COMMONWEALTH OF VIRGINIA
DEPARTMENT OF ENVIRONMENTAL QUALITY

Virginia Stormwater Management Handbook
Technical Review Committee (TRC) Meeting #7
Thursday May 28, 2026

Revised Draft Agenda

Meeting Location:
Department of Environmental Quality
Bank of America, 3rd Floor Conference Room
1111 East Main Street
Richmond, VA 23219

Start – 9:30 AM

Welcome — DEQ Staff

- Sign-In
- Introduction
- FOIA Information
- Past Meeting Minutes

Updates — All

- V1.3 Post-Construction BMP Discussion Topics Follow Up (P-BAS, P-CNV, P-FIL and P-SUP)

Specifications Review — All

- P-FIL-03 Permeable Pavement
- P-FIL-09 Tree Planting

Lunch Break – 12:00 pm — All

Draft Specification Review — All

- Flocculant Specification
- All CMAC Materials

New Topics — All

- Permanent Linear Utility Access Roads

Public Forum — All

Next Steps — DEQ Staff

Wrap Up — DEQ Staff

P-FIL-03 Permeable Pavement

1.0 Definition

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 and/or infiltrated. A variety of permeable pavement surfaces are available, including **pervious concrete, porous asphalt** and **permeable grid pavers** and **interlocking concrete pavers**. Artificial turf can also used as the surface cover for permeable pavement designs. While the specific design may vary, all permeable pavements have a similar structure, consisting of a permeable surface pavement layer, an underlying stone aggregate reservoir layer, and a filter layer or ~~fabric~~ geotextile installed on the bottom. See Figure P-FIL-03-1 and Figure P-FIL-03-2.

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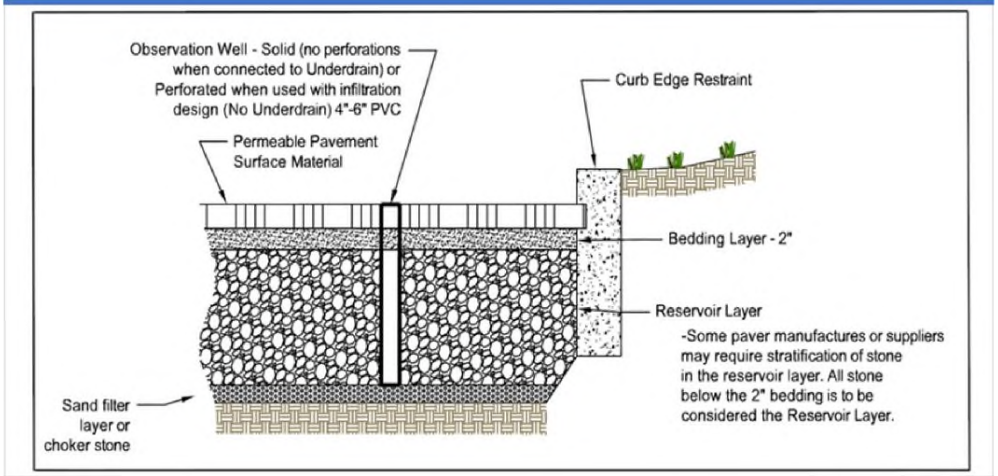
Figure P-FIL-03-1 Types of Permeable Pavement: (clockwise from upper left): Concrete Grid Pavers (Chesapeake Stormwater Network); Pervious Concrete (perviouspavement.org), Permeable Interlocking Concrete Pavers (UC Davis), Porous Asphalt (UC Davis)

Figure P-FIL-03-2 Typical Cross Section



2.0 Purpose and Applicability of Best Management Practice

Since permeable pavement has a very high runoff reduction capability, it should always be considered as an alternative to conventional pavement. Permeable pavement is subject to the same feasibility constraints as most infiltration practices, as described below.

2.1 Feasibility/Limitations

The following feasibility criteria should be evaluated when permeable pavement is considered as the final practice in a treatment train.

Commented [KA1]: ARCADIS TO REVISE FIGURE: (Virginia Asphalt Association) The Bedding Layer and the Sand Filter Layer/Choker Stone are not necessary for PA applications per VDOT Design Details. However, a geotextile fabric is necessary to run along the bottom of the reservoir layer and sides to prevent fines from the soils to migrate and clog the reservoir layer.

Commented [KA2R1]: Recommend labeling the 2" bedding layer as (if needed). Even some interlocking pavers don't require that layer.

Table P-FIL-03-1 Feasibility Criteria	
Constraint	**Criteria**
Available Space	A prime advantage of permeable pavement is that it does not normally require additional space at a new development or redevelopment site, which is an advantage for small sites or areas where land prices are high.
Soils	Soil conditions do not constrain the use of permeable pavement, although they do determine whether an underdrain is needed. Impermeable soils in Hydrologic Soil Groups (HSG) C or D usually require an underdrain, whereas HSG A and B soils often do not. In addition, permeable pavement should never be situated above fill soils unless designed with an impermeable liner and underdrain. If the proposed permeable pavement area is designed to infiltrate runoff without underdrains, it must have a field-verified minimum infiltration rate of 0.5 inch per hour. For initial planning purposes, projected soil infiltration rates can be estimated from the U.S. Department of Agriculture (USDA)-Natural Resources Conservation Service (NRCS) soil data, but they must be confirmed by an onsite infiltration measurement for final design. Native soils must have silt/clay content less than 40% and clay content less than 20%. Refer to Appendix C, Soil Characterization and Infiltration Testing, for soil testing requirements and procedures. Soil testing is not needed for Level 1 permeable pavement where an underdrain is used. Note: Designers should evaluate existing soil properties during initial site layout and seek to configure the site to conserve and protect the soils with the greatest recharge and infiltration rates. Areas of HSG A or B soils shown on USDA-NRCS soil surveys should be considered as primary locations for all types of infiltration.
External Drainage Area	It is acceptable for an external drainage area to contribute runoff to a permeable pavement installation only when the underlying reservoir is drained by an underdrain. When this is allowed, the external drainage area shall not exceed two and one-half times the surface area of the permeable pavement (ratio of 2.5:1), and it should be as close to 100% impervious as practically feasible. This ratio is intended to facilitate the use of a permeable pavement section in a parking stall to treat an area with the dimensions of the width of the adjacent drive aisle and the length of the opposite parking stall. It is important to note that field experience has shown that an upgradient drainage area (even if impervious) can contribute particulates onto the permeable pavement and lead to clogging (Hirschman et al. 2009). Therefore, careful sediment source control and/or a pretreatment strip or sump (e.g., stone or gravel) should be used to control sediment run-on to the permeable pavement section. Any design with an external drainage area contributing “runon” to the permeable pavement section should include requirements for more frequent operation and maintenance inspections.

Commented [KA3]: Discuss: Consider the 2.5:1 run-on ratio. Different types of permeable pavements have been shown to have MUCH higher run-on ratios and functioned successfully. This limitation eliminates the benefits provided by those systems.

Table P-FIL-03-1 Feasibility Criteria	
Constraint	**Criteria**
Pavement Slope	Steep slopes can reduce the stormwater storage capability of permeable pavement and may cause shifting of the pavement surface and base materials. Designers should consider using a terraced design for permeable pavement in sloped areas, especially when the local slope is 5% or greater. The bottom slope of a permeable pavement installation should be as flat as possible (i.e., 0% longitudinal slope) to enable even distribution and infiltration of stormwater, which may result in a variable depth reservoir layer. However, a maximum longitudinal slope of 1% is permissible if an underdrain and an over-drain are employed. Lateral slopes should be
Minimum Hydraulic Head	The elevation difference needed for permeable pavement to function properly is generally nominal, although 2 to 4 feet of head may be needed to drive flows through underdrains. Flat terrain may affect proper drainage of Level 1 permeable pavement designs, so underdrains should have a minimum 0.5% slope.
Minimum Depth to Water Table	A high groundwater table may cause runoff to pond at the bottom of the permeable pavement system. Therefore, a minimum vertical distance of 2 feet must be provided between the bottom of the permeable pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonally high water table.

2.2 Setbacks

To avoid the risk of seepage, permeable pavement practices should not be hydraulically connected to structure foundations. Setbacks to structures will vary, based on the size of the permeable pavement installation. See Table P-FIL-03-2.

Table P-FIL-03-2 Setback/Offset Criteria	
Feature	**Offset***
250 to 1,000 square feet of permeable pavement	5 feet if downgradient from building; 25 feet* if upgradient
1,000 to 10,000 square feet of permeable pavement	10 feet if downgradient from building; 50 feet* if upgradient
More than 10,000 square feet of permeable pavement	25 feet if downgradient from building; 100 feet* if upgradient

Note:

* In some cases, the use of an impermeable liner along the sides of the permeable pavement practice (extending from the surface to the bottom of the reservoir layer) may be used as an added precaution against seepage, and the setback requirements can be relaxed.

At a minimum, due to concerns that high concentrations of urban pollutants may be introduced into the pavement via vehicle tires, small spills, etc., permeable pavement applications (using infiltration or an infiltration sump) on commercial properties should be located a minimum horizontal distance of 100 feet from any water supply well and at least 5 feet downgradient from dry or wet utility lines. If groundwater contamination is a concern, it is recommended that groundwater mapping be conducted to determine possible connections to adjacent groundwater wells.

Residential applications should be a minimum horizontal distance of 50 feet from any water supply well and 35 feet from any septic system (20 feet if the stone reservoir is lined). These setbacks are general guidelines and may be adjusted by the local plan-approving authority on residential applications or if underdrains or liners are used, or if other precautions are taken.

Table P-FIL-03-3 outlines design requirements for each of the three scales of permeable pavement installation.

Table P-FIL-03-3 The Three Design Scales for Permeable Pavement

Design Factor	Micro-Scale Pavement	Small-Scale Pavement	Large-Scale Pavement
Impervious Area Treated	250 to 1,000 square feet	1,000 to 10,000 square feet	More than 10,000 square feet
Typical Applications	Driveways Walkways Court Yards Plazas Individual Sidewalks	Sidewalk Network Fire Lanes Road Shoulders Spill-Over Parking Plazas	Parking Lots with more than 40 spaces Low Speed Residential Streets
Most Suitable Pavement	IP	PA, PC, and IP	PA, PC, and IP
Load Bearing Capacity	Foot traffic Light vehicles	Light vehicles	Heavy vehicles (moving and parked)
Reservoir Size	Infiltrate or detain some or all the Tv	Infiltrate or detain the full Tv and as much of the CPv and design storms as possible	
External Drainage Area?	No	Yes, impervious cover up to ~~twice~~ 2.5 times the permeable pavement area may be accepted as long as sediment source controls	
Observation Well	No	No	Yes
Underdrain?	Rare	Depends on the soils	Backup underdrain
Required Soil Tests	One per practice	Two per practice	One per 5,000 square feet of proposed practice
Building Setbacks*	5 feet if downgradient 25 feet if upgradient	10 feet if downgradient 50 feet if upgradient	25 feet if downgradient 100 feet if upgradient

Commented [KA4]: Move table and intro sentence to Section 2.6 Design Scales.

Table P-FIL-03-3 The Three Design Scales for Permeable Pavement			
Design Factor	Micro-Scale Pavement	Small-Scale Pavement	Large-Scale Pavement

Notes:

* In some cases, the use of an impermeable liner along the sides of the permeable pavement practice (extending from the surface to the bottom of the reservoir layer) may be used as an added precaution against seepage, and the setback requirements can be relaxed.

CPv = channel protection volume

IP = interlocking pavers

PA = porous asphalt

PC = pervious concrete

Tv = treatment volume

2.3 Informed Owner

The property owner should clearly understand the unique maintenance responsibilities inherent with permeable pavement, particularly for parking lot applications. The owner should be capable of performing routine and long-term actions (e.g., vacuum sweeping) to maintain the pavement's hydrologic functions, and avoid future practices (e.g., winter sanding, seal coating or repaving) that diminish or eliminate them. The owner may also be required to contract for more frequent periodic inspections conducted by a qualified engineer or contractor if the installation includes external (i.e., run-on) drainage.

2.4 High Loading Situations

Permeable pavement is not intended to treat sites with high sediment or trash/debris loads, since such loads will cause the practice to clog and fail. Some systems may be designed to account for these conditions such as open joint pavers. Consult the manufacturer regarding use restrictions to ensure long term functionality.

2.5 Limitations

Permeable pavement can be used as an alternative to most types of conventional pavement at residential, commercial, and institutional developments, with two exceptions:

Permeable pavement has not been thoroughly tested on high-speed roads in extreme weather conditions, although it has been successfully applied for low-speed residential streets, parking lanes, and roadway shoulders.

Permeable pavement should not be used to treat runoff from stormwater hotspots, as noted above. Refer to BMP P-FIL-04, Infiltration Practices, for more specific guidance regarding hotspots.

2.6 Design Scales

Permeable pavement can be installed at the following three scales:

1. The smallest scale is termed **micro-scale pavement**, which applies to converting impervious surfaces to permeable surfaces on small lots and redevelopment projects, where the installations may range from 250 to 1,000 square feet in total area. Where redevelopment or retrofitting of existing impervious areas results in a larger footprint of permeable pavers (i.e., small-scale or large-scale installations, as described below), the designer should implement criteria associated with bearing appropriate loads, installation of observation wells and underdrains, conducting soil tests, and ensuring proper building setbacks, as appropriate for the applicable scale.

2. **Small-scale pavement** applications treat portions of a site between 1,000 and 10,000 square feet in area and include areas that only occasionally receive heavy vehicular traffic.
3. **Large scale pavement** applications exceed 10,000 square feet in area and typically are installed within portions of a parking lot.

Regardless of the scale of the permeable pavement installation, the designer should carefully consider the expected traffic load at the proposed site and the consequent structural requirements of the pavement system. Sites with heavy traffic loads will require a thick aggregate base and, in the case of porous asphalt and pervious concrete, may require the addition of an admixture for strength or a specific bedding design. In contrast, most micro-scale applications should have little or no traffic flow.

3.0 Planning and Considerations

3.1 Regional and Special Case Design Adaptations

The design adaptations described below permit permeable pavement to be used on a wider range of sites. However, it is important to not force this practice onto marginal sites. Other runoff reduction practices are often preferred alternatives for difficult sites. See Table P-FIL-03-4, Table P-FIL-03-5, and Table P-FIL-03-6.

3.2 Karst Terrain

Karst terrain is found in much of the Ridge and Valley physiographic region of Virginia. Karst complicates both land development and stormwater design. A detailed geotechnical investigation may be required for any kind of stormwater design in karst terrain (see Appendix E, Site Assessment and Design Guidelines for Stormwater Management in Karst, Virginia, for further guidance).

- The use of Level 2 (i.e., infiltrative) permeable pavement designs at sites with known karst features may cause the formation of sinkholes (especially for large scale pavement applications) and is, therefore, not recommended. Designers should also avoid a Level 2 permeable pavement design if the site is designated as a severe stormwater hotspot or will discharge to areas known to provide groundwater recharge to an aquifer that is used as a water supply source.
- Micro-scale and small-scale permeable pavement installations are acceptable if they are designed according to Level 1 criteria (i.e., they possess an impermeable bottom liner and an underdrain).

The stone used in the reservoir layer should be carbonate in nature to provide extra chemical buffering capacity.

Table P-FIL-03-4 Material Specifications for Underneath the Pavement Surface

Material	Specification	Notes
Bedding Layer	PC: ~~None.~~2 inches of No. 57 stone PA: ~~2 inches of No. 57 stone.~~None IP: 2 inches of No. 8 stone over 4 inches of No. 57	ASTM D448 size No. 8 stone ~~(e.g., 3/8 to 3/16 inch in size). S~~should be washed and clean and free of all fines.
AASHTO No. 2 or No. 3 aggregate Reservoir Layer	~~PC: No. 57 stone. PA: No. 2~~ stone. ~~IP: No. 2, 3, or 4 stone~~.	ASTM D448 size No. 57 stone (e.g., 1 1/2 to 1/2 inch in size); No. 2 Stone (e.g., 3 to 3/4 inch in size). Depth is based on the pavement structural and hydraulic requirements. Should be washed and clean and free of all fines.

Commented [MC5]: Relocate Tables -4, -5 and -6 to either beginning or end of Section 3.0 to avoid confusion

Commented [KA6]: Discuss: Not all permeable pavements are the same, and many are designed without a bedding layer or with different materials in the reservoir layer. The spec will be more open to innovation if, at a minimum, it allows for base layers to be constructed according to the product manufacturer's guidelines, with requirements for Tv capacity.

Table P-FIL-03-4 Material Specifications for Underneath the Pavement Surface

Material	Specification	Notes
Underdrain	Use 4- to 6-inch diameter perforated PVC (AASHTO M 252) pipe, with 3/8 inch perforations at 6 inches on center; each underdrain installed at a minimum 0.5% slope located 20 feet or less from the next pipe (or equivalent corrugated high-density polyethylene may be used for smaller load-bearing applications). Use perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, to connect with the storm drain system. Ts and Ys should be installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys.	
Filter Layer	Per manufacturer's recommendations. For permeable asphalt see the VDOT specification. ~~The underlying native soils should be separated from the stone reservoir by a thin, 2- to 4-inch layer of choker~~	~~The sand should be placed between the stone reservoir and the choker stone, which should be placed on top of the underlying native soils.~~
~~Filter Fabric~~Geotextile (optional)	Use an appropriate ~~filter~~ geotextile fabric for the application based on AASHTO M288-06 Filter Fabric; should have a flow rate greater than ~~125~~ 70 gallons per minute per square foot (ASTM D4491), and an AOS equivalent to a 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 Federal Highway Administration or AASHTO selection criteria.	
Impermeable Liner	Use only in karst regions. Use a 30 mil (minimum) PVC geomembrane liner covered by a 8- to 12-ounce per square yard nonwoven geotextile.	
Observation Well	Use a ~~perforated~~ 4- to 6-inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface. The observation well should be solid when connected to an underdrain and perforated when no underdrain is present.	

