

3.5 Permeable Pavement Systems

Definition. This is a paving system that captures and temporarily stores the Stormwater Retention Volume (SWRv) by filtering runoff through voids in an alternative pavement surface into an underlying stone reservoir. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially (or fully) infiltrate into the soil.

Design variants include:

- P-1 Porous asphalt (PA)
- P-2 Pervious concrete (PC)
- P-3 Permeable pavers (PP)

Other variations of permeable pavement that are DDOE-approved permeable pavement surface materials, such as synthetic turf systems with reservoir layer, are also encompassed in this section.

Permeable pavement systems are not typically designed to provide stormwater detention of larger storms (e.g., 2-year, 15-year), but they may be in some circumstances. Permeable pavement practices shall generally be combined with a separate facility to provide those controls.

There are two different types of permeable pavement design configurations:

- **Standard Designs.** Practices with a standard underdrain design and no infiltration sump or water quality filter (see Figure 3.13).
- **Enhanced Designs.** Practices with underdrains that contain a water quality filter layer and an infiltration sump beneath the underdrain sized to drain the design storm in 48 hours (see Figure 3.14) or practices with no underdrains that can infiltrate the design storm volume in 48 hours (see Figure 3.15).

The particular design configuration to be implemented on a site is typically dependent on specific site conditions and the characteristics of the underlying soils. These criteria are further discussed below.

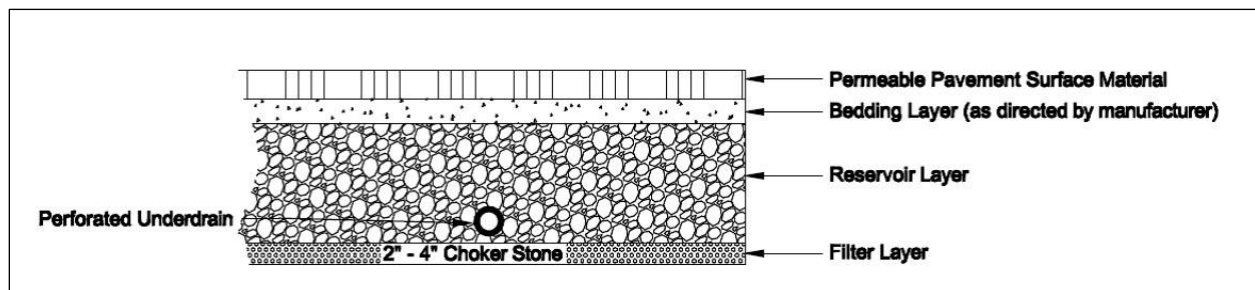


Figure 3.13 Cross section of a standard permeable pavement design.

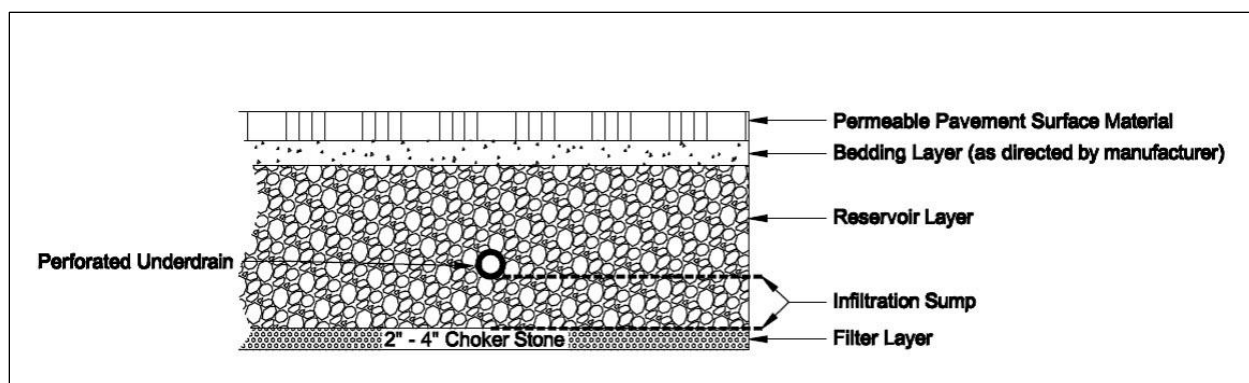


Figure 3.14 Cross section of an enhanced permeable pavement design with an underdrain.

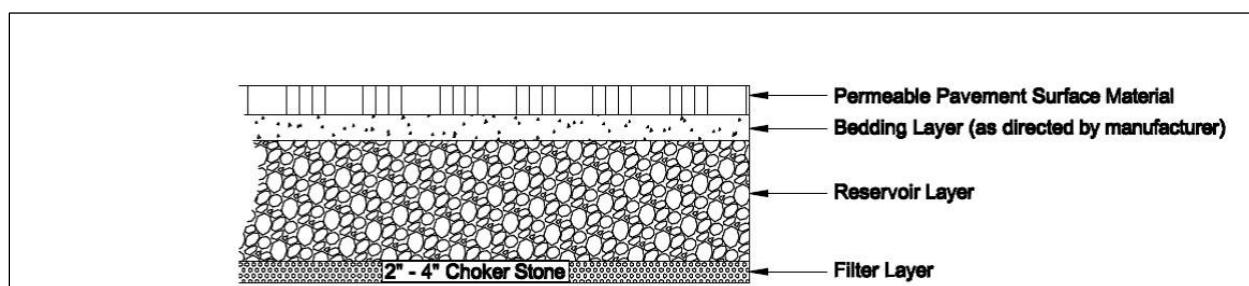


Figure 3.15 Cross section of an enhanced standard permeable pavement design without an underdrain.

