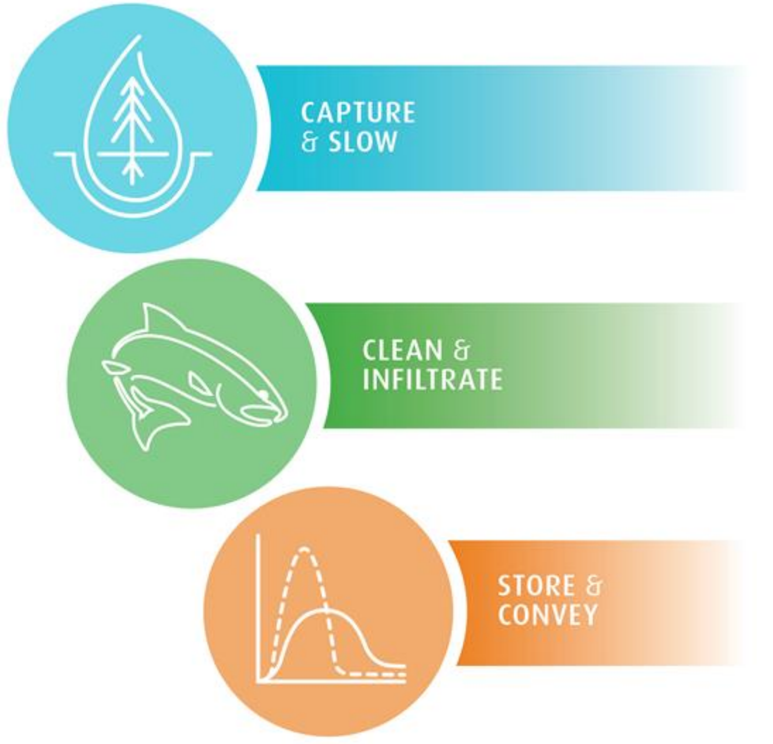


APPENDIX K – PERVIOUS PAVING SYSTEMS

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

Pervious Paving Systems[1]

Description

Pervious paving is a surface layer of paving systems which allows rainfall to percolate into an underlying reservoir base, where rainfall is stored and either exfiltrated to underlying subgrade, or discharged via a subdrain.

The surface component of pervious paving can be:

- Porous asphalt or porous concrete, where fines are not included in the mix, providing a high void ratio that allows water to pass through. There have been problems with surface clogging of this type of pavement.
- Concrete or plastic grid pavers, where a structural load bearing matrix has large voids that are filled with permeable material – usually gravel or soil – and may have grass growing in the void spaces.
- Permeable unit pavers, made up of impervious concrete modular pavers with gapped joints that allow water to percolate between the pavers.

This section outlines permeable unit pavers and porous paving alternatives.

Figure 1 South Valley Estates, Saanich

Figure 2 Permeable paving system, Burnside Gorge Community Centre

[1] **Adapted with permission from Metro Vancouver.**
Original document: Metro Vancouver's Stormwater Source Control Design Guidelines 2012, primary author Kerr Wood Leidal Associates Ltd. with Lanarc Consultants Ltd and Goya Ngan, http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/StormwaterSourceControlDesignGuidelines2012StormwaterSourceControlDesignGuidelines2012.pdf
Adaptations authored by: Opus International Consultants (Canada) Limited
Design guidelines drawings by: Kerr Wood Leidal Associates Ltd

Selection and Application

- Pervious paving does not have a soil layer that treats runoff and is subject to clogging from surface pollutants. Pervious paving should not be used to infiltrate runoff from moderate- to high-traffic roads and parking areas that receive more than 1 vehicle per day per space. For surfaces with higher potential contaminant runoff, absorbent landscaping, rain gardens (and other bioretention facilities) and infiltration swales should be considered.
- Pervious paving is suitable for low traffic areas – e.g., driveways, commuter parking areas, storage yards, bike paths, walkways, recreational vehicle pads, service roads, and fire lanes.

Figure 3 Permeable paving at L'ecole Victor Brodeur, Esquimalt

- Pervious paving can receive runoff from other areas, if the tributary areas have low sediment loads or protection from sediment loads is provided. If the contributing impervious area is greater than 2x the area of pervious paving, alternative solutions such as bioretention facilities and infiltration swales or trench should be considered.
- Grid pavers with soil and grass should be restricted to areas with evening parking (i.e., residential) or periodic day parking to allow sunshine to reach the grass during the daylight hours.
- Suitable for reduction in peak flows and runoff volumes, contaminant removal, and groundwater recharge.
- May be used to retrofit existing developments and redeveloping areas as well as in new developments.
- A greater design and construction control effort is required when compared with impermeable pavements.
- Types of permeable interlocking concrete pavers that have wide joints (some manufacturers) should not be used for disabled persons parking stalls or pedestrian ramps at street crossings.

