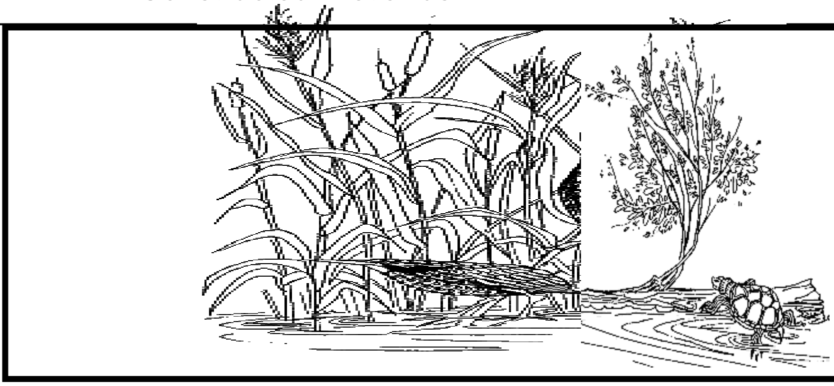
ACTIVITY: Constructed Wetlands

W – 01



Targeted Constituents				
● Significant Benefit	◗ Partial Benefit	○ Low or Unknown Benefit		
◗ Sediment	◗ Heavy Metals	◗ Floatable Materials	◗ Oxygen Demanding Substances	
◗ Nutrients	◗ Toxic Materials	◗ Oil & Grease	◗ Bacteria & Viruses	○ Construction Wastes

Implementation Requirements			
● High	◗ Medium	○ Low	
● Capital Costs	◗ O & M Costs	● Maintenance	◗ Training

Description

Constructed wetlands, or man-made marshes, may be used as a method of stormwater treatment if designed and applied correctly, and are highly desirable as wildlife habitats. Under ideal conditions, a constructed stormwater wetland can be very efficient in removing pollutants through gravitational settling, wetland plant uptake, absorption, physical filtration, and biological decomposition. The pollutant removal efficiency of a constructed wetland is dependent on various design criteria relating to the size and design of the pool area. Other site specific design features and variations in environmental conditions such as soils, climate, hydrology, etc. make it difficult to predict the actual pollutant removal efficiency. Monitoring of many stormwater wetland facilities has confirmed the wide range of pollutant removal efficiencies associated with such systems. Constructed wetlands should be used in conjunction with another BMP until firmly established and pollutant efficiency is verified. This practice is likely to provide significant reductions in most targeted constituents but may not be as reliable as other types of stormwater treatment.

Selection Criteria

The following conditions are ideal locations for constructed wetlands:

- Small outfalls for which adequate water and soil conditions will allow the establishment and permanent growth of wetland vegetation.
- Large industrial and commercial project sites with ample space, for which adequate water and soil conditions will allow the establishment and permanent growth of wetland vegetation.
- Near greenways, parks, landscaping, recreational areas or other aesthetic locations.

Both low- and high-visibility sites are suitable for constructed wetlands. However, the aesthetic problems associated with having a natural and free growing landscape feature in an otherwise manicured development setting should be avoided for high-visibility sites. Additional concerns regarding stagnation or excessive infiltration during the dry summer months may also influence the choice of location. Proper planning, design, and maintenance are critical to ensure the pollutant removal capabilities of a constructed wetland and to insure its acceptance by adjacent landowners.

Design and Sizing Considerations

The regulatory definition of a wetland is an area that is inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions, such as a swamp, marsh, bog or vernal spring.

