Constructed Stormwater Wetland

Practice Description

Stormwater wetlands provide an efficient biological method for removing a wide variety of pollutants (e.g. suspended solids, nutrients (nitrogen, N, and phosphorus, P), heavy metals, toxic organic pollutants, and petroleum compounds) in a managed environment.

Compared with wet ponds, sand filters, bioretention areas, and other stormwater BMPs, wetlands have the best median removal rate for total suspended solids (TSS), nitrate-nitrogen, ammonia-nitrogen, total phosphorus (TN), phosphate-phosphorus, and some metals. Stormwater wetlands can also be used to reduce pollution associated with high levels of fecal coliform and other pathogen contamination. Wetlands temporarily store stormwater runoff in shallow pools that support emergent and riparian vegetation. The storage, complex microtopography, and vegetative community in stormwater wetlands combine to form an ideal matrix for the removal of many pollutants. Stormwater wetlands can also effectively reduce peak runoff rates and stabilize flow to adjacent natural wetlands and streams.

Wetlands are effective sedimentation devices and provide conditions that facilitate the chemical and biological processes that cleanse water. Pollutants are taken up and transformed by plants and microbes, immobilized in sediment, and released in reduced concentrations in the wetland's outflow, as shown in Figure 1.

Plants improve water quality by slowing water flow and settling solids, transforming or immobilizing pollutants, and supplying reduced carbon and attachment area for microbes (bacteria and fungi). Dense strands of vegetation create the quiescent conditions that facilitate the physical, chemical, and biological processes that cleanse the stormwater. Many herbaceous wetland plants die annually. Because the dead plant material requires months or years to decompose, a dense layer of plant litter accumulates in the wetland. Like the living vegetation, the litter creates a substrate that supports bacterial growth and physically traps solids.

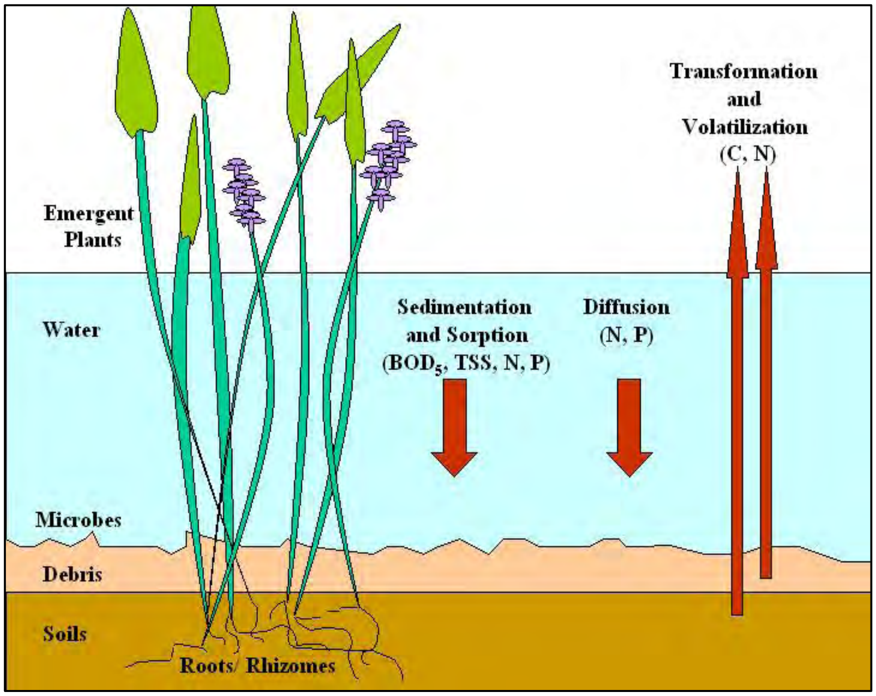

Figure 1 Wetland Microbes, Plants and Soil Transform and Take up Pollutants from Stormwater

Microorganisms, adhering to vegetation, roots, and sediment in the wetland, can decompose organic compounds and convert significant quantities of nitrate directly to nitrogen gas. Large amounts of nitrogen and phosphorus also can be incorporated in new soil and in the extra biomass of the wetland vegetation. Transformations can take place through both aerobic and anaerobic processes. For these reasons, maintaining the health of the vegetative community is critical for effective pollutant removal.