Notes:

AASHTO = American Association of State Highway and Transportation Officials Standard AOS = apparent opening size

ASTM = ASTM International Standard IP = interlocking pavers

PA = porous asphalt PC = pervious concrete

PVC = polyvinyl chloride

Commented [KA7]: VDOT has deleted the filter layer in their spec, but it may be included in other types, so reference is here.

3.3 Coastal Plain

Experience in North Carolina and Virginia has shown that properly-designed and installed permeable pavement systems can work effectively in the demanding conditions of the coastal plain, if the following conditions are met:

- The distance from the bottom of the permeable pavement system to the top of the water table must be at least 2 feet.
- If an underdrain is used beneath permeable pavement, a minimum 0.5% slope must be maintained to ensure proper drainage.

Table P-FIL-03-5 Permeable Pavement Specifications

Material	Specification	Notes
Permeable Interlocking Concrete Pavers	Surface open area: 5% to 15%. Thickness: 3.125 inches minimum for vehicles. Compressive strength: 55 MPa. Open void fill media ~~:~~ ~~A~~aggregate or open joints.	Must conform to ASTM C936 specifications. Reservoir layer required to support the structural load. Must conform to manufacturer's specifications.
Concrete Grid Pavers	Open void content: 20% to 50%. Thickness: 3.5 inches. Compressive strength: 35 MPa. Open void fill media: Aggregate, topsoil and grass, coarse sand.	Must conform to ASTM C1319 specifications. Reservoir layer required to support the structural load.
Plastic Reinforced Grid Pavers	Void content: Depends on fill material. Compressive strength: Varies, depending on fill material. Open void fill media: Aggregate, topsoil and grass, coarse sand.	Reservoir layer required to support the structural load.
Pervious Concrete	Void content: 15% to 25 %. Thickness: 4 to 8 inches. Compressive strength: 2.8 to 28 MPa. Open void fill media: None.	May not require a reservoir layer to support the structural load, but a layer may be included to increase the storage or saturated conductivity/permeability.
Porous Asphalt	Void content: 15% to 20%. Minimum Thickness: ~~3 to 7~~ 4.5 inches in total, ~~total~~ constructed in two layers (depending on traffic load). Open void fill media: None.	Reservoir layer required to support the structural load. ~~The surface layer of the porous asphalt include a polymer modified asphalt binder to resist power steering scuffing and long term performance~~ The PA surface thickness is 1.5 inches using a polymer modified asphalt binder to resist power steering scuffing and provide long-term performance. The PA base thickness is a minimum of 3 inches and may use a polymer modified binder for long-term performance.

Notes:

ASTM = ASTM International Standard MPa = megapascal

3.4 Piedmont/Clay Soils

In areas where the underlying soils are not suitable for complete infiltration, permeable pavement systems with underdrains can still function effectively to reduce runoff volume and nutrient loads.

- If the underlying soils have an Ksat of less than 0.5 inch per hour, an underdrain must be installed to ensure proper drainage from the system.
- Permeable pavement should not be installed over underlying soils with a high shrink or swell potential.
- To promote greater runoff reduction for permeable pavement located on marginal soils, an elevated underdrain configuration may be used.

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Commented [KA8]: Discuss: In Grid Pavers, the 20% to 50% open void content and 3.5" thickness is overly prescriptive and not necessary.

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3.5 Cold Climate and Winter Performance

In cold climates and winter conditions, freeze-thaw cycles may affect the structural durability of the permeable pavement system. In these situations, the following design adaptations may be helpful:

- To avoid damage caused by freezing, designs should not allow water to pond in or above the permeable pavement. An over-drain should be placed at least 6 inches below the pavement section and bedding layer.

- To reduce freezing potential, extend the filter bed and underdrain pipe below the frost line and/or oversize the underdrain by one pipe size.
- Be aware of the long-term maintenance concerns described in Table P-FIL-03-6 regarding “Cold Climate or Wintertime Operation” and reference those issues in the Maintenance Agreement for this practice.

Table P-FIL-03-6 Community and Environmental Concerns

Concern	Requirement
Compliance with the Americans with Disabilities Act (ADA)	Porous concrete and porous asphalt are generally considered to be ADA compliant. Most localities also consider interlocking concrete pavers to be complaint if designers ensure that surface openings between pavers do not exceed 1/2 inch. However, some forms of interlocking pavers may not be suitable for handicapped parking spaces. Interlocking concrete pavers interspersed with other hardscape features (e.g., concrete walkways) can be used in creative designs to address ADA issues.
Groundwater Protection	While well-drained soils enhance the ability of permeable pavement to reduce stormwater runoff volumes, they may also increase the risk that stormwater pollutants might migrate into groundwater aquifers. Designers should avoid the use of infiltration-based permeable pavement in areas known to provide groundwater recharge to aquifers used for water supply. In these source water protection areas, designers should include liners and underdrains in large-scale permeable pavement applications (i.e., when the proposed surface area exceeds 10,000 square feet).
Stormwater Hotspots	Designers should also certify that the proposed permeable pavement area will not accept any runoff from a severe stormwater hotspot. Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk of spills, leaks, or illicit discharges. Examples include certain industrial activities, gas stations, public works areas, petroleum storage areas (for a complete list of hotspots where infiltration is restricted or prohibited. See BMP P-FIL-04, Infiltration Practices. For potential hotspots, restricted infiltration means that a minimum of 50% of the total treatment volume must be treated by a filtering or bioretention practice prior to the permeable pavement system. For known severe hotspots, the risk of groundwater contamination from spills, leaks, or discharges is so great that infiltration of stormwater or snowmelt through permeable pavement is prohibited.

Table P-FIL-03-6 Community and Environmental Concerns	
Concern	**Requirement**
Underground Injection Control Permits	The Safe Drinking Water Act regulates the infiltration of stormwater in certain situations pursuant to the Underground Injection Control Program, which is administered either by the U.S. Environmental Protection Agency (USEPA) or a delegated state groundwater protection agency. In general, the USEPA (2008) has determined that permeable pavement installations are not classified as Class V injection wells, since they are always wider than they are deep. There may be an exception in karst terrain if the discharge from permeable pavement is directed to an improved sinkhole, although this would be uncommon. More guidance on stormwater design in karst terrain can be found in Appendix E, Site Assessment and Design Guidelines for Stormwater Management in Karst, Virginia.
Cold Climate or Wintertime Operation	

Table P-FIL-03-6 Community and Environmental Concerns	
Concern	**Requirement**
Air and Runoff Temperature	Permeable pavement appears to have some value in reducing summer runoff temperatures, which can be important in watersheds with sensitive cold water fish populations. The temperature reduction effect is greatest when runoff is infiltrated into the sub-base, but some cooling may also occur in the reservoir layer, when underdrains are used. The Interlocking Concrete Pavement Institute® (ICPI 2008) notes that the use of certain reflective colors for interlocking concrete pavers can also help moderate surface parking lot temperatures. *Vehicle Safety.* Permeable pavement is generally considered to be a safer surface than conventional pavement, according to research reported by Smith (2006), Jackson (2007) and the American Concrete Institute® (ACI 2008). Permeable pavement has less risk of hydroplaning, more rapid ice melt and better traction than conventional pavement.

4.0 Stormwater Performance Summary

The overall stormwater functions of permeable pavement are shown in Table P-FIL-03-7.

The choice of what kind of permeable pavement to use is influenced by site-specific design factors and the intended future use of the permeable surface. A general comparison of the engineering properties of the three major permeable pavement types is provided in Table P-FIL-03-8. Designers should check with product vendors and the local plan review authority to determine their specific requirements and capabilities. Other paver options, such as concrete grid pavers and reinforced turf pavers, function in the same general manner as permeable pavement.

Table P-FIL-03-7 Summary of Stormwater Functions Provided by Permeable Pavement		
Stormwater Function		
Total Phosphorus EMC Reduction1 by BMP Treatment Process		
Total Nitrogen EMC Reduction[1]		
Annual Runoff Reduction Volume	**Level 1 Design**	**Level 2 Design**
Total Phosphorus Mass Load Removal	45%	75%
Total Nitrogen Mass Load Removal	25%	25%
	59%	81%
	25%	25%
	59%	81%
Channel Protection	Use the Virginia Runoff Reduction Method (VRRM) Compliance spreadsheet to calculate a Curve Number adjustment[2]; or Design extra storage in the stone underdrain layer and peak rate control structure (optional, as needed) to accommodate detention of larger storm volumes.	

Table P-FIL-03-7 Summary of Stormwater Functions Provided by Permeable Pavement		
Stormwater Function	**Level 1 Design**	**Level 2 Design**
Flood Mitigation	Partial. May be able to design additional storage into the reservoir layer by adding perforated storage pipe or chambers.	

Notes:

Source: Center for Watershed Protection (CWP) and Chesapeake Stormwater Network (CSN) 2008; CWP 2007.

1. Change in event mean concentration (EMC) through the best management practice (BMP). Actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate.
2. USDA-NRCS Technical Release 55 Urban Hydrology for Small Watersheds (TR-55) Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events based on the retention storage provided by the practice(s).

Table P-FIL-03-8 Comparative Typical Properties of the Three Major Permeable Pavement Types			
Design Factor	**Porous Concrete**	**Porous Asphalt**	**Interlocking Pavers**
Scale of Application	Small- and large-scale paving applications	Small- and large-scale paving applications	Micro, small- and large-scale paving applications
Pavement Thickness[1]	5 to 8 inches	Minimum3 to 44.5 inches(total)	3 inches
Bedding Layer[1,8]	None	2 inches No. 57 stone	2 inches of No. 8 stone over 4 inches No. 57 stone[8]
Reservoir Layer[2,8]	No. 57 stone	No. 2 or 3 stone	No. 2, 3, or 4 stone
Construction Properties[3]	Cast in place; 7-day cure; must be covered	N/ACast in place; 24-hour cure	No cure period; manual or mechanical installation of pre-manufactured units, over 5,000 square feet/day per machine
Design Permeability[4]	10 feet/day	6 feet/day	2 feet/day
Construction Cost[5]	$8.00 to $15.00 per square foot	$7.00 to $12.50 per square foot	$5.00 to $15.00 per square foot
Minimum Batch Size	500 square feet	N/A500 square feet	NA
Longevity[6]	20 to 30 years	15 to 20 years	20 to 30 years
Overflow	Drop inlet or overflow edge	Drop inlet or overflow edge	Surface, drop inlet or overflow edge
Temperature Reduction	Cooling in the reservoir layer	Cooling in the reservoir layer	Cooling at the pavement surface and reservoir layer
Colors/Texture	Limited range of colors and textures	Black or dark grey color	Wide range of colors, textures, and patterns
Traffic Bearing design. Capacity[7]	Can handle all traffic loads, with appropriate bedding layer		
Surface Clogging	Replace paved areas or install drop inlet	Replace paved areasRemove and Replace surface layer or install drop inlet	Replace permeable stone jointing materials
Other Issues	--	Avoid seal coating	Snowplow damage
Design Reference	ACI #522.1.08	Jackson (2007)	Smith (2006)

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Commented [KA9]: Reference VDOT PA spec.

Table P-FIL-03-8 Comparative Properties of the Three Major Permeable Pavement Types

Design Factor	Porous Concrete	Porous Asphalt	Interlocking Pavers

Notes:

1. Individual designs may depart from these typical cross-sections due to site, traffic and design conditions.
2. Reservoir storage may be augmented by corrugated metal pipes, plastic arch pipe, or plastic lattice blocks.
3. ICPI 2008.
4. Northern Virginia Regional Commission 2007.
5. Based on consultant research.
6. Based on pavement being maintained properly; resurfacing or rehabilitation may be needed after the indicated period.
7. Depends primarily on the onsite geotechnical considerations and structural design computations.
8. Stone sizes correspond to ASTM International Standard D448, Standard Classification for Sizes of Aggregate for Road and Bridge Construction.

5.0 Design Criteria

The major design goal of permeable pavement is to maximize nutrient removal and runoff reduction. To this end, designers may choose to use a baseline permeable pavement design (Level 1) or an enhanced design (Level 2) that maximizes nutrient and runoff reduction. To qualify for Level 2, the design must meet all design criteria shown in the right-hand column of Table P-FIL-03-9. Illustrations are shown on Figure P-FIL-03-3, Figure P-FIL-03-4, Figure P-FIL-03-5, Figure P-FIL-03-6, and Figure P-FIL-03-7.

Table P-FIL-03-9 Permeable Pavement Design Criteria

Level 1 Design	Level 2 Design
Tv = (1)(Rv)(A) / 12 The volume reduced by an upstream BMP1	Tv = (1.1)(Rv)(A) / 12
Soil infiltration is less than 0.5 inch/hour	Soil infiltration rate must exceed 0.5 inch/hour to remove underdrain requirement or use a drawdown design in accordance with Section 5.4.
Underdrain required	1. No underdrain; or 2. If an underdrain is used, provide a 12-inch (minimum) stone reservoir infiltration sump below the underdrain invert that meets the drawdown requirements of Section 6.0 Construction Specifications; or 3. The Tv stone reservoir volume has at least a 48-hour drain time, as regulated by a control structure.
CDA1 = The permeable pavement area plus upgradient parking, if the ratio of external contributing area to permeable pavement does not exceed 2.5:1.	• CDA = The permeable pavement area; or • If option 3 above is used, CDA ratio may be 2.5:1.

Commented [KA10]: Discuss: Are there allowances to increase this ratio if engineering can show a benefit?

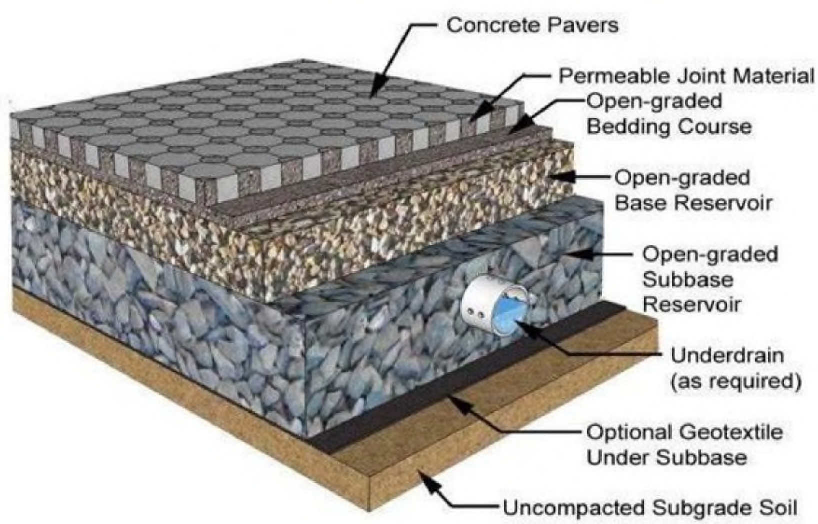
Table P-FIL-03-9 Permeable Pavement Design Criteria	
Level 1 Design	Level 2 Design

Notes:

1. The contributing drainage area to the permeable pavements should be limited to paved surfaces to avoid sediment wash-on. When pervious areas are conveyed to permeable pavement, sediment source controls and/or pretreatment must be provided . A strip or sump should be used.

   The pretreatment may qualify for a runoff reduction credit if designed accordingly.

Figure P-FIL-03-3



Source: Smith 2009

Figure P-FIL-03-4 Typical Section Permeable Pavement Level 1

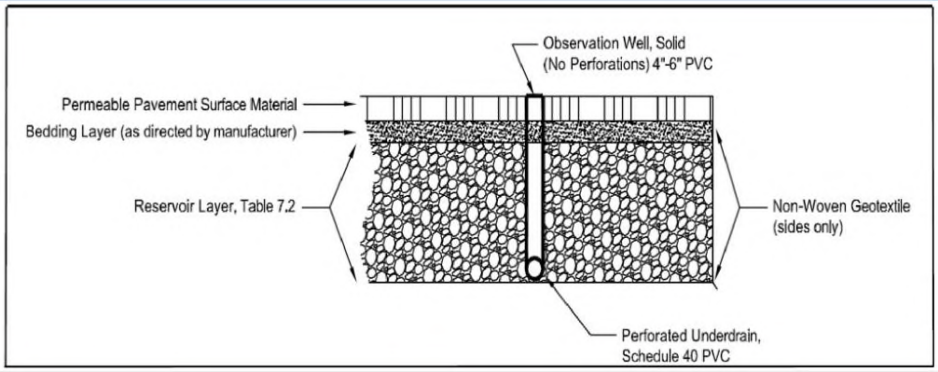
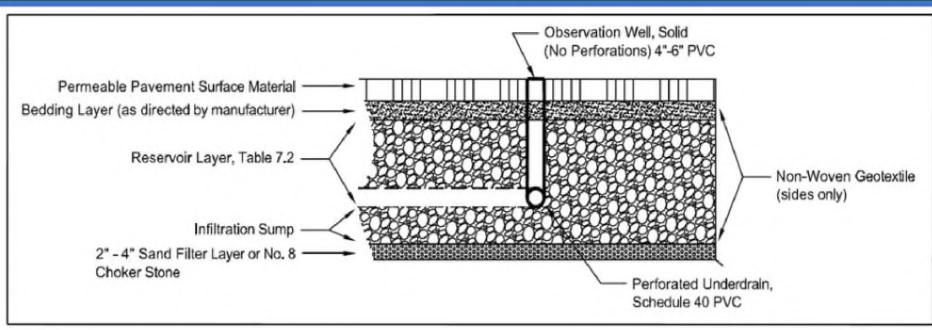


Figure P-FIL-03-5 Typical Section Permeable Pavement Level 2 with Infiltration Sump



Commented [MC11]: FIGURE: ARCADIS
Remove Non-Woven geotextile (sides only) from Figures P-FIL-03-4 and -5

Commented [MC12R11]: Also, change “Reservoir Layer, Table 7.2” to “Reservoir Layer, Table P-FIL-03-4” for all figures

Commented [KA13]: Discuss: All figures show the bedding course again, which isn’t always required by all manufacturers. Delete in figures or remove figures as a whole and refer to manufacturer’s specifications/VDOT?