Natural wetlands are protected and permitted by the Tennessee Department of Conservation in conjunction with the U.S. Army Corps of Engineers. Wetlands can be identified through the presence of certain plants, soil types, insects, etc., in addition to the presence of water or poor drainage. Wetlands may be seasonal, so that it can be very difficult to recognize a wetland during the summer months. Do not disturb natural wetlands without express written permission from TDEC and the U.S. Army Corps of Engineers. Visit the TDEC website for more details on how to obtain an Aquatic Resources Alteration Permit:
http://www.state.tn.us/environment/permits/index.html

In contrast, constructed wetlands are built specifically for treating stormwater runoff, and are not created as mitigation for the loss of natural wetlands. Consequently, constructed wetlands do not necessarily have to meet the stricter standards necessary to replace natural wetlands. Constructed wetlands use larger areas than other types of stormwater treatment BMPs. For small sites with advantageous water and soil conditions, concrete retaining walls can be used for one or more sides to save space. The term "constructed wetland" may also refer to a method of treating small amounts of wastewater and sanitary sewage, typically from a single residence or a small group of residences. Within the context of the BMP Manual, the term "constructed wetland" refers to the treatment of stormwater runoff only, and not for the collection and treatment of wastewater and sanitary sewage.

Constructed wetlands remove dissolved phosphorous, nitrogen, and other nutrients both directly (for aquatic plants) and through the soil (for rooted plants). In addition, wetland vegetation will uptake heavy metals, toxic materials, and other pollutants. Over long periods of time, bioaccumulation of metals such as lead or zinc have been observed in both fish and wildlife in some instances. Sediments should be removed regularly from the wetland forebay, and presence of heavy metals should be monitored. It is conjectured that the wetland soils may need to be replaced every 5 to 10 years in order to improve uptake of heavy metals and phosphorous. Cleaning the forebay and replacing bottom soils is probably adequate to collect and remove heavy metals.

A constructed wetland with additional capacity for extended detention is very similar to a wet detention basin, except with different types of vegetation. Guidelines in this BMP apply to the portion of constructed wetlands below the normal pool elevation. See P-02, Retention Basin, for typical berms, outlet structures, and grading details which are generally applicable to constructed wetlands also. An advantage of a constructed wetland, in addition to aesthetics and wildlife, is that a wetland has smaller required treatment volumes (which may be negotiable) than does a wet detention basin.

The detailed design of a constructed wetland should generally be accomplished by a team that includes a hydrologist or engineer for hydrologic/hydraulic/water balance analyses and a wetland ecology specialist for selecting vegetation and habitat parameters. In addition, a detailed subsurface report should be conducted by a qualified geotechnical engineer prior to design of the wetland. However, the following basic guidelines will assist in making preliminary plans and layouts for a constructed wetland.

Existing Conditions

Site conditions, such as property lines, easements, utilities, structures, etc. that may impose constraints on development should be considered when designing a constructed wetland. Under no conditions, should a constructed wetland be built over an existing utility. Likewise, no utility should be permitted to construct new infrastructure in the location of an existing constructed wetland. Local government land use and zoning ordinances may also specify certain requirements.

All facilities should be a minimum of 20 feet from any structure, property line, or vegetative buffer, and 100 feet from any septic tank/drainfield. Local landuse setbacks and other restrictions may apply.

All facilities should be a minimum of 50 feet from any steep slope (greater than 10%). A site-specific geotechnical report must address the potential impact of a constructed stormwater wetland that is to be installed on, or near, such a slope.

Size

The drainage area criteria for a constructed stormwater wetland is similar to that of a retention basin. Since needs of aquatic plants limit the water depth, constructed wetlands may consume two to three times the site area compared with other stormwater quality BMPs. Therefore, the maximum watershed size depends on the available area on the site that is suitable for a constructed wetland system. The minimum watershed drainage area for constructed stormwater wetlands should be based on the watershed's hydrology and the presence of an adequate base flow to support the selected vegetation. Similar to retention basins, a drainage area of 15 to 20 acres or the presence of a dependable base flow is most desirable to maintain a healthy wetland. A clay liner may be necessary to prevent infiltration if losses are expected to be high.

