

## 18. Permeable Pavement

**Description**  
 Permeable pavement is an alternative to conventional paving materials (concrete and asphalt) that allows stormwater to infiltrate through void spaces for temporary storage. Stormwater can then be infiltrated into the soil or detained and released.

**Permeable pavement designed for INFILTRATION:**

Built Upon Area (BUA) Credit: Receives credit based on the NRCS Hydrologic Soil Group where installed for determining whether a project is low or high density:

- A and B soils: 75% pervious and 25% BUA
- C and D soils: 50% pervious and 50% BUA \*

Pollutant Removal Credit: Receives the regulatory credits listed below for treating its own footprint as well as any other BUA from the site that drains to the pavement (the ratio of additional BUA to permeable pavement area shall not exceed 1:1).

<u>Regulatory Credits</u>	<u>Feasibility Considerations</u>
<p><i>Pollutant Removal</i></p> <p>85% Total Suspended Solids</p> <p>30% Total Nitrogen **</p> <p>60% Total Phosphorus **</p> <p><i>Water Quantity</i></p> <p>yes Peak Attenuation</p> <p>yes Volume Capture</p>	<p>Low Land Requirement</p> <p>Med Cost of Construction</p> <p>Med Maintenance Burden</p> <p>High Treatable Basin Size</p> <p>Med Possible Site Constraints</p> <p>High Community Acceptance</p>

**Permeable pavement designed for DETENTION:**

Built Upon Area (BUA) Credit: Does not receive a reduced BUA credit because it is not designed with the intent to infiltrate a significant amount of stormwater.

Pollutant Removal Credit: Receives the regulatory credits listed below for treating its own footprint as well as any other BUA from the site which drains to the pavement (the ratio of additional BUA to permeable pavement area shall not exceed 1:1).

<u>Regulatory Credits</u>	<u>Feasibility Considerations</u>
<p><i>Pollutant Removal</i></p> <p>70 or 85% Total Suspended Solids ***</p> <p>10% Total Nitrogen **</p> <p>10% Total Phosphorus **</p> <p><i>Water Quantity</i></p> <p>yes Peak Attenuation</p> <p>yes Volume Capture</p>	<p>Low Land Requirement</p> <p>Med Cost of Construction</p> <p>Med Maintenance Burden</p> <p>High Treatable Basin Size</p> <p>Med Possible Site Constraints</p> <p>High Community Acceptance</p>

\* Please note that in D soils, the ponding time may be too long to design permeable pavement for infiltration; in this case, the pavement shall be designed for detention.

\*\* The nutrient regulatory credits are in annual mass load reduction (not concentration).

\*\*\* 70% TSS removal if a geomembrane barrier is used above the subsoil.  
 85% TSS removal if a geomembrane barrier is not used above the subsoil.

**For all Permeable Pavement Types:**

<u>Advantages</u>	<u>Disadvantages</u>
<ul style="list-style-type: none"> <li>• Replaces BUA with materials that infiltrate or detain stormwater.</li> <li>• Eliminates standing water on pavement.</li> <li>• Reduces the pollutant loading, runoff rate, and volume associated with stormwater runoff.</li> <li>• Reduces land consumption by using treatment area for parking/driving.</li> <li>• A useful BMP for heavily developed sites with limited space.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Without proper maintenance it can become clogged by sediment, compromising its effectiveness.</li> <li>• Not applicable for all site conditions.</li> <li>• Pavement installation costs are higher than conventional pavements. However, overall costs may be comparable or lower when considering the cost savings from reduced needs for stormwater piping and land for BMPs.</li> </ul>

**Major Design Elements:**

Throughout the table below and the chapter, three different imperatives are used with the following intended meanings:

- **“Shall”** is used for items that are required to receive straightforward approval of the design as well as the regulatory credits summarized on page 18-1.
- **“Should”** is used for items that are recommended for good design practice and optimum performance.
- **“May”** is used for items that are options to consider in the context of the specific permeable pavement application.

The “shalls” in this chapter are not based on NC stormwater rules (15A NCAC 2H .1000), which do not contain any requirements specific to permeable pavement (a technology not commonly used at the time of rule development). The required design in this chapter is based on current research and the experience and best professional judgment of experts in the field of pavement design and stormwater management.

Design professionals desiring to deviate from this chapter shall provide technical justification that their design is equally or more protective of water quality (vague, anecdotal or isolated evidence is not acceptable). Review staff shall consider deviations from the required items in this chapter on a case-by-case basis. Alternative designs may receive lower regulatory credits.

1. An NC licensed professional with appropriate expertise shall investigate the soils and determine their suitability as a subgrade for permeable pavement.
2. Permeable pavement shall not be installed in the portions of hotspot areas where toxic pollutants are stored or handled (some examples of hotspots are listed in Section 18.3).
3. The seasonal high water table (SHWT) shall be at least two feet below the base of the aggregate storage layer. This requirement may be relaxed to one foot if additional borings and investigation can firmly establish the elevation of the SHWT.
4. All manufacturer requirements, product standards, and industry guidelines shall be followed to ensure lasting effectiveness (in addition to meeting the requirements of this chapter).

5.	The surface of the permeable pavement shall have a slope of $\leq 6\%$ . The surface of the soil subgrade shall have a slope of $\leq 0.5\%$ . Terraces and baffles may be installed to achieve flat subgrades under sloping pavement surfaces.
6.	Washed aggregate base materials shall be used.
7.	In HSG B, C and D, the surface of the soil subgrade under infiltrating permeable pavement should be scarified, ripped or trenched immediately prior to aggregate base placement to maintain the pre-construction subgrade infiltration rate.
8.	Permeable pavement (regardless of whether it is designed for infiltration or detention) shall be designed to treat the water quality storm and to provide safe conveyance of the 10-year, 24-hour storm event via infiltration, bypass or detention and release.
9.	Permeable pavement may be designed to receive runoff from adjacent BUAs such as roofs and conventional pavement (if the soils under the permeable pavement have adequate capacity to infiltrate the additional runoff). The design shall provide storage for the entire runoff volume as explained in this chapter. In addition, there shall be a well-designed system to convey the runoff from the BUA to the permeable pavement.
10.	Runoff from adjoining pervious areas, such as grassed slopes and landscaping, shall be prevented by grading the landscape away from the permeable pavement. Exceptions such as site restrictions on redevelopment projects shall be reviewed on a case-by-case basis.
11.	Permeable pavement shall not be installed until the upslope and adjoining areas are stabilized. After installations, barriers shall be installed to prevent construction traffic from driving on the pavement.
12.	The soil subgrade for the permeable pavement shall be graded when dry. The aggregate base and permeable surface course should be completed as quickly as possible to reduce risk of soil subgrade compaction.
13.	Permeable pavement may be placed on fill material as long as the material is at least as permeable as the in-situ soil after it is placed and prepared. Fill material comprised of HSG A or B shall not be placed on top of an in-situ HSG C or D to receive additional BUA credit.
14.	A minimum of one observation well shall be provided at the low point in the system unless the subgrade is terraced; in that case, there shall be one well for each terrace.
15.	Edge restraints shall be provided around the perimeter of permeable interlocking grid pavers as well as anywhere permeable pavement (of any type) is adjacent to conventional asphalt.
16.	Permeable pavement shall be maintained as specified in Section 18.6 of this chapter.
17.	Permeable pavement signage shall be clearly and permanently posted to prevent use by inappropriate vehicles, and the deposition and storage of particulate matter (except for single family residences, where signage is optional).

## 18.1. Description and Purpose

Permeable pavement is a best management practice that captures stormwater through voids in the pavement surface and filters water through an underlying aggregate reservoir. The reservoir typically allows the water to infiltrate into the soil subgrade. The reservoir can also be designed to detain and release the water to a surface conveyance system if the underlying soil is not suitable for infiltration.



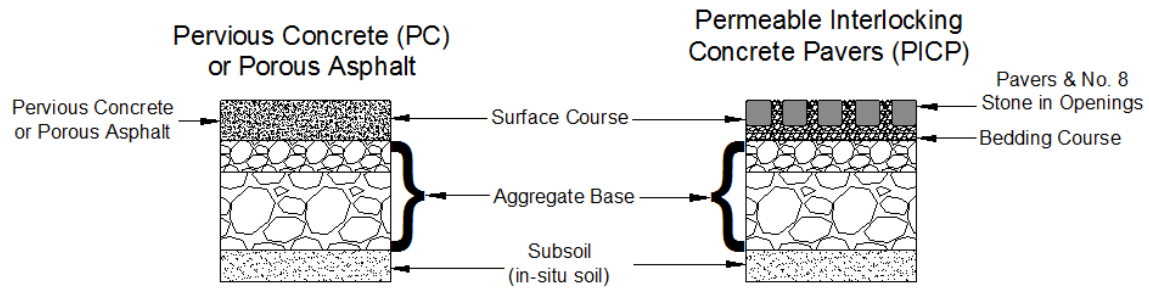
**Figure 18-1.** Permeable pavement reduces runoff volumes and pollutants.

The purpose of permeable pavement is to control the quality and quantity of stormwater runoff while accommodating pedestrians, parking and possibly traffic (if adequate structural support is provided). Permeable pavement is especially useful in existing urban developments where the need to expand parking areas is hindered by lack of space needed for stormwater management. Permeable pavement is also useful in new developments with limited space where land costs are high, and when nutrient reductions or green building certification program are desired.

Permeable pavement can receive two types of stormwater management credits: BUA (built-upon area) and pollutant removal. BUA credit is given to permeable pavements designed to infiltrate the design storm. This credit varies based on the type of soil over which the pavement is installed. Detention systems do not receive a BUA credit because they are not designed to infiltrate a significant amount of stormwater. Pollutant removal credit is given for the surface of the pavement as well as any other BUA from the site treated by the pavement. All of these credits are based on designing, constructing and maintaining the permeable pavement in accordance with this chapter.

Like the other BMPs in this manual, permeable pavements shall be designed based on storing and treating the design storm volume and providing for safe bypass or treatment of the 10-year, 24-hour storm.

This chapter focuses on the most successfully applied types of permeable pavement: permeable interlocking concrete pavers (PICP), porous asphalt (PA) and pervious concrete (PC). Other permeable pavements surfaces are discussed, i.e., concrete grid pavers, and plastic reinforcing grid pavers. See Figure 18-2 below for a primer on the permeable pavement terminology.



**Figure 18-2. Permeable Pavement Cross-Sections Source: NCSU-BAE 2012**

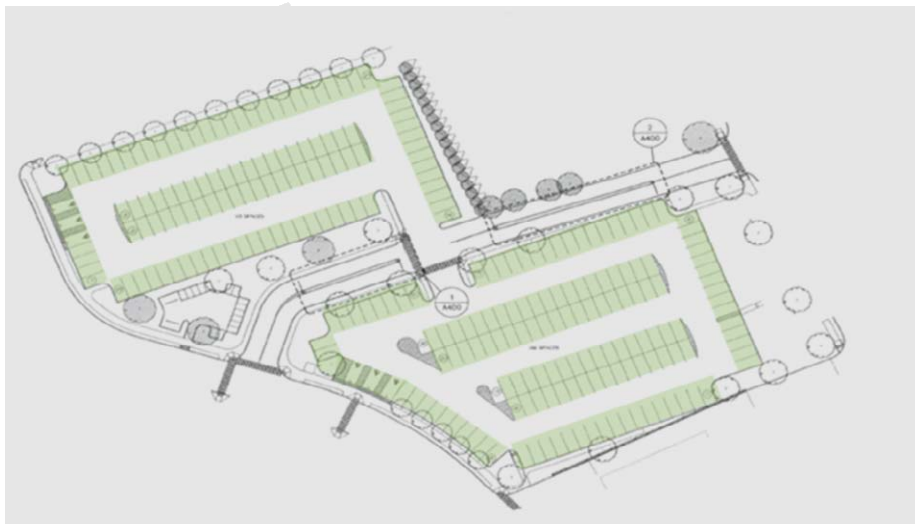
## 18.2. Regulatory Credit

In order to receive the regulatory credits described in this section, permeable pavement systems shall be designed, constructed and maintained in accordance with this chapter.

Permeable pavement can be used to treat stormwater throughout North Carolina. The design of the pavement system is customized based on the soil type at the site. The regulatory credit is also customized based on the type of design. Like other BMPs, permeable pavement receives credit for pollutant removal and can also be designed for volume control. In addition, permeable pavement designed for infiltration can receive credit for built-upon area (BUA) reduction.