The ability of the emergent plants to settle and stabilize suspended solids in sediments and to reduce resuspension is important. The settling characteristic allows the wetland to remove pollutants such as phosphorus, trace metals, and hydrocarbons that are typically adsorbed to the surfaces of suspended particles.

Long-term data from stormwater wetlands indicate that treatment performance for parameters such as 5-day biochemical oxygen demand (BOD5), TSS, and TN typically does not deteriorate over the life of a stormwater wetland. The dissolved oxygen (DO) concentration in wetland outflows may be below 1.0 mg/L. Higher DO concentrations can be achieved by incorporating aeration techniques such as turbulent or cascading discharge zones, or mechanical mixing.

Planning Considerations

Stormwater wetlands occupy somewhat more surface area than a wet detention pond, but have the potential to be better integrated aesthetically into a site design because of the abundance of aquatic vegetation. Stormwater wetlands require a drainage area sufficiently large, or adequate groundwater or surface water supplies, to provide year-round hydration. In sloping terrain, wetland cells can be arranged in series on terraces.

Stormwater wetlands are appropriately located at the lower parts of the development site. Careful planning is needed to be sure that sufficient water will be retained to sustain good wetland plant growth. Since water depths are shallower than in wet detention ponds, water loss by evaporation is an important concern.

Stormwater wetlands are designed in such a way that the distance the water flows from the entrance to the exit is maximized. This allows for sufficient contact time for pollutant removal.

Design Criteria

Converting Erosion- and Sediment-Control Devices

Often, the same basin can be used during construction as a sediment- and erosion-control device and later converted to a stormwater wetland. Before conversion, all accumulated sediment must be removed and properly disposed of; then, the appropriate modifications to the basin depth, geometry, and hydrology, as well as inlet and outlet structures, etc., must be made.

Siting Considerations

In addition to the restrictions and modifications to adapting stormwater wetlands to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question. The following section provides basic guidelines for siting wetlands.

Drainage Area

Wetlands need sufficient drainage area to maintain the permanent pool. In humid regions, this is typically about 25 acres, but a greater area may be needed in regions with less rainfall.

Slope

Wetlands can be used on sites with an upstream slope of up to about 15 percent. The local slope should be relatively shallow, however. While there is no minimum slope requirement, there does need to be enough elevation drop from the inlet to the outlet to ensure that hydraulic conveyance by gravity is feasible (generally about 3 to 5 feet).

Soils/Topography

Wetlands can be used in almost all soils and geology.

Nutrient Reduction

The wetland substrate contains a mixture of sediment, plants, water, and detritus that collectively remove multiple pollutants through a series of complementary physical, chemical, and biological processes. Stormwater wetlands are effective at reducing TSS, TN, and TP.

Some wetlands can be constructed as a pond/wetland system. In these cases, part of the BMP is a pond and part of it is a wetland. These systems are slightly less effective at nitrogen removal than wetland-only designs. In some cases, the pond/wetland systems provide additional benefits that warrant a less effective nitrogen removal BMP and therefore should be considered based on the priority of pollutant removal.

Design Considerations

Design is a six-step process:

1) Understand basic layout concepts
2) Determine the volume of water to treat
3) Determine surface area and depth of each wetland zone
4) Select the soil media type
5) Select the appropriate outlet structure
6) Select plants

Step 1: Understand Basic Layout Concepts

Stormwater Wetland Components

Stormwater wetlands consist of six primary components. Figure 2 provides a conceptual diagram, and brief descriptions are given below.

1. **Inlet**: This is where water enters the wetland. The inlet can be a swale, a pipe, a diverter box, sheet flow, or other method of transporting water to the wetland.

2. **Deep Pool:** This zone consists of permanent deep pools of water that retain water even during drought. Deep pools in a stormwater wetland are one of two types:

a. *Forebay:* The forebay is a deep pool that directly follows the inlet provides two important functions: (1) dissipates runoff velocity and energy and (2) collects gross solids and sediment to ease maintenance of the BMP. The forebay essentially acts as a pretreatment device for the stormwater wetland. The water flows out of the forebay and into the wetland. The entrance to the forebay is deeper than the exit of the forebay. This design will dissipate the energy of the water entering the system, and will also ensure that large solids settle out.

b. *Non-Forebay Deep Pools*: Other deep pools in the wetland are always full of water and are areas where rooted plants do not live. Submerged and floating plants may be used in this area, except around the wetland outlet device. The deep pool at the outlet should be non-vegetated to prevent clogging. Deep pools provide additional pollutant removal and storage volume as well as habitat for aquatic wildlife such as the mosquito-eating fish. Include a deep pool next to the outlet structure to allow for proper drawdown.