The overall goal for a constructed wetland is to capture over well over 90% of the annual stormwater runoff volume for urban areas, using a design storm of 1.0 inch rainfall. For storms that are smaller than 1.0 inch of rainfall, the normal pool elevation will not be completely replaced by newer stormwater during the storm event. This means that in most instances, the average water residence time within the wetland is longer than the average time between storm events, greatly enhancing pollutant removal efficiency of the constructed wetland.

Table W-01-1
Size Criteria for Stormwater Wetlands

Surface area = percentage of area at normal water pool Elevation (without stormwater surge)

Depth range = depth from normal water pool elevation

Volume = percentage of total volume below normal water pool elevation

** The surface area of high marsh should be maximized whenever possible (depending upon the types of vegetation or fish that are selected).

A. Shallow Marsh	Surface Area	Depth Range	Approx. Volumes
Forebay	5 %	18” to 72”	10 %
High marsh	** 45 %	0” to 6”	25 %
Low marsh	40 %	6” to 18”	45 %
Deep water	5 %	12” to 48”	10 %
Micropool	5 %	18” to 72”	10 %

B. Deep Marsh	Surface Area	Depth Range	Approx. Volumes
Forebay	5 %	18” to 72”	5 %
High marsh	** 25 %	0” to 6”	10 %
Low marsh	25 %	6” to 18”	15 %
Deep water	40 %	12” to 48”	60 %
Micropool	5 %	18” to 72”	10 %

Layout

Table W-01-1 shows a basic allocation of different zones within a constructed wetland. The five zones are also shown in Figure W-01-1. Zone percentages for two basic types of wetland (designated as Shallow Marsh and Deep Marsh) can be adjusted to match the target volumes and to support various types of desired vegetation. The zone designated as high marsh (0” to 6” deep) is highly desirable; it generally contains thicker vegetation than low marsh zones. Ecological complexity is promoted by varying water depth through the vegetated area rather than keeping the depth uniform.

The length-to-width ratio of the constructed wetland should generally be at least 2:1, although a 1:1 ratio is usually acceptable with baffles, islands, internal berms or other flow barriers. Dry-weather flow paths should meander back and forth throughout the wetland, as shown in Figures W-01-1 and W-01-2, to maximize contact time with soils and vegetation. Distribute flows equally throughout the wetland and avoid dead spaces. Prevent flow shortcuts by anticipating possible locations; erosion control matting and other geotextile applications may be useful to “armor” shortcut locations.

Islands reduce the total treatment volume (below the normal pool elevation) by a small amount that is usually negligible. Overgrowth of vegetation may actually cause a more significant reduction in storage volume, and can be a factor in whether to harvest vegetation within a constructed wetland. It is important to provide plenty of shade to the wetland during the summer months, since shallow depths will generally allow the water to get warm and thus degrade the downstream environment for many cold-water fish and other organisms.

It is beneficial to incorporate cascades into the wetland layout, possibly by having more than one water surface elevation. Or a cascade can be placed on one fork of a flow path and not on another. A cascade provides aeration and increases oxygen levels in the water. Oxygen is needed for the digestion of organic nutrients and particles in the water. Cascades are aesthetically pleasing and can be fashioned in many ways.

Other layout considerations include maximum side slopes of 4H:1V and preferably side slopes which are 10H:1V or flatter. On very small facilities, retaining walls may be used to conserve space. There must be provisions for vehicle access to the forebay (which requires period cleaning) and to the micropool (which may require maintenance and water level adjustments). Provide adequate freeboard (typically 1 foot) to prevent ponding stormwater or flood damage on adjacent properties.

The forebay may be partially replaced by a baffle box, stormwater quality inlets (media filtration or oil/water separators) or other means to remove floatable debris and coarse sediments. If a detention basin is constructed upstream from the wetland, then the forebay may be eliminated altogether.

For more information on outlet structures and spillways, see P-01, Detention Basin.

