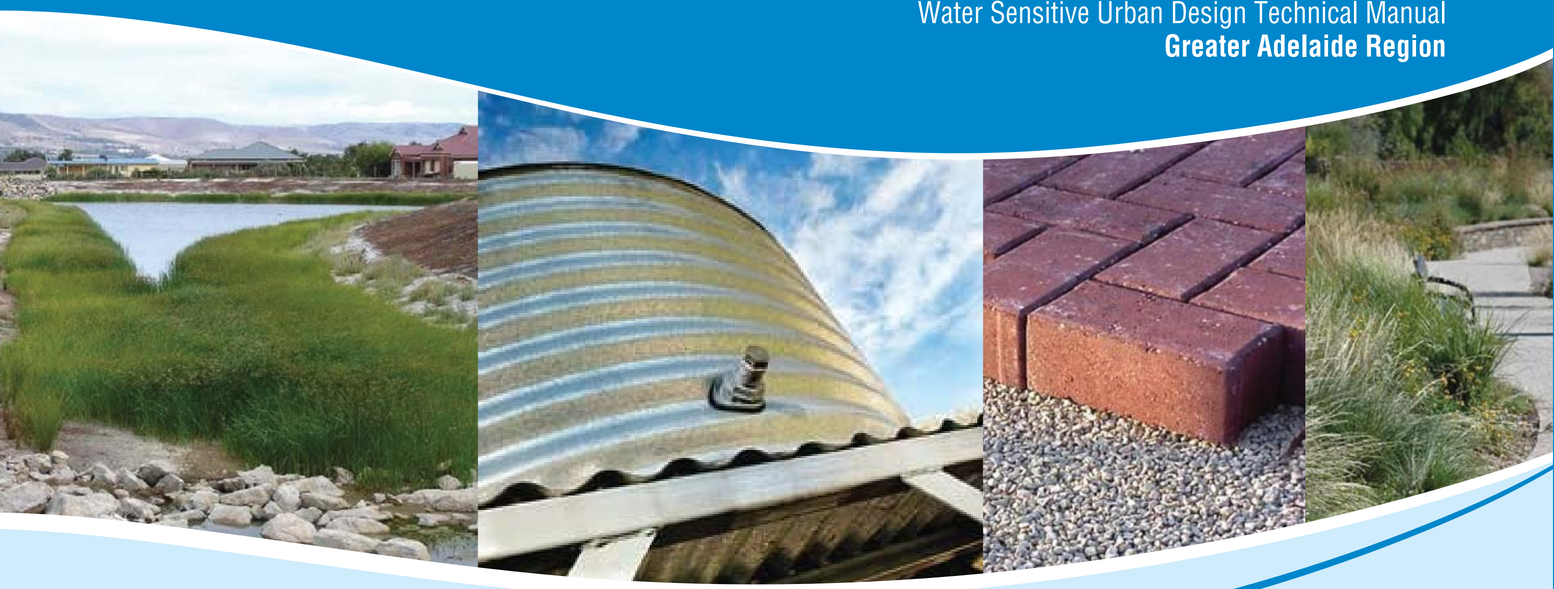
December 2010

Chapter 7

Pervious Pavements

Water Sensitive Urban Design Technical Manual
Greater Adelaide Region



Government of South Australia

Australian Government
Department of the Environment, Water, Heritage and the Arts

Securing tomorrow's water today.

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Water Sensitive Urban Design

Water Sensitive Urban Design (WSUD) is an approach to urban planning and design that integrates the management of the total water cycle into the urban development process. It includes:

- Integrated management of groundwater, surface runoff (including stormwater), drinking water and wastewater to protect water related environmental, recreational and cultural values;
- Storage, treatment and beneficial use of runoff;
- Treatment and reuse of wastewater;
- Using vegetation for treatment purposes, water efficient landscaping and enhancing biodiversity; and
- Utilising water saving measures within and outside domestic, commercial, industrial and institutional premises to minimise requirements for drinking and non drinking water supplies.

Therefore, WSUD incorporates all water resources, including surface water, groundwater, urban and roof runoff and wastewater.

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The project partners gratefully acknowledge all persons and organisations that provided comments, suggestions and photographic material.

In particular, it is acknowledged that material was sourced and adapted from existing documents locally and interstate.

Overall Project Management

Christine Lloyd (Department of Planning and Local Government)

Steering Committee

A group of local government, industry and agency representatives provided input and feedback during preparation of the Technical Manual. This group included representatives from:

- Adelaide and Mt Lofty Ranges Natural Resources Management Board;
- Australian Water Association (AWA);
- Department for Transport, Energy and Infrastructure (DTEI);
- Department of Water, Land and Biodiversity Conservation (DWLBC);
- Environment Protection Authority (EPA);
- Housing Industry Association (HIA);
- Local Government Association (LGA);
- Department of Planning and Local Government (DPLG);
- South Australian Murray-Darling Basin Natural Resources Management Board;
- South Australian Water Corporation;
- Stormwater Industry Association (SIA); and
- Urban Development Institute of Australia (UDIA).

Technical Sub Committee

A technical sub committee, chaired by Dr David Kemp (DTEI), reviewed the technical and scientific aspects of the Technical Manual during development. This group included representatives from:

- Adelaide and Mt Lofty Ranges Natural Resources Management Board;
- City of Salisbury;
- Department for Transport, Energy and Infrastructure (DTEI);
- Department of Health;
- Department of Water, Land and Biodiversity Conservation;
- Department of Planning and Local Government; and
- Urban Development Institute of Australia.

From July 2010, DWLBC was disbanded and its responsibilities allocated to the newly created Department For Water (DFW) and the Department of Environment and Natural Resources (DENR).

Specialist consultant team

Dr Kylie Hyde (Australian Water Environments) was the project manager for a consultant team engaged for its specialist expertise and experience in water resources management, to prepare the Technical Manual.

This team comprised Australian Water Environments, the University of South Australia, Wayne Phillips and Associates and QED Pty Ltd.

Beecham and Associates prepared Chapter 16 of the Technical Manual.

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7.1 Overview

As detailed in **Chapter 1**, there are many different WSUD measures which together form a 'tool kit' from which individual measures can be selected as part of a specific design response suiting the characteristics of any development (or redevelopment). Using pervious pavements is one of those measures.

This chapter of the Technical Documents for the Greater Adelaide Region is aimed at providing an overview of pervious pavements and how they can be utilised to assist in achieving the objectives and targets of WSUD.

Description

Pervious pavement (otherwise known as permeable and porous pavement) is a load bearing pavement structure that is permeable to water.

There is a wide variety of pervious pavement types, each with advantages and disadvantages for various applications.

Pervious pavements fall into two broad categories:

- Porous pavements, which comprise a layer of highly porous material; and
- Permeable pavements, which comprise a layer of paving blocks, typically impervious, specially shaped to allow the ingress of water by way of vertical ′slots‘ or gravel-filled ′tubes‘. There are generally large gaps between impervious paved areas for infiltration.

The common features of pervious pavements include a permeable surface layer overlying an aggregate storage layer. The surface layer of pervious pavement may be either monolithic (such as porous asphalt or porous concrete) or modular (clay or concrete blocks). The reservoir storage layer consists of crushed stone or gravel which is used to store water before it is infiltrated to the underlying soil or discharged towards a piped drainage system.

An example cross section through a pervious pavement is provided in **Figure 7.1**.

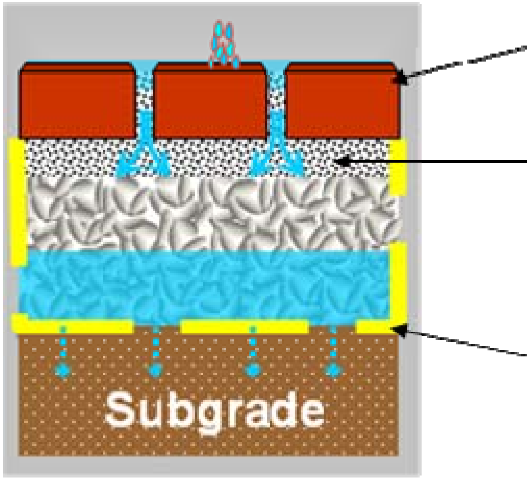


Figure 7.1 Example Cross Section Through a Pervious Pavement

Purpose

Urbanisation causes a significant increase in the area covered with paved (or impervious) surfaces, such as roads, driveways, parking bays and courtyards. Paved surfaces can have significant adverse impacts on the water cycle. They contribute to increased volume and peak runoff discharges, potentially resulting in downstream flooding, streambank erosion, sewer surcharges and the need to increase expensive drainage infrastructure capacity. Paved areas also reduce infiltration to the subsoil which also can result in reduced flow inputs to groundwater systems, upper soil moisture for dependent vegetation and increased downstream pollution of waterways and aquatic habitats.

Pervious paving has many runoff management benefits and can be utilised to promote a variety of water management objectives, including:

- Reduced (or even zero) peak discharges (runoff volumes) from paved areas (by infiltration to the subsoils);
- Delaying runoff peaks by providing retention/detention storage capacity and reducing flow velocities;
- Increased groundwater recharge;
- Potential to harvest runoff for reuse (e.g. storage capacity in the base-course layer can be designed to intercept significant rain fall events);
- Improved runoff quality by removing some sediments and attached pollutants by infiltration through an underlying bedding and base course media ;
- Reduced area of land dedicated solely for runoff management; and
- Being more aesthetically pleasing than conventional paving areas.

Pervious pavements effectively strip a proportion of the runoff from urban areas and infiltrate this to underlying soils and groundwater, thereby providing flood control. They also provide limited water quality control, primarily through mechanical filtration processes. Other treatment processes can be promoted in pervious pavements through appropriate design.

In terms of flood control, the main advantage that pervious pavements have over a bioretention system is their increased infiltration rate. The design infiltration rate for a bioretention system is usually limited to a range of 150 to 350 millimetres/hour. Borgwardt (1994) reported that pervious paving constructed with gravel chips with 2 to 5 millimetre drainage openings had a permeability of 36,000 millimetres/hour 'as laid', which decreased over time. After five years a permeability of 3600 millimetres/hour was measured. However, the infiltration rate of a pervious pavement is in practice dependent on many factors, most notably the degree of clogging which is often related to the age of the pavement. The use of geofabrics in pervious pavements can also reduce the infiltration rate to as low as 2 millimetres/hour

A further issue is that permeable pavements do not generally incorporate overlying surface storage areas and therefore once this infiltration rate is exceeded quite often the permeable pavement is bypassed.

Scale and Application

As discussed above, bitumen, concrete and other hard surface areas (such as paving surrounding buildings) are typically impermeable and result in high runoff rates during a storm event. Runoff can be reduced by interspacing permeable material, such as lawn or pebbles, between widely spaced impermeable pavers, or by installing porous paving. The intent is to create a paved surface where water can infiltrate into the underlying soils.

Pervious paving may also be used as a general measure to reduce the impervious fraction of a site where it is not considered itself as a treatment measure.

Pervious paving can be utilised in:

- Streets with low traffic volumes and light traffic weight (such as cul-de-sacs);
- Car parks and for paving within residential and commercial development (e.g. pedestrian paths or footpaths); and
- Public squares.

