## VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7

# PERMEABLE PAVEMENT

**VERSION 1.8**
**March 1, 2011**

## 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 **interlocking concrete pavers**. While the specific design may vary, all permeable pavements have a similar structure, consisting of a 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.

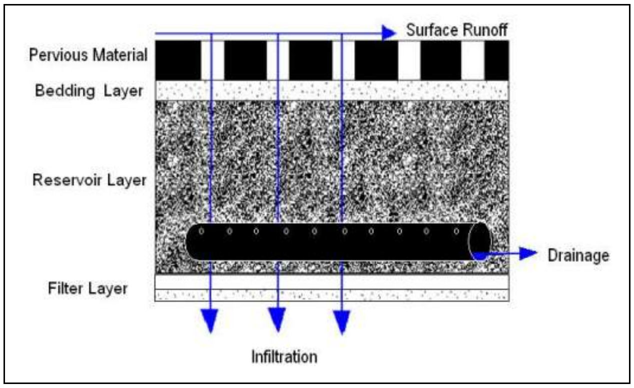


***Figure 7.1. Cross Section of Typical Permeable Pavement (Source: Hunt & Collins, 2008)***

Permeable pavement is typically designed to treat stormwater that falls on the actual 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**.

***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 Reduction[1] by BMP Treatment Process** | 25% | 25% |
| **Total Phosphorus (TP) Mass Load Removal** | 59% | 81% |
| **Total Nitrogen (TN) EMC Reduction[1]** | 25% | 25% |
| **Total Nitrogen (TN) Mass Load Removal** | 59% | 81% |
| **Channel Protection** | ● Use RRM spreadsheet to calculate a Curve Number (CN) adjustment; ***OR***<br>● Design extra storage (optional, as needed) in the stone underdrain layer to accommodate larger storm volumes, and use NRCS TR-55 Runoff Equations [2] to compute a CN adjustment. | |
| **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)

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**, although designers should check with product vendors and their local review authority to determine their specific requirements and capabilities. Designers should also note that there are other paver options, such as concrete grid pavers and reinforced turf pavers, that function in the same general manner as permeable pavement.

***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 [1, 8] |
| **Bedding Layer** [1, 8] | None | 2 inches No. 57 stone | 2 inches of No. 8 stone |
| **Reservoir Layer** [2, 8] | No. 57 stone | No. 2 stone | No. 2 stone<br>3-4 inches of No.57 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*.

## 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 7.3**.

***Table 7.3. Permeable Pavement Design Criteria***

| Level 1 Design | Level 2 Design |
|---|---|
| Tv = (1)(Rv)(A) / 12 – the volume reduced by an upstream BMP [1] | Tv = (1.1)(Rv)(A) / 12 |
| Soil infiltration is less than 0.5 in./hr. | Soil infiltration rate exceeds 0.5 in./hr. |
| Underdrain required | Underdrain not required; ***OR***<br>If an underdrain is used, a 12-inch stone sump must be provided below the underdrain invert; ***OR***<br>The Tv has at least a 48-hour drain time, as regulated by a control structure. |
| CDA = The permeable pavement area plus upgradient parking, as long as the ratio of external contributing area to permeable pavement does not exceed 2:1. | CDA = The permeable pavement area |

[1] The contributing drainage area to the permeable pavements should be limited to paved surfaces, to avoid sediment wash-on, and sediment source controls and/or a pre-treatment strip or sump should be used. When pervious areas are conveyed to permeable pavement, pre-treatment must be provided, and the pre-treatment may qualify for a runoff reduction credit.