Water Balance

The water balance for the constructed wetland must be examined using typical values (maximum, average, minimum) for rainfall, temperature, humidity, water table, evaporation rate, and infiltration rate. The 30-year averages, published by the National Oceanic and Atmospheric Administration, are broken down for each month of the year and represent a good starting point for water balance calculations. Evaporation rates may depend on the amount of sunlight or shade, prevailing wind directions, types of windbreaks (fences can be very beneficial) and other factors. Infiltration rates can be reduced or eliminated by using a geosynthetic liner, clay or concrete. Infiltration rates can be significant in karst areas, sinkholes, fractured bedrock, sands or gravels.

In particular, the water balance must be computed for dry-weather scenarios such as late summer and early fall. A groundwater base flow or stream base flow is very favorable but may not be present during extended periods of dry weather. Drinking water or treated process water can be added during dry weather, provided that water is dechlorinated prior to use within the wetland.

Soils

The soil must be suitable for wetland vegetation. Hydric soils (soils which are normally saturated) are preferable and can be identified by wetland experts using color and texture. If necessary, organic soils must be imported to the site and placed in areas up to 24 inches deep. The soil must have an affinity for phosphorus, for which minerals containing aluminum and iron ions are typically desirable. Do not use soils which contain large concentrations of phosphorus or heavy metals, as these soils may cause concentrations of contaminants to increase in the overlying water.

Minimize water loss by preventing infiltration through the wetland bottom. For this reason, soils with high infiltration rates are not normally suitable for constructed wetlands. Depending on the type of soil, this can be accomplished by compaction, incorporating clay into the soil, or an artificial geosynthetic liner (at least 30 mil thickness, UV resistant, durable throughout extreme temperatures). If a clay liner is used, the following are recommended:

- A clay liner should have a minimum thickness of 12 inches.
- A layer of compacted topsoil (6 to 12 inches thick, minimum) should be placed over the liner.
- Other liners may be used if adequate documentation exists to show that the material will provide the required performance.

Using gravel as the substrate may be a suitable approach in small facilities. Because gravel is lacking in nutrients, emergent species will have to take nutrients directly from the water (Reddy and Smith, Thut). However, harvesting may be more practical if plants can be easily removed from gravel.

The geotechnical subsurface investigation should also identify the presence of any rock or bedrock layers. The excavation of rock to achieve the proper wetland dimensions and hydrology may be too expensive or difficult with conventional earth moving equipment. However, blasting may open seams or create cracks in the underlying rock that may result in unwanted drawdown of the permanent pool. Blasting of rock is not recommended unless a liner is used.

In regions where Karst topography is prevalent, projects may require a thorough soils investigation and specialized design and construction techniques. Since the presence of karst may affect BMP selection, design, and cost, a site should be evaluated during the planning phase of the project.

Vegetation

The overall design of vegetation for a constructed wetland should be performed by a qualified wetland ecologist with adequate experience and training. The wetland ecologist should also be involved during construction and installation in order to achieve best results. Basic types of wetland vegetation (also called hydrophytic vegetation or hydrophytes) can be classified as floating, emergent and submergent. Wetland vegetation species should be selected based upon stress tolerance and hardiness to seasonal variations in water availability. During periods of dry weather, there must be sufficient water to avoid complete desiccation of plant roots.

Placing rooted wetland species from nursery stock throughout the wetland can be expensive when compared to a wet detention basin. However, relying on native volunteer plants to establish themselves would delay complete coverage for several years. Delayed coverage may allow the invasion of undesirable species or dominance by one or two species (such as cattails) which tend to flourish in disturbed conditions. Vegetation can also be established by taking donor soils from existing wetlands, but the soils must be transported and handled carefully. The best times to establish vegetation are typically spring and fall.