3.5.1 Permeable Pavement Feasibility Criteria

Since permeable pavement has a very high retention 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.

Required Space. A prime advantage of permeable pavement is that it does not normally require additional space at a new development or redevelopment site, which can be important for tight sites or areas where land prices are high.

Soils. Soil conditions do not typically constrain the use of permeable pavement, although they do determine whether an underdrain is needed. Underdrains may be required if the measured permeability of the underlying soils is less than 0.5 inches per hour (although utilization of an infiltration sump may still be feasible). When designing an infiltrating permeable pavement practice, designers must verify soil permeability by using the on-site soil investigation methods provided in Appendix O. Impermeable soils will require an underdrain.

In fill soil locations, geotechnical investigations are required to determine if the use of an impermeable liner and underdrain are necessary or if the use of an infiltration sump is permissible (see Section 3.5.4 Permeable Pavement Design Criteria).

Contributing Drainage Area. The portion of the contributing drainage area that does not include the permeable pavement may not exceed 5 times the surface area of the permeable pavement (2 times is recommended), and it should be as close to 100 percent impervious as possible.

Pavement Surface Slope. Steep pavement surface slopes can reduce the stormwater storage capability of permeable pavement and may cause shifting of the pavement surface and base materials. The permeable pavement slope must be less than 5 percent. Designers may consider using a terraced design for permeable pavement in areas with steeper slopes. In all cases, designs must ensure that the slope of the pavement does not lead to flow occurring out of the stone reservoir layer onto lower portions of the pavement surface.

Minimum Hydraulic Head. The elevation difference needed for permeable pavement to function properly is generally nominal, although 2 to 4 feet of head from the pavement surface to the underdrain outlet is typically necessary. This value may vary based on several design factors, such as required storage depth and underdrain location.

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 seasonal high water table.

Setbacks. To avoid the risk of seepage, permeable pavement practices must not be hydraulically connected to structure foundations. Setbacks to structures must be at least 10 feet, and adequate water-proofing protection must be provided for foundations and basements. Where the 10-foot setback is not possible, an impermeable liner may be used along the sides of the permeable pavement practice (extending from the surface to the bottom of the practice).

Proximity to Utilities. Interference with underground utilities should be avoided, if possible. When large site development is undertaken the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the public right-of-way. Consult with each utility company on recommended offsets, which will allow utility maintenance work with minimal disturbance to the permeable paving BMP. For permeable paving BMPs in the public right-of-way, a consolidated presentation of the various utility offset recommendations can be found in Chapter 33.14.5 of the District of Columbia Department of Transportation Design and Engineering Manual, latest edition. Consult the District of Columbia Water and Sewer Authority (DC Water) Green Infrastructure Utility Protection Guidelines, latest edition, for water and sewer line recommendations. Where conflicts cannot be avoided, follow these guidelines:

- Consider altering the location or sizing of the permeable paving BMP to avoid or minimize the utility conflict. Consider an alternate BMP type to avoid conflict.
- Use design features to mitigate the impacts of conflicts that may arise by allowing the permeable paving BMP and the utility to coexist. The permeable paving design may need to incorporate impervious areas, through geotextiles or compaction, to protect utility crossings.
- Work with the utility company to evaluate the relocation of the existing utility and install the optimum placement and sizing of the permeable paving BMP.

- If utility functionality, longevity, and vehicular access to manholes can be assured, accept the permeable paving design and location with the existing utility. Design sufficient soil coverage over the utility or general clearances or other features, such as an impermeable liner, to assure all entities that the conflict is limited to maintenance.

Note: When accepting utility conflict into the permeable paving location and design, it is understood the permeable paving will be temporarily impacted during utility work but the utility will replace the permeable paving or, alternatively, install a functionally comparable permeable paving according to the specifications in the current version of this Stormwater Management Guidebook. Restoration of permeable paving that is located in the public right-of-way will also conform with the District of Columbia Department of Transportation Design and Engineering Manual, with special attention to Chapter 33, Chapter 47, and the Design and Engineering Manual supplements for Low Impact Development and Green Infrastructure Standards and Specifications.

Hotspot Land Uses. Permeable pavements may not be used to treat hotspot runoff. For a list of potential stormwater hotspot operations, consult Appendix P.

On sites with existing contaminated soils, as indicated in Appendix P, infiltration is not allowed. Permeable pavement installations must include an impermeable liner, and the Enhanced Design configuration cannot be used.

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. Sites with a lot of pervious area (e.g., newly established turf and landscaping) can be considered high loading sites and the pervious areas should be diverted if possible from the permeable pavement area. If unavoidable, pretreatment measures, such as a gravel or sod filter strip should be employed (see Section 3.5.3 Permeable Pavement Pretreatment Criteria).

High Speed Roads. Permeable pavement should not be used for high speed roads, although it has been successfully applied for low speed residential streets, parking lanes, and roadway shoulders.

3.5.2 Permeable Pavement Conveyance Criteria

Permeable pavement designs must include methods to convey larger storms (e.g., 2-year, 15-year) to the storm drain system. The following is a list of methods that can be used to accomplish this:

- Place an overdrain—a horizontal perforated pipe near the top of the reservoir layer—to pass excess flows after water has filled the base.
- Increase the thickness of the top of the reservoir layer by as much as 6 inches to increase storage (i.e., create freeboard). The design computations used to size the reservoir layer often assume that no freeboard is present.
- 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.

- Route overflows to another detention or conveyance system.
- Set the storm drain inlets flush with the elevation of the permeable pavement surface to effectively convey excess stormwater runoff past the system. The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.