Figure P-FIL-03-6 Infiltration Sump with an "Upturned Elbow" or Weir Control

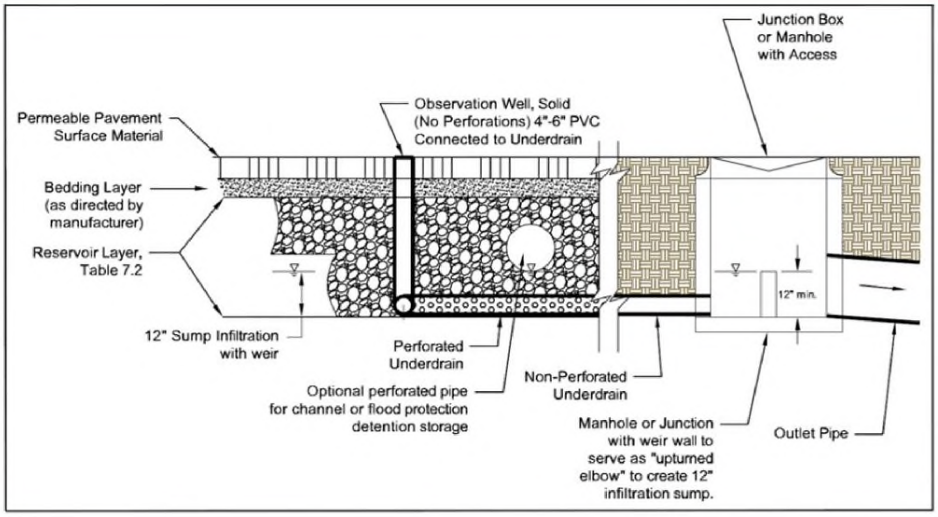
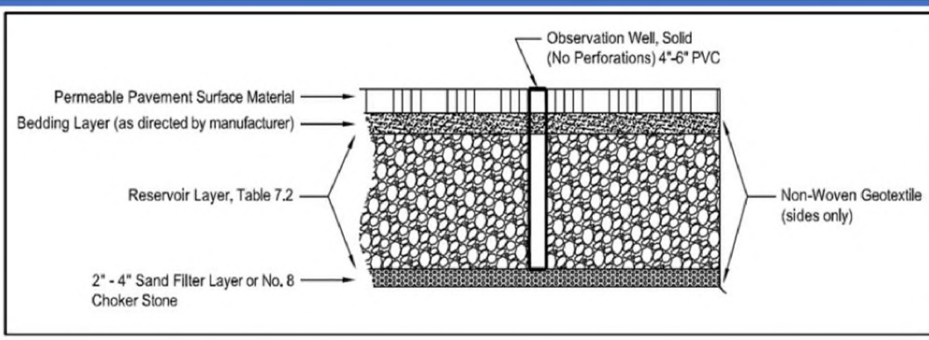


Figure P-FIL-03-7 Typical Section Permeable Pavement Level 2 with Infiltration



Commented [MC14]: FIGURE: ARCADIS
Observation well should be perforated to be consistent with Figure P-FIL-03-2

- Total traffic;
- In-situ soil strength;
- Environmental elements; and
- Surface materials, bedding and reservoir layer design.

The resulting structural requirements may include, but are not limited to, the thickness of the pavement, filter, and reservoir layer. Designers should note that if the underlying soils have a low California Bearing Ratio (less than 4%), they may need to be compacted to at least 95% of the Standard Proctor Density, which generally limits their use for infiltration.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- Virginia Department of Transportation (VDOT) Pavement Design Guide for Subdivision and Secondary Roads in Virginia (2000; or latest edition);
- AASHTO Guide for Design of Pavement Structures (1993); and
- AASHTO Supplement to the Guide for Design of Pavement Structures (1998).

The structural design process for supporting vehicles varies according to the type of pavement selected. ASTM International test methods for characterizing compressive or flexural strengths of pervious concrete are currently being developed. These tests are needed to model pavement fatigue under loads. As an interim step, fatigue equations published by the American Concrete Pavement Association (ACPA 2010) assume such inputs to be comparable in nature (but not magnitude) to those used for conventional concrete pavements. The ACPA design method should be consulted for further information.

General guidelines for pervious concrete surface thickness are published by the National Ready Mix Concrete Association and the Portland Cement Association (Leming 2007).

Porous asphalt (Hansen 2008) and permeable interlocking pavements (Smith 2010) use flexible pavement design methods adopted from the AASHTO Guide for Design of Pavement Structures (1993). One example of a pavement design tool is PAVEXpress. In addition, manufacturer's specific recommendations should be consulted.

Concrete grids only see intermittent traffic and generally only require a minimum 8-inch thick compacted, dense-graded base. The minimum open-graded base and sub-base thicknesses under permeable interlocking concrete grid pavement can generally be used for water storage.

There has been little research or full-scale testing of the structural behavior of open-graded bases used under permeable pavements in order to better characterize the relationships between loads and deformation. Therefore, conservative values (i.e., AASHTO layer coefficients) should be assumed for open-graded base and sub-base aggregates in permeable pavement design.

Regardless of the type of permeable pavement, structural design methods should account for the following in determining surface and base thicknesses to support vehicular traffic:

- Pavement life and total anticipated traffic loads, expressed as 18,000-pound equivalent single axle loads (ESALs); this method of assessing loads accounts for the additional pavement wear caused by trucks;
- Soil strength, expressed in terms of the soaked California Bearing Ratio (CBR), R-value, or resilient modulus (Mr);
- Strength of the surfacing, base, and sub-base materials; and
- Environmental factors, including freezing climates and extended saturation of the soil subgrade.

Soil stability under traffic should be carefully reviewed for each application by a qualified geotechnical or civil engineer and the lowest anticipated soil strength or stiffness values used for design. Structural design for vehicular applications assumes the following:

- Minimum soil CBR of 4% (96-hour soaked per ASTM D1883 or AASHTO T-193); or
- Minimum R-value = 9 per ASTM D2844 or AASHTO T-190; or
- Minimum Mr of 6,500 pounds per square inch (45 MPa) per AASHTO T-307.

Soil compaction required to achieve this criterion will reduce the infiltration rate of the soil. Therefore, the permeability or infiltration rate of soil should be assessed at the density required to achieve one of these values.

Hydraulic Design

The permeable pavement reservoir layer is typically sized to store the water quality treatment volume (*Tv*) and, in some cases, the additional detention volume from larger storms. The infiltration rate will be significantly less than the flow rate through the pavement, so the outflow attributed to infiltration is typically ignored. Equation P-FIL-03-1 is used to determine the depth of the stone reservoir layer required to capture and fully infiltrate the design *Tv* into the underlying soil.

Equation P-FIL-03-1

$$d_{stone} = \frac{(P \times A_I \times Rv_I) + (P \times A_p)}{\eta_r \times A_p}$$

Where:

= Depth of the stone reservoir layer (feet).

= The rainfall depth (in feet) for the Treatment Volume (Level 1 = 1 inch [0.08 foot]; Level 2 = 1.1 inch [0.09 foot]), or other design storm.

= Contributing impervious drainage area (square feet).

= Volumetric runoff coefficient for impervious cover = 0.95.

= Area of permeable pavement (square feet).

= Porosity of reservoir layer (0.4).

Notes for Equation P-FIL-03-1:

1. When contributing drainage area consists of pervious or combined pervious and impervious, the term will refer to the contributing drainage area and the term will be the corresponding volumetric runoff coefficient as calculated using the VRRM Compliance Spreadsheet (or refer to Appendix A for the weighted Rv computation formula).
2. The area of contributing drainage is limited to a ratio of 2.5:1 (external drainage area to the area of permeable pavement) and is allowed only on installations where the stone reservoir is drained by an underdrain; (see Table P-FIL-03-9 above, Level 1 and Level 2 Design Option 3).
3. Equation P-FIL-03-1 assumes that the area or footprint of the stone reservoir is the same as that of the permeable pavement.
4. In cases of highly permeable soils, designers may modify Equation P-FIL-03-1 to account for the outflow of the exfiltration into the subsoils.

When designing permeable pavement Level 2 with infiltration or an infiltration sump, the maximum allowable depth of the reservoir layer (or the infiltration sump) is constrained by the maximum allowable drain time, which is established as two days (48 hours). The maximum reservoir depth is calculated using Equation P-FIL-03-2.

Equation P-FIL-03-2

$$d_{stone-max} = \frac{\frac{1}{2}i + t_d}{\eta_r \times 12}$$

Where:

- = The maximum depth of the infiltration reservoir or the infiltration sump (feet).

= The field-verified infiltration rate for the native soils (inch/hour).

= The maximum allowable time to drain the reservoir layer or sump, 48hours.

= Porosity of reservoir layer.

If the depth of the reservoir layer is too great (i.e., exceeds), or the verified soil infiltration rate is less than 0.5 inch per hour, then the design must include underdrains. An infiltration sump can be installed below the underdrain (to achieve Level 2 performance credit) with soil infiltration rates as low as 0.1 inch per hour.

However, for the volume of the infiltration sump to count for *Tv* storage, the field-verified infiltration rate must be at least 0.5 inch per hour. If the field verified infiltration rate is less than 0.5 inch per hour, the sump will still qualify the facility as a Level 2 design; however, any additional storage needed to hold the Tv must be added above the sump through additional stone. As an option, the entire Tv can be drained by the underdrain with a design drain time of 48 hours, using a control structure on the underdrain outlet.

Permeable pavement can also be designed to address, in whole or in part, the detention storage needed to comply with receiving channel protection and/or flood control requirements. The designer can model various approaches by factoring in storage within the stone aggregate layer, expected soil infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

The permeability of the pavement surface and that of the gravel media is very high. However, the permeable pavement reservoir layer will drain increasingly slower as the storage volume decreases (i.e., the hydraulic head decreases). To account for this change, a conservative stage discharge relationship should be established for routing flow through the stone reservoir. The underdrains can provide hydraulic control to limit flows, or an external control structure can be used at the outlet of the system.

5.2 Over-drain Relief

In all cases, an over-drain (i.e., a perforated pipe drain near the top of the stone reservoir and below the pavement section) should be used to prevent the volume of runoff from backing up into the pavement surface. On pavement sections with a long grade, designers should use a stepped design with an over-drain in each cell to establish level reservoir storage areas and prevent flow from exiting the pavement through the surface at the low end of the grade.

Testing the Soil Infiltration Rate

To design a permeable pavement system without an underdrain, the measured infiltration rate of subsoils must be 0.5 inch per hour or greater. Procedures for testing the site's soil infiltration rate are outlined in BMP P-FIL-04, Infiltration Practices. A minimum of one soil profile and two infiltration tests must be conducted for each facility that has up to 2,500 square feet of surface area. Refer to Appendix C, Soil Characterization and Infiltration Testing, for the number of soil explorations required for larger systems.

5.3 Type of Surface Pavement

The type of pavement should be selected based on a review of the factors in Table P-FIL-03-9 and designed according to the product manufacturer's recommendations.

5.4 Internal Geometry and Drawdowns

Elevated Underdrain (or "upturned elbow"). To promote greater runoff reduction for permeable pavement located on marginal soils, an underdrain should be placed above an infiltration sump as shown on Figure P-FIL-03-5, or it can be placed at the bottom of the reservoir sump with an upturned elbow configuration as shown on Figure P-FIL-03-6. This configuration places the perforated underdrain at the bottom of the stone reservoir layer, with the outlet elevated to the same elevation as the top of the sump. The underdrain transitions to a solid-wall pipe prior to exiting the stone reservoir layer and is directed toward an outlet manhole or other structure. To create the higher outlet elevation, the outlet manhole is configured with an internal weir wall, with the top of the weir set at the same elevation as the top of the stone sump, rather than a vertical bend or elbow on the outlet pipe. This configuration is preferred for ease of maintenance. This design variant can also include a drain orifice in the bottom of the weir to allow the sump to be drained if, over time, the exfiltration into the soil becomes restricted. This orifice should be covered with a plate with a clear label or other indication that it remains blocked under normal operating conditions.

Infiltration Sump. An infiltration sump qualifies the permeable pavement as a Level 2 design; however, the field-verified infiltration rate must be at least 0.5 inch per hour in order for the volume of the infiltration sump to count toward the required Tv storage.

Slow Drawdown. The permeable pavement stone reservoir should be designed to detain the design Tv runoff reduction storage volume. Extending the drawdown for at least 48 hours promotes infiltration even in marginal soils and, therefore, qualifies the design for the Level 2 credit. Control of the drawdown can best be achieved through the design of the weir/control structure in the outlet manhole or junction box.

Conservative Infiltration Rates. Designers should always decrease the measured infiltration rate by a factor of 2 during design (see Equation P-FIL-03-2) to approximate long term infiltration rates.

5.5 Pretreatment

Pretreatment for most permeable pavement applications is not necessary since the surface acts as pretreatment to the reservoir layer below. Additional pretreatment is required if the pavement receives run-on from an adjacent pervious or impervious area. For example, a gravel filter strip can be placed along the edge of the permeable pavement section to trap coarse sediment particles before they reach the permeable pavement surface. Refer to BMP P-SUP-06, Pre-Treatment, for design guidance on gravel filter strips or diaphragms.

5.6 Conveyance and Overflow

Permeable pavement designs should include methods to convey larger storms (e.g., 2-year, 10-year) to the storm drain system. The following is a list of methods that can be used to accomplish this:

- Place a perforated pipe horizontally near the top of the reservoir layer to pass excess flows after water has filled the base. The over-drain pipe should be perforated on the underside only such that the incoming runoff is not captured until the reservoir layer is filled.
- Increase the thickness of the top of the reservoir layer by as much as 6 inches (i.e., create freeboard);.
  Hhowever, the design computations used to size the reservoir layer should not include the additional volume for freeboard.
- Create underground detention within the reservoir layer of the permeable pavement system. Reservoir storage may be augmented by corrugated metal pipes, plastic, or concrete arch structures, etc. Refer to BMP P-SUP-07, Quantity Only Approach to BMPs.
- Route excess flows to another detention or conveyance system that is designed for the management of extreme event flows.
- Set the storm drain inlets flush with the elevation of the permeable pavement surface to effectively convey excess stormwater runoff away from the system. The design should also make allowances

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5.7 Reservoir Layer

The thickness of the reservoir layer is determined by runoff storage needs, the infiltration rate of in situ soils, structural requirements of the pavement sub-base, depth to water table and bedrock, and the frost depth. A soils or geotechnical professional should be consulted regarding the suitability of the soil subgrade.

- The reservoir below the permeable pavement surface should be composed of clean, washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading.
- The storage layer should consist of clean washed stone. The bottom of the reservoir layer or infiltration sump may be completely flat so that runoff will infiltrate evenly through the entire surface. Where underdrains are used in areas of marginal soils, a slight grade of 0.5% may be used to ensure the reservoir drains.

5.8 Underdrains

The use of underdrains is recommended when underlying soils have an infiltration rate of less than 0.5 inch per hour, or when there is a reasonable potential for infiltration rates to decrease over time, or when soils must be compacted to achieve a desired proctor density. Underdrains can also be used to manage extreme storm events and keep detained stormwater from backing up into the permeable pavement.

- An underdrain(s) should be placed within the reservoir and encased in 8 to 12 inches of clean, washed stone.
- The underdrain outlet can be fitted with a flow-reduction orifice as a means of regulating the stormwater detention time. The minimum diameter of any orifice should be 0.5 inch.
- An underdrain(s) can also be installed and capped at a downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability. The underdrain pipe should be straight or include cleanouts above at 45 degree (maximum) horizontal bends, as shown on Figure P-FIL-03-7.
- The perforated underdrain pipe should transition to solid wall pipe before exiting the stone reservoir.

5.9 Maintenance Reduction Features

Maintenance is a crucial element to ensure the long-term performance of permeable pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment, which can be reduced by the following measures:

- **Periodic Vacuum Sweeping**. The pavement surface is the first line of defense in trapping and eliminating sediment that may otherwise enter the stone base and soil subgrade. The rate of sediment deposition should be monitored, and vacuum sweeping performed once or twice per year. This frequency should be adjusted according to the intensity of use and deposition rate on the permeable pavement surface. At least one sweeping pass should occur at the end of winter.
- **Protecting the Bottom of the Reservoir Layer**. There are two options to protect the bottom of the reservoir layer from intrusion by underlying soils. The first method involves covering the bottom with a barrier of choker stone and sand. In this case, underlying native soils should be separated from the reservoir base/subgrade layer by a thin 2- to 4-inch layer of clean, washed, choker stone (i.e., ASTM D448 No. 8 stone) covered by a layer of 6 to 8 inches of course sand.
- The second method is to place a layer of ~~filter fabric~~geotextile on the native soils at the bottom of the reservoir. Some practitioners recommend avoiding the use of ~~filter fabric~~geotextile, since it may become a future plane of clogging within the system; however, designers should evaluate the paving

application and refer to AASHTO M288-06 for an appropriate fabric specification. AASHTO M28806 covers six geotextile applications: Subsurface Drainage, Separation, Stabilization, Permanent Erosion Control, Sediment Control, and Paving Fabrics. However, AASHTO M288-06 is not a design guideline. It is the engineer's responsibility to choose a geotextile for the application that takes into consideration site-specific soil and water conditions. Fabrics for use under permeable pavement should, at a minimum, meet criterion for Survivability Classes (1) and (2). Permeable ~~filter fabric~~geotextile is still recommended to protect the excavated sides of the reservoir layer, to prevent soil piping.

