



**POROUS PAVEMENTS**

**Definition:** Porous pavements are alternatives to conventional concrete and asphalt paving materials that allows for infiltration of storm water into a storage area, with void spaces that provide temporary storage.

**Purpose:** Porous pavements are used to reduce runoff rates and volumes through the infiltration of a greater portion of the rain falling on the area than would occur with conventional paving.

**Components (Depth Zones) and Function:**

- Open graded pavement mix or pavers with open surfaces
- Settling layer
- Open-graded base material
- Filter fabric
- Underdrain (where required)
- Subgrade with *minimal* compaction

**Benefits:**

- Reduces runoff volume, attenuates peak runoff rate and outflow
- Reduces slick surfaces during rain
- Water quality enhancement from filtration of stormwater
- Saves area by using treatment area for parking/driving

**Limitations:**

- Sediment-laden runoff can clog pervious pavement, causing it to fail
- Not appropriate for heavy or high traffic areas
- Applicability generally limited to the Coastal Plain regions
- Incorrect installation practices can clog pores

**Design Considerations:**

- Completed permeable pavement installation must have a slope less than 0.5%
- Soils must have infiltration capacity of at least 0.52 in/hr permeability. Infiltration rate of native soil determines appropriateness and need for underdrain
- Only 2 acre-feet of soil per acre disturbed can be graded for the permeable pavement footprint
- The top 3-ft of soil must have no finer texture than Loamy Very Fine Sand as determined by a soil analysis

**POLLUTION REDUCTION (%)**

80 – 95	TSS (Sediments)
50 – 82	TP (Total Phosphorus)
65 – 85	TN (Total Nitrogen)
? – ?	Pathogens
60 – 90	Metals
? – 62	Hydrocarbons
40 – 80	Runoff Volume/Peak

**SITING CONSIDERATIONS**

- Parking lots
- Residential
- High Density/Ultra Urban Use
- Highway/Road
- A, B, and C soil types.

**FEASIBILITY AND COST**

✓	Vacuum or jet wash to increase pavement life and avoid clogging
✓	Remove debris
✓	Clean out sediments
Median	Land Requirement
M – H	Construction Cost
M – H	Maintenance burden
High	Community Acceptance

## A. GENERAL DESCRIPTION

Porous pavement (also referred to as pervious pavement, permeable pavement, enhanced porosity concrete and porous concrete) is a paved concrete or asphalt driving surface that permits the infiltration of water through the pavement and into the underlying soil. When considering the post-development stormwater runoff from a site, porous pavement is a best management practice (BMP) that allows a developed land surface to “appear” more like undeveloped land – runoff volumes and peak discharges of stormwater runoff from a developed site with porous pavement will be less than on a site without porous pavement. Porous pavement is an excellent application to reduce the effective impervious area on a site, therefore, reducing the design volumes and peak discharges that must be controlled. This will allow a reduction in the cost of other stormwater infrastructure, a fact that may offset the greater placement cost somewhat. Porous pavement can also eliminate problems with standing water, provide for groundwater recharge, control erosion of streambeds and riverbanks, facilitate pollutant removal, reduce thermal pollution of receiving waters, and provide for a more aesthetically pleasing site.

Porous pavements are best applied in areas that experience low vehicular traffic including parking lots and overflow parking areas; portions of streets such as residential parking lanes; driveways; plazas; and pedestrian or golf cart paths. Porous pavements are not recommended, and will not be approved, for use on driving surfaces that experience high traffic volume, heavy loads, and sediment-laden traffic (e.g., construction areas, dump sites).

## B. COMPONENTS

### (1) Open graded pavement mix or pavers with open surfaces

- Allowing water to drain
- Reduction of tire splash/spray in wet weather
- Reduction of noise

### (2) Settling layer

- Serves to stabilize the porous asphalt or concrete layer

### (3) Open-graded base material

- Enhance the stability to acceptable levels by receiving water

### (4) Filter fabric

- Serves to inhibit soil from migrating into the reservoir and reducing storage capacity

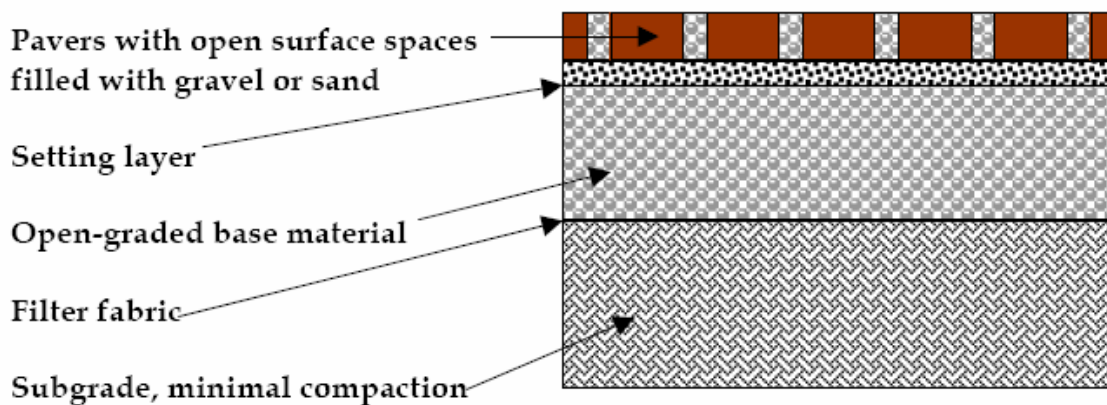
### (5) Bottom filter layer

- Stabilizing the reservoir layer, to protect the underlying soil from compaction
- Acting as the interface between the reservoir layer and the filter fabric covering the underlying soil.