## SECTION 4: TYPICAL DETAILS

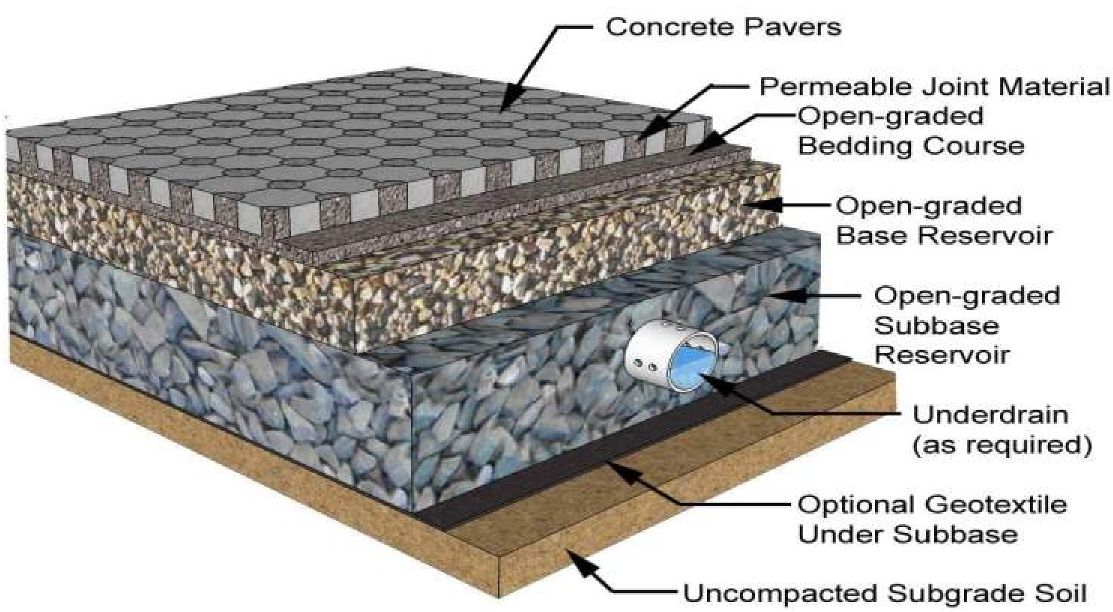


***Figure 7.2. Typical Detail (Source: Smith, 2009)***

## 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 minimum infiltration rate of 0.5 inches per hour. Initially, projected soil infiltration rates can be estimated from USDA-NRCS soil data, but they must be confirmed by an on-site infiltration measurement. Native soils must have silt/clay content less than 40% and clay content less than 20%.

> ***Designers should also 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.*** Any external drainage area contributing runoff to permeable pavement should generally not exceed twice the surface area of the permeable pavement, and it should be as close to 100% impervious as possible. Some field experience has shown that an upgradient drainage area (even if it is impervious) can contribute particulates to 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.

***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 several 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 is 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 seasonal high water table.

***Setbacks.*** Permeable pavement should not be hydraulically connected to structure foundations, in order to avoid harmful seepage. Setbacks to structures and roads vary, based on the scale of the permeable pavement installation (see **Table 7.3** above). At a minimum, small- and large-scale pavement applications should be located a minimum horizontal distance of 100 feet from any water supply well, 50 feet from septic systems, and at least 5 feet down-gradient from dry or wet utility lines. Setbacks can be reduced at the discretion of the local program authority for designs that use underdrains and/or liners.

***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.

***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 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 should not been used for high speed roads, 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 1000 square feet in total area. Where redevelopment or

retrofitting of existing impervious areas results in a larger foot-print of permeable pavers (small-scale or large- scale, as described below), the designer should implement the Load Bearing, Observation Well, Underdrain, Soil Test, and Building Setback criteria associated with the applicable scale.

2. ***Small-scale pavement*** applications treat portions of a site between 1000 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.

**Table 7.4** outlines the different design requirements for each of the three scales of permeable pavement installation.

***Table 7.4. 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<br>Walkways<br>Court Yards<br>Plazas<br>Individual Sidewalks | Sidewalk Network<br>Fire Lanes<br>Road Shoulders<br>Spill-Over Parking<br>Plazas | Parking Lots with more than 40 spaces<br>Low Speed Residential Streets |
| **Most Suitable Pavement** | IP | PA, PC, and IP | PA, PC and IP |
| **Load Bearing Capacity** | Foot traffic<br>Light vehicles | Light vehicles | Heavy vehicles<br>(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** | No | No | Yes |
| **Underdrain?** | Rare | Depends on the soils | Back-up underdrain |
| **Required Soil Tests** | One per practice | Two per practice | One per 5000 sq. ft of proposed practice |
| **Building Setbacks** | 5 feet down-gradient<br>25 feet up-gradient | 10 feet down-gradient<br>50 feet up-gradient | 25 feet down-gradient<br>100 feet up-gradient |

Regardless of the design 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 to contend with.

# 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 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; and
- 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%), they may need to be compacted to at least 95% of the Standard Proctor Density, which generally rules out 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).

