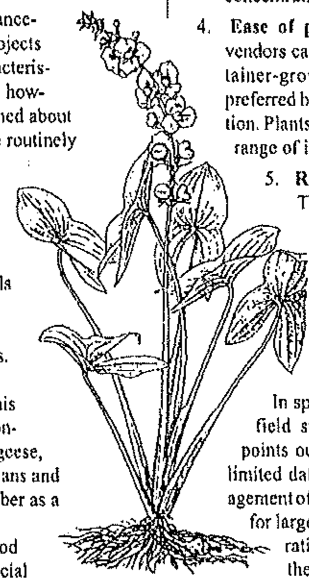
Technical Note 24

Broad-leaf Arrowhead: A Workhorse of the Wetland

The broad-leaf arrowhead *(Sagittaria latifolia)* is a native North American wetland plant found in southern Canada and much of the United States. Many practitioners have found it especially useful for wetland enhancement, restoration, and creation projects because of several desirable characteristics. Marburger (1993) points out, however, there is still much to be learned about its ecology and physiology before routinely investing in large scale planting and management schemes.

The plant is identified by its rosettes of arrowhead-shaped leaves. Flowers are white with three petals and arranged in whorls around a long stalk. Its most distinctive feature is the starchy tuber produced from the rhizomes. This phenomenon gives rise to its common name of *duck potato*. This "potato" portion of the plant is consumed by muskrats, porcupines, geese, and other animals. Native Americans and European settlers also used the tuber as a food source.

While its days as human food have long since past, other beneficial characteristics of broad-leaf arrowhead have propelled it into the field of wetland restoration. Special characteristics include the following.



Adapted from Fassett, 1960

1. **Adaptation to a wide range of conditions.** The plant persists under stabilized water levels of less than 50 cm and few drawdowns and survives in pHs from 5.9-8.8. It has been found in highly calcareous water and in a variety of soil types including sandy loams and silty clays. While it can withstand turbid conditions, it does not tolerate severe sediment deposition.

2. **Nutrient uptake.** Arrowhead rapidly takes up phosphorus from the sediments and retains it in its tissue. In one South Carolina study it had the highest leaf tissue composition of phosphorus of 17 wetland plants analyzed (Boyd, 1970). For this reason Arrowhead is often selected for use in municipal and domestic wastewater treatment systems, constructed wetlands, and for stormwater runoff treatment.

3. **Heavy metal uptake.** In surveys in South Carolina and Michigan, broad-leaf arrowhead was found to have the highest leaf dry weight concentrations of several metals.

4. **Ease of plant propagation.** Wetland plant vendors can supply achenes, tubers, and container-grown plants. Tubers are generally preferred because they require less site preparation. Plants are more costly, but survive a wider range of initial conditions.

5. **Resistance to disease and damage.** There are few reports of population reductions due to pathogens, insect pests, and animal feeding. In some limited situation it may be necessary to enclose areas with protective fencing to keep out muskrats and waterfowl.

Arrowhead rapidly takes up phosphorus from the

In spite of many apparent field successes, Marburger points out there exists only a limited data base on the installation and management of the broad-leaf arrowhead, especially for large-scale applications. Before incorporating the arrowhead in a wetland design the practitioner needs to work with plant vendor to identify:

- If the environmental factors at the site are more favorable for germinating/growing achenes, tubers, or seedlings;
- If environmental factors are right for sustaining a mature population of arrowheads; and
- If pathogens, animal herbivory, and/or other plant species are likely to impact the plant.

—*JS*

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Stormwater Management Fact Sheet: Stormwater Wetland

Description

Stormwater wetlands (a.k.a. constructed wetlands) are structural practices similar to wet ponds (see Wet Ponds Fact Sheet) that incorporate wetland plants in a shallow pool. As stormwater runoff flows through the wetland, pollutant removal is achieved by settling and biological uptake within the practice. Wetlands are among the most effective stormwater practices in terms of pollutant removal, and also offer aesthetic value. While natural wetlands can sometimes be used to treat stormwater runoff that has been properly pretreated, stormwater wetlands are fundamentally different from natural wetland systems. Stormwater wetlands are designed specifically for the purpose of treating stormwater runoff, and typically have less biodiversity than natural wetlands both in terms of plant and animal life. There are several design variations of the stormwater wetland, each design differing in the relative amounts of shallow and deep water, and dry storage above the wetland.

Applicability

Wetlands are widely applicable stormwater treatment practices. While they have limited applicability in highly urbanized settings, and in arid climates, they have few other restrictions.

Regional Applicability

Stormwater wetlands can be applied in most regions of the United States, with the exception of arid climates. In arid, and even in semi-arid climates, it is difficult to design any stormwater practice that has a permanent pool. Because wetlands are relatively shallow, water losses due to evaporation can be high which can be critical for the wetland plants. This makes maintaining the permanent pool in wetlands both more challenging and more important than maintaining the pool of a wet pond (see Wet Pond Fact Sheet).

Ultra Urban Areas

Ultra urban areas are densely developed urban areas in which little pervious surface exists. It is difficult to use wet ponds in the ultra urban watershed because of the land area each wetland consumes. They can, however, be used in these environments if a relatively large area is available downstream of the site.

Stormwater Hotspots

Stormwater hotspots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater. A typical example is a gas station. Wetlands can accept runoff from stormwater hotspots, but need significant separation from groundwater if they will be used for this purpose. Caution also needs to be exercised for stormwater wetlands to ensure that pollutants in stormwater runoff do not work their way up the food chain of aquatic organisms living in or near the wetland.

Stormwater Retrofit

A stormwater retrofit is a stormwater management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other watershed restoration objectives. When retrofitting an entire watershed, stormwater wetlands have the advantage of providing both educational and habitat value. One disadvantage to wetlands, however, is the difficulty storing large amounts of runoff without consuming a large amount of land. It is also possible to incorporate wetland elements into existing practices, such as wetland plantings (see Wet Pond and Dry Extended Detention Pond Fact Sheets).

Cold Water (Trout) Streams

Wetlands pose a moderate risk to cold water systems because of their potential for stream warming. When water remains in the permanent pool, it is heated by the sun. A study in Prince Georges County, MD investigated the thermal impacts of a wide range of stormwater management practices. (Galli, 1990). In this study, only one wetland was investigated, which was an extended detention wetland (*see Design Variations*). The practice increased the average temperature of stormwater runoff that flowed through the practice by about 3 F. While this is less than the temperature increase associated with wet ponds (see Wet Ponds Fact Sheet), it cannot be concluded from one study that wetlands necessarily increase temperatures less than wet ponds. In fact, wetlands may have a greater potential to increase temperature because the shallow portions of wetlands can easily be warmed by the sun.

Locational and Design Considerations

In addition to the broad concerns described above, designers need to consider conditions at the site level. In addition, they need to incorporate design features to improve the longevity and performance of the practice, while minimizing the maintenance burden.

Locational Considerations

Designers need to ensure that stormwater wetlands are feasible for a site. The following section provides basic guidelines for locating wetlands.

Drainage Area

Wetlands need sufficient drainage area to maintain a shallow permanent pool. In humid regions, about twenty-five acres of drainage area are needed, but a larger areas may be needed in regions with less rainfall.

Slope

Wetlands can be used on sites with an upstream slope up to about 15%. 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 three to five feet).

Soils /Topography

Wetlands can be used in almost all soils and geology, with minor design adjustments for regions of karst topography. (See *Design Considerations*).

Groundwater

Unless they receive hotspot runoff, wetlands can often intersect the groundwater table. Some research suggests that pollutant removal is moderately reduced when groundwater contributes substantially to the pool volume (Schueler, 2000) (for more information see *Influence of Groundwater on Performance of Stormwater Ponds in Florida*, Article 78 in The Practice of Watershed Protection). It is assumed that wetlands would have a similar response.

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most wetland designs. These design features can be divided into five basic categories: *pretreatment, treatment, conveyance, maintenance reduction*, and *landscaping* (for more information see the Manual Builder Category).

Pretreatment

Pretreatment is used to settle out coarse sediment particles prior to entry in the main wetland cell. By removing sediments before they reach the wetland, the maintenance burden of the wetland is reduced. In wetlands, pretreatment is achieved with a sediment forebay. A sediment forebay is a small pool (typically about 10% of the volume of the permanent pool). Coarse particles remain trapped in the forebay, and maintenance is performed on this smaller pool, eliminating the need to dredge or clean out sediments from the entire wetland.

Treatment

Treatment design features help enhance the ability of a stormwater treatment practice to remove pollutants. Several features can enhance the ability of wetlands to remove pollutants from stormwater runoff. The purpose of most of these features is to increase the amount of time and flowpath that stormwater remains in the wetland. Some typical design features include:

- The surface area of wetlands should be at least 1% of the drainage area to the practice.
- Wetlands should have a length to width ratio of at least 1.5:1. Making the wetland longer than it is wide helps prevent "short circuiting" of the practice.
- Effective wetland design "complex microtopography". In other words, wetlands should have zones of both very shallow (<6") and moderately shallow (<18") wetlands are incorporated, using underwater earth berms to create the zones. This design will provide a longer flow path through the wetland to encourage settling, and provides two depth zones to encourage plant diversity.

Conveyance

Conveyance of runoff into and through a stormwater practice is a critical component of any stormwater design. Stormwater should be conveyed to and from practices safely and to minimize erosion potential. The outfall of pond systems should always be stabilized to prevent scour. In addition, an emergency spillway should be provided to safely convey large flood events. In order to prevent warming at the outlet channel, designers should provide shade around the channel at the wetlands outlet.

Maintenance Reduction

In addition to regular maintenance activities, several design features can be incorporated to ease the maintenance burden of stormwater wetlands.

One potential maintenance concern in stormwater wetlands is clogging of the outlet. Wetlands should be designed with a non-clogging outlet such as a reverse-slope pipe, or a weir outlet with a trash rack. A reverse slope pipe draws from below the micropool extending in a reverse angle up to the riser and establishes the water elevation of the micropool. Because these outlets draw water from below the level of the micropool, they are less likely to be clogged by floating debris. Another general rule is that no orifice should be less than 3" in diameter (smaller orifices are generally more susceptible to clogging, without specific design considerations to reduce this problem).

Wetlands should incorporate design features that make sediment cleanouts of both the forebay and the shallow pool easier. Wetlands should have direct maintenance access to the forebay, to allow this relatively routine (five to seven year) sediment cleanouts. In addition, the shallow pool should generally have a drain to draw down the wetland for the more infrequent dredging of the main cell of the wetland.

Landscaping

Landscaping of wetlands can make them an asset to a community, and can also enhance their pollutant removal. To ensure the establishment and survival of wetland plants, a landscaping plan should provide detailed information about the plants selected, when they will be planted, and a strategy for maintaining them. The plan should detail wetland plant species, as well as vegetation to be established adjacent to the wetland.

A variety of techniques can be used to establish wetland plants. The most effective technique is the use of nursery stock as dormant rhizomes, live potted plants, or bare root stock. A "wetland mulch," soil from a natural wetland or a designed "wetland mix," can be used to supplement wetland plantings or alone to establish wetland vegetation. Wetland mulch carries with it the seed bank from the original wetland, and can help to enhance diversity in the wetland. The least expensive option to establish wetlands is to allow the wetland to colonize itself. One disadvantage to this last technique is that invasive species such as cattails or *Phragmites* may dominate the wetland (for more information see *Nutrient Dynamics and Plant Diversity in Volunteer and Planted Stormwater Wetlands*, Article 89 in The Practice of Watershed Protection).

When developing a plan for wetland planting, care needs to be taken to ensure that plants are established in the proper depth and within the planting season. This season varies regionally, and is generally between two and three months long in the spring to early summer. Plant lists are available for various regions of the United States through wetland nurseries, extension services, or conservation districts.

Design Variations

There are several variations of the wetland design. The designs differ in the proportion of the volume of the wetland in deep pool, high marsh, low marsh, and whether volume is provided for extended detention above the wetland surface. Other design variations help to make wetland designs practical in cold climates.

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 areas of the shallow wetland design are the forebay at the inlet to the wetland, and the micropool at the outlet. One disadvantage of the shallow marsh design is that the pool is very shallow and 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) (see Figure 1).

