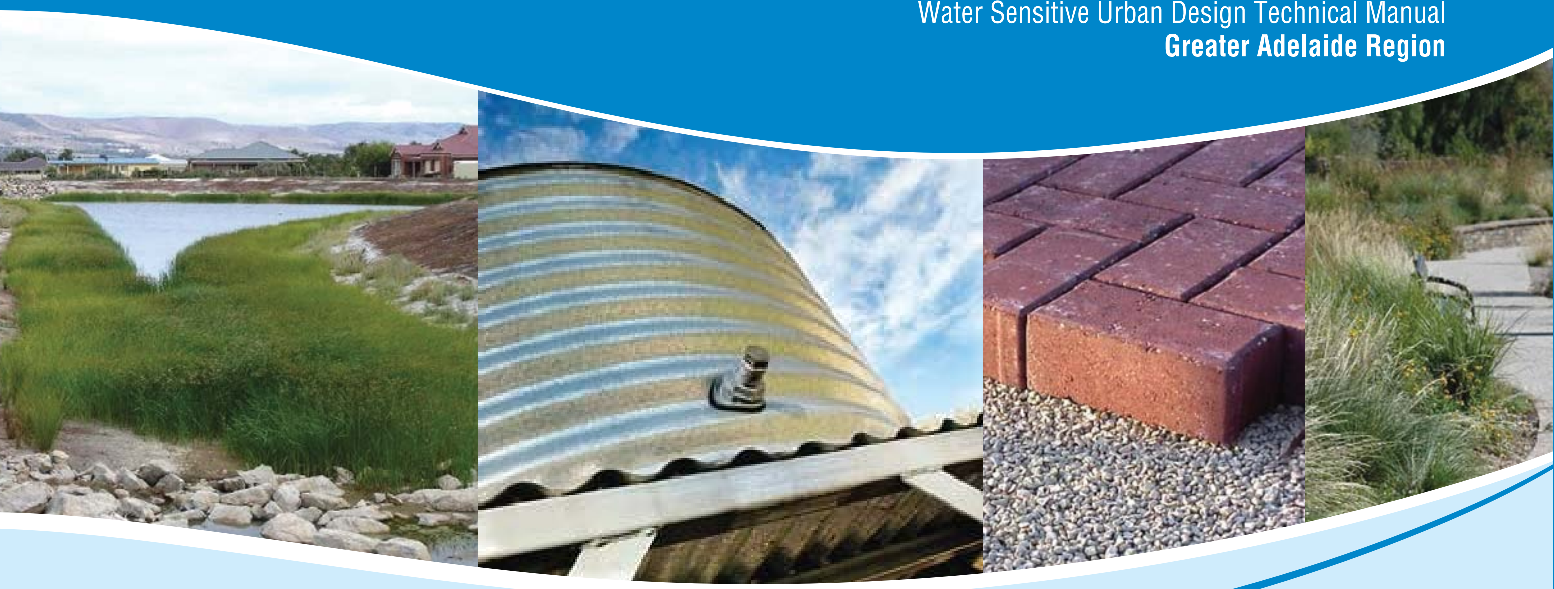
December 2010

Chapter 6

Rain Gardens, Green Roofs and Infiltration Systems

Water Sensitive Urban Design Technical Manual
Greater Adelaide Region



Government of South Australia

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Department of the Environment, Water, Heritage and the Arts

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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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6.1 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).

Source control is one of the most effective ways of managing runoff in an urban catchment. Managing runoff at the source provides more opportunities to achieve a hydrological cycle that is closer to the pre-development (natural) regime.

WSUD measures that can be implemented at the site level include:

- Rain gardens;
- Green roofs; and
- Infiltration systems.

The purpose of this chapter of the WSUD Technical Manual for the Greater Adelaide Region is to provide an overview of these three measures, which each have the ability to intercept runoff, treat it and promote infiltration.

Rain gardens and green roofs are both vegetated WSUD systems. A particular challenge in Adelaide is to provide sufficient water to maintain the vegetation during the long interstorm dry periods commonly experienced in South Australia. In summer, in particular, the vegetation not only suffers from water shortage but often heat stress as well. Chapter 10 describes how to incorporate design features into vegetated streetscape WSUD systems to ameliorate these effects. For lot-scale vegetated WSUD systems, such as raingardens and green roofs, there is often less space available in which to incorporate significant storage volumes.

6.2 Legislative Requirements and Approvals

A thorough investigation of required permits and approvals should be undertaken as part of the conceptual design of any rain garden, green roof or infiltration system.

Consideration also needs to be given to what, if any, risks and/or financial obligations would be transferred to council if it operates the scheme (e.g. operations, maintenance, monitoring and reporting costs).

A proposed rain garden, green roof or infiltration system needs to meet the requirements of the following legislation:

- *Development Act 1993*;
- *Environment Protection Act 1993*;
- *Natural Resources Management Act 2004*;
- *Local Government Act 1999*; and
- *Public and Environmental Health Act 1987*.

Further information regarding legislative requirements and approvals should be sought from your local council.

6.3 Rain Gardens

Description

Rain gardens are shallow planted depressions designed to take the excess rainwater runoff from a house roof or other building, assisting runoff to infiltrate the underlying soil, recharge the groundwater, and reduce peak flows from the site. The rain garden concept can be expanded to incorporate an entire garden or a city streetscape, but of particular interest is its small scale application in the domestic, commercial and industrial garden, where there is potential for a very significant impact on runoff management at the source.

Rain gardens are different to other bioretention systems in that they allow the water to infiltrate the underlying soil to recharge the groundwater.

Rain gardens are typically planted with native plants or sustainable species that are adapted to local climate conditions. Rain gardens are an example of WSUD that can be easily integrated into the landscape to achieve an attractive low maintenance solution.

Purpose

Rain gardens use the technique of retaining runoff for infiltration back into the soil. Through the chemical, biological and physical properties of plants, microbes and soil, the water is filtered before it enters the groundwater, with some degree of pollutant removal occurring.

In addition to retaining and filtering water on site, rain gardens have a number of other attractive benefits for the garden. The promotion of more planting rather than paved surfaces increases the proportion of pervious areas in the built environment. Biodiversity is increased as habitat opportunities are increased for small animals, birds and insects. Rain gardens also provide visual interest through the introduction of ephemeral water features into the garden. The cooling effect of this water can improve the microclimate of the whole garden.

The main functions of rain gardens are water quality control, water conservation and increased amenity. They provide limited flood control, mainly because of their small volume. The low voids ratios of soils used in these systems (a typical value is 0.2) and their limited infiltration rates (typically 150 to 350 millimetres/hour) limits their potential to provide flood control. An approximation of the available flood storage volume is a combination of 20% of the soil volume plus the above lying water ponding volume, although in practice the available soil storage is unlikely to be fully utilised during a high intensity storm event.

Where both the minor and major flood flows must be conveyed over the rain garden surface, velocities should be kept preferably below 0.5 metres/second to avoid scour.

Application / Scale

Rain gardens are a measure that may be implemented at a variety of scales, from domestic through to commercial and industrial sites.

Rain gardens are an especially useful tool that can be implemented and managed by homeowners. Their simplicity and low maintenance functioning, once established, make them an inexpensive WSUD measure applied at the domestic level.

Design Considerations

The following sections provide an overview of the key design issues that must be considered when conceptualising and designing a rain garden.

Plant Species

A wide range of plants are suitable for rain gardens, in particular many local native species. Professional advice should be sourced either from a landscape architect or qualified horticulturalist to provide guidance on the design and installation of appropriate plants for the Greater Adelaide Region.

The following points should be followed when choosing plants for a rain garden:

- In Adelaide plant species can be subjected to periods of inundation followed by longer dry periods;
- Plants should be chosen that naturally occur in wetlands or soaks, such as the sedge and rush families. These species will assist in biological treatment performance, improve the soil structure, and promote good surface and subsurface infiltration properties;
- Perennial rather than annual species are most effective in a rain garden; and
- Plants with deep fibrous root systems promote infiltration but have the potential, if planted extremely close to buildings, to affect the building. Only low shrub and groundcover plantings are recommended.

Since Adelaide has a modified Mediterranean climate with long periods of dry weather in summer and a significant wet weather period in winter it is important to recognise that plants need to be able to withstand this extreme seasonal rainfall condition. Some internet resources regarding plant species selection may not be appropriate for the climate conditions in Adelaide. Appropriate resources include:

- SA Water, Tune Your Garden to Our Climate:

  www.sawater.com.au/NR/rdonlyres/90B3E7E2-A938-4291-A443-8ADC2BAFD364/0/Tuneyourgarden.pdf

- Adelaide Botanic Gardens – Relevant information can be found at links to the SA Water Mediterranean Garden and the Sustainable Landscapes Project. These contain advice on appropriate plants in the Adelaide region:

  www.environment.sa.gov.au/botanicgardens/index.html

Mosquitoes

The concept of rain gardens is to collect and infiltrate the water into the soil as quickly as possible as in the pre-development landscape and not to encourage a semi permanent water body. To prevent breeding of mosquitoes, ensure ponding of water in the garden is limited to no longer than four days. This can be achieved in a number of ways:

- Soils should be selected such that they have an adequate hydraulic conductivity – greater than 1×10^{-6} metre/second or matched to the maximum design pond depth to suit the infiltration properties of the soil; and
- Provide overflow piping to reduce excessive ponding in high runoff events.