Pervious pavements have been found to be most practical and cost effective when serving catchment areas between 0.1 and 0.4 ha (Upper Parramatta River Catchment Trust, 2004). As a guide, the contributing catchment area to pervious area should not exceed 4 to 1. Where sediment and organic loads are high the ratio should be reduced to 2 to 1 (Argue, Ed., 2009).

Acceptable performance can be achieved provided the correct design and construction procedures are followed, including any manufacturer's recommendations.

Performance Efficiency

Pervious pavements can improve the water quality of runoff through several processes, including:

- Filtration of runoff through the pavement media and underlying material;
- Potential biological activity within the base and submedia; and
- An overall reduction of pollutants entering urban streams through reduced runoff volumes.

Pervious pavements are most effective in removing coarse to medium sediments and attached pollutants (such as nutrients, free oils/grease and metals).

An indication of the water quality improvement efficiencies that a correctly designed and maintained pervious paving system is capable of achieving is demonstrated in **Table 7.1**. A wide range is presented due to the high variability in the performance of pervious paving systems.

Table 7.1 Pervious Pavements Performance Efficiencies

Gross Pollutants	Coarse Sediment (0.5–5mm)	Medium Sediment (0.06–0.5mm)	Fine Sediment (< 0.06mm)	Free Oil and Grease	Total Nitrogen	Total Phosphorous	Metals
-	50-80%	30-50%	30-50%	10-50%	40-80%	50-80%	10-50%

Note: Indicative efficiencies are based on average annual load reduction

Sources: Upper Parramatta River Catchment Trust (2004), Melbourne Water (2005) and Urban Water Resource Centre (2002)

7.2 Legislative Requirements and Approvals

Before undertaking a concept design of a pervious pavement system it is important to check whether there are any planning regulations, building regulations or local health requirements that apply to pervious pavements in your area. Refer to the suggested design process in **Section 7.4**.

The legislation which is most applicable to the design and installation of pervious pavements in the Greater Adelaide Region includes:

- *Development Act 1993* and *Development Regulations 2008*; and
- *Environment Protection Act 1993.*

Development Act 1993

Installing pervious pavements will generally be part of a larger development (for new developments), however whenever pervious pavements are planned (such as retrofitting), it is advised that the local council be contacted to:

- Determine whether development approval is required under the *Development Act 1993*; and
- Determine what restrictions (if any) there may be on the installation of pervious pavements on site.

Environment Protection Act 1993

Any development, including the installation of pervious pavements, has the potential for environmental impact, which can result from vegetation removal, stormwater management and construction processes. There is a general environmental duty, as required by Section 25 of the *Environment Protection Act 1993*, to take all reasonable and practical measures to ensure that the activities on the whole site, including during construction, do not pollute the environment in a way which causes or may cause environmental harm.

Aspects of the *Environment Protection Act 1993* which must be considered when considering installation of pervious pavements are discussed below.

Water Quality

Water quality in South Australia is protected under the *Environment Protection Act 1993* and the associated Environment Protection (Water Quality) Policy 2003. The principal aim of the Water Quality Policy is to achieve the sustainable management of waters by protecting or enhancing water quality while allowing economic and social development. In particular, the policy seeks to:

- Ensure that pollution from both diffuse and point sources does not reduce water quality; and
- Promote best practice environmental management.

Through inappropriate management practices, building sites can be major contributors of sediment, suspended solids, concrete wash, building materials and wastes to the stormwater system. Consequently, all precautions will need to be taken on a site to minimise the potential for environmental impact during construction. Guidance can be found in the *EPA Handbook for Pollution Avoidance on Building Sites* (see **Section 7.8**).

Air Quality

Air quality may be affected during the installation of pervious pavements. Dust generated by machinery and vehicular movement during site works, and any open stockpiling of soil or building materials at the site must be managed to ensure that dust generation does not become a nuisance off site.

Waste

Any wastes arising from excavation and construction work on a site should be stored, handled and disposed of in accordance with the requirements of the *Environment Protection Act 1993*. For example, during construction all wastes must be contained in a covered waste bin (where possible) or alternatively removed from the site on a daily basis for appropriate off-site disposal. Guidance can be found in the *EPA Handbook for Pollution Avoidance on Building Sites*.

7.3 Design Considerations

As with other infiltration systems (see **Chapter 6**), designing pervious pavement systems requires consideration of the site conditions and potential contamination of the receiving groundwater environment. There are also some specific considerations for the design of pervious pavements. Some pervious pavement systems have a high failure rate that is attributed to poor design, clogging by fine sediment and excess traffic use (Department of Environment WA 2004).

The factors that will maximise the likely success of a pervious pavement include:

- Low traffic volumes and light vehicle weights;
- Low sediment loads;
- Moderate soil infiltration rates; and
- Regular and appropriate maintenance of the pavement's surface.

Pervious paving must therefore be carefully designed in areas with (Hobart City Council 2006):

- High water table levels;
- Wind blown or loose sands;
- Clay soils that collapse in contact with water; and
- Soils with a hydraulic conductivity of less than 0.36 millimetres/hour.

Design considerations for pervious pavements include:

- Subgrade stability;
- Low permeability liner;
- Pre-treatment of runoff;
- Vegetation;
- Flow management;
- Slope;
- Structural integrity;
- Safety;
- Clogging.

The following sections provide an overview of the key design issues that should be considered when conceptualising and designing pervious pavements.

Subgrade Stability

Many clay soils become weak when subjected to saturated conditions for long periods, combined with heavy, continuous traffic conditions. Pervious pavements may not be suitable where there is a heavy loading due to such traffic as commercial vehicles, particularly where there are clay soils (ACT Planning and Land Authority 2007).

Low Permeability Liner

In some locations, infiltration to clay is undesirable. For example, designers must carefully consider infiltration systems next to footings where the shrinking and swelling of some clays can cause structural damage. A minimum clearance of 5 metres from footings or impermeable lining should be used in these areas (ACT Planning and Land Authority 2007). Argue, Ed., (2009) directly addresses the matter of infiltration in a number of different soil types and the appropriate 'setback' of infiltration systems.

Pre-treatment of Runoff

Pre-treatment of runoff entering a pervious paving system is primarily required to minimise the potential for clogging of the paving media and to protect groundwater quality where infiltration is proposed. Runoff should therefore be treated to remove coarse and medium sized sediments and litter.

Depending on the nature of runoff to the paving system, suitable pre-treatment to pervious paving systems includes:

- Provision of leaf and roof litter guards along the roof gutter;
- Application of buffer strips;
- Swales; or a
- Small sediment forebay.

Vegetation

In modular or grid paving systems, vegetation may be grown in the voids. Vegetated systems have demonstrated good long-term performance in the Greater Adelaide Region.

However, the following factors may result in this being unsuccessful:

- Lack of sufficient soil depth and nutrients for vegetation to grow;
- Heat retained in the pavers; and
- Wear from vehicle movement.

Vegetation should only be considered where these factors will not affect plant growth. The design should demonstrate mitigation of these factors if vegetated systems are proposed.

Non-vegetated systems also have a tendency to develop unplanned vegetation, as organic matter is a high proportion of the clogging material in the pavement voids. Although it may be aesthetically unpleasant, this basic aspect of vegetation in the void spaces may be argued to benefit the infiltration of runoff through the pavement as the roots of the vegetation maintain pathways for the infiltration of runoff. Furthermore, the long Adelaide dry season can lead to the death of some plants species.

Flow Management

Where possible, flows that are ‘above design’ flows should be directed to bypass the pervious paving system. This can be achieved in a number of ways. For example, an overflow pipe or pit, which is connected to the downstream drainage system, can be used.

‘Above design’ flows or overflows from the pervious paving should be diverted towards another WSUD measure or the stormwater (or drainage) system. Design of overflows should demonstrate that overflow will not be directed towards or cause damage to buildings, structures or services.

Slope

The surface of the pervious paving area must be relatively flat or as close to this as possible to ensure a uniform and distributed flow coverage, but also to prevent hydraulic overloading on a small portion of the surface. Some grade is important to ensure that overflows are conveyed past the pervious pavement, however where the grade is too steep it will encourage flow short circuit paths, reducing the performance.

Pervious paving should not be constructed on slopes of greater than 4% unless an engineering design is completed to assess the impact of the paving system on downstream environments, in particular the stability of surrounding areas (Upper Parramatta River Catchment Trust, 2004; Gold Coast City Council 2007).

Structural Integrity

Consideration should be given to structural integrity where pervious pavements are to be used in locations where vehicles may be stopping or turning. Consideration should also be given to the likely loads due to traffic.

Lateral forces on pavers can occur due to forces exerted by turning wheels. Interlocking pavers provide greater resistance to lateral forces and are better suited to vehicle turning locations.

Where vehicles are stopping or turning, slippage can occur between the paver bedding material and basecourse. In such instances it is advisable not to place a geotextile membrane between the two layers.

Safety

Designers must also consider the likelihood of pedestrian traffic across the pavement surface and ensure that the pervious pavement does not present a public safety risk. Key considerations in the design of pervious paving systems in pedestrian traffic areas will include minimising trip hazards and slips and falls associated with a slippery pavement surface. Careful construction tolerances and subsequent maintenance regimes are therefore required.

A particular hazard in this case is where permeable paving with large gaps is applied. It is important that pedestrian traffic be restricted until all voids are filled with an appropriate filling media (such as fine gravel media screenings between 2-5 millimetres). Please also note that this must be gravel screenings, as gravel/sand mixtures will be detrimental to the design infiltration rate for the system.

Clogging

Partial or total clogging of pervious pavements with sediment and oil is a major potential cause of failure and must be avoided. Clogging can occur during or immediately after construction or through long-term use. The design procedure must take account of surface clogging as outlined in the design process section (**Section 7.4**) of this document.

The likelihood of clogging can be avoided by the following measures:

- Avoiding the use of pervious pavement for access ways with high traffic volumes or with regular heavy vehicle traffic;
- Avoiding the installation of pervious pavement in locations that are likely to receive large quantities of sediment and debris washed down by stormwater, or windblown sand or other material;
- Applying, where possible, pre-treatment measures such as sediment traps, vegetated buffer strips or specially designed gutter systems to remove sediments prior to reaching the pervious pavement;
- Protecting pervious pavements from sediment inputs during construction;
- Undertaking regular vacuum sweeping or high pressure hosing to remove sediment material that prevents infiltration.

7.4 Design Process

Overview

The design process for pervious pavements consists of a number of key steps:

- Assess site suitability;
- Identify objectives and targets;
- Consult with council and other relevant authorities;
- Select the pervious pavement type:
- Structural design of a pervious pavement;
- Determine the design flows;
- Size the pervious pavement system;
- Specify pervious pavement layers;
- Check the design objectives;
- Prepare a construction plan; and
- Prepare a maintenance plan.

Further details regarding the detailed design process are contained in **Appendix A** and a design calculation checklist is provided in **Appendix B**.

The design assessment checklist presents the key design features that should be reviewed when assessing the design of a pervious paving system. These considerations include configuration, safety, maintenance and operational issues that need to be addressed during the design phase.

A proposed design should have all necessary approvals for its installation.

Depending on the scale of the development, it should be noted that not all of the suggested steps in the design process will be required. The design process is also discussed in general in **Chapter 3** of the Technical Documents.

Site Suitability

WSUD responds to site conditions and land capability and cannot be applied in a standard way. Careful assessment and interpretation of site conditions is therefore a fundamental part of designing a development that effectively incorporates WSUD.