Whether designed for infiltration or detention, permeable pavement systems may be designed to treat additional BUA up to a 1:1 ratio (additional BUA to pavement area). For example, in the parking lot shown below, the design could include parking stalls with permeable pavement (shaded in light green) and the travel lanes (not shaded) with conventional pavement. The design of the subgrade, aggregate base and underdrain would be tailored to handle the additional stormwater runoff.

**Figure 18-3. Parking Lot with Permeable and Conventional Pavement**



**18.2.1. Permeable Pavement Designed for Infiltration**

**BUA Credit.** Permeable pavement designed to infiltrate the design storm receives credit for a reduction in its built-upon area (BUA) footprint based on its location over the Natural Resource Conservation Service (NRCS) Hydrologic Soil Groups as follows:

- A and B soils: 75% pervious and 25% BUA
- C and D soils: 50% pervious and 50% BUA

The soil groups indicate the potential for infiltration. A soils have the greatest capacity to infiltrate while D soils have the least (see Table 18-1 below). When there is a mix of soils on site or a C or D soil type exhibits a higher than expected infiltration rate, determinations of BUA credit may be made on a case-by-case basis. Fill material comprised of HSG A or B shall not be placed on top of an in-situ HSG C or D to receive additional BUA credit.

The BUA credit will apply only to the pavement permeable pavement and not to any additional BUA that drains to it.

**Table 18-1. Characteristics of NRCS Soil Groups (NRCS TR-55)**

Soil Group	Characteristics
A	Sand, loamy sand or sandy loam. These soils have low runoff potential with high infiltration rates when saturated and consist chiefly of deep, well to excessively drained sands or gravels.
B	Silt loam or loam. These soils have a moderate infiltration rate when saturated and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.
C	Sandy clay loam. These soils have low infiltration rates when saturated and consist chiefly of soils with a layer that substantially impedes downward movement of water and soils with moderately fine to fine structure.
D	Clay loam, silty clay loam, sandy clay, silty clay or clay. These soils have very low infiltration rates when saturated and consist chiefly of clay soils with a high swelling potential, a permanent high water table, a clay layer or other nearly impervious material at or near the surface.

Permeable pavement can be used in low or high density development. A high density site with conventional pavement can use the BUA credit associated with infiltrating permeable pavement and be considered low density when soils are suitable for infiltration. Please note that all other requirements associated with low density development such as the use of vegetated stormwater conveyances and the absence of a piped storm drainage system still apply. For a low density site, the runoff from other BUA such as roofs and conventional pavement would not require treatment by a stormwater BMP (as long as their stormwater is conveyed into a correctly designed vegetated conveyance or sheet flow over vegetated areas).

Some sites are high density even after receiving the BUA credit associated with infiltrating permeable pavement. Those sites shall have stormwater treatment for all of the BUA on the site. This treatment can be provided within the permeable pavement system or by another BMP.

**The only purpose of the BUA credit associated with permeable pavement is to determine the overall BUA percentage of the site.** Permeable pavement used to meet a BUA threshold is designed identically to permeable pavement used as a BMP to treat a high density site. Additional explanation and examples of the application of the BUA credit are available at the [DWQ web site for permeable pavement](#).

**Pollutant removal.** Permeable pavement designed for infiltration also receives credit for treating runoff from the BUA directed to it. This includes the BUA portion of its own footprint (as discussed above) as well as any other BUA from the site draining into it. The following regulatory credits apply:

- 85% Total Suspended Solids
- 30% Total Nitrogen
- 60% Total Phosphorus

The pollutant removal credit is in terms of the mass of each pollutant delivered to the receiving water per year. This concept can be illustrated by the following equation:

**Pollutant Removal (PR) - conceptual explanation:**

$$PR = 100 * \frac{L_u - L_p}{L_u}$$

- where:
- PR = Pollutant removal (% reduction in mass pollutant load delivered to the surface water per year)
  - L<sub>u</sub> = Load of pollutant delivered from untreated BUA to the receiving water (mass/year)
  - L<sub>p</sub> = Load of pollutant delivered from an equal area of permeable pavement to the receiving water (mass/year)

The Neuse, Tar-Pamlico, Jordan and Falls Lake Nutrient Loading Models for New Development include options for implementing permeable pavements designed for infiltration to treat its own footprint as well as to treat the runoff from other BUA that is directed toward it. *[Beginning in December 2012.]*

**Volume control.** Per this chapter’s design section, permeable pavement can be designed with sufficient infiltrative capacity or storage to provide volume control. The mechanism for achieving volume control depends on the soil infiltration rate.

### 18.2.2. Permeable Pavement Designed for Detention

**BUA – No Credit:** Permeable pavement designed for detention does not receive a reduced BUA credit because the pavement system does not infiltrate a significant amount of stormwater.

**Pollutant Removal Credit:** Permeable pavement designed for detention receives the regulatory credits listed below for treating its own footprint as well as any other BUA from the site which drains to the pavement:

- 70% Total Suspended Solids with an impermeable liner above the soil subgrade, OR 85% Total Suspended Solids with no liner above the subgrade
- 10% Total Nitrogen
- 10% Total Phosphorus

The amount of TSS removal credit earned by the pavement depends on whether an impermeable liner is placed between the soil subgrade and the aggregate base. As described below, the designer may choose to use the permeable pavement detention system when ponding time of the design storm exceeds five days. However, if there is no impermeable liner between the aggregate base and the subgrade, then some infiltration occurs even over low permeability soils. There are some cases, however, where a liner is required such as over soils with high shrink-swell when the soils have high shrink-swell potential or where there is a risk of groundwater or soil contamination.

The Neuse, Tar-Pamlico, Jordan and Falls Lake Nutrient Loading Models for New Development include options for implementing permeable pavements designed for detention to treat its own footprint as well as to treat the runoff from other BUA directed toward it. [*Beginning in December 2012.*]

**Volume control.** As described in the Design Section of this chapter, permeable pavement can be designed with sufficient storage to provide volume control.

### 18.3. Design

This BMP Manual chapter does not provide structural design guidance of permeable pavements subject to vehicular traffic. This section only presents the requirements that achieve stormwater credits. The designer shall ensure that the pavement meets its hydrologic and structural goals by involving an NC licensed design professional with appropriate expertise in pavement design.

The key stormwater standards for permeable pavements mirror those required for other BMPs: treatment of the water quality volume (typically the 1 in. or 1.5 in. design storm) and safe conveyance of the 10-year, 24-hour storm through infiltration, bypass or detention.



**18.3.1 Design Step 1: Consider Siting and Feasibility**

There are many concerns when determining if and how permeable pavement should be used at a specific site. These are listed in Table 18-2 below.

**Table 18-2. Siting and Feasibility Considerations**

<b>Installation Size</b>	There is no required minimum or maximum size for a permeable pavement installation. However, large installations may have greater longevity because the overall installation may continue to function even if one portion of the surface becomes clogged.
<b>Buffers and setbacks</b>	Permeable pavement is not allowed in areas where impervious surfaces are not permitted such as protected riparian buffers or the setbacks required under Phase II, Water Supply Watershed, Coastal Counties, HQW, ORW or other stormwater programs.
<b>Proximity to building foundations &amp; utilities</b>	For infiltration designs, the designer shall consider the impact of infiltration on building foundations and utilities. The design may include transitions to conventional pavement if utilities shall cross a permeable pavement installation.
<b>Proximity to water supply wells</b>	For infiltration designs, there shall be a 100 ft setback from water supply wells. This distance may be reduced on a case-by-case basis if the design professional can justify to the permitting authority that the groundwater will be protected from stormwater pollution.
<b>Status of the site as high or low density</b>	This determines whether the runoff from all of the BUA on the site (including roofs and conventional pavement) requires treatment by a stormwater BMP. The permeable pavement may be designed to treat other BUAs on the site.
<b>Soil type</b>	When properly designed, permeable pavements may be used on any soil type, although soil conditions dictate many aspects of the design; for example, whether an underdrain is needed, the depth of the aggregate base, and whether an infiltration or a detention system is used.
<b>Site slopes</b>	Permeable pavement designs are more challenging on sites with steep topography. It may not be cost-effective to meet the requirement for gently sloping pavement surface and almost flat subgrade on a steep site. On steep sites, it may be impractical to divert runoff from pervious areas away from permeable pavement.

**Seasonal high water table** The seasonal high water table shall be at least 2 ft below the bottom of the aggregate base. If the water table exceeds this level, the pavement shall not allow water to exfiltrate. High water tables also compromise the capacity of the in-situ soils to remove pollutants from stormwater prior to its entry into the shallow groundwater table. This requirement can be relaxed to one ft if additional borings can firmly establish the elevation of the SHWT.

**Stormwater hotspots** Permeable pavement shall not be used to treat stormwater hotspots – areas where concentrations of pollutants such as oils and grease, heavy metals and toxic chemicals are likely to be significantly higher than in typical stormwater runoff. Installing permeable pavement in these areas increases the risk of these pollutants entering the groundwater. Examples of development types that often include stormwater hotspots are listed below. However, this is not a comprehensive list. Only the portion of the site where toxic pollutants are stored or handled is considered a hotspot. For example, the parking lot of an airport would not be a hotspot but the airplane hangar and maintenance areas are hotspots.

<b>Stormwater hotspot land uses</b>	Fueling facilities	SIC code “heavy” industries
	Commercial car washes	Airport maintenance areas
	Fleet storage	Railroads and bulk shipping
	Public works yards	Racetracks
	Trucking & distribution centers	Solid waste facilities
	Highway maintenance facilities	Wastewater treatment plants
	Vehicle maintenance areas	Scrap yards

**Redevelopment sites** Care should be taken when implementing permeable pavement at redevelopment sites. Stormwater shall not be infiltrated into contaminated soils because this can cause dispersion of toxic substances to other sites and to groundwater. However, a permeable pavement system designed for detention may work on a contaminated site. If the site history includes land uses listed above, it shall be assumed that contaminated soils are present until detailed investigation determines otherwise. If contaminated soils are present or suspected, the DWQ recommends that the designer consult with an appropriately licensed NC professional.

**Use of permeable pavement** Permeable pavement is typically placed in parking lot stalls and drive lanes, driveways and plazas and is typically avoided in areas with traffic or heavy truck loading. However, permeable pavement can be designed for more intensive uses, although this often requires thicker aggregate bases for flexible pavements such as PICP and PA.


<b>Maintenance access</b>	Because its performance depends on maintenance, the entire permeable pavement surface should be accessible by cleaning equipment, preferably a regenerative air or vacuum street cleaner. The designer shall also consider operational limitations of cleaning machines such as turning radius and overhead clearance.
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### 18.3.2 Design Step 2: Select the Pavement Course

The pavement course should be selected based on the project’s budget and desired appearance as well as the types of applied loads on the permeable pavement. Currently, the most widely used types of pavement courses applied in North Carolina are Permeable Interlocking Concrete Pavers (PICP), Pervious Concrete (PC) and Porous Asphalt (PA). Please note that PA and PICP are flexible pavement and rely on structural support from the aggregate base.

Designers may propose other types of pavement surface and base courses but shall demonstrate that the proposed design functions adequately hydraulically and structurally in the long term. See Table 18-3 below for a summary of the most commonly used pavement courses and some pros and cons of each.

**Table 18-3. Permeable Pavement Types**

<p><b>Permeable Interlocking Concrete Pavers (PICP)</b></p> 	<p>PICPs are a type of unit paving system that drains water through joints between the pavers filled with small, highly permeable aggregates. The pavers are placed on a thin aggregate bedding layer over a thicker choker course and base beneath. The choker course and aggregate base provide uniform support, water storage and drainage.</p> <p><b>Pros:</b> Well suited for plazas, patios, small parking areas and stalls, parking lots and residential streets. PICP can be designed for a significant amount of heavy vehicles and does not require curing time. As compared to PC and PA, PICP is easier and less costly to renovate if it becomes clogged. The Interlocking Concrete Pavement Institute offers a design guide, construction specifications, design software, and a Certified PICP Specialist Course for contractors.</p> <p><b>Cons:</b> PICP often has the highest initial cost for materials and installation. Regular maintenance of PICP may be higher than PC and PA because of the need to refill the joints with aggregate after cleaning and the greater occurrence of weeds.</p>
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**Pervious Concrete (PC)**



PC is produced by reducing the fines in a conventional concrete mix with other changes to create interconnected void spaces for drainage. Pervious concrete has a coarser appearance than standard concrete although mixtures can be designed to provide a denser, smoother surface profile than traditional pervious concrete mixtures.