Minor and Major Rain Events

It is possible to design rain gardens to manage minor and major rain events. The most important drainage element is the overflow path, which allows flows (greater than garden capacity) to be conveyed further along the stormwater runoff management chain.

Infrastructure

Depending on soil types, especially heavy clay soils, excessive wetting and drying cycles associated with rain gardens may cause the soil to expand and contract, as it did in pre-development conditions. Significant soil movement can result in damage to buildings and nearby subsoil infrastructure; therefore the location of the rain garden in heavy soil type areas is important.

If space is a constraint it is possible to place an impermeable liner between the building structure and the rain garden. The liner/water barrier would need to extend into the soil twice the depth of the rain garden, or a minimum of 1 metre. This acts as a bond breaker between the footing and soil movement.

Where infiltration to the native soil is not required, an impermeable liner can be placed beneath the rain garden base and side. This will not be a rain garden but will become a micro wetland or a bioretention system that is connected to the stormwater chain.

Design Process

The key elements of the design process for rain gardens are outlined below.

Design Objectives and Targets

The implementation of WSUD in a development seeks to achieve a range of outcomes relating to water quality, hydrology, conservation and amenity. Design objectives and targets should be determined before the design process commences. **Chapter 3** of the Technical Manual provides guidance on setting objectives and targets.

Selection of a Location

Areas of the property should be identified where rainwater runs from downpipes or from paved areas. Runoff from these areas represents potential sources of water for a rain garden.

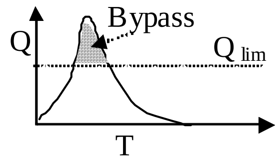
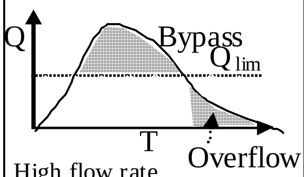
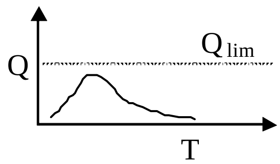
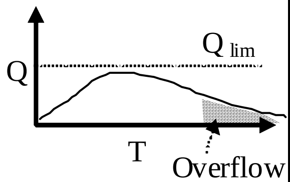
The size of a rain garden will depend on the amount of runoff it receives. For a typical downpipe, 1 or 2 square metres should be enough garden area at the domestic scale (Melbourne Water, 2007). A design for larger gardens may want to consider referring to the size requirements for a bioretention system (refer to **Chapter 10** – Bioretention Systems for Streetscapes).

Gardens may also collect water from driveways, roadways or carparks. This is accomplished using downpipes, or graded kerbs with cutaways.

Design Approach

Many rain gardens are designed without any specific hydraulic capacity but rather to integrate into the landscape design or the space available. This approach is acceptable provided that adequate overflow piping or overland flow is designed into the system. However, a detailed design approach is often required to calculate the required areas for the garden. If this is the case then the hydrological effectiveness curve approach to design may be applied to rain gardens.

The performance of storage systems with a discharge (infiltration or via pipe) can be described (quantified) in terms of hydrological effectiveness, which takes account of EIA (equivalent impervious catchment area), historical rainfall series, storage, infiltration (outflow), bypass and overflow, as illustrated in Figure 6.1.

Runoff event type	**Loss mode:** bypass and/or overflow
 High flow rate Low runoff volume	**BYPASS and NO OVERFLOW***
 High flow rate High runoff volume	**BYPASS and OVERFLOW ****
 Low flow rate Low runoff volume	**NO BYPASS and NO OVERFLOW ***
 Low flow rate High runoff volume	**NO BYPASS and** *OVERFLOW***

R = unshaded area in Figure 6.1 hydrographs/area under each hydrograph expressed as a percentage

Note: Hydrological Effectiveness is identical to the term Retention Efficiency, R used in Argue (Ed., 2009).

Figure 6.1: Hydrological event processes

Equivalent impervious area, A_{EIA} for systems discussed 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.

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).

Most of the curves are based on simulation using more than 20 years of historical rainfall series at 6 minute intervals. The following assumptions were made:

- 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; and
- Infiltration rate (or supply to harvesting systems) is considered to be constant throughout the period of storage.

An example of the utilisation of the hydrological effectiveness curves for the design of a rain garden is contained in **Appendix C**.

Construction Process

The following is a guide to implementing rain gardens on a domestic, commercial or industrial property. It is important to ensure that, where noted in this procedure, a licensed tradesperson is engaged to connect overflow pipes to the site stormwater drainage system.

Excavation

The area of the rain garden should be excavated as a shallow basin to a depth of about 40-80 centimetres into the soil. It is important to ensure this basin has a gentle slope away from any adjacent building, toward the bottom of the garden.

To prevent the transport of water toward building foundations, a root and water barrier sheet of waterproof material is placed in a trench between the rain garden and adjacent buildings.

Water Supply

Conventional runoff disposal systems will have to be arranged to supply the rain garden.

Where downpipes are used, water can be redirected to a rain garden using a flow distributor attached to the end of the downpipe, or through a shallow trench or pipe attached to the end of the downpipe. It is important to ensure that the pipe has a flow spreading mechanism to prevent scouring at the point where it delivers water to the garden. Alternatively, rocks can be embedded near the inflow point to dissipate the energy of the high velocity discharges entering the garden.

Where water is sourced from hard standing surfaces, scouring may still represent a problem and should be discouraged with flow spreading mechanisms in cutaway sections allowing for the entry of runoff. This may be achieved using simple techniques like roughened surfaces on the cutaway.

Pipework will also be required to collect the overflow or excess runoff that occurs in heavy storms and long periods of rainfall.

A vertical standpipe should be installed at the bottom end of the garden which will intersect with the piping that is connected to the conventional stormwater disposal pipe.

It is important to note that the services of a licensed plumber are required to connect this standpipe to the stormwater pipe.

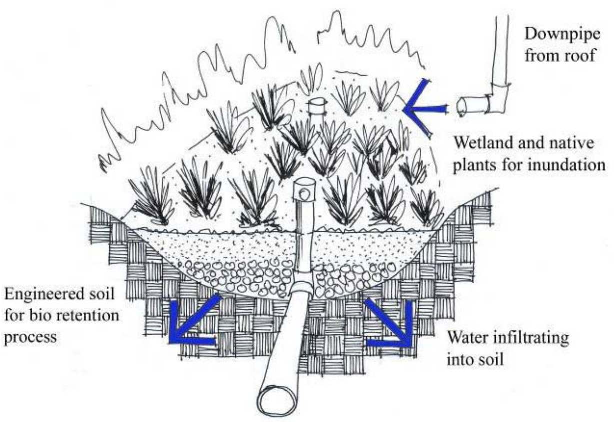


Figure 6.2 Typical Rain Garden Drainage Arrangement

Source: Fifth Creek Studio

Soil Medium Layers

There are several options for the construction of rain gardens. The most important aspect is the use of a soil with adequate drainage qualities.

Firstly, a layer of gravel should be laid into the base surrounding the overflow connecting pipe.

The rest of the garden can be filled with layers of well draining sandy soil (given the recommended infiltration rate). Local landscape suppliers may be able to assist in the choice of an appropriate soil mix (given the infiltration rate) for the planted section of the garden.

It is recommended to leave a 10-15 cm shallow depression at the surface of the rain garden to allow water to pond on the surface before it infiltrates into the garden soil. This excess water can be expected to drain away via the overflow pipe. Note that the overflow pipe should extrude from the surface of your rain garden and collect water that ponds beyond the surface.

The final step in installing a rain garden is the installation of adequate plants and the application of adequate mulching. Pebbles are the best way to achieve this as other mulch mixtures may contain organic matter that pollutes overflow runoff, and may compact over time to inhibit infiltration.

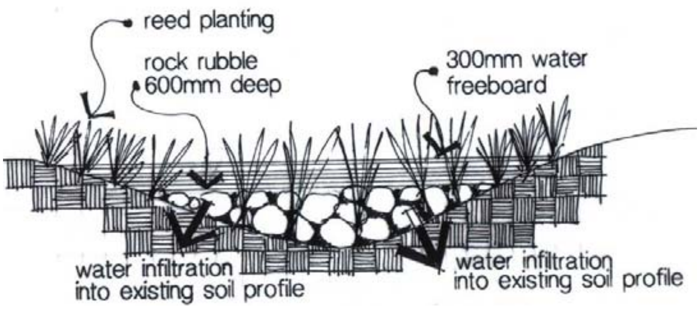


Figure 6.3 Typical Rain Garden Section

Source: Fifth Creek Studio

Opportunities for Retrofitting

Rain gardens represent low cost opportunities for implementing WSUD measures in new and existing sites.

Rain gardens may be easily retrofitted to existing domestic dwellings, commercial and industrial buildings with downpipes connected to subsurface water drains. The required installation procedures are well within the capability of most people to complete by themselves and at their own cost. The only exception to this is the connection of overflow mechanisms, where undertaken, to the street stormwater network. This work must be undertaken by a licensed plumber.

Larger scale rain gardens are an effective way to ensure new, or existing, developments have an attractive, low maintenance landscape tailored to local conditions in the Greater Adelaide Region.

Maintenance Requirements

Rain gardens are a low maintenance, small scale WSUD measure when appropriate vegetation is planted. Under typical climate conditions they should not need to be watered, mowed or fertilised.

