

**VIRGINIA DEQ STORMWATER
DESIGN SPECIFICATION No. 7****PERMEABLE PAVEMENT****VERSION 2.0****January 1, 2013****SECTION 1: DESCRIPTION**

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**. 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 installed on the bottom (See **Figure 7.1** below).

The thickness of the reservoir layer is determined by both a structural and hydrologic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. In low-infiltration soils, some or all of the filtered runoff is collected in an underdrain and returned to the storm drain system. If infiltration rates in the native soils permit, permeable pavement can be designed without an underdrain, to enable full infiltration of runoff. A combination of these methods can be used to infiltrate a portion of the filtered runoff.



Figure 7.1. Types of Permeable Pavement: (clockwise from upper left): **Concrete Grid Pavers** (Chesapeake Stormwater Network); **Pervious Concrete** (www.pervious.pavement.org), **Porous Asphalt** (UC Davis) **Permeable Interlocking Concrete Pavers** (UC Davis)

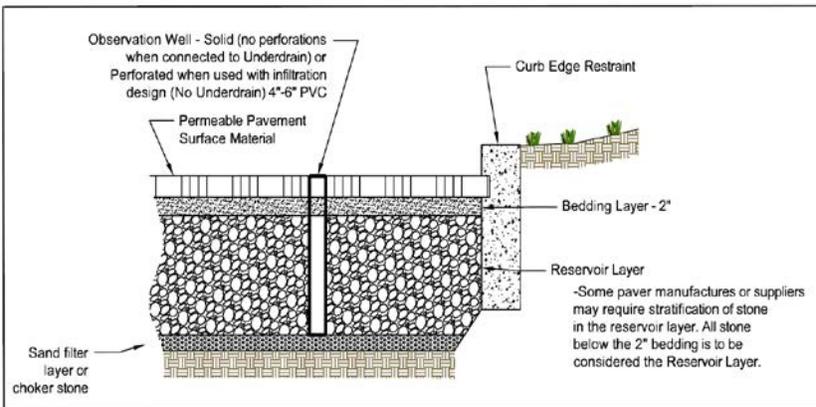


Figure 7.2. Cross Section of Typical Permeable Pavement

Permeable pavement is typically designed to treat stormwater that falls on the pavement surface area, but it may also be used to accept run-on from small adjacent impervious areas, such as impermeable driving lanes or rooftops. However, careful sediment control is needed for any run-on areas to avoid clogging of the down-gradient permeable pavement. Permeable pavement has been used at commercial, institutional, and residential sites in spaces that are traditionally impervious. Permeable pavement promotes a high degree of runoff volume reduction and nutrient removal, and it can also reduce the effective impervious cover of a development site.

SECTION 2: PERFORMANCE

The overall stormwater functions of permeable pavement are shown in **Table 7.1**.

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 7.2**. 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 7.1. Summary of Stormwater Functions Provided by Permeable Pavement

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	45%	75%
Total Phosphorus (TP) EMC Reduction¹ by BMP Treatment Process	25%	25%
Total Phosphorus (TP) Mass Load Removal	59%	81%
Total Nitrogen (TN) EMC Reduction¹	25%	25%
Total Nitrogen (TN) Mass Load Removal	59%	81%
Channel Protection	<ul style="list-style-type: none"> • Use VRRM Compliance spreadsheet to calculate a Curve Number (CN) adjustment²; OR • Design extra storage in the stone underdrain layer and peak rate control structure (optional, as needed) to accommodate detention of larger storm volumes. 	
Flood Mitigation	Partial. May be able to design additional storage into the reservoir layer by adding perforated storage pipe or chambers.	

¹ Change in event mean concentration (EMC) through the practice. Actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).

² NRCS 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).

Sources: CWP and CSN (2008) and CWP (2007)

Table 7.2. Comparative Properties of the Three Major Permeable Pavement Types

Design Factor	Porous Concrete (PC)	Porous Asphalt (PA)	Interlocking Pavers (IP)
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	3 to 4 inches	3 inches
Bedding Layer ^{1, 8}	None	2 inches No. 57 stone	2" of No. 8 stone over 4" No. 57 stone ⁸
Reservoir Layer ^{2, 8}	No. 57 stone	No. 2 stone	No. 2, 3, or 4 stone
Construction Properties ³	Cast in place, seven day cure, must be covered	Cast in place, 24 hour cure	No cure period; manual or mechanical installation of pre-manufactured units, over 5000 sf/day per machine
Design Permeability ⁴	10 feet/day	6 feet/day	2 feet/day
Construction Cost ⁵	\$ 2.00 to \$6.50/sq. ft.	\$ 0.50 to \$1.00/ sq. ft.	\$ 5.00 to \$ 10.00/ sq. ft.
Min. Batch Size	500 sq. ft.		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 & reservoir layer
Colors/Texture	Limited range of colors and textures	Black or dark grey color	Wide range of colors, textures, and patterns
Traffic Bearing Capacity ⁷	Can handle all traffic loads, with appropriate bedding layer design.		
Surface Clogging	Replace paved areas or install drop inlet	Replace paved areas or install drop inlet	Replace permeable stone jointing materials
Other Issues		Avoid seal coating	Snowplow damage
Design Reference	American Concrete Institute # 522.1.08	Jackson (2007) NAPA	Smith (2006) ICPI

