SW-1. Introduction

Source: Texas Sea Grant/Texas AgriLife Ext.

Stormwater Wetlands, sometimes called constructed wetlands, are shallow vegetated depressions that receive stormwater inputs for water quality treatment.

Stormwater Wetlands can be used to:

- Reduce pollutant loads to meet water quality targets (total maximum daily loads or TMDLs) (see **SW-Table 2**).
- Meet partial or full storage requirements for local stormwater detention standards
- Retrofit existing developed areas
- At this point, Stormwater Wetlands do not achieve average annual runoff reduction, so cannot be used to meet the 1-inch performance standard. However, their water quality performance is solid, and they can be used as an alternative stormwater best management practice (BMP) in certain circumstances and/or downstream from other runoff reduction practices, as approved by the local stormwater program and/or West Virginia Department of Environmental Protection (WVDEP).

Stormwater Wetlands typically are less than 1 foot deep (although they have greater depths at the forebay and in micropools) and possess variable microtopography to promote dense and diverse wetland cover. Runoff from each new storm displaces runoff from previous storms, and the long residence time allows multiple pollutant removal processes to operate. The wetland environment provides an ideal setting for gravitational settling, biological uptake, and microbial activity.

Three basic design variations of the Stormwater Wetland concept are discussed in this section:

1. Wetland basin (Level 1)
2. Multi-cell wetland or pond/wetland combination (Level 2)
3. Subsurface gravel wetland (Modified Level 2)

Figure SW-1 illustrates some typical Stormwater Wetland applications. **Figures SW-2** through **SW-4** are schematics of typical Stormwater Wetland designs. **Table SW-1** describes the features of the three design variations and **Table SW-2** describes the pollutant removal performance of Stormwater Wetlands. **Table SW-3** is a design checklist to help guide the design process for Stormwater Wetland systems.

SW-1.1. Planning the Practice

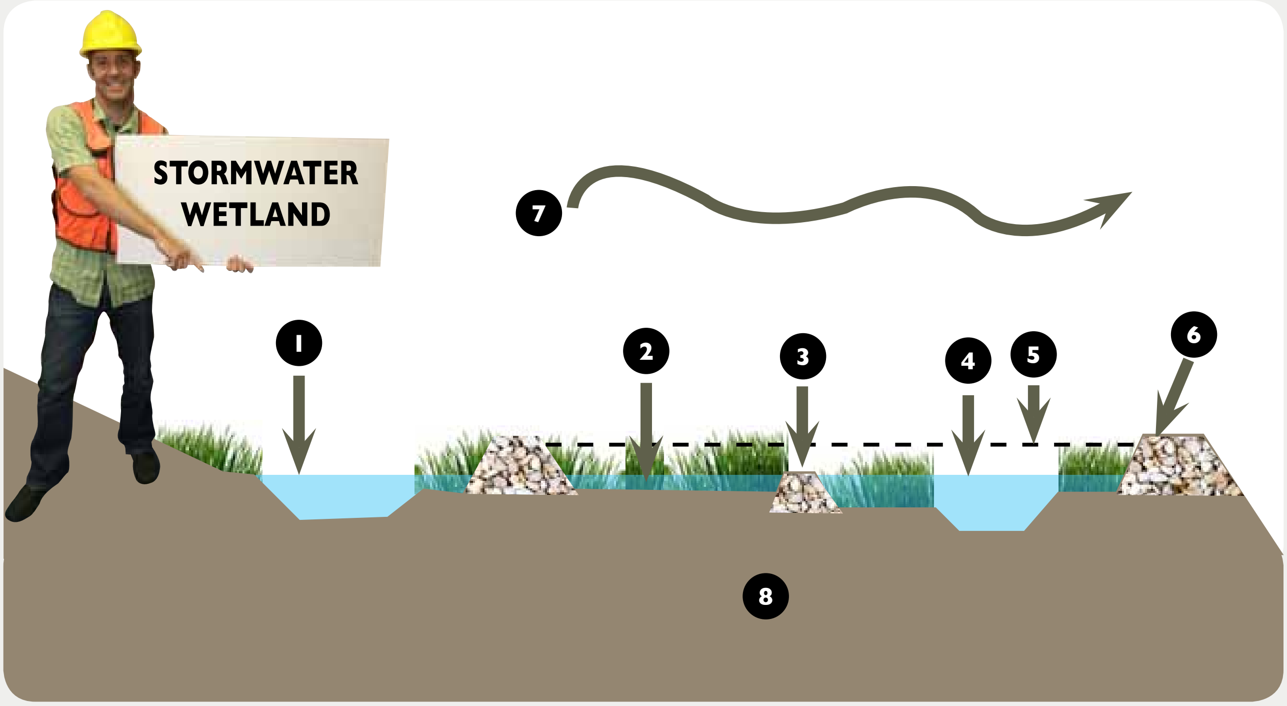
Figure SW-1. Example Applications of Stormwater Wetlands

Typical Stormwater Pond/Wetland System

Typical Multi-Cell Wetland

Subsurface Gravel Wetland
Source: UNH Stormwater Center

Figure SW-2. Schematic Plan and Profile of Stormwater Wetland



1. Pretreatment forebay – Sections SW-4.1, SW-4.4, SW-4.5
2. High marsh zone – Section SW-4.4
3. Weirs & microtopography features – Sections SW-4.1 & SW-4.4
4. Deep pool zones – Section SW-4.4
5. Detention storage above permanent pool – Sections SW-4.1 & SW-4.4
6. Conveyance and overflow, outlet weir, geotechnical testing – Sections SW-4.6 & SW-4.7
7. Geometry of flow through stormwater wetland – Section SW-4.4
8. Stormwater wetland planting – Section SW-4.8

