Chapter 8

BMP OVERVIEW AND SELECTION CRITERIA

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8.0. INTRODUCTION

The application of Best Management Practices (BMPs) to stormwater management has broadened in the past ten years. With EPA's implementation of various kinds of federal stormwater permits for localities with Municipal Separate Storm Sewer Systems (MS4s) and for building construction-related stormwater runoff control (both administered in Virginia through delegation to the DEQ), a broad array of practices has been identified as appropriate for managing stormwater. It is important for stormwater managers to understand the full context of these programs and related stormwater impacts, to see how they fit together and, thus, to understand what kinds of practices to employ for the various purposes. This chapter provides an overview of the various kinds of BMPs that must be employed, but it focuses especially on the "post-construction" practices that must be built during site development with the intent of managing site runoff perpetually after construction is completed. Then the chapter provides useful guidance regarding how to make the best selection of BMPs for a development project.

Flow-Related Issues

Section 4.1.6 of Chapter 4 of this Handbook discusses the hydrologic changes that occur in response to land development and added impervious cover. Maintaining or at least mimicking the pre-development hydrologic conditions is recommended in all cases, but especially for receiving water bodies that are highly or moderately susceptible to stormwater impacts. The relationship between any storm event, no matter how small or how large, and runoff volumes must be thoroughly understood. BMPs that address the full range of hydrologic conditions should be employed to minimize impacts.

In parts of Virginia with particularly cold winter climates, snow melt events pose a significant problem. A large volume of water occurs at the end of the winter when many impediments, such as frozen ground for infiltration basins or frozen permanent pools and clogged outlets for pond systems, may be at their worst. Thus the effectiveness of these BMPs is often compromised during such critical runoff events (CWP, 1997).

Pollutants of Concern

Section 4.5.4 of Chapter 4 of this Handbook discusses the water quality impacts that are common on urban and suburban (or developing) land. That section identifies the most prominent pollutants (see **Table 4.7**), indicates where on the land surface they are most likely to be generated (see **Figure 4.35**), and identifies the treatment mechanisms that are likely to be successful in removing or reducing each type of pollutant.

With careful site planning, developers and municipalities can reduce the amount of impervious area created by pavement and roofs, thus reducing the volume of stormwater runoff and associated pollutants requiring control. By employing BMPs that further reduce runoff volume, site designers can further reduce the negative impacts of development and perhaps avoid the need for some of the traditional stormwater management infrastructure resulting from the use of more traditional BMPs.

8.1. CATEGORIES OF BMPs AND THE MOST EFFECTIVE ORDER OF IMPLEMENTING THEM

Remember that the goal of pollution prevention is to prevent contact of rainfall or stormwater runoff with pollutants, thus reducing pollutant loads to water bodies while maintaining as much of the watershed's natural (predevelopment) hydrology as possible. Thus, ***stormwater control measures (BMPs) are most effective from the perspective of both efficiency and cost when stormwater management is considered and incorporated in the early planning stages of a community, watershed or development project.***

As noted in **Chapter 5**, many, if not most, development sites will need to employ multiple practices in order to satisfy the nutrient reduction requirements in the Regulations and adequately manage the stormwater runoff. Under the treatment train approach, stormwater management begins at the site level with simple methods that minimize the amount of runoff that occurs from a site and methods that prevent pollution from accumulating on the land surface and becoming available for transport in runoff from the site ("source controls" or non-structural BMPs or Better/Environmental Site Design).

The following is a brief description of each of the categories of practices listed in **Table 5.1** (in **Chapter 5**), which reflect the correct order of BMP implementation. Following these descriptions, there will be more specific descriptions of the post-construction BMPs that are more the focus of this Handbook.

8.1.1. Product Substitution

Product substitution refers to one of the classic pollution prevention approaches of reducing the availability of pollutants for future wash-off into stormwater runoff. The most notable example is the introduction of unleaded gasoline, which resulted in an order-of-magnitude reduction of lead levels in stormwater runoff in a decade (Pitt et al., 2004a, b). Similar reductions are expected with the phase-out of methyl tert-butyl ether (MTBE) additives in gasoline. Other examples of product substitution are the ban on coal-tar sealants during parking lot renovation that has reduced PAH runoff (Van Metre et al., 2006), phosphorus-free fertilizers that have measurably reduced phosphorus runoff (Barten and Johnson, 2007), the painting of galvanized metal surfaces, and alternative rooftop surfaces (Clark et al., 2005). Given the importance of coal power plant emissions in the atmospheric deposition of nitrogen and mercury, it is possible that future emissions reductions for such plants may result in lower stormwater runoff concentrations for these two pollutants.

8.1.2. Watershed Land-Use Planning

Communities can address stormwater problems by making land-use decisions that change the location or quantity of impervious cover created by new development. This can be accomplished through zoning, watershed plans, comprehensive land-use plans, or Smart Growth incentives.

The unit process that is managed is the amount of impervious cover, which is strongly related to various residential and commercial zoning categories (Capiella and Brown, 2000). Numerous techniques exist to forecast future watershed impervious cover and its probable impact on the quality of aquatic resources (see discussion of the Impervious Cover Model in **Appendix 5-A (Chapter 5)**; (CWP, 1998a; MD DNR, 2005). Using these techniques and simple or complex simulation models, planners can estimate stormwater flows and pollutant loads through the watershed planning process and alter the location or intensity of development to reduce them.

The level of control that can be achieved by watershed and land-use planning is theoretically high, but relatively few communities have aggressively exercised it. The most common application of down-zoning has been applied to watersheds that drain to drinking water reservoirs (Kitchell, 2002). The strength of this practice is that it has the potential to directly address the underlying causes of the stormwater problem rather than just treating its numerous symptoms. The weakness is that local decisions on zoning and Smart Growth are reversible and often driven by other community concerns and priorities, such as economic development, adequate infrastructure, and transportation. In addition, powerful consumer and market forces often have promoted low-density sprawl development. Communities that use watershed-based zoning often require a compelling local environmental goal, since state and federal regulatory authorities have traditionally been extremely reluctant to interfere with the local land-use and zoning powers.

8.1.3. Conservation of Natural Areas

Natural area conservation protects natural features and environmental resources that help maintain the predevelopment hydrology of a site by reducing runoff, promoting infiltration, and preventing soil erosion. Natural areas can be legally protected by a permanent conservation easement prescribing allowable uses and activities on the parcel and preventing future development. Examples include any areas of undisturbed vegetation preserved at the development site, including forests, wetlands, native grasslands, floodplains and riparian areas, zero-order stream channels, springs and seeps, ridge tops or steep slopes, and stream, wetland, or shoreline buffers. In general, conservation should maximize contiguous area and avoid habitat fragmentation.

While natural areas are conserved at many development sites, most of these requirements are prompted by other local, state, and federal habitat protections, and are not explicitly designed or intended to provide runoff reduction and stormwater treatment. To date, there are virtually no data to quantify the runoff reduction and/or pollutant removal capability of specific types of natural area conservation, or the ability to explicitly link them to site design.

8.1.4. Impervious Cover Reduction

A variety of practices, some of which fall under the broader term “better site design (BSD)” or “environmental site design (ESD),” can be used to minimize the creation of new impervious cover and disconnect or make more permeable the hard surfaces that are needed (Nichols et al., 1997; Richman, 1997; CWP, 1998a). The following is a list of some common impervious cover reduction practices for both residential and commercial areas:

Elements of Environmental Site Design: Single-Family Residential Sites

- Reducing the residential street width
- Reducing the street right-of-way (ROW) width
- Using swales and other BMPs that can be located within the ROW
- Reducing the cul-de-sac radius
- Installing vegetation and, ideally, a bioretention BMP on the island in the center of the cul-de-sac
- Alternative turn-around options, such as hammerheads, are acceptable if they reduce impervious cover
- Narrow sidewalks on one side of the street only (or move pedestrian pathways away from the street entirely)
- Disconnect rooftops from the storm-drain systems
- Minimize driveway length and width or share driveways, and use permeable surfaces
- Allow for cluster or open-space designs (e.g., zero lot line) that reduce lot size or setbacks in exchange for conservation of natural areas
- Permeable pavement in parking areas, driveways, sidewalks, walkways, and patios

Elements of Environmental Site Design: Multi-Family Residential and Commercial Sites

- Design buildings and parking to have multiple levels
- Store rooftop runoff in green roofs, foundation planters, bioretention areas, or cisterns
- Reduce parking lot size by reducing parking demand ratios and stall dimensions
- Use landscaping areas, tree pits, and planters for stormwater treatment
- Use permeable pavement for parking areas, plazas, and courtyards

CWP (1998a) recommends minimum or maximum geometric dimensions for subdivisions, individual lots, streets, sidewalks, cul-de-sacs, and parking lots that minimize the generation of needless impervious cover, based on a national roundtable of fire safety, planning, transportation and zoning experts. Specific changes in local development codes can be made using these criteria, but it is often important to engage as many municipal agencies that are involved in development as possible in order to gain consensus on code changes.

At the present time there is little research available to define the runoff reduction benefits of these practices. However, modeling studies consistently show a 10-45 percent reduction in runoff compared to conventional development (CWP, 1998b, c, 2002). Several monitoring studies have documented a major reduction in stormwater runoff from development sites that employ various forms of impervious cover reduction and LID in the United States and Australia (Coombes et al., 2000; Philips et al., 2003; Cheng et al., 2005) compared to those that do not.

Unfortunately, environmental site design has been slowly adopted by local planners, developers, designers, and public works officials. For example, although the Seattle Green Street project pictured in **Figure 5.2 (Chapter 5)** has been very successful in terms of controlling stormwater, the environmental site design principles used have not been widely adopted in the Seattle area. Existing local development codes may discourage or even prohibit the application of environmental site design practices, and many engineers and plan reviewers are hesitant to embrace them. Impervious cover reduction must be incorporated at the earliest stage of site layout and design to be effective, but outdated development codes in many communities can greatly restrict the scope of impervious cover reduction. Finally, the performance and longevity of impervious cover reduction is dependent on the infiltration capability of local soils, the intensity of development, and the future management actions of landowners.

8.1.5. Earthwork Minimization

This source control measure seeks to limit the degree of clearing and grading on a development site in order to prevent soil compaction, conserve soil structure, prevent erosion from steep slopes, and protect zero-order streams. This concept can be applied in two ways by (1) minimizing the total site area that must be cleared and graded to complete the project; and (2) minimizing the site area that must be cleared and graded at any one time by completing large projects in phases, stabilizing one phase as the next phase is being cleared. This is accomplished by (1) identifying key soils, drainage features, and slopes to protect, and then (2) establishing limits of disturbance beyond which construction equipment is excluded. This element is an important but often under-utilized component of local erosion and sediment control plans.

Numerous researchers have documented the impact of mass grading, clearing, and the passage of construction equipment on the compaction of soils, as measured by increases in bulk density, declines in soil permeability, and increases in the runoff coefficient (Lichter and Lindsey, 1994; Legg et al., 1996; Schueler, 2001a, b; Gregory et al., 2006). Another goal of earthwork minimization is to protect zero-order streams, which are channels with defined banks that emanate from a hollow or ravine with convergent contour lines (Gomi et al., 2002). They represent the uppermost definable channels that possess temporary or intermittent flow. Functioning zero-order channels provide major watershed functions, including groundwater recharge and discharge (Schollen et al., 2006; Winter, 2007), important nutrient storage and transformation functions (Bernot and Dodds, 2005; Groffman et al., 2005), storage and retention of eroded hill slope sediments (Meyers, 2003), and delivery of leaf inputs and large woody debris. Compared to high-order network streams, zero-order streams are disproportionately disturbed by mass grading, enclosure, or channelization (Gomi et al., 2002; Meyers, 2003).

The practice of earthwork minimization is not widely applied across Virginia. This is partly due to the limited performance data available to quantify its benefits, and the absence of local or national design guidance or performance benchmarks for the practice.

8.1.6. Erosion and Sediment Control

Erosion and sediment control are critical to every construction project. Erosion and sediment control predates all other state and federal stormwater management efforts in Virginia. Methods to prevent the export of sediments should be planned during the site design process. These consist of the temporary installation and operation of a series of structural and nonstructural practices (**see Figures 8.1 and 8.2)** throughout the entire construction process to minimize soil erosion and prevent off-site delivery of sediment. Because construction is expected to last for a finite and short period of time, the design standards are usually smaller and thus riskier (25-year versus the 100-

year storm). By phasing construction, thereby limiting the exposure of bare earth at any one time, the risk to the environment is reduced significantly.

The basic practices include clearing limits, dikes, berms, temporary buffers, protection of drainage ways, soil stabilization through hydroseeding or mulching, perimeter controls, and various types of sediment traps and basins. All plans have some component that requires filtration of runoff crossing construction areas to prevent sediment from leaving the site. This usually requires a sediment collection system including, but not limited to, conventional settling ponds and advanced sediment collection devices such as polymer-assisted sedimentation and advanced sand filtration. Silt fences are commonly specified to filter distributed flows, and they require maintenance and replacement after storms. Filter systems are added to inlets until the streets are paved and the surrounding area has a cover of vegetation. Sediment basins are constructed to filter out sediments through rock filters, or are equipped with floating skimmers or chemical treatment to settle out pollutants. Other common erosion and sediment control measures include temporary seeding and rock or ribbed entrances to construction sites to remove dirt from vehicle tires.

Control of runoff's erosive potential is critical. Most erosion and sediment control manuals provide design guidance on the capacity and ability of swales to handle runoff without eroding, on the design of flow paths to transport runoff at non-erosive velocities, and on the dissipation of energy at pipe outlets. Examples include rock energy dissipators, level spreaders, and other such devices. Although erosion and sediment control practices are temporary, they require constant operation and maintenance during the complicated sequence of construction and after major storm events. It is exceptionally important to ensure that practices are frequently inspected and repaired and that sediments are cleaned out.

In Virginia, Erosion and Sediment Control is the subject of a completely separate regulatory program (§ 62.1-44.15:51 et seq., Code of Virginia; 9 VAC 25-840 et seq.; *Virginia Erosion and Sediment Control Handbook, Third Edition*, 1992) and is not addressed further in this Handbook.

Figure 8.1. Temporary Silt Fence

Figure 8.2. Temporary Sediment Basin

8.1.7. Reforestation and Soil Compost Amendments

This set of practices seeks to improve the quality of native vegetation and soils present at the site. Depending on the ecoregion, this may involve forest or meadow plantings, tilling, and amending compacted soils to improve their hydrologic properties.

The goal is to maintain as much predevelopment hydrologic function at a development site as possible by retaining canopy interception, duff/soil layer interception, evapotranspiration, and surface infiltration. The basic methods to implement this practice are described in Cappiella et al. (2006), Pitt et al (2005), Chollak and Rosenfeld (1998), and Balusek (2003).

At this time, there are few monitoring data to assess the degree to which land reforestation or soil amendments can improve the quality of stormwater runoff at a particular development site, apart from the presumptive watershed research that has shown that forests with undisturbed soils have very low rates of surface runoff and extremely low levels of pollutants in runoff (Singer and Rust, 1975; Johnson et al., 2000; Chang, 2006). More data are needed on the hydrologic properties of urban forests and soils whose ecological functions are stressed or degraded by the urbanization process (Pouyat et al., 1995, 2007).

8.1.8. Pollution Prevention BMPs

By far the most effective control of NPS pollution is to *prevent its release*. This is especially true for stormwater hotspots. There are three families of runoff pollution prevention:

- Impervious surface reductions: reducing the amount of hard surfaces;

- Housekeeping techniques: basic clean-up and management practices;

- Construction practices (see E&S control above): techniques to prevent exposed soils from eroding, methods to reduce opportunities for sediment release into stormwater, and methods to catch sediment already suspended in stormwater

The stormwater-related problems associated with hotspots were described in **Chapter 6**. The keys to managing and treating runoff at hotspot sites are as follows:

- **Prevention**. The goal of pollution prevention is to prevent contact of rainfall or stormwater runoff with pollutants, and it is an important element of the post-construction stormwater plan. It is most important to design manage and store toxic materials on the site in a way that prevents opportunities for the pollutants to be exposed to rain and be washed into runoff.

- **Provide pre-treatment** devices between the source material and any stormwater control measures used to control general runoff from the site, especially if they involve infiltration. **Table 8.3** provides a matrix that indicates which control measures are appropriate for use at hotspot locations.

- **Inspect and correctly maintain** all pollution prevention or treatment elements at the site on a routine basis. Because of the extremely toxic nature of hotspot pollutants, it is extremely important that the stormwater control measures at hotspot sites be kept in good working order.

- **Train personnel** at the affected area to ensure that industrial and municipal managers and employees understand and implement the correct stormwater pollution prevention practices needed for their site or operation.

8.1.9. Runoff Volume Reduction – Rainwater Harvesting

A primary goal of stormwater management is to reduce the volume of runoff from impervious surfaces. There are several classes of BMPs that can achieve this goal, including rainwater harvesting systems, vegetated BMPs that evaporate and transpire part of the volume, and infiltration BMPs. For all of these measures, the amount of runoff volume to be captured depends on watershed goals, site conditions including climate, upstream nonstructural practices employed, and whether the chosen BMP is the sole management measure or part of a treatment train. Generally, runoff volume reduction BMPs are designed to handle at least the Treatment Volume from impervious surfaces (first 1-inch of rainfall). In Virginia, control of the 1-year 24-hour storm volume is considered the standard necessary to protect stream channel geomorphology, while base flow recharge can be addressed by capturing a much smaller volume (see **Chapter 10**).

Some designers have reported that in areas with medium to lower percentage of impervious surfaces, they are able to control up to the 100-year storm by enlarging runoff volume reduction BMPs and applying them to the entire site. In retrofit situations, capture amounts as small as 1 cm are a distinct improvement. It should be noted that there are important, although indirect, water quality benefits of all runoff volume reduction BMPs: (1) the reduction in runoff will reduce streambank erosion downstream and the concomitant increases in sediment load, and (2) volume reductions lead to pollutant mass load reductions, even if pollutant concentrations in stormwater are not decreased.

Rainwater harvesting systems refer to the use of captured runoff from roof tops in rain barrels, rain tanks, or cisterns (**Figures 8.3 and 8.4** below). This BMP treats runoff as a resource and is one of the few BMPs that can provide a tangible economic benefit through the reduction of treated water usage. Rainwater harvesting systems have substantial potential as retrofits via the use of rain barrels or cisterns that can replace lawn or garden sprinkling systems. Use of this BMP to provide gray water within buildings (e.g., for toilet flushing) is considerably more complicated due to the need to construct new plumbing and obtain the necessary permits.

The greatest challenge with these systems is the need to use the stored water and avoid having full tanks when the next storm occurs. That is, these BMPs are effective only if the captured runoff can be regularly used for some gray water usage, like car washing, toilet flushing, or irrigation (e.g., golf courses, landscaping, nurseries). In some areas it might be possible to use the water for drinking, showering, or washing, but treatment to potable water quality would be required. Sizing of the required storage is dependent on the climate patterns, the amount of impervious cover, and the frequency of water use. Areas with frequent rainfall events require less storage as long as the water is used regularly, while areas with cold weather will not be able to utilize the systems for irrigation in the winter, and thus require larger storage.

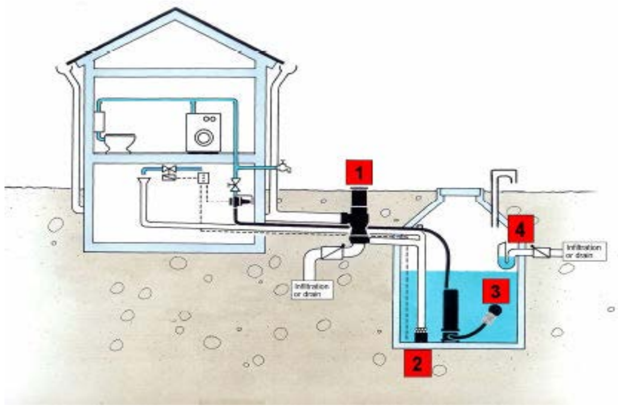

Figure 8.3. Rainwater Harvesting Schematic

Figure 8.4 Above-Ground Rain Tanks

One substantial advantage of these systems is their ability to reduce water costs for the user and the ability to share needs. An example of this interaction is the Pelican Hill development in Irvine, California, where excess runoff from the streets and houses is collected in enormous cisterns and used for watering of a nearby golf course. Furthermore, compared to other BMPs, the construction of rainwater harvesting facilities provides a long term benefit with minimal maintenance cost, although they do require an up-front investment for piping and storage tanks.

Coombes et al. (2000) found that rainwater harvesting achieved a 60-90 percent reduction in runoff volume. However, in general, few studies have been conducted to determine the performance of these BMPs. It should be noted that rainwater harvesting systems do collect airborne deposition and acid rain.

8.1.10. Runoff Volume Reduction

Runoff Volume Reduction – Vegetated

A large and very promising class of BMPMs includes those that use infiltration and evapotranspiration via vegetation to reduce the volume of runoff. These BMPs also directly address water quality of both surface water and groundwater by reducing streambank erosion, capturing suspended solids, and removing other pollutants from stormwater during filtration through the soil (although the extent to which pollutants are removed depends on the specific pollutant and the local soil chemistry). Depending on their design, these BMPs can also reduce peak flows and recharge groundwater (if they infiltrate). These BMPs can often be added as retrofits to developed areas by installing them into existing lawns, rights-of-way, or traffic islands. They can add also beauty and property value.

Flow volume is addressed by this BMP group by first capturing runoff, creating a temporary holding area, and then removing the stored volume through infiltration and evapotranspiration. Swales refer to grassy areas on the side of the road that convey drainage (**Figure 8.5** below). These were first designed to move runoff away from paved areas, but they can now be designed to achieve a certain contact time with runoff, so as to promote infiltration and pollutant removal. Bioretention generally refers to a constructed depression or swale that encloses a filter media mix (often sand and organic material), with vegetation growing on top, to which stormwater runoff from impervious surfaces is directed (**Figure 8.6**). The original rain garden or bioretention facilities were constructed with an impermeable liner at the bottom of the prepared soil to prevent infiltration and instead had a low-level outflow at the bottom. Green roofs are very similar to bioretention BMPs (**Figure 8.7**). They tend to be populated with a light expanded shale-type soil and succulent plants chosen to survive wet and dry periods. Finally, bioinfiltration is similar to bioretention, but it is better engineered to achieve greater infiltration (**Figure 8.8**). All of these devices are usually at the upper end of a treatment train and designed for smaller storms, which minimizes their footprint and allows for incorporation within existing infrastructure (such as traffic control devices and median strips). This allows for distributed treatment of the smaller volumes and distributed volume reduction.

Figure 8.5. Vegetated Wet Swale

Figure 8.6. Parking Area Bioretention

Figure 8.7. Vegetated Roof

Figure 8.8. Retrofit Bioinfiltration

These BMPs work by capturing water in a vegetated area, which then infiltrates into the soil below. They are primarily designed to use plant material and soil to evaporate and transpire the runoff over several days following the storm. A shallow depth of ponding is required, since the inflows may exceed the possible infiltration capacity of the native soil. This ponding is maintained above an engineered sandy soil mixture and is a surface-controlled process (Hillel, 1998). Early in the storm, the soil moisture potential creates a suction process that helps draw water into the BMP. This then changes to a steady rate that is "practically equal to the saturated hydraulic conductivity" of the subsurface (Hillel, 1998). The hydrologic design goal should be to maximize the volume of water that can be held in the soil, which necessitates consideration of the soil hydraulic conductivity (which varies with temperature), climate, depth to groundwater, and time to drain. Usually these devices are designed to empty between 24-72 hours after a storm event. In some cases (usually bioretention), these BMPs have an underdrain.

The choice of vegetation is an important part of the design of these BMPs. Many sites where infiltration is desirable have highly sandy soils, and the vegetation has to be able to endure both wet and dry periods. Long root growth is desired to promote infiltration (Minnesota Council, 2001), and plants that attract birds can reduce the insect population. Bioretention cells may be wet for longer periods than bioinfiltration sites, requiring different plants. Denser plantings or "thorns" may be needed to avoid the destruction caused by humans and animals taking shortcuts through the beds.

The pollutant removal mechanism operating for volume reduction BMPs are different for each pollutant type, soil type, and volume reduction mechanism. For bioretention and BMPs using infiltration, the sedimentation and filtration of suspended solids in the top layers of the soil are extremely efficient. Several studies have shown that the upper layers of the soil capture metals, particulate nutrients, and carbon (Pitt, 1996; Deschesne et al., 2005; Davis et al., 2008).

The removal of dissolved nutrients from stormwater is not as straightforward. While ammonia is caught by the top organic layer, nitrate is mobile in the soil column. Some bioretention systems have been built to hold water in the soil for longer periods in order to create anaerobic conditions that would promote denitrification (Hunt and Lord, 2006). Phosphorus removal is related to the amount of phosphorus in the original soil. Some studies have shown that bioretention cells built with agricultural soils actually *increased* the amount of phosphorus released. Chlorides pass through the system unchecked (Ermilio and Traver, 2006), while oils and greases are easily removed by the organic layer. Hunt et al. (2008) have reported in studies in North Carolina that the drying cycle appears to kill off bacteria. Temperature is not usually a concern, since most storms do not overflow these devices. Green roofs collect airborne deposition and acid rain and may export nutrients when they overflow. However, this must be tempered by the fact that in larger storms, most natural lands would produce nutrients.

A group of new research studies from North America and Australia have demonstrated the value of many of these runoff volume reduction practices to replicate predevelopment hydrology at the site. The results from 11 recent studies are given in **Table 8.1** below, which shows the runoff reduction capability of bioretention. As can be seen, the reduction in runoff volume achieved by these practices is impressive, ranging from 20-99 percent with a median reduction of about 75 percent. Bioswales installed during Seattle's natural drainage systems project also have demonstrated excellent results (see Horner et al., 2003; Jefferies, 2004; Stagge, 2006). Bioinfiltration has been less studied, but one field study concluded that close to 20 percent of the storm volume was removed by bioinfiltration (Sharkey, 2006). Capture of small storms through this kind of BMP appears to be extremely effective in areas where the majority of rain falls in smaller storms.

Table 8.1. Volumetric Runoff Reduction Achieved by Bioretention

Bioretention Design	Location	Runoff Reduction	Reference
Infiltration	CT	99%	Dietz and Clausen (2006)
	PA	86%	Ermiliao and Traver (2006)
	FL	98%	Rushton (2002)
	AUS	73%	Lloyd et al. (2002)
Underdrain	ONT	40%	Van Seters et al. (2006)
	Model	30%	Perez-Perdini et al. (2005)
	NC	40-60%	Smith and Hunt (2007)
	NC	20-29%	Sharkey (2006)
	NC	52-56%	Hunt et al. (2008)
	NC	20-50%	Passeport et al. (2008)
	MD	52-65%	Davis et al. (2008)

Source: NRC (2008)

The strengths of vegetated runoff volume reduction BMPs include the flexibility to use the drainage system as part of the treatment train. For example, bioswales can replace drainage pipes, green roofs can be installed on buildings, and bioretention can replace parking borders, thereby reducing the footprint of the stormwater system. Also, through the use of swales and reducing pipes and inlets, costs can be offset. Vegetated systems are more tolerant of the TSS collected, and their growth cycle maintains pathways for infiltration and prevents clogging. Freeze-thaw cycles also contribute to pathway maintenance. The aesthetic appeal of vegetated BMPs is also a significant strength.

Weaknesses include the dependence of these BMPs on native soil infiltration and the need to understand groundwater levels and karst geology, particularly for those BMPs designed to infiltrate. For bioinfiltration and bioretention, most failures occur early on and are caused by sedimentation and construction errors that reduce infiltration capacity, such as stripping off the topsoil and compacting the subsurface. Once a good grass cover is established in the contributing area, the danger of sedimentation is reduced. Nonetheless, the need to prevent sediment from overwhelming these structures is critical. The longevity of these BMPs and their vulnerability to toxic spills are a concern (Emerson and Traver, 2008), as is their failure to reduce chlorides. Finally, in areas where the land use is a hot spot, or where **(**the BMP could potentially contaminate the groundwater supply, bioretention, non-infiltrating bioswales, and green roofs may be more suitable than infiltration BMPs.

The role of infiltration BMPs in promoting groundwater recharge deserves additional consideration. Although this is a benefit of infiltration BMPs in regions where groundwater levels are dropping, it may be undesirable in a few limited scenarios. For example, in most urban areas, there is so much impervious cover that it would be difficult to “over-infiltrate.” Nonetheless, the use of infiltration BMPs will change local subsurface hydrology, and the ramifications of this – good and bad – should be considered prior to their installation.

Maintenance of vegetated runoff reduction BMPs is relatively simple. A visit after a rainstorm to check for plant health, to check sediment buildup, and to see if the water is ponded can answer many questions. Maintenance includes trash pickup and seasonal removal of dead grasses and weeds. Sediment removal from pretreatment devices is required. Depending on the pollutant concentrations in the influent, the upper layer of organic matter may need to be removed infrequently to maintain infiltration and to prevent metal and nutrient buildup.

At the site level, the chief factors that lead to uncertainty are the infiltration performance of the soil, particularly for the limiting subsoil layer, and how to predict the extent of pollutant removal. Traditional percolation tests are not effective to estimate the infiltration performance; rather, testing hydraulic conductivity is required. Furthermore, the infiltration rate varies depending on temperature and season (Emerson and Traver, 2008). Basing measurements on percent removal of pollutants is extremely misleading, since every site and storm generates different levels of pollutants. The extent of pollutant removal depends on land use, time between storms, seasons, and so forth. These factors should be part of the design philosophy for the site.

Finally, it should also be pointed out that climate is a factor determining the effectiveness of some of these BMPs. For example, green roofs are more likely to succeed in areas having smaller, more frequent storms, compared to areas subject to less frequent, more intense storms.

Runoff Volume Reduction – Subsurface

Infiltration is the primary runoff volume reduction mechanism for subsurface BMPs, such that much of the previous discussion is relevant here. Thus, like vegetated BMPs, these BMPs provide benefits for groundwater recharge, water quality, stream channel protection, peak flow reduction, capture of the suspended solids load, and filtration through the soil (Ferguson, 2002). Because these systems can be built in conjunction with paved surfaces (i.e., they are often buried under parking lots), the amount of water captured, and thus stream protection, may be higher than for vegetated systems. They also have lower land requirements than vegetated systems, which can be an enormous advantage when using these BMPs during retrofitting, as long as the soil is conducive to infiltration.

Similar to vegetated BMPs, this BMP group works primarily by first capturing runoff and then removing the stored volume through infiltration. The temporary holding area is made either of stone or using manufactured vaults. Examples include infiltration trenches, seepage pits (dry wells), and permeable pavement (see **Figures 8.9**, **8.10**, **8.11**, and **8.12** below). As with vegetated BMPs, a shallow depth of ponding is required, since the inflows may exceed the possible infiltration ability of the native soil. In this case, the ponding is maintained within a rock bed under a permeable pavement or in an infiltration trench. These devices are usually designed to empty between 24-72 hours after the storm event.

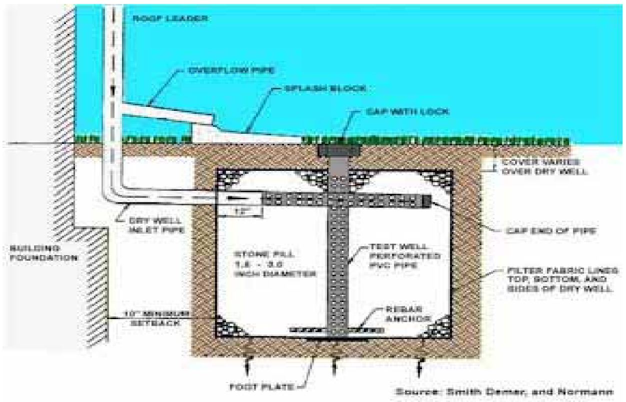

Figure 8.9. Seepage Pit (Dry Well) Schematic

Figure 8.10. Infiltration Trench

Figure 8.11. Porous Asphalt

Figure 8.12. interlocking Permeable Pavers

The infiltration processes operating for these subsurface BMPs are similar to those for the vegetated devices previously discussed. Thus, much like for vegetated systems, the level of control achieved depends on the infiltration ability of the native soils, the percent of impervious surface area in the contributing watershed, land use contributing to the pollutant loadings, and climate. A large number of recent studies have found that permeable pavement can reduce runoff volume by anywhere from 50 percent (Rushton, 2002; Jefferies, 2004; Bean et al., 2007) to as much as 95 percent or greater (van Seters et al., 2006; Kwiatkowski et al., 2007). Villanova University's Stormwater Research and Demonstration Park has successfully demonstrated a retrofit of standard asphalt with permeable pavement.

The strengths of subsurface runoff volume reduction BMPs are similar to those of their vegetated counterparts. Additional attributes include their ability to be installed under parking areas and to manage larger volumes of rainfall. These BMPs typically have few problems with safety or vector-borne diseases because of their subsurface location and storage capacity, and they can be very aesthetically pleasing. The potential of permeable pavement could be particularly far-reaching if one considers the amount of impervious surface in urban areas that is comprised of roads, driveways, and parking lots.

The weaknesses of these BMPs are also similar to those of vegetated systems, including their dependence on native soil infiltration and the need to understand groundwater levels and karst geology. Simply estimating the soil hydraulic conductivity can have an error rate of an order of magnitude. Specifically for subsurface systems that use geotextiles (not permeable pavement), there is a danger of TSS being compressed against the bottom of the geotextile, preventing infiltration. There are no freeze-thaw cycles or vegetated processes that can reopen pathways, so the control of TSS is even more critical to their life span. In most cases (permeable pavement is an exception), pretreatment is required, except for the cleanest of sources (like a slate roof). Typically, manufactured devices, sediment forebays, or grass filter strips are part of the design of subsurface BMPs to capture the larger sediment particles.

The maintenance of subsurface runoff volume reduction BMPs is relatively simple but critical. If inspection wells are installed, a visit after a rainstorm will check that the volume is captured, and later that it has infiltrated. Porous surfaces should undergo periodic vacuum street sweeping when a sediment source is present. Pretreatment devices require sediment removal. The difficulty with this class of BMPs is that, if a toxic spill occurs or maintenance is not proactive, there are no easy corrective measures other than replacement.

Low Impact Development (LID). LID refers primarily to the use of small, engineered, on-site stormwater practices to treat the quality and quantity of runoff at its source. It is discussed here because the BMPs that are thought of as LID – particularly vegetated swales, green roofs, permeable pavement, and rain gardens – are all runoff volume reduction BMPs. They are designed to capture the first portion of a rainfall event and to treat the runoff from a few hundred square meters of impervious cover.

As discussed earlier, several studies have measured the runoff volume reduction of individual LID practices. Fewer studies are available on whether multiple LID practices, when used together, have a cumulative benefit at the neighborhood or catchment scale. Several monitoring studies have clearly documented a major reduction in runoff from developments that employ LID and Environmental Site Design, compared to those that do not. In addition, six studies have documented the runoff reduction benefits of LID at the catchment or watershed scale, using a modeling approach (Alexander and Heaney, 2002; Stephens et al., 2002; Holman-Dodds et al., 2003; Coombes, 2004; Hardy et al., 2004; and Huber et al., 2006).

8.1.11. Peak Flow Reduction and Runoff Treatment

Peak Flow Reduction

After efforts are made to prevent the generation of pollutants and to reduce the volume of runoff that reaches stormwater systems, stormwater management focuses on the reduction of peak flows and associated treatment of polluted runoff. The main class of BMPs used to accomplish this is pond-type practices, versions of which have dominated stormwater management for decades. These include a wide variety of ponds and wetlands, including wet ponds (also known as retention basins), dry extended detention ponds (also known as detention basins), and constructed wetlands. By holding a volume of stormwater runoff for an extended period of time, pond-type BMPs can achieve both water quality improvement and reduced peak flows.

Generally the goal is to hold the flows for at least 24 hours to maximize the opportunity of settling, adsorption, and transformation of pollutants (based on past pollutant removal studies) (Rea and Traver, 2005). For smaller storm events (one-year storms), this added holding time also greatly reduces the outflows from the BMP to a level that the stream channel can handle. Most wet ponds and stormwater wetlands can hold a "treatment volume," such that the flows leaving in smaller storms have been held and "treated" for multiple days. Extended detention dry ponds also greatly reduce the outflow peaks to achieve the required residence times.

Usually pond-type devices are lower in the treatment train of BMPs, if not at the very end. This is both due to their function (they are designed for larger events) and because the required water sources and less permeable soils needed for these BMPs are more likely to be found at the lower areas of the site. Some opportunities exist to naturalize dry ponds or to retrofit wet ponds into stormwater wetlands, but it depends on their site configuration and hydrology. A wet pond is shown in **Figure 8.13**. A stormwater wetland and a dry extended basin are shown in **Figures 8.14 and 8.15.**

Figure 8.13. Wet Pond

Figure 8.14. Constructed Wetland

Figure 8.15. Dry Extended Detention Basin

Simple ponds are little more than a hole in the ground, in which stormwater is piped in and out. Dry ponds are meant to be dry between storms, whereas wet ponds have a permanent pool throughout the year. Detention basins reduce peak flows by restricting the outflows and creating a storage area. Depending on the detention time, outflows can be reduced to levels that do not accelerate erosion, that protect the receiving stream channel, and that reduce flooding.

The flow normally enters the structure through a sediment forebay (**Figure 8.16**), which is included to capture incoming sediment, remove the larger particles through settling, and allow for easier maintenance. Then a meandering path or cell structure is built to "extend" and slow down flows. The main basin is a large storage area (sometimes over the meandering flow paths). Finally, the runoff exits through an outflow control structure built to retard flow.

Figure 8.16. Sediment Forebay, with Wet Pond in the Background

Wet ponds, stormwater wetlands, and (to a lesser extent) dry extended detention basins provide treatment. The first step in the pond treatment process is the settling of larger particles in the sediment forebay. Next, for wet ponds a permanent pool of water is maintained so that, for smaller storms, the new flows push out a volume that has had a chance to interact with vegetation and be "treated." This volume is equivalent to an inch of rain over the impervious surfaces in the drainage area. Thus, what exits the BMP during smaller storm events is base flow contributions and runoff that entered during previous events. For dry extended detention ponds, there is no permanent pool and the outlet is instead greatly restricted. For all of these devices, vegetation is considered crucial to pollutant removal. Indeed, wet ponds are designed with an aquatic bench around the edges to promote contact with plants. The vegetation aids in reduction of flow velocities (through friction), provides growth surfaces for microbes, takes up pollutants such as nutrients, and provides filtering (Braskerud, 2001).

The ability of pond structures to achieve a certain level of control is size related – that is, the more peak flow reduction or pollutant removal required, the more volume and surface area are needed in the basin. Because it is not simply the peak flows that are important, but also the duration of the flows that cause damage to the receiving stream channels (McCuen, 1979; Loucks et al., 2005), some ponds are currently sized and installed in series with runoff volume reduction BMPs.

The strength of pond-type devices is the opportunity to create habitats or picturesque settings in conjunction with stormwater management. The weaknesses of these measures include large land requirements, chloride buildup, possible temperature effects (i.e., warming), and the risk of creating habitat for undesirable species in urban areas. There is a perception that these devices promote mosquitoes, but that has not been found to be a problem when a healthy biological habitat is created (Greenway et al., 2003). Another drawback of this class of BMPs is that they often have limited treatment capacity, in that they can reduce pollutants in stormwater only to a certain level. These so-called irreducible effluent concentrations have been documented mainly for ponds and stormwater wetlands, as well as for sand filters and grass channels (Schueler, 1998). Finally, it should be noted that either a larger watershed (10-25 acres: CWP, 2004) or a continuous water source is needed to sustain wet ponds and stormwater wetlands.

Maintenance requirements for ponds and wetlands include the removal of built-up sediment from the sediment forebay, harvesting of grasses to remove accumulated nutrients, and repair of berms and structures after damaging storm events. Inspection items relate to the maintenance of the dam and sediment forebay.

While the basic hydrologic function of extended detention devices is well known, their performance on a watershed basis is not. Because they do not significantly reduce runoff volume and are designed on a site-by-site basis using synthetic storm patterns, their exclusive use as a flood reduction strategy at the watershed scale is uncertain (McCuen, 1979; Traver and Chadderton, 1992). Much of this variability is reduced when they are coupled with volume reduction BMPs at the watershed level. Pollutant removal is effected by climate, short-circuiting of flows through the device, and by the schedule of sediment removal and plant harvesting. Extreme events can re-suspend captured sediments, thus reintroducing them into the environment. Although it is the subject of much debate, it seems likely that plants will need to be harvested to accomplish nutrient removal (Reed et al., 1998).

Runoff Treatment

As mentioned above, many BMPs associated with runoff volume reduction and extended detention provide a water quality benefit. There are also some BMPs that focus primarily on water quality with little peak flow or volume effect. Designed for smaller storms, these are usually based on filtration, hydrodynamic separation, or small-scale bioretention systems that drain to a subsequent receiving water or other device. Thus, often these BMPs are used in conjunction with other devices in a treatment train or as retrofits under parking lots. They can be very effective as pretreatment devices when used "higher up" in the watershed than infiltration structures. Finally, in some cases these BMPs are specifically designed to reduce peak flows in addition to providing water quality benefits by introducing elements that make them similar to detention basins. This is particularly the case for sand filters.

The sand filter is relied upon as a treatment technology in many regions, particularly those where stream geomorphology is less of a concern, and thus peak flow control and runoff volume reduction are not the primary goals. These devices can be effective at removing suspended sediments and can extend the longevity and performance of runoff volume reduction BMPs. They are also one of the few urban retrofit practices available, due to the ability to implement them within traditional culvert systems. **Figures 8.17 and 8.18** show designs for the Austin sand filter and Delaware sand filter.

Figure 8.17. Austin Sand Filter

Figure 8.18. Delaware Sand Filter

Filters use sand, peat, or compost to remove particulates, similar to the processes used in drinking water treatment plants. Sand filters primarily remove suspended solids and ammonia nitrogen. Biological material, such as peat or compost, provides adsorption of contaminants such as dissolved metals, hydrocarbons, and other organic chemicals.

Manufactured Treatment Devices (MTDs)

There are several types of manufactured stormwater treatment devices in the marketplace, and more are being designed all the time. Hydrodynamic devices use rotational forces to separate the solids from the flow, allowing the solids to settle out of the flow stream. There is a recent class of bioretention-like manufactured devices that combine inlets with planters. In these systems, small volumes are directed to a soil planter area, with larger flows bypassing and continuing down the storm sewer system. In any event, for manufactured treatment devices (MTDs) the user needs to look to the manufacturer's published and reviewed data to understand how the device should be applied.

The level of control that can be achieved with these BMPs depends entirely on sizing of the device based on the incoming flow and pollutant loads. Each unit has a certified removal rate depending on inflow to the BMP. Also, all units have a maximum volume or rate of flow they can treat, such that higher flows are bypassed with no treatment. Thus, the user has to determine what size unit is needed and the number to use, based on the area's hydrologic cycle and what criteria are to be met.

With the exception of some types of sand filters, the strengths of water quality treatment BMPs are that they can be placed within existing infrastructure or under parking lots, and thus do not take up land that may be used for other purposes. They make excellent choices for retrofit situations. For filters, there is a wealth of experience from the water treatment community on their operations. There are several testing protocols, including the new Virginia Technology Assessment Protocol (VTAP), that have been established to validate the performance of MTDs (the sufficiency of the testing protocols is discussed below).

Weaknesses of these devices include their cost and maintenance requirements. Regular maintenance and inspection at a high level are required to remove captured pollutants, to replace mulch, or to rake and remove the surface layer to prevent clogging. In some cases, specialized equipment (vacuum trucks) is required to remove built-up sediment. Although the underground placement of these devices has many benefits, it makes it easy to neglect their maintenance because there are no signs of reduced performance on the surface. Because these devices are manufactured, the unit construction cost is usually higher than for other BMPs. Finally, the numerous testing protocols are confusing and inhibit more widespread applications.

The chief uncertainty with these BMPs is due to the lack of certification of some MTDs. There is also concern about which pollutants are removed by which class of device. For example, hydrodynamic devices and sand filters do not address dissolved nutrients, and in some cases convert suspended pollutants to their dissolved form. Both issues are related to the false perception that a single BMP must be found that will comprehensively treat stormwater. Such pressures often put vendors in a position of trying to certify that their devices can remove *all* pollutants. Most often, these devices can serve effectively as part of a treatment train, and they should be valued for their incremental contributions to water quality treatment. For example, a filter that removes sediment upstream of a bioinfiltration BMP can greatly prolong the life of the infiltration device.

Testing of MTDs

Manufacturers of proprietary BMPs offer a service that can save municipalities/developers time and money. Time is saved by the ability of the manufacturers to quickly select a model matching the needs of the site. A city can minimize the cost of buying the product by requiring the different manufacturers to submit bids for the site. All the benefits of the service will have no meaning, however, if the cities/developers cannot trust the performance claims of the different products. Because the United States does not have, at this time, a national program to verify the performance of MTDs, interested municipalities and developers face a high amount of uncertainty when they select a product. Money could be wasted on products that might have the lowest bid, but do not achieve the water quality goals of the municipality or state.

The U.S. EPA's Environmental Technology Verification (ETV) program was created to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The Wet Weather Flow Technologies Pilot project was established as part of the ETV program to verify commercially available technologies used in the abatement and control of urban stormwater runoff, combined sewer overflows, and sanitary sewer overflows. Ten proprietary BMPs were tested under the ETV program, and the results of the monitoring are available on the National Sanitation Foundation website. Unfortunately, the funding for the ETV program was discontinued before all the stormwater products could be tested. Without a national testing program, some states have taken a more regional approach to verifying the performance of proprietary practices, while most states do not have any type of verification or approval program.

The Washington Department of Ecology has supported a testing protocol called Technology Assessment protocol – Ecology (TAPE) that describes a process for evaluating and reporting on the performance and appropriate uses of emerging MTDs. California, Massachusetts, Maryland, New Jersey, Pennsylvania, and Virginia have sponsored a testing program called Technology Acceptance and Reciprocity Partnership (TARP), through which a number of products are being tested in the field. The state of Wisconsin has prepared a draft technical standard (2006) describing methods for predicting the site-specific reduction efficiency of proprietary sedimentation devices. To meet the criteria in the standard, the manufacturers can either use a model to predict the performance of the practice or complete a laboratory protocol designed to develop efficiency curves for each product. Although none of these state or federal verification efforts have produced enough information to sufficiently reduce the uncertainty in selection and sizing of MTDs, many proprietary practices are being installed around the country, because of the perceived advantage of the service being provided by the manufacturers and the sometimes overly optimistic performance claims.

All those involved in stormwater management, including the manufacturers, will have a much better chance of implementing a cost-effective stormwater program in their cities if the barriers to a national testing program for MTDs are eliminated. Two of the barriers to the ETV program were high cost and the transferability of the results. Also, the ETV testing did not produce results that could be used in developing efficiency curves for the product. There have been discussions about establishing a new national testing program that could reduce testing costs by using laboratory testing instead of field testing. However, many consider field testing to be very important to determine if laboratory test results are actually transferrable to the real world. The new VTAP is Virginia's method of building upon the other existing protocols to better evaluate how MTDs perform. The VTAP will be implemented through the DEQ's Virginia Stormwater BMP Clearinghouse.

8.1.12. Aquatic Buffers and Managed Floodplains

Establishing aquatic buffers, also called stream buffers or riparian buffers (**Figures 8.19 and 8.20** below), involves reserving a vegetated zone adjacent to streams, shorelines, or wetlands in response to development regulations or a local ordinance. In most regions of the country, including Virginia, forest vegetation is preferred. When properly designed, buffers can both reduce runoff volumes and provide water quality treatment of stormwater.

The performance of urban stream buffers cannot be predicted from studies of buffers installed to remove sediment and nutrients from agricultural areas (Lowrance and Sheridan, 2005). Agricultural buffers have been reported to have high sediment and nutrient removal because they intercept sheet flow or shallow groundwater flow in the riparian zone. By contrast, urban stream buffers often receive concentrated surface runoff or may even have a storm drain pipe that short-circuits the buffer and directly discharges into the stream. Consequently, the pollutant removal capability of urban stream buffers is limited, unless they are specifically designed to distribute and treat stormwater runoff (NRC, 2000). This involves the use of level spreaders, grass filters, and berms to transform concentrated flows into sheet flow (Hathaway and Hunt, 2006). Such designed urban stream buffers have been applied widely in the Neuse River basin in North Carolina and in Henrico County in Virginia to reduce urban stormwater nutrient inputs to nutrient-sensitive water bodies.

Figure 8.19. Buffered Stream

Figure 8.20. Residential Riparian Buffer

The primary benefit of buffers is to help maintain aquatic biodiversity within the stream. Numerous researchers have evaluated the relative impact of riparian forest cover and impervious cover on stream geomorphology, aquatic insects, fish assemblages, and various indexes of biotic integrity. As a group, the studies suggest that indicator values for urban stream health increase when riparian forest cover is retained over at least 50 to 75 percent of the length of the upstream network (Goetz et al., 2003; Wang et al., 2003; McBride and Booth, 2005; Moore and Palmer, 2005). There is also general agreement that buffering headwater streams is more important than buffering higher order streams, since the headwaters provide the foundation for the aquatic food chain and ecologic health.

The width of the buffer is also important for enhancing its stream protection benefits. Recommended widths range from 25 to 200 feet depending on stream order, protection objectives, and community ordinances. Eastern Virginia communities subject to the Chesapeake Bay Preservation Act (CBPA) are required to designate lands near streams, rivers and open water as Resource Protection Areas, part of which is a 100-foot wide riparian buffer next to the water. Some other Virginia communities, as well, have added buffer requirements to their local codes to protect water quality, biodiversity, and general stream health. However, the beneficial impact of riparian forest cover may diminish as watershed impervious cover grows beyond 15 percent, when degradation by stormwater runoff can overwhelm the benefits of the riparian forest (Roy et al., 2005, 2006; Walsh et al., 2007).

Maintenance, inspection, and compliance for buffers can be a problem. In most communities, urban stream buffers are simply a line on a map and are not managed in any significant way after construction is over. As such, urban stream buffers are prone to residential encroachment and clearing, and to colonization by invasive plants.

Another important practice is to protect, preserve, or otherwise manage the ultimate 100-year floodplain so that vulnerable property and infrastructure are not damaged during extreme floods. Federal Emergency Management Agency (FEMA), state, and local requirements often restrict or control development on land within the floodway or floodplain. In larger streams, the floodway and aquatic buffer can be integrated together to achieve multiple social objectives.

8.1.13. Stream Rehabilitation

While not traditionally considered an BMP, certain stream rehabilitation practices or approaches can be effective at recreating stream physical habitat and ecosystem function lost during urbanization. When combined with effective BMPs in upland areas, stream rehabilitation practices can be an important component of a larger strategy to address stormwater. From the standpoint of mitigating stormwater impacts, four types of urban stream rehabilitation are common:

- Practices that stabilize streambanks and/or prevent channel erosion/enlargement can reduce downstream delivery of sediments and attached nutrients (**Figures 8.21 and 8.22**). Although the magnitude of sediment delivery from urban-induced stream channel enlargement is well documented, there are very few published data to quantify the potential reduction in sediment or nutrients from subsequent channel stabilization.

Figure 8.21. Before Stream Restoration

Figure 8.22. After Stream Restoration

Streams can be hydrologically reconnected to their floodplains by building up the profile of incised urban streams using grade controls so that the channel and floodplain interact to a greater degree. Urban stream reaches that have been so rehabilitated have increased nutrient uptake and processing rates and, in particular, increased denitrification rates, compared to degraded urban streams prior to treatment (Bukavecas, 2007; Kaushal et al., 2008). This suggests that urban stream rehabilitation may be one of many elements that can be considered to help decrease loads in nutrient-sensitive watersheds.

- Practices that enhance in-stream habitat for aquatic life can improve the expected level of stream biodiversity. However, Konrad (2003) notes that improvement of biological diversity of urban streams should still be considered an experiment, since it is not always clear what hydrologic, water quality, or habitat stressors are limiting. Larson et al. (2001) found that physical habitat improvements can result in no biological improvement at all. In addition, many of the biological processes in urban stream ecosystems remain poorly understood, such as carbon processing and nutrient uptake.

- Some stream rehabilitation practices can indirectly increase stream biodiversity (such as riparian reforestation, which could reduce stream temperatures, and the removal of barriers to fish migration).

It should be noted that the majority of urban stream rehabilitation projects undertaken in the United States are designed for purposes other than mitigating the impacts of stormwater or enhancing stream biodiversity or ecosystem function (Bernhardt et al., 2005). Most stream rehabilitation projects have a much narrower design focus, and are intended to protect threatened infrastructure, naturalize the stream corridor, achieve a stable channel, or maintain local streambank stability (Schueler and Brown, 2004). Improvements in either biological health or the quality of stormwater runoff have rarely been documented.

Unique design models and methods are required for urban streams, compared to their natural or rural counterparts, given the profound changes in hydrologic and sediment regime and stream-floodplain interaction that they experience (Konrad, 2003). While a great deal of design guidance on urban stream rehabilitation has been released in recent years (FISRWG, 2000; Doll and Jennings, 2003; Schueler and Brown, 2004), most of the available guidance has not yet been tailored to produce specific outcomes for stormwater mitigation, such as reduced sediment delivery, increased nutrient processing, or enhanced stream biodiversity. Indeed, several researchers have noted that many urban stream rehabilitation projects fail to achieve even their narrow design objectives for a wide range of reasons (Bernhardt and Palmer, 2007; Sudduth et al., 2007). This is not surprising given that urban stream rehabilitation is relatively new and rarely addresses the full range of in-stream alteration generated by watershed-scale changes. This shortfall suggests that much more research and testing are needed to ensure that urban stream rehabilitation can meet its promise as an emerging BMP.

8.1.14. Municipal Housekeeping

Phase II NPDES/VPDES stormwater permits specifically require municipal good housekeeping as one of the six minimum management measures for MS4s. Although the EPA has not presented definitive guidance on what constitutes "good housekeeping," CWP (2008a) outlines ten municipal operations where housekeeping actions can improve the quality of stormwater, including the following:

- Municipal hotspot facility management;
- Municipal construction project management;
- Road maintenance;
- Street sweeping;
- Storm drain maintenance;
- Stormwater hotline response;
- Landscape and park maintenance;
- BMP maintenance; and
- Employee training.

The overarching theme is that good housekeeping practices at municipal operations provide source treatment of pollutants before they enter the storm drain system. The most frequently applied practices are street sweeping (**Figure 8.23**) and sediment cleanouts of sumps and storm drain inlets (**Figure 8.24**). Most communities conduct both operations at some frequency for safety and aesthetic reasons, although not specifically for the sake of improving stormwater quality (Law et al., 2008).

Figure 8.23. Street Sweeping

Figure 8.24. Catch Basin Cleaning

Numerous performance monitoring studies have been conducted to evaluate the effect of street sweeping on the concentration of stormwater pollutants in downstream storm drain pipes (see Pitt, 1979; Bender and Terstriep, 1994; Brinkman and Tobin, 2001; Zarrielo et al., 2002; Chang et al., 2005; USGS, 2005; Law et al., 2008). The basic finding is that regular street sweeping has a low or limited impact on stormwater quality, depending on street conditions, sweeping frequency, sweeper technology, operator training, and on-street parking. Sweeping will always have a limited removal capability because rainfall events frequently wash off pollutants before the sweeper passes through, and only some surfaces are accessible to the sweeper, thus excluding sidewalk, driveways, and landscaped areas. However, frequent sweeping (i.e., weekly or monthly) has a moderate capability to remove sediment, trash and debris, coarse solids, and organic matter.

Fewer studies have been conducted on the pollutant removal capability of frequent sediment cleanout of storm drain inlets, most in regions with arid climates (Lager et al., 1977; Mineart and Singh, 1994; Morgan et al., 2005). These studies have shown some moderate pollutant removal if cleanouts are done on a monthly or quarterly basis. Most communities, however, report that they clean out storm drains on an annual basis or in response to problems or drainage complaints (Law, 2006).

Frequent sweeping and cleanouts conducted on the dirtiest streets and storm drains appear to be the most effective way to include these operations in the stormwater treatment train. However, given the uncertainty associated with the expected pollutant removal for these practices, street sweeping and storm drain cleanout cannot be relied on as the sole BMPs for an urban area.

8.1.15. Illicit Discharge Detection and Elimination

MS4 communities must develop a program to detect and eliminate illicit discharges to their storm drain system as a stormwater NPDES/VPDES permit condition. Illicit discharges can involve illegal cross-connections of sewage or washwater into the storm drain system or various intermittent or transitory discharges due to spills, leaks, dumping, or other activities that introduce pollutants into the storm drain system during dry weather. National guidance on the methods to find and fix illicit discharges was developed by Brown et al. (2004). Local illicit discharge detection and elimination (IDDE) programs represent an ongoing and perpetual effort to monitor the network of pipes and ditches to prevent pollution discharges.

