Permeable Pavement (PP)

Permeable Interlocking Concrete Pavers; Orange Beach, AL

Site Selection	
Quantity Control	possible
Drainage Area	small
Space Required	small
Works with:	
Steep Slopes	---
Shallow Water Table	---
Poorly Drained Soils	---

General Significance	
Construction Cost	high
Maintenance	med
Community Acceptance	high
Habitat	low
Sun / Shade	either

Synonyms: Pervious pavement, modular paving systems, enhanced porosity concrete, porous pavement, modular plastic permeable paving

Permeable pavement is a pervious surface used in place of traditional concrete or asphalt to infiltrate stormwater. Permeable pavement provides a volume reduction of stormwater runoff through temporary storage. It can be used to reduce peak flows and promote stormwater infiltration in urbanizing watersheds. The application of permeable pavement reduces impervious surface area runoff, which has been linked to streambank erosion, flooding, nonpoint source pollution, and other water quality impairments.

Permeable pavement refers to any pavement that is designed to temporarily store stormwater in a gravel base layer. Stormwater is held in the gravel base layer, or subbase, before leaving the system through exfiltration into surrounding soils or through an underdrain. These systems are suitable for residential driveways, walkways, overflow parking areas, and other low traffic areas that might otherwise be paved as an impervious surface. Permeable pavement can be less expensive than conventional stormwater management practices (i.e. detention basins) due to the decreased need for curb and gutter, stormwater ponds, and catch basins. The failure potential is high when these systems are not designed, constructed, or maintained properly.

Site Selection

Low Traffic Areas: Areas with less than 100 vehicles traveling on them per day are best suited for permeable pavements, as most types cannot structurally support constant traffic or heavy vehicles. When pervious concrete (PC) is sited on high traffic areas, surface raveling or degradation can occur due to vehicles frequently driving back and forth over the surface.

Evaluating Soils: Use the USDA Web Soil Survey to identify soil map units and to make initial interpretations for potential uses and limitations of a site. However, since most soil map units have inclusions of other soils that may be quite different, detailed evaluations should be made at the proposed site by a professional soil scientist or soil classifier. On-site evaluations should properly identify a soil or the hydrologic soil group (HSG) and the final

USDA's online Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm) can be used as a guide to determine the needed soil information for the site, such as the hydrologic soil group (HSG) and depth to water table.

Table 4.3.1
Site Selection: Constraints and Limitations for Permeable Pavement

Constraint	Recommendations
Insufficient Sub-grade Infiltration Rate (<0.5”/hr)	Use other SCM; poorly drained soils are not appropriate for permeable pavement
High Traffic Areas	Use other SCM that can structurally support heavy vehicles, or check with manufacturer of permeable interlocking concrete pavers (PICPs) for structural support limits
Slope	Slopes greater than 2% are not recommended
High Sediment loads	Permeable pavement should not experience high sediment loads that risk clogging system
Heavily Landscaped Areas Adjacent	Maintenance frequency must increase when permeable pavement is sited adjacent to messy vegetation since the system has a higher potential to clog
Regional Stormwater Control	Use another SCM
Reduction in Total Suspended Solids (TSS)	Due to the risk of surface clogging, permeable pavement is not currently designed to capture sediment or reduce TSS

decision for use should be made based on the detailed determination of soil series or HSG. For a detailed list of HSG properties, see Table A.3 in Appendix A on Stormwater Hydrology.

In-situ Soil: Soils should have a minimum infiltration rate of 0.5”/hr as determined by an infiltration test at the initial site visit (see Chapter 5.1 on Rain Gardens for more information on an infiltration test). An underdrain should be used when soils have an infiltration rate of ≤ 0.5”/hr. Suitable soils for this practice are well-drained and have a texture no finer than a loamy very-fine sand. Sandy soils are preferred for permeable pavements because finer textured clay soils do not provide enough structural support. To compensate for clay soils, the gravel base layer can be thicker to provide increased structural support. Placing permeable pavement on fine textured soils (high clay content) can also result in standing water on the surface of the pavement due to inhibited infiltration, which will degrade the surface over time and pose a safety hazard. United States Department of Agriculture (USDA) and Natural Resources Conservation Service (NRCS) hydrologic soil groups (HSG) C and D are not appropriate for permeable pavements, as these usually have greater than 30% clay content and are not well-drained. Sites with a high clay content of 20% or more should be designed with adequate underdrains.

Depth to Groundwater: The runoff volume captured by the system should drain away from the underlying soil within 24 to 48 hours. Additionally, the seasonally high water table should be a minimum of 2’ below the permeable pavement base to allow water to properly exfiltrate from the system and to avoid leaching of captured pollutants into groundwater. To prevent groundwater contamination, permeable pavement is not recommended to treat runoff from a “hotspot”, industrial, or commercial areas that may have potentially high concentrations of soluble pollutants or pesticides.

Commercial or Industrial Sites: Areas considered unsuitable for treatment using these systems include: commercial plant nurseries, industrial rooftops, fueling stations, marinas, loading or unloading zones, vehicle service or maintenance areas, public works storage areas, auto recycle facilities, and similar locations.

Impervious Surface Area: Runoff directed to permeable pavement should be from impervious surface areas. The ratio of impervious surface area to the permeable pavement surface area should not be greater than 3:1.

Site Specific Constraints: Permeable pavement should be sited at least 10’ downslope from buildings and 100’ from drinking water wells.

Slope: Slopes greater than 2% are not recommended for permeable pavement. In some jurisdictions, recommendations are less stringent with suggestions of 6% slope or less in North Carolina (less than 0.5% bottom slope) and no greater than 5% in Knox County, Tennessee. Steep slopes can limit storage capacity of permeable pavement systems; however, partitions or baffles can be used to terrace the subgrade to promote infiltration throughout the entire system.