3. **Shallow water, “low marsh”**: Shallow water includes all areas inundated by the permanent pool to a depth of 3″-6″ with occasional drying during periods of drought. The shallow water zone provides a constant hydraulic connection between the inlet and outlet structure of the stormwater wetland. The top of the shallow water zone represents the top of the permanent pool elevation (PPE). Herbaceous plants, listed in Table 1, are recommended for this area because they are more efficient in the pollutant removal process and less likely to encourage mosquito growth.

4. **Shallow land, “high marsh” or “temporary inundation zone”**: This zone provides the temporary storage volume of the stormwater wetland. The top of the shallow land zone represents the top of the temporary pool elevation (TPE). The shallow land is wet only after a rain event, and rooted plants live in this zone. (See Table 1 at the end of this section for plant selection.) Shallow land in a wetland provides pollutant uptake, shade, and wildlife habitat and should be planted with vegetation able withstand irregular inundation and occasional drought.

5. **Upland**: These areas are never wet, are not a required element of wetland design, and can be eliminated if space is of concern. They may serve as an amenity or provide access for maintenance. Some wetlands have upland areas as an island in the center of the wetland.

6. **Outlet**: The outlet structure consists of a drawdown orifice placed at the top of the shallow water elevation so that stormwater accumulating in the shallow land area will be able to slowly draw down from the wetland. The outlet structure may also be designed to pass larger storm events, which will have a higher flow outlet at the proper elevation.