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 NVRA (2008)
⁵ WERF 2005 as updated by NVRA (2008)
⁶ Based on pavement being maintained properly, Resurfacing or rehabilitation may be needed after the indicated period.
⁷ Depends primarily on on-site geotechnical considerations and structural design computations.
⁸ Stone sizes correspond to ASTM D 448: *Standard Classification for Sizes of Aggregate for Road and Bridge Construction.*

Leadership in Energy and Environmental Design (LEED®). The LEED® point credit system designed by the U.S. Green Building Council (USGBC) and implemented by the Green Building Certification Institute (GBCI) awards points related to site design and stormwater management. Several categories of points are potentially available for new development and redevelopment projects. **Chapter 6** of the *Virginia Stormwater Management Handbook* (2nd Edition, 2013) provides a more thorough discussion of the site planning process and design considerations as related to Environmental Site Design and potential LEED credits. However, the Virginia Department of Environmental Quality is not affiliated with the USGBC or GBCI and any information on applicable points provided here is based only on basic compatibility. **Designers**

should research and verify scoring criteria and applicability of points as related to the specific project being considered through USGBC LEED resources.

Table 7.3. Potential LEED® Credits for Permeable Pavements¹

Credit Category	Credit No.	Credit Description
Sustainable Sites	SS6.1	Stormwater Design: Quantity Control
Sustainable Sites	SS6.2	Stormwater Design: Quality Control
Sustainable Sites	SS7.1	Heat Island Effect: Non-Roof ²
¹ Actual site design and/or BMP configuration may not qualify for the credits listed. Alternatively, the project may actually qualify for credits not listed here. Designers should consult with a qualified individual (LEED AP) to verify credit applicability. ² When using paving materials with a Solar Reflective Index of at least 29 or an open grid surface.		

SECTION 3: DESIGN TABLE

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 7.4**.

Table 7.4. Permeable Pavement Design Criteria

Level 1 Design	Level 2 Design
$T_v = (1)(R_v)(A) / 12$ – the volume reduced by an upstream BMP ¹	$T_v = (1.1)(R_v)(A) / 12$
Soil infiltration is less than 0.5 in./hr.	Soil infiltration rate must exceed 0.5 in./hr to remove underdrain requirement, or use a drawdown design in accordance with Section 6 .
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; OR 3. The T_v stone reservoir volume has at least a 48-hour drain time, as regulated by a control structure.
CDA ¹ = The permeable pavement area plus upgradient parking, as long as the ratio of external contributing area to permeable pavement does not exceed 2.5:1.	<ul style="list-style-type: none"> CDA = The permeable pavement area; OR If option 3 above is used, CDA ratio may be 2.5:1.
¹ The contributing drainage area to the permeable pavements should be limited to paved surfaces in order to avoid sediment wash-on. When pervious areas are conveyed to permeable pavement, sediment source controls and/or pre-treatment must be provided strip or sump should be used. The pre-treatment may qualify for a runoff reduction credit if designed accordingly.	

Commented [csc1]: For the Level 2 version, if they are not allowed to have run-on from off the perm pavement, what would this ration refer to? (i.e., what area would be compared to what other area?) Does this mean that if Level 2-Option 3 is used, they may allow run-on at that ratio?