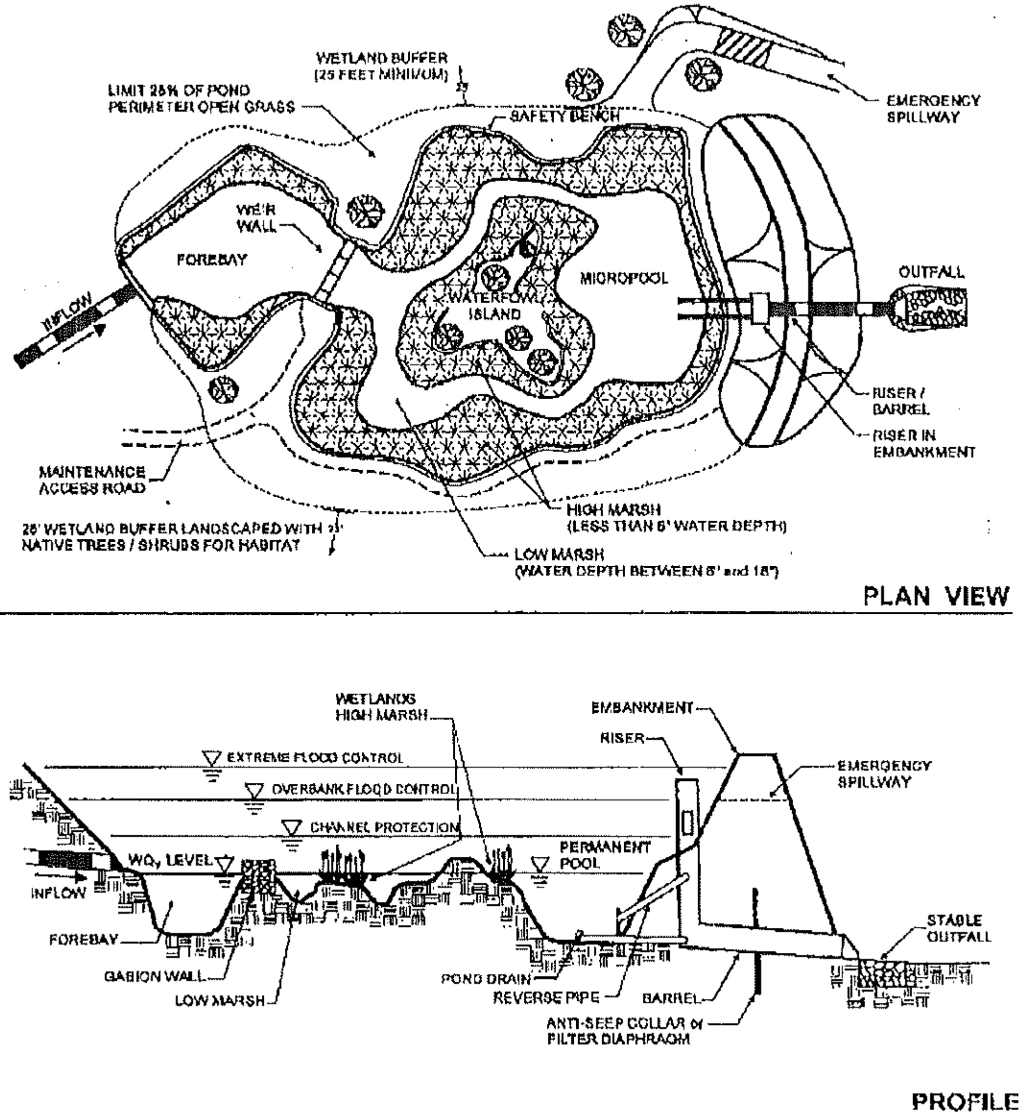
WETLAND BUFFER
(25 FEET MINIMUM)
LIMIT 25% OF POND
PERIMETER OPEN GRASS
SAFETY BENCH
EMERGENCY
SPILLWAY
WEIR
WALL
FOREBAY
INFLOW
MICROPOOL
WATERFOWL
ISLAND
OUTFALL
RISER /
BARREL
RISER IN
EMBANKMENT
MAINTENANCE
ACCESS ROAD
25' WETLAND BUFFER LANDSCAPED WITH
NATIVE TREES / SHRUBS FOR HABITAT
HIGH MARSH
(LESS THAN 6" WATER DEPTH)
LOW MARSH
(WATER DEPTH BETWEEN 6" and 18")
PLAN VIEW
WETLANDS
HIGH MARSH
EMBANKMENT
RISER
EXTREME FLOOD CONTROL
OVERBANK FLOOD CONTROL
CHANNEL PROTECTION
EMERGENCY
SPILLWAY
PERMANENT
POOL
WQv LEVEL
INFLOW
FOREBAY
GABION WALL
LOW MARSH
POND DRAIN
REVERSE PIPE
BARREL
STABLE
OUTFALL
ANTI-SEEP COLLAR or
FILTER DIAPHRAGM
PROFILE

Figure 1

Extended Detention Wetland

This design is similar to the shallow marsh, but with more storage above the surface of the marsh. Stormwater is temporarily ponded above the surface in the *extended detention zone* for between twelve and twenty-four hours. This extended detention wetland 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 planted along the shorelines of the wetlands. (See Figure 2).

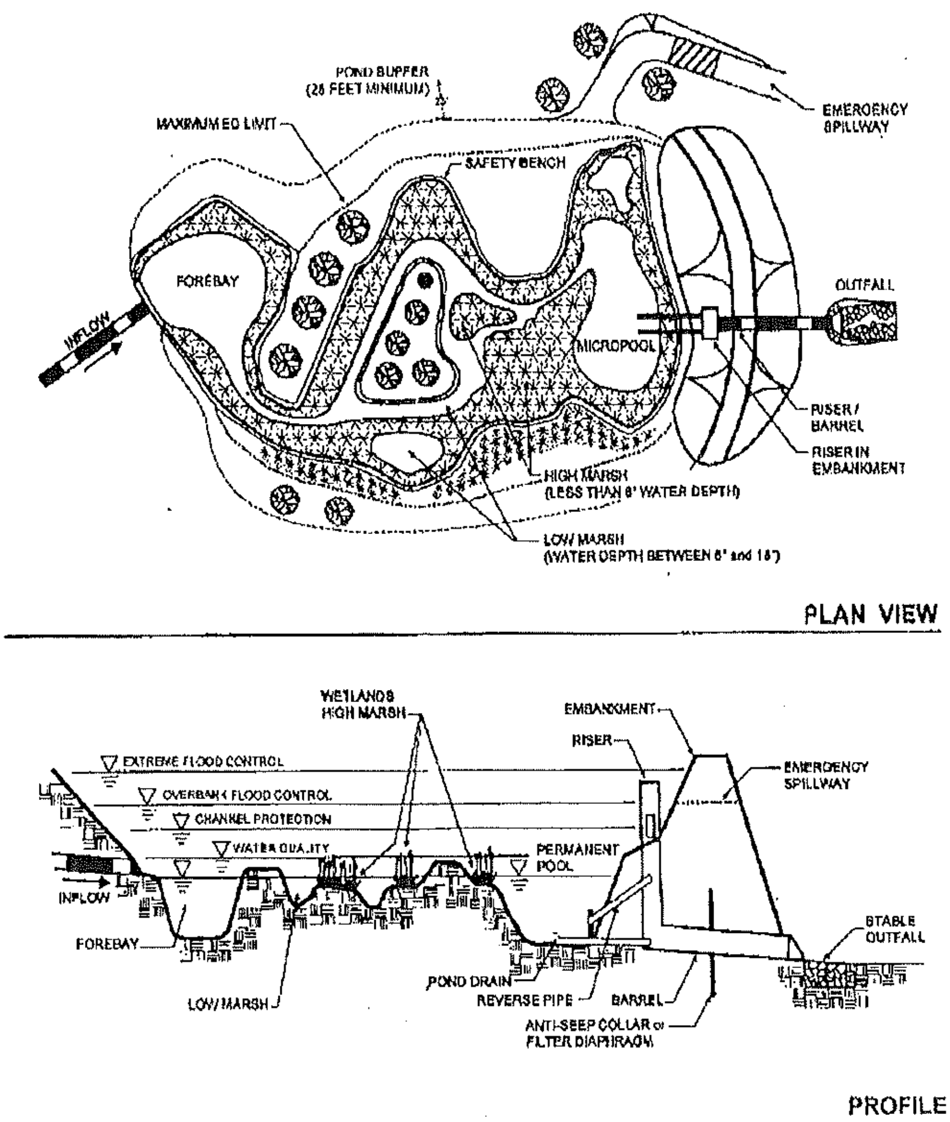

Figure 2

The pond/wetland system combines a wet pond (see Wet Pond Fact Sheet) and 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 much of the practice is relatively deep (i.e., six to eight feet) (see Figure 3).

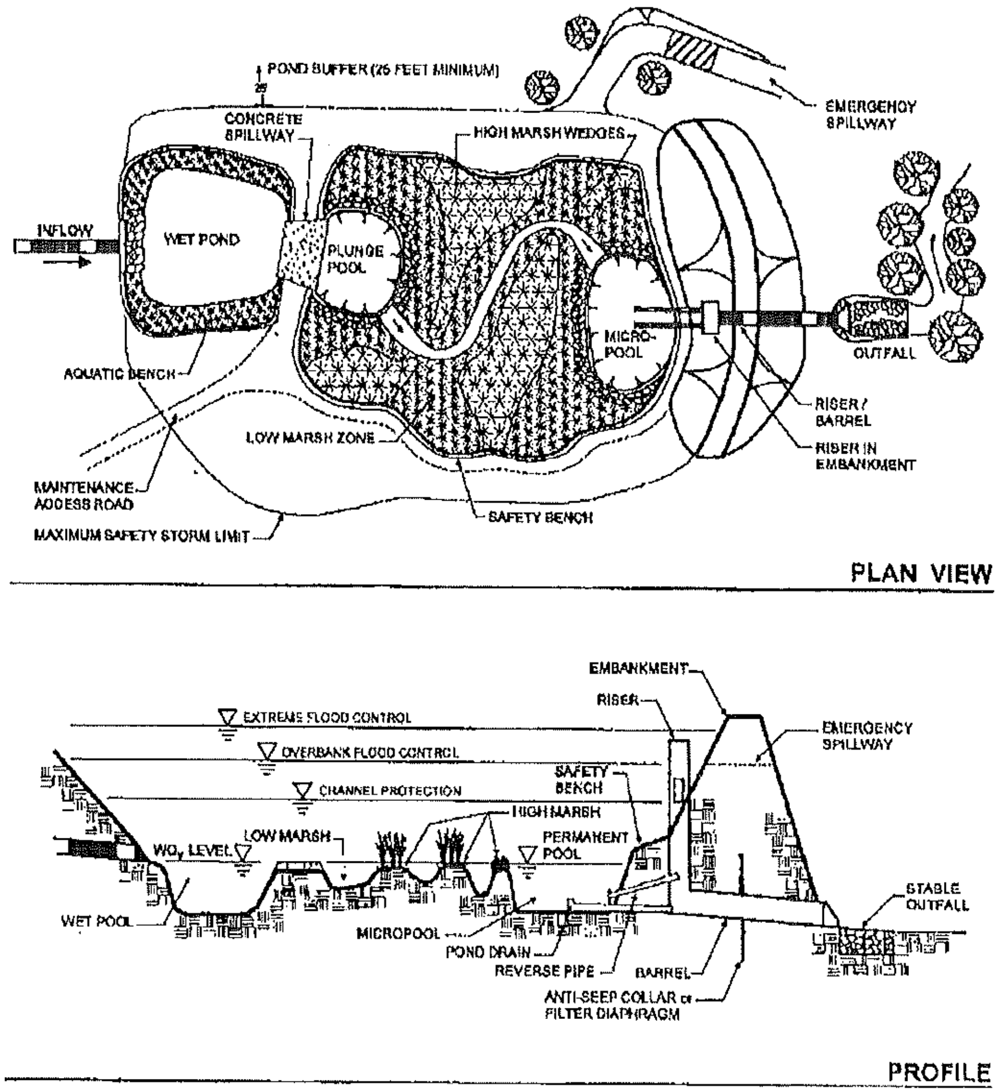

Figure 3

Pocket Wetland

This design is very similar to the Pocket Pond (see Wet Pond Fact Sheet). 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 (Schueler, 2000). This option may be used when there is not significant drainage area to maintain a permanent pool for the stormwater wetland (see Figure 4).

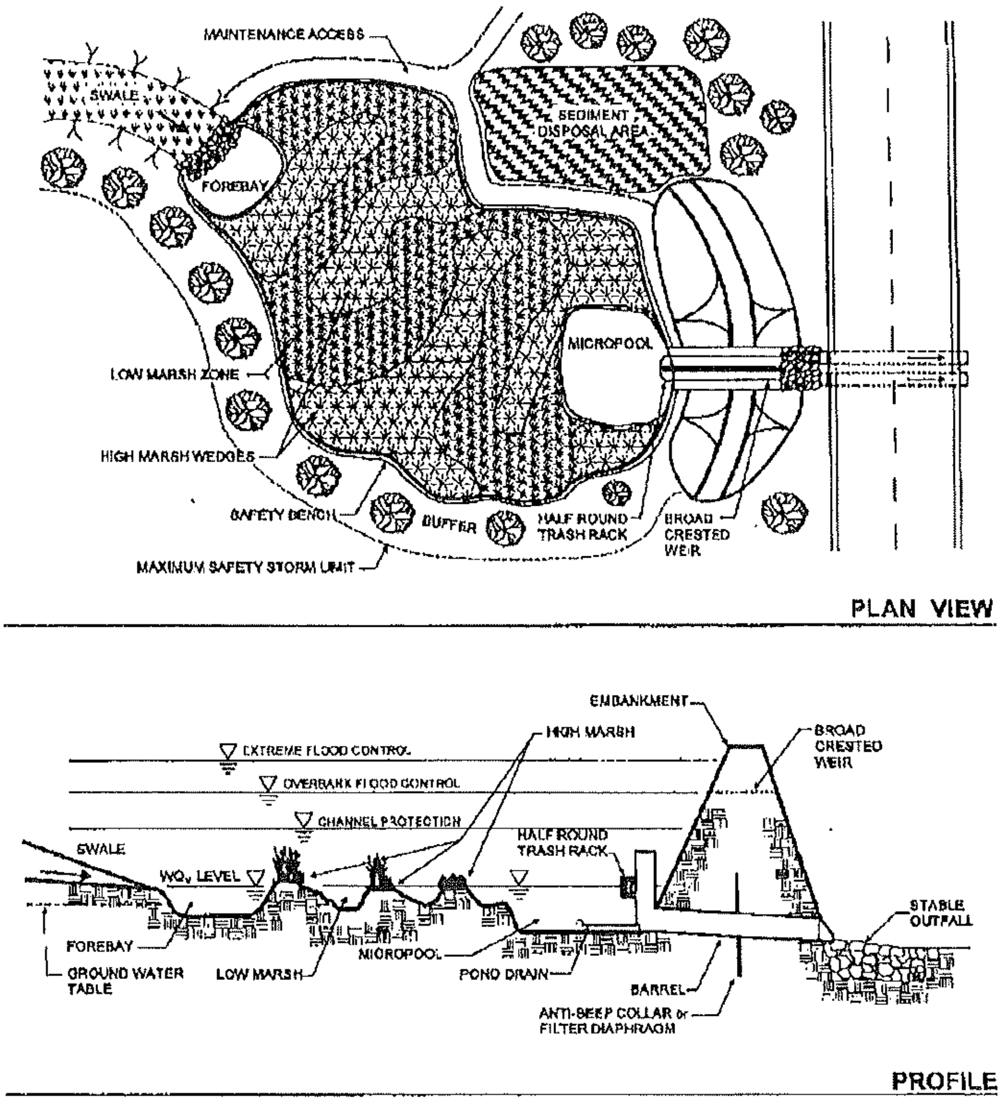

Figure 4

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, as well as by pollutant uptake of 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 a filtering system. A proprietary version of the gravel-based wetland, StormTreat©, operates on a similar principle (for more information see The StormTreat System: A New Technology for Treating Stormwater Runoff, Article 96 in The Practice of Watershed Protection).

Regional Variations

Cold Climates

Cold climates present many challenges to designers of wetlands. During the spring snowmelt, a large volume of runoff occurs in a short time, which carries a relatively high pollutant load. In addition, cold winter temperatures cause freezing of the shallow pool as well as freezing up inlet and outlet structures. Finally, high salt concentrations are spread by road salting which can impact wetland vegetation. Also sediment loads from road sanding can be high, and cause premature loss of treatment capacity.