Common wetland plants include: arrowhead, bulrush, canarygrass, cattails, duckweed, ferns, marshgrass, pond lilies, pondweed, rushes, sedges, skunk cabbage, and woolgrass. Common wetland trees include: alder, ash, cottonwood, dogwood, and some maples. Trees should not have acidic leaves (such as oak trees) or undesirable fruit or nuts. Decaying leaves and stems provide food for many types of insects and other invertebrates, which in turn become food for fish, reptiles, amphibians, and mammals. Trees provide habitats for many birds and animals. Trees also tend to discourage migrating birds (geese and ducks) which severely degrade water quality.

It can be expected that soil adsorption will continue at a slower pace during the winter. For instance, the minimum temperature for cattails, sedges, and bulrushes to function effectively is 50°, 57° and 60° Fahrenheit, respectively. It has been observed during fall and winter months that pollutants may actually be released at a greater rate than being absorbed. The net effect over a 12-month period may be that a constructed wetland is no more effective than a wet pond, particularly with regard to the removal of dissolved phosphorus and metals.

Phosphorous removal has been observed for wastewater applications (rather than stormwater treatment) to occur during the first two or three years, but then declines thereafter and may actually become negative. This effect is thought to be the result of plants reaching maximum density, for which some researchers recommend that mature plant material should be harvested and removed from the wetlands. The uptake of heavy metals is not affected by plant density and maturity. And nitrogen removal does not degrade over time either, because it is a bacteriological process. The nitrogen removal process is very temperature-dependent and therefore much slower in winter.

Annual harvesting of rooted vegetation may or may not be practical or effective at reducing seasonal losses of nutrients and prolonging the life of the constructed wetland facility (USEPA). The benefits of harvesting may depend upon the wetland species (Suziki, Nissanka, and Kurihara). Placing rooted vegetation in gravel beds rather than soil may make harvesting practical. If harvesting is to be done, it should occur twice per season: 1) in the early summer when nutrient content in the plant material is at its peak, and 2) in the early fall as the growing season comes to a close.
Vegetation is planted only after the constructed wetland has been completely created, and then carefully surveyed and regraded. Flood for at least two weeks to ensure wet soils. Drain water from the constructed wetland 2 to 3 days prior to planting. Plant vegetation at staked locations that correspond to the proper normal pool depths. Allow water to re-flood the wetland within 24 hours after planting.

Wildlife

It is beneficial to provide wildlife habitats within and around a constructed wetland. Fences can protect a wetland from human impacts, prevent access by domestic animals such as dogs and cats, and protect children. A particular concern about constructed wetlands is that mosquitoes will breed and thrive. Many types of birds and bats are very useful in reducing mosquitoes. Fish can help to control mosquitoes if a deep pool area is included for fish to reside during dry weather. Typical measures include:

- Mix of deciduous / evergreen trees
- Shrubs, vines and hedges
- Brush piles
- Exposed trunks, snags or logs
- Islands within constructed wetland
- Birdhouses, bath houses, birdfeeders

Construction/ Inspection Considerations

Considerations to be considered during construction are as follows:

- Sometimes additional stabilization of the basin area may be necessary to ensure that the vegetation becomes established and mature prior to the erosion of the planting soil. Annual grasses may be used for this purpose. However, the specified application rates should be reduced to help prevent these grasses from competing with other plants, particularly those emerging from bulbs and rhizomes.
- Grasses should be prohibited from competing with the wetland plants.
- The soil in which the vegetation is planted should be appropriate for the wetland plants selected. Soil tests showing the adequacy of the soil, or a soil enhancement plan should be submitted with the wetland design.
- The soil substrate must be soft enough to permit easy insertion of the plants. If the basin soil is compacted or vegetation has formed a dense root mat, the upper 6 inches of soil should be disked before planting. If soil is imported, it should be laid at least 4 inches deep to provide sufficient depth for plant rooting.
- The window for transplanting emergent stock extends from early April to mid-June. Dormant rhizomes can be planted in fall or winter. To insure availability, ordering stock 3 to 6 months in advance may be necessary.
- A landscape plan should describe any special procedures for planting nursery stock. Most emergent plants may be planted in flooded or dry conditions. If planting is done in dry conditions, then instructions should be included for flooding the wetland immediately following installation.
- Proper handling of nursery stock is crucial. The roots must be kept moist to prevent damage. Plants received from the nursery will be in peat pots or bare-rooted. Bare-rooted plants will have some form of protection to keep the roots moist and may be kept for several days, but out of direct sunlight. For the maximum chance of success, all nursery stock should be planted as soon as possible. A minimum acceptable success rate of the plantings should be specified in the plan.

