Sustainable Technologies
EVALUATION PROGRAM

Permeable Pavement





Permeable pavements are an alternative to traditional impervious pavements that allow stormwater to drain through them and into a storage reservoir below. Depending on the native soil properties and site constraints, the system may be designed for full infiltration, partial infiltration, or as a non-infiltrating detention and filtration only practice. They can be used for low traffic roads, parking, driveways, and walk ways, and are ideal where space for other surface BMPs is imited. Permeable pavement types include:

- permeable interlocking pavers (concrete or composite materials)
- grid systems (concrete or composite materials)
- pervious concrete (poured-in-place or pre-cast)
- porous asphalt
- permeable articulating block/mat systems

DESIGN

GEOMETRY & SITE LAYOUT

Permeable pavement (PP) systems can be used for entire parking lot areas or driveways or can be designed to receive runoff from adjacent impervious pavement. For example, the parking spaces in a lot or road can be permeable while the drive lanes are conventional asphalt. In general, the impervious area should not exceed the size of the PP itself. Drainage areas with clean runoff such as roofs may be up to 4 times the pavement area, but should include filtration pre-treatment to remove coarse debris. This drainage can be conveyed directly to the storage reservoir.

PRETREATMENT

In most PP systems, the surface course or joint fill between pavers provide pretreatment to the reservoir below. To avoid clogging, ensure annual vacuum sweeping and apply preventive practices like avoiding storing snow and other materials on the PP.

STORAGE RESERVOIR

Depth must meet both runoff storage and structural support requirements. The STEP LID Planning and Design Guide wiki provides guidance and a tool to allow for calculation of reservoir depth required to store the design storm runoff volume. Aggregate depth required for structural support often far exceeds that required for design storm storage. Clean washed stone is critical as any fines in the aggregate material will migrate to the bottom and clog the native soil. See Specifications for further details.

UNDERDRAIN

Recommended where native soil infiltration rate is <15 mm/h and needed for non-infiltrating designs with impermeable liners. The perforated pipe may be raised in the cross section or placed on the reservoir bottom and connected to an upturned pipe assembly or riser with optional flow restriction to promote infiltration while meeting design drawdown times.

PERFORATED PIPE

Continuously perforated, smooth interior HDPE or PVC drainage pipe, ≥200 mm interior diameter where possible to reduce risk of freezing and facilitate push camera inspection and cleaning with jet nozzle equipment.

CONVEYANCE AND OVERFLOW

All designs require an overflow outlet connected to a storm sewer with capacity to convey larger storms. This may be achieved with a catchbasin outlet, or water can be directed to a downstream LID practice. Alternatively a gravel diaphragm or trench along the PP's downgradient edge can drain water to the reservoir below.

SUBGRADE

For infiltrating pavements, subgrade slopes should be minimized so that runoff will be able to infiltrate evenly through the entire surface. For steeply sloped sites, check dams, berms or weir structures on the bottom of the pavement should be considered. In non-infiltrating systems the bottom should be sloped 1 to 5% toward the underdrain. Subgrades should be compacted to 95% Standard Proctor Density. If a lesser value is desired to promote infiltration, a thicker sub-base should be considered. Subgrade soils should not be scarified.

EDGE RESTRAINTS

Pavers must abut tightly against the restraints to prevent rotation under load and any consequent spreading of joints. The restraints must be able to withstand the impact of temperature changes, vehicular traffic and snow removal equipment. Metal or plastic stripping may be used for pedestrian or light vehicle applications. Concrete curbs should be supported on a minimum base of 150 mm of aggregate.

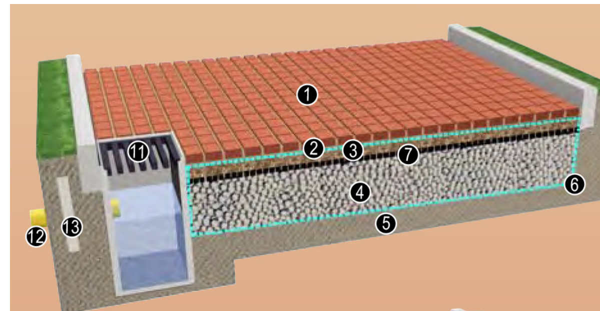
LANDSCAPING

Adjacent landscaped areas should drain away from PP to prevent sediments depositing on the surface. Urban trees also benefit from being surrounded by PP rather than impervious cover, because their roots receive more air and water.