A key problem with stormwater wetlands (particularly shallow marshes), is that the practice has very shallow water depths. Therefore, much of the volume in the wetland can be lost when the surface ices over. One study found that the performance of a wetland system was moderately diminished during the spring snowmelt because the outlet and surface of the wetland had frozen. Sediment and pollutants in snowmelt and rainfall events "skated" over the surface of the wetland, depositing at the outlet of the wetland. When the ice melted, this sediment was washed away by storm events (Oberts, 2000) (for more information see *Performance of Stormwater Ponds and Wetlands in Winter*, Article 71 and *Pollutant Removal Dynamics of Three Canadian Wet Ponds*, Article 75 in The Practice of Watershed Protection). Several design features can help minimize this problem, including:

- Design wetlands "on-line," so that flow continuously moves through the system. This can help prevent outlets from freezing.
- Design wetlands with multiple cells, and a berm or weir separating each cell. This modification helps to retain storage for treatment above the ice layer during the winter season.
- Use outlets that are resistant to freezing. Some examples include weirs, or pipes with large diameters.

The salt and sand used to remove ice from roads and parking lots may also create a problem for wetlands in cold climates. When wetlands receive highway runoff, or parking lots, salt tolerant wetland plant species, such as Pickerelweed or Cord Grass should be used. (Contact a local nursery or extension agency for more information in your region). In addition, designers should consider increasing the size of the sediment forebay to capture the increased sediment load from road sanding.

Karst Topography

In karst (i.e., limestone) topography, the bottom of wetlands should incorporate an impermeable liner to prevent groundwater contamination or sinkhole formation, and to help maintain the shallow pool.

Limitations

Some limitations of stormwater wetlands include:

- Wetlands consume a relatively large amount of space, making them an impractical option on many sites where surface land area is constrained or land prices are high.
- Although design features can minimize the potential of wetlands to become a breeding area for mosquitoes (McLean, 2000), there can be public perception that wetlands are a mosquito source (for more information see *Mosquitos in Constructed Wetlands - A Management Bugaboo?*, Article 100 in The Practice of Watershed Protection).
- Wetlands require careful design and planning to ensure that wetland plants survive and flourish after construction.
- Some evidence exists that stormwater wetlands can release some nutrients during the non-growing season.
- Designers should ensure that wetlands are not built in natural wetlands or high quality forest.

Maintenance Considerations

Several regular maintenance and inspection practices are needed for stormwater wetlands as outlined below:

Table 1. Regular Maintenance Activities for Wetlands (Source: Adapted from WMI, 1997 and CWP, 1998)

Activity	Schedule
Replace wetland vegetation to maintain at least 50% surface area coverage in wetland plants after the second growing season.	One-Time (after construction)
Inspect for invasive vegetation and remove where possible.	Semi-Annual Inspection
Inspect for damage to the embankment and inlet/outlet structures. Repair as necessary. Note signs of hydrocarbon build-up, and deal with appropriately. Monitor for sediment accumulation in the facility and forebay. Examine to ensure that inlet and outlet devices are free of debris and operational.	Annual Inspection
Repair undercut or eroded areas.	As Needed Maintenance
Clean and remove debris form inlet and outlet structures Mow side slopes.	Frequent (3-4 times/year) Maintenance
Supplement wetland plants if a significant portion have not established (at least 50% of the surface area). Harvest wetland plants that have been "choked out" by sediment build-up.	Annual Maintenance (if needed)
Removal of sediment form the forebay.	5 to 7 year Maintenance
Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, plants are "choked" with sediment, or the wetland becomes eutrophic.	20 to 50 year Maintenance

Effectiveness

Stormwater treatment practices can be used to achieve four broad resource protection goals. These Include: *Flood Control, Channel Protection, Groundwater Recharge,* and *Pollutant Removal* (see the Manual Builder Category for more information). Wetlands, however can only meet flood control and channel protection, and pollutant removal goals.

Flood Control

One objective of stormwater treatment practices can be to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. Wetlands can easily be designed for flood control, by providing flood storage above the level of the wetland surface.

Channel Protection

One result of urbanization is the channel erosion caused by increased stormwater runoff. When used for channel protection, wetlands have traditionally been designed to control the *two-year storm*. It appears that this design storm has not been effective in preventing channel erosion, and recent research suggests that control of a smaller storm may be more appropriate (MacRae, 1996). Choosing a smaller design storm (one-year) and providing longer detention time (12 to 24 hours) are thought to be the best methods to reduce channel erosion.

Groundwater Recharge

Wetlands usually cannot provide groundwater recharge. The build-up of sediment and organic matter debris at the bottom of the wetland prevents the downward movement of water into the subsoil.

Pollutant Removal

Wetlands are among the most effective practices for removing stormwater pollutants. Over thirty-five research studies have estimated the effectiveness of wetlands. Wetlands have high pollutant removal rates, and are more effective than any other practice at removing nitrate and bacteria. Table 2 provides pollutant removal data derived from the CWP's National Pollutant Removal Database for Stormwater Treatment Practices:

Table 2. Typical Pollutant Removal Rates of Wetlands (%) (Winer, 2000)

Pollutant	Stormwater Treatment Practice Design Variation			
	Shallow Marsh	ED Wetland[1]	Pond/Wetland System	Submerged Gravel Wetland[1]
TSS	83±51	69	71±35	83
TP	43±40	39	56±35	64
TN	26±49	56	19±29	19
NOx	73±49	35	40±68	81
Metals	36 - 85	(-80) - 63	0 - 57	21 - 83
Bacteria	76[1]	NA	NA	78

1:Data based on fewer than five data points

There is considerable variability in the effectiveness of wetlands, but it is believed that proper design and maintenance may help to improve their performance. The siting and design criteria presented in this sheet reflect the best current information and experience to improve the performance of wetlands.

Cost Considerations

Wetlands are a relatively inexpensive stormwater practice. Construction cost data for wetlands are rare, but one simplifying assumption is that they are typically about 25% more expensive than stormwater ponds of an equivalent volume. Using this assumption, an equation developed by Brown and Schueler (1997) to estimate the cost of Wet Ponds can be modified to estimate the cost of stormwater wetlands using the equation:

$$C = 30.6V^{0.705}$$

Where:

C = Construction, Design and Permitting Cost
V = Wetland Volume needed to control the 10-year storm (cubic feet)
Using this equation, typical construction costs are:
$ 57,100 for a 1 acre-foot facility
$ 289,000 for a 10 acre-foot facility
$ 1,470,000 for a 100 acre-foot facility

Wetlands consume about 3% to 5% of the land that drains to them, which is relatively high compared with other stormwater management practices. In areas where land value is high, this may make wetlands an infeasible option.

For wetlands, the annual cost of routine maintenance is typically estimated at about 3% to 5% of the construction cost. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Wetlands are long-lived facilities (typically longer than 20 years). Thus, the initial investment into these systems may be spread over a relatively long time period.

While no studies are available on wetlands in particular, there is some evidence to suggest that wet ponds may provide an economic benefit by increasing property values. The results of one study suggests that "pond frontage" property can increase the selling price of new properties by about 10% (US EPA, 1995). Another study reported that the perceived value (i.e., the value estimated by residents of a community) of homes was increased by about 15 to 25% when located near a wet pond (Emmerling-Dinovo, 1995). It is anticipated that well-designed wetlands, which incorporate additional aesthetic features, would have the same benefit.

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Stormwater Management Fact Sheet: Wet Pond

Description

Wet ponds (a.k.a. stormwater ponds, retention ponds, wet extended detention ponds) are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season). Ponds treat incoming stormwater runoff by settling and algal uptake. The primary removal mechanism is settling while stormwater runoff resides in the pool. Nutrient uptake also occurs through biological activity in the pond. Wet ponds are among the most cost-effective and widely used stormwater treatment practices. While there are several different versions of the wet pond design, the most common modification is the extended detention wet pond, where storage is provided above the permanent pool in order to detain stormwater runoff in order to provide greater settling.

Applicability

Wet ponds are a widely applicable stormwater treatment practice. While they may not always be feasible in ultra-urban areas or arid climates, they otherwise have few restrictions on their use.

Regional Applicability

Wet extended detention ponds can be applied in most regions of the United States, with the exception of arid climates. In arid regions, it is difficult to justify the supplemental water needed to maintain a permanent pool because of the scarcity of water. Even in semi-arid Austin, TX one study found that 2.6 acre-feet per year of supplemental water were needed to maintain a permanent pool of only 0.29 acre-feet (Saunders and Gilroy, 1997). Other modifications and design variations are needed in semi-arid and cold climates, and karst (i.e., limestone) topography (for more information see *Stormwater Strategies for Arid and Semiarid Watersheds* , Article 66 in the Practice of Watershed Protection and *Performance of Stormwater Ponds in Central Texas*, Article 74 in the Practice of Watershed Protection).

Ultra Urban Areas

Ultra urban areas are densely developed urban areas in which little pervious surface exists. It is difficult to use wet ponds in ultra urban areas because enough land area may not be available for the pond. Wet ponds can, however, be used in an ultra-urban environment if a relatively large area is available downstream of the site.

Stormwater Hotspots

Stormwater hotspots are land use or activities that generate highly contaminated runoff that has pollutant concentrations that exceed those typically found in stormwater. A typical example is a gas station or convenience store. Wet ponds can accept runoff from stormwater hotspots, but need significant separation from groundwater if they are used to treat hotspot runoff.

Stormwater Retrofit

A stormwater retrofit is a stormwater treatment practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other watershed restoration objectives. Wet ponds are widely used for stormwater retrofits, and have two primary applications as a retrofit design. In many communities, dry detention ponds have been designed for flood control in the past. It is possible to modify these facilities to develop a permanent wet pool to provide water quality treatment (see

"Treatment" under *Design Considerations*), and modify the outlet structure to provide channel protection. Alternatively, new wet ponds may be installed in streams, or in open areas as a part of a comprehensive watershed retrofit inventory.

Cold Water (Trout) Streams

Wet ponds pose a risk to cold water streams because of their potential to warm streams. When water remains in the permanent pool, it is heated by the sun. A study in Prince Georges County, MD found that wet ponds increased temperatures by about 9 F from the inlet to the outlet (Galli, 1990).

Siting and Design Considerations

Siting Considerations

Designers need to ensure wet ponds are feasible for the site in question. The following section provides basic guidelines for locating wet ponds.

Drainage Area

Wet ponds need sufficient drainage area to maintain a permanent pool. In humid regions, a drainage area of about twenty-five acres is typically needed, but greater drainage areas are needed in arid and semi-arid regions.

Slope

Wet ponds can be used on sites with an upstream slope up to about 15%. The local slope within the pond should be relatively shallow, however. While there is no minimum slope requirement, there must be enough elevation drop from the pond inlet to the pond outlet to ensure that water can flow through the system by gravity.

Soils /Topography

Wet ponds can be used in almost all soils and geology, with minor design adjustments for regions of karst topography (see *Design Considerations*).

Groundwater

Unless they receive hotspot runoff, ponds can often intersect the groundwater table. However, some research suggests that pollutant removal is moderately reduced when groundwater contributes substantially to the pool volume (Schueler, 1997) (for more information, see *Influence of Groundwater on Performance of Stormwater Ponds in Florida*, Article 78 in The Practice of Watershed Protection.

Design Considerations

There are some design features that should be incorporated into all wet pond designs (see Figure 1). These design features can be divided into five basic categories: *pretreatment*, *treatment*, *conveyance*, *maintenance reduction*, *and landscaping* (for more information, see the Manual Builder Category).

Pretreatment

Pretreatment features are designed to settle out coarse sediment particles before they reach the main pool. By trapping these sediments in the forebay, it is possible to greatly reduce the maintenance burden of the pond. A sediment forebay is a small pool (typically about 10% of the volume of the permanent pool) located near the pond inlet. Coarse sediments are trapped in the forebay, and these sediments are removed from the smaller pool on a five to seven year cycle.

Treatment

Treatment design features help enhance the ability of a stormwater treatment practice to remove pollutants. Several features can enhance the ability of wet ponds to remove pollutants from stormwater runoff. The purpose of most of these features is to increase the amount of time that stormwater remains in the pond.

One technique to increase pond pollutant removal is to increase the volume of the permanent pool. Typically, ponds are sized to be equal to the water quality volume (i.e., the volume of water treated for pollutant removal). Designers may consider using a larger volume to meet specific watershed objectives, such as phosphorous removal. Regardless of the pool size, designers need to conduct a water balance analysis to ensure that sufficient inflow is available to sustain a permanent pool.

Other design features can increase the amount of time stormwater remains in the pond, and help to eliminate short circuiting. Wet ponds should always be designed with a length to width ratio of at least 1.5:1. In addition, the design should incorporate features to lengthen the flow path through the pond, such as underwater berms designed to create a longer flow path through the pond. Combining these two measures helps ensure that the entire pond volume is used to treat stormwater. Another feature that can improve treatment is to use multiple ponds in series as part of a "treatment train" approach to pollutant removal. This redundant treatment can also help slow the rate of flow through the system.

Conveyance

Stormwater should be conveyed to and from all wet ponds safely and to minimize downstream erosion potential. The outfall of pond systems should always be stabilized to prevent scour. In addition, an emergency spillway should be provided to safely convey large flood events. In order to prevent warming at the outlet channel, designers should provide shade around the channel at the pond outlet.

Maintenance Reduction

Several design features can be incorporated to ease the maintenance burden of wet ponds. Maintenance reduction features include techniques to reduce the amount of maintenance needed, as well as techniques to make regular maintenance activities easier.

One maintenance concern in wet ponds is potential clogging of the pond outlet. Ponds should be designed with a non-clogging outlet such as a reverse-slope pipe, or a weir outlet with a trash rack. A reverse slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and establishes the water elevation of the permanent pool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris. Another general rule is that no low flow orifice should be less than 3" in diameter (smaller orifices are more susceptible to clogging).

Direct access is needed to allow maintenance of both the forebay and the main pool of ponds. In addition, ponds should generally have a drain to draw down the pond or forebay to enable periodic sediment clean outs.

Landscaping

Landscaping of wet ponds can make them an asset to a community, and can also enhance the pollutant removal. A vegetated buffer should be created around the pond to protect the banks from erosion, and provide some pollutant removal before runoff enters the pond by overland flow. In addition, ponds should incorporate an *aquatic bench* (a shallow shelf with wetland plants) around the edge of the pond. This feature provides some pollutant uptake, and also helps to stabilize the soil at the edge of the pond and enhance habitat and aesthetic value.

Design Variations

There are several variations of the wet pond design. Some of these design alternatives are intended to make the practice adaptable to various sites and to account for regional constraints and opportunities.