Maintenance

Constructed stormwater wetlands will require active management of the hydrology and vegetation during the first few years or growing seasons in order for it to achieve the performance and functions for which it was designed. Vehicular access and maneuvering room in the vicinity of a constructed wetland is necessary to allow for long-term maintenance. Constructed stormwater wetlands should be designed to duplicate the functions of natural wetlands, while allowing for ongoing maintenance. The designer faces the difficult task of replicating natural wetland hydrology in a constructed setting, while ensuring easy access for maintenance. The following criteria should be observed with regards to maintenance:

- Inspect wetlands at least twice a year and after each extreme storm event. Remove trash and foreign debris. Remove nuisance vegetation and animals if present. Repair or replace areas of erosion or damage. Check sediment deposits and remove if necessary. Clean deposits from the forebay when a loss of capacity is significant, probably every 3 to 5 years depending on the land use, or if concentrations of heavy metals or other pollutants in sediments are reaching a level of concern, typically every 5 to 10 years.
- In general, a constructed wetland should be preceded by other types of stormwater treatment BMPs to remove oil, grease, toxic sediments, heavy metals and coarse sediment. Inspect upstream controls at least twice a year and after each extreme storm event. Perform required maintenance and repairs, particularly for oil/water

separators and for media filtration inlets.

- Removal of sediment depends on the accumulation rate and available storage, in addition to other factors such as watershed size, facility sizing, construction upstream, industrial or commercial activities upstream, etc. The types of sediment should be identified before removal and disposal. Special attention or sampling should be given to sediments accumulated from industrial, manufacturing or heavy commercial sites, fueling centers or automotive maintenance areas, parking areas, or other areas where pollutants are suspected. Treat sediment as potentially hazardous soil until proven otherwise.

- The constructed wetland and its buffer may need a reinforcement planting at the onset of the second growing season after construction. The size and species of plants to be used should be based on the growth and survival rate of the existing plants at the end of their first growing season. Controlling the growth of certain invasive species, such as cattail and phragmites, may also be necessary. These plants can be very hard to contain if they are allowed to spread unchecked. The best strategy may be to design for a wide range of distinct depth zones.

- Research shows that for most aquatic plants the bulk of the pollutants is stored in the roots, not the stems and leaves). Therefore, harvesting before winter dieback is unnecessary. Many unanswered questions remain concerning the long-term pollutant storage capacity of plants.

- The embankment and BMP access road should be mowed biannually, at a maximum, to prevent the growth of trees. Otherwise, the buffer and upland areas should be allowed to grow in meadow conditions.

Cost Considerations

More expensive than a detention or retention pond.