Adjacent Vegetation: Vegetated or other nearby pervious surfaces should be stabilized and not contribute sediment to the permeable pavement surface. Heavily wooded areas adjacent to permeable pavement systems can also be problematic due to excessive debris such as sticks and leaves being ground into the pavement by vehicles and foot traffic. For the same reason, permeable pavement should not be sited near or under extremely messy or high maintenance vegetation. Designers of these systems should be aware that siting permeable pavement near vegetation results in increased maintenance, especially during fall and winter months.

Common Permeable Pavement Variations

Permeable pavements have similar layers of structural support storage and filtering mechanisms including a choker course, subbase layer (reservoir), filter fabric, and underlying soil. The primary difference in each type of permeable pavement cross section is the top layer or the specific type of porous material selected.

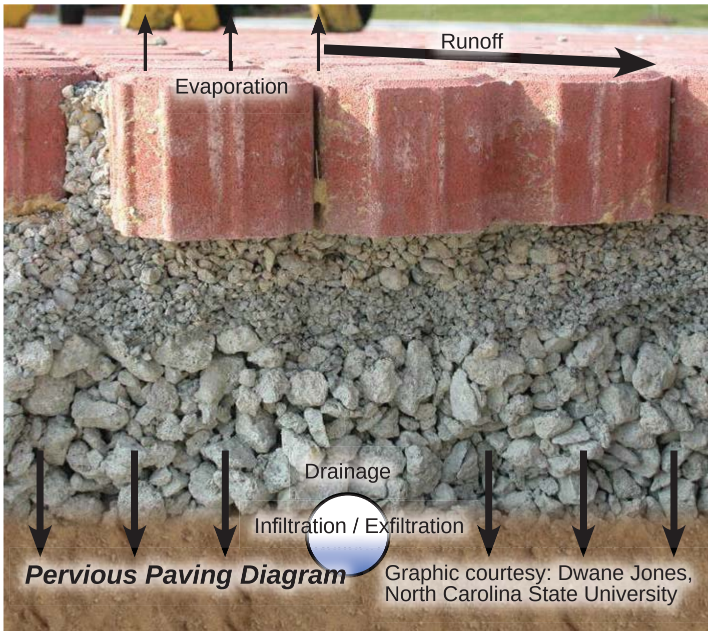
Pervious Concrete (PC): PC is a mixture of coarse washed aggregate, Portland cement, fly ash, and water. The mixture does not contain fine aggregates and their absence creates interconnected void spaces or pores in the mixture to allow for stormwater infiltration, thus making void content a primary component of PC function. Void space for PC should range from 15 – 25% compared to the 5% void space found in traditional concrete. Due to void content, PC does not exhibit compressive strength found in conventional concrete. Following seven days of curing, PC with adequate void content should have a compressive strength of approximately 3,000 pounds per square inch (psi) and an infiltration rate of at least 300”/hr. PC is more widely used in warm climates because it is reported to maintain its consistency during extremely hot weather. PC is appropriate throughout the state of Alabama especially where sandy soils are present.

Porous Asphalt (PA): PA uses fine and coarse aggregates mixed in a bituminous-based binder. Similarly to PC, infiltration occurs in PA through interconnected void spaces. It is suitable to climates that experience winter freezing and thawing due to its ability to hasten snow and ice melt, reducing the amount of salt used during the winter months. Void content should range from 15 – 20% to ensure adequate infiltration. When PA freezes, the void space is maintained and rather than forming a solid block, PA freezes into a porous surface. Continuous infiltration of stormwater aids in reducing freezing and thawing within the subbase layers of the PA, which is expected to decrease frost heaving frequently associated with conventional asphalt. PA is not as strong as conventional asphalt and therefore its placement, design, construction, and installation are essential to its long-term functionality. PA is installed using the same equipment as conventional asphalt; however, compaction should be minimized in order to avoid closing pore spaces. Following installation, PA should not receive traffic for 24 to 48 hours. PA is more expensive compared to conventional asphalt due to the extra cost associated with admixtures; however, PA has shown a lifespan of 30 years, which is double that of conventional asphalt. PA has also been noted to be less expensive compared to PICPs and PC.

Permeable Interlocking Concrete Pavers (PICPs): PICPs are concrete blocks placed with void space between them that are filled with a permeable joint material to encourage infiltration. Void space should range between 8 – 20% of the surface area. These systems are more suited to high traffic areas because they offer the greatest structural strength compared to other permeable pavement types. PICPs do not require any curing and are traffic-ready immediately following installation. The type of PICPs specified is dependent on the strength required by the traffic load of the site. PICPs are available in a variety of shapes, sizes, and colors, and thus are more aesthetically diverse than other permeable pavements. Because the pavers are manufactured and can be installed mechanically, PICPs tend to be more uniform in size and function. Installation is not weather dependent because there is no “plastic” mix that must be monitored for consistency or temperature limitations. PICPs are less expensive compared to conventional concrete and asphalt. Installation and supply costs are noted to be similar for PICPs compared to PC and PA, however, costs spread out over the life of PICPs are noted to be less expensive than PC and PA.

Concrete Grid Pavers (CGPs): CGPs are concrete forms with surrounding void space filled with a fine textured aggregate, sandy loam topsoil and turfgrass, or sand to aid infiltration. Void content ranges from 20 – 50% of the surface area and is dependent on the fill media. Turfgrass is used for these systems due to their shallow roots systems and low overall height. In low traffic situations, CGPs have shown structural support and durability comparable to conventional asphalt.