**Pros:** While not as strong as conventional concrete pavement, PC provides adequate structural support, making it a good choice for travel lanes or heavier vehicles in addition to parking areas and residential streets. The National Ready Mixed Concrete Association provides a contractor training and certification program. The American Concrete Institute publishes a construction specification and a report which provides guidance on structural, hydrological and hydraulic system and component design in addition to mix proportioning and maintenance.

**Cons:** Mixing and installation must be done correctly or PC will not function properly. PC can be subject to surface raveling and deicing salt degradation if not designed and constructed properly. Restoring surface permeability after a significant loss of initial permeability may be difficult without removing and replacing the surface course for the affected area.

**Porous Asphalt (PA)**



PA is similar to conventional (impervious) asphalt except that less fine material is used in the mixture in order to provide for drainage. A modified asphalt binder as specified by the Carolina Asphalt Pavement Association (CAPA) shall be used to ensure long term durability and permeability. PA has a courser appearance than conventional asphalt.

**Pros:** While not as strong as conventional asphalt pavement, PA offers sufficient structural strength for parking lots and streets. The National Asphalt Pavement Association (NAPA) provides a Design, Construction and Maintenance Guide for Porous Asphalt titled *Porous Asphalt Pavement for Stormwater Management*. CAPA provides a *Porous Asphalt Guide Specification* for the Carolinas. Training on PA for engineers and contractors is available through CAPA. For information regarding the use of PA and to obtain a list of qualified contractors, contact CAPA at: [www.carolinaasphalt.org](http://www.carolinaasphalt.org).

**Cons:** Mixing and installation must be done correctly or PA will not function properly. The owner, contractor and designer shall ensure that PA is not confused with standard asphalt. Asphalt sealants or overlays that eliminate surface permeability shall not be used. Restoring surface permeability after a significant loss of initial permeability may be difficult without removing and installing a portion of the surface course.

**Concrete Grid Pavers (CGP)**



CGPs are an “older cousin” to PICPs and have significantly larger openings filled with aggregates, sand, or topsoil and turf grass for infiltration. CGPs are intended for very limited vehicular traffic such as overflow parking (e.g., intermittent stadium parking), emergency access fire lanes around buildings, and median crossovers. CGP is not recommended for regularly used parking areas and for roads intended for PICP or PC.

**Pros:** CGP is less expensive than PICP and GCP can provide a grassed surface. Design, construction and maintenance guidance is available from the Interlocking Concrete Pavement Institute.

**Cons:** CGP is intended for limited vehicular traffic and overloaded pavements often experience differential settlement and paving unit damage. CGP with grass requires mowing and may require watering, fertilizing and re-seeding.

**Plastic Turf Reinforcing Grid (PTRG)**



PTRG, also called geocells, consists of flexible plastic interlocking units that infiltrate water through large openings filled with aggregate or topsoil and turf grass. PTRG is well suited for emergency vehicle access over lawn areas or overflow parking. PTRG is not approved for regularly used vehicular areas such as parking lots or roadways where PICP or PC should be used.

**Pros:** Reduces expenses and maximizes lawn area.

**Cons:** PTRG has less structural strength than the other pavement course options, especially when used under saturated conditions. Like CGP with grass, it shall be mowed, sometimes fertilized and watered. Overuse can kill the turf grass or create ruts from displaced aggregates. Also, sediment from adjacent sources can damage the grass and accelerate clogging.

For PC and PA, it is crucial to specify the proper mix design. For PC, the mix design shall be in accordance with the latest version of ACI 522.1 *Specification for Pervious Concrete*. For PA, the mix design shall be in accordance with NAPA’s *Porous Asphalt Pavements for Stormwater Management* and CAPA’s *Porous Asphalt Guide Specification*. For PICP, PA and PC, the use of certified and qualified contractors in accordance with industry standard documents shall be required and noted on both project plans and specifications.

For all types of permeable pavement, follow manufacturer recommendations, product standards, and industry guidelines to help ensure lasting installations. Manufacturer requirements and industry standards shall be implemented in addition to (and not instead of) the design requirements in this manual. Designers who propose to use a pavement surface other than PICP, PC or PA shall demonstrate that the pavement will function adequately hydraulically and structurally in the long term.

### 18.3.3 Design Step 3: Discuss Surface Type, Maintenance and Site Use with Owner

Before pursuing a permeable pavement design beyond the conceptual stage, the designer shall verify site feasibility and meet with the owner to explain the installation, construction and maintenance requirements of the proposed permeable pavement system. The pavement's maintenance needs may require the owner to purchase new equipment or contract with a new service provider. The required frequency of the maintenance may be greater than conventional pavement in the same location. These costs are likely the same or lower than other BMPs, but it is important to integrate maintenance requirements into the owner's planning for site operations.

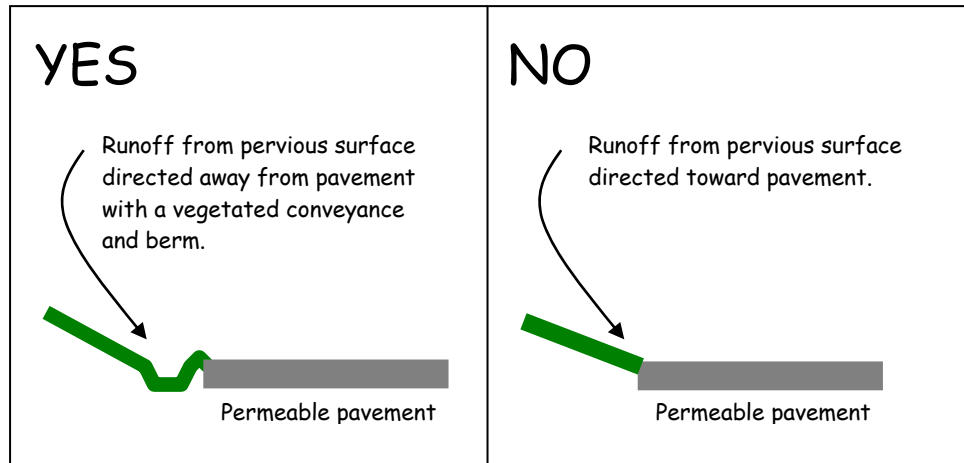
During the discussion with the owner, the designer shall confirm assumptions about the site use and vehicle loading. For example, a parking lot primarily used by passenger cars may also see bus traffic or a pedestrian area may also be driven on by service vehicles. These situations require attention to structural design, specifically base, materials, thicknesses, soil strengths, axle loads and repetitions.

### 18.3.4 Design Step 4: Lay Out the Site Drainage System

To avoid pavement clogging, pervious areas such as lawns and landscaping shall not drain to permeable pavement. Exceptions such as site restrictions on redevelopment projects will be reviewed on a case-by-case basis. The site plan shall show pervious areas graded to flow away from the pavement or include conveyances to route pervious surface runoff elsewhere. These conveyances shall be designed for non-erosive flow during the 10-year, 24-hour storm event, or the local conveyance design standard, whichever is larger.

Figure 18-4 outlines how to direct pervious surface runoff away from permeable pavement. Impervious areas are allowed to drain to the permeable pavement with proper design of the pavement system per this chapter. Examples of areas that may be easily diverted onto the permeable pavement include: travel lanes in parking lots, sidewalks, and roof drains.

Roof downspouts may be directed to the permeable pavement surface, but it is the designer's responsibility to ensure that downspouts are of a sufficient number and spacing to prevent nuisance flooding. The downspouts may also drain directly into the permeable pavement base. Designers who plan to insert a downspout through the pavement surface should consult the [DWQ-Groundwater Section's stormwater injection web site](#) for guidance on reporting requirements per the Underground Injection Control Program. Downspout outlets or ground level impervious surfaces shall not drain more than 1,000 sf to a single point onto the permeable pavement. The area of additional BUA draining to the pavement shall not exceed the area of the pavement itself (in other words, a maximum 1:1 ratio of additional BUA to pavement area).



**Figure 18-4. Schematic of draining pervious areas adjacent to permeable pavement**

The designer shall provide for safe conveyance of all storms in addition to the safe conveyance of the 10-year, 24-hour storm (or other local requirements). In the event of large storms and high intensity rainfall, the flow shall have a means to exit the permeable pavement surface such as via sheet flow, curb cuts and swales, or perimeter catch basins tied to a storm drain system.

**18.3.5 Design Step 5: Conduct In-situ Soil Testing**

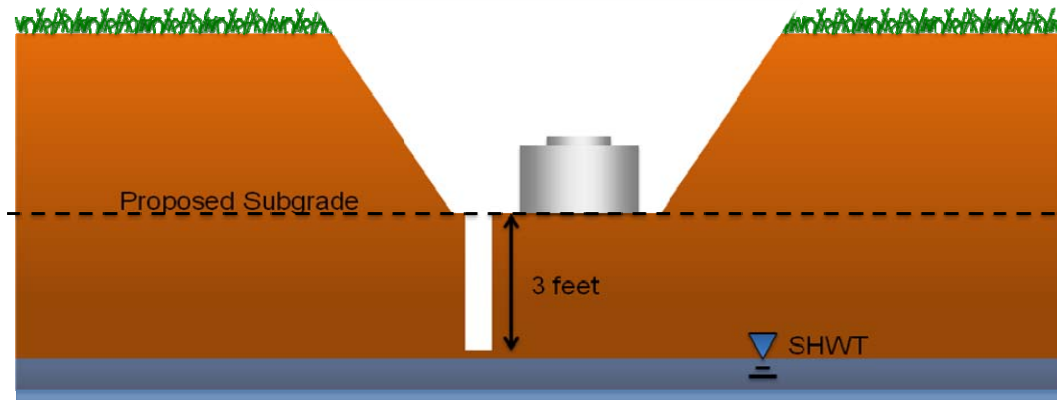
Determining the infiltration rate of the in-situ soil subgrade and the elevation of the seasonal high water table (SHWT) are the most important steps of the hydrologic design process. The soil’s infiltration rate determines the type of permeable pavement design (infiltration or detention) and the pavement’s capacity to treat stormwater from additional BUA. A final measurement of the subgrade infiltration rate occurs when the site has been graded, just prior to installation of the aggregate base or geotechnical liner.

All soil test pits, soil borings, soil permeability tests and associated documentation shall be conducted under the direct supervision of an appropriately licensed North Carolina design professional. During all subsurface investigations and soil test procedures, adequate measures shall be taken to ensure personnel safety and prohibit unauthorized access to the excavations at all times. Entering a soil pit excavated below the water table can be extremely dangerous and should be avoided. Soil pits beneath the water table typically indicate that the site is unsuitable for permeable pavement. Therefore, no further soil study is needed.

Soil test pits shall be dug to the expected subgrade elevation (see Figure 18-5 below). The number of soil test pits for a permeable pavement application shall be as follows:

- Under 2,000 sf: 1 soil test pit
- 2,000 – 20,000 sf: 2 soil test pits
- Over 20,000 sf: 1 soil test pit per 10,000 sf

Placement of the test pits shall be such that it provides adequate characterization of the infiltration area. The total number of required soil profile pits shall be placed equidistant from each other to provide adequate characterization of the infiltration area.



**Figure 18-5. Schematic of a soil test pit (Source: NCSU-BAE)**

One of the most widely accepted methods for in-situ soil infiltration testing is ASTM D 3385 *Standard Test Method for Infiltration Rate in Field Soils Using Double-Ring Infiltrometer*. A double-ring infiltrmeter consists of two concentric metal rings driven into the soil and filled with water as shown in Figure 18-6a. The outer ring helps prevent divergent flow within the soil. The drop in water level or volume within the inner ring is used to calculate an infiltration rate. The infiltration rate is the depth of water per surface area over time. The diameter of the inner ring should be approximately 50% to 70% of the diameter of the outer ring, with a minimum inner ring size of 4 in. Double-ring infiltrmeter testing equipment designed specifically for that purpose may be purchased. Other constant head permeability tests that utilize in-situ conditions and accompanied by an independent published source reference can be used for establishing the permeability rates.

Where soil or groundwater properties vary significantly between soil explorations, additional soil profile pits should be conducted as necessary to resolve such differences and accurately characterize the subsurface conditions below the permeable pavement. The designer shall use the median infiltration rate determined from the in-situ soil testing for design purposes.

