CSN TECHNICAL BULLETIN No. 2
STORMWATER DESIGN IN THE COASTAL PLAIN OF THE CHESAPEAKE BAY WATERSHED
VERSION 0.5

Developing Terrain Specific Design Guidance for the Chesapeake Bay Watershed

This draft has been produced to customize and adapt stormwater design guidance for the demanding conditions of the coastal plain of Delaware, Maryland and Virginia. So please give this a careful review, and e-mail your comments to Tom Schueler at watershedguy@hotmail.com, or post comments or upload information at chesapeakestormwater.net. This draft has annotations highlighting key issues and design needs. This draft is open until December 1, 2008, when a final draft will be produced based on your comments. Thanks in advance for your participation in this important project.

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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 seldom been adapted for much different conditions in the coastal plain. Consequently, guidance for stormwater design 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 Stormwater Design Principles in the Coastal Plain

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

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

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

5. Promote denitrification to maximize nitrogen removal, by creating adjacent anaerobic and aerobic zones in vertical or lateral direction.

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

7. 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

8. 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:

3.1 Higher Coastal Plain Nutrient Concentrations

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

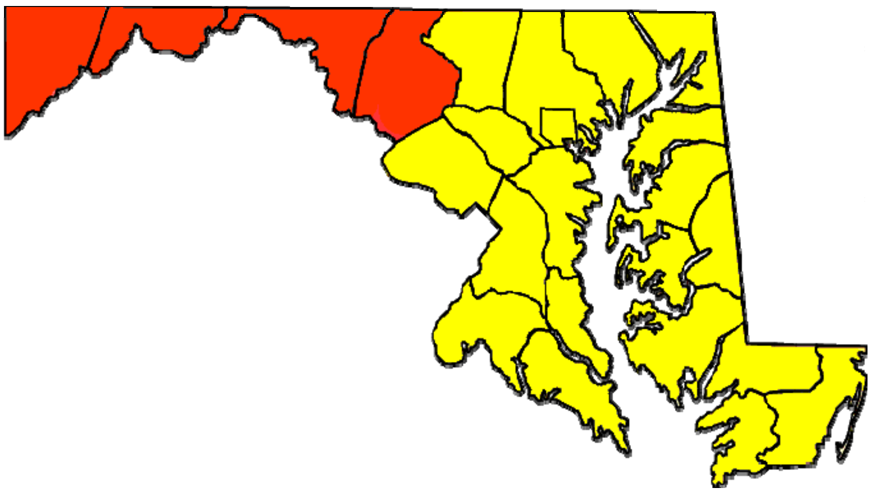
[1] Residential TN in Coastal plain is 2.96 mg/l

Source: Appendix G of Hirschman et al 2008

3.2 Great 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 relaters to whether a channel protection volume is required 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 (need to check this), 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 these should not be exempted from channel protection (need some good references here).

3.4 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 achieve high levels of runoff, 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 (cf Mallin et al 2000, 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)

3.5 Hotspot Concerns in the Coastal Plain

Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater 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 a development site is designated as a hotspot, one or more design responses are required, as shown below:

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.**

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, and defined below:

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	Restricted	**14**	Deduct dead zone from WQv
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			

Preferred 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).

Acceptable 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.

Restricted practices either have limited feasibility in the coastal plain, poor removal capability under certain design configurations or require special design features or testing to ensure they function properly.

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

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 B 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

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.

Rooftop Disconnection: Rooftop disconnection is strongly recommended for all residential lots less than 600 square feet, particularly if it can be combined with a secondary micro-practice to increase runoff reduction and prevent seepage problems. 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.

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). Depending on 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

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 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 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.

Green Roofs: Green roofs are acceptable runoff reduction practice for the coastal plain, but are somewhat limited since rooftops are not a major 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.

5.3 Restricted Stormwater Practices

Wet Ponds: The use of wet ponds is popular in many areas of the coastal plain, 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. However, when ponds are excavated well below the water table can reduce pollutant removal and create stagnant nuisance conditions. Groundwater inputs to these “dugout ponds” displaces available water quality volume, reduces mixing, decreases retention times, and increase dry weather pond outflows. Consequently, no credit for water quality volume may be taken for areas below the seasonally high water table. In addition, pond drains may not be practicable in extremely flat terrain. Fountains and other design features can also be used to increase dissolved oxygen and prevent summer nutrient release from pond sediments. Where land is available, however, shallow constructed wetlands are a superior option to wet ponds for the coastal plain environment.

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, **shallow 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 following design adaptations apply.

- 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

Section 6: References

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