Wet Extended Detention Pond

The Wet Extended Detention Pond combines the treatment concepts of the dry extended detention pond (for more information see Dry Extended Detention Pond Fact Sheet) and the wet pond (see Figure 2). In this design, the water quality volume is split between the permanent pool and detention storage provided above the permanent pool. During storm events, water is detained above the permanent pool and released over 12 to 48 hours. This design has similar pollutant removal to a traditional wet pond, and consumes less space. Wet Extended Detention Ponds should be designed to maintain at least half the treatment volume in the permanent pool. In addition, designers need to carefully select vegetation planted in the extended detention zone to ensure that it can withstand both wet and dry periods.

Pocket Pond

In this design variation, a pond drains a smaller area than a traditional wet pond, and the permanent pool is maintained by intercepting the groundwater. While this design variation achieves less pollutant removal than a traditional wet pond, it may be an acceptable alternative on sites where space is at a premium, or in a retrofit situation.

Water Reuse Pond

Some designers have used wet ponds to act as a water source, usually for irrigation. In this case, the water balance should account for the water that will be taken from the pond. One study conducted in Florida estimated that a water reuse pond could provide irrigation for a 100-acre golf course at about one seventh the cost of the market rate of the equivalent amount of water ($40,000 versus $300,000).

Regional Adaptations

Semi-Arid Climates

In arid climates, wet ponds are not a feasible option (see *Application*), but they may be possible in semi-arid climates if the permanent pool is maintained with a supplemental water source, or if the pool is allowed to vary seasonally. This choice needs to be seriously evaluated, however.

Saunders and Gilroy (1997) reported that 2.6 acre-feet per year of supplemental water were needed to maintain a permanent pool of only 0.29 acre-feet in Austin, TX (for more information see *Stormwater Strategies for Arid and Semiarid Watersheds*, Article 66 in The Practice of Watershed Protection).

Cold Climates

Cold climates present many challenges to designers of wet ponds. The spring snowmelt may have a high pollutant load, and large volume to be treated. In addition, cold winters may cause freezing of the permanent pool or freezing at inlets and outlets. Also, high salt concentrations in runoff resulting from road salting may impact pond vegetation, and sediment loads from road sanding may quickly reduce pond capacity.

One means of effectively dealing with spring snowmelt is to use a seasonally operated pond to capture extra snowmelt during the spring, but retain a smaller permanent pool during warmer seasons. In this option, proposed by Oberts (1994), a wet pond has two water quality outlets, both equipped with gate valves. In the summer, the lower outlet is closed. During the fall and throughout the winter, the lower outlet is opened to draw down the permanent pool. As the spring melt begins, the lower outlet is closed to provide detention for the melt event. This method can act as a substitute to using a minimum extended detention storage volume. When wetlands preservation is a downstream objective, seasonal manipulation of pond levels may not be desired (for more information, see *Performance of Stormwater Ponds and Wetlands in Winter*, Article 71 in The Practice of Watershed Protection). An analysis of the effects on downstream hydrology should be conducted before considering this option. In addition, the manipulation of this system requires some labor and vigilance; a careful maintenance agreement should be confirmed.

Several other modifications help to improve the performance of ponds in cold climates. Designers should consider planting the aquatic buffer with salt-tolerant vegetation if the pond receives road runoff. In order to counteract the effects of freezing on inlet and outlet structures, weirs and larger diameter pipes that are resistant to frost can be used. Designing ponds on-line, which create a continuous flow of water through the pond, also helps prevent freezing of outlet structures. Finally, since freezing of the permanent pool can reduce the effectiveness of pond systems, it may be useful to incorporate extended detention into the design to retain usable treatment area above the permanent pool while it is frozen (for more information, see *Performance of Stormwater Ponds and Wetlands in Winter*, Article 71 in The Practice of Watershed Protection).

Karst Topography

In karst (i.e., limestone) topography, wet ponds should be designed with an impermeable liner to prevent groundwater contamination or sinkhole formation, and to help maintain the permanent pool.

Limitations

Limitations of wet ponds include:

- When improperly located, wet pond construction may cause loss of natural wetlands or high quality forest.
- Although wet ponds consume a small amount of space relative to their drainage areas, they are often inappropriate in dense urban areas because each pond is generally quite large.
- Use of ponds is restricted in arid and semi-arid regions due to the need to supplement the permanent pool.

- In cold water streams, wet ponds are not a feasible due to the potential for stream warming.
- Wet ponds may cause some community concerns regarding safety.

Maintenance Considerations

In addition to incorporating features into the pond design to minimize maintenance, some regular maintenance and inspection practices are needed. The table below outlines these practices.

Table 1. Typical Maintenance Activities for Wet Ponds (Source: WMI, 1997)	
Activity	**Schedule**
• Inspect for damage. • Note signs of hydrocarbon build-up, and deal with appropriately. • Monitor for sediment accumulation in the facility and forebay. • Examine to ensure that inlet and outlet devices are free of debris and operational	Annual Inspection
• Repair undercut or eroded areas.	As Needed Maintenance
• Clean and remove debris form inlet and outlet structures. • Mow side slopes.	Monthly Maintenance
• Removal of sediment form the forebay	5 to 7 year Maintenance
• Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, or the pond becomes eutrophic.	20 to 50 year Maintenance

Effectiveness

Stormwater treatment practices can be used to achieve four broad resource protection goals. These include: *Flood Control, Channel Protection, Groundwater Recharge,* and *Pollutant Removal* (for more information, see the Manual Builder Category.) Wet ponds can generally provide flood control channel protection, and pollutant removal functions.

Flood Control

One objective of stormwater treatment practices is to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. Wet ponds can easily be designed for flood control, by providing flood storage above the level of the permanent pool.

Channel Protection

One result of urbanization is channel erosion caused by increased stormwater runoff. Traditionally wet ponds have been designed to provide control of the two-year storm . It appears that this design storm has not been effective in preventing channel erosion, and recent research suggests that control of a smaller storm may be more appropriate (MacRae, 1996). Choosing a smaller design storm (one-year) and providing longer detention time (12 to 24 hours) is now thought to be the best method to reduce channel erosion.

Groundwater Recharge

Wet ponds generally cannot provide groundwater recharge, as infiltration is impeded by the accumulation of organic debris on the bottom of the pond.

Pollutant Removal

Wet ponds are among the most effective stormwater treatment practices at removing stormwater pollutants. A wide range of research is available to estimate the effectiveness of wet ponds. Table 2 provides pollutant removal estimates derived from CWP's National Pollutant Removal Performance Database for Stormwater Treatment Practices:

Table 2. Pollutant Removal Efficiency of Stormwater Wet Ponds (Winer, 2000)

Pollutant	Removal Efficiency (%)
TSS	80±27[1]
TP	51±21
TN	33±20
NOx	43±38
Metals	29-73
Bacteria	70±32

1: ± values represent one standard deviation

There is considerable variability in the effectiveness of wet ponds, and it is believed that properly designing and maintaining ponds may help to improve their performance. The locational and design criteria presented in this sheet reflect the best current information and experience to improve the performance of wet ponds. A recent joint project between the American Society of Civil Engineers (ASCE) and the US EPA Office of Water may help to isolate specific design features that can improve performance. **The National Stormwater Best Management Practice (BMP)** database is a compilation of stormwater practices which includes both design information and performance data for various practices. As the database expands, inferences about the extent to which specific design criteria influence pollutant removal may be made. For more information on this database, access the ASCE web page at http://www.asce.org.

Cost Considerations

Wet ponds are relatively inexpensive stormwater practices. The construction costs associated with these facilities range considerably. A recent study (Brown and Schueler, 1997) estimated the cost of a variety of stormwater management practices. The study resulted in the following cost equation, adjusting for inflation:

$$C = 24.5V^{0.705}$$

Where:

C = Construction, Design and Permitting Cost
V = Volume in the Pond to Include the 10-Year Storm (cubic feet)
Using this equation, a typical construction costs are:
$ 45,700 for a 1 acre-foot facility
$ 232,000 for a 10 acre-foot facility
$ 1,170,000 for a 100 acre-foot facility

Ponds do not consume a large area (typically 2-3% of the contributing drainage area). Therefore, the land consumed to design the pond will not be very large. It is important to note, however, that these facilities are generally large. Other practices, such as filters or swales, may be "squeezed" into relatively unusable land, but ponds need a relatively large continuous area.

For ponds, the annual cost of routine maintenance is typically estimated at about 3 to 5% of the construction cost. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Ponds are long-lived facilities (typically longer than 20 years). Thus, the initial investment into ponds systems may be spread over a relatively long time period.

In addition to water resource protection benefits of wet ponds, there is some evidence to suggest that they may provide an economic benefit by increasing property values. The results of one study suggest that "pond front" property can increase the selling price of new properties by about 10% (US EPA, 1995). Another study reported that the perceived value (i.e., the value estimated by residents of a community) of homes was increased by about 15 to 25% when located near a wet pond (Emmerling-Dinovo, 1995).

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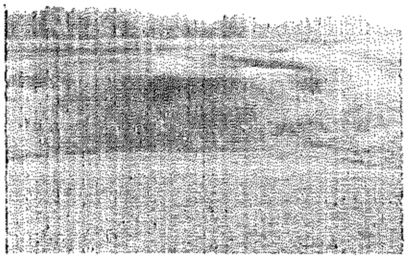
BMP 6.6.1: Constructed Wetland



Constructed Wetlands are shallow marsh systems planted with emergent vegetation that are designed to treat stormwater runoff.

Key Design Elements

- Adequate drainage area (usually 5 to 10 acres minimum) or proof of sustained base flow
  May require investigation of water supply to ensure a sustained baseflow to maintain the wetland
- Maintenance of permanent water surface
- Multiple vegetative growth zones through varying depths
- Robust and diverse vegetation
- Relatively impermeable soils or engineered liner
- Sediment collection and removal
- Adjustable permanent pool and dewatering mechanism
  Maintenance - periodic sediment removal from the forebay and vegetation maintenance

Potential Applications

Residential: Yes
Commercial: Yes
Ultra Urban: Limited
Industrial: Yes
Retrofit: Yes
Highway/Road: Yes

Stormwater Functions

Volume Reduction: Low
Recharge: Low
Peak Rate Control: High
Water Quality: High

Water Quality Functions

TSS: 85%
TP: 85%
NO3: 30%

Description

Constructed Wetlands are shallow marsh systems planted with emergent vegetation that are designed to treat stormwater runoff. While they are one of the best BMPs for pollutant removal, Constructed Wetlands (CWs) can also mitigate peak rates and even reduce runoff volume to a certain degree. They also can provide considerable aesthetic and wildlife benefits. CWs use a relatively large amount of space and require an adequate source of inflow to maintain the permanent water surface.

Variations

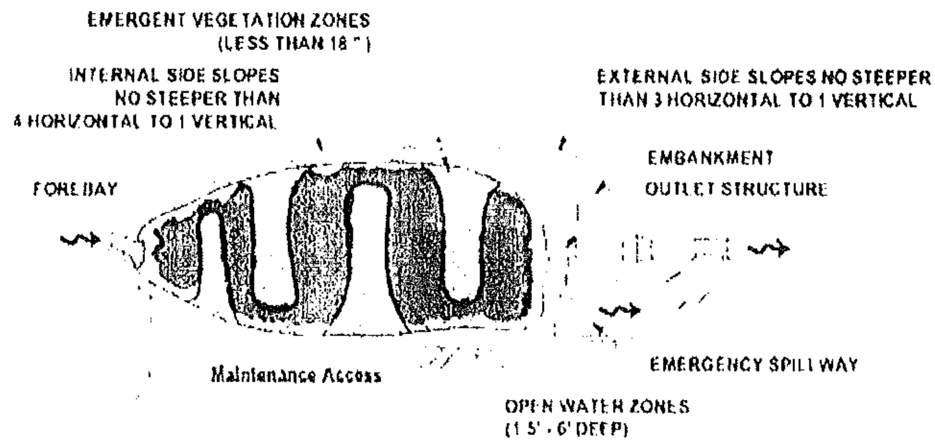
Constructed Wetlands can be designed as either an online or offline facilities. They can also be used effectively in series with other flow/sediment reducing BMPs that reduce the sediment load and equalize incoming flows to the CWs. Constructed Wetlands are a good option for retrofitting existing detention basins. CWs are often organized into four groups:

- Shallow Wetlands are large surface area CWs that primarily accomplish water quality improvement through displacement of the permanent pool.
- Extended Detention Shallow Wetlands are similar to Shallow Wetlands but use extended detention as another mechanism for water quality and peak rate control.
- Pocket Wetlands are smaller CWs that serve drainage areas between approximately 5 and 10 acres and are constructed near the water table.
- Pond/Wetland systems are a combination of a wet pond and a constructed wetland.

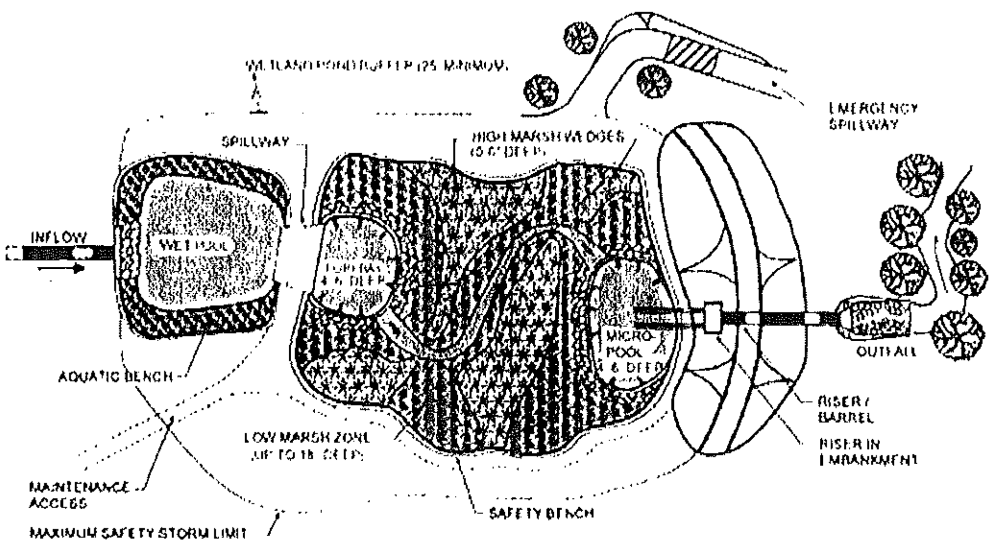
Although this BMP focuses on surface flow Constructed Wetlands as described above, subsurface flow CWs can also be used to treat stormwater runoff. While typically used for wastewater treatment, subsurface flow CWs for stormwater may offer some advantages over surface flow wetlands, such as improved reduction of total suspended solids and oxygen demand. They also can reduce the risk of vectors (especially mosquitoes) and safety risks associated with open water. However, nitrogen removal may be deficient (Campbell and Ogden, 1999). Perhaps the biggest disadvantage is the relatively low treatment capacities of subsurface flow CWs – they are generally only able to treat small flows. For more information, please consult the "References and Additional Resources" list.