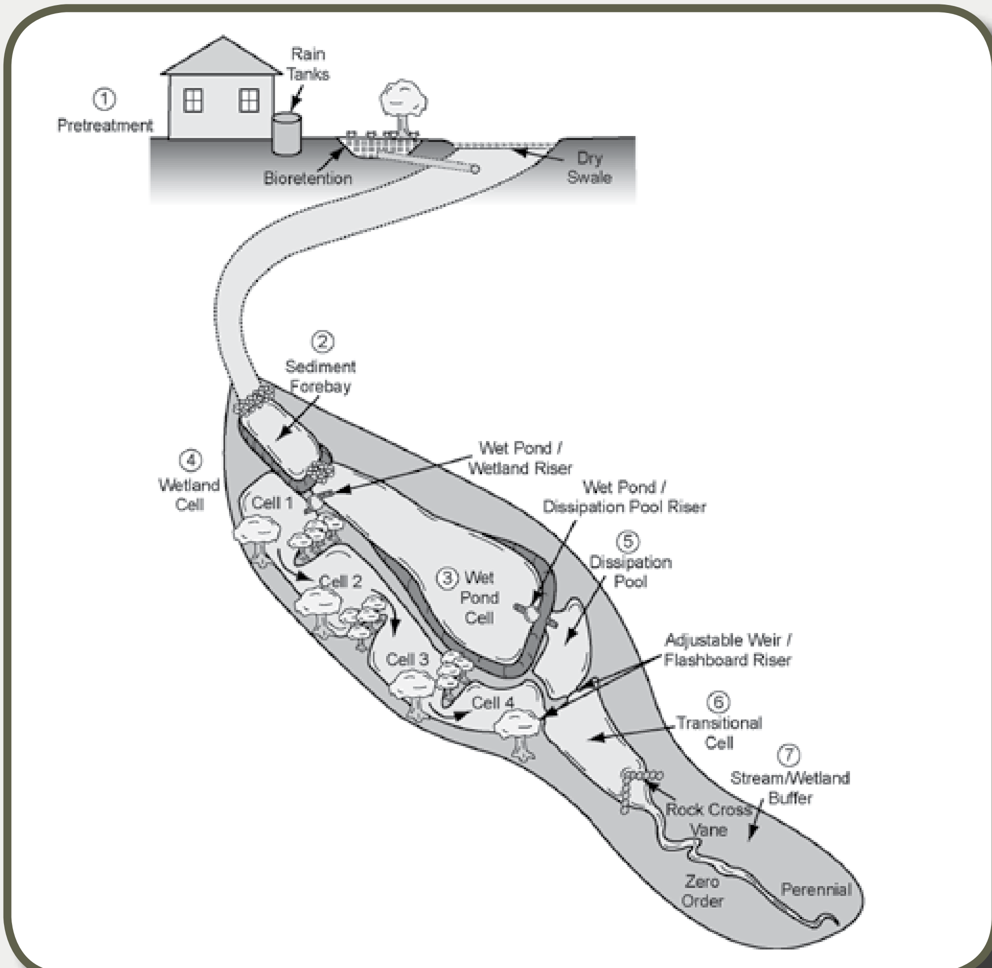


Figure SW-3. Schematic of Pond/Wetland Combination

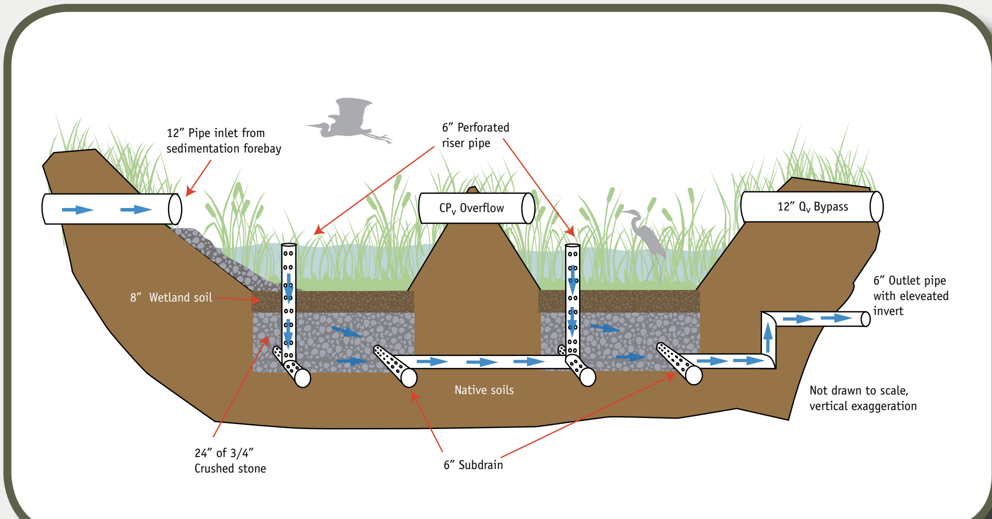


Figure SW-4. Schematic of Subsurface Gravel Wetland
(Source: UNH Stormwater Center)

SW-1.2. Stormwater Wetland Design Options & Performance

Two levels of design that enable Stormwater Wetlands to maximize nutrient reduction are shown in **Table SW-1**. At this point there is no runoff volume reduction credit for Stormwater Wetlands. The overall pollutant removal rates of the Level 1 and 2 designs are shown in **Table SW-2**.

Table SW-1. Stormwater Wetland Design Levels: Descriptions & Performance

Design Level	**Design Variation Descriptions** (See Section 4)	**Applications**	**Performance Achieved Toward Reducing 1" of Rainfall**
Level 1	Wetland Basin • Single cell (w/ forebay) • Uniform wetland depth • Mean depth more than 1 foot • Surface area less than 3% of contributing drainage area • Design Volume = 1.0 x Target Treatment Volume[1]	Sites where the surface area available for a Stormwater Wetland is limited and where the Level 1 performance can meet water quality goals (see **Table SW-2**).	At this point, research indicates minimal average annual runoff reduction (Hirschman et al., 2008). Consequently, there is no runoff reduction assigned to meeting the 1" standard.
Level 2	Multi-Cell Wetland or Pond/ Wetland Combination • Multiple cells (w/ forebay) • Variable depths • Mean depth less than 1 foot • Surface area more than 3% of contributing drainage area • Design Volume = 1.5 x Target Treatment Volume[1]	Sites with more surface area available and where enhanced water quality performance is needed to meet water quality goals.	
	Subsurface Gravel Wetland • 2 cells (w/ forebay) • Saturated gravel layer • Minimum 24" gravel sub-layer • Design and sizing as per UNHSC (2009) and RIDEM (2010)	Sites that require enhanced nutrient removal, especially for nitrogen.	

[1] The Target Treatment Volume (Tv) is the volume associated with 1" of rainfall for the contributing drainage area (CDA). See the Design Compliance Spreadsheet for calculations of the Tv. The Design Volume for a constructed wetland can be the entire Tv or some proportion of it if upstream runoff reduction practices are used.

Table SW-2. Pollutant Removal Performance Values for Stormwater Wetlands

Design Level	Total Suspended Solids (TSS)[1]	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN)[1]
Level 1	TSS = 50%	TP = 50% TN = 25%
Level 2: Multi-Cell or Pond/Wetland	TSS = 80%	TP = 75% TN = 55%
Modified Level 2: Subsurface Gravel Wetland	TSS = 95%[2]	TP = 55%[2] Dissolved Inorganic N = 95%[2]

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration (EMC) as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008). Since Stormwater Wetlands do not have an assigned runoff reduction rate, TR = EMC reduction.
[2]These values are provisional as derived from UNHSC (2007) and USEPA (2008).

SW-1.3. Stormwater Wetland Design Checklist

Table SW-3. Stormwater Wetland Design Checklist

CHECKLIST

This checklist will help the designer with the necessary design steps for Stormwater Wetlands.

- ☐ Ascertain the regulatory context of using a Stormwater Wetland, how the wetland will be used in conjunction with runoff reduction practices, and how the 1" performance standard can be met on the site or partially waived to allow a water quality treatment practice in conjunction with or in lieu of runoff reduction practices. This will likely require consultation with the local program and West Virginia Department of Environmental Protection (WVDEP).
- ☐ Check feasibility for site – **Section SW-3**
- ☐ Determine whether a Level 1 or Level 2 design is best for the site. Use Level 2 unless site constraints necessitate the Level 1 design – **Table SW-1**
- ☐ Complete Design Compliance Spreadsheet to plan and confirm required Stormwater Wetland sizing (Target Treatment Volume), additional practices needed, and overall site compliance – Design Compliance Spreadsheet & **Chapter 3** of Manual
- ☐ Check Stormwater Wetland sizing guidance and make sure there is an adequate footprint on the site– SW-Sections 4.2 & SW-4.3
- ☐ Check design adaptations appropriate to the site – Section SW-6
- ☐ Design Stormwater Wetland in accordance with design criteria and typical details – Sections SW-2 & SW-4
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, and construction sequence notes

4.2.11. Stormwater Wetlands (SW)

SW-2. Typical Details

Typical details for Stormwater Wetland variations (excluding the subsurface gravel wetland) are provided in **Figures SW-5 through SW-7**.