Design Guidelines for Permeable Interlocking Concrete Paving

Pervious pavement designs may be 1 of 3 types:

- Full Infiltration: where all inflow is intended to infiltrate into the underlying subsoil.
- Partial Infiltration: designed so that some water may infiltrate into the underlying soil while the remainder is drained by perforated pipes.
- Partial Infiltration with Flow Restrictor: designed with a perforated pipe and flow restrictor located at the bottom of the drain rock reservoir, allows the gradual decanting of water above the perforated pipe.

Design Guidelines for all 3 types include the following:

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. Geo-technical investigations are recommended with soil permeability testing being the minimum requirement for design. Advice from a professional engineer for design is recommended.
4. Partial infiltration with flow restrictor – designed with a perforated pipe and flow restrictor located at the bottom of the drain rock reservoir. A small orifice in the flow restrictor allows the gradual decanting of water above the perforated pipe, with infiltration occurring as much as possible. These systems are essentially underground detention systems, and are used in cases where the underlying soil has low permeability or there is high water table. This type of design is generally not needed if only upstream paved area is discharged to pervious paving at a ratio of 2:1 or less, but could be used if roof water is discharged to permeable paving at more than 2:1 I/P ratio.

Figure 4 Grass grid at Victoria Island Technology Park

5. Soil subgrade sampling and analysis should be provided by a professional engineer knowledgeable in the local soils. Testing of soil cores taken at the proposed area to be paved should include soil texture classification, sampled moisture content, 96-hour soaked California Bearing Ratio with a target of at least 5% for light vehicular traffic, 15% for heavy vehicles, and on-site infiltration tests using a Double-Ring Infiltrometer taken at the elevation of the proposed base of the reservoir. Infiltration testing should be completed in the winter under saturated conditions.
6. Minimum recommended tested infiltration rate for a full infiltration pavement design is 13 mm/hr. Sites with lower rates will require partial infiltration solutions with drain pipes, and care must be taken that the subbase will remain stable while saturated.
7. At least 30 m should be maintained between permeable pavements and water supply wells.
8. The pavement should be downslope from building foundations, and the foundations should have piped drainage at the footing.
9. To avoid surface plugging, it is critical to protect this GSI from sedimentation both during and after construction. In addition, identify pollutant sources, particularly in industrial/commercial hotspots, that require pre-treatment or source control upstream of this GSI facility.

10. Where it is proposed to drain impermeable surfaces onto pervious pavement surfaces, it is recommended that a maximum ratio of 2:1 impermeable to permeable is used. This may vary by rainfall and soil characteristics as determined by modelling.
11. For draining roof water to pervious pavers, much higher ratios of upstream impervious surface to pervious pavers, such as 50:1, may be used. Sediment loading potential of the upstream surface will determine allowable ratio.
12. Permeable unit pavers should be selected and designed based on a manufacturer's tests that the installed unit paving system can maintain a minimum 28 mm/hr infiltration rate over the pavement life (usually 20 years). This rate includes a factor of safety of 10 – the initial infiltration rate should be >280 mm/hr.
13. Permeable unit pavers are usually 80 mm depth. Provide edge restraint to contain the pavers, similar to standard unit paving. Edge restraints that use spikes are not recommended.
14. Permeable unit paving surface slope should be 1% minimum to avoid ponding on the surface, and related settlement of clay-sized particles.
15. Provision of vegetated joints, and overhanging trees which drop needles onto the pavement have, in research studies, helped to maintain high infiltration capabilities of pervious unit paving. Vegetated joints are not suitable in heavily shaded areas such as under long-term parking.
16. Paver bedding material shall be wrapped with geotextile filter cloth on bottom and all sides. This is critical to the water quality performance of the pavement, and also keeps any intrusion of fines near the surface, where localized clogging could be repaired by replacing only the aggregate above the filter cloth, patching the cloth, and reusing the pavers.
17. Minimum depth from base of drain rock reservoir to water table or solid bedrock 600 mm.
18. Bottom of reservoir: flat in full infiltration designs, minimum 0.1% slope to drain in piped systems.
19. If the pavement is being designed for heavy loads, optional reinforcing grids (geogrid) may be included in the pavement subbase.
20. With infiltration designs, the bottom and sides of all reservoir base and subbase courses shall be contained by a geotextile filter cloth. Geotextile shall be adhered to the drains.
21. Design reservoir water levels and stormwater detention using a continuous modelling program. Base draw down time for the reservoir on the Green-Field runoff rate.
22. If the design is for partial infiltration with a flow restrictor assembly, size the orifice for a design flow that meets local requirements or replicates base flow from the drainage area.
23. Provide a secondary overflow inlet and inspection chamber (catch basin or manhole) at the flow control assembly. If no secondary overflow inlet is installed, provide a non-erodible outlet or spillway to the major storm flow path.
24. Avoid utility or other crossings of the pervious pavement area. Where utility trenches must be constructed crossing below the reservoir, install trench dams at exits to avoid infiltration water following the utility trench.