Applications

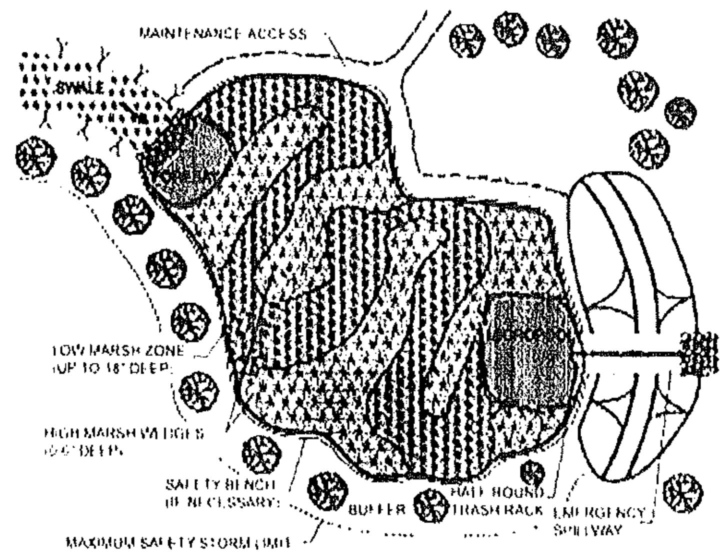
- **Alternating bands of deeper water and shallow marsh.**

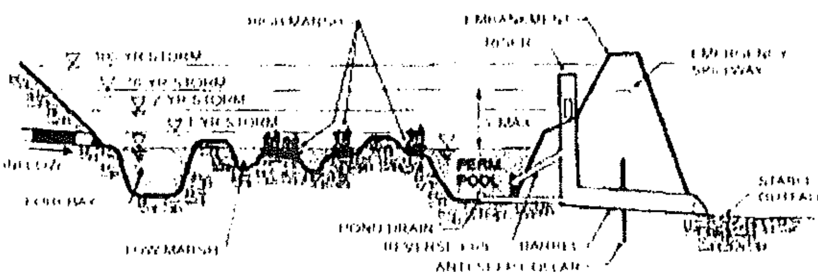


- **Wet Pond/Wetland System**



- **Pocket Wetland**





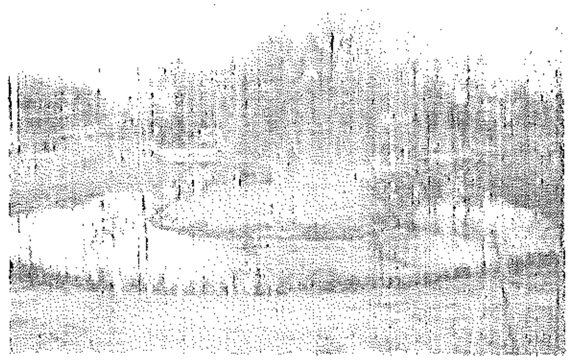
- **Offline Constructed Wetland**
- **Retrofit of existing detention basins**

Design Considerations

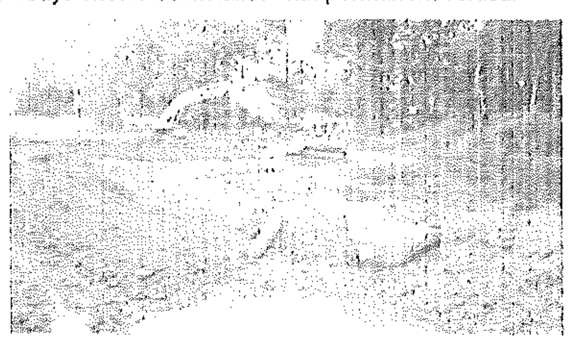
1. HYDROLOGY. Constructed Wetlands must be able to receive and retain enough flow from rain, runoff, and groundwater to ensure long-term viability. Hydrologic calculations (or a water balance) should be performed to verify this. Shallow marsh areas can become dry at the surface but not for greater than one month, even in the most severe drought. A permanent water surface in the deeper areas of the CWs should be maintained during all but the driest periods. A relatively stable normal water surface elevation will reduce the stress on wetland vegetation. A CWs must have a drainage area of at least 10 acres (5 acres for "pocket" wetlands) or some means of sustaining constant inflow. Even with a large drainage area, a constant source of inflow can improve the biological health and effectiveness of a Constructed Wetland. Pennsylvania's precipitation is generally well distributed throughout the year and is therefore suited for CWs.
2. UNDERLYING SOILS. Underlying soils must be identified and tested. Generally hydrologic soil groups "C" and "D" are suitable without modification, "A" and "B" soils may require a clay or synthetic liner. Soil permeability must be tested in the proposed Constructed Wetland location to ensure that excessive infiltration will not cause the CWs to dry out. If necessary, CWs should have a highly- compacted subsoil or an impermeable liner to minimize infiltration.
3. PLANTING SOIL. Organic soils should be used for Constructed Wetlands. Organic soils can serve as a sink for pollutants and generally have high water holding capacities. They will also facilitate plant growth and propagation and may hinder invasion of undesirable species.
4. SIZE AND VOLUME. The area required for a CWs is generally 3 to 5 percent of its drainage area. CWs should be sized to treat the water quality volume and, if necessary, to mitigate the peak rates for larger events.
5. VEGETATION. Vegetation is an integral part of a Wetland system. Vegetation may help to reduce flow velocities, promote settling, provide growth surfaces for beneficial microbes, uptake pollutants, prevent resuspension, provide filtering, limit erosion, prevent short-circuiting, and maintain healthy bottom sediments (Braskerud, 2001). Constructed Wetlands should have several different zones of vegetation as described in Table 6.6.1-1. The emergent vegetation zone (areas not more than 18" deep) should comprise about 60 to 65 percent of the normal water surface area, although recommendations in recent literature range from less than 50 to over 80 percent. Robust, non-invasive, perennial plants that establish quickly are ideal for CWs. The designer should select species that are tolerant of a range of depths, inundation periods, etc. Monoculture planting must be avoided due to the risk from pests and disease. Use local recommended plant lists.

Table 6.6.1-1

Vegetation Zone	Description
Open Water	Areas between 18 inches and 6 feet deep
Emergent	Areas up to 18 inches deep
Low Marsh	Portion of Emergent Zone between 6 and 18 inches deep
High Marsh	Portion of Emergent Zone up to 6 inches deep
Ephemeral Storage	Area periodically inundated during runoff events
Buffer	Area outside of maximum water surface elevation



6. CONFIGURATION.
   a. General. Constructed Wetlands should be designed with a length to width ratio of at least 2:1 wherever possible. If the length to width ratio is lower, the flow pathway through the CWs should be maximized. CWs should not be constructed within 10 feet of the property line or within 50 feet of a private well or septic system. CWs should be designed so that the 10-year water surface elevation does not exceed the normal water surface elevation by more than 3 feet. Slopes in and around Constructed Wetlands should be 4:1 to 5:1 (H:V) wherever possible. Constructed wetlands should be located outside of any natural watercourse.
   b. Forebay/Inflows. Constructed Wetlands should have a forebay at all major inflow points to capture coarse sediment, prevent excessive sediment accumulation in the remainder of the CWs, and minimize erosion by inflow. The forebays should contain 10 to 15 percent of the total permanent pool volume and should be 4 to 6 feet deep (at least as deep as other open water areas). They should be physically separated from the rest of the wetland by a berm, gabion wall, etc. Flows exiting the forebay should be non-erosive to the newly constructed CWs. Vegetation within forebays can increase sedimentation and reduce resuspension/erosion. The forebay bottom can be hardened to facilitate sediment removal. Forebays should be installed with permanent vertical markers that indicate sediment depth. Inflow channels should be fully stabilized. Inflow pipes can discharge to the surface or be partially submerged. CWs should be protected from the erosive force of the inflow to prevent the resuspension of previously collected sediment during large flows.



   c. Vegetation and Open Water Zones. About half of the emergent vegetation zone should be high marsh (up to 6" deep) and half should be low marsh (6" to 18" deep). Varying depths throughout the CWs can improve plant diversity and health. The open water zone (approx. 35 to 40% of the total surface area) should be between 18 inches and 6 feet deep. Allowing a limited 5-foot deep area can prevent short-circuiting by encouraging mixing, enhance aeration of water, prevent resuspension, minimize thermal impacts, and limit mosquito growth. Alternating areas of emergent vegetation zone (up to 18 inches deep) and open water zone – as shown in Figures 6.13-2 and 6.13-4 – can also minimize short-circuiting and hinder mosquito propagation.

d. Outlet. Outlet control devices should be in open water areas 4 to 6 feet deep comprising about 5 percent of the total surface area to prevent clogging and allow the CWs to be drained for maintenance. Outlet devices are generally multistage structures with pipes, orifices, or weirs for flow control. Orifices should be at least 2.5 inches in diameter and should be protected from clogging. Outlet devices should be installed in the embankment for accessibility. It is recommended that outlet devices enable the normal water surface to be varied. This allows the water level to be adjusted (if necessary) seasonally, as the CWs accumulates sediment over time, if desired grades are not achieved, or for mosquito control. The outlet pipe should generally be fitted with an anti-seep collar. Online facilities should have an emergency spillway that can safely pass the 100-year storm with 1 foot of freeboard. All outflows should be conveyed downstream in a safe and stable manner.

e. Safety Benches. All areas that are deeper than 4 feet should have two safety benches, each 4 to 6 feet wide. One should be situated about 1 to 1.5 feet above the normal water elevation and the other 2 to 2.5 feet below the water surface.

7. CONSTRUCTED WETLAND BUFFER. To enhance habitat value, visual aesthetics, and wetland health, a 25-foot buffer should be added from the maximum water surface elevation. The buffer should be planted with trees, shrubs, and native ground covers. Existing trees within the buffer should be preserved. If soils in the buffer will become compacted during construction, soil restoration should take place to aid buffer vegetation.
8. MAINTENANCE ACCESS. Permanent access must be provided to the forebay, outlet, and embankment areas. It should be at least 9 feet wide, have a maximum slope of 15%, and be stabilized for vehicles.
9. PLAN ELEMENTS. The plans detailing the Constructed Wetlands should clearly show the CWs configuration, elevations and grades, depth/vegetation zones, and the location, quantity, and propagation methods of wetland/buffer vegetation. Plans should also include site preparation techniques, construction sequence, as well as maintenance schedules and requirements.
10. REGULATION. Constructed Wetlands that have drainage areas over 100 acres, embankments greater than 15 feet high, or a capacity greater than 50 acre-feet may be regulated as a dam by PADEP (see Title 25, Chapter 105 of the Pennsylvania Code).

Detailed Stormwater Functions

Volume Reduction Calculations

Although not typically considered a volume-reducing BMP, Constructed Wetlands can achieve some volume reduction through evapotranspiration, especially during small storms. An evapotranspiration study could be done to account for potential volume reduction credit. Hydrologic calculations that should be performed to verify that the CWs will have a viable amount of inflow can also predict the water surface elevation under varying conditions. The volume stored between the predicted water level and the lowest outlet elevation will be removed from the storm that occurs under those conditions.

Peak Rate Mitigation Calculations

Peak rate is primarily controlled in Constructed Wetlands through the transient storage above the normal water surface. See in Section 8 for Peak Rate Mitigation methodology.

Water Quality Improvement
Constructed Wetlands improve runoff quality through settling, filtration, uptake, chemical and biological decomposition, volatilization, and adsorption. Constructed Wetlands are effective at removing many common stormwater pollutants including suspended solids, heavy metals, total phosphorus, total nitrogen, toxic organics, and petroleum products. The pollutant removal effectiveness varies by season and may be affected by the age of the wetland. It has been suggested that Constructed wetlands do not remove nutrients in the long term unless vegetation is harvested because captured nutrients are released back into the water by decaying plant material. Even if this is true, nutrients are generally released gradually and during the non-growing season when downstream susceptibility is generally low (Hammer, 1990). See in Section 8 for Water Quality Improvement methodology which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

1. Separate wetland area from contributing drainage area:
    a. All channels/pipes conveying flows to the Constructed Wetland must be routed away from the wetland area until it is completed and stabilized.
    b. The area immediately adjacent to the Constructed Wetland must be stabilized in accordance with the PADEP's Erosion and Sediment Pollution Control Program Manual (2000 or latest edition) prior to construction of the wetland.

2. Clearing and Grubbing:
    a. Clear the area to be excavated of all vegetation.
    b. Remove all tree roots, rocks, and boulders.
    c. Fill all stump holes, crevices and similar areas with impermeable materials.

3. Excavate bottom of Constructed Wetland to desired elevation (Rough Grading).

4. Install surrounding embankments and inlet and outlet control structures.

5. Grade and compact subsoil.

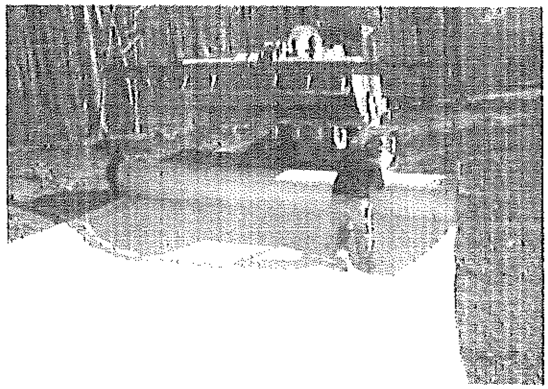
6. Apply and grade planting soil.
a. Matching design grades is crucial because aquatic plants can be very sensitive to depth.

7. Apply geo-textiles and other erosion-control measures.

8. Seed, plant and mulch according to Planting Plan

9. Install any anti-grazing measures, if necessary.

10. Follow required maintenance and monitoring guidelines.



Maintenance Issues

Constructed Wetlands must have a maintenance plan and privately owned facilities should have an easement, deed restriction, or other legal measure to prevent neglect or removal. During the first growing season, vegetation should be inspected every 2 to 3 weeks. During the first 2 years, CWs should be inspected at least 4 times per year and after major storms (greater than 2 inches in 24 hours). Inspections should access the vegetation, erosion, flow channelization, bank stability, inlet/outlet conditions, and sediment/debris accumulation. Problems should be corrected as soon as possible. Wetland and buffer vegetation may require support – watering, weeding, mulching, replanting, etc. – during the first 3 years. Undesirable species should be removed and desirable replacements planted if necessary.