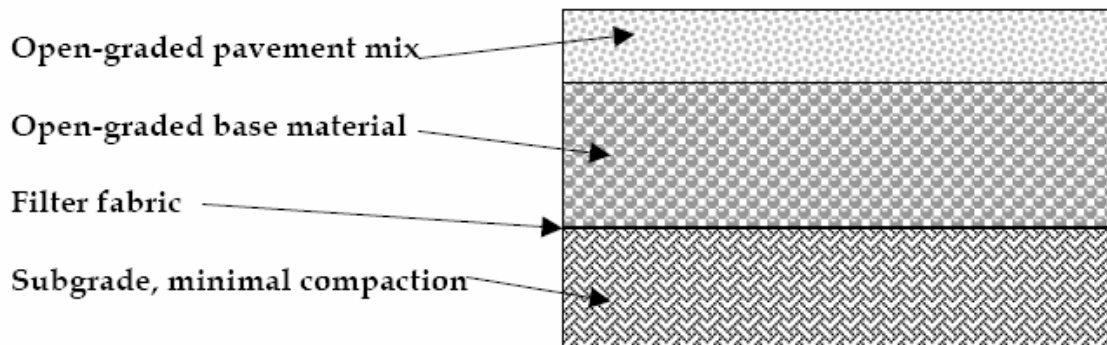
### (6) Underlying Soil

- Filtering out contaminants in water

### Pervious Concrete Block or "Paver" Systems



### Pervious (Open Graded) Concrete and Asphalt Mixes



**Figure 6.1 Porous Pavement Layers**

## C. VARIATIONS AND APPLICATIONS

There are several different forms of porous pavements, varying from a permeable layer of paving material to grid systems. Four different types of permeable surfaces are discussed below

**Porous Asphalt** - Porous asphalt differs from dense asphalt in its use of open-graded aggregate. Because no fine aggregate fills the voids between the single-sized particles, the material is porous and permeable. Porous asphalt can have a porosity of 15%-20%. A surface of porous asphalt is typically placed over a layer of open-graded gravel and crushed stone, with an underlying layer of permeable soil. There are several modifications to the standard design that can be used to increase storage capacity or pass larger flows, including the installation of a perforated pipe in the gravel sublayer, adding a layer of sand, etc.

**Porous Asphalt****Porous Concrete****Plastic Grid Systems****Open-Celled Paving Grids**

**Porous Concrete** - Considered to be more durable than porous asphalt, porous concrete is a mixture of open-graded aggregate, which creates the voids in the structure, and Portland cement. The void space in porous concrete is in the 15%-22% range compared to 3%-5% for conventional pavements. Porous concrete is thought to have a greater ability than porous asphalt to maintain its porosity in hot weather. The permeable surface of porous concrete is typically installed as the top of several permeable layers, similar to the installation of porous asphalt described above.

**Plastic Grid Systems** - These systems are often referred to as *geocells* and are defined by manufactured plastic lattices or mattresses that form networks of box-like cells that are filled with earth material. The lattice is typically 1-2 inches thick and the cells are a few inches wide. Porosity and permeability of these systems is entirely dependent on the cells' fill and vegetation. Like any other pavement surface, geocells require a firm gravel base that provides strength and storage capacity as runoff infiltrates. Geocells are lightweight and easy to transport and install. However, they may similarly be jarred easily by moving traffic.

**Open-Celled Paving Grids** - Commonly called *block pavers* or *grid pavers*, these grids are structural units, such as concrete blocks or bricks with regularly interspersed voids that penetrate their entire thickness. Grids are made of concrete or brick and the open cells are filled with porous aggregate or vegetated soil. Block pavers are more rigid and therefore can bear larger traffic loads than plastic grid systems.

## D. POLLUTION REDUCTION CAPABILITIES AND MECHANISMS

### **Volume Control Capabilities**

Porous pavement is designed primarily for impervious area reduction and the subsequent reduction in stormwater treatment volumes and peak discharges, particularly for smaller storm events. For some smaller sites, trenches can be designed to capture and infiltrate the water quality volume (WQv), and in some cases, the channel protection volume (CPv). Porous pavement has the positive characteristics of volume reduction due to infiltration, groundwater recharge, and an ability to blend into the normal urban landscape relatively unnoticed.