3.5.3 Permeable Pavement Pretreatment Criteria

Pretreatment for most permeable pavement applications is not necessary. Additional pretreatment is recommended if the pavement receives run-off from adjacent pervious areas. For example, a gravel or sod filter strip can be placed adjacent to pervious (landscaped) areas to trap coarse sediment particles before they reach the pavement surface in order to prevent premature clogging.

3.5.4 Permeable Pavement Design Criteria

Type of Surface Pavement. The type of pavement should be selected based on a review of the pavement specifications and properties and designed according to the product manufacturer's recommendations.

Pavement Bottom Slope. For unlined designs, the bottom slope of a permeable pavement installation should be as flat as possible (i.e., 0 percent longitudinal and lateral slopes) to enable even distribution and infiltration of stormwater. On sloped sites, internal check dams or berms, as shown in the diagram Figure 3.16 below, can be incorporated into the subsurface to encourage infiltration. In this type of design, the depth of the infiltration sump would be the depth behind the check dams. The depth and spacing of the barriers is dependent upon the underlying slope and the infiltration rate, as any water retained by the flow barriers must infiltrate within 48 hours. If an underdrain will be used in conjunction with the flow barriers, it can be installed over the top of the barriers, or parallel to the barriers with an underdrain in each cell.

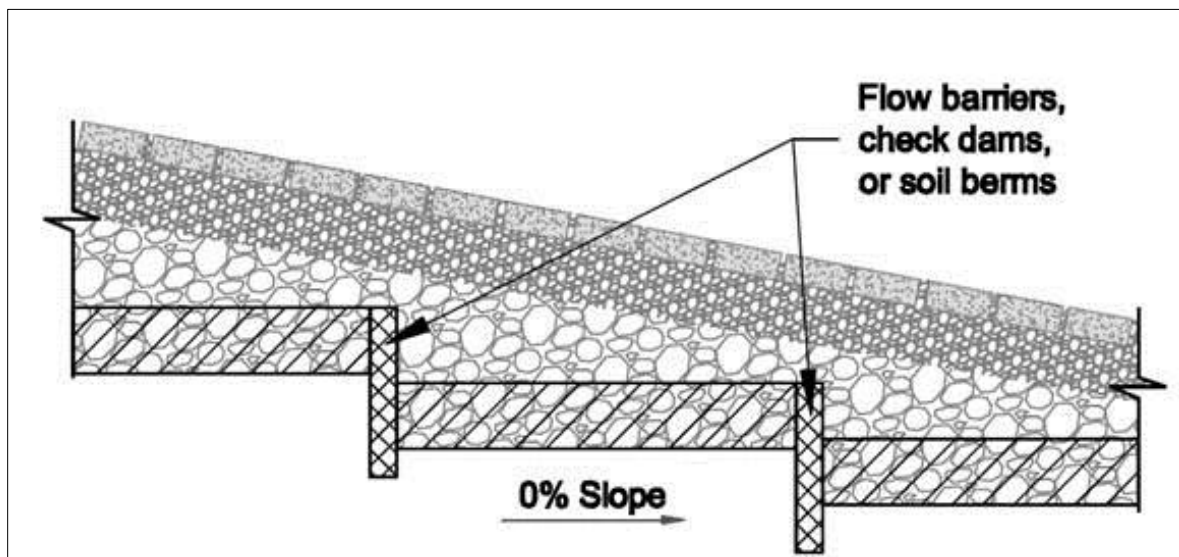


Figure 3.16 Use of flow barriers to encourage infiltration on sloped sites.

Internal Geometry and Drawdowns.

- **Rapid Drawdown.** Permeable pavement must be designed so that the target storage volume is detained in the reservoir for as long as possible—36 to 48 hours—before completely discharging through an underdrain. A minimum orifice size of 1 inch is recommended regardless of the calculated drawdown time.

Note: A 48-hour maximum drawdown time is utilized for permeable pavement rather than the 72-hour value used for other BMPs. This shorter drawdown time, in accordance with industry standards, is intended to ensure that the subgrade does not stay saturated for too long and cause problems with the pavement.

- **Infiltration Sump.** To promote greater retention for permeable pavement located on marginal soils, an infiltration sump can be installed to create a storage layer below the underdrain invert. This design configuration is discussed further below.
- **Conservative Infiltration Rates.** Designers must use 1/2 of the measured infiltration rate during design to approximate long-term infiltration rates (for example, if the measured infiltration rate is 0.7 inches per hour, the design infiltration rate will be 0.35 inches per hour). This requirement is included in Equation 3.2 through Equation 3.4.

Reservoir Layer. The reservoir layer consists of the stone underneath the pavement section and above the bottom filter layer or underlying soils, including the optional infiltration sump. The total 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 frost depth conditions (see Section 3.5.1 Permeable Pavement Feasibility Criteria). A geotechnical engineer should be consulted regarding the suitability of the soil subgrade.

- The reservoir below the permeable pavement surface should be composed of clean, double-washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading (additional chamber structures may also be used to create larger storage volumes).
- The storage layer may consist of clean, double-washed No. 57 stone, although No. 2 stone is preferred because it provides additional structural stability. Other appropriate materials may be used if accepted by DDOE.
- The bottom of the reservoir layer should be completely flat so that runoff will be able to infiltrate evenly through the entire surface. The use of terracing and check dams is permissible.