Selection of where to place the pervious pavements is important and is not only a matter of appearances. An assessment of site conditions is necessary to identify what measures, if any, are required to ensure that the pervious pavements will perform for their entire lifetime.

Pervious pavements show a decline in permeability with exposure to sediment and organic matter through their lifetime. To ensure adequate performance of these pavements it is necessary to design the pavements to utilise only a portion of the 'as new' capacity reported by product manufacturers.

Pervious paving can, in some cases, result in a risk of contamination of shallow aquifers by toxic substances derived from asphalt, vehicular traffic and road use. Assessment of the groundwater should be undertaken to define existing water quality, potential uses (current and future) and suitability for recharge. This will be an important consideration in areas where aquifer storage, transfer and reuse (ASTR) schemes are operating, such as certain catchments in the City of Salisbury. Designers are urged to contact the local council to determine any special prohibitions that may affect the use of infiltration systems (including pervious pavements).

Pervious paving systems should be located in areas so that they avoid:

- High water tables;
- Saline soils;
- Acid sulphate soils;
- Wind blown areas;
- Runoff from areas expected to have a high sediment load;
- High traffic volumes; and
- Services (existing or proposed).

The design should demonstrate avoidance of these kinds of areas or conditions.

Objectives and Targets

The design objectives and targets will vary from one location to another and will depend on site characteristics, development form (including structural integrity requirements) and the requirements of the receiving ecosystems. It is essential that these objectives are established as part of the conceptual design process and discussed with the relevant council prior to commencing the engineering design.

The design approach for pervious pavements is generally based on achieving the following broad objectives:

- For infiltration (or retention) systems, providing sufficient surface area and capacity of the reservoir (sub-base) storage to contain the treatment volume and allow infiltration to the subsoil between storm events; or
- For detention systems, providing sufficient capacity of the reservoir (sub-base) storage to provide adequate detention during high runoff events to reduce peak outlet design discharges to specified pre-development conditions.

Pervious paving systems can be designed to achieve a range of specific objectives including:

- Minimising the volume of runoff from a development;
- Preserving pre-development hydrology;
- Capturing and detaining, or infiltrating, flows up to a particular design flow;
- Utilising WSUD techniques without compromising the hard standing surface requirements such as parking or trafficability;
- Enhancing groundwater recharge or preserving pre-development groundwater recharge; and
- Removing some sediments and attached pollutants by passing runoff through an underlying media layer.

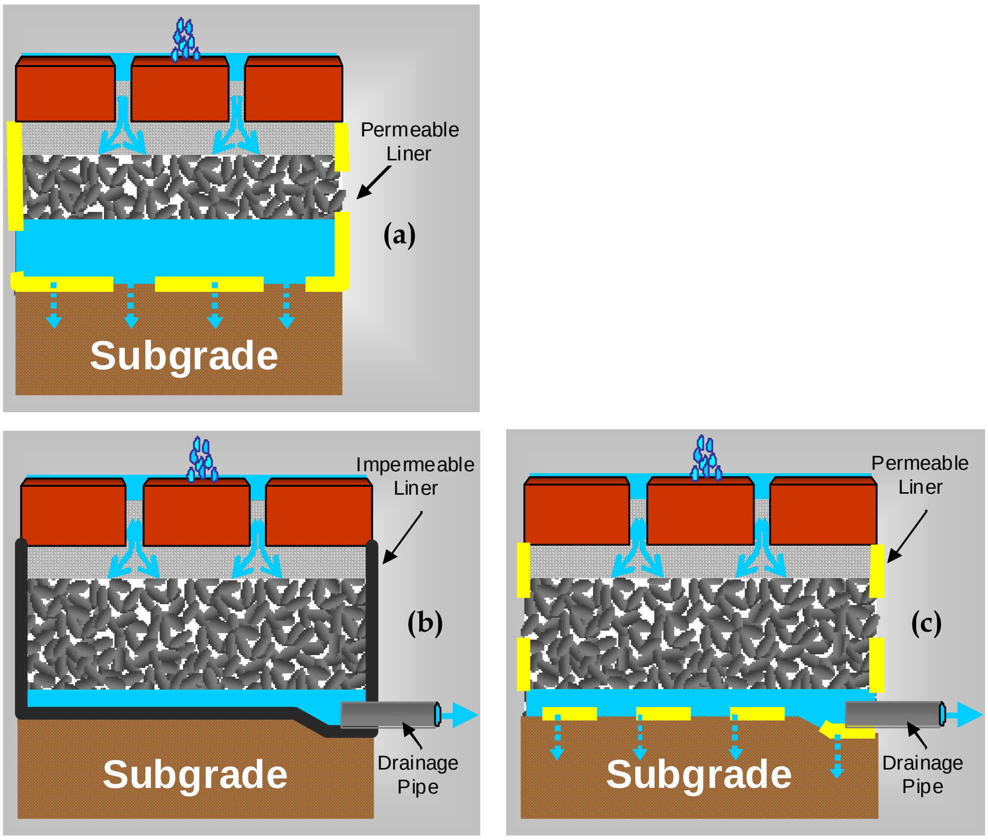


Figure 7.2 (a) Infiltration, (b) Detention and (c) Combined Infiltration and Detention Pervious Pavement Systems

Further information on setting objectives and targets can be found in Chapter 3 of the Technical Manual.

Consultation with Council and Other Relevant Authorities

The designer (or applicant) should liaise with civil designers and council officers prior to proceeding any further to ensure:

- Pervious paving will not result in water damage to existing services or structures;
- Access for maintenance to existing services in maintained;
- No conflicts arise between the location of services and WSUD devices; and
- The objectives and targets are consistent with council directions stated in documents such as strategic plans and stormwater management plans.

The council will also be able to assist with determining whether:

- Development approval is required and, if so, what information should be provided with the development application;
- Any other approving authorities should be consulted; and
- Any specific council requirements need to be taken into consideration.

Land and asset ownership issues are key considerations prior to construction of a WSUD measure, including pervious pavements. A proposed design should clearly identify the asset owner and who is responsible for maintenance and this aspect should also be discussed during a meeting with the local council.

Select Type of Pervious Pavement

A number of pervious paving products are commercially available including:

- Concrete, ceramic or plastic modular pavers – pavers may be made of porous material or if not permeable, designed and installed to leave gaps between the pavers to allow runoff to penetrate into the subsurface;
- Grid or lattice systems – these are made of concrete or plastic grids filled with soil or aggregate that water can percolate through. These systems may also be vegetated (usually with grass); and
- Porous asphalt or concrete (monolithic structures) – open graded asphalt or concrete with reduced or no fines and a special binder that allows water to pass through the pavement by flowing through voids between the aggregate.

Selection of the paving type for a particular application must occur as part of the conceptual design process by assessing the site conditions and desired amenity or built environment/local character requirements against the functional types of paving systems.

Table 7.2 shows a range of suitable applications for different pervious paving types in the Greater Adelaide Region.

Table 7.2 Potential Applications for Pervious Pavements

Condition/Use	Porous Asphalt / Concrete	Porous Pavers / Grid Systems	Interlocking Concrete Paving Systems
Commercial parking lots	Yes	Yes	Yes
Perimeter/overflow parking	Yes	Yes	Yes
Perimeter/light commercial driveways	Yes	Yes	-
Patios/other paved areas	Yes	Yes	-
Sporting courts	Yes	-	-
Industrial storage yards/loading zones	Yes	Yes	-
Parking pads (e.g. caravan parks)	-	Yes	Yes

Source: Gold Coast City Council (2007)

The various types of pervious pavements are discussed in more detail below.

Porous Paving

There are different types of porous pavements, including:

- Porous asphalt pavement;
- Porous concrete pavement; and
- Modular interlocking concrete bricks with internal or external drainage cells.

Porous pavers make up the surface of the porous paving system; however there are a number of layers to the overall system.

The porous pavement is typically laid on top of a high void aggregate or gravel base layer, with a geotextile in between. The runoff passes through the pore spaces of the pavement, through the geotextile and into the aggregate/gravel layer, which provides temporary storage as the water gradually infiltrates into the subsoil. Where the subsoil has low permeability, the water can be removed by providing a slow drainage outlet to the receiving stormwater system.

Where base soils have low porosity, water is removed by 'slow drainage' to another WSUD measure, nearby drainage path or receiving water.

The aggregate also serves as the road or parking area's support base and must be sufficiently thick to support expected traffic loads. A final filter layer may be provided at the base of the paving system below the aggregate layer. This can be fine sand mixed with base course material that contains the underdrainage system and is the final layer prior to infiltration to surrounding soils or discharge to a piped drainage system.

Geotextile fabric is generally used to separate the surrounding fine soils from the base course material. It can also be used to provide separation between the bedding layer and the base course layer.

In the Greater Adelaide Region, soils are predominately clay and hence porous paving usually requires a drainage sublayer of material to discharge excess water laterally to the drainage system. Special consideration is required where changes in soil moisture result in significant swelling, particularly where there is infrastructure vulnerable to differential movement.

These pavements can be sensitive to clogging from fine sediments and excessive organic matter. Any decision to install these pavements should consider nearby sources of sediment (exposed soil and beaches) and organic material (trees and shrubbery). After the pavement has been installed it should be protected from short-term sources of sediments (a load of landscaping material for a garden for instance or development work such as new house construction). Porous pavement should be scheduled as a final step in any development process.

Permeable Pavements

Permeable pavements comprise a layer of paving blocks, typically impervious but specially shaped to allow the ingress of water by way of vertical 'slots' or gravel-filled 'tubes'. The blocks are placed on fine (2 to 5 millimetre) aggregate bedding screenings and may be underlain by a layer of non-woven geotextile fabric.

This surface sits on a substructure reservoir of gravel, typically gap-graded and thick, 200-400 millimetres in carpark applications where vehicle and truck wheel loads require such measures. Substructures of half this depth are satisfactory where permeable paving is used in footpaths or pedestrian only concourse areas (Argue, Ed., 2009).

In all other respects, permeable pavements operate and behave in much the same manner as porous pavements. Pollutant removal by absorption, filtering and biological decomposition is similarly successful (Argue, Ed., 2009).

Structural Design of a Pervious Pavement

The structural design methodology for a pervious pavement system is not currently covered by this Technical Manual. However, the key consideration in the design of pervious paving is the structural integrity of the system. The key consideration is not dissimilar to a standard pavement, except that the base course must be able to infiltrate runoff. Design software (the Lockpave-PermPave software package) is available to address the structural design of a pervious pavement (see **Section 7.5**).

Pavements for Stormwater Harvesting and Reuse

Porous and permeable pavements present a unique opportunity to harvest and store urban stormwater that would otherwise contribute to excessive overland runoff into the conventional stormwater pipe and channel network. With minimal surface infrastructure, porous and permeable pavements provide a serviceable, hard standing area that facilitates water harvesting, treatment and reuse. There are several options for the design and construction of such a system. After infiltrating through the pavement surface, the stormwater can be stored in a submerged tank, or in proprietary plastic cell systems. It can also be stored in a matrix of base course aggregate contained within an impermeable membrane (Beecham and Myers, 2007).

A harvesting and reuse system has been constructed at the Mawson Lakes Campus of the University of South Australia. This is shown in Figure 7.3. The system contains a cut-out display window (on the left-hand side of the photograph in Figure 7.3) so that the cross-sectional structure of the system, including the current stored water level, can be viewed. Without labour costs, the system in Figure 7.3 cost approximately $2,200 to construct in 2007.