The water quality significance of illicit discharges has been difficult to define since they occur episodically in different parts of a municipal storm drain system. Field experience in conducting outfall surveys does indicate that illicit discharges may be present at 2-5 percent of all outfalls at any given time. Given that pollutants are being introduced into the receiving water during dry weather, illicit discharges may have an amplified effect on water quality and biological diversity.

Many communities indicate that they employ a citizen hotline to report illicit discharges and other water quality problems (Brown et al., 2004), which sharply increases the number of illicit discharge problems observed.

8.1.16. Stormwater Management Education

Like IDDE, public information and education about stormwater is one of the six minimum management measures that MS4 communities must address in their stormwater NPDES/VPDES permits. Stormwater education involves municipal efforts to make sure individuals understand how their daily actions can positively or negatively influence water quality and work to change specific behaviors linked to specific pollutants of concern (Schueler, 2001c). Targeted behaviors include lawn fertilization and pesticide application, clipping and leaf disposal, littering, car fluid recycling, car washing, household hazardous waste management, septic system maintenance, and pet waste pickup.

Communities may use a wide variety of messages to make the public aware of the behavior and more desirable alternatives through internet websites, utility bill inserts, brochures and fact sheets, radio, television, newspaper ads, special events, workshops, or door-to-door outreach by volunteer educators. Communities can also coordinate programs to engage citizens in stormwater pollution prevention and watershed management activities, such as stream monitoring, stream clean-ups, adopt-a-stream programs, tree planting days, and storm drain stenciling.

Several communities have performed before-and-after surveys to assess both the penetration rate for these campaigns and their ability to induce changes in actual behaviors. Significant changes in behaviors have been recorded (see Schueler, 2002), although few studies are available to link specific stormwater quality improvements to the educational campaigns (but see Turner, 2005; CASQA, 2007).

8.1.17. Residential Stewardship

This BMP involves municipal programs to enhance residential stewardship to improve stormwater quality. Residents can undertake a wide range of activities and practices that can reduce the volume or quality of runoff produced on their property or in their neighborhood as a whole. This may include installing rain barrels or rain gardens, planting trees, xeriscaping, downspout disconnection, storm drain marking, household hazardous waste pickups, proper disposal of waste oil products (**Figure 8.25**), carefully managing application of de-icing products to sidewalks and driveways, and yard waste composting (CWP, 2005). This expands on stormwater education in that a municipality provides a convenient delivery service to enable residents to engage in positive watershed behavior.

The effectiveness of residential stewardship is enhanced when carrots are provided to encourage the desired behavior, such as subsidies, recognition, discounts, and technical assistance (CWP, 2005). Consequently, communities need to develop a targeted program to educate residents and help them engage in the desired behavior.

Figure 8.25. Don't Pour Waste Oil Products Down the Storm Drain!

8.2. OVERVIEW OF POST-CONSTRUCTION BMPs

This section generally describes the post-construction Stormwater Control Measures (BMPs) that may be used in Virginia to manage stormwater runoff. Given the large number and wide variety of MTDs in the marketplace and the pace at which new devices are being introduced, this Handbook will not provide any detail about such devices. However, additional information can be found at the Virginia Stormwater BMP Clearinghouse web site at http://www.vwrrc.vt.edu/swc/ and in Minton (2005). More specific information about ESD practices and techniques can be found in CWP (1998a). The various BMPs were selected based on their ability to achieve, at varying degrees, the following:

1. Can capture and treat the full Treatment Volume (T_v)
2. Can reduce the volume of stormwater runoff
3. Can remove total phosphorus (TP) from site runoff (regulatory compliance criteria)
4. Can remove total nitrogen (TN) from site runoff
5. Can remove total suspended solids (TSS) from runoff
6. Can remove other pollutants as well (e.g., hydrocarbons, bacteria, metals)
7. Can address stormwater quantity (channel protection criteria, and flood protection) criteria

8. Have acceptable longevity in the field, when maintained properly.

8.2.1. Pollutant Removal Mechanisms

Stormwater control measures remove pollutants from stormwater runoff through various physical, chemical, and biological processes. **Table 8.2** lists the major stormwater pollutant removal processes and the affected stormwater pollutants.

Table 8.2. Stormwater Pollutant Removal Processes

Process	Pollutants Affected
Gravity settling of particulate pollutants	Solids, BOD, pathogens, particulate COD, phosphorus, nitrogen, synthetic organics, particulate metals
Filtration and physical straining of pollutants through a filter media or vegetation	Solids, BOD, pathogens, particulate COD, phosphorus, nitrogen, synthetic organics, particulate metals
Infiltration of particulate and dissolved pollutants	Solids, BOD, pathogens, particulate COD, phosphorus, nitrogen, synthetic organics, particulate metals
Adsorption on particulates and sediments	Dissolved phosphorus, metals, synthetic organics
Photodegradation	COD, petroleum hydrocarbons, synthetic organics, pathogens
Gas exchange and volatilization	Volatile organics, synthetic organics
Biological uptake and biodegradation	BOD, COD, petroleum hydrocarbons, synthetic organics, phosphorus, nitrogen, metals
Chemical precipitation	Dissolved phosphorus, metals
Ion exchange	Dissolved metals
Oxidation	COD, petroleum hydrocarbons, synthetic organics
Nitrification and denitrification	Ammonia, nitrate, nitrite
Density separation and removal of floatables	Petroleum hydrocarbons

Source: NRC (2008)

Since many pollutants in urban stormwater runoff are attached to solid particles, treatment practices designed to remove suspended solids from runoff will remove other pollutants as well. Exceptions to this rule include nutrients, which are often in a dissolved form, soluble metals and organics, and extremely fine particulates (i.e., having a diameter smaller than 10 microns), which can only be removed by treatment practices other than traditional separation methods.

8.2.2. Approved Virginia Non-Proprietary Stormwater Control Measures

Virginia's approved BMPs can be organized into five groups, from rooftop to stream:

- Runoff volume reduction – primary benefit is reducing the volume of runoff leaving the site
- Swales or open channels – runoff conveyance practices that also provide various levels of pollution removal
- Filtering systems – primary benefit is removing nutrients, sediment, heavy metals, grease and oil from runoff
- Infiltration practices – these combine runoff volume reduction (runoff soaks into the soil) and pollution treatment (primarily from filtering)
- Basins –reduce the rate of runoff (detention), also improve pollution removal (wet ponds), and also add wildlife habitat (constructed wetlands)

8.2.2.1. Runoff Volume Reduction

1. ***Vegetated Roof (#5) (Figure 8.26).*** Vegetated roofs (also known as *green roofs* or *eco roofs*) are alternative roof surfaces that typically consist of waterproofing and drainage materials and an engineered growing media that is designed to support plant growth. Vegetated roofs capture and temporarily store stormwater runoff in the engineered growing media before it is conveyed into the storm drain system. A portion of the captured stormwater evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and associated pollutant loads. The water quality treatment processes exhibited by vegetated roofs are runoff volume reduction and plant uptake (biological transformation).

Figure 8.26. Vegetated Roof

Figure 8.27. Downspout Disconnection

2. ***Downspout Disconnection (#1) (Figure 8.27.*** This strategy involves treating runoff close to its source by intercepting rooftop runoff and infiltrating, filtering, treating, or reusing it before it moves from the roof into the storm drain system. Two kinds of practices are allowed. The first is for simple rooftop disconnection, whereas the second involves disconnection combined with supplementary runoff treatment, including the following:

    - Compost amended soils in the filter path
    - Installation of dry wells or french drains

- Installation of rain gardens or front yard bioretention
- Storage and reuse in a rain tank or cistern
- Storage and release in a foundation planter

The water quality treatment processes exhibited by downspout disconnection vary, depending upon the supplementary treatment practices used. Simple disconnection and rainwater harvesting (rain tanks or cisterns) rely on the processes of runoff volume reduction, settling (sedimentation), and filtering (filtration). The various forms of supplemental infiltration add the processes of adherence (sorption) to the soil and plant uptake (biological transformation) or removal by bacteria.

3. ***Rainwater Harvesting (#6) (Figure 8.28).*** Rain tanks intercept, divert, store, and release rainfall for future use. The term *Rainwater Harvesting* is used as the title of this specification, but it is also known as a cistern or rain tank system. Rainwater that falls on a rooftop is collected and conveyed into an above- or below-ground storage tank where it can be used for landscape irrigation, non-potable water, and on-site stormwater disposal. Typically, pre-fabricated rain tanks range from 200 to 10,000 gallons in size. The capture and re-use of rainwater can significantly reduce stormwater runoff volumes and pollutant loads (through the water quality treatment processes of runoff volume reduction and sedimentation). By providing a reliable and renewable source of water to end users, rain tanks can also have environmental and economic benefits beyond stormwater management (increased water conservation, water supply during drought, decreased demand on municipal or groundwater supply, etc). Rain tanks can be combined with other on-site practices, such as rain gardens, to enhance their runoff reduction and nutrient removal capability. The water quality treatment processes exhibited by rainwater harvesting practices are runoff volume reduction, settling (sedimentation), and filtering (filtration).

Figure 8.28.. Rainwater Harvesting Tank

Figure 8.29. Filter Strip with Level Spreader (gravel pad as pre-treatment)

4. ***Soil Compost Amendments (#4).*** Soil restoration is an ESD practice applied after construction to restore soil porosity by adding compost and tilling it deep into the soil profile. These soil amendments can reduce the generation of runoff from compacted urban lawns and may also be used to enhance the runoff reduction performance of downspout disconnections, grass

channels, filter strips, and tree clusters. The water quality treatment process exhibited by soil compost amendments are those of infiltration practices: runoff volume reduction, settling (sedimentation), filtering (filtration), adherence (sorption) to the soil, and plant uptake (biological transformation) or removal by bacteria.

5. ***Sheet Flow to Vegetated Filters or Conserved Open Space (#2) (Figure 8.29).*** Filter strips are vegetated areas that treat sheet flow delivered from adjacent impervious areas by slowing runoff velocities and allowing sediment and attached pollutants to settle out. The two design variants are (1) sheet flow into a conserved natural area, and (2) sheet flow to a grass filter strip. The design, installation and management of these design variants are quite different. In some cases, filter strips can treat concentrated flows, but only if the concentrated flow is converted to sheet flow by an engineered level spreader. The water quality treatment processes employed by filter strips are runoff volume reduction, settling (sedimentation), filtering (filtration), adherence (sorption) to the soil, and plant uptake (biological transformation).

8.2.2.2. Swales or Open Channels

The following practices are explicitly designed to capture and treat the full Treatment Volume (T_v) within dry or wet cells formed by check dams or other means, or within the channel itself through a slow velocity and relatively long resistance time.

1. ***Grass Channel (#3) (Figure 8.30*** *below****).*** Grass Channels can provide runoff filtering and treatment within the conveyance system and produce less runoff and pollutants than a traditional system of curb and gutter, storm drain inlets, and pipes. Grass channels provide a modest amount of runoff reduction and pollutant removal that varies depending on the underlying soil permeability. Grass Channels, however, are not capable of providing the same stormwater functions as Dry Swales, since they lack the engineered soil media and storage volumes. Their runoff reduction performance can be boosted when Soil Compost Amendments are added to the bottom of the swale. Grass channels are a preferable alternative to both curb and gutter and storm drains as a stormwater conveyance system where development density, topography and soils permit. The water quality treatment processes employed by grass channels are runoff volume reduction (minimal), settling (sedimentation), filtering (filtration), adherence (sorption) to the soil, and plant uptake (biological transformation).

2. ***Dry Swale (#10) (Figure 8.31*** *below****).*** While Grass Channels and Dry Swales are both considered variations of the open channel concept, they are fundamentally different in terms of their designs. Dry swales are essentially volume-based shallow bioretention cells that are configured as a linear channel that temporarily stores and then filters the desired Treatment Volume. Grass channels are conveyance systems that can provide water quality treatment based on flow rate-based design criteria.

Figure 8.30. Grass Channel

Figure 8.31. Dry Swale

Dry Swales rely on the same pre-mixed soil media filter below the channel as is used for bioretention practices. If soils are extremely permeable, runoff infiltrates into underlying soils. In most cases, however, the runoff treated by the soil media flows into an underdrain, which conveys treated runoff back to the conveyance system further downstream. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale. Dry Swales may appear as simple grass channels with similar shape and turf cover, while others may have more elaborate landscaping. Dry Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees. The water quality treatment processes employed by Dry Swales are runoff volume reduction, settling (sedimentation), filtering (filtration), sorption to the soil, and plant uptake (biological transformation).

8.2.2.3. Filtering Systems

The following practices capture and temporarily store the Treatment Volume (T_v) before passing it through a filter bed of sand, organic matter, soil, or other media.

1. ***Filtering Practices (#12) (Figure 8.32** below**).*** Employing stormwater filters is a useful practice to treat stormwater runoff from small, highly impervious sites. Stormwater filters capture, temporarily store, and treat stormwater runoff by passing it through an engineered filter media, collecting it in an underdrain, and then returning it back to the storm drain system. The filter consists of two chambers: the first is devoted to settling, and the second serves as a filter bed consisting of sand or an organic filter media. Because they consume very little surface land area and have few site restrictions, stormwater filters are a versatile option that offers moderate pollutant removal performance at small sites where space is limited. The water quality treatment process employed by filtering practices are settling (sedimentation), filtering (filtration), adherence (sorption) to the soil, and plant uptake (biological transformation) or removal by bacteria.

Figure 8.32. Sand Filter

Figure 8.33. Bioretention Filter Cell

2. ***Bioretention (#9) (Figure 8.33).*** Individual bioretention areas serve highly impervious drainage areas less than five acres in size. Surface runoff is directed into a shallow landscaped depression that incorporates many of the pollutant removal mechanisms that operate in forested ecosystems. The primary component of a bioretention practice is the filter bed, which has a mixture of sand, soil, and organic material as the filtering media. The filter is composed of a sand/soil bed with a surface layer of mulch. During storms, runoff temporarily ponds 6-12 inches above the mulch layer and then rapidly filters through the bed.

   Normally, the filtered runoff is collected in an underdrain and returned to the storm drain system. The underdrain consists of a perforated pipe in a gravel jacket installed along the bottom of the filter bed. Bioretention creates a good environment for runoff reduction, filtration, biological uptake, and microbial activity, and provides high pollutant removal. Bioretention can become an attractive landscaping feature with high amenity value and community acceptance. The water quality treatment processes employed by dry swales are runoff volume reduction, settling (sedimentation), filtering (filtration), adherence (sorption) to the soil, separation from solution (precipitation) onto the media, and plant uptake (biological transformation) or removal by bacteria.

8.2.2.4. Infiltration Practices

The following practices capture and temporarily store the T_v before allowing it to infiltrate into the B and/or C soil horizons. Runoff that discharges directly into limestone (karst) areas may be treated by certain kinds of infiltration practices (e.g., small-scale infiltration, permeable pavers and, perhaps, micro-bioretention/rain gardens).

1. ***Permeable Pavement (#7) (Figures 8.34 and 35).*** Permeable pavements are alternative paving surfaces that allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir where it is temporarily stored. Often, the filtered runoff is collected in an underdrain and returned to the storm drain system. If infiltration rates in native soils permit, permeable pavement practices can be designed without an underdrain for full

infiltration. A combination of these methods can be used to infiltrate a portion of the filtered runoff.

Figure 8.34. Permeable Asphalt Pavement

Figure 8.35. Permeable Interlocking Pavers

There are a variety of permeable pavement surfaces available in the commercial marketplace, including pervious concrete, porous asphalt, permeable interlocking concrete pavers, concrete grid pavers, and plastic grid pavers. While the specific design configuration may vary according to each product, nearly all permeable pavement types have the same general structure, consisting of a surface layer, aggregate base, and sub-base. The aggregate base layer serves to retain stormwater and also supports the design traffic loads. Permeable pavements are typically designed to treat rainfall on the pavement surface area, but can also be used to treat run-on from small adjacent impervious areas, such as impermeable driving lanes or rooftops.

Permeable pavements promote runoff reduction and provide high pollutant removal. Permeable pavement can also be used to reduce the impervious cover of a development site. The water quality treatment process employed by permeable paving materials is mainly runoff volume reduction. Pre-treatment must be provided to remove sediment, which would otherwise clog the pores in the paving material. A filter fabric is typically installed beneath the aggregate base, as well. So little or no treatment (filtering, etc.) is provided within the structure.

2. ***Infiltration Practices (#8) (Figure 8.36** below**).*** Infiltration practices utilize temporary surface or underground storage to allow incoming stormwater runoff to exfiltrate into underlying soils. Runoff first passes through multiple pretreatment mechanisms to trap sediment and organic matter before it reaches the practice. As the stormwater penetrates the underlying soil, water quality treatment processes such as chemical adsorption (sorption, precipitation) and biological transformation processes remove pollutants. Infiltration practices are suitable for use in residential and other urban areas where *measured* soil permeability rates exceed 0.5 inch per hour. Infiltration is not recommended at sites designated as stormwater hotspots, to prevent possible groundwater contamination.

   Infiltration has the highest runoff reduction capability of any stormwater practice, and probably comes closest to replicating predevelopment hydrology. On the other hand, infiltration practices have experienced consistent problems and failures over the years. These anecdotal reports, along with groundwater concerns, have limited the use of infiltration practices. Toward this end, the Department, with assistance from the Chesapeake Stormwater Network and the Center for Watershed protection, has prepared a new infiltration practice design specification that should result in more widespread use of infiltration and better water quality protection and runoff management, while minimizing the risk of failure.

Figure 8.36. Infiltration Trench Construction

Figure 8.37. Bioinfiltration Cell

3. ***Bioinfiltration (#9) (Figure 8.37):*** Bioinfiltration (Level 2 Bioretention and Level 2 Dry Swale) can also be designed to infiltrate runoff into native soils. This can be done at sites with highly permeable soils, a low groundwater table, and a low risk of groundwater contamination. This type of design features the use of a "partial exfiltration" system that promotes greater groundwater recharge. Underdrains are only installed beneath a portion of the filter bed or are eliminated altogether, thereby increasing stormwater infiltration. Bioretention is also known as a "rain garden" when used on individual residential lots, often without an underdrain. The water quality treatment processes employed by Bioinfiltration are runoff volume reduction, settling (sedimentation), filtering (filtration), adherence (sorption) to the soil, separation from solution (precipitation) onto the soil, and plant uptake (biological transformation) or removal by bacteria.

8.2.2.5. Basins (Ponds and Wetlands)

Practices that have one or more permanent pools capable of treating the Treatment Volume (T_V) and may incorporate extended detention or significant shallow marsh areas. Basins are the final element in the roof-to-stream runoff reduction sequence. However, they should only be considered after all other upland runoff reduction techniques have been exhausted, and there is still a remaining water quality or channel protection volume to manage.

1. ***Constructed Wetlands (#13) (Figure 8.38).*** Constructed Wetlands are shallow depressions that receive stormwater inputs for treatment. Wetlands are typically less than one foot deep (although they have deeper pools at the forebay and micropool) and possess variable microtopography to promote dense and diverse wetland cover. Runoff from each new storm displaces runoff from previous storms, and the long residence time allows multiple pollutant removal processes to operate. The wetland environment provides an ideal environment for gravitational settling, biological uptake, and microbial activity. The water quality treatment processes exhibited by constructed wetlands are settling (sedimentation), flotation of light solids, adherence (sorption) to bottom soils, chemical separation from solution (precipitation) in the water, and biological transformation by bacteria and plant uptake.

Figure 8.38. Constructed Wetland

Figure 8.39. Small Wet Pond

2. ***Wet Ponds (#14) (Figure 8.39).*** Wet Ponds consist of a permanent pool of standing water that promotes a better environment for gravitational settling, biological uptake, and microbial activity. Runoff from each new storm enters the pond and partially displaces pool water from previous storms. The pool also acts as a barrier to re-suspension of sediments and other pollutants deposited during earlier storms. When sized properly, Wet Ponds have a residence time that ranges from many days to several weeks, which allows numerous pollutant removal mechanisms to operate. Wet Ponds can also provide extended detention (ED) above the permanent pool to help meet channel protection requirements. The water quality treatment processes exhibited by Wet Ponds are settling (sedimentation), flotation of light solids, adherence (sorption) to bottom soils, chemical separation from solution (precipitation) in the water, and biological transformation free floating algae.

3. ***Extended Detention (#15) (Figure 8.40** below**).*** Extended Detention (ED) ponds rely on gravitational settling as their primary pollutant removal mechanism. Consequently, they generally provide fair to good removal of particulate pollutants but low or negligible removal for soluble pollutants, such as nitrate and soluble phosphorus. Extended Detention is different from stormwater detention, which is used for peak discharge or flood control purposes and often detains flows for just a few minutes or hours. This option relies on 12 to 24 hour detention of stormwater runoff after each rain event. An under-sized outlet structure restricts stormwater flow so it backs up and is stored within a pond or wetland. The temporary ponding enables particulate pollutants to settle and reduces stress on downstream banks. The use of ED alone generally has the lowest overall pollutant removal rate of any stormwater treatment option. As

a result, ED is normally combined with wet ponds or constructed wetlands to maximize pollutant removal rates. The water quality treatment process exhibited by extended detention basins is mainly settling (sedimentation).

Figure 8.40. Dry Extended Detention Basin

8.2.2.6. Manufactured Treatment Devices (MTDs) *(Figures 8.41 and 8.42)*

Virginia allows the use of certain Manufactured Treatment Devices (MTDs) for which pollution removal performance has been verified and certified through by the Virginia Stormwater BMP Clearinghouse Committee and the DEQ. There is a wide variety of products within this category, which provides different kinds of stormwater management options, ranging from underground detention storage to flow control to filtering technologies.

8.2.2.7. Treatment Trains

BMPs suitable to meet channel protection and overbank flood criteria should not be used by themselves to also address water quality requirements but should, instead, be combined in a "treatment train" with one or more other BMPs to meet water quality requirements. Pre-treatment BMPs are designed to improve water quality and enhance the effective design life of practices by consolidating sedimentation location, but they also cannot meet the water quality requirements by themselves. Pre-treatment practices must be combined with other water quality BMPs to meet the water quality criteria. It is important that the various BMPs employed in a treatment train should use *different* treatment mechanisms in order to maximize pollution removal (e.g., rooftop disconnection to a grass channel to biofilters and bioretention to a constructed wetland, as depicted in **Figure 8.41** below).

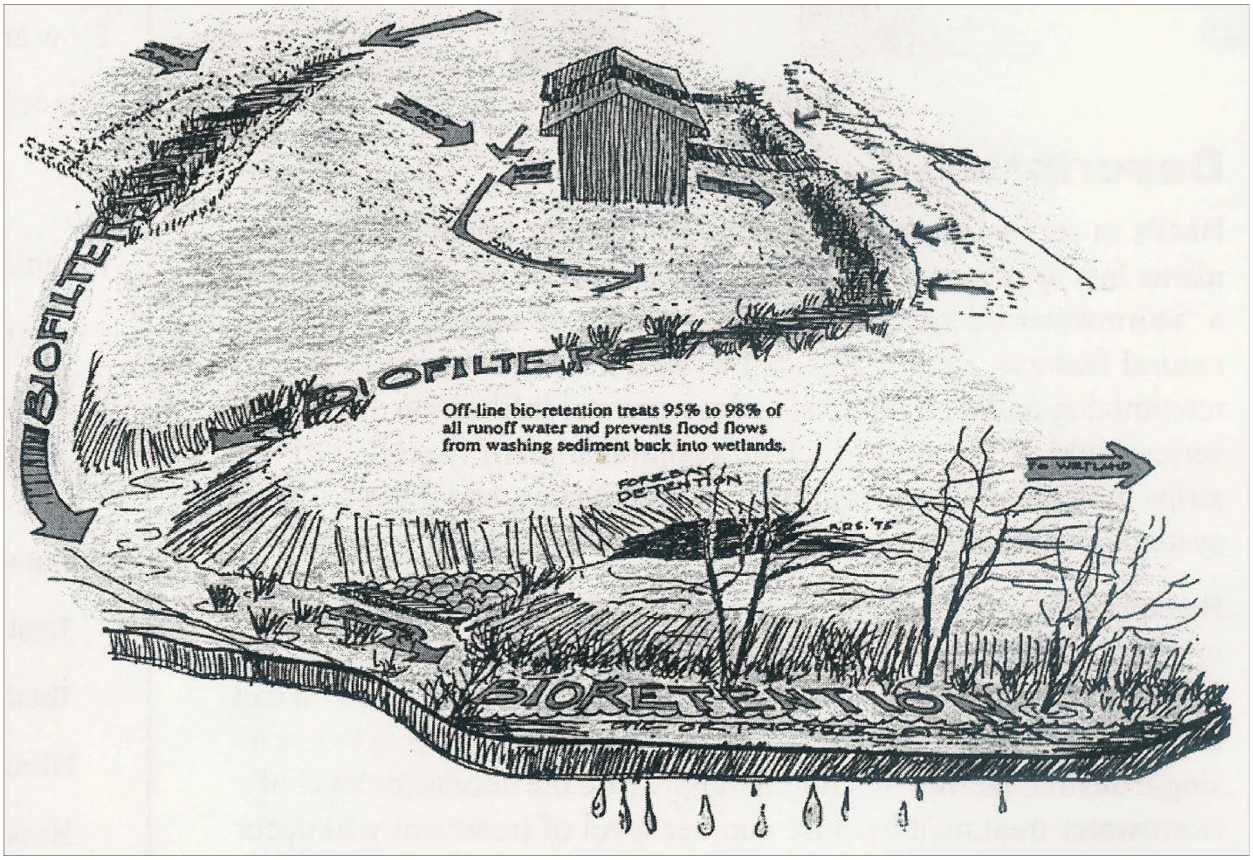

Figure 8.41. Treatment Train
Source: Robert Sykes, Dept. of Landscape Architecture, University of Minnesota

8.3. POST-CONSTRUCTION BMP DESIGN & CONSTRUCTION STANDARDS AND SPECIFICATIONS

Complete standards and specifications for Virginia-approved post-construction BMPs and MTDs can be found on the Virginia BMP Clearinghouse web site, at http://www.vwrrc.vt.edu/swc/.
For each public domain BMP, criteria are provided to address the following topics:

Description: Describes the practice and explains its purpose and how it functions.

Performance: Identifies how well the practice addresses various objectives of stormwater management.

- Runoff Reduction (which includes Groundwater Recharge)
- Total Phosphorus Removal
- Total Nitrogen Removal
- Total Suspended Solids (TSS) Removal
- Channel Protection
- Flood Mitigation

Design Table: Identifies the sizing criteria for the practice needed to accommodate the full T_v and geotechnical or other testing that must be done to provide information needed to correctly design the facility.

Typical Graphical Details: Provides visual guidance regarding how to correctly design and build the particular practice.

Physical Feasibility and Design Applications: Identifies site considerations and physical constraints that determine where a practice may be applied or that may restrict the use of a practice.

Design Criteria: Identifies the specific standards and specifications that govern the correct design of specific devices, including dimensions, components, orientation, etc. The design criteria include but is not limited to information about the following:

- ***Pretreatment:*** Identifies the type of measures used to trap coarse elements before they enter the facility, thus reducing the maintenance burden and ensuring a long-lived practice.
- ***Conveyance:*** Identifies how to convey runoff to the practice in a manner that is safe, minimizes erosion and disruption to natural channels, and promotes filtering and infiltration.
- ***Geometry:*** Identifies any practice-specific configurations, such as optimum length-to-width-to-depth ratios, minimum flow lengths, etc.
- ***Material Specifications:*** Identifies the specific kinds of materials (e.g., stone sizes, landscaping materials, etc.) needed to correctly construct the particular practice.
- ***Environmental/Landscaping:*** Identifies how to reduce secondary environmental impacts of facilities through features that minimize disturbance of natural stream systems and comply with environmental regulations. Provides landscaping that enhances the pollutant removal and aesthetic value of the practice.
- ***Maintenance Considerations for the Design:*** Identifies the design elements that ease the maintenance burden.

Regional and Climate Design Adaptations: Identifies considerations and adaptations needed to address particular kinds of regional characteristics or climate variations, including the following:

- Hot spots
- Ultra-Urban Development Sites
- Infill and Redevelopment Sites
- Single-Family Lots
- Karst terrain
- Coastal plain
- Steep terrain
- Sensitive Waters
    - Lakes and Water Supply Reservoirs
    - Trout and Other High-Quality Streams
    - Groundwater Drinking Water Source Areas
    - Wetlands
    - Impaired Waters
- Cold climates/winter performance

- Linear/highway sites

Construction Sequence and Inspection: Identifies factors important to the proper construction and long-term viability of the particular practice.

Maintenance: How to maintain the long-term performance of the practice through regular maintenance activities.

Community and Environmental Considerations: Addresses issues such as physical safety, potential for vectors, aesthetics, etc.

References: A list of resources from which the criteria and information in the design specification were taken.

Overviews of the public domain post-construction BMPs that DEQ has approved for use in Virginia can be found in Section 8.4.2 (above) of this chapter.

8.4 BMP SELECTION CATEGORY DESCRIPTIONS AND TABLES

8.4.1 Land Use (Table 8.3 below)

Which practices are best suited for the proposed land use at this site? In this step, the designer makes an initial screening to select practices that are best suited to a particular land use.

Rural. This column identifies BMPs that are best suited to treat runoff in rural or very low density areas (e.g., typically at a density of less than ½ dwelling unit per acre) with few neighborhoods and relatively large amounts of open space. Stormwater control measures with larger area demands may be easier to locate with appropriate buffers in rural areas. Additionally, typical stormwater pollutants from rural areas include sediments and nutrients, which can be effectively managed by most stormwater control measures. As a result, most BMPs are suitable for rural areas.

Residential. This column identifies the best treatment options in medium to high density residential developments, which typically have limited space and higher property values compared to rural undeveloped land. Also, stormwater control measures in residential areas are likely to be located in close proximity to residences. Public safety and nuisance insects are common concerns related to control measures in residential areas. BMPs with large land requirements or open pools of water may be less desirable in these areas. In some situations, stormwater ponds or other open water practices may be incorporated into the landscape as amenities to provide for habitat, recreation, and aesthetic value.

Roads and Highways. This column identifies the best practices to treat runoff from major roadway and highway systems, which typically generate high stormwater pollutant loads due to vehicle traffic and winter deicing activities. Sediments, metals, chlorides, and hydrocarbons are the primary pollutants associated with roads and highways. Nitrogen from vehicle exhausts and bacteria are also commonly present in road and highway runoff. As a result, most treatment practices provide some treatment benefit but do not adequately address all of the water quality impacts associated with this land use. In addition, open water and deep pools can also be a safety issue near roads and highways.

Commercial/Industrial Development. This column identifies practices that are suitable for commercial and industrial development, which often have more intensive traffic, increased risk of spills, and exposure of materials to precipitation. Pollutants associated with these land uses can vary significantly, depending on the nature of activities at each site, although traffic-related pollutants such as sediments, metals, and hydrocarbons are commonly present in runoff from most commercial and industrial sites. These developments may also have more available space for locating stormwater control measures.

Hotspot Land Uses. This column examines the capability of BMPs to treat runoff from designated hotspots. BMPs that receive hotspot runoff may have design restrictions, as noted.

Ultra-Urban Sites. This column identifies BMPs that work well in the ultra-urban environment, where population is dense, land area and space are limited, stormwater infrastructure is already in place, a wide range of potential pollutants is present, and original soils have been disturbed. Ultra-urban sites are the most restrictive in terms of BMP selection. Stormwater control measures appropriate for ultra-urban sites are also frequently used at redevelopment and infill sites and to retrofit existing urban development.

Table 8.3. BMP Selection Matrix 1 – Land Use

BMP Group	Specific BMP	Rural	Residential	Roads and Highways	Commercial/ Industrial	Hotspots	Ultra-Urban[1]
Runoff Volume Reduction	Rooftop Disconnection 1	○	○	●	○	○	◗
	Sheet flow to Veg. Filter/Open Space	○	○	○	○	◗[2]	◗
	Soil Compost Amendments	○	○	○	○	◗[2]	○
	Vegetated Roof	●	◗	●	○	○	○
	Rainwater Harvesting	○	○	●	○	○[3]	○
Swales & Open Channels	Grass Channel	○	◗	○	◗	◗[4]	◗
	Dry Swale	○	◗	○	◗	◗[4]	●
Filtering Systems	Bioretention 1	◗	◗	○	○	○[4]	○[1]
	Filtering Practice	●	●	○	○	○[5]	○
Infiltration Practices	Permeable Pavement	◗	◗	●	◗	●	○
	Infiltration	◗	◗	○	○	●	◗
	Urban Bioretention	◗	◗	○	○	○[2] (Needs underdrain)	○
	Bioretention 2	◗	◗	○	○	○[2] (Needs underdrain)	○
Basins	Wet Swale	○	○	○	●	◗	●
	Constructed Wetland	○	○	○	◗	◗[2]	●
	Wet Pond	○	○	○	◗	◗[5]	●
	Extended Detention	○	○	○	◗	◗[5]	●
Mfr Treatment Devices	Hydrodymanic Devices	●	○	○	○	●	○
	Filtration Devices	●	○	○	○	◗	○
	Storage Devices	●	●	●	○	◗[2,4]	○

○ Appropriate. Good option in most cases.
◗ Depends. Suitable under certain conditions, or may be used to treat a portion of the site.
● Least appropriate. Seldom or never suitable.

[1] Secondary treatment practices and stormwater treatment trains are typically more appropriate for Ultra-Urban land uses

[2] Not allowed unless pretreatment provided to remove hydrocarbons, trace metals, and toxicants

[3] Unless the roof is considered a hotspot

[4] Acceptable option, if not designed as an exfilter. (An exfilter is a conventional stormwater filter without an underdrain system. The filtered volume ultimately infiltrates into the underlying soils.)

[5] Acceptable option, but may require an impermeable liner to reduce risk of groundwater contamination.

8.4.2 Physical Feasibility (Table 8.4 below)

Are there any physical constraints at the project site that may restrict or preclude the use of a particular BMP? In this step, the designer screens the various BMP design criteria to determine if the soils, water table, drainage area, slope or head conditions present at a particular development site might limit the use of a BMP. More detailed testing protocols are often needed to confirm physical conditions at the site. The following are the primary factors.

Soil Infiltration Rate. The key evaluation factors are based on an initial investigation of the NRCS Hydrologic Soil Groups at the site. Note that more detailed geotechnical tests are usually required for infiltration feasibility and during design to confirm permeability and other factors. Knowledge of all soil groups present on the site is needed for runoff calculations, but the presence of HSG-A or HSG-D soils are most likely to constrain the choice of certain BMPs.

Water Table Separation. This column indicates the minimum depth to the seasonally high water table from the bottom elevation, or floor, of a BMP. A relatively shallow depth to water table may limit the choice of certain BMPs.

Shallow Soils/Depth to Bedrock. Likewise, this column indicates the minimum depth to bedrock from the bottom elevation, or floor, of a BMP. A relatively shallow depth to bedrock may also limit the choice of certain BMPs.

Contributing Drainage Area. This column indicates the minimum or maximum drainage area that is considered optimal for a practice. If the drainage area present at a site is slightly greater than the maximum allowable drainage area for a practice, some leeway is warranted where a practice meets other management objectives. Likewise, the minimum drainage areas indicated for ponds and wetlands should not be considered inflexible limits, and may be increased or decreased depending on water availability (base flow or groundwater), mechanisms employed to prevent clogging, or the ability to assume an increased maintenance burden.

Slope. This column evaluates the effect of slope on the practice. Specifically, the slope guidance refers to how flat the area where the practice is installed must be and/or how steep the contributing drainage area or flow length can be.

Hydraulic Head. This column provides an estimate of the elevation difference needed for a practice (from the inflow to the outflow) to allow for gravity operation.

Karst Geology. This column provides information regarding the appropriateness of the various BMPs for installation in karst environments and conditions that apply to those BMPs in such areas. Karst is a dynamic landscape formed over the millenia by the dissolution of bedrock such as limestone, dolomite, and marble. Karst is characterized by landscape features such sinkholes, springs, caves, a highly irregular soil-rock interface, and typically a poorly defined surface drainage network. Karst terrain is considered to be any landscape underlain by carbonate bedrock in the shallow subsurface or any area expressing characteristic karst features. Karst poses many challenges to BMP selection and design. Many sinkholes form due to the collapse of the surface sediments caused by the intrusion of stormwater from the surface. Some BMPs inadvertently promote sinkhole formation that may threaten the integrity of the practice as well as structures on the site. In addition, Karst geology provides rapid pathways for water to travel from the surface to deep groundwater and aquifers, so it should be assumed that any treated or untreated runoff that is infiltrated will reach the drinking water supply in karst areas.

Table 8.4. BMP Selection Matrix 2 – Physical Feasibility

BMP Group	Specific BMP	Soils [1]	Water Table Separation	Depth to Bedrock/ Shallow Soils	Contrib. Drainage Area (Ac.)	Max. Site Slope[2]	Hydraulic Head (Ft.)	Karst Geology or a Sinkhole	Cold Climate (cf Table 8.5)
Runoff Volume Reduction	Rooftop Disconnect.	Join with additional runoff reduction practice on C-D soils	2 feet	2 feet	Maximum 1,000 sq. ft. to each roof discharge point	1-2%	1 foot	Preferred	Frozen ground may hinder disposal of water
	Sheet flow to Vegetated Filter or Conserved Open Space	Any soil except fill; best to use w/ compost amend's on C-D soils	2 feet	2 feet	3 max.	6% for consrv filter; 8% for grass filter strip	1 to 2 feet	Preferred	No concerns or needed adapta-tions
	Soil Compost Amendments	HSG B-D soils	1.5 feet	1.5 feet	Contrib. Imperv. area should not exceed area of amended soil	10%	1 foot	OK	OK, except for areas used for snow storage
	Vegetated Roof	NA	NA	NA	NA	NA	1 to 2 feet	Preferred	Plan for snow loading and hardy veg. cover
	Rainwater Harvesting	NA	Below-grade tanks must be above water table	Below-grade tanks must be above bedrock	Rooftop (only) area draining to the tank	NA	Varies with purpose and design	Preferred	Locate indoors or under-ground; others should be operated season-ally
Swales & Open Channels	Grass Channel	Must achieve additional res. time (min. 10 minutes) if C-D soils	2 feet	2 feet	5 max.	2-4%	2 to 3 feet	OK [3]	OK
	Dry Swale	Made Soil; must use underdrain if on C-D soils	2 feet	2 feet	5 max.	4%	3 to 5 feet	Prefer'd [3]	Medium benefit & limitation

<table>
<tr><th>BMP Group</th><th>Specific BMP</th><th>Soils [1]</th><th>Water Table Separation</th><th>Depth to Bedrock/ Shallow Soils</th><th>Contrib. Drainage Area (Ac.)</th><th>Max. Site Slope[2]</th><th>Hydraulic Head (Ft.)</th><th>Karst Geology or a Sinkhole</th><th>Cold Climate (cf Table 8.5)</th></tr>
<tr><td>Filtering Systems</td><td>Filtering Practice</td><td>NA</td><td>2 feet</td><td>2 feet</td><td>5 max.[4]; 0.5 to 2 preferred</td><td>NA</td><td>2 to 10 feet</td><td>Prefer'd, but must use imper-meable liner</td><td>OK if place below frost line and use pretreat-ment; Chlorides will move through untreated</td></tr>
<tr><td></td><td>Bioretention 1 (with underdrain)</td><td>Made Soil</td><td>2 feet</td><td>2 feet</td><td>5 max. [4]; 0.5 to 2 preferred</td><td>1-5%</td><td>4 to 5 feet</td><td>OK, but must use under-drain and imper-meable liner</td><td>OK; use salt-tolerant veg. and pretreat-ment; Chlorides will move through untreated</td></tr>
<tr><td rowspan="5">Infiltration Practices</td><td>Permeable Pavement 1</td><td>Must use underdrain on C-D soils</td><td rowspan="3">2 feet</td><td rowspan="3">2 feet</td><td rowspan="2">Ratio of contrib. pavement area to Permeable Pavement area may not exceed 2:1</td><td rowspan="2">1-3%</td><td rowspan="2">2 to 4 feet</td><td rowspan="3">Large-scale or Level 2 Prohibit-ed; Small-scale OK; must have liner and under-drain; extensive pre-treatment required</td><td rowspan="3">Limited; Use special design features; Active mgmt needed to prevent infiltra-tion of chlorides and soluble toxics</td></tr>
<tr><td>Permeable Pavement 2</td><td>Minimum measured f_c > 0.5 inch/hour</td></tr>
<tr><td>Infiltration</td><td>Minimum measured f_c > 0.5 inch/hour</td><td>< 2, and close to 100% impervious</td><td>0-5%</td><td>2 to 4 feet</td></tr>
<tr><td>Urban Bioretention</td><td>NA</td><td>2 feet</td><td>2 feet</td><td>5 max. [4]; 0.5 to 2 preferred</td><td>1-5%</td><td>4 to 5 feet</td><td>Preferred</td><td>OK; use salt-tolerant veg. and pretreat-ment; Chlorides will move through untreated</td></tr>
<tr><td>Bioretention 2 (Bioinfiltration, with no underdrain)</td><td>Made Soil; use underdrain if C or D [3] base soils</td><td>3 feet</td><td>2 feet</td><td>5 max.[4]; 0.5 to 2 preferred</td><td>1-5%</td><td>4 to 5 feet</td><td>Not Recmd, esp. large scale; extensive pre-treatment required</td><td>OK; use salt-tolerant veg. and pretreat-ment; Chlorides will move through untreated</td></tr>
</table>

BMP Group	Specific BMP	Soils [1]	Water Table Separation	Depth to Bedrock/ Shallow Soils	Contrib. Drainage Area (Ac.)	Max. Site Slope[2]	Hydraulic Head (Ft.)	Karst Geology or a Sinkhole	Cold Climate (cf Table 8.5)
Basins	Wet Swale	Best on HSG C or D soils	Below water table	2 feet below bottom of swale	5 max..	2% thru swale	2 feet	Not Recmd	Medium benefit & limitation
	Constructed Wetland	HSG-A or B soils may require liner	Below water table if no hotspot or aquifer present; otherwise, a 2 foot separation	2 feet below bottom of wetland	25 min. [6]	NA	2 to 4 feet	OK; use imper-meable liner; limit depth; geotech. tests needed; max. ponding depth	OK; use salt-tolerant vegeta-tion
	Wet Pond	HSG-A or B soils may require liner	Below water table if no hotspot or aquifer present; otherwise, a 2 foot separation	2 feet below bottom of wetland	25 min. [5]	NA	6 to 8 feet	Not Recmd [6]	OK; limit depth to avoid stratifica-tion; adapt outlet structure
	Extended Detention 1	HSG-A or B soils may require liner	2 feet	2 feet	< 10	NA	6 to 10 feet	Not Recmd [6]	OK
	Extended Detention 2				> 10				
Mfr Treatment Devices	Hydrodymanic Devices	NA	Varies with device; Must have clearance below bottom of device	Varies with device; Must have clearance below bottom of device	?	NA	?	OK	?
	Filtration Devices	NA			?	NA	?	OK	?
	Storage Devices	NA			?	NA	?	Must have liner and under-drain; Signifi-cant pre-treatment required	?

KEY: OK = not restricted; WT = water table; PT = pretreatment; f_c = soil permeability

1 USDA-NRCS Hydrologic Soil Groups (HSGs)

2 Refers to post-construction slope across the location of the practice

3 Denotes a required limit, other elements are planning level guidance and may vary somewhat, depending on site conditions

4 Drainage area can be larger in some instances.

5 10 acres may be feasible if ground water is intercepted and/or if water balance calculations indicate a wet pool can be sustained, and an anti-clogging device must be installed

6 If detention is used, then an impermeable liner must be placed at the bottom of the basin and geotechnical tests should be conducted to determine the maximum allowable depth

Cold Climate/Winter Conditions. This column presents guidance on how to choose BMPs for areas of Virginia where much colder temperatures, greater snowfall, and more ice prevail. While there may be fewer runoff events during winter months, snow and ice may significantly impact the operation of some BMPs during winter rain events and periods of snowmelt. Some of these potential impacts are (1) pipe freezing, (2) ice formation on permanent pools, (3) reduced biological activity, and (4) reduced soil infiltration. Frozen conditions typically inhibit performance throughout the winter and generate a significant volume of melt water and associated pollutant loads. In particular, melt water from roadways typically has high chloride and sediment content from salt and sand treatments. **Table 8.5** summarizes winter operation and cold weather considerations for various stormwater treatment practices.

Table 8.5. BMP Selection Matrix 3 – Winter and Cold Weather Stormwater Control Operational Criteria

Category	Practice	Pipe Freezing	Ice Formation	Reduced Biological Activity	Reduced Soil Infiltration
Ponds	Wet Ponds	●	●	◖	○
	Extended Detention Ponds	●	●	◖	○
	Vegetated Roofs	●	◖	○	○
Wetlands	Constructed Wetlands	●	●	●	○
	Wet Swales	○	◖	◖	○
Infiltration	Level 1 Infiltration	◖	◖	○	●
	Level 2 Infiltration	○	◖	○	●
	Level 2 Bioretention	○	◖	○	●
	Level 2 Dry Swale	○	◖	◖	◖
	Permeable Pavement	◖	●	○	●
Filters	Surface Filtering Practices	◖	◖	○	●
	Underground Filtering Practices	○	○	○	○
	Level 1 Bioretention	◖	◖	○	●
	Level 1 Dry Swale	◖	◖	○	●
	Sheet flow to Vegetated Filter or Conserved Open Space	○	◖	○	◖

Key: ● = Significant
◖ = Moderately Significant
○ = Least Significant

8.4.3 Critical Water Resources (Table 8.6 below)

What watershed protection goals need to be met in the water resources the site drains to? The design and implementation of BMPs is strongly influenced by the nature and sensitivity of the receiving waters. In some cases higher pollutant removal, more recharge or other environmental performance is warranted to fully protect the resource quality and human health and/or safety. Critical resource areas include: *groundwater and source water areas, high value trout streams, other freshwater streams, freshwater lakes and ponds, drinking water reservoirs, freshwater wetlands, and coastal waters (including tidal wetlands)*, as described below. **Table 8.6** below outlines the key design variables and considerations that must be addressed for sites that drain to any of the above critical resource areas.

Table 8.6. BMP Selection Matrix 4 – Critical Water/Watershed Resources

BMP Group	Specific BMP	Groundwater, Source Water Areas and Septic Systems	100-Year Flood Plains	Trout and Other Freshwater Streams	Freshwater Lakes and Ponds	Freshwater Wetlands (May be regulated)	Coastal Waters (incl. Tidal Wetlands	Impaired Waters
General Location		Setbacks from wells and septic systems	Restrict grading & fill; no raising 100-year water surface elevation	Outside the stream buffer, where required or otherwise established	Outside of shoreline buffer, where required or otherwise established	Outside of wetland buffer, where required or otherwise established	Outside of wetland buffer, where required or otherwise established	Selection based on Pollutant Removal for Target Pollutant
Runoff Volume Reduction	Rooftop Disconnect.	OK	OK	Preferred; best if used with suppl. practices	OK	OK	Preferred	OK; best if used with suppl. practices
	Sheet flow to Vegetated Filter or Conserved Open Space	OK	OK	Preferred	OK	Does NOT apply to jurisdic-tional wetlands	Preferred	OK
	Soil Compost Amendments	OK	OK	Preferred	OK	OK	OK	OK
	Vegetated Roof	NA	NA	OK	NA	NA	OK	NA
	Rainwater Harvesting	OK [1]	OK	Preferred	OK	OK	Preferred	OK
Swales & Open Channels	Grass Channels	Pre-treat hotspots prior to discharge to channel or swale	OK	Preferred; link w/ other BMPs to protect channel and prevent flooding	OK; dry swale provides the best TP removal	OK, dry swale provides the best TP removal	Restricted (poor bacteria removal)	OK
	Dry Swales						Preferred	
Filtering Systems	Filtering Practices	OK – a Preferred practice		Preferred, but link w/ other BMPs to protect channel and prevent flooding	OK -- get moderate to high TP removal	OK, moderate to high TP removal	OK, moderate to high bacteria and TN removal	Preferred practices
	Bioretention 1	OK, with cautions for PSHs		Preferred practice	Preferred practice	Preferred practice	Preferred; mod to high bacteria and TN removal	
Infiltration Practices	Permeable Pavement	100 foot SD from water supply wells; pre-treat runoff in limestone regions; Restricted, if site is a PSH; may need injection well permit	Use only practices with imper-meable liners and under-drains	Preferred if site has appropriate soils	Preferred, if site has appropriate soils, in which case these are preferred practices	Preferred, if site has appropriate soils	Preferred	Restricted for some target pollutants
	Infiltration						Lg. scale OK; small scale restricted	
	Urban Bioretention			Extremely limited feasibility			OK	
	Bioretention 2			Preferred if site has appropriate soils			Preferred; mod to high bacteria and TN removal	

BMP Group	Specific BMP	Groundwater, Source Water Areas and Septic Systems	100-Year Flood Plains	Trout and Other Freshwater Streams	Freshwater Lakes and Ponds	Freshwater Wetlands (May be regulated)	Coastal Waters (incl. Tidal Wetlands	Impaired Waters
Basins Basins	Wet Swales	Preferred practice	OK	OK, but use only shaded swales near trout streams	OK	Preferred practice	Preferred	Preferred practice
	Constructed Wetlands	Preferred practice	OK	OK, but use only wooded wetlands near trout streams	Some designs restricted due to seasonally variable P removal, combined with other treatments	Preferred practice, but no use of existing natural wetlands	Preferred	Preferred practice
	Wet Ponds	Pre-treat hotspots; provide a 2 foot SD from seasonal high groundwater elevation	May not locate ponds in the flood plain	Restricted due to pool and stream warming concerns; overland erosion and channel protection is necessary	Design for enhance TP removal; use ponds with wetlands for best TP removal	Design for enhance TP removal; use ponds with constr. (NOT natural) wetlands for best TP removal	OK; Moderate bacteria removal; good to moderate TN removal; max. normal pool depth of 4 feet; Provide long ED (> 48 hrs) for max. bacteria die-off	Preferred practice
	Extended Detention	Does not meet Treatment Volume pre-treatment requirements	May not locate ponds in the flood plain	Not recm'd near trout streams unless need to provide for channel protection and flood protection; then use special design; Not recm'd within stream	Generally not necessary if discharge is directly to a large lake	Not recm'd within natural wetlands, nor should they inundate or otherwise change the wetland's hydroperiod	Restricted (limited feasibility)	May be restricted if warming is part of impairment
Mfr Treatment Devices	Hydrodymanic Devices	OK	May not locate in the flood plain	?	OK	?	OK	?
	Filtration Devices			?		?		?
	Storage Devices			?		?		?

NOTES: SD = separation distance; ED = extended detention PSH = potential stormwater hotspot

[1] This is a matter of the scale of the use of rainwater harvesting; if sufficient water is diverted for recycling, a nearby aquifer may be deprived of recharge water.

8.4.4 Stormwater Management Capability (Table 8.7 below)

Can one BMP meet all design criteria, or is a combination of practices needed? In this step, designers can screen the BMP list to determine if a particular BMP can meet each of the SWM criteria: *water quality, groundwater recharge, receiving channel/overland flow protection, and flood control* storage requirements. At the end of this step, the designer can screen the BMP options down to a manageable number and determine if a single BMP or a group of BMPs (e.g., a treatment train) are needed to meet stormwater sizing criteria at the site.

Water Quality Treatment. This column indicates whether each practice can be used to provide for effective water quality treatment (i.e., pollutant removal). For more detail on specific pollutant removal, consult **Table 8.8** below**.**

Runoff Volume Reduction. This column indicates whether each practice can provide for a reduction of runoff volume from the site, which contributes to pollutant removal and may contribute to groundwater recharge, depending on the specific practice. Obviously, the more runoff can be reduced in ways that keep it on the development site, the less runoff will be discharged from the site.

Groundwater Recharge. This column indicates whether each practice can provide for groundwater recharge. It may also be possible to accomplish some groundwater recharge by using Environmental Site Design techniques (see **Chapter 6**).

Receiving Channel/Overland Flow Protection. This column indicates whether the BMP can typically provide for the channel protection storage volume. The finding that a particular BMP cannot meet the channel protection requirement does not necessarily imply that the BMP should be eliminated from consideration, but is a reminder that more than one practice may be needed at a site (e.g., a bioretention area and a downstream extended detention pond).

Flood Control. This column indicates whether a BMP can typically meet the overbank and extreme flood control criteria for the site. Again, the finding that a particular BMP cannot meet the channel protection requirement does not necessarily imply that the BMP should be eliminated from consideration, but is a reminder that more than one practice may be needed at a site (e.g., a bioretention area and a downstream extended detention pond).

8.4.5 Pollutant Removal

How do each of the BMP options compare in terms of pollutant removal? In this step, the designer views removal of select pollutants to determine the best BMP options for water quality. It is important to note that the Total Pollutant Reductions (TR) indicated in **Table 8.8** below for TP, TN, and TSS reflect a combination of pollutant removal processes. These numbers assume a typical concentration for each pollutant in the total site runoff. These concentrations are typically expressed as an amount per unit of volume (e.g., 0.26 mg/L of TP). When part of the total runoff volume is removed through the use of Runoff Reduction practices (e.g., rainwater capture, infiltration, etc.), the pollutants in that removed volume are removed from the remaining runoff that must still be managed. Then, as Stormwater Treatment processes (e.g., settling, filtration, chemical conversion, vegetation uptake, etc.) are applied to that remaining runoff, the actual concentration of pollutant in the runoff is further reduced. So the total mass load removal of pollutants is a result of the combination of runoff volume reduction and supplementary treatment practices. **Table 8.8** examines the capability of each BMP option to remove specific pollutants from stormwater runoff.

Table 8.7. BMP Selection Matrix 5 – Stormwater Management Capability

BMP Group	Specific BMP	Water Qual. Treatment	Runoff Volume Reduction	Groundwater Recharge	Channel/ Overland Flow Protection	Flood Control
Runoff Volume Reduction	Vegetated Roof	●	○	●	◖ [4]	●
	Rooftop Disconnection	●	○	●	◖ [4]	●
	Rainwater Harvesting	●	○	●	◖ [4]	●
	Soil Compost Amendments	●	○	◖	◖ [4]	●
	Sheet flow to Vegetated Filter or Conserved Open Space	●	◖	◖	●	●
Swales & Open Channels	Grass Channel	○	○	○	●	●
	Dry Swale	○	○	○ [1]	◖ [4]	●
Filtering Systems	Filtering Practice	○	●	●	●	●
	Bioretention 1	○	○	○ [1]	◖ [4]	●
Infiltration Practices	Permeable Pavement 1	○	○	◖	◖ [4]	○ [2]
	Permeable Pavement 2	○	○	○	◖ [4]	○ [2]
	Infiltration	○	○	○	◖ [4]	○ [2]
	Bioretention 2	○	○	○	○	○ [2]
Basins	Constructed Wetland	○	○	○ [3]	○	○
	Wet Swale 1	○	◖	●	●	●
	Wet Swale 2	○	●	●	●	●
	Wet Pond	○	○	○	○	○
	Extended Detention 1	●	●	●	○	○
	Extended Detention 2	◖	◖	◖	○	○
Mfr Treatment Devices	Hydrodynamic Devices	Varies	●	●	●	●
	Filtration Devices	Varies	Varies	●	●	●
	Storage Devices	●	○	Varies	Varies	Varies

○ Practice generally meets this stormwater management goal.
◖ Practice may partially meet this goal, or under specific site and design conditions
● Practice can almost never be used to meet this goal.
[1] Provides recharge only if designed as an exfilter system.
[2] Can be used to meet flood control in rare conditions, with very cobbly or highly permeable soils.
[3] Yes, unless impermeable liners are required or the pool intercepts groundwater
[4] By removing/infiltrating water, thus reducing the overall volume of runoff

Table 8.8. BMP Pollutant Removal Efficiencies

Practice	Runoff Volume Reduc.[1] (%RR)	TP EMC Reduc.[2] (%PR)	Total TP Reduc.[3] (%TR)	TN EMC Reduc.[2] (%PR)	Total TN Reduc.[3] (%TR)	TSS EMC Reduc.[2] (%PR)	Total TSS Reduc.[3] (%TR)	Total Bacteria Reduc.[3, 4] (%TR)	Total Metals Reduc.[3] (%TR)	Total Hydro-carbons Reduc.[3] (%TR)
Rooftop Disconnect.[12, 14]	25 or 50[10]	0	25 or 50[10]	0	25	50	50	NA		
Sheet flow to Veg. Filter 1	25 or 50[10]	0	25 or 50[10]	0	25 or 50[10]	50 or 75[10]	50 or 75[10]	20*		
Sheet flow to Veg. Filter and Consrv. Open Space 2 [12]	50 or 75[10]	0	50 or 75[10]	0	50 or 75[10]	60 or 85[10]	60 or 85[10]	20*		
Grass Channel	10 or 20[10]	15	23	20	28	30	35	0	70[7]	62
Soil Compost Amendments	Can be used to decrease runoff coefficient for turf cover at a site. See design specs for Rooftop Disconnect., Sheet Flow to Veg. Filter, and Grass Channel					0	50	NA		
Vegetated Roof 1	45	0	45	0	45	50	70	NA		
Vegetated Roof 2	60	0	60	0	60	50	80	NA		
Rainwater Harvesting	90 [11, 12]	0	90 [11, 12]	0	90 [11, 12]	0	90 [11]	NA		
Permeable Pavement 1	45	25	59	25	59	65	80	NA	99[9]	
Permeable Pavement 2	75	25	81	25	81	65	90	NA	99[9]	
Infiltration 1	50	25	63	15	57	50	75	40*	99[9]	NA
Infiltration 2	90	25	93	15	92	50	95	40*	99[9]	NA
Bioretention 1	40	25	55	40	64	50	70	40*		62+
Bioretention 2	80	50	90	60	90	75	95	40*		62+
Urban Bioretention	40	25	55	40	64	50	70	40*		62+
Dry Swale 1	40	20	52	25	55	40	65	0[5]	70[7]	
Dry Swale 2	60	40	76	35	74	70	90	25*	70[7]	
Wet Swale 1	0	20	20	25	25	40	40	0		
Wet Swale 2	0	40	40	35	35	70	70	0		
Filtering Practice 1	0	60	60	30	30	60	60	35[5]	69[7]	84
Filtering Practice 2	0	65	65	45	45	85	85	70[6]	69[7]	84
Constructed Wetland 1	0	50	50	25	25	50	50	80[7]	42[7]	85
Constructed Wetland 2	0	75	75	55	55	80	80	80	42[7]	85
Wet Pond 1	0	50 (45[13])	50 (45[13])	30 (20[13])	30 (20[13])	50	50	70[7]	62[7]	81
Wet Pond 2	0	75 (65[13])	75 (65[13])	40 (30[13])	40 (30[13])	80	80	70	62[7]	81
Ext. Detention Pond 1	0	15	15	10	10	50	50	30[5]		
Ext. Detention Pond 2	15	15	31	10	24	70	75	60[6]		

[1] **Based upon 1 inch of rainfall – 90% storm** ,Annual average runoff reduction as reported in CWP (2008b)

[2] Change in stormwater event mean concentration (EMC) as it flows through the practice and is subjected to treatment processes, as reported in CWP (2008b)

[3] Total removal (TR) = product of RR and PR

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

[5] Median value from International BMP database.