25. See Table 1 for setbacks for pervious paving. A liner may be required within 1.5 m of infrastructure.

Table 1 Pervious Paving Setbacks

Setback From	Distance (m)
Foundation	0
Property Line	0
Drinking Water Well	30
Septic Field	3
Active or inactive landfill or contaminated site	30
Minimum Slope	1%

Sizing Pervious Paving

In this guide, a simplified sizing approach has been developed that does not require water balance modelling or continuous simulation.

1. In general, pervious paving is sized to infiltrate the rain that falls directly on it and runoff from a limited area of upstream impervious surface. The maximum ratio of impervious paved area to pervious paving area (I/P ratio) allowed will be 2:1. Pervious area refers to the pervious paving area and the I/P ratio will be zero (0) where no impervious area is directed to the pervious paving.
2. This sizing approach does not apply to a partial infiltration reservoir and drain with flow restrictor under pervious paving.
3. Sizing presented here is for infiltration of rainwater for "capture" and prevention of site runoff. Sizing and design according to this guidance will not provide adequate water quality treatment for runoff from high-vehicle-volume and other polluted surfaces. Sizing of treatment, when needed, must be performed separately.

Sizing for Depth Capture Criteria: R mm in 24 hrs

To determine R mm of rain in 24 hrs see Appendix A, Table 1 for area specific typical GSI facility design guideline rainfall capture targets and confirm with respective municipality.

1. Determine the maximum rock depth according to the drain time (4 days max.) and round down to the nearest 50 mm increment for constructability; allowable depth range is 300 to 1,000 mm:

$$D_R = \frac{Ks \times T \times 24}{n}$$

Where:
D_R = Depth (thickness) of rock reservoir (mm)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions
T = allowable drain time (days)
n = porosity of drain rock in reservoir (unitless, e.g., 0.35)

2. Use the following equation to determine the base (bottom) area of pervious paving and rock reservoir required by finding the I/P ratio for the site:

$$I/P = \frac{24 \times Ks + D_R \times n}{R} - 1$$

Where:
I/P = Ratio of impervious tributary area to pervious paving area (unitless)
R = Rainfall capture depth (mm)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions
D_R = Depth (thickness) of rock reservoir (mm)

3. Check that the I/P ratio calculated is less than the maximum allowed (2:1). If it is not, the I/P ratio may be assumed to be a maximum of 2. Recalculate the minimum rock depth using the formula:

$$D_R = \frac{[(I/P + 1) \times R] - (24 \times Ks)}{n}$$

Where:
I/P = 2

4. To find the pervious paving area:

$$PerviousArea = \frac{\text{Impervious TributaryA rea}}{I/P}$$

Guideline Specifications

Materials shall meet Master Municipal Construction Document 2009 requirements, and:

1. Pavers: Permeable interlocking concrete pavers meeting CSA A231.2, designed and tested by the manufacturer for use as part of a permeable unit paving system with an initial infiltration rate >280 mm/hr. and a maintained >28 mm/hr infiltration rate over the pavement life (usually 20 years).
2. Paver bedding course (50 mm thick) and joint filling material shall be open-graded crush 5 mm aggregate (or ASTM No.8 - no sand). A surface finish of 3 mm clean crush aggregate (or ASTM No 89) should be applied to the finish surface and brushed in.
3. Reservoir base course shall be clean crushed stone graded from 5 mm to 20 mm (approximately 100 mm deep or greater – varies with design). In cases where this finer base is not required for water quality treatment, the reservoir base may be the same material as the reservoir subbase.
4. Reservoir subbase shall be clean crushed stone graded from 10 mm to 63 mm, with void space ratio >35% (or ASTM No. 57 – approximately 250 mm deep or greater – varies with design).
5. Pipe: PVC, DR 35, 150 mm min. diameter, with cleanouts. Practical depth of cover over the pipe may be a determinant in depth of base courses.
6. Geosynthetics: as per Section 31 32 19, select for filter criteria or from approved local government product lists.