Limitations

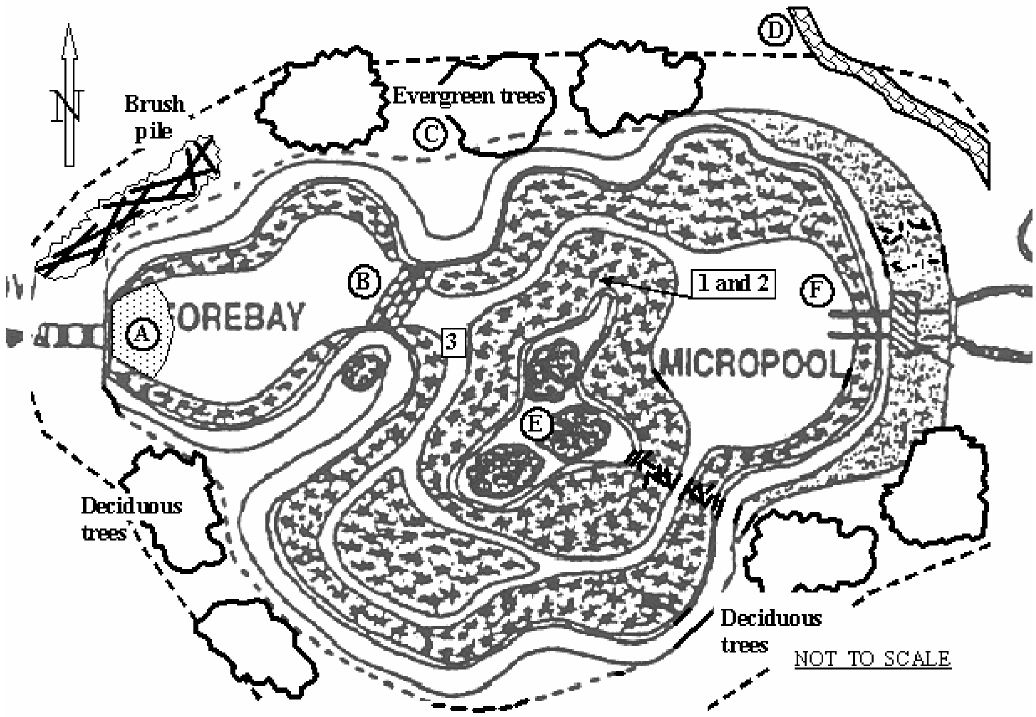
There are many limitations to the task of establishing a self-functioning ecological system such as a constructed wetland. A few limitations are listed here:

- Must have the correct soil types and the appropriate vegetation.
- Requires adequate surface area and volumes to function effectively.
- Difficult to construct and requires careful attention to detail.
- Must have adequate flow to maintain water level.
- Requires constant monitoring to remove nuisance vegetation and animals.
- Burrowing animals can damage geosynthetic liners and increase infiltration.
- Concern for mosquitoes, snakes, spiders and other undesirable wildlife.
- Biological activity decreases with seasonal cold weather, lowering pollutant removal efficiency.
- The conversion of plant species and densities as the wetland matures and becomes acclimated to various environmental factors such as soils, hydrology, climate, and sediment and pollutant load changes the performance of the wetland.
- The uncertainty of the biological cycling processes of phosphorous in the wetland environment.

Additional Information

Additional information regarding constructed wetlands are as follows:

- Constructed stormwater wetlands are generally located in areas with favorable hydrology. These locations are prone to being environmentally sensitive (low-lying) as well, and may contain existing wetlands, shallow marshes, perennial streams, wildlife habitat, etc., which may be protected by state or federal laws. The owner or designer should review local wetland maps and contact local, state, and federal permitting agencies to verify the presence of wetlands, their protected status, and the suitability of the location for a constructed wetland.
- With careful planning, it may be possible to incorporate wetland mitigation into a constructed stormwater wetland. This assumes that the functional value of the existing or impacted wetland can be identified and included, reconstructed, or mitigated for, in the stormwater wetland. Contact TDEC for more information regarding wetland mitigation.



Notes:

A. Culvert outlet velocity should be minimized using efficient design or some type of outlet protection.

B. A gabion wall or riprap berm will provide some filtering capability for removing trash, floating debris and coarse sediment. This will reduce maintenance upon vegetated portions of wetland.

C. Provide a buffer zone (typically 20' to 25') around the wetland using native trees, shrubs and grasses. Evergreen trees (also brush piles or fences) on north side will protect against winter weather. Deciduous trees on south side will provide shade in summer and sunlight in winter.