In addition to an in-situ soil infiltration rate test, a soil boring shall be conducted within each test pit. See Figure 18-6b. The boring shall extend to a depth of three feet below the subgrade elevation or to the water table, whichever occurs first. The borings shall be performed and reported in accordance with ASTM D 1452 *Practice for Soil Investigation and Sampling Auger Borings* and ASTM D 1586 *Test Method for Penetration Test and Split-Barrel Sampling of Soils*. Soil permeability tests shall be conducted on the most hydraulically restrictive horizon or substratum below the subgrade. If the permeability of the most restrictive soil horizon varies greatly from the results of the in-situ infiltration test, then the licensed professional shall consider decreasing the design soil infiltration rate accordingly.





**Figure 18-6a. Double ring infiltration tests apparatus** Source: NCSU-BAE



**Figure 18-6b. Soil boring tests are required for permeable pavements.** Source: NCSU-BAE

### 18.3.6 Design Step 6: Decide On an Infiltration or Detention System

There are some compelling reasons to design a permeable pavement system for infiltration; it will receive credit for BUA reduction plus a higher pollutant removal credit than a comparably sized detention system. In addition, infiltrating systems are more compatible with a Low Impact Development (LID) approach to stormwater because they can help maintain pre-development hydrology. However, an infiltrating system will not work in all situations.

The first step in deciding to use an infiltration or detention system is to determine if the proposed site is appropriate for infiltration. Detention systems with an impermeable liner over the subgrade are required when in-situ soils become unstable when saturated or have high shrink-swell tendencies or the site has contaminated groundwater or soils.

The second step is calculating the ponding time. Like other infiltration BMPs in North Carolina, an infiltrating permeable pavement system shall be capable of infiltrating the rainfall depth associated with the water quality design storm within five days. The equation for estimating ponding time is provided below.

**Ponding Time (T):**

$$T = \frac{P(1+R)}{24 * SF * i}$$

- where:
- T = Ponding time (days)
  - P = Depth of the design storm (inches)
  - R =  $A_a/A_p$ , the ratio of the additional BUA to the permeable pavement area (between 0 and 1)
  - SF = Safety factor (0.2)
  - i = Measured in-situ soil infiltration rate (in/hr)

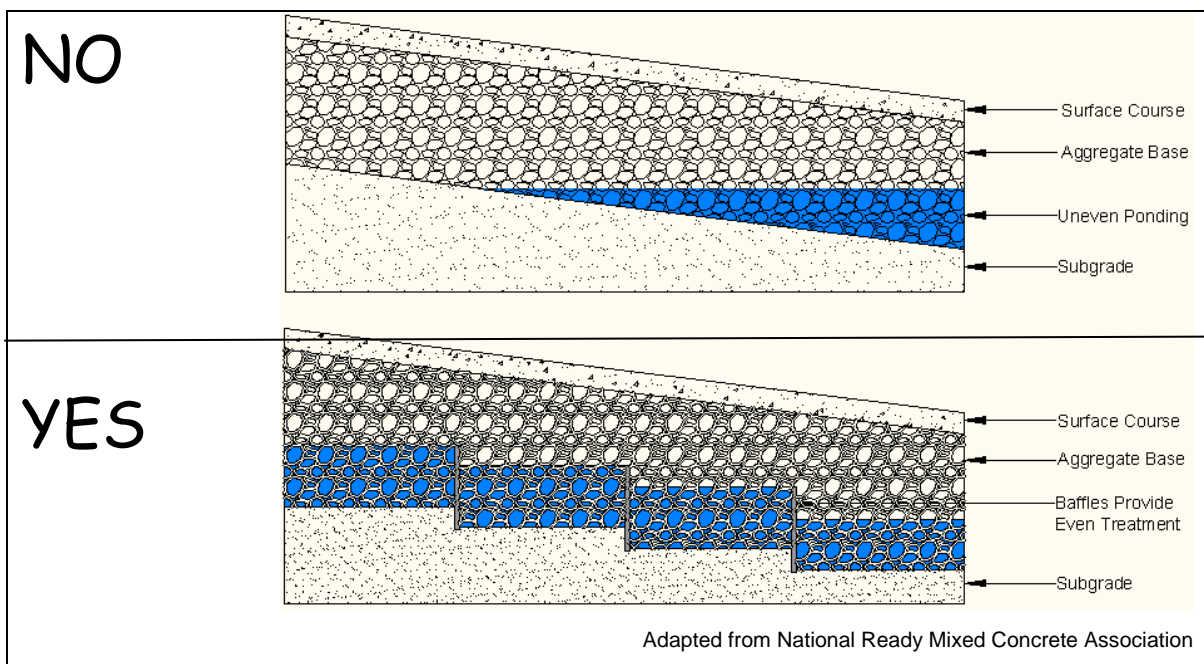
If the ponding time exceeds five days, then the designer can reduce the amount of additional BUA (if any) that drains to the permeable pavement and see if this decreases ponding time to less than five days. Otherwise, the site requires a detention system. It shall be designed to detain the stormwater for a two to five day period. If the designer chooses not to place an impermeable liner on the subgrade, then the system receives 85% TSS removal credit. If an impermeable liner is needed, then the TSS credit is 70%. The higher credit for an unlined system accounts for the enhanced exfiltration.

For any site where the stormwater is not predicted to infiltrate within 48 hours, the DWQ advises consulting a geotechnical engineer to insure that structural pavement design issues are properly addressed.

**18.3.7 Design Step 7: Design Subgrade Slope**

The subgrade bears pavement and traffic loads. In an infiltration design, the subgrade also infiltrates the stormwater that passes through the pavement course and its aggregate base. Whether is the pavement is designed for infiltration or detention, it is crucial that the subgrade be almost flat, i.e., less than 0.5% slope. Besides maximizing infiltration, a flat subgrade provides the most storage capacity within the aggregate base.

Terraces and baffles or graded berms can be used in the subgrade design to store stormwater at different elevations for treatment. See Figure 18-7 below for a schematic configuration of terraces and baffles in the subgrade. The plan drawing set shall include a separate subsurface (subgrade) grading plan, especially for sites with baffles, berms or terraces.



**Figure 18-7. Terraces and baffles under permeable pavement. Source: NCSU-BAE**

**18.3.8 Design Step 8: Design the Aggregate Base for the Design Storm**

In addition to supporting the pavement system, the aggregate base stores the design storm within its void spaces for infiltration or detention and release. The size of the aggregate base stone is selected by the designer based on the needs for structural strength and porosity. The aggregate shall be washed and have 2% or less passing the ASTM No. 200 sieve. Fine particles from unwashed stone can clog the soil subgrade and compromise the ability of the pavement system to store and infiltrate water. The aggregate supplier can likely provide the percentage of voids using ASTM C29 *Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate*.

The first step in designing the aggregate base is to set the aggregate depth needed for the water quality storm. Even for an infiltrating system, the aggregate depth shall be determined based on the assumption that no infiltration occurs during the water quality storm. The formula for  $D_{wq}$  (aggregate depth for the water quality storm) is as follows:

**Aggregate Depth for the Water Quality Storm ( $D_{wq}$ ):**

$$D_{wq} = \frac{P(1 + R)}{n}$$

where:  $D_{wq}$  = Depth of aggregate needed to treat the water quality storm (inches)  
 $P$  = Rainfall depth for the water quality storm (inches)  
 $R$  =  $A_a/A_p$ , the ratio of the additional BUA to the permeable pavement area (between 0 and 1)  
 $n$  = Percent voids, unitless decimal (from ASTM C29)

Please note that the bedding layer of aggregated in a PICP system may not be used to provide storage for the water quality storm.

**18.3.9 Design Step 9: Design for Safe Conveyance of the 10-year, 24-hour Storm**

Permeable pavement designs shall include a mechanism for safely conveying the 10-year, 24-hour storm, which may be accomplished through infiltration, bypass, or detention. The permeable pavement can also be designed to meet local requirements for peak attenuation and volume control for larger storms using the same design process described below for the 10-year, 24-hour storm.

**Infiltration Design Option 1: Infiltrate** requires calculation of the  $D_{10}$  aggregate depth per the formula below. This formula accounts for infiltration during the storm event. Because of this, the aggregate depth for the  $D_{10}$  computed using this formula may be less than the  $D_{wq}$  and it may possibly be less than zero in soils with high infiltration rates. If that is the case, then set the aggregate depth equal to  $D_{wq}$ . The ponding time (T) should also be calculated per the equation shown on page 8-17. If the ponding time exceeds 10 days, then the infiltration option will not be a feasible option and another method of bypassing the 10-year, 24-hour storm shall be used.

**Aggregate Depth to Infiltrate the 10-year, 24-hour Storm ( $D_{10}$ ):**

$$D_{10} = \frac{P_{10}(1 + R) - d * i * SF}{n}$$

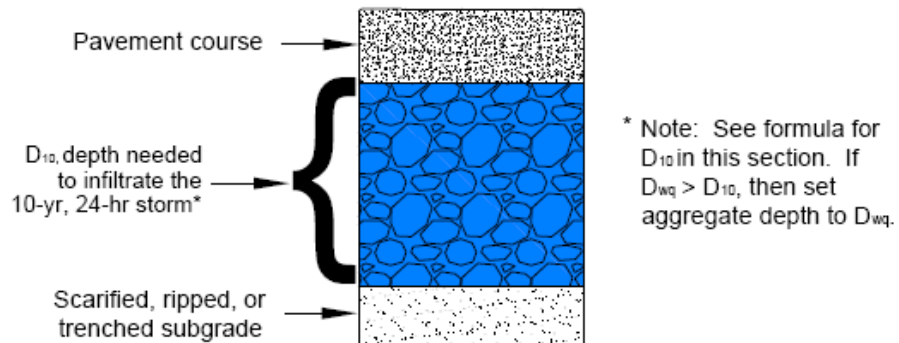
- where:
- $D_{10}$  = Aggregate depth to infiltrate the 10-year, 24-hour storm (inches)
  - $P_{10}$  = Rainfall depth for the 10-year, 24-hour storm (inches)
  - $R$  =  $A_a/A_p$ , the ratio of the additional BUA to the permeable pavement area (between 0 and 1)
  - $d$  = Storm duration (24 hours)
  - $i$  = Soil infiltration rate (in./hr)
  - SF = Safety factor (0.2)
  - $n$  = Percent voids, unitless decimal

Figure 18-8 shows suggested options for conveying the 10-year, 24-hour storm.

**Infiltration Design**

**Suggested Options for 10-year, 24-hour Storm Conveyance**

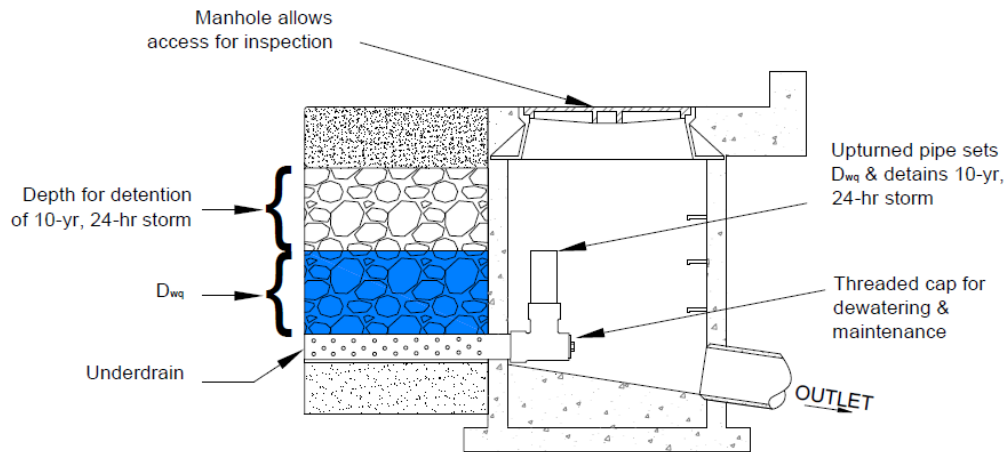
Option 1: Infiltrate



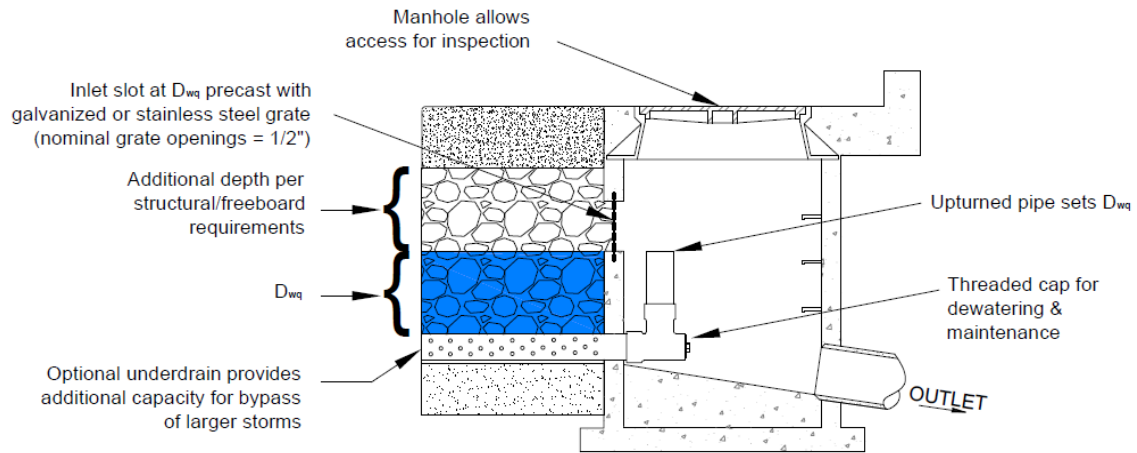
### Infiltration Design (continued)