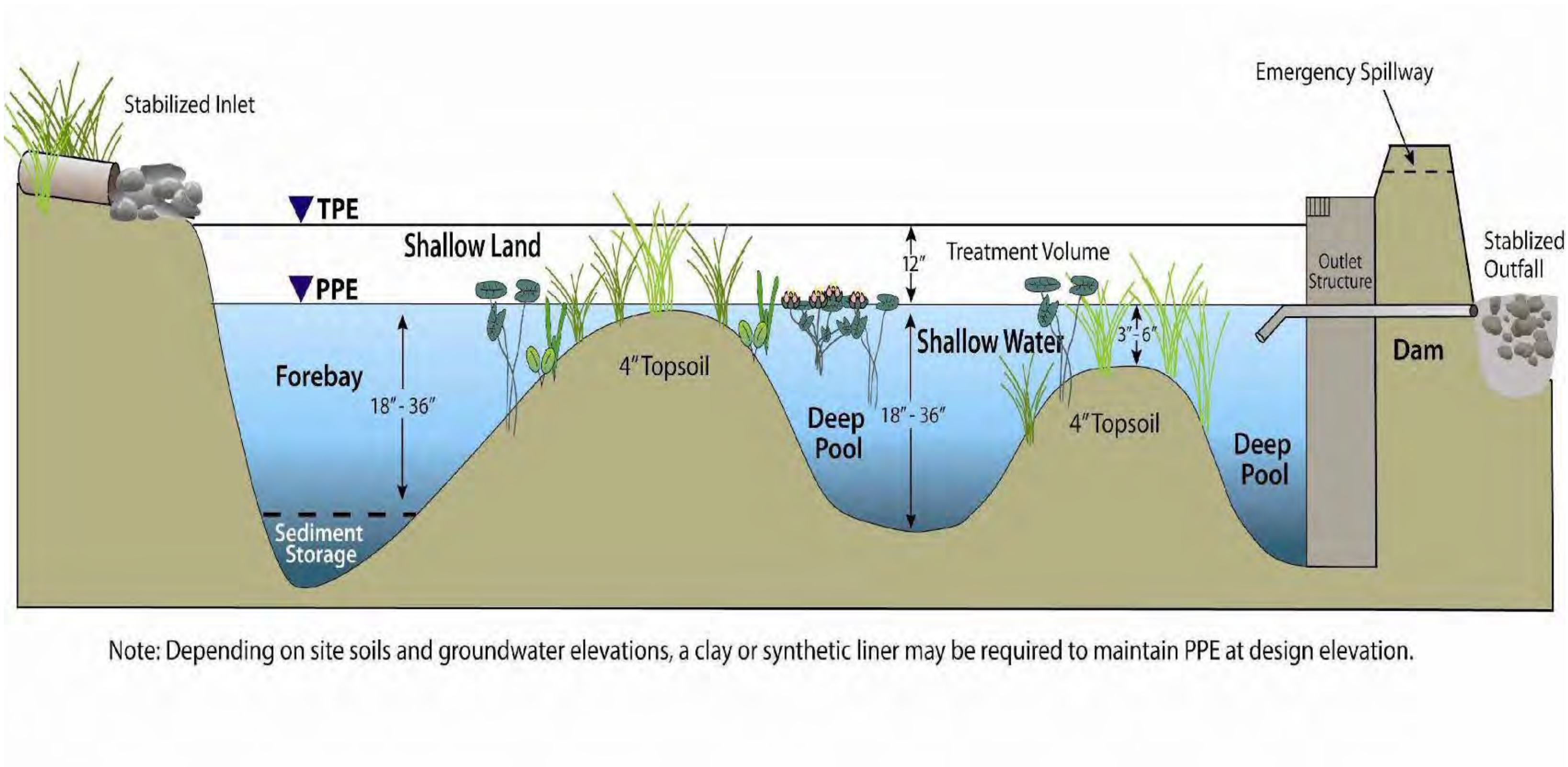

Figure 2 Constructed Stormwater Wetland Conceptual Diagram

Step 2: Determine the Volume of Water to Treat

Water Treatment Volume

A wetland is intended to treat the first flush (1″-1.5″) of a particular design storm. The Simple Method in Appendix A details the volumetric calculation.

Contributing Drainage

There is no minimum or maximum for the drainage area. Instead, any drainage area that contributes a minimum volume of 3,630 cubic feet is allowed. Smaller volumes will be allowed on a case-by-case basis, though supporting calculations such as a water balance or other justification will be required.

Siting Issues

Stormwater wetlands should not be located within existing jurisdictional wetlands or constructed as in-stream impoundments. If there are industrial or commercial land uses in the drainage area, accumulated pollutants may eventually increase environmental risk to wildlife (such as algae blooms). Typical pollutant loads found in residential and commercial settings are unlikely to cause this problem.

Pretreatment Options

Wetlands and pond/wetland systems require the use of a forebay for pretreatment.

Step 3: Determine Surface Area and Depth of Each Wetland Zone

Flow paths from inlet to outlet points within stormwater wetlands should be maximized. Internal berms and irregular shapes are often used to achieve recommended flow paths. The minimum length-to-width ratio shall be 1.5:1; however, 3:1 is highly recommended. Narrow, deep-water zones should be constructed at the wetland inlet and outlet to evenly distribute flow. Inlets also may incorporate pipe manifolds to enhance flow distribution. Deep-water zones perpendicular to the flow direction, and internal berms parallel to the flow, can also be used to reduce the potential for short-circuiting.

The total surface area of the deep-pool topographic zone should be broken into several micropools that are well dispersed throughout the wetland so that the distance for fish to travel within the shallow water zone to reach the entire wetland is minimized. One deep pool should be located at the entrance of the wetland, and one should be located at the exit. Other deep pools can be dispersed throughout the wetland.

The geometric calculations for wetlands are provided below. As opposed to many other types of BMP designs, the permanent volume of water contained in the stormwater wetland is not part of the design calculations, but is merely a result of the breakdown of natural or engineered hydrologic zones and their respective depths.

a. <u>Determine Required Surface Area of Entire Wetland and Each Wetland Zone</u>:

Two factors determine the surface area:

1) The watershed runoff volume that is to be contained (Q_{Volume}), and

2) The depth of water that plants can sustain for several days in the shallow land area (D_{Plants}), the depth of the temporary pool, up to 12 inches (Hunt and Doll, 2000).

The total surface area of the wetland is determined by the quotient of these variables. The surface area of each wetland zone is a percentage of the total required surface area.

Calculations for determining the surface areas of the various wetland zones are provided below.