D. Post signs and place garbage cans as needed along nearby trails, sidewalks or greenways.

E. An island in the center of the wetland can provide a safe haven for wildlife or birds. The island will also prevent shortcutting of flows.

F. Provide adjustable weirs, gate valves, or other means of controlling water surface elevation for long-term operations and maintenance.

Principal zones of a wetland:

1. High marsh
2. Low marsh
3. Deep water
4. Micropool

Figure W-01-1
Typical Wetlands Layout

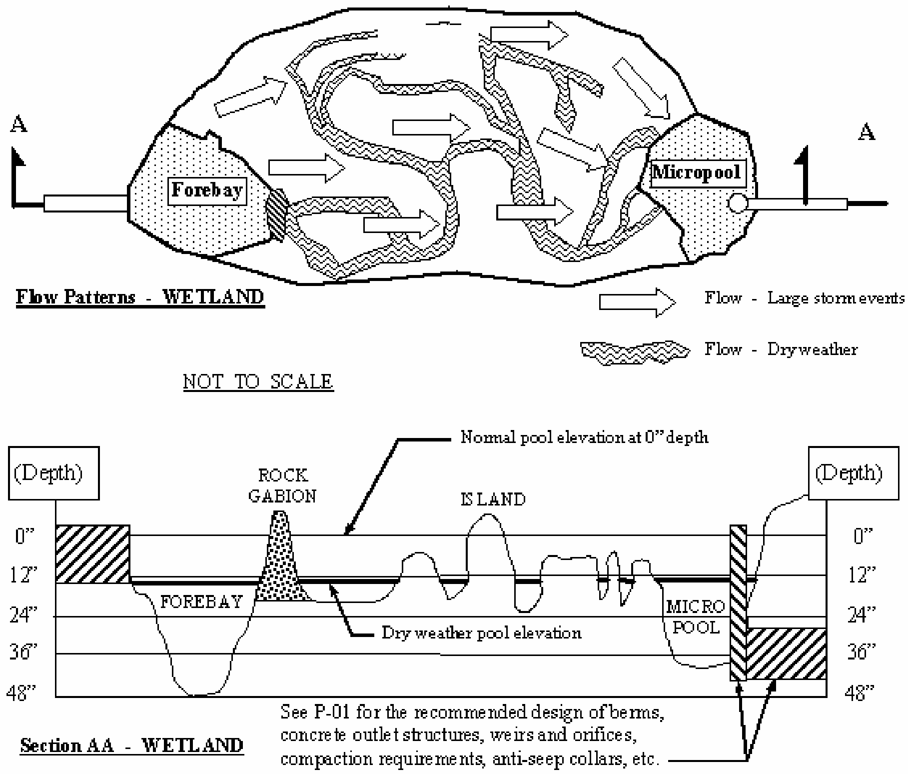


Figure W-01-2
Typical Flow Patterns

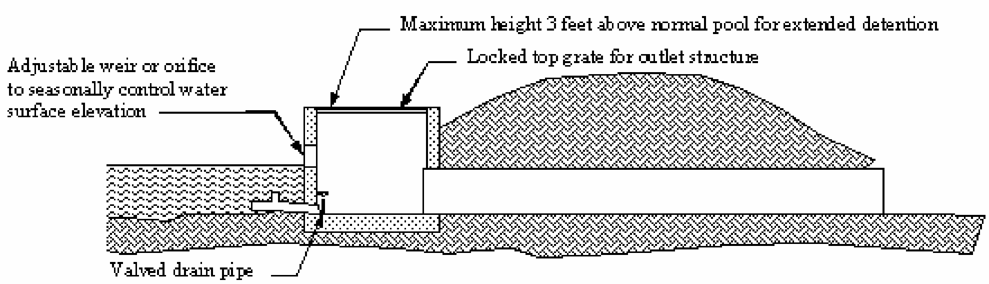


Figure W-01-3
Typical Outlet Structure

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