***Hydraulic Design.*** Permeable pavement is typically sized to store the water quality Treatment Volume ($T_v$) or another design storm volume in the reservoir layer. The infiltration rate typically will be less than the flow rate through the pavement, so that some underground reservoir storage will usually be required. Designers should initially assume that there is no outflow through underdrains, using **Equation 7.1** to determine the depth of the reservoir layer, assuming runoff fully infiltrates into the underlying soil:

***Equation 7.1***

$$d_p = \frac{\{(d_c \times R) + P - (i/2 \times t_f)\ \}}{V_r}$$

Where:

- $d_p$ = The depth of the reservoir layer (ft.)
- $d_c$ = The depth of runoff from the contributing drainage area (not including the permeable paving surface) for the Treatment Volume ($Tv/A_c$), or other design storm (ft.)
- $R$ = $A_c/A_p$ = The ratio of the contributing drainage area ($A_c$, not including the permeable paving surface) to the permeable pavement surface area ($A_p$) [NOTE: With reference to **Table 7.3**, the maximum value for the Level 1 design is R = 2, (the external drainage area $A_c$ is twice that of the permeable pavement area $A_p$; and for Level 2 design R = 0 (the drainage area is made up solely of permeable pavement $A_p$]**.**
- $P$ = The rainfall depth for the Treatment Volume (Level 1 = 1 inch; Level 2 = 1.1 inch), or other design storm (ft.)
- $i$ = The field-verified infiltration rate for native soils (ft./day)
- $t_f$ = The time to fill the reservoir layer (day) – typically 2 hours or 0.083 day
- $V_r$ = The void ratio for the reservoir layer (0.4)

The maximum allowable depth of the reservoir layer is constrained by the maximum allowable drain time, which is calculated using **Equation 2**.

***Equation 7.2***

$$d_{p-\max} = \frac{(i/2 \times t_d)}{V_r}$$

Where:

- $d_{p-max}$ = The maximum depth of the reservoir layer (ft.)
- $i$ = The field-verified infiltration rate for the native soils (ft./day)
- $V_r$ = The void ratio for reservoir layer (0.4 – see assumptions, below)
- $t_d$ = The maximum allowable time to drain the reservoir layer, typically 1 to 2 days (days)

The following design assumptions apply to **Equations 7.1 and 7.2**:

- The contributing drainage area ($A_c$) should not contain pervious areas.
- For design purposes, the native soil infiltration rate (i) should be the field-tested soil infiltration rate divided by a factor of safety of 2. The minimum acceptable native soil infiltration rate is 0.5”/hr.
- The void ratio ($V_r$) for No. 57 stone = 0.4.
- Max. drain time for the reservoir layer should be not less than 24 nor more than 48 hours.

If the depth of the reservoir layer is too great (i.e. $d_p$ exceeds $d_{p\text{-}max}$), or the verified soil infiltration rate is less than 0.5 inches per hour, then the design method typically changes to account for underdrains. The storage volume in the pavements must account for the underlying infiltration rate and outflow through the underdrain. In this case, the design storm should be routed through the pavement to accurately determine the required reservoir depth. Alternatively, the designer may use **Equations 7.3 through 7.5** to approximate the depth of the reservoir layer for designs using underdrains.

**Equation 7.3** can be used to approximate the outflow rate from the underdrain. The hydraulic conductivity, *k*, of gravel media is very high (~17,000 ft./day). 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 permeability coefficient of 100 ft./day can be used to approximate the average underdrain outflow rate.

***Equation 7.3***

$$q_u = k \times m$$

Where:

$q_u$ = Outflow through the underdrain (per outlet pipe, assumed 6-inch diameter) (ft./day)

k = Hydraulic conductivity for the reservoir layer (ft./day – assume 100 ft./day)

m = Underdrain pipe slope (ft./ft.)

Once the outflow rate through the underdrain has been approximated, **Equation 7.4** is used to determine the depth of the reservoir layer needed to store the design storm.

***Equation 7.4***

$$d_p = \frac{\{(d_c \times R) + P - (i/2 \times t_f) - (q_u \times t_f)\}}{V_r}$$

Where:

$d_p$ = Depth of the reservoir layer (ft.)

$d_c$ = Depth of runoff from the contributing drainage area (not including the permeable pavment surface) for the Treatment Volume ($Tv/A_c$), or other design storm (ft.)