Suggested Options for 10-year, 24-hour Storm Conveyance (NCSU-BAE 2012)

#### Option 2: Detain Via Underdrain with Upturned Elbow



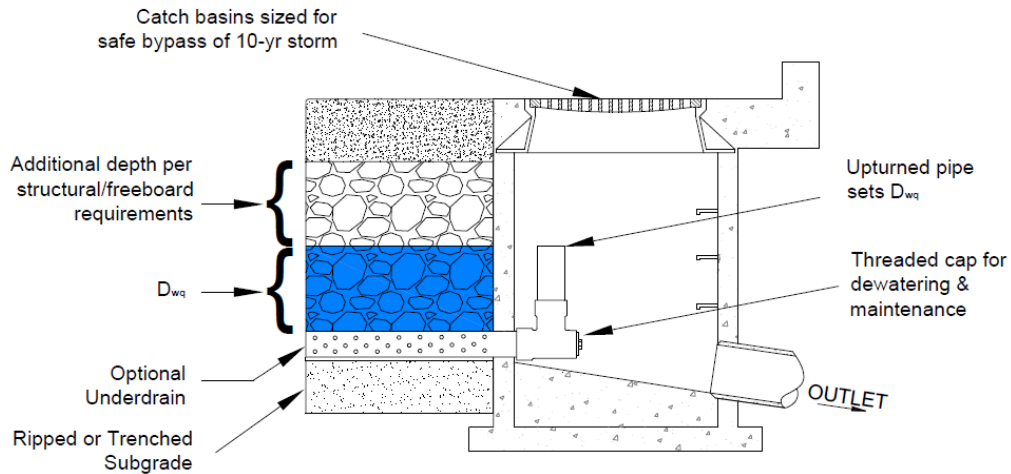
#### Option 3: Bypass via Subsurface Openings in Manhole Structures



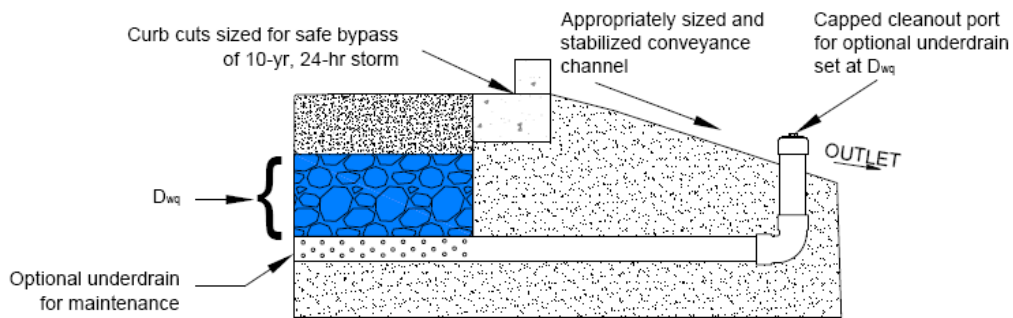
### Infiltration Design (continued)

Suggested Options for 10-year, 24-hour Storm Conveyance (NCSU-BAE 2012)

#### Option 4: Bypass via Catch Basins (PC & PA Only)



#### Option 5: Bypass via Curb Cut and Conveyance (PC Only)

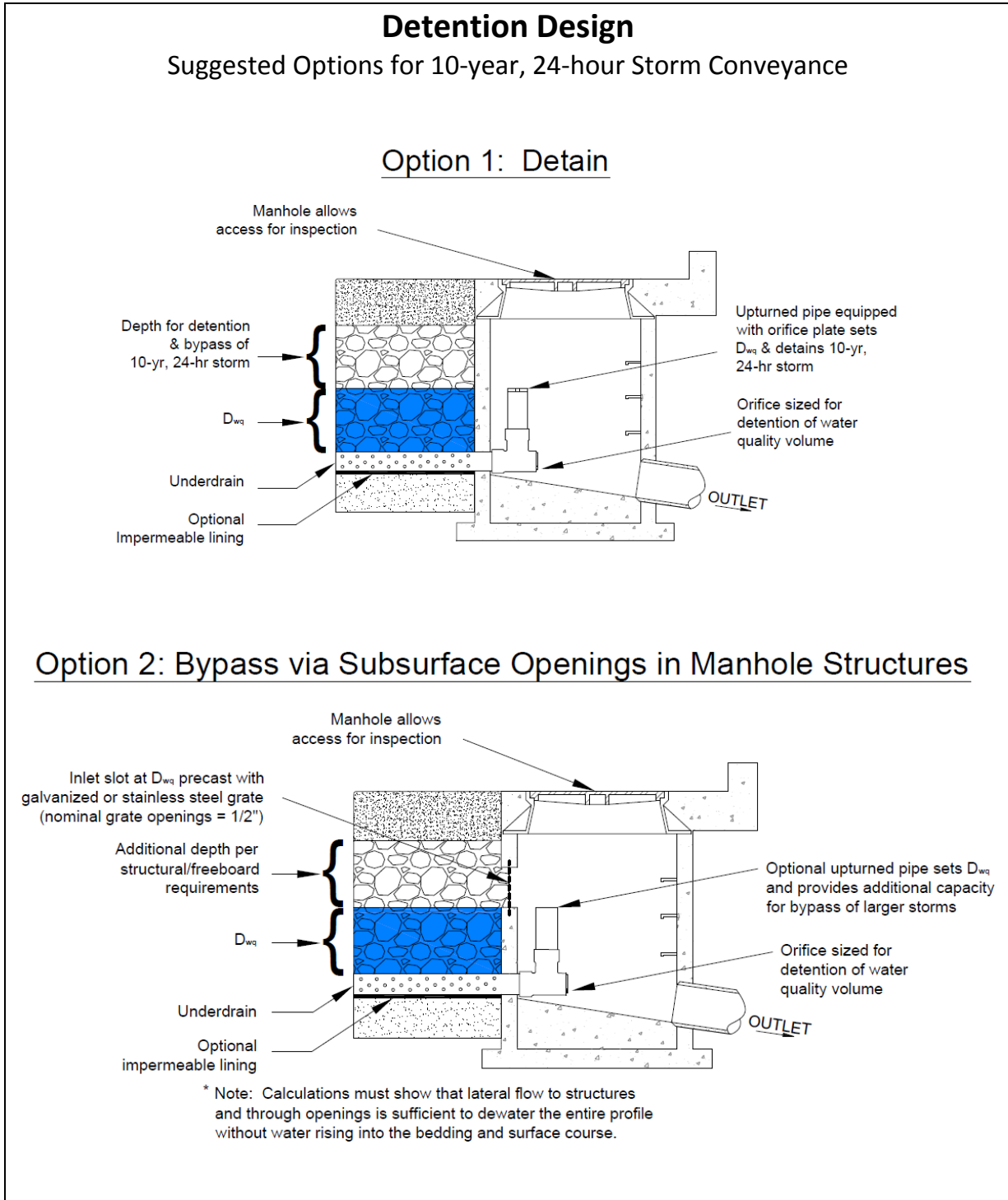


**Figure 18-8. Infiltration design options for conveying the 10-year, 24-hour storm for infiltration pavement designs** Source: NCSU-BAE

For a detention permeable pavement system, all of the options for conveying the 10-year, 24 hour storm require an underdrain because the stormwater does not infiltrate as a primary means of treatment. The underdrain shall be placed on the subgrade with an outlet equipped with a small orifice that drains the water quality storm over a period of two to five days (minimum orifice diameter = 1 in. to prevent clogging). Provide a parallel underdrain at the  $D_{wq}$  for larger storms. The routing calculations are similar to the procedures used for wet detention basins except that the depth and head are

adjusted for the porosity of the aggregate. In addition, the weir equation is adjusted for the flow and head losses through the underdrains.

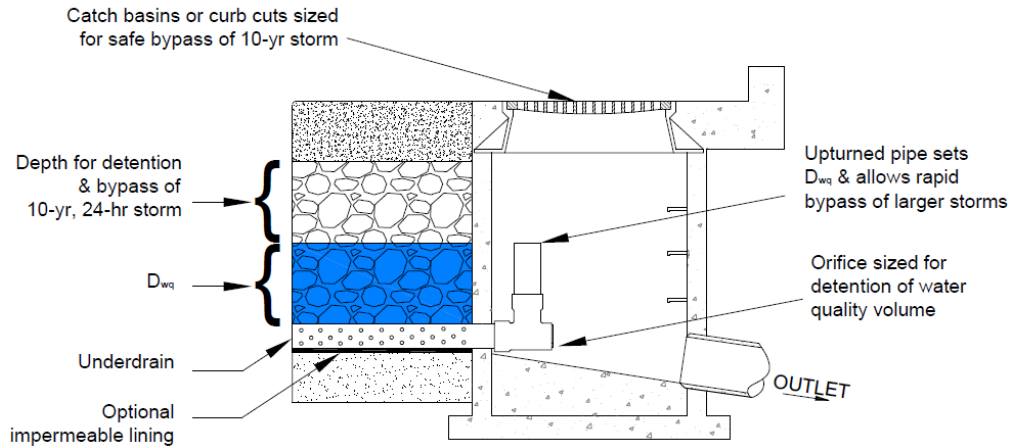
Figure 18-9 shows suggested options for conveyance of the 10-year, 24-hour storm for detention pavement designs.



### Detention Design (continued)

Suggested Options for 10-year, 24-hour Storm Conveyance

#### Option 3: Bypass via Catch Basins (PC & PA Only)



#### Option 4: Bypass via Curb Cut and Conveyance (PC & PA Only)

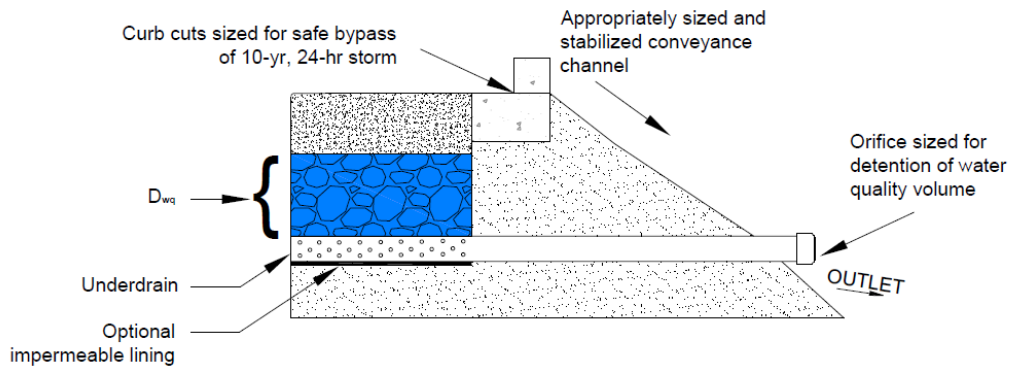


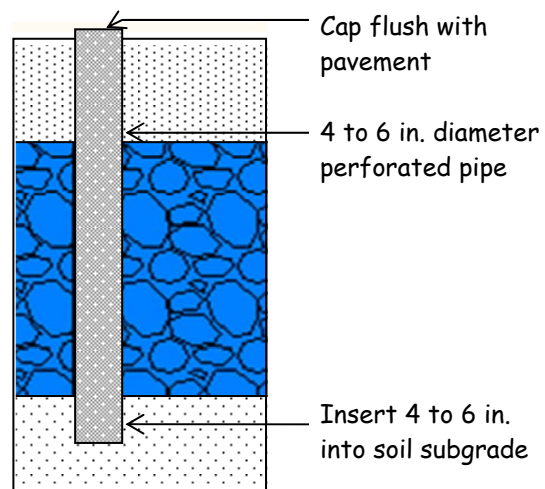
Figure 18-9. Options for conveying the 10-year, 24-hour storm for detention pavement designs Source: NCSU-BAE



### 18.3.10 Design Step 10: Observation Wells

Observations wells enable measurement of the depth of standing water on the subgrade within the permeable pavement system. Observation wells are required for all sites except for single family residential lots with a total permeable pavement area under 2,000 sf. If the subgrade is not terraced, then the observation well shall be placed at the low end of the subgrade slope. If the subgrade is terraced, then one observation well shall be built into the low end of each terrace.

