VIRGINIA DCR STORMWATER
DESIGN SPECIFICATION No. 13

CONSTRUCTED WETLANDS

VERSION 2.0
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SECTION 1: DESCRIPTION

Constructed wetlands, sometimes called stormwater wetlands, are shallow basins that receive stormwater inputs for water quality treatment. The constructed wetland permanent pool is typically six inches to 18 inches deep (although it may have greater depths in the forebay and micropool) and possesses variable microtopography to promote dense and diverse wetland cover (**Figure 13.1**). 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 environment for gravitational settling, biological uptake, and microbial activity.

Constructed wetlands can also help to meet channel protection requirements by utilizing detention storage above the permanent pool to reduce peak flows from the 1-year design storm using the energy balance method described in the Virginia Stormwater Management Program (VSMP) regulations (4VAC50-60-66) (see **Table 13.1**).

Designers should note that a constructed wetland is typically the final element in the roof-to-stream pollutant removal sequence and provides no volume reduction credit, and **should therefore be considered *only* if there is remaining pollutant removal or Channel Protection Volume to manage after all other upland runoff reduction options have been considered and properly credited.**

SECTION 2: PERFORMANCE

The overall stormwater functions of constructed wetlands are summarized in **Table 13.1**. There is no runoff volume reduction credit for constructed wetlands since the runoff reduction pathways of infiltration and extended filtration are generally limited. The constructed wetland functions as a basin that generally discharges a volume equivalent to the entire inflow runoff volume. While a minimal runoff reduction credit is awarded for Level 2 ED ponds, the soils appropriate for constructed wetlands limit the ability of the practice to achieve any measureable volume reduction.

Table 13.1. Summary of Stormwater Functions Provided by Constructed Wetlands

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	0%	0%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	50%	75%
Total Phosphorus (TP) Mass Load Removal	50%	75%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	25%	55%
Total Nitrogen (TN) Mass Load Removal	25%	55%
Channel Protection	Yes. Up to 1 foot of detention storage volume can be provided above the normal pool.	
Flood Mitigation	Yes. Flood control storage can be provided above the normal pool.	
[1] Change in event mean concentration (EMC) through the practice.		

Sources: CWP and CSN (2008), CWP, 2007

Leadership in Energy and Environmental Design (LEED®). The LEED® point credit system designed by the U.S. Green Building Council (USGBC) and implemented by the Green Building Certification Institute (GBCI) awards points related to site design and stormwater management. Several categories of points are potentially available for new development and redevelopment projects. **Chapter 6** of the 2013 *Virginia Stormwater Management Handbook* (2nd Edition) provides a more thorough discussion of the site planning process and design considerations as related to Environmental Site Design and potential LEED credits. However, VDCR is not affiliated with the USGBC or GBCI and any information on applicable points provided here is based only on basic compatibility. **Designers should research and verify scoring criteria and applicability of points as related to the specific project being considered through USGBC LEED resources.**

Table 13.2. Potential LEED® Credits for Constructed Wetlands[1]

Credit Category	Credit No.	Credit Description
Sustainable Sites	SS5.1	Site Development: Protect or Restore Habitat
Sustainable Sites	SS5.2	Site Development: Maximize Open Space[2]
Sustainable Sites	SS6.2	Stormwater Design: Quality Control[3]

[1] Actual site design and/or BMP configuration may not qualify for the credits listed. Alternatively, the project may actually qualify for credits not listed here. Designers should consult with a qualified individual (LEED AP) to verify credit applicability.
[2]Applicable to designs with natural form and with side slopes averaging 4:1 or flatter and vegetated.
[3] Must demonstrate that the system is designed for achieving 80% removal of TSS (Level 2).

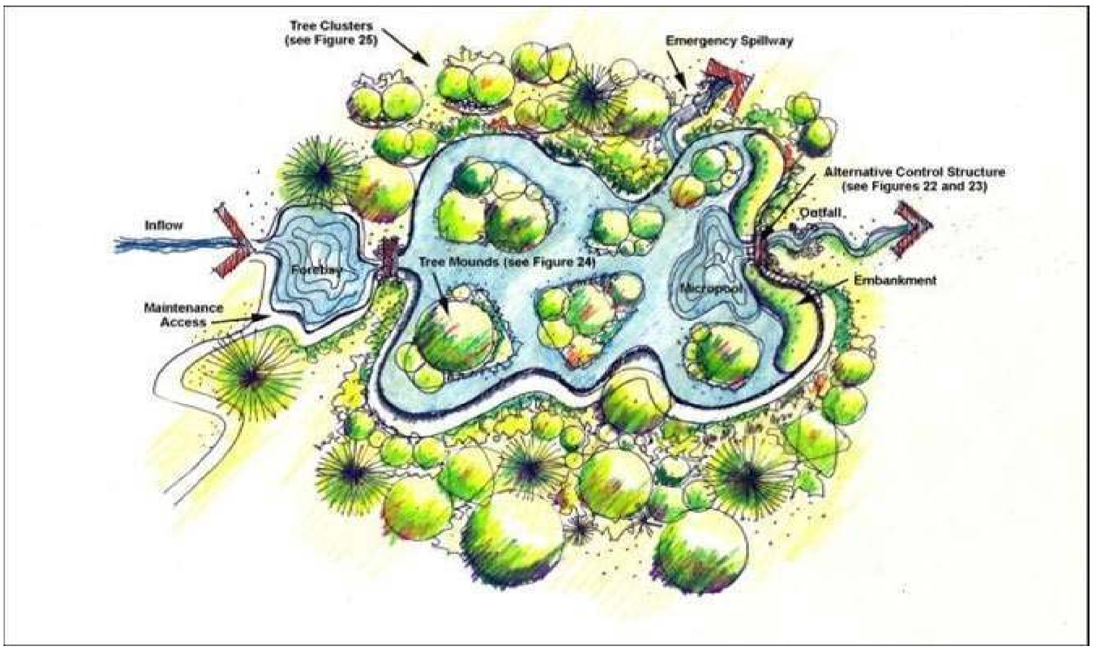

Figure 13.1: Artist's Rendering: Constructed Wetland Basin

SECTION 3: LEVEL 1 AND LEVEL 2 DESIGN TABLE

The two levels of design that enable constructed wetlands to maximize nutrient reduction are shown in **Table 13.3** below.