Some guidance is provided to ensure rain gardens operate effectively as runoff management tools and aesthetic landscape features:

- If it does not rain, rain gardens should be watered (in accordance with water restrictions and water conservation measures) until plants have sufficiently established;
- Rain gardens should be covered with some form of mulch to retain moisture. A variety of different types of mulch is available, but stone types are recommended as they do not leach nutrients into ponded water and will not form a potential clogging layer at the surface of the rain garden;
- Rain gardens may require regular weeding until plants have matured;
- Ensure no areas of extended ponding develop that will facilitate breeding of mosquitoes;
- It is essential to evenly distribute the flow of runoff into rain gardens to limit erosion from significant flows that follow heavy rainfall;
- Rain gardens should be inspected regularly. Plants may require replacement, or erosion may need to be addressed where it was not expected; and
- Provide 'plant indicators' for identifying substrate infiltration rate changes, especially the silting up of the substrate. There are many species that do not tolerate waterlogging over an extended period of time. These species can be incorporated into the planting plan.

Rain gardens are not tolerant of traffic and may require maintenance following accidental abuse or vandalism in public areas.

6.4 Green Roofs

Description

Green roofs are a series of layers consisting of living vegetation growing in substrate over a drainage layer on top of built structures, either new or retrofitted. In this document the inclusion of living walls and green facades will be treated as having similar characteristics and behaviour patterns as green roofs.

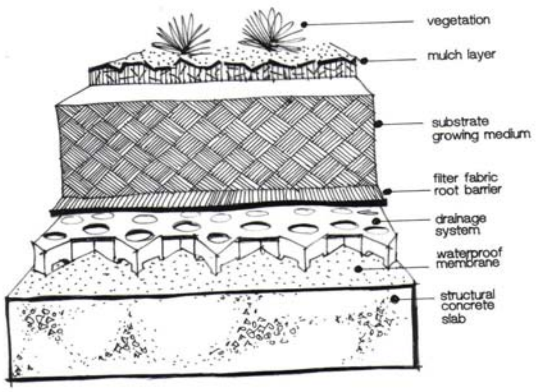


Figure 6.4 Typical Green Roof Construction

Source: Fifth Creek Studios

A green roof is built upon a roof structure, whether new or existing, which is protected by a high quality waterproofing and root repellent system, a drainage layer, a filter cloth and/or root repellent layer, a lightweight growing medium and plants, and finally a mulch layer.

There are four types of green roofs: extensive, semi-intensive, intensive, and elevated landscape. The primary difference between the four types is the depth of the substrate, which in turn has a direct relationship to the runoff holding capacity of each system:

- **Extensive roofs** are generally lightweight systems with low prostrate vegetation and are often inaccessible. These roofs have between 50-150 millimetres substrate depth.
- **Semi-intensive** combines the best features of extensive and intensive, are partially accessible and have greater plant diversity. The depth of the substrate is 150 millimetres +/– 50 millimetres.

- **Intensive** has a substrate depth greater than 150 millimetres, usually accessible for greater use, provides better insulation properties and stormwater management, and has greater biodiversity potential.
- **Elevated landscape** has 600 millimetres or greater depth substrate and creates a new ground plane. This has the greatest potential for biodiversity and topography shaping, and has similar insulation and runoff management potential as the existing ground surface.

Currently in Adelaide, extensive green roofs have not been proven as a successful system, given the available proprietary systems that have been used. The extremely dry humidity and heat in summer creates issues with the root systems of the plants in the shallow substrate. The most appropriate green roof for the Greater Adelaide Region would be the intensive type, which also performs better for runoff management given the increased depth of substrate.

Living walls and green facades provide similar functions to green roofs. Green facades are systems with climbers on vertical support systems grown from planters or inground planting. Living walls are systems where plants are grown in a vertical medium based on the principle of hydroponics for moisture and nutrients.

Figure 6.5 Extensive Roof Example

Source: Fifth Creek Studios

Figure 6.6 Semi-intensive Green Roof Example

Source: Graeme Hopkins, Department of Planning and Local Government

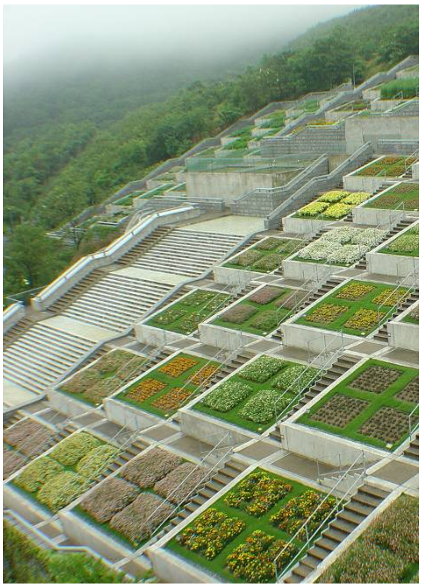


Figure 6.7 Elevated Landscape Example, Awaji Resort, Japan

Source: Graeme Hopkins, Department of Planning and Local Government

Figure 6.8 Intensive Green Roof, Hocking Place, Adelaide

Source: Fifth Creek Studio

Purpose

Green roofs have many benefits to the building, both inside and out, as well as many environmental benefits to the surrounding environs. One of the major drivers for green roofs in North America and Europe is reducing runoff volume and improving runoff quality. This will also be a driver for the Greater Adelaide Region as runoff is a major element of WSUD.

Benefits include:

- Runoff management;
- Improved water quality;
- Reduced impervious areas;
- Reduced heat island effect;
- Reduced air pollution;
- Improved biodiversity;
- Increased insulation;
- Increased carbon dioxide/oxygen exchange; and
- Additional living space.

All of these benefits are equally important in the holistic view but for this particular purpose the elements of water quality, runoff management and the reduction of impervious areas will be dealt with in more detail.

Overall the main function of green roofs is water quality control; they provide limited flood control. Effectively they increase the initial losses in a storm event primarily by increasing the depression storage and vegetation interception losses. These are typically small compared to infiltration losses. The low voids ratios of soils used in these systems (a typical value is 0.2) and their limited infiltration rates (typically 150-350 millimetres/hour) further limits their potential to provide flood control. An approximation of the available flood storage volume is 20% of the soil volume, although in practice the available soil storage is unlikely to be fully utilised during a high intensity storm event.

Reduced Impervious Areas

As cities become more dense, including Adelaide with infill programs, the area of impervious surfaces also increases. Rooftop areas as a percentage of total impervious area can range from 30-35% in suburban developments to as much as 70-75% in business districts. This may even be as high as 80% in some warehouse/semi-industrial districts. If partial usage of rooftops for green roofs were to be implemented, then a considerable reduction in overall runoff volumes could be achieved.

Runoff Management

Green roofs can be an important element in an integrated water sensitive design and planning approach, as the roof is often the first point of contact in the stormwater chain. By intercepting the rain runoff at the source, the green roof eliminates the potential multiplying effect further downstream of the runoff chain. Vegetation assists the management of runoff by reproducing many of the hydrological processes normally associated with the natural environment.

Elements that contribute to this process include:

- Rainwater landing on plant surfaces and then evaporating away;
- Rainwater that falls on the roof substrate can be absorbed by the substrate pores or taken up by the absorbent material in the substrate, and even evaporate back into the atmosphere;
- Rainwater taken up by the plants is either stored in the plant or transpired back into the atmosphere; and
- Rainwater can also be stored and retained within the roof's drainage system.

Storage detention or retention rates for green roofs depend on many variable factors, but as the Greater Adelaide Region, or indeed Australia, does not have any detailed research we can only rely on current observations of existing green roofs and general trends in research in North America and New Zealand as a guide. Overseas studies have found considerable seasonal variations for rainwater retention between summer and winter due to the greater amount of water being returned to the atmosphere in summer through evaporation and transpiration. Retention rates in summer can be between 70-100%, but in winter may be 40-50%.

In a more recent study (Hutchinson et al. 2003) involving stormwater monitoring of two ecoroofs in Portland, Oregon, it was found that the summer retention rate can be up to 100%, and down to 69% at other times of the year for a 100-150 millimetre thick green roof. These studies also showed that for small to moderate storms, the green roofs virtually retained all the rain that fell on them. In large rain events, once the substrate water holding capacity was reached, any extra water would simply run off, therefore reducing the overall percentage of retention.

A further development in technology is the installation of a layer of water-absorbing material within the soil profile. A green roof that has installed this technology in Adelaide has displayed evidence of 100% retention in summer and near that for the rest of the year. Given these outcomes it can be used as a design tool for achieving whatever retention rate is desired.

The graph below in **Figure 6.9** shows the green roof delayed runoff and reduced runoff rate and volume.