Observation wells shall be fitted with a lockable cap installed placed even with the pavement surface to facilitate quarterly inspection and maintenance. Observations of the water depth throughout the estimated ponding time (T) indicate the rate of water infiltration. The observation well shall consist of a rigid 4 to 6 in. diameter perforated PVC pipe. See Figure 8-10.



**Figure 8-10. An observation well enables inspection of water infiltration.**

### 18.3.11 Design Step 11: Geogrids, (Permeable) Geotextiles and (Impermeable) Geomembranes

Not all permeable pavement applications include geogrids, geotextiles and geomembranes, but some circumstances require their use. The advice of a licensed NC design professional with experience in geotechnical design is a valuable resource in addition to the guidance provided below.

**Geogrids** may be used at the top of the soil subgrade to provide additional structural support especially in very weak, saturated soils. All manufacturer requirements shall be followed in the design and installation.

**Geotextiles** consisting of permeable materials should line the sides of the aggregate base to prevent migration of adjacent soils into it and subsequent permeability and storage capacity reduction. This problem is more likely in sandy or loamy soils. Geotextiles are not recommended under the aggregate base in an infiltration design because they can accumulate fines and inhibit infiltration.

**Geomembranes** consisting of impermeable materials should be used to accomplish the following:

- Provide a barrier on the sides and bottom of the aggregate base in a detention design to prevent infiltration into the subgrade typically due to soil instability, the presence of stormwater hotspots, or potential for groundwater contamination. Geomembrane barriers reduce the credit for TSS removal from 85% to 70%.
- Line the sides of the aggregate base whenever structure foundations or conventional pavement are 20 ft or less from the permeable pavement (to avoid the risk of structural damage due to seepage). The isolated use of geomembranes for this purpose will not reduce the credit for TSS removal in the system.

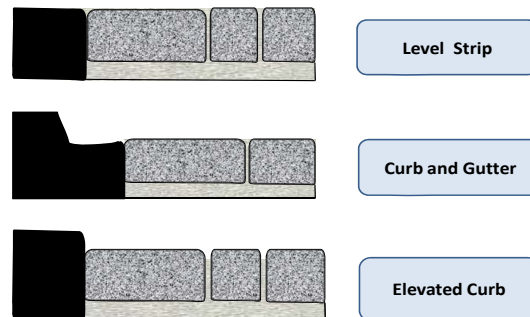
**18.3.12 Design Step 12: Edge Restraints and Intersections of Permeable and Impermeable Pavements**



Edge restraints are essential to the structural longevity of a PICP pavement system. Without edge restraints, pavers can move over time and reduce the surface’s structural integrity. As pavers move, the joints open and pavers can be damaged. PC pavement systems provide adequate structural edge support and do not require perimeter edge restraints.

**Figure 8-11. Edge restraints for the pavers, typically concrete curbs are required for PICP.**

Concrete edge restraints (cast-in-place or precast curbs) are recommended. Flexible, plastic and metal edging supported with spikes are not recommended for vehicular use. Edge restraints shall be flush with the pavement or somewhat higher than the pavement surface. Edge restraints higher than the pavement surface help keep the stormwater on the pavement and prevent stormwater run-on from clogging the permeable pavement. See Figure 18-12a for examples of acceptable edge restraints.



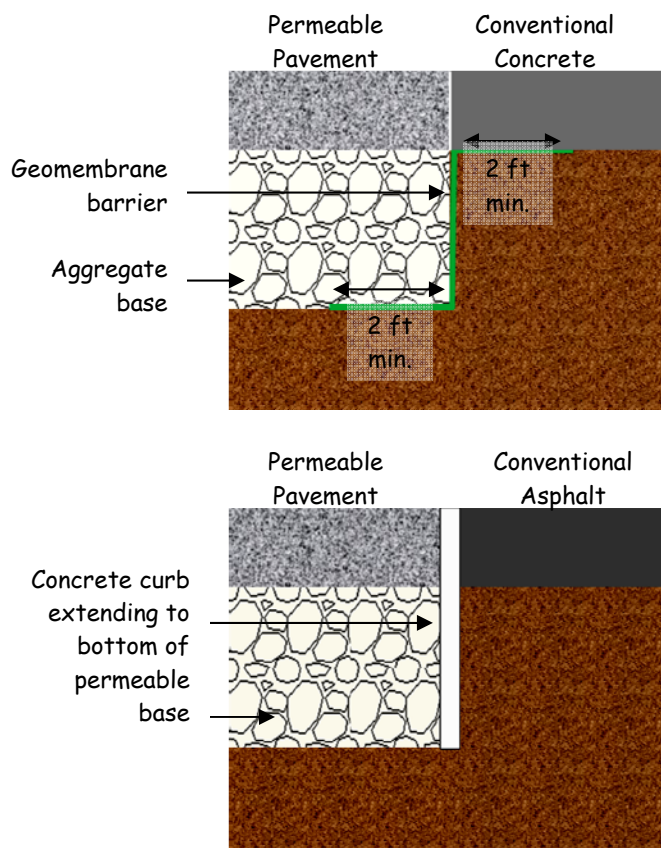
**Figure 18-12. Examples of perimeter edge restraints**

Figure 18-12b shows a concrete perimeter edge restraint used with PICP. In addition to providing structural support, the PICP can provide an attractive edge.



**Figure 18-12b. Perimeter edge restraint used with PICP**

In addition to concrete edge restraints, an important consideration is the boundary between permeable and conventional pavement. The design depends on whether the permeable pavement meets conventional concrete or asphalt as explained below and in Figure 18-13.



**Figure 8-13. Handling pavement transitions**

At intersections between permeable pavement and conventional concrete, a geomembrane barrier should be provided to contain the stormwater under the permeable pavement and protect the base and subgrade under the conventional concrete. There should be a joint between the pavement surfaces for maintenance purposes.

At intersections between permeable pavement and conventional asphalt, a concrete curb that extends below the permeable base should be provided to protect the subgrade under the conventional asphalt. The concrete curb will provide a larger separation between the pavement courses, which will be helpful when the conventional asphalt is resurfaced. An alternative design option uses a concrete curb to protect the asphalt and then an impermeable liner to separate the bases under the asphalt and permeable pavement.

### 18.3.13 Design Step 13: Signage

Signage at permeable pavement installations is required because they are maintained and managed differently than traditional pavements. This promotes prolonged effectiveness and helps prevent damage from conventional pavement management.

Figure 18-14 illustrates an example of a sign for a permeable pavement location. The design is based on a 24 by 18 in. standard size for sign production. The DWQ can provide this image in a high-resolution file for owners who would like to use it for their signs. This graphic is in color but color signs are not required. Large permeable pavement applications may require several signs.



Figure 18-14. Example sign layout for permeable pavement sites

## 18.4. Construction

A preconstruction meeting is highly recommended to ensure contractors understand the need to prevent subgrade compaction and clogging of the pavement surface. The following should be discussed at the meeting:

- Walk through site with builder/contractor/subcontractor to review erosion and sediment control plan/stormwater pollution prevention plan
- Determine when permeable pavement is built in the project construction sequence; before or after building construction, and measures for protection and surface cleaning
- Aggregate material storage locations identified (hard surface or on geotextile)
- Access routes for delivery and construction vehicles identified
- Mock-up location, materials testing and reporting

A preconstruction meeting is also an opportunity to discuss other unique construction considerations for permeable pavement. Construction oversight by a design professional familiar with permeable pavement installation can help ensure that the investment results in adequate long-term performance.

Contractors not familiar with permeable pavement are accustomed to compacting pavement soil subgrades to increase structural strength. However, this is in direct opposition to the correct treatment of soil beneath permeable pavement for an infiltrating design.

### 18.4.1 Construction Step 1: Ensure Acceptable Conditions for Construction

Do not begin construction on permeable pavement until acceptable conditions are present. This includes the following items:

- Pervious surfaces are graded so that they do not discharge to the permeable pavement, except for instances when this is unavoidable, such as redevelopment projects.
- Impervious areas that will drain to the permeable pavement are completed.
- Areas of the site adjacent to the permeable pavement are stabilized with vegetation, mulch, straw, seed, sod, fiber blankets or other appropriate cover in order to prevent erosion and possible contamination with sediments.
- Construction access to other portions of the site is established so that no construction traffic passes through the permeable pavement site during installation. Install barriers or fences as needed.
- The forecast calls for for a window of dry weather to prevent excess compaction or smearing of the soil subgrade while it is exposed.
- All permeable pavement areas are clearly marked on the site.

### 18.4.2 Construction Step 2: Excavate the Pavement Area and Prepare Subgrade Surface

Clear and excavate the area for pavement and base courses while protecting and maintaining subgrade infiltration rates using following these steps:

- Excavate in dry subgrade conditions and avoid excavating immediately after storms without a sufficient drying period.
- Do not allow equipment to cross the pavement area after excavation has begun.
- Operate excavation equipment from outside the pavement area or from unexcavated portions of the area using an excavation staging plan. See Figure 18-15.
- Use equipment with tracks rather than tires to minimize soil compaction when equipment on the subgrade surface is unavoidable.
- Dig the final 9 to 12 in. by using the teeth of the excavator bucket to loosen soil and do not smear the subgrade soil surface. Final grading or smoothing of the subgrade should be done by hand if possible.
- Minimize the time between excavation and placement of the aggregate.



**Figure 18-15. Where possible, excavate soil from the sides of the pavement area to minimize subgrade compaction from equipment. Source: NCSU-BAE**

The final subgrade slope shall not exceed 0.5%. See **Design Step 6: Subgrade Grading** for more information on achieving flat subgrades. The slope of the subgrade shall be checked before proceeding.

After verifying the subgrade slope, scarify, rip or trench the soil subgrade surface of infiltrating pavement systems to maintain the soil’s pre-disturbance infiltration rate. These treatments must occur while the soil is dry. To scarify the pavement, use backhoe bucket’s teeth to rake the surface of the subgrade. To rip the subgrade, use a subsoil ripper to make parallel rips 6 to 9 in. deep spaced 3 ft apart along the length of the permeable pavement excavation as shown in Figure 18-16. In silty or clayey soils, clean coarse sand must be placed over the ripped surface to keep it free-flowing (Brown and Hunt 2009). The sand layer should be adequate to fill the rips.



**Figure 18-16. Ripping the soil subgrade increases its infiltration rate. Source: Tyner**

An alternative to scarification and ripping is trenching. See Figure 18-17. If trenching, then parallel trenches 12 in. wide by 12 in. deep shall be made along the length of the permeable pavement excavation. Excavate trenches every 6 ft (measured from center to center of each trench) and fill with ½ in. of clean coarse sand and 11½ in. of ASTM No. 67 aggregate (Brown and Hunt 2009).



**Figure 18-17. Trenching used to increase the soil infiltration rate. Source: Tyner**

Ripped or trenched (uncompacted) soil subgrade can settle after aggregate base and surface course installation and compaction. Therefore, base compaction requires special attention to means and methods in the construction specifications and during construction inspection to minimize future settlement from ripped or trenched soil subgrades.

**18.4.3 Construction Step 3: Test the Subgrade Soil Infiltration Rate (Infiltration Systems Only)**

Conduct a direct measurement of the soil’s infiltration rate immediately after excavation and before the aggregate is placed. Infiltration rate testing shall be conducted by an appropriately-qualified professional. See **Design Step 5: Conduct In-situ Soil Testing** for soil testing methods. Depending on the contract documents, this testing might be done by the contractor (or a subcontractor), the designer (or designer’s subcontractor), or a third-party hired by the owner. The results of the testing shall be given to the designer of record for review.