[6] Q3 value from International BMP database.
[7] Median value from the National Pollutant Removal Performance Database (NPRPD, managed by the Center for Watershed Protection)
[8] Average of zinc and copper, but only zinc for infiltration.
[9] Based on fewer than five data points (i.e., independent monitoring studies).
[10] The lower rate is for Hydrologic Soil Group (HSG) class C and D soils; the higher rate is for HSG class A and B soils
[11] Credit up to 90% is possible if all water from storms 1 inch or less is used through demand, and the tank is sized such that no overflow occurs. Total credit is not to exceed 90% as an isolated practice.
[12] See BMP design specification for an explanation of how additional pollutant removal can be achieved.
[13] Lower nutrient removals in parentheses apply to wet ponds in coastal plain terrain.
[14] The removal can be increased to 50% for HSG C and D soils by adding soil compost amendments, and may be higher yet if combined with secondary runoff reduction practices.

Source: Adapted from CWP (2008b) and Volume II of the Northern Marianas/Guam Stormwater Management Manual (2006)

8.4.6 Community and Environmental Factors (Table 8.9 below)

Do the remaining BMPs have any important community or environmental benefits or drawbacks that might influence the selection process? In this last step, **Table 8.9** is used to assess the following community and environmental considerations involved in BMP selection:

Maintenance. This column assesses the relative effort needed to maintain the BMP, in terms of three criteria: (1) frequency of scheduled maintenance, (2) chronic maintenance problems (such as clogging), and (3) reported failure rates. It should be noted that the regulations require routine BMP inspection and maintenance under certain circumstances, for which Virginia requires a long-term Maintenance Agreement between the BMP owner and the local jurisdiction within which the BMP is located. This provides legal assurance that routine maintenance will be done to assure the continued proper functioning of the BMP.

Overall Affordability. The BMPs are ranked according to (1) their relative construction cost per impervious acre treated and (2) their long-term maintenance costs. These costs exclude design, land acquisition, and other costs.

Community acceptance. This column assesses community acceptance, as measured by three factors: (1) market and preference surveys, (2) reported nuisance problems, and (3) visual orientation (i.e., is it prominently located or is it in a discrete underground or other out-of-sight location). It should be noted that a low rank can often be improved by a better landscaping plan.

Safety. This column provides a comparative index that expresses the relative public safety of a BMP. An open circle indicates a reasonably safe BMP, while a darkened circle indicates that deep pools may present potential public safety risks. The safety factor is included at this stage of the screening process because liability and safety are of paramount concern in many residential settings. It should be noted that a low rank can be improved by using measures that restrict access, such as fencing. However, such measures may affect the ranking related to aesthetics.

Habitat. BMPs are evaluated on their ability to provide wildlife or wetland habitat, assuming that an effort is made to landscape them appropriately. Objective criteria include size, water features, wetland features, and vegetative cover of the BMP and its buffer.

Aesthetic, Recreational Benefits or Other Concerns. BMPs are evaluated on their ability to (1) provide a perceived positive influence on the visual appearance of the lot or development, (2) contribute to the recreational value at the lot, development or community scale, ideally as part of a community greenway network, or (3) provide other perceived ancillary benefits.

Table 8.9. BMP Selection Matrix 6 – Community and Environmental Factors

BMP Group	Specific BMP	Ease of Maintenance	Overall Affordability	Community Acceptance	Safety	Habitat	Aesthetics and Other Concerns
Runoff Volume Reduction	Vegetated Roof	◖	◖	◖	○	●	Invasive veg. and water leaks; reg. inspection and maint. can address these
	Rooftop Disconnect.	○ to ◖	○ to ◖	◖	○	●	Impediments to use in existing local health and building codes
	Rainwater Harvesting	●	◖	◖	○	●	
	Soil Compost Amendments	○	○	○	○	○	Helps prevent standing water and adds soil moisture for plant materials
	Sheet flow to Veg. Filter and Conserv. Open Space	○	○	○	○	○	Inc. into landscape; overgrown vegetation
Swales & Open Channels	Grass Channels	○	○	○	○	●	Attractive natural drainage mechanism
	Dry Swales	○	◖	○	○	●	Attractive natural drainage mechanism with enhanced infiltration and treatment
Filtering Systems	Filtering Practices	●	●	○	○	●	Filter media replacement; Underground practices are not seen and therefore often not maintained
	Bioretention 1	◖	◖	◖	○	◖	Inc. into landscape; mosquitoes; overgrown vegetation
Infiltration Practices	Permeable Pavement	●	◖	◖	○	●	Susceptible to failure if poorly installed or maintained
	Infiltration	●	◖	○	○	●	Susceptible to failure if poorly installed or maintained
	Bioretention 2	◖	◖	◖	○	◖	Inc. into Landscape; Mosquitoes; Overgrown vegetation

BMP Group	Specific BMP	Ease of Maintenance	Overall Affordability	Community Acceptance	Safety	Habitat	Aesthetics and Other Concerns
Basins	Constructed Wetlands	◖	◖	◖	◖	○	Undesirable animals; Mosquitoes; Overgrown vegetation and unsightly conditions
	Wet Swales	○	●	◖	○	◖	Undesirable animals; Mosquitoes; Overgrown vegetation and unsightly conditions
	Wet Ponds	○	○	◖	●	○	Geese, Odors, Mosquitoes, Floatable Trash; Safety & liability concerns
	Extended Detention 1	○	○	◖	●	●	Undesirable animals; Overgrown vegetation and unsightly conditions
Mfr Treatment Devices	Hydrodymanic Devices	◖	●	○	○	●	Underground practices are not seen and therefore often not maintained
	Filtration Devices	●	●	○	○	●	Underground practices are not seen and therefore often not maintained
	Storage Devices	◖	●	○	○	●	Underground practices are not seen and therefore often not maintained
○ High or Good or Easy ◖ Medium ● Low or Difficult							

8.4.7 Consideration of Regulatory Restrictions and Setbacks (Table 8.10 below)

Table 8.10 presents an overview of ten site-specific considerations of environmental resources or infrastructure present on the site or Virginia rules or conditions that may apply that will influence where a BMP can be located on the site (i.e., setback or similar restriction).

Table 8.10. Location-Specific Restrictions and Setbacks

Factor	Considerations
Jurisdictional Wetland U.S. Army Corps of Engineers(USACE) Section 404 Permit and/or Va. Department of Environmental Quality (DEQ) Section 401 Water Quality Certification and Wetlands and Water Protection Permits	• Wetlands should be delineated prior to siting BMPs • Demonstrated that the impact to a wetland complies with all of the following principles in descending order of priority: (1) avoid direct or indirect impacts; (2) minimize impact by limiting the degree or magnitude of activity; and (3) mitigate unavoidable impacts through wetland restoration or creation, providing justification that no practical upland treatment alternatives exist. • Always check with local, state and federal jurisdictions for applicable regulations. • Using natural wetlands for stormwater treatment is **strongly discouraged**, unless they are severely impaired and construction would enhance or restore wetland functions; impacts to natural wetlands will require state and federal permits. • Direct pipe outfalls to natural wetlands should be restricted; stormwater must be treated prior to discharge into a natural wetland and, where practical, excess stormwater flows should be conveyed away from jurisdictional wetlands. • BMPs are restricted from location within the Chesapeake Bay Preservation Act RPA buffer. • RPA buffers may be used as a non-structural filter strip accepting sheet flow, not concentrated flows.
Stream Channel USACE Section 404 Permit and/or Va. DEQ Section 401 Water Quality Certification and Wetlands and Water Protection Permits	• All waterways (including streams, ponds, lakes, etc.) should be delineated prior to design. • Use of any Waters of the U.S. for stormwater quality treatment is contrary to the goals of the Clean Water Act and should be avoided. • BMPs should not be placed on-line (in-stream) under most conditions and will require federal and state permits, if necessary, providing justification that no practical upland treatment alternatives exist. • If an on-line pond is necessary, its use for channel protection or flood protections purposes are preferred to use for water quality treatment. • Implement measures that reduce downstream warming. • Activities such as excavation, shore protection, structures, dams, and water level controls are regulated. • State (DEQ) water quality standards apply and may not be violated.
Shoreland Management, Chesapeake Bay Preservation Areas, and Stream Buffers Va. Marine Resource Commission (VMRC) and/or Applicable shoreland development ordinances	• VMRC regulates tidal wetlands (elevations below 1.5 x the mean high tide elevation), associated shorelands, and all state bottoms (the land beneath streams, rivers, etc. that comprise state waters). • All Tidewater Virginia local governments (§ 62.1-44.15:67 et seq., Code of Virginia) have Chesapeake Bay Preservation Area ordinances that require buffers and setbacks from shorelines; other localities outside Tidewater Virginia may also have shoreland development ordinances with similar requirements. • Consider how stormwater outfall channels will cross a buffer to reach a stream.

Factor	Considerations
100-Year Floodplain Va. Department of Conservation and Recreation (DCR) Division of Dam Safety and Floodplain Management and Applicable local floodplain management ordinances and stormwater review authority	• Grading and fill for BMP construction is strongly discouraged within the ultimate 100-year floodplain, as delineated on FEMA flood insurance rate maps, FEMA flood boundary and floodway (or more stringent local) maps. • Floodway fill may not raise the 100-year water surface elevation by more than 0.5 feet (local regulations may be more stringent).
Water Wells Local health authority	• Observe local wellhead protection zones and minimum setbacks. • Consult the Virginia Department of Health, the local health department, and the local water utility. • A 100-foot setback for infiltration practices and 50-foot setback for other BMPs is recommended. • There should be no infiltration of confirmed hotspot runoff; runoff from potential hotspot runoff should be restricted and have suitable pre-treatment.
Utilities Local review authority	• Contact “Miss Utility” to locate existing utilities prior to design. • Note the location of proposed utilities to serve development. • BMPs are discouraged within utility easements or rights-of-way for public or private utilities.
Septic Drain Fields Local health authority	• Consult the local health authority. • A minimum 50-foot setback from a drainfield edge is recommended for BMP location.
Roads Virginia Department of Transportation (VDOT) and/or Local transportation authority or DPW	• Consult the local transportation authority, DPW or subdivision ordinance/regulations for setback requirements from local roads and streets. • Consult VDOT for setbacks from state-maintained roads. • Approval must also be obtained for any stormwater discharges to a local or state-owned storm drain or conveyance channel.
Structures Local review authority	• Consult the local review authority for any BMP setback from structures.

Factor	Considerations
Karst (Sinkholes) Local review authority EPA Region III UIC Pgm Virginia Cave Board	• Geotechnical testing is recommended and may be required within karst areas. • Existing sinkholes should be identified and delineated on site plans. • BMPs should be designed to be off-line to limit volumes and flow rates managed by individual practices; infiltration or pooling of stormwater near sinkholes is discouraged; sinkhole formation is less likely when practices such as bioretention and vegetated filters are used; sinkholes should be remediated and stormwater directed away from these areas during and after construction. • Any discharge of stormwater runoff to a sinkhole or other karst feature must meet the water quality control criteria set out in 9 VAC 25-870-63 and the water quantity control criteria set out in 9 VAC 25-870-66 of the Virginia Stormwater Management Regulations • Formation of sinkholes within an BMP is evidence of failure; sinkholes occurring within BMPs should be repaired as soon as feasible after the first observation, using appropriate engineering techniques (e.g., VDOT IIM228 – *Sinkholes: Guidelines for the Discharge of Stormwater at Sinkholes; WVDEP, 2004; MDE, 2000; etc.*). • Consistent with federal environmental regulations at 40 CFR parts 144-148, some karst features receiving runoff may be considered to be class V injection wells and must be registered as such with the EPA Region III. To ensure compliance in cases where stormwater runoff is discharged to a karst feature, DEQ recommends coordination with the EPA Groundwater & Enforcement Branch (3WP22), U.S. EPA Region 3, 1650 Arch Street, Philadelphia, PA 19103 (Phone: 215-814-5427; FAX: 215-814-2318).

8.4.8 Spatial Scale At Which Practices Are Applied (8.11 below)

The matrix provided in **Table 8.11** below compares the different spatial scales at which the various stormwater control measures can be applied to reduce runoff and remove pollution. The major change in the new BMP design specifications is that most practices are applied at a smaller spatial scale than has been done in the past. This means that more practices will be needed at each site. Note that the area ranges specified in **Table 8.11** for contributing drainage areas (CDAs) are approximate, and may actually be greater or smaller depending on the specific design and site characteristics. Multiple BMPs of the same or different kind may be used in combination to treat a larger CDA.

Table 8.11. Comparison of Practices Based on Contributing Drainage Area Served

Practice	Spec No.	Space [1]	Micro Scale	Small Scale	Normal Scale	Moderate Scale	Large Scale
Rooftop Disconnection	1	Nominal	250 to 1000 sq. ft.				
Sheet Flow to Veg. Filter or Conserved Open Space	2	15-25%		1000 to 5000 sq. ft.	5000 to 25,000 sq. ft.		
Grass Channels	3	5-15%			20,000 sf to 250,000 sq. ft.		
Soil Compost Amendments	4	Nominal	250 sq. ft. to 2 acres				
Vegetated Roofs	5	Nominal	Residential 250 to 2000 sq. ft.	Commercial 2,000 to 200,000 sq. ft.			
Rainwater Harvesting	6	Nominal					
Permeable Pavement	7	Nominal	250 to 1000 sq. ft.	1000 to 10,000 sq. ft.	10,000 to 200,000 sq. ft.		
Infiltration	8	1-4%	250 to 2500 sq. ft.	2500 to 20,000 sq. ft.	20,000 to 100,000 sq. ft.		
Bioretention	9	3-5%	250 to 2500 sq. ft.	2500 to 20,000 sq. ft.	20,000 to 100,000 sq. ft.		
Urban Bioretention	9A	Nominal	250 to 2500 sq. ft.	2500 to 20,000 sq. ft.			
Dry Swales	10	5-15%			20,000 to 250,000 sq. ft.		
Wet Swales	11	5-15%			20,000 to 250,000 sq. ft.		
Filtering Practices	12	0-3%			20,000 to 250,000 sq. ft.		
Constructed Wetlands	13	3%					10 + acres, unless favorable water balance
Wet Ponds	14	1-3%					
Extended Detention Ponds	15	1-3%					

[1] Typical footprint of BMPs as a percent of the total site area

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Appendix 8-A

EXAMPLE BMP DESIGN CHECKLISTS

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8-A.1.0. INTRODUCTION

Design and plan review checklists provide general guidance, for both the designer and plan reviewer, regarding the proper design of BMPs. Some items listed on the checklists may not apply to every design, so it is up to the designer to indicate items as "*not applicable*" (or "*NA*") where appropriate. Similarly, the reviewer must be able to distinguish which items are required, based on the local conditions or requirements, and verify the status of those items.

These checklists can be used as tools to provide designers with the necessary information needed to develop an approvable plan, as well as to provide the plan review authority with a consistent review procedure. The various "basin" checklists (Constructed Wetlands, Wet Pond, and Extended Detention Basin) have items included that reflect design criteria in Appendices A through E of the document entitled *Introduction to the New Virginia Stormwater Design Specifications*, found on the Virginia Stormwater BMP Clearinghouse web site at the following URL:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

These appendices address a number of design issues common to basin-type practices, such as the sediment forebay, earthen embankment, principal spillway, emergency spillway, and pond landscaping.

8-A.2.0. ROOFTOP DISCONNECTION: DESIGN CHECKLIST

Plan Submission Date____________________
Project Name____
Site Plan/Permit Number____
Practice No./Location on Site____
Owner____ Phone Number_________________
BMP Designer____________________________________ Phone Number_________________
General Contractor_______________________________ Phone Number_________________

______ **Signature and stamp of licensed professional design consultant and owner certification**

Plan Status

_______ Approved
_______ Not Approved

Legend:

✓	- Complete
Inc.	- Incomplete/Incorrect
N/A	- Not Applicable

Compensatory device type (include if the pervious area flow path is less than the required minimum length): ***(NOTE: See the separate plan review checklist for the compensatory device)***

- ☐ Dry Well (Micro-Infiltration, Stormwater Design Specification No. 8)
- ☐ French Drain (Micro-Infiltration, Stormwater Design Specification No. 8)
- ☐ Amended Soils (Stormwater Design Specification No. 4)
- ☐ Rain Garden (Micro-Bioretention, Stormwater Design Specification No. 9)
- ☐ Stormwater Planter (Micro-Bioretention, Stormwater Design Specification No. 9, Appendix A))
- ☐ Other: ___________________________

I. SUPPORTING INFORMATION

_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design (infiltration basin, infiltration trench, etc.).
_______ Provide a site map showing the location of this BMP and showing:
  ______ Facility area and any compensatory devices
  ______ Contributing drainage area (CDA) boundaries and acreage
  ______ Areas of the site compensated for in water quality calculations
_______ Provide topography of the site
_______ Provide a soil map for the site
_______ Provide soil boring logs with Unified Soils Classifications, showing:
  ______ Depth to seasonal high groundwater table (minimum 2 ft. - 4 ft. below the design bottom of the facility)
  ______ Depth to bedrock (minimum 2 ft. - 4 ft. below the design bottom of the facility)
  ______ Soil suitability for infiltration (HSG A or B soils or use soil amendments)
_______ If located in Karst environment, any provide additional geophysical investigation and recommendations

II. COMPUTATIONS

A. Hydrology

_______ Provide runoff curve number determinations (re- and post-developed conditions) with worksheets.
_______ Provide time of concentration (pre- and post-developed conditions), with worksheets.
_______ Provide hydrograph generation (pre- and post-developed conditions) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)

B. Hydraulics

_______ Specify assumptions and coefficients used.
_______ Hydraulic head required = 1-3 ft. for Micro-Infiltration and Micro-Bioretention
_______ Provide a stage-storage table and curve
_______ Show that compensatory devices are able to drain within 48 hours following a storm.

C. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA, pollutant load, pollutant load removal, and treatment volume requirements, all generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet)
_______ When soil amendments are used in the downspout discharge flow path, the Runoff Reduction Spreadsheet will self-credit improved runoff volume reduction based on the change of the soil drainage characteristics (see Stormwater Design Specification No. 4)

III. PLAN REQUIREMENTS

A. BMP Plan View Information

_______ Show the limits of clearing and grading, noting that they should be identified and protected by acceptable signage, silt fence, snow fence, or other comparable barrier.
_______ Show the layout and dimensions of the BMP(s)

1. Simple Rooftop Disconnection

______ Maximum rooftop area treated = 1,000 sq. ft.
______ Longest flow path (roof/gutter) = 75 ft.
______ Disconnection length = longest flow path, but no less than 40 ft.
______ Distance downspouts are extended from buildings or foundations = 5 ft. for simple foundations if grade is < 1% (15 ft. in karst areas)

2. Rooftop Disconnection to Micro-Infiltration (Dry Well or French Drain)

______ Maximum rooftop area treated = 250 to 2,500 sq. ft.
______ Runoff reduction sizing based on Stormwater Design Specification #8
______ Observation well NOT required
______ Soil test/boring required = 1 per practice
______ Distance downspouts are extended from buildings or foundations = 5 ft. down-gradient for simple foundations (15 ft. in karst areas), or 25 ft. up-gradient

3. Rooftop Disconncection to Micro-Bioretention (Rain Garden, Stormwater Planter, etc.)

______ Maximum rooftop area treated = 1,000 sq. ft.
______ Type of inflow to secondary practice = sheet flow or roof leader
______ Runoff reduction sizing based on a bioretention surface area = 5% of roof area (Level 1) or 6% of roof area (Level 2); for Stormwater Planters, an infiltration planter is sized to store a minimum of 1/2-inch of runoff from the contributing roof area
______ Observation well NOT required
______ Underdrain and gravel layer = Required for Level 1; Optional for Level 2, depending on soils (refer to Stormwater Design Specification No. 9, Table 2)
______ Soil test/boring required = 1 per practice, but only when an underdrain is NOT used
______ Distance downspouts are extended from buildings or foundations = 5 ft. down-gradient for simple foundations (15 ft. in karst areas), or 25 ft. up-gradient
______ Stormwater filter planters can be placed right next to the building; infiltration planters must be placed a minimum of 10 ft. from the building

B. BMP Section Views & Related Details

1. Simple Rooftop Disconnection

______ Disconnection slope = < 2% (or < 5% with specified turf reinforcement)
______ Distance downspouts are extended from buildings or foundations = 5 ft. for simple foundations if grade is < 1% (15 ft. in karst areas)
______ Pre-treatment = external (leaf screens, etc.)

2. Rooftop Disconnection to Micro-Infiltration (Dry Well or French Drain)

______ Recommended maximum depth = 3 ft.
______ Minimum soil infiltration rate = 0.5 in./hr.
______ Observation well NOT required
______ Pre-treatment = external (leaf screens, grass filter strip, etc.)
______ Soil test/boring required = 1 per practice
______ Distance downspouts are extended from buildings or foundations = 5 ft. down-gradient for simple foundations (15 ft. in karst areas), or 25 ft. up-gradient

3. Rooftop Disconncection to Micro-Bioretention (Rain Garden, Stormwater Planter, etc.)

______ Type of inflow to secondary practice = sheet flow or roof leader
______ Minimum soil infiltration rate = 0.5 in./hr. (or use underdrain)
______ Observation well NOT required
______ Pre-treatment = external (leaf screens, etc.)
______ Underdrain and gravel layer = Required for Level 1; Optional for Level 2, depending on soils (refer to Stormwater Design Specification No. 9, Table 2)
______ Stormwater filter planters must have an overflow pipe installed to prevent water from spilling over the side when excess rainfall occurs
______ Minimum filter media depth = 18 in. for Level 1; 24 inches for Level 2; for a stormwater planter, 30 in. for an infiltration planter, and a min. 18 in. for a filter planter
______ Media source = mixed on site consistent with Stormwater Design Specification No. 9; planting media should have an infiltration rate of at least 2 in./hr., and the sand/gravel on the planter bottom should have a rate of at least 5 in./hr.
______ Soil test/boring required = 1 per practice, but only when an underdrain is NOT used
______ Distance downspouts are extended from buildings or foundations = 5 ft. down-gradient for simple foundations (15 ft. in karst areas), or 25 ft. up-gradient
______ Stormwater filter planters can be placed right next to the building; infiltration planters must be placed a minimum of 10 ft. from the building

C. Landscape Plan (perimeter)

_______ Provide a planting schedule and specifications (transport / storage / installation / maintenance)
_______ Ensure that plant selection is appropriate for the site's vegetation climatic zone (4-8 in Virginia), emphasizing native species
_______ Specify preservation measures for existing vegetation
_______ Ensure that topsoil / planting soil is included in the final grading
_______ The construction contract should include a *Care and Replacement Warranty* to ensure that new vegetation is properly established and survives during the first growing season following construction.

D. Construction Notes

_______ Construction sequence for BMP(s) and E&S controls:
______ Install applicable temporary E&S control measures.
______ Convey base flow around secondary practice while it is being constructed.
______ Prepare the bottom surface of the stone reservoir,
______ Lay down filter fabric, if applicable.
______ Install french drain tile, if applicable.
______ Place aggregate for dry well or french drain.

- ______ Install overflow and underdrain, if applicable.
- ______ Place bioretention media, if applicable.
- ______ For other compensatory BMP(s), see the plan review checklists for those practices
- ______ Install temporary and permanent stabilization measures

E. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.

- ______ Include a Maintenance Narrative which describes the long-term maintenance requirements.

_______ Record a deed restriction, drainage easement, and/or other enforceable mechanism, including GPS coordinates of the area, to ensure property owner awareness, access for inspections and maintenance, and that downspouts remain disconnected.

IV. COMMENTS

By: ________________________________ Date: ____________________

8-A.3.0. SHEET FLOW TO VEGETATED FILTER AREAS AND CONSERVED OPEN SPACE: DESIGN CHECKLIST

Plan Submission Date____________________
Project Name____________________
Site Plan/Permit Number____________________
Practice No./Location on Site____________________
Owner____________________ Phone Number____________________
BMP Designer____________________ Phone Number____________________
General Contractor____________________ Phone Number____________________

______ **Signature and stamp of licensed professional design consultant and owner certification**

Plan Status

_______ Approved
_______ Not Approved

Legend:
___ - Complete
Inc. - Incomplete/Incorrect
N/A - Not Applicable

Control device type:

- ☐ Engineered Level Spreader (ELS)
- ☐ Level Spreader with vegetated lip
- ☐ Gravel Diaphragm (GD)
- ☐ Permeable Berm (PB)
- ☐ Other: ____________________

Receiving filter area:

- ☐ Vegetated filter area (amended soils with dense turf cover or herbaceous cover, shrubs and trees
- ☐ Forested/vegetated buffer/open space (undisturbed soils and native veg.)
- ☐ Other: ____________________

Facility Type: Level 1 ____________________ Level 2 ____________________

I. SUPPORTING INFORMATION

_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design (infiltration basin, infiltration trench, etc.).

_______ Provide a site map showing location of this BMP and showing:
- ______ Facility area, control devices, and receiving filter area
- ______ Contributing drainage area (CDA) boundaries and acreage
- ______ Topography
- ______ Areas of the site compensated for in water quality calculations

_______ Show the location of boundary spreaders:
- ______ Gravel Diaphragm and/or Engineered Level Spreader at the top of a conserved open space filter area
- ______ Gravel Diaphragm and/or Engineered Level Spreader at the top of a vegetated filter strip AND a Permeable Berm at the toe of the filter area.

_______ Provide a soil map for site and area of facility

_______ Provide soil boring logs with Unified Soils Classifications

II. COMPUTATIONS

A. Hydrology

_______ Provide runoff curve number determinations (pre- and post-developed conditions), with worksheets.

_______ Provide time of concentration (pre- and post-developed conditions), with worksheets.

_______ Provide a hydrograph generation (pre- and post-developed condition) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)

B. Hydraulics

_______ Specify assumptions and coefficients used.
_______ Provide a stage-storage table and curve
_______ Show that compensatory devices are able to drain within 48 hours following a storm.

C. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA, pollutant load, pollutant load removal, and treatment volume requirements, all generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet)
_______ When soil amendments are used, the Runoff Reduction Spreadsheet will self-credit improved runoff volume reduction based on the change of the soil drainage characteristics (see Stormwater Design Specification No. 4)

III. PLAN REQUIREMENTS

A. BMP Plan View Information (see example graphics in Design Specification No. 2)

_______ Show limits of clearing and grading, noting that they should be identified and protected by acceptable signage, silt fence, snow fence, or other comparable barrier.
_______ Show the layout and dimensions of the BMP(s)
_______ Maximum flow length = 150 ft. from adjacent *pervious* area OR 75 ft. from adjacent *impervious* area
_______ Show location of perimeter protection of Conserved Open Space(s) and note that no grading or heavy equipment access is allowed except for temporary disturbances associated with incidental utility construction, restoration operations, or management of nuisance vegetation

1. If Soils Are Amended

______ Show the full length and width of any area of amended soils

2. Engineered Level Spreader

______ Avoiding concentrated flows:
______ Length of ELS lip = 13 lin. ft. per each 1 cfs of inflow (min. 13 lin. ft.; max 130 lin. ft.) for vegetated filter strips or for undisturbed conserved open space with at least 90% veg. cover (per Section 6.2 of the Design Specification)
______ Length of ELS lip = 40 lin. ft. per 1 cfs for forested or reforested filter areas
______ Overflow/bypass to a reinforced swale designed to convey all peak flows greater than the water quality design storm (1-inch rainfall)

3. Gravel Diaphragm

______ Show the location, if applicable, at top of veg. filter area or conserv. open space slope

4. Permeable Berm

______ Show the location, if applicable, at the toe of the vegetated filter area slope
______ Show the location of the outlet pipe (or gravel lens with perforated pipe) through berm

B. BMP Section Views & Related Details (see example graphics in Design Specification No. 2)

_______ Topographic conditions meet minimum slope and width requirements
_______ The first 10 ft. of filter must be 1-2% slope in all cases
_______ 0.5% - 3% slope for conserved open space or 1% - 4% slope for veg. filter strip = minimum 35 ft. filter width
_______ 3% -6% slope for conserved open space or 4% - 6% slope for veg. filter strip = minimum 50 ft. filter width
_______ 6% - 8% slope for veg. filter strip = minimum 65 ft. width

1. If Soils Are Amended

______ Note the depth to which soil compost amendments must be incorporated

2. Engineered Level Spreader

______ Avoiding concentrated flows:

- ______ Length of ELS lip = 13 lin. ft. per each 1 cfs of inflow (min. 13 lin. ft.; max 130 lin. ft.) for veg. filter strips or for undisturbed conserved open space with at least 90% veg. cover (per Section 6.2 of the Design Specification)
- ______ Length of ELS lip = 40 lin. ft. per 1 cfs for forested or reforested filter areas
- ______ Overflow to reinforced swale if ELS designed for 1-in./hr. storm

______ Section through the ELS system, including the forebay or ELS channel/trench located above the ELS, consistent with the Design Specification (No. 2)

______ Detail showing any temporary or permanent biodegradable fabric or matting (EC-2, or EC-3) employed to stabilize steeper slopes

______ Ends of ELS tied back into the natural slope to prevent scouring around the ends

3. Gravel Diaphragm

______ Show a section through the gravel diaphragm, if used, at top of veg. filter area or conserv. open space slope, consistent with the Design Specification (No. 2)

______ Filter fabric, stone and other materials should be consistent with the Design Spec

4. Permeable Berm

______ Show a section through the permeable berm at toe of veg. filter area slope, consistent with the Design Specification (No. 2)

______ Note the filter media composition and other materials, which should be consistent with the Design Specification

C. Landscape Plan

_______ There should be NO grading or clearing of native vegetation within conserved open space area; invasive species may be removed, if the locality approves

_______ Provide specifications for any compost amendments used and depth of incorporation (see Stormwater Design Specification No. 4) – soil amendments should NOT be incorporated until after the gravel diaphragm or level spreader are installed

_______ Ensure that planting specifications for the conserved open space or vegetated filter areas are consistent with the Stormwater Design Specification No. 2.

_______ Provide a planting schedule and specifications (transport / storage / installation / maintenance)

_______ Ensure that plant selection is appropriate for the site's vegetation climatic zone (4-8 in Virginia), emphasizing native vegetation

_______ Specify preservation measures for existing vegetation

_______ Ensure that topsoil / planting soil is included in the final grading

_______ The construction contract should include a *Care and Replacement Warranty* to ensure that new vegetation is properly established and survives during the first growing season following construction.

D. Construction Notes

_______ Construction sequence for BMP(s) and E&S controls:

- ______ The filter area should be clearly marked off before construction begins to prevent construction traffic from compacting the area
- ______ Install applicable temporary E&S control measures.
- ______ Convey base flow around secondary practice while it is being constructed.
- ______ Install temporary and permanent stabilization measures.

_______ In addition:

1. Conserved Open Space

_______ Perimeter of Conserved Open Space should be protected by acceptable signage, super silt fence, snow fence, chain link fence, orange safety fence or other comparable methods

_______ Note that no clearing, grading or heavy equipment access is allowed except for temporary disturbances associated with incidental utility construction, restoration operations or management of nuisance vegetation

_______ Note (if applicable) that (1) construction of the gravel diaphragm or engineered level spreader shall not commence until the contributing drainage area has been stabilized and perimeter E&S controls have been removed and cleaned out; and (2) stormwater should not be diverted into the filter area until the gravel diaphragm and/or level spreader are installed and stabilized.

_______ Note that any light grading necessary at the filter area boundary must be done with tracked vehicles to prevent compaction

2. Vegetated Filter Strips

_______ Note that only vehicular traffic necessary for the filter strip construction should be allowed within 10 feet of the filter strip boundary

_______ Note that if existing topsoil is stripped during grading, it shall be stockpiled and stabilized for later use

_______ Note that construction runoff shall be directed away from the proposed filter strip area, using perimeter silt fence or, preferably, a diversion dike.

_______ Note (if applicable) that (1) construction of the gravel diaphragm or engineered level spreader shall not commence until the contributing drainage area has been stabilized and perimeter E&S controls have been removed and cleaned out; and (2) stormwater should not be diverted into the filter area until the gravel diaphragm and/or level spreader are installed and stabilized and until the turf cover is dense and well-established.

_______ Note that amended soils should be hand-raked to the most level slope without using heavy equipment, but that any light grading necessary to achieve desired elevations and slopes must be done with tracked vehicles to prevent compaction.

_______ Note that compost amendments and/or topsoil shall be incorporated evenly across the filter strip area, stabilized with seed, and, if slopes exceed 3%, protected by biodegradable E&S control matting or blankets (EC-2).

E. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.

    ______ Include a Maintenance Narrative which describes the long-term maintenance requirements of the facility and all components, including installation/maintenance of signage; removal and disposal of trash, debris and sediment accumulations; and mowing.

_______ Record a deed restriction, drainage easement, and/or other enforceable mechanism, including GPS coordinates of the area, to ensure property owner awareness, access for inspections and maintenance, and that the filter area is remains intact and fully functional.

_______ Provide sufficient facility access from the public ROW or roadway to both the filter area and accessory practices.

IV. COMMENTS

By: ______________________ Date: ______________

8-A.4.0. GRASS CHANNELS: DESIGN CHECKLIST

Plan Submission Date____________________
Project Name______________________________
Site Plan/Permit Number______________________________
Practice No./Location on Site______________________________
Owner______________________________ Phone Number__________________
BMP Designer______________________________ Phone Number__________________
General Contractor______________________________ Phone Number__________________

______ **Signature and stamp of licensed professional design consultant and owner certification**

Plan Status

_______ Approved
_______ Not Approved

Legend:

✓	- Complete
Inc.	- Incomplete/Incorrect
N/A	- Not Applicable

Type of pretreatment facility:

- ☐ Check Dams (channel flow)
- ☐ Tree Check Dams (channel flow)
- ☐ Grass Filter Strip (sheet flow)
- ☐ Gravel or Stone Diaphragm (sheet flow)
- ☐ Gravel or Stone Flow Spreaders (concentrated flow)
- ☐ Other: __________________________
- ☐ None

I. SUPPORTING INFORMATION

_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design (infiltration basin, infiltration trench, etc.).
_______ Provide a site map of the location of this BMP showing:
  ______ Grass channel area and per-treatment practice
  ______ Contributing drainage area (CDA) boundaries and acreage, not to exceed 5 acres for any individual grass channel
  ______ Topography
  ______ Areas of the site compensated for in water quality calculations
_______ Provide a soil map for site and area of the grass channel
_______ Provide soil boring logs with Unified Soils Classifications
_______ Pre-treatment is recommended for grass channels to dissipate energy, trap sediments and slow down runoff velocity.
_______ Minimum depth to bedrock in karst areas is 18 inches.
_______ Minimum depth to groundwater in coastal areas is 12 inches.
_______ In areas of steep terrain, terracing a series of grass channel cells may work on slopes of from 5% to 10% grade, where the drop in elevation between check dams should be no more than 18 inches and the check dams should be armored on the down-slope side with suitably sized stone to prevent erosion.

II. COMPUTATIONS

A. Hydrology

_______ Provide runoff curve number determinations (pre- and post-developed conditions), with worksheets.
_______ Provide time of concentration (pre- and post-developed conditions), with worksheets.

_______ Provide hydrograph generation (pre- and post-developed condition) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)

B. Hydraulics

_______ Show that compensatory devices are able to drain within 48 hours following a storm.
_______ Grass channels are designed based on peak flow rate – the maximum flow velocity of the channel must be less than 1 foot per second during a 1-inch water quality storm event
_______ The longitudinal slope of the channel should, ideally, be between 1% and 2% in order to avoid scour and short-circuiting within the channel; longitudinal slopes up to 4% are acceptable, but check dams will be necessary to reduce the effective slope in order to meet the limiting velocity requirements)
_______ Verify hydraulic capacity using Manning's Equation or an accepted equivalent method, such as erodibility factors and vegetal retardance
  ______ The flow depth for the peak treatment volume (1-inch rainfall) should be maintained at 3 inches or less
  ______ Manning's "n" value for grass channels should be 0.2 for flow depths up to 4 inches, decreasing to 0.03 at a depth of 12 inches (which applies to the 2-year and 10-year storms if an on-line application
  ______ Peak flow rates for the 2-year and 10-year frequency storms must be non-erosive or subject to site-specific analysis of the channel lining material and vegetation
  ______ The 10-year peak flow rate must be contained within the channel banks, with a minimum of 6 inches of freeboard
_______ Specify assumptions and coefficients used.
_______ Provide a stage-storage table and curve
_______ Calculations for peak flow depth and velocity should reflect any increase in flow along the length of the channel, as appropriate. If a single flow is used, the flow at the outlet should be used.
_______ The hydraulic residence time should be a minimum of 9 minutes for the treatment volume (1-inch rainfall) design storm. If flow enters the channel at multiple locations, a 9-minute minimum hydraulic residence time should be demonstrated for each entry point, using equations in Stormwater Design Specification No. 3.
_______ The minimum length may be achieved with multiple swale segments connected by culverts with energy dissipators

C. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA, pollutant load, pollutant load removal, and treatment volume requirements, all generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet)
_______ When soil amendments are used, the Runoff Reduction Spreadsheet will self-credit improved runoff volume reduction based on the change of the soil drainage characteristics (see Stormwater Design Specification No. 4)
_______ Specific sizing/dimensions determined from criteria in Stormwater Design Specification No. 3.
_______ Grass channels should NOT be used as stand-alone water quality treatment systems in Coastal Plain settings, due to poor nutrient and bacteria removal rates (Dry Swales or Wet Swales are a better choice).

III. PLAN REQUIREMENTS

A. BMP Plan View Information (see example graphics in Design Specification No. 2)

_______ Show the limits of clearing and grading, noting that they should be identified and protected by acceptable signage, silt fence, snow fence, or other comparable barrier.
_______ Layout and dimensions of the grass channel and pre-treatment device(s)
_______ The bottom width of the channel should be from 4 to 8 feet. If a channel must be wider, incorporate benches, check dams, level spreaders or multi-level cross-sections to prevent braiding and erosion along the channel bottom.
_______ Grass channels should generally be aligned adjacent to and the same length (minimum) as the contributing drainage area identified for treatment.

_______ In karst areas, the channel may have off-line cells and must be connected to an adequate discharge point.
_______ In coastal areas, the channel may have off-line cells and must be connected to the ditch system.

B. BMP Section Views & Related Details (see example graphics in Design Specification No. 2)

_______ Topographic conditions must meet minimum slope and width requirements.
_______ Grass channels should be designed with a trapezoidal or parabolic cross-section. A parabolic shape is preferred for aesthetic, maintenance and hydraulic reasons.
_______ The channel side slopes should be 3H:1V or flatter. For ease of mowing and routine maintenance, side slopes should be no steeper than 4H:1V. Flatter slopes are encouraged to aid in pre-treatment of sheet flows entering the channel.
_______ The longitudinal slope of the channel should, ideally, be between 1% and 2% in order to avoid scour and short-circuiting within the channel; Longitudinal slopes up to 4% are acceptable, but check dams will be necessary to reduce the effective slope in order to meet the limiting velocity requirements). A minimum slope of 0.5% must be maintained in karst or coastal areas to ensure positive drainage.

C. Check Dams (generally discouraged in karst areas, where flow spreaders flush with the ground surface and spaced along the channel length may be useful in spreading flows more evenly across the channel width)

_______ Check dams should be should configured with elevated driveway culverts or be composed of wood, concrete, rip-rap, or other non-erodible material, underlain with filter fabric conforming to the following standards:
- ______ Needled, non-woven, polypropylene geotextile.
- ______ Grab Tensile Strength (ASTM D4632): ∃ 120 lbs.
- ______ Mullen Burst Strength (ASTM D3786): ∃ 225 lbs./sq. in.
- ______ Flow Rate (ASTM D4491): ∃ 125 gpm/sq. ft.
- ______ Apparent Opening Size (ASTM D4751): ∃ US #70 or #80 sieve

_______ Wood used for check dams should consist of pressure-treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.
_______ It is necessary to compute check dam materials, based on the surface area and depth used in the design computations.
_______ Check dams should be spaced (based on the channel slope) as needed to increase residence time and provide adequate storage for the treatment volume (1-inch rainfall) or any additional volume attenuation requirements. The ponded water at a downhill check dam should not touch the toe of the upstream check dam.
_______ The maximum desired check dam height is 12 inches (for maintenance purposes). However, for challenging sites, a maximum of 18 inches can be allowed, with additional design elements to ensure the stability of the check dam and the adjacent and underlying soils The average ponding depth throughout the channel should be 12 inches.
_______ Soil plugs serve to help minimize the potential for blow-out of the soil media underneath the check dams due to hydrostatic pressure from the upstream ponding. Soil plugs are appropriate for Grass Channels (1) on slopes of 4% or greater, or (2) with check dams equal to or greater than 12-inches in height.
_______ Armoring may be needed at the downstream toe of the check dam to prevent erosion.
_______ Check dams must be firmly anchored into the side-slopes to prevent outflanking; check dams must also be anchored into the channel bottom so as to prevent hydrostatic head from pushing out the underlying soils.
_______ Check dams must be designed with a center weir sized to pass the channel design storm peak flow (10-year storm event for man-made channels).
_______ Check dams should be designed and constructed so as to facilitate easy mowing of the channel.
_______ Each check dam should have a weep hole or similar drainage feature so it can dewater after storms.
_______ Individual channel segments formed by check dams or driveways should generally be at least 25 to 40 feet in length.

D. Diaphragms

_______ Pea gravel used to construct pre-treatment diaphragms should consist of washed, open-graded, course aggregate between 3 and 10 mm in diameter and must conform to local design standards.

E. Soil Compost Amendments

_______ The compost-amended strip should extend over the length and width of the channel bottom, and the compost should be incorporated to a depth as outlined in Stormwater Design Specification No. 4.

_______ The amended area will need to be rapidly stabilized with perennial, salt tolerant grass species.

_______ For grass channels on steep slopes, it may be necessary to install a protective biodegradable geotextile fabric to protect the compost-amended soils. Care must be taken to consider the erosive characteristics of the amended soils when selecting an appropriate geotextile.

_______ For redevelopment or retrofit applications, the final elevation of the grass channel (following compost amendment) must be verified as meeting the original design hydraulic capacity.

F. Landscape Plan

_______ Choose grass species that can withstand both wet and dry periods as well as relatively high-velocity flows. Taller and denser grasses are preferable, though the species is less important than the ability to provide effective stabilization. (Consult Standard and Specification 3.32 of the Virginia E&S Control Handbook for a list of acceptable grass species.)

_______ For channels adjacent to roads and parking lots, salt-tolerant species should be chosen.

_______ Use grass seed, NOT sod.

_______ Seed at a density that achieves a 90% turf cover by the end of the second growing season.

_______ Provide specifications for any compost amendments used, including the depth of incorporation (see Stormwater Design Specification No. 4)

_______ Provide immediate stabilization of the channel bed and banks using a biodegradable erosion control fabric (netting or mats) durable enough to last at least two growing seasons (conforming to Standard and Specification 3.36 of the Virginia E&S Control Handbook).

_______ Provide a planting schedule and specifications (transport / storage / installation / maintenance)

_______ Ensure that plant selection is appropriate for the site's vegetation climatic zone (4-8 in Virginia), emphasizing native species

_______ Specify preservation measures for existing vegetation

_______ Ensure that topsoil / planting soil is included in the final grading

_______ The construction contract should include a *Care and Replacement Warranty* to ensure that new vegetation is properly established and survives during the first growing season following construction.

G. Construction Notes

_______ Ideally, grass channels should be constructed during months that are best for establishing turf cover without irrigation (February 15 – April 15; September 15 – November 15).

_______ Applicable temporary E&S control measures

_______ Ideally, grass channels should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. If this is not feasible, temporary E&S controls such as dikes, silt fences and similar measures should be integrated into the channel design. Specifically, barriers should be installed at key check dam locations, and E&S control fabric should be used to protect the channel bottom.

_______ Grass channel construction should begin only after the entire contributing drainage area has been stabilized with vegetation. Sediment accumulation must be removed during final grading to achieve the design cross-section.

_______ Stormwater flows should be bypassed and not allowed into the grass channel until the bottom and side slopes are stabilized.

_______ Construction sequence for BMP(s) and E&S controls:

   ______ Grade the channel to the final dimensions shown on the plan.

______ Install check dams, driveway culverts and internal pre-treatment features as shown on the plan

______ Fill material used to construct the check dams should be placed in 8- to 12-inch lifts and compacted to prevent settlement. The top of each check dam should be constructed level at the design elevation.

______ (Optional) Till the bottom of the channel to a depth of 1 foot and incorporate compost amendments according to Stormwater Design Specification No. 4.

______ Add soil amendments as needed, hydro-seed the bottom and banks of the channel, and peg in erosion control fabric or blanket where needed. After initial planting, a biodegradable E&S control fabric should be used, conforming to Standard and Specification 3.36 of the VESCH.

______ Prepare planting holes for any trees and shrubs, then plant materials as shown in the landscaping plan and water them weekly in the first two months.

H. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.

______ Include a Maintenance Narrative which describes the long-term maintenance requirements for the grass channels and all their components, including removal and disposal of trash, debris and sediment accumulations; and mowing.

_______ Record a deed restriction, drainage easement, and/or other enforceable mechanism, including GPS coordinates of the area, to ensure property owner awareness, access for inspections and maintenance, and that the grass channels remain intact and fully functional.

_______ Provide sufficient facility access from the public ROW or roadway to the grass channels for inspection and maintenance.

IV. COMMENTS

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By: ______________________________ Date: ____________________

8-A.5.0. SOIL COMPOST AMENDMENTS: DESIGN CHECKLIST

Plan Submission Date____________________
Project Name____________________
Site Plan/Permit Number____________________
Practice No./Location on Site____________________
Owner____________________ Phone Number____________________
BMP Designer____________________ Phone Number____________________
General Contractor____________________ Phone Number____________________

______ Signature and stamp of licensed professional design consultant and owner certification

Plan Status

_______ Approved
_______ Not Approved

Legend:

- ___✓___ - Complete
- _Inc._ - Incomplete/Incorrect
- _N/A_ - Not Applicable

I. SUPPORTING INFORMATION

_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design (infiltration basin, infiltration trench, etc.).
_______ Provide a site map showing location of area(s) where soil compost amendments are to be applied
_______ Show the contributing drainage area (CDA) boundaries and acreage, not to exceed 5 acres for any individual Grass Channel
_______ Provide topography of the site
_______ Provide a soil map for site and area of soil amendments
_______ Provide two soil tests (pre-construction to determine soil properties to a depth 1 foot below the proposed amendment area, and 1 week after amendments have been incorporated):
  ______ First test done every 5,000 sq. ft. to determine bulk density, porosity, pH, salts, and soil nutrients (to determine potential drainage problems and what amendments are needed)
  ______ Second test done to determine any further nutritional requirements, pH, adjustment, or organic matter adjustments are need for plant growth (done in conjunction with the final construction inspection to ensure tilling or subsoiling has achieved design depths).
_______ Provide soil boring logs with Unified Soils Classifications
_______ Show the areas of the site compensated for in water quality calculations
_______ The following are site conditions where soil compost amendments should NOT be used:
  ______ Existing soils have high infiltration rates (HSG A and B), although amendments may be needed were B-soils are mass-graded, in order to maintain the runoff reduction rate.
  ______ The water table or bedrock is within 1.5 feet of the soil surface
  ______ The slope exceeds 10%; terracing may be needed on slopes between 5% and 10%
  ______ Existing soils are saturated or seasonally wet
  ______ Incorporation of compost would harm tree roots (keep amendments outside the tree drip line)
  ______ The downhill slope runs toward an existing or proposed building foundation.
  ______ The contributing impervious surface area exceeds the surface are of the amended soils.
  ______ The area under consideration will be used for snow storage
_______ The following site conditions involve special considerations:
  ______ In karst areas, ensure the soil pH is adjusted as needed to conform to the pre-existing soil conditions found in limestone-dominated areas.
  ______ In coastal areas, depth to groundwater should be a minimum of 2 feet to ensure the entire depth of soil amendment will not become saturated

II. COMPUTATIONS

A. Hydrology

_______ Provide runoff curve number determinations (pre- and post-developed conditions), with worksheets.
_______ Provide time of concentration (pre- and post-developed conditions), with worksheets.
_______ Provide hydrograph generation (pre- and post-developed conditions) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)

B. Hydraulics

_______ Specify assumptions and coefficients used.
_______ Provide a stage-storage table and curve

C. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA, pollutant load, pollutant load removal, and treatment volume requirements, all generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet)
_______ When soil amendments are used, the Runoff Reduction Spreadsheet will self-credit improved runoff volume reduction based on the change of the soil drainage characteristics (see Stormwater Design Specification No. 4)

III. PLAN REQUIREMENTS

A. BMP Plan View Information (see example graphics in Design Specification No. 2)

_______ Show the limits of clearing and grading, noting that they should be identified and protected by acceptable signage, silt fence, snow fence, or other comparable barrier.
_______ Show the layout and dimensions of the soil amendment area
_______ Topographic conditions must meet minimum slope requirements

B. Landscape Plan

_______ Use grass seed, NOT sod.
_______ Seed at a density that achieves a 90% turf cover by the end of the second growing season.
_______ Provide material specifications for any compost amendments used, including the depth of incorporation (see Stormwater Design Specification No. 4)
_______ Provide a planting schedule and specifications (transport / storage / installation / maintenance)
_______ Ensure that plant selection is appropriate for the site's vegetation climatic zone (4-8 in Virginia), emphasizing native species
_______ Specify preservation measures for existing vegetation
_______ Ensure that topsoil / planting soil is included in the final grading
_______ The construction contract should include a *Care and Replacement Warranty* to ensure that new vegetation is properly established and survives during the first growing season following construction.

C. Construction Notes

_______ For rooftop disconnection, vegetative filter strip or grass channel applications, see the checklists for those practices. For larger, more expansive areas, the following criteria apply:
    ______ Ideally, the soil amendment area should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment.
    ______ Prior to construction, the proposed soil amendment area should be deep-tilled to a depth of 2 to 3 feet using a tractor and subsoiler with two deep shanks (curved metal bars) to create rips perpendicular to the direction of flow.
    ______ A second deep tilling to a depth of 12-18 inches is needed after final building lots have been graded.
    ______ It is important to have dry conditions at the site prior to incorporating compost.
    ______ Incorporate the acceptable compost mix into the soil using a rototiller or similar equipment at the volumetric rate of 1 part compost to 2 parts soil.

______ The site should be leveled and seed or sod used to establish a vigorous grass cover.
______ Lime and/or irrigation may be needed initially to help the grass grow quickly.
______ Areas of compost amendments exceeding 2500 sq. ft. should employ simple E&S control measures, such as silt fence, to reduce the potential for erosion and to trap sediment.

D. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ If the soil amendment area exceeds 10,000 sq. ft., provide a standard BMP Maintenance Agreement, indicating person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.
_______ Record a deed restriction or other enforceable mechanism, including GPS coordinates of the area, to ensure the infiltrating areas are not disturbed or converted to other uses.
_______ To educate the property owner, provide a maintenance narrative which describes the short-term and long-term maintenance requirements.
_______ Provide sufficient facility access from the public ROW or roadway to the grass channels for inspection and maintenance.

IV. COMMENTS

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By: ______________________________ Date: ____________________

8-A.6.0. VEGETATED ROOF: DESIGN CHECKLIST

Plan Submission Date_____________________
Project Name____
Site Plan/Permit Number____
Practice No./Location on Site____
Owner____ Phone Number__________________
BMP Designer____ Phone Number__________________
General Contractor____________________________________ Phone Number__________________

______ Signature and stamp of licensed professional design consultant and owner certification

Plan Status

_______ Approved
_______ Not Approved

Legend:

✓	- Complete
Inc.	- Incomplete/Incorrect
N/A	- Not Applicable

Facility Type: Level 1 ____________________________ Level 2 _____________________________

Type of Vegetated Roof:

- ☐ Extensive (shallower planting media, herbaceous vegetation)
- ☐ Intensive (planting media typically twice as deep, can have shrubs and trees among vegetative cover – typically qualify as Level 2 roofs)

I. SUPPORTING INFORMATION

_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design (infiltration basin, infiltration trench, etc.).

_______ Show the location of the BMP roof on the site map.

_______ A structural engineer, architect or other qualified professional should be involved with the design to ensure that the building has enough structural capacity to support the additional weight of the water held in the planting media (typical fully saturated *extensive* vegetated roof loads range from 15-25 lbs./sq. ft.).

_______ Adequate access to the roof must be provided to deliver and stockpile construction materials and perform routine maintenance. The roof hatch or trap door should be not less than 16 sq. ft. in area with a minimum dimension of 24 inches.

_______ Vegetated roofs can be applied to most roof surfaces, although concrete roof decks are preferred. Certain roof materials, such as exposed treated wood and uncoated galvanized metal, are not appropriate decks for vegetated roofs.

_______ Vegetated roof surfaces should not be located near rooftop electrical or HVAC systems.

_______ Vegetated roof designs should comply with the Virginia Uniform Statewide Building Code with respect to roof drains and emergency overflow devices.

_______ Vegetated roofs can be used as retrofits, based on the roof area, age, structural capacity and accessibility, as well as the owner's ability to provide necessary maintenance.

_______ Special design adaptations:

- ______ In karst areas, direct the roof downspout discharges at least 15 feet away from the building to minimize the risk of sinkhole formation
- ______ In coastal areas, designers should choose plant materials that tolerate drought and salt spray.
- ______ In cold climates, it is important to match the plant materials to the plant hardiness zone, design the roof so the growing media is not subject to freeze-thaw cycles, and provide greater structural capacity to account for winter snow loads.
- ______ Where acid rain falls, growing media can neutralize the pH of the rainfall; however, it is not clear whether the acid rain will impair plant growth or leach minerals from the growing media.

I. COMPUTATIONS

A. Hydrology

_______ Determine the runoff curve number (pre-development and post-development conditions), providing the worksheets; post-development recommendations for 4 design storm events are provided in Table 5.1 of Stormwater Design Specification No. 5.

_______ Determine the time of concentration (pre- and post-developed conditions), providing the worksheets.

_______ Generate hydrographs (pre- and post-developed conditions) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method), providing the results.

