VIRGINIA DEQ STORMWATER
DESIGN SPECIFICATION No. 13

CONSTRUCTED WETLANDS

VERSION 1.9
March 1, 2011

SECTION 1: DESCRIPTION

Constructed wetlands, sometimes called stormwater wetlands, are shallow depressions that receive stormwater inputs for water quality treatment. Wetlands are typically 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 (**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 are the final element in the roof-to-stream runoff reduction sequence. They should only be considered for use after all other upland runoff reduction opportunities have been exhausted and there is still a remaining water quality or Channel Protection Volume to manage.

SECTION 2: PERFORMANCE

The overall stormwater functions of constructed wetlands are summarized in **Table 13.1**.

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

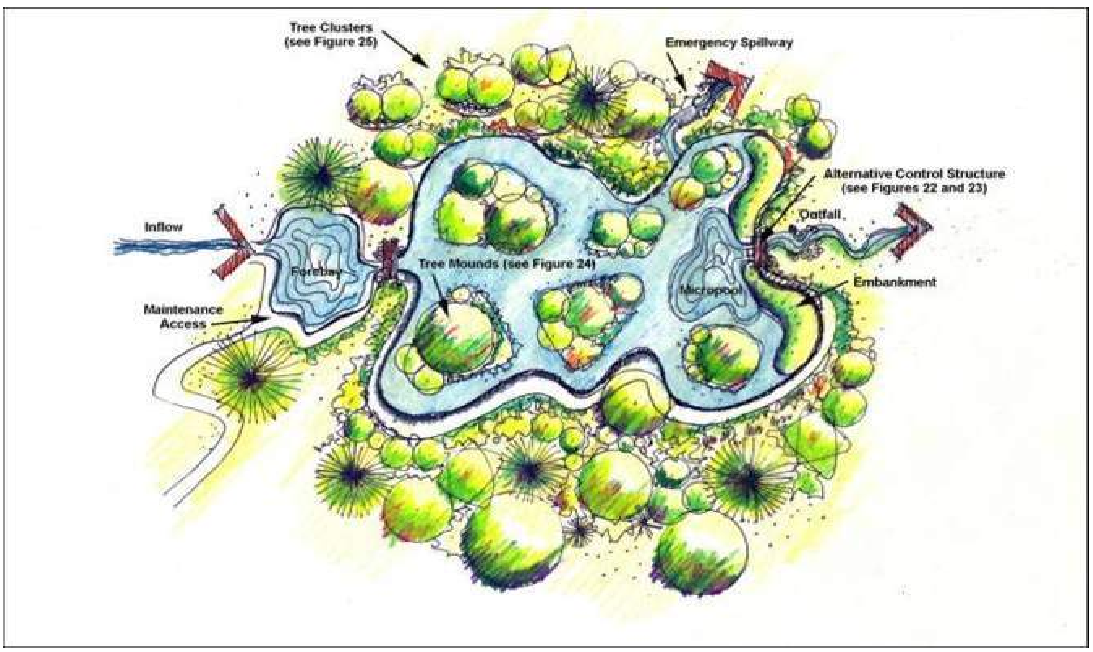


Figure 13.1: Plan View Constructed Wetland Basin

SECTION 3: DESIGN TABLE

The two levels of design that enable constructed wetlands to maximize nutrient reduction are shown in **Table 13.2** below. At this point, there is no runoff volume reduction credit for constructed wetlands, although this may change based on future research.

Table 13.2. Constructed Wetland Design Criteria

Level 1 Design (RR:0; TP:50; TN:25)	Level 2 Design (RR:0; TP:75; TN:55)
$T_V = [(R_V)(A)] / 12$ – 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)[1,2]	Multiple cells or a multi-cell pond/wetland combination[1,2]
Extended Detention (ED) for T_V (24 hr)[3] or Detention storage (up to 12 inches) above the wetland pool for channel protection (1-year storm event)	No ED. (limited water surface fluctuations allowed during the 1-inch and 1-year storm events – refer to **Section 6)**
Uniform wetland depth [2]	Diverse microtopography with varying depths [2]
Mean wetland depth is *more* than 1 foot	Mean wetland depth is *less* than 1 foot
The surface area of the wetland is *less* than 3% of the contributing drainage area (CDA).	The surface area of the wetland is *more* than 3% of the CDA.
Length/Width ratio *OR* Flow path = 2:1 or more	Length/Width ratio *OR* Flow path = 3:1 or more
Length of shortest flow path/overall length = 0.5 or more [3]	Length of shortest flow path/overall length = 0.8 or more [4]
Emergent wetland design	Mixed wetland design
[1] Pre-treatment Forebay required – refer to **Section 6.4** [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 [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 4: TYPICAL DETAILS

Typical details for the three major constructed wetland variations are provided in **Figures 13.2 to 13.4**.