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SECTION 4: TYPICAL DETAILS

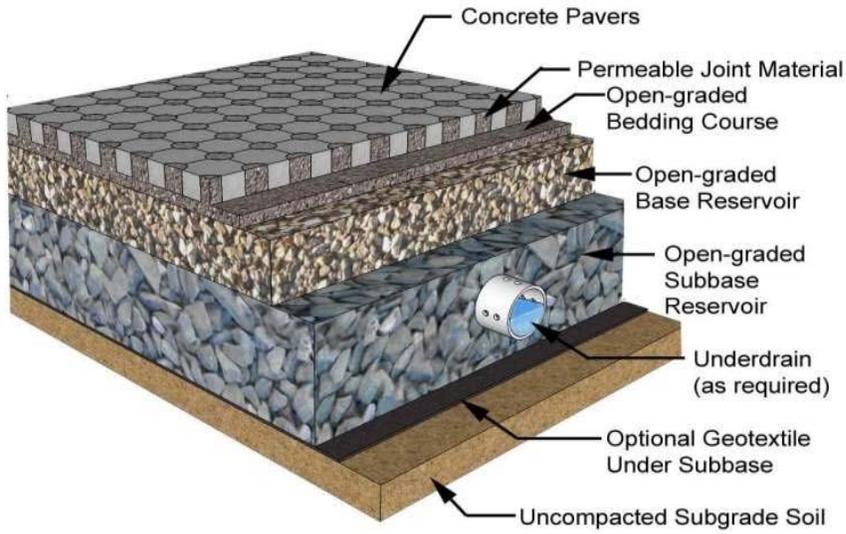


Figure 7.3. Typical Detail (Source: Smith, 2009)