B. Hydraulics

_______ The drainage layer below the growing media should be designed to convey the 10-year storm without backing up water into the growing media, conveying the flow to an outlet or overflow system such as a traditional rooftop drainage system with inlets set slightly above the elevation of the vegetated roof surface.

_______ Specify assumptions and coefficients used.

_______ Provide a stage-storage table and curve.

C. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA, pollutant load, pollutant load removal, and treatment volume requirements, all generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet)

III. PLAN REQUIREMENTS

A. BMP Plan View Information (see example graphics in Design Specification No. 2)

_______ Layout and dimensions of the vegetated roof.

- ______ A 2-foot wide vegetation-free zone is recommended along the perimeter of the roof (may be a 1-foot setback for very small vegetated roof applications), with a 1-foot vegetation-free zone around all roof penetrations, to act as a firebreak.
- ______ The roof design should include strategically located non-vegetated walkways (e.g., permeable paver blocks) to allow for easy access to the roof for weeding and making spot repairs.
- ______ Size (surface area) to address the required treatment volume per equation in Stormwater Design Specification #5 or per manufacturer recommendations.
- ______ Show the layout of the outlet or overflow system and locations of roof drains

B. BMP Section Views & Related Details (see example graphics in Design Specification No. 2)

_______ Vegetated roofs are composed of up to 8 different systems or layers, which may consist of a wide variety of materials and differ in cost, performance and structural load. Proprietary designs are available. The entire system must be assessed to meet the design requirements (see Stormwater Design Specification No. 5).

_______ Roof drains immediately adjacent to the growing media should be boxed and protected by flashing extending at least 3 inches above the growing media, to prevent clogging.

C. Planting Plan

_______ The planting plan must be prepared by a landscape architect, botanist or other professional experienced with vegetated roofs.

_______ Plant materials are selected based on local climate (plant hardiness zone) and design objectives, as well as toleration of the difficult growing conditions on building rooftops. Selected plants should be fire-resistant and able to withstand heat, cold and high winds; the primary groundcover for most vegetated roof installations is a hardy, low-growing succulent such as *Sedum, Delosperma, Talinum, Semperivum,* or *Hieracium*. Plant choices can be much more diverse for deeper *intensive* vegetated roof systems.

_______ The species selection and planting plan layout should reflect the building location in terms of its height, exposure to wind, snow loading, heat stress, sun orientation, and shading by trees or surrounding buildings. Note: Most effective vegetated roof plant species will *NOT* be native to Virginia or the Chesapeake Bay watershed.
_______ Species should also be selected to match the expected rooting depth of the growing media.
_______ Accent plants may be included to provide seasonal diversity and color.
_______ Due to limited vegetated roof plant nurseries in the region, designers should order plant materials 6-12 months prior to the expected planting date and to have the plants contract-grown.
_______ The planting period extends from spring to early fall, but it is important to allow plants enough time to root thoroughly prior to the first killing frost.
_______ Typically, most vegetated roofs will not require supplemental irrigation, except for temporary irrigation during dry months as the roof vegetation becomes established.
_______ Plants can be established using cuttings, plugs, mats and, more rarely, seedlings or containers; some vendors also provide mats, rolls, or proprietary roof planting modules.
_______ Initial fertilization may be needed to support growth, using a slow-release fertilizer with minerals.
_______ Hand weeding must be performed regularly during the first 2 years.
_______ The construction contract should include a *Care and Replacement Warranty* that specifies a minimum survival for species planted of 75% after the first growing season, and a minimum effective ground cover of 75% for flat roofs and 90% for pitched roofs.

D. Construction Notes

_______ An experienced installer should be retained to construct the vegetated roof system.
_______ The roof system should be constructed in sections to facilitate easier inspection and maintenance.
_______ Construction sequence:
_______ Construct the roof deck with the appropriate slope and material.
    ______ Install the waterproofing method according to the manufacturer's specifications.
    ______ Conduct a flood test to ensure the system is water-tight, by placing 2 inches of water over the membrane for 48 hours.
    ______ Add the additional system components, taking care not to damage the waterproofing.
    ______ Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.
    ______ The growing media should be mixed prior to delivery to the site.
    ______ The media should be spread evenly over the filter fabric surface and covered until planting, to prevent weeds from growing.
    ______ Sheets of exterior-grade plywood can be laid over the growing media to accommodate foot or wheelbarrow traffic (however, limit this traffic to reduce compaction).
    ______ Moisten the growing media prior to planting.
    ______ Plant the vegetation in accordance with the planting plan of ASTM E2400.
    ______ Water the plants immediately after planting and routinely during the establishment period and, especially, during the first summer (generally 12-18 months for full establishment).

E. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.
    ______ Include a Maintenance Narrative which describes the long-term maintenance requirements of the facility and all components.
_______ Record a deed restriction or other enforceable mechanism, including GPS coordinates of the area, to ensure the the vegetated roof is not converted to a conventional roof surface (in order to maintain this component of the site's stormwater management plan).
_______ Avoid the use of herbicides, insecticides and fungicides, because their presence can result in deterioration of the waterproof membrane and contaminate runoff discharged from the roof.
_______ Avoid power-washing so that the cleaning agents do not harm the rooftop plant communities.

IV. COMMENTS

By: ______________________ Date: ______________

8-A.7.0. RAINWATER HARVESTING: DESIGN CHECKLIST

Plan Submission Date____________________
Project Name____________________
Site Plan/Permit Number____________________
Practice No./Location on Site____________________
Owner____________________ Phone Number____________________
BMP Designer____________________ Phone Number____________________
General Contractor____________________ Phone Number____________________

______ **Signature and stamp of licensed professional design consultant and owner certification**

Plan Status
_______ Approved
_______ Not Approved

Legend:
__✓__ - Complete
__Inc.__ - Incomplete/Incorrect
__N/A__ - Not Applicable

Secondary BMPs used with Rainwater Harvesting:

- ☐ Rooftop Disconnection (No. 1)
- ☐ Sheet Flow to Veg Filter/Open Space (No. 2)
- ☐ Grass Channel (No. 3)
- ☐ Infiltration (No. 8)
- ☐ Micro-Bioretention (rain garden) (No. 9)
- ☐ Storage and release in Foundation Planter (No. 9, Appendix A)
- ☐ Dry Swale (No. 10)
- ☐ Underground infiltration soak-away pit
- ☐ Other: ____________________

I. SUPPORTING INFORMATION

_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design and the purpose for which the harvested rainwater will be used, including any of the following:

- ______ Outdoor non-potable uses, including irrigation, car washing, etc.
- ______ Indoor, non-potable uses, such as toilet flushing, fire suppression, etc., assuming building code and health department regulations allow such uses and appropriate regulatory approvals are obtained.
- ______ Indoor, potable uses, including food preparation, drinking water, showers, etc., assuming building code and health department regulations allow such uses and appropriate regulatory approvals are obtained.
- ______ Use of rainwater as a resource to meet on-site demand (above) or design in conjunction with infiltration to promote groundwater recharge
- ______ Pollutant reduction (realized only due to reduced volume of runoff leaving the site)
- ______ Reduction in peak flows (realized due to reduced volume of runoff leaving the site)

_______ Show the location of BMP on the site map; adequate space is needed to house the tank and overflow (this is rarely a problem if considered during initial design and site layout).

_______ Underground utilities or other obstructions should be identified prior to determining the final tank location.

_______ The plan should identify and provide sufficient details to construct the six primary components of the rainwater harvesting system:

- ______ Roof surface
  - ______ The rooftop should be made of smooth, non-porous material with efficient drainage (sloped roof or efficient roof drain system)
  - ______ If the harvested rainwater will have potable uses or uses with significant human exposure, ensure that the roofing materials do not leach toxic chemicals.
  - ______ In general, avoid harvesting rainwater from roofs with asphalt sealcoats, tar and gravel, painted roofs, galvanized metal roofs, sheet metal or any material that may contain asbestos or may leach trace metals and other toxic compounds.

- ______ Some industrial roof surfaces may be designated as "hot spots," limiting the use and benefits of harvesting the rainwater.

______ Collection and conveyance system (e.g., gutters, downspouts and pipes to the stroage tank)

- ______ Runoff should be routed from rooftops to cisterns in closed roof drain systems or storm drain pipes, avoiding surface drainage which could increase contamination of the water
- ______ Aluminum, round-bottom gutters and round downspouts are generally recommended.
- ______ Gutter slopes should be 0.5% for 2/3 of the length and 1% for the remaining 1/3.
- ______ Gutters should be sized to contain the 1-inch rainfall event (treatment volume) at a rate of 1 inch/hour.
- ______ If volume control credit is desired for channel protection and flood protection purposes, gutters should be sized to convey 1-year and 10-year design storms.
- ______ Pipes connecting the downspouts to the storage tank should have a minimum slope of 1.5% and be sized to convey the intended design storm.

______ Pre-screening and first flush diverter (filters out sediment, leaves, contaminants and debris).

- ______ Pre-filtration devices that filter out large debris should be low-maintenance or maintenance free (e.g., leaf screens, gutter guards, etc.)
- ______ For larger tank systems, the initial first flush (0.02 – 0.06 inches of rooftop runoff) must be diverted from the tank and directed to an acceptable non-erodible pervious flow path or secondary BMP for infiltration (preferably the same practice that receives tank overflows).
- ______ A 95% filter efficiency (including the first flush diversion) must be achieved for the 1-inch rainfall event. For the 1-year and 10-year design storms, the filtering must have a minimum efficiency of 90%.
- ______ If **leaf screens** are used, note in the maintenance agreement that they must be cleaned regularly to be effective and maintain flow from the gutters into the storage tank.
- ______ If a **roof washer** tank is used just ahead of the storage tank, note in the maintenance agreement that they must be cleaned regularly to be effective.
- ______ A **first flush diverter**, which filters out small contaminants such as dust, pollen and animal feces, require the ability to actively drain the first flush water volume to a pervious area (filter path) following each rainstorm (this is the preferred pre-treatment method if the harvested water is intended for indoor uses).
- ______ A **vortex filter** can be used to filter rooftop rainwater for larger rooftop areas.

______ Storage tank

- ______ The tank volume must be calculated to meet the water demand *and* the stormwater treatment volume credit objectives.
- ______ Dead storage below the outlet to the distribution system and an air gap at the top of the tank should be added to the total volume. For gravity-fed systems, a minimum of 6 inches of dead storage should be provided. For systems using a pump, the dead storage depth is be based on the pump specifications.
- ______ The system should be sealed using a water-safe, non-toxic substance.
- ______ Storage tanks should be opaque or otherwise protected from direct sunlight to inhibit algae growth and should be screened to inhibit mosquito breeding and reproduction.
- ______ The relationship of tank location to site topography should be considered as they relate to all inlet and outlet invert elevations in the system and to the amount of pumping that may be needed. The total elevation drop will be realized beginning from the downspout leaders to the final mechanism receiving gravity-fed discharge and/or overflow from the cistern.
- ______ Storage tanks should be placed on native soils or on fill in accordance with the manufacturer's guidelines.

- ______ The soil pH must be considered in relation to the material of which the tank/cistern is made.
- ______ Storage tanks should be designed to be watertight to prevent water damage when placed near building foundations.
- ______ Rainfall pH must also be considered (Virginia rain tends to be acidic, from 4.5-5.0), due to the risk of leaching metals form the roof surface, tank lining or water laterals to interior connections. Limestone or other neutralizing substances may be added in the tank to buffer acidity.
- _______ Underground storage tanks are most appropriate in areas where the tank can be buried *above* the water table and in a manner that it will not be subject to flooding. If buried *below* the water table, special design features must be employed to prevent the tank from “floating,” etc.
- ______ Underground systems should be placed in areas without vehicle traffic and designed to support the overlying sediment and other anticipated loads, or otherwise be designed to support live loads from heavy trucks (this may increase construction costs).
- ______ Underground systems should have a standard size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance purposes. The opening must be able to be locked or otherwise secured to prevent unwanted access.

______ Distribution system

- ______ The system should be equipped with an appropriately sized pump that produces sufficient pressure for all end-uses.
- ______ The typical pump and pressure tank arrangement consists of a multi-stage centrifugal pump that draws water from the storage tank and sends it to a pressure tank, where it is stored for distribution.
- ______ The municipal code may require the separate plumbing to be labeled as non-potable.
- ______ Any hookup to a municipal backup water supply must have a backflow prevention device, subject to local codes, to keep municipal water separate from stored rainwater. This may include incorporating an air gap to separate the two supplies.
- ______ Distribution lines must be buried beneath the frost line. If above-ground outdoor pipes are installed, they must be insulated or heat-wrapped to prevent freezing and ensure uninterrupted operation during the winter.
- ______ Distribution lines to the building must have shut-off valves that are accessible when snow cover is present.
- ______ A drain plug or cleanout sump, draining to a pervious area, must be installed to allow the system to be completely emptied.

______ Overflow, filter path or secondary runoff reduction practice(s)

- ______ An overflow mechanism must be included in the system design to handle and individual storm event or multiple events in succession that exeed the capacity of the storage tank.
- ______ Overflow pipes must have a capacity equal to or grater than the inflow pipe(s) and have a diameter and slope sufficient to drain the storage tank while maintaining an adequate freeboard height.
- ______ Overflow pipes must be screened to prevent access to the tank by rodents and birds.
- ______ The filter path should be a pervious or grass corridor that extends from the overflow to the next runoff reduction practice, the street, an adequate existing or proposed channel, or the storm drain system.
- ______ The filter path must be graded with a slope that results in sheet flow conditions.
- ______ If compacted or impermeable soils are present along the filter path, compost amendments may be necessary (see Stormwater Design Specification #4).

II. COMPUTATIONS

A. Hydrology

_______ The contributing drainage area is the impervious area draining to the tank, generally only the rooftop surface. Paved surfaces can be included in rare circumstances with appropriate treatment.

_______ Determine the time of concentration (pre- and post-developed conditions), providing the worksheets.

_______ Generate hydrographs (re- and post-developed conditions) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)

B. Hydraulics

_______ The required hydraulic head depends upon the ultimate use/destination of the harvested water.

_______ Specify the assumptions and coefficients used.

_______ Provide a stage-storage table and curve.

_______ Show that compensatory devices are able to drain within 48 hours following a storm.

C. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA

_______ The Cistern Design Spreadsheet (explanation and instructions provided in Stormwater Design Specification No. 6) must be used to determine cistern sizing, including the treatment volume requirements, and by extension, pollutant load removal (provide a copy of the spreadsheet calculations)

_______ IMPORTANT NOTE: In order to adequately address the required design treatment volume, the design specification assumes the practice will achieve a dedicated year-round drawdown. While seasonal uses (such as warm weather irrigation, etc.) may be incorporated into the site design, they are not considered to contribute to the treatment volume credit (for stormwater management purposes) unless a drawdown at an equal or greater rate is also realized during non-seasonal periods (e.g., infiltration during non-irrigation months, etc.). Designing for constant drawdown of the stored water is also important in assuring that the tank will have sufficient storage capacity for future rainstorms.

III. PLAN REQUIREMENTS

A. BMP Plan View Information (see example graphics in Design Specification No. 2)

_______ Show the layout and dimensions of the rainwater harvesting system.

- ______ In general, underground tanks should be set at least 10 feet from any building foundation.
- ______ Cistern overflow devices should be designed to avoid causing ponding or soil saturation within 10 feet of building foundations.
- ______ The roof design should include strategically located non-vegetated walkways (e.g., permeable paver blocks) to allow for easy access to the roof for weeding and making spot repairs.
- ______ Ensure sizing (surface area) sufficient to address the required treatment volume consistent with the equation in Stormwater Design Specification No. 5 or manufacturer recommendations.
- ______ Show the layout of the outlet or overflow system and locations of roof drains

B. BMP Section Views & Related Details (see example graphics in Design Specification No. 2)

_______ Show sections through the system and, as appropriate, through system components

C. Planting Plan

_______ Provide a planting schedule and specifications (transport / storage / installation / maintenance)

_______ Ensure plant selection appropriate for the site’s vegetation climatic zone (4-8 in Virginia)

_______ The construction contract should include a *Care and Replacement Warranty* to ensure that new vegetation is properly established and survives during the first growing season following construction.

D. Construction Notes

_______ It is advisable that a single contractor, with a plumbing license and familiar with rainwater harvesting system sizing, installation and placement, install the rainwater harvesting system, outdoor irrigation system, and secondary runoff reduction practices.
_______ The tank location must be identified on the site and the tank installed.
_______ All downspouts or roof drains must be routed to pre-screening devices and first flush diverters.
_______ The pre-treatment system must be installed.
_______ Mosquito screens must be installed on all openings.
_______ The overflow device must be installed and directed, as shown on the plans.
_______ The catchment area and overflow area must be stabilized.
_______ The secondary runoff reduction practice(s) must be installed.

E. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.
    ______ Include a maintenance narrative describing the purpose of the facility and the property owner's primary responsibilities for long-term maintenance requirements of all its components, require the owner to pay to have the system inspected according to a specified schedule, and authorize the qualifying local program staff to access the property for inspection or corrective action in the event this is not done.
_______ Record a drainage easement to allow for inspection and maintenance. The easement should include the tank, the filter path, and any secondary runoff reduction practice(s).
_______ Provide sufficient facility access from public ROW or roadway to facilitate inspection and maintenance.
_______ If the system is located on a private residential lot, its existence and purpose must be noted on the deed of record.

IV. COMMENTS

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By: ______________________ Date: ______________

8-A.8.0. PERMEABLE PAVEMENT: DESIGN CHECKLIST

Plan Submission Date____________________
Project Name____________________
Site Plan/Permit Number____________________
Practice No./Location on Site____________________
Owner____________________ Phone Number____________________
BMP Designer____________________ Phone Number____________________
General Contractor____________________ Phone Number____________________

______ **Signature and stamp of licensed professional design consultant and owner certification**

Plan Status

_______ Approved
_______ Not Approved

Legend:
- ___ - Complete
- Inc. - Incomplete/Incorrect
- N/A - Not Applicable

Facility Type: Level 1 ____________________ Level 2 ____________________

Type of Pre-Treatment Facility:
- ☐ Stone diaphragm
- ☐ Grass filter strip
- ☐ Other: ____________________

I. SUPPORTING INFORMATION

_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design (infiltration basin, infiltration trench, etc.).

_______ **S**howing the location of the permeable pavement area on the site map, including the following:
- ______ Facility area
- ______ Contributing drainage area (CDA) boundaries and acreage
- ______ Proposed topographic contours
- ______ Delineation of FEMA 100-year floodplain
- ______ Areas of the site compensated for in water quality calculations

_______ Provide a soil map for the site and permeable pavement area and its CDA, showing the facility boundaries

_______ Show soil boring locations and provide the soil boring logs with Unified Soils Classifications and descriptions (at least one boring must be taken to confirm the underlying soil properties *at the depth where infiltration is designed to occur,* to ensure that depth to the groundwater table/bedrock or karst is identified)

_______ Provide the results of soil infiltration rate testing to confirm a subsoil infiltration rate of at least 0.5-inch/hour for Level 2 design (minimum of one infiltration test per 1,000 sq. ft. of planned permeable pavement area)

_______ Confirm the depth to seasonal high groundwater table and bedrock (minimum 2 ft. below the design bottom of the facility)

_______ If karst is present, a detailed geotechnical investigation is recommended to ensure the installation does not aggravate potential karst impacts (e.g., sinkholes, etc.) and an impermeable liner (min. 30 mil PVC Geo-membrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile) must be place beneath the permeable pavement, which must be designed *ONLY* to meet the Level 1 design criteria

II. COMPUTATIONS

A. Hydrology

_______ Determine the runoff curve number (pre- and post-developed conditions), providing the worksheets.
_______ Determine the time of concentration (pre- and post-developed conditions), providing the worksheets.
_______ Generate hydrographs (pre- and post-developed conditions) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)

B. Hydraulics

_______ Verify that 2 to 4 feet of hydraulic head is available to drive flows through the facility
_______ Verify that the pavement will drain within 48 hours following a storm (minimum 36 hours).
_______ Specify the assumptions and coefficients used.
_______ Provide a stage-storage table and curve
_______ The designer may use the *PICP Permeable Design Pro Software* to design the pavement, including hydraulics (software available from the Interlocking Concrete Pavement Institute, at www.icpi.org)

C. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA, pollutant load, pollutant load removal, and treatment volume requirements, all generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet)

III. PLAN REQUIREMENTS

A. BMP Plan View Information

_______ Show the limits of clearing and grading, noting that they should be identified and protected by acceptable signage, silt fence, snow fence, or other comparable barrier.
_______ Show the layout and dimensions of permeable pavement facility
_______ Ensure the proper orientation and slope of the facility, including pre-treatment, to avoid short-circuiting
_______ Show the location of the observation well(s)

B. BMP Section Views & Related Details

1. Porous Asphalt

_______ Subgrade preparation
_______ Aggregate
- ______ Bedding layer: 2-inch layer of VDOT No. 8 choker stone (ASTM D448 size, 3/8 to 3/16 inch diameter)
  - ______ Reservoir layer (required to support structural load): VDOT No. 2 open graded course aggregate or equivalent
- ______ Filter layer: 2 to 4 inch layer of No. 8 choker stone laid over the native soil and covered by a 6 to 8 inch layer of coarse sand (e.g., ASTM C 33, 0.02-0.04 inch diameter particles)

_______ Porous asphalt surface layer
- ______ Void content: 15% to 20%
- ______ Thickness: Typically 3 to 7 inches, depending on the traffic load
- ______ Open void fill media: None

_______ Underdrains
_______ Observation well (perforated vertical 4 to 6 inch diameter Schedule 40 PVC pipe – AASHTO M 252 – with 3/8-inch diameter perforations at 6 inches on center and a lockable cap, installed flush with the surface) and underdrain pipes, which are of the same material – or equivalent corrugated HDPE may be used for smaller load-bearing applications – installed at a minimum 0.5% slope for the full length of the permeable pavement cell and located no more than 20 feet

from the next pipe. Non-perforated pipe may be used to connect with the storm drain system, and Ts and Ys may be installed, as needed, based on the underdrain configuration. Cleanout pipes should be extended to the surface with vented caps at the Ts and Ys.) Ensure there are no perforations in clean-outs and observation wells within 1 foot of the surface.

_______ Filter fabric: (Optional) Non-woven, polypropylene geotextile with:

- ______ Grab tensile strength: ∃ 120 lbs. (ASTM D4632)
- ______ Mullen burst strength: ∃ 225 lbs./sq. in. (ASTM D3786)
- ______ Flow rate: > 125 gpm/sq. ft. (ASTM D4491)
- ______ Apparent opening size (AOS): equivalent to US #70 or #80 sieve (ASTM D4751). The geotextile AOS selection is based on the percent passing the No. 200 sieve in "A" soil subgrade, using FHWA or AASHTO selection criteria.

2. Pervious Concrete

_______ Subgrade preparation

_______ Aggregate

- ______ Bedding layer: None
- ______ Reservoir layer (may not be needed to support structural load, but may be included to increase runoff storage or infiltration): VDOT No. 57 open graded course aggregate (ASTM D448 size, 1-1/2 to 1/2 inch diameter) or equivalent
- ______ Filter layer: 2 to 4 inch layer of No. 8 choker stone (ASTM D448 size, 3/8 to 3/16 inch diameter) laid over the native soil and covered by a 6 to 8 inch layer of coarse sand (e.g., ASTM C 33, 0.02-0.04 inch diameter particles)

_______ Permeable concrete surface layer

- ______ Void content: 15% to 25%
- ______ Thickness: Typically 4 to 8 inches
- ______ Compressive strength: 2.8 to 28 Mpa.
- ______ Open void fill media: aggregate

_______ Underdrains

_______ Observation well

_______ Filter fabric: (Optional) Non-woven, polypropylene geotextile with:

- ______ Grab tensile strength: ∃ 120 lbs. (ASTM D4632)
- ______ Mullen burst strength: ∃ 225 lbs./sq. in. (ASTM D3786)
- ______ Flow rate: > 125 gpm/sq. ft. (ASTM D4491)
- ______ Apparent opening size (AOS): equivalent to US #70 or #80 sieve (ASTM D4751). The geotextile AOS selection is based on the percent passing the No. 200 sieve in "A" soil subgrade, using FHWA or AASHTO selection criteria.

3. Permeable Interlocking Concrete Pavers (PICP)

_______ Subgrade preparation

_______ Aggregate

- ______ Bedding layer: 2-inch layer of No. 8 choker stone (ASTM D448 size, 3/8 to 3/16 inch diameter) laid over 3 to 4 inches of VDOT No. 57 open graded course aggregate (ASTM D448 size, 1-1/2 to 1/2 inch diameter) or equivalent
- ______ Reservoir layer (required to support structural load): VDOT No. 57 open graded course aggregate (ASTM D448 size, 1-1/2 to 1/2 inch diameter) or equivalent
- ______ Filter layer: 2 to 4 inch layer of No. 8 choker stone laid over the native soil and covered by a 6 to 8 inch layer of coarse sand (e.g., ASTM C 33, 0.02-0.04 inch diameter particles)

_______ Concrete paver surface layer (must conform to ASTM C936 specifications)

- ______ Surface open area: 5% to 15%
- ______ Thickness: 3.125 inches for vehicles
- ______ Compressive strength: 55 Mpa.
- ______ Open void fill media: aggregate

_______ Underdrains

_______ Observation well

_______ Filter fabric: (Optional) Non-woven, polypropylene geotextile with:

- ______ Grab tensile strength: ∃ 120 lbs. (ASTM D4632)
- ______ Mullen burst strength: ∃ 225 lbs./sq. in. (ASTM D3786)
- ______ Flow rate: > 125 gpm/sq. ft. (ASTM D4491)
- ______ Apparent opening size (AOS): equivalent to US #70 or #80 sieve (ASTM D4751). The geotextile AOS selection is based on the percent passing the No. 200 sieve in "A" soil subgrade, using FHWA or AASHTO selection criteria.

4. Concrete Grid Pavers

_______ Subgrade preparation

_______ Aggregate

- ______ Bedding layer: 2-inch layer of No. 8 choker stone (ASTM D448 size, 3/8 to 3/16 inch diameter) laid over 3 to 4 inches of VDOT No. 57 open graded course aggregate (ASTM D448 size, 1-1/2 to 1/2 inch diameter) or equivalent
- ______ Reservoir layer (required to support structural load): VDOT No. 57 open graded course aggregate (ASTM D448 size, 1-1/2 to 1/2 inch diameter) or equivalent
- ______ Filter layer: 2 to 4 inch layer of No. 8 choker stone laid over the native soil and covered by a 6 to 8 inch layer of coarse sand (e.g., ASTM C 33, 0.02-0.04 inch diameter particles)

_______ Concrete paver surface layer (must conform to ASTM C1319 specifications)

- ______ Open void area: 20% to 50%
- ______ Thickness: 3. 5 inches
- ______ Compressive strength: 35 Mpa.
- ______ Open void fill media: aggregate, coarse sand, topsoil and grass

_______ Underdrains

_______ Observation well

_______ Filter fabric: (Optional) Non-woven, polypropylene geotextile with:

- ______ Grab tensile strength: ∃ 120 lbs. (ASTM D4632)
- ______ Mullen burst strength: ∃ 225 lbs./sq. in. (ASTM D3786)
- ______ Flow rate: > 125 gpm/sq. ft. (ASTM D4491)
- ______ Apparent opening size (AOS): equivalent to US #70 or #80 sieve (ASTM D4751). The geotextile AOS selection is based on the percent passing the No. 200 sieve in "A" soil subgrade, using FHWA or AASHTO selection criteria.

5. Plastic Reinforced Grid Pavers

_______ Subgrade preparation

_______ Aggregate

- ______ Bedding layer: 2-inch layer of No. 8 choker stone (ASTM D448 size, 3/8 to 3/16 inch diameter) laid over 3 to 4 inches of VDOT No. 57 open graded course aggregate (ASTM D448 size, 1-1/2 to 1/2 inch diameter) or equivalent
- ______ Reservoir layer (required to support structural load): VDOT No. 57 open graded course aggregate (ASTM D448 size, 1-1/2 to 1/2 inch diameter) or equivalent
- ______ Filter layer: 2 to 4 inch layer of No. 8 choker stone laid over the native soil and covered by a 6 to 8 inch layer of coarse sand (e.g., ASTM C 33, 0.02-0.04 inch diameter particles)

_______ Concrete paver surface layer

- ______ Void content: Depends on fill material
- ______ Compressive strength: Varies, depending on fill material
- ______ Open void fill media: Aggregate, coarse sand, topsoil and grass

_______ Underdrains

_______ Observation well

_______ Filter fabric: (Optional) Non-woven, polypropylene geotextile with:

- ______ Grab tensile strength: ∃ 120 lbs. (ASTM D4632)
- ______ Mullen burst strength: ∃ 225 lbs./sq. in. (ASTM D3786)

______ Flow rate: > 125 gpm/sq. ft. (ASTM D4491)
______ Apparent opening size (AOS): equivalent to US #70 or #80 sieve (ASTM D4751). The geotextile AOS selection is based on the percent passing the No. 200 sieve in "A" soil subgrade, using FHWA or AASHTO selection criteria.

C. Landscape Plan (perimeter)

_______ Where grass is used in grid pavers, include specifications appropriate for the site's vegetation climatic zone (4-8 in Virginia)
_______ Specify preservation measures for existing vegetation surrounding permeable pavement area

D. Construction Notes

_______ Permeable pavement areas should be clearly marked off and remain *outside* the limits of land disturbance during construction to prevent soil compaction by heavy equipment. Permeable pavement areas should *not* be used during construction as sites for temporary sediment traps or basins.
_______ Traffic control to avoid tracking mud and fine sediment
_______ Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.
_______ Ensure that pre-treatment structures are properly installed and working effectively.
_______ Construction sequence:
- ______ Construction inspections should occur before, during and after installation to ensure the permeable pavement installation is constructed according to specifications. Use detailed inspection checklists that require sign-offs by qualified individuals at critical states of construction, to ensure the contractor's interpretation of the plan is consistent with the designer's intent.
- ______ Construction of the permeable pavement facility should begin only *after* site work is completed and the entire contributing drainage area has been stabilized with dense and healthy vegetation.
- ______ Temporary E&S control measures (typically silt fence) to prevent sediment from moving into the stone base material or onto the pavement surface during construction), to avoid clogging
- ______ Excavators or backhoes (with arms with adequate extension) should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions.
  - ______ For micro-scale and small-scale installations, excavators should avoid setting up inside the facility footprint to avoid compaction.
  - ______ Where feasible, use the cell construction approach, splitting the proposed permeable pavement area into 500 to 1,000 sq. ft. temporary cells with a 10 to 15 foot earth bridge in between, so the cells can be excavated from the side.
  - ______ Excavated material should be place away from the open excavation to avoid jeopardizing the stability of the side walls.
- ______ Scarify or till the native soils along the bottom and sides of the permeable pavement system to a depth of 3 to 4 inches prior to placing the filter layer or filter fabric.
- ______ For large scale paving applications with weak soils, the soil subgrade may need to be compacted to 95% of the Standard Proctor Density to achieve the desired load-bearing capacity (effectively eliminating any infiltration function, so this must be addressed during the hydrologic design stage).
- ______ If used, filter fabric should be installed next along the bottom and sides of the reservoir layer.
  - ______ Filter fabric strips should overlap down-slope by a minimum of 2 feet and should be secured a minimum of 4 feet beyond the edge of the excavation.
  - ______ Where the filter layer extends beyond the edge of the pavement (to convey runoff to the reservoir layer), install an additional layer of filter fabric 1 foot below the surface to prevent sediments from entering the reservoir layer.
  - ______ Do not trim excess filter fabric until the site is fully stabilized.
- ______ Install the observation well(s) and, if used, install the underdrains.
  - ______ Check aggregate material prior to installation to confirm that it is clean and washed and meets specifications and is installed to the correct depth

- ______ Check elevations (underdrain inverts, inflow and outflow point inverts, depth of aggregate installations, etc.) and the surface slope.
- ______ Provide a minimum of 2 inches of aggregate above and below the underdrains.
- ______ Underdrains should slope down towards the outlet at a grade of 0.5% or steeper.
- ______ Up-gradient ends of underdrains in the reservoir layer should be capped, but *not* the downstream ends.
- ______ Where an underdrain pipe is connected to a structure, there must be *no* perforations within 1 foot of the structure.
- ______ Ensure there are no perforations in clean-outs and observation wells within 1 foot of the surface.

______ Moisten and spread 6-inch lifts of the appropriate clean, washed stone aggregate (usually No. 2 or No. 57 stone).

- ______ Check aggregate material prior to installation to confirm that it is clean and washed and meets specifications and is installed to the correct depth.
- ______ Place at least 4 inches of additional aggregate above the underdrain(s), and then compact it using a vibratory roller in static mode until there is no visible movement of the aggregate.
- ______ Do not crush the aggregate with the roller.

______ Install the design depth of bedding layer, depending on the type of pavement to be used.

______ Install paving materials according to manufacturer or industry specifications for the type of pavement to be used (see Stormwater Design Specification No. 7 for specific guidance).

- ______ Make sure the permeable pavement surface is even, that water spreads evenly across it, and the storage bed drains within 36 to 48 hours.

______ Implement any remaining permanent stabilization measures.

______ Log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

E. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.

- ______ Include a Maintenance Narrative which describes the long-term maintenance requirements of the facility and all components.

_______ Record a deed restriction or other enforceable mechanism, including GPS coordinates of the area, to ensure the the permeable pavement is not converted to conventional pavement (in order to maintain this component of the site's stormwater management plan).

IV. COMMENTS

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By: ______________________________ Date: ____________________

8-A.9.0. INFILTRATION PRACTICES: DESIGN CHECKLIST

Plan Submission Date_____________________
Project Name____
Site Plan/Permit Number____
Practice No./Location on Site____
Owner____ Phone Number__________________
BMP Designer____ Phone Number__________________
General Contractor____________________________________ Phone Number__________________

______ Signature and stamp of licensed professional design consultant and owner certification

Plan Status

_______ Approved
_______ Not Approved

Legend:

___✓___ - Complete
__Inc.__ - Incomplete/Incorrect
__N/A__ - Not Applicable

Facility Type: Level 1 ____________________________ Level 2 ______________________________

Hydraulic Configuration:

- ☐ On-line facility
- ☐ Off-line facility (sized to receive only a portion of the Treatment Volume)

Type of Infiltration Facility:

- ☐ Surface facility (basin)
- ☐ Subsurface facility

Type of Pre-Treatment Facility:

- ☐ Sediment forebay (above ground)
- ☐ Sedimentation chamber
- ☐ Plunge pool
- ☐ Stone diaphragm
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: _______________________

I. SUPPORTING INFORMATION

_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design.

_______ Show the location of this BMP on the site map, including:

- ______ Facility area
- ______ Contributing drainage area (CDA) boundaries and acreage (not to exceed 2 acres and as close to 100% impervious as possible)
- ______ Proposed topographic contours
- ______ If a basin, the embankment area: centerline principal spillway, emergency spillway, abutments
- ______ Delineation of FEMA 100-year floodplain
- ______ Areas of the site compensated for in water quality calculations

_______ Provide topography for the site area, showing that the slope of the CDA does not exceed 15%.

_______ Provide a soil map for site and area of the facility, showing the CDA and facility boundaries (HSG A and B soils are prime locations for infiltration facilities)

_______ Provide soil boring locations and soil boring logs with Unified Soils Classifications and descriptions (at least one boring must be taken to confirm the underlying soil properties *at the depth where infiltration is designed to occur,* to ensure that depth to the groundwater table/bedrock or karst is identified). NOTE: To be suitable, native soils must have a silt/clay content of less than 40% and a clay content of less than 20%. Furthermore, infiltration facilities should *not* be located above fill soils, and “urban” soils that have been previously disturbed or graded are not good sites for infiltration. Nor should they be located where they will receive regular dry weather flows from sources such as sump pumps or irrigation systems, or any flows from hot spot areas, etc.

_______ Provide results of soil infiltration rate testing to confirm a subsoil infiltration rate of 0.5 to 1 inch/hour for Level 1 design or 1 to 4 inches/hour for a Level 2 design (the number of infiltration tests should be based on the scale of the planned infiltration facility area – see Table 8.3 and Appendix 8-A in Stormwater Design Specification No. 8).

_______ Depth to seasonal high groundwater table and bedrock (minimum 2 ft. below the design bottom of the facility)

_______ NOTE: An EPA UIC permit may be required for a facility exceeding 20,000 sq. ft. if the surface width is less than the maximum depth.

_______ Avoid installing geotextile filter fabric along the *bottom* of infiltration facilities (causes clogging). A layer of coarse washed choker stone is more effective.

_______ If karst is present, a detailed geotechnical investigation is recommended to ensure the installation does not aggravate potential karst impacts (e.g., sinkholes, etc.) and an impermeable liner (min. 30 mil PVC Geo-membrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile) must be place beneath the infiltration facility. Where karst is present, there must be at least 4 feet of vertical separation between the bottom of the infiltration facility and the karst layer. Furthermore, only micro-scale or small-scale infiltration facilities may be used, and they must be designed *ONLY* to meet the Level 1 design criteria (incorporating an underdrain). NOTE: Bioretention should be preferred to infiltration in karst locations.

II. COMPUTATIONS

A. Hydrology

_______ Confirm a soil infiltration rate of 0.5 inch/hour minimum. NOTE: The *design* infiltration should be calculated to be 50% of the measured infiltration rate, to provide a factor of safety.

_______ A porosity value of 0.40 must be used in the design of stone reservoirs, although a larger value may be used if perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials are installed within the reservoir to detain runoff.

_______ Determine the runoff curve number (pre- and post-developed conditions), providing the worksheets.

_______ Determine the time of concentration (pre- and post-developed conditions), providing the worksheets.

_______ Generate hydrographs (pre- and post-developed conditions) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)

B. Hydraulics

_______ Verify that there is sufficient hydraulic head to drive flows through the facility:

- _____ 1 to 3 feet for micro-scale infiltration
- _____ 1 to 5 feet for small-scale infiltration
- _____ 2 to 6 feet for conventional large-scale infiltration

_______ The Treatment Volume should be infiltrated or drained from the facility within 36 to 48 hours.

_______ Specify the assumptions and coefficients used.

_______ Provide a stage-storage table and curve.

_______ Provide storm drainage and hydraulic grade line calculations.

C. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA, pollutant load, pollutant load removal, and treatment volume requirements, all generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet)

_______ Specific sizing/dimensions must be determined from criteria in Stormwater Design Specification No. 8.

III. PLAN REQUIREMENTS

A. BMP Plan View Information

_______ Show the limits of clearing and grading, noting that they should be identified and protected by acceptable signage, silt fence, snow fence, or other comparable barrier.

_______ Show the layout and dimensions of the infiltration facility

- ______ Micro-scale infiltration from 250 to 2,500 sq. ft. (dry well, french drain, paving blocks)
- ______ Small-scale infiltration from 2,500 to 20,000 sq. ft. (infiltration trench)
- ______ Large-scale conventional infiltration from 20,000 to 100,000 sq. ft. (infiltration trench or basin)

_______ Show the location and confirm the proper orientation (to prevent short-circuiting) of all conveyance system outfalls into the basin with pre-treatment and outlet protection designed in accordance with the VE&SCH

_______ Ensure proper setbacks from building foundations, down-gradient slopes, etc.:

- ______ 5 feet down-gradient from dry or wet utility lines
- ______ 5 feet down-gradient and 25 feet up-gradient from building foundations for micro-scale infiltration facilities
- ______ 10 feet down-gradient and 50 feet up-gradient from building foundations for small-scale infiltration facilities
- ______ 25 feet down-gradient and 100 feet up-gradient from building foundations for large-scale infiltration facilities
- ______ In cold climate areas, 25 feet from roadways to prevent potential frost heaving of the pavement
- ______ 50 feet from septic systems
- ______ 100 feet from any water supply well
- ______ 200 feet from down-gradient slopes with greater than 20% grade

_______ Infiltration basin features:

- ______ Top of bank and basin bottom elevations
- ______ Elevations of treatment volume and maximum design water surface elevations for all appropriate design storms and safety storms
- ______ Side slope (H:V) of basin storage area and embankment (upstream and downstream slopes)
- ______ Sediment forebay
- ______ Maintenance access to the sediment forebay and riser structure

_______ Safety fence during construction, but *not after* completion of construction.

_______ Location of observation well for facilities larger than micro-scale (perforated vertical 6 inch diameter Schedule 40 PVC pipe – AASHTO M 252 – with 3/8-inch diameter perforations at 6 inches on center and a lockable cap, installed flush with the ground surface, with one for every 50 feet of length of the infiltration practice) and any underdrain pipes, which are of the same material – or equivalent corrugated HDPE may be used for smaller load-bearing applications – installed at a minimum 1.0% slope for the full length of the infiltration cell and located no more than 20 feet from the next pipe. Non-perforated pipe may be used to connect with the storm drain system, and Ts and Ys may be installed, as needed, based on the underdrain configuration. Cleanout pipes should be extended to the surface with vented caps at the Ts and Ys.) Ensure there are no perforations in clean-outs and observation wells within 1 foot of the surface. NOTE: An underdrain is required only for large-scale conventional infiltration facilities and for micro-scale infiltration facilities on marginal soils (where the underdrain must be elevated. Install non-perforated pipe with one or more caps, as needed from the structure.

B. BMP Section Views & Related Details

1. Pre-Treatment Practices

_______ Minimum 2 pre-treatment practices required for micro-scale infiltration facilities, but no minimum pre-treatment volume required.

_______ Minimum 3 pre-treatment practices required for small-scale infiltration facilities, and pre-treatment volume is required to be 15% of the Treatment Volume.

_______ Minimum 3 pre-treatment practices required for large-scale conventional infiltration facilities, and pre-treatment volume is required to be 25% of the Treatment Volume. If the facility footprint exceeds 20,000 sq. ft., a surface pre-treatment cell must be provided (e.g., sand filter or dry sediment basin).
_______ Pre-treatment facilities designed so exit velocities are non-erosive for the 2-year design storm and evenly distribute runoff flows across the width of the facility (using a level spreader, etc.)
_______ In cold climate areas, oversize pre-treatment measures by up to 40% to account for additional sediment load caused by road sanding.

2. Infiltration Basin *(also refer to the checklists for Extended Detention Facilities – Section 8-A.16.0 – regarding Earthen Embankments, Principal Spillways, Emergency Spillways, etc.)*
_______ Best if designed to be off-line, to avoid damage from the erosive velocities of larger storms.
_______ Elevations of treatment volume and maximum design water surface elevations for all appropriate design storms and safety storms
_______ Maximum depth no greater than 1 foot (a maximum of 2 feet if pre-treatment cells are used)
_______ Bottom of the basin should be flat (i.e., 0% longitudinal and lateral slopes). A maximum longitudinal slope of 1% is permissible if an underdrain is used.
_______ Top of dam elevations: constructed height and settled height (allowing for 10% settlement).
_______ Adequate freeboard
_______ Top width labeled
_______ Elevation of crest of emergency spillway
_______ Principal/emergency spillway, with side slopes labeled.
_______ Existing ground and proposed improvements profile along center line of embankment
_______ Existing ground and proposed improvements profile along center line of principal spillway
_______ Typical grading section through the basin
_______ Typical grading section through the forebay
_______ Existing ground and proposed improvements along center line of emergency spillway
_______ Dimensions of zones for zoned embankment
_______ Foundation Cut Off Trench or Key Trench
  ______ Materials labeled
  ______ Bottom width (4' minimum, or greater, as specified in the geotechnical report).
  ______ Side slopes labeled (4H:1V maximum steepness).
  ______ Depth (4' minimum or as specified in the geotechnical report)

3. Infiltration Trench
_______ Dimensions provided
_______ Maximum depth:
  ______ 3 feet for micro-scale infiltration facilities
  ______ 5 feet for small-scale infiltration trenches
  ______ 6 feet for large-scale conventional infiltration trenches
  ______ In cold climate areas, the bottom of the trench should extend below the frost line.
_______ Bottom of the trench should be flat (i.e., 0% longitudinal and lateral slopes). A maximum longitudinal slope of 1% is permissible if an underdrain is used.
_______ Aggregate specifications:
  ______ Reservoir stone must be clean washed VDOT No. 1 Open-Graded Coarse Aggregate (diameter of 3.5 to 1.5 inches) or equivalent.
  ______ Stone jacket for the underdrain must be clean double-washed VDOT No. 57 open graded course aggregate (ASTM D448 size, 1-1/2 to 1/2 inch diameter) or equivalent, free of all soil fines, installed 3 inches above the underdrain and 12 inches below it.
_______ Filter fabric installed on the sides of the infiltration facility (to prevent piping) must be non-woven polyprene geotextile with a flow rate of $>$ 110 gpm/sq. ft. (Geotex 351 or equivalent).
_______ The trench surface can be covered by a 3-inch layer of river stone or pea gravel. Turf is acceptable when there is sub-surface inflow (e.g., a roof leader).

C. Landscape Plan

_______ Where grass is used on the infiltration facility surface, include specifications appropriate for the site's vegetation climatic zone (4-8 in Virginia)

_______ Specify preservation measures for existing vegetation surrounding the infiltration area

_______ Keep adjacent vegetation from forming an overhead canopy above the infiltration facility, in order to keep leaf litter, fruits and other vegetative litter from clogging the stone.

D. Construction Notes

_______ Infiltration areas should be clearly marked off and remain *outside* the limits of land disturbance during construction to prevent soil compaction by heavy equipment. Infiltration areas should *not* be used during construction as sites for temporary sediment traps or basins, which can clog the base soils with fine sediments.

_______ Provide traffic control to avoid tracking mud and fine sediment and compacting the soil.

_______ Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.

_______ Ensure that pre-treatment structures are properly installed and working effectively.

_______ Keep the infiltration facility "off-line" until construction is complete.

_______ Construction sequence:

- ______ Construction inspections should occur before, during and after installation to ensure the infiltration facility is constructed according to specifications. Use detailed inspection checklists that require sign-offs by qualified individuals at critical states of construction, to ensure the contractor's interpretation of the plan is consistent with the designer's intent.
- ______ Construction of the infiltration facility should begin only *after* site work is completed and the entire contributing drainage area has been stabilized with dense and healthy vegetation.
- ______ Temporary E&S control measures (typically super silt fence, diversion berms, etc.) to prevent sediment from moving into the stone base material or onto the pavement surface during construction), to avoid clogging. The plan should indicate the conditions that must be met before runoff may be directed to a conventional infiltration basin.
- ______ Excavators or backhoes (with arms with adequate extension) should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions.
  - ______ The floor of the facility should be completely level, but equipment should be kept off the floor to prevent soil compaction.
- ______ Correctly install filter fabric on the trench sides.
  - ______ Trim large tree roots flush with the sides of the trench to prevent puncturing or tearing of the filter fabric.
  - ______ When laying out the geotextile, the width should include sufficient material to compensate for perimeter irregularities in the trench and for a 6-inch minimum overlap at the top of the trench.
  - ______ Tuck filter fabric under the sand layer on the bottom of the trench.
  - ______ Place stones or other anchoring objects on the fabric at the trench sides to keep the trench open during windy periods.
  - ______ Place natural soils in any voids that occur between the fabric and the excavated sides of the trench, to ensure the fabric conforms smoothly to the sides of the excavation.
- ______ Scarify or till the native soils along the bottom and sides of the permeable pavement system to a depth of 3 to 4 inches prior.
- ______ Spread 6 inches of sand on the bottom as a filter layer.
- ______ Install and anchor the observation well(s) and, if used, install the underdrains.
  - ______ Check aggregate material prior to installation to confirm that it is clean and washed and meets specifications and is installed to the correct depth
  - ______ Check elevations (underdrain inverts, inflow and outflow point inverts, depth of aggregate installations, etc.) and the surface slope.
  - ______ Provide a minimum of 2 inches of aggregate above and below the underdrains.
  - ______ Underdrains should slope down towards the outlet at a grade of 0.5% or steeper.

    ______ Up-gradient ends of underdrains in the reservoir layer should be capped, but *not* the downstream ends.
    ______ Where an underdrain pipe is connected to a structure, there must be *no* perforations within 1 foot of the structure.
    ______ Ensure there are no perforations in clean-outs and observation wells within 1 foot of the surface.
  ______ Moisten and spread 1-foot lifts of the appropriate clean, washed stone aggregate (usually No. 2 or No. 57 stone).
    ______ Check aggregate material prior to installation to confirm that it is clean and washed and meets specifications and is installed to the correct depth.
    ______ Place at least 4 inches of additional aggregate above the underdrain(s), and then compact it using a vibratory roller in static mode until there is no visible movement of the aggregate.
    ______ Do not crush the aggregate with the roller.
  ______ Use sod to establish a dense turf cover for at least 10 feet on each side of the infiltration facility, to reduce erosion and sloughing. If the vegetation is seeded instead, use native grasses primarily due to their adaptability to the local climate and soil conditions.
  ______ Implement any remaining permanent stabilization measures.
  ______ Log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

E. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.
  ______ Include a Maintenance Narrative which describes the long-term maintenance requirements of the facility and all components, including removal and disposal of trash, debris and sediment accumulations, and regular mowing.
_______ Record a deed restriction or other enforceable mechanism, including GPS coordinates of the area, to ensure that infiltration areas are not converted to other uses.
_______ Provide sufficient facility access from public ROW or roadway to facilitate inspection and maintenance.

IV. COMMENTS

By: ______________________________ Date: ____________________

8-A.10.0. BIORETENTION PRACTICES: DESIGN CHECKLIST

Plan Submission Date____________________
Project Name____
Site Plan/Permit Number____________________________________
Practice No./Location on Site_______________________________
Owner_______________________________ Phone Number______________
BMP Designer__________________________ Phone Number______________
General Contractor______________________ Phone Number______________

______ **Signature and stamp of licensed professional design consultant and owner certification**

Plan Status

_______ Approved
_______ Not Approved

Legend:

☐	- Complete
Inc.	- Incomplete/Incorrect
N/A	- Not Applicable

Facility Type: Level 1 ____________________ Level 2 ____________________

Hydraulic Configuration:

- ☐ On-line facility
- ☐ Off-line facility

Type of Pre-Treatment Facility:

- ☐ Sedimentation chamber
- ☐ Plunge pool
- ☐ Stone diaphragm
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: ______________

I. SUPPORTING INFORMATION

_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design.

_______ Show the location of this BMP on the site map, including the following:

- ______ Facility area
- ______ Contributing drainage area (CDA) boundaries and acreage.
- ______ Embankment area
- ______ Delineation of FEMA 100-year floodplain (bioretention should be constructed *outside* the limits of the floodplain).
- ______ Areas of site compensated for in water quality calculations

_______ If the Bioretention facility will receive runoff from a hotspot land use, then an underdrain must be used.

_______ Bioretention facilities must not be located where they will receive regular dry weather flows or flow from sources such as sump pumps, irrigation water, chlorinated wash-water or swimming pool discharge, or other flows that are not stormwater runoff.

_______ Provide topography for the site area, showing that the slope of the CDA is between 1% and 5%.

_______ Provide a soil map for site and area of facility, showing CDA and facility boundaries

_______ Show the soil boring locations and provide the soil boring logs with Unified Soils Classifications and descriptions (at least one boring must be taken to confirm the underlying soil properties *at the depth where biofiltration or bioinfiltration is designed to occur,* to ensure that depth to the groundwater table/bedrock or karst is identified). HSG-B, C or D soils typically require an underdrain, whereas HSG-A soils generally do not.

_______ Provide the results of soil infiltration rate testing to confirm a minimum subsoil infiltration rate of $>$ 0.5 inch/hour ($>$ 1 inch/hour in order to avoid the use of an underdrain). The number of infiltration tests is based on the scale of the planned infiltration facility area – see Tables 9.2 and 9.3 in Stormwater Design Specification No. 9 and Appendix 8-A in Stormwater Design Specification No. 8).

_______ Confirm the depth to seasonal high groundwater table (minimum 2 ft. below the design bottom of the facility, or 1 ft. if in a coastal area and a large-diameter underdrain is used that only partially dewaters the bed)

_______ Confirm the depth to bedrock (minimum 2 ft. below the design bottom of the facility)

_______ If karst is present, a detailed geotechnical investigation is recommended to ensure the installation does not aggravate potential karst impacts (e.g., sinkholes, etc.) and an impermeable liner (recommend a min. 30 mil PVC Geo-membrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile) must be place beneath the bioretention facility. Where karst is present, there must be at least 3 feet of vertical separation between the bottom of the bioretention facility and the karst layer. Furthermore, only micro-scale or small-scale bioretention facilities not exceeding 20,000 sq. ft. may be used, and they must be designed *ONLY* to meet the Level 1 design criteria (incorporating an underdrain).

_______ Identify potential conflicts with other (existing?) structural components (pipes, underground utilities, etc.)

_______ Avoid installing geotextile filter fabric along the *bottom* of bioretention facilities (causes clogging).

II. COMPUTATIONS

A. Hydrology

_______ Determine the runoff curve numbers (pre- and post-developed conditions), providing the worksheets.

_______ Determine the time of concentration (pre- and post-developed conditions), providing the worksheets.

_______ Generate hydrographs (pre- and post-developed conditions) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)

_______ Urban Bioretention facilities, in particular, should be designed to fully drain within 24 hours following each storm.

B. Hydraulics

_______ Ensure that 4 to 5 feet of hydraulic head (3 to 5 feet for Urban Bioretention) are available above the bottom elevation needed to tie the underdrain into the storm drain system, in order to drive runoff through the filter bed. Less head is necessary for HSG-A soils.

_______ Specify assumptions and coefficients used.

_______ Provide a stage-storage table and curve

_______ Provide for large storm overflow or bypass

_______ Provide storm drainage and hydraulic grade line calculations.

C. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA, pollutant load, pollutant load removal, and treatment volume requirements, all generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet)

_______ Provide specific sizing/dimensions determined from criteria in Stormwater Design Specification No. 9.

III. PLAN REQUIREMENTS

A. BMP Plan View Information

_______ Show the limits of clearing and grading, noting that they should be identified and protected by acceptable signage, silt fence, snow fence, or other comparable barrier.

_______ Show the layout and dimensions of the bioretention facilities / planters. NOTE: The maximum contributing drainage area for a micro-bioretention facility (e.g., rain garden) is 0.5 acre (3% of the CDA or 5% of the roof area for Level 1 or 4% of the CDA or 6% of the roof area for Level 2); for an urban bioretention facility is 2,500 sq. ft., and for a conventional bioretention facility is 2.5 acres.

_______ Observe proper setbacks from building foundations, down-gradient slopes, etc.:

- ______ 5 feet down-gradient from wet utility lines. NOTE: Dry utility lines (e.g., gas, electric, cable and telephone, etc.) may cross under bioretention areas if they are double-cased.
- ______ 10 feet down-gradient from building foundations for urban bioretention. NOTE: If the facility is lined and an underdrain is used, there is no minimum setback requirement.
- ______ 5 feet down-gradient and 25 feet up-gradient from building foundations for micro-scale (rain garden) facilities
- ______ 10 feet down-gradient and 50 feet up-gradient from building foundations for standard bioretention facilities with a 0.5 acre or smaller CDA
- ______ 25 feet down-gradient and 100 feet up-gradient from building foundations for standard bioretention facilities with a CDA of between 0.5 to 2.5 acres.
- ______ If an in-ground basement or other special conditions exist, the design should be reviewed by a licensed engineer. NOTE: A special footing or drainage design may be used to justify a reduction of the setbacks noted above.
- ______ In cold climate areas, 25 feet from roadways to prevent potential frost heaving of the pavement
- ______ 100 feet from any water supply well (50 feet if the biofilter is lined)

_______ Design Urban Bioretention, in particular, to minimize interference with pedestrian traffic and allow for frequent landscape and facility maintenance

_______ Geometry:

- ______ Level 1: Length of the shortest flow path/overall length = 0.3 *OR* other design methods are used to prevent short-circuiting; a one-cell design (not including the pre-treatment cell.
- ______ Level 2: Length of the shortest flow path/overall length = 0.8 *OR* other design methods are used to prevent short-circuiting; a two-cell design (not including the pre-treatment cell.