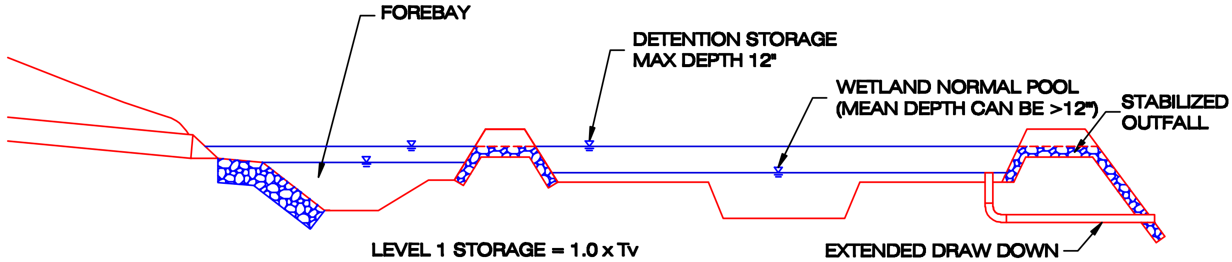


Figure SW-5. Typical profile for Level 1 Design

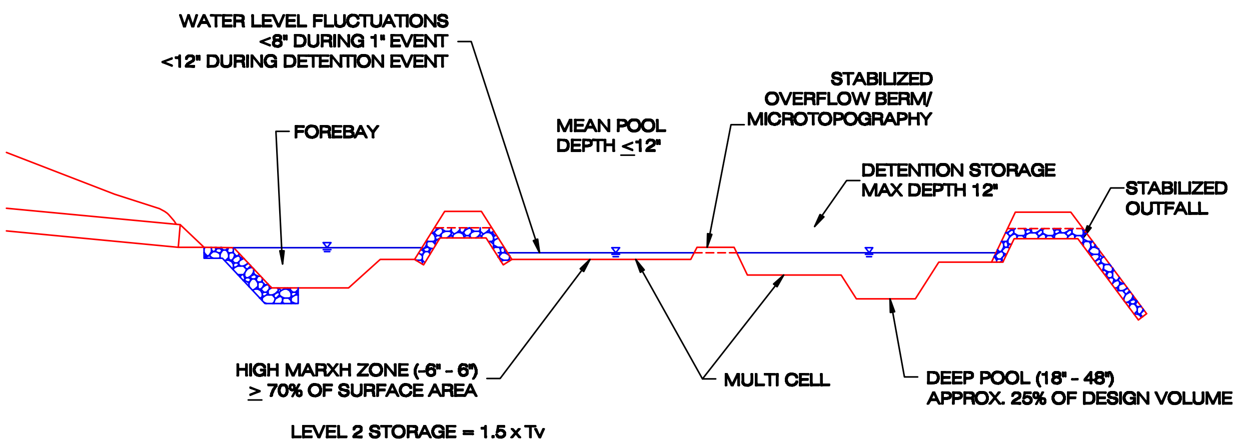


Figure SW-6. Typical profile for Level 2 Design

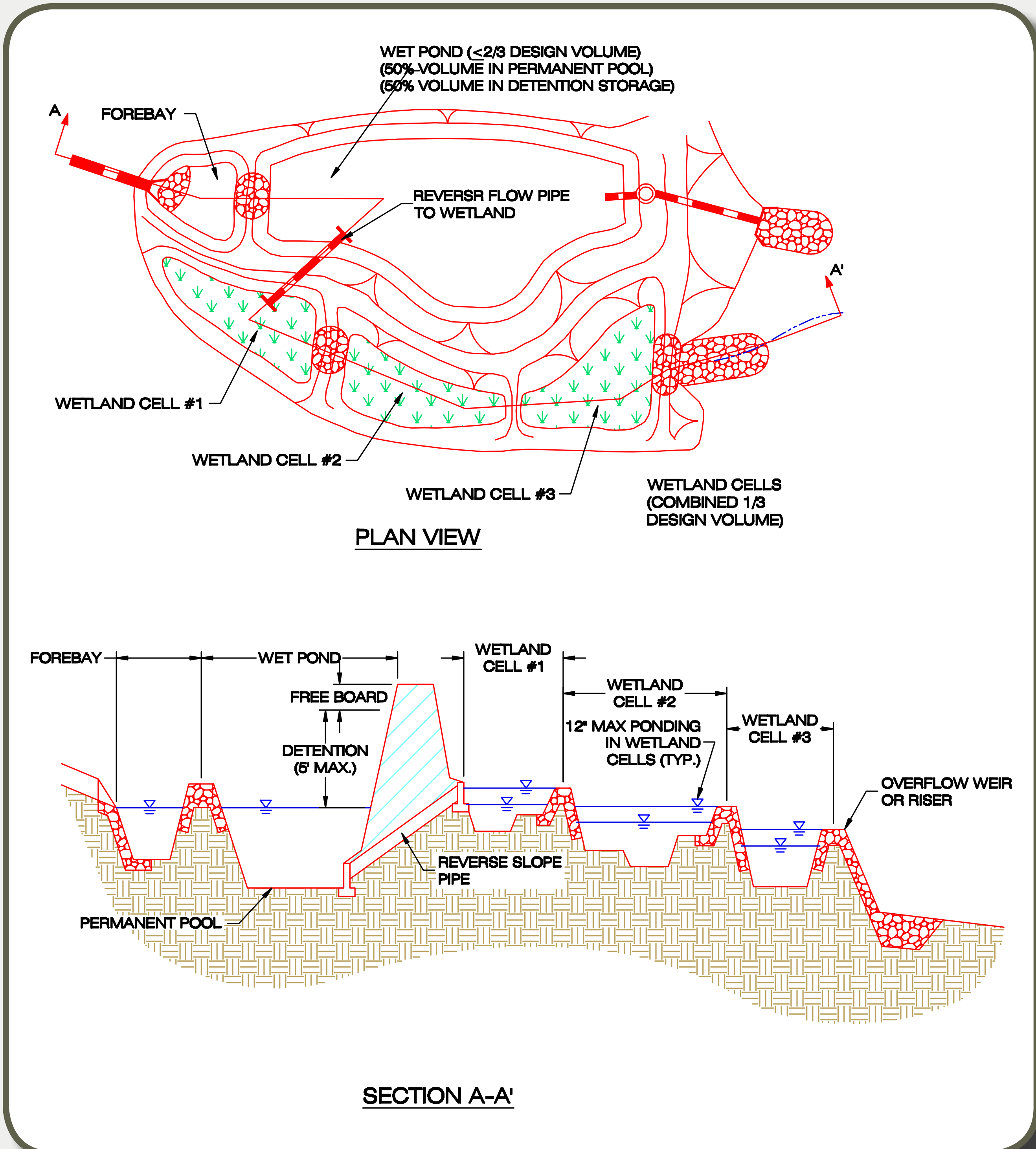


Figure SW-7. Typical Plan and Section for Pond/Wetland Combination

4.2.11. Stormwater Wetlands (SW)

SW-3. Feasibility Criteria and Design Considerations

Stormwater Wetland designs are subject to the following site constraints:

Adequate Water Balance. Wetlands must have enough water supplied from groundwater, runoff or baseflow so that the permanent pools will not draw down by more than 2 feet after a 30-day summer drought. A simple water balance calculation must be performed using the equation provided in **Section SW-4.3., Water Balance**.

Contributing Drainage Area (CDA). The CDA must be large enough to sustain a permanent water level within the Stormwater Wetland. If the only source of wetland hydrology is stormwater runoff, then several dozen acres of drainage area are typically needed to maintain constant water elevations. Smaller drainage areas are acceptable if the bottom of the wetland intercepts the groundwater table or if the designer or approving agency is willing to accept periodic wetland drawdown. Stormwater Wetlands typically have a drainage area of 10 to 25 acres.

Space Requirements. Stormwater Wetlands normally require a footprint that takes up about 3% of the contributing drainage area, depending on the average depth of the wetland and the extent of its deep pool features.

Steep Slopes. A design alternative to the Stormwater Wetland in steep terrain is the Regenerative Stormwater Conveyance (RSC) System (see **Specification 4.2.7**, **Regenerative Stormwater Conveyance**). The RSC can be used to bring stormwater down steeper grades through a series of step pools. This can serve to bring stormwater down outfalls where steep drops can create design challenges. Alternately, Stormwater Wetlands on steep sites can be split into various cells with adequate conveyance between cells in order to take advantage of flatter spots on the site.

Available Hydraulic Head. The depth of a Stormwater Wetland is usually constrained by the hydraulic head available on the site. The bottom elevation is fixed by the elevation of the existing downstream conveyance system to which the wetland will ultimately discharge. Because Stormwater Wetlands are typically shallow, the amount of head needed (usually a minimum of 2 to 4 feet) is typically less than for wet ponds.

Minimum Setbacks. Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines, structures, utilities, and wells. As a general rule, the edges of Stormwater Wetlands should be located at least 10 feet away from property lines, 25 feet from building foundations, 50 feet from septic system fields, and 100 feet from drinking water wells.

Depth to Water Table. The depth to the groundwater table is not a major constraint for Stormwater Wetlands, since a high water table can help maintain wetland conditions. However, designers should keep in mind that high groundwater inputs may reduce pollutant removal rates and increase excavation costs.

Soils. Soil tests should be conducted to determine the infiltration rates and other subsurface properties of the soils underlying the proposed wetland. Highly permeable soils will make it difficult to maintain a healthy permanent pool. Underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool. Most HSG A soils and some HSG B soils will require a liner.

Trout Streams. The use of Stormwater Wetlands in watersheds containing trout streams is generally not recommended due to the potential for stream warming, unless (1) other upland runoff reduction practices are fully utilized, and (2) a linear/mixed wetland design using trees as part of the planting plan is applied to minimize stream warming.

Use of or Discharges to Natural Wetlands. Stormwater Wetlands should not be located within jurisdictional waters, including wetlands. Theoretically, this can be done by obtaining a section 404 permit from the appropriate federal regulatory agency, but this approach is discouraged strongly. In addition, designers should investigate the status of adjacent wetlands to determine if the discharge from the Stormwater Wetland will change the hydroperiod of an immediately downstream natural wetland (see Cappiella et al., 2005 for guidance on minimizing stormwater discharges to existing wetlands).

Regulatory Status. Stormwater Wetlands built for the express purpose of stormwater treatment are not considered jurisdictional wetlands in most regions of the country, but designers should check with their wetland regulatory authorities to ensure this is the case.

Perennial Streams. Locating a Stormwater Wetland along or within a perennial stream will require both Section 401 and Section 404 permits from the state or federal regulatory authority. As with natural wetlands, this design approach is discouraged strongly. If perennial streams are involved, off-line designs that remove the Stormwater Wetland from the stream channel should be used.

Community and Environmental Concerns. Stormwater Wetland designs should strive to address the following:

- **Aesthetics and Habitat.** Stormwater Wetlands can create wildlife habitat and can also become an attractive community feature. Designers should think carefully about how the wetland plant community will evolve over time, since the future plant community seldom resembles the one initially planted. Invasive control is a major concern with the long-term management of Stormwater Wetlands.
- **Existing Forests.** Given the large footprint of a Stormwater Wetland, there is a strong chance that the construction process may result in extensive tree clearing. The designer should preserve mature trees during the facility layout, and may consider creating a wooded wetland (see Cappiella et al., 2006).
- **Safety Risk.** Stormwater Wetlands are safer than other types of ponds, although forebays and micropools should be designed with aquatic benches to reduce safety risks.
- **Mosquito Risk.** Mosquito control can be a concern for Stormwater Wetlands if they are under-sized or have a small CDA. Deepwater zones serve to keep mosquito populations in check by providing habitat for fish and other pond life that prey on mosquito larvae. Few mosquito problems are reported for well designed, properly-sized and frequently-maintained Stormwater Wetlands; however, no design can eliminate them completely. Simple precautions can be taken to minimize mosquito breeding habitat within Stormwater Wetlands, for example, constant inflows, benches that create habitat for natural predators, and constant pool elevations (MSSC, 2005).