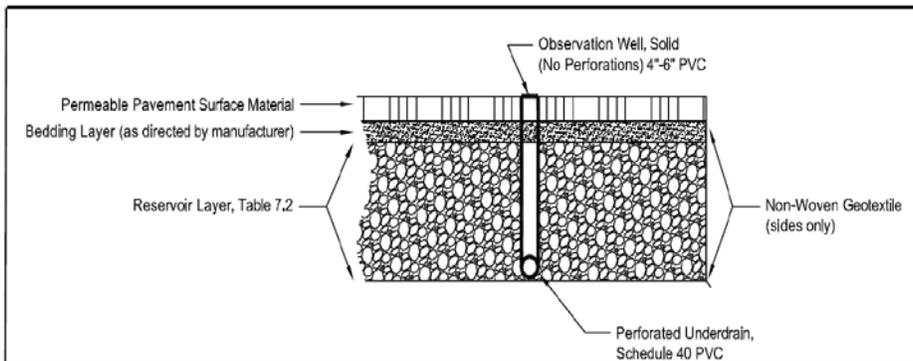


Figure 7.4. Typical Section Permeable Pavement Level 1

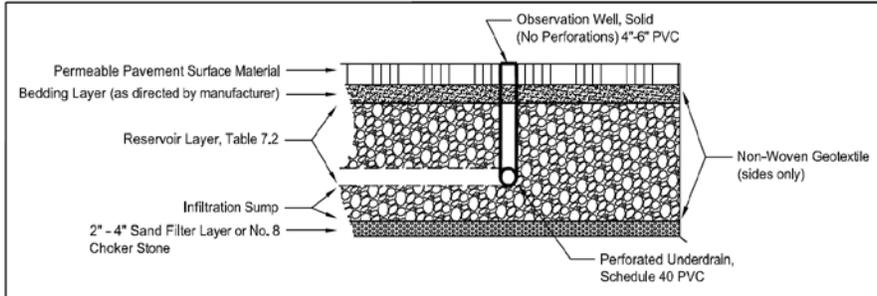


Figure 7.5. Typical Section Permeable Pavement Level 2 with Infiltration Sump

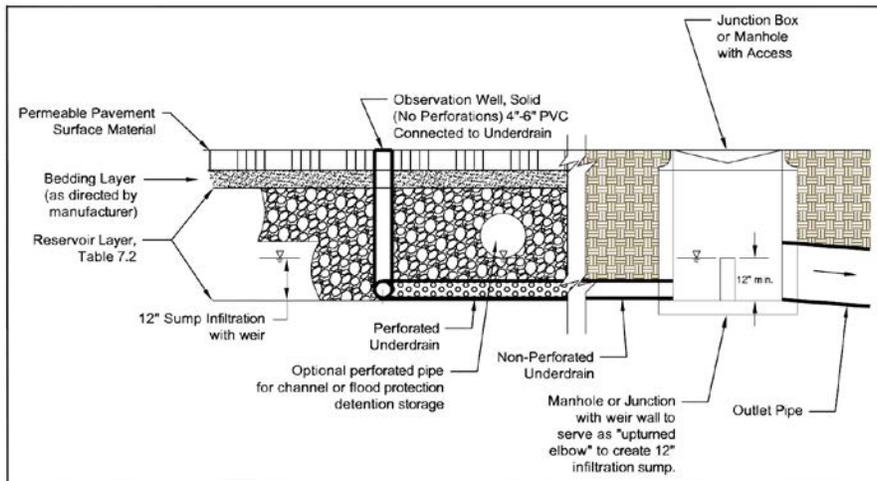


Figure 7.6 Infiltration Sump with an "Upturned Elbow" or Weir Control

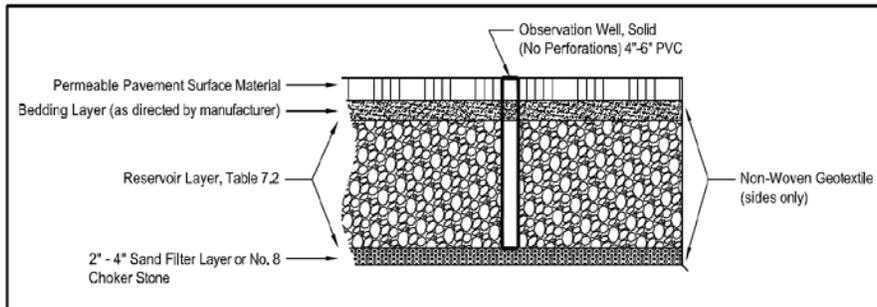


Figure 7.7. Typical Section Permeable Pavement Level 2 with Infiltration

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

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.

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 can be important for tight 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 inches per hour. For initial planning purposes, projected soil infiltration rates can be estimated from USDA-NRCS soil data, but they must be confirmed by an on-site infiltration measurement for final design. Native soils must have silt/clay content less than 40% and clay content less than 20%. Refer to **Appendix 8-A** of the **Stormwater Design Specification No. 8: Infiltration** 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. In particular, areas of HSG A or B soils shown on 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 (**Table 7.4** above, Level 1 and Level 2 Design Option 3). 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 pre-treatment 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 “run-on” to the permeable pavement section should include requirements for more frequent operation and maintenance inspections.

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 five percent 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. However, a maximum longitudinal slope of 1% is permissible if an underdrain and an over-drain are employed. Lateral slopes should be 0%.

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.

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 7.5** below).

- 250 to 1,000 square feet of permeable pavement = 5 feet if down-gradient from building; 25 feet* if up-gradient.
- 1,000 to 10,000 square feet of permeable pavement = 10 feet if down-gradient from building; 50 feet* if up-gradient.
- More than 10,000 square feet of permeable pavement = 25 feet if down-gradient from building; 100 feet* if up-gradient.

** 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 down-gradient 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 7.5 outlines the different design requirements for each of the three scales of permeable pavement installation.

Table 7.5. The Three Design Scales for Permeable Pavement

Design Factor	Micro-Scale Pavement	Small-Scale Pavement	Large-Scale Pavement
Impervious Area Treated	250 to 1000 sq. ft.	1000 to 10,000 sq. ft.	More than 10,000 sq. ft.
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 & parked)
Reservoir Size	Infiltrate or detain some or all of 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 the permeable pavement area may be accepted as long as sediment source controls and/or pretreatment is used	
Observation Well Underdrain?	No Rare	No Depends on the soils	Yes Back-up underdrain
Required Soil Tests	One per practice	Two per practice	One per 5000 sq. ft of proposed practice
Building Setbacks*	5 feet if down-gradient 25 feet if up-gradient	10 feet if down-gradient 50 feet if up-gradient	25 feet if down-gradient 100 feet if up-gradient

*Refer to Section 5 for more information on setbacks

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 (“run-on”) drainage.

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.

Groundwater Protection. Section 10 of this design specification presents a list of potential stormwater hotspots that pose a risk of groundwater contamination. Infiltration of runoff from designated hotspots is highly restricted or prohibited.

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; and

- Permeable pavement should not be used to treat runoff from stormwater hotspots, as noted above. Refer to **Section 10.1 of Stormwater Design Specification No. 8 (Infiltration)** for more specific guidance regarding hotspots.

Design Scales. Permeable pavement can be installed at the following three scales:

1. The smallest scale is termed **Micro-Scale Pavements**, which applies to converting impervious surfaces to permeable ones 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 foot-print 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 250 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.

SECTION 6: DESIGN CRITERIA

6.1. Sizing of Permeable Pavement

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 will vary according to the type of pavement selected and the manufacturer's specific recommendations. 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; 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:

- 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 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 1993 AASHTO *Guide for Design of Pavement Structures* (AASHTO, 1993). 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 lb equivalent single axle loads or 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 (M_r)

- Strength of the surfacing, base and sub-base materials
- 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 D 1883 or AASHTO T 193); or
- Minimum R-value = 9 per ASTM D 2844 or AASHTO T-190; or
- Minimum M_R of 6,500 psi (45 MPa) per AASHTO T-307

Soil compaction required to achieve this criteria 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 (T_v) 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 7.1** is used to determine the depth of the stone reservoir layer required to capture and fully infiltrate the design T_v into the underlying soil.