_______ Show the location of all conveyance system outfalls (inlets) into the facility with pre-treatment and outlet protection designed in accordance with the VE&SCH

_______ Ensure the proper geometry and orientation of the facility and inlets to the facility to avoid short-circuiting

_______ Show the top-of-bank and basin bottom elevations

_______ Show the treatment volume and maximum water surface elevations for all appropriate design storms and safety storms

_______ Show the location of the underdrain, if applicable

_______ Ensure and show adequate maintenance access to the facility

_______ Show the location of the observation well

B. BMP Section Views & Related Details

1. Micro-Bioretention Facility (Rain Garden)

_______ Pre-treatment:

- ______ Level 1: External (leaf screens, grass filter strip, energy dissipators, etc.)
- ______ Level 2: External *plus* a grass filter strip

_______ Inflow: From sheet flow or a roof leader

_______ Facility may be a single-cell design (can be divided into smaller cells at downspout locations)

_______ Maximum ponding depth: 6 inches.

_______ Show the elevations of treatment volume and maximum design water surface elevations for all appropriate design storms and safety storms

_______ Show the facility rim elevations: constructed height and settled height (allowing for 10% settlement).

_______ Ensure adequate freeboard

_______ Provide a typical grading section through the facility

_______ Filter media:

- ______ Depth: minimum 18 inches for Level 1; minimum 24 inches for Level 2; recommended maximum depth is 36 inches for both.
- ______ Media mixed on site or supplied by vendor for Level 1, but *must* be supplied by vendor for Level 2
- ______ P-index: Between 20 and 30 for a media mix, *OR* between 7 and 21 mg/kg of P in the soil media (see Section 6.6 of Stormwater Design Specification No. 9)
- ______ Cation Exchange Capacity (CEC): Soils with a CEC exceeding 10 are preferred for pollutant removal.
- ______ Infiltration Rate: Between 1 to 2 inches per hour
- ______ Media mix: Equivalent to loamy sand, with the following composition:
  - ______ 85% to 88% sand
  - ______ 8% to 12% soil fines
  - ______ 3% to 5% organic matter
- ______ Mulch cover: 2 to 3-inch layer composed of shredded, aged hardwood bark mulch

_______ Underdrain:

- ______ Level 1: Corrugated HDPE or equivalent
- ______ Level 2: Corrugated HDPE or equivalent, with a minimum 6-inch stone sump below the invert; *OR* none, if soil infiltration requirements are met
- ______ A minimum of 3 inches of VDOT #57 clean washed stone (less than 1% passing a #200 sieve) must be laid and packed above and below the pipe.

_______ Cleanouts are *not* needed

_______ In cold climates (winter or otherwise) it is advisable to extend the filter bed and underdrain pipe below the frost line and/or oversize the underdrain by on pipe size to reduce the potential for freezing.

_______ Vegetation:

- ______ Level 1: Turf or herbaceous cover (alternative to mulch), or shrubs (minimum 1 of these 3 choices)
- ______ Level 2: Turf or herbaceous cover (alternative to mulch), shrubs, or trees (minimum 2 of these 4 choices)

2. Standard Bioretention Filter or Bioretention Basin

_______ Pre-treatment:

- ______ Level 1: A pre-treatment cell, grass filter strip, gravel diaphragm, gravel flow spreader, or another approved (manufactured) pre-treatment device.
- ______ Level 2: A pre-treatment cell *plus* one of the following: a grass filter strip, gravel diaphragm, gravel flow spreader, or another approved (manufactured) pre-treatment device.

_______ Inflow: From sheet flow, curb cuts, trench drains, concentrated flow, or the equivalent

_______ Maximum ponding depth: 6 inches (preferred) to 12 inches. NOTE: Ponding depths greater than 6 inches will require a specific planting plan to ensure appropriate plant selection.

_______ Show the elevations of treatment volume and maximum design water surface elevations for all appropriate design storms and safety storms

_______ Show the facility rim elevations: constructed height and settled height (allowing for 10% settlement).

_______ Ensure adequate freeboard

_______ Provide a typical grading section through the facility

_______ Filter media:

- ______ Depth: minimum 24 inches for Level 1; minimum 36 inches for Level 2; recommended maximum depth is 6 feet for both.

- ______ Media mixed on site or supplied by vendor for Level 1, but *must* be supplied by vendor for Level 2
- ______ P-index: Between 20 and 30 for a media mix, *OR* between 7 and 21 mg/kg of P in the soil media (see Section 6.6 of Stormwater Design Specification No. 9)
- ______ Cation Exchange Capacity (CEC): Soils with a CEC exceeding 10 are preferred for pollutant removal.
- ______ Infiltration Rate: Between 1 to 2 inches per hour
- ______ Media mix: Equivalent to loamy sand, with the following composition:
  - ______ 85% to 88% sand
  - ______ 8% to 12% soil fines
  - ______ 3% to 5% organic matter
- ______ Mulch cover: 2 to 3-inch layer composed of shredded, aged hardwood bark mulch

_______ Underdrain:
- ______ Level 1: Schedule 40 PVC with clean-outs
- ______ Level 2: Schedule 40 PVC with clean-outs *and* with a minimum 12-inch stone sump below the invert; *OR* none, if soil infiltration requirements are met
- ______ A minimum of 3 inches of VDOT #57 clean washed stone (less than 1% passing a #200 sieve) must be laid and packed above and below the pipe.

_______ In cold climates (winter or otherwise) it is advisable to extend the filter bed and underdrain pipe below the frost line and/or oversize the underdrain by on pipe size to reduce the potential for freezing.

_______ Conveyance and Overflow:
- ______ For on-line bioretention: Incorporate an overflow structure to safely convey larger storms through the bioretention area. The following criteria apply to overflow structures:
  - ______ The overflow associated with the 2-year and 10-year design storms should be controlled so that velocities are non-erosive at the outlet point (to prevent downstream erosion)
  - ______ Common overflow systems within bioretention practices consist of an inlet structure, where the top of the structure is placed at the maximum water surface elevation of the bioretention area, which is typically 6 to 12 inches above the surface of the filter bed (6 inches is preferred).
  - ______ The overflow capture device (typically a yard inlet) should be scaled to the application; this may be a landscape grate inlet or a commercial-type structure.
  - ______ The filter bed surface should generally be flat so the bioretention area fills up like a bathtub.
- ______ For off-line bioretention (preferred): Create an alternate flow path at the inflow point into the structure so that when the maximum ponding depth is reached, the incoming flow is diverted past the facility (so that the excess flows do not pass over the filter bed and through the facility, but additional flow is able to enter as the ponding water filters through the soil media).

_______ Vegetation:
- ______ Level 1: A planting template to include turf or herbaceous cover (alternative to mulch), shrubs, and/or trees to achieve surface area coverage of at least 75% within 2 years.
- ______ Level 2: A planting template to include turf or herbaceous cover (alternative to mulch), shrubs, and/or trees to achieve surface area coverage of at least 90% within 2 years. If using turf, it must be combined with other vegetation.

3. Urban Bioretention (planters, etc.)

_______ Pre-treatment (keep in mind the aesthetic qualities of the visible materials):
- ______ A pre-treatment cell, grass filter strip, gravel diaphragm, gravel flow spreader, or another approved (manufactured) pre-treatment device.
- ______ A trash rack between the pre-treatment cell and the main filter bed, allowing trash to be collected from a single location.
- ______ Trash racks across curb cuts, keeping trash in the gutter, accessible to street-sweeping equipment.

______ A pre-treatment area above the ground or a manhole or removable grate directly over the pre-treatment area.

_______ Inflow: From sheet flow, curb cuts, trench drains, roof drains, concentrated flow, or the equivalent

_______ Inlets should be stabilized with VDOT #3 stone, a splash block, river stone, or another acceptable energy dissipation measure.

_______ Surface slope: 1% toward the outlet, unless a stormwater planter is used.

_______ Maximum ponding depth: 6 inches (preferred) to 12 inches. NOTE: Ponding depths greater than 6 inches will require a specific planting plan to ensure appropriate plant selection.

_______ Filter media:

______ Depth: minimum 30 inches; recommended maximum depth is 4 feet. NOTE: If large trees and shrubs are planted, the *minimum* depth should be 4 feet.

______ Media mixed on site or supplied by vendor for Level 1, but *must* be supplied by vendor for Level 2

______ P-index: Between 20 and 30 for a media mix, *OR* between 7 and 21 mg/kg of P in the soil media (see Section 6.6 of Stormwater Design Specification No. 9)

______ Cation Exchange Capacity (CEC): Soils with a CEC exceeding 10 are preferred for pollutant removal.

______ Infiltration Rate: Between 1 to 2 inches per hour

______ Media mix: Equivalent to loamy sand, with the following composition:

______ 85% to 88% sand

______ 8% to 12% soil fines

______ 3% to 5% organic matter

______ Filter media in a box should be extended from one wall to within 6 inches of the opposite wall, and it may be centered in the box or offset to one side.

______ Filter media must be separated from the soil by non-woven geotextile fabric or a 2 to 3 inch layer of either washed VDOT #8 stone or 1/8 to 3/8-inch pea gravel.

______ Mulch cover: 2 to 3-inch layer composed of shredded, aged hardwood bark mulch.

_______ Waterproof stormwater planters near building foundations by using a watertight concrete shell or an impermeable liner, to prevent seepage.

_______ Expanded tree pits:

______ The bottom of the soil/media layer must be a minimum of 4 inches below the root ball of trees and shrubs being planted.

______ Where portions of extended tree pits are covered with permeable pavers or cantilevered sidewalks, ensure the filter media is connected beneath these surfaces so roots can share the space.

______ Installing a removable tree pit grate (capable of supporting H-20 axel loads) over the filter bed media can prevent pedestrian traffic and trash accumulation.

______ Low, wrought iron fences can help restrict pedestrian traffic across the tree pit bed and protect pedestrians where there is a drop-off from the sidewalk to the bioretention cell.

______ Each tree needs a minimum of 400 cubic feet of shared root space.

_______ Stormwater Curb Extensions: It may be necessary to provide a barrier to keep water from saturating the adjacent road or street's sub-base and ensure it continues to be capable of supporting H-20 axel loads.

_______ Underdrain:

______ Slotted Schedule 40 PVC pipe greater than 4 inches in diameter, with clean-outs.

______ A minimum of 2 inches of VDOT #57 clean washed stone (less than 1% passing a #200 sieve) must be laid and packed above and below the pipe.

______ Minimum underdrain pipe slope is 0.5%.

_______ Overflows can either be diverted from entering the bioretention cell or dealt with via an overflow inlet. Optional methods include:

______ Curb openings sized to capture only the treatment volume and bypass higher flows through the existing gutter.

______ Landscaping-type inlets or standpipes with trash guards.

______ A pre-treatment chamber with a weir design that limits flow to the filter bed area.

_______ Any grates used above Urban Bioretention areas must be removable to allow maintenance access.
_______ Stencil or otherwise permanently mark each Urban Bioretention unit as a "stormwater management facility," indicating that (1) it has a water quality protection purpose, (2) it may pond briefly after a storm, and (3) it is not to be disturbed except for required maintenance.
_______ Vegetation:
    ______ Urban Bioretention cells can vary from formal gardens or naturalized landscapes, depending on the degree of landscape maintenance that can be provided
    ______ Where less frequent maintenance may be available and trash accumulation is a concern, use a "turf and trees" landscape model, perhaps including some herbaceous flowering plants.
    ______ Choose native trees and shrubs known to be hearty in the polluted air and compacted soils of urban settings, although some ornamental species can be used.
    ______ Selected vegetation must be tolerant of road salts, drought, and inundation.

C. Landscape Plan

_______ Consider the importance of aesthetics and visual characteristics (foliage form, texture, color, etc.)
_______ Consider visibility, traffic considerations and other safety issues
_______ Provide a planting schedule and specifications (transport / storage / installation / maintenance)
_______ Plant selection should be appropriate for the site's vegetation climatic zone (4-8 in Virginia), emphasizing native species
_______ Check whether future tree canopy heights associated with Urban Bioretention practices will interfere with existing overhead utility lines.
_______ Specify preservation measures for existing vegetation
_______ The construction contract should include a *Care and Replacement Warranty* that specifies a minimum survival for species planted of 75% after the first growing season, and a minimum effective ground cover of 75% for flat roofs and 90% for pitched roofs.

D. Ecological Considerations

_______ Consider sun and wind exposure
_______ Consider the effects upon bioretention area from adjacent plant communities
_______ Wildlife benefits appropriate for the location may be included in plant material layout
_______ Consider any insect and disease infestation at or near the facility site

E. Construction Notes

_______ Planned bioretention areas should be clearly marked off and remain *outside* the limits of land disturbance during construction to prevent soil compaction by heavy equipment.
_______ Bioretention areas *may* be used during construction as sites for temporary sediment traps or basins, provided the construction plans include notes and graphical details specifying the following:
    ______ The maximum excavation depth at the construction stage must be at least 1 foot above the post-construction installation.
    ______ The facility must contain an underdrain.
    ______ Showing the proper procedures for converting the temporary sediment controls to a permanent bioretention facility, including dewatering, cleanout and stabilization.
_______ Provide traffic control to avoid tracking mud and fine sediment into the facility and compacting the soil.
_______ Store materials in a protected area to keep them free from mud, dirt and other foreign materials.
    ______ Obtain filter media from an approved vendor and store it on an adjacent impervious area or on plastic sheeting.
_______ Where any Urban Bioretention facilities are constructed in the road or right-of-way, the construction sequence may need to be adjusted to account for traffic control, pedestrian access and utility notification.

_______ Construction sequence:

- ______ Construction inspections should occur before, during and after installation to ensure the bioretention facility is constructed according to specifications.
  - ______ Use detailed inspection checklists that require sign-offs by qualified individuals at critical states of construction, to ensure the contractor's interpretation of the plan is consistent with the designer's intent.
- ______ Check the proposed site for existing utilities prior to any excavation.
- ______ The designer and the installer/contractor should have a pre-construction meeting, checking the boundaries of the CDA and the actual inlet elevations to ensure they conform to the original design.
  - ______ The designer should clearly communicate, in writing, any project changes determined during the pre-construction meeting to the installer and the plan review/inspection authority.
- ______ Construction of the bioretention facility should begin only *after* site work is completed and the entire contributing drainage area has been stabilized with dense and healthy vegetation.
- ______ It may be necessary to block certain curb or other inlets while the bioretention area is being constructed.
- ______ Temporary E&S control measures (typically silt fence, diversion berms, EC fabric, etc.) to prevent sediment from moving into the filter media or stone base material during construction), to avoid clogging (particularly if the practice relies on infiltration), and to protect the facility's vulnerable side slopes from erosion during construction.
- ______ Ensure that pre-treatment structures are properly installed and working effectively.
- ______ Excavators or backhoes (with arms with adequate extension) should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions.
  - ______ Contractors should use a cell construction approach in larger bioretention basins, with the basin split into 500 to 1,000 sq. ft. temporary cells with a 10 to 15 foot earth bridge in between each cell, so that cells can be excavated from the side.
  - ______ The floor of the facility should be completely level, but equipment should be kept off the floor to prevent soil compaction.
  - ______ It may be necessary to rip the bottom soils to a depth of 6 to 12 inches to promote greater infiltration.
- ______ Correctly install geotextile fabric on the excavation sides.
  - ______ Trim large tree roots flush with the sides of the excavation to prevent puncturing or tearing of the filter fabric.
  - ______ When laying out the geotextile, the width should include sufficient material to compensate for perimeter irregularities in the trench and for a 6-inch minimum overlap at the top of the excavation.
  - ______ Place stones or other anchoring objects on the fabric at the trench sides to keep the trench open during windy periods.
  - ______ Place natural soils in any voids that occur between the fabric and the excavated sides of the trench, to ensure the fabric conforms smoothly to the sides of the excavation.
- ______ Install and anchor the observation well(s) and, if used, install the underdrains.
  - ______ Check aggregate material prior to installation to confirm that it is clean and washed and meets specifications and is installed to the correct depth
  - ______ Check elevations (underdrain inverts, inflow and outflow point inverts, depth of aggregate installations, etc.) and the surface slope.
  - ______ Provide the correct depth and type of aggregate above and below the underdrains.
  - ______ Underdrains should slope down towards the outlet at a grade of 0.5% or steeper.
  - ______ Up-gradient ends of underdrains in the reservoir layer should be capped, but *not* the downstream ends.

- ______ Where an underdrain pipe is connected to a structure, there must be *no* perforations within 1 foot of the structure.
- ______ Ensure there are no perforations in clean-outs and observation wells within 1 foot of the surface.

______ Place approximately 3 inches of choker stone/pea gravel on the stone above the underdrain(s) as a filter between the underdrain stone layer and the soil filter media.

______ Place the filter media by hand (to avoid compaction and maintain porosity) in 12-inch lifts, with no machinery allowed directly on the media surface during or after construction, until the design top elevation is achieved.

- ______ Overfill the media above the proposed finished surface elevation to allow for natural settling. Lifts may be lightly watered to encourage settling.
- ______ After the final lift is placed, rake the media to level it, saturate it, and allow it to settle for at least one week prior to installing plant materials. Check for settlement and add additional media, if needed, to achieve the design elevation.

______ Prepare planting holes for any trees and shrubs, install the vegetation, and water accordingly.

______ Install any temporary irrigation equipment.

______ Place the surface cover in the bioretention cells (mulch, river stone or turf), depending on the design.

- ______ If coir or jute matting will be used instead of mulch, the matting will need to be installed prior to planting, and holes or slits will have to be cut in the matting to install the plants.

______ Install the plant materials as shown in the landscaping plan, and water them during weeks of no rain for the first two months following installation.

- ______ The construction contract should include a *Care and Replacement Warranty* to ensure that vegetation is properly established and survives during the first growing season following construction.

______ Implement any remaining permanent stabilization measures.

______ Log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

E. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.

- ______ Include a Maintenance Narrative which describes the long-term maintenance requirements of the facility and all components, including removal and disposal of trash, debris and sediment accumulations, periodic replacement of soil media, care of the vegetation, and mowing.

_______ Record a deed restriction, drainage easement, and/or other enforceable mechanism, including GPS coordinates of the area, to ensure the bioretention areas are not disturbed or converted to other uses.

_______ Provide sufficient facility access from the public ROW or roadway to both the bioretention facility and any pre-treatment practices.

IV. COMMENTS

____
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By: ________________________ Date: ______________

8-A.11.0. DRY SWALES: DESIGN CHECKLIST

(NOTE: Think of this practice as linear bioretention)

Plan Submission Date_____________________
Project Name____
Site Plan/Permit Number____
Practice No./Location on Site____
Owner____ Phone Number___________________
BMP Designer____ Phone Number___________________
General Contractor_____________________________________ Phone Number___________________

______ **Signature and stamp of licensed professional design consultant and owner certification**

Plan Status

_______ Approved
_______ Not Approved

Legend:
__✓__ - Complete
__Inc.__ - Incomplete/Incorrect
__N/A__ - Not Applicable

Facility Type: Level 1 ____________________________ Level 2 ______________________________

Type of Dry Swale:
- ☐ Dry Conveyance Swale
- ☐ Dry Treatment Swale

Hydraulic Configuration:
- ☐ On-line (typical)
- ☐ Off-line (more rare, for Level 2 designs only)

Type of Pre-Treatment Facility:
- ☐ Sediment Forebay
- ☐ Check Dam
- ☐ Tree Check Dam
- ☐ Grass Filter Strip
- ☐ Gravel Diaphragm
- ☐ Pea Gravel Flow Spreader
- ☐ Other: _____________________

I. SUPPORTING INFORMATION

_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design.

_______ Show the location of the BMP on the site map, including:
- ______ Swale area
- ______ Contributing drainage area (CDA) boundaries and acreage
- ______ Delineation of FEMA 100-year floodplain
- ______ Areas of site compensated for in water quality calculations

_______ Provide topography for the site area, showing that the slope of the CDA is between 1% and 4%, but preferably not exceeding 2%.
- ______ Check dams can be used to reduce the effective slopes of the swale and lengthen the contact time to enhance filtering and/or infiltration.
- ______ In areas of steep terrain, Dry Swales *can* be implemented on slopes of up to 20% gradient, as long as a terraced multiple-cell design is used to dissipate energy prior to filtering.
  - ______ Limit the drop in elevation between cells to 1 foot.
  - ______ Armor the swale with river stone or a suitable equivalent.
  - ______ Drop structures and energy dissipators must be carefully designed and constructed.

_______ Provide a soil map for the site and area of the Dry Swale(s), including the CDA

_______ Provide soil boring locations and soil boring logs with Unified Soils Classifications and descriptions (at least one boring must be taken to confirm the underlying soil properties *at the depth where biofiltration or bioinfiltration is designed to occur,* to ensure that depth to the groundwater table/bedrock or karst is identified). HSG-C or D soils typically require an underdrain, whereas HSG-A and B soils generally do not.

_______ Provide the results of soil infiltration rate testing to confirm a minimum subsoil infiltration rate of > 0.5 inch/hour to avoid the use of an underdrain. Use the infiltration test procedures provided in Appendix 8-A in Stormwater Design Specification No. 8 (Infiltration).

_______ Confirm the depth to the seasonal high groundwater table (minimum 2 ft. below the design bottom of the facility, or 1 ft. if in a coastal area and an underdrain is used that has a minimum slope of 0.5% and is connected to the drainage system). NOTE: Wet Swales are preferred in coastal plain settings.

_______ Confirm the depth to bedrock (minimum 2 ft. below the design bottom of the facility)

_______ If karst is present, a detailed geotechnical investigation is recommended to ensure the installation does not aggravate potential karst impacts (e.g., sinkholes, etc.) and an impermeable liner (recommend a min. 30 mil PVC Geo-membrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile) and underdrain must be place beneath the Dry Swale (Level 1 design only).

_______ Identify potential conflicts with other (existing?) structural components (pipes, underground utilities, etc.).

- _____ Consult local utility design criteria for the horizontal and vertical clearance between utilities and swales.
- _____ Utilities can cross linear swales if they are specially protected (e.g., double casing).
- _____ Water and sewer lines generally need to be placed under road pavements to enable the use of adjacent Dry Swales.
- _____ The bottom elevation of a swale should be a minimum 1 foot below the invert elevation of any adjacent road bed.

_______ Dry Swales should be located so as to avoid inputs of springs, irrigation water, chlorinated wash water, or other dry weather flows.

II. COMPUTATIONS

A. Hydrology

_______ Determine the runoff curve number (pre- and post-developed conditions), providing the worksheets.

_______ Determine the time of concentration (pre- and post-developed conditions), providing the worksheets.

_______ Generate hydrograph (pre- and post-developed conditions) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)

_______ Confirm that there is adequate drainage area and/or base flow

B. Hydraulics

_______ The treatment volume must be completely filtered within a maximum of 6 hours following a storm.

_______ Typically require 3 to 5 feet of hydraulic head (between the inflow point and the downstream storm drain invert).

_______ The swale must be designed with enough capacity to:

- _____ Convey runoff from the 2-year and 10-year design storms at non-erosive velocities with at least 3 inches of freeboard.
- _____ Contain the 10-year flow within the banks of the swale (tends to drive the surface dimensions).

_______ The bottom width and slope must be designed so that the velocity from a 1-inch rainfall will not exceed 3 ft./sec. (check dams can be incorporated to reduce flow volume and velocity)

_______ Specify assumptions and coefficients used.

_______ Provide a stage-storage table and curve

_______ Provide storm drainage and hydraulic grade line calculations (evaluate the flow profile through the channel at normal depth, as well as flow depth over the top of check dams).

_______ Account for any check dams placed within the swale

C. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA, pollutant load, pollutant load removal, and treatment volume requirements, all generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet)

_______ Determine specific sizing/dimensions from criteria in Stormwater Design Specification No. 10.

III. PLAN REQUIREMENTS

A. BMP Plan View Information

_______ Show limits of clearing and grading, noting that they should be identified and protected by acceptable signage, silt fence, snow fence, or other comparable barrier.

_______ Show the locations and dimensions of pre-treatment practices:

  ______ A grass filter strip for a Dry *Conveyance* Swale

  ______ For a Dry *Treatment* Swale, may use a variety of pre-treatment practices, depending on they type of flow entering the swale, with one at each inflow point to the swale (to trap coarse sediment to prevent clogging of the filter media).

_______ Layout and dimensions of Dry Swale. NOTE: The maximum contributing drainage area for a Dry Swale is 5 acres (preferably less); a Dry Swale should be approximately 3% to 10% of the size of the CDA, depending on the amount of impervious cover..

_______ Dry Swales are not subject to normal building setbacks, given their position in the landscape.

_______ Runoff originating from hotspot sources should *not* be treated by Level 2 (infiltrating) Dry Swales; an impermeable liner should be used.

_______ Proper geometry and orientation to avoid short-circuiting:

  ______ A parabolic cross-sectional shape is preferred for hydraulic, maintenance and aesthetic purposes; a trapezoidal shape may be used as long as the soil filter bed boundaries lay in the flat bottom of the swale

  ______ Side slopes should be no steeper than 3H:1V to facilitate ease of mowing; flatter slopes are encouraged, where space is available, to enhance pre-treatment of sheet flows entering the swale.

  ______ Dry Swales should have a bottom width of from 4 to 8 feet to provide adequate filtering area; if the swale will be wider than 8 feet, the designer should incorporate berms, check dams, level spreaders or multi-level cross-sections to prevent braiding and erosion of the swale bottom.

  ______ The longitudinal slope should be relatively flat (2% or less for a Level 1 design, and 1% or less for a Level 2 design), to allow for temporary ponding of the treatment volume within the channel. The minimum recommended slope is 0.5% (unless the swale is off-line, similar to a bioretention facility), but slopes up to 4% are acceptable if check dams are used.

_______ Location of all conveyance system outfalls into the swale with pre-treatment and outlet protection designed in accordance with the VE&SCH

_______ Top of bank and basin bottom elevations

_______ Elevations of treatment volume and maximum design water surface elevations for all appropriate design storms and safety storms

_______ Location of underdrain, if applicable

_______ Location of observation well(s)

_______ Location of check dams, if applicable:

  ______ Stone energy dissipators are required at the downstream toe of check dams to prevent erosion.

  ______ The check dam must be designed to spread runoff evenly over the Dry Swale's filter bed surface, through a depressed weir (in the center of the check dam) with a length equal to the filter bed width (sized to convey the depth of flow for the appropriate design storm).

  ______ Check dams must be spaced correctly, consistent with criteria in Stormwater Design Specification No. 10.

_______ Adequate maintenance access to the facility

B. BMP Section Views & Related Details

_______ Sections through pre-treatment practices.
_______ Elevations of treatment volume and maximum design water surface elevations for all appropriate design storms and safety storms; the maximum ponding depth is a Dry Swale should not exceed 12 inches at the most downstream point.
_______ Adequate freeboard
_______ Swale bank elevations: constructed height and settled height (allowing for 10% settlement).
_______ Typical grading section through the facility, showing basin bottom slope
_______ Underdrain, if applicable:
  ______ Underdrains are provided to ensure Dry Swales drain properly after storms.
  ______ Underdrains must be 6-inch Schedule 40 PVC with 3/8-inch perforations and clean-outs; use non-perforated pipe to connect to the storm drain system.
  ______ Install the underdrain with two layers of stone:
    _______ A 12-inch deep underdrain stone layer must be composed of 1-inch clean, double-washed stone (VDOT #57 aggregate) free of all soil and fines, with the underdrain set 4 inches above the bottom of this layer of stone. NOTE: The depth of this storage layer (9 to 18 inches) will depend on the target treatment and storage volumes needed to meet water quality, channel protection, and/or flood protection criteria.
    _______ In cold climates, extend the underdrain pipe below the frost line and oversize the pipe by one pipe size, to reduce the risk of freezing.
_______ Choker layer: A 2 to 4-inch layer of sand laid over a 2 inch layer of VDOT #8 or #89 choker stone (washed gravel) laid above the underdrain encasement stone layer and immediately below the filter layer.
_______ Observation well(s):
  ______ Installed along the length of the swale, if the contributing drainage area exceeds 1 acre.
  ______ Wells should be tied into any T's or Y's in the underdrain system.
  ______ Each well should be flush with the ground surface, with a vented cap.
_______ Filter media:
  ______ Depth: minimum 18 inches above choker stone layer.
  ______ Media mixed on-site (for smaller applications) or supplied by an approved vendor.
  ______ P-index: Between 20 and 30 for a media mix, *OR* between 7 and 21 mg/kg of P in the soil media (see Section 6.6 of Stormwater Design Specification No. 9)
  ______ Cation Exchange Capacity (CEC): Soils with a CEC exceeding 10 are preferred for pollutant removal.
  ______ Infiltration Rate: Between 1 to 2 inches per hour
  ______ Media mix: Equivalent to loamy sand, with the following consistent, homogenous composition:
    ______ 85% to 88% sand
    ______ 8% to 12% soil fines
    ______ 3% to 5% organic matter
    ______ Alternative: Use 100% sand for the first 18 inches of the filter, and add a combination of topsoil and leaf compost for the top 4 inches, where turf cover will be maintained.
    ______ The volume of the media mix should be 110% of the product of the surface area and the media depth, to account for settling.
_______ Filter fabric (side slopes):
  ______ Non-woven polyprene geotextile with a flow rate of > 110 gal./min./sq. ft. (e.g., Geotex 351 or equivalent).
  ______ Apply immediately above the underdrain only.
_______ Topsoil should be a 4-inch layer of loamy sand or sandy loam texture, with less than 5% clay content, a corrected pH of 6 to 7, and at least 2% organic content.
_______ Surface cover should be turf (as specified in the landscaping plan) or river stone.

_______ Check dam details:
- ______ Made of non-erosive material such as pressure-treated logs or timbers, wood from water-resistant tree species such as cedar, hemlock, swamp oak or locust, gabions, riprap, or concrete.
- ______ Check dams must be firmly anchored into the side slopes to prevent outflanking and be stable during the 10-year design storm.
- ______ The height of the check dam relative to the normal channel elevation should not exceed 12 inches. For greater than 12-inch high check dams or swale slopes greater than 4%, special features such as drop structures are required to ensure non-erosive flows.
- ______ Each check dam should have a minimum of one weep hole or a similar drainage feature so it can dewater after storms (for slopes less than 2%, at least 3 weep holes in each check dam).
- ______ Soil plugs, appropriate for Dry Swales of 4% or steeper slopes or with 12-inch high check dams, help minimize the potential for blow-out of the soil filter media beneath check dams, due to hydrostatic pressure from the upstream ponding.

_______ Erosion control fabric for side slopes: where flow velocities dictate, use woven biodegradable erosion control fabric or mats (EC2) that are durable enough to last at least two growing seasons.

C. Landscape Plan

_______ Provide a planting schedule and specifications (transport / storage / installation / maintenance)

_______ Plant selection must be appropriate for the site's vegetation climatic zone (4-8 in Virginia)

_______ Where Dry Swales receive runoff from road surfaces in areas of cold climate, they should be planted with salt-tolerant grass species.

_______ The construction contract should include a *Care and Replacement Warranty* that specifies a minimum survival for species planted of 75% after the first growing season, and a minimum effective ground cover of 75% for flat roofs and 90% for pitched roofs.

_______ Specify preservation measures for existing vegetation

E. Construction Notes

_______ Ideally, planned Dry Swale areas should be clearly marked off and remain *outside* the limits of land disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical, since swales are a key part of the natural drainage system at most sites. Therefore, temporary E&S controls such as dikes, silt fences, etc. should be integrated into the swale design throughout the construction sequence.

_______ Dry Swale areas *may* be used during construction as sites for temporary sediment traps or basins, provided the construction plans include notes and graphical details specifying the following:
- ______ The maximum excavation depth at the construction stage must be at least 1 foot above the post-construction installation.
- ______ The facility must contain an underdrain.
- ______ Showing the proper procedures for converting the temporary sediment controls to a permanent Dry Swale, including dewatering, cleanout and stabilization.

_______ Provide traffic control to avoid tracking mud and fine sediment and compacting the soil.

_______ Store materials in a protected area to keep them free from mud, dirt and other foreign materials.
- ______ Obtain filter media from an approved vendor and store it on an adjacent impervious area or on plastic sheeting.

_______ Where Dry Swales are constructed in the road or right-of-way, the construction sequence may need to be adjusted to account for traffic control, pedestrian access and utility notification.

_______ Construction sequence:
- ______ Construction inspections should occur before, during and after installation to ensure the bioretention facility is constructed according to specifications.
  - ______ Use detailed inspection checklists that require sign-offs by qualified individuals at critical states of construction, to ensure the contractor's interpretation of the plan is consistent with the designer's intent.
  - ______ Check the proposed site for existing utilities prior to any excavation.

    ______ After the first big storm, verify whether the sheet flow, shallow concentrated flow or fully concentrated flow assumed in the plan actually occurred in the field and verify that the swale drains completely within 6 hours. Adjust the plan as necessary.

______ The designer and the installer/contractor should have a pre-construction meeting, checking the boundaries of the CDA and the actual inlet elevations to ensure they conform to the original design.

    ______ The designer should clearly communicate, in writing, any project changes determined during the pre-construction meeting to the installer and the plan review/inspection authority.

______ Construction of the bioretention facility should begin only *after* site work is completed and the entire contributing drainage area has been stabilized with dense and healthy vegetation.

______ It will be necessary to divert flow while the Dry Swale is being constructed, until the filter bed and side slopes are fully stabilized.

______ Temporary E&S control measures (typically silt fence, diversion berms, EC fabric, etc.) to prevent sediment from moving into the filter media or stone base material during construction), to avoid clogging (particularly if the practice relies on infiltration), and to protect the facility's vulnerable side slopes from erosion during construction.

______ Ensure that pre-treatment structures are properly installed and working effectively.

______ Excavators or backhoes (with arms with adequate extension) should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions.

______ Rip, roto-till or otherwise scarify the swale's bottom soils to promote greater infiltration.

______ Correctly install geotextile fabric on the side slopes.

    ______ When laying out the geotextile, the width should include sufficient material to compensate for perimeter irregularities in the trench and for a 6-inch minimum overlap at the top of the excavation.

    ______ Place stones or other anchoring objects on the fabric at the trench sides to keep the trench open during windy periods.

______ Install and anchor the observation well(s) and, if used, install the underdrains.

    ______ Check elevations (underdrain inverts, inflow and outflow point inverts, depth of aggregate installations, etc.) and the surface slope.

    ______ Check aggregate material prior to installation to confim that it is clean and washed and meets specifications.

    ______ Provide the correct depth and type of aggregate layers above and below the underdrains.

    ______ Up-gradient ends of underdrains in the reservoir layer should be capped, but *not* the downstream ends.

    ______ Ensure there are no perforations in clean-outs and observation wells within 1 foot of the surface.

______ Place the filter media by hand (to avoid compaction and maintain porosity) in 12-inch lifts, with no machinery allowed directly on the media surface during or after construction, until the design top elevation is achieved.

    ______ Overfill the media above the proposed finished surface elevation to allow for natural settling. Lifts may be lightly watered to encourage settling.

    ______ After the final lift is placed, rake the media to level it, saturate it, and allow it to settle for at least a few days prior to installing plant materials. Check for settlement and add additional media, if needed, to achieve the design elevation.

______ Install check dams, driveway culverts and internal pre-treatment features, as specified in the plan.

______ Install erosion control fabric, prepare planting holes for any trees and shrubs, install the vegetation, and water accordingly.

______ Install any temporary irrigation equipment.

______ Install the plant materials as shown in the landscaping plan, and water them during weeks of no rain for the first two months following installation.

- ______ The construction contract should include a *Care and Replacement Warranty* to ensure that vegetation is properly established and survives during the first growing season following construction.
- ______ Implement any remaining permanent stabilization measures.
- ______ Log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

E. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.

- ______ Include a Maintenance Narrative which describes the long-term maintenance requirements of the facility and all components, including removal and disposal of trash, debris and sediment accumulations, periodic replacement of soil media, care of the vegetation, and mowing.

_______ Record a deed restriction, drainage easement, and/or other enforceable mechanism, including GPS coordinates of the area, to ensure the dry swale areas are not disturbed or converted to other uses.

_______ Provide sufficient facility access from the public ROW or roadway to both the bioretention facility and any pre-treatment practices.

IV. COMMENTS

By: ______________________ Date: ______________

8-A.12.0. WET SWALES: DESIGN CHECKLIST

(NOTE: Think of this practice as a linear constructed wetland)

Plan Submission Date____________________
Project Name____________________
Site Plan/Permit Number____________________
Practice No./Location on Site____________________
Owner____________________ Phone Number____________________
BMP Designer____________________ Phone Number____________________
General Contractor____________________ Phone Number____________________

______ **Signature and stamp of licensed professional design consultant and owner certification**

Plan Status

_______ Approved
_______ Not Approved

Legend:

___	- Complete
Inc.	- Incomplete/Incorrect
N/A	- Not Applicable

Facility Type: Level 1 ____________________ Level 2 ____________________

Hydraulic Configuration:

- ☐ On-line facility
- ☐ Off-line facility

Type of pretreatment facility:

- ☐ Check Dams (channel flow)
- ☐ Tree Check Dams (channel flow)
- ☐ Grass Filter Strip (sheet flow)
- ☐ Gravel or Stone Diaphragm (sheet flow)
- ☐ Gravel or Stone Flow Spreaders (concentrated flow)
- ☐ Other: ____________________
- ☐ None

I. SUPPORTING INFORMATION

_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design.

_______ Show the location of this BMP on the site map, including the following:

- ______ Swale area
- ______ Contributing drainage area (CDA) boundaries and acreage (should not exceed 5 acres).
- ______ Delineation of FEMA 100-year floodplain
- ______ Areas of site compensated for in water quality calculations

_______ Provide topography for the site area, showing that the slope of the CDA is between 1% and 2%.

- ______ Check dams can be used to reduce the effective slopes of the swale and lengthen the contact time to enhance treatment.
- ______ An alternative for steep slopes is the *Regenerative Conveyance System (RCS)*, which conveys water down the slopes through a series of step pools that provide treatment (see Stormwater Design Specification No. 11).

_______ Provide a soil map for site and area of facility, including the CDA.

_______ Provide soil boring locations and soil boring logs with Unified Soils Classifications and descriptions (at least one boring must be taken to confirm the underlying soil properties). Wet Swales work best when constructed over the more impermeable HSG-C or D soils.

_______ Confirm the depth to the seasonal high groundwater table.

- ______ NOTE: It is permissible for wet swales to intersect the water table; this may reduce pollutant removal and increase excavation costs.

_______ Identify potential conflicts with other (existing?) structural components (pipes, underground utilities, etc.).

_______ Wet Swales are not recommended for the following situations:

- ______ To treat runoff from stormwater hotspots, due to the potential interaction with the water table and the risk that hydrocarbons, trace metals and other pollutants could migrate into the groundwater.
- ______ Karst areas.
- ______ Residential areas, due to the risk of mosquito breeding.

II. COMPUTATIONS

A. Hydrology

_______ Determine the runoff curve number (pre- and post-developed conditions), providing the worksheets.

_______ Generate hydrographs (pre- and post-developed conditions) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)

_______ Determine the time of concentration (pre- and post-developed conditions), providing the worksheets.

_______ Confirm that there is adequate drainage area and/or base flow.

B. Hydraulics

_______ If designed as an on-line practice (Level 1 design), the swale must be designed with enough capacity to:

- ______ Convey runoff from the 2-year and 10-year design storms at non-erosive velocities with adequate freeboard.
- ______ Contain the 10-year flow within the banks of the swale with adequate freeboard. (tends to drive the surface dimensions).

_______ If designed as an off-line practice (Level 2 design), a bypass or diversion structure must be designed to divert the large storm (e.g., when the flow rate and/or volume exceeds the treatment volume) to an adequate channel or conveyance system.

- ______ The Wet Swale is then designed to meet the volume, velocity and residence time criteria for

_______ Wet Swales are designed based on peak flow rate – the maximum flow velocity of the channel must be less than 1 foot per second during a 1-inch water quality storm event

_______ The longitudinal slope of the channel should, ideally, be between 1% and 2% in order to avoid scour and short-circuiting within the channel; longitudinal slopes up to 4% are acceptable, but check dams will be necessary to reduce the effective slope in order to meet the limiting velocity requirements)

_______ Verify hydraulic capacity using Manning's Equation or an accepted equivalent method, such as erodibility factors and vegetal retardance

- ______ The flow depth for the peak treatment volume (1-inch rainfall) should be maintained at 3 inches or less
- ______ Manning's "n" value for grass channels should be 0.2 for flow depths up to 4 inches, decreasing to 0.03 at a depth of 12 inches (which applies to the 2-year and 10-year storms if an on-line application
- ______ Peak flow rates for the 2-year and 10-year frequency storms must be non-erosive or subject to site-specific analysis of the channel lining material and vegetation
- ______ The 10-year peak flow rate must be contained within the channel banks, with a minimum of 6 inches of freeboard

_______ Specify assumptions and coefficients used.

_______ Provide a stage-discharge table and curve (provide equations).

_______ Route post-development hydrographs for appropriate design storms (2-yr., 10-yr., or as required by watershed conditions) and safety storms (100-yr. or as required)

_______ Provide storm drainage and hydraulic grade line calculations.

_______ Calculations for peak flow depth and velocity should reflect any increase in flow along the length of the channel, as appropriate. If a single flow is used, the flow at the outlet should be used.

_______ The hydraulic residence time should be minimum of 9 minutes for the treatment volume (1-inch rainfall) design storm. If flow enters the channel at multiple locations, a 9-minute minimum hydraulic residence time should be demonstrated for each entry point, using equations in Stormwater Design Specification No. 3 (Grass Channels).

C. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA, pollutant load, pollutant load removal, and treatment volume requirements, all generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet)

_______ Indicate the treatment volume for extended detention (if added) with draw-down calculation

_______ Determine specific sizing/dimensions from criteria in Stormwater Design Specification No. 11.

III. PLAN REQUIREMENTS

A. BMP Plan View Information

_______ Show the limits of clearing and grading, noting that they should be identified and protected by acceptable signage, silt fence, snow fence, or other comparable barrier.

_______ Show the locations and dimensions of pre-treatment practices and all conveyance system outfalls into the swale

_______ Wet Swales are not subject to normal building setbacks, given their position in the landscape.

_______ Show the layout and dimensions of the Wet Swale.

- ______ A Wet Swale should be approximately 5% to 15% of the size of the CDA, depending on the amount of impervious cover (NOTE: The maximum contributing drainage area for a Wet Swale is 5 acres).
- ______ Surface dimensions are largely determined by the need to pass the 10-year design storm.
- ______ The minimum length may be achieved with multiple swale cells connected by culverts with energy dissipators.

_______ Ensure the proper geometry and orientation, to avoid short-circuiting:

- ______ A parabolic cross-sectional shape is preferred for hydraulic, maintenance and aesthetic purposes; a trapezoidal shape may be used as long as the soil filter bed boundaries lay in the flat bottom of the swale
- ______ Side slopes should be no steeper than 4H:1V to enable wetland plant growth; flatter slopes are encouraged, where space is available, to enhance pre-treatment of sheet flows entering the swale. Under no circumstances are the side slopes to be steeper than 3H:1V.
- ______ Wet Swales should have a bottom width of from 4 to 8 feet to provide adequate filtering area; if the swale will be wider than 8 feet, the designer should incorporate berms, check dams, level spreaders or multi-level cross-sections to prevent braiding and erosion of the swale bottom.

_______ Indicate the top-of-bank and swale bottom elevations

_______ Indicate the elevations of treatment volume and maximum design water surface elevations for all appropriate design storms and safety storms.

- ______ The average normal pool depth (dry weather) throughout the swale should be 6 inches or less.
- ______ The maximum temporary ponding depth in any single wet Swale cell should not exceed 18 inches at the most downstream point (e.g., at a check dam or driveway culvert).

_______ Show the location of check dams, if applicable:

- ______ Stone energy dissipators are required at the downstream toe of check dams to prevent erosion.
- ______ The check dam must be designed to spread runoff evenly over the Wet Swale's surface, through a depressed weir (in the center of the check dam) with a length equal to the bed width (sized to convey the depth of flow for the appropriate design storm).
- ______ Check dams must be spaced correctly:
  - ______ Cells formed by check dams or driveways should be at least 25 to 40 feet in length.

______ Check dams should also be spaced as needed to maintain the effective longitudinal slope of 2% for Level 1 Wet Swales or 1% for Level 2 Wet Swales.

_______ Show adequate maintenance access to the facility

B. BMP Section Views & Related Details

_______ Show cross-sections through the swale, showing:

______ Various water surface elevations (treatment volume and maximum design water surface elevations for all appropriate design storms and safety storms) and adequate freeboard.

______ Side slopes, top width, swale bank elevations: constructed height and settled height (allowing for 10% settlement).

______ Wetland planting areas.

_______ Ensure the proper geometry:

______ Wet Swales should be designed with a trapezoidal or parabolic cross-section. A parabolic shape is preferred for aesthetic, maintenance and hydraulic reasons.

______ Side slopes should be no steeper than 4H:1V to enable wetland plant growth; flatter slopes are encouraged, where space is available, to enhance pre-treatment of sheet flows entering the swale. Under no circumstances are the side slopes to be steeper than 3H:1V.

______ The longitudinal slope should be relatively flat (2% or less for a Level 1 design, and 1% or less for a Level 2 design), to allow for temporary ponding of the treatment volume within the channel. The minimum recommended slope is 0.5% (unless the swale is off-line), but slopes up to 4% are acceptable if check dams are used.

C. Check Dams

_______ Check dams should be composed of wood, concrete, stone, or other non-erodible material, or should be configured with elevated driveway culverts.

_______ Check dams should be underlain with filter fabric conforming to the following standards:

______ Needled, non-woven, polypropylene geotextile.

______ Grab Tensile Strength (ASTM D4632): ∃ 120 lbs.

______ Mullen Burst Strength (ASTM D3786): ∃ 225 lbs./sq. in.

______ Flow Rate (ASTM D4491): ∃ 125 gpm/sq. ft.

______ Apparent Opening Size (ASTM D4751): ∃ US #70 or #80 sieve

_______ Wood used for check dams should consist of pressure-treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.

_______ It is necessary to compute check dam materials, based on the surface area and depth used in the design computations.

_______ Check dams should be spaced based on the channel slope, as needed to increase residence time and provide adequate storage for the treatment volume (1-inch rainfall) or any additional volume attenuation requirements. The ponded water at a downhill check dam should not touch the toe of the upstream check dam.

_______ The maximum desired check dam height is 12 inches (for maintenance purposes). However, for challenging sites, a maximum of 18 inches can be allowed, with additional design elements to ensure the stability of the check dam and the adjacent and underlying soils The average ponding depth throughout the channel should be 12 inches.

_______ Armoring may be needed at the downstream toe of the check dam to prevent erosion.

_______ Check dams must be firmly anchored into the side-slopes to prevent outflanking; check dams must also be anchored into the channel bottom so as to prevent hydrostatic head from pushing out the underlying soils.

_______ Check dams must be designed with a center weir sized to pass the channel design storm peak flow (10-year storm event for man-made channels).

_______ Each check dam should have a weep hole or similar drainage feature so it can dewater after storms.

_______ Individual channel segments formed by check dams or driveways should generally be at least 25 to 40 feet in length.

D. Diaphragms

_______ Pea gravel used to construct pre-treatment diaphragms should consist of washed, open-graded, course aggregate between 3 and 10 mm in diameter and must conform to local design standards.

E. Landscape Plan

_______ Provide a planting schedule and specifications (transport / storage / installation / maintenance)

_______ Select plant materials appropriate for the site's vegetation climatic zone (6-8 in Virginia), emphasizing native plant materials.

- ______ Plant materials must be able to withstand both wet and dry periods as well as relatively high velocity flows within the swale.
- ______ Wet Swales should be planted with wet-footed species, such as sedges or wet meadow vegetation.
- ______ If the swale is adjacent to a roadway where winter conditions will require the use of road salts in the CDA, then salt-tolerant non-woody plant species should be specified.

_______ It may be advisable to incorporate sand or compost into the surface soils to promote a better growing environment.

_______ Specify preservation measures for existing vegetation

_______ The construction contract should include a *Care and Replacement Warranty* that specifies a minimum survival for species planted of 75% after the first growing season, and a minimum effective ground cover of 75% for flat roofs and 90% for pitched roofs.

D. Construction Notes

_______ Ideally, planned Wet Swale areas should be clearly marked off and remain *outside* the limits of land disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical, since swales are a key part of the natural drainage system at most sites. Therefore, temporary E&S controls such as dikes, silt fences, etc. should be integrated into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, and E&S control fabric should be used to protect the channel bottom.

_______ Wet Swale areas *may* be used during construction as sites for temporary sediment traps or basins, provided the construction plans include notes and graphical details specifying the following:

- ______ The maximum excavation depth at the construction stage must be at least 1 foot above the post-construction installation.
- ______ Show the proper procedures for converting the temporary sediment controls to a permanent Wet Swale, including dewatering, cleanout and stabilization.

_______ Wet Swale construction should begin only after the entire contributing drainage area has been stabilized with vegetation. Sediment accumulation must be removed during final grading to achieve the design cross-section.

_______ Ideally, Wet Swales should be constructed during months that are best for establishing vegetative cover without irrigation (February 15 – April 15; September 15 – November 15).

_______ It will be necessary to divert flow while the Wet Swale is being constructed, until the bed and side slopes are fully vegetated.

_______ Show applicable temporary E&S control measures.

_______ Construction sequence for BMP(s) and E&S controls:

- ______ Construction inspections should occur before, during and after installation to ensure the stormwater wetland is constructed according to specifications.
  - ______ Use detailed inspection checklists that require sign-offs by qualified individuals at critical states of construction, to ensure the contractor's interpretation of the plan is consistent with the designer's intent.

- ______ Check the proposed site for existing utilities prior to any excavation.
- ______ Install applicable temporary E&S Controls prior to construction.
- ______ Grade the channel to the final dimensions shown on the plan.
- ______ Install check dams, driveway culverts and internal pre-treatment features as shown on the plan
- ______ Fill material used to construct the check dams should be placed in 8- to 12-inch lifts and compacted to prevent settlement. The top of each check dam should be constructed level at the design elevation.
- ______ (Optional) Till the bottom of the channel to a depth of 1 foot and incorporate compost amendments according to Stormwater Design Specification No. 4.
- ______ Planting soil should be loam or sandy loam with a high organic content, placed by mechanical methods, and spread by hand to a depth of at least 4 inches for shallow wetlands.
    - ______ Planting soil should be tamped as directed in the design specifications, but it should not be overly compacted.
    - ______ After the planting soil is placed, it should be saturated and allowed to settle for at least one week prior to installation of plant materials.
    - ______ No machinery should be allowed to traverse over the planting soil during or after construction.
- ______ Redirect previously diverted flows into the Wet Swale to allow it to fill up to normal pool elevation.
    - ______ Wetland planting areas should be at least partially inundated during planting to promote plant survivability.
    - ______ Surveyed planting zones should be marked on the as-built or design plan, and the locations should be identified in the field, using stakes or flags.
- ______ Propagate the stormwater wetland between mid-April and mid-June, using three simultaneous techniques to propagate the emergent community over the wetland bed:
    - ______ Initial planting of container-grown wetland plant stock.
    - ______ Broadcast wetland seed mixes over the higher wetland elevations, to establish diverse emergent wetlands.
        - ______ Seeding of Switchgrass or wetland seed mixes as a ground cover is recommended for all zones above 3 inches below the normal pool elevation.
        - ______ Hand broadcasting or hydroseeding can be used to spread seed, depending on the size of the wetland cell.
- ______ After initial planting, a biodegradable E&S control fabric may be used, conforming to Standard and Specification 3.36 of the VESCH.
- ______ Prepare planting holes for any trees and shrubs, then plant materials as shown in the landscaping plan and water them weekly in the first two months.
- ______ Install goose protection for newly planted or newly growing vegetation, especially emergents and herbacious plants.
    - ______ Place netting, webbing, or string installed in a criss-cross pattern over the surface area of the wetland above the level of the emergent plants.
- ______ Implement any remaining permanent stabilization measures.
- ______ Conduct a final inspection, log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

E. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.

- ______ Include a Maintenance Narrative which describes the long-term maintenance requirements of the facility and all components, including removal and disposal of trash, debris and sediment accumulations, and care of the vegetation.

_______ Record a deed restriction, drainage easement, and/or other enforceable mechanism, including GPS coordinates of the area, to ensure the wet swale area is converted to other uses.

_______ Provide sufficient facility access from the public ROW or roadway to both the wet pond and any pre-treatment practices.

IV. COMMENTS

By: ______________________ Date: ______________

8-A.13.0. FILTERING PRACTICES: DESIGN CHECKLIST

-

Plan Submission Date____________________
Project Name____________________
Site Plan/Permit Number____________________
Practice No./Location on Site____________________
Owner____________________ Phone Number____________________
BMP Designer____________________ Phone Number____________________
General Contractor____________________ Phone Number____________________

______ **Signature and stamp of licensed professional design consultant and owner certification**

Plan Status

_______ Approved
_______ Not Approved

Legend:

___ - Complete
Inc. - Incomplete/Incorrect
N/A - Not Applicable

Facility Type: Level 1 ____________________ Level 2 ____________________

Facility Type:

- G Non-Structural Sand Filter
- G Surface Sand Filter
- ☐ Organic Media Filter
- ☐ Underground Sand Filter
- ☐ Proprietary Filter
- ☐ Other: __________________

Hydraulic Configuration:

- ☐ On-line facility
- ☐ Off-line facility

☐ **FILTER TREATS HOSPOT RUNOFF**

Pre-Treatment:

- G Wet or Dry Sedimentation Chamber designed as level spreaders and sized to accommodate 25% of the treatment volume
- G Forebay
- ☐ Compost-amended grass filter path
- ☐ Gravel Diaphragm
- ☐ Check Dam
- ☐ Engineered Level Spreader
- ☐ Proprietary device
- ☐ Other: __________________

I. SUPPORTING INFORMATION

_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design.
_______ Show the location of this BMP on the site map, including the following:
  ______ Filter facility area
  ______ Contributing drainage area (CDA) boundaries, acreage and land cover
  ______ Delineation of FEMA 100-year floodplain
  ______ Areas of site compensated for in water quality calculations
_______ Provide topography of the site area.
_______ Provide a soil map for site and area of facility, including the CDA
_______ Provide the soil boring locations and the soil boring logs with Unified Soils Classifications and soil descriptions (at least one boring must be taken to confirm the underlying soil properties).
  ______ At least one soil boring must be taken at a low point within the footprint of the proposed filtering practice to establish the depth to groundwater/bedrock and to evaluate the soil suitability
  ______ Confirm that there is a minimum of 2 feet separation distance between the seasonally high groundwater table and/or bedrock and the bottom invert of the filtering practice.
  ______ If karst is present, a detailed geotechnical investigation is recommended to ensure the installation does not aggravate potential karst impacts (e.g., sinkholes, etc.)

_______ Identify potential conflicts with other (existing?) structural components (pipes, underground utilities, etc.).
_______ Special conditions:
- ______ Filters work well in karst areas, assuming that they are water tight and that excavation does not extend into a karst layer.
- ______ In coastal plain settings, the Perimeter Sand Filter and the Non-Structural Sand Filter work best, subject to the following criteria:
  - ______ The combined depth of the underdrain and sand filter bed can be reduced to from 24 to 30 inches
  - ______ Consider maximizing the length of the filter or provide treatment in multiple connected cells.
  - ______ The minimum depth to seasonally high groundwater may be relaxed to 1 foot, as long as the filter is equipped with a large diameter underdrain (e.g., 6 inches) that is only partially efficient at dewatering the filter bed.
  - ______ Maintain an underdrain slope of at least 0.5% to ensure positive drainage and to tie it into the receiving ditch or conveyance system.
- ______ In steep terrain:
  - ______ Slope gradient contributing runoff to sand filters can be increased to 15%, as long as a two-cell, terraced design is used to dissipate erosive energy prior to the filter.
  - ______ The drop in elevation between cells should be limited to 1 foot and the slope should be armored with river stone or a suitable equivalent.
- ______ In cold climate of for winter performance (problem is ice forming over the filter bed):
  - ______ Place a weir between the pre-treatment chamber and filter bed to reduce ice formation.
  - ______ Extend the filter bed below the frost line to prevent freezing within the filter bed.
  - ______ Oversize the underdrain to encourage more rapid drainage and to minimize freezing of the filter bed.
  - ______ Expand the sediment chamber to account for road sand. Pre-treatment chambers should be sized to accommodate up ot 40% of the treatment volume.

II. COMPUTATIONS

A. Hydrology

_______ Determine the runoff curve number (pre- and post-developed conditions), providing the worksheets.
_______ Determine the time of concentration (pre- and post-developed conditions), providing the worksheets.
_______ Generate hydrographs (pre- and post-developed conditions) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)

B. Hydraulics

_______ The hydraulic head required for filters varies from 2 to 10 feet, depending on the design variant; sufficient hydraulic head is critical to the proper function of filtering systems.
_______ Confirm that the design will result in the facility dewatering within 40 hours after a storm event.
_______ Specify the assumptions and coefficients used.
_______ Provide a stage-storage table and curve
_______ Provide for large storm overflow or bypass
_______ Provide storm drainage and hydraulic grade line calculations.

C. Water Quality

_______ A maximum contributing drainage area (CDA) of 5 acres is recommended for surface sand filters, and a maximum CDA of 2 acres is recommended for perimeter or underground filters, to minimize clogging.

