CSN TECHNICAL BULLETIN No. 2
STORMWATER DESIGN IN THE COASTAL PLAIN OF THE CHESAPEAKE BAY WATERSHED

VERSION 1.0

This final draft was produced to customize and adapt stormwater design guidance for the demanding conditions of the coastal plain of Delaware, Maryland and Virginia, and has been reviewed by a wide range of Tidewater engineers and planners. CSN would like to acknowledge the assistance of Greg Hoffman, Sadie Drescher, Dave Hirschman and Laurel Woodworth of CWP, Joe Battiata of WEF, Jenifer Tribo of HRPDC, Randy Greer from DNREC and the many individuals who provided feedback at a March 2009 workshop. Support was provided from the Center for Watershed Protection, through a through a CITEET grant from NOAA

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Section 1 Why the Coastal Plain is Different?

Most stormwater practices were originally developed in the Piedmont physiographic region and have not been adapted for much different conditions in the coastal plain. Consequently, much of the available stormwater design guidance is strongly oriented toward the rolling terrain of the Piedmont with its defined headwater streams, minimal shallow groundwater flow, low wetland density, and well drained soils.

By contrast, stormwater design in the mid-Atlantic coastal plain is strongly influenced by unique physical constraints, pollutants of concern and resource sensitivity of the coastal waters. Application of traditional stormwater practices in the coastal plain is severely constrained by physical factors such as flat terrain, high water table, altered drainage, extensive groundwater interactions, poorly-drained soils and extensive wetland complexes. The significance of these constraints is described below:

- ***Flat Terrain*** – The most notable feature of the coastal plain is its uniformly flat terrain which creates several watershed planning challenges. The low relief makes it possible to develop land without regard to topography. From a hydrologic standpoint, flat terrain increases surface water/groundwater interactions and reduces head available to treat the quality of stormwater or move floodwaters through the watershed during the intense tropical storms and hurricanes for which the region is especially prone.

- ***High Water Table*** - In much of the coastal plain, the water table exists within a few feet of the surface. This strong interaction increases the movement of pollutants through shallow groundwater and diminishes the feasibility or performance of many stormwater practices.

- ***Highly Altered Drainage*** – The coastal plain stream network has been severely altered by 300 years of ditching, channelization, agricultural drainage and mosquito control. The headwater stream network in many coastal plain watersheds no longer exists as a natural system, with most zero, first and second streams replaced by ditches, canals and road drainage.

- ***Poorly Drained Soils*** – Portions of the coastal plain have soils that are poorly drained and frequently do not allow infiltration. As a result, the coastal plain watersheds contain extensive wetland complexes and have a greater density of wetlands than any other physiographic region in the country (Dahl, 2006). Wetland cover in many coastal plain watersheds exceeds 25%, which exceeds the national average of 7% (Dahl, 2006).

- ***Very Well-Drained Soils –*** In other parts of the coastal plain, particularly near the coast line, soils are sandy and extremely permeable, with infiltration rates exceeding four inches per hour or more. While these soils are exceptionally good for infiltrating stormwater runoff and promoting recharge, there is a stronger risk of stormwater pollutants rapidly migrating into groundwater. This is a particular design concern, given the strong reliance on groundwater for drinking water supply (see next bullet).

- ***Drinking Water Wells, Septic Systems*** – A notable aspect of the coastal plain is a strong reliance on public or private wells to provide drinking water (USGS, 2006). As a result, designers need to consider groundwater protection as a first priority when they are considering how to dispose of stormwater. At the same time, development in the coastal plain relies extensively on septic systems or land application to treat and dispose of domestic wastewater. Designers need to be careful in how they design and locate stormwater so they do not reduce the effectiveness of adjacent septic systems.

- ***Conversion of Croplands with Land Application.*** Land application of animal manure and domestic wastewater on croplands is a widespread practice across the coastal plain. When these croplands are converted to land development, there is a strong concern that infiltration through nutrient enriched soils may actually increase nutrient export from the site.

- ***Pollutants of Concern-*** Watershed managers in the Piedmont have historically focused on phosphorus control, which is frequently a limiting nutrient for fresh waters but seldom for coastal waters. By contrast, the key pollutants of concern in coastal plain watersheds are nitrogen, bacteria and metals. These pollutants have greater ability to degrade the quality of unique coastal plain aquatic resources such as shellfish beds, swimming beaches, estuarine and coastal water quality, seagrass beds, migratory bird habitat and tidal wetlands. Yet, the design of many stormwater practices is still rooted in phosphorus control. The design and engineering of stormwater practices need to be greatly modified to achieve greater reductions in nitrogen, bacteria and metals to improve coastal water quality.

- ***Unique Development Patterns*** -The development patterns of coastal plain watersheds are also unique, with development concentrated around waterfronts, water features and golf courses rather than an urban core. The demand for vacation rental, second home and retirement properties also contributes to sprawl forms of development.

- ***Shoreline Buffers and Critical Areas-*** Many of the Bay states in the coastal plain have special stormwater and zoning requirements for lands within 1000 feet or more of mean high tide. These are known as the Critical Area in Maryland and the Chesapeake Bay Protection area in Virginia. Both include special shoreline buffer and stormwater pollutant reduction requirements that strongly influence how stormwater practices are designed and located. In addition, the predominance of shoreline development often means that stormwater must be provided on small land parcels a few hundred feet from tidal waters. Consequently, many development projects within these Critical Area zones must rely on micro stormwater practices to comply with Critical Area requirements.

- ***The Highway as the Receiving System*** - The stormwater conveyance system for much of the coastal plain is frequently tied to the highway ditch system, which is often the low point in the coastal plain drainage network. New upland developments often must get approvals from highway authorities to discharge to their drainage system, which may already be at or over capacity with respect to handling additional stormwater runoff from larger events. The prominence of the highway drainage network in the coastal plain has several implications, the greatest of which is that designers have to obtain both a local and highway agency approval for their project. In many cases, these results in conflicting design requirements.

- ***Sea Level Rise*** - Another unique aspect of the tidal waters of the coastal plain is the forecasted rise in sea level over the next thirty to fifty years as a result of subsidence and climate change. The consensus predictions are for sea level in the Chesapeake Bay of at least a foot in the coming decades. This large change in average and storm elevations in the transition zone between tidal waters and shoreline development a few feet above it has design implications for the choosing where to outfall or discharge treated stormwater.

