management practices. Surface sand filters can be designed as excavations, with earthen side slopes, or as structural concrete or block structures.

- Perimeter Sand Filters: Perimeter sand filters (Figure 8.23) are enclosed stormwater management practices that are typically located just below grade in a trench along the perimeter of parking lot, driveway or other impervious surface. Perimeter sand filters

Surface Sand Filter

Perimeter Sand Filter

Figure 8.21: Various Filtration Practices

consist of a pretreatment forebay and a filter bed chamber. Stormwater runoff is conveyed into a perimeter sand filter through grate inlets located directly above the system.

Other design variants, including the underground sand filter and the organic filter, are intended primarily for use on ultra-urban development sites, where space is limited, or for use at stormwater hotspots, where enhanced removal of particular stormwater pollutants (e.g., heavy metals) is desired. Additional information about these *limited application stormwater management practices* is provided in Section 8.7 of this CSS.

Stormwater Management "Credits"

Filtration practices have been assigned quantifiable stormwater management "credits" that can be used to help satisfy the SWM Criteria presented in this CSS:

- Stormwater Runoff Reduction: None. Although *filtration practices* provide moderate to high removal of many of the pollutants of concern typically contained in post-construction stormwater runoff, recent research shows that they provide little, if any, reduction of post-construction stormwater runoff volumes (Hirschman et al., 2008).

- Water Quality Protection: Assume that a *filtration practice* provides an 80% reduction in TSS loads, a 30% reduction in TN loads and a 40% reduction in bacteria loads.

- Aquatic Resource Protection: Although uncommon, on some development sites, a *filtration practice* can be designed to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).

- Overbank Flood Protection: Although relatively rare, on some development sites, a *filtration practice* can be designed to attenuate the overbank peak discharge (Q_{p25}).

- Extreme Flood Protection: Although relatively rare, on some development sites, a *filtration practice* can be designed to attenuate the extreme peak discharge (Q_{p100}).

In order to manage post-construction stormwater runoff and be eligible for these "credits," it is *recommended* that filtration practices satisfy the planning and design criteria outlined below.

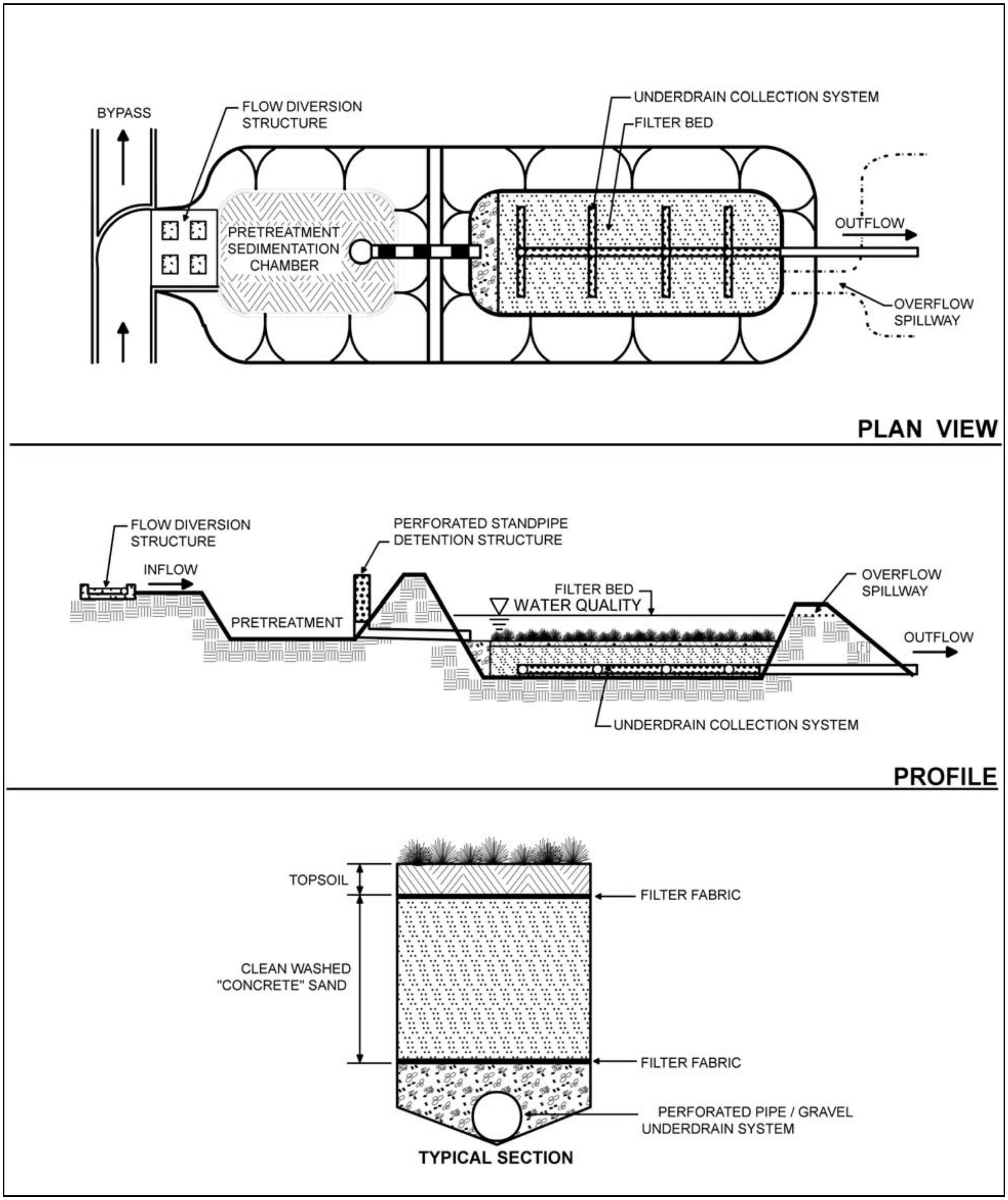

Figure 8.22: Schematic of a Typical Surface Sand Filter
(Source: Center for Watershed Protection)

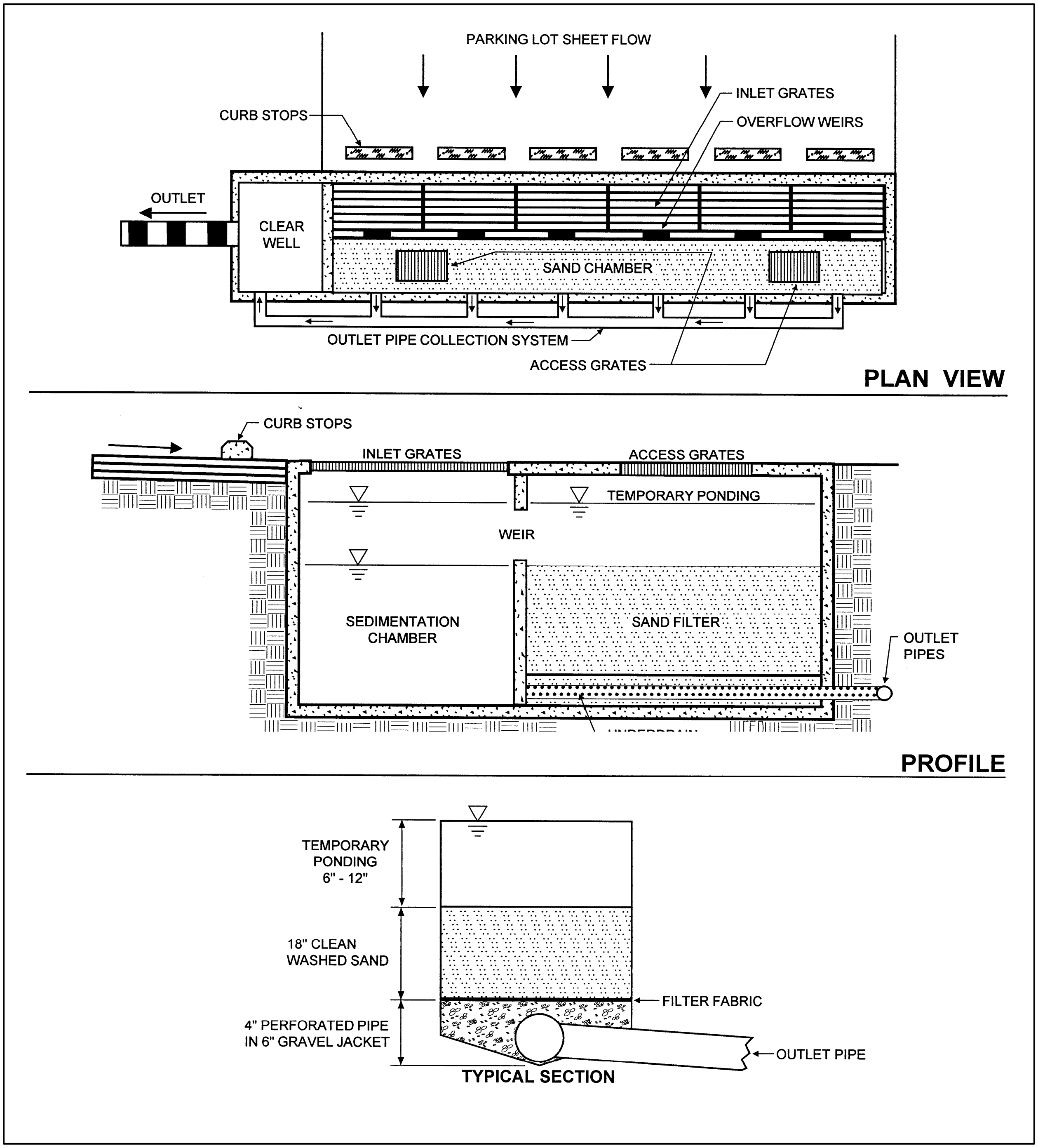

Figure 8.23: Schematic of a Typical Perimeter Sand Filter
(Source: Center for Watershed Protection)

Overall Feasibility

The criteria listed in Table 8.13 should be evaluated to determine whether or not a filtration practice is appropriate for use on a development site.