Underdrains. Most permeable pavement designs will require an underdrain (see Section 3.5.1 Permeable Pavement Feasibility Criteria). Underdrains can also be used to keep detained stormwater from flooding permeable pavement during extreme events. Multiple underdrains are necessary for permeable pavement wider than 40 feet, and each underdrain must be located 20 feet or less from the next pipe or the edge of the permeable pavement. (For long and narrow applications, a single underdrain running the length of the permeable pavement is sufficient.) The underdrain should be perforated schedule 40 PVC pipe (corrugated HDPE may be used for smaller load-bearing applications), with 3/8-inch perforations at 6 inches on center. The underdrain must be encased in a layer of clean, double washed No. 57 stone, with a minimum 2-

inch cover over the top of the underdrain. The underdrain system must include a flow control to ensure that the reservoir layer drains slowly (within 36 to 48 hours).

- The underdrain outlet can be fitted with a flow-reduction orifice within a weir or other easily inspected and maintained configuration in the downstream manhole as a means of regulating the stormwater detention time. The minimum diameter of any orifice is 1 inch. The designer should verify that the volume will draw down completely within 36 to 48 hours.
- On infiltration designs, an underdrain(s) can be installed and capped at the downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.

All permeable pavement practices must include observation wells. The observation well is used to observe the rate of drawdown within the reservoir layer following a storm event and to facilitate periodic inspection and maintenance. The observation well should consist of a well-anchored, perforated 4- to 6-inch diameter PVC pipe that is tied into any Ts or Ys in the underdrain system. The well should extend vertically to the bottom of the reservoir layer and extend upwards to be flush with the surface (or just under pavers) with a lockable cap.

Infiltration Sump (optional, required for underdrained Enhanced Designs). For unlined permeable pavement systems, an optional upturned elbow or elevated underdrain configuration can be used to promote greater retention for permeable pavement located on marginal soils (see Figure 3.14). The infiltration sump must be installed to create a storage layer below the underdrain or upturned elbow invert. The depth of this layer must be sized so that the design storm can infiltrate into the subsoils in a 48-hour period. The bottom of the infiltration sump must be at least 2 feet above the seasonally high water table. The inclusion of an infiltration sump is not permitted for designs with an impermeable liner. In fill soil locations, geotechnical investigations are required to determine if the use of an infiltration sump is permissible.

In order to improve the infiltration rate of the sump, it may be designed as a series of 1-foot wide trenches spread 5 feet apart, which are excavated after compaction of the existing soils is performed. Excavation of these trenches may allow access to less compacted, higher permeability soils and improve the effectiveness of the infiltration sump (Brown and Hunt, 2009). Regardless of the infiltration sump design, the infiltration rate must be field verified.

Filter Layer (optional). To protect the bottom of the reservoir layer from intrusion by underlying soils, a filter layer can be used. The underlying native soils should be separated from the stone reservoir by a 2 to 4 inch layer of choker stone (e.g., No. 8).

Geotextile (optional). Geotextile fabric is another option to protect the bottom of the reservoir layer from intrusion by underlying soils, although some practitioners recommend avoiding the use of fabric beneath permeable pavements since it may become a future plane of clogging within the system. Geotextile fabric is still recommended to protect the excavated sides of the reservoir layer, in order to prevent soil piping. An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability must be used.

Impermeable Liner. An impermeable liner is not typically required, although it may be utilized in fill applications where deemed necessary by a geotechnical investigation, on sites with contaminated soils, or on the sides of the practice to protect adjacent structures from seepage. Use a 30-mil (minimum) PVC geomembrane liner. (Follow manufacturer's instructions for installation.) Field seams must be sealed according to the liner manufacturer's specifications. A minimum 6-inch overlap of material is required at all seams.

Material Specifications. Permeable pavement material specifications vary according to the specific pavement product selected. A general comparison of different permeable pavements is provided in Table 3.13 below, but designers should consult manufacturer's technical specifications for specific criteria and guidance. Table 3.14 describes general material specifications for the component structures installed beneath the permeable pavement. Note that the size of stone materials used in the reservoir and filter layers may differ depending on the type of surface material.

Table 3.13 Permeable Pavement Specifications for a Variety of Typical Surface Materials

Material	Specification	Notes
Permeable Pavers (PP)	Void content, thickness, and compressive strength vary based on type and manufacturer Open void fill media: aggregate, topsoil and grass, coarse sand, etc.	Reservoir layer required to support the structural load.
Pervious Concrete (PC)	Void content: 15% to 25%. Thickness: typically 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 infiltration.
Porous Asphalt (PA)	Void content: 15% to 20%. Thickness: typically 3 to 7 in. (depending on traffic load). Open void fill media: None.	Reservoir layer required to support the structural load.

Table 3.14 Material Specifications for Typical Layers Beneath the Pavement Surface

Material	Specification	Notes
Bedding Layer	PC: 3 to 4 inches of No. 57 stone if No. 2 stone is used for Reservoir Layer PA: 3 to 4 inches of No. 57 stone PP: Follow manufacturer specifications	ASTM D448 size No. 8 stone (e.g., 3/8 to 3/16 inch in size). Must be double-washed and clean and free of all fines.
Reservoir Layer	PC: No. 57 stone or No. 2 stone PA: No. 2 stone PP: Follow manufacturer specifications	ASTM D448 size No. 57 stone (e.g., 1 1/2 to 1/2-inch in size); No. 2 Stone (e.g., 3 inches to 3/4 inches in size). Depth is based on the pavement structural and hydraulic requirements. Must be double-washed and clean and free of all fines. Other appropriate materials may be used if accepted by DDOE.