Construction Practices shall meet Master Municipal Construction Document 2009 requirements, and:

1. Isolate the permeable paving site from sedimentation during construction, either by use of effective erosion and sediment control measures upstream, or by delaying the excavation of 300 mm of material over the final subgrade of the pavement until after all sediment-producing construction in the drainage area has been completed.
2. The subgrade should be compacted to 95% standard proctor for walk/bike areas, and 95% modified proctor for vehicular areas. Remove and replace soft areas.
3. Scarify subgrade (native) soil prior to placement of filter cloth and aggregate to ensure the subsurface has not sealed due to equipment or raindrops.
4. Prevent natural or fill soils from intermixing with the reservoir base, sub-base, or bedding courses and filter cloths. All contaminated stone aggregate and cloth must be removed and replaced.
5. Reservoir drain rock subbase and base courses shall be installed in 100 mm to 150 mm lifts and compacted with at least 4 passes with a minimum 9 T steel drum roller.
6. When all base courses are compacted, the surface should be topped with filter cloth and a layer of bedding aggregate, and the surface graded carefully to final slopes, as the bedding aggregate will compact down much less than sand. Unit pavers shall be placed tightly butt jointed according to manufacturer's specifications. Blocks should be vibrated with a vibrating plated compactor. Following a first pass, a light dressing of 3-mm single size clean stone should be applied to the surface and brushed in, approximately 2 kg/m^2. Blocks should again be vibrated and any debris brushed off.

7. For maintenance, the surface should be brushed at least twice a year with a mechanical suction brush (vacuum sweeper) – in the spring and in autumn after leaf fall.

Pervious Paving Design Example for Capture of R mm/24-hour Criteria

Scenario Description

Pervious paving is proposed to capture a portion of the runoff from a paved parking area (see illustration below).