Equation 7.1

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

Where:

- d_{stone} = Depth of the stone reservoir layer (ft.)
- P = The rainfall depth (in feet) for the Treatment Volume (Level 1 = 1 inch (0.08 ft); Level 2 = 1.1 inch (0.09 ft)), or other design storm
- A_I = Contributing impervious drainage area, (ft²)
- Rv_I = Volumetric runoff coefficient for impervious cover = 0.95
- A_P = Area of permeable pavement (ft²)
- η_r = Porosity of reservoir layer (0.4)

NOTES for Equation 7.1:

1. When contributing drainage area consists of pervious or combined pervious and impervious, the term A_I will refer to the contributing drainage area and the term Rv_I will be the corresponding volumetric runoff coefficient as calculated using the VRRM Compliance Spreadsheet (or refer to **Chapter 11** 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 ((Table 7.4 above, Level 1 and Level 2 Design Option 3).

3. Equation 7.1 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 7.1 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 7.2.

Equation 7.2

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

Where:

- $d_{stone-max}$ = The maximum depth of the infiltration reservoir or the infiltration sump (ft.)
 i = The field-verified infiltration rate for the native soils (in./hr.)
 t_d = The maximum allowable time to drain the reservoir layer or sump, 48hours
 η_r = Porosity of reservoir layer

If the depth of the reservoir layer is too great (i.e. d_{stone} exceeds $d_{stone-max}$), or the verified soil infiltration rate is less than 0.5 inches 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 inches per hour. **However, for the volume of the infiltration sump to count for T_v storage, the field-verified infiltration rate must be at least 0.5 inches per hour.** If the field verified infiltration rate is less than 0.5 inches per hour, the sump will still qualify the facility as a Level 2 design; however, any additional storage needed to hold the T_v must be added above the sump through additional stone. As an option, the entire T_v 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

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underdrains can provide hydraulic control to limit flows, or an external control structure can be used at the outlet of the system.

Over-drain Relief. In all cases, an over-drain (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, in order to establish level reservoir storage areas and prevent flow from exiting the pavement through the surface at the low end of the grade.

6.2. 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 **Appendix 8-A of Design Specification No. 8 (Infiltration)**. A minimum of one soil profile and two infiltration tests must be conducted for each facility that has up to 2,500 ft² of surface area. Refer to **Table 8-A.2** for the number of soil explorations required for larger systems.

6.3. Type of Surface Pavement

The type of pavement should be selected based on a review of the factors in **Table 7.2** above, and designed according to the product manufacturer's recommendations.

6.4. 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 in **Figure 7.4** above, or it can be placed at the bottom of the reservoir sump with an "upturned elbow" configuration as shown in **Figure 7.5** above. 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 towards an outlet manhole or other structure. In order 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-(Level 2).** An infiltration sump qualifies the permeable pavement as a Level 2 design; however, the field-verified infiltration rate must be at least 0.5 inches per hour in order for the volume of the infiltration sump to count towards the required T_v storage.
- **Slow Drawdown.** The permeable pavement stone reservoir should be designed to detain the design T_v 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 (Equation 7.2 above), to approximate long term infiltration rates.

Commented [csc5]: Does this mean one-half the measured rate, or 2 orders of magnitude less? If the former, it would be simpler and clearer to say "decrease the measured infiltration rate by half."

6.5. Pre-treatment

Pre-treatment for most permeable pavement applications is not necessary, since the surface acts as pre-treatment to the reservoir layer below. Additional pre-treatment 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.

6.6. Conveyance and Overflow

Permeable pavement designs should include methods to convey larger storms (e.g., 2-yr, 10-yr) 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 placement and/or design should be such that the incoming runoff is not captured (e.g., placing the perforations on the underside only). The over-drain pipe should be perforated on the underside only, so 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). ~~However, 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.
- 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 for relief of unacceptable ponding depths during larger rainfall events, as would be required on traditional paved areas.

6.7. 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 (see Section 7 below). 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.

6.8 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 in **Figure 7.7** above.
- The perforated underdrain pipe should transition to solid wall pipe before exiting the stone reservoir.

6.9. 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 done once or twice a 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 (ASTM D 448 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 on the native soils at the bottom of the reservoir. , Some practitioners recommend avoiding the use of filter fabric, 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 M288-06 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 is still recommended to protect the excavated sides of the reservoir layer, in order 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 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.

6.10. Material Specifications

Permeable pavement material specifications vary according to the specific pavement product selected. **Table 7.6** below 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 upon whether the system is PC, PA or IP (see **Table 7.2** above). A general comparison of different permeable pavements is provided in **Table 7.7** below, but designers should consult manufacturer's technical specifications for specific criteria and guidance.