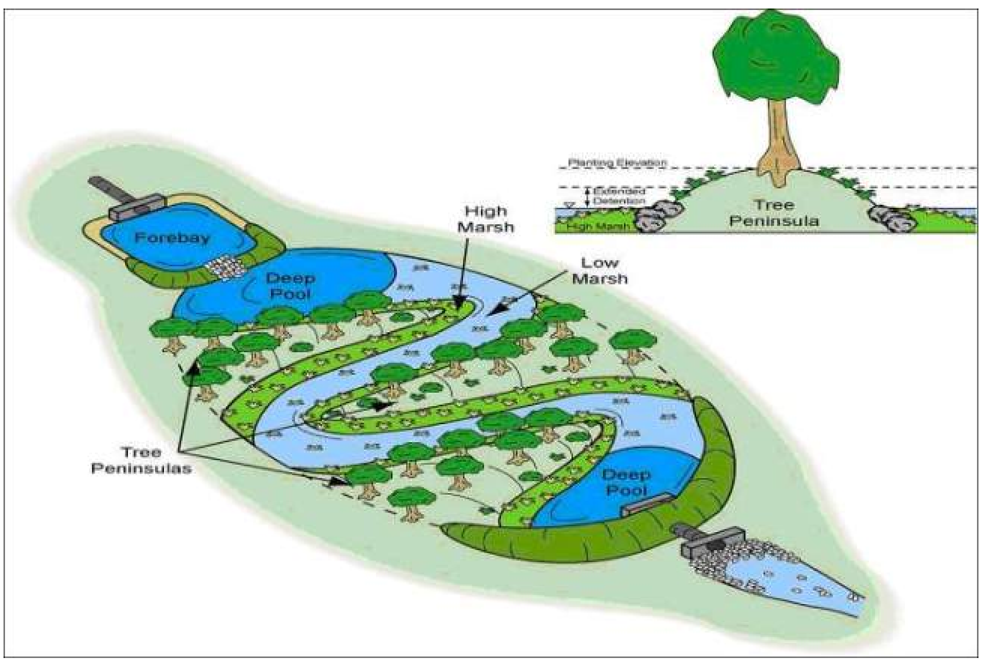
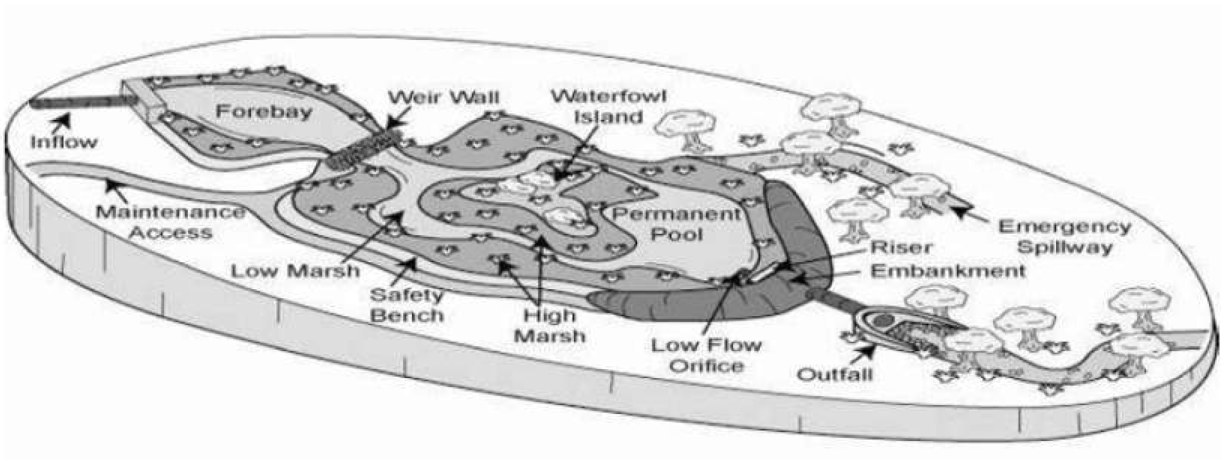
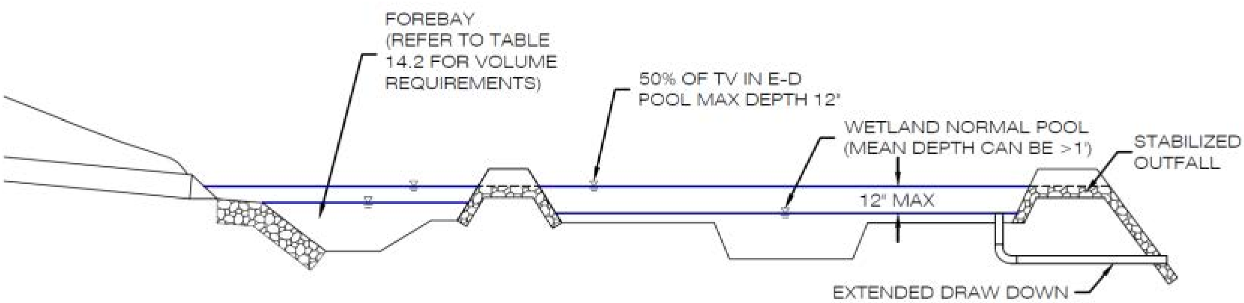