Table 8.13: Factors to Consider When Evaluating the Overall Feasibility of Using a Filtration Practice on a Development Site	
Site Characteristic	**Criteria**
Drainage Area	Surface sand filters can be used to manage stormwater runoff from contributing drainage areas of up to 10 acres in size. Perimeter sand filters can be used to manage stormwater runoff from contributing drainage areas of up to 2 acres in size.
Area Required	Filtration practice surface area requirements vary according to the size of the contributing drainage area and the amount of head available at the development site. In general, filtration practices require about 3-5% of the size of their contributing drainage areas.
Slope	Although filtration practices may be used on development sites with slopes of up to 6%, they should be designed with slopes that are as close to flat as possible to help ensure that stormwater runoff is evenly distributed over the filter bed.
Minimum Head	5 feet for surface sand filters 2 to 3 feet for perimeter sand filters
Minimum Depth to Water Table	2 feet
Soils	No restrictions

Feasibility in Coastal Georgia

Several site characteristics commonly encountered in coastal Georgia may present challenges to site planning and design teams that are interested in using filtration practices to manage post-construction stormwater runoff on development and redevelopment sites. Table 7.15 identifies these common site characteristics and describes how they influence the use of filtration practices. The table also provides site planning and design teams with some ideas about how they can work around these potential design constraints.

Table 8.14: Challenges Associated with Using Filtration Practices in Coastal Georgia		
Site Characteristic	**How it Influences the Use of Filtration Practices**	**Potential Solutions**
• *Poorly drained soils*, such as hydrologic soil group C and D soils	• Since they are equipped with underdrains, the presence of poorly drained soils does not influence the use of filtration practices on development sites.	

Table 8.14: Challenges Associated with Using Filtration Practices in Coastal Georgia		
Site Characteristic	**How it Influences the Use of Filtration Practices**	**Potential Solutions**
• *Well drained soils*, such as hydrologic soil group A and B soils	• May allow stormwater pollutants to reach groundwater aquifers with greater ease.	• Use filtration practices and bioretention areas (Section 8.6.3) with liners and underdrains to intercept and treat stormwater runoff at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers. • In areas that are not considered to be stormwater hotspots and areas that do not provide groundwater recharge to water supply aquifers, use non-underdrained bioretention areas (Section 8.6.3) and infiltration practices (Section 8.6.5) to significantly reduce stormwater runoff rates, volumes and pollutant loads.
• *Flat terrain*	• May be difficult to provide adequate drainage and may cause stormwater runoff to pond in the filtration practice for extended periods of time.	• Ensure that the filtration practice will drain completely within 36 hours of the end of a rainfall event to prevent the formation of nuisance ponding conditions.
• *Shallow water table*	• May be difficult to provide 2 feet of clearance between the bottom of the filtration practice and the top of the water table. • May occasionally cause stormwater runoff to pond in the filtration practice.	• Ensure that the distance from the bottom of the filtration practice to the top of the water table is at least 2 feet. • Use stormwater ponds (Section 8.6.1), stormwater wetlands (Section 8.6.2) and wet swales (Section 8.6.6), instead of bioretention areas to intercept and treat stormwater runoff in these areas.

Site Applicability

Filtration practices can be used to manage stormwater runoff on a wide variety of development sites. They are particularly well suited for intercepting and treating stormwater runoff from small, highly impervious areas (e.g., parking lots) on development sites where space for other stormwater management practices is limited. Filtration practices should primarily be considered for use on parts of commercial, industrial and institutional development sites where fine sediment (e.g., clay, silt) loads will be relatively low, as high sediment loads will cause them to clog and fail. When compared with other stormwater management practices, filtration practices have a relatively high construction cost, a relatively high maintenance burden and require a relatively small amount of surface area.

Planning and Design Criteria

It is *recommended* that filtration practices meet all of the planning and design criteria provided in Section 3.2.4 of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001) to be eligible for the stormwater management “credits” described above.

Construction Considerations

To help ensure that filtration practices are successfully installed on a development site, site planning and design teams should consider the following recommendations:

- To prevent practice failure due to sediment accumulation and pore clogging, filtration practices should only be installed after their contributing drainage areas have been completely stabilized. To help prevent practice failure, stormwater runoff may be diverted around the filtration practice until the contributing drainage area has become stabilized.
- Simple erosion and sediment control measures, such as temporary seeding and erosion control mats, should be used within any landscaped filtration practices (e.g., surface sand filters). Appropriate measures should be taken (e.g., temporary diversion) to divert post-construction stormwater runoff around a landscaped filtration practice until vegetative cover has been established.
- To help prevent soil compaction, heavy vehicular and foot traffic should be kept out of filtration practices during and after construction.
- Construction contracts should contain a replacement warranty that covers at least three growing seasons to help ensure adequate growth and survival of the vegetation planted within a landscaped filtration practice.

Maintenance Requirements

Maintenance is very important for filtration practices, particularly in terms of ensuring that they continue to provide measurable stormwater management benefits over time. Consequently, a legally binding inspection and maintenance agreement and plan should be created to help ensure that they are properly maintained after construction is complete. Table 8.15 provides a list of the routine maintenance activities typically associated with filtration practices.

Table 8.15: Routine Maintenance Activities Typically Associated with Filtration Practices

Activity	Schedule
• Ensure that the contributing drainage area is stabilized prior to installation of the filtration practice. • If applicable, water to ensure plant growth and survival. • If applicable, inspect vegetative cover following rainfall events. Plant replacement vegetation in eroded areas.	As Needed (During Construction)
• Inspect to ensure that contributing drainage area and filtration practice are clear of sediment, trash and debris. Remove any accumulated sediment and debris. • Ensure that the contributing drainage area is stabilized. Plant replacement vegetation as needed. • Check to ensure that the filtration practice is properly dewatering after storm events. • Ensure that activities in the contributing drainage area do not produce high sediment or oil and grease loads. • If a permanent water surface has been included in the design (e.g., perimeter sand filter), check to ensure that the filter chamber is not leaking and that the permanent water surface is maintained.	Monthly

Table 8.15: Routine Maintenance Activities Typically Associated with Filtration Practices	
Activity	**Schedule**
• Inspect for damage, paying particular attention to inlets, outlets and overflow spillways. Repair or replace any damaged components as needed. • Check to see that the filter bed is free of sediment and that the sediment chamber is not more than 50% full of sediment. Remove accumulated sediment as necessary. • If applicable, inspect filter chamber concrete for deterioration, spalling or cracking. • Inspect inflow areas to ensure that stormwater runoff is not bypassing the filtration practice. • Check for noticeable odors outside of the filter chamber.	Annually
• If filter bed is clogged or partially clogged, manual manipulation of the filter bed may be required. Remove the top 2 to 3 inches of the filter bed and till or otherwise cultivate the top of the filter bed. Replace the filter media with sand that meets the specifications provided above. • Replace any clogged filter fabric.	As Needed

It should be noted that sediments removed from filtration practices that do not receive stormwater runoff from stormwater hotspots are typically not considered to be toxic and can be safely disposed through either land application or landfilling. Check with the local development review authority to identify any additional constraints on the disposal of sediments removed from filtration practices.

Additional Resources

Atlanta Regional Commission (ARC). 2001. "Sand Filters." *Georgia Stormwater Management Manual*. Volume 2. Technical Handbook. Section 3.2.4. Atlanta Regional Commission. Atlanta, GA. Available Online: http://www.georgia stormwater.com/.

Atlanta Regional Commission (ARC). 2001. "Organic Filters." *Georgia Stormwater Management Manual*. Volume 2. Technical Handbook. Section 3.3.3. Atlanta Regional Commission. Atlanta, GA. Available Online: http://www.georgia stormwater.com/.

Atlanta Regional Commission (ARC). 2001. "Underground Sand Filters." *Georgia Stormwater Management Manual*. Volume 2. Technical Handbook. Section 3.3.4. Atlanta Regional Commission. Atlanta, GA. Available Online: http://www. georgiastormwater.com/.

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8.6.5 Infiltration Practices

Description

Infiltration practices, which may also be classified as a runoff reducing low impact development practice (Section 7.8.14), are shallow excavations, typically filled with stone or an engineered soil mix, that are designed to intercept and temporarily store post-construction stormwater runoff until it infiltrates into the underlying and surrounding soils. If properly designed, they can provide significant reductions in post-construction stormwater runoff rates, volumes and pollutant loads on development sites. Consequently, infiltration practices can be used to help satisfy the SWM Criteria presented in this CSS.