• *Surface Area*: The total surface area of the wetland is

$$\frac{Q_{Volume}(ft^3)}{D_{Plants}(ft)} = \_\_\_ \text{ (SF)}$$

(Note: D_{Plants} can be up to 12 inches.) This surface area, in square feet (SF), is distributed to the various wetland zones as outlined below:

- Deep Pools: Ideally, several deep pools should be provided throughout the wetland.
  - Non-Forebay: 5-10% of wetland surface
  - Forebay: 10% of wetland surface
- Shallow Water (low marsh): 40% of wetland surface.
- Shallow Land (high marsh): 30-40% of wetland surface (maximize if pathogens are target pollutant).
- Upland: This is an optional design element. If upland area is included, it will not replace any of the required calculated surface area.

b. Design Depth of Each Wetland Zone: Determine the appropriate depth for each wetland zone. The following depths are recommended for each wetland zone as illustrated in Figure 2:

- Deep Pools:
  - Non-Forebay: 18-36" (include one at the outlet structure for proper drawdown).
  - Forebay: 18-36" plus additional depth for sediment accumulation (deepest near inlet to dissipate energy, more shallow near the exit).
- Shallow Water (low marsh): 3-6". A primary cause of wetland failure is designing this layer to be too deep.
- Shallow Land (high marsh): Up to 12". This is the depth, D_{Plants}, used in the surface area calculation, and is also the depth of the temporary pool.
- Upland: Up to 4 feet above the shallow land zone.

c. Double Check the Volume: Ensure that the volume of the shallow land section can accommodate the treatment volume necessary for the wetland (as was calculated in Step 2). The shallow land zone acts as the temporary pool and contains the treatment volume after a rain event.

Step 4: Select the Soil Media Type

A soil analysis should be conducted within the stormwater facility area to determine the viability of soils to ensure healthy vegetation growth and to provide adequate infiltration rates through the topsoil. For wetlands designed to utilize a clay or synthetic liner, at least four (4) inches of quality topsoil shall be added to the top of the liner to support plant growth. Imported or in situ soils may be amended with organic material, depending on soil analysis results, to enhance suitability as a planting media.

Step 5: Select the Appropriate Outlet Structure

The outlet design must be accessible to operators, easy to maintain, and resistant to fouling by floating or submerged plant material or debris. Wetlands should have both low- and high-capacity outlets. High-capacity outlets, such as weir boxes or broadcrested spillways, should be provided unless bypasses are provided for storms in excess of the first flush volume. The low-capacity outlet is typically a drawdown orifice and should be able to draw down the temporary pool within 2-5 days. Multiple-outlet structures are often used to balance the volume control requirements and maintenance needs. Additionally, designers can choose to install manual drawdown valves or flashboard risers (also called sliding weir plates) so that maintenance personnel can drain the wetland for maintenance purposes. If installed, drawdown valves should be secured so that only intended personnel can access them. Also, trash racks are recommended on the outlet structure to keep floating plants from clogging the outlet.

An ideal outlet structure should contain the following features:

- High-capacity weir box overflow;
- Low-capacity drawdown sized to draw down the temporary pool (shallow land zone) in 2-5 days; and
- Easy accessibility for operation and maintenance.

Overflow Structure Maintenance Considerations

Stormwater wetland maintenance must be considered when designing outlet structures. Occasionally, wetlands may require complete drawdown. The structures in Figure 3 show the low-capacity drawdown orifice, the high-capacity overflow, and a manually operated valve for maintenance purposes. Alternatively, a flashboard riser can be used to draw water down for maintenance, as shown in Figure 4.

Figure 3 Outlet Structures with Manual Drawdown Valve for Maintenance

Figure 4 Outlet Structure with Flashboard Riser for Maintenance (Photos Courtesy of NC State Science House & BAE)

One method to help ensure that the drawdown orifice does not clog is to turn the orifice downward below the normal pool as shown in Figure 5. This prevents floating debris or vegetation from clogging the orifice. The site in Figure 5 has been drained for maintenance.

Figure 5 Outlet Structure with Down-Turned Drawdown Orifice

The overflow structure should be located near the edge of the wetland so that it can be accessed easily for maintenance, as shown in Figure 6.

