C-5. Permeable Pavement

Design Objective

Permeable pavement 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.

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 development 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.

Design Volume

The design volume for an infiltrating pavement system is equivalent to the volume that is stored in the aggregate and infiltrated into the ground within a 72-hour period. The design volume for a detention pavement system is the volume that is release slowly from the aggregate for a two to five-day period.

Important Links

Rule 15A NCAC 2H .1055. MDC for Permeable Pavement

SCM Credit Document, C-5. Credit for Permeable Pavement

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Built-upon Area Credit for Infiltrating Pavement

Infiltrating permeable pavement that is designed per the MDC may be considered as 100% pervious for the following purposes:

1. On new projects: As a tool to keep a project below the BUA threshold for high density or to reduce the volume of the SCM that is treating the balance of the project.

2. On existing projects: As a tool to add a driveway, parking area, road, patio or other paved area while still adhering to a BUA restriction imposed by development covenants, SCM design or permit conditions.

The BUA credit for infiltrating permeable pavement cannot be used to create an exemption from the permit requirements in 15A NCAC 02H .1019(2)(c) [Coastal Stormwater Requirements], because the permeable pavement must be reviewed to determine whether it meets the MDC.

Figure 1. Permeable Pavement Example: Cross-Section (NCSU-BAE)

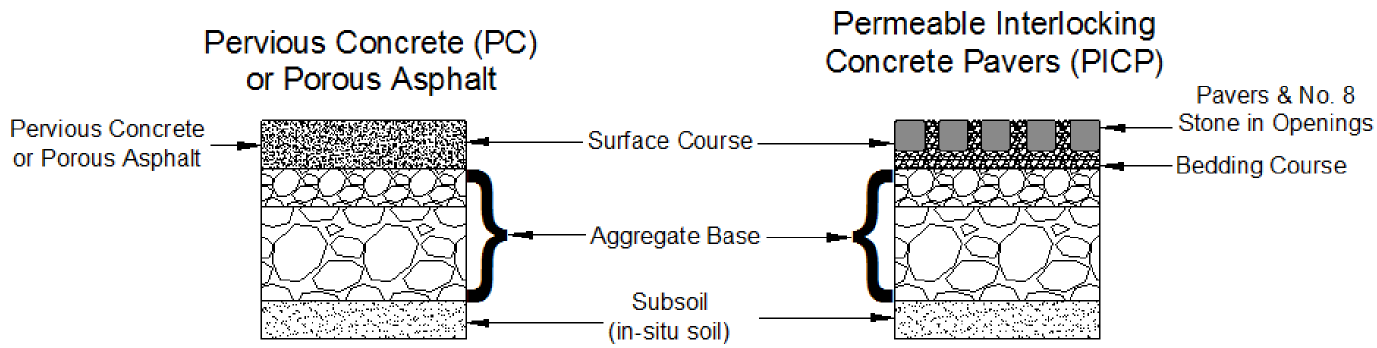
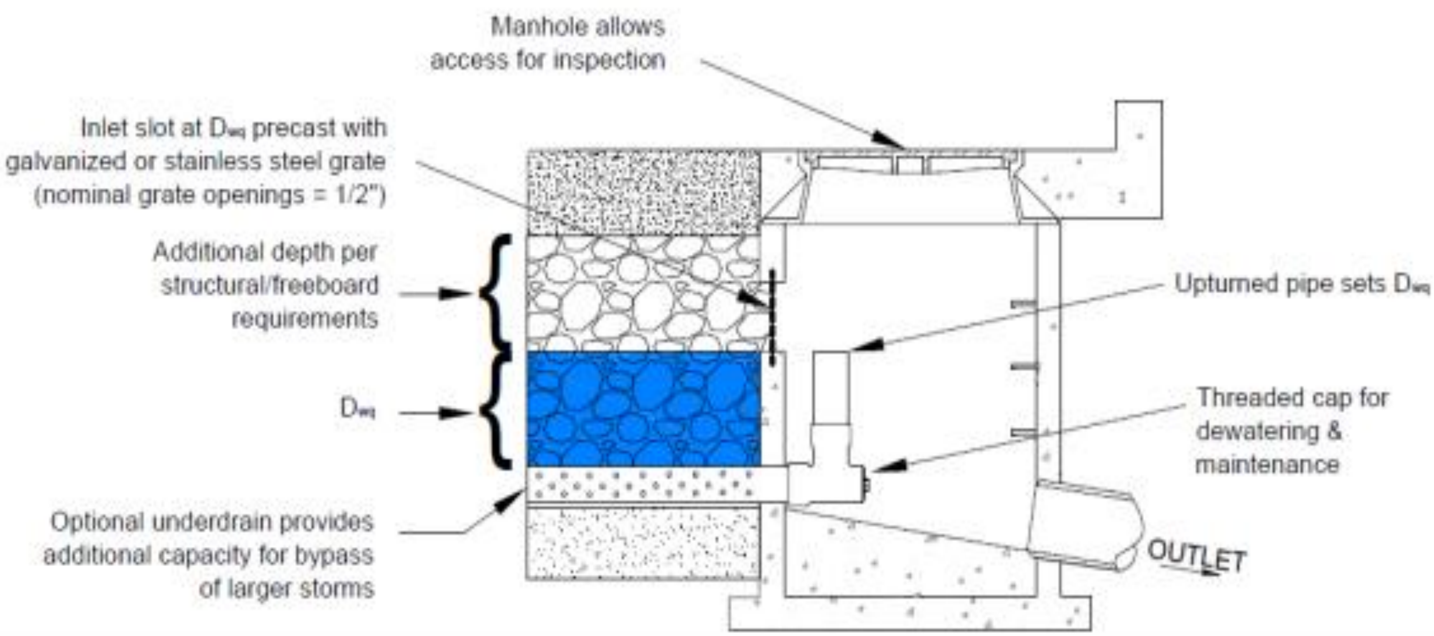