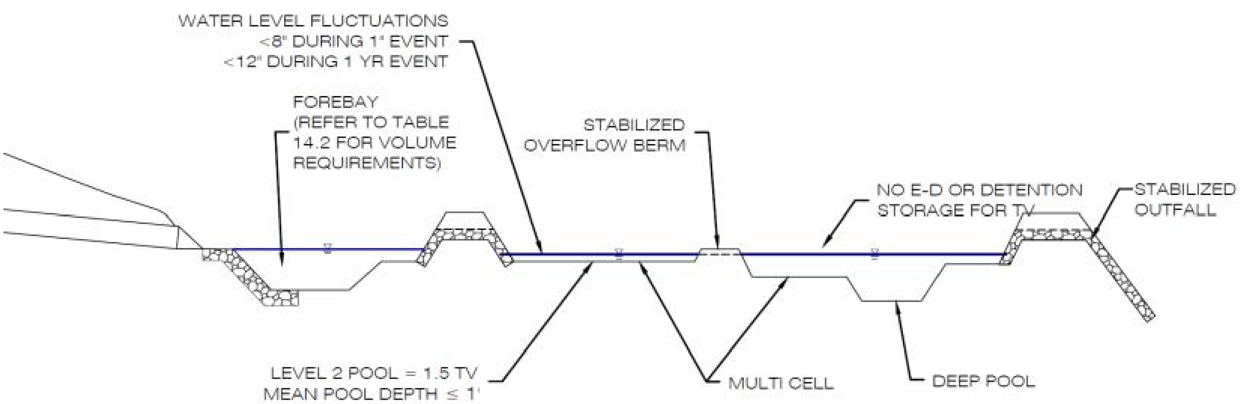
Figure 13.2. Mixed Wetland (Emergent and Forested) Basin



Plan View



Typical Cross-Section Level 1



Typical Cross Section Level 2

Figure 13.3. Plan and Cross-Sections of Constructed Wetland Level I and Level 2 Configurations