Figure 4 Outlet Structure Near Wetland Edge, Orifice Easily Accessible for Maintenance

Overflow structures that are several feet into the wetland, as shown in Figure 7, are difficult to reach and likely will not be maintained.

Figure 5 Outlet Structure Not Near Wetland Edge, Orifice *Not* Easily Accessible for Maintenance

Step 6: Select Plants

High pollutant-removal efficiencies in a stormwater wetland depend on a dense cover of emergent plant vegetation. Although various plant types differ in their abilities to remove pollutants from the water column, in general, the specific plant species do not appear to be as important for stormwater wetland functioning as plant growth survival and plant densities (Kadlex and Knight, 1996). In particular, species should be used that have high colonization and growth rates, can establish large areas that continue through the winter dormant season, have a high potential for pollutant removal, and are very robust in continuously or periodically flooded environments. Non-invasive species should be used. Native species are preferred.

Shrubs and wetland plants should be designed to minimize solar exposure of open water areas. A landscape plan should be prepared by a qualified design professional that outlines the methods to be used for maintaining wetland plant coverage.

A stormwater wetland facility consists of the area of the wetland, including bottom and side slopes, plus maintenance/access buffers around the wetland. Minimum elements of a stormwater wetland landscape plan include:

- Delineation of planting (pondscaping) zones;
- Selection of corresponding plant species;
- A minimum of ten (10) different species total, of which at least five (5) are emergent species, with no more than 30% of a single species;
- Buffers are recommended as centipede grass;
- Minimum plant quantities and sizes per 200 ft^2 of shallow water area: 50 herbaceous plants of at least 4-cubicinch container (equivalent to 2 ft on center minimum; 1.5 ft on center recommended)
- Minimum plant quantities and plant sizes per 200 ft^2 of shallow land area:

  50 herbaceous plants of at least 4-cubic inch container, OR

  8 shrubs of at least 1-gallon container (equivalent to 5 ft on center minimum; 3 ft on center recommended), OR

  1 tree of at least 3-gallon container and 40 grass-like herbaceous plants of at least 4-cubic inch container
- Source of plant materials (wetland seed mixes are not allowed);
- Planting layout;
- Sequence and timing for preparing wetland bed (including soil amendments, initial fertilization, and watering, as needed);
- Growing medium specifications (soil specifications); and
- Specification of supplementary plantings to replenish losses.

Soil bioengineering techniques, such as the use of fascines, stumps or logs, and coconut fiber rolls, can be used to create shallow land cells in areas of the stormwater wetland that may be subject to high flow velocities. The landscape plan should also provide elements that promote greater wildlife and waterfowl use within the wetland and buffers, as well as aesthetic considerations.

Five (5) or more species of emergent wetland plants should be selected in order to optimize treatment processes as well as to promote ecological mosquito control (i.e., attract a variety of predator insects for natural mosquito control). Use of trees and shrubs should be limited if mosquitoes are of concern, and these are best planted around the perimeter of the wetland. Cattails shall not be planted, as they can quickly take over and choke out other plants in the wetland, which will limit biodiversity and ultimately lead to mosquito infestation.

Plant recommendations are listed in Table 1. The listing of plant species is not exhaustive, and additional wetland plant species may be suitable that are not shown below. There are many excellent plant references in publication as well as recommendations from wetland scientists and landscape architects.

Table 1: Wetland Plant Recommendations

DEEP POOL

Botanical Name	**Common Name**
Floating Aquatic Plants	
Lemna spp.	Duckweed
Nelumbo lutea	American lotus
Nuphar lutea ssp. *polysepala*	Rocky Mtn Pond-lily
Nuphar lutea ssp. *advena*	Yellow Pond-lily
Submerged Aquatic Plants	
Eleocharis acicularis	Needle spikerush
Eleocharis quadrangulata	Squarestem spikerush
Elodea canadensis	Canadian waterweed
Elodea nuttallii	Western waterweed