Figure 2. Permeable Pavement Example: Outlet for Infiltration System (NCSU-BAE)



Guidance on the MDC

PERMEABLE PAVEMENT MDC 1: SOIL INVESTIGATION
For infiltrating pavement systems, site-specific soil investigation shall be performed to establish the hydraulic properties and characteristics within the proposed footprint and at the proposed elevation of the permeable pavement system.

Guidance on soil testing is provided in Chapter A-2.

PERMEABLE PAVEMENT MDC 2: SHWT REQUIREMENTS
The minimum separation between the lowest point of the subgrade surface and the SHWT shall be:

(a) two feet for infiltrating pavement systems; however, the separation may be reduced to no less than one foot if the applicant provides a hydrogeologic evaluation that demonstrates that the water table will subside to its pre-storm elevation within five days or less; and

(b) one foot for detention pavement systems.

Guidance on soil testing and hydrogeologic evaluation is provided in Chapter A-2.

PERMEABLE PAVEMENT MDC 3: SITING
Permeable pavement shall not be installed in areas where toxic pollutants are stored or handled.

Permeable pavement shall not be used in areas where concentrations of 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.

Table 1: Hot Spots Where Permeable Pavement may not be Appropriate

Fueling facilities	SIC code “heavy” industries	Commercial car washes
Fleet storage	Airport maintenance areas	Public works yards
Trucking & distribution centers	Wastewater treatment plants	Road maintenance areas
Vehicle maintenance areas	Racetracks	Scrap yards
Solid waste facilities	Railroads and bulk shipping	Landfills