$R$ = $A_c/A_p$ = The ratio of the contributing drainage area ($A_c$) (not including the permeable pavment surface) to the permeable pavement surface area ($A_p$)

$P$ = The rainfall depth for the Treatment Volume (Level 1 = 1 inch; Level 2 = 1.1 inch), or other design storm (ft.)

$i$ = The field-verified infiltration rate for the native soils (ft./day)

$t_f$ = The time to fill the reservoir layer (day) – typically 2 hours or 0.083 day

$V_r$ = The void ratio for the reservoir layer (0.4)

$q_u$ = Outflow through Underdrain (ft/day)

The maximum allowable depth of the reservoir layer is constrained by the maximum allowable drain time, which is calculated using **Equation 7.5**.

***Equation 7.5***

$$d_{p-\max} = \frac{\{(i/2 \times t_d) + (q_u \times t_d)\}}{V_r}$$

Where:

$d_{p-max}$ = The maximum depth of the reservoir layer (ft.)
$i$ = The field-verified infiltration rate for the native soils (ft./day)
$V_r$ = The void ratio for the reservoir layer (0.4)
$t_d$ = The time to drain the reservoir layer (day – typically 1 to 2 days)
$q_u$ = The outflow through the underdrain (ft./day)

If the depth of the reservoir layer is still too great (i.e. $d_p$ exceeds $d_{p-max}$), the number of underdrains can be increased, which will increase the underdrain outflow rate.

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, 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.

## 6.2. Soil Infiltration Rate Testing

To design a permeable pavement system *without* an underdrain, the measured infiltration rate of subsoils must be 0.5 inch per hour or greater. On-site soil infiltration rate testing procedures are outlined in Appendix 8-A of the Infiltration Design Specification (No. 8). A minimum of one test must be taken per 1,000 sq. ft. of planned permeable pavement surface area. In most cases, a single soil test is sufficient for micro-scale and small-scale applications. At least one soil boring must be taken to confirm the underlying soil properties *at the depth where infiltration is designed to occur* (i.e., to ensure that the depth to water table, depth to bedrock, or karst is defined). Soil infiltration testing should be conducted within any confining layers that are found within 4 feet of the bottom of a proposed permeable pavement system.

## 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.*** To promote greater runoff reduction for permeable pavement located on marginal soils, an elevated underdrain should be installed with a stone jacket that creates a 12 to 18 inch deep storage layer *below* the underdrain invert. The void storage in this layer can help qualify a site to achieve Level 2 design.

- ***Rapid Drawdown.*** When possible, permeable pavement should be designed so that the target runoff reduction volume stays in the reservoir layer for at least 36 hours before being discharged through an underdrain.

- ***Conservative Infiltration Rates.*** Designers should always decrease the measured infiltration rate by a factor of 2 during design, to approximate long term infiltration rates.

### 6.5. Pretreatment

Pretreatment for most permeable pavement applications is not necessary, since the surface acts as pretreatment to the reservoir layer below. Additional pretreatment may be appropriate if the pavement receives run-on from an adjacent pervious or impervious area. For example, a gravel filter strip can be used to trap coarse sediment particles before they reach the permeable pavement surface, in order to prevent premature clogging.

### 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).
- Increase the thickness of the top of the reservoir layer by as much as 6 inches (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 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 past the system (typically in remote areas). The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.

### 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 frost depth conditions (see **Section 7**). A 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 may consist of clean washed No. 57 stone, although No. 2 stone is preferred because it provides additional storage and structural stability.
- The bottom of the reservoir layer should be completely flat so that runoff will be able to infiltrate evenly through the entire surface.

### 6.8 Underdrains

The use of underdrains is recommended when there is a reasonable potential for infiltration rates to decrease over time, when underlying soils have an infiltration rate of less than 1/2-inch per hour, or when soils must be compacted to achieve a desired Proctor density. Underdrains can also be used to manage extreme storm events to 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.

### 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 nonwoven, polypropylene geotextile that is permeable, although some practitioners recommend avoiding the use of filter fabric since it may become a future plane of clogging within the system. Permeable filter fabric is still recommended to protect the excavated sides of the reservoir layer, in order to prevent soil piping. The second method is to form 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.

- ***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.*** Most local communities now require from 5% to 10% (or more) of the area of parking lots to be in landscaping. Large-scale permeable pavment 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 fruits will inadvertently clog the paving surface.