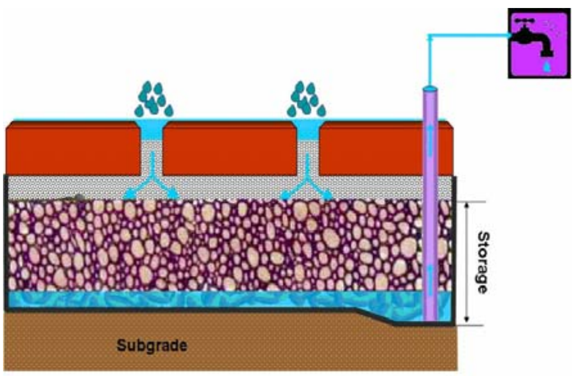


Figure 7.3 Water harvesting and reuse in a permeable pavement system at the University of South Australia

Determining the Design Flows

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

- A minor storm event for sizing the surface area, detention or retention volume and overflow pit of the paving system; and
- A major storm event for overflow or bypass of the system. These flows will flow over or bypass the system and enter the stormwater drainage system (either piped system or overland flow).

A range of hydrologic methods can be applied to estimate design flows. If typical catchment areas are relatively small, the Rational Method design procedure is considered suitable. For further information see **Section 7.5**.

Sizing Pervious Pavements

The rate at which water can flow through the surface is a key design measure of pervious pavements. This information is available from the pavement manufacturers and is essential in ensuring that the paved area is appropriately sized to cater for design flows.

For design, it is recommended that the design infiltration rate be based on 'effective' design life infiltration rate. The 'effective' life can be chosen on the basis of minimum infiltration rate or structural deterioration. Evidence suggests that the infiltration rate of pervious pavements reduce to about 20% of their initial rate after 10 years and this is a suitable ratio to adopt in the design process. For example, where a manufacturer specifies an infiltration rate of 1200 millimetres/hour for their product, practitioners are advised to apply an infiltration rate of 240 millimetres/hour.

The size of a pervious paving system requires consideration of:

- The volume and frequency of runoff discharged to the paved area;
- The available detention or retention volume; and
- The infiltration rate (product of 'infiltration area' and hydraulic conductivity of the paving system).

The required 'detention volume' is defined by relating the volume of inflow and outflow for a particular design storm, and then deriving the 'infiltration area' to ensure the system empties prior to the commencement of the next storm event.

Where the design objective for a particular pervious paving system is peak discharge attenuation or the capture and infiltration of a particular design storm event, then the design storm approach may be adopted for sizing the pervious paving system and a check for emptying time is performed to ensure the system can manage successive storm events.

The emptying time check is necessary as the limitation with the design approach is the inability to account for antecedent conditions that might affect the hydraulic performance. In particular, the greatest uncertainty is the available storage at the onset of the design storm event. This uncertainty is overcome by undertaking continuous simulation modelling using historical rainfall data at small time steps (i.e. 6 minutes). The outcome of continuous simulation is the ability to determine the hydrological effectiveness of the drainage system and hence its performance for managing runoff whether it is for flood, treatment or harvesting.

An alternative means for sizing pervious pavement can be using PermPave software, which has been developed by the Concrete Masonry Association of Australia (see **Chapter 15** and **Section 7.5**).

If treatment or harvesting performance is required, hydrological effectiveness curves can be used which have been developed for the Greater Adelaide Region (see **Appendix C**). The alternate design approaches are described in more detail in the Appendices.

Specify Pervious Paving Layers

The following design and specification requirements should be documented as part of the design process for pervious pavement systems:

Pervious Paving Surface

The pervious paving layer will depend on the type of paving selected through the design process. The pervious paving surface type should be specified along with any proprietary requirements and specifications.

Retention / Aggregate Layer

Where the 'detention volume' is created through the use of a gravel-filled trench then the gravel should be angular and clean (free of fines) stone/gravel with a uniform size of between 20 and 100 millimetres in diameter. The material utilised should be documented. In Adelaide, dolomite is a suitable angular aggregate material and is often relatively inexpensive.

Geotextile Fabric

Geotextile fabric should 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. Geotextile fabric with a minimum perforation or mesh of 0.25 millimetres should be used. The type of geotextile fabric utilised should be documented. As previously noted, geotextiles may have an influence on the structural integrity of a system where vehicular traffic is stopping and starting aggressively and regularly. The geotextile layer may form a slip plane in the pavement construction.

Alternative means to preventing the migration of surface layers to the base course will be careful application of soil filter criteria as described below.

Filter Media Mixing

The simplest way to prevent two layers of basecourse material from mixing is through the use of a permeable geotextile product. However, there is some concern over the use of geotextiles at the surface of a pavement construction due to the potential formation of a 'slip plane' (Prof Brian Shackel, pers. Comm.). This concern is founded on the potential for the geotextile to prevent an adequate interlock between the 2-5 millimetre aggregate laying course and the larger layer of base course immediately beneath.

In cases where this 'slip plane' effect is expected to eventuate the use of a geotextile is inappropriate. Other methods must be used to ensure that the laying course does not simply mix with the base course. Designers can refer to and adapt geotechnical engineering literature where similar problems have been encountered for the construction of filters and dam walls.

Retention Criterion

The retention criterion is established to prevent one layer mixing with another to produce a more heterogeneous mixture of materials. Designers must ensure that layers of soil or aggregate materials remain as discrete layers. This has been progressively addressed, but for larger particle materials such as those applied in permeable pavements, Reddi (2003) indicates that:

'It is generally established that if the pore spaces in filters are small enough to hold the 85% size (D_{85}) of adjacent soils in place, the finer soil particles will also be held in place.'

$$\frac{D_{15}}{d_{85}} < 4$$

Where:

D_{15} = Laying course particle size according to 15% finer
d_{85} = Particle size of base course material corresponding to 85% finer

Permeability Criterion

Particle size variation between discrete layers must also be selected to ensure there is not a build up of excess pore pressure that will inhibit flow. This is not particularly important in aggregate layers as the pore spaces are generally sufficiently large to ensure that pore pressure does not build up excessively. Designers should ensure that they satisfy the general criteria outlined by Reddi (2003):

$$\frac{D_{15}}{d_{15}} < 4$$

Where:

D_{15} = Laying course particle size according to 15% finer
d_{15} = Particle size of base course material corresponding to 15% finer

Impermeable lining

Where pervious pavements are to be used for stormwater harvesting and reuse, impermeable liners can be used to create an underlying storage volume in the basecourse layer, as shown in Figure 7.3. The most suitable materials for this liner are 0.75mm polypropylene and 1 mm high density polyethylene (HDPE). The latter material is stronger but is less flexible and therefore more difficult to handle on site. Both material types can be ordered in pre-welded shapes to fit the size of the excavated hole. A layer of sand is normally laid underneath the base of the liner for protection. A polypropylene liner sized for a pavement the size of a single car space (5m by 3m) and welded to the shape of a 1 m deep excavation, costs approximately $450 including local delivery.

Check the Design Objectives

This step involves confirming the design objectives, defined as part of the conceptual design, to ensure the correct pervious paving system design method is selected. The treatment performance of the system should be confirmed (including revisiting and checking of any modelling used to assess treatment performance).

Construction Process

Numerous challenges exist that must be appropriately considered to ensure successful construction and establishment of pervious paving, including:

- Sediment loads during construction phase which can clog the paving surface; and
- Construction traffic and other works which can damage paving surface and layers.

Where large scale pervious paving systems are proposed, a detailed construction and establishment plan, including temporary protective measures, should be prepared.

To prevent premature clogging, pervious pavement should generally not be placed until all of the surface drainage areas contributing to the pavement have been stabilised. In addition, it is critical to ensure that any pre-treatment system for pervious paving is fully operational before flows are introduced.

During construction, heavy equipment should not be used on the pervious pavement area to prevent compaction of soils and subsequent reduction of infiltration rates.

Figure 7.3 Construction of the Linden Gardens Car Park

Source: Courtesy of the City of Burnside

If at the commencement of operations there is some clogging of the pavement surface, then the surface should be tilled, vacuum swept or high pressure hosed to clean or unblock the surface.

An example Construction Checklist in **Appendix B** presents the key items to be reviewed when inspecting the pervious paving during and at the completion of construction.

Maintenance Requirements

For efficient operation of pervious pavements it is essential that the gaps between the paver and the underlying bedding layer do not become clogged by fine sediment. To prevent this from occurring, pervious pavements require the following maintenance activities:

- High pressure hosing, sweeping or vacuuming (depending on the manufacturer's specifications) to remove sediments and restore/maintain porosity;
- Repair of potholes and cracks;
- Replacement of clogged/water logged areas;
- Rectification of any differences in pavement levels;
- Maintenance of the surface vegetation (if present) including weeding or mowing where appropriate; and
- Periodic replacement of aggregate layer (about every 20 years) and replacement of geotextile fabric.

Following construction, pervious pavements should be inspected every month (or after each major rainfall event) for the initial six months of operation to determine whether or not the infiltration zone requires immediate maintenance. After the initial six months, inspections may be extended to the frequencies shown in the example Inspection and Maintenance Checklist for Pervious Pavements in **Appendix B**.

Inspections can include checking for:

- Areas of sediment build-up and clogging and blockage of the underlying aggregate or filter layers;
- Potholes and cracking;
- Areas of significant pavement deflection;
- Areas of scour, litter build up, sediment accumulation or blockages of inlet points;
- Blockage of the outlet pipe (if applicable);
- Surface ponding (which would indicate clogging or blockage of the underlying aggregate);
- Stabilisation of the contributing catchment area to ensure that it is not a significant source of sediment;
- Effective operation of any pre-treatment systems; and
- Dewatering of the system following storm events.

Concrete grid, ceramic and modular plastic block pavers require less maintenance than asphaltic porous paving as they are less easily clogged. They are also easier to repair.

The performance and life of these pavements can be increased by regular vacuum sweeping or high pressure hosing (once every three months) to remove sediments.

As with traditional pavements, asphalt porous paving requires occasional resurfacing. Concrete grid, ceramic and plastic modular blocks require a maintenance schedule similar to that for conventional road surfaces. This involves retaining the pavers and removing trapped sediment.

All maintenance activities should be specified in an approved maintenance plan (and associated maintenance inspection forms) to be documented and submitted to council as part of the development approval process. Maintenance personnel and asset managers will use this plan to ensure the pervious paving continues to function as designed.

In addition to checking and maintaining the function of pre-treatment elements, the maintenance checklist can be used during routine maintenance inspections of the pervious paving and kept as a record of the asset condition. More detailed site specific maintenance schedules should be developed for major pervious paving systems and include a brief overview of the operation of the system and key aspects to be checked during each inspection.

7.5 Design Tools

Various design tools are available for the concept and detailed design of pervious pavements as detailed in **Chapter 15** and discussed briefly below.

PermPave

One of the modelling tools which can assist the design process of pervious pavements is PermPave. PermPave has been developed to undertake a basic assessment of the hydrological performance of concrete segmental permeable pavement design inputs for:

- Flood mitigation: using design rainfall approach according to the Institution of Engineer's *Australian Rainfall and Runoff*. Outputs include inflow and outflow hydrographs, pavement required storage capacity and depth;
- Water quality improvement: a simple water quality improvement analysis is based on hydrological effectiveness, derived from continuous time series modelling using 6 minute historical rainfall data; and
- Water harvesting: yields-storage relationship and suggested storage, based on unit storage volume benefit and dis-benefit approach.