Material	Specification	Notes
Underdrain	Use 4- to 6-inch diameter perforated PVC pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications), with 3/8-inch perforations at 6 inches on center. Perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, is used to connect with the storm drain system. T's and Y's should be installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface.	
Infiltration Sump (optional)	An aggregate storage layer below the underdrain invert. The material specifications are the same as Reservoir Layer.	
Filter Layer (optional)	The underlying native soils should be separated from the stone reservoir by a 2 to 4 inch layer of choker stone (e.g., No. 8).	
Geotextile (optional)	Use an appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability.	
Impermeable Liner (optional)	Where appropriate use a thirty mil (minimum) PVC Geomembrane liner (follow manufacturer's instructions for installation)	
Observation Well	Use a perforated 4- to 6-inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface.	

Permeable Pavement Sizing. The thickness of the reservoir layer is determined by both a structural and hydraulic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. Permeable pavement structural and hydraulic sizing criteria are discussed below.

Structural Design. If permeable pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific recommendations should be consulted. The thickness of the permeable pavement and reservoir layer must be sized to support structural loads and to temporarily store the design storm volume (e.g., the water quality, channel protection, and/or flood control volumes). On most new development and redevelopment sites, the structural support requirements will dictate the depth of the underlying stone reservoir.

The structural design of permeable pavements involves consideration of four main site elements:

- Total traffic
- In-situ soil strength
- Environmental elements
- 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 (CBR) (less than 4 percent), they may need to be compacted to at least 95 percent of the Standard Proctor Density, which may limit their use for infiltration.

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

- AASHTO Guide for Design of Pavement Structures (1993)
- AASHTO Supplement to the Guide for Design of Pavement Structures (1998)

Hydraulic Design. Permeable pavement is typically sized to store the SWRv or larger design storm volumes in the reservoir layer. The storage volume in the pavements must account for the underlying infiltration rate and outflow through any underdrains. The design storm should be routed through the pavement to accurately determine the required reservoir depth. The depth of the reservoir layer or infiltration sump needed to store the design storm can be determined by using Equation 3.2.

Equation 3.2 Reservoir Layer or Infiltration Sump Depth

$$d_p = \frac{\left(\frac{P \times Rv_I \times DA}{A_p} \right) - \left(\frac{i}{2} \times t_f \right)}{\eta_r}$$

where:

- d_p = depth of the reservoir layer (or depth of the infiltration sump for enhanced designs with underdrains) (ft)
- P = rainfall depth for the SWRv or other design storm (ft)
- Rv_I = runoff coefficient for impervious cover (0.95)
- DA = total drainage area, including contributing drainage area and permeable pavement surface area (ft²)
- A_p = permeable pavement surface area (ft²)
- i = field-verified infiltration rate for the subgrade soils (ft/day). If an impermeable liner is used in the design then $i = 0$.
- t_f = time to fill the reservoir layer (day) (assume 2 hours or 0.083 day)
- η_r = effective porosity for the reservoir layer (0.35)

This equation makes the following design assumptions:

- The contributing drainage area (DA) does not contain pervious areas.
- For design purposes, the field-tested subgrade soil infiltration rate (i) is divided by 2 as a factor of safety to account for potential compaction during construction. If the subgrade will be compacted to meet structural design requirements of the pavement section, the design infiltration rate of the subgrade soil shall be based on measurement of the infiltration rate of the subgrade soil subjected to the compaction requirements.
- The porosity (η_r) for No. 57 stone is 0.35.

The depth of the reservoir layer cannot be less than the depth required to meet the pavement structural requirement. The depth of the reservoir layer may need to be increased to meet structural or larger storage requirements.

Designers must ensure that the captured volume will drain from the pavement in 36 to 48 hours. For infiltration designs without underdrains or designs with infiltration sumps, Equation 3.3 can be used to determine the drawdown time in the reservoir layer or infiltration sump.

Equation 3.3 Drawdown Time

$$t_d = \frac{d_p \times \eta_r}{\left(\frac{i}{2}\right)} = \frac{d_p \times \eta_r \times 2}{i}$$

where:

- t_d = drawdown time (specify unit of measure)
- d_p = depth of the reservoir layer (or the depth of the infiltration sump, for enhanced designs with underdrains) (ft)
- η_r = effective porosity for the reservoir layer (0.35)

For designs with underdrains, the drawdown time should be determined using the hydrological routing or modeling procedures used for detention systems with the depth and head adjusted for the porosity of the aggregate.

The total storage volume provided by the practice, S_v , should be determined using Equation 3.4.

Equation 3.4 Permeable Pavement Storage Volume

$$S_v = (d_p \times \eta_r \times A_p) + \left(\frac{i \times t_f}{2}\right)$$

where:

- S_v = storage volume (ft³)
- d_p = depth of the reservoir layer (or depth of the infiltration sump for enhanced designs with underdrains) (ft)
- η_r = effective porosity for the reservoir layer (0.35)
- A_p = permeable pavement surface area (ft²)
- i = field-verified infiltration rate for the subgrade soils (ft/day). If an impermeable liner is used in the design then $i = 0$.
- t_f = time to fill the reservoir layer (day) (assume 2 hours or 0.083 day)

Detention Storage Design. Permeable pavement can also be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The designer can model various approaches by factoring in storage within the

stone aggregate layer (including chamber structures that increase the available storage volume), expected 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.

Once runoff passes through the surface of the permeable pavement system, designers should calculate outflow pathways to handle subsurface flows. Subsurface flows can be regulated using underdrains, the volume of storage in the reservoir layer, the bed slope of the reservoir layer, and/or a control structure at the outlet (see Section 3.5.2 Permeable Pavement Conveyance Criteria).

3.5.5 Permeable Pavement Landscaping Criteria

Permeable pavement does not have any landscaping needs associated with it. However, large-scale permeable pavement applications should be carefully planned to integrate the typical landscaping features of a parking lot, such as trees and islands, in a manner that maximizes runoff treatment and minimizes the risk that sediment, mulch, grass clippings, leaves, nuts, and fruits will inadvertently clog the paving surface. Bioretention areas (see Section 3.6 Bioretention) may be a good design option to meet these needs.