Plastic Reinforcement Grids (PRGs): PRGs are modular plastic grid units that may be round or honeycomb shaped. These plastic grids provide void spaces, which are either filled with gravel or support turfgrass. Void content is dependent on the fill media. Over time, PRGs may shift



Pervious Paving Diagram

Graphic courtesy: Dwane Jones, North Carolina State University

Pervious Concrete

Porous Asphalt
Courtesy National Center for Asphalt Technology

Permeable Interlocking Concrete Pavers

Concrete Grid Pavers

Plastic Reinforcement Grids

and become lifted out of the soil, especially in parking areas where rear tires sit.

Design

Permeable pavement is typically designed to treat the first flush of the selected water quality design storm. The first flush contains the highest concentration of pollutants, see Appendix A on Stomrwater Hydrology for more information on the first flush. The design storm may be dependent on regulatory requirements.

The porous surface selected should be suitable for its intended application. If it is a load-bearing surface, then the pavers, concrete, or asphalt selected should be designed to support the maximum load. It is preferred that the manufacturer make the site design. Specific design requirements for structural stability are beyond the scope of this handbook. A model such as the Interlocking Concrete Pavement Institute's (ICPI) Permeable Design Pro Software (http://www.icpi.org/node/1298) should be used to determine if the system could structurally perform as needed. The American Association of State Highway and Transportation Officials (AASHTO) Flexible Pavement Method for structural design requirements should also be referenced.

Components

Pretreatment: Pretreatment devices such as vegetated swales or filter strips should be used to capture sediment before it enters the permeable pavement surface. See Chapter 4.4 on Grassed Swales, Infiltration Swales, and Wet Swales.

PC Components: The top layer of PC may be as thick as 8" depending on the design and site requirements. Coarse aggregate that is roughly 3/8" (#8 or #89 stone) should be used in the mixture. The absence of fine aggregates provides the void content necessary for infiltration. Next, there is a top filter layer of choking stone (0.5" diameter aggregate) at a depth of 1 to 2" to help stabilize the PC and provide rapid infiltration into the layer below. The next layer is the subbase/reservoir layer for temporary storage of stormwater. The subbase layer is comprised of 1.5 – 2.5" diameter aggregate (#3 or #2 stone) and typically ranges from 2 – 4' deep, but can be a minimum of 9". The depth of the subbase layer is based on the desired storage volume and on-site infiltration rates. The bottom filter layer consists of either 6" of sand or 2" of 0.5" diameter crushed stone; this layer stabilizes the subbase layer and protects the underlying soils from compaction. All aggregates used in the PC mixture and other layers should be washed. A layer of filter fabric should be placed before any aggregate layers are laid to discourage the migration of soil particles.

PA Components: The first layer is the PA layer and it may be as thick as 7", although 2 – 4" is typical. This layer is followed by a 1 – 2" choker course, which provides a level surface and is comprised of small open-graded aggregate. A subbase or base course (reservoir) beneath this layer helps to increase strength and storage capacity of the PA and is usually 18 – 36" deep. Depth of the subbase is dependent on the amount of storage desired and the expected traffic load. The first 3 – 4" of the subbase should contain ¾" (#57) diameter stones to initiate a high infiltration rate into the lower layer of the subbase. The rest of the subbase should contain ¾ to 2.5" diameter stone. All aggregates used in the PA mixture and other layers should be washed. A layer of geotextile fabric is used as a filter between the subbase and underlying soil, similarly to PC.

PICPs Components: The concrete pavers in PICPs are approximately 3" thick. Spacer bars on PICPs are recommended for mechanically installed pavers and for high traffic areas. Pavers installed manually do not require spacer bars. The openings between the pavers are filled with a 3/8" (#8 or #89) stone; the bedding course below the pavers is typically 1.5 – 2" thick layer of the same size stone. The bedding and joint material should be washed, free of debris, and symmetrically shaped. Below the bedding course is a 4" layer of ¾" (#57) stone to provide an open-graded base. The subbase below is comprised of 2.5" (#2) stone and this depth varies based on the design and existing soil conditions on site. All aggregates used in the layers of PICPs should be washed. A layer of filter fabric is placed between the subbase and the underlying soil.

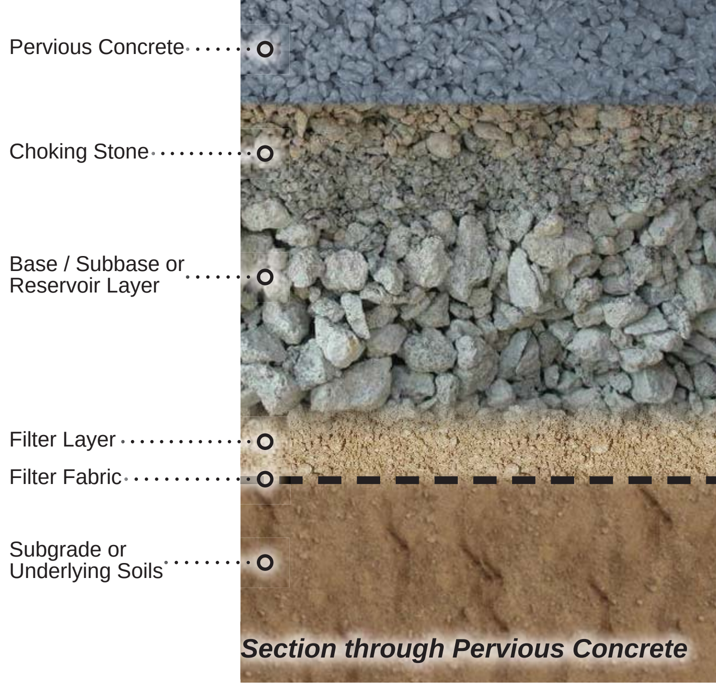
CGPs Components: Grid pavers may use masonry sand or a #10 stone dust with an 8"/hr infiltration rate between the grids for stormwater infiltration. If turfgrass is desired between grids, a sandy loam with a minimum infiltration rate of 1"/hr should be used. Below this layer is a 1" filter layer of masonry sand or #10 stone dust. The reservoir layer is a minimum of 9" and is comprised of 1.5 – 2.5" (#3 or #2) diameter stone. All stone and sand components should be washed and free of debris. The last filter layer is 8" of masonry sand followed by a layer of filter fabric.