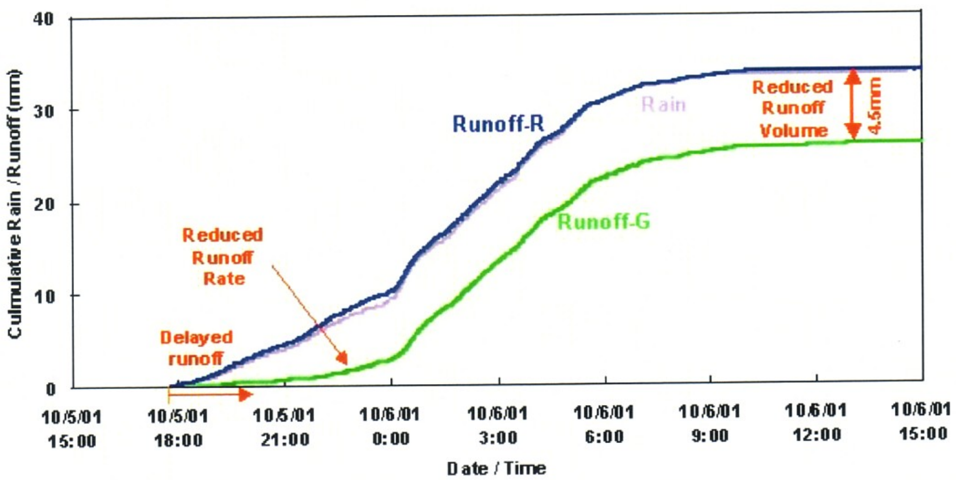


Figure 6.9 Cumulative Runoff Graph

Demonstrating the reduction in runoff volume, delayed and reduced rate of runoff caused by the green roofs. Runoff-G is a 150 millimetre grass covered green roof. Runoff- R is a membrane covered reference roof.

Source: National Research Council Institute for Research in Construction (http://irc.nrc-cnrc.gc.ca/index_e.html)

Water Quality

Green roofs not only retain rainwater, but also moderate the temperature of the water and act as a natural filter for any runoff. This occurs through infiltration and the bioretention process in the substrate.

A recent innovative development in green roof design is to install constructed wetlands as an integral part of the green roof system. Taking the known benefits of constructed wetlands and adding this element to the runoff management role of green roofs is an important WSUD technique.

A demonstration case is the John Deere Works in Mannhein, Germany where it was decided to begin treating the wastewater from the company's manufacturing and assembly operations with a constructed wetland on the factory roof. The wetland includes a combination of sedges, rushes and irises grown hydroponically in 50 millimetres of water. It breaks down carbon and nitrogen compounds present in the wastewater while sequestering phosphates and heavy metals (Earth Pledge 2005).

Figure 6.10 Constructed Wetland, John Deere Works, Germany

Source: Graeme Hopkins, Department of Planning and Local Government

Application / Scale

Green roofs are appropriate for commercial and industrial structures as well as residential buildings. They can be installed on flat roofs but also can be built on slopes up to 30 degrees. They can be incorporated into new construction or retrofitted into existing buildings.

Design Considerations

This section provides an overview of the key design issues that should be considered when conceptualising and designing a green roof for runoff management. The factors that need to be taken into consideration for the design of storage detention/retention rates include:

- Season of the year;
- Number and type of layers used in the system;
- Depth of substrate;
- Angle of slope of the roof;
- Physical properties of the growing media;
- Type of plants incorporated in the roof;
- Intensity of rainfall; and
- Local climate.

The design of the green roof system has typical components as follows:

- Waterproof membrane over structural roofing system;
- Root protection barrier (often incorporated in the waterproofing membrane);
- Drainage layer;
- Filter layer (prevents fine particles in the growing medium from interfering with the drainage layer);
- Water storage system (optional);
- Growing medium;
- Mulch layer; and
- Vegetation layer.

Structural considerations

Structural considerations for the design of green roofs include:

- The green roof needs to be designed to carry the load of a totally saturated substrate (growing medium), drainage system and the foliage weight of all the plants;
- Heaviest loads should be located over structural supports such as columns or walls;
- Lightest or thin substrates should be located at the midspan of the concrete slab or roof beam;
- Always consult a qualified structural engineer for structural suitability, whether for a new or existing structure.

Landscaping Considerations

A wide spectrum of plants from coastal or arid areas of Australia may be suitable for use on green roofs having adapted to extreme environmental conditions, including temperature extremes, high UV load, drought, salt laden winds in coastal areas, shallow nutrient depleted soils, or in some cases pure sand (Mibus 2006).

Plant selection is a critical element in green roof success, and advice from a professional landscape architect or horticulturist who is experienced in green roof design should be obtained. Green roof microclimate is an extreme environment for plants to survive and careful selection of well proven species is required.

Factors that must be considered for plant selection include:

- The higher the green roof, the harder or harsher the environment, therefore the choice of plant species becomes critical and the smaller the plant pallet;
- The orientation of roof or roof slope – whether it is a north facing roof with full sun exposure, or south facing with shading;
- The roof context – if it is overshaded by other buildings all day or part of the day;
- Plant layout – using sustainable landscape principles to maximize benefits;
- Do not use species that have the potential to become 'garden escapees' or weeds.

A useful guide for plant selection is the "Rooftop Gardens Fact Sheet" produced by Adelaide City Council, which provides plant lists for local native sustainable green roofs and for sustainable green roofs. This Fact Sheet is available from Adelaide City Council and provides proven species for Adelaide's climate (see **Section 6.6**).

It is important to consider the topography of the green roof surface, as even small undulations can create microclimates that may benefit many different habitats and greater biodiversity. The greater the biodiversity in the soil the greater the capacity of the soil substrate layer for improving the water quality; also the greater the depth of substrate the greater the retention ability of the green roof.

It should be noted that the timing of planting is critical to optimum establishment of plants on a green roof. Poor timing can result in excessive erosion, plant losses and additional costs.

Figure 6.11 Typical Native Plant Species for Adelaide, Hocking Place, Adelaide

Source: Fifth Creek Studio

Maintenance Requirements

Aside from initial watering and occasional fertilisation, a properly designed green roof does not require much maintenance. Initially the plants will need regular watering until they are fully established (usually within six months). The occasional weeding in the beginning and regular fertilisation of the soil layer are the only other maintenance requirements. Applying a slow release fertiliser twice a year is sufficient.

If the green roof is designed with water retention capacity then additional irrigation is not required once establishment has occurred. If extreme heat wave conditions occur then the use of subsoil dripper irrigation will be required over this period. In extensive roofs the vegetation layer does not grow vertically but the plant species habit is to spread horizontally because the thin soil layer does not support tall vertical growth.

6.5 Infiltration Systems

Description

Infiltration systems generally consist of a shallow excavated trench or 'tank', designed to detain (and retain) a certain volume of runoff and subsequently infiltrate the stored water to the surrounding soils. They reduce runoff volumes by providing a pathway for treated runoff to recharge local groundwater aquifers.

There are four basic types of infiltration systems:

- Soakaways;
- Infiltration trenches;
- Infiltration basins; and
- Leaky wells.

Infiltration systems typically consist of a storage that is made up from void spaces in media such as single size gravel or manmade structures.

The storage is usually wrapped up in geotextile type fabric and 'clean' water is allowed to infiltrate to the native surrounding soil. It is important that infiltration systems only receive 'clean' water; even runoff from roofs often requires some form of pre-filtering.

Infiltration trenches typically hold runoff within a subsurface trench prior to infiltrating into the surrounding soils. They usually comprise a shallow, excavated trench filled with reservoir storage aggregate. Infiltration trenches are similar in concept to infiltration basins, however trenches store runoff water below ground within a pit and tank system, whereas basins utilise above ground storage.

Soakaway systems (refer **Figure 6.12**) are similar, but simply allow water to "soakaway" with minimal storage. They can be below (as illustrated) or above ground systems. Leaky well systems consist of large diameter perforated or pervious pipes or wells that again have limited storage volumes. Both systems rely on the permeability of surrounding soils to disperse inflows. Leaky wells and soakaways are ideally suited to sandy soils which have inherent higher permeability and provide a passive irrigation mechanism for increasing soil moisture within close proximity (metres) of the infiltration area. They can be very effective in managing runoff as well as irrigating gardens and community landscapes.

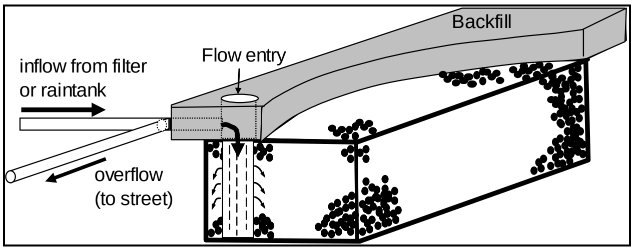


Figure 6.12 Simple Soakaway with Overflow Example

Source: IEAust (2006)

Purpose

Infiltration systems are an effective tool to achieve three primary goals:

- Runoff reduction;
- Pollution reduction; and
- Harvesting and retention of runoff.

The primary purpose of infiltration systems is to capture and infiltrate flows (not treat them).

Infiltration systems are designed to infiltrate runoff on site, thereby reducing the overall volume of water that runs off a site to the urban drainage network. This also reduces the impact of development on peak flow volumes.

Infiltration systems are usually applied with the aim of achieving a specific reduction in the annual runoff volume. Some local government authorities do not permit the use of infiltration systems in locations where they are deemed to be unsuitable.

When applied to promote infiltration, it is important to recognise that the infiltration system is not a primary method of flood mitigation, but a way of taking pressure off conventional urban drainage systems. It is considered appropriate to adopt a design process based on hydrological effectiveness curves where this is the case.

Infiltration systems may also be used as a flood mitigation measure. It is important in this case to design infiltration systems using the design storm method in this case. The design storm method is outlined in Section 11.6 of IEAust (2006). It is important that all systems designed using the design storm method also adhere to the requirements of the *Development Act 1993,* Ministers Specification SA 78AA (Planning SA 2003).

Infiltration systems reduce pollution in urban waterways in two ways. By minimising the conveyance of runoff from urban catchment surfaces to waterways, the accompanying volume of pollutants is prevented form entering the urban drainage network. Infiltration systems also cleanse runoff via a variety of processes, primarily filtration, which improves the quality of water leaving the system.