## 6.10. Material Specifications

Permeable pavement material specifications vary according to the specific pavement product selected. **Table 7.5** 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 whether the system is PC, PA or IP (see **Table 7.2** above). A general comparison of different permeable pavements is provided in **Table 7.6** below, but designers should consult manufacturer's technical specifications for specific criteria and guidance.

**Table 7.5. Material Specifications for Underneath the Pavement Surface**

| Material | Specification | Notes |
|---|---|---|
| **Bedding Layer** | PC: None<br>PA: 2 in. depth of No. 8 stone<br>IP: 2 in. depth of No. 8 stone over 3 to 4 inches of No. 57 | ASTM D448 size No. 8 stone (e.g. 3/8 to 3/16 inch in size). Should be double-washed and clean and free of all fines. |
| **Reservoir Layer** | PC: No. 57 stone<br>PA: No. 2 stone<br>IP: No. 57 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 double-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, 0.02-0.04 inch). | 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 a needled, non-woven, polypropylene geotextile with Grab Tensile Strength equal to or greater than 120 lbs (ASTM D4632), with a Mullen Burst Strength equal to or greater than 225 lbs./sq. in. (ASTM D3786), with 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. | |

**Table 7.6. Different Permeable Pavement Specifications**

| Material | Specification | Notes |
|---|---|---|
| **Permeable Interlocking Concrete Pavers** | Surface open area: 5% to 15%.<br>Thickness: 3.125 inches for vehicles.<br>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%.<br>Thickness: 3.5 inches.<br>Compressive strength: 35 Mpa.<br>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.<br>Compressive strength: varies, depending on fill material.<br>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 %.<br>Thickness: typically 4 to 8 inches.<br>Compressive strength: 2.8 to 28 Mpa.<br>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 %.<br>Thickness: typically 3 to 7 in. (depending on traffic load). Open void fill media: None. | Reservoir layer required to support the structural load. |

## 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 not to 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 regions 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; and the Virginia SWM Handbook).

- 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 are, 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 aquifers 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.

### 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.

### 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**).

### 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. Ensure complete drainage of the permeable pavement system within 24 hours following a rainfall event.
- 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.
- 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.

## 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 subbase, 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 bedding 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 utilize 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.*** Filter fabric should be installed on the bottom and the sides of the reservoir layer. In some cases, an alternative filter layer, as described in **Section 8.6** may be warranted. Filter 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 filter fabric 1 foot below the surface to prevent sediments from entering into the reservoir layer. Excess filter fabric should not be trimmed until the site is fully stabilized.

***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 shall 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.*** Moisten and spread 6-inch lifts of the appropriate clean, 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.*** 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 1-1/2 to 2 inches of washed ASTM D 448 No.8 stone. The thickness of the bedding layer is to be based on the block manufacturer's recommendation or that of a qualified professional.

***Step 9.*** 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$^{o}$F and 260$^{o}$F, with a minimum air temperature of 50$^{o}$F, to ensure that 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%, 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 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:
  - Drive the concrete truck as close to the project site as possible.
  - 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.
  - 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.
  - Compact the pavement with a steel pipe roller. Care should be taken so that 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. 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).
  - 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 VDOT 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 No. 57 stone in a single lift. Level the filter course and 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 (2) passes are in vibratory mode, with the final two (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 one-third (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 VDOT No. 8 stone, although VDOT 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.

### 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 detailed inspection checklists that require sign-offs by qualified individuals at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intent.

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 that it is clean and washed, meets specifications and is installed to the correct depth.
- Check elevations (e.g., the invert of the underdrain, inverts for the inflow and outflow points, etc.) and the surface slope.
- Make sure the permeable pavement surface is even, runoff evenly spreads across it, and the storage bed drains within 48 hours.
- Ensure that 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 local BMP maintenance tracking database.

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

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

In addition, the maintenance agreements should also note which conventional parking lot maintenance tasks must be *avoided* (e.g., sanding, re-sealing, re-surfacing, power-washing). 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 will need to (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to a deed restriction, drainage easement or other mechanism enforceable by the qualifying local program to help ensure that the permeable pavement system is maintained and functioning. The mechanism should, if possible, grant authority for local agencies 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.

One preventative maintenance task for large-scale applications involves 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 stones between pavement blocks.

## 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. The following are suggested 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 C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010). 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 meltwater 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.

***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.

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