3.5.6 Permeable Pavement Construction Sequence

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

Soil Erosion and Sediment Controls. The following soil erosion and sediment control guidelines must be followed during construction:

- All permeable pavement areas must be fully protected from sediment intrusion by silt fence or construction fencing, particularly if they are intended to infiltrate runoff.
- Permeable pavement areas intended to infiltrate runoff must remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment and loss of design infiltration rate (unless the area has been determined to have a low CBR and will require compaction during the permeable pavement construction phase). Where it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, there are several possible outcomes for the impacted area.
 - ♦ If excavation in the proposed permeable pavement areas can be restricted then remediation can be achieved with deep tilling practices. This is only possible if in-situ soils are not disturbed any deeper than 2 feet above the final design elevation of the bottom of the aggregate reservoir course. In this case, when heavy equipment activity has ceased, the area is excavated to grade, and the impacted area must be tilled to a depth of 12 inches below the bottom of the reservoir layer.
 - ♦ Alternatively, if it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, and excavation of the area cannot be restricted cannot be met, then infiltration tests will be required prior to installation of the permeable pavement to ensure that the design infiltration rate is still present. If tests reveal the loss of design

infiltration rates then deep tilling practices may be used in an effort to restore those rates. In this case further testing must be done to establish design rates exist before the permeable pavement can be installed.

- ◆ Finally, if it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, and excavation of the area cannot be restricted, and infiltration tests reveal design rates cannot be restored, then a resubmission of the SWMP will be required.
- Permeable pavement areas must be clearly marked on all construction documents and grading plans.
- During construction, care should be taken to avoid tracking sediments onto any permeable pavement surface to avoid post construction clogging and long term maintenance issues.
- Any area of the site intended ultimately to be a permeable pavement area with an infiltration component must not be used as the site of a temporary sediment trap or basin. If locating a temporary sediment trap or basin on an area intended for permeable pavement is unavoidable, the outcomes are parallel to those discussed for heavy equipment compaction.
 - ◆ If it is possible restrict the invert of the sediment trap or basin at least 1 foot above the final design elevation of the bottom of the aggregate reservoir course of the proposed permeable pavement then remediation can be achieved with proper removal of trapped sediments and deep tilling practices.
 - ◆ An alternate approach to deep tilling is to use an impermeable linear to protect the in-situ soils from sedimentation while the sediment trap or basin is in use.
 - ◆ In each case, all sediment deposits in the excavated area must be carefully removed prior to installing the sub-base, base, and surface materials. The plan must also show the proper procedures for converting the temporary sediment control practice to a permeable pavement BMP, including dewatering, cleanout, and stabilization.

Permeable Pavement Installation. The following is a typical construction sequence to properly install permeable pavement, which may need to be modified depending on the particular type of permeable pavement that is being installed.

Step 1: Stabilize Drainage Area. Construction of the permeable pavement should 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 bedding materials.

Step 2: Install Soil Erosion and Sediment Control Measures for the Bioretention. As noted above, temporary soil 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 contaminated by sediment must be removed and replaced with clean material.

Step 3: Minimize Impact of Heavy Installation Equipment. Where possible, excavators or backhoes should work from the sides to excavate the reservoir layer to its appropriate design

depth and dimensions. For small 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 utilize 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 wide earth bridge in between, so cells can be excavated from the side. Excavated material should be placed away from the open excavation so as to not jeopardize the stability of the side walls.

Step 4: Promote Infiltration Rate. The native soils along the bottom 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 geotextile fabric. In large-scale paving applications with weak soils, the soil subgrade may need to be compacted to 95 percent of the Standard Proctor Density to achieve the desired load-bearing capacity.

Note: This may reduce or eliminate the infiltration function of the installation, and it must be addressed during hydrologic design.

Step 5: Order of Materials. Geotextile fabric should be installed on the sides of the reservoir layer (and the bottom if the design calls for it). Geotextile fabric strips should overlap down-slope by a minimum of 2 feet and be secured a minimum of 4 feet beyond the edge of the excavation. Where the filter layer extends beyond the edge of the pavement (to convey runoff to the reservoir layer), install an additional layer of geotextile fabric 1 foot below the surface to prevent sediment from entering into the reservoir layer. Excess geotextile fabric should not be trimmed until the site is fully stabilized.

Step 6: Install Base Material Components. Provide a minimum of 2 inches of aggregate above and below the underdrains. The up-gradient end of underdrains in the reservoir layer should be capped. Where an underdrain pipe is connected to a structure, there shall be no perforations within 1 foot of the structure. Ensure there are no perforations in clean-outs and observation wells within 1 foot of the surface.

Step 7: Stone Media. Spread 6-inch lifts of the appropriate clean, double washed stone aggregate (usually No. 2 or No. 57 stone). 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: Reservoir Media. Install the desired depth of the bedding layer, depending on the type of pavement, as indicated in Table 3.14.

Step 9: Paving Media. Paving materials shall be installed in accordance with manufacturer or industry specifications for the particular type of pavement.

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

- Install porous asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the filter course. The laying temperature should be between 230°F and 260°F, with a minimum air temperature of 50°F, to ensure the surface does not stiffen before compaction.