Table 13.3. Constructed Wetland Design Criteria

Level 1 Design (RR:0; TP:50; TN:25)	Level 2 Design (RR:0; TP:75; TN:55)
$Tv = [(R_V)(A)] / 12$ – the volume reduced by an upstream BMP	$Tv = [1.5(R_V)(A)] / 12$ – the volume reduced by an upstream BMP
Single cell (with a forebay and micropool outlet)[1,2] **Section 6.5**	Multiple cells or a multi-cell pond/wetland combination[1,2] **Sections 6.2 and 6.5**
Extended Detention (ED) for 50% of Tv (24 hr)[3] or Detention storage (up to 12 inches) above the wetland pool for channel protection (1-year storm event); **Section 6.2**	No ED or detention storage. (limited water surface fluctuations allowed during the 1-inch and 1-year storm events; **Section 6.2)**
Uniform wetland depth [2] Allowable mean wetland depth is > than 1 foot; **Section 6.2**	Diverse microtopography with varying depths [2]**;** Allowable mean wetland depth ≤1 foot; **Section 6.2**
The surface area of the wetland is *less* than 3% of the contributing drainage area (CDA); **Section 6.2**.	The surface area of the wetland is *more* than 3% of the CDA; **Section 6.2**
Length/Width ratio *OR* Flow path = 2:1 or more Length of shortest flow path/overall length = 0.5 or more [3] **Section 6.3**	Length/Width ratio *OR* Flow path = 3:1 or more Length of shortest flow path/overall length = 0.8 or more [4] **Section 6.3**
Emergent wetland design, **Section 6.7**	Emergent and Upland wetland design, **Section 6.7**
[1] Pre-treatment Forebay required – refer to **Section 6.5** [2] Internal Tv storage volume geometry – refer to **Section 6.6** [3] Extended Detention may be provided to meet a maximum of 50% of the Treatment Volume; Refer to Design Specification 15 for ED design – refer to **Section 6.2** [4] In the case of multiple inlets, the flow path is measured from the dominant inlets (that comprise 80% or more of the total pond inflow), **Section 6.3**	

SECTION 4: TYPICAL DETAILS

Typical details for the three major constructed wetland variations are provided in **Figures 13.2 to 13.5**.