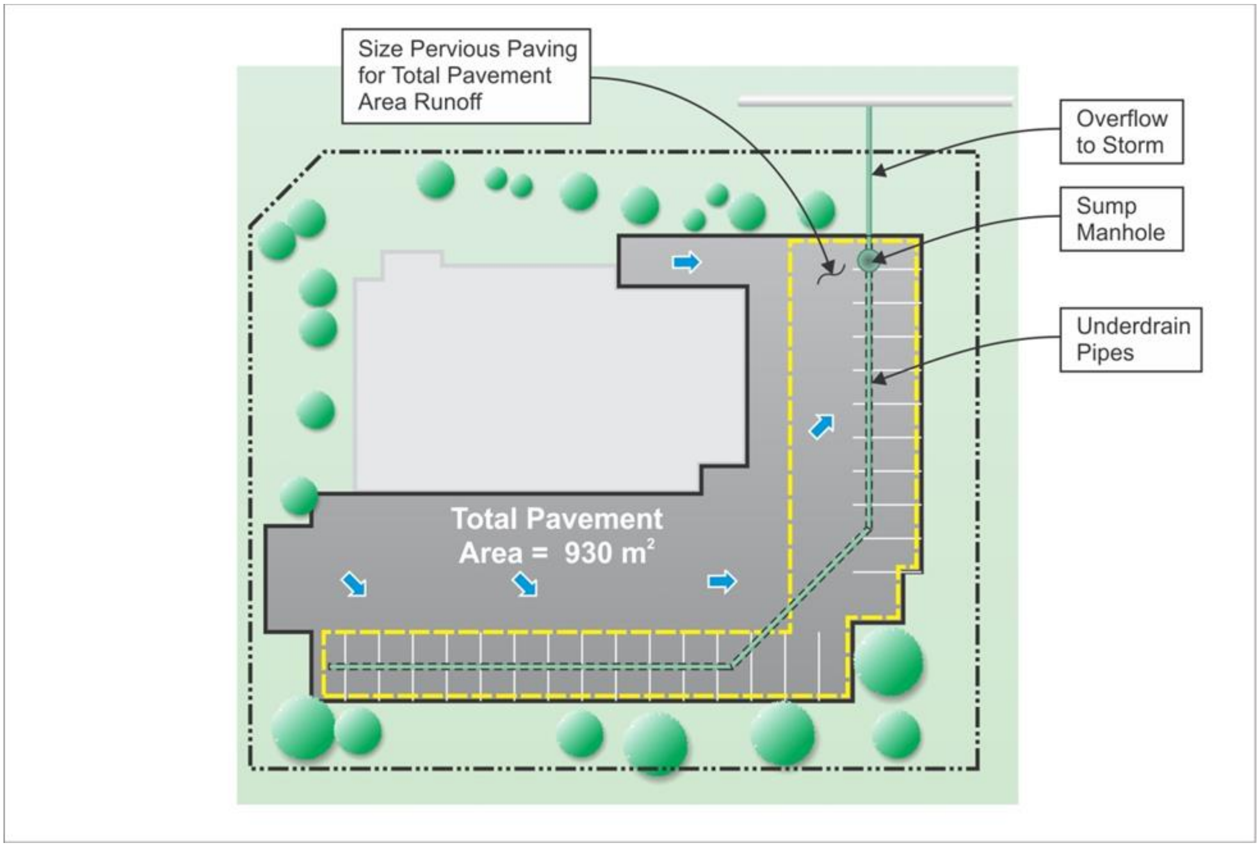


Figure 5 Example – Parking Area Draining to Pervious Paving

The following parameters are known:

- Total pavement area = 930 m^2
- Native soil infiltration rate = 2.0 mm/hr
- 2-year 24-hour rain depth = 53 mm
- Capture target is 72 % of 2-year 24-hour rain amount = 38 mm

Determine the pervious paving area and rock reservoir depth.

Sizing

Determine the maximum rock depth based on the 4-day maximum drain time:

$$D_R = \frac{Ks \times T \times 24}{n} = \frac{2.0mm/hr \times 4days \times 24hr/day}{0.35} = 548mm$$

Use the following equation to determine the base (bottom) area of pervious paving and rock reservoir required by finding the I/P ratio for the site:

$$I/P = \frac{24 \times Ks + D_R \times n}{R} - 1$$

$$I/P = \frac{24hr \times 2mm/hr + 548mm \times 0.35}{38mm} - 1 = 5.3$$

Check that the I/P ratio calculated is less than the maximum allowed (2:1). If it is not, the I/P ratio may be assumed to be a maximum of 2. Recalculate the minimum rock depth using the formula:

$$D_R = \frac{[(I/P + 1) \times R] - (24 \times Ks)}{n}$$

$$D_R = \frac{[(2+1) \times 38mm] - (24hr \times 2mm/hr)}{0.35} = 189mm$$

Check that the rock trench depth is less than the maximum calculated above (189 mm <548 mm, therefore OK).

Calculate the pervious paving area:

$$PerviousArea = \frac{imperviousTributaryArea}{I/P}$$

$$PerviousArea = \frac{930sq.m. - PerviousArea}{2}$$

$$2 \times PerviousArea = 930sq.m. - PerviousArea$$

$$PerviousArea = \frac{930sq.m.}{3} = 310sq.m$$

Hydraulic Components

- **Inlet**: The impervious pavement runoff sheet flows onto the pervious paving.
- **Overflow**: The site grading and pavement grading must allow overland flow to the municipal major system (typically roadway surface) for any water that overwhelms the infiltration capacity of the pervious paving.
- **Underdrain**: A perforated pipe located along the top of the rock layer decants excess water into a sump manhole when the rock layer is full of water. The sump is connected to the municipal storm sewer connection.

Maintenance

- Vacuum sweep the pervious paving annually to remove built up fines on the surface. Some systems such as plastic grid panels cannot be swept.
- Underdrain sump should be inspected annually and cleaned, as required. Sediment should be removed from the sump bottom.

GSI Driver Effectiveness – Runoff Reduction and Contaminant Removal

International Stormwater BMP Database http://www.bmpdatabase.org/ is a recommended resource for performance summaries of GSI facilities and latest research.