Water harvesting schemes can be undertaken with the application of infiltration systems. Collection of water after infiltration using subsurface storages, or a combination of pervious pipes and offline storages, can be undertaken. They therefore present an opportunity to address the pressing needs of the community to employ other sources of water for fit for purpose use.

Infiltration systems effectively strip a proportion of the runoff from urban areas and infiltrate this to underlying soils and groundwater. They also provide limited water quality control, primarily through mechanical filtration processes. Other treatment processes can be enhanced using engineered soils or geofabrics.

Application / Scale

Infiltration systems are limited to soils with good infiltrative capacity.

They should also be sited with adequate buffer distances from foundations, neighbouring properties and existing inground infrastructure.

Infiltration systems can be operated at a variety of scales, from receiving the overflow from a rainwater tank, to regional scale systems receiving treated runoff from large catchments.

Infiltration trenches are best suited to small (< 2 hectare catchment) residential, commercial and industrial developments with high percentages of impervious areas, including parking lots, high density residential housing and roadways.

Infiltration trenches are commonly used with overlying pervious pavements as an effective water treatment chain.

Infiltration basins are best suited to medium to large (5 to 50 hectare catchment) residential, commercial and industrial developments with high percentages of impervious areas, including parking lots, high density residential housing and roadways (Upper Parramatta River Catchment Trust, 2004).

Design Considerations

The following sections provide an overview of the key design issues that should be considered when conceptualising and designing an infiltration system. A typical infiltration strategy is illustrated in **Figure 6.13**.

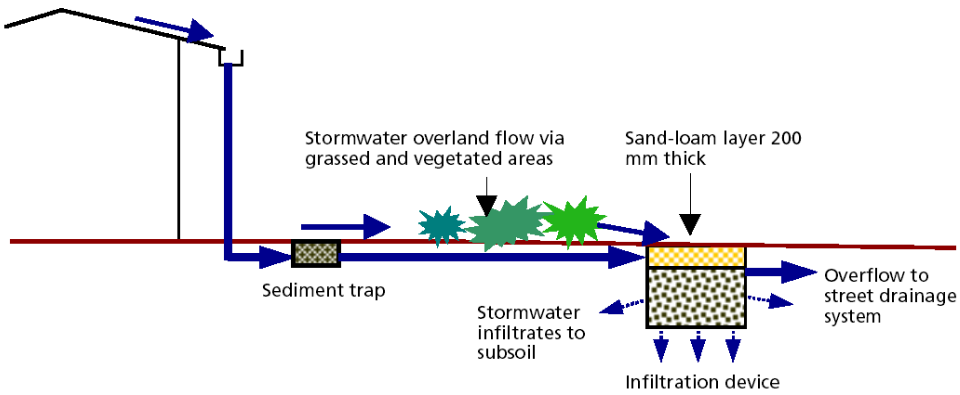


Figure 6.13 Typical Infiltration Strategy

Source: Water Sensitive Urban Design in the Sydney Region Practice Note 5 – Infiltration Devices

The *Development Act 1993* Ministers Specification SA 78AA (Planning SA 2003) contains a variety of considerations that must be adhered to in the design of infiltration systems. These include tables on the required size of infiltration systems and positioning of infiltration systems on a site.

A number of these design considerations are discussed briefly below.

Depth

The *Development Act 1993* Ministers Specification SA78AA (Planning SA 2003) has limited excavation depth for an infiltration system to 1.5 metres due to the restrictions imposed on excavations greater than 1.5 metres by the South Australian Occupational Health, Safety and Welfare Regulations 1995.

A permit is required to construct an infiltration system greater than 2.5 metres under the requirements of the *Natural Resources Management Act 2004*.

Site Setback Distances

In accordance with the *Development Act 1993* Ministers Specification SA 78AA (Planning SA 2003) the use of infiltration systems is restricted to soil types A and S or Class M-D where the characteristic surface movement (or ys value) is equal to or less than 25 millimetres, as defined in the document AS 2870 Residential Slabs and Footings – Construction, and where the following conditions exist:

- The slope of the natural ground does not exceed 1 in 10;
- The depth to rock is 1.2 metres or greater; and
- The groundwater table is permanently below 1.5 metres from the natural ground surface or the final ground surface, whichever is the lowest.

The design of infiltration systems must take into consideration their proximity to existing structures and boundaries. The *Development Act 1993* Ministers Specification SA 78AA (Planning SA 2003) specifies that:

- Retention devices shall be located a minimum of 3 metres from all property boundaries, (excluding front boundaries and/or reserves) and 3 metres from footings of all structures located on the allotment; and
- A minimum clear spacing of 1 metre between the sides of the retention device and any service trench is required.

Further recommendations are provided by Argue (Ed., 2009) on the appropriate setback of infiltration systems with respect to different soil types.

Design Process

The key elements of the design process for infiltration systems are outlined below.

Design Objectives and Targets

The implementation of WSUD in a development seeks to achieve a range of outcomes relating to water quality, hydrology, conservation and amenity.

Each of these outcomes is met by ensuring development complies with the appropriate objectives and targets identified for the site. Before any other activities are undertaken with respect to site planning, the objectives for the infiltration system should be clearly established.

For example, infiltration systems can be designed to achieve a range of objectives, including:

- Minimising runoff volume;
- Preserving pre-development hydrology; and
- Enhancing groundwater recharge.

Selection of Type of Infiltration System

As outlined above, a range of infiltration systems are available. In general, selection of the type of infiltration system is determined by the size of the contributing catchment.

Design Methods

There are two approaches to the design of infiltration systems. These are:

- The design storm method; and
- Design using hydrological effectiveness curves.

Design Storm Method

The design storm method should be applied where an infiltration system is being used for flood mitigation. In this case, the infiltration system may be considered the primary tool for flood mitigation.

A primary consideration in the design process of infiltration systems is the requirements set out in the South Australian *Development Act 1993* Ministers Specification SA 78AA – On-Site Retention of Stormwater (Planning SA 2003).

The design storm method for flood mitigation by infiltration systems is outlined in Section 11.6 of IEAust (2006).

A more comprehensive outline of the design storm method is also available in Argue (Ed., 2009).

Hydrological Effectiveness Curves

The hydrological effectiveness curve approach to design may be applied where the infiltration system is being utilised to promote infiltration only. In this case, the infiltration system must bypass flow in excess of its infiltration capacity to another flood mitigation system. An example of this situation may be in the case of retrofitting existing sites or to address local requirements for on-site retention.

The design methodology using hydrological effectiveness curves is outlined in **Chapter 11** of IEAust (2006).

Construction Process

In accordance with the *Development Act 1993* Ministers Specification SA 78AA (Planning SA 2003) all gutters and pipe work required to direct roof runoff to the infiltration device and pipe work from the infiltration system to the off-site system shall be designed and installed in accordance with AS/NZS 3500.3.2 Plumbing and Drainage – Stormwater Drainage.

It is important to note that blockage of infiltration systems can be an issue where infiltration systems are presented with a high sediment load. As indicated by Argue (Ed., 2009) the performance of infiltration systems applies to 'established residential neighbourhoods'.

Poor on-site management of runoff during the construction phase can lead to complete blockage of infiltration systems. Simple measures, such as scheduling infiltration system construction to the final phase of construction or preventing runoff from entering the system during the construction phase, are recommended.

Maintenance Requirements

Infiltration systems, by their very nature, trap and retain sediment in their structure for the term of their effective life. This characteristic makes them susceptible to clogging, especially in situations where they are exposed to high sediment loading.

Maintenance for infiltration systems is therefore aimed at ensuring the system does not clog with sediments and that an appropriate infiltration rate is maintained and pre-treatment measures are operating properly.

In accordance with the *Development Act 1993* Ministers Specification SA 78AA (Planning SA 2003):

- In addition to the installation of filtration devices to the on-site runoff retention system, retention trenches and wells should be inspected and cleaned on a regular basis; and
- Overflow, discharge or bleed off pipes from roof-mounted appliances such as evaporative air conditioners, hot water services and solar heaters should not discharge onto the catchment area.

Argue (Ed., 2009) recommends regular inspection and corrective maintenance, such as desilting, be undertaken. The issue of their widespread use, according to Argue (Ed., 2009), hinges upon the lifespan which can be expected for installations.

An example Infiltration System Inspection and Maintenance Checklist is provided in **Appendix D**.

Approximate Costs

The construction costs for infiltration systems depend largely on the surface area/width and depth and the volume of excavation required.

Excavation costs would also depend on subsurface ground conditions, with rates varying from $20/cubic metre in light soils to over $50/cubic metre in soft, rippable rock (Upper Parramatta River Catchment Trust, 2004).

The estimated unit rate construction costs for a typical 1 metre wide x 1 metre nominal infiltration trench is summarised in **Table 6.1**.

Table 6.1 Estimated Unit Rate Construction Cost of Infiltration Trench

Works Description	Quantity	Unit	Rate	Cost ($/m)
Excavate trench (1 m x 1.25 m) and stockpile	1.25	m^3/m	20	25
Supply and install geofabric liner	4.0	m^2/m	5	20
Supply and place perforated pipe (100 mm diameter)	1.0	m/m	13	13
Supply and place gravel storage layer	1.0	m^3/m	65	65
Supply and place filter layer (150 mm minimum thick)	0.15	m^3/m	45	7
Supply and place topsoil layer (100 mm minimum thick)	0.1	m^3/m	70	7
Supply and apply grass seed, fertiliser and watering	1.0	m^2/m	1.0	1
TOTAL				138

Source: Upper Parramatta River Catchment Trust (2004)

Maintenance costs will differ depending on the scale of the device. No approximate costs regarding maintenance of infiltration systems are available at present.