MONITORING WELLS

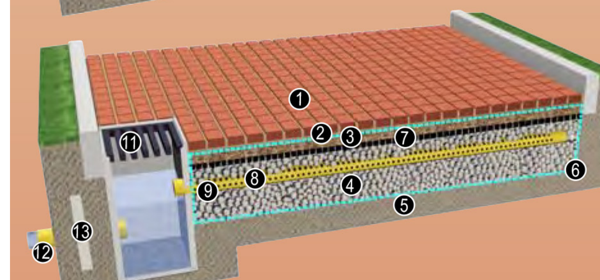
A vertical standpipe consisting of an anchored 100 to 150 mm diameter pipe with perforations along the part of its length within the storage reservoir, embedded 150 mm into native soil. A lockable cap is recommended for monitoring storm drainage times.

PP Design	Ability to meet stormwater criteria		
	Water balance	Water quality	Stream erosion control
No underdrain	Yes	Yes - size for water quality storage requirement	Partial - based on available storage volume and soil infiltration rate
With underdrain	Moderate - based on native soil infil. rate and storage below underdrain	Yes - size for water quality storage requirement	Partial - based on available storage volume and soil infiltration rate
With underdrain & liner	No, but some volume reduction through evaporation	Yes - size for water quality storage requirement	Partial - based on available storage volume and soil infiltration rate



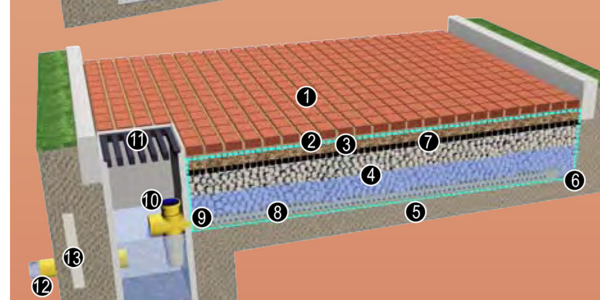
Full Infiltration

Where rainfall is intended to infiltrate into the underlying subsoil. Candidate in sites with subsoil permeability > 15mm/hr.



Partial Infiltration

Designed so that most water may infiltrate into the underlying soil while the surplus overflow is drained by perforated pipes that are placed near the top of the drain rock reservoir. Suitable for subsoil permeability >1 and < 15mm/hr.



Partial Infiltration with Flow Restrictor

Where subsoil permeability is < 1mm/hr, water is removed at a controlled rate through a bottom pipe system and flow restrictor assembly. Systems are essentially underground detention systems, used where the underlying soil has very low permeability or in areas with high water table. Also provides water quality benefits. However this should not be needed if I/P≤ 2.

1. Permeable Pavers (Min. 80mm thickness)
2. Aggregate Bedding Course - not sand (50mm depth)
3. Open Graded Base (depth varies by design application)
4. Open Graded Sub-base (depth varies by design application)
5. Subsoil - flat and scarified in infiltration designs
6. Geotextile on All Sides of Reservoir
7. Optional Reinforcing Grid for Heavy Loads
8. Perforated Drain Pipe 150mm Dia. Min.
9. Geotextile Adhered to Drain at Opening
10. Flow Restrictor Assembly
11. Secondary Overflow Inlet at Catch Basin
12. Outlet Pipe to Storm Drain or Swale System. Locate Crown of Pipe Below Open Graded Base (no. 3) to Prevent Heaving During Freeze/Thaw Cycle
13. Trench Dams at All Utility Crossings

Source: Greater Vancouver Sewerage and Drainage District, 2012

PLANNING CONSIDERATIONS

Soil | PP can be constructed over any soil type, but hydrologic soil group A and B are best for achieving water balance objectives. For systems located in native soils with an infiltration rate of <15 mm/hr (i.e. hydraulic conductivity of <$1x10^{-6}$ cm/s), an underdrain is recommended. Native soil infiltration rate should be confirmed by hydraulic conductivity measurement under field saturated conditions. Where expansive clays are present, a non-infiltrating design may be necessary.