- 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.
- 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 1664. If the estimated coating area is not above 95 percent, additional anti-stripping agents must be added to the mix.
- Transport the mix to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. The mix shall be covered during transportation to control cooling.
- Test the full permeability of the pavement surface by application of clean water at a rate of at least five gallons per minute over the entire surface. All water must infiltrate directly, without puddle formation or surface runoff.
- Inspect the facility 18 to 30 hours after a significant rainfall (greater than 1/2 inch) or artificial flooding to determine if the facility is draining properly.

Installation of Pervious Concrete. The basic installation sequence for pervious concrete is outlined by the National Ready Mixed Concrete Association (NRMCA) (NRMCA 2004). 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 NRMCA. The basic installation procedure is as follows:

- Drive the concrete truck as close to the project site as possible.
- Water the underlying aggregate (reservoir layer) before the concrete is placed, so the aggregate does not draw moisture from the freshly laid pervious concrete.
- After the concrete is placed, approximately 3/8 to 1/2 inches is struck off, using a vibratory screed. This is to allow for compaction of the concrete pavement.
- Compact the pavement with a steel pipe roller. Care should be taken to ensure over-compaction does not occur.
- Cut joints for the concrete to a depth of 1/4 inch.
- The curing process is very important for pervious concrete. Concrete installers should follow manufacturer specifications to the extent allowed by on-site conditions when curing pervious concrete. This typically requires covering the pavement with plastic sheeting within 20 minutes of the strike-off, and may require keeping it covered for at least seven (7) days. Do not allow traffic on the pavement during the curing period.
- Remove the plastic sheeting only after the proper curing time. Inspect the facility 18 to 30 hours after a significant rainfall (greater than 1/2 inch) or artificial flooding, to determine if the facility is draining properly.

Installation of Permeable Interlocking Concrete Pavers. The basic installation process is described in greater detail by Smith (2006):

- Place edge restraints for open-jointed pavement blocks before the bedding layer and pavement blocks are installed. Permeable interlocking concrete pavement (IP) systems

require edge restraints to prevent vehicle loads from moving the paver blocks. Edge restraints may be standard curbs or gutter pans, or precast or cast-in-place reinforced concrete borders a minimum of 6 inches wide and 18 inches deep, constructed with Class A3 concrete. Edge restraints along the traffic side of a permeable pavement block system are recommended.

- Place the double washed No. 57 stone in a single lift. Level the filter course and 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 2 passes are in vibratory mode, with the final 2 passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.
- Place and screed the bedding course material (typically No. 8 stone).
- 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 1/3 of the full unit size.
- Pavers may be placed by hand or with mechanical installers. Fill the joints and openings with stone. Joint openings must be filled with ASTM D 448 No. 8 stone; although, No. 8P or No. 9 stone may be used where needed to fill narrower joints. Remove excess stones from the paver surface.
- Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000-lbf, 75- to 95-Hz plate compactor.
- Do not compact within 6 feet of the unrestrained edges of the pavers.
- The system must be thoroughly swept by a mechanical sweeper or vacuumed immediately after construction to remove any sediment or excess aggregate.
- Inspect the area for settlement. Any blocks that settle must be reset and re-inspected.
- Inspect the facility 18 to 30 hours after a significant rainfall (1/2 inch or greater) or artificial flooding to determine whether the facility is draining properly.

Construction Supervision. Supervision before, during, and after construction by a qualified professional is recommended to ensure permeable pavement is built in accordance with these specifications. Inspection checklists that require sign-offs by qualified individuals should be used at critical stages of construction to ensure the contractor's interpretation of the plan is consistent with the designer's intent.

DDOE's construction phase inspection checklist for permeable pavement practices can be found in Appendix K.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of permeable pavement installation:

- Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.
- The contributing drainage area should be stabilized prior to directing water to the permeable pavement area.

- Check the aggregate material to confirm it is clean and washed, meets specifications and is installed to the correct depth. Aggregate loads that do not meet the specifications or do not appear to be sufficiently washed may be rejected.
- Check elevations (e.g., the invert of the underdrain, inverts for the inflow, and outflow points.) and the surface slope.
- Make sure the permeable pavement surface is even, runoff spreads evenly across it, and the storage bed drains within 48 hours.
- Ensure caps are placed on the upstream (but not the downstream) ends of the underdrains.
- Inspect the pretreatment structures (if applicable) to make sure they are properly installed and working effectively.
- Once the final construction inspection has been completed, log the GPS coordinates for each facility and submit them for entry into the BMP maintenance tracking database.

Runoff diversion structures are recommended to protect larger permeable pavement applications from early runoff-producing storms away from, particularly when up-gradient conventional asphalt areas drain to the permeable pavement. This can help reduce the input of fine particles often produced shortly after conventional asphalt is laid.

3.5.7 Permeable Pavement Maintenance Criteria

Maintenance is a required and 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. Periodic street sweeping will remove accumulated sediment and help prevent clogging; however, it is also critical to ensure that surrounding land areas remain stabilized.

The following tasks must be avoided on ALL permeable pavements:

- Sanding
- Re-sealing
- Re-surfacing
- Power washing
- Storage of snow piles containing sand
- Storage of mulch or soil materials
- Construction staging on unprotected pavement

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. The frequency of maintenance will depend largely on the pavement use, traffic loads, and the surrounding land use.

One preventative maintenance task for large-scale applications (e.g., parking lots) involves vacuum sweeping on a frequency consistent with the use and loadings encountered in the site.

Many experts consider an annual, dry-weather sweeping in the spring months to be important. The contract for sweeping should specify that a vacuum sweeper be used that does not use water spray, since spraying may lead to subsurface clogging. Typical maintenance tasks are outlined in Table 3.15.