Pollutant removal in pervious pavement systems occurs by the filtering of stormwater that is infiltrated into the underlying fabric (if part of the design) or soil subgrade. As with all treatment GSI facilities that use infiltration to remove pollutants, one must ensure that there are sufficient organic content and adsorption capacity in the subgrade soils to remove contaminants and protect groundwater quality. Research indicates that pervious pavement systems are efficient at removing several of the common stormwater pollutants if they include a good subgrade soil for infiltration and filtering. Estimates of GSI driver effectiveness are shown below:

Table 2 Runoff Reduction and Contaminant Removal Summary Table

Pervious Paving Systems for GSI Facilities	
GSI Driver	***Estimated Effectiveness or Typical % Reduction or Removal**
Capture & Slow – Volume Runoff Reduction	85% without underdrain 45% with underdrain
Store & Convey – Rate Control Delay Peak	Medium to high without under drain Medium with underdrain
Clean & Infiltrate – Water Quality Treatment	Highly variable with design, BSM, native soil and depth, plant type. Below are typical results. Research has observed good retention and at times production and export. Export is more likely with an underdrain.
Heavy Metals (Copper, Lead, Zinc)	72-98
Oil and Grease / Hydrocarbons	80
Phosphorus	45-65
Nitrogen	50-60
Total Suspended Solids (TSS)	74-90
Bacteria (Fecal coliform bacteria or E. coli)	NA

**Sources:*
http://www.sustainabletechnologies.ca/wp/wp-content/uploads/2013/02/4.7-Permeable-Pavement.pdf
https://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
http://www.bmpdatabase.org/

Maintenance

Maintenance is a crucial element to ensure the long term performance of pervious pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment that can reduce the pavement's flow capacity. Maintenance requirements for pervious paving will vary based on:

- Type of pervious paving system
- Ownership
- Type of use
- Level of traffic
- Contributing catchments

ACTIVITY	OBJECTIVE	SCHEDULE
Visually check observation ports	Ensure that the subgrade soils are not clogged and are draining properly	Twice annually
Inspect for ponding water	Ensure that the subgrade soils are not clogged and are draining properly	Following heavy rains (25 cm in 24 hours)
Manually sweep large debris and leaves	Ensure adequate flow capacity of pavers	Once annually in fall or as needed
Vacuum sweep with commercial sweeping machine (dependent on paving system)	Keep pavers clean and decrease sediment clogging	Twice annually
Manually remove weeds	Ensure perviousness of pavers	Annually or as needed
Refill gravels between pavers or open-celled systems	Maintain proper functioning of pervious paving	Annually minimum

Routine Maintenance

Most of the routine maintenance procedures are typical landscape care activities.

Non-routine Maintenance

The most common non-routine maintenance problem involves ponding water. If water remains on the surface for more than 72 hours after a storm, repairs may be needed.

ACTIVITY	OBJECTIVE	SCHEDULE
Reconstruction of part or all of the pervious surface	Restore desired infiltration rates	As needed (infrequent, 15-20 years)
Replace or clean sub-surface soils	Restore desired infiltration rates	As needed (infrequent, 15-20 years)
Replace damaged pavers	Maintain proper functioning of paving system	By inspection