The program incorporates methods outlined in the Institution of Engineer's *Australian Rainfall and Runoff*, as well as Australian Runoff Quality (IEAust 2006) documents.

Sizing the pavement for flood management is undertaken using the design storm method, while the hydrological effectiveness approach is adopted for water quality and harvesting design. The software is relatively simple to use and has several inbuilt features that allows the user to consider primary objects, traffic conditions, effective service life, geotechnical properties, etc.

The Lockpave-PermPave Software Package is able to assist with the structural design of interlocking concrete segmental pavements and permeable pavements (available to order from **www.cmaa.com.au/html/CMAA_TechInfo.html**).

Hydrological Effectiveness Curves

The performance of storage systems with a discharge (infiltration or pipe) can be described (quantified) in terms of hydrological effectiveness, which takes account of A_{EIA} (equivalent impervious catchment area), historical rainfall series, storage, infiltration (outflow), bypass and overflow.

It should be noted that 'hydrological effectiveness' is identical to the term 'retention efficiency' used in Argue, Ed., (2009).

A set of hydrological effectiveness curves has been generated for the Greater Adelaide Region which is presented in **Appendix C**. The curves allow the user to assess the approximate performance of pervious pavements for a range of rainfall regions.

The derivation of the curves is based on a continuous water balance simulation using more than 20 years of historical rainfall series at 6 minute intervals. The following assumptions were made in the development of the curves:

- Equivalent impervious catchment area, A_{EIA} is determined, incorporating an appropriate volumetric runoff coefficient;
- All runoff is directed to storage and the facility excludes a bypass passage;
- Overflow occurs when the storage component fills;
- Infiltration rate (or supply to harvesting systems) is considered to be constant throughout the period of storage.

An example of the use of the hydrological effectiveness curves is contained in **Appendix D**.

7.6 Approximate Costs

The construction cost for pervious pavements depends largely on the type of pervious pavement selected (i.e. no fines asphalt/concrete or block) and the depth of the underlying gravel reservoir layer. The construction cost of pervious paving is similar to that of traditional pavement and is less than the cost of traditional paving when savings in stormwater infrastructure is considered. Research shows that pervious paving can be up to three times less expensive than traditional road and stormwater management approaches (Hobart City Council 2006).

However, the supply cost for pervious pavement is typically greater than conventional pavements (Upper Parramatta River Catchment Trust, 2004).

The estimated unit rate construction costs for a typical pervious pavement area (using block pavers with a 400 mm thick base course layer) is summarised in **Table 7.3**.

Table 7.3 Estimated Construction Cost of Permeable Block Pavement

Works Description	Quantity	Unit	Rate	Cost ($/m²)
Excavate and profiling subgrade surface	1	m²	2	2
Supply permeable pavement blocks	1	m²	40	40
Install pavement blocks	1	m²	25	25
Supply and install geofabric liners	2	m²	5	10
Supply and place gravel reservoir layer (350 mm thick)	0.35	m³/m²	55	19.2
Supply and place bedding layer (50 mm thick)	0.35	m³/m²	45	2.2
TOTAL				98.4

Source: Upper Parramatta River Catchment Trust (2004)

These cost estimates are provided as an indication only and current, locally specific cost estimates should always be obtained.

7.7 Case Studies

Parking Bay, Kirkcaldy Avenue, City of Charles Sturt

Two permeable pavement parking bays were constructed along Kirkcaldy Avenue, Grange, in 1999. The bays were designed to collect, treat and infiltrate runoff generated on the roadway and the parking bays themselves. The scheme reduces both storm runoff (peak flow and volume) and pollution conveyance to downstream waterways.

Figure 7.4 Kirkcaldy Avenue Pervious Pavements

Source: Courtesy of University of South Australia

The catchment consists of the two parking bays and approximately 90 metres of Kirkcaldy Avenue carriageway (limited to half the road pavement); a total of 650 square metres.

The pavement comprises:

- Permeable pavement blocks (80 millimetres in deep);
- No fine sand jointing between pavers;
- 2 to 5 millimetres screenings (50 millimetres depth);
- 20 millimetres screenings, surrounded by geotextile fabric (150 millimetres minimum depth);
- Runoff drains to the roadway kerb and gutter which are directed to the permeable pavement surface. It then infiltrates this surface and fills the storage voids in the pavement base material before slowly infiltrating to the underlying soil;
- The pavement is designed to retain all runoff generated from the catchment area during storm events up to and including the 5 year ARI event. This translates to the capture of more than 95% of all stormwater runoff;
- In periods between storms, water stored in the pavement infiltrates to the underlying soil making this storage available for the next event;

- In large storms (>5 year ARI), short-term ponding occurs on the pavement (up to 40 millimetres depth). Excess runoff continues past the parking bays and enters the existing stormwater network via side entry pits at the northern end of Kirkcaldy Avenue;
- Allowance is made in the design for a 90% reduction in infiltration capacity over the 20 year design life. To avoid exceeding this level of blockage, it was recommended that the permeable surface be cleaned twice a year with a mechanical suction brush;
- Pollutants borne within the runoff are contained on site, the majority being trapped within the pavement layers, improving water quality in the nearby creek system; and
- The system provides increased levels of soil moisture, available to trees and grass in the vicinity of the parking bays.

Car Park, Linden Gardens, City of Burnside

City of Burnside has a water conservation goal of reducing total water consumption in the City by 25% by 2020.

The Linden Gardens Project demonstrates ways to collect and manage stormwater on site. The project involved the use of permeable paving (Hydrapave) to improve stormwater quality and provide stormwater detention.

The project also involved the inclusion of a mini wetland, a 70 metre soakage trench and a rainwater tank providing on-site stormwater retention. The rainwater tank is utilised for garden irrigation. Local indigenous plant species are used in a domestic or commercial scale setting.

Figure 7.5 Construction of the Pervious Pavements, Linden Gardens

Source: Courtesy of City of Burnside

The car park area is 670 square metres. Construction commenced in mid November 2002 and the site was completed with plantings in place by mid February 2003. Maintenance of the carpark consists of a regular visit by the City of Burnside street sweeper truck at about one month intervals.

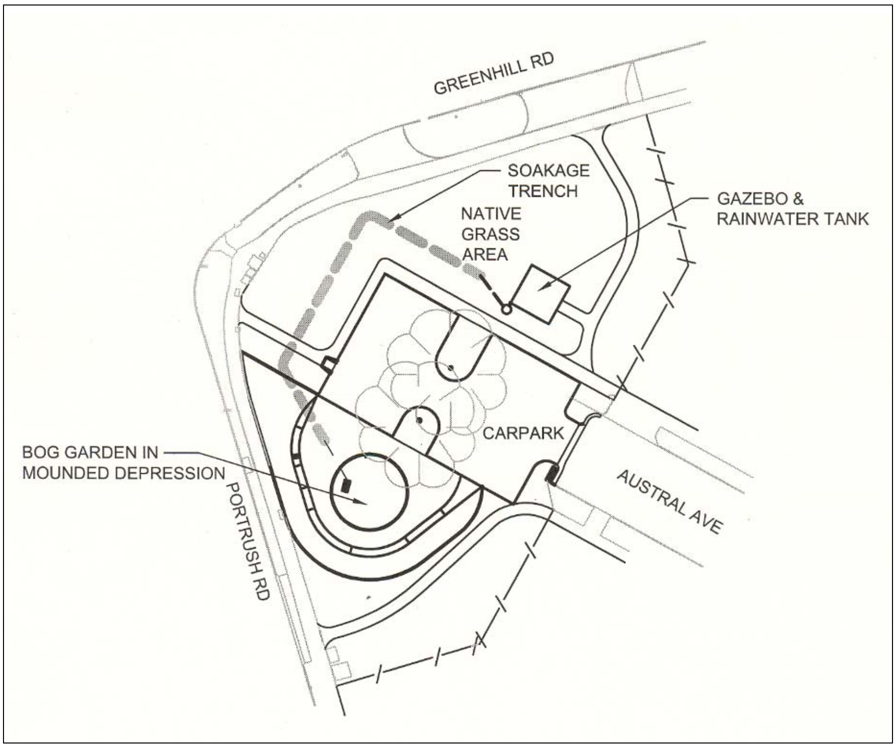


Figure 7.6 Location Plan of the Pervious Pavements, Linden Gardens

Source: Courtesy of the City of Burnside

The costs for the development were approximately:

- Total Cost: About $130,000
- Carpark: About $33,000 ($100/m²)

$14,000 of the total cost was paid for by grant money.

7.8 Useful Resources and Further Information

Fact Sheets

www.wsud.org/downloads/Planning%20Guide%20&%20PN's/06-Paving.pdf

Practice Note 6 Paving – WSUD in the Sydney Region

www.goldcoast.qld.gov.au/gcplanningscheme_policies/attachments/policies/policy11/section_13_11_porous_and_permeable_paving.pdf

Porous and permeable paving guidelines – Gold Coast

Legislation

www.epa.sa.gov.au/pdfs/info_noise.pdf

EPA Information – Environmental Noise

www.epa.sa.gov.au/xstd_files/Water/Report/building_sites.pdf

EPA Handbook for Pollution Avoidance on Building Sites

http://www.legislation.sa.gov.au/LZ/C/POL/ENVIRONMENT%20PROTECTION%20(NOISE)%20POLICY%202007/CURRENT/2007.-.UN.PDF

Environment Protection (Industrial Noise) Policy 1994

www.epa.sa.gov.au/pdfs/info_construction.pdf

EPA information – Construction Noise

General Information

www.cmaa.com.au

Concrete Masonry Association – PermPave Software

www.wsud.melbournewater.com.au/content/treatment_measures/porous_paving.asp

Melbourne Water

www.urbanwater.info/engineering/BuiltEnvironment/PorousPavements.cfm

Urban Water Information

Design Information

http://portal.water.wa.gov.au/portal/page/portal/WaterManagement/Stormwater/StormwaterMgtManual/chapter9/Content/Chapter%2009%20BMP%203.3%20-%20Infiltration%20Systems%20-%20Pervious%20Pav.pdf

*Pervious Pavements – Stormwater Management Manua*l, Western Australia

http://www.wsud.org/tools-resources/

Water Sensitive Urban Design Technical Guidelines for Western Sydney

Suppliers

www.atlantiscorp.com.au

Atlantis

www.rocla.com.au

Rocla Products

www.cmbrick.com.au/

Ecopave

www.boral.com.au/brandstories/hydrapave.asp?site=Boral&AUD=

Boral (HydraPave)

http://tepc.com.au/catalog.php?id=9

Total Erosion and Pollution Control

(Websites current at August 2010)

7.9 References

ACT Planning and Land Authority (2007). *Water Sensitive Urban Design General Code.* Canberra, ACT. July. **www.legislation.act.gov.au/ni/2008-27/copy/64663/pdf/2008-27.pdf**.

Argue, J. R. (Ed, 2009) *WSUD: basic procedures for 'source control' of stormwater - a Handbook for Australian practice.* Editor: Argue, J.R., Authors: Argue, J.R., Allen, M.D., Geiger, W.F., Johnston, L.D., Pezzaniti, D., Scott, P., Centre for Water Management and Reuse, University of South Australia, 5th Printing, February 2009, ISBN 1-920927-18-2, Adelaide.