(Source: Center for Watershed Protection)

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Pretreatment should be provided upstream of all infiltration practices
- Infiltration practices should be designed to completely drain within 48 hours of the end of a rainfall event
- Underlying native soils should have an infiltration rate of 0.5 in/hr or more
- The distance from the bottom of an infiltration practice to the top of the water table should be 2 feet or more

BENEFITS:

- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates, volumes and pollutant loads
- Can be integrated into development plans as attractive landscaping features

LIMITATIONS:

- Can only be used to manage runoff from relatively small drainage areas of 2-5 acres in size
- Should not be used to "receive" stormwater runoff that contains high sediment loads

SITE APPLICABILITY

☑ Rural Use	M Construction Cost
☑ Suburban Use	H Maintenance
☑ Urban Use	L Area Required

STORMWATER MANAGEMENT "CREDITS"

- ☑ Runoff Reduction
- ☑ Water Quality Protection
- ☑ Aquatic Resource Protection
- ☑ Overbank Flood Protection
- ☑ Extreme Flood Protection

☑ = practice has been assigned quantifiable stormwater management "credit" that can be used to address this SWM Criteria

STORMWATER MANAGEMENT PRACTICE PERFORMANCE

Runoff Reduction

80% - Annual Runoff Volume
Varies[1] - Runoff Reduction Volume

Pollutant Removal[2]

80% - Total Suspended Solids
60% - Total Phosphorus
60% - Total Nitrogen
N/A - Metals
80% - Pathogens

1 = varies according to storage capacity of the infiltration practice
2 = expected annual pollutant load removal

Discussion

Infiltration practices (Figure 8.24), which may also be classified as a runoff reducing low impact development practice (Section 7.8.14), are shallow excavations, typically filled with stone or an engineered soil mix, that are designed to intercept and temporarily store post-construction stormwater runoff until it infiltrates into the underlying and surrounding soils. If properly designed, they can provide significant reductions in post-construction stormwater runoff rates, volumes and pollutant loads on development sites.

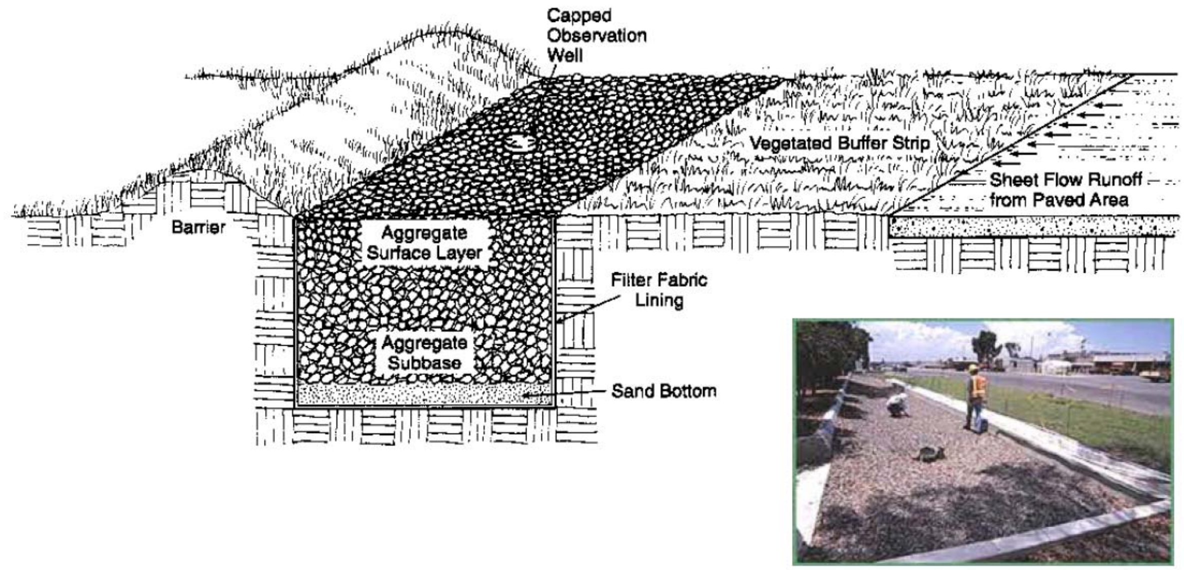

Figure 8.24: Infiltration Trench
(Source: Center for Watershed Protection)

Although infiltration practices can provide significant reductions in post-construction stormwater runoff rates, volumes and pollutant loads, they have historically experienced high rates of failure due to clogging caused by poor design, poor construction and neglected maintenance. If infiltration practices are to be used on a development site, great care should be taken to ensure that they are adequately designed, carefully installed and properly maintained over time. They should only be applied on development sites that have permeable soils (i.e., hydrologic soil group A and B soils) and that have a water table and confining layers (e.g., bedrock, clay lenses) that are located at least 2 feet below the bottom of the trench or basin. Additionally, infiltration practices should always be designed with adequate pretreatment (e.g., vegetated filter strip, sediment forebay) to prevent sediment from reaching them and causing them to clog and fail.

There are two major variations of infiltration practices, namely infiltration trenches and infiltration basins (Figure 8.25). A brief description of each of these design variants is provided below:

- Infiltration Trenches: Infiltration trenches are excavated trenches filled with stone (Figure 8.26). Stormwater runoff is captured and temporarily stored in the stone reservoir, where it is allowed to infiltrate into the surrounding and underlying native soils. Infiltration trenches can be used to manage post-construction stormwater runoff from contributing drainage areas of up to 2 acres in size and should only be used on development sites where sediment loads can be kept relatively low.

- Infiltration Basins: Infiltration basins are shallow, landscaped excavations filled with an engineered soil mix. They are designed to capture and temporarily store stormwater runoff in the engineered soil mix, where it is subjected to the hydrologic processes of evaporation and transpiration, before being allowed to infiltrate into the surrounding soils. They are essentially non-underdrained bioretention areas (Section 8.6.3), and should also only be used on development sites where sediment loads can be kept relatively low.

Infiltration Trench

Infiltration Basin (During Installation)

Figure 8.25: Infiltration Practices

Stormwater Management "Credits"

Infiltration practices have been assigned quantifiable stormwater management "credits" that can be used to help satisfy the SWM Criteria presented in this CSS:

- Stormwater Runoff Reduction: Subtract 100% of the storage volume provided by an *infiltration practice* from the runoff reduction volume (RR_v) conveyed through the *infiltration practice*.

- Water Quality Protection: Assume that an *infiltration practice* provides an 80% reduction in TSS loads, an 60% reduction in TN loads and an 80% reduction in bacteria loads.

- Aquatic Resource Protection: Although uncommon, on some development sites, an *infiltration practice* can be designed to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).

- Overbank Flood Protection: Although relatively rare, on some development sites, an *infiltration practice* can be designed to attenuate the overbank peak discharge (Q_{p25}).

- Extreme Flood Protection: Although relatively rare, on some development sites, an *infiltration practice* can be designed to attenuate the extreme peak discharge (Q_{p100}).

The storage volume provided by an infiltration trench can be determined using the following equation:

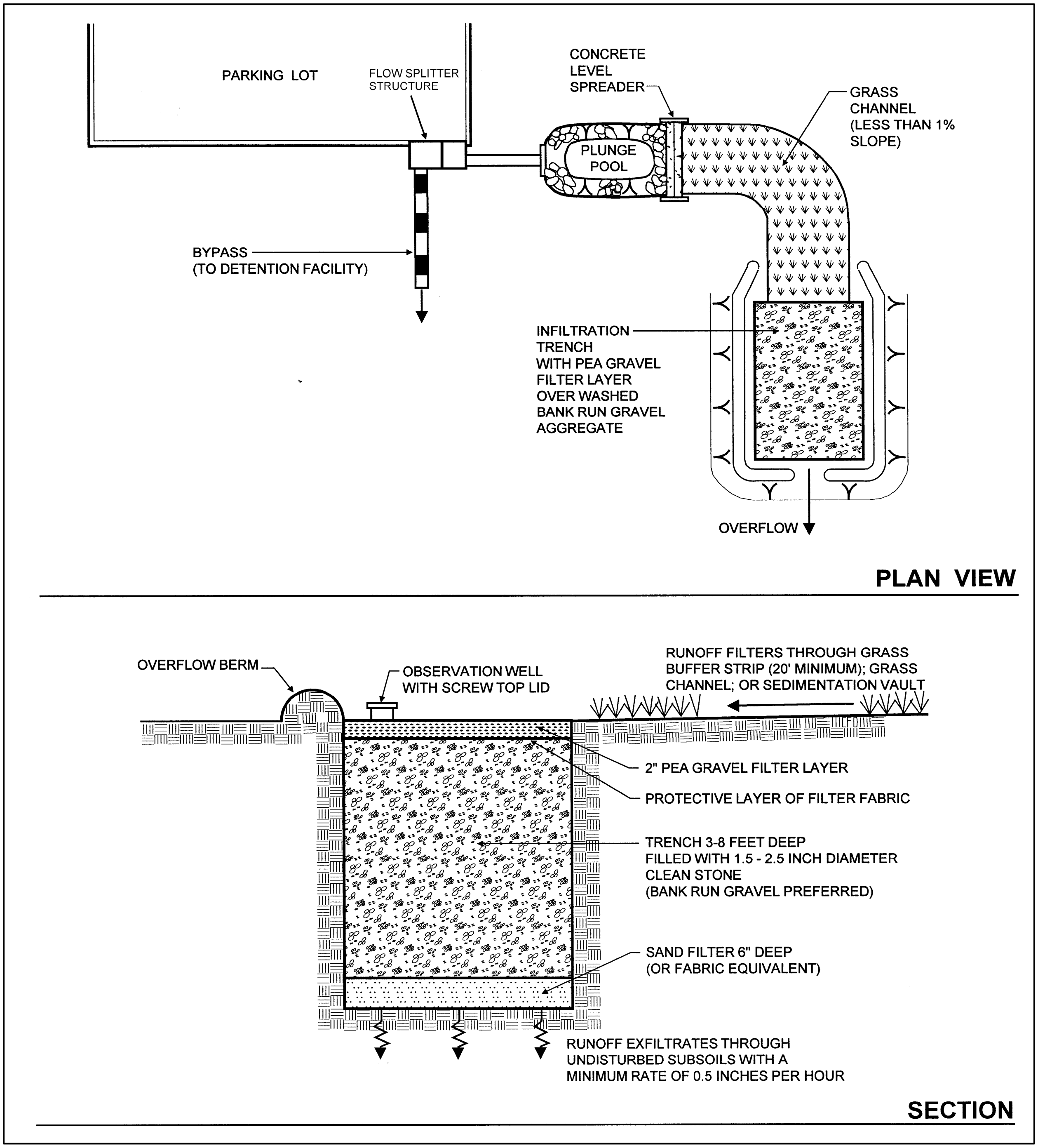

Figure 8.26: Schematic of a Typical Infiltration Trench
(Source: Center for Watershed Protection)

Storage Volume = Surface Area x Depth x Void Ratio

A void ratio (i.e., void space/total volume) of 0.32 should be used in all storage volume calculations, unless more specific aggregate void ratio data are available.