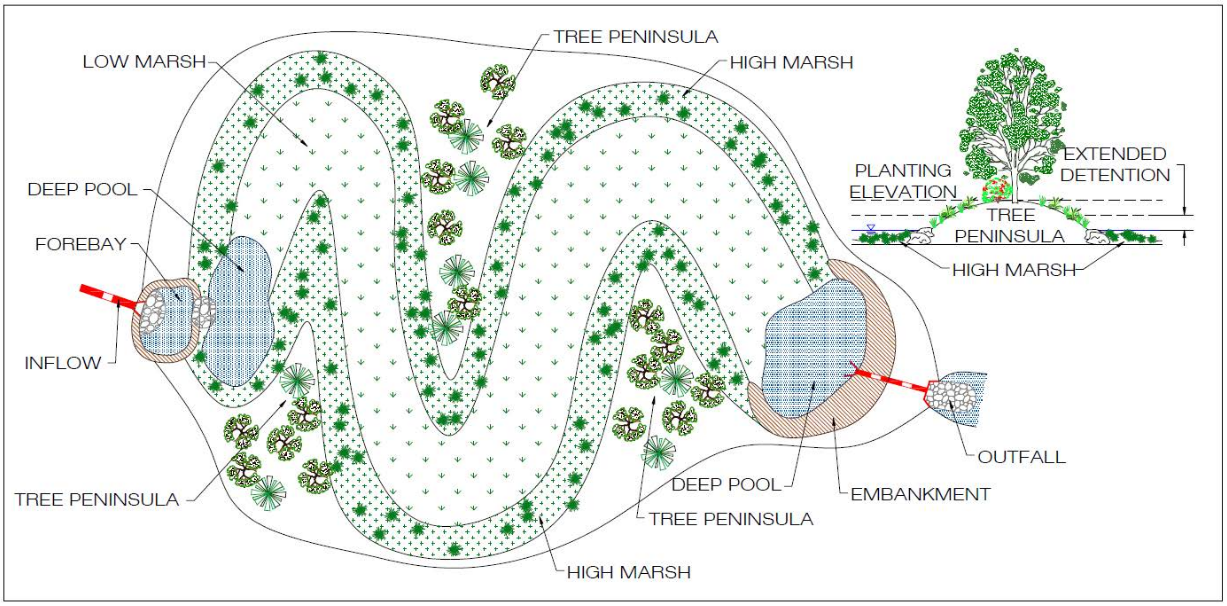

Figure 13.2 Constructed Wetland Level 1 with Forested Peninsulas

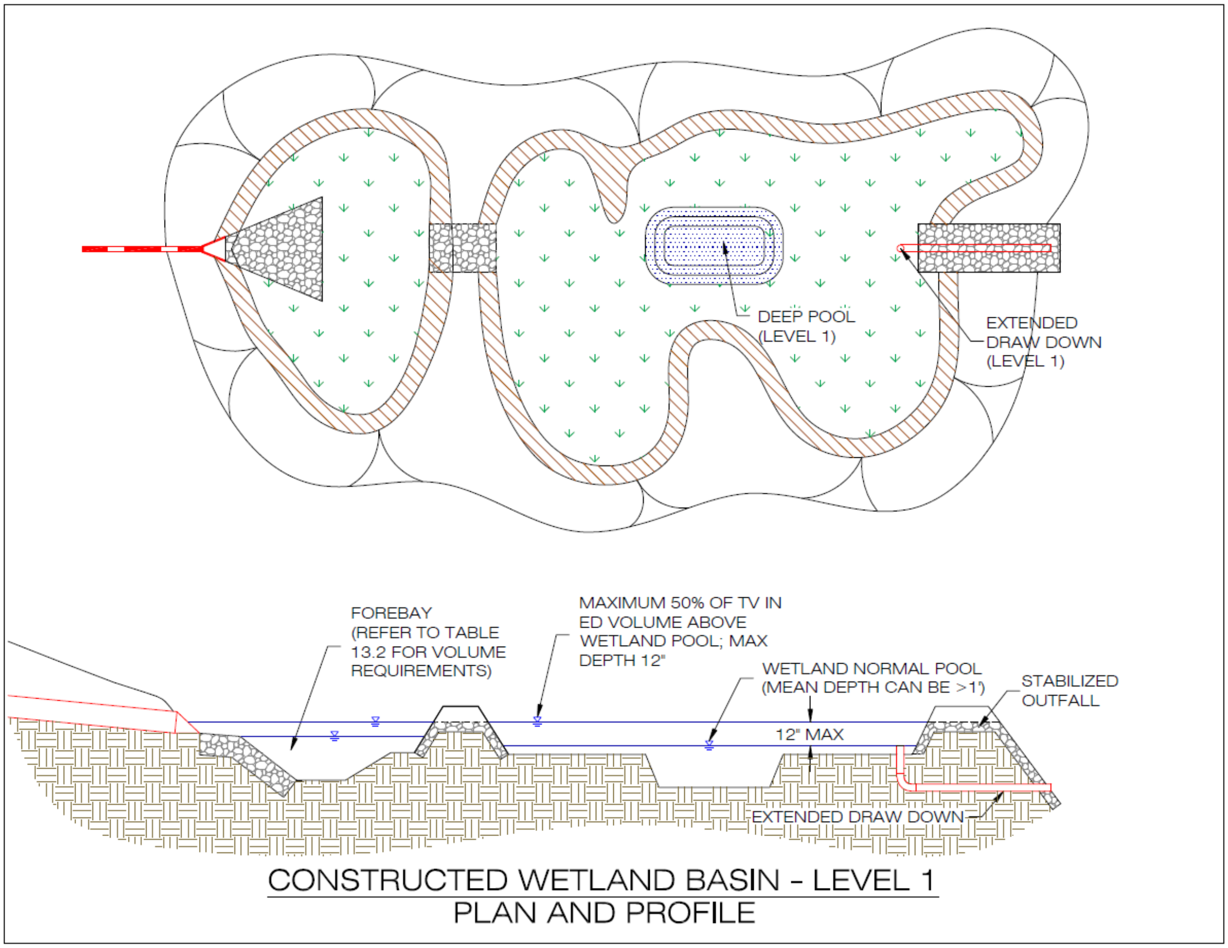

Figure 13.3. Level 1 Constructed Wetland Plan and Cross Section

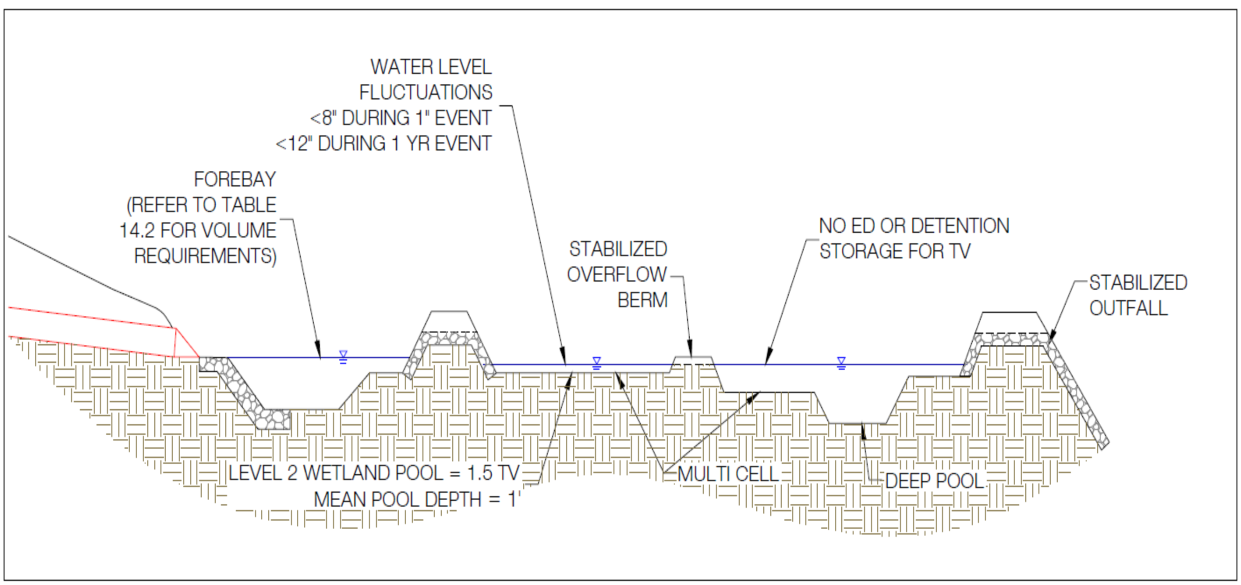

Figure 13.4. Level 2 Constructed Wetland Cross Section

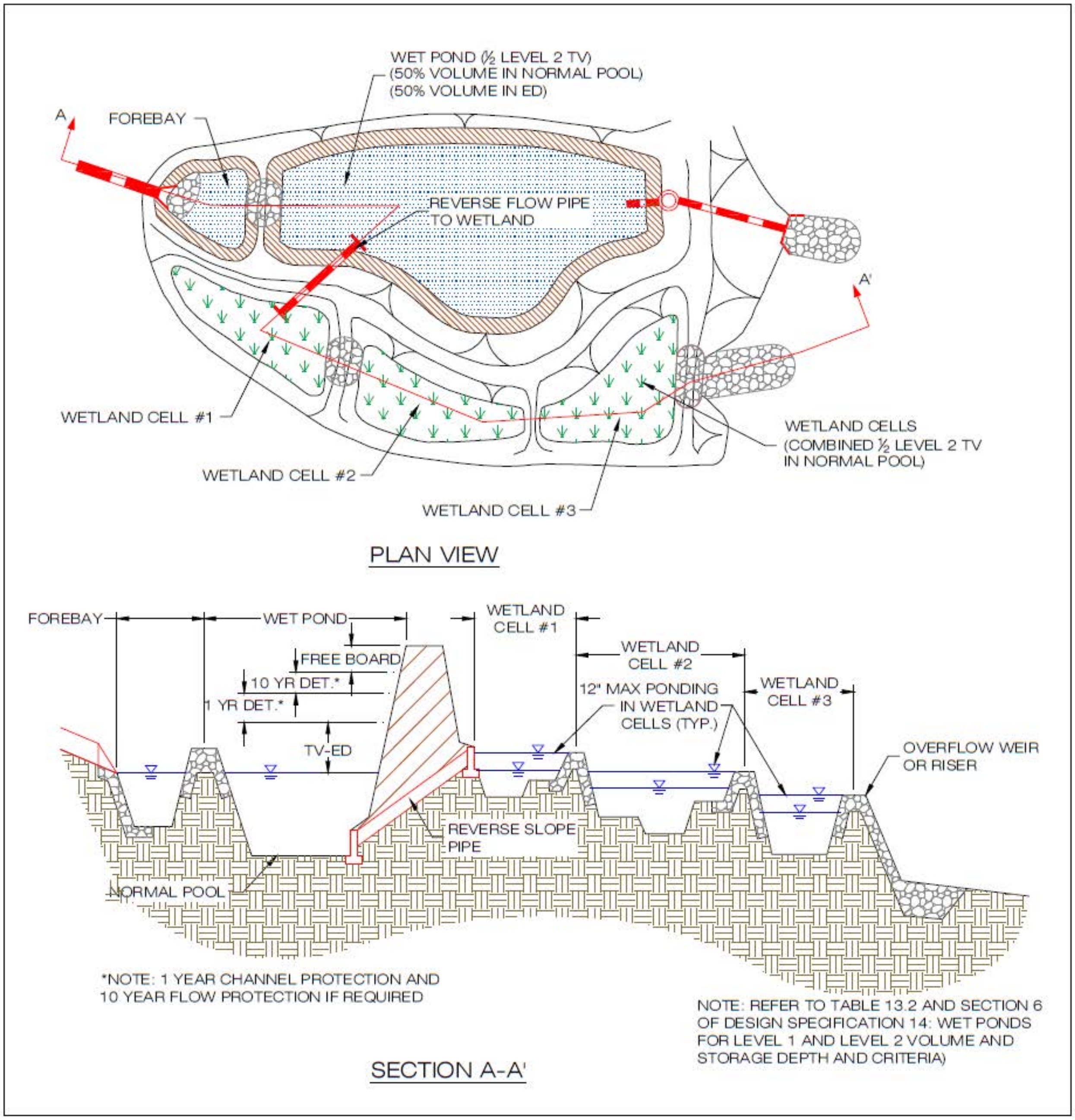

Figure 13.5. Constructed Wetland Level 2 – Pond-Wetland Combination– Plan and Section

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

The following feasibility criteria should be evaluated when designing a wet pond.

Space Requirements. Constructed wetlands normally require a footprint that takes up about 3% of the contributing drainage area, depending on the contributing drainage area's impervious cover and the constructed wetland's pool average depth.

Adequate Water Balance. The proposed wetland must have enough water supplied from groundwater, runoff or baseflow so that the wetland micropools will not go completely dry after a 30-day summer drought. A simple water balance calculation must be performed using the equation provided in **Section 6.2**.