4.2.11. Stormwater Wetlands (SW)

SW-4. Design Criteria

SW-4.1. Design Variations

Stormwater Wetlands are designed based on three major factors: (1) the desired plant community (an emergent wetland as in Level 1 design; a mixed emergent and forest wetland; or an emergent/pond combination as in Level 2 design); (2) the contributing hydrology (groundwater, surface runoff or dry weather flow); and (3) the landscape position (linear or basin) (Cappiella, et al., 2008).

To simplify design, three basic design variations are presented for Stormwater Wetlands:

1. Wetland basin – Level 1 design
2. Multi-cell wetland or pond/wetland combination – Level 2 design
3. Subsurface gravel wetland – modified Level 2 design

Wetland Basin (Level 1). Consists of a single cell (including a forebay) with a relatively uniform water depth. A portion of the Design Volume can be in the form of detention storage above the wetland pool, if required by local stormwater detention standards. However, this storage depth should not exceed 12 inches. Wetland basins can be used at the terminus of a storm drain pipe or open channel after upland opportunities for runoff reduction have also been applied.

Multi-Cell Wetland and Multi-Cell Pond/Wetland Combination systems (Level 2). These designs provide more treatment by creating a longer and sinuous flow path, more residence time, and more contact with wetland vegetation. The Design Volume is also increased for the Level 2 design. As with Level 1, detention storage above the permanent pool is limited to 12 inches. The pond/wetland combination design involves a wet pond cell in parallel or series with Stormwater Wetland cells. Small storms (e.g., those associated with 1 inch of rainfall) flow through the wetland cells while diverting the larger storm runoff into the wet pond cell. This is so the wetland cells are not subject to the higher water level fluctuations associated with rising and falling detention storage.

Further guidance on the pond/wetland combination is provided below:

- The wet pond cell has three primary functions: (1) pre-treatment to capture and retain heavy sediment loads or other pollutants (such as trash, oils and grease, etc.); (2) provisions for an extended supply of flow to support wetland conditions between storms; and (3) storage volume for larger storms if required by local detention requirements.
- The discharge from the pond cell to the wetland cells should ideally consist of a reverse slope-pipe. The design may also consist of an additional smaller pipe with a valve or other control to allow for hydrating the wetland with a trickle flow from the wet pond normal pool during dry periods.

As an alternative, the water quality storm can be diverted into the wetland cell for treatment by using a low flow diversion sized for the Tv peak flow rate, while the larger storms are routed into the wet pond cell.

- The wetland should be divided into sub-cells to cascade down the grade differential or slope. Ideally, different pool depths are established with sand berms (anchored by rock at each end), back-filled coir fiber logs, or forested peninsulas (extending as wedges across 90% of the wetland width). Grade drops between cells should be stabilized as needed based on the design flow and velocity.

Subsurface Gravel Wetland (Modified Level 2). This design variation consists of a sediment forebay followed by a series of horizontal flow-through cells designed to retain and filter the entire Design Volume (UNHSC, 2009). Nutrient removal occurs as stormwater passes through wetland plants and soil, then a microbe-rich saturated gravel bed. Runoff greater than the Design Volume overflows the wetland via an emergency spillway, after a short period of detention. See UNHSC (2009) and RIDEM (2010) for more detailed design specifications for subsurface gravel wetlands.

It should be noted that the remainder of this specification applies to the first two design variations. The design references listed above for subsurface gravel wetlands should be consulted for the design of those systems, since they are a unique subset of Stormwater Wetlands.

SW-4.2. Stormwater Wetland Sizing for Water Quality Treatment

A Note on Terminology Describing Volume

There are two types of volumes that the designer should consider when designing a BMP plan:

Target Treatment Volume (Tv) = Volume associated with managing 1" of rainfall based on the size and land cover of the CDA, as determined by the Design Compliance Spreadsheet. Any given BMP may treat the full Tv, or only part of it if used in conjunction with other practices as part of a treatment train.

Design Volume (Dv) = The volume designed into a particular practice based on storage in the practice, as prescribed in the BMP specification. Note that, while Stormwater Wetlands can be designed to store temporarily a particular Dv, they do not meet the MS4 General Permit criteria to "keep and manage on-site the first one-inch of rainfall" and thus do not have an associated runoff reduction credit and do not contribute to reducing the overall Tv. However, Stormwater Wetlands do achieve pollutant removal rates as outlined in Table SW-2. Designers should check with the local plan approval authority on use and approval of Stormwater Wetlands as part of an overall BMP plan.

Since Stormwater Wetlands are usually the terminal practice in a treatment train (e.g., the farthest downstream), the Dv is the remaining volume after upstream runoff reduction practices are employed to reduce the Tv.

See **Chapter 3** for more information on the runoff reduction design methodology.

For the purposes of this sizing section, the sizing relates to the Dv of the Stormwater Wetland being designed.

Stormwater Wetlands should be designed to capture and treat the remaining Tv discharged from upstream runoff reduction practices, as ascertained using the Design Compliance Spreadsheet (see **Chapter 3**). As described in the text box above, this volume is known as the Dv.

To qualify for the higher nutrient reduction rates associated with the Level 2 designs, Stormwater Wetlands must have a Design Volume that is 50% greater than the Level 1 design. Research has shown that larger Stormwater Wetlands with longer residence times enhance nutrient removal rates. Design Volume credit can be taken for the following:

Wetland Basin – Level 1 design: Dv = 1.0 x Tv as reduced byupstream runoff reduction practices

- The entire water volume below the normal pool (including deep pools);
- Detention storage up to 12 inches above the normal pool; and
- Any void storage within a submerged rock, sand or stone layer within the wetland.

Multi-Cell Wetland or Pond/Wetland Combination – Level 2 design: Dv = 1.5 x Tv as reduced by upstream runoff reduction

- The entire water volume below the normal pool of each wetland cell (including deep pools).
- Any void storage within a subsurface rock, sand or stone layer within the wetland cells.
- For pond/wetland combinations, up to 2/3 of the total required Design Volume can be provided in the pond cell, as follows:
  - o A minimum of ½ of the volume allocated to the pond cell is in the permanent pool (in other words, up to 1/3 of the total Design Volume).
  - o The remaining volume allocated to the pond cell can be in the form of detention storage provided above the permanent pool.

Subsurface Gravel Wetland – Level 2 design [Sizing as per UNHSC (2009) and RIDEM (2010)]:

- All storage within forebays, wetland cells, and gravel beds.

SW-4.3 Water Balance: Sizing for Minimum Pool Depth

Initially, it is recommended that there be no minimum drainage area requirement for the system, although it may be necessary to calculate a water balance for the wet pond cell, especially when its CDA is less than 10 acres.

Adequate Water Balance is Essential for Success of Stormwater Wetlands

The number one design factor for Stormwater Wetlands is water balance, and this may not be entirely dependent on the size of the CDA. Stormwater Wetlands must have an adequate supply of water from runoff, baseflow, and/or groundwater in order to maintain water levels during dry periods.

If the hydrology for the Stormwater Wetland is not supplied by groundwater or dry weather flow inputs, a simple water balance calculation must be performed, using **Equation SW-1** (Hunt et al., 2007), to assure the deep pools will not go completely dry during a 30-day summer drought.

Equation SW-1. The Hunt Water Balance Equation for Acceptable Water Depth in a Stormwater Wetland

$$DP = RF_m * EF * WS/WL - ET - INF - RES$$

Where:

DP	=	Depth of pool (inches)
RFm	=	Monthly rainfall during drought (inches)
EF	=	Fraction of rainfall that enters the Stormwater Wetland (CDA * Rv)
WS/WL	=	Ratio of CDA to wetland surface area
ET	=	Summer evapotranspiration rate (inches; assume 8 or locally appropriate number)
INF	=	Monthly infiltration loss (assume 7.2 inches @ 0.01 inch/hour)
RES	=	Reservoir of water for a factor of safety (assume 6 inches)

Using **Equation SW-1**, setting the groundwater and (dry weather) base flow to zero and assuming a worst case summer rainfall of 0 inches, the minimum depth of the pool calculates as follows:

Equation SW-2. Minimum Depth of the Permanent Pool

$$\text{Depth of Pool (DP)} = 0\text{''} (RF_m) - 8\text{''} (ET) - 7.2\text{''} (INF) - 6\text{''} (RES) = 21.2 \text{ inches}$$

Therefore, unless there is other input, such as base flow or groundwater, the minimum depth of the pool **should be at least 21 to 22 inches**. This condition automatically kicks the design to a Level 1 design.