The storage volume provided by an infiltration basin can be determined using the following equation:

Storage Volume = Surface Area x [Ponding Depth + (Depth of Planting Bed x Void Ratio)]

A void ratio (i.e., void space/total volume) of 0.32 should be used in all storage volume calculations, unless more specific planting bed void ratio data are available.

In order to manage post-construction stormwater runoff and be eligible for these "credits," it is *recommended* that infiltration practices satisfy the planning and design criteria outlined below.

Overall Feasibility

The criteria listed in Table 8.16 should be evaluated to determine whether or not an infiltration practice is appropriate for use on a development site.

Table 8.16: Factors to Consider When Evaluating the Overall Feasibility Of Using an Infiltration Practice on a Development Site

Site Characteristic	Criteria
Drainage Area	Infiltration trenches can be used to manage stormwater runoff from contributing drainage areas up to 2 acres in size. Although infiltration basins can be used to manage stormwater runoff from contributing drainage areas as large as 5 acres in size, contributing drainage areas of between 2,500 square feet and 2 acres are preferred.
Area Required	Infiltration practice surface area requirements vary according to the size of the contributing drainage area and the infiltration rate of the soils on which the infiltration practice will be located. In general, infiltration practices require about 5% of the size of their contributing drainage areas.
Slope	Although infiltration practices may be used on development sites with slopes of up to 6%, they should be designed with slopes that are as close to flat as possible to help ensure that stormwater runoff is evenly distributed over the infiltration bed.
Minimum Head	Unless a shallow water table is found on the development site, all infiltration trenches should be designed to be at least 36 inches deep. Infiltration basins may be designed with a maximum ponding depth of 12 inches, although a ponding depth of 9 inches is recommended to help prevent the formation of nuisance ponding conditions. Unless a shallow water table is found on the development site, all infiltration basin planting beds should be at least 36 inches deep.
Minimum Depth to Water Table	2 feet
Soils	Infiltration practices should be designed to completely drain within 48 hours of the end of a rainfall event. Consequently, infiltration practices generally should not be used on development sites that have soils with infiltration rates of less than 0.25 inches per hour (i.e., hydrologic soil group C and D soils).

<u>Feasibility in Coastal Georgia</u>

Several site characteristics commonly encountered in coastal Georgia may present challenges to site planning and design teams that are interested in using infiltration practices to manage post-construction stormwater runoff on a development site. Table 8.17 identifies these common site characteristics and describes how they influence the use of infiltration practices on development sites. The table also provides site planning and design teams with some ideas about how they can work around these potential constraints.

Table 8.17: Challenges Associated with Using Infiltration Practices in Coastal Georgia

Site Characteristic	How it Influences the Use of Infiltration Practices	Potential Solutions
• *Poorly drained soils*, such as hydrologic soil group C and D soils	• Reduces the ability of infiltration practices to reduce stormwater runoff rates, volumes and pollutant loads.	• Infiltration practices should not be used on development sites that have soils with infiltration rates of less than 0.25 inches per hour (i.e., hydrologic soil group C and D soils). • Use other low impact development and stormwater management practices, such as rainwater harvesting (Section 7.8.12) and underdrained bioretention areas (Section 8.6.3), to manage post-construction stormwater runoff in these areas.
• *Well drained soils*, such as hydrologic soil group A and B soils	• Enhances the ability of infiltration practices to reduce stormwater runoff rates, volumes and pollutant loads, but may allow stormwater pollutants to reach groundwater aquifers with greater ease.	• Avoid the use of infiltration-based stormwater management practices, including infiltration practices, at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers, unless adequate pretreatment is provided upstream of them. • Use bioretention areas (Section 8.6.3) and dry swales (Section 8.6.6) with liners and underdrains at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers.
• *Flat terrain*	• Does not influence the use of infiltration practices. In fact, infiltration practices should be designed with slopes that are as close to flat as possible.	

Table 8.17: Challenges Associated with Using Infiltration Practices in Coastal Georgia		
Site Characteristic	**How it Influences the Use of Infiltration Practices**	**Potential Solutions**
• *Shallow water table*	• May be difficult to provide 2 feet of clearance between the bottom of the infiltration practice and the top of the water table. • May occasionally cause stormwater runoff to pond in the bottom of the infiltration practice.	• Ensure that the distance from the bottom of the infiltration practice to the top of the water table is at least 2 feet. • Reduce the depth of the stone reservoir in infiltration trenches to 18 inches. • Reduce the depth of the planting bed in infiltration basins to 18 inches. • Use stormwater ponds (Section 8.6.1), stormwater wetlands (Section 8.6.2) and wet swales (Section 8.6.6), instead of infiltration practices to intercept and treat stormwater runoff in these areas.
• *Tidally-influenced drainage system*	• Does not influence the use of infiltration practices.	

Site Applicability

Infiltration practices can be used to manage post-construction stormwater runoff on development sites in rural, suburban and urban areas where the soils are permeable enough and the water table is low enough to provide for the infiltration of stormwater runoff. While infiltration trenches are particularly well-suited for use on small, medium-to-high density development sites, infiltration basins can be used on larger, lower density development sites. Infiltration practices should only be considered for use on development sites where fine sediment (e.g., clay, silt) loads will be relatively low, as high sediment loads will cause them to clog and fail. In addition, infiltration practices should be carefully sited to avoid the potential contamination of water supply aquifers. When compared with other stormwater management practices, infiltration practices have a moderate construction cost, a moderate maintenance burden and require a relatively small amount of surface area.

Planning and Design Criteria

It is *recommended* that infiltration practices meet all of the following criteria to be eligible for the stormwater management "credits" described above:

<u>General Planning and Design</u>

- Infiltration trenches should be used to manage post-construction stormwater runoff from relatively small drainage areas of 2 acres or less. The stormwater runoff rates and volumes from larger contributing drainage areas typically become too large to be properly managed within an infiltration trench.
- Although infiltration basins can be used to manage post-construction stormwater runoff from contributing drainage areas as large as 5 acres in size, contributing drainage areas of between 2,500 square feet and 2 acres are preferred. Multiple infiltration basins can be used to manage stormwater runoff from larger contributing drainage areas.
- Although infiltration practices may be used on development sites with slopes of up to 6%, they should be designed with slopes that are as close to flat as possible to help ensure that stormwater runoff is evenly distributed over the stone reservoir or planting bed.

- Infiltration practices should be used on development sites that have underlying soils with an infiltration rate of 0.25 inches per hour (in/hr) or greater, as determined by NRCS soil survey data and subsequent field testing. Field infiltration test protocol, such as that provided by the City of Portland, OR (Portland, OR, 2008) on the following website: http://www.portlandonline.com/shared/cfm/image.cfm?id=_202911, can be used to conduct field testing, but should be approved by the local development review authority prior to use.
- Although the number of infiltration tests needed on a development site will ultimately be determined by the local development review authority, at least one infiltration test is recommended for each infiltration practice that will be used on the development site.
- Since clay lenses or any other restrictive layers located below the bottom of an infiltration practice will reduce soil infiltration rates, infiltration testing should be conducted within any confining layers that are found within 4 feet of the bottom of a proposed infiltration practice.
- Infiltration practices should be designed to provide enough storage for the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event). The required dimensions of an infiltration practice that will be filled with stone (e.g., infiltration trench) can be determined using the following equation:

$$A_{in} = (RR_v) \div \{(n)(d_{in}) + [(i_{soil})(t_{fill}) \div 12]\}$$

Where:
A_{in} = surface area of infiltration trench (ft^2)
RR_v = stormwater runoff volume generated by target runoff reduction rainfall event (ft^3) (e.g., 85th percentile rainfall event)
n = porosity of fill media (use n = 0.32 for clean, washed stone specified below)
d_{in} = depth of stone reservoir (ft) (use 3 feet or more, unless a shallow water table is found on the development site)
i_{soil} = infiltration rate of underlying native soils (ft/day)
t_{fill} = average time for stone reservoir to fill (hour) (use t_{fill} = 2 hours)

The required dimensions of an infiltration practice that will be filled with an engineered soil mix (e.g., infiltration basin) can be determined using the following equation, which is based on Darcy's Law:

$$A_{bio} = (RR_v)(d_{bio}) \div [(k_{bio})(h_{bio} + d_{bio})(t_{drain})]$$

Where:
A_{bio} = surface area of infiltration basin (ft^2)
RR_v = stormwater runoff volume generated by target runoff reduction rainfall event (ft^3) (e.g., 85th percentile rainfall event)
d_{bio} = depth of infiltration basin planting bed (ft) (use 36 inches or more, unless a shallow water table is found on the development site)
k_{bio} = coefficient of permeability of infiltration basin planting bed (ft/day) (use k_{bio} = 0.5 ft/day for engineered soil mix specified below)
h_{bio} = average height of ponded water above infiltration basin (ft) (use 50% of maximum ponding depth)
t_{drain} = design infiltration basin drain time (days) (use 48 hours or less)

- Infiltration practices should be designed to completely drain within 48 hours of the end of a rainfall event. Where site characteristics allow, it is preferable to design infiltration practices to drain within 24 hours of the end of a rainfall event to help prevent the formation of nuisance ponding conditions.