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA. For Level 1 designs, the contributing drainage area may contain some pervious area; for Level 2 designs, the CDA must be nearly 100% impervious (preferred condition).
_______ Determine the pollutant load, pollutant load removal, and treatment volume requirements, generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet).
_______ Keep in mind that Level 2 designs are sized for a treatment volume that is 25% greater than for Level 1 practices.
_______ Also, keep in mind that for Level 2 designs, the runoff reduction value (normally 0) may be increased if a second cell is used for infiltration or bioinfiltration (Bioretention Level 2). The RR credit should be proportional to the fraction of the treatment volume designed to be infiltrated.
_______ Determine specific sizing/dimensions from criteria in Stormwater Design Specification No. 12.

III. PLAN REQUIREMENTS

A. BMP Plan View Information

_______ Show the limits of clearing and grading, noting that they should be identified and protected by acceptable signage, silt fence, snow fence, or other comparable barrier.
_______ Show the layout and dimensions of the filtering facilities (one cell for Level 1 design; two cells for Level 2)
_______ Sand and organic surface filters typically consume approximately 2% to 3% of the CDA, while perimeter sand filters typically consume less than 1% of the CDA. Underground filters generally consume no surface area except for their manholes.
_______ NOTE: Surface area and storage volume of the filter media relates to the treatment volume (Equations 12.1 and 12.2 in Stormwater Design Specification No. 12)
_______ Ensure proper orientation to avoid short-circuiting
_______ Ensure adequate maintenance access to the facility
_______ Show the observation well location

B. BMP Section Views & Related Details

_______ Details will vary depending upon the type of filter employed:

1. Non-Structural Sand Filter – applied to sites less than 2 acres in size and essentially the same as a Bioretention Basin (Stormwater Design Specification No. 9), with the following exceptions:
_______ The bottom is lined with an impermeable filter fabric and *always* has an underdrain.
_______ The surface cover is sand, turf or pea gravel (*not* trees, shrubs, or herbaceous material).
_______ The filter media is 100% sand.
_______ The filter has two cells, with a dry or wet sedimentation chamber preceding the sand filter bed.

2. Surface Sand Filter (more economical)
_______ Designed with both the filter bed and sediment chamber located at ground level
_______ Normally constructed of pre-cast or cast-in-place concrete
_______ Usually designed to be off-line facilities, so that only the treatment volume is directed to the filter.
_______ Can be installed in the bottom of a dry Extended Detention Basin (see Stormwater Design Specification No. 15).

3. Organic Media Filter
_______ Essentially the same as surface sand filters, except the sand is replaced with an organic filtering medium (e.g., peat/sand filter, leaf compost filter, etc.) that is better at removing metals and hydrocarbons. However, organic media can actually leach soluble nitrate and phosphorus back into the discharge water.

4. Underground Sand Filter (more expensive, but they consume very little surface area)
_______ Filtering components are installed underground

5. Perimeter Sand Filter (more economical)

_______ Incorporates a sediment chamber and filter bed, but flow enters through grates, usually at the edge of a parking lot.

_______ Usually designed as an on-line practice (i.e., all flows enter the system), where larger flows bypass by entering an overflow chamber

_______ Requires only about 2 feet of hydraulic head, so can be used on sites with little topographic relief

6. Proprietary Filters

_______ Follow the design criteria provided by the manufacturer

_______ Conveyance and Overflow:

- ______ For off-line filter systems, show the internal flow splitter or overflow device that bypasses runoff from larger storm events around the filter.
- ______ For on-line filter systems, show how the device will safely pass the local design storm(s) (1-year and/or 10-year storms) without re-suspending or flushing previously trapped material.
- ______ Ensure that the facility will dewater within 40 hours after a storm event.
- ______ Filtering practices typically have an impermeable liner meeting the following criteria:
  - ______ Needled, non-woven polypropylene geotextile (do *not* use heat-set or heat-calendared fabrics)
  - ______ Grab Tensile Strength (ASTM D4632) = ∃ 120 lbs.
  - ______ Mullen Burst Strength (ASTM D3786) = ∃ 225 lbs./sq. in.
  - ______ Flow Rate (ASTM D4491) = ∃ 125 gpm/sq. ft.
  - ______ Apparent Opening Size (ASTM D4751) = US #70 or #80 sieve.

_______ Underdrain:

- ______ Pipes comply with AASHTO M252 and ASTM F405
- ______ If the underdrain must meet ASTM F758, it must be perforated with slots that have a maximum width of 3/8-inch and provide a minimum inlet area of 1.76 sq. in. per linear foot of pipe.
- ______ If underdrain meets ASTM F949, it must be perforated with slots that have a maximum width of 3/8-inch and provide a minimum inlet area of 1.5 sq. in. per linear foot of pipe.
- ______ Underdrain pipe with precision-machined slots is preferred to pipe with standard round-hole perforations.
- ______ The stone jacket for the underdrain must meet VDOT #57 stone specifications or the ASTM equivalent (1-inch maximum diameter).

_______ Filter Media:

- ______ Normal filter media consists of clean, washed medium aggregate concrete sand with individual grains between 0.2 and 0.04 inches in diameter (AASHTO M-6/ASTM C-33)
- ______ Organic media can be used, such as a peat/sand mixture or a leaf compost mixture, but this is not recommended unless metals and hydrocarbons are a particular issue in site runoff

_______ Surface Cover:

- ______ For surface sand filters, surface cover should consist of a 3-inch layer of topsoil on top of a non-woven filter fabric laid above the sand layer (pea gravel inlets in the topsoil layer where sheet flow enters, at margins around the filter bed, or at locations in the middle of the bed, to promote infiltration).
- ______ For underground sand filters, surface cover should have a pea gravel layer on top of a coarse non-woven filter fabric laid over the sand layer.

_______ Media depth can range from 12 to 18 inches.

_______ Maintenance Reduction Design Features:
- ______ Observation wells and cleanouts (facilitates inspection and maintenance)
  - ______ Surface sand filters should include an observation well, consisting of a 6-inch diameter non-perforated PVC pipe fitted with a lockable cap.
  - ______ Install the observation well flush with the ground surface.
  - ______ Typically, a cleanout pipe will be tied into the end of each underdrain pipe run.
  - ______ The portion of the cleanout pipe/observation well in the underdrain layer should be perforated.
  - ______ Provide at least one cleanout pipe for every 2,000 sq. ft. of filter surface area.
- ______ Good maintenance access must be provided, such that a vacuum truck or similar equipment can get close enough to the sedimentation chamber and filter to perform cleanouts.
- ______ Installing media depths deeper than 18 inches can facilitate the removal of 1 to 3 inches of sand during maintenance without have to necessarily replace it.
- ______ Access to the headbox and clearwell of *underground* sand filters must be provided by manholes at least 30 inches in diameter, along with steps to the areas where maintenance will occur.
- ______ Install stormwater filters at the site so that inspection and maintenance personnel can easily see them. Provide adequate signs or markings at manhole access points for underground filters.
- ______ For underground filters, note that special OSHA rules and training apply to protect workers that must access them.

C. Landscape Plan

_______ Consider the importance of aesthetics and visual characteristics (foliage form, texture, color, etc.)
_______ Consider visibility, traffic considerations and other safety issues
_______ Provide a planting schedule and specifications (transport / storage / installation / maintenance)
_______ Plant selection appropriate for the site's vegetation climatic zone (4-8 in Virginia) , emphasizing native species.
_______ Specify preservation measures for existing vegetation
_______ Where applicable, ensure that topsoil / planting soil is included in final grading

D. Construction Notes

_______ The future location of filtering practices may be used as the site of a temporary sediment trap or basin during site construction, as long as the design elevations are set with final cleanout and conversion in mind.
- ______ The bottom elevation of the filtering practice should be lower than the bottom elevation of the temporary sediment basin.
- ______ Appropriate procedures must be implemented to prevent discharge of turbid waters when the temporary basin is converted to the filtering practice.
- ______ Then the sediment basin must be dewatered, dredged and regraded to the design dimensions for the post-construction stormwater filter.

_______ Construction sequence for filtering practices and E&S controls
_______ Stabilize the drainage area.
- ______ Construct filtering practices only *after* the CDA to the facility is completely stabilized.

_______ Install E&S controls for the filtering practice.
- ______ It is extremely important that stormwater is diverted around the filtering practice as it is being constructed, in order to prevent sediment from clogging the filter bed during construction.
- ______ Install silt fence around the perimeter of the sand filter.
- ______ Install erosion control fabric on exposed side-slopes with gradients exceeding 4H:1V.
- ______ Rapidly stabilize exposed soils around the filter by hydro-seed, sod, mulch or other locally-approved method of soil stabilization.

_______ Assemble construction materials, make sure they meet design specifications, and prepare staging areas

_______ Clear and strip the project area to the desired subgrade.
_______ Excavate/grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the filtering practice.
_______ Install the filter structure
- ______ Check all design elevations (concrete vaults for surface, underground and perimeter sand filters).
- ______ Upon completion of the filter structure shell, plug inlets and outlets temporarily and fill the structure with water to the brim to check for water-tightness (maximum allowable leakage is 5% of the water volume in a 24-hour period).
- ______ If the structure fails the test, perform repairs to make the structure watertight before any sand is place into it.

_______ Install the gravel, underdrains, and choker layer of the filter.
_______ Place the filter media:
- ______ Spread sand across the filter bed in 1 foot lifts up to the design elevation.
- ______ Manually rake the sand.
- ______ Add clean water until the sedimentation chamber and filter bed are completely full.
- ______ Allow the facility to drain, hydraulically compacting the sand layers.
- ______ After 48 hours of draining and drying, refill the structure to the final top elevation of the sand filter bed.

_______ Filter fabric installation:
- ______ Install the permeable filter fabric over the sand.
- ______ Add a 3-inch topsoil layer and pea gravel inlets.

_______ Immediately stabilize with permanent grass species.
- ______ Water the grass as needed to develop a vigorous grass cover (do not activate the filter system until vigorous cover is present)

E. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.
- ______ Include a Maintenance Narrative which describes the long-term maintenance requirements of the facility and all components, including removal and disposal of trash, debris and sediment accumulations, periodic replacement of soil media, care of the vegetation, and mowing.

_______ Record a deed restriction, drainage easement, and/or other enforceable mechanism, including GPS coordinates of the area, to ensure the bioretention areas are not disturbed or converted to other uses.
_______ Provide sufficient facility access from the public ROW or roadway to both the filtration facility and any pre-treatment practices.
_______ To prevent freezing in cold climates and winter weather, require or clearly recommend that filters be inspected before the onset of winter (prior to the first freeze) to dewater wet chambers and scarify the filter surface.

IV. COMMENTS

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By: ______________________________ Date: ____________________

8-A.14.0. CONSTRUCTED WETLANDS: DESIGN CHECKLIST

Plan Submission Date____________________
Project Name____
Site Plan/Permit Number____
Practice No./Location on Site____
Owner____ Phone Number__________________
BMP Designer______________________________________ Phone Number__________________
General Contractor__________________________________ Phone Number__________________

______ **Signature and stamp of licensed professional design consultant and owner certification**

Plan Status

_______ Approved
_______ Not Approved

Legend:
- ___ - Complete
- Inc. - Incomplete/Incorrect
- N/A - Not Applicable

Facility Type: Level 1 ____________________________ Level 2 ______________________________

Hydraulic Configuration:
- ☐ On-line facility
- ☐ Off-line facility

Type of wetland:
- ☐ Constructed Wetland Basin (Level 1 – emergent))
- ☐ Constructed multi-cell wetland (Level 2 – emergent and forest)
- ☐ Constructed multi-cell pond/emergent wetland combination (Level 2)

Type of Pre-Treatment Facility:
- ☐ Sediment forebay (above ground)
- ☐ Vegetated buffer area
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: ___________________

I. SUPPORTING INFORMATION

_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design.
_______ Show the location of this BMP on the site map, including the following:
  ______ The basin pool area
  ______ The contributing drainage area (CDA) boundaries, acreage and land cover, sufficient to sustain a permanent water level within the constructed wetland.
  ______ Delineation of FEMA 100-year floodplain
  ______ Areas of the site compensated for in water quality calculations
_______ Provide topography of the site area, including the constructed wetland area.
_______ Provide a geotechnical report with recommendations and earthwork specifications and a description of any borrow area involved
_______ Provide a soil map for site and area of facility, showing CDA and facility boundaries
_______ Provide soil boring locations and soil boring logs with Unified Soils Classifications and soil descriptions.
  ______ Borings should be taken below the proposed embankment, in the vicinity of the proposed outlet area, and in at least two locations within the planned wetland treatment area.
  ______ Determine the physical characteristics of the soils regarding:
    ______ Suitability for use as structural fill or spoil.
    ______ Bearing capacity, buoyancy, etc. pertaining to outlet structure design.
    ______ Compaction/composition needs for the embankment.
    ______ Evaluation of potential infiltration losses (and the consequent need for a liner).

______ Depth to bedrock.
______ Depth to seasonal high groundwater table (NOTE: It is permissible for wet swales to intersect the water table; this may reduce pollutant removal and increase excavation costs).

_______ If karst is present, a detailed geotechnical investigation is recommended to ensure the constructed wetland does not aggravate potential karst impacts (e.g., sinkholes, etc.):
______ Must maintain at least 3 feet of vertical separation from the underlying karst layer.
______ Must employ an impermeable liner that meets the requirements of Stormwater Design Specification No. 13.
______ Must use shallow, linear and multiple-cell wetland configurations rather than deep basin configurations (e.g., a pond/wetland or ED wetland).

_______ Constructed wetlands are ideal for coastal settings with flat terrain, low hydraulic head and high water table conditions:
______ Choose shallow, linear and multiple-cell configurations
______ Acceptable to excavate below the water table, as follows:
______ 6 inches below to provide the requisite hydrology for wetland planting zones.
______ Up to 3 feet below for micro-pools, forebays and other deep pool features.
______ The volume below the seasonably high groundwater table may count toward the Treatment Volume, as long as the other primary geometric and design requirements for the wetland are met (e.g., flow path, microtopography, etc.)
______ Plant selection should focus on species that are wet-footed and can tolerate some salinity.
______ Consider creating forested wetlands, since a greater range of coastal plain tree species (Atlantic White Cedar, Bald Cypress, Swamp Tupelo, etc.) can tolerate periodic inundation.
______ Consider using the Regenerative Conveyance System (RCS) where there is considerable drop in elevation from the channel to the outfall location (see Stormwater Design Specification No. 13).

_______ Constructed wetlands are not effective at sites with steep terrain.
______ May be able to terrace wetland cells in a linear configuration, as with the Regenerative Conveyance System.

_______ Where cold winter climates are typical, make the following adjustments:
______ Treat larger runoff volumes in the spring by adopting seasonal operation of the permanent pool.
______ Plant salt-tolerant vegetation (to deal with higher chloride content of road salts).
______ Do not submerge inlet pipes and provide a minimum 1% pipe slope to discourage ice formation.
______ Locate low-flow orifices so they withdraw at least 6 inches below the typical ice layer.
______ Angle trash racks to prevent ice formation.
______ Over-size the riser and weir structures to avoid ice formation and freezing pipes.
______ If road sanding is prevalent in the CDA, increase the forebay size to accommodate additional sediment loading.

_______ Constructed wetlands are generally *not* recommended in watersheds containing trout streams, due to the potential for stream warming, unless:
______ All other upland runoff reduction opportunities have been exhausted.
______ The Channel Protection Volume has not been provided through other means.
______ A linear/mixed wetland design is applied to minimize stream warming.

_______ A constructed wetland should *not* be built within an existing perennial stream or natural wetland nor should a constructed wetland discharge to jurisdictional waters without local/state/federal approvals and the necessary permit(s).
______ Constructed wetlands built for stormwater management purposes are typically *not* considered jurisdictional wetlands, but the designer should confirm this with applicable wetland regulatory authorities.

_______ Identify potential conflicts with other (existing?) structural components (pipes, underground utilities, etc.).

_______ The designer should check to see whether sediments removed from the forebay can be spoiled (deposited) on-site or must be hauled away.

II. COMPUTATIONS

A. Hydrology

_______ Determine the runoff curve number determinations (pre- and post-developed conditions), providing the worksheets.
_______ Determine the time of concentration (pre- and post-developed conditions), providing the worksheets.
_______ Generate hydrographs (pre- and post-developed conditions) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)
_______ Ensure that there is adequate drainage area and/or water balance from groundwater, runoff or baseflow so the wetland will not go completely dry after a 30-day summer drought.

B. Hydraulics

_______ Specify assumptions and coefficients used.
_______ Typically, 2 to 4 feet of hydraulic head are need to drive flow through the wetland.
_______ Provide a stage-storage table and curve
_______ Weir/orifice control analysis for riser structure discharge openings and riser crest.
    ______ Carefully design the low-flow orifice to minimize clogging, as follows:
        ______ Recommend a minimum 3-inch diameter orifice to minimize clogging of an outlet or extended detention pipe when it is surface-fed (still susceptible to clogging from floating vegetation and debris).
        ______ Smaller openings (down to 1-inch in diameter) are permissible, using internal orifice plates within the pipe.
        ______ All outlet pipes should be adequately protected by trash racks, half-round CMP, or reverse-sloped pipes extending to mid-depth of the micropool.
_______ Barrel: conduct an inlet/outlet control analysis
_______ Conduct a riser/outlet structure flotation analysis (factor of safety = 1.25 min.).
_______ Provisions for use as a temporary sediment basin riser with clean out schedule & instructions for conversion to a permanent facility.
_______ Conduct an emergency spillway adequacy/capacity analysis (100-year design storm) with required embankment freeboard.
_______ Provide for large storm overflow or bypass
_______ Provide a stage-discharge table and curve (provide equations).
_______ Route post-development hydrographs for appropriate design storms (1-yr., 10-yr., or as required by watershed conditions) and safety storms (100-yr. or as required)
_______ Provide storm drainage and hydraulic grade line calculations.

C. Downstream impacts

_______ Conduct a danger reach study.
_______ Evaluate 100-year floodplain impacts.
_______ Provide downstream hydrographs at critical study points.
_______ Demonstrate safe conveyance to an “adequate” receiving channel.
    ______ If the receiving channel is natural and (1) has never been enhanced or “restored, OR (2) if stream channel erosion or localized flooding is an existing predevelopment condition, then conduct appropriate “energy balance” calculations to demonstrate safe conveyance from the facility to the receiving channel" (provide computations).

D. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA, pollutant load, pollutant load removal, and treatment volume requirements, all generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet)
_______ Calculate the treatment volume for extended detention (if added) with draw-down calculation
_______ Determine specific sizing/dimensions from criteria in Stormwater Design Specification No. 13.

III. PLAN REQUIREMENTS

A. BMP Plan View Information

_______ Show limits of clearing and grading, noting that they should be identified and protected by acceptable signage, silt fence, snow fence, or other comparable barrier.
_______ Setbacks (Note: local codes rule):
- ______ Minimum 10 feet from property lines.
- ______ Minimum 25 feet from building foundations.
- ______ Minimum 50 feet from septic system drainfields.
- ______ Minimum 100 feet from private wells.

_______ Pre-Treatment:
- ______ Show all pre-treatment practices.
- ______ A sediment forebay should be considered an integral pre-treatment practice for all constructed wetlands.
  - ______ A forebay should be located at every major inlet to trap sediment and preserve the capacity of the main wetland treatment cell.
  - ______ A major inlet is any individual storm drain inlet pipe or open channel conveying runoff from at least 10% of the wetland's CDA.
  - ______ The forebay is considered a separate cell in both Level 1 and Level 2 designs, formed by an acceptable barrier (e.g., earthen berm, concrete weir, gabion baskets, etc.)
  - ______ The forebay should be at least 4 feet deep and equipped with a variable width aquatic bench around the perimeter, for safety purposes. The aquatic bench should be 4 to 6 feet wide at a depth of 1 to 2 feet below the water surface, transitioning to zero width at grade.
  - ______ Show the location of the metered rod that monitors long-term sediment accumulation (in the center of the pool, as measured lengthwise along the low flow water travel path).
  - ______ The bottom of the forebay may be hardened (e.g., with concrete, asphalt, or grouted riprap) to make sediment removal easier.

_______ Show the locations of all conveyance system outfalls into basin
_______ Show the layout and dimensions of basin features: permanent pool, sediment forebay, embankment, emergency spillway. basin side slopes, basin bottom, etc.
- ______ The footprint is typically *less* than 3% of the CDA for Level 1 designs and *more* than 3% of the CDA for Level 2 designs.

_______ Pool geometry
- ______ Show the wet/dry weather flow paths
- ______ Reflect the proper length-to-width ratio as specified in the BMP design specifications
- ______ Reflect the proper orientation to avoid short-circuiting
- ______ Reflect the side slopes (H:V) of basin storage area and embankment (upstream and downstream slopes)
- ______ Provide an aquatic bench for safety

_______ Indicate the location of outlet protection per VE&SCH Std. & Spec. 3.18
_______ Indicate the top-of-bank and basin bottom elevations
_______ Indicate the elevations of the permanent pool, the treatment volume and the maximum design water surface elevations for all appropriate design storms and safety storms
_______ Snow any shoreline protection measures
_______ Show the location and dimensions of the riser and barrel
_______ Identify the pool depth zones on the plan

_______ Identify the constructed wetland/shallow marsh areas on the plan
_______ Provide basin liner specifications
_______ Provide sufficient maintenance access to the forebay, safety benches, riser structure, embankment, emergency spillway, basin shoreline, extended drawdown device, principal spillway outlet, stilling basin, toe drains, and likely sediment accumulation areas. The access road must:
- ______ Be constructed of load bearing materials able to withstand the expected frequency of use.
- ______ Have a minimum width of 12 feet.
- ______ Possess a maximum profile grade of 15%.
- ______ Have sufficient turn-around area.
- ______ A maintenance right-of-way or easement must extend to the stormwater pond from a public or private road.

B. BMP Section Views & Related Details

1. Pre-Treatment

_______ The forebay should be sized to hold 0.25 inch of runoff per impervious acre of the CDA, but no less than 0.1 inch per impervious acre.
- ______ For smaller stormwater facilities, a more appropriate sizing criterion of 10% of the total required pool or detention volume may be more practical.
- ______ This volume should be a maximum of 4 feet deep (or a depth determined by the summer drought water balance) near the inlet to adequately dissipate turbulent inflow without re-suspending previously deposited sediment, and then transition to a depth of 1 foot at the entrance to the first wetland cell.

_______ The forebay should be equipped with a variable width aquatic bench around the perimeter of the 4-foot depth, for safety purposes. The aquatic bench should be4 to 6 feet wide at a depth of 1 to 2 feet below the water surface, transitioning to zero width at grade.
_______ The volume of the forebay is part of the treatment volume of the stormwater basin for which it provides pre-treatment.
- ______ However, for dry facilities, the forebay does *not* represent available storage volume if it remains full of water.
- ______ A dry forebay must be carefully designed to avoid the resuspension of previously deposited sediments.

_______ The total volume of all forebays should be at least 15% of the total Treatment Volume. The relative size of individual forebays should be proportional to the percentage of their total inflow to the wetland.
_______ Separation between the forebay and the main basin may be achieved through the use of an earthen berm, gabion baskets, concrete, or a riprap wall.
_______ A designed overflow section should be constructed on the top of the separation to allow flow to exit the forebay at non-erosive velocities during the 2-year and 10-year frequency design storms.
- ______ The overflow section may be set at the permanent pool elevation or the extended detention volume elevation.

_______ The bottom of the forebay(s) may be hardened (e.g., with concrete, asphalt, or grouted rip-rap) to make sediment removal easier.
_______ Providing a hardened access or staging pad adjacent to the forebay helps protect the forebay and basin from excessive erosion from heavy equipment operation used for maintenance.
_______ Provide a typical grading section through the forebay, including typical side slopes, aquatic bench, shoreline protection, etc.

2. Wetland Cells

_______ Since most constructed wetlands are on-line facilities, they need to be designed to safely pass the maximum design storm (e.g., the 10-year and 100-year design storms).

- ______ Ponding depths for the more frequent Treatment Volume storm (1-inch rainfall) and Channel Protection storm (1-year event) are limited in order to avoid adverse impacts to plant materials.
- ______ Overflow for the less frequent 10- and 100-year storms should likewise be carefully designed to minimize the depth of ponding (a maximum of 4 feet over the wetland pool is recommended).
- ______ The use of flashboard risers is strongly recommended to control or adjust water elevations in wetlands constructed on relatively flat terrain.
- ______ Alternatively, a weir can be designed to accommodate passage of larger storms flows at relatively low ponding depths.
- ______ Level 1 designs may incorporate extended detention that meets a maximum of 50% of the treatment volume or up to 12 inches of detention storage above the wetland pool (for channel protection); Level 2 designs may *not* incorporate extended detention.

_______ Internal design geometry:

- ______ Internal design geometry and depth zones are critical in maintaining the pollutant removal capability and plant diversity of constructed wetlands.
- ______ When feasible, wetlands should be irregularly shaped with long, sinuous flow paths, multiple cells (Level 2), and a high ratio of surface area to volume (see Stormwater Design Specification No. 13).
- ______ Flow Path:
  - ______ Overall flow path through the wetland (length-to-width ratio):
    - ______ Level 1 design: 2L:1W.
    - ______ Level 2 design: 3L:1W.
  - ______ Ratio of the shortest flow path (closest inlet to the outlet) to the overall length:
    - ______ Level 1 design: 0.5.
    - ______ Level 2 design: 0.8.
    - ______ If unable to meet these targets, then the drainage area served by these "closer" inlets should constitute no more than 20% of the total CDA.
- ______ Side slopes should be from 4H:1V to 5H:1V to promote better establishment and growth of wetland vegetation, provide for easier maintenance, and create a more natural appearance.
- ______ The slope profile within individual wetland cells should generally be flat from inlet to outlet (adjusting for microtopography). The recommended elevation drop between wetland cells should be no more than 1 foot.

_______ Proper surface area/depth allocations for permanent pool/shallow marsh/constructed wetland.

- ______ Indicate the elevations of permanent pool, treatment volume and maximum design water surface elevations for all appropriate design storms and safety storms
- ______ Pool depths:
  - ______ Level 1 wetlands have a uniform depth with the mean pool depth greater than 1 foot.
  - ______ Level 2 wetlands have variable depths with the mean pool depth # 1 foot.
- ______ At least 25% of the Treatment Volume must be provided in at least three (3) deeper pools of from 18 to 48 inches, located at the inlet (forebay), center, and outlet (micropool) of the wetland.
- ______ High Marsh Zone: At least 70% of the wetland surface must exist in the high marsh zone (-6 inches to +6 inches, relative to normal pool elevation)
- ______ Transition Zone: The **Low Marsh Zone** (-6 inches to -18 inches below the normal pool elevation) is ***no longer an acceptable wetland zone***, and is only allowed as a short transition zone from the deeper pools to the high marsh zone.
  - ______ This transition zone should have a maximum slope of 5H:1V, or preferably flatter, from the deep pool to the high marsh zone.
  - ______ It is advisable to install biodegradable erosion control fabrics or similar materials during construction to prevent erosion and slumping of this transition zone.

______ Micro-topographic features (mix of above-pool vegetation, shallow pools and deep pools) that promote dense and diverse vegetative cover (Level 2 designs require at least two of the following):
______ Tree peninsulas, high marsh wedges or rock filter cells configured perpendicular to the flow path.
______ Tree islands above the normal pool elevation and maximum extended detention zone, formed by coir fiber logs.
______ Inverted root wads or large woody debris.
______ Gravel diaphragm layers within high marsh zones.
______ Cobble sand weirs.
______ Additional deeper pools.

3. Embankment (or dam)

_______ Type of embankment:
______ Homogenous embankment
______ Zoned embankment

_______ The earthen embankment must be designed to be stable against any force condition or combination of force conditions that may develop during the life of the structure (including differential settlement within the embankment, seepage through the embankment and foundation, or sharing stresses within the embankment and foundation) and is dependent upon:
______ Construction materials
______ Foundation conditions
______ Embankment height and cross-section geometry
______ Normal and maximum pool levels
______ Purpose of structure (i.e., retention, extended detention, etc.).

_______ Embankment geometry:
______ Top of dam elevations: constructed height and settled height (allowing for 10% settlement).
______ Height (based on the freeboard requirements): There must be at least 1 foot of freeboard between the maximum 100-year storm water surface elevation (WSE) to the lowest point on the top of the embankment (excluding the emergency spillway).
______ An embankment *without* an emergency spillway must provide at least 2 feet of freeboard between the maximum 100-year storm water surface elevation (WSE) to the lowest point on the top of the embankment.
______ NOTE: The spillway design storm WSE, if specified, may be substituted for the 100-year storm WSE in either of the above situations.
______ Top width varies with embankment height and should be shaped to provide positive drainage.
______ The top of the embankment must be level in order to avoid possible overtopping in one location in cases of extreme storms or spillway failure.
______ Embankment slopes should be no steeper than 3H:1V, if feasible, with a maximum combined upstream and downstream slope of 5:1 (i.e., 3H:1V downstream face and 2H:1V upstream face).
______ For embankments exceeding 15 feet in height, a 6 to 10 foot wide bench should be provided at intervals of 10 to 15 feet of height, particularly if slopes are steeper than 3H:1V.

_______ The embankment cross-section must be designed to provide an adequate factor of safety to protect against sliding, sloughing, or rotation in the embankment or foundation. Slope stability depends upon:
______ Physical characteristics of the fill materials
______ Configuration of the site
______ Foundation materials
______ Shear strength
______ Compressibility
______ Permeability

_______ Internal drainage systems in embankments (e.g., drainage blankets, toe drains, etc.) should be designed so that the collection conduits discharge downstream of the embankment at a location where access for observation is possible by maintenance personnel.
_______ Adequate erosion protection is recommended along the contact point between the face of the embankment and the abutments, where runoff concentrates.
    ______ Evaluate whether a gutter surface other than sod is necessary (riprap is generally preferred over a paved concrete gutter).
_______ Trees, shrubs or any other woody plants should not be planted or allowed on the embankment or adjacent areas extending at least 25 feet beyond the embankment toe and abutment contacts.
_______ Indicate the top of embankment elevations: constructed height and settled height (allowing for 10% settlement).
_______ Indicate the elevation of the crest of the emergency spillway.
_______ Indicate the emergency spillway, with side slopes.
_______ Indicate the emergency spillway inlet, level, and outlet sections.
_______ Show the existing ground and proposed improvements profile along the center line of the embankment.
_______ Show the existing ground and proposed improvements profile along the center line of the principal spillway
_______ Provide a typical grading section through the pond, including typical side slopes with the aquatic bench, shoreline protection, etc.
_______ Show the existing ground and proposed improvements along the center line of the emergency spillway
_______ Show the dimensions of zones for any zoned embankment

4. Seepage Control

_______ The contact point between the embankment soil, the foundation material, and the conduit is the most likely location for *piping* to occur, due to the discontinuity in materials and the difficulty in compacting the soil around the pipe.
_______ All utility conduits (except the principal spillway) should be installed away from the embankment.
    ______ When utility conduits through the embankment cannot be avoided, they should meet the requirements for spillways:
        ______ Watertight joints
        ______ No gravel bedding
        ______ Restrained to prevent joint separation due to settlement
_______ Phreatic line (4:1 slope measured from the principal spillway design high water elevation) is the upper limit of the *saturation zone*..
    ______ At a minimum, this should be the 10-year design storm water surface elevation.
    ______ If the phreatic line intersects the downstream slope of the embankment, a qualified soil scientist should be consulted to decide if additional controls, such as an internal drain, are needed.
_______ Seepage control should be included in the design if the following conditions exist:
    ______ Pervious layers in the foundation are not intercepted by the cutoff.
    ______ Possible seepage from the abutments may create a wet embankment.
    ______ The phreatic line intersects the downstream slope.
    ______ Special conditions exist that require drainage to ensure a stable embankment.
_______ Seepage may be controlled by:
    ______ A foundation, abutment or embankment drains.
    ______ A downstream drainage blanket.
    ______ A downstream toe drain (often desirable for homogeneous embankments).
    ______ A combination of these measures.
_______ Seepage along pipe conduits that extend through an embankment should be controlled by use of the following to prevent piping failures along conduit surfaces:
    ______ Anti-seep collar (provide detail).
        ______ The Bureau of Reclamation, the U.S. Army Corps of Engineers, and the USDA *no longer recommend* the use of anti-seep collars, in deference to *graded filters*

or *filter diaphragms* and *drainage blankets* (more complex to design, but less complicated and more cost-effective to construct and allow for easier placement of fill material).

- ______ Size, based on the length of pipe in the saturation zone (aim is a minimum 15% increase in seepage length).
- ______ Spacing and location of collars on barrel:
  - ______ Maximum collar spacing is 14 times the minimum projection above the pipe.
  - ______ Minimum collar spacing is 5 times the minimum projection above the pipe.
  - ______ Collar dimensions should extend a minimum of 2 feet in all directions around the pipe.
- ______ Anti-seep collars should be placed within the saturation zone. Where the spacing limit will not allow this, then at least one collar must be in the saturation zone.
- ______ All anti-seep collars and their connections to the conduit should be completely water-tight and made of material compatible with the conduit. NOTE: Dimple bands are *not* considered water-tight.
- ______ Metals must be shielded from dissimilar materials with rubber or plastic insulation at least 24 mils thick.
- ______ Anti-seep collars should be placed a minimum of 2 feet from pipe joints unless flanged joints are used.
- ______ Collars size should be calculated using the procedure specified in Chapter 13 of the *Virginia Stormwater Management Handbook (2011).*

______ The embankment filter and drainage diaphragm should be designed by a professional geotechnical engineer.

- ______ These devices channel seepage flow through a filter of fine graded material, such as sand, which traps any embankment material being transported.
- ______ The flow is then conveyed out of the embankment through a perforated toe drain or other acceptable technique.
- ______ The critical design element: the filter material grain size distribution is based on the grain size distribution of the embankment fill and foundation material.
  - ______ The diaphragm should consist of sand, meeting fine concrete aggregate requirements (at least 15% passing the No. 40 sieve, but no more than 10% passing the No. 100 sieve).
  - ______ The diaphragm should be a minimum of 3 feet thick and should extend vertically upward and horizontally at least 3 times the pipe diameter and vertically downward at least 24 inches beneath the barrel invert, or to rock, whichever is encountered first.
  - ______ The diaphragm should be placed immediately downstream of the cutoff trench, approximately parallel to the centerline of the dam.
  - ______ The diaphragm should be discharged at the downstream toe of the embankment.
  - ______ The opening sizes for slotted and perforated pipes in drains must be designed using the filter criteria.
  - ______ A second filter layer may be required around the drain pipe in order to alleviate the need for many very small openings.
  - ______ Fabric should *not* be used around the perforated pipe as it may clog, rendering the perforations impenetrable to water.

5. Foundation and Cut Off Trench or Key Trench

_______ Label all materials

_______ The presence of rock in the embankment foundation area requires specific design and construction recommendations (provided by the geotechnical engineering analysis) to ensure a proper bond between the foundation and the embankment.

_______ Generally, no blasting should be permitted within 100 feet of the foundation and abutment area.

- ______ If blasting is necessary, it should be carried out under controlled conditions to reduce adverse effects on the rock foundation (e.g., over-blasting, opening fractures, etc.), especially critical in karst topography.

_______ Show the cut-off trench bottom width (4 foot minimum or greater as specified in the geotechnical report).

_______ Show the cut-off trench depth (4 foot minimum or as specified in the geotechnical report)

_______ Show the cut-off trench side slopes (no steeper than 1H:1V).

6. Multi Stage Riser and Barrel System

_______ Principal spillways should be sized according to calculation procedures in Chapter 13 of the *Virginia Stormwater Management Handbook (2011).*

_______ The principal spillway should be located within the embankment and accessible from dry land to ensure easy access for maintenance.

- ______ Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.

_______ Provide a schedule of materials and clearly label them in drawings.

_______ Drop inlet spillways (riser and barrel system) should be designed as follows:

- ______ Full flow is established in the outlet conduit and riser at the lowest hydraulic head over the riser crest that is feasible. Indicate the crest elevation of riser structure.
  - ______ The facility must operate without excessive surging, noise, vibration, or vortex action at any stage.
  - ______ Therefore, the riser must have a larger cross-sectional area than the outlet conduit.

_______ Headwall or conduit spillways consist of a pipe extending through an embankment with a headwall at the upstream end. The headwall is typically oversized to provide an adequate surface against which to compact the embankment fill.

_______ Weir spillways should be designed as follows:

- ______ When used as the principal spillway, it should be armored with concrete or other non-erosive material.
- ______ At the spillway, armoring should extend from the upstream face of the embankment to a point downstream of the spillway toe.

_______ All principal spillways should be constructed of non-erosive material with an anticipated life expectancy similar to that of the stormwater management facility.

_______ Pre-cast riser structures may *not* be substituted if the plans call for a cast-in-place structure, unless approved by the design engineer and the plan approving authority.

- ______ Sections of pre-cast structures must be anchored together to meet stability and flotation requirements.

_______ A separate principal spillway and emergency spillway is generally recommended, unless:

- ______ Topography/abutments are too steep.
- ______ Existing or proposed development conditions impose constraints.
- ______ Other factors (e.g., a road embankment is used as the dam, the basin is excavated, etc.)
- ______ In such instances, a combined principal/emergency spillway that passes both low flows and extreme flows may be considered for use, in the form of a drop inlet spillway, a headwall/conduit spillway, or some other design that achieves equivalent results.
  - ______ It is very important to protect such combined spillways from clogging.

_______ Conduits/structures through embankments:

- ______ Limit the number of conduits that penetrate through the embankment.
- ______ Indicate the barrel diameter, inverts, and slope (%).
- ______ Show the inverts and dimensions of control release orifices/weirs

- ______ Show the structure dimensions
- ______ Show the extended detention (if added) orifice protection
- ______ NOTE: A cause of embankment failure is the separation of pipe joints due to differential settlement and pipe deflection.
- ______ All connections to pipes must be completely water-tight.
    - ______ The drain pipe (or barrel) connection to the riser should be welded all around when both are metal.
    - ______ A rubber or neoprene gasket should be used when joining pipe sections.
    - ______ The end of each pipe should be re-rolled by enough corrugations to fit the band width.
    - ______ Helically corrugated pipe should have either continuous welded seams or lock seams with internal caulking or a neoprene bead.
    - ______ The following connection types are acceptable:
        - ______ For pipes less than 24 inches in diameter:
            - ______ Flanges with gaskets on both ends of the pipe
            - ______ A 12-inch wide standard lap type band with a 12-inch wide by ½-inch thick closed cell circular neoprene gasket.
            - ______ A 12-inch wide hugger type band with O-ring gaskets having a minimum diameter of 3/8 inch greater than the corrugation depth.
        - ______ For pipes ∃ 24 inches in diameter:
            - ______ A 24-inch long annular corrugated band using rods and lugs.
            - ______ A 24-inch wide by 3/8 inch thick closed cell circular neoprene gasket.
- ______ Corrugated metal pipe (CMP) must meet or exceed the minimum required design thickness.
    - ______ Steel pipe and its appurtenances should be galvanized and fully bituminous-coated and should conform to the requirements of AASHTO Specification M-190 Type A with water-tight coupling bands.
        - ______ Any bituminous coating damaged or otherwise removed should be replaced with cold-applied bituminous coating compound.
        - ______ Steel pipes with polymeric coatings should have a minimum coating thickness of 0.01 inches (10 mils) on both sides of the pipe.
        - ______ Coated corrugated steel pipe should meet the requirements of AASHTO M-245 and M-246; the following coatings or an approved equivalent may be used: Nexon, Plasti-Cote, Blac-Clad, and Beth-Cu-Loy.
    - ______ Aluminum coated steel pipe and its appurtenances should conform to the requirements of AASHTO Specification M-274 with water-tight coupling bands or flanges.
        - ______ Any aluminum coating damaged or otherwise removed should be replaced with cold-applied bituminous coating compound.
    - ______ Aluminum pipe and its appurtenances should conform to the requirements of AASHTO Specification M-196 or M-211 with water-tight coupling bands or flanges.
        - ______ Aluminum surfaces that are to be in contact with concrete should be painted with one coat of zinc chromate primer, and hot-dipped galvanized bolts may be used for connections.
        - ______ The pH of the surrounding soils should be between 4 and 9.
    - ______ The contractor and project inspector should verify the metal thickness, corrugation size, proper connecting bands, and gasket type.
    - ______ Maximum allowable deflection of CMP conduits is 5% of the pipe diameter.
    - ______ Water-tight joints are necessary to prevent infiltration of embankment soils into the conduit.
        - ______ All joints must be constructed as specified by the pipe manufacturer.

        - ______ Field joints (the ends of the pipes are cut off in the field) should *not* be accepted.
        - ______ With larger pipe sizes, it may be difficult to get water-tight joints, even if the deflection is within design parameters.
        - ______ In such cases, the designer may choose to specify a heavier gage pipe.
    - ______ Bands:
        - ______ All connectors must be composed of the same material as the pipe.
        - ______ Metals must be shielded from dissimilar materials with rubber or plastic insulation at least 24 mils thick.
        - ______ 6-inch hugger bands and "dimple bands" should not be accepted for CMP conduits.
        - ______ For pipes ≤ 24 inches in diameter, use 12-inch wide bands with 12-inch O-ring or flat neoprene gaskets.
        - ______ For larger pipes, use 24-inch wide bands with 24-inch wide flat gaskets and four "rod and lug" type connectors.
        - ______ Flanged pipe with gaskets may also be used.
        - ______ All pipe gaskets should be properly lubricated with the material provided by the manufacturer, and tensioned, to prevent deterioration of the gasket material.
            - ______ Flat gaskets must be factory welded or solvent-glued into a circular ring, with no overlaps or gaps
    - ______ The pipe should be firmly and uniformly bedded throughout its length:
        - ______ Where rock or soft, spongy or other unstable soil is encountered, it should be removed and replaced with suitable soil that is subsequently compacted to provide adequate structural support.
        - ______ Under no conditions should gravel bedding be placed under a conduit through the embankment.
    - ______ Installation of a concrete pipe cradle will help to reduce the risk of piping under the barrel and the subsequent failure of the embankment, resulting from differential settlement.
        - ______ The concrete cradle may not be necessary along the entire length of the conduit to prevent piping, but it is recommended since gravel bedding under an embankment conduit is *never* appropriate unless it is designed as a filter or drainage diaphragm
        - ______ If the external load (e.g., from height of the embankment, anticipated construction traffic, the weight of compaction equipment, etc.) on the barrel is enough to warrant provision for its maximum supporting strength, then a concrete cradle should be installed along the conduit's entire length.
- ______ Reinforced concrete pipe should have bell and singular spigot joints with rubber gaskets and should equal or exceed ASTM Designation C-361.
    - ______ Bell and spigot pipe should be placed with the bell end upstream.
    - ______ Joints should be made consistent with manufacturer recommendations.
    - ______ After the joints are sealed for the entire run of pipe, the bedding should be placed so that all spaces under the pipe are filled.
        - ______ All reinforced concrete pipe conduits should be laid in a *concrete* bedding for their entire length.
        - ______ This bedding should consist of high slump concrete placed under the pipe and up the sides of the pipe at least 25% of its outside diameter, and preferably to the spring line, with a minimum thickness of 3 inches, or otherwise as shown on the drawings.
    - ______ Care should be taken to prevent any deviation from the original line and grade of the pipe.
- ______ Polyvinyl Chloride (PVC) pipe should be PVC-1120 or PVC-1220 conforming to ASTM D-1785 or ASTM D-2241.
    - ______ Joints and connections to anti-seep collars should be completely water-tight.

    - ______ The pipe should be firmly and uniformly bedded throughout its length.
      - ______ Where rock or soft, spongy or other unstable soil is encountered, it should be removed and replaced with suitable soil that is subsequently compacted to provide adequate structural support.
  - ______ All conduits penetrating dam embankments should be designed using the following criteria:
    - ______ Conduits and structures penetrating an embankment should have a smooth surface without protrusions or indentations that will hinder compaction of embankment materials.
    - ______ All conduits should be circular in cross-section except cast-in-place reinforced concrete box culverts. This is also true where multiple conduits are employed.
    - ______ Conduits should be designed to withstand the external loading from the proposed embankment without yielding, buckling or cracking, all of which will result in joint separation.
    - ______ Conduit strength should not be less than the values shown in the design specifications for corrugated steel, aluminum, and PVC pipes, and the applicable ASTM standards for other materials.
      - ______ The designer or contractor should obtain a manufacturer's certification that the pipe meets plan requirements for design load, pipe thickness, joint design, etc.
    - ______ Inlet and outlet flared-end sections should be made from materials that are compatible with the pipe.
    - ______ All pipe joints should be made water-tight by using flanges with gaskets, coupling bands with gaskets, bell and spigot ends with gaskets, or by welding.
    - ______ Where multiple conduits are employed, sifficient space should be provided between the conduits and installed anti-seep collars to allow for backfill material to be placed between the conduits with earth-moving equipment and easy access by hand-operated compaction equipment.
      - ______ The distance between conduits should be ∃ 1/2 of the pipe diameter, but not less than 2 feet.
  - ______ Cathodic protection should be provided for *coated welded steel* and *galvanized corrugated metal pipe* when soil and resistivity studies indicate the need for a protective coating against acidic soils.
- _______ Outlet protection must be used for the downstream toe of a spillway structure to help dissipate the high-energy flow through the spillway and to prevent excessive erosion in the receiving channel.
  - ______ The type of outlet protection depends on the flow velocities associated with the spillway.
  - ______ Riprap is the preferred form of outlet protection, designed according to Chapter 13 of the *Virginia Stormwater Management Handbook (2011)* and the *Virginia Erosion and Sediment Control Handbook (1992).* Gabion baskets are also an acceptable outlet protection material.
    - ______ The bottom of the riprap apron should be constructed at 0% slope along its length.
    - ______ The end of the apron should match the grade and alignment of the receiving channel.
    - ______ If the receiving channel is well-defined, the riprap should be place on the channel bottom and side slopes (no steeper than 2H:1V) for the entire length, as required in the design criteria in Chapter 13 of the *Virginia Stormwater Management Handbook (2011)* and the *Virginia Erosion and Sediment Control Handbook (1992).*
    - ______ Riprap placement should not alter the channel's geometry.
    - ______ Excavation of the channel bed and banks may be required to construct the full thickness of the apron.
    - ______ If the barrel discharges into the receiving channel at an angle, the opposite bank must be protected up the 10-year storm elevation. In no instance should the total length of outlet protection be shortened.

______ If a permit requires that no work may be performed in the stream or channel, then the outlet structure must be moved back to allow for adequate protection.
______ The horizontal alignment of the apron should have no bends within the design length.
______ Additional riprap should be placed if a significant change in grade occurs at the downstream end of the outfall apron.
______ Filter fabric should be placed between the riprap and the underlying soil to prevent soil movement into and through the riprap.

_______ All control structures should have a trash rack or debris control device, designed as follows:
______ All trash rack and debris control components should be made of stainless steel or galvanized metal meeting VDOT specifications.
______ Trash racks attached to a concrete spillway structure should be secured with stainless steel anchor bolts.
______ Openings for trash racks should be no larger than 1/2 of the minimum conduit dimension and, to discourage child access, bar spacing should be no greater than 1 foot apart. The clear distance between the bars on large storm discharge openings generally should be no less than 6 inches.
______ Flat grates for trash racks are *not* acceptable.
______ Inlet structures that have flow over the top should have a non-clogging trash rack (e.g., a hood-type inlet that allows passage of water from underneath the trash rack into the riser, or a vertical or sloped grate).
______ The designer should verify that the surface area of the vertical perimeter of a raised grate equals the area of the horizontal top opening, to allow adequate flow passage should the top horizontal surface become clogged.
______ Metal trash racks and monitoring hardware should be constructed of galvanized or stainless steel.
______ Methods to prevent clogging of extended detention orifices in dry extended detention bains should be carefully designed, since these orifices are usually very small and located at the invert or bottom of the basin.

_______ All drop inlet spillways designed for pressure flow should have adequate anti-vortex devices (*not* required if weir control is maintained in the riser through all flow stages, including the maximum design storm or safety storm):
______ The device may be a baffle or plate installed on top of the riser, or a headwall set on one side of the riser.

_______ The design of a principal spillway riser structure should include a *flotation* or *buoyancy* calculation (see Chapter 13 of the *Virginia Stormwater Management Handbook, 2011*).
______ The downward force of the riser and footing (to which the riser must be firmly attached) is the *structure weight*, which must be 1.25 times greater than the buoyant force acting on the riser.

_______ Stormwater management facilities having permanent impoundments may be designed so that the permanent pool can be drained to simplify maintenance and sediment removal.
______ The draining mechanism will usually consist of a valve or gate attached to the spillway structure and an inlet pipe projecting into the reservoir area, with a trash rack or debris control device.
______ The typical configuration of a drainpipe will place the valve inside the riser structure with the pipe extending out to the pool area.
______ This configuration results in the drainpipe being pressurized by the hydraulic head associated with the permanent pool.
______ Pressurized pipes should have mechanical joints in order to avoid possible leaks and seepage resulting from the innate pressure.
______ In all cases, valves should be secured to prevent unauthorized draining of the facility.
______ Basin drains should be designed with sufficient capacity to pass the 1-year frequency design storm with limited ponding in the reservoir area, so that sediment removal and other maintenance functions are not hampered.

______ An uncontrolled or rapid drawdown of a stormwater basin could cause a slide in the saturated upstream slope of the dam embankment or shoreline area.
______ Therefore, the design of the basin drain system should include specific operating instructions for the owner.
______ Generally, the drawdown rate should not exceed 6 inches per day.
______ For embankment or shoreline slopes of clay or silt, the drawdown rate may be as low as 1 inch per week to ensure slope stability.

7. Emergency Spillway

_______ Vegetated emergency spillways must be built in existing, undisturbed earth/rock or "cut" in the abutments at one or both ends of an earthen embankment or over a topographic saddle anywhere on the periphery of the basin. They should *never* be located on any portion of the embankment fill material.
_______ Excavated emergency spillways consist of three elements:
______ An inlet channel, through which *subcritical* flow enters the spillway.
______ The inlet channel should have a straight alignment and grade.
______ The cross-sectional area of flow in the inlet channel should be large in comparison to the flow area at the control section.
______ Where the depth of the channel changes to provide for the increased flow area, the bottom width should be altered gradually to avoid abrupt changes in the shape of the sloping channel banks.
______ A level section, which controls the depth of flow.
______ The maximum design water surface elevation (normally for the 100-year storm) through the emergency spillway should be at least 1 foot lower than the settled top of the embankment and should be confined by undisturbed earth or rock.
______ The bottom width of the spillway should not exceed 35 times the design depth of flow, to avoid damage by meandering flow and accumulated debris.
______ Whenever the required bottom width is likely to be excessive, consideration should be given to incorporation of a spillway at each end of the dam.
______ The two spillways do not need to be of equal width if their total capacity meets design requirements.
______ An exit channel, through which either *critical* or *supercritical* flow discharges from the spillway
______ The alignment of the exit channel must be straight to a point far enough below the embankment to ensure that any flow escaping the exit channel cannot damage the embankment.
______ The exit channel should have the same cross-section as the control section.
______ The slope of the exit channel must be:
______ Adequate to discharge the peak flow within the channel.
______ No greater than that which will produce maximum permissible velocities for the soil type or the planned grass cover.
______ The slope range of the exit channel is selected to ensure *supercritical* flow in the channel.
______ The control section is the point on the spillway where the flow passes through *critical* depth, usually installed close to the intersection of the earthen embankment and the emergency spillway centerlines.
_______ The type of soil and vegetative cover used in the emergency spillway will influence the spillway design dimensions and geometry.
______ Vegetation provides a degree of retardance to the flow through the spillway, depending mostly on the height and density of the vegetative cover chosen.
_______ Hydraulic design for emergency spillways must be done in accordance with criteria provided in *Appendix C: Vegetated Emergency Spillways* of the *Introduction to the New Virginia Stormwater Design Specifications* (as posted on the Virginia Stormwater BMP Clearinghouse web site at http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html) and in Chapter 13 of the *Virginia Stormwater Management Handbook (2011)*.
_______ Spillway side slopes should be no steeper than 3H:1V unless the spillway is excavated into rock.

_______ Show the existing ground and proposed improvements along the center line of the emergency spillway

C. Landscape Plan

_______ The landscaping plan should be jointly developed by the design engineer and a wetlands expert or experienced landscape architect

_______ It may be advisable to use a subcontractor who specializes in aquatic landscaping.

_______ The plan should outline a detailed schedule for the installation, care, maintenance and possible reinforcement or replacement of vegetation in the wetland and its buffer for up to 10 years after the original planting.

_______ The plan should indicate how appropriate wetland plants will be established within each inundation zone (e.g., wetland plants, seed mixes, volunteer colonization, tree and shrub stock, etc.) and whether soil amendments are needed to get plants started.

_______ Include a plan view with topography at a contour interval of no more than 1 foot and spot elevations throughout the cell showing the wetland configuration, different planting zones, microtopography, grades, site preparation, and construction sequence.

_______ Provide a planting schedule and specifications (transport / storage / installation / maintenance) for emergent, perennial, shrub and tree species, quantity of each species, stock size, type of root stock to be installed, and spacing.

- ______ *Plan early*. As much as 6 to 9 months of lead time may be needed to fill orders for wetland plant stock from aquatic plant nurseries.
- ______ Plant stock should be nursery grown (unless otherwise approved by the local regulatory authority) and should be healthy and vigorous native species free from defects, decay, disfiguring roots, sun-scald, injuries, abrasions, diseases, insects, pests, and all forms of infestations or objectionable disfigurements.

_______ Plant selection must be appropriate for the site’s vegetation climatic zone (6-8 in Virginia)

- ______ Plant materials should be wet-footed species but must be able to withstand both wet and dry periods as well as relatively high velocity flows within the swale.
- ______ If the swale is adjacent to a roadway where winter conditions will require the use of road salts in the CDA, then salt-tolerant non-woody plant species should be specified.
- ______ To the degree feasible, the species list should contain native species found in similar local wetlands.
- ______ Plant 5 to 7 species of emergent wetland plants, with at least four (4) of these designated as aggressive colonizers.
- ______ No more than 25% of the high marsh surface area needs to be planted, with individual plants 18 inches on center within each single species cluster. If done properly, the entire wetland should be colonized within three years.
- ______ Trees and shrubs should be integrated into the design in tree islands, peninsulas, and fringe buffer areas (Level 2 design).
  - ______ Trees may be planted in clusters to share rooting space on compacted wetland side slopes.
  - ______ Planting holes should be amended with compost (a 2:1 ratio of loose soil to compost) prior to planting.
- ______ Vary the size and age of the plant stock to promote a diverse structure.
- ______ Plants should be kept in containers of water or moist coverings to protect their root systems and keep them moist when transporting them to the planting location.
- ______ Buffer areas should be over-planted with a small stock of fast-growing successional species to achieve quick canopy closure and shade out invasive plant species.

_______ The construction contract should include a *Care and Replacement Warranty* that specifies a minimum survival for species planted of 75% after the first growing season, and a minimum effective ground cover of 75% for flat roofs and 90% for pitched roofs.

_______ Specify preservation measures for existing vegetation

D. Construction Notes

_______ Ideally, planned constructed wetland areas should be clearly marked off and remain *outside* the limits of land disturbance during construction to prevent soil compaction by heavy equipment.

- ______ Constructed wetland areas *may* be used during construction as sites for temporary sediment traps or basins, provided the construction plans include notes and graphical details specifying the facility will be de-watered, dredged and re-graded to design dimensions after the original site construction is complete.

_______ Ideally, stormwater wetlands should be constructed during months that are best for establishing vegetative cover without irrigation (February 15 – April 15; September 15 – November 15).

_______ In some cases, it will be necessary to divert flow while the stormwater wetland is being constructed, so that no sediment flows into the wetland area until installation and stabilization are complete.

- ______ Flow diversions may be required to meet additional requirements of and obtain permits from state and federal regulatory agencies.

_______ Construction sequence (Phase 1: Wetland construction):

- ______ Construction inspections should occur before, during and after installation to ensure the stormwater wetland is constructed according to specifications.
  - ______ Use detailed inspection checklists that require sign-offs by qualified individuals at critical states of construction, to ensure the contractor's interpretation of the plan is consistent with the designer's intent.
  - ______ The following are critical inspection points:
    - ______ During initial site preparation and installation of E&S Controls.
    - ______ Excavation and grading (e.g., interim and final elevations).
    - ______ Embankment construction
    - ______ Wetland installation (e.g., microtopography, soil amendments, and staking of planting zones)
    - ______ Planting phase (with the wetland expert or landscape architect).
- ______ Check the proposed site for existing utilities prior to any excavation.
- ______ Assemble the construction materials on-site, making sure they meet design specifications, and prepare any staging areas.
- ______ Clear, grub and strip the areas designated for borrow sites, embankment construction, and structural work to the desired subgrade, removing all trees, vegetation, roots and other objectional material.
  - ______ All cleared and grubbed material should be disposed of outside and below the limits of the embankment and reservoir.
  - ______ When specified, a sufficient quantity of topsoil should be stockpiled in a suitable location for use on the embankment and other designated areas.
- ______ Install applicable temporary E&S control measures prior to construction.
- ______ Areas surrounding the wetland area that are graded or denuded during construction of the wetland must be planted with turf grass, native plant materials or other approved methods of soil stabilization. Grass sod is preferred over grass seed, to prevent seed colonization of the wetland.
- ______ Excavate the core trench for the embankment and install the spillway (outlet) pipe, including the downstream rip-rap apron (energy dissipation) protection..
  - ______ The cutoff trench should be excavated into impervious material along or parallel to the centerline of the embankment.
  - ______ Trench side slopes should be laid back in steps at a 1H:1V slope or flatter. (from page 6; conflicts with 2:1 specified on page 10, Earthen Embankment Spec?).
  - ______ Backfill should be compacted with construction equipment, rollers, or hand tampers to assure maximum density and minimum permeability.
- ______ Install the riser pipe or overflow structure, ensuring the top invert of the overflow weir is constructed level and at the proper design elevation (flashboard risers are strongly recommended).