### **Pollutant Removal Capabilities**

The quality of the runoff entering a porous paving or permeable paver with storage bed system is a primary consideration in determining whether such systems are advisable and, if so, in designing the systems themselves. The planning of such systems must consider which pollutants will be present in the runoff and whether these pollutants will degrade groundwater quality. Certain soils can have a limited capacity for the treatment of bacteria and the soluble forms of nitrogen, phosphorus, and other pollutants like road salts and pesticides. Such pollutants are either attenuated in the soil column or go directly to the water table.

**Table 6.1 Pollutant removal efficiency of porous pavements**

Parameter	Removal Efficiency (%)
Total Suspended Solids	80 – 95
Total Phosphorus	50 – 82
Total Nitrogen	65 – 85
Pathogens	NA
Heavy Metals	60 – 90
Hydrocarbons	- 62
Runoff Peak Flow	40 – 80

Unfortunately, the soils that normally have the highest and, therefore, most suitable permeability rates also have the least ability to treat such pollutants. As a result, pretreatment of soluble pollutants prior to entry into a pervious paving system's storage bed may be necessary in these soils. Pretreatment measures may include vegetated filter strips, bioretention systems (where the infiltration basin takes the place of the standard underdrain), and certain sand filters. Alternatively, the existing soil below the infiltration basin bottom may be augmented or replaced by soils with greater soluble pollutant removal rates.

### **Pollutant Removal Mechanisms**

Porous pavement is passive water treatment by absorption of runoff into adjacent soils, where bacteria and other microbes decompose nonpoint surface pollutants before they can reach groundwater or surface waters like streams, ponds, lakes, or estuaries. Porous pavement can become a low-cost "infiltration" technique that uses the interaction of the chemical, physical, and biological processes between soils and water to filter out sediments and other soluble

constituents from urban runoff. As the stormwater percolates into the ground, fine material suspended in the water is captured within the soil. The resulting treated runoff percolates through to the groundwater. The soil layer and the microbes living in the soil enhance filtration, and the vegetation aids constituent removal.

Porous pavements are less able to absorb and store heat than conventional pavements because of (1) reduction of heat storage capacity by the lower density of the material (15 to 25% void spaces) and (2) reduction of the heat absorbing capacity of the pavement due to the lighter colors of some porous pavement systems. These factors allow porous pavement systems to approach natural ground cover in heat absorbing and storage capacity.

## E. PLANNING AND DESIGN CRITERIA

The following design and implementation considerations must be incorporated into greenroofs:

### Design and Site Considerations

- Porous pavements systems can be used where the underlying in-situ subsoils have an infiltration rate greater than 0.5 inches per hour. Therefore, porous pavements systems are not suitable on sites with hydrologic group D or most group C soils, or soils with a high (>30%) clay content. During construction and preparation of the subgrade, special care must be taken to avoid compaction of the soils.
- Porous pavements systems should typically be used in applications where the pavement receives tributary runoff only from impervious areas. Actual pervious surface area sizing will depend on achieving a 24 hour minimum and 48 hour maximum draw down time for the design storm volume.
- If runoff is coming from adjacent pervious areas, it is important that those areas be fully stabilized to reduce sediment loads and prevent clogging of the porous paver surface. Pretreatment using filter strips or vegetated swales for removal of coarse sediments is recommended.
- Porous pavements systems should not be used on slopes greater than 5% with slopes of no greater than 2% recommended. For slopes greater than 1% barriers perpendicular to the direction of drainage should be installed in sub-grade material to keep it from washing away, or filter fabric should be placed at the bottom and sides of the aggregate to keep soil from migrating into the aggregate and reducing porosity.
- A minimum of four feet of clearance is recommended (may be reduced to two feet in coastal areas) between the bottom of the gravel base course and underlying bedrock or the seasonally high groundwater table.
- Porous pavements systems should be sited at least 10 feet down-gradient from buildings and 100 feet away from drinking water wells.
- To protect groundwater from potential contamination, runoff from designated hotspot land uses or activities must not be infiltrated. Porous pavements should not be used for manufacturing and industrial sites, where there is a potential for high concentrations of soluble pollutants and heavy metals. In addition, porous pavements should not be considered for areas with a high pesticide concentration. Porous pavement is also not

suitable in areas with karst geology without adequate geotechnical testing by qualified individuals and in accordance with local requirements.

- Porous pavements system designs must use some method to convey larger storm event flows to the conveyance system. One option is to use storm drain inlets set slightly above the elevation of the pavement. This would allow for some ponding above the surface, but would accept bypass flows that are too large to be infiltrated by the porous pavements system, or if the surface clogs.
- For the purpose of sizing downstream conveyance and structural control system, porous pavements surface areas can be assumed to 35% impervious.
- For treatment control, the design volume should be, at a minimum, equal to the water quality volume. The water quality storage volume is contained in the surface layer, the aggregate reservoir, and the sub-grade above the seasonal high water table – if the sub-grade is sandy. The storm duration (fill time) is normally short compared to the infiltration rate of the subgrade, a duration of two hours can be used for design purposes. The total storage volume in a layer is equal to the percent of voids times the volume of the layer. Alternately storage may be created on the surface through temporary ponding, though this would tend to accelerate clogging if coarse sediment or mud settles out on the surface.
- The pit excavation should be limited to the width and depth specified in the design. Excavated material should be placed away from the open trench as not to jeopardize the stability of the trench sidewalls. The bottom of the excavated trench should not be loaded so as to cause compaction, and should be scarified prior to placement of sand. The sides of the trench shall be trimmed of all large roots. The sidewalls shall be uniform with no voids and scarified prior to backfilling. All infiltration trench facilities should be protected during site construction, and should be constructed after upstream areas have been stabilized.
- An observation well consisting of perforated PVC pipe 4 to 6 inches in diameter should be placed at the downstream end of the facility and protected. The well should be used to determine actual infiltration rates.
- Details of construction of the concrete layer are beyond the scope of this manual. However, construction of porous pavements is exacting, and requires special handling, timing, and placement to perform adequately (LACDPW, 2000, Paine, 1992, Maryland, 1984).