SHALLOW WATER

Botanical Name	**Common Name**
Herbaceous Plants	
Acorus subcordatum	Sweetflag
Alisma subcordatum	Water plantain
Hydrolea quadrivalvis	Waterpod
Iris virginica	Blue flag iris
Juncus effusus var. pylaei or solutus	Soft rush
Ludwigia spp.	Primrose willow
Peltandra virginica	Arrow arum
Pontederia cordata	Pickerelweed
Sagittaria latifolia	Duck Potato
Sagittaria lancifolia	Bulltongue
Saururus cernuus	Lizard’s tail
Schoenoplectus tabernaemontani	Soft stem bulrush
Schoenoplectus americanus	Three-square bulrush
Schoenoplectus pungens var. pungens	Common threesquare
Scirpus cyperinus	Woolgrass
Zizaniopsis miliacea	Giant cutgrass

SHALLOW LAND	
Botanical Name	**Common Name**
Herbaceous Plants	
Asclepias incarnata	Swamp Milkweed
Carex tenera	Quill sedge
Chelone glabra	White Turtlehead
Eupatoriadelphus dubius	Dwarf Joe Pye Weed
Eupatoriadelphus fistulosus	Joe Pye Weed
Eupatoriadelphus maculatus	Spotted trumpetweed
Hibiscus coccineus	Scarlet rose mallow
Hibiscus laevis	Halberdleaf rosemallow
Kosteletzkya virginica	Seashore Mallow
Lobelia cardinalis	Cardinal flower
Lobelia elongata	Longleaf lobelia
Lobelia siphilitica	Great blue Lobelia
Rhynchospora colorata	Starrush whitetop
Saccharum baldwinii	Narrow plumegrass
Shrubs	
Aronia arbutifolia	Red Chokeberry
Cephalanthus occidentalis	Common Buttonbush
Clethra alnifolia	Sweet pepperbush
Cornus amomum	Silky dogwood
Cyrilla racemiflora	TiTi
Gordonia lasianthus	Bushy St. Johnswort
Hypericum densiflorum	Possumhaw
Ilex deciduas	Inkberry
Ilex glabra	InkberryVirginia Sweetspire
Itea virginica	Swamp Rose
Rosa palustris	Creeping Blueberry
Vaccinium crassifolium	Possumhaw
Viburnum nudum var. nudum	Loblolly Bay

Design Variations

There are several variations of the wetland design. The designs are characterized by the volume of the wetland in deep pool, high marsh, and low marsh, and whether the design allows for detention of small storms above the wetland surface.

Shallow Marsh

In the shallow marsh design, most of the wetland volume is in the relatively shallow high marsh or low marsh depths. The only deep portions of the shallow wetland design are the forebay at the inlet to the wetland and the micropool at the outlet. One disadvantage to this design is that, since the pool is very shallow, a large amount of land is typically needed to store the water quality volume (i.e., the volume of runoff to be treated in the wetland).

Extended Detention Wetland

This design is the same as the shallow marsh, with additional storage above the surface of the marsh. Stormwater is temporarily ponded above the surface in the extended detention zone for 12 to 24 hours. This design can treat a greater volume of stormwater in a smaller space than the shallow wetland design. In the extended detention wetland option, plants that can tolerate wet and dry periods should be specified in the extended detention zone.

Pond/Wetland System

The pond/wetland system combines the wet pond design (see *Wet Pond Practice*) with a shallow marsh. Stormwater runoff flows through the wet pond and into the shallow marsh. Like the extended detention wetland, this design requires less surface area than the shallow marsh because some of the volume of the practice is in the relatively deep (i.e., 6-8 feet) pond.

Pocket Wetland

This design is very similar to the pocket pond (see *Wet Pond Practice*). In this design, the bottom of the wetland intersects the groundwater, which helps to maintain the permanent pool. Some evidence suggests that groundwater flows may reduce the overall effectiveness of stormwater-management practices (Brown and Schueler, 1997). This option may be used when there is not significant drainage area to maintain a permanent pool.

Gravel-Based Wetlands

In this design, runoff flows through a rock filter with wetland plants at the surface. Pollutants are removed through biological activity on the surface of the rocks and pollutant uptake by the plants. This practice is fundamentally different from other wetland designs because, while most wetland designs behave like wet ponds with differences in grading and landscaping, gravel-based wetlands are more similar to filtering systems.

Construction Considerations

The wetland must be stabilized within 14 days of construction. Consider construction sequencing so that vegetation can be planted and the wetland brought online within 14 days. Plants may need to be watered during this time if the device is not brought online the same day. Stabilization may be in the form of final vegetation plantings or a temporary means until the vegetation becomes established. A good temporary means of stabilization is a wet hydroseed mix. For rapid germination, scarify the soil to a half-inch prior to hydroseeding.