- ***Hurricanes and Flooding.*** Communities face to challenges when it comes to handling flooding events in the coastal plain. First, due to their location on the coast they are subject to rainfall intensities that are 10 to 20% greater for the same design storm event compared to further inland. Second, the flat terrain lacks enough head to quickly move water out of the conveyance system (which may be further complicated by backwater effects by tidal surges).

Section 2. General Coastal Plain Stormwater Design Principles

The following initial guiding principles are offered on the design of stormwater practices in the coastal plain:

1. Use micro-scale and small-scale practices for development projects within 500 feet of shoreline or tidal waters.

2. Exploit opportunities for upland runoff reduction prior to using wet ponds, and incorporate essential coastal plain design features within any ponds employed. be

3. Keep all stormwater practices out of the shoreline buffer area, except for the use of conservation filters at their outer boundary.

4. Relax some design criteria to keep practice depths shallow and respect the water table.

5. Emphasize design factors that can increase bacteria removal (and certainly not exacerbate bacteria problems).

6. Promote de-nitrification to maximize nitrogen removal, by creating adjacent anaerobic and aerobic zones in vertical or lateral direction.

7. Utilize plant species that reflect the native coastal plain plant community.

8. Take a linear design approach to spread treatment along the entire length from the rooftop to tidal waters, maximizing the use in-line treatment in the swale and ditch system

9. Consider the effect of sea level rise on future elevations of stormwater practices and infrastructure. In some cases, it may make more sense to utilize site design to "raise the bridge" by increase the vertical elevation of building pads at coastal plain development sites

Section 3. Sizing Stormwater Practices in the Coastal Plain

Several factors influence the sizing of stormwater practices in the coastal plain:

Higher Coastal Plain Nutrient Concentrations on Stormwater Runoff. A recent data analysis indicates there is a strong statistical difference in the nutrient concentrations between the coastal plain and piedmont physiographic regions in Virginia. Hirschman et al (2008) analyzed more than 753 storm events and found that median event concentrations of nutrients are 15 to 25% higher in the coastal plain, as compared to the piedmont. The reason for the higher nutrient concentrations is unclear, but may be related to the greater stormwater/groundwater interaction that occurs, along with possible soil nutrient enrichment due to land application and septic system leachate.

Table 1:
Comparison of Nutrient Storm Event Mean Concentrations in the Virginia Piedmont versus Coastal Plain (N=753 storm events)

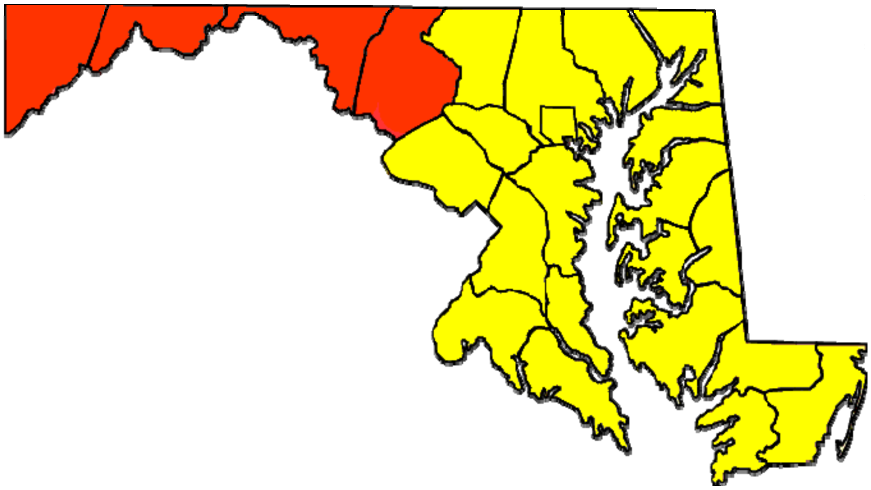
Nutrients	Coastal Plain	Piedmont
Total Nitrogen [1]	2.13 mg/l	1.70 mg/l
Total Phosphorus	0.27 mg/l	0.22 mg/l

[1] Residential TN in Coastal plain is 2.96 mg/l

Source: Appendix G of Hirschman et al 2008

Greater Water Quality Storm Events - Rainfall intensities are consistently greater in the coastal plain than the piedmont. Rainfall frequency spectrum analyses conducted at numerous weather stations in Maryland to statistically determine the 90% storm event that defines the water quality volume (MDE, 2000). The analysis determined that while the 90% storm was 1.0 inch or less in the Piedmont Stations and further west, it ranged from 1.1 to 1.2 inches in the coastal plain, with the greatest values near the coast. As a result, MDE elected to utilize different water quality storms in the two regions as shown in Figure 1.

Figure 1: Distribution of Water Quality Storm Events in MD (MDE, 2000)
(red=0.9 inches, yellow =1.0 inch)



3.3 Channel Protection Exemption? - Another key issue relates to whether a channel protection volume is needed to protect coastal plain stream channels from erosion. The 2000 MDE manual contained two specific exemptions from channel protection for portions of the coastal plain: (a) the entire Eastern Shore of Maryland and (b) any direct discharges or outfalls to tidal waters. The 2008 proposed VA DCR regulations do not contain any specific exemptions for the coastal plain and the proposed DENREC regulations require channel protection for coastal plain streams. While the tidal outfall exemption is reasonable, the growing body of geomorphic research on coastal plain streams strongly suggests that they should not automatically be exempted from channel protection.

3.4 The Prevalence of Wet Ponds - Wet ponds are extremely popular in coastal plain sommunities, since excavated sediments can be used for fill elsewhere in the site, and the pond can also be used to temporarily store floodwater from larger design storm events. According to a major survey by Law (2008), wet ponds were the most common stormwater practice in the coastal plain, with 81% of communities reporting their use. In some tidewater communities with high water tables, such as Newport News, VA, wet ponds treat 80% of the total land area at which stormwater practices are applied.