6.6 Useful Resources and Further Information

Fact Sheets

www.waterforgood.sa.gov.au

Water For Good fact sheets – Stormwater Use and Wastewater Recycling

www.melbournewater.com.au/content/library/publications/fact_sheets/drainage/how_to_build_a_rain garden.pdf

How to Build a Rain Garden fact sheet

www.brisbane.qld.gov.au/bccwr/lib184/stormwater_factsheet_sml.pdf

Stormwater Garden fact sheet

www.adelaidecitycouncil.com/adccwr/publications/guides_factsheets/fact%20sheet%20-%20rooftop%20gardens.pdf

Adelaide City Council Rooftop Gardens fact sheet

www.wsud.org/downloads/Planning%20Guide%20&%20PN%27s/05-Infiltration.pdf

Water Sensitive Urban Design in the Sydney Region Practice Note 5 – Infiltration Devices

www.brisbane.qld.gov.au/bccwr/lib184/wsud%20practice%20note%2007%20infiltration%20measures.pdf

Practice Note 7 Infiltration Measures, Brisbane City Council

Legislation Information

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

Construction Noise information sheet, EPA

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

Environmental Noise information sheet, EPA

www.epa.sa.gov.au/pdfs/bccop1.pdf

Stormwater Pollution Prevention Code of Practice for the Building and Construction Industry, EPA

http://dataserver.planning.sa.gov.au/publications/654p.pdf

Guide for Applicants, Department of Planning and Local Government web site

http://dataserver.planning.sa.gov.au/publications/948p.pdf

Development Act 1993 Ministers Specification SA 78AA

General Information

www.brisbane.qld.gov.au/documents/Water/stormwaterharvestingguideline.pdf

Stormwater Gardens – Bioretention Basins for Urban Streets, Brisbane City Council

http://greenroofs.wordpress.com/

Green Roofs Australia

www.urbanecology.org.au/christiewalk/roofgarden.html#main

Christie Walk Rooftop Garden

www.landscapesa.com.au

The Landscape Association of South Australia

www.lid-stormwater.net/greenroofs_maintain.htm

Low Impact Development Urban Design Tools – Green Roofs

www.greenroofs.com

Greenroof industry portal

www.edcmag.com/

Environmental Design and Construction

www.fytogreen.com.au/products/roofgarden/index.html

The Fytogreen Roof Garden System

(Websites current at August 2010)

6.7 References

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.

Earth Pledge (2005). *Green Roofs: Ecological Design & Construction*, Schiffer Publishing, **USA**.

Hutchinson, D., Abrams, P., Retzlaff, R., Liptan, T. (2003). *Stormwater Monitoring for Ecoroofs in Portland, Oregon, USA*. Greening Rooftops for Sustainable Communities, Chicago.

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

Mibus, R. (2006). *Green Roofs in the Changing Australian Landscape.* Melbourne.

Planning SA (2003). *On-Site Retention of Stormwater*. Government of South Australia. Adelaide. September. http://dataserver.planning.sa.gov.au/publications/948p.pdf.

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/.

(Websites current at August 2010)

Appendix A
Annual Rainfall in the Greater Adelaide Region

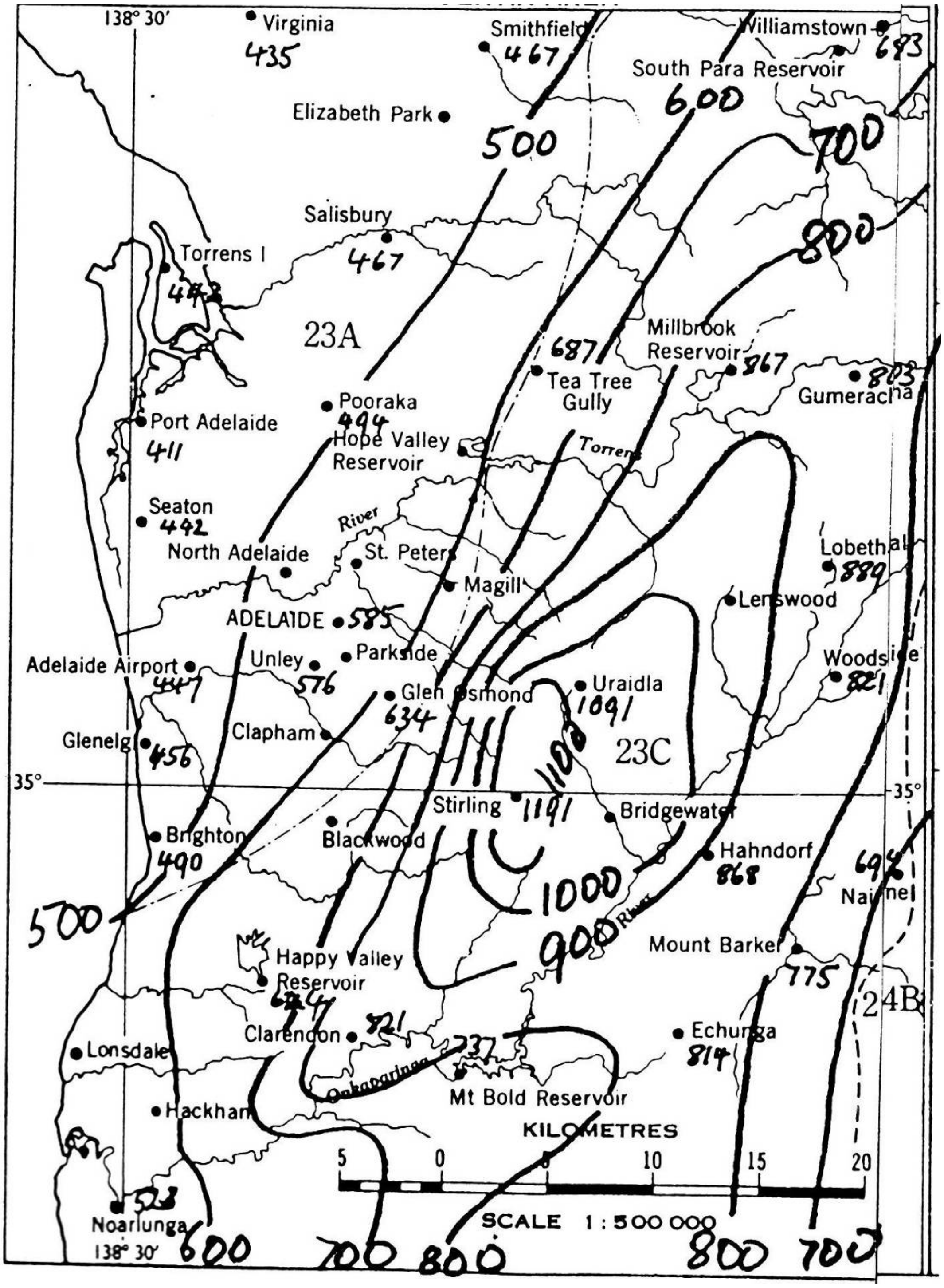
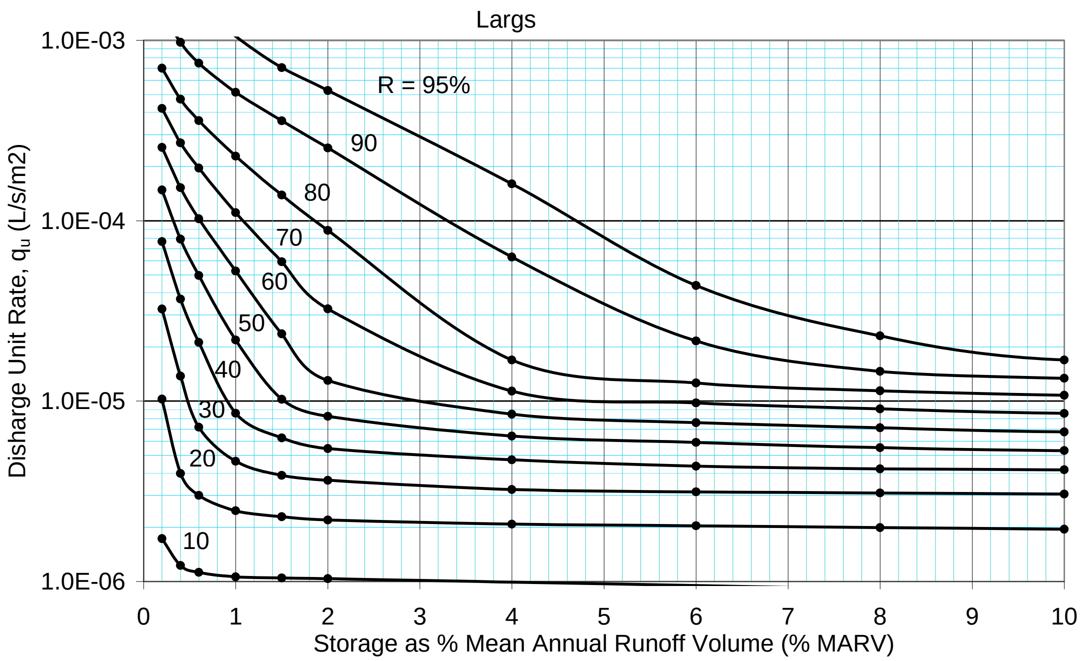