## F. CONSTRUCTION SPECIFICATIONS

The following specifications are provided for informational purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

### Stone

- For infiltration beds, 2-inch to 1-inch uniformly graded coarse aggregate, with a wash loss of no more than 0.5% or later and shall have voids 40% as measured by ASTM-C29.

- Choker base course aggregate for beds shall be 3/8 inch to 3/4 inch uniformly graded coarse aggregate AASHTO size number 57 per Table 4, AASHTO Specifications, Part I, 13th Ed., 1998 (p. 47).

### Non-Woven Geotextile

- Consist of needled nonwoven polypropylene fibers and meet the following properties:
  - a. Grab Tensile Strength (ASTM-D4632)  $\geq$  120 lbs
  - b. Mullen Burst Strength (ASTM-D3786)  $\geq$  225 psi
  - c. Flow Rate (ASTM-D4491)  $\geq$  95 gal/min/ft<sup>2</sup>
  - d. UV Resistance after 500 hrs (ASTM-D4355)  $\geq$  70%
  - e. Heat-set or heat-calendared fabrics are not permitted.

### Pipe

- Continuously perforated, smooth interior, with a minimum inside diameter of 6-inches.
- High-density polyethylene (HDPE) pipe shall meet AASHTO M252, Type S or AASHTO M294, Type S.

### Storm Drain Inlets and Structures

- Concrete Construction: Concrete construction shall be in accordance with Section 1001,
- PennDOT Specifications, 1990 or latest edition.
- Precast concrete inlets and manholes: Precast concrete inlets may be substituted for cast-in-place structures and shall be constructed as specified for cast-in-place. Type M standard PennDOT inlet boxes will be modified to provide minimum 12" sump storage and bottom leaching basins, open to gravel sumps in sub-grade, when situated in the recharge bed.
- All PVC Catch Basins/Cleanouts/Inline Drains shall have H-10 or H-20 rated grates, depending on their placement (H-20 if vehicular loading).
- Steel reinforcing bars over the top of the outlet structure shall conform to ASTM A615, grades 60 and 40.
- Permanent turf reinforcement matting shall be installed according to manufacturers' specifications.

### Pervious Bituminous Asphalt

- Bituminous surface course for **pervious paving** shall be two and one-half (2.5) inches thick with a bituminous mix of 5.75% to 6% by weight dry aggregate. **In accordance with ASTM D6390, drain down of the binder shall be no greater than 0.3%.** If more absorptive aggregates, such as limestone, are used in the mix, then the amount of bitumen is to be based on the testing procedures outlined in the National Asphalt Pavement Association's Information Series 131 – "Pervious Asphalt Pavements" (2003) or PennDOT equivalent.
- Use neat asphalt binder modified with an elastomeric polymer to produce a binder meeting the requirements of PG 76-22 as specified in AASHTO MP-1. The elastomer polymer shall be styrene-butadiene-styrene (SBS), or approved equal, applied at a rate of 3% by weight of the total binder. The composite materials shall be thoroughly blended at the asphalt refinery or terminal prior to being loaded into the transport vehicle. The

polymer modified asphalt binder shall be heat and storage stable. Aggregate shall be minimum 90% crushed material and have a gradation of:

<b>U.S. Standard Sieve Size</b>	<b>Percent Passing</b>
½ (12.5 mm)	100
3/8 (9.5 mm)	92-98
4 (4.75 mm)	34-40
8 (2.36 mm)	14-20
16 (1.18 mm)	7-13
30 (0.60 mm)	0-4
200 (0.075mm)	0-2

- Add hydrated lime at a dosage rate of 1.0% by weight of the total dry aggregate to mixes containing granite. Hydrated lime shall meet the requirements of ASTM C 977. The additive must be able to prevent the separation of the asphalt binder from the aggregate and achieve a required tensile strength ratio (TSR) of at least 80% on the asphalt mix when tested in accordance with AASHTO T 283. The asphaltic mix shall be tested for its resistance to stripping by water in accordance with ASTM D-1664. If the estimated coating area is not above 95 percent, anti-stripping agents shall be added to the asphalt.
- Pervious pavement shall not be installed on wet surfaces or when the ambient air temperature is 50 degrees Fahrenheit or lower. The temperature of the bituminous mix shall be between 300 degrees Fahrenheit and 350 degrees Fahrenheit (based on the recommendations of the asphalt supplier).