SECTION 7: REGIONAL & 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.

7.1. 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 CSN Technical Bulletin No. 1 or **Appendix 6-B** or **Chapter 6** of the *Virginia Stormwater Management Handbook*, 2nd edition, 2013).

- The use of Level 2 (i.e. infiltration) 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 the 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 7.6. Material Specifications for Underneath the Pavement Surface

Material	Specification	Notes
Bedding Layer	PC: None PA: 2 in. of No. 57 stone IP: 2 in. of No. 8 stone over 4 inches of No. 57 stone	ASTM D448 size No. 8 stone (e.g. 3/8 to 3/16 inch in size). Should be washed and clean and free of all fines.
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 inch 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.
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 HDPE may be used for smaller load-bearing applications). 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 installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys.	
Filter Layer	The underlying native soils should be separated from the stone reservoir by a thin, 2 to 4 inch layer of choker stone (e.g. No. 8) covered by a 6 to 8 inch layer of coarse sand (e.g. ASTM C 33, gradation).	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 (optional)	Use an appropriate filter fabric for the particular application based on AASHTO M288-06 Filter Fabric should have a Flow Rate greater than 125 gpm/sq. ft. (ASTM D4491), and an Apparent Opening Size (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 FHWA or AASHTO selection criteria.	
Impermeable Liner	Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd.2 non-woven geotextile. NOTE: THIS IS USED ONLY FOR KARST REGIONS.	
Observation Well	Use a perforated 4 to 6 inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface.	

7.2. Coastal Plain

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

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

Table 7.7. Different Permeable Pavement Specifications

Material	Specification	Notes
Permeable Interlocking Concrete Pavers	Surface open area: 5% to 15%. Thickness: 3.125 inches for vehicles. Compressive strength: 55 Mpa. Open void fill media: aggregate	Must conform to ASTM C936 specifications. Reservoir layer required to support the structural load.
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 C 1319 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: 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	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.

7.3. 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 infiltration rate of less than 0.5 in./hr., 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/swell potential.
- To promote greater runoff reduction for permeable pavement located on marginal soils, an elevated underdrain configuration may be used (see **Section 8.3**).

Commented [csc6]: Shouldn't this refer to Section 6.4 of 6.8 instead? Section 8.3 addresses construction inspections.

7.4. 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 ~~upper~~-over-drain ~~or overflow perforated pipe (see Section 6.6 above)~~ should be placed at least 6 inches below the pavement section and bedding layer.
- ~~Extend the filter bed and underdrain pipe below the frost line and/or oversize the underdrain by one pipe size, to reduce the freezing potential.~~
- ~~Be aware of the long-term maintenance concerns described in Section 10 below regarding "Cold Climate or Winter Time Operation," and reference those issues in the Maintenance Agreement for this practice.~~
- ~~Large snow storage piles should be located in adjacent grassy areas so that sediments and pollutants in snowmelt are partially treated before they reach the permeable pavement.~~

- ~~Sand 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 interlocking pavers (IP) can be plowed similar to traditional pavements, using similar equipment and settings.~~
- ~~Owners should be judicious when using chloride products for deicing over all permeable pavements designed for infiltration, since the salts will most assuredly be transmitted into the groundwater.~~

Commented [C7]: These points can be deleted here because they are repeated in Section 10.

SECTION 8: CONSTRUCTION

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

8.1 Necessary Erosion & 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, care should be taken to avoid tracking sediments onto any permeable pavement surface to avoid clogging.
- Any area of the site intended ultimately 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.

8.2. Permeable Pavement Construction Sequence

The following is a typical construction sequence to properly install permeable pavement, which may need to be modified to depending on whether Porous Asphalt (PA), Pervious Concrete (PC) or Interlocking Paver (IP) 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 (E&S) 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 1000 sq. ft. temporary cells with a 10 to 15 foot earth bridge in between, so that 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. 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 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 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 towards the outlet at a grade of 0.5% or steeper. The up-gradient 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 clean-outs 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 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 D 448 No.57 stone. The filter course must be leveled and pressed (choked) into the reservoir base with at least four (4) 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 D 448 No.8 stone.

Step 10. Install paving materials 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).
 1. 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 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 1664. If the estimated coating area is not above 95%, additional anti-stripping 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 five 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 that the facility is draining properly.
- **Installation of Pervious Concrete.** The basic installation sequence for pervious concrete is outlined by the American Concrete Institute (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 NRMCA. 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, approximately 3/8 to 1/2-inch is struck off, 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 seven (7) days. Do not allow traffic on the pavement during this time period.