- **Observation Well**. An observation well consisting of a well-anchored,~~ perforated~~ 4- to 6-inch (diameter) PVC pipe that extends vertically to the bottom of the reservoir layer should be installed at the downstream end of all large-scale permeable pavement systems. The observation well should be solid if connected to an underdrain or perforated if an underdrain is not present. The observation well should be fitted with a lockable cap installed flush with the ground surface (or under the pavers) to facilitate periodic inspection and maintenance. The observation well is used to observe the rate of drawdown within the reservoir layer following a storm event.
- **Overhead Landscaping**. Many local communities now require from 5% to 10% (or more) of the area of parking lots to be in landscaping. Large-scale permeable pavement applications should be carefully planned to integrate this landscaping in a manner that maximizes runoff treatment and minimizes the risk that sediment, mulch, grass clippings, leaves, nuts, and other organic material will inadvertently clog the paving surface.

6.0 Construction Specifications

Experience has shown that proper installation is critical to the effective operation of a permeable pavement system.

6.1 Necessary Erosion and Sediment Controls

- All permeable pavement areas should be fully protected from sediment intrusion by silt fence or construction fencing, particularly if they are intended to infiltrate runoff.
- Permeable pavement areas should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. Permeable pavement areas should be clearly marked on all construction documents and grading plans. To prevent soil compaction, heavy vehicular and foot traffic should be kept out of permeable pavement areas during and immediately after construction.
- During construction, do not track sediments onto any permeable pavement surface to avoid clogging.
- Any area of the site intended to be a permeable pavement area should generally not be used as the site of a temporary sediment basin. Where locating a sediment basin on an area intended for permeable pavement is unavoidable, the invert of the sediment basin must be a minimum of 2 feet above the final design elevation of the bottom of the aggregate reservoir course. All sediment deposits in the excavated area should be carefully removed prior to installing the sub-base, base, and surface materials.

6.2 Permeable Pavement Construction Sequence

Commented [KA15]: Reference the VDOT construction specification in their spec.

The following is a typical construction sequence to properly install permeable pavement, which may need to be modified to depending on whether porous asphalt, pervious concrete, or interlocking paver designs are employed.

Step 1. Construction of the permeable pavement shall only begin after the entire contributing drainage area has been stabilized. The proposed site should be checked for existing utilities prior to any excavation. Do not install the system in rain or snow, and do not install frozen aggregate materials.

Step 2. As noted above, temporary erosion and sediment controls are needed during installation to divert stormwater away from the permeable pavement area until it is completed. Special protection measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the excavation process. The proposed permeable pavement area must be kept free from sediment during the entire construction process. Construction materials that are contaminated by sediments must be removed and replaced with clean materials.

Step 3. Where possible, excavators or backhoes should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions. For micro-scale and small-scale pavement applications, excavating equipment should have arms with adequate extension so they do not have to work inside the footprint of the permeable pavement area (to avoid compaction). Contractors can use a cell construction approach, whereby the proposed permeable pavement area is split into 500- to 1,000-square-foot temporary cells with a 10- to 15-foot earth bridge in between, such that cells can be excavated from the side. Excavated material should be placed away from the open excavation to prevent jeopardizing the stability of the side walls.

Step 4. The native soils along the bottom and sides of the permeable pavement system should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the filter layer or filter geotextile fabric. In 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. (Note: This effectively eliminates the infiltration function of the installation, and it must be addressed during hydrologic design.)

Step 5. The filter layer should be installed on the bottom of the reservoir layer and, where appropriate, filter geotextile fabric can be placed on the sides.

Step 6. Provide a minimum of 2 inches of aggregate above and below the underdrains. The underdrains should slope down toward the outlet at a grade of 0.5% or steeper. The upgradient end of underdrains in the reservoir layer should be capped. Where an underdrain pipe is connected to a structure, there should be no perforations within 1 foot of the structure. Ensure that there are no perforations in cleanouts and observation wells within 1 foot of the surface.

Step 7. Spread 6-inch lifts of the appropriate clean, washed stone aggregate. Place at least 4 inches of additional aggregate above the underdrain, 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.

Step 8. Install over-drain if required and connect into the outlet conveyance system.

Step 9. Install the desired depth of the bedding layer, depending on the type of pavement, as follows: •

Pervious Concrete: No bedding layer is used.

- **Porous Asphalt**: The bedding layer for porous asphalt pavement consists of 1 to 2 inches of clean, washed ASTM D448 No.57 stone. The filter course must be leveled and pressed (choked) into the reservoir base with at least four passes of a 10-ton steel drum static roller.
- **Interlocking Pavers**: The bedding layer for open-jointed pavement blocks should consist of 2 inches of washed ASTM D448 No.8 stone.

Step 10. Install paving materials in accordance with manufacturer or industry specifications for the pavement.

- **Installation of Porous Asphalt**. The following has been excerpted from various documents, most notably Jackson (2007).

   1. Install porous asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the filter course a minimum of 2 lifts over the reservoir layer. The laying temperature should be

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between 230 degrees Fahrenheit (°F) and 260°F, with a minimum air temperature of 50°F to ensure that the surface does not stiffen before compaction.

2. Complete compaction of the surface course when the surface is cool enough to resist a 10-ton roller. One or two passes of the roller are required for proper compaction. More rolling could cause a reduction in the porosity of the pavement.
3. The mixing plant must provide certification of the aggregate mix, abrasion loss factor, and asphalt content in the mix. Test the asphalt mix for its resistance to stripping by water using ASTM D1664. If the estimated coating area is not above 95%, additional antistripping agents must be added to the mix.
4. Transport the mix to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. Cover the mix during transportation to control cooling.
5. Test the full permeability of the pavement surface by application of clean water at a rate of at least 5 gallons per minute over the entire surface. All water must infiltrate directly, without puddle formation or surface runoff.
6. Inspect the facility 18 to 30 hours after a significant rainfall (greater than 1/2 inch) or artificial flooding to determine whether the facility is draining properly.

- **Installation of Pervious Concrete**. The basic installation sequence for pervious concrete is outlined by ACI (2008). It is strongly recommended that concrete installers successfully complete a recognized pervious concrete installers training program, such as the Pervious Concrete Contractor Certification Program offered by the National Ready Mixed Concrete Association. The basic installation procedure is as follows:

1. Drive the concrete truck as close to the project site as possible.
2. Water the underlying aggregate (reservoir layer) before the concrete is placed, so that the aggregate does not draw moisture from the freshly laid pervious concrete.
3. After the concrete is placed, strike off/remove approximately 3/8 to 1/2 inch using a vibratory screed. This is to allow for compaction of the concrete pavement.
4. Compact the pavement with a steel pipe roller. Care should be taken so that over compaction does not occur.
5. Cut joints for the concrete to a depth of 1/4 inch.
6. The curing process is very important for pervious concrete. Cover the pavement with plastic sheeting within 20 minutes of the strike-off, and keep it covered for at least 7 days. Do not allow traffic on the pavement during this time.

- **Installation of Interlocking Pavers**. The basic installation process is described in greater detail by Smith (2006). Permeable paver job foremen should successfully complete the ICPI's Interlocking Concrete Paver Installer Course or Permeable Interlocking Concrete Pavement Course. The following installation method also applies to clay paving units. Contact manufacturers of composite units for installation specifications.

1. Moisten, place, and level the No. 2 stone sub-base and compact it in minimum 12-inch-thick lifts with four passes of a 10-ton steel drum static roller until there is no visible movement. The first two passes are in vibratory mode with the final two passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.
2. Place edge restraints before the base layer, bedding and pavers are installed. Permeable interlocking pavement systems require edge restraints to prevent vehicle loads from moving the pavers. Edge restraints may be standard concrete curbs or curbs and gutters.
3. Moisten, place, and level the No. 57 base stone in a single lift (4 inches thick). Compact it into the reservoir course beneath with at least four passes of a 10-ton steel drum

static roller until there is no visible movement. The first two passes are in vibratory mode, with the final two passes in static mode.

4. Place and screed the bedding course material (typically No. 8 stone, 2 inches thick).
5. Place pavers by hand or with mechanical installers.
6. Fill gaps at the edge of the paved areas with cut pavers or edge units. When cut pavers are needed, cut the pavers with a paver splitter or masonry saw. Cut pavers no smaller than one-third of the full unit size, if subject to tire movement.
7. Fill the joints and openings with stone if required. Joint openings must be filled with No. 8 or 9 stone per the paver manufacturer's recommendation. Sweep and remove excess stones from the paver surface.
8. Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000 pound-force, 75- to 95-hertz plate compactor. Do not compact within 6 feet of the unrestrained edges of the pavers.
9. Thoroughly sweep the surface after construction to remove all excess aggregate.
10. Inspect the area for settlement. Any paving units that settle must be reset and reinspected.
11. The contractor should return to the site within 6 months to top up the paver joints with stones.

6.3 Construction Inspection

Inspections before, during, and after construction are needed to ensure that permeable pavement is built in accordance with these specifications. Use a detailed inspection checklist that requires signoffs by qualified individuals at critical stages of construction and ensure that the contractor's interpretation of the plan is consistent with the designer's intent. The basic elements of a permeable pavement construction checklist are provided at the end of this design specification.

Once the final construction inspection has been completed, log the Global Positing System coordinates for each facility and submit them for entry into the local BMP maintenance tracking database. It may be advisable to divert the runoff from the first few runoff-producing storms away from larger permeable pavement applications, particularly when upgradient conventional asphalt areas drain to the permeable pavement. This can help reduce the input of fine particles that are often produced shortly after conventional asphalt is laid down.

7.0 Operations and Maintenance Considerations

7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of the permeable pavement BMP, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification requirements to the local program upon transfer of ownership, and right-of-entry for local program personnel.

- The Regulation requires that all post-construction BMPs, including permeable pavement installations, must be covered by a long-term maintenance agreement and drainage easement to allow inspection and maintenance.
- The maintenance agreements should note which conventional parking lot maintenance tasks must be avoided. Signs should be posted on large parking lots to indicate their stormwater function and special maintenance requirements. When micro-scale or small-scale permeable pavement are installed on private residential lots, owners should be provided a document that explains the purpose of the permeable pavement and outlines: (1) the routine maintenance needs; (2) the long-

term maintenance plan; and (3) the basic parameters of the deed restriction, drainage easement, or other mechanism enforceable by the VESMP authority to help ensure that the permeable pavement system is maintained and functioning.

- The mechanism should, if possible, grant authority for the VESMP Authority to access the property for inspection or corrective action.

7.2 Maintenance Tasks

It is difficult to prescribe the specific types or frequency of maintenance tasks that are needed to maintain the hydrologic function of permeable pavement systems over time. Most installations work reasonably well year after year with little or no maintenance, whereas some have problems right from the start. Maintain in accordance with manufacturer's specifications.

The following activities must be avoided on all permeable pavements:

- Sanding;
- Resealing with an application rate and material that impedes the permeability of the surfaceResealing;;
- Resurfacing with non--porous non-compatible materials;
- Power washing;
- Storage of snow piles containing sand;
- Storage of mulch or soil materials; and
- Construction staging on unprotected pavement.

A preventative maintenance task for large-scale applications involves regenerative air vacuum sweeping on a frequency consistent with the use and loadings encountered in the parking lot. Many consider an annual, dry weather sweeping in the spring months to be important. Except for porous asphalt with a base layer that has larger air voids to allow flushing of the structure, Tthe contract for sweeping should specify that a vacuum sweeper be used that does not use water spray, since spraying may lead to subsurface clogging. Vacuum settings for large-scale interlocking paver applications should be calibrated so they *do not* pick up the small stones between pavement blocks.

Table P-FIL-03-10 Recommended Maintenance Tasks for Permeable Pavement Practices

Task Maintenance	Frequency[1]
For the first 6 months following construction, the practice and contributing drainage area should be inspected at least twice after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization.	After installation
Mow grass in grid paver applications.	At least once every 1 to 2 months during the growing season
Stabilize the contributing drainage area to prevent erosion. Remove any soil or sediment deposited on pavement. Replace or repair any necessary pavement surface areas that are degenerating or spalling.	As needed
Vacuum pavement with a standard street sweeper to prevent clogging.	2 to 4 times per year (depending on use)
Conduct a maintenance inspection. y Spot weed grass applications.	Annuall

Commented [KA17]: Discuss: There are specific ASTM tests (ASTM C701/C-1701-M09; ASTM C-1781/C-140) that can determine the surface infiltration rate of a permeable pavement which can be a useful trigger to require maintenance. Should we reference here?

Table P-FIL-03-10 Recommended Maintenance Tasks for Permeable Pavement Practices	
Task Maintenance	**Frequency[1]**
Remove any accumulated sediment in pretreatment cells and inflow points.	Once every 2 to 3 years
Conduct maintenance using a regenerative street sweeper. Replace any necessary joint material.	If clogged

Note:

1. Required frequency of maintenance will depend on pavement use, traffic loads, and surrounding land use.

7.3 Maintenance Inspections

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each permeable pavement site, particularly at large-scale applications.

Maintenance of permeable pavement is driven by annual inspections that evaluate the condition and performance of the practice. Any permeable pavement installation that captures external drainage (run-on) should be inspected more frequently during the first year (including during all four seasons) to ensure that there are no unexpected loads of sediment or pavement particulates from the contributing area. If so, the property owner should assess ways to limit the contributions, or the maintenance schedule should be adjusted to ensure the pavement does not become clogged.

The following are suggested routine annual maintenance inspection points for permeable pavements:

- The drawdown rate should be measured at the observation well for 3 days following a storm event in excess of 1/2 inch in depth. If standing water is still observed in the well after 3 days, this is a clear sign that clogging is a problem.
- Inspect the surface of the permeable pavement for evidence of sediment deposition, organic debris, staining, or ponding that may indicate surface clogging. If any signs of clogging are noted, schedule a vacuum sweeper (do not use brooms or water spray) to remove deposited material. Then, test sections by pouring water from a 5-gallon bucket to verify the clogging has stopped and the permeable pavement is working properly.
- Inspect the structural integrity of the pavement surface, looking for signs of surface deterioration such as slumping, cracking, spalling, or broken pavers. Replace or repair affected areas, as necessary.
- Check inlets, pretreatment cells, and any flow diversion structures for sediment buildup and structural damage. Note whether any sediment needs to be removed.
- Inspect the condition of the observation well and make sure it is still capped.
- Generally, inspect any contributing drainage area for any controllable sources of sediment or erosion.

An example maintenance inspection checklist for permeable pavement is provided in Appendix H, BMP Inspection Checklist. Based on inspection results, specific maintenance tasks will be triggered and scheduled to keep the facility in operating condition.

8.0 References

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P-FIL-09 Tree Planting

1.0 Definition

Tree plantings as a pollution-reduction practice pertain to new, individually planted trees on developed land. Credited area only accounts for precipitation that falls on the tree canopy area. Additionally, this measure does not require a specific soil media be used.

2.0 Purpose and Applicability of Best Management Practice

Because of their hydrological and biological functions, tree plantings reduce stormwater runoff and improve local water quality. They perform these functions through interception, throughfall, infiltration, transpiration, and absorption.

Tree plantings provide pollution reduction credit for every new, individually planted tree on developed land. The trees do not need to be planted in a contiguous area and are not intended to produce forest-like conditions.

Trees cannot receive credit as a best management practice (BMP) when:

- Planted to replace others that are removed through land disturbance;
- Planted to meet planning requirements, or any other local, state, or federal requirements;
- Financed through local, state, and federal programs
- Planted to meet water quality requirements through the Virginia Runoff Reduction Method (VRRM) as forest or mixed open land cover, or as part of other BMPs (e.g., urban bioretention, sheet flow to a vegetated filter strip, manufactured treatment devices).

Regarding treatment trains, when runoff flows through the BMP tree plantings area flow into downstream practices within the contributing drainage area (CDA), the canopy area (144 ft^2) should be entered into the VRRM spreadsheets in the tree planting input fields and be excluded from the CDA of the BMP to which they flow. Any remaining runoff volume and nutrient loads will be computed in the treatment train features of the VRRM spreadsheets. Tree plantings cannot be used downstream of other BMPs.

3.0 Planning and Considerations

Tree plantings can be used at commercial, institutional, and residential sites. Like bioretention and other post-construction stormwater BMPs, they are typically planted in parking lot islands and edges; road medians, roundabouts, interchanges, and cul-de-sacs; rights-of-way or commercial setbacks; courtyards; and/or residential properties.

4.0 Stormwater Performance Summary

There are two subclasses to tree plantings including tree canopy over pervious and tree canopy over impervious. Each new tree planted for this design specification is eligible for a credit area of 144 square feet (ft^2), which equals approximately 300 trees per acre.

Table P-FIL-09-1 Summary of Stormwater Functions Provided by Tree Plantings

Stormwater Function	Tree Canopy Over Pervious[1]		Tree Canopy Over Impervious
	HSG A/B	HSG C/D	
Annual Runoff Reduction Volume	16.0%	12.0%	3.5%
Total Phosphorus Event Mean Concentration (EMC) Reduction by BMP Treatment Process	0	0	0
Total Phosphorus Mass Load Removal	16.0%	12.0%	3.5%
Total Nitrogen EMC Reduction by BMP Treatment Process	0	0	0
Total Nitrogen Mass Load Removal	16.0%	12.0%	3.5%

Notes:

Source: Adapted from Hynicka and Divers 2016.

See Appendix A, Runoff Reduction Computation Methodology for Tree Planting Over Turf (located at the end of this specification).

5.0 Design Criteria

The design criteria for tree planting are summarized in Table P-FIL-09-2. Additional detail is included in the subsequent text.