______ Construct the embankment and any internal berms in 8- to 12-inch lifts, compacted with appropriate equipment.

- ______ Areas on which fill is to be placed should be scarified before its placement.
- ______ The most permeable borrow material should be placed in the downstream portions of the embankment.
- ______ Install the principal spillway or overflow weir concurrently with fill placement and *not excavated into the embankment*. A vertical trench through the embankment material (in order to place the spillway pipe) should not be allowed under any circumstances.
  - ______ Ensure that the top invert of the principal spillway or any overflow weir is constructed level and at the proper design elevation (at least 1 foot below the crest of the emergency spillway). Flashboard risers are strongly recommended for use in constructed wetlands.
- ______ Filter and Drainage Layers:
  - ______ In order to achieve maximum density of clean sands, filter layers should be flooded with clean water and vibrated just after the water drops below the sand surface.
  - ______ The filter material should be placed in lifts of no more than 12 inches in thickness.
  - ______ Up to 4 feet of embankment material may be laced over a filter material layer before excavating back down to expose the previous layer.
  - ______ After removing any unsuitable materials, the trench may be filled with additional 12-inch lifts of filter material, flooded, and vibrated as described above, until the top of adjacent fill is reached.
  - ______ The contractor should ensure that a qualified professional inspect filter and drainage diaphragms, ensuring that backfill material meets specifications for quality, lift thickness, placement, moisture content, and dry unit weight.
- ______ Fill material should be taken from an approved, designated borrow area or stockpile.
  - ______ Fill material should be free of roots, stumps, wood, rubbish, stones greater than 6 inches in diameter, and frozen or other objectionable materials.
  - ______ Fill material for the center of the embankment and the cutoff trench should conform to Unified Soil Classification GC, SC, or CL.
  - ______ Fill material that is beside pipes or structures should be of the same type and quality as specified for the adjoining fill material.
    - ______ The fill material should be placed in horizontal lifts not to exceed 4 inches in thickness and compacted by hand tampers or other manually directed compaction equipment.
    - ______ The material should completely fill all spaces under and beside the pipe.
    - ______ During backfilling, equipment should not be driven closer the 4 feet horizontally to any part of a structure.
    - ______ Equipment should *NEVER* be driven *over* any part of a structure or pipe, unless compacted fill has been placed to a depth specified by the structural live load capacity of the structure or pipe, that adequately distributes the load.
  - ______ Consideration may be given to the use of other materials in the embankment based on the recommendation of a geotechnical engineer supervising the design and construction.
  - ______ The surface layer of compacted fill should be scarified prior to placement of at least 6 inches of topsoil, which must be properly stabilized.

______ Fill material should be compacted with appropriate compaction equipment.
______ The number of necessary passes by the compaction equipment over the fill material may vary with soil conditions.
______ Fill material should contain sufficient moisture so that the required degree of compaction will be obtained with the equipment used.
______ The minimum required density is 95% of maximum dry density with a moisture content within ± 2% of the optimum, unless otherwise specified by the engineer.
______ Each layer of fill should be compacted as necessary to obtain minimum density.
______ Compaction tests should be performed regularly throughout the embankment construction.
______ Typically, one test per 5,000 sq. ft. on each layer of fill or as directed by the geotechnical engineer.
______ Use either a Standard Proctor Test (ASTM D698) or a Modified Proctor Test (ASTM D1557 – usually more appropriate for earthen dams).
______ A new Proctor test is required if the material changes from that previously tested.
______ The engineer should certify, at the time of construction, that each fil layer meets the minimum density.
______ A geotechnical or construction inspector should be on site during embankment construction to do the following:
______ Test fill compaction
______ Observe foundation preparation.
______ Observe pipe installation.
______ Observe riser construction.
______ Observe filter installation, etc.
______ Construct the emergency spillway in cut or structurally stabilized soils.
______ Excavate/grade until the appropriate elevations and desired contours are achieved for the bottom and side slopes of the wetland.
______ Rough up the interim elevations with a skid loader or other similar equipment to achieve the desired topography across the wetland.
______ Spot surveys should be made to ensure that the interim elevations for the wetland are 3 to 6 inches below the final elevations.
______ Install micro-topographic features and soil amendments (essential for wetland plant survival).
______ Planting soil within the wetland should be loam or sandy loam with a high organic content, placed by mechanical methods, and spread by hand to a depth of at least 4 inches for shallow wetlands.
______ Planting soil should be tamped as directed in the design specifications, but it should not be overly compacted.
______ After the planting soil is placed, it should be saturated and allowed to settle for at least one week prior to installation of plant materials.
______ No machinery should be allowed to traverse over the planting soil during or after construction.
______ Stabilize exposed soils with temporary seed mixtures appropriate for a wetland environment. All wetland features above the normal pool elevation should be temporarily stabilized by hydro-seeding or seeding over straw.
_______ Construction sequence (Phase 2: Establishing wetland vegetation):
______ Finalize the wetland landscaping plan. Several weeks standing time is needed following wetland construction so that the designer can more precisely predict the following two things:
______ Where the inundation zones are located in and around the wetland.
______ Whether the final grade and wetland microtopography will persist over time.

- ______ Selection of appropriate species and additional soil amendments, based on actual field confirmation of soil properties and the actual depths and inundation frequencies occurring within the wetland.

______ Open up the wetland construction, to allow the wetland cell(s) to fill up to normal pool elevation.

- ______ Inundation must occur in stages so the deep pool and high marsh plant materials can be placed effectively and safely.
- ______ Wetland planting areas should be at least partially inundated during planting to promote plant survivability.

______ Measure (to the nearest inch) and stake planting depths at the onset of the planting season.

- ______ It may be necessary to modify the planting plan to reflect altered depths or a change in the availability of wetland plant stock.
- ______ Surveyed planting zones should be marked on the as-built or design plan, and the locations should be identified in the field, using stakes or flags.

______ Propagate the stormwater wetland between mid-April and mid-June, using three simultaneous techniques to prapogate the emergent community over the wetland bed:

- ______ Initial planting of container-grown wetland plant stock.
- ______ Broadcast wetland seed mixes over the higher wetland elevations, to establish diverse emergent wetlands.
  - ______ Seeding of switchgrass or wetland seed mixes as a ground cover is recommended for all zones above 3 inches below the normal pool elevation.
  - ______ Hand broadcasting or hydroseeding can be used to spread seed, depending on the size of the wetland cell.
- ______ Allow volunteer plants from upstream or the forest buffer to establish on their own (over the next 3 to 5 years).

______ Install goose protection for newly planted or newly growing vegetation, especially emergents and herbacious plants.

- ______ Place netting, webbing, or string installed in a criss-cross pattern over the surface area of the wetland above the level of the emergent plants.

______ Plant the wetland fringe and buffer area in the zone generally extending from 1 to 3 feet above the normal pool elevation (from the shoreline fringe to about half of the maximum water surface elevation for the 2-year storm) with vegetation that can tolerate both wet and dry periods.

______ Implement any remaining permanent stabilization measures.

______ Conduct a final inspection, log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

E. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.

- ______ Include a Maintenance Narrative which describes the long-term maintenance requirements of the facility and all components, including installation/maintenance of safety signage; removal and disposal of trash, debris and sediment accumulations; and periodic harvesting and disposal of overgrown or old wetland plant materials. The narrative should also include a list of qualified contractors that can perform inspection and maintenance services plus contact information for local or state assistance to solve common nuisance problems.

_______ Record a deed restriction, drainage easement, and/or other enforceable mechanism, including GPS coordinates of the area, to ensure the constructed wetland area is not disturbed or converted to other uses.

_______ Provide sufficient facility access from the public ROW or roadway to both the constructed wetland and any pre-treatment practices.

IV. COMMENTS

By: ______________________ Date: ______________

8-A.15.0. WET PONDS: DESIGN CHECKLIST

Plan Submission Date_____________________
Project Name_____________________
Site Plan/Permit Number_____________________
Practice No./Location on Site_____________________
Owner_____________________ Phone Number_____________________
BMP Designer_____________________ Phone Number_____________________
General Contractor_____________________ Phone Number_____________________

______ **Signature and stamp of licensed professional design consultant and owner certification**

Plan Status
_______ Approved
_______ Not Approved

Legend:
__ __ - Complete
Inc. - Incomplete/Incorrect
_N/A_ - Not Applicable

Facility Type: Level 1 _____________________ Level 2 _____________________

Hydraulic Configuration:
- ☐ On-line facility
- ☐ Off-line facility

Wet Pond Configuration:
- ☐ Wet Pond with 100% of permanent pool in a single cell
- ☐ Wet ED and/or multi-cell Wet Pond
- ☐ Pond/Wetland Combination

Type of wetlands incorporated:
- ☐ Emergent
- ☐ Forested

Type of Pre-Treatment Facility:
- ☐ Sediment forebay (above ground)
- ☐ Vegetated buffer area
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: _____________________

I. SUPPORTING INFORMATION

_______ Wet ponds with high embankments or large drainage areas and impoundments may be regulated under the Virginia Dam Safety Act and Regulations, requiring a state permit.
_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design.
_______ Show the location of this BMP on the site map, including:
  ______ The basin pool area
  ______ The contributing drainage area (CDA) boundaries, acreage (typically between 10 and 25 acres) and land cover, sufficient to sustain a permanent water level within the constructed wetland.
  ______ Delineation of FEMA 100-year floodplain
  ______ Areas of the site compensated for in the water quality calculations
_______ Provide topography for the site area.
_______ Provide the geotechnical report with recommendations and earthwork specifications and a description of any borrow area involved.
_______ Provide a soil map for site and area of facility, including the CDA
_______ Show the soil boring locations and provide the soil boring logs with Unified Soils Classifications and soil descriptions.
  ______ Borings should be taken below the proposed embankment, in the vicinity of the proposed outlet area, and in at least two locations within the planned basin treatment area.
  ______ Determine the physical characteristics of the soils regarding:
    ______ Suitability for use as structural fill or spoil.

______ Bearing capacity, buoyancy, etc. pertaining to outlet structure design.
______ Compaction/composition needs for the embankment.
______ Depth to groundwater bedrock.
______ Depth to seasonal high groundwater table: if the water table is close to the surface, it may make excavation difficult and expensive, and groundwater inputs can also reduce the pollutant removal rates of wet ponds.
______ Evaluation of potential infiltration losses (and the consequent need for a liner).

_______ Wet ponds are generally not recommended to be used in karst areas and should be the option of last resort. If karst is present, a detailed geotechnical investigation is recommended to ensure the wet pond does not aggravate potential karst impacts (e.g., sinkholes, groundwater contamination, etc.):

______ A minimum of 6 feet of unconsolidated soil material must exist between the bottom of the pond and the top of the underlying karst layer.
______ The maximum temporary or permanent water elevation with the basin must not exceed 6 feet.
______ Employ an impermeable liner that meets the requirements of Stormwater Design Specification No. 14.
______ Annual maintenance inspections must be conducted to detect sinkhole formation. Sinkholes that develop should be reported immediately after they have been observed and should be repaired, abandoned, adapted or observed over time following the guidance prescribed by the appropriate local or state groundwater protection authority.

_______ The use of wet ponds is constrained in coastal plain sites due to flat terrain, low hydraulic head and high water table (constructed wetlands are preferred). Wet ponds may be considered *acceptable* in coastal settings if the following design considerations apply:

______ Slightly lower nutrient removal rates are assigned to coastal plain wet ponds.
______ If a “pocket pond” (one that has a small CDA and is supplied solely by groundwater and runoff) is constructed in a coastal setting, then it must meet the minimum design geometry requirements for all ponds, in order to avoid nuisance conditions.

_______ The use of wet ponds is highly constrained at sites with steep terrain.

______ May be able to terrace pond cells in a linear configuration where slopes do not exceed 10% by using a 1 to 2 foot armored elevation drop between individual cells.

_______ Where cold winter climates are typical, make the following adjustments:

______ Treat larger runoff volumes in the spring by adopting seasonal operation of the permanent pool.
______ Plant salt-tolerant vegetation at pond benches (to deal with higher chloride content of road salts).
______ Do not submerge inlet pipes and provide a minimum 1% pipe slope to discourage ice formation.
______ Locate low-flow orifices so they withdraw at least 6 inches below the typical ice layer.
______ Angle trash racks to prevent ice formation.
______ Over-size the riser and weir structures to avoid ice formation and freezing pipes.
______ If road sanding is prevalent in the CDA, increase the forebay size by 25% to accommodate additional sediment loading.

_______ Wet ponds are poorly suited to treat runoff within open channels located in highway rights-of-way, unless storage is available in a cloverleaf interchange or in an expanded right-of-way and special VDOT design criteria are used.

_______ Wet ponds are generally *not* recommended in watersheds containing trout streams, due to the potential for stream warming.

_______ A wet pond should *not* be built within an existing perennial stream or natural wetland nor should a wet pond discharge to jurisdictional waters without local/state/federal approvals and the necessary permit(s).

_______ Identify potential conflicts with other (existing?) structural components (pipes, underground utilities, etc.).

_______ The designer should check to see whether sediments removed from the forebay can be spoiled (deposited) on-site or must be hauled away.

II. COMPUTATIONS

A. Hydrology

_______ Determine the runoff curve number (pre- and post-developed conditions), providing the worksheets.
_______ Determine the time of concentration (pre- and post-developed conditions), providing the worksheets.
_______ Generate hydrograph (pre- and post-developed conditions) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)
_______ Confirm that there is adequate drainage area and/or water balance from groundwater, runoff or baseflow so the wet pond will not experience unacceptable drawdown after a 30-day summer drought (minimum 24-inch deep reservoir recommended).

B. Hydraulics

_______ Specify assumptions and coefficients used.
_______ Typically, 6 to 8 feet of hydraulic head are need to drive flow through the wetland.
_______ Provide a stage-storage table and curve
_______ Weir/orifice control analysis for riser structure discharge openings and riser crest.
  ______ Carefully design the low-flow orifice to minimize clogging, as follows:
    ______ All outlet pipes should be adequately protected by an acceptable external trash racks or by internal orifice protection that may allow for smaller diameters.
    ______ Recommend a minimum 3-inch diameter orifice to minimize clogging of an outlet or extended detention pipe when it is surface-fed (still susceptible to clogging from floating vegetation and debris).
    ______ Smaller openings (down to 1-inch in diameter) are permissible, using internal orifice plates within the pipe.
    ______ Another option is a submerged reverse-slope pipe that extends downward from the riser to an inflow point 1 foot below the normal pool elevation.
    ______ Alternative methods must employ a broad-crested rectangular V-notch (or proportional) weir, protected by a half-round CMP that extends at least 12 inches below the normal pool elevation.
_______ Barrel: Conduct an inlet/outlet control analysis
_______ Conduct a riser/outlet structure flotation analysis (factor of safety = 1.25 min.).
_______ Conduct appropriate calculations for use as a temporary sediment basin riser with clean out schedule & instructions for conversion to a permanent facility.
_______ Provide for large storm overflow or bypass: emergency spillway adequacy/capacity analysis (100-year design storm) with required embankment freeboard.
_______ Provide a stage-discharge table and curve (provide equations).
_______ Route post-development hydrographs for appropriate design storms (1-yr., 10-yr., or as required by watershed conditions) and safety storms (100-yr. or as required)
_______ Provide storm drainage and hydraulic grade line calculations.

C. Downstream impacts

_______ Conduct a danger reach study.
_______ Describe the 100 year floodplain impacts.
_______ Provide downstream hydrographs at critical study points.
_______ Demonstrate safe conveyance to an “adequate” receiving channel.
  ______ If the receiving channel is natural and (1) has never been enhanced or “restored, OR (2) if tream channel erosion or localized flooding is an existing predevelopment condition, then conduct appropriate “energy balance” calculations to demonstrate safe conveyance from the facility to the receiving channel" (provide computations).

D. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA, pollutant load, pollutant load removal, and treatment volume requirements, all generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet)
_______ Indicate the treatment volume for extended detention (if added) with draw-down calculation
_______ Determine specific sizing/dimensions from criteria in Stormwater Design Specification No. 14.

III. PLAN REQUIREMENTS

A. BMP Plan View Information

_______ Show the limits of clearing and grading, noting that they should be identified and protected by acceptable signage, silt fence, snow fence, or other comparable barrier.
_______ Setbacks (local codes rule):
- ______ Minimum 20 feet from property lines.
- ______ Minimum 25 feet from building foundations.
- ______ Minimum 100 feet from septic system drainfields and private wells.

_______ Pre-Treatment:
- ______ Show all pre-treatment practices.
- ______ A sediment forebay should be considered an integral pre-treatment practice for all wet ponds.
  - ______ A forebay should be located at every major inlet to trap sediment and preserve the capacity of the main pond treatment cell.
  - ______ A major inlet is any individual storm drain inlet pipe or open channel conveying runoff from at least 10% of the wet pond's CDA.
  - ______ The forebay is considered a separate cell in both Level 1 and Level 2 designs, formed by an acceptable barrier (e.g., earthen berm, concrete weir, gabion baskets, etc.)
  - ______ Show the location of the metered rod that monitors long-term sediment accumulation (in the center of the pool, as measured lengthwise along the low flow water travel path).

_______ Show the locations of all conveyance system outfalls (inlets) into basin
_______ Show the layout and dimensions of basin features: permanent pool, sediment forebay, embankment, emergency spillway. basin side slopes, basin bottom, etc.
- ______ The footprint is typically between 1% and 3% of the CDA, depending on the pond depth (deeper ponds need a smaller footprint).

_______ Pool geometry
- ______ Show the wet/dry weather flow path
- ______ Confirm the proper orientation to avoid short-circuiting
- ______ Internal design geometry and depth zones are critical in maintaining the pollutant removal capability.
- ______ Wet ponds should have an irregular shape and a long flow path from inlet to outlet, to increase water residence time and pond performance.
- ______ Flow Path:
  - ______ Overall flow path through the wetland (length-to-width ratio):
    - ______ Level 1 design: 2L:1W.
    - ______ Level 2 design: 3L:1W.
  - ______ Ratio of the shortest flow path (closest inlet to the outlet) to the overall length:
    - ______ Level 1 design: 0.5.
    - ______ Level 2 design: 0.8.
    - ______ If unable to meet these targets, then the drainage area served by these "closer" inlets should constitute no more than 20% of the total CDA.
- ______ Treatment volume storage may be provided by a combination of a permanent pool, a shallow marsh and/or extended detention storage.
  - ______ The permanent pool storage may be divided among multiple cells
  - ______ Performance is enhanced by multiple treatment cells, longer flow paths, high surface area-to-volume ratios, and/or redundant treatment methods.

______ A berm or simple weir should be used instead of pipes to separate multiple pond cells.

______ Stormwater pond benches:

______ A safety bench is a flat bench located just outside of the perimeter of the permanent pool to allow for maintenance access and reduce safety risks when the pond side slopes exceed 5H:1V.

______ The safety bench generally extends 8 to 15 feet outward from the normal water edge to the shoulder of the stormwater pond side slope.

______ An aquatic bench is a shallow area just inside the perimeter of the normal pool that promotes growth of aquatic and wetland vegetation.

______ The bench also serves as a safety feature, reduces shoreline erosion, and conceals floatable trash.

______ The bench should extend up to 10 feet inward from the normal shoreline and have an irregular configuration.

_______ Safety features:

______ End walls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent a hazard.

______ The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.

______ Warning signs prohibiting swimming must be posted.

_______ Show outlet protection per VE&SCH Std. & Spec. 3.18

______ Must be stable for the 10-year design storm.

______ The channel immediately below the pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance.

______ This is done typically by placing appropriately-sized riprap over filter fabric, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5 ft./sec.).

______ Flared pipe sections, which discharge at or near the stream invert or into a step/plunge pool, should be used at the spillway outlet.

_______ Indicate the top-of-bank and basin bottom elevations

_______ Indicate the elevations of the permanent pool, the treatment volume and the maximum design water surface elevations for all appropriate design storms and safety storms

_______ Show any shoreline protection provided

_______ NOTE: Fencing the perimeter of wet ponds is discouraged, except at or above the maximum water surface elevation in the rare instances when the pond slope is a vertical wall.

_______ Show the location and dimensions of the riser and barrel.

_______ Identify the pool depth zones on the plan

_______ Identify any wetland/shallow marsh areas incorporated into the pond plan

_______ Show sufficient maintenance access to the forebay, safety benches, riser structure, embankment, emergency spillway, basin shoreline, extended drawdown device, principal spillway outlet, stilling basin, toe drains, and likely sediment accumulation areas. Access roads must:

______ Be constructed of load bearing materials.

______ Have a minimum width of 12 feet.

______ Possess a maximum profile grade of 15%.

______ Have sufficient turn-around area.

______ A maintenance right-of-way or easement must extend to the stormwater pond from a public or private road.

B. BMP Section Views & Related Details

1. Pre-Treatment

_______ The forebay should be sized to hold 0.25 inch of runoff per impervious acre of the CDA, but no less than 0.1 inch per impervious acre.
- ______ For smaller stormwater facilities, a more appropriate sizing criterion of 10% of the total required pool or detention volume may be more practical.
- ______ This volume should be a maximum of 4 feet deep (or a depth determined by the summer drought water balance) near the inlet to adequately dissipate turbulent inflow without re-suspending previously deposited sediment, and then transition to a depth of 1 foot at the entrance to the first wet pond cell.

_______ The forebay should be equipped with a variable width aquatic bench around the perimeter of the 4-foot depth, for safety purposes. The aquatic bench should be4 to 6 feet wide at a depth of 1 to 2 feet below the water surface, transitioning to zero width at grade.

_______ The volume of the forebay is part of the treatment volume of the stormwater basin for which it provides pre-treatment.
- ______ However, for dry facilities, the forebay does *not* represent available storage volume if it remains full of water.
- ______ A dry forebay must be carefully designed to avoid the resuspension of previously deposited sediments.

_______ The total volume of all forebays should be at least 15% of the total Treatment Volume. The relative size of individual forebays should be proportional to the percentage of their total inflow to the wet pond.

_______ Separation between the forebay and the main basin may be achieved through the use of an earthen berm, gabion baskets, concrete, or a riprap wall.

_______ A designed overflow section should be constructed on the top of the separation to allow flow to exit the forebay at non-erosive velocities during the 2-year and 10-year frequency design storms.
- ______ The overflow section may be set at the permanent pool elevation or the extended detention volume elevation.

_______ The bottom of the forebay(s) may be hardened (e.g., with concrete, asphalt, or grouted rip-rap) to make sediment removal easier.

_______ Providing a hardened access or staging pad adjacent to the forebay helps protect the forebay and basin from excessive erosion from heavy equipment operation used for maintenance.

_______ Provide a typical grading section through the forebay, including typical side slopes, aquatic bench, shoreline protection, etc.

2. Embankment (or dam) and Ponding Areas

_______ Indicate the type of embankment:
- ______ Homogenous embankment
- ______ Zoned embankment

_______ The earthen embankment must be designed to be stable against any force condition or combination of force conditions that may develop during the life of the structure (including differential settlement within the embankment, seepage through the embankment and foundation, or sharing stresses within the embankment and foundation) and is dependent upon:
- ______ Construction materials
- ______ Foundation conditions
- ______ Embankment height and cross-section geometry
- ______ Normal and maximum pool levels
- ______ Purpose of structure (i.e., retention, extended detention, etc.).

_______ Embankment geometry:

  ______ Top of dam elevations: constructed height and settled height (allowing for 10% settlement).

    ______ Height (based on the freeboard requirements):

      ______ There must be at least 1 foot of freeboard between the maximum 100-year storm water surface elevation (WSE) to the lowest point on the top of the embankment (excluding the emergency spillway).

      ______ An embankment *without* an emergency spillway must provide at least 2 feet of freeboard between the maximum 100-year storm water surface elevation (WSE) to the lowest point on the top of the embankment.

      ______ NOTE: The spillway design storm WSE, if specified, may be substituted for the 100-year storm WSE in either of the above situations.

  ______ The top width varies with embankment height and should be shaped to provide positive drainage.

  ______ The top of the embankment must be level in order to avoid possible overtopping in one location in cases of extreme storms or spillway failure.

  ______ Embankment slopes should be no steeper than 3H:1V, if feasible, with a maximum combined upstream and downstream slope of 5:1 (i.e., 3H:1V downstream face and 2H:1V upstream face).

  ______ For embankments exceeding 15 feet in height, a 6 to 10 foot wide bench should be provided at intervals of 10 to 15 feet of height, particularly if slopes are steeper than 3H:1V.

  ______ The slope profile within a wet pond should be at least 0.5% to 1% to promote positive flow through the pond.

_______ Pond side slopes should be from 4H:1V to 5H:1V to promote better establishment and growth of wetland vegetation, provide for easier maintenance, and create a more natural appearance.

_______ Stormwater pond benches:

  ______ The maximum slope of the safety bench is 5%.

  ______ An aquatic bench should have a maximum depth of 18 inches below the normal pool water surface elevation.

_______ Liners: When a stormwater pond is located over highly permeable soils or fractured bedrock, a liner may be needed to sustain a permanent pool of water. Acceptable liners include (1) a clay liner consistent with the criteria in Stormwater Design Specification No. 14, (2) a 30-mil poly liner, (3) bentonite, (4) use of chemical soil additives, or (5) an engineering design approved by the local regulatory authority.

_______ Inlet pipe inverts should generally be located at or slightly below the permanent pool elevation.

  ______ Inlet areas should be stabilized to ensure that non-erosive conditions exist during storm events up to the overbank flood event (10-year design storm).

_______ Since most wet ponds are typically on-line facilities, they need to be designed to safely pass the maximum design storm (e.g., the 10-year and 100-year design storms).

  ______ Level 1 designs may incorporate extended detention associated with the treatment volume of up to 12 inches of detention storage above the permanent pool (at least 10% of the Level 2 surface area) at its maximum water surface elevation. The maximum ED and channel protection detention levels can be up to 5 feet above the wet pond permanent pool elevation.

_______ Show the elevations of permanent pool, treatment volume and maximum design water surface elevations for all appropriate design storms and safety storms

_______ Proper surface area/depth allocations for permanent pool and any shallow marsh/constructed wetlands

_______ The embankment cross-section must be designed to provide an adequate factor of safety to protect against sliding, sloughing, or rotation in the embankment or foundation. Slope stability depends upon:
- ______ Physical characteristics of the fill materials
- ______ Configuration of the site
- ______ Foundation materials
  - ______ Shear strength
  - ______ Compressibility
  - ______ Permeability

_______ Internal drainage systems in embankments (e.g., drainage blankets, toe drains, etc.) should be designed so that the collection conduits discharge downstream of the embankment at a location where access for observation is possible by maintenance personnel.

_______ Adequate erosion protection is recommended along the contact point between the face of the embankment and the abutments, where runoff concentrates.
- ______ Evaluate whether a gutter surface other than sod is necessary (riprap is generally preferred over a paved concrete gutter).

_______ Pond drain: Except for flat areas of the coastal plain, each wet pond should have a drain pipe that can completely or partially drain the permanent pool.
- ______ In cases where a low level drain is not feasible (such as in an excavated pond), a pump wet well should be provided to accommodate a temporary pump intake when needed to drain the pond.
- ______ The drain pipe should have an up-turned elbow or protected intake within the pond, to prevent sediment deposition, and a pipe diameter capable of draining the pond within 24 hours.
- ______ The pond drain must be equipped with an adjustable valve located within the riser, where it will not be normally inundated and can be operated in a safe manner.

_______ Trees, shrubs or any other woody plants should not be planted or allowed on the embankment or adjacent areas extending at least 25 feet beyond the embankment toe and abutment contacts.

_______ Safety features:
- ______ The principal spillway opening must be designed and constructed to prevent access by small children.
- ______ An emergency spillway and associated freeboard must be provided in accordance with Stormwater Design Specification No. 14 and applicable local or state dam safety requirements.
- ______ Manage the contours of the stormwater pond to eliminate drop-offs or other safety hazards.

_______ Indicate the top of embankment elevations: constructed height and settled height (allowing for 10% settlement).

_______ Show the existing ground and proposed improvements profile along the center line of the embankment.

_______ Show the existing ground and proposed improvements profile along the center line of the principal spillway

_______ Provide a typical grading section through the pond, including typical side slopes with the aquatic bench, shoreline protection, etc.

_______ Show the dimensions of zones for any zoned embankment

3. Seepage Control

_______ All utility conduits (except the principal spillway) should be installed away from the embankment.
- ______ When utility conduits through the embankment cannot be avoided, they should meet the requirements for spillways:
  - ______ Watertight joints
  - ______ No gravel bedding
  - ______ Restrained to prevent joint separation due to settlement

_______ The contact point between the embankment soil, the foundation material, and the conduit is the most likely location for *piping* to occur, due to the discontinuity in materials and the difficulty in compacting the soil around the pipe.

_______ Phreatic line (4:1 slope measured from the principal spillway design high water elevation through the embankment) is the upper limit of the *saturation zone*..

- ______ At a minimum, this should be the 10-year design storm water surface elevation.
- ______ If the phreatic line intersects the downstream slope of the embankment, a qualified soil scientist should be consulted to decide if additional controls, such as an internal drain, are needed.

_______ Seepage control should be included in the design if the following conditions exist:

- ______ Pervious layers in the foundation are not intercepted by the cutoff.
- ______ Possible seepage from the abutments may create a wet embankment.
- ______ The phreatic line intersects the downstream slope.
- ______ Special conditions exist that require drainage to ensure a stable embankment.

_______ Seepage may be controlled by:

- ______ Foundation, abutment or embankment drains.
- ______ A downstream drainage blanket.
- ______ A downstream toe drain (often desirable for homogeneous embankments).
- ______ A combination of these measures.

_______ Seepage along pipe conduits that extend through an embankment should be controlled by use of the following to prevent piping failures along conduit surfaces:

- ______ Anti-seep collar (provide detail).
  - ______ The Bureau of Reclamation, the U.S. Army Corps of Engineers, and the USDA *no longer recommend* the use of anti-seep collars, in deference to *graded filters* or *filter diaphragms* and *drainage blankets* (more complex to design, but less complicated and more cost-effective to construct and allow for easier placement of fill material).
  - ______ Size, based on the length of pipe in the saturation zone (aim is a minimum 15% increase in seepage length).
  - ______ Spacing and location of collars on barrel:
    - ______ Maximum collar spacing is 14 times the minimum projection above the pipe.
    - ______ Minimum collar spacing is 5 times the minimum projection above the pipe.
    - ______ Collar dimensions should extend a minimum of 2 feet in all directions around the pipe.
  - ______ Anti-seep collars should be placed within the saturation zone. Where the spacing limit will not allow this, then at least one collar must be in the saturation zone.
  - ______ All anti-seep collars and their connections to the conduit should be completely water-tight and made of material compatible with the conduit. NOTE: Dimple bands are *not* considered water-tight.
  - ______ Metals must be shielded from dissimilar materials with rubber or plastic insulation at least 24 mils thick.
  - ______ Anti-seep collars should be placed a minimum of 2 feet from pipe joints unless flanged joints are used.
  - ______ Collars size should be calculated using the procedure specified in Chapter 13 of the *Virginia Stormwater Management Handbook (2011).*
- ______ The embankment filter and drainage diaphragm should be designed by a professional geotechnical engineer.
  - ______ These devices channel seepage flow through a filter of fine graded material, such as sand, which traps any embankment material being transported.
  - ______ The flow is then conveyed out of the embankment through a perforated toe drain or other acceptable technique.
  - ______ The critical design element: the filter material grain size distribution is based on the grain size distribution of the embankment fill and foundation material.

- ______ The diaphragm should consist of sand, meeting fince concrete aggregate requirements (at least 15% passing the No. 40 sieve, but no more than 10% passing the No. 100 sieve).
- ______ The diaphragm should be a minimum of 3 feet thick and should extend vertically upward and horizontally at least 3 times the pipe diameter and vertically downward at least 24 inches beneath the barrel invert, or to rock, whichever is encountered first.
- ______ The diaphragm should be placed immediately downstream of the cutoff trench, approximately parallel to the centerline of the dam.
- ______ The diaphragm should be discharged at the downstream toe of the embankment.
- ______ The opening sizes for slotted and perforated pipes in drains must be designed using the filter criteria.
- ______ A second filter layer may be required around the drain pipe in order to alleviate the need for many very small openings.
- ______ Fabric should *not* be used around the perforated pipe as it may clog, rendering the perforations impenetrable to water.

4. Foundation and Cut Off Trench or Key Trench

_______ Label all materials

_______ The presence of rock in the embankment foundation area requires specific design and construction recommendations (provided by the geotechnical engineering analysis) to ensure a proper bond between the foundation and the embankment.

_______ Generally, no blasting should be permitted within 100 feet of the foundation and abutment area.

- ______ If blasting is necessary, it should be carried out under controlled conditions to reduce adverse effects on the rock foundation (e.g., over-blasting, opening fractures, etc.), especially critical in karst topography.

_______ Indicate the cut-off trench bottom width (4 foot minimum or greater as specified in the geotechnical report).

_______ Indicate the cut-off trench depth (4 foot minimum or as specified in the geotechnical report)

_______ Indicate the cut-off trench side slopes (no steeper than 1H:1V).

5. Multi Stage Riser and Barrel System

_______ Principal spillways should be sized according to calculation procedures in Chapter 13 of the *Virginia Stormwater Management Handbook (2011).*

_______ The principal spillway should be located within the embankment and accessible from dry land to ensure easy access for maintenance.

- ______ Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.

_______ Provide a schedule of materials and clearly label them in drawings.

_______ Drop inlet spillways (riser and barrel system) should be designed as follows:

- ______ Full flow is established in the outlet conduit and riser at the lowest hydraulic head over the riser crest that is feasible. Indicate the crest elevation of riser structure.
  - ______ The facility must operate without excessive surging, noise, vibration, or vortex action at any stage.
  - ______ Therefore, the riser must have a larger cross-sectional area than the outlet conduit.

_______ Headwall or conduit spillways consist of a pipe extending through an embankment with a headwall at the upstream end. The headwall is typically oversized to provide an adequate surface against which to compact the embankment fill.

_______ Weir spillways should be designed as follows:

- ______ When used as the principal spillway, it should be armored with concrete or other non-erosive material.
- ______ At the spillway, armoring should extend from the upstream face of the embankment to a point downstream of the spillway toe.

_______ All principal spillways should be constructed of non-erosive material with an anticipated life expectancy similar to that of the stormwater management facility.

_______ Pre-cast riser structures may not be substituted if the plans call for a cast-in-place structure, unless approved by the design engineer and the plan approving authority.

- ______ Sections of pre-cast structures must be anchored together to meet stability and flotation requirements.

_______ A separate principal spillway and emergency spillway is generally recommended, unless:

- ______ Topography/abutments too steep.
- ______ Existing or proposed development conditions impose constraints.
- ______ Other factors (e.g., a road embankment is used as the dam, the basin is excavated, etc.)
- ______ In such instances, a combined principal/emergency spillway that passes both low flows and extreme flows may be considered for use, in the form of a drop inlet spillway, a headwall/conduit spillway, or some other design that achieves equivalent results.
  - ______ It is very important to protect such combined spillways from clogging.

_______ Conduits/structures through embankments:

- ______ Limit the number of conduits that penetrate through the embankment.
- ______ Indicate the barrel diameter, inverts, and slope (%).
- ______ Show the inverts and dimensions of control release orifices/weirs
- ______ Show the structure dimensions
- ______ Show the extended detention (if added) orifice protection
- ______ A cause of embankment failure is the separation of pipe joints due to differential settlement and pipe deflection.
- ______ All connections to pipes must be completely water-tight.
  - ______ The drain pipe (or barrel) connection to the riser should be welded all around when both are metal.
  - ______ A rubber or neoprene gasket should be used when joining pipe sections.
  - ______ The end of each pipe should be re-rolled by enough corrugations to fit the band width.
  - ______ Helically corrugated pipe should have either continuous welded seams or lock seams with internal caulking or a neoprene bead.
  - ______ The following connection types are acceptable:
    - ______ For pipes less than 24 inches in diameter:
      - ______ Flanges with gaskets on both ends of the pipe
      - ______ A 12-inch wide standard lap type band with a 12-inch wide by ½-inch thick closed cell circular neoprene gasket.
      - ______ A 12-inch wide hugger type band with O-ring gaskets having a minimum diameter of 3/8 inch greater than the corrugation depth.
    - ______ For pipes ∃ 24 inches in diameter:
      - ______ A 24-inch long annular corrugated band using rods and lugs.
      - ______ A 24-inch wide by 3/8 inch thick closed cell circular neoprene gasket.
- ______ Corrugated metal pipe (CMP) must meet or exceed the minimum required design thickness.
  - ______ Steel pipe and its appurtenances should be galvanized and fully bituminous-coated and should conform to the requirements of AASHTO Specification M-190 Type A with water-tight coupling bands.
    - ______ Any bituminous coating damaged or otherwise removed should be replaced with cold-applied bituminous coating compound.
    - ______ Steel pipes with polymeric coatings should have a minimum coating thickness of 0.01 inches (10 mils) on both sides of the pipe.
    - ______ Coated corrugated steel pipe should meet the requirements of AASHTO M-245 and M-246; the following coatings or an approved equivalent may be used: Nexon, Plasti-Cote, Blac-Clad, and Beth-Cu-Loy.

- ______ Aluminum coated steel pipe and its appurtenances should conform to the requirements of AASHTO Specification M-274 with water-tight coupling bands or flanges.
  - ______ Any aluminum coating damaged or otherwise removed should be replaced with cold-applied bituminous coating compound.
- ______ Aluminum pipe and its appurtenances should conform to the requirements of AASHTO Specification M-196 or M-211 with water-tight coupling bands or flanges.
  - ______ Aluminum surfaces that are to be in contact with concrete should be painted with one coat of zinc chromate primer, and hot-dipped galvanized bolts may be used for connections.
  - ______ The pH of the surrounding soils should be between 4 and 9.
- ______ The contractor and project inspector should verify the metal thickness, corrugation size, proper connecting bands, and gasket type.
- ______ Maximum allowable deflection of CMP conduits is 5% of the pipe diameter.
- ______ Water-tight joints are necessary to prevent infiltration of embankment soils into the conduit.
  - ______ All joints must be constructed as specified by the pipe manufacturer.
  - ______ Field joints (the ends of the pipes are cut off in the field) should *not* be accepted.
  - ______ With larger pipe sizes, it may be difficult to get water-tight joints, even if the deflection is within design parameters.
  - ______ In such cases, the designer may choose to specify a heavier gage pipe.
- ______ Bands:
  - ______ All connectors must be composed of the same material as the pipe.
  - ______ Metals must be shielded from dissimilar materials with rubber or plastic insulation at least 24 mils thick.
  - ______ 6-inch hugger bands and “dimple bands” should not be accepted for CMP conduits.
  - ______ For pipes $\leq$ 24 inches in diameter, use 12-inch wide bands with 12-inch O-ring or flat neoprene gaskets.
  - ______ For larger pipes, use 24-inch wide bands with 24-inch wide flat gaskets and four “rod and lug” type connectors.
  - ______ Flanged pipe with gaskets may also be used.
  - ______ All pipe gaskets should be properly lubricated with the material provided by the manufacturer, and tensioned, to prevent deterioration of the gasket material.
    - ______ Flat gaskets must be factory welded or solvent-glued into a circular ring, with no overlaps or gaps
- ______ The pipe should be firmly and uniformly bedded throughout its length:
  - ______ Where rock or soft, spongy or other unstable soil is encountered, it should be removed and replaced with suitable soil that is subsequently compacted to provide adequate structural support.
  - ______ Under no conditions should gravel bedding be placed under a conduit through the embankment.
- ______ Installation of a concrete pipe cradle will help to reduce the risk of piping under the barrel and the subsequent failure of the embankment, resulting from differential settlement.
  - ______ The concrete cradle may not be necessary along the entire length of the conduit to prevent piping, but it is recommended since gravel bedding under an embankment conduit is *never* appropriate unless it is designed as a filter or drainage diaphragm

    - ______ If the external load (e.g., from height of the embankment, anticipated construction traffic, the weight of compaction equipment, etc.) on the barrel is enough to warrant provision for its maximum supporting strength, then a concrete cradle should be installed along the conduit's entire length.

- ______ Reinforced concrete pipe should have bell and singular spigot joints with rubber gaskets and should equal or exceed ASTM Designation C-361.
  - ______ Bell and spigot pipe should be placed with the bell end upstream.
  - ______ Joints should be made consistent with manufacturer recommendations.
  - ______ After the joints are sealed for the entire run of pipe, the bedding should be placed so that all spaces under the pipe are filled.
    - ______ All reinforced concrete pipe conduits should be laid in a *concrete* bedding for their entire length.
    - ______ This bedding should consist of high slump concrete placed under the pipe and up the sides of the pipe at least 25% of its outside diameter, and preferably to the spring line, with a minimum thickness of 3 inches, or otherwise as shown on the drawings.
  - ______ Care should be taken to prevent any deviation from the original line and grade of the pipe.
- ______ Polyvinyl Chloride (PVC) pipe should be PVC-1120 or PVC-1220 conforming to ASTM D-1785 or ASTM D-2241.
  - ______ Joints and connections to anti-seep collars should be completely water-tight.
  - ______ The pipe should be firmly and uniformly bedded throughout its length.
    - ______ Where rock or soft, spongy or other unstable soil is encountered, it should be removed and replaced with suitable soil that is subsequently compacted to provide adequate structural support.
- ______ All conduits penetrating dam embankments should be designed using the following criteria:
  - ______ Conduits and structures penetrating an embankment should have a smooth surface without protrusions or indentations that will hinder compaction of embankment materials.
  - ______ All conduits should be circular in cross-section except cast-in-place reinforced concrete box culverts. This is also true where multiple conduits are employed.
  - ______ Conduits should be designed to withstand the external loading from the proposed embankment without yielding, buckling or cracking, all of which will result in joint separation.
  - ______ Conduit strength should not be less than the values shown in the design specifications for corrugated steel, aluminum, and PVC pipes, and the applicable ASTM standards for other materials.
    - ______ The designer or contractor should obtain a manufacturer's certification that the pipe meets plan requirements for design load, pipe thickness, joint design, etc.
  - ______ Inlet and outlet flared-end sections should be made from materials that are compatible with the pipe.
  - ______ All pipe joints should be made water-tight by using flanges with gaskets, coupling bands with gaskets, bell and spigot ends with gaskets, or by welding.
  - ______ Where multiple conduits are employed, sufficient space should be provided between the conduits and installed anti-seep collars to allow for backfill material to be placed between the conduits with earth-moving equipment and easy access by hand-operated compaction equipment.
    - ______ The distance between conduits should be ∃ 1/2 of the pipe diameter, but not less than 2 feet.
- ______ Cathodic protection should be provided for *coated welded steel* and *galvanized corrugated metal pipe* when soil and resistivity studies indicate the need for a protective coating against acidic soils.

_______ Outlet protection must be used for the downstream toe of a spillway structure to help dissipate the high-energy flow through the spillway and to prevent excessive erosion in the receiving channel.

- ______ The type of outlet protection depends on the flow velocities associated with the spillway.
- ______ Riprap is the preferred form of outlet protection, designed according to Chapter 13 of the *Virginia Stormwater Management Handbook (2011)* and the *Virginia Erosion and Sediment Control Handbook (1992).* Gabion baskets are also an acceptable outlet protection material.
  - ______ The bottom of the riprap apron should be constructed at 0% slope along its length.
  - ______ The end of the apron should match the grade and alignment of the receiving channel.
  - ______ If the receiving channel is well-defined, the riprap should be place on the channel bottom and side slopes (no steeper than 2H:1V) for the entire length, as required in the design criteria in Chapter 13 of the *Virginia Stormwater Management Handbook (2011)* and the *Virginia Erosion and Sediment Control Handbook (1992).*
  - ______ Riprap placement should not alter the channel's geometry.
  - ______ Excavation of the channel bed and banks may be required to construct the full thickness of the apron.
  - ______ If the barrel discharges into the receiving channel at an angle, the opposite bank must be protected up the the 10-year storm elevation. In no instance should the total length of outlet protection be shortened.
  - ______ If a permit requires that no work may be performed in the stream or channel, then the outlet structure must be moved back to allow for adequate protection.
  - ______ The horizontal alignment of the apron should have no bends within the design length.
  - ______ Additional riprap should be placed if a significant change in grade occurs at the downstream end of the outfall apron.
  - ______ Filter fabric should be placed between the riprap and the underlying soil to prevent soil movement into and through the riprap.

_______ All control structures should have a trash rack or debris control device, designed as follows:

- ______ All trash rack and debris control components should be made of stainless steel or galvanized metal meeting VDOT specifications.
- ______ Trash racks attached to a concrete spillway structure should be secured with stainless steel anchor bolts.
- ______ Openings for trash racks should be no larger than 1/2 of the minimum conduit dimension and, to discourage child access, bar spacing should be no greater than 1 foot apart. The clear distance between the bars on large storm discharge openings generally should be no less than 6 inches.
- ______ Flat grates for trash racks are *not* acceptable.
- ______ Inlet structures that have flow over the top should have a non-clogging trash rack (e.g., a hood-type inlet that allows passage of water from underneath the trash rack into the riser, or a vertical or sloped grate).
- ______ The designer should verify that the surface area of the vertical perimeter of a raised grate equals the area of the horizontal top opening, to allow adequate flow passage should the top horizontal surface become clogged.
- ______ Metal trash racks and monitoring hardware should be constructed of galvanized or stainless steel.
- ______ Methods to prevent clogging of extended detention orifices in dry extended detention basins should be carefully designed, since these orifices are usually very small and located at the invert or bottom of the basin.

_______ All drop inlet spillways designed for pressure flow should have adequate anti-vortex devices (*not* required if weir control is maintained in the riser through all flow stages, including the maximum design storm or safety storm):

_____ The device may be a baffle or plate installed on top of the riser, or a headwall set on one side of the riser.

_______ The design of a principal spillway riser structure should include a *flotation* or *buoyancy* calculation (see Chapter 13 of the *Virginia Stormwater Management Handbook, 2011*).

_____ The downward force of the riser and footing (to which the riser must be firmly attached) is the *structure weight*, which must be 1.25 times greater than the buoyant force acting on the riser.

_______ Stormwater management facilities having permanent impoundments may be designed so that the permanent pool can be drained to simplify maintenance and sediment removal.

_____ The draining mechanism will usually consist of a valve or gate attached to the spillway structure and an inlet pipe projecting into the reservoir area, with a trash rack or debris control device.

_____ The typical configuration of a drainpipe will place the valve inside the riser structure with the pipe extending out to the pool area.

_____ This configuration results in the drainpipe being pressurized by the hydraulic head associated with the permanent pool.

_____ Pressurized pipes should have mechanical joints in order to avoid possible leaks and seepage resulting from the innate pressure.

_____ In all cases, valves should be secured to prevent unauthorized draining of the facility.

_____ Basin drains should be designed with sufficient capacity to pass the 1-year frequency design storm with limited ponding in the reservoir area, so that sediment removal and other maintenance functions are not hampered.

_____ An uncontrolled or rapid drawdown of a stormwater basin could cause a slide in the saturated upstream slope of the dam embankment or shoreline area.

_____ Therefore, the design of the basin drain system should include specific operating instructions for the owner.

_____ Generally, the drawdown rate should not exceed 6 inches per day.

_____ For embankment or shoreline slopes of clay or silt, the drawdown rate may be as low as 1 inch per week to ensure slope stability.

6 Emergency Spillway

_______ Vegetated emergency spillways must be built in existing, undisturbed earth/rock or "cut" in the abutments at one or both ends of an earthen embankment or ovr a topographic saddle anywhere on the periphery of the basin. They should *never* be located on any portion of the embankment fill material.

_______ Excavated emergency spillways consist of three elements:

_____ An inlet channel, through which *subcritical* flow enters the spillway.

_____ The inlet channel should have a straight alignment and grade.

_____ The cross-sectional area of flow in the inlet channel should be large in comparison to the flow area at the control section.

_____ Where the depth of the channel changes to provide for the increased flow area, the bottom width should be altered gradually to avoid abrupt changes in the shape of the sloping channel banks.

_____ A level section, which controls the depth of flow.

_____ The maximum design water surface elevation (normally for the 100-year storm) through the emergency spillway should be at least 1 foot lower than the settled top of the embankment and should be confined by undisturbed earth or rock.

_____ The bottom width of the spillway should not exceed 35 times the design depth of flow, to avoid damage by meandering flow and accumulated debris.

_____ Whenever the required bottom width is likely to be excessive, consideration should be given to incorporation of a spillway at each end of the dam.

_____ The two spillways do not need to be of equal width if their total capacity meets design requirements.

- ______ An exit channel, through which either *critical* or *supercritical* flow discharges from the spillway
  - ______ The alignment of the exit channel must be straight to a point far enough below the embankment to ensure that any flow escaping the exit channel cannot damage the embankment.
  - ______ The exit channel should have the same cross-section as the control section.
  - ______ The slope of the exit channel must be:
    - ______ Adequate to discharge the peak flow within the channel.
    - ______ No greater than that which will produce maximum permissible velocities for the soil type or the planned grass cover.
    - ______ The slope range of the exit channel is selected to ensure *supercritical* flow in the channel.
- ______ The control section is the point on the spillway where the flow passes through *critical* depth, usually installed close to the intersection of the earthen embankment and the emergency spillway centerlines.

_______ The type of soil and vegetative cover used in the emergency spillway can be used to establish the spillway design dimensions and geometry.

- ______ Vegetation provides a degree of retardance to the flow through the spillway, depending mostly on the height and density of the vegetative cover chosen.

_______ Hydraulic design for emergency spillways must be done in accordance with criteria provided in *Appendix C: Vegetated Emergency Spillways* of the *Introduction to the New Virginia Stormwater Design Specifications* (as posted on the Virginia Stormwater BMP Clearinghouse web site at http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html) and in Chapter 13 of the *Virginia Stormwater Management Handbook (2011)*.

_______ Spillway side slopes should be no steeper than 3H:1V unless the spillway is excavated into rock.

_______ Show the existing ground and proposed improvements along the center line of the emergency spillway

C. Landscape Plan

_______ The landscaping plan must indicate the methods to be used to establish and maintain vegetative cover in the Wet Pond and its buffer area, including the following:

- ______ Delineation of pondscaping zones within both the pond and buffer.
- ______ Selection of corresponding plant species.
- ______ The planting plan.
- ______ The sequence for preparing the wetland benches (including soil amendments, if needed).
- ______ Sources of native plant material.
- ______ Elements that promote diverse wildlife and waterfowl use within the wet pond and buffer.
- ______ Woody vegetation may not be allowed to grow within 15 feet of the toe of the embankment nor within 25 feet from the principal spillway structure.
- ______ A vegetated buffer should be provided that extends at least 25 feet outward from the maximum water surface elevation of the wet pond.
- ______ Permanent structures (e.g., buildings) should *not* be constructed within the buffer area.
- ______ Existing trees within the buffer area should be preserved during construction.
- ______ Due to soil compaction, planting holes should be 3 times deeper and wider than the diameter of the root ball for ball-and-burlap stock, and 5 times deeper and wider for container-grown stock.
- ______ Avoid species that require full shade, or are prone to wind damage.
- ______ Extra mulching around the base of trees and shrubs is strongly recommended as a means of conserving moisture and suppressing weeds.

_______ Provide a planting schedule and specifications (transport / storage / installation / maintenance)

_______ Ensure that plant selection is appropriate for the site's vegetation climatic zone (4-8 in Virginia), emphasizing native species

_______ Specify preservation measures for existing vegetation

_______ Ensure that topsoil / planting soil is included in final grading plan.

D. Construction Notes

_______ Ideally, planned wet pond areas should be constructed after the contributing drainage area is completely stabilized.

_______ Wet pond areas *may* be used during construction as sites for temporary sediment traps or basins (properly sized for E&S control purposes), provided the construction plans include notes and graphical details specifying the facility will be de-watered, dredged and re-graded to design dimensions after the original site construction is complete.

- ______ Installation of the permanent riser should be initiated during the construction phase
- ______ Design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction wet pond in mind.
- ______ The bottom elevation of the permanent wet pond should be lower than the bottom elevation of the temporary sediment basin.
- ______ Appropriate procedures should be implemented to prevent discharge of turbid waters when the basin is being converted into a wet pond.

_______ In some cases, it will be necessary to divert flow while the wet pond is being constructed, so that no sediment flows into the pond area until installation and stabilization are complete.

- ______ Flow diversions may be required to meet additional requirements of and obtain permits from state and federal regulatory agencies.

_______ Construction sequence:

- ______ Construction inspections should occur before, during and after installation to ensure the stormwater wetland is constructed according to specifications.
  - ______ Use detailed inspection checklists that require sign-offs by qualified individuals at critical states of construction, to ensure the contractor's interpretation of the plan is consistent with the designer's intent.
  - ______ The following are critical inspection points:
    - ______ During initial site preparation and installation of E&S Controls.
    - ______ Excavation and grading (e.g., interim and final elevations).
    - ______ Installation of the embankment, the riser/primary spillway, and the outlet structure.
    - ______ Pondscaping installation and final stabilization.
- ______ Check the proposed site for existing utilities prior to any excavation.
- ______ Assemble the construction materials on-site, making sure they meet design specifications, and prepare any staging areas.
- ______ Clear, grub and strip the areas designated for borrow sites, embankment construction, and structural work to the desired subgrade, removing all trees, vegetation, roots and other objectional material.
  - ______ All cleared and grubbed material should be disposed of outside and below the limits of the embankment and reservoir.
  - ______ When specified, a sufficient quantity of topsoil should be stockpiled in a suitable location for use on the embankment and other designated areas.
- ______ Install applicable temporary E&S control measures prior to construction.
- ______ Excavate the core trench for the embankment and install the spillway (outlet) pipe, including the downstream rip-rap apron (energy dissipation) protection..
  - ______ The cutoff trench should be excavated into impervious material along or parallel to the centerline of the embankment.
  - ______ Trench side slopes should be laid back in steps at a 1H:1V slope or flatter. (from page 6; conflicts with 2:1 specified on page 10, Earthen Embankment Spec?).
  - ______ Backfill should be compacted with construction equipment, rollers, or hand tampers to assure maximum density and minimum permeability.
- ______ Install the riser pipe or overflow structure, ensuring the top invert of the overflow weir is constructed level and at the proper design elevation.
- ______ Construct the embankment and any internal berms in 8- to 12-inch lifts, compacted with appropriate equipment.
  - ______ Areas on which fill is to be placed should be scarified before its placement.

- ______ The most permeable borrow material should be placed in the downstream portions of the embankment.
- ______ Install the principal spillway or overflow weir concurrently with fill placement and *not excavated into the embankment*. A vertical trench through the embankment material (in order to place the spillway pipe) should not be allowed under any circumstances.
  - ______ Ensure that the top invert of the principal spillway or any overflow weir is constructed level and at the proper design elevation (at least 1 foot below the crest of the emergency spillway). Flashboard risers are strongly recommended for use in constructed wetlands.
- ______ Filter and Drainage Layers:
  - ______ In order to achieve maximum density of clean sands, filter layers should be flooded with clean water and vibrated just after the water drops below the sand surface.
  - ______ The filter material should be placed in lifts of no more than 12 inches in thickness.
  - ______ Up to 4 feet of embankment material may be laced over a filter material layer before excavating back down to expose the previous layer.
  - ______ After removing any unsuitable materials, the trench may be filled with additional 12-inch lifts of filter material, flooded, and vibrated as described above, until the top of adjacent fill is reached.
  - ______ The contractor should ensure that a qualified professional inspect filter and drainage diaphragms, ensuring that backfill material meets specifications for quality, lift thickness, placement, moisture content, and dry unit weight.
- ______ Fill material should be taken from an approved, designated borrow area or stockpile.
  - ______ Fill material should be free of roots, stumps, wood, rubbish, stones greater than 6 inches in diameter, and frozen or other objectionable materials.
  - ______ Fill material for the center of the embankment and the cutoff trench should conform to Unified Soil Classification GC, SC, or CL.
  - ______ Fill material that is beside pipes or structures should be of the same type and quality as specified for the adjoining fill material.
    - ______ The fill material should be placed in horizontal lifts not to exceed 4 inches in thickness and compacted by hand tampers or other manually directed compaction equipment.
    - ______ The material should completely fill all spaces under and beside the pipe.
    - ______ During backfilling, equipment should not be driven closer the 4 feet horizontally to any part of a structure.
    - ______ Equipment should *NEVER* be driven *over* any part of a structure or pipe, unless compacted fill has been placed to a depth specified by the structural live load capacity of the structure or pipe, that adequately distributes the load.
  - ______ Consideration may be given to the use of other materials in the embankment based on the recommendation of a geotechnical engineer supervising the design and construction.
  - ______ The surface layer of compacted fill should be scarified prior to placement of at least 6 inches of topsoil, which must be properly stabilized.
- ______ Fill material should be compacted with appropriate compaction equipment.
  - ______ The number of necessary passes by the compaction equipment over the fill material may vary with soil conditions.
  - ______ Fill material should contain sufficient moisture so that the required degree of compaction will be obtained with the equipment used.