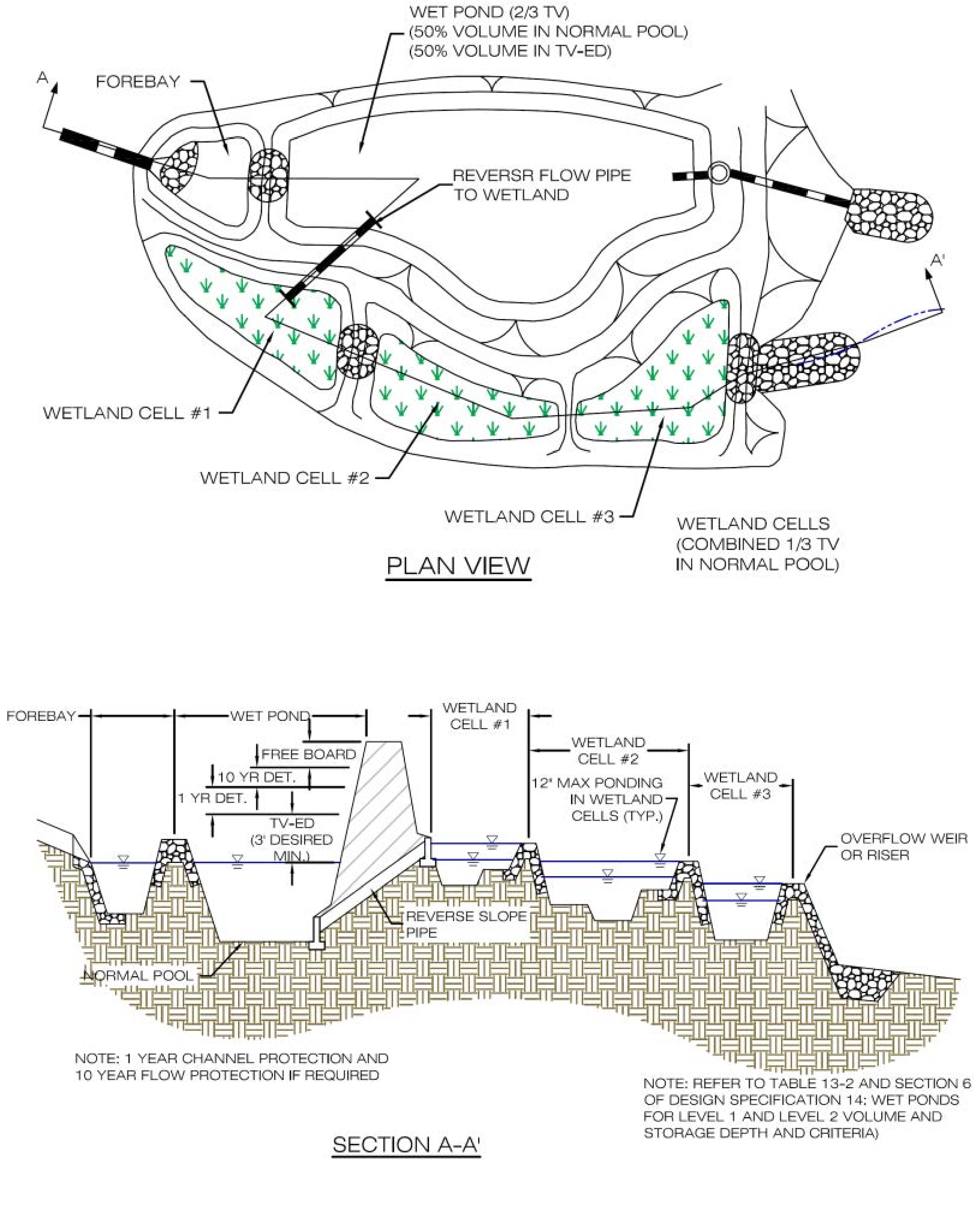


Figure 13.4. Pond-Wetland Combination – Plan and Section

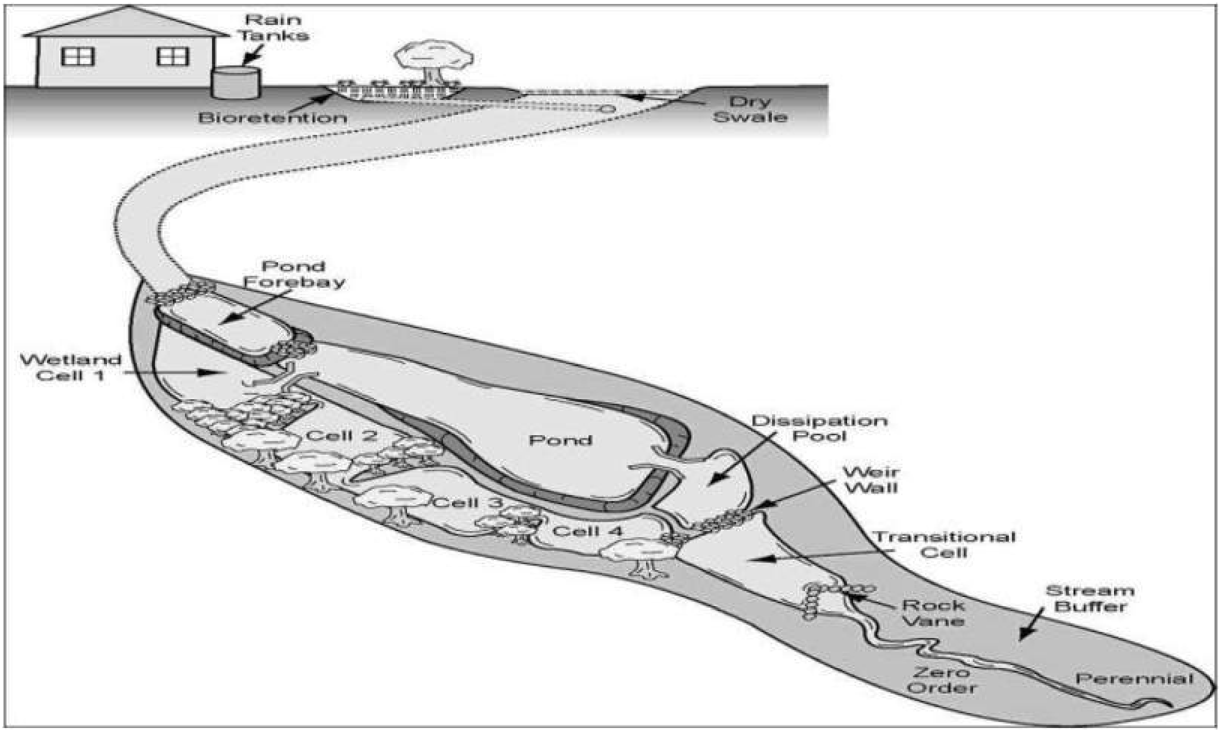


Figure 13.5. Pond-Wetland Combination

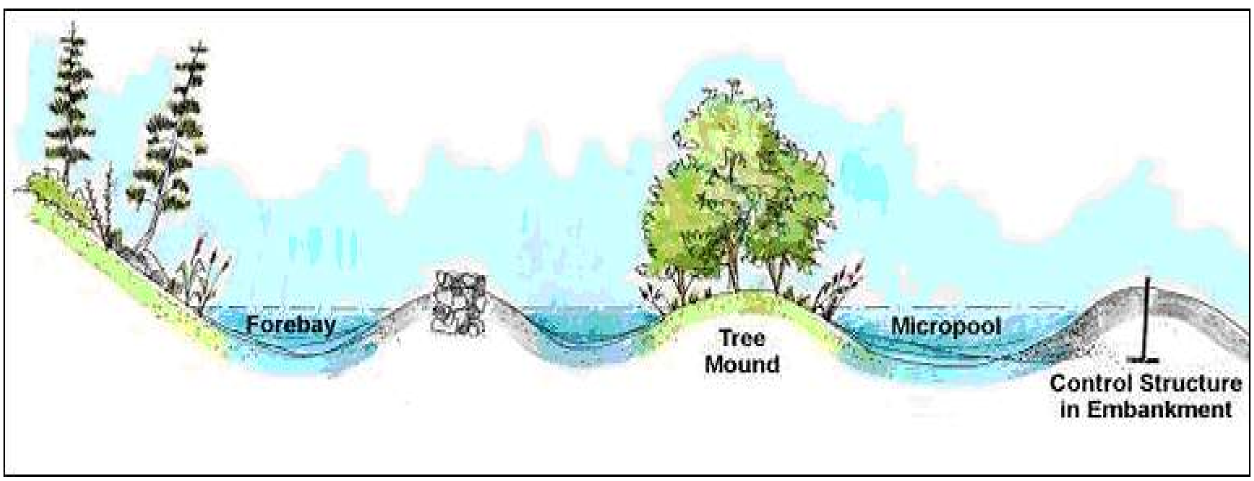


Figure 13.6. Cross Section of Linear Wetland Cell

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Constructed wetland designs are subject to the following site constraints.

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 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.

Space Requirements. Constructed 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.

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 typically 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 bring stormwater down steeper grades through a series of step pools. This can serve to bring stormwater down the coastal plain outfalls where steep drops on the edge of the tidal receiving system can create design challenges. Refer to Section 7: Regional and Special Case Design Adaptations.