Since most coastal wet ponds are excavated well below the water table, they are strongly influenced by groundwater. Recent research profiled in Appendix A indicates that coastal plain “dugout wet ponds” have diminished nutrient removal capability (particularly for nitrogen) and extremely low rates of annual runoff reduction. In addition, under certain conditions, coastal plain wet ponds can create stagnant nuisance conditions (including harmful algal blooms). Field studies have also revealed that many coastal plain wet ponds are frequently installed without design features to ensure their effective function.

3.5 Comparative Reduction of Runoff, Nitrogen and Bacteria - As noted earlier, the pollutants of concern in the coastal plain tend to be slightly different, which has a strong influence on the selection of stormwater practices. Table 2 presents the most recent estimates of the runoff reduction, nitrogen removal and bacterial removal rates for 15 classes of stormwater practices. As can be seen, there is significant variability in the capability of different classes of stormwater practices to reduce runoff and provide nitrogen or bacteria reduction. It is worth noting that while there a wide range of studies examining nitrogen removal EMC rates, relatively few have occurred in the coastal plain. The situation is even worse for bacteria, where the actual data on *f. coli* or *e. coli* removal is sparse for all physiographic regions (Schueler, 2000 and 2007).

Table 2 Comparative Runoff Reduction, Nitrogen and Bacteria Removal

Practice	Annual Runoff Reduction (%) [1]	Nitrogen EMC Removal (%) [2]	Bacteria Removal [3]
Constructed Wetland	0	25 to 55 [4]	60
Bioretention	40 to 80	40 to 50	40*
Rain Tank/Cistern	15 to 45 [5]	0	NA
Wet Swale	0	25 to 35	0
Dry Swale	40 to 60	25 to 35	25*
Rooftop Disconnection	25 to 50	0	NA
Permeable Pavers	45 to 75	25	ND
Filter Strips	25 to 50	15	20*
Sand Filters	0	30 to 45	40
Infiltration	50 to 90	15	40*
Urban Bioretention	40	40	40*
Compost Amendments	25 to 50	0	NA
Green Roofs	45 to 60	0	NA
Wet Ponds	0	30 to 40	70
Dry ED Ponds	0 to 15	10	35
Grass Channel	10 to 20	20	-25

[1] Annual average runoff reduction as reported in Hirschman et al (2008)

[2] Change in stormwater event mean concentration (EMC) as it flows through the practice, as reported in CWP (2008). Total mass reduction is product of EMC reduction and runoff reduction.

[3] Bacteria removal rates as reported by Schueler et al, 2007. An asterisk denotes where monitoring data is limited, and estimates should be considered extremely provisional.

[4] Where a range of numbers are shown in the cell, this refers to the Level 1/Level 2 design features as outlined in Hirschman et al (2008).

[5] Runoff reduction can be increased if rain tanks are coupled with a secondary runoff reduction practice (rain garden, filter path or front-yard retention).

NA indicates the practice is not designed for bacterial removal or is located far up in treatment pathway such that bacteria source areas are largely absent (e.g., green roofs and cisterns)

In some cases, practices such as grass channels or ditches have been found to have low or negative rates for bacteria removal (Mallin et al, 2001). Given the limited bacteria data, the numbers shown in Table 2 should be considered provisional, and designers should maximize the design factors to enhance bacteria removal presented in Table 3.

Table 3: Design strategies to increase microbial reduction strategies

- Create high light conditions to promote UV in areas of standing water
- Design to prevent re-suspension of bottom sediments in treatment system
- Reduce turf around open water to prevent geese and waterfowl
- Use shallow wetlands and benches to create natural micro-predators for bacteria
- Add a layer of organic matter into sand filter media
- Avoid use of grass channels (dry or wet swales are preferred)
- Maximize infiltration and filtration of runoff through soils
- Maintain setbacks to prevent interaction of stormwater and septic leaching fields
- Utilize filter strips at edge of shoreline and stream buffers
- Avoid use of turf around ponds and wetlands to prevent geese colonization
- Address all bacteria source areas

Adapted from Schueler (2000)

3.6 Hotspot Concerns in the Coastal Plain - Stormwater hotspots are operations or activities that are known to produce higher concentrations of runoff pollutants and/or have a greater risk for spills, leaks or illicit discharges. Given that many portions of the coastal plain rely on groundwater as a primary source of drinking water, it is important to take steps to minimize the risk of groundwater contamination by polluted stormwater. A list of potential land uses or operations that may be designated as a stormwater hotspot is provided in the Bay-wide Stormwater Design Specification for Infiltration (No. 8).

Communities should carefully review development proposals to determine if future operations, in all or part of the site, will be designated as a stormwater hotspot. If so, stormwater treatment and pollution prevention practices must then be customized at the hotspot to prevent contamination of surface or groundwater, particularly if it discharges to a drinking water source. Depending on the severity of the hotspot, one or more of the following management strategies may be required

1. **Stormwater Pollution Prevention Plan** (SWPPP). This plan is required as part of an industrial or municipal stormwater permit, and outlines pollution prevention and treatment practices that will be implemented to minimize polluted discharges from the site.

2. **Restricted Infiltration**. A minimum of 50% of the total WQv must be treated by a filtering or bioretention practice prior to any infiltration. Portions of the site that are not associated with the hotspot generating area should be diverted away and treated by an acceptable stormwater practice.

3. **Infiltration Prohibition.** The risk of groundwater contamination from spills, leaks or discharges is so great at these sites that infiltration of stormwater runoff is **prohibited.** In these cases, an alternative stormwater practice such as a closed bioretention area, sand filter or constructed wetland must be used to filter runoff before it reaches surface or groundwater.

3.7 Altered Drainage Systems -- When designing stormwater management systems in the Coastal Plain, it is important to recognize that the original drainage patterns in a given watershed may have been significantly altered through the creation of constructed drainage channels and/or stream channelization. Thus, not only is much of the original surface storage lost, but the drainage network is much more hydraulically "efficient" compared to a more natural wetland/stream system. In addition, most constructed drainage systems were designed to prevent crop damage from standing water, not as conveyance *3*systems based on a specific storm frequency. For example, it has been estimated that the typical constructed drainage channel in Delaware's Coastal Plain only has the capacity to convey the runoff from a 1-year to 2-year storm event under *pre-developed conditions*. Further exacerbating this situation is the fact that there is typically no defined floodplain to contain flows that exceed the capacity of the channel itself.