Once established, properly designed and installed Constructed Wetlands should require little maintenance. They should be inspected at least semiannually and after major storms as well as rapid ice breakup. Vegetation should maintain at least an 85 percent cover of the emergent vegetation zone. Annual harvesting of vegetation may increase the nutrient removal of CWs; it should generally be done in the summer so that there is adequate regrowth before winter. Care should be taken to minimize disturbance, especially of bottom sediments, during harvesting. The potential disturbance from harvesting may outweigh its benefits unless the CWs receives a particularly high nutrient load or discharges to a nutrient sensitive waterbody. Sediment should be removed from the forebay before it occupies 50 percent of the forebay, typically every 3 to 7 years.

Cost Issues

The construction cost of Constructed Wetlands can vary greatly depending on the configuration, location, site-specific conditions, etc. Typical construction costs in 2004 dollars range from approximately $30,000 to $65,000 per acre (USEPA Wetlands Fact Sheet, 1999). Costs are generally most dependent on the amount of earthwork and the planting. Annual maintenance costs have been reported to be approximately 2 to 5 percent of the capital costs although there is very little data available to support this.

Specifications:

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting.

The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Excavation**
   a. The area to be used for the CWs should be excavated to the required depth below the desired bottom elevation to accommodate any required impermeable liner, organic matter, and/or planting soil.
   b. The compaction of the subgrade and/or the installation of any impermeable liners will follow immediately.
2. **Subsoil Preparation**
   a. Subsoil shall be free from hard clods, stiff clay, hardpan, ashes, slag, construction debris, petroleum hydrocarbons, or other undesirable material. Subsoil must not be delivered in a frozen or muddy state.
   b. Scarify the subsoil to a depth of 8 to 10 inches with a disk, rototiller, or similar equipment.
   c. Roll the subsoil under optimum moisture conditions to a dense seal layer with four to six passes of a sheepsfoot roller or equivalent. The compacted seal layer shall be at least 8 inches thick.
3. **Impermeable Liner**
   a. If necessary, install impermeable liner in accordance with manufacturer's guidelines.
   b. Place a minimum 12 inches of subsoil on top of impermeable liner in addition to planting soil.
4. **Planting Soil (Topsoil)**
   a. See Local Specifications for general Planting Soil requirements.
   b. Use a minimum of 12 inches of topsoil in marsh areas of the Wetland. If natural topsoil from the site is to be used it must have at least 8 percent organic carbon content (by weight) in the A-horizon for sandy soils and 12% for other soil types.
   c. If planting soil is being imported it should be made up of equivalent proportions of organic and mineral materials.
   d. Lime should not be added to planting soil unless absolutely necessary as it may encourage the propagation of invasive species.
   e. The final elevations and hydrology of the wetland zones should be evaluated prior to planting to determine if grading or planting changes are required.
5. **Vegetation**
   a. Plant Lists for Constructed Wetlands can be found in Appendix B. No substitutions of specified plants will be accepted without prior approval of the designer. Planting locations shall be based on the Planting Plan and directed in the field by a qualified wetland ecologist.
   b. All wetland plant stock shall exhibit live buds or shoots. All plant stock shall be turgid, firm, and resilient. Internodes of rhizomes may be flexible and not necessarily rigid. Soft or mushy stock shall be rejected. The stock shall be free of deleterious insect infestation, disease and defects such as knots, sun-scald, injuries, abrasions, or disfigurement that could adversely affect the survival or performance of the plants.
   c. All stock shall be free from invasive or nuisance plants or seeds such as those listed in Appendix B.
   d. During all phases of the work, including transport and onsite handling, the plant materials shall be carefully handled and packed to prevent injuries and desiccation. During transit and onsite handling, the plant material shall be kept from freezing and shall be kept covered, moist, cool, out of the weather, and out of the wind and sun. Plants shall be watered to maintain moist soil and/or plant conditions until accepted.
   e. Plants not meeting these specifications or damaged during handling, loading, and unloading will be rejected.

f. Detailed planting specifications can be found in Appendix B.

6. **Outlet Control Structure**
   a. Outlet control structures shall be constructed of non-corrodible material.
   b. Outlets shall be resistant to clogging by debris, sediment, floatables, plant material, or ice.
   c. Materials shall comply with applicable specifications (PennDOT or AASHTO, latest edition)

References

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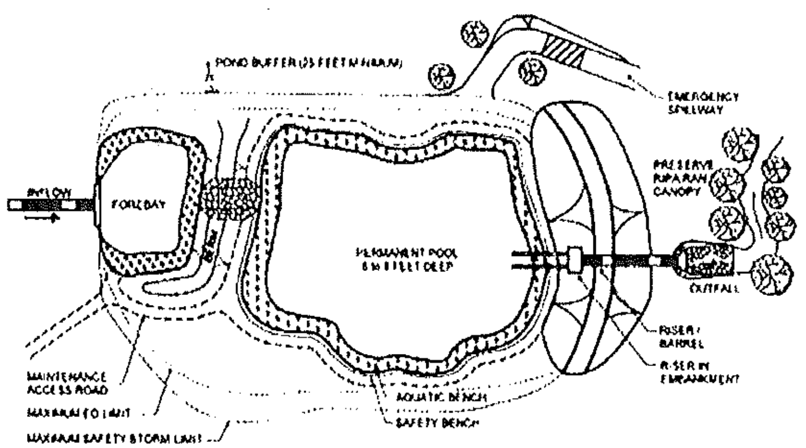
BMP 6.6.2: Wet Pond/Retention Basin

Wet Ponds/Retention Basins are stormwater basins that include a substantial permanent pool for water quality treatment and additional capacity above the permanent pool for temporary runoff storage.

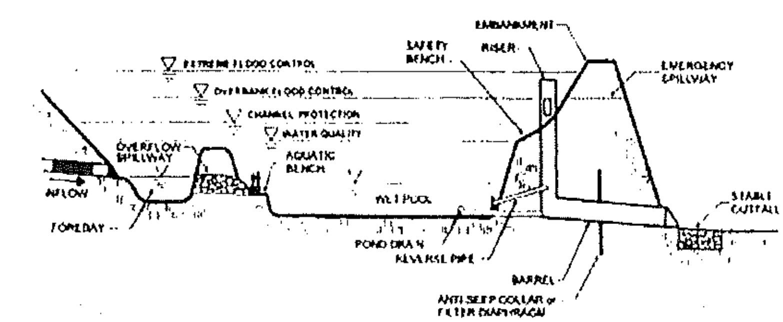
Key Design Elements	Potential Applications
• Adequate drainage area (usually 5 to 10 acres minimum) or proof of sustained baseflow • Natural high groundwater table • Maintenance of permanent water surface • Should have at least 2 to 1 length to width ratio • Robust and diverse vegetation surrounding wet pond • Relatively impermeable soils • Forebay for sediment collection and removal • Dewatering mechanism	Residential: Yes Commercial: Yes Ultra Urban: Yes Industrial: Yes Retrofit: Yes Highway/Road: Yes **Stormwater Functions** Volume Reduction: Low Recharge: Low Peak Rate Control: High Water Quality: Medium **Water Quality Functions** TSS: 70% TP: 60% NO3: 30%

Description

Wet Detention Ponds are stormwater basins that include a permanent pool for water quality treatment and additional capacity above the permanent pool for temporary storage. Wet Ponds should include one or more forebays that trap course sediment, prevent short-circuiting, and facilitate maintenance. The pond perimeter should generally be covered by a dense stand of emergent wetland vegetation. While they do not achieve significant groundwater recharge or volume reduction, they can be effective for pollutant removal and peak rate mitigation. Wet Ponds (WPs) can also provide aesthetic and wildlife benefits. WPs require an adequate source of inflow to maintain the permanent water surface. Due to the potential to discharge warm water, wet ponds should be used with caution near temperature sensitive waterbodies. Properly designed and maintained WPs generally do not support significant mosquito populations (O'Meara).



PLAN VIEW



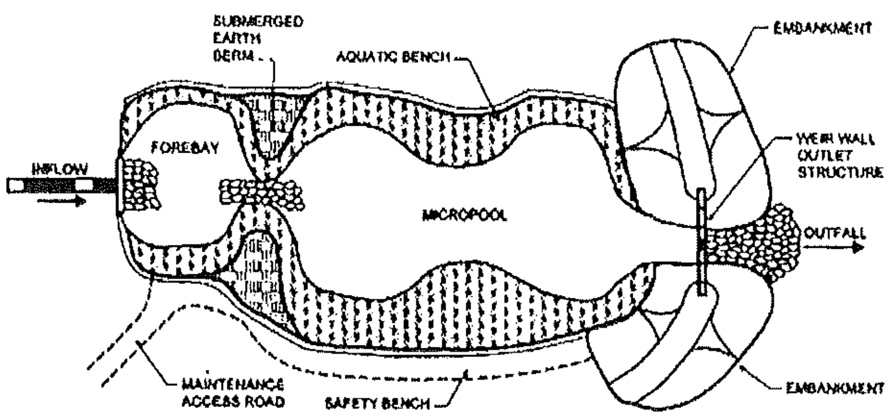
PROFILE

Variations

Wet Ponds can be designed as either an online or offline facilities. They can also be used effectively in series with other sediment reducing BMPs that reduce the sediment load such as vegetated filter strips, swales, and filters. Wet Ponds may be a good option for retrofitting existing dry detention basins. WPs are often organized into three groups:

- Wet Ponds primarily accomplish water quality improvement through displacement of the permanent pool and are generally only effective for small inflow volumes (often they are placed offline to regulate inflow).
- Wet Detention Ponds are similar to Wet Ponds but use extended detention as another mechanism for water quality and peak rate control.
- Pocket Wet Ponds are smaller WPs that serve drainage areas between approximately 5 and 10 acres and are constructed near the water table to help maintain the permanent pool. They often include extended detention as well.

This BMP focuses on Wet Detention Ponds as described above because this tends to be the most common and effective type of Wet Pond. For more information on other types of wet ponds, please consult the "References and Additional Resources" list.



Applications

- **Wet Ponds**
- **Wet Detention Ponds**
- **Pocket Wet Pond**
- **Offline Wet Pond**
- **Retrofit for existing detention basins**

Design Considerations

1. HYDROLOGY. Wet Ponds should be able to receive and retain enough flow from rain, runoff, and groundwater to ensure long-term viability. A permanent water surface in the deeper areas of the WP should be maintained during all but the driest periods. A relatively stable permanent water surface elevation will reduce the stress on vegetation in and adjacent to the pond. A WP should have a drainage area of at least 10 acres (5 acres for Pocket Wet Ponds) or some means of sustaining constant inflow. Even with a large drainage area, a constant source of inflow can improve the biological health and effectiveness of a Wet Pond while discouraging mosquito growth. Pennsylvania's precipitation is generally well distributed throughout the year and is therefore suited for WPs.
2. UNDERLYING SOILS. Underlying soils must be identified and tested. Generally hydrologic soil groups "C" and "D" are suitable without modification, "A" and "B" soils may require modification to reduce permeability. Soil permeability must be tested in the proposed Wet Pond location to ensure that excessive infiltration will not cause the WP to dry out.
3. PLANTING SOIL. Organic soils should be used for shallow areas within Wet Ponds. Organic soils can serve as a sink for pollutants and generally have high water holding capacities. They will also facilitate plant growth and propagation and may hinder invasion of undesirable species.
4. SIZE AND VOLUME. The area required for a WP is generally 1 to 3 percent of its drainage area. WPs should be sized to treat the water quality volume and, if necessary, to mitigate the peak rates for larger events.
5. VEGETATION. Vegetation is an integral part of a Wet Pond system. Vegetation in and adjacent to a pond may enhance pollutant removal, reduce algal growth, limit erosion, improve aesthetics, create habitat, and reduce water warming (Mallin et al., 2002; NJ DEP, 2004; University of Wisconsin, 2000). Wet Ponds should have varying depths to encourage vegetation in shallow areas. The emergent vegetation zone (areas not more than 18" deep) generally supports the majority of aquatic vegetation and should include the pond perimeter. Robust, non-invasive, perennial plants that establish quickly are ideal for WPs. The designer should select species that are tolerant of a range of depths, inundation periods, etc. Monoculture planting should be avoided due to the risk from pests and disease. See local sources for recommended plant lists or Appendix B.

6. CONFIGURATION.
   a. General. Wet Ponds should be designed with a length to width ratio of at least 2:1 wherever possible. If the length to width ratio is lower, the flow pathway through the WP should be maximized. A wedge-shaped pond with the major inflows on the narrow end can prevent short-circuiting and stagnation. WPs should not be constructed within 10 feet of the property line or within 50 feet of a private well or septic system. Slopes in and around Wet Ponds should be 4:1 to 5:1 (horizontal:vertical) or flatter wherever possible (10:1 max. for safety/aquatic benches, see 6.d. below). Wet Ponds should have an average depth of 3 to 6 feet and a maximum depth of 8 feet. This should be shallow enough to minimize thermal stratification and short-circuiting and deep enough to prevent sediment resuspension, reduce algal blooms, and maintain aerobic conditions. Wet ponds should not be constructed within a natural watercourse.
   b. Forebay/Inflows. Wet Ponds should have a forebay at all major inflow points to capture coarse sediment, prevent excessive sediment accumulation in the remainder of the WP, and minimize erosion by inflow. The forebays should contain 10 to 15 percent of the total permanent pool volume and should be 4 to 6 feet deep. They should be physically separated from the rest of the pond by a berm, gabion wall, etc. Flows exiting the forebay should be non-erosive to the newly constructed WP. Vegetation within forebays can increase sedimentation and reduce resuspension/erosion. The forebay bottom can be constructed of hardened materials to facilitate sediment removal. Forebays should be installed with permanent vertical markers that indicate sediment depth. Inflow channels should be fully stabilized. Inflow pipes can discharge to the surface or be partially submerged. Forebays should be offline (out of the path of higher flows) to prevent resuspension of previously collected sediment during large storms.
   c. Outlet. Outlet control devices should draw from open water areas 5 to 7 feet deep to prevent clogging and allow the WP to be drained for maintenance and to provide for additional temperature benefits. Outlet devices are generally multistage structures with pipes, orifices, or weirs for flow control. A reverse slope pipe terminating 2 to 3 feet below the normal water surface, minimizes the discharge of warm surface water and is less susceptible to clogging by floating debris. Orifices, if used, should be at least 2.5 inches in diameter and should be protected from clogging. Outlet devices should be installed in the embankment for accessibility. If possible, outlet devices should enable the normal water surface to be varied. This allows the water level to be adjusted (if necessary) seasonally, as the WP accumulates sediment over time, if desired grades are not achieved, or for mosquito control. A pond drain should also be included which allows the permanent pool to be completely drained for maintenance within 24 hours. The outlet pipe should generally be fitted with an anti-seep collar through the embankment. Online facilities should have an emergency spillway that can safely pass the 100-year storm with 1 foot of freeboard. All outflows should be conveyed downstream in a safe and stable manner.
   d. Safety/Aquatic Benches. All areas that are deeper than 4 feet should have two safety benches, totaling 15 feet in width. One should start at the normal water surface and extend up to the pond side slopes at a maximum slope of 10 percent. The other should extend from the water surface into the pond to a maximum depth of 18 inches, also at slopes no greater than 10 percent.
7. WET POND BUFFER. To enhance habitat value, visual aesthetics, water temperature, and pond health, a 25-foot buffer should be added from the maximum water surface elevation. The buffer should be planted with trees, shrubs, and native ground covers. Except in maintenance access areas, turf grass should not be used. Existing trees within the buffer should be preserved. If soils in the buffer will become compacted during construction, soil restoration should take place to aid buffer vegetation.