Inlet and outlet channels should be protected from scour that may occur during periods of high flow. Standard erosion-control measures should be used. *Volume 1 - Erosion and Sediment Control Manual* can provide information on erosion- and sediment-control techniques.

The stormwater wetland should be staked at the onset of the planting season. Water depths in the wetland should be measured to confirm the original planting zones. At this time, it may be necessary to modify the planting plan to reflect altered depths or the availability of wetland plant stock. Surveyed planting zones should be marked on an “as-built” or record design plan and located in the field using stakes or flags.

The wetland drain should be fully opened for no more than 3 days prior to the planting date (which should coincide with the delivery date for the wetland plant stock), to preserve soil moisture and workability.

The most common and reliable technique for establishing an emergent wetland community in a stormwater wetland is to transplant nursery stock obtained from local aquatic plant nurseries. The optimal period for transplanting extends from early April to mid-June so that the wetland plants will have a full growing season to build the root reserves needed to survive the winter. However, some species may be planted successfully in early fall. Contact your nursery well in advance of construction to ensure that they will have the desired species available.

Post-nursery care of wetland plants is very important in the interval between delivery of the plants and their subsequent installation because they are prone to desiccation. Stock should be frequently watered and shaded.

Safety Considerations

The permanent pool of water presents an attractive play area to children and thus may create safety problems. Engineering design features that discourage child access are recommended. Trash racks and other debris-control structures should be sized to prevent entry by children. Other safety considerations include using fences around the spillway structure, embankment, and stormwater wetland slopes; using shallow safety benches around the stormwater wetland; and posting warning signs.

Fencing of stormwater wetlands is not generally aesthetically pleasing but may be required by the local review authority. A preferred method is to engineer the contours of the stormwater wetland to eliminate drop-offs and other safety hazards as discussed above. Riser openings must restrict unauthorized access. Endwalls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent falls.

Common Problems

The landscape professional managing the wetland must understand the biological requirements of the plants and manage water levels appropriately to provide for their needs. For example, growing conditions are most critical during seed germination and early establishment. However, optimum conditions are not always required once the vegetated community becomes established.

Although wetland plants require water for growth and reproduction, they can be killed by drowning in excessively deep water. Usually, initial growth is best with transplanted plants in wet, well-aerated soil. Occasional inundation, followed by exposure of the majority of the vegetation to air, enables the plants to obtain oxygen and grow optimally. Conversely, frequent soil saturation is important for wetland plant survival.

If a minimum coverage of 70 percent is not achieved in the planted wetland zones after the second growing season, supplemental planting should be completed. Coverage of 90 to 95 percent is desirable.

Dramatic shifts can occur as plant succession proceeds. The plant community reflects management and can indicate problems or the results of improvements. For example, a requirement of submerged aquatic plants, such as pondweed (*Potamogeton* spp.), is light penetration into the water column. The disappearance of these plants may indicate inadequate water clarity. The appearance of invasive species or development of a monoculture is also a sign of a problem with the aquatic/soil/vegetative requirements. For instance, many invasive species can quickly spread and take over a wetland. If cattails become invasive, they can be removed by a licensed aquatic pesticide applicator by wiping aquatic glyphosate, a systemic herbicide, on the cattails.

Unlike maintenance requirements for wet or dry stormwater ponds, sediment should only be selectively removed from stormwater wetlands, primarily from the forebay. Sediment removal disturbs stable vegetation cover and disrupts flow paths through the wetland. The top few inches of sediment should be stockpiled so that it can be replaced over the surface of the wetland after the completion of sediment removal to re-establish the vegetative cover using its own seed bank. Accumulated sediment should be removed from around inlet and outlet structures.

Maintenance

- Immediately following construction of the stormwater wetland, bi-weekly inspections will be conducted and wetland plants will be watered bi-weekly until vegetation becomes established (commonly six weeks).
- No portion of the stormwater wetland will be fertilized after the first initial fertilization that is required to establish the wetland plants.
- Stable groundcover will be maintained in the drainage area to reduce the sediment load to the wetland.
- Once a year, a dam safety expert should inspect the embankment.