Since local jurisdictions have not traditionally treated these constructed channels the same as natural streams, they often do not have floodplain ordinances or other controls in place to prevent potential impacts to adjacent properties under historic development patterns. Therefore, watersheds having a large percentage of altered drainage systems may require relatively stringent over-management techniques if adequate runoff reduction methods are not feasible. In cases where regulatory floodplains have not been established, one option for new development would be to provide adequate lot-free open space adjacent to altered drainage systems to accommodate out-of-bank occurrences. Although it may not be feasible to extend the limits of this open space to accommodate the 100-year storm event, it seems reasonable to accommodate at least the 10-year storm in order to minimize impacts.

3.8 Discharges to Wetlands -- Recent research has clearly shown that direct and indirect stormwater discharges can have a deleterious impact on sensitive streams and wetlands at extremely low levels of land development (Wright et al 2007, Cappiella et al 2006). Consequently, a greater level of protection is needed to safeguard each of these important ecosystems from stormwater discharges, as follows:

- Define a series of sensitive wetland types that merit special protection (e.g., bogs, fens and others, see Wright et al, 2007).
- Explicitly prohibit the use of natural wetlands for stormwater treatment of any kind
- Require full runoff reduction up to the channel protection volume prior to discharge to a downgradient sensitive wetland
- Require modeling and monitoring analyses to confirm no changes in post development hydroperiod in sensitive wetlands, which is operationally defined as mo more than six inches of additional water level fluctuation for a one-inch storm

Section 4. Applicable Stormwater Treatment Practices

This section evaluates the comparative applicability of the range of potential stormwater practices, and classifies them as preferred, acceptable or restricted, as shown in Table 4:

Table 4 Comparison of the Applicability of Stormwater Practices for Coastal Plain

Stormwater Treatment Practice	Suitability for Coastal Plain	Baywide Design Spec No.	Design and Implementation Notes
Constructed Wetland	Preferred	**13**	Shallow, linear, multiple cell designs
Shallow Bioretention	Preferred	**9**	Relaxed filter bed and WT depth , soil nutrient testing
Rain Tank/Cistern	Preferred	**6**	Above-ground tanks
Wet Swale	Preferred	**13a**	On and off-line cells
Shallow Dry Swale	Preferred	**10**	Relaxed filter bed and WT depth, soil nutrient testing
Rooftop Disconnection	Preferred	**1**	Via front-yard bioretention
Permeable Pavers	Preferred	**7**	Underdrain when infiltration rates is lo or WT table is high
Filter Strips	Preferred	**2**	Conservation filters to stream or shoreline buffers
Sand Filters	Acceptable	**12**	Perimeter or non-structural sand filters most practical
Small Scale Infiltration	Acceptable	**8**	Wide and shallow designs with CDA max of 20,000 sf IC
Urban Bioretention	Acceptable	**9a**	Curb extensions, foundation planters and tree pits
Compost Amendments	Acceptable	**4**	For B.C, D soils at least two feet above WT
Green Roofs	Acceptable	**5**	Coastal species selection
Wet Ponds	Acceptable	**14**	See Appendix A
Dry ED Ponds	Restricted	**15**	Constrained by head requirements
Grass Channel	Restricted	**3**	Poor bacteria removal
Large Scale Infiltration	Restricted	**8**	Depends on soil infiltration rate and nutrient composition
WT= water table, CDA=contributing drainage area, IC= impervious cover, WQv= water quality volume			

Section 5. Specific Design Criteria for Stormwater Treatment Practices

The ensuing discussion highlights some possible design adaptation for the coastal plain, and should be considered a starting point and not an ending point

5.1 Criteria for Preferred Stormwater Practices. These stormwater practices possess two properties—they are widely feasible at most development sites in the coastal plain (with some design adaptations) and have either a high rate of runoff reduction and/or a strong capability to remove pollutants of concern in the coastal plain (e.g., nitrogen/bacteria).

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

- Shallow, linear and multiple cell wetland configurations are preferred.
- Deeper basin configurations, such as the pond/wetland system and the ED wetland have limited application in the coastal plain.
- It is acceptable to excavate up to six inches below the seasonally high water table to provide the requisite hydrology for wetland planting zones, and up to three feet below for micropools, forebays and other deep pool features.
- The volume below the seasonably high water table is acceptable for the WQv as long as the other primary geometric and design requirements for the wetland are met (e.g., flow path, microtopography)
- Plant selection should focus on species that are wet-footed and can tolerate some salinity.
- A greater range of coastal plain tree species can tolerate periodic inundation, so designers should consider forested wetlands, using species such as Atlantic white cedar, bald cypress and swamp tupelo.
- The use of flashboard risers is recommended to control or adjust water elevations in constructed wetlands in flat terrain
- The regenerative conveyance system is particularly suited for coastal plain situations where there is a significant drop in elevation from the channel to the outfall location (see Appendix A Baywide Stormwater Design Specification No. 13)

Bioretention: Either the Level 1 (underdrain) or Level 2 (infiltration) design can be used for bioretention, depending on soil permeability and local water table conditions. The following design adaptations can help make bioretention work better in the coastal plain:

- A linear approach to bioretention using multiple cells leading to the ditch system helps conserve head
- The minimum depth of the filter bed can be relaxed to 18 to 20 inches if head or water tables conditions are problematic.
- Bioretention media should be secured from an approved vendor to ensure nutrient content of soil and compost are within acceptable limits. The use of on-site soils in the coastal plain is discouraged due to their probable nutrient enrichment, unless soil tests have been performed.
- Other tips to reduce vertical footprint are to limit surface ponding to six to nine inches, and save additional depth by shifting to a turf cover rather than mulch

- The minimum depth to the seasonally high water table can be one foot, as long as the bioretention area is equipped with an large diameter underdrain (e.g., six inches) that is only partially efficient at dewatering the bed
- It is important to maintain at least a 0.5% slope in the underdrain to ensure drainage and tie it into the ditch or conveyance system
- The mix of plant species selected should reflect coastal plain plant communities, and should be more wet footed and salt tolerant than typical Piedmont applications. See Baywide Design Specification No. 9 for a list of plant species suitable for coastal bioretention.