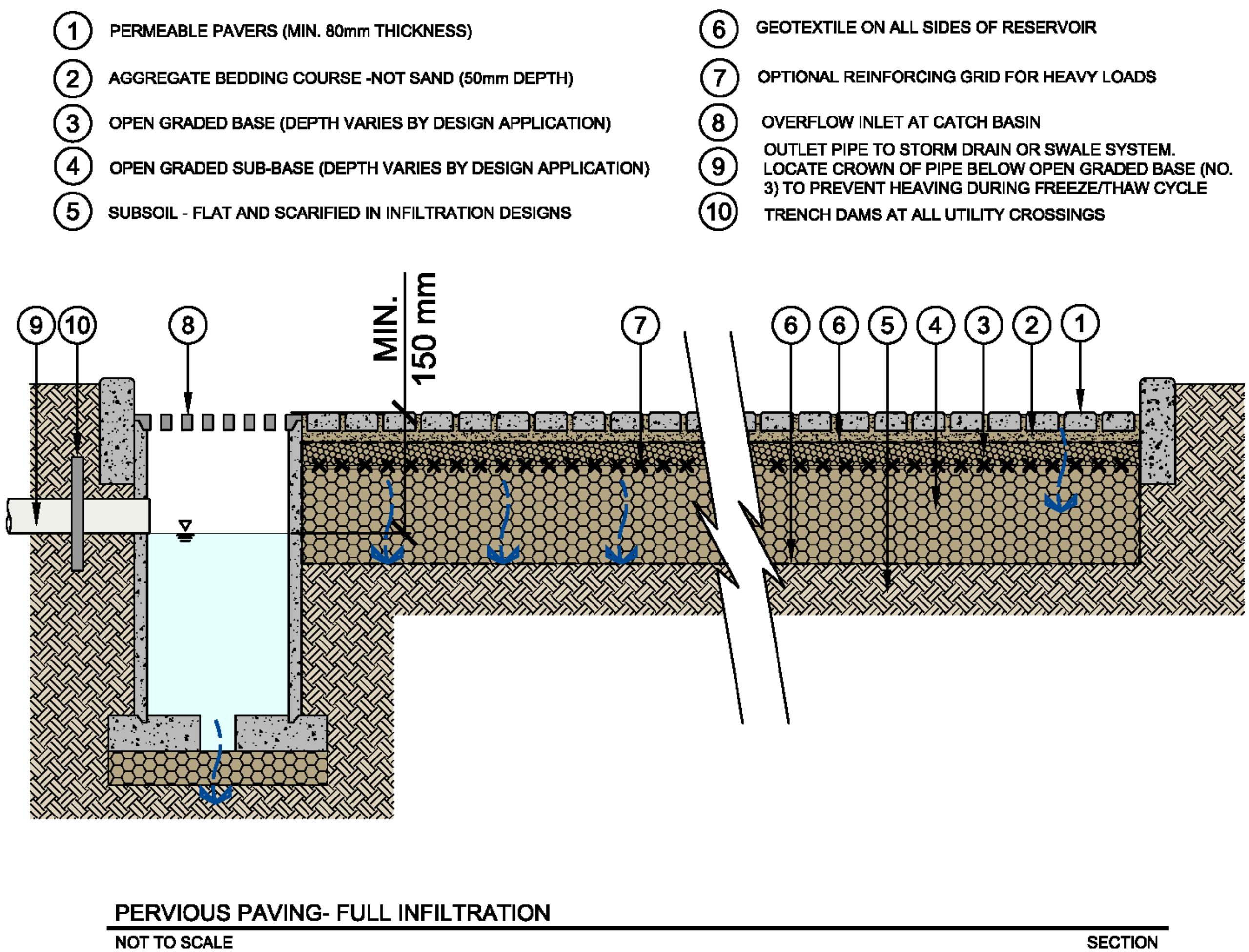


Figure 6 Pervious Paving – Full Infiltration (Not to scale, Section)