### **Pervious Concrete**

- Weather Limitations: Do not place Portland cement pervious pavement mixtures when the ambient temperature is 40 degrees Fahrenheit or lower or 90 degrees Fahrenheit or higher, unless otherwise permitted in writing by the Engineer.
- Test Panels: Regardless of qualification, Contractor is to place, joint and cure at least two test panels, each to be a minimum of 225 sq. ft. at the required project thickness to demonstrate to the Engineer's satisfaction that in-place unit weights can be achieved and a satisfactory pavement can be installed at the site location.
- Test panels may be placed at any of the specified Portland Cement pervious locations. Test panels shall be tested for thickness in accordance with ASTM C 42; void structure in accordance with ASTM C 138; and for core unit weight in accordance with ASTM C 140, paragraph 6.3.
- Satisfactory performance of the test panels will be determined by: Compacted thickness no less than ¼" of specified thickness.
- Void Structure: 15% minimum; 21% maximum. Unit weight plus or minus 5 pcf of the design unit weight.
- If measured void structure falls below 15% or if measured thickness is greater than ¼" less than the specified thickness or if measured weight falls less than 5 pcf below unit weight, the test panel shall be removed at the contractor's expense and disposed of in an approved landfill.

- If the test panel meets the above-mentioned requirements, it can be left in-place and included in the completed work.

## G. OPERATION AND MAINTENANCE REQUIREMENTS

### Common Maintenance Issues

The primary goal of pervious pavement maintenance is to prevent the pavement surface and/or underlying infiltration bed from being clogged with fine sediments. To keep the system clean throughout the year and prolong its life span, the pavement surface should be vacuumed biannually with a commercial cleaning unit. Pavement washing systems or compressed air units are not recommended. All inlet structures within or draining to the infiltration beds should also be cleaned out biannually.

Planted areas adjacent to pervious pavement should be well maintained to prevent soil washout onto the pavement. If any washout does occur it should be cleaned off the pavement immediately to prevent further clogging of the pores. Furthermore, if any bare spots or eroded areas are observed within the planted areas, they should be replanted and/or stabilized at once. Planted areas should be inspected on a semiannual basis. All trash and other litter that is observed during these inspections should be removed.

Superficial dirt does not necessarily clog the pavement voids. However, dirt that is ground in repeatedly by tires can lead to clogging. Therefore, trucks or other heavy vehicles should be prevented from tracking or spilling dirt onto the pavement. Furthermore, all construction or hazardous materials carriers should be prohibited from entering a pervious pavement lot.

### Special Maintenance Considerations:

- Prevent Clogging of Pavement Surface with Sediment
- Vacuum pavement 2 or 3 times per year
- Maintain planted areas adjacent to pavement
- Immediately clean any soil deposited on pavement
- Do not allow construction staging, soil/mulch storage, etc. on unprotected pavement surface
- Clean inlets draining to the subsurface bed twice per year

### Repairs

Potholes in the pervious pavement are unlikely; though settling might occur if a soft spot in the subgrade is not removed during construction. For damaged areas of less than 50 square feet, a declivity could be patched by any means suitable with standard pavement, with the loss of porosity of that area being insignificant. The declivity can also be filled with pervious mix. If an area greater than 50 sq. ft. is in need of repair, approval of patch type should be sought from either the engineer or owner. Under no circumstance should the pavement surface ever be seal coated. Any required repair of drainage structures should be done promptly to ensure continued proper functioning of the system.

Table 6.2 Recommended maintenance activities for porous pavement	
Inspection Activities	Suggested Schedule
Ensure that the porous pavement surface is free of sediment and debris (e.g., mulch, leaves, trash, etc.) Ensure that the contributing area upstream of the porous pavement surface is free of sediment and debris.	As needed
Check to make sure that the porous pavement dewateres between storms.	Monthly
Inspect the surface for structural integrity. Inspect for evidence of deterioration or spalling	Annually
Maintenance Activities	Suggested Schedule
Ensure that contributing area and porous pavement surface are clear of debris (e.g., mulch, leaves, trash, etc.) Ensure that the contributing and adjacent area is stabilized and mowed, with clippings removed.	As needed, based on inspection
Vacuum sweep porous pavement surface to keep free of sediment.	Typically three to four times a year
Replace the porous pavement, including the top and base course, as needed.	Upon failure

**Sample Inspection and Maintenance Provisions**

Important maintenance procedures:

- Stable groundcover will be maintained in the drainage area to reduce the sediment load to the porous pavement.
- The area around the perimeter of the permeable pavement will be stabilized and mowed, with clippings removed.
- Any weeds that grow in the porous pavement will be sprayed with pesticide immediately. Weeds will not be pulled, since this could damage the fill media.
- Once a year, the porous pavement surface will be vacuum swept.