Rain Tanks

- Above ground tank designs are preferred to below ground tanks
- Tanks should be combined with automated irrigation, front-yard bioretention or other secondary practices to maximize their runoff reduction rates

Wet Swales: These swales work well in areas of high water table, and consist of a series of on-line or off-line storage cells. Designers should design cells such that underlying soils are typically saturated, but do not cause standing water in between storm events. It may also be advisable to incorporate sand or compost into surface soils to promote a better growing environment. Wet swales should be planted with wet-footed species, such as sedges or wet meadows. Wet swales are not recommended in residential areas due to concerns about mosquito breeding.

Dry Swale: Dry swales work well at many coastal plain sites, but require several design adaptations to improve their feasibility, as noted below:

- The minimum depth of the filter bed can be relaxed to 18 to 20 inches, if head or water table conditions are problematic
- The minimum depth to the seasonally high water table can be reduced to one foot, as long as the dry swale area is equipped with an underdrain
- A minimum underdrain slope of 0.5% slope must be maintained to ensure positive drainage and be tied into the ditch system at a downstream point.
- Dry swales should not be forced into marginal sites, when wet swales or linear wetlands would work better (e.g., if the water table is within 30 inches of swale invert).

Rooftop Disconnection: Rooftop disconnection is strongly recommended for all residential lots less than 6000 square feet, particularly if it can be combined with a secondary micro-practice to increase runoff reduction and prevent seepage problems. The disconnection corridor should have a minimum slope of 1% and two feet of vertical separation to the water table. See Baywide Design Specification No. 1 for the four primary micro-practice options.

Permeable Pavement: Experience in North Carolina has shown that properly designed and installed permeable pavement systems can work effectively in the demanding conditions of the coastal plain, as long as underlying soils are moderately to highly permeable.

- Designers should avoid the use of non-underdrain permeable pavement systems, at stormwater hotspot facilities and in areas known to provide groundwater recharge to aquifers used as a water supply.
- Designers should ensure that the distance from the bottom of the permeable pavement system to the top of the water table is at least 2 feet.
- If an underdrain is used beneath permeable pavement, a minimum 0.5% slope must be maintained to ensure proper drainage.
- Avoid using permeable pavement if the site will be exposed to blowing sand (i.e., near coastal sand dunes).

Filter Strips: The use of conservation filter strips is highly recommended in the coastal plain, particularly when sheetflow or concentrated flow discharges to the outer boundary of shoreline, stream or wetland buffer. Grass filter strips can also be used to treat runoff from small areas of impervious cover (e.g., less than 5000 square feet). In both cases, however, the water table must be at lest 18 inches below the ground surface, Depending on surface flow conditions, the strip must have a gravel diaphragm, pervious berm or engineered level spreader conforming to the new requirements outlined in Bay-wide Stormwater Design Specification No. 2.

5.2 Acceptable Stormwater Practices. This group of stormwater practices can work at many sites in the coastal plain, but either require major design adaptations or have low to moderate capability to reduce the coastal pollutants of concern.

Filtering Practices: The flat terrain, low head and high water table of the coastal plain make several filter designs difficult. The perimeter sand filter and the non-structural sand filter, however, have the least head requirements and can work effectively at many small coastal plain sites, when the following design adaptations are made:

- The combined depth of the underdrain and sand filter bed can be reduced to 24 to 30 inches.
- Designers may wish to maximize the length of the stormwater filter or provide treatment in multiple connected cells.
- The minimum depth to the seasonally high water table can be reduced to one foot, as long as the filter is equipped with an large diameter underdrain (e.g., six inches) that can dewater the bed if groundwater mounds.
- It is important to maintain at least a 0.5% slope in the underdrain to ensure drainage and to tie it into the ditch or conveyance system

Urban Bioretention: Three forms of bioretention for highly urban areas can work acceptably within the coastal plain- stormwater curb extensions, expanded tree planters, and foundation planters - particularly when above ground design variants are used. The general coastal plain design modifications for regular bioretention should also be consulted

Small Scale Infiltration: The **c**oastal plain is an acceptable environment for micro-infiltration and small-scale infiltration practices, particularly if designers choose to infiltrate less than full water quality volume in a single practice (and use secondary practices to achieve the remaining runoff reduction). Some other design modifications for small scale infiltration in the coastal plain include:

- Designers should maximize the surface area of the infiltration practice, and keep the depth of infiltration to less than 24 inches.
- Where soils are extremely permeable (more than 4.0 inches per hour) shallow bioretention is a preferred alternative.
- Where soils are more impermeable (i.e., marine clays with less than 0.5 inches/hour), designers may want to shifted to bioretention with underdrains
- The minimum depth to the water table should be kept to at least two feet.

Compost Amendments: Designers should evaluate drainage and water table elevations to ensure the entire depth of soil amendment will not become saturated (i.e., a minimum separation depth of two feet from groundwater). Compost amendments are most cost effective when used to boost the runoff reduction capability of grass filter strips, grass channels and rooftop disconnection.

Green Roofs: Green roofs are acceptable runoff reduction practice for the coastal plain, but are somewhat limited since rooftops are not a major runoff source area for nutrients or bacteria. Designers should consult with a qualified botanist or landscape architect to choose the most appropriate plant material, such as indigenous varieties of grass and *sedum* species that can tolerate drought and salt spray.

Wet Ponds: A major research review was conducted to establish the performance of coastal plain wet ponds, which is provided in Appendix A. The key findings were that:

- Expected nutrient removal rates are slightly reduced in the coastal plain due to the influence of groundwater,
- Certain design features are essential to achieving them (multiple cells, benches, flow path, etc.)
- Additional design features such as pond landscaping and bubblers/floating island could improve their function.
- Wet ponds could produce and or export harmful algal blooms if they interact with brackish ground or surface waters

Consequently, special design recommendations are proposed for coastal plain wet ponds, as outlined in Table 5. Where land is available, shallow constructed wetlands are a preferred over wet ponds in high water table coastal plain environments.