Figure A1 Annual Rainfall in the Greater Adelaide Region

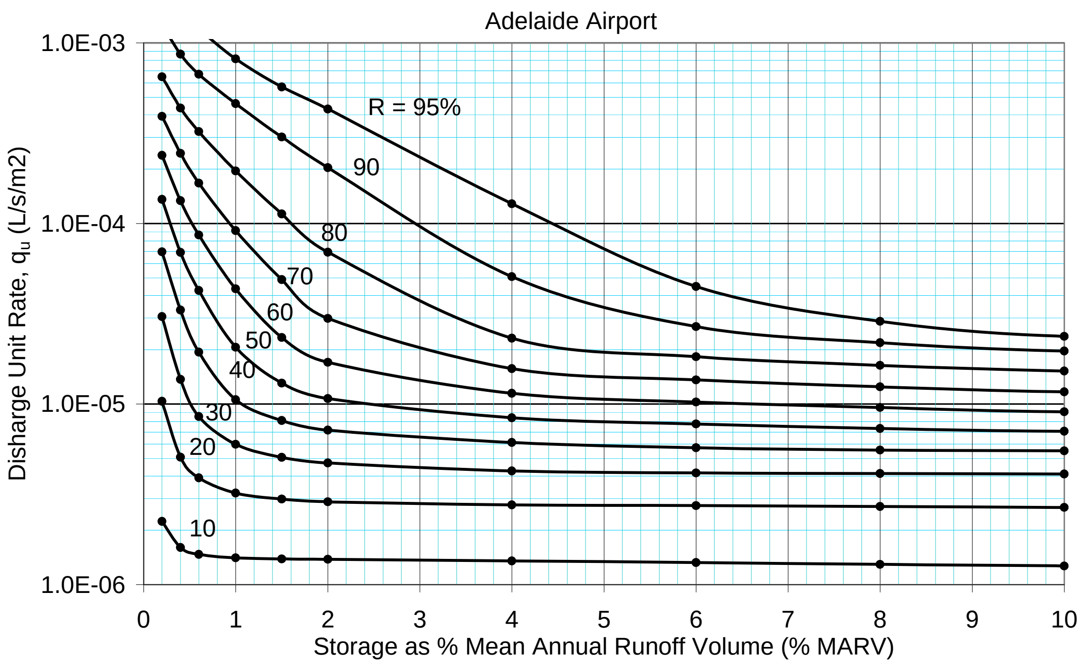
Appendix B

Hydrological Effectiveness Curves for the Greater Adelaide Region

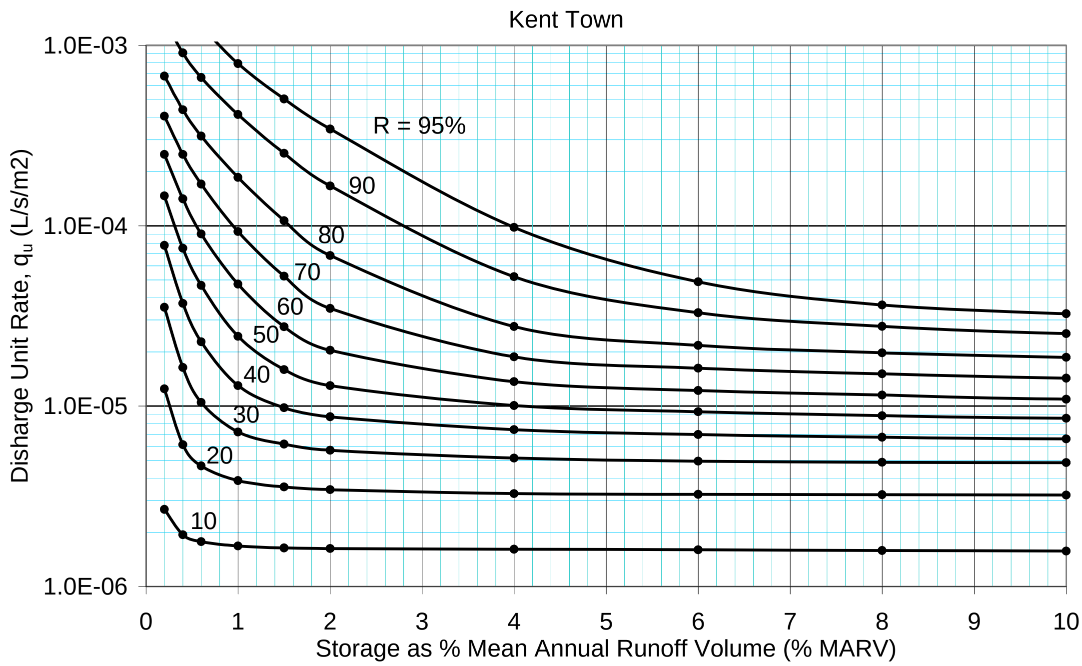
300-400 millimetres per annum



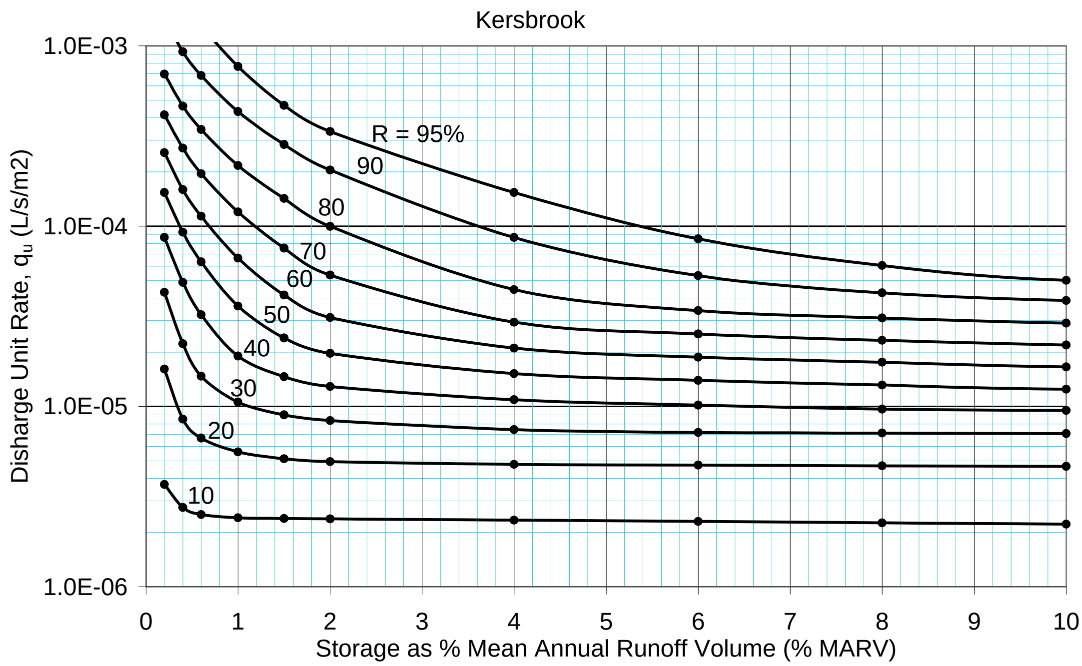
400-500 millimetres per annum



500-600 millimetres per annum



600-800 millimetres per annum



Appendix C

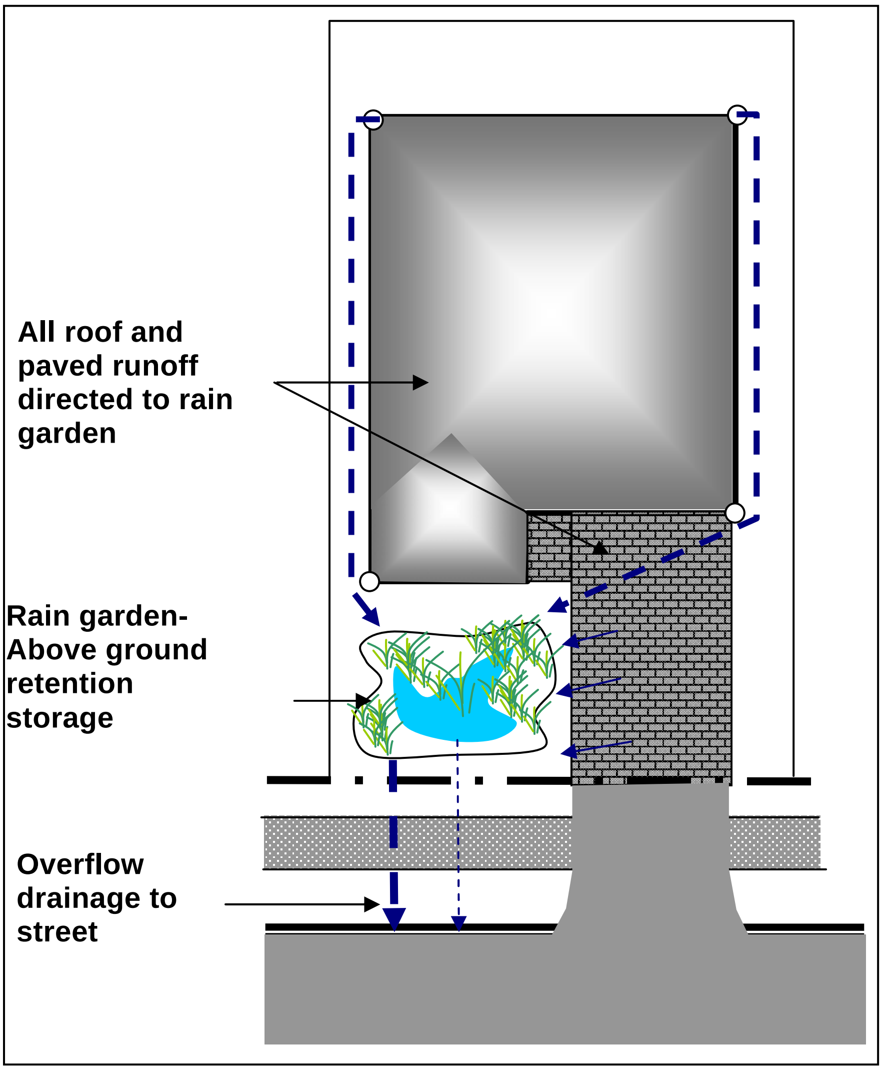
Example of Utilising the Hydrological Effectiveness Curves to Design a Rain Garden