Wellhead Protection | PP should not be used for road or parking surfaces within two (2) year time-of-travel wellhead protection areas.

Site Topography | PP surface should be at least 1% and no greater than 5%.

Water Table | The PP reservoir base should be ≥ 1 m above the seasonally high water table or top of bedrock. Where this cannot be achieved, site specific analysis would be required (see Hantush Groundwater Mounding Tool on LID Wiki site).

Pollution Hot Spot Runoff | To prevent groundwater contamination, runoff from pollution hot spots should not be treated by a PP design that allows for infiltration.

Karst | Full or partial infiltration designs are not suitable in areas of known or implied karst topography.

Setback from Buildings | PP should be located downslope of building foundations. Setback is only required if the PP receives runoff from other surfaces, in which case a setback ≥ 4 m downgradient is recommended. Lesser separation is possible where foundations are protected by a geomembrane.

CONSTRUCTION

Sediment control | The treatment area should be fully protected during construction so that no sediment reaches the PP system. Construction traffic should be blocked from the PP and its drainage areas once the pavement has been installed.

Base construction | The stone aggregate should be placed in 100 to 150 mm lifts and compacted with a minimum 9 ton steel drum vibratory roller. A Light Weight Deflectometer may be used to test compaction of the stone against specifications.

Weather | Porous asphalt and pervious concrete will not properly pour and set in extremely high and low temperatures.

Pavement placement | Properly installed PP requires trained and experienced producers and construction contractors.

OPERATION AND MAINTENANCE

Annual inspections of PP should be conducted in the spring to ensure continued infiltration performance. Check for deterioration and whether water is draining between storms. The pavement reservoir should drain completely within 72 hours of a storm event. The following maintenance procedures and preventative measures should be incorporated into a maintenance plan:

- **Surface sweeping:** Sweeping should occur annually with a commercial vacuum sweeping unit. Joint fill aggregate removed during vacuuming of interlocking pavers should be replaced. While washing with high pressure sprayers or air compression units is generally discouraged as they can push fines deeper into the pavement, STEP research has shown that pressure washing at an angle to the surface can loosen fines and improve vacuuming efficacy for segmented pavers.
- **Grid pavers:** Grid paver systems that have been planted with grass should be mowed regularly with the clippings removed. Grassed grid pavers may require periodic watering and fertilization to establish and maintain healthy vegetation.
- **Underdrain:** Underdrain pipes should be CCTV inspected every 5 years and cleaned as needed.
- **Heavy vehicles:** Trucks and other heavy vehicles should be prevented from tracking or spilling dirt onto the PP.
- **Hazardous materials:** All hazardous material storage and carrier traffic should be prohibited from entering a PP area to prevent groundwater contamination.
- **Drainage areas:** Impervious areas draining to the PP should be regularly swept and kept clear of debris. Runoff from adjacent landscaped areas should be diverted away from the pavement unless well stabilized with vegetation.
- **Winter maintenance:** Sand should not be spread on PP as it can quickly lead to clogging. Deicers should only be used in moderation and only when needed. Research has shown that de-icing salt application can be significantly reduced on PP while still retaining slip resistance. PP is plowed for snow removal like any other pavement. Plowed snow piles should not be stored on PP systems. Plow blades can be fitted with rubber to prevent chipping.