Table P-FIL-09-2 Summary of Design Elements for Tree Plantings

Design Element	Design Summary
Credit	
Credit Area	1 new tree = 144 ft^2 based on the average area under the canopy from the drip line to the tree trunk. No CDA is allowed.
Site Assessment Design Elements	
1-Site Information	Include information about location, property owner, and current land use.
2-Climate	Determine U.S. Department of Agriculture (USDA) Plant Hardiness Zone, sunlight exposure, and any microclimate features.
3-Topography	Identify steep slopes and low-lying areas within the development site.
4-Tree Inventory	Submit a pre-development tree inventory to the Virginia Erosion and Stormwater Management Program (VESMP) or VDEQ when the agency is the Virginia Stormwater Management Program (VSMP) authority.
5-Soil Testing	Perform soil tests to determine texture, drainage, compaction, pH, soil chemistry, seasonal high-water table, and other soil features.
6-Site Hydrology	Determine runoff to and from the tree planting area (include floodplain connections if in a riparian area).

Commented [MC1]: P Hynicka and Divers 2016 page 16of21

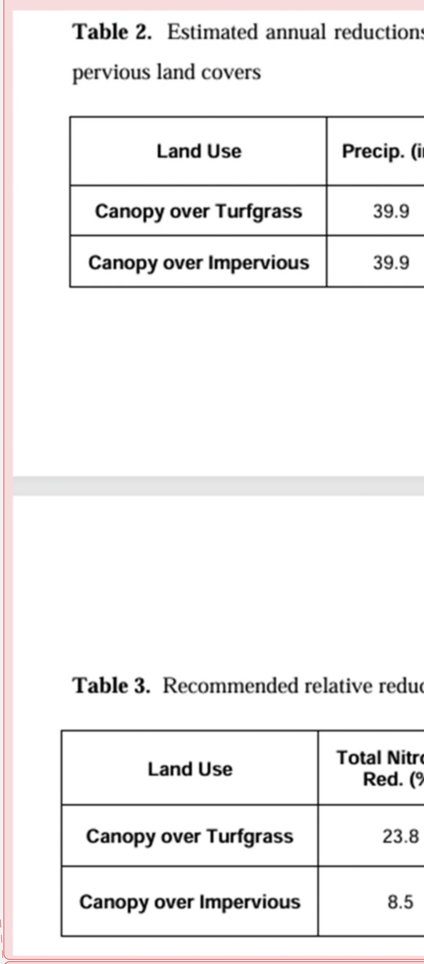
Table 2. Estimated annual reductions pervious land covers

Land Use	Precip. (in
Canopy over Turfgrass	39.9
Canopy over Impervious	39.9

Table 3. Recommended relative reduct

Land Use	Total Nitro Red. (%
Canopy over Turfgrass	23.8
Canopy over Impervious	8.5

Commented [MC2R1]: Reduced efficiencies from Hynicka and Divers study is to account for foliage cover and growing seasons, no change

Commented [AK3R1]: Additionally, the study looked at leachate so it is not a direct comparison.

Table P-FIL-09-2 Summary of Design Elements for Tree Plantings

Design Element	Design Summary
7-Potential Planting Conflicts	Identify the presence of potential planting conflicts (space limitations, setbacks, hot spots, sight lines, bedrock, etc.).
8-Planting and Maintenance Logistics	Document logistical factors impacting tree survival and future maintenance needs (site access, water source, party responsible for maintenance).
9-Pre-development map	Develop site map that includes features found during the site assessment.
Site Preparation Design Elements	
Soil Amendments	Amend as needed based on soil analysis.
Species Selection	Refer to a qualified professional such as a forester with experience in Virginia , Virginia Licensed Landscape Architect, Certified Virginia Nursery and Landscape Association (VNLA) Horticulturalist, or -International Society of Arboriculture (ISA) Certified Arborist. Use the findings of the site assessment and consider the space needed by the tree at maturity. The Virginia Department of Forestry has information about finding a forester at https://dof.virginia.gov/forest-management-health/landowner-assistance/find-a-
Tree Selection	Comply with the American Standard for Nursery Stock (ANSI 2014) minimum of 6 to 8 feet in height and/or 1 to $1^1/_2$ inches diameter breast height (DBH).
Planting Plan	Developed by a VNLA Certified Horticulturalist, Licensed Landscape Architect, or Certified Landscape Designer, or equivalent licensed professional.
Planting Design Elements	
Tree Planting Logistics	Prepare to obtain and/or store trees and associated materials.
Substitutions	Substitutions that differ from the approved plan need to be signed off by the professional and resubmitted to the VESMP or VSMP authority.
Planting Techniques	Follow planting procedures of ANSI A300 Part 6 (Planting and Transplanting) and/or American Association of Nurserymen (AAN) standards.
Steep Slopes	Stabilize steep slopes until vegetation is established and create terrace for new tree plantings if needed.
Soil Enhancement	Add fertilizer or compost to backfill if needed based on the soil analysis.
Mulch	Follow mulching procedures of ANSI A300 Part 6 (Planting and Transplanting).
Tree Protection	Install tree stakes, fencing, and signage as needed based on AAN standards.
Post-planting Design Elements	
As-Built Requirements	Requires certification to verify BMP install per the approved plan.
Inspection	Have qualified professional perform inspections after initial planting.
Tree Replacement	Notify the VESMP or VSMP authority if a tree replacement is needed.
Maintenance	Requires a tree maintenance plan.
Maintenance Agreement	Requires a deeded maintenance agreement.

5.1 Credit

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5.1.1 Credit Area

The drainage area of the tree includes the precipitation that falls within the 144 ft^2 delineated tree canopy area.

The water quality credit area for each newly planted tree equals 144 ft^2 when planted within pervious landcover. The water quality credit provided does not include stormwater runoff from surrounding areas that flow into the canopy coverage area of the newly planted tree. Credit is not provided for new trees planted to replace trees within the development site that were removed as part of the overall development plan.

Note that water quantity run-on to the canopy land use area (i.e., 144 ft^2) must be considered in terms of localized erosion issues and potential overwatering.

5.2 Site Assessment Design Elements

To effectively use trees as a stormwater BMP, a site assessment must be performed. The site assessment may be based on the Urban Reforestation Site Assessment (URSA) as described in the Urban Watershed Forestry Manual -- Part 3. Urban Tree Planting Guide. The purpose of performing the assessment is to help determine what tree species will thrive at the site and identify site conditions that need to be improved. The nine site elements of the URSA include:

1. **General Site Information** – Include information about the location, and property owner at the site.

   Location: Describe the site location, being as specific as possible, and using a consistent system for identifying planting sites. The description may include noting the site address, nearest cross streets, GPS coordinates, page and grid of area map, subwatershed name, name of site, specific site identification, or all of these.

   Property Owner: Provide the name of the property owner and contact information.

2. **Climate** – Use climate data to help select tree species.

   USDA Plant Hardiness Zone: Determine the plant hardiness zone, which is based on the average lowest temperatures for the region and can be found using the USDA Plant Hardiness Zone Map (https://planthardiness.ars.usda.gov/).

   Sunlight Exposure: Determine how much sun is received in the planting area during the growing season: full sun (> 6 hours of direct sunlight), partial sun (<6 hours of full sunlight but receives filtered light for most of the day), or shade (<6 hours of filtered light). Identify tall structures that may block sunlight.

   Microclimate Features: Microclimates are fine-scale climate variations, such as windy areas or small heat islands caused by asphalt and concrete. If either of these microclimate factors exist in the planting area, select tree species that are tolerant of drought.

3. **Topography** – Identify local topographic features that may present planting difficulties.

   Steep Slopes: Note the presence of any steep slopes (typically defined as greater than 15%) that can make access difficult for planting and may require special planting techniques. Species planted on slopes should be more resistant to drought, as they will dry out faster. Also, special care should be taken not to disturb slopes during site preparation and planting, to prevent soil erosion.

   Low-Lying Areas: Note the presence of any low-lying areas and mark them on the site map. Trees can be planted in low-lying areas and used to treat stormwater runoff, provided the species selected are tolerant of some standing water.

4. **Tree Inventory** – Conduct a tree inventory.

   The tree inventory should document the trees present on the development site prior to development. For each tree in the inventory, record the species, its DBH (in inches), and height (in feet). Mark the location of each tree on the site map. Indicate which trees will be preserved during construction. Submit the inventory as part of the plan set.

5. **Soil Testing** – Soil testing is required within the planting site. The soil test procedures are available in BMP P-FIL-04, Infiltration Practices.

The results of the soil tests determine if soil amendments or tilling will be needed. The results of the soil test combined with the physical characteristics of the site will be used to select appropriate tree species. Periodic soil testing may be necessary if the health of the tree becomes an issue.

Soil testing is performed to determine porosity (amount of available pore space), permeability (how interconnected pore spaces are), and infiltration rate (how quickly the water moves through the soil). These soil properties affect the amount of air, moisture, and nutrients that are available in the root zone and how much runoff is absorbed into the ground instead of flowing over the ground.

Some soil properties of importance include the following:

- Texture: Soil texture (such as loam, sandy loam, or clay) refers to the proportion of sand, silt and clay sized particles that make up the mineral fraction of the soil.
- Drainage: Evaluate the soil drainage to help select tree species that are tolerant of the site drainage conditions. Soil drainage can generally fall into one of three categories: poor, moderate, or excessive. Soils with grey mottling or have a foul odor are also indicators of poor drainage.
- Compaction: Evaluating soil compaction is necessary to determine if tillage and compost are needed. A bulk soil density test performed in a soil testing lab can be used to determine soil compaction.
- pH: Evaluating soil pH is important so that tree species that are tolerant of the soil pH may be chosen
- Soil Chemistry: A soil analysis can be used to identify specific nutrient, organic matter, and mineral deficiencies, or confirm soil contamination. Soil samples may be sent to a lab to be analyzed for organic matter content, salt content, and availability of key nutrients such as phosphorus, potassium, calcium, and magnesium.
- Seasonal High-Water Table: Identify if the planting area is in an area with a seasonal high-water table, which will impact species selection.
- Other Soil Features: Record active or severe erosion, potential soil contamination, recent construction or soil disturbance, debris or rubble in soil, or other unusual soil conditions in the planting area. If erosion is present, note the extent and severity of erosion. If a site is suspected of contamination, further investigation should be conducted before proceeding with the project (e.g., research the site history, consult with landowner, conduct an environmental site assessment, pursue cleanup options). If soils are very disturbed, amendments may be needed, or it may be necessary to bring in new soil.

6. Hydrology – It is important to understand the hydrological conditions of the development site in its predevelopment condition to determine potential drainage conditions that may impact the proposed planting area(s). Also, understanding the site hydrology is needed for tree selection.

Site Hydrology: Note whether the planting area is an upland or riparian site.

Storm Water Runoff to Planting Site: Document any types of stormwater runoff that flow to the planting site. Stormwater may enter the planting site from a pipe, open channel, or as sheet flow.

Floodplain Connection (Riparian Areas Only): If the planting area is riparian, note the presence of levees or other structures that restrict flood flows onto the floodplain, and the bank height. In such areas, upland species may be more suited to the hydrology of the site than floodplain species.

7. Potential Planting Conflicts – Identify the presence of potential planting conflicts to define specific planting locations, select tree species, or identify special methods to improve the growing environment.

Space Limitations: Note the presence of aboveground or belowground space limitations, such as overhead wires, pavement, structures, signs, lighting, existing trees, or underground utilities.

Local Ordinance Setbacks: Record setbacks between trees and infrastructure that are mandated by local ordinance or utility. Check with local utility companies to determine their clearance requirements.

Hot Spots: The tree canopy area (144 ft2) cannot receive stormwater from hot spot areas.

Sight lines**:** When considering a location for planting, clear lines of sight must be provided.

Bedrock: Tree root growth can be restricted by the presence of bedrock within the planting area.

Other Limiting Factors: Document other potentially limiting factors such as nearby sidewalks or roads that could contribute runoff containing deicing salts and other pollutants, trash piles and debris, animal impacts (deer, beaver), mowing conflicts, presence of wetlands, insects or disease, or heavy pedestrian traffic. These factors will need to be addressed before planting.

8. **Planting and Maintenance Logistics** – Planning needs to include logistical factors that may influence tree survival and future maintenance needs.

Site Access: Determine access to the site for the delivery of planting material and equipment used for planting and maintenance.

Water Source: Note the presence and type of water sources since newly planted trees must be watered regularly the first year or two after planting. The existence of a nearby water source for irrigation makes this critical maintenance task much easier.

Party Responsible for Maintenance: Identify the party responsible for maintenance. They will need to know the maintenance schedule and proper maintenance techniques.

9. **Pre-development Site Map** – The site map should include the following:

- Site boundary, landmark features (e.g., roads, streams) and adjacent land use and cover
- Location of proposed planting area
- Identify climatic features within the proposed planting area, e.g., sun exposure, microclimate.
- Typography: Indicate areas with steep slopes or depressions.
- Current vegetative cover: indicate trees to be removed during development, preserved trees, and invasive species
- Location and results of soil samples
- Flow paths to planting area, location of outfalls
- Above or below ground space limitations (e.g., utilities, structures)
- Other limiting factors (e.g., trash dumping, pedestrian paths)
- Water source and access points
- Scale and north arrow
- Conditions that impact tree species selection, such as pests or other natural factors/diseases (e.g., blight, molds, fungus, insects).

5.3 Site Preparation Design Elements

The site preparation phase considers the findings of the site assessment. This phase is important to help with the success of the new tree plantings as a BMP.

- **Soil Amendments** – Soils on developed lands often need to be amended to support healthy trees. Compost is often used to increase soil organic matter, decrease bulk density, improve drainage, provide nutrients, and increase water and nutrient holding capacity. Peat amendments can also increase organic matter and water and nutrient holding capacity, in addition to increasing acidity. Other amendments include gypsum, which can be added to urban soils to decrease soil sodicity; limestone, which is used to decrease soil acidity; and sulfur, which increases soil acidity. Soil compaction, pH, and drainage should be evaluated at the planting site to determine the need for soil amendments. Refer to BMP P-FIL-08, Soil Compost Amendment, and BMP P-FIL-04, Infiltration Practices.
- **Species Selection** – Tree species selection is dependent upon site conditions as determined in the site assessment. A qualified professional should select native tree species suitable for the planting site.

  To ensure that the selected tree species is suitable for the available space and desired use of the site at maturity, consider the following:

- The mature height and spread of trees will not interfere with proposed or developed structures and overhead utilities.
- The root development will not interfere with walls, sidewalks, driveways, patios, and other paved surfaces or affect water and sewer lines, septic systems, or underground drainage systems.
- Selected tree species should be tolerant of de-icing salts if there is a chance these will be used near the planting site.
- Plant native trees, if possible, because they are adapted to growing in local climatic conditions and may require fewer pesticides and fertilizers. To help planners and designers avoid selecting invasive species, the Virginia Department of Conservation and Recreation maintains a list of invasive species on their website at https://www.dcr.virginia.gov/natural-heritage/invsppdflist (DCR 2022).

- **Tree Selection** – All trees must comply with the American Standard for Nursery Stock (ANSI 2014). All new trees shall be a minimum of 6 to 8 feet in height or 1 to $1^{1}/_{2}$ inches DBH. Planting larger tree stock should help attain the desired stormwater management goals more rapidly, although it should be noted larger trees can be more difficult to establish.

  All selected tree stock should be grown within a similar region as the planting site to be adapted to local climate variability.

  Individual trees should be inspected to ensure they are of high quality. The following are important factors in selecting nursery trees:

  - Healthy well-balanced crown
  - Straight trunk or trunks that meet the planting plan specification for single or multi-stem trees
  - No sign of disease or insects
  - No significant wounds or scars from pruning
  - Branches evenly distributed along trunk
  - Minimal to no circling roots

Planting Plan – The planting plan should be prepared by a qualified professional and needs to contain the following elements:

- Post-development site layout and proposed site grading
- List of trees to be planted, include common name, botanical name, size and planting location (include allowed substitutions of species)
- Tree stock to be ordered, sources of trees, when to order trees & plant trees, planting warranty.
- Post-nursery care and initial maintenance requirements
- Identification of water source
- Description of post-planting tree protection

5.4 Planting Design Elements

- **Tree Planting Logistics** – The recommended planting season runs from October through March. Container-grown and balled-and-burlapped (B&B) trees can be planted from October through mid-December. However, trees should not be planted when the ground is frozen.

  Determine the best places to purchase plant materials and plan for ordering and purchase. Availability is usually related to the type of plant material and the species. Place orders early to ensure the availability of the species and stock desired. Trees need to be inspected to ensure they are in good condition.

  If trees are not planted immediately, a temporary storage location must be identified. Proper storage and preparation of plant materials before planting is essential to ensure that new trees will establish and thrive. After receiving trees, they should be kept covered, shaded, and moist or watered until placed in the ground. The root balls of B&B stock should be thoroughly watered and kept moist with a covering of peat moss, straw or saw dust until planted. When moving B&B stock and container trees, the root ball should always be supported (never pick it up by the trunk).

Substitutions – The trees that are planted shall be of the species and size specified on the approved plans. If a substitution is necessary that differs from the approved plan, it should be signed off by the professional and resubmitted to the VESMP or VSMP authority.

Planting Techniques – Follow Part 6 of the American National Standard for Tree Care Operations – Tree, Shrub, and Other Woody Plant Management – Standard Practices (Planting and Transplanting) (ANSI A300).

Once the plant is placed in the hole, the top of the roots or root ball should be level or slightly above level with the surface of the ground. It is generally better to plant the tree a little high, that is, with the base of the trunk flare 2 to 3 inches above the soil, rather than at or below the original growing level.