PRGs Components: PRGs are placed over fine textured gravel or a sandy loam soil when turfgrass is used. The subbase below uses a well-draining, washed aggregate. The depth of the subbase layer is site dependent and may be a minimum of 9". Filter fabric is placed between the subbase and underlying soil. The structural specifications for these products are highly varied. Most manufacturers can provide specific design and construction information based on their product specifications.

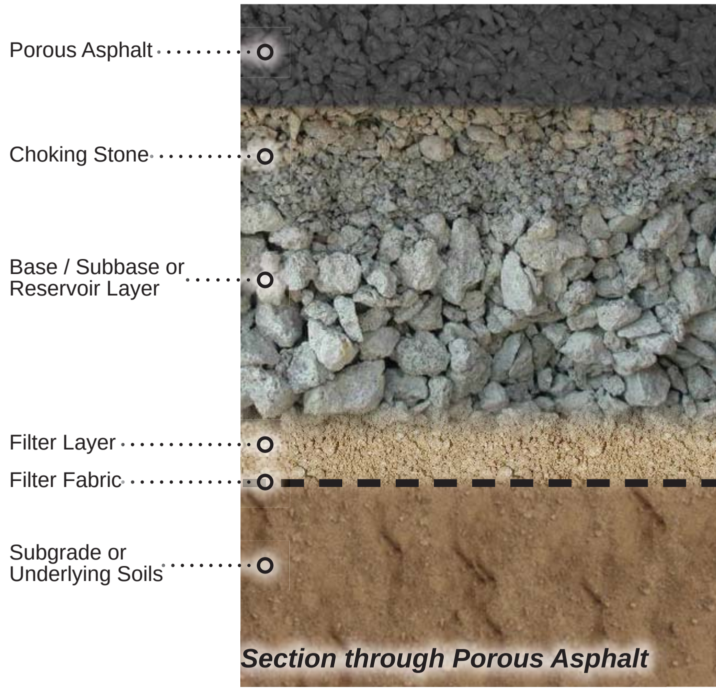
Underdrain: A perforated underdrain system with clean outs should be used for soils with infiltration rates less than 0.5"/hr. Underdrains are typically used when there is a desire to tie into existing stormwater conveyance networks. Perforated PVC pipes are used for underdrains and placed at the subbase layer. A 4-6" perforated or slotted PVC pipe (Schedule 40). A filter fabric "sock" over the underdrain is optional per the design engineer.

Overflow: Stormwater conveyance inlets can be raised above the pavement surface to allow minimal ponding before high flows bypass the permeable pavement system during major storms.

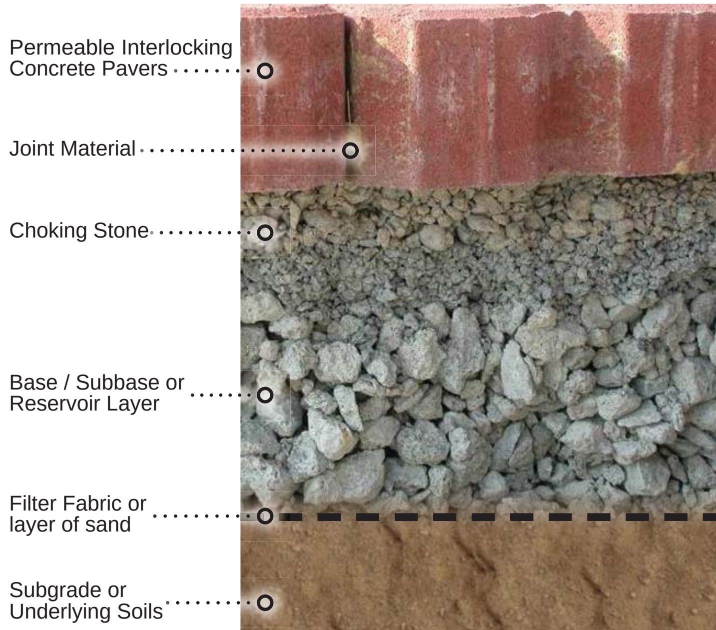
Subbase: The subbase of these systems has the potential to provide enough water storage to reduce stormwater quantity and significantly reduce the peak flow of larger storm events when the subbase is level. This is the layer that the underdrain is placed within. An aggregate base must be used for most permeable pavements types. Aggregates used should be washed, bank-run gravel, 1 - 2.5" diameter, with a void space of approximately 40%. Alabama Department of Transportation (ALDOT) #3 stone and #57 stone are acceptable. Crush and run should not be used for the pavement base due to the tendency of



Section through Pervious Concrete



Section through Porous Asphalt



Section through PICP

fine particles to clog the bottom of the pavement section. This material should have a porosity of approximately 0.32 or greater. Fine particles should not be present as they will clog the system.

Top Course/Choker Layer/Bedding Depth: This layer should be a fine gravel or layer of sand, ASTM C-33 concrete sand or ALDOT fine aggregate size #10 stone dust, to serve as a filter. Filter fabric is placed under the permeable pavement and above the gravel base, around this entire layer.

Interlocking Concrete Paver Infill: The infill is selected based on application and desired infiltration rate. Similar to the top course layer, ASTM C-33 concrete sand or ALDOT fine aggregate size #10 sand can be used when no vegetation is desired (infiltration rates of 8"/hr). If grass cover is desired, a sandy loam soil is recommended; however, the infiltration rate decreases to approximately 1"/hr.