SW-4.4. Design Geometry for Stormwater Wetlands

Research and experience have shown that the internal design geometry and depth zones are critical in maintaining the pollutant removal capability and plant diversity of Stormwater Wetlands. Wetland performance is enhanced when the wetland has multiple cells, longer flowpaths, and a high ratio of surface area to volume. Whenever possible, Stormwater Wetlands should be irregularly shaped with long, sinuous flow paths. The following design elements are required for Stormwater Wetlands:

Multiple-Cell Wetlands (Level 2 designs). When a Level 2 design is selected, the wetland should be divided into at least four internal sub-cells of different elevations: the forebay, at least two wetland cells, and a micro-pool outlet. The first cell (the forebay) is deeper and is used to receive runoff from the pond cell or the inflow from a pipe or open channel and distribute it evenly into successive wetland cells (see **Section SW-4.5**). The purpose of the wetland cells is to create an alternating sequence of aerobic and anaerobic conditions to maximize nitrogen removal. The fourth wetland cell is located at the discharge point and serves as a micro-pool with an outlet structure or weir.

Each wetland sub-cell can be differentiated by sand berms (anchored by rock at each end), back-filled coir fiber logs, or forested peninsulas extending as wedges across 95% of the wetland cell width (see section below on micro-topography). If there are elevation drops greater than 1 foot between cells, then the designer should consider using an earthen berm with a spillway, concrete weir, gabion baskets, or other means that provide adequate freeboard to pass expected peak rates (these approaches also applicable to the forebay and micro-pool). In addition, stable conveyance between cells should be provided based on the elevation change and expected velocities.

Micro-Topographic Features. While the slope profile within individual wetland cells should generally be flat from inlet to outlet, Stormwater Wetlands must have internal structures that create variable micro-topography. This is defined as a mix of above-pool vegetation, shallow pools, and deep pools that promote dense and diverse vegetative cover. Designers will need to incorporate at least two of the following internal design features to meet the microtopography requirements for Level 2 designs:

- Tree peninsulas, high marsh wedges or rock filter cells configured perpendicular to the flow path.
- Tree islands above the normal pool elevation and maximum detention zone, formed by coir fiber logs.
- Inverted root wads or large woody debris.
- Gravel diaphragm layers within high marsh zones.
- Cobble sand weirs.

Detention Storage Ponding Depth. Where a Stormwater Wetland basin (Level 1 design) incorporates detention storage for larger storms, the detention elevation above the permanent pool should be 1 vertical foot or less.

Where a Level 2 design is used, the detention storage limits are as follows:

- Multi-cell wetlands must be designed so that the water level fluctuation associated with the maximum "Design Volume" storm (a 1-inch rainfall event) is limited to 6 to 8 inches.
- The maximum water level fluctuation during the larger design storm associated with local detention requirements (as applicable) should be limited to 12 inches in the wetland cells. This can be achieved by using a long weir structure capable of passing large flows at relatively low hydraulic head. If this standard cannot be met within the Stormwater Wetland footprint, the designer should use the pond/wetland combination design or an "off-line" design whereby the wetland receives only flow associated with the Design Volume, and larger flows are diverted to other detention facilities.
- For the pond/wetland combination, the maximum detention storage depth may be up to 5 feet above the wet pond cell permanent pool (but not the wetland cells).

Pool Depths. Level 1 wetland designs may have a mean pool depth greater than 1 foot. Level 2 wetland cells must have a mean pool depth less than or equal to 1 foot.

Deep Pools. Approximately 25% of the wetland Design Volume must be provided in at least three deeper pools – located at the inlet (forebay), center, and outlet (micro-pool) of the wetland. Approximately 60% of this overall deep pool volume should be allocated to the forebays. Each deep pool should have a depth of 18 to 48 inches. Refer to sizing based on water balance in **Sections SW-4.2 and SW-4.3** for additional guidance on the minimum depth of the deep pools.

High Marsh Zone. Approximately 70% of the wetland surface area must exist in the high marsh zone (-6 inches to +6 inches relative to the normal pool elevation).

Transition Zone. The low marsh zone (-6 to -18 inches below the normal pool elevation) is **no longer an acceptable wetland zone**, and is only allowed as a short transition zone from the deeper pools to the high marsh zone. In general, this transition zone should have a maximum slope of 5H:1V (or preferably flatter) from the deep pool to the high marsh zone. It is advisable to install biodegradable erosion control fabrics or similar materials during construction to prevent erosion or slumping of this transition zone.

Flow Path. In terms of the flow path, there are two design objectives:

- The **overall flow path through the wetland** can be represented as the length-to-width ratio and/or the flow path ratio (see **Figure SW-8**). At least one of these ratios must be at least 2:1 for Level 1 designs and 3:1 for Level 2 designs.
- The **shortest flow pat**h represents the distance from the closest inlet to the outlet (see **Figure SW-8, bottom**). The ratio of the shortest flow path to the overall length must be at least 0.5 for Level 1 designs and 0.8 for Level 2 designs. In some cases – due to site geometry, storm sewer infrastructure, or other factors – some inlets may not be able to meet these ratios. However, the drainage area served by these "closer" inlets should constitute no more than 20% of the total CDA.

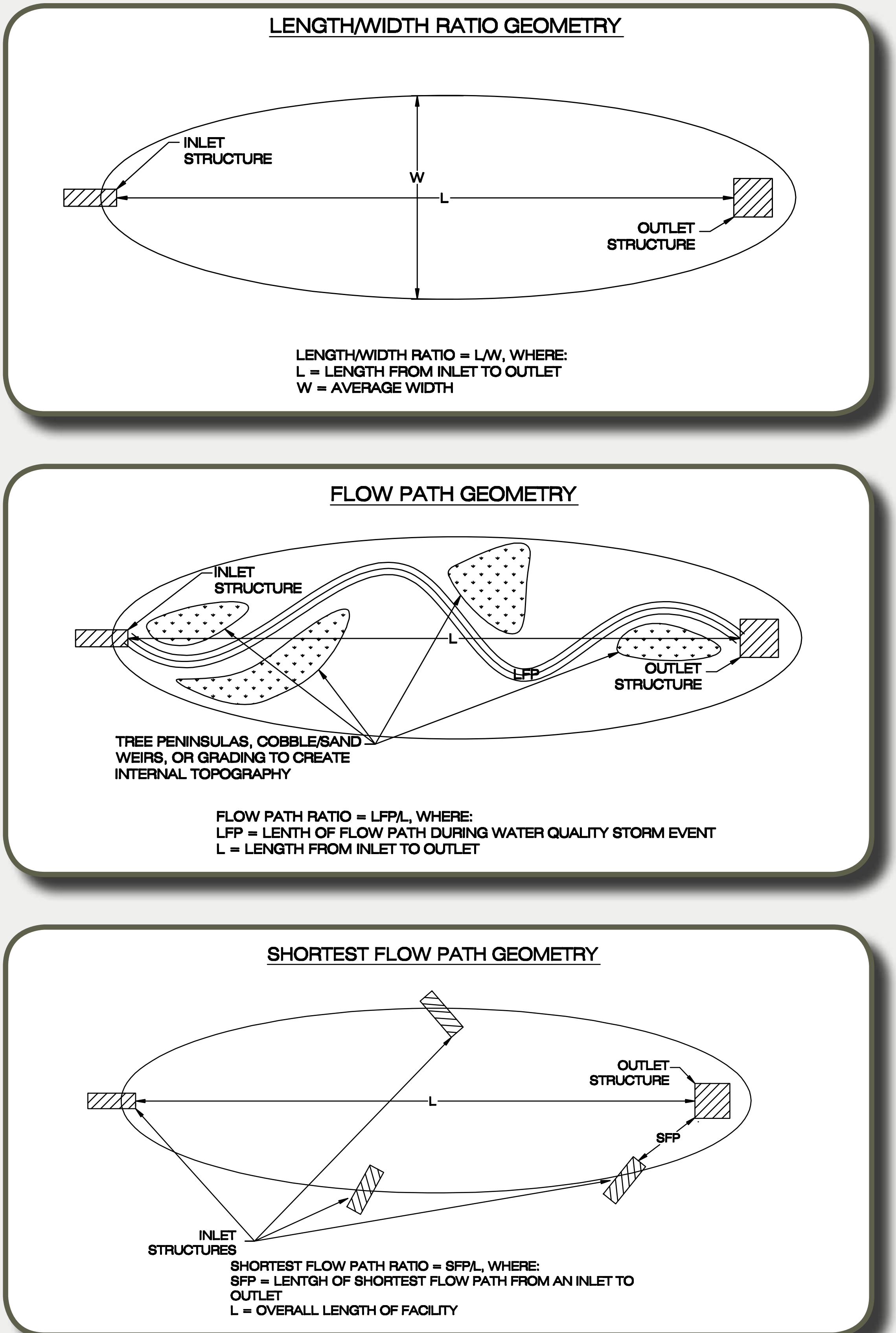


Figure SW-8. Design geometry factors: (1) Length/Width Ratio (top), (2) Flow Path Ratio (middle), and (3) Shortest Flow Path Ratio.

Side Slopes. Side slopes for the wetland should generally have gradients of 4H:1V to 5H:1V. Such mild slopes promote better establishment and growth of the wetland vegetation. They also contribute to easier maintenance and a more natural appearance.