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 constructed 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 private wells.

Depth to Water Table. 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.

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.

Use of or Discharges to Natural Wetlands. It can be tempting to construct a stormwater wetland *within* an existing natural wetland, but ***this should never be done 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. Constructed 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, but designers should check with their wetland regulatory authorities to ensure this is 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 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 (1-year) ponding is allowed above the wetland pool. However, the storage depth for the T_v and channel protection above the pool is limited to 12 inches (the T_v extended detention and 1-year storm detention is inclusive – not additive). Constructed wetland basins can be used at the terminus of a storm drain pipe or open channel (usually after upland opportunities for runoff reduction have also been applied). They generally follow the design criteria in **Section 6** of this specification.

Multi-Cell Wetland and *multi-cell pond/wetland combination* systems (Level 2 designs) are effective in moderately- to highly-urban areas where space is a premium and providing adequate surface area or grade drop is difficult. The Level 2 design options do not include any Treatment Volume (extended detention) storage or channel protection (detention) storage above the wetland cell pools. The critical design factor is the depth of temporary ponding allowed above the wetland cell pools to pass the larger design storms or if the wetland cell pools are hydraulically connected to the pond cell. A preferred design is illustrated in **Figure 13.4** and **13.5** 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***.

The *Pond/Wetland* combination design involves a wet pond cell in parallel or series with constructed wetland cells designed 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, as described in the following bulleted information:

- The wet pond cell can be sized to store up to two-thirds of the Treatment Volume through a permanent pool and temporary detention. Refer to **Section 6** for detention storage design criteria. The wet pond cell will have variable water levels, but should be designed to have a minimum extended detention draw-down pool depth of 3 feet (if possible) to provide a steady supply of flow to the wetland cells).
- 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 (e.g., the channel protection and flood control design storms).
- The Pond/Wetland combination will typically include ED storage for the TV and possibly the channel protection and flooding volume within the wet pond cell. The wet pond cell ED discharge can be directed into the wetland cell (while managing the flow in the wetland cell with a maximum 12 inch ponding depth) and the larger storm discharge directed to the downstream conveyance system. The discharge from the pond cell to the wetland cell 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.
- ***No detention or extended detention is allowed within the wetland cell*** in order to prevent frequent water level fluctuations from reducing the diversity and function of wetland cover. Refer to **Section 6** for additional details.
- The wetland should be divided into sub-cells to cascade down the grade differential. 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 95% of the wetland width), stabilized as needed based on the design flow and velocity. The vegetative target is to ultimately achieve a 50-50 mix of emergent and forested wetland vegetation within all four cells.

SECTION 6: DESIGN CRITERIA

6.1. Sizing of Constructed Wetlands

Constructed wetlands should be designed to capture and treat the remaining Treatment Volume (T_v), and the channel protection volume (if needed) discharged from the upstream runoff reduction practices, using the accepted local or state calculation methods.

To qualify for the higher nutrient reduction rates associated with the Level 2 design, constructed wetlands must be designed with a Treatment Volume that is 50% greater than the T_v 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. Runoff Treatment Volume credit can be taken for the following:

Constructed Wetland Basin – Level 1 design:

- The entire water volume below the normal pool (including deep pools);
- Extended detention (ED) up to 1 foot above the normal pool; and
- Any void storage within a submerged rock, sand or stone layer within the wetland.

Constructed Multi-Cell Wetland – Level 2 design (1.5 T_v):

- 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 T_v):

- The entire water volume below the normal pool of the wetland cells (including deep pools);
- Any void storage within a submerged rock, sand or stone layer within the wetland cells;
- Up to 2/3 of the total required Treatment Volume when provided in a separate pond cell as follows:
    - The permanent pool volume (a minimum of 50% or 1/3 of the total T_v); and
    - The extended detention storage above the pool (a maximum of 50% or 1/3 of the total T_v). Refer to Stormwater Design Specification 14 for design details for wet ponds.

6.2. 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 when it's CDA is less than 10 acres (Refer to Stormwater Design Specification No 14: Wet Pond).

Similarly, if the hydrology for the constructed wetland is not supplied by groundwater or dry weather flow inputs, a simple water balance calculation must be performed, using **Equation 13.1** (Hunt et al., 2007)**,** to assure the deep pools will not go completely dry during a 30 day summer drought.