Design Guidance

The following is a series of design steps based on current research, design, and installation. Consult manufacturers or other resources for additional design information.

1. **Determine Treatment Volume or Peak Flow**

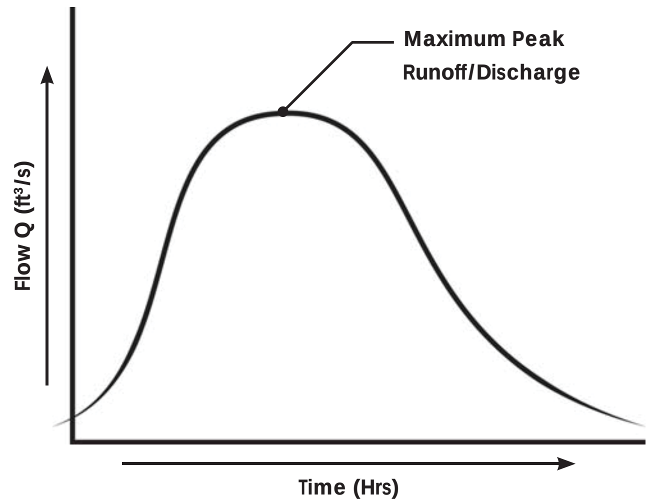
   The Rational Method, as shown in EQN 4.3.1, is used to calculate the peak flow, where the **estimated design discharge (Q)**, is equal to the product of **the Composite Runoff Coefficient (C)**, **Rainfall Intensity (i)**, and **watershed area (A)**. The **Rainfall Intensity (i)** is for a designated design storm for the particular geographic region of Alabama where the site is located.

   The **Composite Runoff Coefficient (C)** is based on the land use and surface for the total contributing watershed area. Increased impervious surface cover results in a higher coefficient. For a table of Rational Runoff Coefficients and a more detailed explanation of hydrological calculations, see Stormwater Hydrology in Appendix A.

2. **Calculate the Runoff Volume**

   To calculate a peak flow reduction, or a volume reduction of stormwater, many sources recommend assigning a "reduction in imperviousness" to the pavement or treating the pavement as a percentage of pervious surface. This percent of pervious surfaces assigned is dependent on the quantity of gravel base the system has and the type of pavement used. For Alabama, if the gravel base depth is greater than 6" of washed stone base, the system will assume a 60% credit for reduction in imperviousness. Systems with less than 6" of base will assume a 40% credit.

   These credit assumptions allow designers to



EQN 4.3.1

$$Q = CiA$$

C = Runoff coefficient (dimensionless) See Table A.2 in Appendix A on Stormwater Hydrology
i = Rainfall intensity (in/hr)
A = Watershed area (ac)

EQN 4.3.2

$$R_v = 0.05 + (0.9 * I_a)$$

R_v = Rational runoff coefficient (in/in)
I_a = Percent impervious / total drainage area

EQN 4.3.3

$$V = 3630 * R_d * R_v * A$$

R_d = Design rainfall depth (in)
R_v = Rational runoff coefficient (in/in)
A = Area (ac)
V = Peak runoff volume (ft³)

EQN 4.3.4

$$S = \left(\frac{1000}{CN}\right) - 10$$

CN = Land use curve number
S = Maximum potential retention after rainfall begins

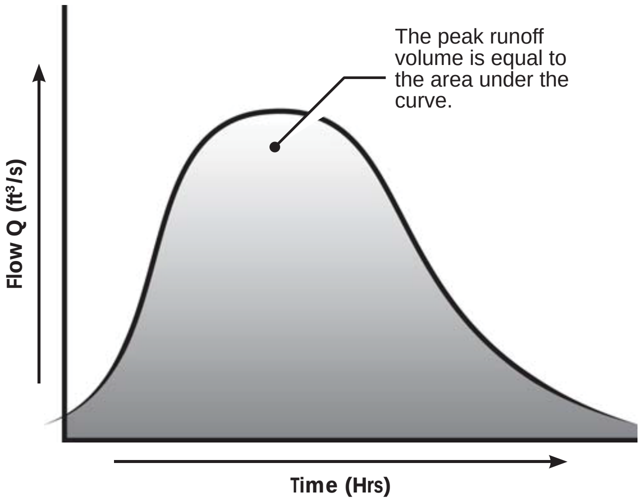
EQN 4.3.5

$$Q = \frac{(P - (0.2S))^2}{P + 0.8S}$$

S = Maximum potential retention after rainfall begins
P = Precipitation depth (in)
Q = Runoff depth (in)

EQN 4.3.6

Volume ______ ac - in*3630 = ______ ft³



determine the peak runoff volume using either the Simple Method (EQN 4.3.2 and Y.3) or the Discrete Curve Number Method (EQNs 4.3.4 and Y.5)

The **runoff coefficient (R_v)** is calculated for the Simple Method, EQN 4.3.2.

I_a is the percent impervious (%) or impervious area divided by the total drainage area. The peak runoff volume is then calculated using EQN 4.3.3.

R_d is the design rainfall depth (in), R_v is the rational runoff coefficient (in/in), and A is area in acres.

To calculate the runoff volume using the Discrete Curve Number Method, a curve number of 61 is assigned for managed grass or the pervious credit and a curve number (CN) of 98 for impervious areas. EQNs 4.3.4 and Y.5 are used to calculate a **maximum potential retention after rainfall begins (S)** by using corresponding land use curve number (CN). Then use the **maximum potential retention after rainfall begins (S)** and **precipitation depth (P)** to calculate the **runoff depth (Q)**.

The **runoff depth, Q** (in) calculated for both the impervious and pervious drainage area fraction can be multiplied by their respective areas (ac) and summed for a total runoff volume, as shown in EQN 4.3.6.