- Infiltration trenches should be located in a lawn or other pervious area and should be designed so that the top of the dry well is located as close to the surface as possible. Infiltration trenches should not be located beneath a driveway, parking lot or other impervious surface.
- Broader, shallower infiltration trenches perform more effectively by distributing stormwater runoff over a larger surface area. However, a minimum depth of 36 inches is recommended for all infiltration trench designs to prevent them from consuming a large amount of surface area on development sites. Whenever practical, the depth of infiltration trenches should be kept to 60 inches or less.
- Unless a shallow water table is found on the development site, all infiltration trenches should be designed to be at least 36 inches deep. If a shallow water table is found on the development site, the depth of the stone reservoir may be reduced to 18 inches.
- Infiltration trenches should be filled with clean, washed stone. The stone used in the infiltration trench should be 1.5 to 2.5 inches in diameter, with a void space of approximately 40% (e.g., GA DOT No. 3 Stone). Unwashed aggregate contaminated with soil or other fines may not be used in the trench.
- Underlying native soils should be separated from the stone reservoir by a thin, 2 to 4 inch layer of choker stone (i.e., ASTM D 448 size No. 8, 3/8" to 1/8" or ASTM D 448 size No. 89, 3/8" to 1/16"). The choker stone should be placed between the stone reservoir and the underlying native soils.
- The top and sides of the infiltration trench should be lined with a layer of appropriate permeable filter fabric. The filter fabric should be a non-woven geotextile with a permeability that is greater than or equal to the infiltration rate of the surrounding native soils. The top layer of the filter fabric should be located 6 inches from the top of the excavation, with the remaining space filled with pea gravel (i.e., ASTM D 448 Size No. 8, 3/8" to 1/8") or other appropriate landscaping. This top layer serves as a sediment barrier and, consequently, will need to be replaced over time. Site planning and design teams should ensure that the top layer of filter fabric can be readily separated from the filter fabric used to line the sides of the infiltration trench.
- Unless a shallow water table is found on the development site, all infiltration basin planting beds should be at least 36 inches deep. If a shallow water table is found on the development site, the depth of the planting bed may be reduced to 18 inches.
- The soils used within infiltration basin planting beds should be an engineered soil mix that meets the following specifications:
  - Texture: Sandy loam or loamy sand.
  - Sand Content: Soils should contain 85%-88% clean, washed sand.
  - Topsoil Content: Soils should contain 8%-12% topsoil.
  - Organic Matter Content: Soils should contain 3%-5% organic matter.
  - Infiltration Rate: Soils should have an infiltration rate of at least 0.25 inches per hour (in/hr), although an infiltration rate of between 1 and 2 in/hr is preferred.
  - Phosphorus Index (P-Index): Soils should have a P-Index of less than 30.
  - Exchange Capacity (CEC): Soils should have a CEC that exceeds 10 milliequivalents (meq) per 100 grams of dry weight.
  - pH: Soils should have a pH of 6-8.
- The organic matter used within an infiltration basin planting bed should be a well-aged compost that meets the specifications outlined in Section 7.8.1.
- Underlying native soils should be separated from the planting bed by a thin, 2 to 4 inch layer of choker stone (i.e., ASTM D 448 size No. 8, 3/8" to 1/8" or ASTM D 448 size No. 89, 3/8" to 1/16"). The choker stone should be placed between the planting bed and the underlying native soils.

- Infiltration practices should be preceded by a pea gravel (i.e., ASTM D 448 Size No. 8, 3/8” to 1/8”) diaphragm or equivalent level spreader device (e.g., concrete sills, curb stops, curbs with “sawteeth” cut into them) and appropriate pretreatment device, such as a vegetated filter strip (Section 7.8.6) or sediment forebay.
- The depth from the bottom of an infiltration practice to the top of the water table should be at least 2 feet to help prevent ponding and ensure proper operation of the infiltration practice. On development sites with high water tables, small stormwater wetlands (i.e., pocket wetlands) (Section 8.6.2) should be used to intercept and treat post-construction stormwater runoff.
- To help prevent damage to building foundations and contamination of groundwater aquifers, infiltration practices should be located at least:
    - 10 feet from building foundations
    - 10 feet from property lines
    - 100 feet from private water supply wells
    - 1,200 feet from public water supply wells
    - 100 feet from septic systems
    - 100 feet from surface waters
    - 400 feet from public water supply surface waters
- An observation well should be installed in every infiltration practice. An observation well consists of a 4 to 6 inch perforated PVC (AASHTO M 252) pipe that extends to the bottom of the infiltration practice. The observation well can be used to observe the rate of drawdown within the infiltration practice following a storm event. It should be installed along the centerline of the infiltration practice, flush with the elevation of the surface of the infiltration practice. A visible floating marker should be provided within the observation well and the top of the well should be capped and locked to prevent tampering and vandalism. Appendix B in Volume 2 of the *Georgia Stormwater Management Manual* provides additional information about observation wells.
- Consideration should be given to the stormwater runoff rates and volumes generated by larger storm events (e.g., 25-year, 24-hour storm event) to help ensure that these larger storm events are able to safely bypass the infiltration practice. An overflow system should be designed to convey the stormwater runoff generated by these larger storm events safely out of the infiltration practice. Methods that can be used to accommodate the stormwater runoff rates and volumes generated by these larger storm events include:
    - Using storm drain inlets set slightly above the elevation of the surface of an infiltration trench to collect excess stormwater runoff. This will create some ponding on the surface of the infiltration trench, but can be used to safely convey excess stormwater runoff off of the surface of the trench.
    - Using yard drains or storm drain inlets set at the maximum ponding depth of an infiltration basin to collect excess stormwater runoff.
    - Using a spillway with an invert set slightly above the elevation of maximum ponding depth to convey the stormwater runoff generated by larger storm events safely out of an infiltration basin.
    - Placing a perforated pipe (e.g., underdrain) near the top of the stone reservoir or planting bed to provide additional conveyance of stormwater runoff after the infiltration trench or basin has been filled.

<u>Landscaping</u>

- The landscaped area above the surface of an infiltration trench may be covered with pea gravel (i.e., ASTM D 448 size No. 8, 3/8” to 1/8”). This pea gravel layer provides sediment removal and additional pretreatment upstream of the infiltration trench and can be easily removed and replaced when it becomes clogged.

- Alternatively, an infiltration trench may be covered with an engineered soil mix, such as that prescribed for use in infiltration basins, and planted with managed turf or other herbaceous vegetation. This may be an attractive option when infiltration trenches are placed in disturbed pervious areas (e.g., lawns, parks, community open spaces).
- A landscaping plan should be prepared for all infiltration basins. The landscaping plan should be reviewed and approved by the local development review authority prior to construction.
- Vegetation commonly planted in infiltration basins includes native trees, shrubs and other herbaceous vegetation. When developing a landscaping plan, site planning and design teams should choose vegetation that will be able to stabilize soils and tolerate the stormwater runoff rates and volumes that will pass through the infiltration basin. Vegetation used in infiltration basins should also be able to tolerate both wet and dry conditions. See Appendix F of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001) for a list of grasses and other plants that are appropriate for use in infiltration basins installed in the state of Georgia.
- A mulch layer, consisting of 2-4 inches of fine shredded hardwood mulch or shredded hardwood chips, should be included on the surface of an infiltration basin.
- Methods used to establish vegetative cover within an infiltration basin should achieve at least 75 percent vegetative cover one year after installation.
- To help prevent soil erosion and sediment loss, landscaping should be provided immediately after an infiltration basin has been installed. Temporary irrigation may be needed to quickly establish vegetative cover within an infiltration basin.

Construction Considerations

To help ensure that infiltration practices are successfully installed on a development site, site planning and design teams should consider the following recommendations:

- To prevent practice failure due to sediment accumulation and pore clogging, infiltration practices should only be installed after their contributing drainage areas have been completely stabilized. To help prevent infiltration practice failure, stormwater runoff may be diverted around the infiltration practice until the contributing drainage area has become stabilized.
- Simple erosion and sediment control measures, such as temporary seeding and erosion control mats, should be used within any landscaped infiltration practices. Appropriate measures should be taken (e.g., temporary diversion) to divert post-construction stormwater runoff around a landscaped infiltration practice until vegetative cover has been established.
- To help prevent soil compaction, heavy vehicular and foot traffic should be kept out of infiltration practices before, during and after construction. This can typically be accomplished by clearly delineating infiltration practices on all development plans and, if necessary, protecting them with temporary construction fencing.
- Excavation for infiltration practices should be limited to the width and depth specified in the development plans. Excavated material should be placed away from the excavation so as not to jeopardize the stability of the side walls.
- The sides of all excavations should be trimmed of all large roots that will hamper the installation of the permeable filter fabric used to line the sides and top of an infiltration trench.
- The native soils along the bottom of an infiltration practice should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the choker stone and stone reservoir or engineered soil mix.