SW-4.5. Pre-treatment Forebay

Sediment forebays are considered an integral design feature of all Stormwater Wetlands (including Level 1 designs). A forebay must be located at every major inlet (see definition below) to trap sediment and preserve the capacity of the main wetland treatment cells. Other forms of pre-treatment for sheet flow and concentrated flow for minor inflow points should be designed consistent with pretreatment criteria found in **Specification 4.2.3**, Bioretention.

The following criteria apply to forebay design:

- A major inlet is defined as an individual storm drain inlet pipe or open channel conveying runoff from least 10% of the Stormwater Wetland's CDA.
- The forebay consists of a separate cell in both the Level 1 and Level 2 designs, and it is formed by an acceptable barrier (e.g., an earthen berm, concrete weir, gabion baskets, etc.).
- The forebay should be a maximum of 4 feet deep (or as determined by the summer drought water balance, Equations SW-1 and SW-2) near the inlet, and then transition to a 1 foot depth at the entrance to the first wetland cell.
- The forebay should be equipped with a variable width aquatic bench, which is a shallow vegetated bench around the perimeter that provides both habitat and safety features. The aquatic bench should be 4 to 6 feet wide at a depth of approximately 1 foot below the water surface at its inner edge (closest to the deep water), transitioning to zero depth at grade.
- The relative size of individual forebays should be proportional to the percentage of the total inflow to the wetland. Similarly, any outlet protection associated with the end section or end wall should be designed according to state or local design standards.
- The bottom of the forebay may be hardened (e.g., with concrete, asphalt, or grouted riprap) to make sediment removal easier.
- The forebay should be equipped with a metered rod in the center of the pool (as measured lengthwise along the low flow water travel path) for long-term monitoring of sediment accumulation.

SW-4.6. Conveyance and Overflow

Since most Stormwater Wetlands are on-line facilities, they need to be designed to safely pass the maximum design storm (e.g., the 10-year and 100-year design storms).

While many different options are available for setting the normal pool elevation, it is strongly recommended that removable flashboard risers be used, given their greater operational flexibility to adjust water levels following construction (see Hunt et al, 2007). Also, a weir can be designed to accommodate passage of the larger storm flows at relatively low ponding depths.

SW-4.7. Geotechnical Testing

Soil borings should be taken below the proposed embankment, in the vicinity of the proposed outlet area, and in at least two locations within the planned wetland treatment area. Soil boring data is needed to (1) determine the physical characteristics of the excavated material; (2) determine its adequacy for use as structural fill or spoil; (3) provide data for the designs of outlet structures (e.g., bearing capacity and buoyancy); (4) determine compaction/composition needs for the embankment; (5) define the depth to groundwater and/or bedrock; and (6) evaluate potential infiltration losses (and the consequent need for a liner).

SW-4.8. Stormwater Wetland Planting Criteria

An initial wetland planting plan is required for any Stormwater Wetland and should be jointly developed by the engineer and a wetlands expert or experienced landscape architect. The plan should outline a detailed schedule for the care, maintenance and possible reinforcement of vegetation in the wetland and its buffer for up to 10 years after the original planting.

The plan should outline a realistic, long-term planting strategy to establish and maintain desired wetland vegetation. The plan should indicate how wetland plants will be established within each inundation zone (e.g., wetland plants, seed-mixes, volunteer colonization, and tree and shrub stock) and whether soil amendments are needed to get plants started. At a minimum, the plan should contain the following:

- Plan view(s) with topography at a contour interval of no more than 1 foot and spot elevations throughout the cell showing the wetland configuration, different planting zones (e.g., high marsh, deep water, upland), microtopography, grades, site preparation, and construction sequence.
- A plant schedule and planting plan specifying emergent, perennial, shrub and tree species, quantity of each species, stock size, type of root stock to be installed, and spacing. To the degree possible, the species list for the Stormwater Wetland should contain plants found in similar local wetlands.

The local regulatory authority will usually establish any more specific vegetative goals to achieve in the wetland landscaping plan. The following general guidance is provided:

Use Native Species Where Possible. Table SW-4 provides a list of common native shrub and tree species and **Table SW-5** provides a list of common native emergent, submergent and perimeter plant species, all of which have proven to do well in Stormwater Wetlands in the mid-Atlantic region and are generally available from most commercial nurseries (for a list of some of these nurseries, see **Appendix F**). Other native species can be used that appear in state-wide plant lists. The use of native species is strongly encouraged, but in some cases, non-native ornamental species may be added as long as they are not invasive. Invasive species such as cattails, Phragmites and purple loosestrife should never be planted. See **Appendix F** for a more comprehensive plant list for stormwater management facilities, including stormwater wetlands.

Match Plants to Inundation Zones. The various plant species shown in **Tables SW-4** and **SW-5** should be matched to the appropriate inundation zone. The first four inundation zones are particularly applicable to Stormwater Wetlands, as follows:

- o **Zone 1:** -6 inches to -12 below the normal pool elevation
- o **Zone 2:** -6 inches to the normal pool elevation)
- o **Zone 3:** From the normal pool elevation to + 12 inches above it)
- o **Zone 4:** +12 inches to + 36 inches above the normal pool elevation (i.e., above detention storage zone)

Aggressive Colonizers. To add diversity to the wetland, 5 to 7 species of emergent wetland plants should be planted, using at least four emergent species designated as aggressive colonizers (shown in bold in **Table SW-**5). No more than 25% of the high marsh wetland surface area needs to be planted. If the appropriate planting depths are achieved, the entire wetland should be colonized within three years. Individual plants should be planted 18 inches on center within each single species "cluster."

Table SW-4. Popular and Versatile Native Trees and Shrubs for Stormwater Wetlands

Shrubs		Trees	
Common & Scientific Names	Zone[1]	Common & Scientific Names	Zone[1]
Button Bush (Cephalanthus occidentalis)	2, 3	Atlantic White Cedar (Charnaecyparis thyoides)	2, 3
Common Winterberry (Ilex verticillatta)	3, 4	Bald Cypress (Taxodium distichum)	2, 3
Elderberry (Sambucus canadensis)	3	Black Willow (Salix nigra)	3, 4
Indigo Bush (Amorpha fruticosa)	3	Box Elder (Acer Negundo)	2, 3
Inkberry (Ilex glabra)	2, 3	Green Ash (Fraxinus pennsylvanica)	3, 4
Smooth Alder (Alnus serrulata)	2, 3	Grey Birch (Betula populifolia)	3, 4
Spicebush (Lindera benzoin)	3, 4	Red Maple (Acer rubrum)	3, 4
Swamp Azalea (Azalea viscosum)	2, 3	River Birch (Betula nigra)	3, 4
Swamp Rose (Rosa palustris)	2, 3	Swamp Tupelo (Nyssa biflora)	2, 3
Sweet Pepperbush (Clethra ainifolia)	2, 3	Sweetbay Magnolia (Magnolia virginiana)	3, 4

Trees (continued, Table SW-4)	
Common & Scientific Names	**Zone[1]**
Sweetgum (Liquidambar styraciflua)	3, 4
Sycamore (Platanus occidentalis)	3, 4
Water Oak (Quercus nigra)	3, 4
Willow Oak (Quercus phellos)	3,4

[1]Zone 1: -6 to -12 inches below the normal pool elevation
Zone 2: -6 inches to the normal pool elevation
Zone 3: From the normal pool elevation to +12 inches
Zone 4: +12 to +36 inches; above detention storage zone

Table SW-5. Popular and Versatile Native Emergent and Submergent Vegetation for Stormwater Wetlands

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Arrow Arum (Peltandra virginica)	2	Emergent	Up to 1 ft.	High; berries are eaten by wood ducks	Full sun to partial shade
Broad-Leaf Arrowhead (Duck Potato) (Saggitaria latifolia)	2	Emergent	Up to 1 ft.	Moderate; tubers and seeds eaten by ducks	Aggressive colonizer

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Blueflag Iris* (Iris versicolor)	2, 3	Emergent	Up to 6 in.	Limited	Full sun (to flower) to partial shade
Broomsedge (Andropogon virginianus)	2, 3	Perimeter	Up to 3 in.	High; songbirds and browsers; winter food and cover	Tolerant of fluctuating water levels and partial shade
Bulltongue Arrowhead (Sagittaria lancifolia)	2, 3	Emergent	0-24 in	Waterfowl, small mammals	Full sun to partial shade
Burreed (Sparganium americanum)	2, 3	Emergent	0-6	Waterfowl, small mammals	Full sun to partial shad
Cardinal Flower * (Lobelia cardinalis)	3	Perimeter	Periodic inundation	Attracts hummingbirds	Full sun to partial shade
Common Rush (Juncus spp.)	2, 3	Emergent	Up to 12 in.	Moderate; small mammals, waterfowl, songbirds	Full sun to partial shade
Common Three Square (Scipus pungens)	2	Emergent	Up to 6 in.	High; seeds, cover, waterfowl, songbirds	Fast colonizer; can tolerate periods of dryness; full sun; high metal removal