Example: Rain garden ('natural' drainage)

Task:

Determine storage volume of the rain garden needed to manage 95% of the average annual runoff.

If required depth exceeds maximum allowable, determine slow drainage necessary to limit depth to maximum allowable.



Location: Adelaide (see Figure in **Appendix A**).

Average annual rainfall:

X = 545 millimetres/year.

Soil: medium clay, k_h = 1.0×10^{-5} metre/second.

Moderation factor, U = 1.0

Contributing Catchment:

Roof area A_{EIA} = 200 square metres

Paved area A_{EIA} = 30 square metres

Space available for garden = 25 square metres

Storage: Surface ponding e_S = 1.

Hydrological (treatment) effectiveness, R = 95%

Step 1: Determine infiltration rate and unit discharge rate

According to Argue (Ed., 2009) 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' augerhole method.

When the hydraulic conductivity results from the 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 Argue (Ed., 2009):

Clay soils, U = 2.0;

Sandy clay soils, U = 1.0;

Sandy soils, U = 0.5.

Hence,

Infiltration discharge unit rate, q,

$$q = \frac{k_h \times U \times A_{avail}}{A_{EIA}} \text{ L/s/m}^2 \text{ of EIA}$$

$$q = 1.0 \times 10^{-5} \times 25/230$$

$$= 1.1 \times 10^{-6} \text{ L/s/ m}^2$$

Step 2: Determine mean annual runoff volume (MARV)

Locate q on **Figure C1**.

It can be seen that it is not possible to achieve 95% hydrological effectiveness. Maximum possible pond depth above low flow discharge point is 150 millimetres. This translates to a storage of 3 cubic metres.

Mean annual runoff volume (MARV) is (230+25) x 545 mm/yr = 144.0m^3

The storage ratio β (%MARV) is 2.2%

Step 3: Determine unit discharge rate, q

Locate β on Figure C1.

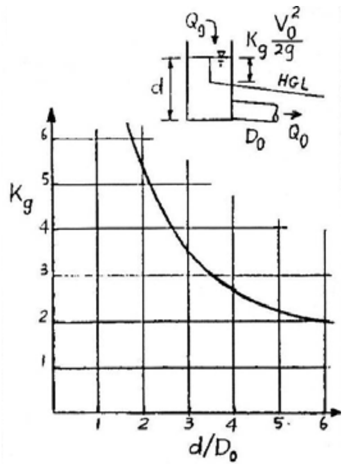
It can be seen that to achieve 95% hydrological effectiveness a unit discharge rate, q = 3.0×10^{-4} L/s/m^2 (EIA) is required, hence a slow release discharge is required.

Step 4: Determine required discharge rate to street drainage

Total discharge is made up of infiltration and piped flow, hence the slow discharge rate required is:

$q_{pipe} = q_{total} - q_{infiltration} = 3.0 \times 10^{-4} - 1.1 \times 10^{-6} = 3.0 \times 10^{-4}$ L/s/m^2 (EIA)

$Q_{pipe} = q_{pipe} \times EIA = 3.0 \times 10^{-4} \times 255 = 0.7$ L/s



Discharge coefficient relationship

Step 5: Determine the pipe size required to discharge 0.7 L/s.

Using the velocity head equation with an average upstream water depth of 100 millimetres above the pipe invert and a pond depth to pipe diameter ratio of 6, an initial discharge coefficient of 2.0 is selected.

$H = k(v^2/2g)$……………….Velocity head equation

$A_{pipe} = Q / (Hx2g/k)^{-0.5} = 0.0007$

Hence diameter of pipe or orifice required d_{pipe} = 30 mm

The pond depth to diameter ratio is 3.3 and from the discharge coefficient graph, k_g should be about approximately 3. Using k = 3, the revised diameter is 33 millimetres.

This is a low flow rate that would provide a residence time (rain garden volume/discharge rate) of more than 10 days. A hose or orifice with a 30 millimetre diameter will provide necessary discharge rate. It will be important to protect the discharge outlet from blockage (e.g. with leaves). This can be achieved by placing coarse gravel around the outlet.

Solution

A rain garden with a surface storage of 3 cubic metres and with a low flow discharge via a garden hose or discharge opening (e.g. orifice) of 33 millimetres diameter will enable greater than 95% of the average annual runoff to be managed.

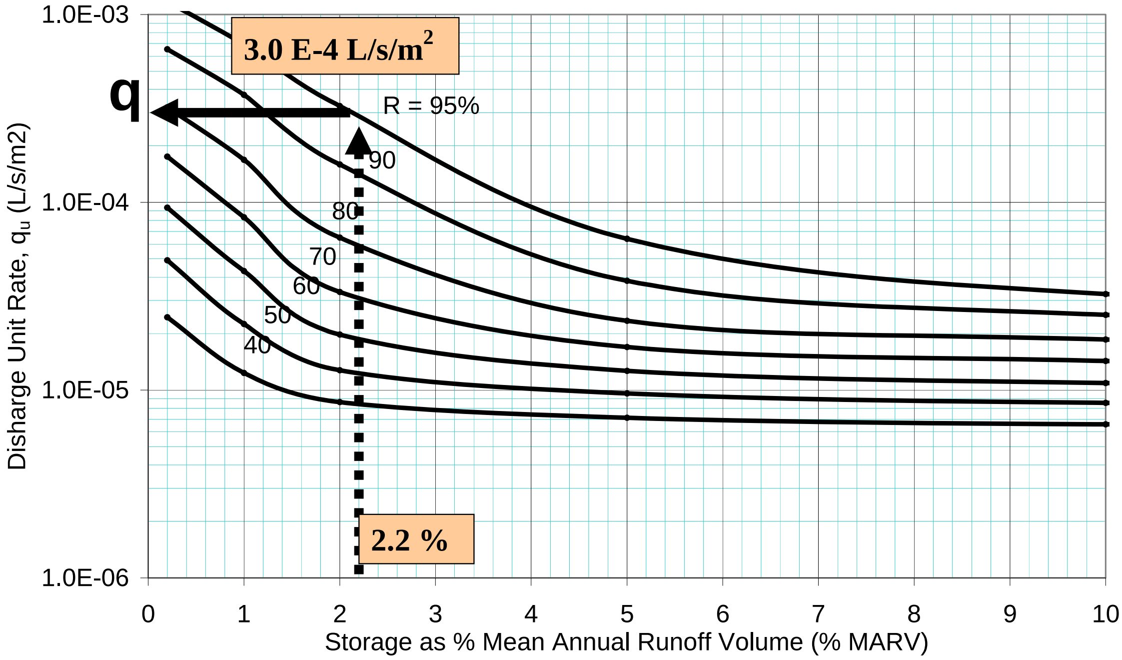


Figure C1 Hydrological Effectiveness Graph, Adelaide (Kent Town)

Appendix D
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.

Rain Gardens, Green Roofs and Infiltration Systems

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 (m^2)	
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)

Infiltration System

Inspection and Maintenance Checklist

Asset ID:		**Date of Visit:**	
Inspection Frequency:		**Time of Visit:**	
Location:			
Description:			
Inspected By:			
Weather Conditions:			

Items Inspected	Checked Y/N	Action Required (Details) Y/N
Debris Cleanout (every 6 months)		
1. Surface clear of debris		
2. Inlet area clear of debris		
3. Overflow clear of debris		
Sediment Traps, Forebays Or Pre-treatment (every 6 months)		
4. Trapping sediment effectively		
5. Facility not more than 50% full of sediment		
Surface (every 6 months)		
6. Evidence of surface erosion / scouring		
Surface Vegetation (if applicable) (every 6 months)		
7. Vegetation condition		
8. Vegetation trimming / maintenance		
9. Weed infestation		

Items Inspected	Checked Y/N	Action Required (Details) Y/N
Dewatering (every 3 to 6 months)		
10. Dewatering between storms		
11. Top aggregate layer / geofabric need replacing		
12. Entire aggregate requires replacing		
Outlet / Overflow (every 12 months)		
13. Outlet / overflow condition		
14. Evidence of erosion downstream		
Comments on Inspection		
Actions Required		
1.		
2.		
3.		
4.		
5.		