Contributing Drainage Area (CDA). The contributing drainage area 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 a minimum of 10 to 25 acres of drainage area are typically needed to maintain adequate 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.

Available Hydraulic Head. The depth of a constructed 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 constructed wetlands are shallow, the amount of head needed (usually a minimum of 2 to 4 feet) is typically less than for wet ponds.

Steep Slopes. A modification of the Constructed Wetland (and linear wetland or wet swale system) is the Regenerative Conveyance System (RCS). The RCS can be used to convey stormwater down steep grades through a series of step pools. This configuration is ideal for coastal plain outfalls where steep drops on the edge of the tidal escarpment create design challenges. Refer to **Section 7**: Regional and Special Case Design Adaptations.

Minimum Setbacks. Local subdivision and zoning ordinances and design criteria should be consulted to determine minimum setbacks for impoundments to property lines, structures, utilities, and wells. Generally, the edges of constructed wetlands should be located at least 20 feet away from property lines, 25 feet from building foundations, 50 feet from septic system fields, and 100 feet from private wells.

Depth to Water Table and Bedrock. The depth to the groundwater table is not a major constraint for constructed 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 (refer to Section 7.2 of Stormwater Design Specification No. 14: Wet Pond).

Soils. Geotechnical tests should be conducted to determine the infiltration rates and other subsurface properties of the soils underlying the proposed wetland. If soils are permeable or karst geology is a concern (see **Section 7.1**), it may be necessary to use an impermeable liner.

Highly permeable soils make it difficult to maintain a constructed wetland pool. Soil explorations should be conducted at proposed stormwater wetland sites to identify soil infiltration and the presence of karst topography. Underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool. Most group A soils and some group B soils will require a liner in order to maintain the wetland pool. A stormwater wetland should be the option of last resort if karst topography is present. Refer to **Section 7** for additional guidance when designing near karst topography. At a minimum, an impermeable clay or (preferably) geosynthetic liner will be required (**Section 6.9**).

Geotechnical explorations should also be conducted at the proposed embankment to properly design the embankment cut-off trench and fill material.

Trout Streams. The use of constructed wetlands in watersheds containing trout streams is generally ***not*** recommended due to the potential for stream warming, ***unless*** (1) all other upland runoff reduction opportunities have been exhausted, (2) the Channel Protection Volume has not been provided, and (3) a linear/mixed wetland design is applied to minimize stream warming.

Karst. Stormwater wetlands are not recommended in or near karst terrain. An alternative practice or combination of practices should be employed at the site. See CSN Technical Bulletin No.1 (2008) and guidance in Chapter 6 (Appendix 6-A) of the latest edition of the Virginia Stormwater Management Handbook for guidance on wet pond design in karst terrain.

Use of or Discharges to Natural Wetlands. A stormwater wetland ***should never be constructed*** *within* an existing natural wetland ***unless*** it is part of a broader effort to restore a degraded urban wetland and is approved by the local, state, and/or federal wetland regulatory authority. In general, stormwater wetlands may not be located within jurisdictional waters, including wetlands, without obtaining a section 404 permit from the appropriate local, state, and/or federal regulatory agency. In addition, designer should investigate the status of adjacent wetlands to determine if the discharge from the constructed wetland will change the hydroperiod of a downstream natural wetland (see Wright et al, 2006 for guidance on minimizing stormwater discharges to existing wetlands).

Regulatory Status. Constructed wetlands built for the express purpose of stormwater treatment are not considered jurisdictional wetlands in most regions of the country as long as the owner continues to ensure proper maintenance and function of the BMP. Designers should check with their local wetland regulatory authority to ensure this to be the case.

Perennial streams. Locating a constructed wetland along or within a perennial stream is strongly discouraged and will require both ~~a~~ Section 401 and Section 404 permits from the state or federal regulatory authority.

Design Applications

Constructed wetlands are designed based on three major factors: (1) **the desired plant community** (an emergent wetland – Level 1 design; a mixed wetland – emergent and forest; or an emergent/pond combination – Level 2 design); (2) **the contributing hydrology** (groundwater, surface runoff or dry weather flow); and (3) the **landscape position** (linear or basin).

To simplify design, three basic design variations are presented for constructed wetlands:

1. Constructed wetland basin – Level 1 design
2. Constructed multi-cell wetland – Level 2 design
3. Constructed multi-cell pond/wetland combination – Level 2 design (see **Figure 13.5**)

> ***IMPORTANT NOTE: Two wetland designs that have been referenced in past design manuals (Schueler, 1992) are no longer allowed or are highly constrained. These include the extended detention (ED) wetland (with more than 1 foot of vertical extended detention storage) and the pocket wetland (unless it has a reliable augmented water source, such as the discharge from a rain tank).***

A *Constructed Wetland Basin* (Level 1 design) consists of a single cell (including a forebay) with a uniform water depth. A portion of the Treatment Volume (*Tv*) can be in the form of extended detention (ED) above the wetland pool (refer to Design Specification 15: ED Ponds for the ED design criteria). In addition, channel protection detention ponding (1-year *Energy Balance*) is allowed above the wetland pool. However, the storage depth for both the *Tv* and channel protection above the pool is limited to 12 inches (the *Tv* extended detention and 1-year storm detention is inclusive – not additive).

Multi-Cell Wetland system (Level 2 design) does not include any *Tv* storage above the wetland cell pools – the entire *Tv* volume is provided in the permanent pool of the wetland (**Section 6.2**). Similarly, the multi-cell wetland Level 2 design does not accommodate channel protection (detention) storage above the wetland cell. The critical design factor therefore is the depth of temporary ponding allowed above the wetland cell pools to pass the *Tv* or larger design storms: maximum of 8 inches during the *Tv* (1-inch) event, and a maximum of 12 inches during the 1-year event..

The *Pond/Wetland Combination* design is intended to create a wet pond cell either in parallel or in series with constructed wetland cells. The constructed wetland cell is designed similar to the multi-cell wetland – no ED or detention storage is allowed above the wetland cell permanent pool. The wet pond cell can be designed comparable to the Level 2 wet pond with 50% of the wet pond cell *Tv* in the form of the permanent pool, and 50% of the wet pond cell *Tv* in 24-hour ED. The combined design is intended to convey small storms through the wetland cells while diverting (or overflowing with minimal ponding depth) the larger storm runoff into the wet pond cell.

A preferred design is illustrated in **Figure 13.2** above, with the wetland cells independent of the detention ponding, ***allowing for a greater temporary ponding depth in the pond component, while keeping the temporary storage depth to a maximum (12 inches) in the wetland***.

When constructed in series upstream of the wetland cells, the wet pond cell potentially has three 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 (e.g., the channel protection and flood control design storms).

SECTION 6: DESIGN CRITERIA

6.1. Sizing of Constructed Wetlands

Constructed wetlands should be designed to capture and treat the remaining *Tv*, and the channel protection volume (if needed) discharged from the upstream runoff reduction practices.