8. MAINTENANCE ACCESS. Permanent access must be provided to the forebay, outlet, and embankment areas. It should be at least 9 feet wide, have a maximum slope of 15%, and be stabilized for vehicles.
9. PLAN ELEMENTS. The plans detailing the Wet Ponds should clearly show the WP configuration, inlets and outlets, elevations and grades, safety/aquatic benches, and the location, quantity, and propagation methods of pond/buffer vegetation. Plans should also include site preparation techniques, construction sequence, as well as maintenance schedules and requirements.
10. REGULATION. Wet Ponds that have drainage areas over 100 acres, embankments greater than 15 feet high, or a capacity greater than 50 acre-feet may be regulated as a dam by PADEP (see Title 25, Chapter 105 of the Pennsylvania Code).

Detailed Stormwater Functions

Volume Reduction Calculations

Although not typically considered a volume-reducing BMP, Wet Ponds can achieve some volume reduction through infiltration and evapotranspiration, especially during small storms. According to the International Stormwater BMP Database, wet ponds have an average annual volume reduction of 7 percent (Strecker et al., 2004). Hydrologic calculations that should be performed to verify that the WP will have a viable amount of inflow can also predict the water surface elevation under varying conditions. The volume stored between the predicted water level and the lowest outlet elevation will be removed from the that design storm.

Peak Rate Mitigation Calculations

Peak rate is primarily controlled in Wet Ponds through the transient storage above the normal water surface. See Section 8 for Peak Rate Mitigation methodology.

Water Quality Improvement

Wet Ponds improve runoff quality through settling, filtration, uptake, chemical and biological decomposition, volatilization, and adsorption. WPs are relatively effective at removing many common stormwater pollutants including suspended solids, heavy metals, total phosphorus, total nitrogen, and pathogens. The pollutant removal effectiveness varies by season and may be affected by the age of the WP. It has been suggested that this type of BMP does not provide significant nutrient removal in the long term unless vegetation is harvested because captured nutrients are released back into the water by decaying plant material. Even if this is true, nutrients are usually released gradually and during the non-growing season when downstream susceptibility is generally low (Hammer, 1990). See Section 8 for Water Quality Improvement methodology, which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

1. Separate wet pond area from contributing drainage area:
    a. All channels/pipes conveying flows to the WP should be routed away from the WP area until it is completed and stabilized.
    b. The area immediately adjacent to the WP should be stabilized in accordance with the PADEP's *Erosion and Sediment Pollution Control Program Manual* (2000 or latest edition) prior to construction of the WP.

2. Clearing and Grubbing:
    a. Clear the area to be excavated of all vegetation.
    b. Remove all tree roots, rocks, and boulders.
    c. Fill all stump holes, crevices and similar areas with impermeable materials.

3. Excavate bottom of WP to desired elevation (Rough Grading).

4. Install surrounding embankments and inlet and outlet control structures.

5. Grade and prepare subsoil.

6. Apply and grade planting soil.
    a. Matching design grades is crucial because aquatic plants can be very sensitive to depth.

7. Apply erosion-control measures.

8. Seed, plant and mulch according to Planting Plan

9. Install any anti-grazing measures, if necessary.

10. Follow required maintenance and monitoring guidelines.

Maintenance Issues

Wet Ponds should have a maintenance plan and privately owned facilities should have an easement, deed restriction, or other legal measure to prevent neglect or removal. During the first growing season or until established, vegetation should be inspected every 2 to 3 weeks. WPs should be inspected at least 4 times per year and after major storms (greater than 2 inches in 24 hours) or rapid ice breakup. Inspections should access the vegetation, erosion, flow channelization, bank stability, inlet/outlet conditions, embankment, and sediment/debris accumulation. The pond drain should also be inspected and tested 4 times per year. Problems should be corrected as soon as possible. Wet Pond and buffer vegetation may need support (watering, weeding, mulching, replanting, etc.) during the first 3 years. Undesirable species should be carefully removed and desirable replacements planted if necessary.

Once established, properly designed and installed Wet Ponds should require little maintenance. Vegetation should maintain at least an 85 percent cover of the emergent vegetation zone and buffer area. Annual harvesting of vegetation may increase the nutrient removal of WPs; if performed it should generally be done in the summer so that there is adequate regrowth before winter. Care should be taken to minimize disturbance, especially of bottom sediments, during harvesting. The potential disturbance from harvesting may outweigh its benefits unless the WP receives a particularly high nutrient load or discharges to a nutrient sensitive waterbody. Sediment should be removed from the forebay before it occupies 50 percent of the forebay, typically every 5 to 10 years.

Cost Issues

The construction cost of Wet Ponds can vary greatly depending on the configuration, location, site-specific conditions, etc. Typical construction costs in 2004 dollars range from approximately $25,000 to $50,000 per acre-foot of storage (based on USEPA, 1999). Costs are generally most dependent on the amount of earthwork and the planting. Annual maintenance costs have been reported to be approximately 3 to 5 percent of the capital costs although there is little data available to support this.In addition to the construction and maintenance costs, there is the cost or loss of value for the property involved.

Specifications:

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Excavation**
    a. The area to be used for the WP should be excavated to the required depth below the desired bottom elevation to accommodate any required impermeable liner, organic matter, and/or planting soil.
    b. The compaction of the subgrade and/or the installation of any impermeable liners will follow immediately.
2. **Subsoil Preparation**
    a. Subsoil shall be free from hard clods, stiff clay, hardpan, ashes, slag, construction debris, petroleum hydrocarbons, or other undesirable material. Subsoil must not be delivered in a frozen or muddy state.
    b. Scarify the subsoil to a depth of 8 to 10 inches with a disk, rototiller, or similar equipment.
    c. Roll the subsoil under optimum moisture conditions to a dense layer with four to six passes of a sheepsfoot roller or equivalent. The compacted layer shall be at least 8 inches thick.
3. **Planting Soil (Topsoil)**
    a. Use a minimum of 12 inches of topsoil in the emergent vegetation zone (less than 18" deep) of the pond. If natural topsoil from the site is to be used it must have at least 8 percent organic carbon content (by weight) in the A-horizon for sandy soils and 12% for other soil types.
    b. If planting soil is being imported it should be made up of equivalent proportions of organic and mineral materials.
    c. Lime should not be added to planting soil unless absolutely necessary as it may encourage the propagation of invasive species.
    d. The final elevations and hydrology of the vegetative zones should be evaluated prior to planting to determine if grading or planting changes are required.
4. **Vegetation**
    a. Plant Lists for WPs can be found locally. No substitutions of specified plants will be accepted without prior approval of the designer. Planting locations shall be based on the Planting Plan and directed in the field by a qualified wetland ecologist.
    b. All Wet Pond plant stock shall exhibit live buds or shoots. All plant stock shall be turgid, firm, and resilient. Internodes of rhizomes may be flexible and not necessarily rigid. Soft or mushy stock shall be rejected. The stock shall be free of deleterious insect infestation, disease and defects such as knots, sun-scald, injuries, abrasions, or disfigurement that could adversely affect the survival or performance of the plants.
    c. All stock shall be free from invasive or nuisance plants or seeds.
    d. During all phases of the work, including transport and onsite handling, the plant materials shall be carefully handled and packed to prevent injuries and desiccation. During transit and onsite handling, the plant material shall be kept from freezing and shall be kept covered, moist, cool, out of the weather, and out of the wind and sun. Plants shall be watered to maintain moist soil and/or plant conditions until accepted.
    e. Plants not meeting these specifications or damaged during handling, loading, and unloading will be rejected.
    f. Detailed planting specifications can be found locally, and in Appendix B.
5. **Outlet Control Structure**
    a. Outlet control structures shall be constructed of non-corrodible material.
    b. Outlets shall be resistant to clogging by debris, sediment, floatables, plant material, or ice.
    c. Materials shall comply with applicable specifications (PennDOT or AASHTO, latest edition)

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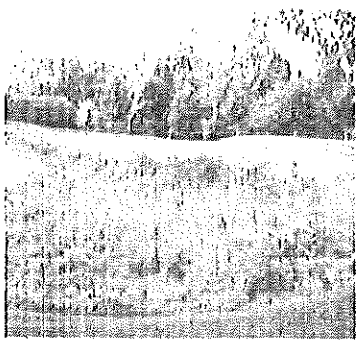
BMP 6.6.3: Dry Extended Detention Basin



A dry extended detention basin is an earthen structure constructed either by impoundment of a natural depression or excavation of existing soil, that provides temporary storage of runoff and functions hydraulically to attenuate stormwater runoff peaks. The dry detention basin, as constructed in countless locations since the mid-1970's and representing the primary BMP measure until now, has served to control the peak rate of runoff, although some water quality benefit accrued by settlement of the larger particulate fraction of suspended solids. This extended version is intended to enhance this mechanism in order to maximize water quality benefits.

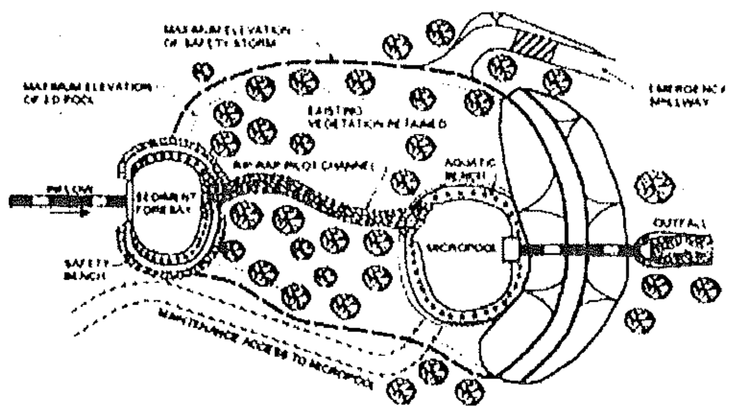
The basin outlet structure must be designed to detain runoff from the stormwater quality design storm for extended periods. Some volume reduction is also achieved in a dry basin through initial saturation of the soil mantle (even when compacted) and some evaporation takes place during detention. The net volume reduction for design storms is minimal, especially if the precedent soil moisture is assumed as in other volume reduction BMPs.

Key Design Elements	
• Evaluation of the device chosen should be balanced with cost • Hydraulic capacity controls effectiveness • Ideal in combination with other BMPs • Regular maintenance is necessary including periodic sediment removal	**Potential Applications** Residential: Yes Commercial: Yes Ultra Urban: Yes Industrial: Yes Retrofit: Yes Highway/Road: Yes **Stormwater Functions** Volume Reduction: Low Recharge: None Peak Rate Control: High Water Quality: Low **Water Quality Functions** TSS: 60% TP: 40% NO3: 20%

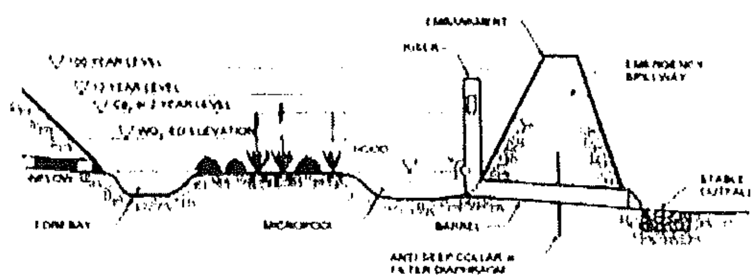
Description

Dry extended detention basins are surface stormwater structures which provide for the temporary storage of stormwater runoff to prevent downstream flooding impacts. Water quality benefits may be achieved with extended detention of the runoff volume from the water quality design storm.

- The primary purpose of the detention basin is the attenuation of stormwater runoff peaks.
  - Detention basins should be designed to control runoff peak flow rates of discharge for the 1 year through 100 year events.
  - Inflow and discharge hydrographs should be calculated for each selected design storm. Hydrographs should be based on the 24-hour rainfall event.



PLAN VIEW



PROFILE

- Basins should be designed to provide water quality treatment storage to capture the computed runoff volume of the water quality design storm.
  - Detention basins should have a sediment forebay or equivalent upstream pretreatment. The forebay should consist of a separate cell that is offline (so as to not resuspend sediment, formed by an acceptable barrier and will need periodic sediment removal.

- A micropool storage area should be designed where feasible for the extended detention of runoff volume from the water quality design storm.
- Flow paths from inflow points to outlets should be maximized.

Variations

Sub-surface extended detention

Extended detention storage can also be provided in a variety of sub-surface structural elements, such as underground vaults, tanks, large pipes or other structural media placed in an aggregate filled bed in the soil mantle. All such systems are designed to provide runoff peak rate mitigation as their primary function, but some pollutant removal may be included. Regular maintenance is needed, since the structure must be drained within a design period and cleaned to assure detention capacity for subsequent rainfall events. These facilities are usually intended for space-limited applications and are not intended to provide significant water quality treatment.

- Underground vaults are typically box shaped underground stormwater storage facilities constructed of reinforced concrete, while tanks are usually constructed of large diameter metal or plastic pipe. They may be situated within a building, but the use of internal space is frequently not cost beneficial.
    - Storage design and routing methods are the same as for surface detention basins.
    - Underground vaults and tanks do not provide water quality treatment and should be used in combination with a pretreatment BMP.