GENERAL SPECIFICATIONS

Material	Specification
Pervious concrete	• NO4-RG-S7 mix with air entrainment proven to have the best freeze-thaw durability after 300 freeze-thaw cycles. • 28 day compressive strength = 5.5 to 20 MPa, void ratio = 14% - 31%, Permeability = 900 to 21,500 mm/hr. • Thickness will range from 100 mm to 150 mm depending on the expected loads. • Proprietary pre-cast pervious concrete slabs meeting required specifications are also available.
Porous asphalt	• Open-graded asphalt mix with a minimum of 16% air voids. • Thickness will range from 50 mm to 100 mm depending on the expected loads. • Polymers can be added to provide additional strength for heavy loads. • See University of New Hampshire Stormwater Centre for detailed design specifications for porous asphalt.
Permeable pavers	• Permeable pavers should conform to manufacturer specifications. • ASTM No. 8 (5 mm dia.) crushed aggregate is recommended for fill material in the paver openings. For narrow joints between interlocking shapes, a smaller sized aggregate may be used. Open space between pavers (i.e. joint space) typically ranges between 5 and 15% of the total surface area. • Pavers shall meet the min. material and standard specification for precast concrete pavers as set out in CSA A231.2 (in Canada) and ASTM C936 (in the US) • Min. paver thickness is 80 mm for vehicular applications and 60 mm for pedestrian applications. Max. joint width of 15 mm for pedestrian applications. • Detailed design guidance for PICP is provided by ASCE (2018) and the Interlocking Concrete Pavement Institute (icpi.org/technical-center)
Stone reservoir	• All aggregates should meet the following criteria: (i) maximum wash loss of 0.5%, (ii) minimum durability index of 35, (iii) maximum abrasion of 10% for 100 revolutions and maximum of 50% for 500 revolutions • Most OPSS aggregates are not recommended for PP, with the exception of 'granular O'. • The granular subbase material shall consist of granular material graded in accordance with ASTM D 2940. Material should be clear crushed 50 mm diameter stone with void space ratio of 0.4. • The granular base material shall be crushed stone conforming to ASTM C 33 No 57. Material should be clear crushed 20 mm diameter stone. • The granular bedding material shall be graded in accordance with ASTM C 33 No 8. Typical bedding thickness is 40 to 75 mm. Material should be 5 mm diameter stone or as determined by the Design Engineer. In Ontario, high performance bedding (1 to 9 mm diameter) or equivalent is often used. • See LID Planning and Design Wiki (Permeable Pavements: Sizing) to size aggregate bed depth and multiply by application area to get total volume.
Geotextile	• Geotextiles are not always necessary and may be prone to eventual clogging. Consider using sand or fine aggregates instead. Where they are necessary (typically on low strength soils of CBR <4) between stone reservoir and native soil, material specifications should conform to Ontario Provincial Standard Specification (OPSS) 1860 for Class II geotextile fabrics. Geotextile socks on pipes should conform to ASTM D6707 with a min. water flow rate conforming to ASTM D4491 (12,263 L/min/m^2 at 5 cm head). • Should be woven monofilament or non-woven needle punched fabrics. Woven slit film and non-woven heat bonded fabrics should not be used as they are prone to clogging. • Primary considerations are: (i) suitable apparent opening size (AOS) for non-woven fabrics, or percent open area (POA) for woven fabrics, to maintain water flow even with sediment and microbial film build-up, (ii) max. forces to be exerted on the fabric (i.e tensile, tear and puncture strengths required), (iii) load bearing ratio of the underlying native soil (i.e. is geotextile needed to prevent downward migration of aggregate into the native soil?), (iv) grain size distribution of the overlying aggregate material, and (v) permeability of the native soil.
Underdrain (optional)	• PVC or HDPE, continuously perforated with smooth interior and a minimum inside diameter of 200 mm. • Perforations in pipes should be 10 mm in diameter. • A standpipe from the underdrain to the pavement surface can be used for monitoring and maintenance of the underdrain. The top of the standpipe should be covered with a screw cap and a vandal-proof lock. • Pipes should terminate 0.3 m short from the sides of the base.

For more information:

Visit the online LID Stormwater Management Planning and Design Guide for more information including links to all sources cited: wiki.sustainabletechnologies.ca.

LID Stormwater Inspection and Maintenance Guide (TRCA, 2016): sustainabletechnologies.ca.

LID Construction Guide (CVC, 2012): sustainabletechnologies.ca.

The water component of the Sustainable Technologies Evaluation Program is a collaboration of:

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