- Construction contracts should contain a replacement warranty that covers at least three growing seasons to help ensure adequate growth and survival of the vegetation planted within a landscaped infiltration practice.

Maintenance Requirements
Maintenance is very important for infiltration practices, particularly in terms of ensuring that they continue to provide measurable stormwater management benefits over time. Consequently, a legally binding inspection and maintenance agreement and plan should be created to help ensure that they are properly maintained after construction is complete. Table 8.18 provides a list of the routine maintenance activities typically associated with infiltration practices.

Table 8.18: Routine Maintenance Activities Typically Associated with Infiltration Practices

Activity	Schedule
• Ensure that the contributing drainage area is stabilized prior to installation of the infiltration practice. • If applicable, water to promote plant growth and survival. • If applicable, inspect vegetative cover following rainfall events. Plant replacement vegetation in any eroded areas.	As Needed (During Construction)
• Inspect to ensure that contributing drainage area and infiltration practice are clear of sediment, trash and debris. Remove any accumulated sediment and debris. • Ensure that the contributing drainage area is stabilized. Plant replacement vegetation as needed. • Check observation well to ensure that infiltration practice is properly dewatering after storm events.	Monthly
• Inspect pretreatment devices for sediment accumulation. Remove accumulated sediment, trash and debris. • In infiltration trenches, inspect top layer of filter fabric and pea gravel or landscaping for sediment accumulation. Remove and replace if clogged. • Inspect infiltration practicefor damage, paying particular attention to inlets, outlets and overflow spillways. Repair or replace any damaged components as needed. • Inspect infiltration practice following rainfall events. Check observation well to ensure that complete drawdown has occurred within 72 hours after the end of a rainfall event. Failure to drawdown within this timeframe may indicate infiltration practice failure.	Annually (Semi-Annually During First Year)
• Perform total rehabilitation of the infiltration practice, removing stone or planting bed and excavating to expose clean soil on the sides and bottom of the practice.	Upon Failure

Additional Resources

Atlanta Regional Commission (ARC). 2001. “Infiltration Trench.” *Georgia Stormwater Management Manual*. Volume 2. Technical Handbook. Section 3.2.5. Atlanta Regional Commission. Atlanta, GA. Available Online: http://www.georgia stormwater.com/.

Minnesota Pollution Control Agency (MPCA). 2006. “Infiltration Practices.” *Minnesota Stormwater Manual*. Chapter 12. Minnesota Pollution Control Agency. Available Online: Available Online: http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html.

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8.6.6 Swales

Description

Swales are vegetated open channels that are designed to manage post-construction stormwater runoff within wet or dry cells formed by check dams or other control structures (e.g., culverts). They are designed with relatively mild slopes to force stormwater runoff to flow through them slowly and at relatively shallow depths, which encourages sediment and other stormwater pollutants to settle out. Swales differ from grass channels (Section 7.8.7), in that they are designed with specific features that enhance their ability to manage stormwater runoff rates, volumes and pollutant loads on development sites.

(Source: Center for Watershed Protection)

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Maximum contributing drainage area of 5 acres or less
- Swales should be designed to safely convey the overbank flood protection rainfall event (e.g., 25-year, 24-hour event)
- Swales may be designed with a slope of between 0.5% and 4%, although a slope of between 1% and 2% is recommended
- Swales should be designed to be between 2 and 8 feet wide to prevent channel braiding

BENEFITS:

- Provides moderate to high removal of many of the pollutants of concern typically contained in post-construction stormwater runoff
- Less expensive than traditional drainage (e.g., curb and gutter, storm drain) systems

LIMITATIONS:

- Can only be used to manage runoff from relatively small drainage areas of 5 acres in size
- Should not be used on development or redevelopment sites with slopes of less than 0.5%
- Potential for nuisance ponding to occur in wet swales

SITE APPLICABILITY

☑ Rural Use
☑ Suburban Use
✱ Urban Use

M Construction Cost
M Maintenance
M Area Required

STORMWATER MANAGEMENT "CREDITS"

☑ Runoff Reduction
☑ Water Quality Protection
☑ Aquatic Resource Protection
☑ Overbank Flood Protection
☑ Extreme Flood Protection

☑ = practice has been assigned quantifiable stormwater management "credits" that can be used to address this SWM Criteria

STORMWATER MANAGEMENT PRACTICE PERFORMANCE

Runoff Reduction

0%[1]/40%-80%[2] - Annual Runoff Volume
0%[1]/Varies[3] - Runoff Reduction Volume

Pollutant Removal[4]

80%[1]/80%[2] - Total Suspended Solids
30%[1]/50%[2] - Total Phosphorus
30%[1]/50%[2] - Total Nitrogen
20%[1]/40%[2]- Metals
N/A - Pathogens

1 = wet swale
2 = dry swale
3= varies according to storage capacity of the dry swale
4 = expected annual pollutant load removal

Discussion

Swales (also known as *enhanced swales*, *vegetated open channels* or water *quality swales*) are vegetated open channels that are designed to manage post-construction stormwater runoff within wet or dry cells formed by check dams or other control structures (e.g., culverts). They are designed with relatively mild slopes to force stormwater runoff to flow through them slowly and at relatively shallow depths, which encourages sediment and other stormwater pollutants to settle out. Check dams and/or berms installed perpendicular to the flow path further promote settling and also encourage stormwater runoff to infiltrate into the underlying native soils. Swales differ from grass channels (Section 7.8.7), in that they are designed with specific features that enhance their ability to manage stormwater runoff rates, volumes and pollutant loads on development sites.

There are several variations of swales that can be used to manage post-construction stormwater runoff on development sites, the most common of which include dry swales and wet swales (Figure 8.27). A brief description of each of these design variants is provided below:

- Dry Swales: Dry swales (Figure 8.28) (also known as *bioswales*), which may also be classified as a low impact development practice (Section 7.8.15), are vegetated open channels that are filled with an engineered soil mix and are planted with trees, shrubs and other herbaceous vegetation. They are essentially linear bioretention areas (Section 8.6.3), in that they are designed to capture and temporarily store stormwater runoff in the engineered soil mix, where it is subjected to the hydrologic processes of evaporation and transpiration, before being conveyed back into the storm drain system through an underdrain or allowed to infiltrate into the surrounding soils. This allows them to provide measurable reductions in post-construction stormwater runoff rates, volumes and pollutant loads on development sites.

- *Wet Swales*: Wet swales (Figure 8.29) (also known as *wetland channels* or *linear stormwater wetlands*) are vegetated channels designed to retain water and maintain hydrologic conditions that support the growth of wetland vegetation. A high water table or poorly drained soils are necessary to maintain a permanent water surface within a wet swale. The wet swale essentially acts as a linear wetland treatment system, where the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event) is intercepted and treated over time.

Dry Swale

Wet Swale

Figure 8.27: Various Swales

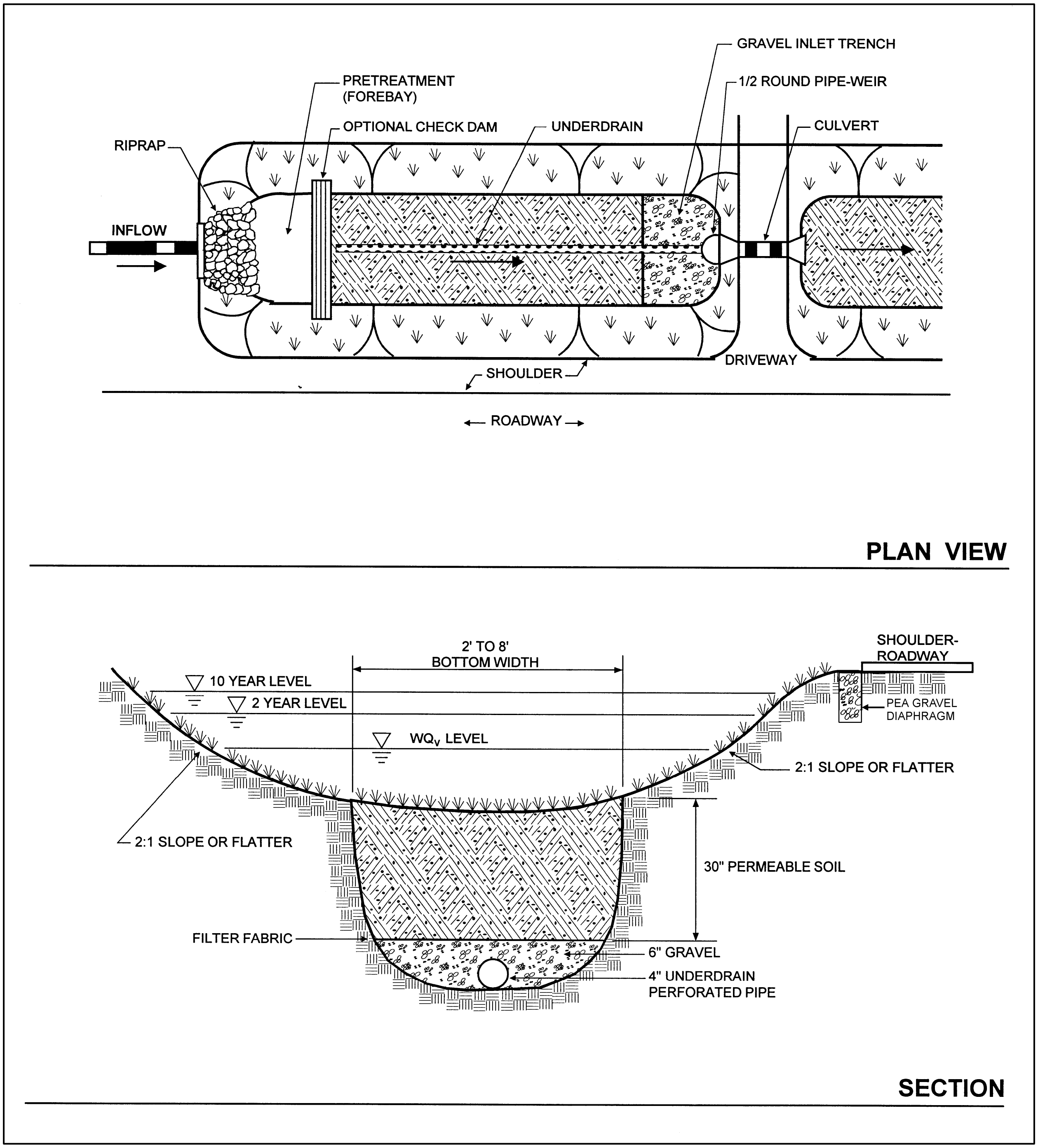

Figure 8.28: Schematic of a Typical Dry Swale
(Source: Center for Watershed Protection)