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

(Smith 2011). Permeable paver job foremen should successfully complete the PICP Installer Technician Course training program offered by the Interlocking Concrete Pavement Institute. 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 curb 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 (4) 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. Pavers may be placed 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 (1/3) of the full unit size, if subject to tire movement.
7. Fill the joints and openings with stone. Joint openings must be filled with No. 8, 89 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 lbf, 75- to 95-Hz 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 re-inspected.
11. The contractor should return to the site within 6 months to top up the paver joints with stones.

Commented [csc8]: In the original spec, this was No. 8P. Is 89 correct?

8.3. 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 sign-offs by qualified individuals at critical stages of construction and to 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 GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

Commented [csc9]: Why were the construction inspection bullet points from the original spec deleted here? Wouldn't they be useful to know?

It may be advisable to divert the runoff from the first few runoff-producing storms away from larger permeable pavement applications, particularly when up-gradient 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.

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

The Virginia Stormwater Management regulations (9 VAC 25-870) specify the circumstances under which a maintenance agreement must be executed between the owner and the VSMP authority, and sets forth inspection requirements, compliance procedures if maintenance is neglected, notification to the local program upon transfer of ownership, and right-of-entry for local program personnel.

- The regulations require 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* (see **Section 9.2** below). Signs should be posted on larger 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, homeowners should be provided a simple 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 VSMP Authority to help ensure that the permeable pavement system is maintained and functioning.
- The mechanism should, if possible, grant authority for the VSMP authority to access the property for inspection or corrective action.

9.2. 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.

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

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. 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. Vacuum settings for large-scale interlocking paver applications should be calibrated so they *do not* pick up the small stones between pavement blocks.

Table 7.8. Recommended Maintenance Tasks for Permeable Pavement Practices

Maintenance Task	Frequency ¹
<ul style="list-style-type: none"> 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
<ul style="list-style-type: none"> Mow grass in grid paver applications 	At least 1 time every 1-2 months during the growing season
<ul style="list-style-type: none"> Stabilize the CDA 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
<ul style="list-style-type: none"> Vacuum pavement with a standard street sweeper to prevent clogging 	2-4 times per year (depending on use)
<ul style="list-style-type: none"> Conduct a maintenance inspection Spot weeding of grass applications 	Annually
<ul style="list-style-type: none"> Remove any accumulated sediment in pre-treatment cells and inflow points 	Once every 2 to 3 years
<ul style="list-style-type: none"> Conduct maintenance using a regenerative street sweeper Replace any necessary joint material 	If clogged
¹ Required frequency of maintenance will depend on pavement use, traffic loads, and surrounding land use.	

9.3. 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 area (run-on) should be inspected more frequently during the first year (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 three (3) days following a storm event in excess of 1/2-inch in depth. If standing water is still observed in the well after three 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 (no brooms or water spray) to remove deposited material. Then, test sections by pouring water from a five gallon bucket to ensure they work.
- 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 if 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 can be accessed in **Appendix 9-C** of **Chapter 9** of the *Virginia Stormwater Management Handbook* (2nd edition, 2013). Based on inspection results, specific maintenance tasks will be triggered and scheduled to keep the facility in operating condition.

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

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 Stormwater Design Specification No. 8: Infiltration). For potential hotspots, restricted infiltration means that a minimum of 50% of the

total T_v 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*.

Underground Injection Control Permits. The Safe Drinking Water Act regulates the infiltration of stormwater in certain situations pursuant to the Underground Injection Control (UIC) Program, which is administered either by the EPA or a delegated state groundwater protection agency. In general, the EPA (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 CSN Technical Bulletin No. 1 (2008), and Appendix 6-C of Chapter 6 of the Virginia Stormwater Management Handbook (2010).

Cold Climate or Winter Time Operation. Experience has shown that permeable pavement can operate properly in snow and ice conditions, and there is evidence that a permeable surface increases melting rates compared to conventional pavement (thereby reducing the need for deicing chemicals). However, in larger parking lot applications certain snow management practices need to be modified to maintain the hydrologic function of the permeable pavement. These include not applying sand for traction and educating snowplow operators to keep blades from damaging the pavement surface. The jointing material for interlocking concrete paver systems (typically No. 8 stone) can be spread over surface ice to increase tire traction.