The porous pavement will be inspected **once a quarter and within 24 hours after every storm event greater than 1.0 inches (or 1.5 inches if in a Coastal County)**. Records of inspection and maintenance will be kept in a known set location and will be available upon request. Inspection activities shall be performed as follows. Any problems that are found shall be repaired immediately.

Table 6.3 Sample Inspection and Maintenance Agreement for porous pavement		
BMP element:	Potential problems	How to remediate the problems
<b>The perimeter of the porous pavement</b>	Areas of bare soil and/or erosive gullies have formed.	Regrade the soil if necessary to remove the gully, and then plant a ground cover and water until it is established. Provide lime and a one-time fertilizer application.
	Vegetation is too short or too long.	Maintain vegetation at a height of 3 to 6 inches (remove clippings).
<b>The surface of the porous pavement</b>	Trash/debris is present.	Remove the trash/debris.
	Weeds are growing on the surface of the permeable pavement.	Do not pull the weeds (may pull out media as well). Spray them with pesticide.
	Sediment is present on the surface.	Vacuum sweep the pavement.
	The structure is deteriorating or damaged.	Consult an appropriate professional.
	The pavement does not water between storms.	Vacuum sweep the pavement. If the pavement still does not dewater, consult a professional.

## H. CONSTRUCTION AND MAINTENANCE COSTS

- Pervious asphalt, with additives, is generally 10% to 20% higher in cost than standard asphalt on a unit area basis.
- Pervious concrete as a material is generally more expensive than asphalt and requires more labor and experience for installation due to specific material constraints.
- Pervious paver blocks vary in cost depending on type and manufacturer.

The added cost of a pervious pavement/infiltration system lies in the underlying stone bed, which is generally deeper than a conventional subbase and wrapped in geotextile. However, this additional cost is often offset by the significant reduction in the required number of inlets and pipes. Also, since pervious pavement areas are often incorporated into the natural topography of a site, there generally is less earthwork and/or deep excavations involved. Furthermore, pervious pavement areas with subsurface infiltration beds often eliminate the need (and associated costs, space, etc.) for detention basins. When all of these factors are considered, pervious pavement with infiltration has proven itself less expensive than the impervious pavement with associated stormwater management. Recent installations have averaged between \$2000 and \$2500 per parking space, for the pavement and stormwater management.

## I. DESIGN PROCEDURE

### Step 1. Confirm Concept Design and Treatment Performance

#### A. Check Service Locations

As part of the confirmation of objectives and review of the conceptual design, the designer must check that there are no existing or proposed services in the proposed site for the porous paving.

The designer should liaise with civil designers and GCCC officers to ensure:

- porous paving will not result in water damage to existing services or structures
- access for maintenance to existing services is maintained
- no conflicts arise between the location of services and WSUD devices.

### Step 2. Pretreatment Design

An assessment of the groundwater must be undertaken to define existing water quality, potential uses (current and future) and suitability for recharge.

Pretreatment measures include the provision of leaf and roof litter guards along the roof gutter, vegetated swales, sediment forebays or buffer strips.

### Step 3. Determine Design Flows

The hydraulic design for porous paving should be based on the following design flows:

- minor Storm Event for sizing the surface area, detention volume and overflow pit of the paving system
- major Storm Event for overflow or bypass of the system. These flows will flow over or bypass the system and enter the stormwater drainage event.

**Step 4. Size Porous Paving System****A. Design Storm Selection ( $Q_{des}$ )**

Select the design storm to capture for detention or infiltration. This must occur in consultation with GCCC and will generally relate to 3 month ARI and 1 year ARI design storms.

**B. Detention Volume**

The required 'detention volume' of a porous paving system is defined by the difference in inflow and outflow volumes for the duration of a storm. The inflow volume ( $V_i$ ) will depend on the source runoff being routed through the porous paving system.

Inflow may include: (a) rainfall onto the porous paving system only and (b) a combination of rainfall onto the porous paving system and runoff from other impervious areas.

The inflow volume for the design storm on the porous paving system (treatment surface) only is (Argue 2007):

$$V_i = A_s \square i / (10^3 \times 360) \square D$$

Where,

$V_i$  = inflow volume

$A_s$  = estimate surface area of the paving ( $m^2$ )

$i$  = average rainfall intensity for design storm (mm/hr)

$D$  = duration of storm (hr)

The inflow for a combination of rainfall onto the porous paving system and runoff from other impervious areas is

$$V_i = Q_{des} \square D$$

Where,

$V_i$  = inflow volume (for storm duration  $D$ ) ( $m^3$ )

$Q_{des}$  = design storm flow for sizing (Rational Method,  $Q = CIA/360$ ) ( $m^3/s$ )

$D$  = storm duration (hrs x 3600 s/hr)

Outflow from the porous paving system is via the base (and on some cases the sides) of the infiltration media and is dependent on the area and depth of the structure. It is calculated using the filtration rate through the filter layer media and the storm duration.