Designers should use the BMP design treatment volume, Tv_{BMP} (defined as the treatment volume based on the contributing drainage area, Tv_{DA}, less any volume reduced by upstream runoff reduction practices), to size and design the permanent pool volume, as well as any of the pond appurtenances (forebays, etc.). If additional detention storage is proposed above the Level 2 wet pond cell for channel protection and/or flood control, designers should use the adjusted curve number reflective of the volume reduction provided by the upstream practices to calculate the developed condition peak flow rates (including the energy balance) to determine detention requirements - Refer to Chapter 11 of the Virginia Stormwater Handbook.)

To qualify for the higher nutrient reduction rates associated with the Level 2 design, constructed wetlands must be designed with a *Tv* that is 50% greater than the *Tv* for the Level 1 design [i.e., $1.50(R_v)(A)$]. Research has shown that larger constructed wetlands with longer residence times enhance nutrient removal rates.

The runoff Tv_{BMP} credit can be taken for the following:

***Constructed Wetland Basin – Level 1 design*:**
- The entire water volume below the normal pool (including deep pools);
- 24-hour ED storage volume (maximum of 50% of *Tv*)above the normal pool;
- 1-year channel protection detention and detention volume depth above the wetland normal pool must not exceed 1 foot (the *Tv* ED and 1-year storm detention is inclusive, not additive); and
- Any void storage within a submerged rock, sand or stone layer within the wetland.

Constructed Multi-Cell Wetland – Level 2 design (1.5 Tv):
- The entire water volume below the normal pool of each cell (including deep pools);
- Any void storage within a submerged rock, sand or stone layer within the wetland cells.

Constructed multi-cell pond/wetland combination – Level 2 (1.5 Tv):
- The entire water volume below the normal pool of the wetland cells including deep pools (minimum of 50% of the total Level 2 Tv);
- Any void storage within a submerged rock, sand or stone layer within the wetland cells;
- Up to 50% of the total Level 2 *Tv* when provided in a separate pond cell as follows:
    - The pond cell permanent pool volume (a minimum of 50% of the pond cell design volume); and
    - The extended detention storage above the pond cell permanent pool (a maximum of 50% of the pond cell design volume).
    - Refer to Stormwater Design Specification 14 for design details for wet ponds.

Treatment Volume Storage. The **Level 1** wetland design combined maximum water level fluctuation during the water quality design (*Tv*) and channel protection (1-year) storm is limited to

12 inches. This is managed by the combination of surface area and outlet structure: increasing the surface area of the storage volume and utilizing a long crested weir structure capable of passing large flows at relatively low hydraulic head.

Level 2 multi-cell wetland must be designed so that the *Tv* water level fluctuation is limited to 8 inches during the maximum *Tv* event (1-inch rainfall), and a maximum of 12 inches during the 1-year event. Similar to the Level 1 criteria for the ED volume, this can be achieved by using a long weir structure capable of passing large flows at relatively low hydraulic head.

The **Level 2 pond/wetland combination** has no detention or ED storage above the wetland cell and will typically include ED storage above the permanent pool of the wet pond cell (although it's not required). The wet pond cell can be sized to manage up to one-half of the pond/wetland combination design Tv_{BMP} (Tv_{BMP} = 1.5 Tv_{DA} less any volume reduced by upstream runoff reduction practices) in the form of the permanent pool volume and ED volume above the permanent pool. Designers should be aware that establishing a pond cell sized at less than one-half of the Tv_{BMP} or a pond cell permanent pool sized at less than one-half of the pond cell volume will likely generate nuisance conditions related to inadequate pool volume unless provisions for an adequate water balance (such as a base flow or high water table) are provided.

In all cases, it is recommended that an upstream diversion structure be designed to bypass the larger design storms..

Water Balance Testing. A water balance calculation is recommended to document that sufficient inflows to the pond exist to compensate for combined infiltration and evapo-transpiration losses during a 30-day summer drought without creating unacceptable drawdowns. While it is preferred to avoid an arbitrary minimum drainage area requirement for the system, especially if the hydrology for the constructed wetland is supplied by groundwater or dry weather flow inputs, it may be necessary to calculate a water balance for the wetland and/or pond/wetland combination to assure the deep pools will not go completely dry during a 30 day summer drought. (**Equation 13.1**, Hunt et al., 2007).

Specific water balance computation to determine the wet pond cell minimum pool depth can be computed - refer to Stormwater Design Specification No 14: Wet Pond).

Equation 13.1. 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)
- RF_m = Monthly rainfall during drought (inches)
- EF = Fraction of rainfall that enters the stormwater wetland ($CDA \ast R_v$)
- WS/WL = Ratio of contributing drainage area to wetland surface area
- ET = Summer evapotranspiration rate (inches; assume 8)
- 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 13.1**, 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:

Depth of Pool (DP) = 0” (RF_m) – 8” (*ET*) – 7.2” (*INF)* – 6” (*RES*) = 21.2 inches

Therefore, unless there is other input, such as base flow or groundwater, the minimum depth of the pool **should be at least 22 inches** (rather than the 18” minimum depth noted in **Section 6.6**).

6.3. Internal Design Geometry

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 wetland. Wetland performance is enhanced when the wetland has multiple cells, longer flowpaths, and a high ratio of surface area to volume. Whenever possible, constructed 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). A Level 2 design stormwater wetland should be divided into at least four internal sub-cells of different elevations: the forebay, a micro-pool outlet, and two additional cells. Cells can be formed 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 width). The vegetative target is to ultimately achieve a 50-50 mix of emergent and forested wetland vegetation within all four cells.

The first cell is the forebay (refer to **Section 6.5**). The forebay is used to receive runoff from the pond cell or the inflow from a pipe or open channel and distribute it as sheet flow into successive wetland cells. The surface elevation of the second cell is the normal pool elevation. It may contain a forested island or a sand wedge channel to promote flows into the third cell, which is 3 to 6 inches lower than the normal pool elevation. 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.

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. The variable pool depths promote open water areas and adjacent areas of dense and diverse vegetative cover.

- ***Deep Pools.*** Approximately 25% of the wetland *Tv* should be provided in at least three deeper pools – located at the inlet (forebay), center, and outlet (micropool) of the wetland –with each pool having a depth of from 18 to 48 inches. Refer to sizing based on water balance in **Section 6.2** for additional guidance on the minimum depth of the deep pools.
- ***High Marsh Zone.*** Approximately 70% of the wetland surface area should be 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 considered an effective 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.

Micro-Topographic Features. Stormwater wetlands must have internal structures to create the variable micro-topography described above. 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 extended detention zone, formed by coir fiber logs.
- Inverted root wads or large woody debris.
- Gravel diaphragm layers within high marsh zones.
- Internal weirs and/or baffles made of cobble and backfilled with sand, gabion baskets, or stabilized earthen berms.

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.

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 *OR* the flow path ratio (see the *Introduction to the New Virginia Stormwater Design Specifications* for diagrams and equation). These ratios must be at least 2:1 for Level 1 designs and 3:1 for Level 2 designs.
- The ***shortest flow path*** represents the distance from the closest inlet to the outlet (see the *Introduction to the New Virginia Stormwater Design Specifications*). 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 contributing drainage area.