Some additional winter maintenance considerations:

- Large snow storage piles should be located in adjacent grassy areas so that sediments and pollutants in snowmelt are partially treated before they reach the permeable pavement.
- Sand or cinders should not be applied for winter traction over permeable pavement or areas of standard (impervious) pavement that drain toward permeable pavement, since this will quickly clog the system. If applied, the materials must be removed by vacuuming in the spring.
- 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, Pervious Concrete and Permeable Interlocking Concrete Pavers can be plowed similar to traditional pavements, using similar equipment and settings.
- Owners should be judicious when using chloride products for deicing over all permeable pavements designed for infiltration, since the salts will most assuredly be transmitted into the groundwater. Salt can be applied but environmentally sensitive deicers are recommended. permeable pavement applications will generally require less salt application than traditional pavements.

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.

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 ACI (2008). Permeable pavement has less risk of hydroplaning, more rapid ice melt and better traction than conventional pavement.

Sample Construction Inspection Checklist for Permeable Pavement: The following checklist provides a basic outline of the anticipated items for the construction inspection of permeable pavement for use as stormwater BMPs. This checklist does not necessarily differentiate between the types of pavement materials and the different construction requirements. The designer and the VSMP Authority personnel should consult with the manufacturer of the material to ensure that proper construction oversight and inspections are provided. Also, users of this information may wish to incorporate these items into a VSMP Authority Construction Checklist format consistent with the format used for erosion and sediment control and BMP construction inspections.

- Pre-construction meeting**
 - Walk through site with builder/contractor/subcontractor to review the SWPPP (erosion and sediment control plan, the stormwater management plan, and the Pollution Prevention plan)
 - Determine when permeable pavement is built in project construction sequence; before or after building construction and determine measures for protection and surface cleaning.
 - Identify the tentative schedule for construction and verify the requirements and schedule for interim inspections and sign-off.
 - Aggregate material locations identified (hard surface or on geotextile)
- Material Storage**
 - Materials stored in protected area free from mud, dirt and other foreign materials.
- Sediment management**
 - Access routes for delivery and construction vehicles identified
 - Vehicle tire/track washing station location/maintenance (if specified in the erosion and sediment control plan/SWPPP)
 - Contributing drainage areas are stabilized and are not eroding
- Excavation**
 - Utilities located and marked by local service
 - Excavated area marked with paint and/or stakes
 - Excavation size and location conforms to plan
 - Runoff is diverted around the excavation area to a stabilized conveyance.
 - If excavation is used as a sediment trap: verify that the bottom elevation of the proposed stone reservoir is lower than the bottom elevation of the existing trap.
 - Subgrade surface is free of rocks and roots, and large voids. Any voids should be refilled with the base aggregate to create a level surface for the placement of aggregates and underdrain (if required).
 - For Level 2 permeable pavement, ensure the bottom of the excavation is scarified prior to placement of stone.
 - No groundwater seepage or standing water is present. Any standing water is dewatered to an acceptable dewatering device.
 - The excavation has achieved the proper elevations and grade as noted on the approved plans.
 - Certification of Excavation Inspection:** Inspector certifies the successful

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completion of the Excavation steps listed above.

Filter Layer and Underdrain Placement

- All aggregates, including, as required, the filter layer (choker stone & sand), the reservoir layer, and bedding layer are clean and washed and otherwise conform to specifications as certified by quarry.
- Underdrain size and perforations meet the specifications.
- Placement of filter layer and initial layer of reservoir layer aggregates (approximately 2 inches) spread (not dumped) to avoid aggregate segregation; or
- Impermeable liner meets project specifications and is placed in accordance with manufacturers specifications.
- Placement of underdrain, observation wells, and underdrain fittings (45 degree wyes, cap at upstream end, etc.) in accordance with the approved plans.
- Invert elevations of underdrain and outlet structure and surface gradient in accordance with approved plans.
- Certification of Filter Layer and Underdrain Placement Inspection:** Inspector certifies the successful completion of the filter layer and underdrain placement steps listed above.

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Stone Reservoir Aggregate Placement

- Sides of excavation covered with geotextile, when required, prior to placing stone reservoir aggregate; no tears or holes, or excessive wrinkles are present.
- Thickness, placement, compaction and surface tolerances meet specifications and approved plans.
- Certification of Stone Reservoir Aggregate Placement Inspection:** Inspector certifies the successful stone reservoir layer placement steps listed above.

Bedding Layer and Pavement Installation

- Certification of Pavement Installation:** Contractor and/or manufacturer certifies that permeable pavement has been placed in accordance with manufacturers specifications (surface is even, runoff spreads evenly across surface, storage bed drains within 48 hours, etc.).
- All erosion and sediment control practices have been removed.
- Pre-treatment structures (if applicable) are properly installed and functioning effectively.
- Follow-up inspection and as-built survey/certification has been scheduled.
- GPS coordinates have been documented for all permeable pavement installations on the parcel.

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