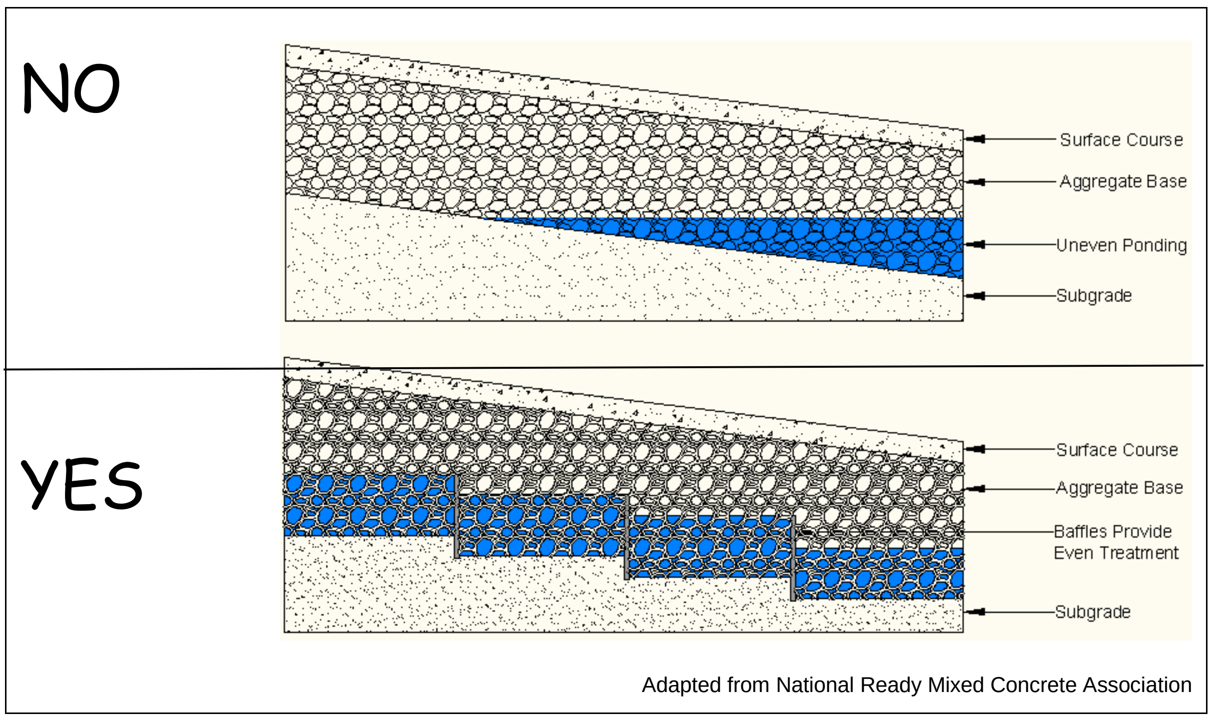
Care should be taken when implementing permeable pavement at redevelopment sites. Stormwater shall not be infiltrated into contaminated soils because this can cause dispersion of toxic substances to other sites and to groundwater. However, a permeable pavement system designed for detention may work on 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 DEQ recommends that the designer consult with an appropriately licensed NC professional.

PERMEABLE PAVEMENT MDC 4: SOIL SUBGRADE SLOPE
The soil subgrade surface shall have a slope of less than or equal to two percent.

Whether is the pavement is designed for infiltration or detention, it is crucial that the subgrade be almost flat, i.e., less than or equal to a 2% 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 3 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 3. Terraces and Baffles under Permeable Pavement. (NCSU-BAE)



PERMEABLE PAVEMENT MDC 5: STONE BASE
Washed aggregate base materials shall be used.

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. If the aggregate is not washed, then the fines that are interspersed with it will eventually was to the top of the subgrade and possibly clog the in-situ soils, preventing infiltration. 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 only way to be certain that the aggregate has been washed is to be present on the site when it is delivered.**

Equation 1 can be used to determine the depth of aggregate needed for the design volume. Please note that the bedding layer of aggregated in a PICP system may not be used to provide storage for the water quality storm.

Equation 1: Aggregate Depth for the Design 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, ratio of the additional BUA to permeable pavement area
N = Percent voids, unitless decimal (from ASTM C29)

PERMEABLE PAVEMENT MDC 6: PAVEMENT SURFACE
The proposed pavement surface shall have a demonstrated infiltration rate of at least 50 inches per hour using a head less than or equal to 4 inches.

The pavement surface should be selected based on the desired appearance and 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 2 below for a summary of the most commonly used pavement courses and some pros and cons of each.

Table 2: Permeable Pavement Types

Type of Pavement	DEQ Guidance
Permeable Interlocking Concrete Pavers (PICP) 	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. **Pros:** Well suited for plazas, patios, small parking areas and stalls, parking lots and residential streets. PICP can be designed for a significant load 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. **Cons:** 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.
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 like conventional (impervious) asphalt except that less fine material is used in the mixture to provide for drainage, resulting in has a coarser appearance than conventional asphalt. A modified asphalt binder as specified by the Carolina Asphalt Pavement Association (CAPA) shall be used to ensure long term durability and permeability. **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. **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 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 CGP 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.