If the soil for backfilling contains too much rock or construction debris, screen soil or replace it with local topsoil. When the hole is about three fourths refilled, straighten and level the tree. Use water to settle the backfill or tamp lightly. Water heavily and fill the hole with backfill to its original level. Remove all wires, or ropes from the stems or trunk to prevent them from strangling the tree as it grows. Trees must be watered well after planting.

Steep slopes – Steep slopes require additional measures to ensure planting success and reduce erosion, especially if the slope receives stormwater runoff from upland land uses. Depending on the steepness of the slope and the runoff volume, rill or gully erosion may occur on these slopes, requiring a twofold approach: controlling the stormwater and stabilizing the slope.

Erosion control blankets are recommended to temporarily stabilize soil on slopes until vegetation is established. Erosion control fabrics come in a variety of weights and types and should be combined with vegetation establishment such as seeding. Other options for stabilizing slopes include applying compost or bark mulch, or sodding

Fertilization – Fertilization is usually not needed for newly planted trees. If needed, follow the recommendations of the American National Standards Institute (ANSI A300 Part 6). Use only fertilizer that contains the nutrients needed, and do not apply an excess amount of fertilizer.

Mulch – The ground under the canopy area for each newly planted tree needs to be covered with organic mulch. Mulch protects the plants from temperature extremes, maintains soil moisture, prevents erosion, increases infiltration, helps control weeds, and adds organic matter. If planting a cluster of trees, mulch the entire planting area. Use slow-decomposing organic mulches, such as shredded bark, compost, leaf mulch, or wood chips (grass clippings and sawdust are not recommended for use as mulch). Mulch should be applied near, but not touching, the trunk and spread out to the perimeter of the planting. Refer to ANSI A300 (American National Standard for Tree Care Operations – Tree, Shrub, and Other Woody Plant Management –Standard Practices [Part 6: Planting and Transplanting]) for specifics on proper mulching techniques.

Tree Protection – Follow the procedures outlined in the American National Standards Institute (ANSI A300 Part 6: Planting and Transplanting).

- Stakes: Trees may require temporary support from stakes and guy-lines, but this support should only be utilized with top-heavy trees, in windy environments, or when recommended by an arborist. If staking is necessary for support, use three stakes in conjunction with a flexible tie material to hold the tree upright while minimizing injury to the trunk. Keep slack in the tie material to provide flexibility. To prevent damage to the root ball, stakes should be placed in undisturbed soil beyond the outer edges of the root ball. Remove support staking and ties within a year of planting.
- Fencing: Fencing can be used to help prevent damage from animals (deer, beavers) and mowers. Use fencing material with openings that are sufficient to prevent unwanted access to the tree. Fencing should be at least 3' high to protect trees from beavers and will need to be higher to prevent deer browsing. Place fencing an appropriate distance from the tree trunk as needed to meet the desired purpose.
- Signage: Development sites in highly visible areas (e.g., school yards, parks, urban settings, government buildings) that utilize newly planted trees as a BMP should have a marker to indicate the water quality purpose. The sign should also state that the trees are not to be disturbed except for authorized maintenance.

5.5 Post-Planting Design Elements

- **As-Built Requirements** – After the new trees have been planted, the owner/developer must have an as-built certification. The as-built certification verifies that the BMP was installed per the approved plan. Supporting documents verifying tree type (~~such as~~for example invoices) and compost certification should be provided.
- **Inspection** – Tree inspections are to be performed by professionals who can diagnose tree health. An inspection schedule should be created for each site.

Initial planting inspection: Each tree should be inspected for proper planting and post-planting protection immediately after initial planting. New trees must have a species identification tag from the nursery at the time of inspection. Tags shall be removed after inspection to prevent girdling. The initial planting inspection should consider the quality of the woody plant material, planting installation, and growing conditions. Ensure trees are correctly spaced and planted according to the planting plan and are free from conflicts, etc. Address points from the Initial Inspections column in Table P-FIL-09-3 below.

Short-term Inspection (3 months-1 year): After the initial planting, trees should be inspected at least once before the warranty period expires. Trees should be inspected after major storm events to check for any damage that may have occurred. The inspection should assess points from the Short- and Longterm Inspections column in Table P-FIL-09-3 below.

Table P-FIL-09-3 Inspection Checklists

Initial Inspection	Short- and Long-term Inspections
Assess tree health.	Assess tree vigor and overall health.
Determine that planted tree species are those in the planting plan.	Determine if pruning is needed for damaged, dead, or diseased branches.
Ensue trees are spaced and planted according to the planting plan. Inspect that trees are planted at the correct height.	Inspect trees for signs of insect damage and disease.
Ensure stakes are installed properly (if needed).	Evaluate if additional mulch is needed.
Assess that mulch has been properly applied around trees.	Determine if stakes need to be adjusted or removed.
Check that trees have been well watered.	
Assess that trees are free from conflicts.	

Source: Adapted from Cappiella et al. 2006.

- **Tree Replacement** – If a tree is dying or dies, notify the VESMP or VSMP authority. A new tree needs to be planted during the next appropriate planting period (spring/fall) from the time of death and needs to be planted in an appropriate location. Perform an assessment to determine the reason for the decline in health and use this information when selecting the new replacement tree.
- **Maintenance** – Regular maintenance will help ensure establishment and success of newly planted trees as a BMP. Maintenance includes activities such as watering, removing temporary supports, controlling weeds and pests, and pruning. A potential source of water would include a rain tank system (*See* BMP P-BAS-04 Rainwater Harvesting). Watering is generally needed for the first three years and then only during periods of drought. All pruning of branches should be done according to proper American National Standards Institute recommendations (ANSI A300 Part 1: Tree, Shrub, and Other Woody Plant Maintenance – Standard Practice, Pruning).

Commented [MC4]: For discussion: comment made that as-builts should also be recommended 1 year after NOT, to show trees are still living/healthy

Commented [AK5R4]: What is the enforcement mechanism?

Table P-FIL-09-4 Example Inspection and Maintenance Schedule

Inspection and Maintenance Activity	Year 1		Year 3		Year 5+
Regularly inspect tree health and survival.	X	X	X	X	X
Water trees.	X	X	X		
Remove any supporting stakes and guywires.		X			
Implement invasive species and noxious weed control as needed.	X	X	X	X	X
Prune damaged, dead, or diseased branches.		X	X	X	X
Implement integrated pest management methods as needed.	X	X	X	X	X
Remove trash and fallen branches from area.	X	X	X	X	X
Remove any limbs damaged in storms that might pose a danger.	X	X	X	X	X

Source: Adapted from Cappiella et al. 2006; originally derived from Hairston-Strang (2005) and Palone and Todd (1998).

- **Maintenance Agreement** - The Virginia Erosion and Stormwater Management Regulation (9 VAC 875-535) specifies the circumstances under which a maintenance agreement must be executed between the owner and the VESMP of VSMP Authority, and sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.
- All tree plantings must include a long-term maintenance agreement consistent with the provisions of the VESMP Regulation and must include the recommended maintenance tasks and a copy of an annual inspection checklist.
- When tree plantings are applied on private residential lots, homeowners should be educated regarding their routine maintenance needs by being provided a simple document that explains their purpose and routine maintenance needs.
- A deed restriction, drainage easement or other mechanism enforceable by the VESMP or VSMP Authority must be in place to help ensure that new tree plantings are maintained and not converted or disturbed, as well as to pass the knowledge along to any subsequent owners. The mechanism should, if possible, grant authority for the VESMP or VSMP Authority to access the property for inspection or corrective action.

6.0 References

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Urban Watershed Forestry Manual -- By Cappiella et al. 2005-2006

Part 1: Methods for Increasing Forest Cover in a Watershed -- https://owl.cwp.org/mdocs-posts/urban-watershed-forestry-manual-part-1/

Part 2: Conserving and Planting Trees at Development -- https://owl.cwp.org/mdocs-posts/urban-watershed-forestry-manual-part-2/

Part 3: Urban Tree Planting Guide -- https://owl.cwp.org/mdocs-posts/urban-watershed-forestry-manual-part-3/

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https://www.epa.gov/sites/default/files/2016-1/documents/final_stormwater_trees_technical_memo_508.pdf (accessed August 16, 2023).

Vermont Manual (https://dec.vermont.gov/sites/dec/files/wsm/stormwater/docs/Permitinformation/2017%20VSMM_Rule_and_Design_Guidance_04172017.pdf

New trees should be planted following appropriate procedures (e.g., the International Society of Arboriculture's Planting New Trees, http://www.treesaregood.com/treecare/resources/New_TreePlanting.pdf).

Planting shall only be performed when weather and soil conditions are suitable for planting.

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Virginia Cooperative Extension. 2017. Planting Trees. Publication 426-702. https://www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/426/426-702/426-702.pdf (accessed August16, 2023).

7.0 Appendix A Runoff Reduction Computation Methodology for Tree Planting Over Turf

Hynicka and Divers (2016) provide the basis for the runoff reduction values and pollutant removal efficiencies for the Tree Planting BMP. However, where other VRRM BMPs base the mass phosphorus removal efficiency on runoff reduction, Hynicka and Divers (2016) base phosphorus reduction on leachate removal. To ensure consistency among VRRM BMPs, this design specification calculates pollutant removal efficiencies through the following methodology.

1. Hydrologic Soil Group (HSG) A/B soils have a greater storage capacity than C/D soils, and thus a lower runoff coefficient. Based on the volumetric runoff coefficient (R_v) for turf, the average A/B R_v is 0.175, and the average C/D R_v is 0.235.

   Dividing the A/B R_v by the C/D R_v yields 0.75. This indicates that ~~runoff is approximately 75% lower for A/B vs. C/D soils~~runoff for A/B soils is approximately 75% of the level of C/D soils. The runoff reduction (RR) capacity ratio can be approximated by the inverse of this value, 1/.75=1.333.
2. Item 1 above implies, for turf, that the runoff storage capacity of A/B soils is 1.333 times greater than C/D soils.
3. Knowing item 2, above, an equation can be created that approximates the runoff reductions of A/B and C/D soils using both the above information and knowledge regarding the breakdowns of the various HSG soils groups throughout the Chesapeake Bay watershed:

$$X_{AB}(0.64) + X_{CD}(0.36) = RR_{TOTAL}$$

$$X_{AB} = 1.33(X_{CD})$$

Where:

X_{AB} = runoff reduction percentage of AB soils.

X_{CD} = runoff reduction percentage of CD soils.

0.64 = proportion (64%) of Chesapeake Bay watershed made up of A and B soils.

0.36 = proportion (36%) of Chesapeake Bay watershed made up of C and D soils.

RR_{TOTAL} = runoff reduction proportion (not percentage) as indicated in Hynicka and Divers 2016.

Commented [MC6]: Wording updated, resulting calculations were not affected

Commented [MC7R6]: The subsequent equations were not based on the errant statement. Rather, they were based on the inverse runoff ratio between the two Rv values:

0.235 / 0.175 = 1.3

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A direct solution to the above equation with RRTOTAL= 0.29 yields XCD = ~~~0.24~~, or 24% and XAB = ~~~0.32,~~ or 32%.

Because leaves affect runoff reduction and pollutant removal efficiencies, the values are reduced to account for foliage cover. A six-month growing season would extend from May 1 to October 31. Therefore, annual percent values are reduced by half.

Although nominal 1.5% and 4% nitrogen and phosphorus removals were suggested in the study due to uptake and entrapment in woody biomass, those credits were not included in Table P-FIL-09-1 due to relatively high uncertainty in values and overall low magnitude improvements.

C-SCM-14 Flocculant Chemical Additives

Revised Draft — incorporating Arcadis redlines and TRC Meeting #6 (April 16, 2026) comments

Commented [MD1]: *How to read this document: Clean revised text is presented throughout. TRC-driven changes (beyond the Arcadis redlines) are marked with a callout block like this one, explaining the source comment and what was changed.*

1.0 Definition

Flocculants are chemical additives used to enhance the coagulation and removal of suspended sediment from construction stormwater runoff. This aggregation process, called flocculation, makes the particles heavy enough to settle out of the water, which reduces turbidity and prevents soil erosion from leaving a disturbed area. Applied to construction stormwater using passive or active delivery systems, they work by neutralizing the electrical charges that keep particles separated and are often used in conjunction with other erosion control measures like sediment basins or wattles.

2.0 Purpose and Applicability of Best Management Practice

Flocculants shall be used as part of a sediment control treatment train with other construction BMPs. Direct application to bare or disturbed soil for temporary stabilization or dust control is also permitted under this specification, provided a downstream perimeter or sediment control measure is in place to capture treated runoff.

Commented [MD2]: *TRC Change — Treatment train framing (§2.0): The prior draft language ("can be used for...dust control,* or *as part of a treatment train") implied flocculants could substitute for a treatment train approach. Per TRC discussion, flocculants are a supplement to the erosion control system, not a stand-alone BMP. The bullet has been revised to require a downstream PCM/SCM even for direct soil applications.*

Only products listed on the Virginia DEQ Approved Flocculant Product List may be used. (List will be maintained as a live link on the DEQ webpage, like the Manufactured Treatment Device list.)

The purpose of flocculants is to complement, not replace, construction BMPs. They are used to maximize sediment removal and water quality but do not provide pollutant load reduction credit for water quality compliance purposes.

Commented [MD3]: *TRC Change — Treatment train ≠ compliance credit (§2.0): The TRC noted that "treatment train" must not imply the flocculant use provides water quality compliance credit. The sentence above has been added to make this explicit.*

Use of cationic flocculants, water-soluble polymers, or other chemical additives that possess a net positive (cationic) charge is permitted only with prior written DEQ approval. See Section 6.0 for the approval process and required submittals.

Commented [MD4]: *TRC Change — Permittee-focused language (§2.0): The prior draft included language describing what DEQ will do ("DEQ will review and approve or request additional controls"). Per TRC comment, the Handbook should be directed at the permittee. DEQ's internal review role has been removed here; the permittee's obligation (obtain written approval, follow Section 6.0) is retained.*

3.0 Planning and Considerations

Use flocculants in combination with other construction BMPs in the Handbook, never as a stand-alone construction BMP for a drainage area.

Provide clear, site-specific justification for flocculant use, describing the unique sediment control challenges present and how the use of flocculants in conjunction with other construction BMPs will provide the preferred solution. Also provide a map showing: locations where flocculant will be applied and stored on site, points of discharge, and soil types.

Select flocculant products based on site-specific soil conditions and water characteristics. Conduct performance testing (e.g., jar testing) and consult manufacturer recommendations to ensure compatibility and effectiveness.

A qualified manufacturer representative or stormwater professional shall assist with site-specific soil and water testing and product selection, including flocculant type, dose, and application method, to ensure effective sediment control and regulatory compliance.

Prior to flocculant application, confirm compatibility with all applicable Virginia Pollutant Discharge Elimination System (VPDES) and Virginia Water Protection (VWP) permits, and any local regulatory requirements.

4.0 Stormwater Performance Summary

Sediment Removal Efficiency: High

Erosion Control Efficiency: Low

The use of flocculants is intended to improve the effectiveness of sediment and erosion control measures at construction sites, particularly in conditions where conventional BMPs may not sufficiently control fine or colloidal sediment (e.g., colloidal clays that can pass through silt fence or remain suspended in sediment basins even when properly designed and installed).

Commented [MD5]: *TRC Change — Colloidal clay context (§4.0): The TRC specifically highlighted colloidal clays as the primary driver for flocculant use. A clarifying parenthetical has been added to reinforce the intended use case.*

5.0 Design Criteria

Only products listed on the Virginia DEQ Approved Flocculant Product List (live link on DEQ webpage) may be used.

Both active (metered dosing) and passive (blocks, logs, soil/matting applications) dosing systems are permitted.

Introduce flocculants at points of high turbulence (e.g., basin inlets, slope drains) to ensure thorough mixing and maximize sediment removal. Flocculants may also be applied directly to disturbed soils as part of stabilization, dust control, or treatment train applications.

Apply flocculant products according to manufacturer guidance, DEQ-approved limits, and site-specific jar testing results. Adjust dosing as needed based on performance and monitoring outcomes. For Polyacrylamide (PAM), use site-specific jar testing to determine optimal dosage, typically within the range of 1–5 mg/L.

Conduct jar testing as the primary method for evaluating flocculant performance and determining appropriate dosing. Repeat jar tests whenever soil conditions or application configurations change. Follow manufacturer guidance and EPA-recommended protocols for performance evaluation.

Monitor treated water for sediment and turbidity. Adjust application rates, methods, or product selection within manufacturer-recommended and DEQ-approved ranges based on field observations. Document all adjustments and rationale in the project SWPPP for review.

Monitor field turbidity using a clear turbidity tube (minimum 60 cm in length) with a Secchi pattern or similar visual threshold, supplemented with handheld turbidity meters or other approved methods as needed. Record observations in the project SWPPP and use them to guide corrective actions. If water clarity does not meet visual or instrument-based standards, consult the manufacturer to adjust BMPs or flocculant application accordingly and document in the SWPPP.

Commented [MD6]: *TRC Change — Visual monitoring ≠ water quality sampling (§5.0): Per TRC discussion and staff response, visual inspection is for observable conditions (turbidity, fish kills) and does not constitute water quality sampling. Toxicity confirmation comes from a product being on the DEQ Approved List, not from field water quality sampling. Language requiring "confirmation of no toxicity" through monitoring has been removed. The visual monitoring requirements above reflect this intent.*

Flocculant Use Pathways:

Flocculants may be incorporated into a project in one of two ways:

Commented [MD7]: *TRC Change — Two pathways (§3.0): The TRC identified that the draft did not address the scenario where flocculants are added as a corrective measure in the field. This new sub-section formalizes both pathways and clarifies documentation requirements for each.*

1. Specified on Design Plans: Flocculant use is identified during the design phase, included in the Erosion and Sediment Control (ESC) Plan and SWPPP, with product selection, dosing approach, and application locations documented prior to construction. Jar test results dictating product selection and dosing must be included in the SWPPP prior to use and in the ESC Plan if available at that time.
2. Field Revision: If turbidity issues are identified after construction begins, flocculant use may be added via a field revision to the ESC Plan or SWPPP. All required documentation (site-specific justification, map, product selection, jar test results, etc.) must be submitted and approved by the VESMP/VSMP authority prior to use.