Beecham, S. and Myers, B. (2007), *Structural and Design Aspects of Porous and Permeable Block Pavements*, JAustCeramSoc, 43(1), pp74-81.

Borgwardt, S. (1994). Institute for Planning Green Spaces and for Landscape Architecture. University of Hanover.

Department of Environment WA (2004). *Stormwater Management Manual for Western Australia.* Perth, Western Australia. **http://portal.environment.wa.gov.au/portal/page?_pageid=55,1508622&_dad=portal&_schema=PORTAL**.

Gold Coast City Council (2007). *Water Sensitive Urban Design Guidelines.* June. **www.goldcoast.qld.gov.au/gcplanningscheme_policies/policy_11.html#guidelines**.

Hobart City Council (2006). *Water Sensitive Urban Design Site Development Guidelines and Practice Notes*. Hobart. **www.hobartcity.com.au/content/InternetWebsite/Environment/Stormwater_and_Waterways/Water_Sensitive_Urban_Design.aspx**

IEAust (2006). *Australian Runoff Quality: A Guide to Water Sensitive Urban Design*. New South Wales.

Melbourne Water (2005). WSUD *Engineering Procedures: Stormwater*. CSIRO Publishing.

Reddi, L. N. (2003). *Seepage in Soils: Principles and Applications*. Hoboken, John Wiley and Sons.

Upper Parramatta River Catchment Trust (2004). *Water Sensitive Urban Design, Technical Guidelines for Western Sydney*. Prepared by URS Australia Pty Ltd. **www.wsud.org/tools-resources/**.

Urban Water Resource Centre (2002). Permeable Pavement – Port Adelaide Enfield Council Carpark. University of South Australia.

(Websites current at August 2010)

Appendix A

Design of Pervious Pavements Using the Design Storm Approach

Pervious Pavements Design Process Details

[Note: Equally important in the design of pervious paving systems for hydraulic performance is the structural performance of a pervious pavement system. The scope of this document does not currently cover the structural design of a pervious pavement. However, the reader is directed to the following design tool for the structural design of a permeable pavement:

The Lockpave-PermPave Software Package - Structural Design of Interlocking Concrete Segmental Pavements and Permeable Pavements (available to order from **www.cmaa.com.au/html/CMAA_TechInfo.html**)]

Design Storm Selection (Q_{des})

The first step is the selection of the design storm to capture for detention, retention or infiltration. This must occur in consultation with the council and will generally relate to the 3 month ARI and 1 year ARI design storms.

Retention Volume

The required 'retention volume' of a pervious 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 pervious paving system. Inflow may include:

- Rainfall onto the pervious paving system only; or
- A combination of rainfall onto the pervious paving system and runoff from other impervious areas.

The inflow volume for the design storm on the pervious paving system (treatment surface) only is (Gold Coast City Council 2007):

$$V_i = \frac{A_s \times i}{10^3} \times D$$

Where:

V_i = inflow volume

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

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

D = duration of storm (hrs)

The inflow for a combination of rainfall onto the pervious paving system and runoff from other impervious areas is determined, as the product of the design storm flow and the storm duration (Gold Coast City Council 2007):

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

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 pervious paving system is via the base (and in 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 (Gold Coast City Council 2007):

$$Q_{\max} = K_{sat} \times A \times \frac{h_{\max} + d}{d}$$

Where:

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

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

A = area of the pervious 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 ponding above the surface of the pervious paving, and conditions are likely to be fully drained, then (Gold Coast City Council 2007):

$$\frac{h_{\max} + d}{d} = 1$$

Outflow volume is calculated as (Gold Coast City Council 2007):

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

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 a pervious paving system can be calculated as follows (Gold Coast City Council 2007):

$$V_d = \frac{V_i - V_o}{p}$$

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 pervious paving system.

In cases where zero surface flow is required, all design storm events should be assessed to determine the maximum storage requirement.

Depth

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

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 pervious paving should be determined using two steps:

Calculate surface area based on the volume and required depth; and

Check surface area has capacity to infiltrate peak flows for design storm.

The surface area of the pervious paving system should be checked using the following equation (Gold Coast City Council 2007):

$$A_s = \frac{Q_{peak}}{(1 - B) \times K_{sat}}$$

Where:

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

B = blockage factor (this should be estimated based on non-pervious structural elements (e.g. plastic/concrete grids)

K_{sat} = saturated hydraulic conductivity of paving surface (e.g. concrete/asphalt)/or pervious material between pavers.

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; and
- 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 pervious 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 pervious 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 (Gold Coast City Council 2007).

The flow capacity of the perforations is thus (Gold Coast City Council 2007):

$$Q_{perf} = B \times C_d \times A\sqrt{2 \times g \times h}$$

Where:

Q_{perf} = flow through perforations (m^3/s)

C_d = orifice discharge coefficient (0.6)

A = total area of the orifice (m^2)

g = gravity (9.81 m/s^2)

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.

Under-drains should be extended vertically to the surface of the pervious 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.

Check Emptying Time

Emptying time is defined as the time taken to fully empty a detention volume following the cessation of rainfall. This is an important design consideration as the computation procedure associated with the outflow volume assumes the storage is empty prior to the commencement of the design storm event.

Australian Runoff Quality (IEAust 2006) suggests an emptying time of the detention storage of pervious 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 calculated 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) (Gold Coast City Council 2007):

$$t_e = \frac{1000 \times V_d \times \rho}{A_{\inf} \times K_{sat}}$$

Where:

t_e = emptying time (hours)

V_d = detention volume (m^3)

ρ = voids ratio of storage

A_{inf} = infiltration area (m^2)

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

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 sublayers. 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 (Gold Coast City Council 2007).

Appendix B
Checklists

The *Site Inspection Checklist* was developed specifically for these guidelines. The remaining checklists have been modified for South Australian designs and conditions from checklists and forms provided in Upper Parramatta River Catchment Trust (2004), Melbourne Water (2005b), IEAust (2006), Gold Coast City Council (2007) and BMT WBM (2008).

All parts of all checklists should be completed. Even if design checks or field inspections were not performed, it is important to record the reasons for this in the relevant checklists.

Pervious Pavement

Site Inspection Checklist

Asset ID:		**Date of Visit:**	
Location:		**Time of Visit:**	
Description:			
Inspected by:			
Weather:			

Site Information:	Comments
1. Site dimensions (m)	
2. Area (m²)	
3. Current site use	
4. Existing structures: Age Condition Construction	
5. Sealed pavements (type and condition)	
6. Unsealed surface	
7. Drains: Presence Type Condition Outlet point	
8. Surface runoff	
Site Safety:	**Comments**
1. Potential contamination sources	
2. Identify any confined spaces (indicate if specific training required for access)	
3. Environmental hazards (snakes, sun exposure, etc)	
4. Other hazards	

Photographs:	Comments
1. Number of photographs taken	
2. Location of stored photographs	
3. Any further information regarding photographs	
Local and Regional Information:	**Comments**
1. Topography	
2. Hydrology	
3. Adjacent sites (including current use, buildings, physical boundaries): North East South West	
Fieldwork Logistics:	**Comments**
1. Access (include width, height, weight restrictions)	
2. Other restrictions	
Other Information:	**Comments**
Attachments:	**Comments**

Sketch of Site

(on this page please provide a rough sketch of the site plan)

Pervious Pavement

Design Calculation Checklist

Calculation Task	Outcome	Units
Catchment Characteristics:		
1. Catchment area contributing to paving system		ha (or m^2)
2. Catchment land use (ie residential, commercial etc)		
3. Storm event entering pervious paving system (minor or major)		year ARI
4. Estimated surface area of paving system		ha (or m^2)
Confirm Design Objectives and Pavement Type:		
5. Confirm design objective as defined by conceptual design		
6. Confirm treatment performance		
7. Confirm paving type		
8. Detention system only		
Pre-treatment Design:		
9. Appropriate treatment to avoid clogging		
Determine Design Flows:		
10. Minor storm		year ARI
11. Major storm		year ARI
12. Time of concentration		minutes
13. Design runoff coefficient:		
Minor storm		
Major storm		
14. Peak design flows:		
Minor storm		m^3/s
Major storm		m^3/s
Size Pervious Paving System:		
15. Design storm flow		m^3/s

Calculation Task	Outcome	Units
16. Inflow volume		m^3
17. Outflow volume		m^3
18. Detention volume		m^3
19. Depth		m
20. Surface area check ok		m^2
Under-drain Design and Check:		
21. Flow capacity of filter media		m^3/s
22. Perforations inflow check		
23. Pipe diameter		mm
24. Number of pipes		
25. Capacity of perforations		m^3/s
26. Check perforation capacity > filter media capacity		
Emptying Time Check:		
27. Calculated emptying time		hrs
28. Emptying time okay (12 – 48 hrs)		
Impermeable Lining Check:		
29. Impermeable lining required		
Pervious Paving Layers Specified:		
30. Pervious paving surface type and depth		m
31. Bedding layer material and depth		m
32. Underdrainage layer material and depth		m
Inflow / Overflow Structures		
33. Overflow pipe:		
34. Pipe capacity		m^3/s
35. Pipe size		mm diam
36. Overflow pit:		
37. Pit capacity		m^3/s
38. Pit size		mm x mm

Pervious Pavements

Design Assessment Checklist

Asset ID:				
Pervious Paving Location:				
Hydraulics:	Minor Storm (m^3/s):		Major Storm (m^3/s):	
Area:	Catchment Area (ha):		Infiltration Area (m^2):	
	Detention Volume (m^3):			

Pavement Type	Yes	No
1. Pavement type appropriate to site based on traffic load, amenity and built environment character		
2. Pervious paving is detention system only (no infiltration)		
3. Pervious paving on slope less than 4%		
Pre-treatment	**Yes**	**No**
4. Appropriate pre-treatment provided		
5. Contributing catchment adequately stabilised and not a source of sediment		
Pervious Paving System	**Yes**	**No**
6. Design objective established		
7. Has the appropriate design storm been selected		
8. Pervious paving system designed appropriately and checks for detention volume and surface area undertaken		
9. Under-drainage provided flowing away from other conventional paved surfaces to stormwater network		
10. Emptying time checked		
11. Impermeable lining included		
12. Pervious paving layers specified appropriately		

Flow Management	Yes	No
13. Overall flow conveyance system sufficient for design flood event		
14. Bypass/overflow sufficient for conveyance of design flood event		
Comments		

Pervious Pavements

Construction Inspection Checklist (During Construction)

Asset ID:		**Inspected by:**	
Site:		**Date:**	
Constructed by:		**Time:**	
Contact During Visit:		**Weather Conditions:**	

Items Inspected	**Checked Y/N**	**Satisfactory Y/N**
A. Functional Installation		
Preliminary Works		
1. Erosion and sediment control		
2. Traffic control measures		
3. Location same as plans		
4. Site protection from existing flows (diverted around site)		
5. Excavation as designed		
6. Side slopes are stable		
Pre-treatment		
7. Contributing catchment stabilised / not a sediment source		
Structural components		
8. Location and levels of pervious paving system and overflow points as designed		
9. Pipe joints and connections as designed		
10. Concrete and reinforcement as designed		
11. Inlets appropriately installed		
12. Correct fill media/modular system used		