If the soil test shows an infiltration rate(s) that are lower than the rate(s) used in the final design, then the designer shall check the calculations and may need to adjust the design. First, recalculate the ponding time (T) to insure that it is still less than five days.

If the recalculated T exceeds five days, there are three options:

- Reduce the additional BUA (if any) draining to the pavement.
- Increase the infiltration capacity through additional scarification, ripping or trenching the soil.
- Increase the storage capacity by increasing the aggregate depth.

If the recalculated T exceeds five days, set T equal to five days and calculate the maximum depth,  $P_{max}$ , which can be infiltrated in five days as follows:

**Maximum Depth that Can Be Infiltrated in Five Days ( $P_{max}$ ):**

$$P_{max} = \frac{24 * 5 * i}{(1 + R)}$$

- where:
- $P_{max}$  = Depth of the storm that can be infiltrated in five days (inches)
  - $i$  = Soil infiltration rate (in/hr)
  - $R$  =  $A_a/A_p$ , the ratio of the additional BUA to the permeable pavement area (between 0 and 1)

Next, calculate the added depth of aggregate that will need to be added in order to provide adequate storage for subsequent storms:

**Additional Aggregate Depth for Underestimated Infiltration Rate ( $D_{add}$ ):**

$$D_{add} = \frac{P(1 + R) - P_{max}}{n}$$

- where:
- $D_{add}$  = Additional depth of aggregate base needed (inches)
  - $P$  = Depth of the design storm (inches)
  - $R$  =  $A_a/A_p$ , the ratio of the additional BUA to the permeable pavement area (between 0 and 1)
  - $P_{max}$  = Depth of the storm that can be infiltrated in five days (inches)
  - $n$  = Porosity (unitless decimal)

Revise the construction documents as needed to account for these changes. The DWQ recommends that any changes to the design be discussed with the pavement design engineer.

#### 18.4.4 Construction Step 5: Place Geotextiles and Geomembrane (If Applicable)

If using geotextiles or geomembranes, then follow the manufacturer's recommendations so for the appropriate overlap between rolls of material. Secure geotextile or geomembrane so that it will not move or wrinkle when placing aggregate.

#### 18.4.5 Construction Step 6: Place Catch Basins, Observation Well(s) and Underdrain System

Place the catch basins and observation wells according to the design plans and verify that the elevations are correct.

If an upturned elbow design is used, then the underdrains are placed first. See Figure 18-18. In such case, verify the following:

- Elevations of the underdrains and upturned elbows are correct.
- Dead ends of pipe underdrains are closed with a suitable cap placed over the end and held firmly in place.
- Portions of the underdrain system within one foot of the outlet structure are solid and not perforated.



**Figure 18-18. Underdrain with upturned elbow outlet to create detention**

Source: NCSU-BAE

#### 18.4.6 Construction Step 7: Place and Compact Aggregate Base

Inspect all aggregates to insure they are clean, free of fines and conform to the plans and specifications. If aggregates delivered to the site cannot be immediately placed into the excavation, they should be stockpiled on an impervious surface, geotextile, or on an impervious material to keep the aggregate free of sediment. If aggregate becomes contaminated with sediment, then it shall be replaced with clean materials.

Before placing the aggregate base, remove any accumulation of sediments on the finished soil subgrade. Use light, tracked equipment. If the excavated subgrade surface is subjected to rainfall before placement of the aggregate base, the resulting surface crust must be excavated to at least an additional 2 in. depth, raked or scarified to break up the crust. For sites with an impermeable liner or geotextiles, remove any accumulated sediments and check placement. Slopes and elevations shall be checked on the soil subgrade and the finished elevation of base (after compaction) or bedding materials to assure they conform to the plans and specifications.



All aggregate shall be spread (not dumped) by a front-end loader or from dump trucks depositing from near the edge of the excavated area or resting directly on deposited aggregate piles. See Figure 18-19. Moisten and spread the washed stone without driving on the soil subgrade. Be careful not to damage underdrains and their fittings, catch basins, or observation wells during compaction. Follow compaction recommendations by the permeable pavement manufacturer or that from industry guidelines. See Figure 18-20. Be sure that corners, areas around utility structures and observation wells, and transition areas to other pavements are adequately compacted. Do not crush aggregates during compaction as this generates additional fines that may clog the soil subgrade.



**Figure 18-19.** A dump truck deposits aggregate directly into excavated area for spreading. Source: NCSU-BAE



**Figure 18-20.** Compacting the open-graded aggregate base Source: NCSU-BAE

#### **18.4.7 Construction Step 8: Install Curb Restraints and Pavement Barriers**

Edge restraints and barriers between permeable and impervious pavement shall be installed per design. Before moving on to Construction Step 9, be certain that the design and installation are consistent.

#### **18.4.8 Construction Step 9: Install Bedding and Pavement Courses**

The bedding and pavement course installation procedures depend on the permeable pavement surface. It is important to follow the specifications and manufacturer’s installation instructions.

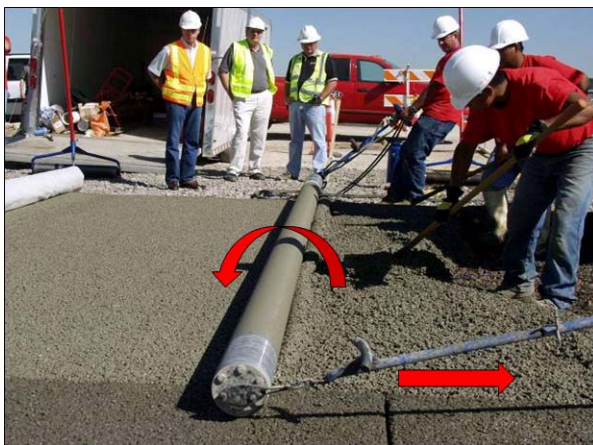


For PICP, a 4 in. thick choker course over the base transitions to a 2 in. thick bedding layer that provides a smooth surface for the pavers. See Figure 18-21. The bedding course shall be installed in accordance with manufacturer or industry guide specifications. Improper bedding materials or installation can cause significant problems in the performance of the pavers and stone jointing materials between them.

**Figure 18-21. A 2 in. thick bedding course of aggregate is being screed smooth prior to placing the concrete pavers.**

If constructing a PICP pavement, use a contractor that holds a PICP Specialist Certificate from the Interlocking Concrete Pavement Institute. A list of contractors can be obtained from the Interlocking Concrete Pavement Institute.

PC pavements shall be constructed in accordance with the latest version of ACI 522.1 *Specification for Pervious Concrete*. Installation of PC may be accomplished using the One-Step or the Two-Step method. The Two-Step method is more commonly used and it separates the steps of strike-off from pervious concrete compaction. In this method, the pervious concrete usually requires a more traditional, stiffer mix. The One-Step method uses a counter-rotating roller screed to simultaneously strike-off and compact the pervious concrete. This method requires pervious concrete with a more flowable mix so that the screed can more adequately compact the mixture. Both methods require dense-paste pervious concrete mixtures. These mixes are defined by chemical admixtures that reduce the viscosity of the cement paste so that it will stick to and not run off the aggregates. The mixes provide greater cohesion that increases strength and durability.



**Figure 18-22. The One-step method levels, strikes off and compacts the pervious concrete. Source: NCSU-BAE**



**Figure 18-23. Pervious concrete paving lane filled between cured lanes forms a parking lot. Source: NCSU-BAE**

If constructing a PA pavement, use a contractor that is qualified per Carolina Asphalt Paving Institute (CAPA). In addition, be certain that the contractor follows the Design, Construction and Maintenance Guide for Porous Asphalt (by the National Asphalt Pavement Association) in conjunction with CAPA's *Porous Asphalt Guide Specification*, which will ensure that the binder mix is appropriate for the North Carolina climate.

#### **18.4.9 Construction Step 10: Protect the Pavement through Project Completion**

If is preferable to have the permeable pavement installed at the end of the site construction timeline. If that is not possible, protect the permeable pavement until project completion. This shall be done by:

- Route construction access through other portions of the site so that no construction traffic passes through the permeable pavement site. Install barriers or fences as needed.
- If this is not possible, protect the pavement per the construction documents. Protection techniques that may be specified include mats, plastic sheeting, barriers to limit access, or moving the stabilized construction entrance
- Schedule street sweeping during and after construction to prevent sediment from accumulating on the pavement.

#### **18.4.10 Construction Step 11: As-Built Inspection**

After installation, an appropriately licensed NC design professional shall perform a final as-built inspection and certification that includes:

- Ensuring that the pavement is installed per the plans and specifications.
- Ensuring that the surface is not damaged, free from fines and sediment.
- Checking that all pervious surfaces drain away from the pavement and that soil around the pavement is stabilized with vegetation
- Preparing the as-built plans that include any changes to the underdrains, observation well locations, terrace layouts, aggregate depth or storage structures, any revised calculations, etc.
- Testing the pavement surface permeability using the NCSU Simple Infiltration Test (see Maintenance Section 18.6.4) or other appropriate test such as ASTM C1701 *Standard Test Method for Infiltration Rate of In-Place Pervious Concrete*.

Any deficiencies found during the as-built inspection shall be promptly addressed and corrected.

### **18.5. Cost**

The initial cost of permeable pavement structure is usually higher than the cost of traditional pavement structure. The additional costs are from the surfacing and the underlying aggregate bed which is generally thicker than a conventional pavement base. Project costs vary due to the availability of materials, transport costs, project size, installation methods, site conditions and design goals.

When conducting a cost analysis for the site, consider savings from eliminating or reducing cost from traditional conveyance systems, such as, curbs, gutters, and storm drains. In addition, since permeable pavement can be used as a BMP, it can reduce or eliminate the need for other stormwater BMPs and provide land normally designated for stormwater management. Long-term maintenance costs should also be considered. Overall, permeable pavement as a stormwater management measure may yield significant long-term savings. However, construction and maintenance costs vary with each project and should be considered for each site.

## 18.6. Maintenance



**Figure 18-24. Preventing clogging is a primary maintenance function.**

Like all other BMPs, permeable pavements require maintenance to provide long-term stormwater benefits. As shown in Figure 18-24, the majority of maintenance efforts are keeping the surface from clogging as well as avoiding pollutants such as deicing salts that might affect groundwater quality. Regular inspection will determine whether the pavement surface and reservoir are functioning as intended.

### 18.6.1 Directions for Maintenance Staff

Communication with maintenance staff is crucial regarding permeable pavement locations and required management practices for keeping pavement unclogged. Maintenance staff must:

- Clean the surface with portable blowers frequently, especially during the fall and spring to remove leaves and pollen before they irreversibly reduce the pavement's surface permeability.
- Not stockpile soil, sand, mulch or other materials on the permeable pavement. Not wash vehicles parked on the permeable pavement.
- Place tarps to collect any spillage from soil, mulch, sand or other materials transported over the pavement.
- Cover stockpiles of same near the permeable pavement.
- Bag grass clippings or direct them away from the permeable pavement.
- Not blow materials onto the permeable pavement from adjacent areas.
- Not apply sand during winter storms.
- Immediately remove any material deposited onto the permeable pavement during maintenance activities. Remove large materials by hand. Remove smaller organic material using a hand-held blower machine.
- Remove weeds growing in the joints of PICPs by spraying them with a systemic herbicide such as glyphosate and then return within the week to pull them by hand.

After the weeds are removed from paver joints, the pavement shall be swept (with a vacuum sweeper if possible) to remove the sediment and discourage future weed growth.

### **18.6.2 Future Construction Projects**

If not properly managed, future construction projects on a permeable pavement site can convey sediment to its surface. In order to prevent pavement clogging from future construction projects, the owner or prime contractor shall insure that the contractors on the site:

- Route construction traffic away from the permeable pavement. Sediment from muddy tire tracks can be deposited on the pavement and sometimes the equipment may exceed the loading pavement loading capacity.
- Install and frequently inspect erosion and sediment controls.
- Inspect the site to insure new grading patterns do not result in the pavement receiving run-on from landscaped areas especially with bare soil. If this occurs, then the site requires regrading. After re-grading, disturbed areas shall be promptly stabilized with vegetation.
- Schedule cleaning with a regenerative air or vacuum street sweeper during and after construction.

### **18.6.3 Snow and Ice Management**

Permeable pavement can be more effective at melting snow and ice than conventional pavements. When snow and ice melts, the water infiltrates into the aggregate base rather than staying on the pavement surface and refreezing. Therefore, light snow and ice accumulation generally do not require removal. The base and soil act as a heat sink which helps drain water before it freezes and slows the rate of surface freezing.