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Duckweed (Lemna sp.	1, 2	Submergent / Emergent	Yes	High; food for waterfowl and fish	May biomagnify metals beyond concentrations found in the water
Joe Pye Weed (Eupatorium purpureum)	2, 3	Emergent	Drier than other Joe-Pye Weeds; dry to moist areas; periodic inundation	Butterflies, songbirds, insects	Tolerates all light conditions
Lizard's Tail (Saururus cernus)	2	Emergent	Up to 1 ft.	Low; except for wood ducks	Rapid growth; shade-tolerant
Marsh Hibiscus (Hibiscus moscheutos)	2, 3	Emergent	Up to 3 in.	Low; nectar	Full sun; can tolerate periodic dryness
Pickerelweed (Pontederia cordata)	2, 3	Emergent	Up to 1 ft.	Moderate; ducks, nectar for butterflies	Full sun to partial shade
Pond Weed (Potamogeton pectinatus)	1	Submergent	Yes	Extremely high; waterfowl, marsh and shore birds	Removes heavy metals from the water
Rice Cutgrass (Leersia oryzoides)	2, 3	Emergent	Up to 3 in.	High; food and cover	Prefers full sun, although tolerant of shade; shoreline stabilization
Sedges (Carex spp.)	2, 3	Emergent	Up to 3 in.	High; waterfowl, songbirds	Wetland and upland species

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Softstem Bulrush (Scipus validus)	2, 3	Emergent	Up to 2 ft.	Moderate; good cover and food	Full sun; aggressive colonizer; high pollutant removal
Smartweed (Polygonum spp.)	2	Emergent	Up to 1 ft.	High; waterfowl, songbirds; seeds and cover	Fast colonizer; avoid weedy aliens, such as P. Perfoliatum
Spatterdock (Nuphar luteum)	2	Emergent	Up to 1.5 ft.	Moderate for food, but High for cover	Fast colonizer; tolerant of varying water levels
Switchgrass (Panicum virgatum)	2, 3, 4	Perimeter	Up to 3 in.	High; seeds, cover; waterfowl, songbirds	Tolerates wet/dry conditions
Sweet Flag * (Acorus calamus)	2, 3	Perimeter	Up to 3 in.	Low; tolerant of dry periods	Tolerates acidic conditions; not a rapid colonizer
Waterweed (Elodea canadensis)	1	Submergent	Yes	Low	Good water oxygenator; high nutrient, copper, manganese and chromium removal
Wild celery (Valisneria americana)	1	Submergent	Yes	High; food for waterfowl; habitat for fish and invertebrates	Tolerant of murky water and high nutrient loads

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Wild Rice (Zizania aquatica)	2	Emergent	Up to 1 ft.	High; food, birds	Prefers full sun
Woolgrass (Scirpus cyperinus)	3, 4	Emergent	yes	High: waterfowl, small mammals	Fresh tidal and nontidal, swamps, forested wetlands, meadows, ditches

[1]Zone 1: -6 to -12 **OR** -18 inches below the normal pool elevation
Zone 2: -6 inches to the normal pool elevation
Zone 3: From the normal pool elevation to +12 inches
Zone 4: +12 to +36 inches; above detention storage zone
* Not a major colonizer, but adds color (Aggressive colonizers are shown in **bold** type)

Suitable Tree Species. The major shift in Stormwater Wetland design is to integrate trees and shrubs into the design, in tree islands, peninsulas, and fringe buffer areas. Deeper-rooted trees and shrubs that can extend to the Stormwater Wetland's local water table are important for creating a mixed wetland community. **Table SW-4** above presents some recommended tree and shrub species in the mid-Atlantic region for different inundation zones. A good planting strategy includes varying the size and age of the plant stock to promote a diverse structure. Using locally grown container or bare root stock is usually the most successful approach, if planting in the spring. Trees may be planted in clusters to share rooting space on compacted wetland side-slopes. Planting holes should be amended with compost (a 2:1 ratio of loose soil to compost) prior to planting.

Pre- and Post-Nursery Care. Plants should be kept in containers of water or moist coverings to protect their root systems and keep them moist when in transporting them to the planting location. As much as six to nine months of lead time may be needed to fill orders for wetland plant stock from aquatic plant nurseries (**Appendix F**).

4.2.11. Stormwater Wetlands (SW)

SW-5. Materials Specifications

Stormwater Wetlands are generally constructed with materials obtained on-site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possibly stone for inlet and outlet stabilization, and filter fabric for lining banks or berms.

Plant stock should be nursery grown, unless otherwise approved by the local regulatory authority, and should be healthy and vigorous native species free from defects, decay, disfiguring roots, sun-scald, injuries, abrasions, diseases, insects, pests, and all forms of infestations or objectionable disfigurements, as determined by the local regulatory authority.

4.2.11. Stormwater Wetlands (SW)

SW-6. Design Adaptations

SW-6.1. Karst Terrain

Even shallow pools in karst terrain can increase the risk of sinkhole formation and groundwater contamination. Designers should always conduct geotechnical investigations in karst terrain to assess this risk during the project planning stage. If Stormwater Wetlands are employed in karst terrain, the designer must:

- Employ an impermeable liner that meets the requirements outlined in **Table SW-6.**
- Maintain at least 3 feet of vertical separation from the underlying karst bedrock layer.
- Shallow, linear and multiple cell wetland configurations are preferred.
- Deeper basin configurations, such as the pond/wetland system have limited application in karst terrain.

Table SW-6. Required Groundwater Protection Liners for Ponds in Karst Terrain

Situation	Criteria
Not excavated to bedrock	24 inches of soil with a maximum hydraulic conductivity of 1×10^{-5} cm/sec
Excavated to or near bedrock	24 inches of clay[1] with maximum hydraulic conductivity of 1×10^{-6} cm/sec
Excavated to bedrock within wellhead protection area, in recharge are for domestic well or spring, or in known faulted or folded area	24 inches of clay[1] with maximum hydraulic conductivity of 1×10^{-7} cm/sec and a synthetic liner with a minimum thickness of 60 mil.

[1] Plasticity Index of Clay: Not less than 15% (ASTM D-423/424)
Liquid Limit of Clay: Not less than 30% (ASTM D-2216)
Clay Particles Passing: Not less than 30% (ASTM D-422)
Clay Compaction: 95% of standard proctor density (ASTM D-2216)

Source: WVDEP, 2006 and VA DCR, 1999

SW-6.2. Steep Terrain

Some adjustment can be made by terracing wetland cells in a linear manner as with Regenerative Stormwater Conveyance Systems (**Specification 4.2.7, Regenerative Stormwater Conveyance**) or by dividing the system into discrete cells to take advantage of relatively flat areas on a site.

SW-6.3. Cold Climate and Winter Performance

Wetland performance decreases when snowmelt runoff delivers high pollutant loads. Shallow Stormwater Wetlands can freeze in the winter, which allows runoff to flow over the ice layer and exit without treatment. Inlet and outlet structures close to the surface may also freeze, further diminishing wetland performance. Salt loadings are higher in cold climates due to winter road maintenance. High chloride inputs have a detrimental effect on native wetland vegetation and can shift the wetland plant composition to more salt-tolerant but less desirable species, such as cattails (Wright et al., 2006). Designers should choose salt-tolerant species when crafting their planting plans and consider specifying reduced salt applications in the CDA, when they actually have control of this. The following design adjustments are recommended for Stormwater Wetlands installed in higher elevations and colder climates.

- Treat larger runoff volumes in the spring by adopting seasonal operation of the permanent pool (see MSSC, 2005).
- Plant salt-tolerant wetland vegetation.
- Do not submerge inlet pipes and provide a minimum 1% pipe slope to discourage ice formation.
- Locate low flow orifices so they are located at least 6 inches below the typical ice layer.
- Angle trash racks to prevent ice formation.
- Over-size the riser and weir structures to avoid ice formation and freezing pipes.
- If road sanding is prevalent in the contributing drainage area, increase the forebay size to accommodate additional sediment loading.

SW-6.4. Linear Highway Sites

Under certain circumstances, linear wetland cells and regenerative conveyance systems may be suitable to treat runoff within open channels located in the highway right of way.

4.2.11. Stormwater Wetlands (SW)

SW-7. Construction & Installation

SW-7.1. Construction Sequence

The construction sequence for Stormwater Wetlands depends on site conditions, design complexity, and the size and configuration of the proposed facility. The following two-stage construction sequence is recommended for installing an on-line wetland facility and establishing vigorous plant cover.

Stage 1 Construction Sequence: Wetland Facility Construction.

Step 1: Stabilize Drainage Area. Stormwater Wetlands should only be constructed after the CDA to the wetland is completely stabilized. If the proposed wetland site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be de-watered, dredged and re-graded to design dimensions after the original site construction is complete.

Step 2: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas.

Step 3: Clear and Strip the project area to the desired sub-grade.