PERMEABLE PAVEMENT MDC 7: RUNOFF FROM ADJACENT AREAS

Runoff to the permeable pavement from adjacent areas shall meet these requirements:

(a) The maximum ratio of additional built-upon area that may drain to permeable pavement is 1:1. Screened rooftop runoff shall not be subject to the 1:1 loading limitation.

(b) Runoff from adjacent pervious areas shall be prevented from reaching the permeable pavement except for incidental, unavoidable runoff from stable vegetated areas.

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. Impervious areas may 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. 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).

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.

PERMEABLE PAVEMENT MDC 8: DRAWDOWN TIME
Infiltrating permeable pavement systems shall be designed to dewater the design volume to the bottom of the subgrade surface within 72 hours. In-situ soils may be removed and replaced with infiltration media or infiltration media may be placed on top of in-situ soils if the applicant provides a soils report demonstrates that the modified soil profile allows for infiltration of the design volume within 72 hours.

Before determining drawdown time, the designer should first determine if the site is appropriate for infiltration. In areas where in-situ soils become unstable when saturated, have high shrink-swell tendencies or there is contamination of groundwater or soils, a detention system should be used.

For infiltrating pavement, the designer may use the soil test results to calculate the drawdown time for the depth of stormwater that will be conveyed to the pavement system using Equation 2 below.

Equation 2: Drawdown Time

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

where:

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

If the drawdown time exceeds three 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 will require a detention pavement system that detains the stormwater for two to five days. For any site where the stormwater is not predicted to infiltrate within 48 hours, the DEQ advises consulting a geotechnical engineer to ensure that structural pavement design issues are properly addressed.

PERMEABLE PAVEMENT MDC 9: OBSERVATION WELL
Permeable pavement shall be equipped with a minimum of one observation well placed at the low point in the system. If the subgrade is terraced, then there shall be one observation well for each terrace. Observation wells shall be capped.

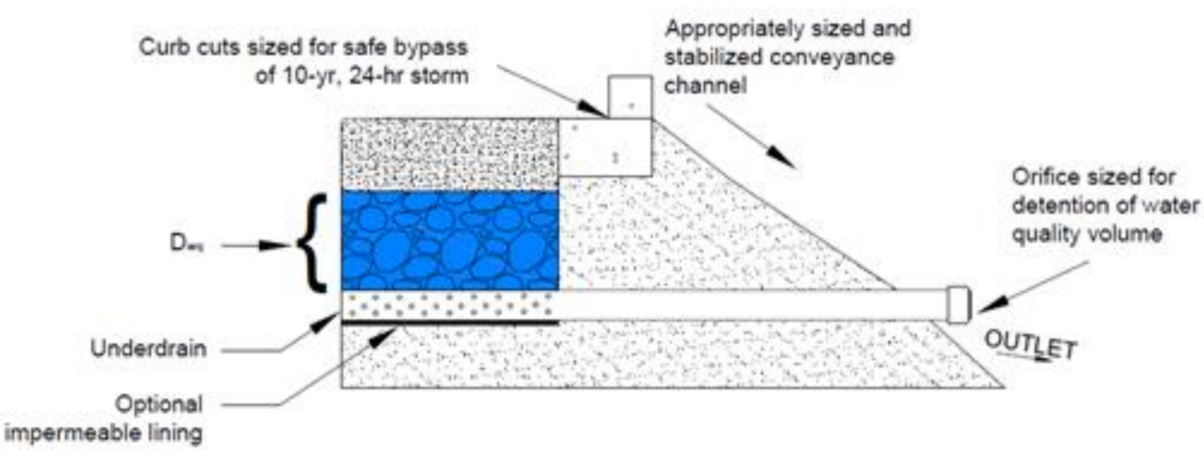
An observation well enables the owner to measure the depth of standing water in the permeable pavement system. Observation wells shall be fitted with a lockable cap installed placed even with the pavement surface to facilitate quarterly inspection.
Observations of the water depth throughout the estimated ponding time (T) indicate the rate of water infiltration. The observation well shall consist of a rigid 4 to 6-inch diameter perforated PVC pipe. The lower end of the PVC pipe should be placed below the elevations of the subgrade surface; therefore, the elevation of water within the pipe will match the elevation of water within the stone base.