Table 5: Level 1 and 2 Wet Pond Design Guidance: Coastal Plain

Level 1 Design (RR:0 [1]; TP:45; TN:20)	Level 2 Design (RR:0; TP:65; TN:30)
TV= (1.0)(Rv)(A)/12	TV = 1.5 (Rv) (A) /12
Single Pond Cell (with forebay)	Wet ED [2] or Multiple Cell Design [3]
Flow path = 1:1 or more [4]	Flow path = 1.5:1 or more
Standard aquatic benches	Wetlands more than 10% of pond area
Turf in pond buffers	Pond landscaping to discourage geese
No Internal Pond Mechanisms	Aeration (preferably bubblers that extend to or near the bottom or floating islands
Maintenance access to forebay/riser	Maintenance access to forebay/riser

[1] Runoff reduction can be computed for wet ponds designed for water reuse and upland irrigation

[2] Extended Detention provided to meet the water quality volume

[3] At least three internal cells including the forebay

[4] in the case of multiple inlets, flow path is measured for the dominant inlets (that compromise 80% or more of total pond inflow)

5.3 Restricted Stormwater Practices. The last group of stormwater practices have limited feasibility in the coastal plain and or poor removal capability for the pollutants of concern. In most cases, these practices are not recommended to function as the primary stormwater practice at coastal plain development sites

ED Ponds: The lack of head and high water table of many coastal plain sites severely constrain the application of ED ponds. Excavating ED ponds below the water table creates unacceptable conditions within the basin. No credit for water quality volume may be taken for areas below the seasonally high water table. In general, **s***hallow constructed wetlands are a superior option to ED ponds for the coastal plain environment.*

Grass Channel: Although grass swales work reasonably well in the flat terrain and low head conditions of many coastal plain sites, they have very poor nutrient and bacteria removal rates, and should not be used as a standalone system. Dry swales or wet swales are a much superior option to the grass channel, unless the soils are in the highly permeable HSG "A" group. In these situations:

- The minimum depth to the seasonally high water table can be 18 inches.
- A minimum slope of 0.5% must be maintained to ensure positive drainage.
- The grass channel may have off-line cells and should be tied into the ditch system

Large Scale Infiltration: Large scale infiltration, defined as individual practices that serve a contributing drainage area of more than 20,000 to 100,000 square feet of impervious cover, can work well in coastal plain sites where soils have an infiltration rate between 0.5 to 4.0 inches per hour. Where soils are extremely permeable (more than 4.0 inches per hour), a two-cell system consisting of a shallow bioretention or filtering practice leading to the infiltration practice should be used to provide for pollutant filtering prior to introduction into groundwater. Infiltration should not be used if the site is a designated stormwater hotspot.

APPENDIX A
TECHNICAL UPDATE: COASTAL PLAIN WET POND RESEARCH AND IMPLCIATIONS FOR DESIGN

This appendix is an outgrowth from a Tidewater Virginia workshop on stormwater wet pond design held on March 22-23, 2009, where there was considerable debate about the original recommendation to restrict the water quality volume (WQv) only to pool storage that is above the seasonably high water table. Workshop participants requested the technical documentation for the proposed restriction, which as initially drafted, would have restricted the feasibility of the most widely-used stormwater best management practice in the Tidewater area. This appendix summarizes recent wet pond research, and presents the basis for refined design and sizing criteria for wet ponds in the coastal plain.

1. REVIEW OF EXISTING RESEARCH ON COASTAL PLAIN WET PONDS

Several recent studies and reviews have explored the performance of wet pond performance in coastal plain conditions, particularly as it relates to the influence of groundwater (Mallin et al, 2002, Drescher et al, 2007, Harper and Baker, 2007, DeLorenzo and Fulton, 2009, Hirschman and Woodworth, 2009). These studies expand on the original review of wet pond/groundwater influence developed by Schueler (2001). Table 1 summarizes the nine coastal plain wet pond pollutant removal performance studies, all of which had some groundwater interaction. The basic findings from this review include the following:

- It was not possible to statistically compare the population of wet ponds in the *National Stormwater Pollutant Removal Database* that are influenced by groundwater versus those that are not. The primary reasons relate to small sample size, variability in the degree of coastal plain groundwater interaction, and considerable differences in design, sizing and residence time among the individual wet ponds studied. Nevertheless, it is evident that the groundwater influence in coastal plain wet ponds constrains the maximum degree of nutrient removal that can be obtained, compared to other physiographic regions in the watershed where groundwater is not an influence.

- The analysis of individual coastal plain studies shows that wet pond performance clearly falls into one of two general groups. The first group consists of relatively standard wet pond designs that do not appear to be capable of meeting either Bay-wide Level 1 or Level 2 performance criteria for N and P removal (see shaded cells in Table A-1). As a group, these wet ponds have low or even negative removal rates.

- The second group of wet ponds performed much better and could generally meet Level 1 removal rates, and sometimes, Level 2 removal rates. This group of wet ponds incorporated much more sophisticated design features and geometry. For example, the Silver Stream pond had a length to width ratio of nearly 18: 1, two cells, a 2 foot depth and extensive macrophyte and wetland cover (Mallin et al, 2002). Similarly, the Greenwood pond was composed of three cells, was oversized (1.25 inches of storage), and contained extensive wetland benches, aeration fountains, and water reuse (McCann, 1995). The Tampa Bay pond was retrofit to increase detention time from 1 to 7 days, and included wet extended detention pond and wetland design elements (Rushton, 1997). The last top performer was a five-cell wet pond in South Carolina, with a very long residence time and extensive wetland elements (Messersmith, 2007).