The maximum filtration rate represents the maximum rate of flow through the paving system and is calculated by applying Darcy's equation as follows:

$$Q_{max} = K_{sat} \square A \square (h_{max} + d) / d$$

Where,

$Q_{max}$  = maximum filtration rate ( $m^3/s$ )

$K_{sat}$  = filter layer saturated hydraulic conductivity (m/s)

$A$  = area of the porous paving ( $m^2$ )

$h_{max}$  = depth of pondage above the soil filter (m)

$d$  = depth of filter media (m)

Given there is no detention depth or pondage above surface of the porous paving, and conditions are likely to be fully drained, then:

$$(h_{max} + d)/d = 1$$

Outflow volume is calculated as:

$$V_o = Q_{max} \square D$$

Where  $V_o$  = outflow volume ( $m^3$ )

$Q_{max}$  = maximum filtration rate ( $m^3/s$ )

$D$  = duration of storm event

Thus, the required detention volume ( $V_d$ ) of an porous paving system can be computed as follows

$$V_d = (V_i - V_o)/P$$

Where,

$V_d$  = required detention volume ( $m^3$ )

$V_i$  = inflow volume ( $m^3$ )

$V_o$  = outflow volume ( $m^3$ )

$p$  = porosity of the retention trench (gravel = 0.35)

Note: Volume calculations may need to be revised if further steps in the design process result in changes to the expected surface area of the porous paving system.

### C. Depth

The depth of the porous paving system will be determined from site constraints and the structural requirements of the paving system

### D. Surface Area Check

To this point in the design process an assumed surface area may have been used. A check and final surface area of the porous paving should be determined using two steps:

- calculate surface area based on the volume and required depth
- check surface area has capacity to infiltrate peak flows for design storm.

The surface area of the porous paving system should be checked using the following equation from Argue (2007):

$$A_s = Q_{peak} / ((1-B) \square K_{sat})$$

Where,

$Q_{peak}$  = Peak inflow to porous paving surface ( $m^3/s$ )

B = Blockage Factor (this should be estimated based on nonporous structural elements (e.g. plastic/concrete grids)

K<sub>sat</sub> = saturated hydraulic conductivity of paving surface (e.g. concrete/asphalt)/or porous material between pavers

### Step 5. Underdrainage Design and Check

To ensure slotted pipes are of adequate size, several checks are required to ensure:

- the perforations are adequate to pass the maximum filtration rate
- the pipe itself has sufficient capacity
- that the material in the filter layer will not be washed into the perforated pipes (consider a transition layer).

The capacity of the perforated under-drains need to be greater than the maximum filtration rate to ensure the filter media drains freely and does not become the hydraulic ‘control’ in the porous paving system (i.e. to ensure the filter layer sets the travel time for flows from the aggregate layer rather than the perforated under-drainage system).

To ensure the perforated under-drainage system has sufficient capacity to collect and convey the maximum filtration rate, it is necessary to determine the capacity for flows to enter the under-drainage system via the perforations in the pipes. To do this, orifice flow can be assumed and the sharp edged orifice equation used. Firstly, the number and size of perforations needs to be determined (typically from manufacturer’s specifications) and used to estimate the flow rate into the pipes, with the maximum driving head being the depth of the porous paving system. It is conservative, but reasonable to use a blockage factor to account for partial blockage of the perforations by the drainage layer media. A 50 % blockage of the perforations should be used.

The flow capacity of the perforations is thus:

$$Q_{\text{perf}} = B \cdot C_d \cdot A \cdot \text{SQRT}(2 \cdot g \cdot h)$$

Where

$Q_{\text{perf}}$  = flow through perforations (m<sup>3</sup>/s)

$C_d$  = orifice discharge coefficient (0.6)

$A$  = total area of the orifice (m<sup>2</sup>)

$g$  = gravity (9.81 m/s<sup>2</sup>)

$h$  = maximum depth of water above the pipe (m)

$B$  = blockage factor (0.5)

If the capacity of the drainage system is unable to collect the maximum filtration rate additional under-drains will be required.

After confirming the capacity of the under-drainage system to collect the maximum filtration rate, it is necessary to confirm the conveyance capacity of the underdrainage system is sufficient to convey the collected runoff. To do this, Manning’s equation can be used (which

assumes pipe full flow but not under pressure). The Manning's roughness used will be dependant on the type of pipe used (refer to QUDM Table 5.21.3 (DPI, IMEA & BCC 1992)).

Under-drains should be extended vertically to the surface of the porous paving system to allow inspection and maintenance when required. The vertical section of the under-drain should be unperforated and capped to avoid short-circuiting of flows directly to the drain.

### Step 6. Check Emptying Time

Emptying time is defined as the time taken to fully empty a detention volume following the cessation of rainfall. *Australian Runoff Quality* (Engineers Australia 2006) suggests an emptying time of the detention storage of porous paving systems to vary from 12 hours to 84 hours. Designers should aim to have a drainage time of 24 to 48 hours. Emptying time is computed simply as the ratio of the volume of water in temporary storage (dimension of storage x porosity) to the filtration rate through the filter layer (hydraulic conductivity x infiltration area):

$$t_e = 1000 \square V_d \square P / (A_{inf} \square K_{sat})$$

Where,

$t_e$  = emptying time (hours)

$V_d$  = detention volume (m<sup>3</sup>)

$P$  = perimeter length of the infiltration area (m)

$A_{inf}$  = infiltration area (m<sup>2</sup>)

$K_{sat}$  = filter layer saturated hydraulic conductivity (mm/hr).