Items Inspected	Checked Y/N	Satisfactory Y/N
13. Provision of geofabric around aggregate layer		
B. Sediment And Erosion Control		
14. Stabilisation immediately following earthworks		
15. Silt fences and traffic control in place		
16. Temporary protection layers in place (if appropriate)		
C. Operational Establishment		
17. Temporary protection layers removed		
18. Surface of paving installed/ cleaned		
Comments On Inspection		
Actions Required		
1.		
2.		
3.		
Inspection Officer Signature:		

Pervious Pavements

Construction Inspection Checklist (After Construction)

Asset ID:		**Inspected by:**	
Site:		**Date:**	
Constructed by:		**Time:**	
Contact During Visit:		**Weather Conditions:**	

Items Inspected	Checked Y/N	Satisfactory Y/N
1. Confirm level of inlets and outlets		
2. Traffic control in place		
3. Confirm structural element sizes		
4. Layers of paving system as specified		
5. Confirm pre-treatment is working		
6. Check for uneven settling of surface		
7. No surface clogging		
8. Maintenance access provided		
9. Construction generated sediment and debris removed		
Comments On Inspection		
Actions Required		
1.		
2.		
3.		
4.		
Inspection Officer Signature:		

Pervious Pavements

Inspection Maintenance Form

Asset ID:		**Date of Visit:**	
Location:		**Time of Visit:**	
Description:			
Inspected by:			
Weather:			

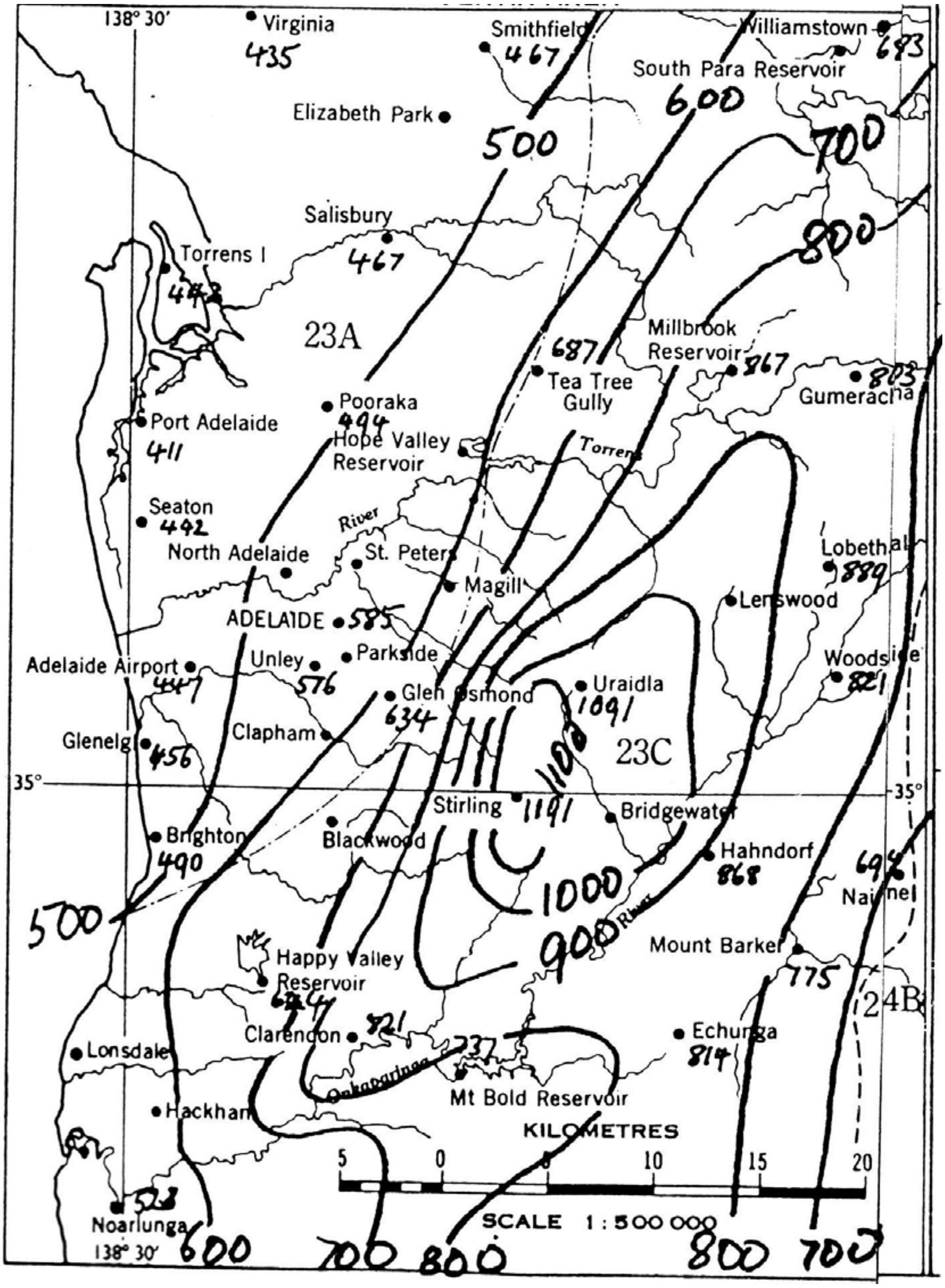
Items Inspected	Checked Y/N	Maintenance Needed Y/N	Inspection Frequency
Debris Cleanout			3 months
1. Pavement surface clear of debris			
Pavement Surface			3 months
2. Sediment build up			
3. Potholes			
4. Cracking of pavement			
5. Significant pavement deflection			
6. Damage/vandalism			
Dewatering			3 months
7. Pavement surface dewatering between storms			
8. Replacement required of clogged pavement			
Outlet / Overflow			annual
9. Outlet condition			
10. Evidence of erosion downstream			

Comments On Inspection
Actions Required
1.
2.
3.
4.
5.

Appendix C

Design Using Hydrological Effectiveness Type Curves

Annual Rainfall for Greater Adelaide Region



Equivalent impervious area (EIA) for pervious pavements involves use of runoff coefficients that are significantly less than those used to determine this parameter in flood control design. The reason for this is the high proportion of small runoff events – incorporating greater (relative) losses – that provide the database of these systems. A_{EIA} should therefore be calculated for use in the hydrological effectiveness graphs applying a factor of 0.83 to the conventional C_{10} values in flood control practice. Thus, for example, for paved areas, A::

$A_{EIA} = C_{10} \times 0.83 \times A = 0.75A$

Where: $C_{10} = 0.90$

It is possible, using sets of hydrological effectiveness curves, to determine the storage requirement or discharge rate necessary to achieve a target efficiency for particular circumstances. Storage requirement is expressed in terms of mean annual runoff volume (% MARV); discharge refers to the flow rate leaving the device whether it be through, for example, infiltration or slow drainage to an aquifer or a combination of both.

Each set of hydrological effectiveness curves takes account of all independent variables, as explained above. Therefore, a unit discharge rate, q, is introduced as a function of flow rate leaving the device and effective impervious area (EIA).

The set of hydrological curves for the Greater Adelaide Region is presented below in the following format:

Horizontal axis – storage expressed as a % of mean annual runoff volume %(MARV), β

$$\beta = \frac{\forall}{A_{EIA} \times X} \text{ x100}$$

Where:

$\forall$ = storage volume (m^3)

A_{EIA} = equivalent impervious area (m^2)

(incorporating an appropriate volumetric runoff coefficient)

X = average annual rainfall (m)

Vertical axis – discharge unit rate, q, stated in L/s per m^2 of equivalent impervious area

Where infiltration is the only form of discharge:

$$Q_d = k_h \times U \times A_{avail}$$

Hence:

$$q = \frac{k_h \times U \times A_{avail}}{A_{EIA}}$$

Where:

k_h = host soil hydraulic conductivity (m/s)

U = moderation factor (see below)

A_{avail} = base area of infiltration device (m²)

A_{EIA} = catchment EIA (m²)

For 'slow' release to a drainage system or to meet a harvesting demand:

$$q = \frac{Q_d}{A_{EIA}}$$

Q_d= constant discharge rate (L/s)

Combinations of the two forms of discharge (infiltration and pipe) are possible: 'composite' values (simple addition) of q are needed in such cases.

Soil moderation factor, U

According to Allen et al (2005), five soil permeability categories are provided :

Sandy soil :	$k_h > 5\times10^{-5}$ m/s
Sandy clay :	k_h between 1×10^{-5} and 5×10^{-5} m/s
Medium clay and some rock :	k_h between 1×10^{-6} and 1×10^{-5} m/s
Heavy clay :	k_h between 1×10^{-8} and 1×10^{-6} m/s
Constructed clay :	$k_h < 1\times10^{-8}$ m/s,

Where k_h is the value of hydraulic conductivity determined by Jonasson's (1984) 'falling head' auger hole method.

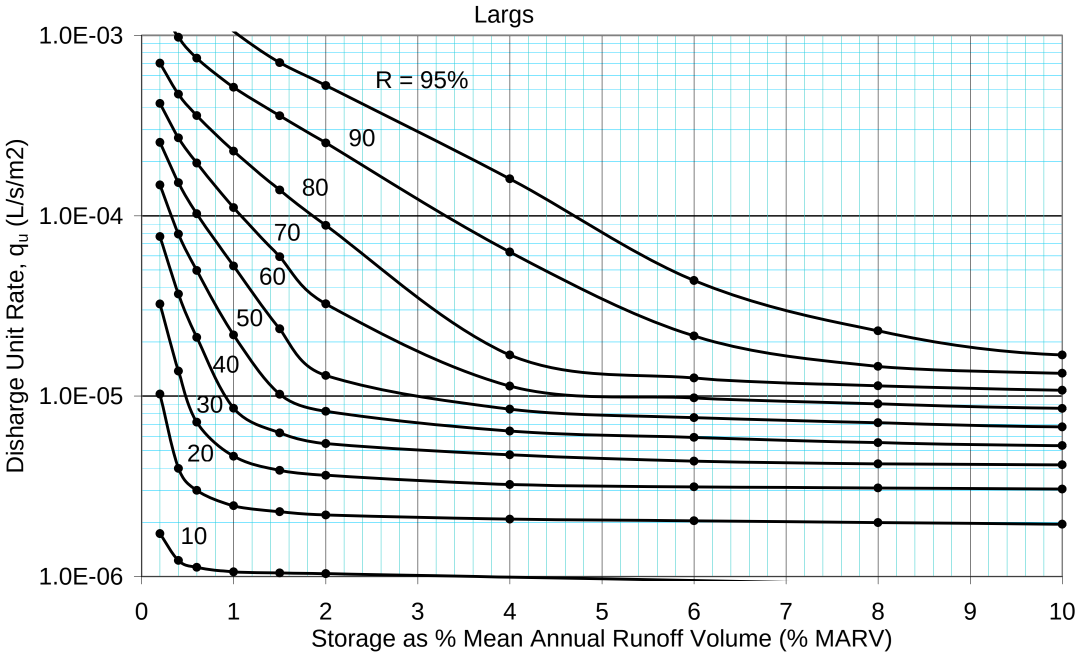
When the hydraulic conductivity results from a small volume infiltration test are compared with field data from infiltration systems, it is found that field hydraulic conductivity is different. This observation has led to the introduction of a correction factor, moderation factor, U, which should be applied to hydraulic conductivity, kh, in the formulae which follow (Argue 2004):