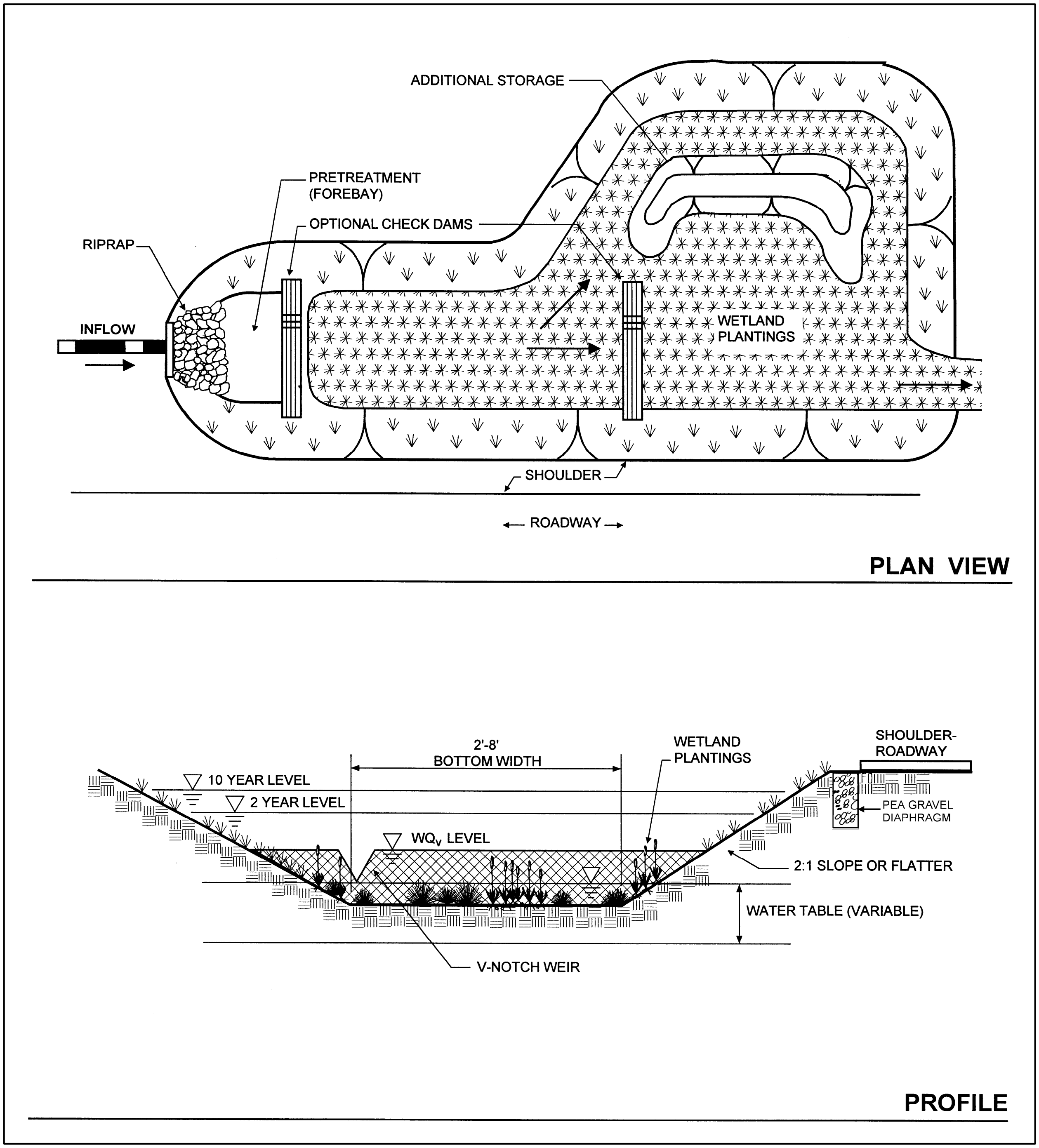

Figure 8.29: Schematic of a Typical Wet Swale
(Source: Center for Watershed Protection)

Stormwater Management "Credits"

Swales have been assigned quantifiable stormwater management "credits" that can be used to help satisfy the SWM Criteria presented in this CSS:

- Stormwater Runoff Reduction: Subtract 100% of the storage volume provided by a non-underdrained *dry swale* from the runoff reduction volume (RR_v) conveyed through the *dry swale*. Subtract 50% of the storage volume provided by an underdrained *dry swale* from the runoff reduction volume (RR_v) conveyed through the *dry swale*.

  Although *wet swales* provide moderate to high removal of many of the pollutants of concern typically contained in post-construction stormwater runoff, recent research shows that they provide little, if any, reduction of post-construction stormwater runoff volumes (Hirschman et al., 2008).

- Water Quality Protection: Assume that a *dry swale* provides an 80% reduction in TSS loads, a 50% reduction in TN loads and a 60% reduction in bacteria loads. Assume that a *wet swale* provides an 80% reduction in TSS loads, a 25% reduction in TN loads and a 40% reduction in bacteria loads.

- Aquatic Resource Protection: Although uncommon, on some development sites, a *wet or dry swale* can be designed to provide 24-hours of extended detention for the aquatic resource protection volume (ARP_v).

- Overbank Flood Protection: Although relatively rare, on some development sites, a *wet or dry swale* can be designed to attenuate the overbank peak discharge (Q_{p25}).

- Extreme Flood Protection: Although relatively rare, on some development sites, a *wet or dry swale* can be designed to attenuate the extreme peak discharge (Q_{p100}).

The storage volume provided by a dry swale can be determined using the following equation:

Storage Volume = Surface Area x [Ponding Depth + (Depth of Planting Bed x Void Ratio)]

A void ratio (i.e., void space/total volume) of 0.32 should be used in all storage volume calculations, unless more specific planting bed void ratio data are available.

In order to manage post-construction stormwater runoff and be eligible for these "credits," it is *recommended* that swales satisfy the planning and design criteria outlined below.

Overall Feasibility

The criteria listed in Table 8.19 should be evaluated to determine whether or not a dry swale is appropriate for use on a development site.

Table 8.19: Factors to Consider When Evaluating the Overall Feasibility of Using a Swale on a Development Site

Site Characteristic	Criteria
Drainage Area	Wet and dry swales can be used to manage stormwater runoff from contributing drainage areas of up to 5 acres in size.

Table 8.19: Factors to Consider When Evaluating the Overall Feasibility of Using a Swale on a Development Site	
Site Characteristic	**Criteria**
Area Required	Wet and dry swale surface area requirements vary according to the size of the contributing drainage area and the infiltration rate of the soils on which the swale will be located. In general, dry swales require about 5-10% of the size of their contributing drainage areas. Wet swales typically require about 10-20% of their contributing drainage areas.
Slope	Although swales may be installed on development sites with slopes of between 0.5% and 4%, it is recommended that they be designed with slopes of between 1% and 2% to help ensure adequate drainage.
Minimum Head	1 to 2 feet for wet swales 3 to 4 feet for dry swales. Unless a shallow water table is found on the development site, all dry swale planting beds should be at least 30 inches deep.
Minimum Depth to Water Table	No restrictions for wet swales, although 2 feet of separation is recommended at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers. 2 feet for dry swales
Soils	No restrictions for wet swales, although poorly drained soils (i.e., hydrologic soil group C or D soils) are usually adequate to maintain a permanent water surface in a wet pond. Wet swales constructed on development sites with permeable soils (i.e., hydrologic soil group A or B soils) may require a liner. Dry swales should be designed to completely drain within 48 hours of the end of a rainfall event. Consequently, non-underdrained dry swales generally should not be used on development sites that have soils with infiltration rates of less than 0.25 inches per hour (i.e., hydrologic soil group C and D soils). Underdrained dry swales may be used to manage stormwater runoff on development sites that have soils with infiltration rates of less than 0.25 inches per hour.

Feasibility in Coastal Georgia

Several site characteristics commonly encountered in coastal Georgia may present challenges to site planning and design teams that are interested in using swales to manage post-construction stormwater runoff on a development site. Table 8.20 identifies these common site characteristics and describes how they influence the use of swales on development sites. The table also provides site planning and design teams with some ideas about how they can work around these potential constraints.