For larger accumulations of snowfall, sand shall never be applied on or adjacent to permeable pavement in order to avoid surface clogging. In addition, pollutants such as deicing materials and fertilizer shall not be applied to (non-grassed) pavement surfaces because these chemicals infiltrate through the aggregate base to the subgrade and possibly to the groundwater.

PICP, PC and PA can be plowed like conventional pavements. For CGP and PTRG, the blade should be set about 1 in. higher than usual to avoid damaging them. A rubber strip can also be applied to the blade to protect them. Piles of plowed snow shall not be placed upon permeable pavement surfaces to avoid concentrations of dirt and sediment when the snow eventually melts.

### **18.6.4 Testing the Pavement Surface Infiltration Rate**

The simplest way to see if permeable pavement is infiltrating rain is to look for puddles during and after a storm. Permeable pavement should not have puddles; puddles are a sure sign of surface clogging.

Because inspection and maintenance activities may not always coincide with rain events, NCSU developed a simple infiltration test to evaluate pavement surface clogging severity and extent. Simple Infiltration Test procedures are available at the [DWQ's web site for permeable pavement](#).

The Simple Infiltration Test shall be done on all permeable pavement applications at least one time a year, except for single family residential lots with a total permeable pavement area of under 2,000 sf. Whenever the Simple Infiltration Test indicates that maintenance is needed, the design professional shall work with the owner to:

- Determine the cause of the permeable pavement clogging and correct it. Previous sections with instructions for maintenance staff, future construction projects, and snow and ice management may assist in evaluating the cause of clogging. Efforts to renovate the clogged pavement are short lived unless the underlying problems are addressed.
- Vacuum the pavement in accordance with the next section.
- Check the observation wells to insure that the pavement is not clogging beneath the surface.

### 18.6.5 Surface Cleaning

Surface cleaning is required whenever puddles are present or surface infiltration testing indicates that one or more areas on a permeable pavement application are clogged. The DWQ recommends vacuum cleaning the entire pavement area rather than only the clogged portion since the majority of the expense is equipment mobilization. Owners are encouraged to clean PC and PA on an annual, or more frequent basis, because surface infiltration is very difficult to restore after it has become clogged, and the surface replacement is expensive.

The three main types of street cleaners are described below: mechanical, regenerative air and vacuum. Vacuum or regenerative air street sweepers are required because they are effective at cleaning the pore spaces in the pavement surface.



**Figure 18-24. Sweeper equipment for cleaning sidewalks**  
Source: NCSU-BAE

Mechanical sweepers are the most common. They come in various sizes for cleaning pedestrian or vehicular pavements, and they generally do not use a vacuum. See Figure 18-24. They employ brushes that initially move litter toward the machine center and lift trash onto a conveyor belt for temporary storage inside the machine. The brush bristles can penetrate CGP, but not other types of permeable pavement. For other pavement types, mechanical sweepers may be used for removing trash, leaves, and other organic material, but the mechanical sweeper is not likely to be effective in removing sediment.



**Figure 18-25. Regenerative air vacuum truck** Source: TYMCO, Inc.

Regenerative air cleaners are the second most common. They work by directing air at a high velocity within a confined box the rides across the pavement. The uplift from the high velocity effectively loosens dust and other fine particles on and near the pavement surface and lifts them into a hopper at the back of the truck. This equipment removes surface-deposited sediments from all pavement types. This equipment is recommended for regular preventive maintenance.



**Figure 18-26. A true vacuum truck can help restore infiltration to severely clogged permeable pavement.**  
Source: NCSU-BAE

Vacuum street cleaners are the least common and most expensive. They apply a strong vacuum to a relatively narrow area that lifts particles both at and below the surface of the pavement. Vacuum sweepers have demonstrated their ability to suction 3 to 4 inches of gravel from PICP and have the ability to restore infiltration to some types of pavements that have been grossly neglected. (Hunt, NCSU-BAE)

Regular PICP cleaning requires operator adjustment of the vacuum force from regenerative air equipment to minimize uptake of aggregate jointing materials. In some cases, the paver joints may require refilling. In contrast, vacuum street cleaners have demonstrated their ability in removing as much as 3 to 4 in. of aggregates from clogged PICP joints that have not received any cleaning for years. This cleaning can restore surface infiltration for PICP as well for other grossly neglected permeable pavement surfaces (Hunt NCSU-BAE).

### 18.6.6 Inspecting Observation Wells

The observation well allows the owner to determine how well the aggregate base and underdrains are functioning. Follow these steps to inspect the observation wells:

- Wait five days after a rainfall exceeding 1 in. or 1.5 in. if in a Coastal County. If no additional rain occurs in the five days, open each observation well.
- Visually assess whether water is present. If visual assessment isn't possible, use a yard stick or other water-level measurement method.
- If water is present, the soil subgrade is clogged and/or underdrains are not functioning. Note the locations of the observation wells with water present.
- The owner (or site manager) should consult the designer or other appropriate professional regarding possible remedies.

The designer or other appropriate design professional determines the actions needed to restore the BMP so that it functions and achieves regulatory credit. For a detention system, this may require repair of underdrains or other infrastructure. For an infiltration system, this shall require subgrade infiltration rate investigation and may lead to redesign or replacement.

**18.6.7 Pavement Cracking**

Cracked areas shall be repaired using the same materials as the original permeable pavement or, in the case of PC and PA small areas can be replaced with standard (impermeable) materials. The impervious repaired area shall not to exceed 5% of the total surface area. Figure 18-27 shows a small concrete patch in a PC area. Larger repaired areas shall be made from materials that infiltrate rain water in a similar manner as the original surface. Pavement that has buckled or shown major instability may require a major renovation or replacement. In this case, consult a pavement professional.



**Figure 18-27. Patching areas of permeable pavement with impervious material shall not exceed 5% of the total area.**

Asphalt sealcoats or overlays that eliminate surface permeability shall not be used.

**18.6.8 Required Operation and Maintenance Provisions**

After permeable pavement is constructed, it shall be inspected **once a quarter**. The inspector shall check each BMP component and address any deficiencies in accordance with Table 18-4 below. The person responsible for maintaining the permeable pavement shall keep a signed and notarized Operation and Maintenance Agreement and inspection records. These records shall be available upon request.

Once a year, the Simple Infiltration Test shall be performed and any deficiencies in surface permeability shall be addressed as described in Sections 18.6.4 and 18.6.5.

At all times, the pavement shall be kept free of:

- Debris and particulate matter through frequent blowing that removes such debris, particularly during the fall and spring.
- Piles of soil, sand, mulch, building materials or other materials that could deposit particulates on the pavement.
- Piles of snow and ice.
- Chemicals of all kinds, including deicers.



**Table 18-4  
Inspection Process and Required Remedies**

<b>BMP element:</b>	<b>Potential problem:</b>	<b>How to remediate the problem:</b>
<b>The perimeter of the permeable pavement</b>	Areas of bare soil and/or erosive gullies	Regrade the soil if necessary to remove the gully, then plant ground cover and water until established.
	A vegetated area drains toward the pavement.	Regrade the area so that it drains away from the pavement, then plant ground cover and water until established.
<b>The surface of the permeable pavement</b>	Trash/debris present	Remove the trash/debris.
	Weeds	Do not pull the weeds (may pull out media as well). Spray them with a systemic herbicide such as glyphosate and then return within the week to remove them by hand. (Another option is to pour boiling water on them or steam them.)
	Sediment	Vacuum sweep the pavement.
	Rutting, cracking or slumping or damaged structure	Consult an appropriate professional.
<b>Observation well</b>	Water present more than five days after a storm event	Clean out clogged underdrain pipes. Consult an appropriate professional for clogged soil subgrade.
<b>Educational sign</b>	Missing or is damaged.	Replace the sign.

**18.7. Resources**

ACI Committee 522, *Report on Pervious Concrete*, American Concrete Institute, Farmington Hills, MI, ACI 522R-10, March 2010.

Brown, R.A., Hunt, W.F., *Urban Waterways: Improving Exfiltration from BMPs*, North Carolina Cooperative Extension, AG-588-17W, 2009

Hansen, K., *Porous Asphalt Pavements for Stormwater Management*, National Asphalt Pavement Association, Information Series 131, Lanham, Maryland, 2008.

Hunt, W. F., *Urban Waterways: Maintaining Permeable Pavements*, North Carolina Cooperative Extension, Raleigh, NC, AG-588-23, 2008

Leming, M. L., Malcom, H. R., and Tennis, P. D., *Hydrologic Design of Pervious Concrete*, EB303, Portland Cement Association, Skokie, Illinois, and National Ready Mixed Concrete Association, Silver Spring, Maryland, USA, 2007.

Smith, D.R., *Permeable Interlocking Concrete Pavements*, Fourth Edition, Interlocking Concrete Pavement Institute, Herndon, Virginia, 2011.

Tyner, J. S., W. C. Wright, and P. A. Dobbs. 2009. Increasing exfiltration from pervious concrete and temperature monitoring. *J. Environ. Manage.* 90(8): 2636-2641.

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**September 28, 2007 Changes:**

1. Major Design Elements:
  - i. Reformatted to include numbered requirements.
  - ii. Corrected the wording referring to the fraction of impervious surfaces used in the Simple Method. The Simple Method is no longer referenced.
  - iii. Deleted the incorrect formatting in the word “pavement”.

September 1, 2010 Changes:

1. Removed requirement to reduce credit by 50% when draining to SA waters.
2. Clarified permeable pavement slope requirements at the surface and subgrade; added figures 18-4 and 18-5.

October 16, 2012 Changes:

The chapter has been completely re-written to allow permeable pavements to be used throughout the state over a wide array of soil types. The BUA (Built-Upon Area) reduction credit for permeable pavements has been revised and, for the first time, permeable pavements can be used to receive pollutant removal credit. With these changes, there is a greater responsibility for designing, installing, and maintaining permeable pavements for successful long-term operation. The document includes considerably more technical guidance than in the previous chapter. The chapter now:

1. Allows permeable pavement to be used throughout the state and receive stormwater credit. (Credit for permeable pavement was previously limited to the Coastal Plain/Sandhills areas and soils with a minimum of 0.52 inches/hour infiltration rate.)
2. Provides a design option for pavement that detains (rather than infiltrates) stormwater for soils with very low permeability or where other extenuating circumstances exist (such as contaminated soils/groundwater). Permeable pavements receive customized stormwater credits depending on whether they are designed for infiltration or detention of stormwater.
3. Expands BUA reduction credit from 60% maximum to 75% maximum. Permeable pavement designed to infiltrate stormwater in Hydrologic Soil Groups (HSGs) A and B now receives credit as 75% pervious and 25% impervious. Permeable pavement designed to infiltrate stormwater in HSGs C and D now receives credit as 50% pervious and 50% impervious.

4. Allows permeable pavement to treat other BUA from the site that drains to it (the ratio of additional BUA to permeable pavement area may not exceed a 1:1 ratio). Most pavement systems receive credit for 85% TSS removal.
5. Requires a site-specific soil infiltration rate test for design purposes.
6. Maintains the requirement for 2' separation between the bottom of the pavement system and the seasonal high water table but added methods to reduce that separation requirement if additional soils data is available.
7. Recommends that designers use Pervious Concrete (PC), Porous Asphalt (PA) or Permeable Interlocking Concrete Pavers (PICP) as a surface course for permeable pavement (based on field observations of permeable pavement applications in North Carolina). Other surface courses may be used but the designer is responsible for showing that they will work effectively.
8. Adds several design equations for calculating parameters such as ponding time and aggregate depths for both the Water Quality Storm and the 10-year, 24-hour storm.
9. Requires observation well(s) on all sites except for single family residential lots with a total permeable pavement area under 2,000 sf to enable monitoring of performance.
10. Requires that permeable pavements shall be designed to provide safe bypass of the 10-year, 24-hour storm. The 10-year, 24-hour storm may also be infiltrated or detained.
11. Includes a detailed section on construction.
12. Requires signs for permeable pavement sites (except single family residential) to emphasize the importance of proper management.
13. Requires maintenance inspections on all permeable pavement systems after construction and periodically throughout the life of the pavement.
14. Requires a surface infiltration rate test to be performed annually to assure pavement is infiltrating.
15. Revises the requirement for annual street sweeping and now requires sweeping only when maintenance activities indicate problems with surface clogging.
16. Includes many additional photos and diagrams throughout the chapter to assist in the design and construction process.