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 ($CDA * R_v$)
	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. 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).

6.4. Pre-treatment Forebay

Sediment forebays are considered an integral design feature 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. 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. 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 constructed wetland's contributing drainage area.
- 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 **Equation 13.1**) 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 around the perimeter of the 4-foot depth area for safety purposes. The aquatic bench should be 4 to 6 feet wide at a depth of 1 to 2 feet below the water surface, transitioning to zero width at grade.
- The total volume of all forebays should be at least 15% of the total Treatment Volume. 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.

6.5. 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 Treatment Volume 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.

6.6. 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 ~~a~~ 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, 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). When a Level 2 design is selected, the 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 (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 as sheetflow 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.

ED and Detention Ponding Depth. Where a stormwater wetland (Level 1 design) incorporates ED as a part of the T_v, the ED volume may not extend more than 1 vertical foot above the normal pool elevation. Similarly, if channel protection detention storage is provided, the total ED and detention depth must not exceed 1 foot (the T_v ED and 1-year storm detention is inclusive, not additive).

Where a Level 2 design Multi-Cell Wetland or Pond/Multi-Cell Wetland Combination is used, the ED and detention storage limits are as follows:

- Multi-Cell Wetlands (Level 2 designs) must be designed so that the T_v water level fluctuation is limited to 6 to 8 inches during the maximum water quality storm (i.e., a 1-inch rainfall event).
- The maximum water level fluctuation during the channel protection (1-year) storm 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, or designing an upstream diversion structure to bypass the larger storms.
- The detention storage depth for the T_v and channel protection design may be up to 5 ft above the wet pond cell permanent pool.

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 Treatment Volume must 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 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 *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.

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.

6.7. Micro-Topographic Features

Stormwater wetlands must have internal structures that create variable micro-topography, which 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 extended detention zone, formed by coir fiber logs.
- Inverted root wads or large woody debris.
- Gravel diaphragm layers within high marsh zones.
- Cobble sand weirs (see Stormwater Design Specification No. 11: Wet Swales, for standard details).
- Additional deeper pools.

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).

6.9. Wetland Landscaping Plan

An initial wetland landscaping 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. 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 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 constructed 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 13.3** provides a list of common native shrub and tree species and **Table 13.4** 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 13.5**). 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 13.3 and 13.4** 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
  - **Zone 2**: -6 inches to the normal pool elevation)
  - **Zone 3**: From the normal pool elevation to + 12 inches above it)
  - **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 13.4**). 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 13.3. 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			

Table 13.4. 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 colonizer; high pollutant removal

Plant	Zone	Form	Inundation Tolerance	Wildlife Value	Notes
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)					

- ***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. 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-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 karst terrain to assess this risk during the project planning stage. If constructed wetlands are employed in karst terrain, the designer must:

- Employ an impermeable liner that meets the requirements outlined in **Table 13.6**.
- Maintain at least 3 feet of vertical separation from the underlying karst layer.
- Shallow, linear and multiple cell wetland configurations are preferred.
- Deeper basin configurations, such as the pond/wetland system and the ED wetland have limited application in karst terrain.

Table 13.6. 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 Stormwater Management Handbook, 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 Treatment Volume, 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 Spillway Pipe.

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 (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 ~~of~~ 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 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 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 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 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 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 17: 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 17: 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)

A construction phase inspection checklist for Constructed Wetlands can be accessed at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement must be executed between the owner and the local program. 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.

It is also recommended that the maintenance agreement include a list of qualified contractors that can perform inspection or maintenance services, as well as 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. The CWP *Pond and Wetland Maintenance Guidebook* (2004) provides some excellent templates of how to respond to these problems.

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. Inspections and Ongoing Maintenance

Ideally, 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) or at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

A more detailed maintenance inspection form is also available from Appendix B of CWP's *Stormwater Pond and Wetland Maintenance Guidebook* (2004).

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.

9.4. Non-Routine Maintenance

Sediment Removal. Frequent sediment removal from the forebay is essential to maintain the function and performance of a constructed wetland. Maintenance plans should schedule cleanouts approximately every 5 years, or when inspections indicate that 50% of the forebay sediment storage capacity has been filled. 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.

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.

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 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).

SECTION 11: REFERENCES

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