### Step 7. Check Requirement for Impermeable Lining

The saturated hydraulic conductivity of the natural soil profile surrounding the paving system should be tested together with depth to groundwater, chemical composition and proximity to structures and other infrastructure. This is to establish if an impermeable liner is required at the base (only for systems designed to preclude ex-filtration to in-situ soils) and/or sides of the pavement sub-layers. If the saturated hydraulic conductivity of the paving system is more than one order of magnitude (10 times) greater than that of the surrounding in-situ soil profile, no impermeable lining is required.

### Step 8. Specify Porous Paving Layers Elements

The following design and specification requirements must be documented as part of the design process for porous pavement systems.

#### A. Porous Paving Surface

The porous paving layer will depend on the type of paving decided on through the design process. The porous paving surface type must be specified along with any proprietary requirements and specifications. The pavers are set on a coarse sand or fine gravel bedding layer. The purpose of this layer is to provide a smooth, flat surface on which to lay the porous paving.

**B. Retention/ Aggregate Layer**

Where the 'detention volume' is created through the use of a gravel-filled trench then the gravel must be clean (free of fines) stone/ gravel with a uniform size of between 25 - 100 mm diameter.

**C. Geofabric**

Geofabric must be installed along the side walls and through the base of the detention volume to prevent the migration of in-situ soils, and material from the bedding and filter layers into the system. Geofabric with a minimum perforation or mesh of 0.25 mm should be used.

**Step 9. Size Overflow Pit/Pipe**

Overflow from a porous paving system can be via overflow pipes located just underneath the sand bedding layer, in the top of the detention/ aggregate layer or can be via an overflow pit or similar structure.

**A. Overflow Pipes**

Pipe flows are to be calculated in accordance with Section 3.5 and QUDM (DPI, IMEA & BCC 1992) which use standard pipe equations that account for energy losses associated with inlet and outlet conditions and friction losses within the pipe. For most applications, the pipe or culvert will operate under outlet control with the inlet and outlet of the pipe/ culvert being fully

submerged. With relatively short pipe connections, friction losses are typically small and can be computed using Manning's equation. The total energy (head) loss ( $\Delta H$ ) of the connection is largely determined by the inlet and outlet conditions and the total losses can be computed using the expression as provided in QUDM (DPI, IMEA & BCC 1992):

$$\Delta H = h_f + h_s$$

where

$h_f = Sf \cdot L$  = head loss in pipe due to friction (m)

$h_s = (K_{in} + K_{out}) \cdot V^2/2g$  = head loss at entry and exit (m)

$Sf$  = friction slope which is computed from Manning's Equation (m/m)

$L$  = is the length pipe (m)

$K_{in} + K_{out}$  = the head loss coefficients for the inlet and outlet conditions (typically, and conservatively, assumed to be 0.5 and 1.0 respectively)

$V$  = velocity on flow in pipe (m/s)

$g$  = gravity (9.79 m/s<sup>2</sup>)

**B. Overflow Pit**

In porous paving systems, the overflow pit is designed so that the pit crest is at the level of the pavement surface. It may be raised slightly above the surface of the paving to ensure flows do not divert to the overflow pit before infiltrating the pavement surface.

To size an overflow pit, two checks should be made to test for either drowned or free flowing conditions. A broad crested weir equation can be used to determine the length of weir required (assuming free flowing conditions) and an orifice equation used to estimate the area

between openings required in the grate cover (assuming drowned outlet conditions). The larger of the two pit configurations should be adopted (as per Section 5.10 QUDM (DPI, IMEA & BCC 1992)). In addition, a blockage factor is to be used that assumes the grate is 50 % blocked. For free overfall conditions (weir equation):

$$Q_{\text{weir}} = B \square C_w \square L \square h^{3/2}$$

Where  $Q_{\text{weir}}$  = flow into pit (weir) under free overfall conditions ( $\text{m}^3/\text{s}$ )

$B$  = blockage factor (= 0.5)

$C_w$  = weir coefficient (= 1.66)

$L$  = length of weir (perimeter of pit) (m)

$h$  = flow depth above the weir (pit) (m)

Once the length of weir is calculated, a standard sized pit can be selected with a perimeter at least the same length of the required weir length.

For drowned outlet conditions (orifice equation):

$$Q_{\text{orifice}} = B \square C_d \square A \square \text{SQRT}(2 \square g \square h)$$

Where

$B$ ,  $g$  and  $h$  have the same meaning as above

$Q_{\text{orifice}}$  = flow rate into pit under drowned conditions ( $\text{m}^3/\text{s}$ )

$C_d$  = discharge coefficient (drowned conditions = 0.6)

$A$  = area of orifice (perforations in inlet grate) ( $\text{m}^2$ )

When designing grated field inlet pits, reference is to be made to the procedure described in QUDM Section 5.10.4 (DPI, IMEA & BCC 1992)