- ______ The minimum required density is 95% of maximum dry density with a moisture content within ± 2% of the optimum, unless otherwise specified by the engineer.
- ______ Each layer of fill should be compacted as necessary to obtain minimum density.

______ Compaction tests should be performed regularly throughout the embankment construction.

- ______ Typically, one test per 5,000 sq. ft. on each layer of fill or as directed by the geotechnical engineer.
- ______ Use either a Standard Proctor Test (ASTM D698) or a Modified Proctor Test (ASTM D1557 – usually more appropriate for earthen dams).
- ______ A new Proctor test is required if the material changes from that previously tested.
- ______ The engineer should certify, at the time of construction, that each fil layer meets the minimum density.

______ A geotechnical or construction inspector should be on site during embankment construction to do the following:

- ______ Test fill compaction
- ______ Observe foundation preparation.
- ______ Observe pipe installation.
- ______ Observe riser construction.
- ______ Observe filter installation, etc.

______ Construct the emergency spillway in cut or structurally stabilized soils.

______ Excavate/grade until the appropriate elevations and desired contours are achieved for the bottom and side slopes of the pond.

______ Install outlet pipes, including the downstream rip-rap apron (energy dissipation) protection.

______ Stabilize exposed soils with temporary seed mixtures appropriate for the pond buffer. All areas above the normal pool elevation should be temporarily stabilized by hydroseeding or seeding over straw.

______ Plant the pond buffer area and implement any remaining permanent stabilization measures.

______ Conduct a final inspection, log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

E. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.

- ______ Include a Maintenance Narrative which describes the long-term maintenance requirements of the facility and all components, including installation/maintenance of safety signage; removal and disposal of trash, debris and sediment accumulations; mowing; and periodic harvesting and disposal of overgrown or old aquatic plant materials.

_______ Record a deed restriction, drainage easement, and/or other enforceable mechanism, including GPS coordinates of the area, to ensure the wet pond is not converted to other uses.

_______ Provide sufficient facility access from the public ROW or roadway to both the wet pond and any pre-treatment practices.

IV. COMMENTS

By: ______________________ Date: ______________

8-A.16.0. EXTENDED DETENTION PONDS: DESIGN CHECKLIST

Plan Submission Date_____________________
Project Name____
Site Plan/Permit Number____
Practice No./Location on Site____
Owner____ Phone Number__________________
BMP Designer____ Phone Number__________________
General Contractor____________________________________ Phone Number__________________

______ **Signature and stamp of licensed professional design consultant and owner certification**

Plan Status

_______ Approved
_______ Not Approved

Legend:

✓	- Complete
Inc.	- Incomplete/Incorrect
N/A	- Not Applicable

Facility Type: Level 1 ____________________________ Level 2 ______________________________

Design Configuration:

- ☐ Micropool ED Pond
- ☐ Wet ED Pond (see Stormwater Design Specification No. 14)
- ☐ Limited ED above Wetlands (see Stormwater Design Specification No. 13)

Type of Pre-Treatment Facility:

- ☐ Sediment forebay (above ground)
- ☐ Vegetated buffer area
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: ___________________

Hydraulic Configuration:

- ☐ On-line facility
- ☐ Off-line facility

I. SUPPORTING INFORMATION

_______ ED ponds with high embankments or large drainage areas and impoundments may be regulated under the Virginia Dam Safety Act and Regulations, requiring a state permit.
_______ Provide a concise narrative describing the stormwater management strategy, describing how this practice fits into the overall plan, and stating all assumptions made in the design.
_______ Show the location of this BMP on the site map, including:
    ______ The basin pool area
    ______ The contributing drainage area (CDA) boundaries, acreage and land cover, sufficient to sustain a permanent water level within the constructed wetland.
    ______ Delineation of FEMA 100-year floodplain
    ______ Areas of site compensated for in water quality calculations
_______ Provide topography for the site area, including the ED pond area, its CDA and any pre-treatment practices.
_______ Provide the geotechnical report with recommendations and earthwork specifications and a description of any borrow area involved.
_______ Provide a soil map for site and area of facility, including the CDA
_______ Show the soil boring locations and provide the soil boring logs with Unified Soils Classifications and soil descriptions.
    ______ Borings should be taken below the proposed embankment, in the vicinity of the proposed outlet area, and in at least two locations within the planned basin treatment area.

- ______ Determine the physical characteristics of the soils regarding:
  - ______ Infiltration rate: infiltration through the bottom of the pond is encouraged unless it will impair the integrity of the embankment.
  - ______ Suitability for use as structural fill or spoil.
  - ______ Bearing capacity, buoyancy, etc. pertaining to outlet structure design.
  - ______ Compaction/composition needs for the embankment.
  - ______ Depth to groundwater and bedrock not less than 2 feet below the floor of the pond.
  - ______ Evaluation of potential infiltration losses (and the consequent need for a liner).

_______ ED ponds are normally combined with other stormwater treatment options within those facilities (e.g., wet pond, constructed wetland) to enhance their performance and appearance.

_______ ED ponds are generally discouraged for use in karst areas and should be considered the practice of last resort. If karst is present, a detailed geotechnical investigation is recommended to ensure the ED pond does not aggravate potential karst impacts (e.g., sinkholes, groundwater contamination, etc.):

- ______ A minimum of 3 feet of unconsolidated soil material must exist between the bottom of the pond and the top of the underlying karst layer.
- ______ Employ an impermeable liner that meets the requirements of Stormwater Design Specification No. 13 (Constructed Wetlands).
- ______ Annual maintenance inspections must be conducted to detect sinkhole formation. Sinkholes that develop should be reported immediately after they have been observed and should be repaired, abandoned, adapted or observed over time following the guidance prescribed by the appropriate local or state groundwater protection authority.
- ______ The use of ED ponds is constrained in coastal plain sites due to flat terrain, low hydraulic head and high water table (constructed wetlands are preferred).

_______ The use of ED ponds is highly constrained at sites with steep terrain.

_______ Where cold winter climates are typical, make the following adjustments:

- ______ Plant salt-tolerant vegetation at pond benches (to deal with higher chloride content of road salts).
- ______ Do not submerge inlet pipes and provide a minimum 1% pipe slope to discourage standing water and ice formation.
- ______ Place all pipes below the frost line to prevent frost heave and pipe freezing.
- ______ Locate low-flow orifices in the micropool, so they withdraw at least 6 inches below the typical ice layer.
- ______ Angle trash racks to prevent ice formation.
- ______ If road sanding is prevalent in the CDA, increase the forebay size by 25% to accommodate additional sediment loading.

_______ ED ponds are poorly suited to treat runoff within open channels located in highway rights-of-way, unless storage is available in a cloverleaf interchange or in an expanded right-of-way and special VDOT design criteria are used.

_______ ED ponds are generally *not* recommended in watersheds containing trout streams, due to the potential for stream warming.

- ______ However, where other upland runoff reduction practices cannot meet the full Channel Protection Volume requirement, a micropool ED pond may be used if the following criteria are met:
  - ______ It must be designed with a maximum 12-hour detention time
  - ______ It must have a minimum pool volume sufficient to prevent clogging
  - ______ It must be planted with trees so it becomes fully shaded
  - ______ It must be located outside of any required stream buffer areas.

_______ An ED pond should *not* be built within an existing perennial stream or natural wetland nor should an ED pond discharge to jurisdictional waters without local/state/federal approvals and the necessary permit(s).

_______ Identify potential conflicts with other (existing?) structural components (pipes, underground utilities, etc.).

_______ The designer should check to see whether sediments removed from the forebay can be spoiled (deposited) on-site or must be hauled away.

II. COMPUTATIONS

A. Hydrology

- _______ Determine runoff curve number (pre- and post-developed conditions), providing the worksheets.
- _______ Determine the time of concentration (pre- and post-developed conditions), providng the worksheets.
- _______ Generate hydrographs (pre- and post-developed conditions) for appropriate design and safety storms (USDA-NRCS methods or modified rational-critical storm duration method)
- _______ Ensure that there is adequate drainage area and/or base flow

B. Hydraulics

- _______ Specify assumptions and coefficients used.
- _______ Typically, 6 to 10 feet of hydraulic head are need to drive flow through the wetland.
- _______ Provide a stage-storage table and curve
  - ______ Average treatment volume extended detention drawdown time is 24 hours or less for Level 1 designs and 36 hours or less for Level 2 designs.
  - ______ Vertical treatment volume fluctuation may exceed 4 feet for Level 1 designs but may not exceed 4 feet for Level 2 designs.
- _______ Weir/orifice control analysis for riser structure discharge openings and riser crest.
  - ______ Consider providing a micropool at the outlet structure.
    - ______ The micropool should be designed to that the depth will not draw down by more than 2 feet during a 30 day summer drought, but should be at least 4 feet deep.
    - ______ Use a submerged reverse-slope pipe that extends downward from the riser to an inflow point at mid-depth of the normal pool or micropool.
    - ______ Install a down-turned elbow or half-round CMP over a riser orifice (circular, rectangular, V-notch, etc.) to pull water from at least 12 inches below the micropool surface.
  - ______ Use a perforated pipe under a gravel blanket with an orifice control at the end in the riser structure to supplement the primary outlet.
  - ______ Carefully design the low-flow orifice to minimize clogging, as follows:
    - ______ All outlet pipes should be adequately protected by an acceptable external trash racks or by internal orifice protection that may allow for smaller diameters.
    - ______ Recommend a minimum 3-inch diameter orifice to minimize clogging of an outlet or extended detention pipe when it is surface-fed (still susceptible to clogging from floating vegetation and debris).
    - ______ Smaller openings (down to 1-inch in diameter) are permissible, using internal orifice plates within the pipe.
- _______ Barrel: Conduct an inlet/outlet control analysis
- _______ Conduct a riser/outlet structure flotation analysis (factor of safety = 1.25 min.).
- _______ Conduct appropriate calculations for use as a temporary sediment basin riser with clean out schedule & instructions for conversion to a permanent facility.
- _______ Provide for large storm overflow or bypass: emergency spillway adequacy/capacity analysis (100-year design storm) with required embankment freeboard.
- _______ Provide a stage-discharge table and curve (provide equations).
- _______ Route post-development hydrographs for appropriate design storms (1-yr., 10-yr., or as required by watershed conditions) and safety storms (100-yr. or as required)
- _______ Provide storm drainage and hydraulic grade line calculations.

C. Downstream impacts

- _______ Conduct a danger reach study.
- _______ Describe the 100 year floodplain impacts.
- _______ Provide downstream hydrographs at critical study points.

_______ Demonstrate safe conveyance to an "adequate" receiving channel.

- ______ If the receiving channel is natural and (1) has never been enhanced or "restored, OR (2) if stream channel erosion or localized flooding is an existing predevelopment condition, then conduct appropriate "energy balance" calculations to demonstrate safe conveyance from the facility to the receiving channel" (provide computations).

D. Water Quality

_______ Provide a tabulation of land cover areas (impervious cover, managed turf, forest cover) in the CDA, pollutant load, pollutant load removal, and treatment volume requirements, all generated by using the Virginia Runoff Reduction Method spreadsheet (provide spreadsheet)

_______ Determine specific sizing/dimensions from criteria in Stormwater Design Specification No. 15.

III. PLAN REQUIREMENTS

A. BMP Plan View Information

_______ Show the limits of clearing and grading, noting that they should be identified and protected by acceptable signage, silt fence, snow fence, or other comparable barrier.

_______ Setbacks (local ordinances rule):

- ______ Minimum 10 feet from property lines.
- ______ Minimum 25 feet from building foundations.
- ______ Minimum 50 feet from septic system drainfields
- ______ Minimum 100 feet from private wells.

_______ Pre-Treatment:

- ______ Show all pre-treatment practices.
- ______ A sediment forebay should be considered an integral pre-treatment practice for all ED ponds. Consider providing an over-sized forebay to trap sediment, trash and debris before it reaches the ED pond's low-flow orifice.
  - ______ The forebay is considered a separate cell in both Level 1 and Level 2 designs, formed by an acceptable barrier (e.g., earthen berm, concrete weir, gabion baskets, etc.). Any outlet protection associated with the end section or end wall should be designed according to state and local standards.
  - ______ A forebay should be located at every major inlet to trap sediment and preserve the capacity of the main pond treatment cell.
  - ______ A major inlet is any individual storm drain inlet pipe or open channel conveying runoff from at least 10% of the ED pond's CDA.
  - ______ The relative size of individual forebays should be proportional to the percentage of the total inflow to the ED Pond.
  - ______ The total volume of all forebays should be at least 15% of the total Treatment Volume (inclusively, thereby satisfying the Level 1 design permanent pool volume requirement). However, a micropool is still encouraged for maintenance benefits.
  - ______ The outlet from each forebay should be designed in such a manner that it acts as a level spreader to distribute runoff evenly across the entire bottom surface area of the main basin treatment cell. Therefore, there should be no low-flow pilot channel constructed in the basin bottom.
  - ______ Show the location of the metered rod that monitors long-term sediment accumulation (in the center of the pool, as measured lengthwise along the low flow water travel path).

_______ Show the locations of all conveyance system outfalls (inlets) into basin

- ______ Inlets should be stabilized to ensure that non-erosive conditions exist during storm events up to the overbank flood event (the 10-year storm).
- ______ Inlet pipe inverts should generally be located at or slightly below the forebay pool elevation.

_______ Show the layout and dimensions of basin features: permanent pool, sediment forebay, embankment, emergency spillway. basin side slopes, basin bottom, etc.

______ The footprint is typically between 1% and 3% of the CDA, depending on the pond depth (a deeper pond needs a smaller footprint).

_______ Pool geometry – wet/dry weather flow path

- ______ Internal design geometry and depth zones are critical in maintaining the pollutant removal capability.
- ______ Ensure proper orientation and inlet locations to avoid short-circuiting
- ______ Ensure that there is adequate surface area
- ______ Show the wet/dry weather flow path:
  - ______ Overall flow path through the wetland (length-to-width ratio):
    - ______ Level 1 design: 2L:1W.
    - ______ Level 2 design: 3L:1W.
    - ______ Internal berms, baffles or topography can be used to extend flow paths and/or create multiple pond cells.
  - ______ Ratio of the shortest flow path (closest inlet to the outlet) to the overall length:
    - ______ Level 1 design: 0.4.
    - ______ Level 2 design: 0.7.
    - ______ If unable to meet these targets, then the drainage area served by these “closer” inlets should constitute no more than 20% of the total CDA.
- ______ The permanent pool storage may be divided among multiple cells
  - ______ A berm or simple weir should be used instead of pipes to separate multiple pond cells.
- ______ ED pond benches:
  - ______ A safety bench is a flat bench located just outside of the perimeter of the permanent pool to allow for maintenance access and reduce safety risks when the pond side slopes exceed 5H:1V.
    - ______ The safety bench generally extends 8 to 15 feet outward from the normal water edge to the shoulder of the stormwater pond side slope.
  - ______ An aquatic bench is a shallow area just inside the perimeter of the normal pool that promotes growth of aquatic and wetland vegetation.
    - ______ The bench also serves as a safety feature, reduces shoreline erosion, and conceals floatable trash.
    - ______ The bench should extend up to 10 feet inward from the normal shoreline and have an irregular configuration.
  - ______ Both the safety bench and the aquatic bench should be landscaped with vegetation that hinders or prevents access to the pool.
  - ______ Micropool ED ponds should *not* have a low flow pilot channel, but instead must be constructed in a manner whereby flows are evenly distributed across the pond bottom, to promote the maximum infiltration possible.

_______ Other safety features:

- ______ End walls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent a hazard.
- ______ The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.

_______ Outlet protection per VE&SCH Std. & Spec. 3.18

- ______ Stable for the 10-year design storm.
- ______ The channel immediately below the pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance.
  - ______ This is done typically by placing appropriately-sized riprap over filter fabric, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5 ft./sec.).
- ______ Flared pipe sections, which discharge at or near the stream invert or into a step/plunge pool, should be used at the spillway outlet.

_______ Indicate the top-of-bank and basin bottom elevations

_______ Indicate the elevations of permanent pool, treatment volume and maximum design water surface elevations for all appropriate design storms and safety storms

_______ Fencing the perimeter of ED ponds is discouraged, except at or above the maximum water surface elevation in the rare instances when the pond slope is a vertical wall.
_______ Identify the riser and barrel materials and label their dimensions
_______ Identify the pool depth zones on the plan, ensuring adequate surface area for each depth zone
_______ Provide sufficient maintenance access to the forebay, micropool, safety benches, riser structure, embankment, emergency spillway, basin shoreline, extended drawdown device, principal spillway outlet, stilling basin, toe drains, and likely sediment accumulation areas. Access roads must:
    ______ Be constructed of load bearing materials able to withstand the expected frequency of use.
    ______ Have a minimum width of 12 feet.
    ______ Possess a maximum profile grade of 15%.
    ______ Have sufficient turn-around area.
    ______ A maintenance right-of-way or easement must extend to the stormwater basin from a public or private road.

B. BMP Section Views & Related Details

1. Pre-Treatment

_______ The forebay should be sized to hold 0.25 inch of runoff per impervious acre of the CDA, but no less than 0.1 inch per impervious acre.
    ______ For smaller stormwater facilities, a more appropriate sizing criterion of 10% of the total required pool or detention volume may be more practical.
    ______ This volume should be a maximum of 4 feet deep (or a depth determined by the summer drought water balance) near the inlet to adequately dissipate turbulent inflow without re-suspending previously deposited sediment, and then transition to a depth of 1 foot at the entrance to the first wetland cell.
_______ The forebay should be equipped with a variable width aquatic bench around the perimeter of the 4-foot depth, for safety purposes. The aquatic bench should be 4 to 6 feet wide at a depth of 1 to 2 feet below the water surface, transitioning to zero width at grade.
_______ The volume of the forebay is part of the treatment volume of the stormwater basin for which it provides pre-treatment.
    ______ However, for dry facilities, the forebay does *not* represent available storage volume if it remains full of water.
    ______ A dry forebay must be carefully designed to avoid the resuspension of previously deposited sediments.
_______ The total volume of all forebays should be at least 15% of the total Treatment Volume. The relative size of individual forebays should be proportional to the percentage of their total inflow to the ED pond.
_______ Separation between the forebay and the main basin may be achieved through the use of an earthen berm, gabion baskets, concrete, or a riprap wall.
_______ A designed overflow section should be constructed on the top of the separation to allow flow to exit the forebay at non-erosive velocities during the 2-year and 10-year frequency design storms.
    ______ The overflow section may be set at the extended detention volume elevation.
_______ The bottom of the forebay(s) may be hardened (e.g., with concrete, asphalt, or grouted rip-rap) to make sediment removal easier.
_______ Providing a hardened access or staging pad adjacent to the forebay helps protect the forebay and basin from excessive erosion from heavy equipment operation used for maintenance.
_______ Provide a typical grading section through the forebay, including typical side slopes, aquatic bench, shoreline protection, etc.

2. Embankment (or dam) and Ponding Areas

_______ Type of embankment:
- ______ Homogenous embankment
- ______ Zoned embankment

_______ The earthen embankment must be designed to be stable against any force condition or combination of force conditions that may develop during the life of the structure (including differential settlement within the embankment, seepage through the embankment and foundation, or sharing stresses within the embankment and foundation) and is dependent upon:
- ______ Construction materials
- ______ Foundation conditions
- ______ Embankment height and cross-section geometry
- ______ Normal and maximum pool levels
- ______ Purpose of structure (i.e., extended detention).

_______ Embankment geometry:
- ______ Top of dam elevations: constructed height and settled height (allowing for 10% settlement).
  - ______ Height (based on the freeboard requirements): There must be at least 1 foot of freeboard between the maximum 100-year storm water surface elevation (WSE) to the lowest point on the top of the embankment (excluding the emergency spillway).
  - ______ An embankment *without* an emergency spillway must provide at least 2 feet of freeboard between the maximum 100-year storm water surface elevation (WSE) to the lowest point on the top of the embankment.
  - ______ NOTE: The spillway design storm WSE, if specified, may be substituted for the 100-year storm WSE in either of the above situations.
- ______ Top width varies with embankment height and should be shaped to provide positive drainage.
- ______ The top of the embankment must be level in order to avoid possible overtopping in one location in cases of extreme storms or spillway failure.
- ______ Embankment slopes should be no steeper than 3H:1V, if feasible, with a maximum combined upstream and downstream slope of 5:1 (i.e., 3H:1V downstream face and 2H:1V upstream face).
- ______ For embankments exceeding 15 feet in height, a 6 to 10 foot wide bench should be provided at intervals of 10 to 15 feet of height, particularly if slopes are steeper than 3H:1V.
- ______ The slope profile within an ED pond should be at least 0.5% to 1% to promote positive flow through the pond.

_______ Basin side slopes should be from 4H:1V to 5H:1V to promote better establishment and growth of vegetation, provide for easier maintenance, and create a more natural appearance.

_______ ED pond benches:
- ______ The maximum slope of the safety bench is 5%.
- ______ An aquatic bench should have a maximum depth of 18 inches below the normal pool water surface elevation.

_______ Inlet pipe inverts should generally be located at or slightly below the permanent pool elevation.
- ______ Inlet areas should be stabilized to ensure that non-erosive conditions exist during storm events up to the overbank flood event (10-year design storm).

_______ Since most ED ponds are typically on-line facilities, they need to be designed to safely pass the maximum design storm (e.g., the 10-year and 100-year design storms) with adequate freeboard between the maximum design water surface elevation and the top of the embankment.

_______ Show the elevations of the permanent pool, treatment volume and maximum design water surface elevations for all appropriate design storms and safety storms
- ______ The maximum Treatment Volume water surface elevation must not extend more than 5 feet above the basin floor or normal pool elevation for a Level 1 design, or 4 feet for a Level 2 design.
- ______ The maximum vertical elevation for ED and channel protection detention over shallow wetlands is 1 foot.

- ______ Larger flood control storms (e.g., the 10-year design storm) may exceed the 5 foot vertical limit if they are managed by a multi-stage outlet structure.

_______ The embankment cross-section must be designed to provide an adequate factor of safety to protect against sliding, sloughing, or rotation in the embankment or foundation. Slope stability depends upon:
- ______ Physical characteristics of the fill materials
- ______ Configuration of the site
- ______ Foundation materials
  - ______ Shear strength
  - ______ Compressibility
  - ______ Permeability

_______ Internal drainage systems in embankments (e.g., drainage blankets, toe drains, etc.) should be designed so that the collection conduits discharge downstream of the embankment at a location where access for observation is possible by maintenance personnel.

_______ Adequate erosion protection is recommended along the contact point between the face of the embankment and the abutments, where runoff concentrates.
- ______ Evaluate whether a gutter surface other than sod is necessary (riprap is generally preferred over a paved concrete gutter).

_______ Pond drain: Except for flat areas of the coastal plain, each ED pond designed to have a permanent pool should have a drain pipe that can completely or partially drain the permanent pool.
- ______ In cases where a low level drain is not feasible (such as in an excavated pond), a pump wet well should be provided to accommodate a temporary pump intake when needed to drain the pond.
- ______ The drain pipe should have an up-turned elbow or protected intake within the pond, to prevent sediment deposition, and a pipe diameter capable of draining the pond within 24 hours.
- ______ The pond drain must be equipped with an adjustable valve located within the riser, where it will not be normally inundated and can be operated in a safe manner.

_______ Trees, shrubs or any other woody plants should not be planted or allowed on the embankment or adjacent areas extending at least 25 feet beyond the embankment toe and abutment contacts.

_______ Safety features:
- ______ The principal spillway opening must be designed and constructed to prevent access by small children.
- ______ An emergency spillway and associated freeboard must be provided in accordance with Stormwater Design Specification No. 15 and applicable local or state dam safety requirements.
- ______ Manage the contours of the basin to eliminate drop-offs or other safety hazards.

_______ Indicate the top of embankment elevations: constructed height and settled height (allowing for 10% settlement).

_______ Show the existing ground and proposed improvements profile along the center line of the embankment.

_______ Show the existing ground and proposed improvements profile along the center line of the principal spillway

_______ Provide a typical grading section through the pond, including typical side slopes with the aquatic bench, shoreline protection, etc.

_______ Show the dimensions of zones for any zoned embankment.

3. Seepage Control

_______ All utility conduits (except the principal spillway) should be installed away from the embankment.
- ______ When utility conduits through the embankment cannot be avoided, they should meet the requirements for spillways:
  - ______ Watertight joints
  - ______ No gravel bedding
  - ______ Restrained to prevent joint separation due to settlement

_______ The contact point between the embankment soil, the foundation material, and the conduit is the most likely location for *piping* to occur, due to the discontinuity in materials and the difficulty in compacting the soil around the pipe.

_______ The phreatic line (4:1 slope measured from the principal spillway design high water elevation through the embankment) is the upper limit of the *saturation zone*..

- ______ At a minimum, this should be the 10-year design storm water surface elevation.
- ______ If the phreatic line intersects the downstream slope of the embankment, a qualified soil scientist should be consulted to decide if additional controls, such as an internal drain, are needed.

_______ Seepage control should be included in the design if the following conditions exist:

- ______ Pervious layers in the foundation are not intercepted by the cutoff.
- ______ Possible seepage from the abutments may create a wet embankment.
- ______ The phreatic line intersects the downstream slope.
- ______ Special conditions exist that require drainage to ensure a stable embankment.

_______ Seepage may be controlled by:

- ______ Foundation, abutment or embankment drains.
- ______ A downstream drainage blanket.
- ______ A downstream toe drain (often desirable for homogeneous embankments).
- ______ A combination of these measures.

_______ Seepage along pipe conduits that extend through an embankment should be controlled by use of the following to prevent piping failures along conduit surfaces:

- ______ Anti-seep collar (provide detail).
  - ______ The Bureau of Reclamation, the U.S. Army Corps of Engineers, and the USDA *no longer recommend* the use of anti-seep collars, in deference to *graded filters* or *filter diaphragms* and *drainage blankets* (more complex to design, but less complicated and more cost-effective to construct and allow for easier placement of fill material).
  - ______ Size, based on the length of pipe in the saturation zone (aim is a minimum 15% increase in seepage length).
  - ______ Spacing and location of collars on the barrel:
    - ______ Maximum collar spacing is 14 times the minimum projection above the pipe.
    - ______ Minimum collar spacing is 5 times the minimum projection above the pipe.
    - ______ Collar dimensions should extend a minimum of 2 feet in all directions around the pipe.
  - ______ Anti-seep collars should be placed within the saturation zone. Where the spacing limit will not allow this, then at least one collar must be in the saturation zone.
  - ______ All anti-seep collars and their connections to the conduit should be completely water-tight and made of material compatible with the conduit. NOTE: Dimple bands are *not* considered water-tight.
  - ______ Metals must be shielded from dissimilar materials with rubber or plastic insulation at least 24 mils thick.
  - ______ Anti-seep collars should be placed a minimum of 2 feet from pipe joints unless flanged joints are used.
  - ______ Collar size should be calculated using the procedure specified in Chapter 13 of the *Virginia Stormwater Management Handbook (2011).*
- ______ The embankment filter and drainage diaphragm should be designed by a professional geotechnical engineer.
  - ______ These devices channel seepage flow through a filter of fine graded material, such as sand, which traps any embankment material being transported.
  - ______ The flow is then conveyed out of the embankment through a perforated toe drain or other acceptable technique.
  - ______ The critical design element: the filter material grain size distribution is based on the grain size distribution of the embankment fill and foundation material.

_____ The diaphragm should consist of sand, meeting fine concrete aggregate requirements (at least 15% passing the No. 40 sieve, but no more than 10% passing the No. 100 sieve).
_____ The diaphragm should be a minimum of 3 feet thick and should extend vertically upward and horizontally at least 3 times the pipe diameter and vertically downward at least 24 inches beneath the barrel invert, or to rock, whichever is encountered first.
_____ The diaphragm should be placed immediately downstream of the cutoff trench, approximately parallel to the centerline of the dam.
_____ The diaphragm should be discharged at the downstream toe of the embankment.
_____ The opening sizes for slotted and perforated pipes in drains must be designed using the filter criteria.
_____ A second filter layer may be required around the drain pipe in order to alleviate the need for many very small openings.
_____ Fabric should *not* be used around the perforated pipe as it may clog, rendering the perforations impenetrable to water.

4. Foundation and Cut Off Trench or Key Trench

_______ Label all materials
_______ The presence of rock in the embankment foundation area requires specific design and construction recommendations (provided by the geotechnical engineering analysis) to ensure a proper bond between the foundation and the embankment.
_______ Generally, no blasting should be permitted within 100 feet of the foundation and abutment area.
_____ If blasting is necessary, it should be carried out under controlled conditions to reduce adverse effects on the rock foundation (e.g., over-blasting, opening fractures, etc.), especially critical in karst topography.
_______ Show the cut-off trench bottom width (4 foot minimum or as specified in the geotechnical report).
_______ Show the cut-off trench depth (4 foot minimum or as specified in the geotechnical report)
_______ Show the cut-off trench side slopes labeled (no steeper than 1H:1V).

5. Multi Stage Riser and Barrel System

_______ Principal spillways should be sized according to calculation procedures in Chapter 13 of the *Virginia Stormwater Management Handbook (2011).*
_______ The principal spillway should be located within the embankment and accessible from dry land to ensure easy access for maintenance.
_____ Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.
_______ Provide a schedule of materials and clearly label them in drawings.
_______ Drop inlet spillways (riser and barrel system) should be designed as follows:
_____ Full flow is established in the outlet conduit and riser at the lowest hydraulic head over the riser crest that is feasible. Indicate the crest elevation of riser structure.
_____ The facility must operate without excessive surging, noise, vibration, or vortex action at any stage.
_____ Therefore, the riser must have a larger cross-sectional area than the outlet conduit.
_______ Headwall or conduit spillways consist of a pipe extending through an embankment with a headwall at the upstream end. The headwall is typically oversized to provide an adequate surface against which to compact the embankment fill.
_______ Weir spillways should be designed as follows:
_____ When used as the principal spillway, it should be armored with concrete or other non-erosive material.
_____ At the spillway, armoring should extend from the upstream face of the embankment to a point downstream of the spillway toe.
_______ All principal spillways should be constructed of non-erosive material with an anticipated life expectancy similar to that of the stormwater management facility.

- _______ Pre-cast riser structures may not be substituted if the plans call for a cast-in-place structure, unless approved by the design engineer and the plan approving authority.
  - ______ Sections of pre-cast structures must be anchored together to meet stability and flotation requirements.
- _______ A separate principal spillway and emergency spillway is generally recommended, unless:
  - ______ Topography/abutments too steep.
  - ______ Existing or proposed development conditions impose constraints.
  - ______ Other factors (e.g., a road embankment is used as the dam, the basin is excavated, etc.)
  - ______ In such instances, a combined principal/emergency spillway that passes both low flows and extreme flows may be considered for use, in the form of a drop inlet spillway, a headwall/conduit spillway, or some other design that achieves equivalent results.
    - ______ It is very important to protect such combined spillways from clogging.
- _______ Conduits/structures through embankments:
  - ______ Limit the number of conduits that penetrate through the embankment.
  - ______ Indicate the barrel diameter, inverts, and slope (%).
  - ______ Show the inverts and dimensions of controlled release orifices/weirs
  - ______ Show the structure dimensions
  - ______ Show the extended detention orifice protection
  - ______ NOTE: A cause of embankment failure is the separation of pipe joints due to differential settlement and pipe deflection. All connections to pipes must be completely water-tight.
    - ______ The drain pipe (or barrel) connection to the riser should be welded all around when both are metal.
    - ______ A rubber or neoprene gasket should be used when joining pipe sections.
    - ______ The end of each pipe should be re-rolled by enough corrugations to fit the band width.
    - ______ Helically corrugated pipe should have either continuous welded seams or lock seams with internal caulking or a neoprene bead.
    - ______ The following connection types are acceptable:
      - ______ For pipes less than 24 inches in diameter:
        - ______ Flanges with gaskets on both ends of the pipe
        - ______ A 12-inch wide standard lap type band with a 12-inch wide by ½-inch thick closed cell circular neoprene gasket.
        - ______ A 12-inch wide hugger type band with O-ring gaskets having a minimum diameter of 3/8 inch greater than the corrugation depth.
      - ______ For pipes ∃ 24 inches in diameter:
        - ______ A 24-inch long annular corrugated band using rods and lugs.
        - ______ A 24-inch wide by 3/8 inch thick closed cell circular neoprene gasket.
  - ______ Corrugated metal pipe (CMP) must meet or exceed the minimum required design thickness.
    - ______ Steel pipe and its appurtenances should be galvanized and fully bituminous-coated and should conform to the requirements of AASHTO Specification M-190 Type A with water-tight coupling bands.
      - ______ Any bituminous coating damaged or otherwise removed should be replaced with cold-applied bituminous coating compound.
      - ______ Steel pipes with polymeric coatings should have a minimum coating thickness of 0.01 inches (10 mils) on both sides of the pipe.
      - ______ Coated corrugated steel pipe should meet the requirements of AASHTO M-245 and M-246; the following coatings or an approved equivalent may be used: Nexon, Plasti-Cote, Blac-Clad, and Beth-Cu-Loy.

- ______ Aluminum coated steel pipe and its appurtenances should conform to the requirements of AASHTO Specification M-274 with water-tight coupling bands or flanges.
  - ______ Any aluminum coating damaged or otherwise removed should be replaced with cold-applied bituminous coating compound.
- ______ Aluminum pipe and its appurtenances should conform to the requirements of AASHTO Specification M-196 or M-211 with water-tight coupling bands or flanges.
  - ______ Aluminum surfaces that are to be in contact with concrete should be painted with one coat of zinc chromate primer, and hot-dipped galvanized bolts may be used for connections.
  - ______ The pH of the surrounding soils should be between 4 and 9.
- ______ The contractor and project inspector should verify the metal thickness, corrugation size, proper connecting bands, and gasket type.
- ______ Maximum allowable deflection of CMP conduits is 5% of the pipe diameter.
- ______ Water-tight joints are necessary to prevent infiltration of embankment soils into the conduit.
  - ______ All joints must be constructed as specified by the pipe manufacturer.
  - ______ Field joints (the ends of the pipes are cut off in the field) should *not* be accepted.
  - ______ With larger pipe sizes, it may be difficult to get water-tight joints, even if the deflection is within design parameters.
  - ______ In such cases, the designer may choose to specify a heavier gage pipe.
- ______ Bands:
  - ______ All connectors must be composed of the same material as the pipe.
  - ______ Metals must be shielded from dissimilar materials with rubber or plastic insulation at least 24 mils thick.
  - ______ 6-inch hugger bands and “dimple bands” should not be accepted for CMP conduits.
  - ______ For pipes $\leq$ 24 inches in diameter, use 12-inch wide bands with 12-inch O-ring or flat neoprene gaskets.
  - ______ For larger pipes, use 24-inch wide bands with 24-inch wide flat gaskets and four “rod and lug” type connectors.
  - ______ Flanged pipe with gaskets may also be used.
  - ______ All pipe gaskets should be properly lubricated with the material provided by the manufacturer, and tensioned, to prevent deterioration of the gasket material.
    - ______ Flat gaskets must be factory welded or solvent-glued into a circular ring, with no overlaps or gaps
- ______ The pipe should be firmly and uniformly bedded throughout its length:
  - ______ Where rock or soft, spongy or other unstable soil is encountered, it should be removed and replaced with suitable soil that is subsequently compacted to provide adequate structural support.
  - ______ Under no conditions should gravel bedding be placed under a conduit through the embankment.
- ______ Installation of a concrete pipe cradle will help to reduce the risk of piping under the barrel and the subsequent failure of the embankment, resulting from differential settlement.
  - ______ The concrete cradle may not be necessary along the entire length of the conduit to prevent piping, but it is recommended since gravel bedding under an embankment conduit is *never* appropriate unless it is designed as a filter or drainage diaphragm

        - ______ If the external load (e.g., from the height of the embankment, anticipated construction traffic, the weight of compaction equipment, etc.) on the barrel is enough to warrant provision for its maximum supporting strength, then a concrete cradle should be installed along the conduit's entire length.
- ______ Reinforced concrete pipe should have bell and singular spigot joints with rubber gaskets and should equal or exceed ASTM Designation C-361.
    - ______ Bell and spigot pipe should be placed with the bell end upstream.
    - ______ Joints should be made consistent with manufacturer recommendations.
    - ______ After the joints are sealed for the entire run of pipe, the bedding should be placed so that all spaces under the pipe are filled.
        - ______ All reinforced concrete pipe conduits should be laid in a *concrete* bedding for their entire length.
        - ______ This bedding should consist of high slump concrete placed under the pipe and up the sides of the pipe at least 25% of its outside diameter, and preferably to the spring line, with a minimum thickness of 3 inches, or otherwise as shown on the drawings.
    - ______ Care should be taken to prevent any deviation from the original line and grade of the pipe.
- ______ Polyvinyl Chloride (PVC) pipe should be PVC-1120 or PVC-1220 conforming to ASTM D-1785 or ASTM D-2241.
    - ______ Joints and connections to anti-seep collars should be completely water-tight.
    - ______ The pipe should be firmly and uniformly bedded throughout its length.
        - ______ Where rock or soft, spongy or other unstable soil is encountered, it should be removed and replaced with suitable soil that is subsequently compacted to provide adequate structural support.
- ______ All conduits penetrating dam embankments should be designed using the following criteria:
    - ______ Conduits and structures penetrating an embankment should have a smooth surface without protrusions or indentations that will hinder compaction of embankment materials.
    - ______ All conduits should be circular in cross-section except cast-in-place reinforced concrete box culverts. This is also true where multiple conduits are employed.
    - ______ Conduits should be designed to withstand the external loading from the proposed embankment without yielding, buckling or cracking, all of which will result in joint separation.
    - ______ Conduit strength should not be less than the values shown in the design specifications for corrugated steel, aluminum, and PVC pipes, and the applicable ASTM standards for other materials.
        - ______ The designer or contractor should obtain a manufacturer's certification that the pipe meets plan requirements for design load, pipe thickness, joint design, etc.
    - ______ Inlet and outlet flared-end sections should be made from materials that are compatible with the pipe.
    - ______ All pipe joints should be made water-tight by using flanges with gaskets, coupling bands with gaskets, bell and spigot ends with gaskets, or by welding.
    - ______ Where multiple conduits are employed, sufficient space should be provided between the conduits and installed anti-seep collars to allow for backfill material to be placed between the conduits with earth-moving equipment and easy access by hand-operated compaction equipment.
        - ______ The distance between conduits should be ∃ 1/2 of the pipe diameter, but not less than 2 feet.
- ______ Cathodic protection should be provided for *coated welded steel* and *galvanized corrugated metal pipe* when soil and resistivity studies indicate the need for a protective coating against acidic soils.

_______ Outlet protection must be used for the downstream toe of a spillway structure to help dissipate the high-energy flow through the spillway and to prevent excessive erosion in the receiving channel.

- ______ The type of outlet protection depends on the flow velocities associated with the spillway.
- ______ Riprap is the preferred form of outlet protection, designed according to Chapter 13 of the *Virginia Stormwater Management Handbook (2011)* and the *Virginia Erosion and Sediment Control Handbook (1992).* Gabion baskets are also an acceptable outlet protection material.
  - ______ The bottom of the riprap apron should be constructed at 0% slope along its length.
  - ______ The end of the apron should match the grade and alignment of the receiving channel.
  - ______ If the receiving channel is well-defined, the riprap should be placed on the channel bottom and side slopes (no steeper than 2H:1V) for the entire length, as required in the design criteria in Chapter 13 of the *Virginia Stormwater Management Handbook (2011)* and the *Virginia Erosion and Sediment Control Handbook (1992).*
  - ______ Riprap placement should not alter the channel's geometry.
  - ______ Excavation of the channel bed and banks may be required to construct the full thickness of the apron.
  - ______ If the barrel discharges into the receiving channel at an angle, the opposite bank must be protected up the the 10-year storm elevation. In no instance should the total length of outlet protection be shortened.
  - ______ If a permit requires that no work may be performed in the stream or channel, then the outlet structure must be moved back to allow for adequate protection.
  - ______ The horizontal alignment of the apron should have no bends within the design length.
  - ______ Additional riprap should be placed if a significant change in grade occurs at the downstream end of the outfall apron.
  - ______ Filter fabric should be placed between the riprap and the underlying soil to prevent soil movement into and through the riprap.

_______ All control structures should have a trash rack or debris control device, designed as follows:

- ______ All trash rack and debris control components should be made of stainless steel or galvanized metal meeting VDOT specifications.
- ______ Trash racks attached to a concrete spillway structure should be secured with stainless steel anchor bolts.
- ______ Openings for trash racks should be no larger than 1/2 of the minimum conduit dimension and, to discourage child access, bar spacing should be no greater than 1 foot apart. The clear distance between the bars on large storm discharge openings generally should be no less than 6 inches.
- ______ Flat grates for trash racks are *not* acceptable.
- ______ Inlet structures that have flow over the top should have a non-clogging trash rack (e.g., a hood-type inlet that allows passage of water from underneath the trash rack into the riser, or a vertical or sloped grate).
- ______ The designer should verify that the surface area of the vertical perimeter of a raised grate equals the area of the horizontal top opening, to allow adequate flow passage should the top horizontal surface become clogged.
- ______ Metal trash racks and monitoring hardware should be constructed of galvanized or stainless steel.
- ______ Methods to prevent clogging of extended detention orifices in dry extended detention basins should be carefully designed, since these orifices are usually very small and located at the invert or bottom of the basin.

_______ All drop inlet spillways designed for pressure flow should have adequate anti-vortex devices (*not* required if weir control is maintained in the riser through all flow stages, including the maximum design storm or safety storm):

    ______ The device may be a baffle or plate installed on top of the riser, or a headwall set on one side of the riser.

_______ The design of a principal spillway riser structure should include a *flotation* or *buoyancy* calculation (see Chapter 13 of the *Virginia Stormwater Management Handbook, 2011*).

    ______ The downward force of the riser and footing (to which the riser must be firmly attached) is the *structure weight*, which must be 1.25 times greater than the buoyant force acting on the riser.

_______ Stormwater management facilities having permanent impoundments may be designed so that the permanent pool can be drained to simplify maintenance and sediment removal.

    ______ The draining mechanism will usually consist of a valve or gate attached to the spillway structure and an inlet pipe projecting into the reservoir area, with a trash rack or debris control device.

    ______ The typical configuration of a drainpipe will place the valve inside the riser structure with the pipe extending out to the pool area.

        ______ This configuration results in the drainpipe being pressurized by the hydraulic head associated with the permanent pool.

        ______ Pressurized pipes should have mechanical joints in order to avoid possible leaks and seepage resulting from the innate pressure.

        ______ In all cases, valves should be secured to prevent unauthorized draining of the facility.

        ______ Basin drains should be designed with sufficient capacity to pass the 1-year frequency design storm with limited ponding in the reservoir area, so that sediment removal and other maintenance functions are not hampered.

        ______ An uncontrolled or rapid drawdown of a stormwater basin could cause a slide in the saturated upstream slope of the dam embankment or shoreline area.

            ______ Therefore, the design of the basin drain system should include specific operating instructions for the owner.

            ______ Generally, the drawdown rate should not exceed 6 inches per day.

            ______ For embankment or shoreline slopes of clay or silt, the drawdown rate may be as low as 1 inch per week to ensure slope stability.

6 Emergency Spillway

_______ Vegetated emergency spillways must be built in existing, undisturbed earth/rock or “cut” in the abutments at one or both ends of an earthen embankment or ovr a topographic saddle anywhere on the periphery of the basin. They should *never* be located on any portion of the embankment fill material.

_______ Excavated emergency spillways consist of three elements:

    ______ An inlet channel, through which *subcritical* flow enters the spillway.

        ______ The inlet channel should have a straight alignment and grade.

        ______ The cross-sectional area of flow in the inlet channel should be large in comparison to the flow area at the control section.

        ______ Where the depth of the channel changes to provide for the increased flow area, the bottom width should be altered gradually to avoid abrupt changes in the shape of the sloping channel banks.

    ______ A level section, which controls the depth of flow.

        ______ The maximum design water surface elevation (normally for the 100-year storm) through the emergency spillway should be at least 1 foot lower than the settled top of the embankment and should be confined by undisturbed earth or rock.

        ______ The bottom width of the spillway should not exceed 35 times the design depth of flow, to avoid damage by meandering flow and accumulated debris.

        ______ Whenever the required bottom width is likely to be excessive, consideration should be given to incorporation of a spillway at each end of the dam.

            ______ The two spillways do not need to be of equal width if their total capacity meets design requirements.

- ______ An exit channel, through which either *critical* or *supercritical* flow discharges from the spillway
  - ______ The alignment of the exit channel must be straight to a point far enough below the embankment to ensure that any flow escaping the exit channel cannot damage the embankment.
  - ______ The exit channel should have the same cross-section as the control section.
  - ______ The slope of the exit channel must be:
    - ______ Adequate to discharge the peak flow within the channel.
    - ______ No greater than that which will produce maximum permissible velocities for the soil type or the planned grass cover.
    - ______ The slope range of the exit channel is selected to ensure *supercritical* flow in the channel.
- ______ The control section is the point on the spillway where the flow passes through *critical* depth, usually installed close to the intersection of the earthen embankment and the emergency spillway centerlines.

_______ The type of soil and vegetative cover used in the emergency spillway can be used to establish the spillway design dimensions and geometry.

- ______ Vegetation provides a degree of retardance to the flow through the spillway, depending mostly on the height and density of the vegetative cover chosen.

_______ Hydraulic design for emergency spillways must be done in accordance with criteria provided in *Appendix C: Vegetated Emergency Spillways* of the *Introduction to the New Virginia Stormwater Design Specifications* (as posted on the Virginia Stormwater BMP Clearinghouse web site at http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html) and in Chapter 13 of the *Virginia Stormwater Management Handbook (2011)*.

_______ Spillway side slopes should be no steeper than 3H:1V unless the spillway is excavated into rock.

_______ Show the existing ground and proposed improvements along the center line of the emergency spillway

C. Landscape Plan

_______ The landscaping plan must indicate the methods to be used to establish and maintain vegetative cover in the ED Pond and its buffer area, including the following:

- ______ Consider including design elements that promote diverse wildlife and waterfowl use within the ED pond and buffer.
- ______ Show the delineation of pondscaping zones within both the pond and buffer.

_______ Provide a planting schedule and specifications (transport / storage / installation / maintenance)

- ______ Ensure that plant selection is appropriate for the site's vegetation climatic zone (4-8 in Virginia) , emphasizing native species if feasible.
- ______ Identify the sources of native plant material.
- ______ Avoid species that require full shade, or are prone to wind damage.
- ______ The planting plan should allow the pond to mature into a native forest in the right places, but yet keep mowable turf along the embankment and all access areas.
  - ______ A wooded wetland approach may be a good option for many ED ponds.
- ______ Specify the sequence for preparing the wetland bed, if one is included with the ED pond (including soil amendments, if needed).
- ______ Woody vegetation may not be allowed to grow within 15 feet of the toe of the embankment nor within 25 feet from the principal spillway structure.
- ______ A vegetated buffer should be provided that extends at least 25 feet outward from the maximum water surface elevation of the ED pond.
- ______ Existing trees within the buffer area should be preserved during construction.
- ______ Permanent structures (e.g., buildings) should *not* be constructed within the buffer area.
- ______ Due to soil compaction, planting holes should be 3 times deeper and wider than the diameter of the root ball for ball-and-burlap stock, and 5 times deeper and wider for container-grown stock.
- ______ Extra mulching around the base of trees and shrubs is strongly recommended as a means of conserving moisture and suppressing weeds.

_______ Specify preservation measures for existing vegetation

_______ Ensure that topsoil / planting soil is included in final grading plan.

D. Construction Notes

_______ Ideally, planned ED pond areas should be constructed after the contributing drainage area is completely stabilized.

_______ ED pond areas *may* be used during construction as sites for temporary sediment traps or basins (properly sized for E&S control purposes), provided the construction plans include notes and graphical details specifying the facility will be de-watered, dredged and re-graded to design dimensions after the original site construction is complete.

- ______ Installation of the permanent riser should be initiated during the construction phase
- ______ Design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction ED pond in mind.
- ______ The bottom elevation of the permanent ED pond should be lower than the bottom elevation of the temporary sediment basin.
- ______ Appropriate procedures should be implemented to prevent discharge of turbid waters when the basin is being converted into a ED pond.

_______ In some cases, it will be necessary to divert flow while the ED pond is being constructed, so that no sediment flows into the pond area until installation and stabilization are complete.

- ______ Flow diversions may be required to meet additional requirements of and obtain permits from state and federal regulatory agencies.

_______ Construction sequence:

- ______ Construction inspections should occur before, during and after installation to ensure the stormwater wetland is constructed according to specifications.
  - ______ Use detailed inspection checklists that require sign-offs by qualified individuals at critical states of construction, to ensure the contractor's interpretation of the plan is consistent with the designer's intent.
  - ______ The following are critical inspection points:
    - ______ During initial site preparation and installation of E&S Controls.
    - ______ Excavation and grading (e.g., interim and final elevations).
    - ______ Installation of the embankment, the riser/primary spillway, and the outlet structure.
    - ______ Pondscaping installation and final stabilization.
- ______ Check the proposed site for existing utilities prior to any excavation.
- ______ Assemble the construction materials on-site, making sure they meet design specifications, and prepare any staging areas.
- ______ Clear, grub and strip the areas designated for borrow sites, embankment construction, and structural work to the desired subgrade, removing all trees, vegetation, roots and other objectional material.
  - ______ All cleared and grubbed material should be disposed of outside and below the limits of the embankment and reservoir.
  - ______ When specified, a sufficient quantity of topsoil should be stockpiled in a suitable location for use on the embankment and other designated areas.
- ______ Install applicable temporary E&S control measures prior to construction.
- ______ Excavate the core trench for the embankment and install the spillway (outlet) pipe, including the downstream rip-rap apron (energy dissipation) protection..
  - ______ The cutoff trench should be excavated into impervious material along or parallel to the centerline of the embankment.
  - ______ Trench side slopes should be laid back in steps at a 1H:1V slope or flatter. (from page 6; conflicts with 2:1 specified on page 10, Earthen Embankment Spec?).
  - ______ Backfill should be compacted with construction equipment, rollers, or hand tampers to assure maximum density and minimum permeability.
- ______ Install the riser pipe or overflow structure, ensuring the top invert of the overflow weir is constructed level and at the proper design elevation.
- ______ Construct the embankment and any internal berms in 8- to 12-inch lifts, compacted with appropriate equipment.

- ______ Areas on which fill is to be placed should be scarified before its placement.
- ______ The most permeable borrow material should be placed in the downstream portions of the embankment.
- ______ Install the principal spillway or overflow weir concurrently with fill placement and *not excavated into the embankment*. A vertical trench through the embankment material (in order to place the spillway pipe) should not be allowed under any circumstances.
  - ______ Ensure that the top invert of the principal spillway or any overflow weir is constructed level and at the proper design elevation (at least 1 foot below the crest of the emergency spillway). Flashboard risers are strongly recommended for use in constructed wetlands.
- ______ Filter and Drainage Layers:
  - ______ In order to achieve maximum density of clean sands, filter layers should be flooded with clean water and vibrated just after the water drops below the sand surface.
  - ______ The filter material should be placed in lifts of no more than 12 inches in thickness.
  - ______ Up to 4 feet of embankment material may be laced over a filter material layer before excavating back down to expose the previous layer.
  - ______ After removing any unsuitable materials, the trench may be filled with additional 12-inch lifts of filter material, flooded, and vibrated as described above, until the top of adjacent fill is reached.
  - ______ The contractor should ensure that a qualified professional inspect filter and drainage diaphragms, ensuring that backfill material meets specifications for quality, lift thickness, placement, moisture content, and dry unit weight.
- ______ Fill material should be taken from an approved, designated borrow area or stockpile.
  - ______ Fill material should be free of roots, stumps, wood, rubbish, stones greater than 6 inches in diameter, and frozen or other objectionable materials.
  - ______ Fill material for the center of the embankment and the cutoff trench should conform to Unified Soil Classification GC, SC, or CL.
  - ______ Fill material that is beside pipes or structures should be of the same type and quality as specified for the adjoining fill material.
    - ______ The fill material should be placed in horizontal lifts not to exceed 4 inches in thickness and compacted by hand tampers or other manually directed compaction equipment.
    - ______ The material should completely fill all spaces under and beside the pipe.
    - ______ During backfilling, equipment should not be driven closer the 4 feet horizontally to any part of a structure.
    - ______ Equipment should *NEVER* be driven *over* any part of a structure or pipe, unless compacted fill has been placed to a depth specified by the structural live load capacity of the structure or pipe, that adequately distributes the load.
  - ______ Consideration may be given to the use of other materials in the embankment based on the recommendation of a geotechnical engineer supervising the design and construction.
  - ______ The surface layer of compacted fill should be scarified prior to placement of at least 6 inches of topsoil, which must be properly stabilized.
- ______ Fill material should be compacted with appropriate compaction equipment.
  - ______ The number of necessary passes by the compaction equipment over the fill material may vary with soil conditions.

- ______ Fill material should contain sufficient moisture so that the required degree of compaction will be obtained with the equipment used.
- ______ The minimum required density is 95% of maximum dry density with a moisture content within $\pm$ 2% of the optimum, unless otherwise specified by the engineer.
- ______ Each layer of fill should be compacted as necessary to obtain minimum density.

______ Compaction tests should be performed regularly throughout the embankment construction.

- ______ Typically, one test per 5,000 sq. ft. on each layer of fill or as directed by the geotechnical engineer.
- ______ Use either a Standard Proctor Test (ASTM D698) or a Modified Proctor Test (ASTM D1557 – usually more appropriate for earthen dams).
- ______ A new Proctor test is required if the material changes from that previously tested.
- ______ The engineer should certify, at the time of construction, that each fil layer meets the minimum density.

______ A geotechnical or construction inspector should be on site during embankment construction to do the following:

- ______ Test fill compaction
- ______ Observe foundation preparation.
- ______ Observe pipe installation.
- ______ Observe riser construction.
- ______ Observe filter installation, etc.

______ Construct the emergency spillway in cut or structurally stabilized soils.

______ Excavate/grade until the appropriate elevations and desired contours are achieved for the bottom and side slopes of the pond.

______ Install outlet pipes, including the downstream rip-rap apron (energy dissipation) protection.

______ Stabilize exposed soils with temporary seed mixtures appropriate for the pond buffer. All areas above the normal pool elevation should be temporarily stabilized by hydroseeding or seeding over straw.

______ Plant the pond buffer area and implement any remaining permanent stabilization measures.

______ If the ED pond has a permanent pool, the contractor should measure the actual constructed pond depth at three locations within the permanent pool (fore-bay, mid-pond, and at the riser), and these depths should be marked and geo-referenced on an as-built drawing. This will facilitate long-term maintenance.

______ Implement any remaining permanent stabilization measures.

______ Conduct a final inspection, log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

E. Maintenance Items (can include BMP Operation & Maintenance Inspection Checklists from Chapter 9, Appendix 9-C of this Handbook)

_______ Provide a Maintenance Agreement, indicating the person or organization responsible for maintenance, authorizing access for inspections and maintenance, and including a maintenance inspection checklist.

- ______ Include a Maintenance Narrative which describes the long-term maintenance requirements of the facility and all components, including installation/maintenance of safety signage; removal and disposal of trash, debris and sediment accumulations; and mowing.

_______ Record a deed restriction, drainage easement, and/or other enforceable mechanism, including GPS coordinates of the area, to ensure the ED pond is not converted to other uses.

_______ Provide sufficient facility access from the public ROW or roadway to both the ED pond and any pre-treatment practices.

IV. COMMENTS

By: ______________________ Date: ______________

8-A.17.0. REFERENCES

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