Table A-1: Review of Coastal Plain Wet Pond Nutrient Removal Performance [3]

Study	**State**	**Name**	**TP**	**TN**
Mallin, 2002	Wilmington NC	Ann McCrary	23 [2]	(-3.5)
Mallin 2002	"	Silver Stream	58	40
Mallin, 2002	"	Echo Farms	(-35)	(-41)
Gain, 1996 [1]	Orlando, FL	FDOT	30	16
Kantrowitz 1995 [1]	Florida	St Joes	40	23
McCann 1995 [1]	Orlando, FL	Greenwood	62	(-11)
Rushton, 1997 [1]	Tampa Bay, FL	TB Detention	57-62	16-33
Messersmith 2007	South Carolina	5 cell pond	70	40
Messersmith, 2007	South Carolina	1 cell pond	(-2)	(-5)
Baywide LEVEL 1 [4]			**50**	**30**
Baywide LEVEL 2			**75**	**40**

Notes:

[1] As reported in CWP *National Stormwater Pollutant Removal Database (2008)*

[2] Removal measured as monthly concentration entering and leaving pond (N=29)

[3] Due to differences in pond design, sizing and stormwater monitoring protocols, the nine studies cannot be directly compared to each other, or aggregated to compute an overall average

[4] Nutrient event mean concentration (EMC) reduction rates reported in the Bay-wide wet pond design specification

- Another important study was conducted by Harper and Barker (2007) who examined the relationship between detention time and nutrient removal in a population of 19 Florida wet ponds and urban lakes with average residence times ranging from 1 to 500 days, all of which were presumed to have a high degree of groundwater interaction. Harper and Barker found a strong statistical relationship between detention time and mass removal rate with r^2 in the range of 0.8 to 0.9. In general, the curves show a sharp increase in nutrient removal in the first 5 to 15 days, followed by a more gradual increase with longer detention times. After 100 days of detention time, the removal rate for phosphorus and nitrogen was 75% and 42%, respectively.

- The Harper detention time equation was used to define the expected detention time for the proposed Bay-wide Level 1 and 2 wet pond sizing criteria (i.e., 1.0 inch and 1.5 inches, respectively). The resulting detention times were then inserted into the Florida nutrient mass removal equations to obtain a prediction of nutrient removal rates under the proposed Bay-wide criteria, as shown in Table A-

2. Since the Harper detention time equation was developed using Florida ponds, it is not recommended as a hard rule for setting a minimum detention time for ponds in the Chesapeake Bay. It does, however, provide additional evidence that groundwater influenced wet ponds sized according to the new Bay-wide have limits on their maximum expected nutrient removal rates. Specifically, the proposed pond sizing criteria appear capable of surpassing Level 1 phosphorus removal rates (50%), but cannot achieve the Level 2 rate of 75%. In the case of nitrogen, the proposed sizing criteria can only meet Level 1 nitrogen removal rates (30%) when ponds are sized to Level 2 design (e.g., 1.5 inches).

Table A-2. Predicted Nutrient Removal Based on Harper Pond Equation

VA DCR Pond Criteria	Wet Pond Sizing Criteria	Annual Detention Time [1]	Predicted P Mass Removal (%) [2]	Predicted N Mass Removal (%) [3]
Level 1	TV= (1.0)(Rv)(A)/12	**9 days**	**55**	**10**
Level 2	TV= (1.5)(Rv)(A)/12	**13.5 days**	**58**	**33**

Source: Equations in Harper and Barker (2007)
[1] page 5.34 [2] page 5.38 [3] page 5.39

Harper and Baker (2007) also address the issue of pond stratification and depth, which is at the heart of the groundwater-WQv exclusion debate. The authors are unambiguous on this point- the depth of a coastal plain wet pond, including the depth below groundwater, by itself, is not a particularly useful design parameter. This conclusion is also reinforced by an independent study of Florida ponds by Ceilla and Everham (2008).

The authors note that the key pond design issue is actually the trophic state of the pond, which determines the depth of the anoxic zone which increases nutrient release from the sediments. The trophic state is a measure of the degree of eutrophication in a pond which, in turn, is a function of the pond's nutrient input and residence time. Residence time is expressed as the pond pool volume divided by the annual runoff input from its catchment. Thus, pool depth is not always a reliable indicator of longer detention time. Indeed, based on prior limnological research, there may be cases where a deeper pond may have a longer detention time (and be less eutrophic) than a shallow pond.

Based on Florida pond and lake data, Harper and Barker (2007) present an equation to estimate the depth of the anoxic zone (see Page 6.48). When this equation is solved for typical summer trophic data reported by Drescher et al (2007) for SC coastal wet ponds (pond chlorophyll-*a* 40 ug/l, pond TP of 0.10 mg/l, TN of 1.0 mg/l and an assumed Secchi depth of 1 foot), it implies a typical anoxic depth for coastal plain wet ponds of about five feet. While the anoxic depth is likely to shallower in other seasons of the year, this helps explain the diminished performance of coastal plain wet ponds.

Several comprehensive studies shed light on the behavior of coastal plain wet ponds. Lewitus and Holland (2003) the SC Harmful Bloom Program initial results documented the first widespread SC red tide and several toxic blooms (including *Pfiesteria*) in surface waters. *Pfiesteria* has caused many NC fish kills and is linked to human neurological illnesses

(Burkholder and Glasgow, 1997). Brackish and freshwater stormwater ponds were also contaminated with *Pfiesteria* like organisms and potentially or known toxic harmful algal blooms (HABs) (Lewitus and Holland, 2003). More recently, Lewitus et al (2008) reported that eutrophic brackish ponds were "hot spots" for HABs and presented research for over 200 HABs over the last four years. Stormwater ponds are increasing in coastal communities and these low flow systems with high nutrient loading are algae incubators.

Brock (2006) documented 23 HABs out of 232 residential stormwater pond samples and concluded that "no matter the salinity or temperature in the ponds, size of the ponds, or development surrounding the ponds, harmful and nuisance phytoplankton persist in these coastal stormwater detention ponds." Another comprehensive review by Drescher et al (2007) describes a baseline study of 112 randomly selected SC wet ponds, and reviews data from other coastal plain states.

The baseline study indicated that while dissolved oxygen (DO) was generally high (greater than 4.0 mg/l in 79% of ponds) and nutrients were generally low (total nitrogen < 0.95 mg/l and total phosphorus < 0.09 mg/l) the coastal ponds were eutrophic to hyper-eutrophic with respect to chlorophyll-*a* concentration (32% of ponds had chl-*a* ≥ 40 ug/l). A majority of hyper-eutrophic wet ponds (chl-*a* more than 60 ug/l) contained HABs. The limiting nutrient in these coastal wet ponds was nitrogen rather than phosphorus, and the surface waters were fresh (salinity <2ppt for 110 ponds).