6.0 Construction Specifications

Install and maintain dosing systems per manufacturer instructions.

Inspect dosing equipment daily during use and after each rain event; repair or remove malfunctioning equipment immediately.

For passive devices, ensure they are securely anchored in the flow path and not buried or bypassed by runoff. Replace or reposition passive flocculant devices that become ineffective due to coating, drying, or displacement.

Do not over-apply flocculants; excessive dosages may reduce effectiveness and increase environmental risk.

Flocculants, when used as part of a sediment-control treatment train, are to be applied upstream of a final Perimeter Control Measure (PCM) or Sediment Control Measure (SCM). Ensure that stormwater is treated through a PCM or SCM prior to discharge. Do not discharge flocculant-treated water directly into an MS4. This approach maximizes sediment removal and prevents untreated releases to the stormwater system.

Commented [KA8]: Discuss.

Conduct all construction and installation activities in accordance with the approved SWPPP and manufacturer's guidelines. Perform jar tests, or other approved means, at each site to verify the effectiveness and safety of the selected flocculant under site-specific conditions. Note, this may include more than one test location based on differing soil types across the site including strata. Demonstrate sediment removal performance and confirm that no adverse chemical or toxicity impacts occur to receiving waters.

Document all jar tests, operational procedures, treatment application rates, and schedules. Make these records available for DEQ review upon request.

Cationic Flocculant Approval Process:

Commented [MD9]: *TRC Change — Robust cationic approval language (§6.0): Staff committed at the TRC meeting to developing more robust approval process language covering aquatic resources downstream, soil type/condition considerations, and the approval process for both anionic and cationic products. The cationic approval section has been restructured as a clear checklist of required submittals, and explicit consideration of downstream aquatic resources has been added.*

Cationic flocculants may not be used without prior written DEQ approval. To request approval, the permittee shall submit the following to DEQ:

- Product chemistry data
- EPA/DEQ protocol toxicity data
- Site-specific risk assessment, including consideration of aquatic resources (e.g., known sensitive species, designated use waters) downstream of the proposed application area
- Justification for cationic use over anionic alternatives
- Proposed monitoring and contingency plan

DEQ may require additional construction stormwater BMPs, enhanced sediment basins, increased monitoring, or other site-specific controls to prevent water quality violations associated with cationic chemical discharge. Suspend use immediately and notify DEQ if aquatic toxicity or water quality violations are observed.

Manufacturers or applicants may propose new products for inclusion on the Approved List by submitting required data to DEQ.

7.0 Operations and Maintenance Considerations

Train all site personnel in flocculant handling, dosing, and spill response.

Store flocculant products to prevent contact with stormwater prior to application. Clean up any spills immediately.

Inspect application systems and sediment removal BMPs routinely, especially after rainfall events.

Conduct visual turbidity monitoring for influent and effluent during chemical treatment, following the manufacturer's recommendations. Visual inspection is for observable field conditions (e.g., turbidity, evidence of fish kills or aquatic stress) and does not require water quality sampling. If visual inspection indicates inadequate sediment control, consult the manufacturer to adjust the application rate, method, or product selection as needed. Maintain a log of daily visual inspections in the SWPPP.

Keep detailed records in the project SWPPP of chemical use, equipment maintenance, monitoring results, and any unforeseen incidents.

If any fish kills, unexplained aquatic toxicity, or violations of water quality standards are observed, immediately suspend flocculant use and notify DEQ. All chemical treatment must be suspended until corrective actions are reviewed and approved by DEQ.

Sediment recovered from flocculant treatment is not classified as hazardous waste solely because of flocculant use. Dewatered sediment may be reused as fill or land-applied, provided it meets applicable federal, state, and local standards for stability and environmental safety.

8.0 References

- Applied Polymer Solutions. 2024. Technical Bulletin 2: Anionic Polyacrylamide (PAM) Guidance for Erosion and Sediment Control in Construction Stormwater. APS, Greensboro, NC.
- Maryland Department of the Environment. Standards for Use of Chemical Additives for Sediment Control.
- North Carolina Department of Environmental Quality. Construction Stormwater Flocculant Guidance.
- Minnesota Pollution Control Agency. Polyacrylamide (PAM) for Construction Stormwater.
- U.S. Environmental Protection Agency. 2019. Use of Treatment Chemicals for Particulate Removal from Construction Stormwater. EPA-832-F-19-001.
- Washington Department of Ecology. Stormwater Management Manual for Western Washington, Appendix III-D.

Commented [MD10]: *TRC Change — Visual inspection clarification (§7.0): Staff agreed the prior language was ambiguous and could be read to require water quality sampling. The sentence above clarifies that visual inspection is observational only. Toxicity is addressed through product listing, not field sampling.*

Commented [MD11]: *TRC Change — Hazardous waste statement (§7.0): Staff agreed at the TRC meeting to revise the hazardous waste statement to clarify that the* use of flocculants alone *does not constitute hazardous waste. The phrase "solely as a result of flocculant use" has been added for precision.*

Chapter 6 Stormwater Site Design and BMP Selection

Section 6.3.3.4 Post-Construction Stormwater BMP Selection

Under this heading towards the end:

Stormwater Function – Volume Reduction and PR

Determine how each BMP option compares in terms of PR. In this step, focus on the removal of select pollutants to determine the best BMP options for water quality. Table 6-21 examines the capability of each BMP option to remove specific pollutants from stormwater runoff. Total pollutant reductions (TR) indicated in Table 6-21 for TP, TN, and TSS reflect a combination of PR 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 milligram per liter of TP). When part of a site's total runoff volume is removed through the use of RR practices (e.g., rainwater capture, infiltration), the pollutants in that portion of the site runoff are removed from the remaining runoff that must still be managed. Then, as stormwater treatment processes (e.g., settling, filtration, chemical conversion, vegetation uptake) are applied to the 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 6-21 Pollutant Removal Efficiencies and Volume Removal Rates for Post-Construction BMPs

BMP Category	Specific BMP	Runoff Volume Reduction[1] (%RR)	TP EMC Reduction[2] (%PR)	Total TP Reduction[3] (%TR)	TN EMC Reduction[2] (%PR)	Total TN Reduction[3]

See chart - no change. This new section is below it.

Volume reduction is a key component of stormwater management and a function of most BMPs. As a supplement to post-construction BMP design, developing technology using active/adaptive flow control devices/systems, including continuous monitoring and adaptive control (CMAC) may assist with active storage volume management and potentially decrease the BMP footprint. CMAC is an automated valve that integrates information directly from field-deployed sensors with real-time weather forecast data to directly monitor performance and make automated and predictive control decisions to actively manage stormwater storage and flows within a facility. Active/adaptive flood control devices (FCDs) can be integrated into the design of any type of new structural BMPs, treatment trains, or applied as a retrofit to optimize BMP design. Benefits from the incorporation of active/adaptive FCDs include the restoration of pre-development hydrology (reducing the volume of stormwater released during a precipitation event and decreasing peak flow rates released by the BMP), mitigation of flood frequency and magnitude, maximizing the volume of water available for reuse, mitigation of downstream erosion issues, and increased resilience against a changing climate. Perhaps one of the most unique functions of active/adaptive control systems is the ability to adapt to changes in management objectives and/or changing weather patterns without modifying the physical structure of the BMP.

As with all stormwater installations, active/adaptive FCD applications should be fully vetted by the responsible governmental entity(ies) and comply with all state and local requirements. Common hydrologic and hydraulic modeling tools such as HydroCAD or EPA SWMM 5 can be used to verify that flow rate requirements are being met. Maximum allowable outflow rates can be programmed into the system software and should be verified as a part of the as-built. The design, installation, and operation of active/adaptive flow controls should consider selection and location of hardware to optimize maintenance, redundancy and fail-safes across physical, mechanical, and cloud-based infrastructure, and security.

P-SUP-07 Quantity Only Approach to BMPs

5.0 Design Criteria

Table P-SUP-07-8 Conveyance and Overflow

Parameter	Details
Internal Slope	To keep the detention basin dry after a storm event, the basin should be sloped along the basin floor leading to the outlet structure. Promoting positive drainage within the basin may result in drier soils between rain events. Turf grass can also be used in dry bottom basins. Basins with turf grass will need minimum bottom slopes of 0.5% to 1% toward the outlet structure to ensure adequate drainage between events. Basins with a permanent wet pool can be flat with no slope through the practice. Areas above the normal high water elevations of the detention facility should be sloped toward the basin to allow drainage. Careful finish grading is required to avoid creation of upland surface depressions that may retain runoff. The bottom area of storage facilities should be graded toward the outlet to prevent standing water conditions.
Principal Spillway	The principal spillway will be designed with acceptable anti-flotation, anti-vortex, anti-seep collar, and trash rack devices. Trash racks must be installed at the intake of the outlet structure and designed to avoid acting as the hydraulic control for the outlet system. The spillway must generally be accessible from dry land. Refer to P- SUP-02 Principal Spillways for design criteria.
Emergency Spillway	Detention basins must be constructed with overflow capacity to safely pass the 100-year design storm event without overtopping the embankment and causing structural damage to the facility through either the primary spillway (with 2 feet of freeboard to the settled top of embankment) or a vegetated or armored emergency spillway (with at least 1 foot of freeboard to the settled top of embankment). Refer to P-SUP-03 Vegetated Emergency Spillway for design criteria.
Non-Clogging Low-Flow Orifice	Detention basins with drainage areas of 10 acres or less, where small-diameter outlet pipes and orifices are typical, are prone to chronic clogging by organic debris and sediment. Vertical perforated risers wrapped in gravel are the preferred orifice. Horizontal perforated extensions wrapped in gravel help to maintain a dry basin bottom. Conventional trash racks need to have spacing that is half the diameter of the orifice. This is not practical for orifices with diameters 3 inch or less; consequently, orifices less than 3 inches in diameter should be avoided. Refer to P-SUP-02 Principal Spillways for design criteria and information regarding low-flow orifice design.

Adequate Outfall Protection	The design must specify an outfall that will be stable for the maximum (pipe-full) design discharge (the 10-year design storm event or the maximum flow when surcharged during the emergency spillway design event, whichever is greater). The channel immediately below the pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance with care taken to minimize tree clearing along the downstream channel. Outlet protection or energy dissipation should be provided consistent with C-ECM-15 Outlet Protection.
Inlet Protection	Inlet areas should be stabilized to ensure non-erosive conditions during storm events up to the overbank flood event (i.e., the 10-year storm event). Outlet protection or energy dissipation should be provided consistent with C-ECM-15 Outlet Protection. Inlet pipe inverts should generally be located at or slightly below the forebay pool elevation. Inlet pipes should not be fully submerged at normal pool elevations. Where the inlet pipe needs to be submerged, pipe velocities must support minimum velocities for sediment flushing per Virginia Department of Transportation (VDOT) Drainage Manual requirements. A hydraulic grade line analysis considering the tailwater effects of the normal pool elevation will be completed that shows the adequacy of the upstream storm system during the 10-year storm.
Dam Safety Permits	Detention basins with high embankments or large drainage areas and impoundments may be regulated under the Virginia Dam Safety Act (§ 10.1-606.1 et seq., Code of Virginia) and the Virginia Dam Safety regulations (4 VAC 50-20 et seq.). Refer to P-SUP-01 Earthen Embankment for additional information.
Continuous Monitoring and Adaptive Control (CMAC)	For detention basins equipped with CMAC, the required physical storage volume may be reduced relative to standard passive basin requirements. Designers may utilize hydraulic modeling and continuous simulation to demonstrate that the efficiency of active controls maintains compliance with required peak discharge rates and storm event management using less physical storage. Refer to Support Component P-SUP-09 Continuous Monitoring and Adaptive Control (CMAC) for guidance on CMAC design and applications.

Table P-SUP-07-11 Underground Basin Design Variations

Variations	Description	Recommendations
Storage component variations	Underground pipes and chambers	High-density polyethylene (HDPE), corrugated metal pipe (CMP), concrete, or PVC pipe materials are recommended to be placed within the stone storage.

		Pipe should be installed observing manufacturer's pipe spacing, minimum cover, and maximum cover recommendations. A minimum of 4 inches of stone bedding under pipe or chamber structure should be provided. Multiple pipe sizes can be used to maximize storage. Provide access to pipes larger than 36 inches in diameter. Proprietary chambers should be installed in accordance with manufacturer's recommendations.
	Underground vaults	Provide human access to vaults. Proprietary vaults should be installed in accordance with manufacturer's recommendations.
	Underground plastic grid storage	Various structure types can be stacked and interlocked. Grid systems are commonly known for their ability to provide a high void space efficiently for storage of stormwater. Proprietary products should be installed in accordance with manufacturer's recommendations.
~~Active/Adaptive Systems~~Continuous Monitoring and Adaptive Control (CMAC)	Uses rainfall forecasting and system storage to improve performance	For underground detention basins equipped with CMAC, the required physical storage volume may be reduced relative to standard passive basin requirements. Designers may utilize hydraulic modeling and continuous simulation to demonstrate that the efficiency of active controls maintains compliance with required peak discharge rates and storm event management using less physical storage. Refer to Support Component P-SUP-09: Continuous Monitoring and Adaptive Control (CMAC) for guidance on CMAC

		design, ~~and~~ applications, operation and maintenance. ~~Incorporation of active and adaptive flow control devices can improve volume and/or peak rate performance.~~

P-SUP-09 Continuous Monitoring and Adaptive Controls (CMAC)

1.0 Definition

Continuous Monitoring and Adaptive Control (CMAC) is a stormwater management approach that automates the use of real-time water level monitoring, weather forecasting, and outflow rate control to dynamically manage stormwater storage and treatment. It integrates information directly from field-deployed sensors with real-time weather forecast data (e.g., NOAA) to monitor performance and make automated, predictive control decisions to actively manage stormwater storage and flows.

2.0 Purpose and Applicability of Best Management Practice

CMAC transforms traditional passive infrastructure into modern, intelligent infrastructure that maximizes stormwater management benefits and informs compliance and asset management. Through a rules-based control system, CMAC continuously monitors facility water levels and analyzes incoming precipitation data to calculate available storage in real time. This allows for an active management cycle that begins with a pre-storm drawdown, where automated outflow devices like actuated gates or valves discharge stored water to maximize capacity before the first drop falls. After the rainfall event, the system initiates a post-storm retention phase designed to improve treatment processes like settling and denitrification while maximizing infiltration. CMAC is most effective when applied to detention/retention practices such as extended detention ponds, wet ponds, constructed wetlands, rainwater harvesting systems, and underground detention basins, as these generally provide the greatest potential controllable volume.

CMAC technology significantly enhances stormwater management by optimizing peak flow attenuation and increasing residence times, which improves water quality and promotes groundwater recharge. Discharging stored water ahead of a storm event and minimizing wet weather releases allows for a reduction in the physical footprint of a structural BMP without compromising performance standards, providing developers with a high-efficiency solution that balances regulatory compliance with maximized land-use potential. By enabling real-time performance verification and the flexibility to adapt to climate-driven precipitation changes without physical modifications, CMAC maximizes the efficiency of both new and existing infrastructure while offering a resilient, data-driven alternative to traditional designs.

3.0 Planning and Considerations

CMAC can be successfully applied to a wide variety of situations and scenarios. To ensure optimal and reliable performance, a site must maintain consistent access to a power source and a reliable cellular or wide-area network signal. Power may be provided through 120VAC line power or, for sites with sufficient sunlight to maintain battery levels, via 24VDC solar installations. Ultimately, designers should collaborate with certified CMAC providers to optimize these configurations and ensure the site's unique characteristics are accounted for in order to support long-term performance.

When retrofitting/upgrading an existing BMP with CMAC to accommodate new construction, technical feasibility should be confirmed by determining the available control volume and utilizing hydraulic models to evaluate both upstream runoff and downstream network impacts. Designers must prioritize logistical reliability by ensuring year-round maintenance access, securing a continuous power source (utility grid or solar), verifying robust cellular connectivity, and resolving any land ownership or easement requirements. An ideal candidate site features a concentrated low-flow orifice suitable for automated valve installation; however, for facilities with complex or large-diameter outlets, a new outlet structure or weir wall may be specified upstream to facilitate control. The retrofitted facility must be inspected to verify adherence to its original design parameters and continues to function as intended without exacerbating downstream flow. As with all stormwater infrastructure, CMAC retrofits must be fully vetted by the responsible governing entities and comply with all applicable state and local regulations.

4.0 Stormwater Performance Summary

When included in the design of a BMP, CMAC can provide enhanced performance by reducing the volume of stormwater released during a precipitation event, decreasing peak flow rates released by the BMP, and increasing residence time for the improved removal of pollutants such as Total Suspended Solids (TSS), Total Phosphorus (TP), and Total Nitrogen (TN) in comparison to equivalent passive design practices.