6.4 Geotechnical Testing

Soil borings should be conducted within the footprint of the proposed embankment, in the vicinity of the proposed outlet structure, 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 to determine its adequacy as structural fill or other use; (2) determine the need and appropriate design depth of the embankment cut-off trench; (3) provide data for the designs of outlet works (e.g., bearing capacity and buoyancy); (4) determine the depth to groundwater and bedrock and; (5) evaluate potential infiltration losses (and the potential need for a liner)..

Additional guidance on geotechnical criteria for impoundment facilities can be found in **Appendix A: Earthen Embankments** of the Introduction to the New Virginia Stormwater Design Specifications, as posted on the Virginia Stormwater BMP Clearinghouse web site:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

Guidance on soil explorations in general can be found in **Appendix 8-A** of **Stormwater Design Specification No. 8 (Infiltration).**

6.5. Pre-treatment Forebay

Sediment forebays are considered an integral design feature to maintain the longevity of all stormwater wetlands. A forebay must be located at every major inlet to trap sediment and preserve the capacity of the main wetland treatment cell.

Refer to **Appendix D: Sediment Forebays** of the Introduction to the New Virginia Stormwater Design Specifications, as posted on the Virginia Stormwater BMP Clearinghouse web site for design forebay design information, at the following web address:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

Other forms of pre-treatment for sheet flow and concentrated flow for minor inflow points should be designed consistent with pretreatment criteria found in Design Spec No. 9: Bioretention.

6.6. Conveyance and Overflow

- The slope profile within individual wetland cells should generally be flat from inlet to outlet (adjusting for microtopography). The recommended maximum elevation drop between wetland cells should be 1 foot or less.
- Since most constructed 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 the ponding depths for the more frequent *Tv* storm (1 inch of rainfall) and channel protection storm (1-year event) are limited in order to avoid adverse impacts to the planting pallet, the overflow for the less frequent 10- and 100-year storms should likewise be carefully designed to minimize the depth of ponding. A maximum depth of 4 feet over the wetland pool is recommended).
- 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.

- The discharge from the pond cell to the wetland cell in a Level 2 pond/wetland combination should ideally consist of a reverse slope-pipe. The reverse slope pipe takes flow from the pond from below the surface and helps to minimize the potential for clogging by organic matter (leaves, sticks, etc.). The design can also include an additional smaller pipe with a valve or other control to allow for hydrating the wetland with a trickle flow from the wet pond permanent pool during dry periods.

6.9. Wetland Landscaping Plan

An wetland landscaping plan is required for all stormwater wetland designs 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 since many plants will adapt to the hydrology and may require thinning or additional plantings. More details on preparing a wetland landscaping plan can be found throughout this specification.

- 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 the emergent (Level 1) and the mixed forest plant selection (Level 2). The plan should specify 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 constructed wetland should contain native plants found in similar local wetlands.

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

- ***Use Native Species Where Possible.*** **Table 13.4** provides a list of common native shrub and tree species and **Table 13.5** 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 **Table 13.6**). 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.
- ***Match Plants to Inundation Zones.*** The various plant species shown in **Tables 13.4 and 13.5** should be matched to the appropriate inundation zone. The first four inundation zones are are particularly applicable to stormwater wetlands, as follows:
    - **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 ED Zone)

(Note that the Low Marsh Zone (-6 inches to -18 inches below the normal pool elevation) has been dropped since experience has shown that few emergent wetland plants flourish in this deeper 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 13.5**). 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 13.4. Popular, Versatile and Available Native Trees and Shrubs for Constructed Wetlands

Shrubs		**Trees**	
Common & *Scientific* Names	**Zone**	**Common & *Scientific* Names**	**Zone**
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
		Sweetgum *(Liquidambar styraciflua)*	3, 4
		Sycamore *(Platanus occidentalis)*	3, 4
		Water Oak *(Quercus nigra)*	3, 4
		Willow Oak *(Quercus phellos)*	3,4
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 ED zone			

- ***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 13.3** 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. It is recommended that buffer planting areas be over-planted with a small stock of fast growing successional species to achieve quick canopy closure and shade out invasive plant species. 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 (**Table 13.5**).

Table 13.5. Popular, Versatile and Available Native Emergent and Submergent Vegetation for Constructed Wetlands

Plant	Zone	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
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; ull sun; high metal removal
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
Softstem Bulrush *(Scipus validus)*	2, 3	Emergent	Up to 2 ft.	Moderate; good cover and food	Full sun; aggressive

Plant	Zone	Form	Inundation Tolerance	Wildlife Value	Notes
					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 murkey water and high nutrient loads
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
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 ED zone * Not a major colonizer, but adds color (Aggressive colonizers are shown in **bold** type)					

For more guidance on planting trees and shrubs in wet pond buffers, consult the following:

- Cappiella et al (2006)
- DCR's Riparian Buffer Modification & Mitigation Guidance Manual, available online at: http://www.dcr.virginia.gov/chesapeake_bay_local_assistance/ripbuffmanual.shtml
- Appendix E: Landscaping of the Introduction to the New Virginia Stormwater Design Specifications , as posted on the Virginia Stormwater BMP Clearinghouse web site:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

6.8. Maintenance Reduction Features

The following design criteria will help to avoid significant maintenance problems pertaining to constructed wetlands:

Maintenance Access. Good access is needed so crews can remove sediments, make repairs and preserve wetland treatment capacity).

- Maintenance access must be provided to the forebay, safety benches, and outlet riser area.
- Risers should be located in embankments to ensure easy access.

- Access roads must (1) be constructed of load bearing materials, (2) have a minimum width of 12 feet, and (3) possess a maximum profile grade of 15%.
- Turnaround areas may also be needed, depending on the size and configuration of the wetland.

Clogging Reduction. If the low flow orifice clogs, it can result in a rapid change in wetland water elevations that can potentially kill wetland vegetation. Therefore, designers should carefully design the flow control structure to minimize clogging, as follows:

- A minimum 3-inch diameter orifice is recommended in order to minimize clogging of an outlet or extended detention pipe when it is surface fed.. It should be noted, however, that even a 3 inch orifice will be very susceptible to clogging from floating vegetation and debris.
- Smaller openings (down to 1 inch in diameter) are permissible, using internal orifice plates within the pipe.
- All outlet pipes should be adequately protected by trash racks, half-round CMP, or reverse-sloped pipes extending to mid-depth of the micropool. Refer to guidance on low-flow orifice design in **Chapter 13** of the ***Virginia Stormwater Handbook*** (2010).