A southeastern coastal stormwater pond water quality indicator and HAB state of the knowledge report was developed by DeLorenzo and Fulton (2009) who documented the presence of a wide range of HABs in coastal wet ponds, including blue green algae blooms (cyanobacteria), dinoflagellate blooms such as *Pfiesteria* and red tides, and raphidophytes. While the presence of algal blooms indicates that wet ponds are working to reduce nutrients, HABs can release toxins that can kill fish, contaminate shellfish and, in some cases, affect human health.

For example, a raphidophyte bloom (*Herosigma akashiwo*) extended 8 km off Bulls Bay, SC, in April 2003 and resulted in an estimated 10,000 fish kill. Cyanobacteria (e.g., *Microcystis*, *Oscillatoria*, and *Anabaena*) were the most common HAB in freshwater ponds. Dinoflagellates and raphidophytes (e.g., *Heterosigma akashiwo*, *Chattonella subsalsa*, and *Fibrocapsa japonica*) were the most common HAB in brackish and salt water ponds DeLorenzo and Fulton (2009) note several examples where HABs in hyper-eutrophic wet ponds were exported to adjacent tidal waters. These findings are important since HABs produce toxins already associated with fish kills and are in close proximity to wildlife and humans with largely unknown consequences.

Another set of studies evaluated the condition of large populations of wet ponds as they were actually installed and maintained in coastal plain conditions (Hirschman and Woodworth, 2009 and SC and NC studies summarized in Drescher at al, 2007). Most of the wet ponds were built according to pre-2000 design standards. Field evaluations indicated that a large fraction of VA, NC and SC wet ponds fail to meet minimum design guidelines with respect to forebay installation, minimum length to width ratio, and aquatic benches, and that many were encountering functional problems relating to a lack of maintenance (sediment deposition, excessive plant growth, trees on embankment).

In both SC and VA, the worst performing wet ponds were in commercial areas as compared to residential areas, which may reflect the fact they were squeezed into the site and had a small contributing drainage area. Indeed, anecdotal evidence from several designers at the March tidewater stormwater design workshop indicated that shallow wet ponds with small contributing drainage areas frequently produced the most nuisance conditions and maintenance problems.

2. IMPLICATIONS FOR COASTAL PLAIN WET POND DESIGN

Wet ponds can be considered an *"acceptable"* stormwater practice for use in the coastal plain where the water table is within four feet of the land surface. It is noted that constructed wetlands are a preferred alternative when space is available.

Adjustments to Nutrient Removal The numerous lines of evidence reviewed indicate that standard designs of coastal plain wet ponds *cannot* achieve the desired nutrient removal rates in the current Bay-wide design specification for wet ponds, based on current design, detention times, the influence of groundwater and other factors. Therefore, slightly lower nutrient removal rates are proposed for coastal plain wet ponds to reflect real world performance data for phosphorus and nitrogen removal. Specifically, Level 1 and 2 total removal rates for TP are now proposed to be 45 and 65% respectively, and Level 1 and 2 TN removal rates are reduced to 20% and 30%, respectively. These slightly lower removal rates are supported by pond research and the detention time relationships.

Essential Design Elements. The research validates the importance of incorporating specific design elements to achieve desired nutrient removal performance, including forebays, minimum flow path, expanded wetland cover and multi-cell construction. Given their importance in promoting nutrient removal, these factors are considered essential minimum design features for all wet ponds, as shown in Table 5 of the Technical Bulletin. Two additional design elements are recommended to distinguish Level 2 from Level 1 ponds, based on comments from designers and local stormwater managers. The first relates to pond landscaping to discourage geese. The second involves the use of internal mechanical devices to increase re-aeration and/or nutrient reduction..

Remove Pool Depth Restrictions. The research suggests that there is no technical basis for reducing the water quality volume to account for groundwater inputs, even when the water table is high, once the overall nutrient removal rates are adjusted. Reliable removal can be achieved by groundwater-influenced ponds, if they achieve the detention time associated with the treatment volume sizing and contain the requisite internal design features to promote nutrient removal. There is some indication that, on average, about one foot wet pond pool depth will be anoxic in the summer, which is accounted for in the slightly reduced maximum nutrient removal rates.

Restrictions on Brackish Ponds. Wet ponds are discouraged in cases where groundwater input to the pond is brackish or is hydraulically connected to tidal waters (more than 5 parts per thousand or ppt). Given the potential for strong association of HABs with hyper-eutrophic wet ponds, it may not be wise to allow ponds to intersect the water table when it is brackish, and there are other nutrient sources in the contributing drainage area (e.g., golf courses, septic systems, land application of biosolids).

Pocket Ponds. Another issue relates to wet ponds with a small contributing drainage area that are solely supplied by runoff and groundwater, and often create nuisance conditions and fluctuating water levels. There is virtually no data on these "pocket ponds" that are frequently installed on small commercial sites. Rather than mandating an arbitrary minimum drainage area, it is recommended instead that these pocket ponds must meet the minimum design geometry requirements for all ponds (i.e., sediment forebay cell, aquatic benches, maximum side-slopes of 5: 1 and length to width ratio of 1:1).

In addition, the pond water balance equation must demonstrate that the pond will not draw down more than two feet during a thirty day summer drought (Using the pond drawdown equation in Table 2 of the Bay-wide wet pond specification). Designers should strictly adhere to the same design requirements that apply to other wet ponds, which should greatly reduce the number of nuisance ponds that are forced into tight sites (i.e., by reducing or eliminating essential pond design elements).

Increasing Runoff Reduction for Water Reuse Ponds. Several designers noted that the guidance neglected the possibility of achieving runoff reduction through water re-use (i.e., pumping pond water back into the contributing drainage area for use in seasonal landscape irrigation). While this practice is not common, it has been applied to golf course ponds and accepted computational methods are available (Wanielista and Yousef, 1993 and McDaniel and Wanielista, 2005). It is recommended that designers be allowed to take credit for annual runoff reduction achieved by pond water reuse, as long as acceptable modeling data is provided for documentation.

Benchmarking Sediment Deposition in Coastal Ponds. To facilitate maintenance, contractor will mark and geo- reference the actual constructed depth of three areas within the permanent pool on the as-built drawing (forebay, mid-pond and outflow). This simple feature will enable future inspectors to determine pond sediment deposition rates to schedule sediment cleanouts.

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