Figure 4. Observation Well

PERMEABLE PAVEMENT MDC 10: DETENTION SYSTEMS
Pavement systems may be designed to detain stormwater in the Updated July 19, 2016 aggregate for a period of two to five days.

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.

Figure 4. Permeable Pavement Example: Outlet for Detention System (NCSU-BAE)



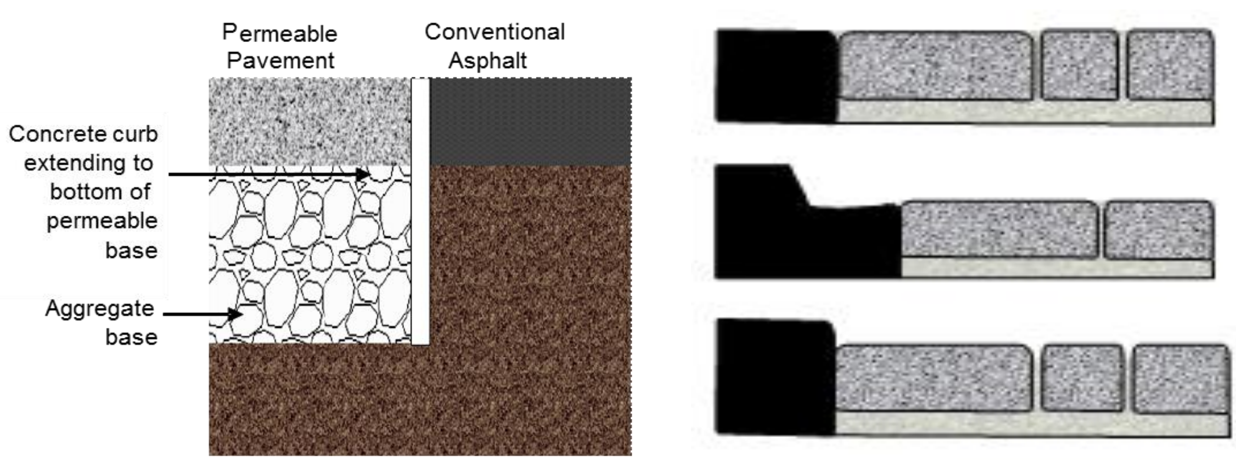
PERMEABLE PAVEMENT MDC 11: EDGE RESTRAINTS
Edge restraints shall be provided around the perimeter of permeable interlocking concrete pavers (PICP) and grid pavers.

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. The structural edge of PA systems can be enhanced by an edge restraint; they are recommended for PA, but not required.

Figure 5. Edge Restraints on PICP

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. In addition to providing structural support, the PICP can provide an attractive edge. See Figure 6 below for examples of acceptable edge restraints.

Figure 6. Edge Restraints: Example Cross-Sections



In addition to concrete edge restraints, an important consideration is the boundary between permeable and conventional pavement. 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. Concrete curbs provide more separation between the pavement courses, which is 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.

PERMEABLE PAVEMENT MDC 12: GRADE WHEN DRY
The soil subgrade for infiltrating permeable pavement shall be graded when there is no precipitation.

Grading soils when they are wet is almost certain to cause a severe decrease in the soil infiltration rate and might result in a failure of the permeable pavement system.

PERMEABLE PAVEMENT MDC 13: INSPECTIONS AND CERTIFICATIONS
After installation, permeable pavement shall be protected from sediment deposition until the site is completed and stabilized. An in-situ infiltration permeability test shall be conducted and certified on the pavement after site stabilization.

After installation, a final as-built inspection and certification should be performed 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 that are discovered shall be promptly addressed and corrected.

Recommendations

PERMEABLE PAVEMENT RECOMMENDATION 1: SIGNAGE
Provide signage to encourage proper maintenance of permeable pavement.

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 8 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 DEQ 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.

The owner should consider whether this sign should also be provided in Spanish.