Both the Rational Method (EQNs 4.3.2 and Y.3) and the Discrete Curve Number Method (EQN 4.3.4 and Y.5) can be applied using the weighted credits/ratios.

3. **Calculate the Depth of Subbase**

   Calculating the depth of gravel base course (subbase/reservoir) is one of the more important aspects of permeable pavement design regardless of the type of permeable product selected. The gravel base course should have a minimum of 9" depth. This minimum depth does not include the top or choker course layers. The minimum storage requirement of the base layer should be the water quality volume. The **water quality volume (V)** can be calculated using EQNs 4.3.2 and Y.3. Once **V** is determined, the **surface area (SA)** and **porosity (n)** of the base layers can be used to calculate base depth. EQN 4.3.7 is used to compute the depth of base.

EQN 4.3.7

$$d = \frac{V}{SA} * n$$

V = Peak runoff volume (ft^3)
SA = Total surface area of pavement (ft^2)
n = Porosity of aggregate
d = Depth of base (ft)

   The depth of base (d), is equal to the **water quality volume (V)**, as calculated using the Simple Method or the Discrete Curve Number Method, divided by the total **surface area (SA)** of the permeable pavement, and then multiplied by the **porosity of the aggregate used (n)**. The porosity value is the void space divided by the total volume of fill material. A value of **0.32** is recommended.

4. **Check Actual Storage**

   Once the layers and materials are determined, EQN 4.3.8 can be used to determine the actual storage of the system. This is a check to ensure that the depth of storage needed for the water quality storm is met.

   It is important to note, that the design presented above is not complete, but these steps will allow a designer to determine whether the design meets the standards to handle the peak flow in storing the water quality volume. While pavement capacity has been calculated, structural integrity needs to be determined.

EQN 4.3.8

$$\text{Act. Storage} = \sum \left(\text{Material (s)} * \frac{\%\ \text{porosity}}{100} \right) + \left(\text{thickness} * \frac{\text{joint space }\%}{100} * \frac{\text{porosity }\%}{100} \right)$$


Strike off and compression at Duck Samford Park; Auburn, Alabama. Photo Courtesy Michael Hein

Construction

Industry standards and manufacturer specifications should be consulted in the implementation of permeable pavement practices.

Please review proper sediment control practices in the Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas

(http://swcc.alabama.gov/pages/erosion_handbook.aspx).

Compaction: Construction should be sequenced to avoid clogging and compaction that may inhibit functionality of permeable pavements. During construction, compaction of the underlying soil should be avoided.

Slope: The grade of the subgrade layer should not be less than 0.5% (slope) to maintain the storage capacity of the system. If slopes greater than 1% must be used for the subgrade, a series of perpendicular barriers or dams can be used to keep the subgrade from washing away.

Clogging: Once installed, care should be taken to avoid surface clogging of the pavement. If construction begins upslope, erosion and sediment control best management practices (BMPs) are imperative to reduce sediment entering the permeable pavement. Permeable pavements are not designed to treat concentrated flows or runoff from unstabilized areas. Newly developed residential areas are particularly at risk for sediment clogging due to the construction of new home sites and sequencing of these activities. Permeable pavement should never be taken advantage of as a temporary sediment control measure during construction.

Testing: Any testing should be done prior to installation to determine density, compressive strength, void content, and mixture consistency.

Retrofits: Permeable pavement can be incorporated into an initial site design or as a retrofit alternative to conventional pavement; however, retrofits can be expensive and are generally only suggested when resurfacing is necessary.

Pervious Concrete (PC) Construction

Moisture: The subgrade should be moist (without standing water) at PC placement in order to prevent moisture loss from the bottom of the concrete layer. PC is prone to drying during placement due to the amount of void spaces present.

PC Mixture: PC mix can be difficult to place due to its rigidity. An experienced concrete company or contractor is recommended to install permeable pavement, especially PC. The consistency of PC can be tricky, specifically the amount of water in the mix can be difficult to determine. The mix of fly ash, Portland cement, aggregates, and water makes mixing difficult and this can result in the desire to add water while mixing on site. However, when too much water is added, the mixture becomes too wet and pores are likely to become sealed. A dry mixture with too little water cannot bind together and may result in surface raveling later.

Admixtures: PC is difficult to work with due to the absence of sand in the mixture, thus creating necessary void spaces. This causes the mixture to dry out quickly on site and the timeframe to install it becomes slim. A chemical admixture regimen can aid in the mixing, handling, and overall performance of PC. These chemical admixtures include a hydration stabilizer, water reducing agent, and a viscosity-modifying agent to aid in placement of PC (See Table 4.3.2).

Ready Mix Truck: A ready mix truck with rear discharge and one chute is typically used for PC. The chute should be steep and angled down to facilitate PC removal from the truck. The mix may need to be manually removed from the chute using shovels or other tools. Using admixtures can alleviate some of the strain associated with mix removal from the truck because these additives increase workability and flow of the mix from the truck.

PC Placement: Once placement begins, it should be continuous and the surface should be struck off using a vibrating screed. Temporary boards can be added to the forms so that striking off can be 0.5 – 1” above the forms to compensate for compaction that will occur later. After striking off, PC should be consolidated or compacted to the top of the forms (temporary boards are removed) using a steel or weighted roller. The use of hydraulic roller screeds is common for PC installation. A hydraulic roller screed uses stainless steel tubes that rotate in the opposite direction the concrete was placed. It is recommended that consolidation take place within approximately 15 minutes after placement as PC can dry out quickly. Edge raveling is avoided by using a float or steel tamp that is approximately 1’ x 1’ to compact the edges. Having a sufficient construction crew in place is necessary so that one group can be placing and the other group striking off and consolidating.