Table 3.15 Typical Maintenance Tasks for Permeable Pavement Practices

Frequency	Maintenance Tasks
After installation	<ul style="list-style-type: none"> For the first 6 months following construction, the practice and CDA should be inspected at least twice after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization.
Once every 1–2 months during the growing season	<ul style="list-style-type: none"> Mow grass in grid paver applications
As needed	<ul style="list-style-type: none"> Stabilize the CDA to prevent erosion Remove any soil or sediment deposited on pavement. Replace or repair any pavement surfaces that are degenerating or spalling
2–4 times per year (depending on use)	<ul style="list-style-type: none"> Mechanically sweep pavement with a standard street sweeper to prevent clogging
Annually	<ul style="list-style-type: none"> Conduct a maintenance inspection Spot weed for grass applications
Once every 2–3 years	<ul style="list-style-type: none"> Remove any accumulated sediment in pretreatment cells and inflow points
If clogged	<ul style="list-style-type: none"> Conduct maintenance using a regenerative street sweeper or a vacuum sweeper Replace any necessary joint material

Seasonal Maintenance Considerations: Winter maintenance for permeable pavements is similar to standard pavements, with a few additional considerations:

- Large snow storage piles should be located in adjacent grassy areas so that sediment and pollutants in snowmelt are partially treated before they reach the permeable pavement.
- Sand or cinders should never be applied for winter traction over permeable pavement or areas of standard (impervious) pavement that drain toward permeable pavement, since it will quickly clog the system.
- When plowing plastic reinforced grid pavements, snow plow blades should be lifted 1/2 inch to 1 inch above the pavement surface to prevent damage to the paving blocks or turf. Porous asphalt (PA), pervious concrete (PC), and some permeable pavers (PP) can be plowed similar to traditional pavements, using similar equipment and settings.
- Chloride products should be used judiciously to deice above permeable pavement designed for infiltration, since the salt will be transmitted through the pavement. Salt can be applied but environmentally sensitive deicers are recommended. Permeable pavement applications will generally require less salt application than traditional pavements.

When permeable pavements are installed on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs and (2) understand the long-term maintenance plan.

It is recommended that a qualified professional conduct a spring maintenance inspection and cleanup at each permeable pavement site, particularly at large-scale applications. DDOE's maintenance inspection checklists for permeable pavements and the Maintenance Service Completion Inspection form can be found in Appendix L.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit C of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.5.8 Permeable Pavement Stormwater Compliance Calculations

Permeable pavement retention value varies depending on the design configuration of the system.

Enhanced Designs. These permeable pavement applications have an infiltration sump and water-quality filter, but no underdrain. Enhanced designs receive 100 percent retention value for the amount of storage volume (Sv) provided by the practice (Table 3.16). Since the practice gets 100 percent retention value, it is not considered an accepted total suspended solids (TSS) treatment practice.

Table 3.16 Enhanced Permeable Pavement Retention Value and Pollutant Removal

Retention Value	= Sv
Accepted TSS Treatment Practice	N/A

Note: If using an infiltration sump design, only the volume stored in the sump can be counted as the Enhanced Design Storage Volume (Sv). Any volume stored in the practice above the sump is counted as a standard design. When using the Site Design Spreadsheet, the Sv of the infiltration sump should be entered into the cell "Storage Volume Provided by the Practice" in the Permeable Pavement – Enhanced row. Permeable Pavement – Standard should then be selected as the downstream practice. Next, in the Permeable Pavement - Standard row, the Sv provided above the infiltration sump should be entered into the cell "Storage Volume Provided by the Practice," and the surface area of the pavement should be entered in the "Area of Practice" cell.

Standard Designs. These permeable pavement applications have an underdrain, but no infiltration sump or water quality filter. Standard designs receive a retention value of 4.5 cubic

feet per 100 square feet of practice area and are an accepted TSS removal practice for the amount of storage volume (S_v) provided by the practice (Table 3.17).

Table 3.17 Standard Permeable Pavement Retention Value and Pollutant Removal

Retention Value	= S_v
Accepted TSS Treatment Practice	N/A

The practice must be sized using the guidance detailed in Section 3.5.4.

Permeable pavement also contributes to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the retention value achieved by the practice from the total runoff volume for the 2-year, 15-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a Reduced Natural Resource Conservation Service Curve Number for the site or drainage area. The Reduced Curve Number can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

3.5.9 References

- American Association of State Highway and Transportation Officials (AASHTO). 1993. AASHTO Guide for Design of Pavement Structures, 4th Edition with 1998 Supplement. Washington, D.C.
- Brown, R. and W. Hunt. 2009. "Improving Exfiltration from BMPs: Research and Recommendations." North Carolina Cooperative Extension Service Bulletin. Urban Waterways Series.
- Hunt, W. and K. Collins. 2008. "Permeable Pavement: Research Update and Design Implications." North Carolina Cooperative Extension Service Bulletin. Urban Waterways Series.
- Jackson, N. 2007. Design, Construction and Maintenance Guide for Porous Asphalt Pavements. National Asphalt Pavement Association (NAPA), Porous Asphalt Pavements for Stormwater Management: Design, Construction, and Maintenance Guide (IS-131). Lanham, MD, 2008. <http://store.asphalt pavement.org/index.php?productID=179>
- National Ready Mixed Concrete Association (NRMCA). 2004. Concrete in Practice – 38: Pervious Concrete. Silver Spring, MD. <http://nrmca.org/aboutconcrete/cips/38p.pdf>
- Smith, D. 2006. Permeable Interlocking Concrete Pavement-selection design, construction and maintenance. Third Edition. Interlocking Concrete Pavement Institute. Herndon, VA.
- Virginia DCR Stormwater Design Specification No. 7: Permeable Pavement Version 1.7. 2010.