Table 13.6. Native Nursery Sources in the Chesapeake Bay

State	Nursery Name	Nursery Web Site
MD	American Native Plants **W**	www.amricannativeplantsonline.com
MD	Ayton State Tree Nursery	www.dnr.state.md.us/forests/nursery
MD	Chesapeake Natives. Inc.	www.chesapeakenatives.org
MD	Clear Ridge Nursery, Inc. **W**	www.clearridgenursery.com
MD	Environmental Concern **W**	www.wetland.org
MD	Lower Marlboro Nursery **W**	www.lowermarlboronursery.com
MD	Homestead Gardens	www.homesteadgardens.com
NJ/VA	Pinelands Nursery **W**	www.pinelandsnursery.com
PA	Appalachian Nursery	www.appnursery.com
PA	Octoraro Native Plant Nursery	www.OCTORARO.com
PA	Redbud Native Plant Nursery **W**	www.redbudnativeplantnursery.com
PA	New Moon Nursery, Inc. **W**	www.newmoonnursery.com
PA	Sylva Native Nursery/Seed Co. **W**	www.sylvanative.com
VA	Lancaster Farms, Inc.	www.lancasterfarms.com
VA	Nature by Design **W**	www.nature-by-design.com
Notes: This is a partial list of available nurseries and does NOT constitute an endorsement of them. For updated lists of native plant nurseries, consult the following sources: Virginia Native Plant Society www.vnps.org Maryland Native Plant Society www.mdflora.org Pennsylvania Native Plant Society www.pawildflowers.org Delaware Native Plant Society www.delawarenativeplants.org **W:** indicates that nursery has an inventory of emergent wetland species		

6.10. Constructed Wetland Material Specifications

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. The basic material specifications for **Earthen Embankments**, **Principal Spillways**, **Vegetated Emergency Spillways** and **Sediment Forebays** shall be as specified in **Appendices A** through **D** of the *Introduction to the New Virginia*

Stormwater Design Specifications, as posted on the Virginia Stormwater BMP Clearinghouse web site, at the following URL:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

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.

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. 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 areas of karst terrain to assess this risk and rule out the presence of karst during the project planning stage. If these studies indicate that less than 3 feet of vertical separation exists between the bottom of the proposed wetland and the underlying soil-bedrock interface, stormwater wetlands should not be used due to the risk of sinkhole formation and groundwater contamination. If constructed wetlands are employed in karst terrain, shallow, linear and multiple cell wetland configurations are preferred. Deeper wetland configurations, such as the pond/wetland system and the ED wetland have limited application in karst terrain. In addition, the designer must implement the following:.

- Employ an impermeable liner that meets the requirements outlined in **Table 13.7**.
- Maintain at least 3 feet of vertical separation from the underlying karst layer.

Table 13.7. 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 x 10^{-5} cm/sec
Excavated to or near Bedrock	24 inches of clay[1] with maximum hydraulic conductivity of 1 x 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 x 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

7.2. Coastal Plain

Constructed wetlands are an ideal practice for the flat terrain, low hydraulic head and high water table conditions found at many coastal plain development sites. The following design adaptations can make them work more effectively in coastal plain settings:

- Shallow, linear and multiple-cell wetland configurations are preferred.
- It is acceptable to excavate up to 6 inches below the seasonally high groundwater table to provide the requisite hydrology for wetland planting zones, and up to 3 feet below for micropools, forebays and other deep pool features.
- The volume below the seasonably high groundwater table is acceptable for the *Tv*, as long as the other primary geometric and design requirements for the wetland are met (e.g., flow path and microtopography).
- Plant selection should focus on species that are wet-footed and can tolerate some salinity.
- A greater range of coastal plain tree species can tolerate periodic inundation, so designers should consider creating forested wetlands, using species such as Atlantic White Cedar, Bald Cypress and Swamp Tupelo.
- The use of flashboard risers is recommended to control or adjust water elevations in wetlands constructed on flat terrain.
- The regenerative conveyance system is particularly suited for coastal plain situations, where there is a significant drop in elevation from the channel to the outfall location (see Stormwater Design Specification #11: Wet Swales).

7.3. Steep Terrain – Regenerative Conveyance Systems

Constructed wetlands are not an effective practice at development sites with steep terrain. Some adjustment can be made by terracing wetland cells in a linear manner as with Regenerative Conveyance Systems (RSC).

Regenerative stormwater conveyance (RSC) systems are open-channel, sand seepage filtering systems that utilize a series of shallow aquatic pools, riffle weir grade controls, native vegetation and underlying sand channel to treat and safely detain and convey storm flow, and convert stormwater to groundwater via infiltration at coastal plain outfalls and other areas where grades make traditional practices difficult to implement. RSC systems combine features and treatment benefits of swales, infiltration, filtering and wetland practices. In addition, they are designed to convey flows associated with extreme floods (i.e., 100 year return frequency event) in a non-erosive manner, which results in a reduction of channel erosion impacts commonly encountered at conventional stormwater outfalls and headwater stream channels.

RCS systems are referred to as Step Pool Storm Conveyance (SPSC) channels in Ann Arundel County, MD where systems have been installed and observed. The physical characteristics of the SPSC channel are best characterized by the Rosgen A or B stream classification types, where "bedform" occurs as a step/pool cascading channel which often stores large amounts of sediment in the pools associated with debris dams" (Rosgen, 1996). Due to their ability to safely convey large flood events, RSC systems do not require flow splitters to divert smaller events for water quality treatment, and reduce the need for storm drain infrastructure in the conveyance system.

These structures feature surface/subsurface runoff storage seams and an energy dissipation design that is aimed at attenuating the flow to a desired level through energy and hydraulic power equivalency principles. RSC systems have the added benefit of creating dynamic and diverse ecosystems for a range of plants, animals, amphibians and insects. These ecosystems enhance pollutant uptake and assimilation and provide a natural and native aesthetic at sites. RSC systems are unique in that they can be located on the front or tail end of a treatment system and still provide water quality and groundwater recharge benefits. Where located on the front end of a treatment train, they provide water quality, groundwater recharge, and channel protection, while also providing non-erosive flow conveyance that delivers flow to the stormwater quantity practice - a constructed wetland, wet pond, ED Pond, or combination.

The Ann Arundel County design specification can be found at:

http://www.aacounty.org/DPW/Watershed/StepPoolStormConveyance.cfm

7.4. Cold Climate and Winter Performance

Wetland performance decreases when snowmelt runoff delivers high pollutant loads. Shallow constructed 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 contributing drainage area, 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 withdraw 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.

7.5. Linear Highway Sites

Wet swales, linear wetland cells and regenerative conveyance systems are particularly well suited and considered preferred practices to treat runoff within open channels located in the highway right of way.

SECTION 8: CONSTRUCTION

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.

8.1. Stage 1 Construction Sequence: Wetland Facility Construction

Step 1: Stabilize Drainage Area. Stormwater wetlands should only be constructed after the contributing drainage area 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 (E&S) 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 contributing drainage area so that no sediment flows into the wetland areas. In some cases, a phased or staged E&S 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 Outlet Works. 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 6: Construct the Embankment and any Internal Berms in 8 to 12-inch lifts or as directed by geotechnical recommendations, and compact as required with appropriate equipment.

Step 7: Construct the Emergency Spillway in cut or structurally stabilized soils.

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 (Bowers, 1992). 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: Stabilize Exposed Soils with temporary seed mixtures appropriate for a wetland environment. All wetland features above the normal pool elevation should be temporarily stabilized by hydro-seeding or seeding over straw.

8.2. Stage 2 Construction Sequence: Establishing the Wetland Vegetation

Step 11: 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 12: Open Up the Wetland Connection. Once the final grades are attained, the pond and/or contributing drainage area connection should be opened to allow the wetland cell to fill up to the normal pool elevation. Gradually inundate the wetland erosion of unplanted features. 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 13: 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 14: 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 recommended 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 15: Install Goose Protection to Protect Newly Planted or Newly Growing Vegetation. This is particularly critical for newly established emergents and herbacacious plants, as predation by Canada geese can quickly dessimate 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 16: Plant the Wetland Fringe and Buffer Area. This zone generally extends from 1 to 3 feet above the normal pool elevation (from the shoreline fringe to about half of the maximum water surface elevation for the 2-year storm). 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.