5.0 Design Criteria

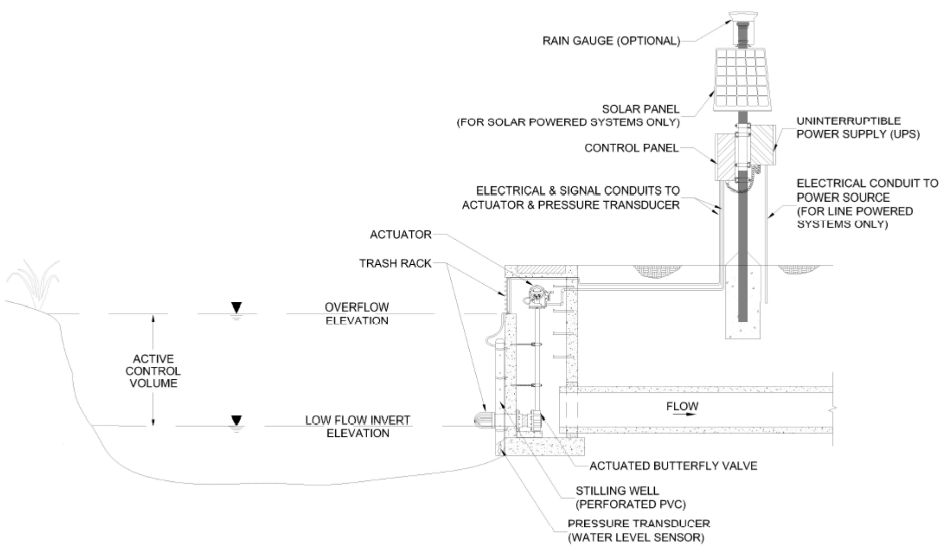
A complete CMAC solution requires specific physical hardware, including:

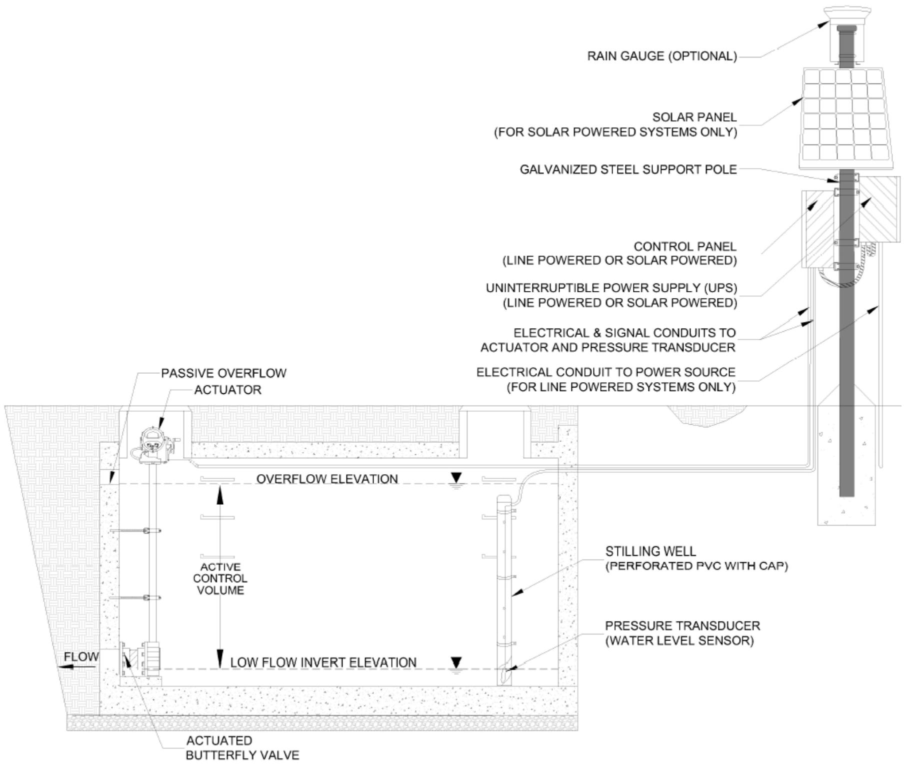
- Water Level Sensor: Measures the water level(s) in the system.
- Outflow Control Device: Controls the discharge of water from the system. Examples include an actuated valve, slide gate, or pump.
- On-Site Control Panel: Interfaces with sensors and outflow control devices, manages fail-safe logic, and connects to the global controller via wide-area networking technologies.

The system requires a global controller, which is a redundantly-deployed, highly-available networked application that supervises operations at multiple locations, integrates with data sources, sets target set points, and sends alerts to people and other systems when issues occur with the physical hardware, wide-area networking, or any integrated data sources that interfere with normal operations. These systems must be powered by either 120VAC line power or 24VDC solar installations and must include a battery backup to maintain operability during power interruptions. Real-time internet connectivity is also required to allow the control system to receive software configuration changes, weather forecasts, and current targets, and transmit data on observed environmental and internal system states.

CMAC is most accurately modeled using continuous simulation models tools, for example, EPA SWMM. CMAC behavior can be represented with other modeling software, although these approximations may not represent the full functionality of the CMAC system.

The "active control volume" in a CMAC system is the volume in a storage unit that can be actively controlled by CMAC technology. In the diagrams below, the active control volume is in between the flow control point (invert of the actuated valve) and the passive overflow weir. A permanent pool can be maintained using the software settings, therefore it is preferable to put the controlled outlet as low as possible in the water column to allow for greater flexibility in the controllable volume. The performance objectives of the facility will inform this aspect of the design.





<u>Software Notes</u>
The outlet control device (i.e. actuated valve) changes positions based on the outflow rate dictated by the software. All CMAC systems should have a failsafe position for power outages, loss of cellular connection, or failed hardware.

Common Configurations:

- Modulate throughout storm events to avoid overflow and allow release of water at smaller rates during wet weather conditions. This configuration helps to minimize larger overflows and to maximize captured wet weather runoff.
- Fully open the control valve for large storms that are forecast to overtop the passive overflow, which will allow the system to resemble a passive system during the hydrograph peak.
- Baseflow target set for wet or dry weather that does not change based on storm size.
- Intermediate elevations in the water column used as targets for wet or dry weather, not related to passive overflow elevations.

Outlet Structure Design

- The outlet structure design should establish a storage volume that fits minimum design storm runoff criteria from the site with an outlet control point.
- A typical design actively controls a low flow orifice in an outlet structure or weir wall at the bottom of the water column (to maximize controllable volume). The volume between the low flow orifice with actuated-valve and the next passive outflow point (mid-stage weir or orifice) is considered the controllable volume.
- The minimum height of the overflow should be sized to capture the design storm dictating basin size.

Maximize Control Volume

The overflow or weir wall height is increased to attain a larger control volume while meeting regulatory and local jurisdiction requirements such as discharge rate or water surface elevations. When routing larger storm events, the actuated valve can throttle to increase the orifice size. For hydraulic modeling purposes, the weir wall should be modeled under both clogged and unclogged valve scenarios. This simulation is a safety measure that represents a total mechanical and electrical failure of the system occurring simultaneously with a large storm event, ensuring the facility can safely manage peak volumes even under worst-case operational conditions.

Valve Sizing

Valve sizing for CMAC systems should be determined by calculating the passive valve diameter required to discharge the full control volume over time in accordance with design specifications. Utilize data from as-built plans or existing hydrology reports for baseline data in calculations. All jurisdiction-specific design storms should be modeled with an equivalent actuated valve size to ensure specific discharge rates are met. A key benefit of this technology is that the system control logic can be adjusted to limit the valve opening for various return intervals, such as 2-year or 10-year events; for instance, a 12-inch valve required for a 100-year storm can be programmed to mimic a smaller diameter through partial closure to accurately meet the flow requirements of a 1-year or 2-year rainfall event.

Hardware Placement & Specification

Hardware placement and specification is imperative to consider during design and is specific to each site. The level sensor, control panel, and outflow control device must be clearly identified within the proposed plan layout of the site and section views.

Level Sensor Placement:

- The water level sensor should be placed in a location where the full water column in the facility can be measured.

- A stilling well should be installed upstream of the outlet control device as far away from the orifice as possible. Typically, a pressure transducer is the instrument of choice; however, other level sensors may be considered.
- For confined space installation, the stilling well should be placed near an access point (e.g. manhole, inspection port).
- In cold climates, consider design alternatives that place the pressure transducer/stilling well in deeper water to reduce the risk of freezing.

Commented [MC1]: Discuss/quantify distance 'as far as possible'

Control Panel:

- The control panel can run on 120VAC line power or as a 24VDC solar installation. An internal battery backup should be provided for all actuated valves running on 120VAC.
- Locate the control panel on a pole or building wall (outdoors), or mounted to an interior wall (indoors).
- For indoor installations, a minimum clearance of 10 feet should be maintained between the control panel and any electrical box with voltage less than 240V. The control panel shall be installed in a separate room from any electrical box with voltage greater than 240V.
- Indoor control panel installation should be accessible by the VESMP authority for inspection until the Notice of Termination is issued.
- If a backup generator will be permanently installed onsite, it is recommended that the control panel be incorporated in the powered circuit. Generators must comply with all applicable permits.
- Place solar panels:
  - In an unobstructed location facing South to ensure maximum sunlight
  - A minimum of 4 feet above high flood level.
  - As close to the control point as possible to minimize cable and conduit runs
- If theft is a concern, the hardware may be placed within fencing or on a higher pole. For solar powered sites, the batteries may be secured in a heavy-duty job box.

<u>Outflow Control Device:</u>

- An actuated valve is typically mounted to the internal wall or weir wall in the stormwater facility's outlet structure, on the downstream side.
- The orifice on which the valve is mounted will typically match the valve size.
- Additional support below the actuated valve shall be specified by the Engineer of Record to support a minimum of 600 lbs (or the final weight of the actuated valve, whichever is greater).
- Trash rack requirements should be met per the criteria outlined in P-SUP-02 as specified by the engineer of record.

<u>Conduit Connections:</u>

- Include a project-specific wiring diagram in the project's electrical plans.

- Buried conduit is required from the actuated-valve and level sensor to the control panel. Clearly identify these components on the site plan.
- The electrical diagram requires a junction box in between the control panel and valve/level sensor for conduit runs greater than 100 feet. The junction box can be installed above grade, or mounted inside the outlet structure.
- Plan sets with multiple onsite sensors and control panels will also include call outs in the Piping and Instrumentation Diagram (P&ID) and mechanical sheets.

To ensure public safety is not compromised, CMAC systems must be designed for comprehensive fail-safe operation through integrated software configurations and physical design redundancies. This framework requires the system to explicitly manage specific failure scenarios, such as a loss of power, which triggers the outflow control device to automatically move to a predetermined safe position—whether fully or partially open or closed—based on design and permitting requirements. In the event of a loss of communication, the system is designed to revert to local control logic or a passive operational mode. Furthermore, the system maintains a "data trust" protocol by evaluating the plausibility and timeliness of all inputs, reverting to a safe state if sensor observations are deemed unrealistic due to environmental interference or malfunctions. Physical design considerations also account for hardware or mechanical failures, such as a clogged valve, by ensuring the facility can still safely pass required storm flows through its passive overflow. CMAC systems are held to the same standards as existing controls.

Operational control is maintained through both remote and local manual overrides; the CMAC software should support secure web-based remote control featuring a time- and identity-based lock-out to prevent simultaneous operation by multiple users, while facilitating local control via the control panel or mechanical tools like a hand wheel or T-wrench. System security is addressed by securing physical hardware within fencing or on elevated structures to prevent theft or vandalism, utilizing remote control systems that do not rely on static, publicly routable IP addresses, and ensuring all data transmitted over wide-area networks is fully encrypted in transit.

6.0 Construction Specifications

The CMAC system is installed following completion of the outlet control structure and weir. Installation requires coordination between the contractor, structure manufacturer, and CMAC vendor to ensure compatibility of mechanical, electrical, and control components.

Structural and Mechanical Requirements

- Construct the outlet control structure to support the full weight and operational loading of the actuated valve assembly.
- Provide a dedicated structural support (e.g., concrete cradle or bracket system) where the valve is not floor-supported.
- Align orifice elevation and mounting interface with valve geometry to ensure full support and proper operation.

- Maintain access to the valve and actuator for maintenance and manual operation.

Sensor Installation

- Install water level sensors upstream of the control device in a location free from hydraulic turbulence.
- House sensors within a stilling well where required; Ensure stilling well diameter and configuration are compatible with sensor type and installation method.
- Consider accessibility for inspection, cleaning, and calibration as they relate to sensor placement.

Conduit and Electrical

- Provide separate conduit runs for power and low-voltage signal wiring.
- Minimize bends and allow for straightforward cable pulls between sensor, actuator, and control panel in the conduit routing.
- Seal all penetrations and terminations to prevent water intrusion.
- Install wiring in accordance with applicable electrical codes and manufacturer requirements.

Control Panel Installation

- Mount the control panel above anticipated flood elevation and in a location accessible for maintenance.
- Ensure solar installations are oriented and located for reliable power generation.

Installation Coordination

- Coordinate coordinate installation sequencing with the CMAC vendor to confirm compatibility with control hardware, wiring, and communication requirements.
- Verify all installation details against manufacturer documentation prior to execution.

Testing and Commissioning

- Test the system for communication, valve operation, and fail-safe behavior.
- Perform sensor calibration using field measurements referenced to known structural elevations.
- Verify final system configuration in coordination with the CMAC provider.

Recordation of Software Configuration

- File a configuration report with as-built design plans to record the control logic used to meet design and permit requirements. This is critical to ensure the stormwater facility is meeting regulatory requirements and properly functioning.

7.0 Operations and Maintenance Considerations

A CMAC system actively manages stormwater by continuously monitoring site conditions and adjusting hardware in response to real-time data, without requiring an operator to be on-site. The system integrates weather forecasts to execute pre-storm drawdowns, hosts the logic that controls all hardware behavior, and delivers 24/7 diagnostics with automated alerts for any hardware or connectivity issue.

This autonomous capability is sustained by an active software subscription, which maintains the secure data links and processing infrastructure the system depends on to operate. An active subscription powers the system's core intelligence by enabling forecast integration for proactive, weather-driven drawdowns and hosting the autonomous logic required to process sensor data. It ensures reliable connectivity via secure cellular or satellite links and maintains system integrity through 24/7 monitoring and instant alerts, keeping you informed of hardware health and performance in real time.

Like any mechanical and electronic system deployed in the field, CMAC hardware requires routine attention to perform reliably over time. The maintenance schedule outlined below is designed to be manageable; most activities occur biannually and can be completed during a single site visit. Keeping up with this schedule is what preserves the autonomous performance that makes the system valuable in the first place. Regulatory requirements may also mandate annual reporting to verify that the system is operating as intended and meeting design standards such as maximum allowable release rate. Operators can satisfy this requirement using their own data access or by requesting an annual summary from the vendor.

The following table outlines maintenance activities and corrective actions for each system component.

Component	**Activity**	**Frequency**
Control Panel	• Inspect interior for water intrusion or pest activity; if moisture is present, dry the interior and re-seal potential openings (conduit junctions, cable glands, door gaskets). • Perform “tug-test” on terminal block wiring to ensure a secure connection; secure any loose connections. Ensure all breakers are “ON”.	Biannually
Battery Backup for Line-Powered Sites	• Check battery charge with a multimeter. If voltage is low or the failsafe test fails, replace the batteries. • Inspect battery posts and terminal lugs for corrosion; clean and tighten connections as needed. • When replacing batteries, replace all units at the same time even if only one has failed.	Biannually
Solar Power Kit (if applicable)	• Clean solar panels with a damp soft cloth using water only; do not use chemical cleaners.	Biannually

	• Check battery charge with a multimeter. (Batteries should have near equal charge; if voltages are unequal, inspect battery posts and terminal lugs for corrosion and ensure connections are tight. Voltage imbalance is an indicator of cell degradation and should be monitored; plan for replacement if imbalance persists or worsens, if the site experiences service disruption, or if charge retention appears to be shortening.	
Water Level Sensor	• Winterize and de-winterize if needed. • Ensure stilling well is securely mounted and free of damage. • Inspect stilling well for obstructions and water level sensor for fouling. If fouling occurs, clean gently with a damp cotton cloth. • Inspect bellows and junction boxes for moisture; if moisture is present, replace the desiccant and/or bellows. • Gather and verify field measured water level against dashboard reading; recalibrate if values do not align. • Calibrate any time the sensor is re-located, after winterization, or when data shown on the dashboard does not match observed values. • Recalibrate any time the water level sensor is relocated or re-installed.	Biannually and during every site visit
Rain Gage (if applicable)	• Clear debris and obstructions from the collection cone and exit orifice. • Confirm wiring is intact and connected to the correct terminals within the control panel. • Manually rock the tipping bucket to test operation and confirm rainfall is reported accurately. If the tipping bucket is stuck, manually clear obstructions and retest functionality.	Biannually and during every site visit
Valve & Actuator	• Inspect valve for debris or obstructions; clean as needed. • Exercise valve (0–100%) in "Local" mode from the control panel, and confirm observed valve position matches dashboard reading and local control input. If the valve does not reach fully opened/closed, inspect for internal debris or a degraded gasket.	Biannually and as needed based on alerts

	• Exercise valve (0-100%) in "Remote/Manual" mode and confirm observed valve position matches remotely issued commands and dashboard readings. • Inspect valve seat and disk for wear or damage. If the valve does not reach fully open or closed, inspect for debris, gasket degradation, or actuator misalignment. • Confirm open/close limits and torque settings are correctly configured per manufacturer specifications. • Verify fail-safe position is set correctly; test by interrupting power and confirming valve moves to intended fail-safe position.	
Gate	• Inspect gate and stem for misalignment, corrosion, or physical damage. • Clean stem using brush with stainless steel or brass bristles. Do not use steel bristles or hand grinders. • Lubricate stem per gate manufacturer recommendations; use a marine-grade, environmentally safe grease. • Check for bronze dust or shavings around lift nut area. If present, inspect and replace lift nuts if dust or shavings are found. • Observe gate in motion. If excessive backlash is observed when stopping or starting, have the mechanical linkages inspected by the manufacturer and replace all recommended parts.	Biannually or more depending on use frequency and as needed based on alerts
Trash Rack and Stilling Well	• Inspect for debris and obstructions. Clean as needed. • If the orifice is obstructed, draw down the pond to clear the rack in accordance with programmed maximum outflows.	Biannually and during every site visit

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