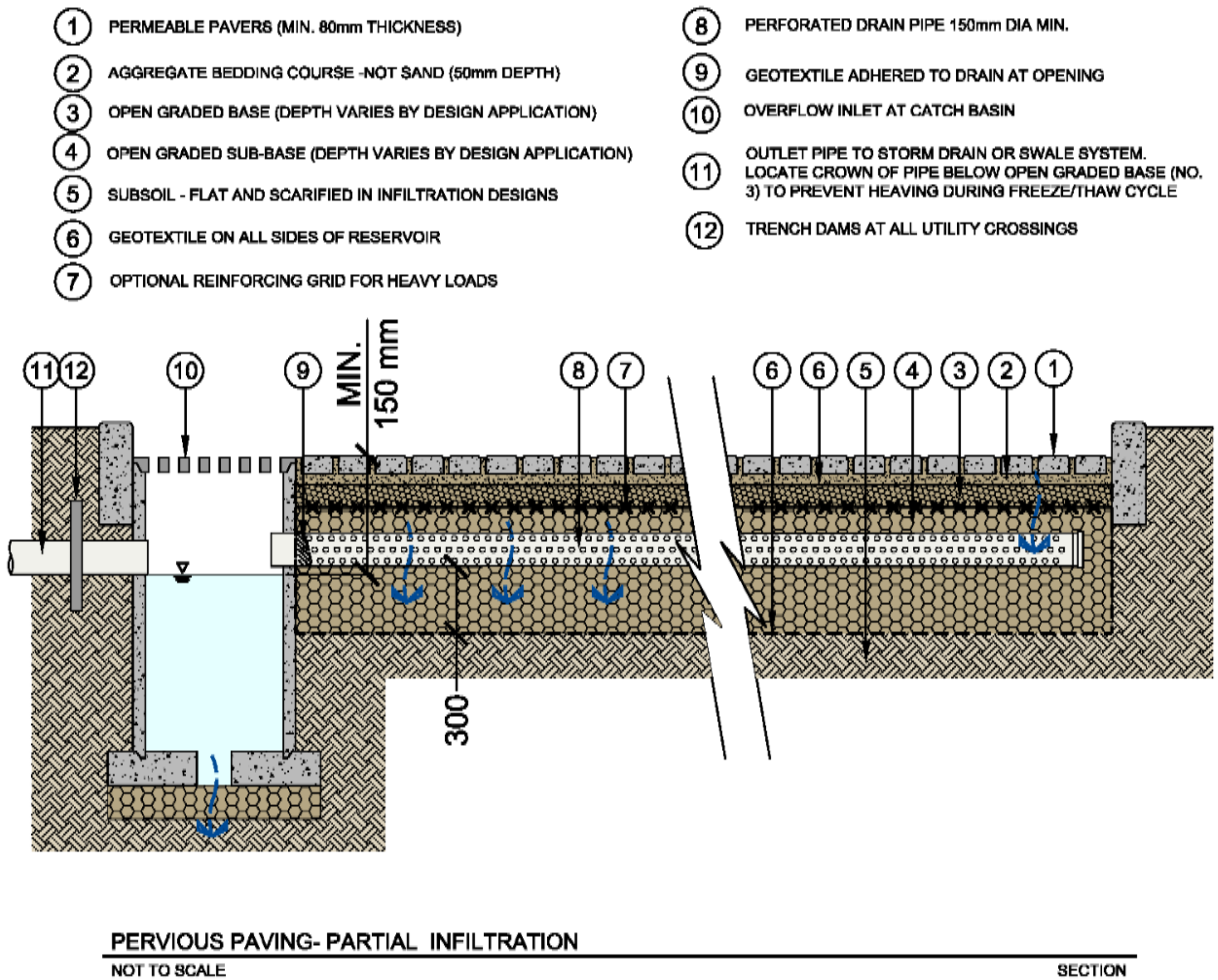
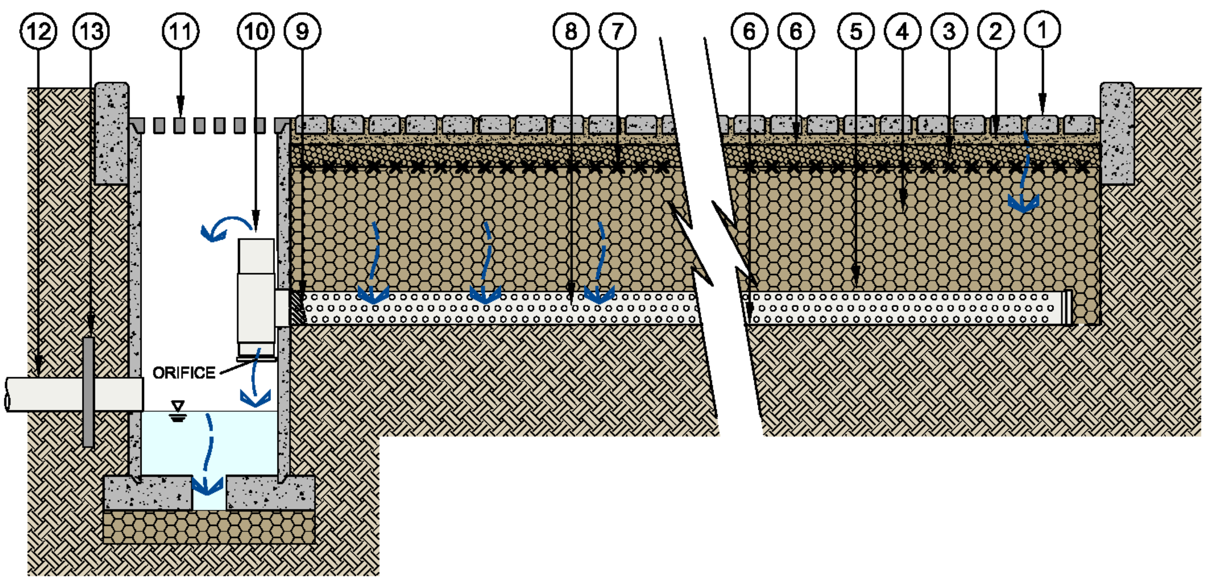


Figure 7 Pervious Paving – Partial Infiltration (Not to scale, Section)

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. 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



PERVIOUS PAVING- PARTIAL INFILTRATION WITH FLOW RESTRICTOR

NOT TO SCALE — SECTION

Figure 8 Pervious Paving – Partial Infiltration with Flow Restrictor (Not to Scale, Section)