8.3. 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 E&S 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)

Upon final inspection and acceptance, the GPS coordinates should be logged for all constructed wetlands and submitted for entry into the local BMP maintenance tracking database.

A construction phase inspection checklist for Constructed Wetlands can be accessed at the end of this specification.

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

The Virginia Stormwater Management regulations (4 VAC 50-60) specify the circumstances under which a maintenance agreement must be executed between the owner and the VSMP authority, and 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.

- Restrictive covenants or other mechanism enforceable by the VSMP authority must be in place to help ensure that stormwater wetlands are maintained, as well as to pass the knowledge along to any subsequent property owners.
- Access to stormwater wetlands should be covered by a drainage easement to allow access by the VSMP authority to conduct inspections and perform maintenance when necessary.
- All stormwater wetlands must include a long term maintenance agreements consistent with the provisions of the VSMP regulations, and must include the recommended maintenance tasks and a copy of an annual inspection checklist.
- The maintenance agreement should also include contact information for owners to get local or state assistance to solve common nuisance problems, such as mosquito control, geese, invasive plants, vegetative management and beaver removal.

9.2. First Year Maintenance Operations

Successful establishment of constructed wetland areas requires that the following tasks be undertaken in the first two years:

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 contributing drainage area 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 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, 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.

9.3. Maintenance Inspections

Maintenance of constructed wetlands should be driven by annual inspections that evaluate the condition and performance of the wetland, including the following:

- Measure sediment accumulation levels in forebays and micropools.
- Monitor the growth and survival of emergent wetlands and tree/shrub species. Record the species and approximate coverage, and note the presence of any invasive plant species.
- Inspect the condition of stormwater inlets to the wetland for material damage, erosion or undercutting.
- Inspect upstream and downstream banks for evidence of sloughing, animal burrows, boggy areas, woody growth or gully erosion that may undermine embankment integrity.
- Inspect the wetland outfall channel for erosion, undercutting, rip-rap displacement, woody growth, etc.
- Inspect the condition of the principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, etc.
- Inspect the condition of all trash racks, reverse-sloped pipes, and flashboard risers for evidence of clogging, leakage, debris accumulation, etc.
- Inspect maintenance access to ensure it is free of woody vegetation, and check to see whether valves, manholes and locks can be opened or operated.
- Inspect internal and external side slopes of the wetland for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately.
- Cleanups should be scheduled at least once a year to remove trash, debris and floatables.

Based on inspection results, specific maintenance tasks will be triggered. Example maintenance inspection checklists for Constructed Wetlands can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010).

9.4. Non-Routine Maintenance

Managing vegetation is an important ongoing maintenance task at every constructed 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.

Control Invasive Species. 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 and Harvesting of Woody Growth. 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 constructed 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.

Sediment Removal. Frequent sediment removal from the forebay is essential to maintain the function and performance of a constructed wetland. For planning purposes, maintenance plans should anticipate cleanouts approximately every 5 to 7 years, or when inspections indicate that 50% of the forebay sediment storage capacity has been filled. (Absent an upstream eroding channel or other source of sediment, the frequency of sediment removal should decrease as the drainage area stabilizes.) The designer should also check to see whether removed sediments can be spoiled on-site or must be hauled away. Sediments excavated from constructed wetlands are not usually considered toxic or hazardous. They can be safely disposed of by either land application or land filling.

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

Constructed wetlands can generate the following community and environmental concerns that may need to be addressed during design.

Aesthetics and Habitat. Constructed 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.

Existing Forests. Given the large footprint of a constructed 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 he/she may consider creating a wooded wetland (see Cappiella *et al*., 2006b).

Stream Warming Risk. Constructed wetlands have a moderate risk of causing stream warming. If a constructed wetland will discharge to temperature-sensitive waters, the designer should consider using the wooded wetland design to shade the water, and any extended detention storage should be released in less than 12 hours.

Safety Risk. Constructed 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 contributing drainage area. Few mosquito problems are reported for well designed, properly-sized and frequently-maintained constructed wetlands; however, no design can eliminate them completely. Simple precautions can be taken to minimize mosquito breeding habitat within constructed wetlands (e.g., constant inflows, benches that create habitat for natural predators, and constant pool elevations – see Walton 2003 and MSSC, 2005).

Sample Construction Inspection Checklist for Constructed Wetlands: The following checklist provides a basic outline of the anticipated items for the construction inspection of Constructed wetlands. Inspectors should review the plans carefully, and adjust these items and the timing of inspection verification as needed to ensure the intent of the design and the inspection is met. Finally, users of this information may wish to incorporate these items into a VSMP Authority Construction Checklist format consistent with the format used for erosion and sediment control and BMP construction inspections.

Pre-Construction Meeting

☐ Pre-construction meeting with the contractor designated to install the constructed wetlands practice has been conducted.

☐ Identify the tentative schedule for construction and verify the requirements and schedule for interim inspections and sign-off.

☐ Subsurface investigation and soils report supports the placement of a constructed wetland practice in the proposed location.

☐ Impervious cover has been constructed/installed and area is free of construction equipment, vehicles, material storage, etc.

☐ All pervious areas of the contributing drainage areas have been adequately stabilized with a thick layer of vegetation and erosion control measures have been removed.

☐ **Certification of Stabilization Inspection:** Inspector certifies that the drainage areas are adequately stabilized in order to convert the sediment basin/trap (if the area has been used for sediment control) and construct the wetland.

Excavation of Constructed Wetland Cells

☐ Stormwater has been diverted around the area of the constructed wetland to a stabilized conveyance and perimeter erosion control measures to protect the facility during construction have been installed.

☐ Materials (wetland soils and plants, erosion control materials such as stone, soil stabilization matting, etc.) are available.

☐ Construction of the embankment (including core trench, riser and barrel or weir overflow, emergency spillway overflow, outlet protection, etc.) in accordance with approved plans.

☐ Excavation of internal micro-topographic features: depth zones, aquatic bench, berms with overflow weirs, etc., in accordance with approved plans.

☐ Installation of pretreatment, including forebays, gravel diaphragms, energy dissipators, etc., is in accordance with the approved plans.

☐ Impermeable liner, when required, meets project specifications and is placed in accordance with manufacturers specifications.

☐ Placement of wetland soils and amendments in accordance with approved plans.

☐ **Certification of Excavation Inspection:** Inspector certifies that the excavation has achieved all the appropriate grades and grade transitions as shown on the approved plans.

Wetland Plantings and Stabilization

☐ Exposed soils on side slopes, internal berms, and embankments are stabilized with seed mixtures, stabilization matting, mulch, etc., in accordance with approved plans.

☐ External bypass structure is built in accordance with the approved plans.

☐ Appropriate number and spacing of plants are installed and protected in accordance with the approved plans.

☐ All erosion and sediment control practices have been removed.

☐ Follow-up inspection and as-built survey/certification has been scheduled.

☐ GPS coordinates have been documented for the constructed wetland installation.

SECTION 11: REFERENCES

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