- Underground detention beds can be constructed by excavating a subsurface area and filling with uniformly graded aggregate for support of overlying land uses.
    - This approach may be used where space is limited but subsurface infiltration is not feasible due to high water table conditions or shallow soil mantle.
    - As with detention vaults and tanks, this facility provides minimal water quality treatment and should be used in combination with a pretreatment BMP.
    - It is recommended that underground detention facilities not be lined to allow for even minimal infiltration, except in the case where toxic contamination is possible.

Applications

- **Low Density Residential Development**
- **Industrial Development**
- **Commercial Development**
- **Urban Areas**

Design Considerations

1. **Storage Volume, Depth and Duration**

   a. Extended detention basins should be designed to mitigate runoff peak flow .rates.b. An emergency outlet or spillway which is capable of conveying the spillway design flood (SDF) should be included in the design. The SDF is usually equal to the 100-year design flood
   c. Extended detention basins should be designed to treat the runoff volume produced by the water quality design storm.

d. Extended Detention Basins are designed to achieve a specified detention time. Details on the detention time are outlined in Chapter 3.
e. The lowest elevation within an extended dry detention basin should be at least 2 feet above the seasonal high water table. If high water table conditions are anticipated, then the design of a wet pond, constructed wetland or bioretention facility should be considered.

2. **Dry Extended Detention Basin Location**

a. Extended detention basins should be located down gradient of disturbed or developed areas on the site. The basin should collect as much site runoff as possible, especially from the site's impervious surfaces (roads, parking, buildings, etc.).
b. Extended detention basins should not be constructed on steep slopes, nor should slopes be significantly altered or modified to reduce the steepness of the existing slope, for the purpose of installing a basin.
c. Extended detention basins should not worsen the runoff potential of the existing site by removal of trees for the purpose of installing a basin.
d. Extended detention basins should not be constructed in areas with high quality and/or well draining soils, which are adequate for the installation of BMPs capable of achieving stormwater infiltration.
e. Extended detention basins should not be constructed within jurisdictional waters, including wetlands.

3. **Basin Sizing and Configuration**

a. Basins should be shaped to maximize the length of stormwater flow pathways and minimize short-circuited inlet-outlet systems. Basins should have a minimum width of 10 feet. A minimum length-to-width ratio of 2:1 is recommended to maximize sedimentation.
b. Irregularly shaped basins are encouraged and appear more natural.
c. If site conditions inhibit construction of a long, narrow basin, baffles constructed from earthen berms or other materials can be incorporated into the pond design to "lengthen" the stormwater flow path. Care should be taken to ensure the design storage capacity is provided after baffle installation.
d. Low flow channels, if required, should always be vegetated with a maximum slope of 3 percent to encourage sedimentation. Alternatively, other BMPs may be considered such as wet ponds, constructed wetlands or bioretention.

4. **Embankments**

a. Embankments should be less than 15 feet in height and should have side slopes no steeper than 3:1 (H:V).
b. The basin should have a minimum freeboard of 1 foot above the SDF elevation.

5. **Inlet Structures**

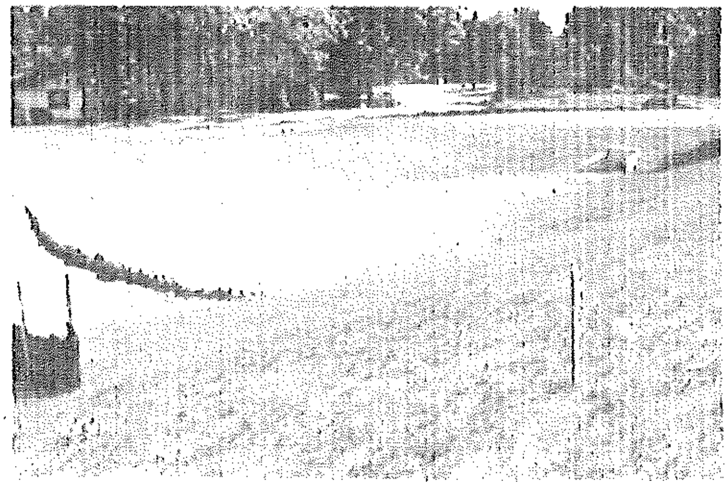
a. Inlet structures to basin should not be submerged at the normal pool depth.
b. Erosion protection measures should be utilized to stabilize inflow structures and channels.

6. **Outlet Design**

   a. In order to meet designs storm requirements, dry extended detention basins should have a multistage outlet structure. Three elements are typically included in this design:
      1. A low-flow outlet that controls the extended detention and functions to slowly release the water quality design storm.
      2. A primary outlet that functions to attenuate the peak of larger design storms.
      3. An emergency overflow outlet/spillway
   b. The primary outlet structure should incorporate weirs, orifices, pipes or a combination of these to control runoff peak rates for required design storms. Water quality storage should be provided below the invert of the primary outlet. When routing basins, the low-flow outlet should be included in the depth-discharge relationship.
   c. Energy dissipaters are to be placed at the end of the primary outlet to prevent erosion. If the basin discharges to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel and to reestablish a forested riparian zone between the outlet and natural channel. Where feasible, a multiple orifice outlet system is preferred to a single pipe.
   d. The orifice should typically be no smaller than 2.5 inches in diameter. However, the orifice diameter may be reduced to 1 inch if adequate protection from clogging is provided.
   e. The hydraulic design of all outlet structures should consider any tailwater effects of downstream waterways.
   f. The primary and low flow outlet should be protected from clogging by an external trash rack.

7. **Sediment Forebay**

   a. Forebays should be incorporated into the extended detention design. The forebay storage volume is included for the water quality volume requirement.
   b. Forebays should be vegetated to improve filtering of runoff, to reduce runoff velocity, and to stabilize soils against erosion. Forebays are typically constructed as shallow marsh areas and should adhere to the following design criteria:
      1. It is recommended that forebays have a minimum length of 10 feet.
      2. Storage should be provided to trap the anticipated sediment volume produced over a period of 2 years.
      3. Forebays should be protected from the erosive force of the inflow to prevent resuspension of previously collected sediment during large storms (typically constructed offline).



8. **Vegetation and Soils Protection**
   a. Care should be taken to prevent compaction of in situ soils in the bottom of the extended detention basin in order to promote healthy plant growth and to encourage infiltration. If soils compaction is not prevented during construction, soils should be restored as discussed in BMP 6.7.3 – Soils Amendment & Restoration.
   b. It is recommended that basin bottoms be vegetated in a diverse native planting mix to reduce maintenance needs, promote natural landscapes, and increase infiltration potential. Vegetation may include trees, woody shrubs and meadow/wetland herbaceous plants.
   c. Woody vegetation should not be planted on the embankments or within 25 feet of the emergency overflow spillway.
   d. Meadow grasses or other deeply rooted herbaceous vegetation is recommended on the interior slope of embankments.
   e. Fertilizers and pesticides should not be used.

9. **Special Design Considerations**
   a. Ponds that have embankments higher than 15 feet, have a drainage of more than 100 acres or will impound more that 50 acre-feet of runoff during the high-water condition will be regulated as dams by PADEP. The designer shall consult Pennsylvania Chapter 105 to determine which provisions may apply to the specific project in question.
   b. Extended detention ponds should not be utilized as recreation areas due to health and safety issues. Design features that discourage access are recommended.

Detailed Stormwater Functions

Peak Rate Mitigation

Inflow and discharge hydrographs should be calculated and routed for each design storm. Hydrographs should be based on a 24-hour rainfall event.

Water Quality Improvement

Water quality mitigation is partially achieved by retaining the runoff volume from the water quality design storm for a minimum prescribed period as specified in Chapter 3. Sediment forebays should be incorporated into the design to improve sediment removal. The storage volume of the forebay may be included in the calculated storage of the water quality design volume.

Construction Sequence

1. Install all temporary erosion and sedimentation controls.
   a. The area immediately adjacent to the basin must be stabilized in accordance with the PADEP's *Erosion and Sediment Pollution Control Program Manual* (2000 or latest edition) prior to basin construction.
2. Prepare site for excavation and/or embankment construction.
   a. All existing vegetation should remain if feasible and should only be removed if necessary for construction.
   b. Care should be taken to prevent compaction of the basin bottom.
   c. If excavation is required, clear the area to be excavated of all vegetation. Remove all tree roots, rocks, and boulders only in excavation area
3. Excavate bottom of basin to desired elevation (if necessary).
4. Install surrounding embankments and inlet and outlet control structures.
5. Grade subsoil in bottom of basin, taking care to prevent compaction. Compact surrounding embankment areas and around inlet and outlet structures.
6. Apply and grade planting soil.
7. Apply geo-textiles and other erosion-control measures.
8. Seed, plant and mulch according to Planting Plan
9. Install any anti-grazing measures, if necessary.

Maintenance Issues

Maintenance is necessary to ensure proper functionality of the extended detention basin and should take place on a quarterly basis. A basin maintenance plan should be developed which includes the following measures:

- All basin structures expected to receive and/or trap debris and sediment should be inspected for clogging and excessive debris and sediment accumulation at least four times per year, as well as after every storm greater than 1 inch.
  - Structures include basin bottoms, trash racks, outlets structures, riprap or gabion structures, and inlets.
- Sediment removal should be conducted when the basin is completely dry. Sediment should be disposed of properly and once sediment is removed, disturbed areas need to be immediately stabilized and revegetated.
- Mowing and/or trimming of vegetation should be performed as necessary to sustain the system, but all detritus should be removed from the basin.
  - Vegetated areas should be inspected annually for erosion.
  - Vegetated areas should be inspected annually for unwanted growth of exotic/invasive species.
  - Vegetative cover should be maintained at a minimum of 95 percent. If vegetative cover has been reduced by 10%, vegetation should be reestablished.

Cost Issues

The construction costs associated with dry extended detention basins can range considerably. One recent study evaluated the cost of all pond systems (Brown and Schueler, 1997). Before adjusting for inflation from 1997, the cost of dry extended detention ponds can be estimated with the equation:

$$C = 12.4V^{0.760}$$

Where:

C = Construction, Design and Permitting Cost
V = Volume needed to control the 10-year storm (cubic feet)
Using this equation, a typical construction costs (1997) are:
$ 41,600 for a 1 acre-foot pond
$ 239,000 for a 10 acre-foot pond
$ 1,380,000 for a 100 acre-foot pond

Dry extended detention basins utilizing highly structural design features (rip-rap for erosion control, etc.) are more costly than naturalized basins. There is an installation cost savings associated with a natural vegetated slope treatment which is magnified by the additional environmental benefits provided. Long-term maintenance costs are reduced when more naturalized approaches are utilized due to the ability of native vegetation to adapt to local weather conditions and a reduced need for maintenance, such as mowing and fertilization.

Normal maintenance costs can be expected to range form 3 to 5 percent of the construction costs on an annual basis.

These costs don't include the cost or value of the property.

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Site Preparation**
    a. All excavation areas, embankments, and where structures are to be installed shall be cleared and grubbed as necessary, but trees and existing vegetation should be retained and incorporated within the dry detention basin area where possible.
    b. Where feasible, trees and other native vegetation should be protected. A minimum 10-foot radius around the inlet and outlet structures can be cleared to allow construction.
    c. Any cleared material should be used as mulch for erosion control or soil stabilization.
    d. Care should be taken to prevent compaction of the bottom of the reservoir. If compaction should occur, soils should be restored and amended.

2. **Earth Fill Material & Placement**
    a. The fill material should be taken from approved designated excavation areas. It should be free of roots, stumps, wood, rubbish, stones greater than 6 inches, or other

objectionable materials. Materials on the outer surface of the embankment must have the capability to support vegetation.

b. Areas where fill is to be placed should be scarified prior to placement. Fill materials for the embankment should be placed in maximum 8-inch lifts. The principal spillway should be installed concurrently with fill placement and not excavated into the embankment.

c. The movement of the hauling and spreading equipment over the site should be controlled. For the embankment, each lift should be compacted to 95% of the standard proctor. Fill material should contain sufficient moisture so that if formed in to a ball it will not crumble, yet not be so wet that water can be squeezed out.

3. **Embankment Core**

   a. The core should be parallel to the centerline of the embankment as shown on the plans. The top width of the core should be at least four feet. The height should extend up to at least the 10-year water elevation or as shown on the plans. The side slopes should be 1 to 1 or flatter. The core should be compacted with construction equipment, rollers, or hand tampers to assure maximum density and minimum permeability. The core should be placed concurrently with the outer shell of the embankment.

4. **Structure Backfill**

   a. Backfill adjacent to pipes and structures should be of the type and quality conforming to that specified for the adjoining fill material. The fill should be placed in horizontal layers not to exceed four inches in thickness and compacted by hand tampers or other manually directed compaction equipment. The material should fill completely all spaces under and adjacent to the pipe. At no time during the backfilling operation should driven equipment be allowed to operate closer than four feet to any part of the structure. Equipment should not be driven over any part of a concrete structure or pipe, unless there is a compacted fill of 24 inches or greater over the structure or pipe.

   b. Structure backfill may be flowable fill meeting the requirements of the PADOT Standard Specifications for Construction. Material should be placed so that a minimum of 6 inches of flowable fill should be under (bedding), over and, on the sides of the pipe. It only needs to extend up to the spring line for rigid conduits. Average slump of the fill material should be 7 inches to assure flowability of the mixture. Adequate measures should be taken (sand bags, etc.) to prevent floating the pipe. When using flowable fill all metal pipe should be bituminous coated. Adjoining soil fill should be placed in horizontal layers not to exceed 4 inches in thickness and compacted by hand tampers or other manually directed compaction equipment.

   c. Refer to Chapter 220 Of PennDot Pub. 408 (2000).

5. **Rock Riprap**

   a. Rock riprap should meet the requirements of Pennsylvania Department of Transportation Standard Specifications.

6. **Stabilization**

   a. All borrow areas should be graded to provide proper drainage and left in a sightly condition. All exposed surfaces of the embankment, spillway, spoil and borrow areas, and berms should be stabilized by seeding, planting and mulching.

7. **Operation and Maintenance**

   a. An operation and maintenance plan in accordance with Local or State Regulations will be prepared for all basins. As a minimum, a dam and inspection checklist should be included as part of the operation and maintenance plan and performed at least annually.

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160 Attachment 8

APPENDIX H

DEP LEVEE DATA[1]

[1] Editor's Note: The levee data is on file in the Township offices.