Curing: PC should be misted following its placement and it should be covered using plastic sheeting for at least 7 days to cure. The curing process begins 20 minutes or less following compaction and jointing. Plastic sheeting may be held down using lumber, stakes, or rebar. When not cured properly, PC can be prone to surface deterioration and excessive raveling.

Striping: Once cured, striping of PC can be completed. Striping paint does not appear to reduce infiltration or seal pores.

Control Joints: Although cracking of PC is unlikely, control joints can be spaced a minimum of 20’ apart to combat concrete shrinking, which may lead to surface cracking.

Cutting Joints: A rolling joint tool or “pizza cutter” should be used soon after PC is placed. Cutting joints with a saw is not recommended because the slurry created from cutting can clog void spaces and saw cut joints generally suffer from surface raveling.

Table 4.3.2

Chemical Admixture Type	Purpose
Polycarboxylate-based Mid-range Water Reducer	Minimizes the need to add water on site, decreases the amount of water needed for the mixture, thus increasing and maximizing the compressive strength of the coarse mixture
Hydration Stabilizer	Extends time frame of plasticity by slowing the rate of hydration in the mixture
Viscosity-modifying	Lubricates the mixture to aid in discharge from the truck and placement

Bury et al., 2006

Maintenance

Several preventative maintenance steps such as proper maintenance access, site selection, and mixture consistency of PC can be taken to circumvent future maintenance obstacles. Any eroded areas or soil wash out should be immediately stabilized.

Clogging: Over time, some level of clogging is expected to occur from sediments and other materials deposited from vehicles, wind, runoff, and surface deterioration. Regularly performed maintenance activities can preserve infiltration rates. Clogged surfaces are easily noted by pouring a gallon of water on the pavement surface. Clogging does not always result in sealed pores. Clogged (not sealed) permeable pavement has been shown to still exhibit infiltration rates exceeding 1"/hr. Underlying soils have been shown to influence surface infiltration rates of clogged permeable pavements.

Clogged PC or PA: When PC or PA fails due to improper mixture consistency or extreme clogging, 0.5" diamiter holes can be drilled every few feet to facilitate infiltration; however, holes too close together can damage structural integrity of the pavement.

Clogged PICP: If PICPs become severely clogged, joint material replacement is necessary to restore infiltration. A vacuum street sweeper can be used to remove joint material to a depth of 4". Be sure to vacuum a test section to verify that only joint material or aggregate is being removed rather than the gravel base layer.

Maintenance Access: A 20' wide maintenance access road or right of way should be provided for maintenance of permeable pavement. The access road should be stable, strong enough to hold heavy vehicles such as a street sweeper, and have a minimum drive path of 12'.

Raveling: Slight raveling of surface particles of PC is expected during the first few weeks following installation, but any additional raveling can be problematic for infiltration. As surface particles are loosened, void spaces may be filled with these particles leading to decreased infiltration rates.

Mechanical Street Sweepers: Mechanical street sweepers are the most common and use multiple brushes to loosen particles that are lifted onto a conveyor for temporary storage.

Regenerative Air Street Sweepers: Regenerative air street sweepers are the second most common and are used to remove surface particles through air that is blown onto the surface of the pavement, thus creating a vacuum between the bottom of the truck and pavement surface.

Vacuum Street Sweepers: Vacuum street sweepers are the most expensive street sweeper, and therefore, less common. Vacuum street sweepers have a strong vacuum system that can remove particles from above and below the paver surface.

Preventative Street Sweeping: Preventative street sweeping should be performed at least annually, but quarterly

Table 4.3.3
Maintenance Schedule

Task	How Often	Comments
Street Sweeping	Quarterly	Street sweeping will remove surface debris that can potentially clog the permeable pavement surface. Quarterly street sweeping is suggested, but increased frequency is recommended.
Inspection for Surface Deterioration	Quarterly	Inspections should be made once a quarter or following a 0.5" or greater rain event.
Inspect for Sediment	Monthly	Confirm that permeable pavement surface is free of sediment and debris.
Weed Removal	When they appear	Weeds should be eradicated using glyphosate. Hand pulling can disturb joint material in PICPs.
Mowing of Adjacent Land Areas	When needed	Clippings should be collected and removed from the site.
Stabilize Surrounding Land	When needed	Surrounding land should always be stabile to minimize sediment entry into the permeable pavement.

is better. Preventing clogging through street sweeping will eliminate the need for more stringent, restorative measures. Preventative street sweeping for PICPs, PC, and PA is generally done using a regenerative air street sweeper.

Restorative Street Sweeping: A mechanical street sweeper has shown to be effective for restorative cleaning of concrete grid pavers filled with sand. Restorative cleaning of PC, PICPs, and PA should be done using a vacuum street sweeper.

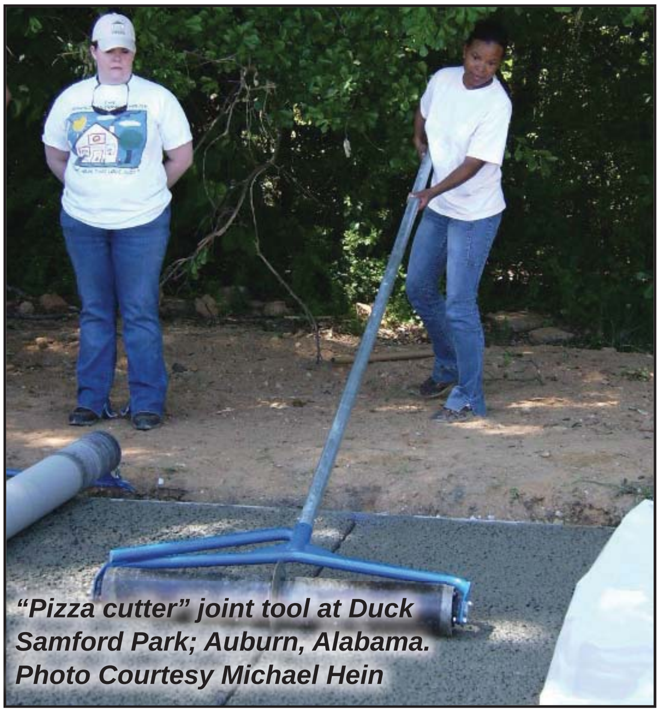
Pressure Washing: Pressure washing using a narrow, cone shaped nozzle is recommended for PC, and a wide spray nozzle is recommended for PICPs. In some cases, pressure washing has restored 80 – 90% of permeability.