Step 4: Install Erosion and Sediment Controls prior to construction, including temporary dewatering devices, sediment basins, and stormwater diversion practices. All areas surrounding the wetland that are graded or denuded during construction of the wetland are to be planted with turf grass, native plant materials or other approved methods of soil stabilization. Grass sod is preferred over seed to reduce seed colonization of the wetland. During construction the wetland must be separated from the CDA so that no sediment flows into the wetland areas. In some cases, a phased or staged erosion and sediment control plan may be necessary to divert flow around the Stormwater Wetland area until installation and stabilization are complete.

Step 5: Excavate the Core Trench for the Embankment and Install the Spillway Pipe. Follow standard embankment construction procedures.

Step 6: Install the Riser or Outflow Structure and ensure that the top invert of the overflow weir is constructed level and at the proper design elevation (flashboard risers are strongly recommended by Hunt et al, 2007).

Step 7: Construct the Embankment and any Internal Berms in 8 to 12-inch lifts and compacted with appropriate equipment.

Step 8: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the wetland. This is normally done by "roughing up" the interim elevations with a skid loader or other similar equipment to achieve the desired topography across the wetland. Spot surveys should be made to ensure that the interim elevations are 3 to 6 inches below the final elevations for the wetland.

Step 9: Install Micro-Topographic Features and Soil Amendments within wetland area. Since most Stormwater Wetlands are excavated to deep sub-soils, they often lack the nutrients and organic matter needed to support vigorous growth of wetland plants. It is therefore essential to add sand, compost, topsoil or wetland mulch to all depth zones in the wetland. The importance of soil amendments in excavated wetlands cannot be over-emphasized; poor survival and future wetland coverage are likely if soil amendments are not added. The planting soil should be a high organic content loam or sandy loam, placed by mechanical methods, and spread by hand. Planting soil depth should be at least 4 inches for shallow wetlands. No machinery should be allowed to traverse over the planting soil during or after construction. Planting soil should be tamped as directed in the design specifications, but it should not be overly compacted. After the planting soil is placed, it should be saturated and allowed to settle for at least one week prior to installation of plant materials.

Step 10: Construct the Emergency Spillway in cut or structurally stabilized soils.

Step 11: Install Outlet Pipes, including the downstream rip-rap apron protection.

Step 12: Stabilize Exposed Soils with temporary (annual) seed mixtures appropriate for a wetland environment. All wetland features above the normal pool elevation should be temporarily stabilized. Avoid perennial and invasive seed mixes, such as fescues.

Stage 2 Construction Sequence: Establishing the Wetland Vegetation.

Step 13: Finalize the Wetland Landscaping Plan. At this stage the engineer, landscape architect, and wetland expert work jointly to refine the initial wetland landscaping plan after the Stormwater Wetland has been constructed. Several weeks of standing time is needed so that the designer can more precisely predict the following two things:

- Where the inundation zones are located in and around the wetland; and
- Whether the final grade and wetland microtopography will persist over time.

This allows the designer to select appropriate species and additional soil amendments, based on field confirmation of soils properties and the actual depths and inundation frequencies occurring within the wetland.

Step 14: Open Up the Wetland Connection. Once the final grades are attained, the pond and/or CDA connection should be opened to allow the wetland cell to fill up to the normal pool elevation. Inundation must occur in stages so that deep pool and high marsh plant materials can be placed effectively and safely. Wetland planting areas should be at least partially inundated during planting to promote plant survivability.

Step 15: Measure and Stake Planting Depths at the onset of the planting season. Depths in the wetland should be measured to the nearest inch to confirm the original planting depths of the planting zone. At this time, it may be necessary to modify the plan to reflect altered depths or a change in the availability of wetland plant stock. Surveyed planting zones should be marked on the as-built or design plan, and their locations should also be identified in the field, using stakes or flags.

Step 16: Propagate the Stormwater Wetland. Three techniques are used in combination to propagate the emergent community over the wetland bed:

1. Initial Planting of Container-Grown Wetland Plant Stock. The transplanting window extends from early April to mid-June. Planting after these dates is quite chancy, since emergent wetland plants need a full growing season to build the root reserves needed to get through the winter. If at all possible, the plants should be ordered at least 6 months in advance to ensure the availability and on-time delivery of desired species.
2. Broadcasting Wetland Seed Mixes. The higher wetland elevations should be established by broadcasting wetland seed mixes to establish diverse emergent wetlands. Seeding of switchgrass or wetland seed mixes as a ground cover is an option for all zones above 3 inches below the normal pool elevation. Hand broadcasting or hydroseeding can be used to spread seed, depending on the size of the wetland cell.
3. Allowing "Volunteer" Wetland Plants to Establish on Their Own. The remaining areas of the Stormwater Wetland will eventually (within 3 to 5 years) be colonized by volunteer species from upstream or the forest buffer.

Step 17: Install Goose Protection to Protect Newly Planted or Newly Growing Vegetation. This is particularly critical for newly established emergent and herbaceous plants, as predation by Canada geese can quickly decimate wetland vegetation. Goose protection can consist of netting, webbing, or string installed in a criss-cross pattern over the surface area of the wetland, above the level of the emergent plants.

Step 18: Plant the Wetland Fringe and Buffer Area. This zone generally extends from 1 to 3 feet above the normal pool elevation. Consequently, plants in this zone are infrequently inundated (5 to 10 times per year), and must be able to tolerate both wet and dry periods.

SW-7.2. Construction Inspection.

Construction inspections are critical to ensure that Stormwater Wetlands are properly constructed and established. Multiple site visits and inspections are recommended during the following stages of the wetland construction process:

- Pre-construction meeting
- Initial site preparation (including installation of project erosion and sediment controls)
- Excavation/grading (e.g., interim/final elevations)
- Wetland installation (e.g., microtopography, soil amendments and staking of planting zones)
- Planting phase (with an experienced landscape architect or wetland expert)
- Final inspection (develop a punch list for facility acceptance)

A construction phase inspection checklist for Stormwater Wetlands can be found in Appendix A.

SW-8. Maintenance Criteria

SW-8.1. Maintenance Agreements

Section C.b.5.ii(C) of the MS4 General Permit requires a maintenance agreement and plan between the property owner or operator and the local program authority (for municipal separate storm sewer systems). This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel. Stormwater Wetlands must be covered by a drainage easement to allow inspection and maintenance.

SW-8.2. First 2 Years Maintenance Operations

Successful establishment of Stormwater Wetland areas requires that the following tasks be undertaken in the first two years (CWP, 2004):

- **Initial Inspections.** During the first 6 months following construction, the site should be inspected at least twice after storm events that exceed 1/2 inch of rainfall.
- **Spot Reseeding.** Inspectors should look for bare or eroding areas in the CDA or around the wetland buffer, and make sure they are immediately stabilized with grass cover.
- **Watering.** Trees planted in the buffer and on wetland islands and peninsulas need watering during the first growing season. In general, consider watering every three days for the first month, and then weekly during the first growing season (April - October), depending on rainfall.
- **Reinforcement Plantings.** Regardless of the care taken during the initial planting of the wetland and buffer, it is probable that some areas will remain unvegetated and some species will not survive. Poor survival can result from many unforeseen factors, such as predation, poor quality plant stock, water level changes, and/or drought. Thus, it is advisable to budget for an additional round of reinforcement planting after one or two growing seasons. Construction contracts should include a care and replacement warranty extending at least two growing seasons after initial planting, to selectively replant portions of the wetland that fail to fill in or survive. If a minimum coverage of 50% is not achieved in the planted wetland zones after the second growing season, reinforcement planting will be required.

SW-8.3. Inspections and On-going Maintenance

Ideally, maintenance of Stormwater Wetlands should be driven by annual inspections that evaluate the condition and performance of the wetland. Based on inspection results, specific maintenance tasks will be triggered. An example maintenance inspection checklist for Stormwater Wetlands can be found in Appendix A.

Managing vegetation is an important ongoing maintenance task at every Stormwater Wetland and for each inundation zone. Following the design criteria above should result in a reduced need for regular mowing of the embankment and access roads. Vegetation within the wetland, however, will require some annual maintenance.

Designers should expect significant changes in wetland species composition to occur over time. Inspections should carefully track changes in wetland plant species distribution over time. Invasive plants should be dealt with as soon as they begin to colonize the wetland. As a general rule, control of undesirable invasive species (e.g., cattails and Phragmites) should commence when their coverage exceeds more than 15% of a wetland cell area. Although the application of herbicides is not recommended, some types (e.g., Glyphosate) have been used to control cattails with some success. Extended periods of dewatering may also work, since early manual removal provides only short-term relief from invasive species. While it is difficult to exclude invasive species completely from Stormwater Wetlands, their ability to take over the entire wetland can be reduced if the designer creates a wide range of depth zones and a complex internal structure within the wetland.

Thinning or harvesting of excess forest growth may be periodically needed to guide the forested wetland into a more mature state. Vegetation may need to be harvested periodically if the Stormwater Wetland becomes overgrown. Thinning or harvesting operations should be scheduled to occur approximately 5 and 10 years after the initial wetland construction. Removal of woody species on or near the embankment and maintenance access areas should be conducted every 2 years.

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