Figure 9. Example Sign Layout

***PERMEABLE PAVEMENT RECOMMENDATION* 2: GEOGRIDS, GEOTEXTILES, AND GEOMEMBRANES**
Geogrids and geotextiles may be used in accordance with manufacturer and designer recommendations. Geomembranes are not recommended on infiltration designs but may be used on detention designs.

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 (permeable) 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 (impermeable) 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 feet 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.

PERMEABLE PAVEMENT RECOMMENDATION 3: DISCUSSION 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.

PERMEABLE PAVEMENT RECOMMENDATION 4: CONSIDER STRUCTURAL STRENGTH
The manual and rules do not provide structural design guidance of permeable pavements subject to vehicular traffic. 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.

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.

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 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.

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.

The final subgrade slope shall not exceed 0.5%. The slope of the subgrade shall be checked before proceeding. **Where possible, excavate soil from the sides of the pavement area to minimize subgrade compaction from equipment.** 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 feet 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.

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 course sand and 11½ in. of ASTM No. 67 aggregate (Brown and Hunt 2009).

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.

Figure 10. Good Construction Practices, from left to right: Grading from the Side (NCSU), Scarifying the Subgrade (Tyner), Trenching the Subgrade (Tyner)

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. If the soil infiltration rate has diminished so that a 72-hour drawdown time is no longer possible, then rip or trench the subgrade further to restore the original infiltration rate.

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.

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

Place the catch basins and observation wells per 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 11.

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 11. Upturned Elbow (NCSU-BAE)

Construction Step 7: Place and Compact Aggregate Base

Inspect all aggregates to insure they are free of fines and conform to design specifications. If aggregates delivered to the site cannot be immediately placed, then they should be stockpiled on an impervious surface or geotextile to keep the aggregate free of sediment.

Before placing the aggregate base, remove any accumulation of sediments on the finished soil subgrade using 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-inch 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.

Figure 12. Aggregate Placement and Compaction (NCSU-BAE)

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. 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 12. 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.

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.

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 13. 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 13. Upturned Elbow (NCSU-BAE)

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 14. Compacting Pervious Concrete (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.

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.

Maintenance

Like all other SCMs, permeable pavements require maintenance to provide long-term stormwater benefits.

As shown in Figure 15, 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.

Figure 15. Clogged Pavement

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.

Future Construction Projects

If not properly managed, future construction projects on a permeable pavement site can convey sediment to its surface. 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.

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 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.

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 NCSU's Stormwater Group Web Site.

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 ensure that the pavement is not clogging beneath the surface.

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. DEQ recommends vacuum cleaning the entire pavement area rather than only the clogged portion since most 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 16. Mechanical Sweeper (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 16. 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 17. Regenerative Air Cleaner (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. Vacuum Truck (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 can 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).

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.

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

Figure 19. Pavement Patch

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.

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 3: Inspection Process and Required Remedies

BMP element:	Potential problem:	How to remediate the problem:
The perimeter of the permeable pavement	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.
The surface of the permeable pavement	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.
Observation well	Water present more than five days after a storm event	Clean out clogged underdrain pipes. Consult an appropriate professional for clogged soil subgrade.
Educational sign	Missing or is damaged.	Replace the sign.

Old Versus New Design Standards

The following is a summary of some of the changes in permeable pavement design standards between the archived version of the BMP Manual and the current MDC for permeable pavement. It is intended to capture the highlights only; any permeable pavement MDC that are not captured in this table are still required per 15A NCAC 02H .1055.

	Old manual requirements	New MDC
Additional BUA directed to permeable pavement	1:1 maximum ratio between pavement area and contributing drainage area. Runoff from pervious areas may not be directed to pavement.	1:1 maximum ratio; however, screened rooftop runoff is not subject to the 1:1 loading limitation. Runoff from pervious areas may not be directed to pavement except for small, unavoidable areas.
BUA credit	Infiltrating permeable pavement in A and B soils considered to be 75% pervious, 25% impervious. In C and D soils, considered to be 50% pervious, 50% impervious	Infiltrating permeable pavement considered to be 100% pervious in all soils
Slope of the subgrade surface	May not be greater than 0.5%	May not be greater than 2%
Minimum pavement surface infiltration rate for maintenance	Not specified	50 inches/hour must be maintained.
Signage	Required	Recommended

Resources

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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.

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