Power Blowing: Power blowing is helpful to remove surface debris such as leaves or other plant material that may have collected on the pavement surface.

Combined Forms of Maintenance: Pressure washing and vacuum sweeping are frequently performed together for PC maintenance. These regenerative cleaning methods can restore infiltration capacity by 200%. Combined pressure washing and power blowing has shown a 200-fold increase in infiltration rates on PC.


Surface Raveling; Auburn, Alabama


Placing plastic sheeting over pervious concrete at Duck Samford Park; Auburn, Alabama. Photo Courtesy Michael Hein


"Pizza cutter" joint tool at Duck Samford Park; Auburn, Alabama. Photo Courtesy Michael Hein


Weeds in PICP; Orange Beach, Alabama

Mixture Consistency (Left to Right): A dry mixture, an ideal mixture, and a wet mixture.
Source: Tennis, Paul, D.; Leming, Michael, L.; and Akers, David, J., Pervious Concrete Pavements, EB302.02, Portland Cement Association, Skokie, Illinois, and National Ready Mixed Concrete Association, Silver Spring, Maryland, USA, 2004, 36 pages

Nuisance Species: Permeable pavements utilizing vegetation and PICPs will require removal of unwanted plants or weeds. Weed eradication should be done using glyphosate or other systemic herbicide, followed by actual removal of weeds one week later. Pulling weeds by hand without the use of herbicide can result in dislodging or disturbance of joint material or sand. When PRGs are used with turfgrass, mowed clippings should be bagged and disposed of off site.

Maintenance Agreements: Maintenance agreements should be in place prior to installation of any type of permeable pavement. Equipment availability, labor, and the responsible party should be outlined. Specific maintenance activities and frequency should be outlined in a maintenance schedule. Site inspections and record keeping are important to document the functionality of permeable pavements. All data sheets should be kept in one location for reporting purposes. For more information, see Appendix C on Maintenance.

Pollutant Removal

Table 4.3.4
Pollutant Removal Table

Sediment	Nutrients		Metals	Pathogens
	N	P		
a. No Data	No Data	No Data	No Data	No Data
b. - -	80%	80%	90%	- -
c. - -	65%	50%	60%	- -
d. - -	80%	80%	90%	- -
e. - -	80%	80%	90%	Insufficient Data
f. 99%	No Data	42%	97%*	No Data

Sources:
a. North Carolina Department of Environment and Natural Resources, 2007
b. City of Auburn, 2011
c. Georgia Manual, 2001 - Pervious Concrete
d. Georgia Manual, 2001 - Modular Paving Systems
e. Knox County, 2008
f. Roseen and Ballestero, 2008 - Porous Asphalt

Unlike other structural low impact development (LID) stormwater control measures (SCMs), permeable pavement does not rely on the use of vegetation for pollutant removal; any pollutant removal that occurs is due to the volume reduction of surface stormwater runoff. As a result, soluble and particulate pollutants are often removed by these systems through deposition, absorption, and filtration in underlying soil layers. Research has shown permeable pavements to decrease concentrations of heavy metals, motor oil, sediments, and nutrients in stormwater runoff from a site.

Quantity Reduction: Due to high surface infiltration rates, permeable pavements reduce both water quantity and peak discharges. Any surface runoff from permeable pavement should only occur during high intensity storms when the pavement cannot infiltrate stormwater quickly enough to capture it completely. A North Carolina study examined surface infiltration rates and found that most permeable pavements exhibited infiltration rates greater than 2”/hr. Under these conditions, in order for surface runoff to occur a storm would need to have an intensity exceeding 2”/hr.

Total Suspended Solids (TSS): TSS reductions were not quantified because it is not recommended that these systems trap sediment due to their propensity to clog.

Sediment Bound Pollutants: Both phosphorus and metals are known to be bound to sediments and will naturally accumulate on the pavement surface. Metals are captured in the top 1 – 2” of the pavement void space, and standard street sweeping should remove most heavy metals when the void space consists of sand. Removal of sediment particles from the surface of permeable pavement improves functionality, infiltration, and can also enhance pollutant removal. In an Auburn University study, surface runoff from impervious areas was found to have five times the amount of TSS compared to the leachate from a PC parking lot on campus, indicating the removal or filtration of sediment particles.

CGPs: Additionally, permeable pavements that employ the use of sand as a filter, for example CGPs, have been shown to exhibit higher overall total nitrogen reductions.

Underlying Soils: Underlying soils can affect pollutant removal efficiency of permeable pavements. In general, sandy soils boast higher infiltration rates but offer less treatment of stormwater pollutants. In contrast, clay soils show decreased infiltration, but their higher cation exchange capacity can aid in pollutant capture. Additionally, bacteria that assist in the treatment process are present not only in the underlying soils, but have also shown growth in gravel base layers.

Temperature: Although not quantified, water temperature reductions are assumed because runoff is immediately infiltrated into the pavement surface rather than remaining on the surface where it would be heated by the sun before being discharged into a stormwater conveyance network. Moreover, stormwater stored in the gravel layer subbase or reservoir is held before being released into the surrounding soil, or underdrain system, allowing water to cool before discharged.

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