Table 8.20: Challenges Associated with Using Swales in Coastal Georgia		
Site Characteristic	**How it Influences the Use of Swales**	**Potential Solutions**
• *Poorly drained soils*, such as hydrologic soil group C and D soils	• Since they are designed to have a permanent water surface, the presence of poorly drained soils does not influence the use of wet swales on development sites. In fact, the presence of poorly drained soils may help maintain a permanent water surface within a wet swale. • Reduces the ability of dry swales to reduce stormwater runoff rates, volumes and pollutant loads.	• Use wet swales or underdrained dry swales to intercept, convey and treat post-construction stormwater runoff in these areas. • Use additional low impact development and stormwater management practices, such as rainwater harvesting (Section 7.8.12) to supplement the stormwater management benefits provided by swales in these areas.
• *Well drained soils*, such as hydrologic soil group A and B soils	• May be difficult to maintain a permanent water surface within a wet swale. • Enhances the ability of dry swales to reduce stormwater runoff rates, volumes and pollutant loads. • May allow stormwater pollutants to reach groundwater aquifers with greater ease.	• Avoid the use of infiltration-based stormwater management practices, including non-underdrained dry swales, at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers, unless adequate pretreatment is provided upstream of them. • Use dry swales and bioretention areas (Section 8.6.3) with liners and underdrains at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers.
• *Flat terrain*	• May be difficult to provide adequate drainage and may cause stormwater runoff to pond in the swale for extended periods of time.	• Design swales with a slope of at least 0.5% to help ensure adequate drainage. • Where soils are well drained, use non-underdrained dry swales, non-underdrained bioretention areas (Section 8.6.3) and infiltration practices (Section 8.6.5), to reduce stormwater runoff rates, volumes and pollutant loads and prevent ponding in these areas. • Ensure that the underlying native soils or underdrain system will allow a dry swale to drain completely within 48 hours of the end of a rainfall event to prevent the formation of nuisance ponding conditions.

Table 8.20: Challenges Associated with Using Swales in Coastal Georgia		
Site Characteristic	**How it Influences the Use of Swales**	**Potential Solutions**
• *Flat terrain*	• May be difficult to provide adequate drainage and may cause stormwater runoff to pond in the swale for extended periods of time.	• Where soils are poorly drained, use wet swales and small stormwater wetlands (i.e., pocket wetlands) (Section 8.6.2) to intercept and treat stormwater runoff.
• *Shallow water table*	• May be difficult to provide 2 feet of clearance between the bottom of a dry swale and the top of the water table. • May occasionally cause stormwater runoff to pond in a dry swale.	• Ensure that the distance from the bottom of a dry swale to the top of the water table is at least 2 feet. • Reduce the depth of the planting bed in a dry swale to 18 inches. • Use wet swales to intercept, convey and treat post-construction stormwater runoff in these areas.
• *Tidally-influenced drainage system*	• May occasionally prevent stormwater runoff from being conveyed through a swale, particularly during high tide.	• Investigate the use of other low impact development practices, such as rainwater harvesting (Section 7.8.12) to manage post-construction stormwater runoff in these areas.

Site Applicability

Swales can be used to manage post-construction stormwater runoff on a wide variety of development sites, including residential, commercial and institutional development sites in rural, suburban and urban areas. They are well suited for use on residential and institutional development sites that have low to moderate development densities. They can be used to "receive" stormwater runoff from nearly all small impervious and pervious drainage areas, including local streets and roadways, highways, driveways, small parking areas and disturbed pervious areas (e.g., lawns, parks, community open spaces). When compared with other stormwater management practices, swales have a moderate construction cost, a moderate maintenance burden and require a moderate amount of surface area.

Planning and Design Criteria

It is *recommended* that swales meet all of the planning and design criteria provided in Section 3.2.6 of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001) to be eligible for the stormwater management "credits" described above.

Construction Considerations

To help ensure that swales are successfully installed on a development site, site planning and design teams should consider the following recommendations:

- To prevent practice failure due to sediment accumulation and pore clogging, swales should only be installed after their contributing drainage areas have been completely stabilized. To help prevent practice failure, stormwater runoff may be diverted around a swale until the contributing drainage area has become stabilized.

- Simple erosion and sediment control measures, such as temporary seeding and erosion control mats, should be used within all wet and dry swales. Appropriate measures should be taken (e.g., temporary diversion) to divert post-construction stormwater runoff around a swale until vegetative cover has been established.
- To help prevent soil compaction, heavy vehicular and foot traffic should be kept out of swales during and after construction.
- The native soils along the bottom of a dry swale should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the engineered soil mix.
- Construction contracts should contain a replacement warranty that covers at least three growing seasons to help ensure adequate growth and survival of the vegetation planted within a swale.

Maintenance Requirements

Maintenance is very important for swales, particularly in terms of ensuring that they continue to provide measurable stormwater management benefits over time. Consequently, a legally binding inspection and maintenance agreement and plan should be created to help ensure that they are properly maintained after construction is complete. Table 8.21 provides a list of the routine maintenance activities typically associated with swales.

Table 8.21: Routine Maintenance Activities Typically Associated with Swales

Activity	Schedule
• Water to promote plant growth and survival. • Inspect swales following rainfall events. Plant replacement vegetation in any eroded areas.	As Needed (Following Construction)
• Inspect to ensure that contributing drainage area and swale are clear of sediment, trash and debris. Remove any accumulated sediment and debris. • Ensure that the contributing drainage area is stabilized. Plant replacement vegetation as needed. • Check to ensure that dry swales are properly dewatering after storm events.	Monthly
• If applicable, inspect pretreatment devices for sediment accumulation. Remove accumulated sediment, trash and debris. • Inspect swale for sediment accumulation. Remove sediment when it accounts for 25% or more of the original channel cross-section. • Inspect swale and side slopes for erosion and the formation of rills and gullies. Plant replacement vegetation in any eroded areas. • Inspect swale for dead or dying vegetation. Plant replacement vegetation as needed.	Annually (Semi-Annually During First Year)
• If a dry swale filter bed is clogged or partially clogged, manual manipulation of the bed may be required. Remove the top 2 to 3 inches of the filter bed and till or otherwise cultivate the top of the bed. Replace the filter media with an appropriate engineered soil mix.	As Needed

It should be noted that sediments removed from swales that do not receive stormwater runoff from stormwater hotspots are typically not considered to be toxic and can be safely disposed through either land application or landfilling. Check with the local development review authority to identify any additional constraints on the disposal of sediments removed from swales.

Additional Resources

Atlanta Regional Commission (ARC). 2001. "Enhanced Swales." *Georgia Stormwater Management Manual*. Volume 2. Technical Handbook. Section 3.2.6. Atlanta Regional Commission. Atlanta, GA. Available Online: http://www.georgia stormwater.com/.

8.7 Limited Application Stormwater Management Practice Profile Sheets

The reader is referred to Sections 3.3 and 3.4 of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001) for more information on the limited application stormwater management practices that can be used to manage post-construction stormwater runoff in coastal Georgia. The profile sheets describe each of the limited application stormwater management practices and discuss how to properly apply and design them on development sites. The limited application stormwater management practices profiled in Sections 3.3 and 3.4 of Volume 2 of the *Georgia Stormwater Management Manual* include:

<u>Water Quantity Management Practices</u>

- 3.4.1 Dry Detention Basins
- 3.4.1 Dry Extended Detention Basins
- 3.4.2 Multi-Purpose Detention Areas
- 3.4.3 Underground Detention Systems

<u>Water Quality Management Practices</u>

- 3.3.3 Organic Filters
- 3.3.4 Underground Filters
- 3.3.5 Submerged Gravel Wetlands
- 3.3.6 Gravity (Oil-Grit) Separators
- 3.3.9 Alum Treatment Systems
- 3.3.10 Proprietary Systems

Information about how each of these stormwater management practices can be used to help satisfy the SWM Criteria presented in this CSS is provided in Table 8.1.

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Atlanta Regional Commission (ARC). 2001. *Georgia Stormwater Management Manual*. Volume 2. Technical Handbook. Atlanta Regional Commission. Atlanta, GA. Available Online: http://www.georgiastormwater.com/.

City of Portland, OR. 2008. *Portland Stormwater Management Manual*. City of Portland, OR. Bureau of Environmental Services. Available Online: http://www.portlandonline.com/bes/index.cfm?c=47952.

Fraley-McNeal, L., T. Schueler and R. Winer. 2007. *National Pollutant Removal Performance Database*. Version 3. Center for Watershed Protection. Ellicott City, MD. Available Online: http://www.cwp.org/Resource_Library/Center_Docs/SW/bmpwriteup_092007_v3.pdf.

Hirschman, D., K. Collins and T. Schueler. 2008. *Runoff Reduction Method*. Center for Watershed Protection. Ellicott City, MD. Available Online: http://www.cwp.org/Resource_Library/Center_Docs/SW/RRTechMemo.pdf.

Merrill, T.R., Coastal Georgia Regional Development Center (CGRDC) and EMC Engineering Services, Inc. 2006. *Green Growth Guidelines: A Low Impact Development Strategy for Coastal Georgia*. Prepared for: Georgia Department of Natural Resources (DNR) Coastal Management Program. Brunswick, GA. Available Online: http://crd.dnr.state.ga.us/content/displaycontent.asp?txtDocument=969.

Strecker, E., M. Quigley, B. Urbonas and J. Jones. 2004. "Stormwater Management: State of the Art in Comprehensive Approaches to Stormwater". *The Water Report*. 6:1-10.

Winer, R. 2000. *National Pollutant Removal Performance Database for Stormwater Treatment Practices*. 2nd Edition. Center for Watershed Protection. Ellicott City, MD. Available Online: http://www.cwp.org/Resource_Library/Center_Docs/SW/nprpdatabase.pdf.

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