Clay soils - U = 2.0

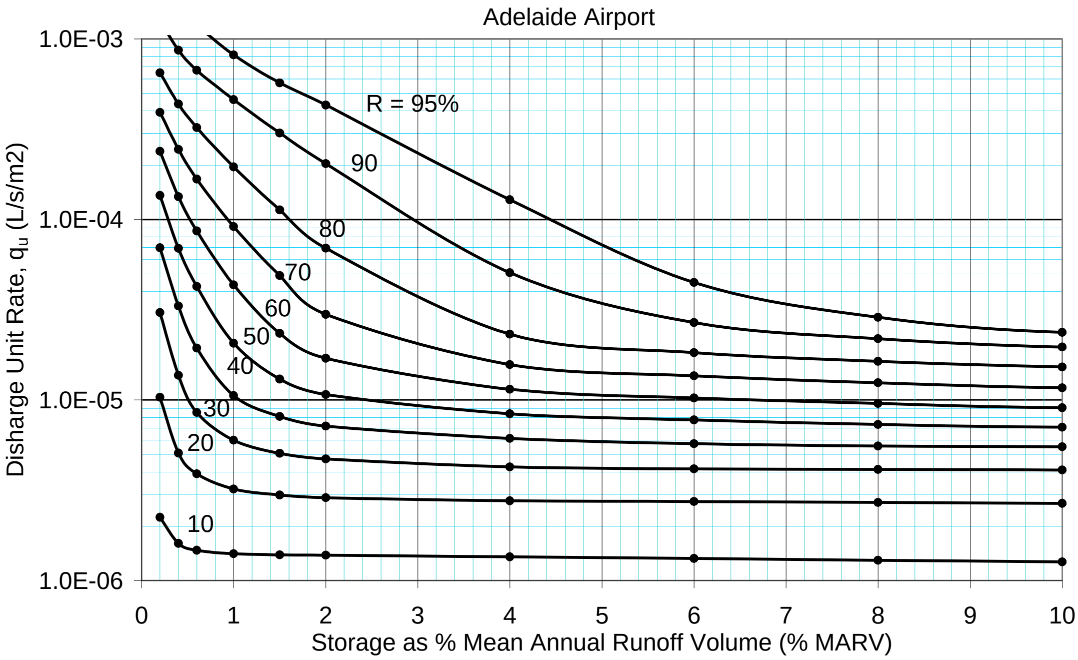
Sandy clay soils - U = 1.0

Sandy soils - U = 0.5

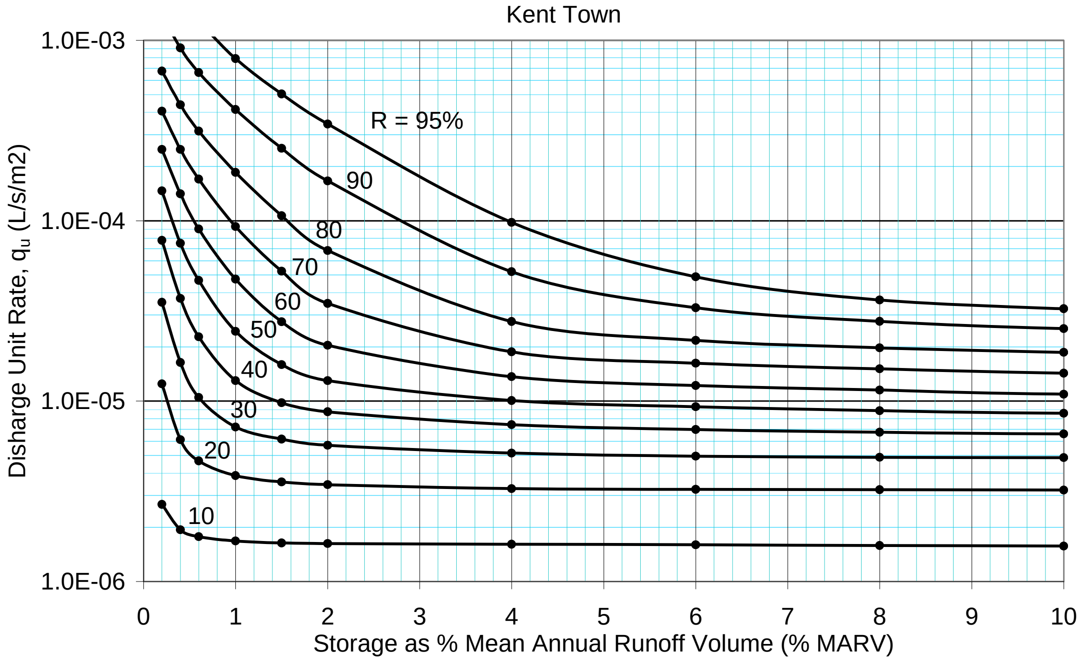
Rainfall = 300-400 millimetres per annum



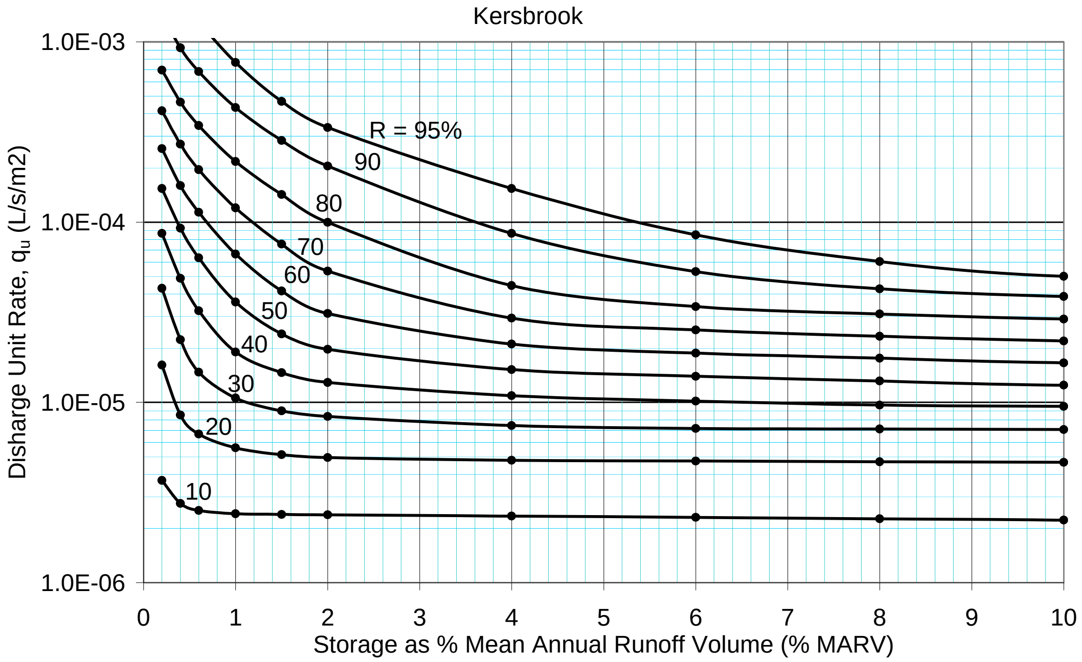
Rainfall = 400-500 millimetres per annum



Rainfall = 500-600 millimetres per annum



Rainfall = 600-800 millimetres per annum



Appendix D

Hydrological Effectiveness Type Curves Illustrative Example

Hydrological Effectiveness Type Curves Illustrative Example

Location: Adelaide (Kent Town)

Average annual rainfall: X = 545 mm/yr

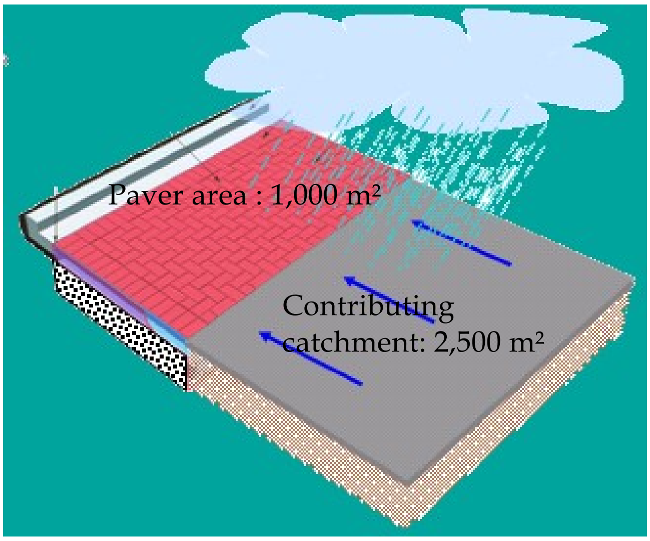
Soil: Medium clay, $k_h = 1 \times 10^{-6}$ m/s

Moderation factor, U = 2.0

Contributing catchment: = 2500 m² (EIA)

Space available: A_{avail} = 1000 m²

Combined Equivalent Impervious Area (EIA) = 3500 m²



Storage device: gravel-filled basecourse S = 0.2

Hydrological effectiveness, R = 95%

Objective: Determine depth of permeable paving basecourse (if required depth exceeds maximum allowable, determine slow drainage, necessary to limit depth to maximum allowable)

Step 1: Determine volume of soak away

According to Allen et al (2005), five soil permeability categories are provided:

Sandy soil:	$k_h > 5\times10^{-5}$ m/s
Sandy clay:	k_h between 1×10^{-5} and 5×10^{-5} m/s
Medium clay and some rock:	k_h between 1×10^{-6} and 1×10^{-5} m/s

Heavy clay: k_h between 1×10^{-8} and 1×10^{-6} m/s

Constructed clay: $k_h < 1\times10^{-8}$ m/s,

Where k_h is the value of hydraulic conductivity determined by Jonasson's (1984) 'falling head' auger hole method.

When the hydraulic conductivity results from a small volume infiltration test are compared with field data from infiltration systems, it is found that field hydraulic conductivity is different. This observation has led to the introduction of a correction factor, moderation factor, U, which should be applied to hydraulic conductivity, k_h, in the formulae which follow (Allen et al. 2005):

Clay soils - U = 2.0

Sandy clay soils - U = 1.0

Sandy soils - U = 0.5;

Hence:

Moderated hydraulic conductivity:

k_h = $(1 \times 10^{-6}) \times U$

= $1 \times 10^{-6} \times 2.0$ = 2×10^{-6} m/s

For sandy soils the moderation factor U = 2. For further information about the moderation factor refer to **Chapter 10** of the Technical Manual.

Infiltration discharge unit rate, q, L/s/m² of EIA

$$q = \frac{k_h \times U \times A_{avail}}{A_{EIA}}$$

$q = 2 \times 10^{-6} \times 1000/3500$

$= 5.7 \times 10^{-4}$ L/s/ m²

Locate q on figure;

It can be seen that the required storage ratio β (%MARV) is 1.3%.

Hence volume of soak away required:

$$\beta = \frac{\forall}{A_{EIA} \times X} \text{ x } 100\ldots\ldots\ldots\ldots$$

$\forall$ = (β / 100) x EIA x X

$\forall$ = 0.013 x 3500 x 0.545

$\forall$ = 24.8 m³

Step 2: Determine depth, H, of soak away

$\forall = H \times A_{avail} \times eS..$

Hence, depth required: $H = \dfrac{\forall}{A_{avail} \times e_s}$

$H = 24.8/(1000 \times 0.2)$

$= 124$ mm (say 130 mm)