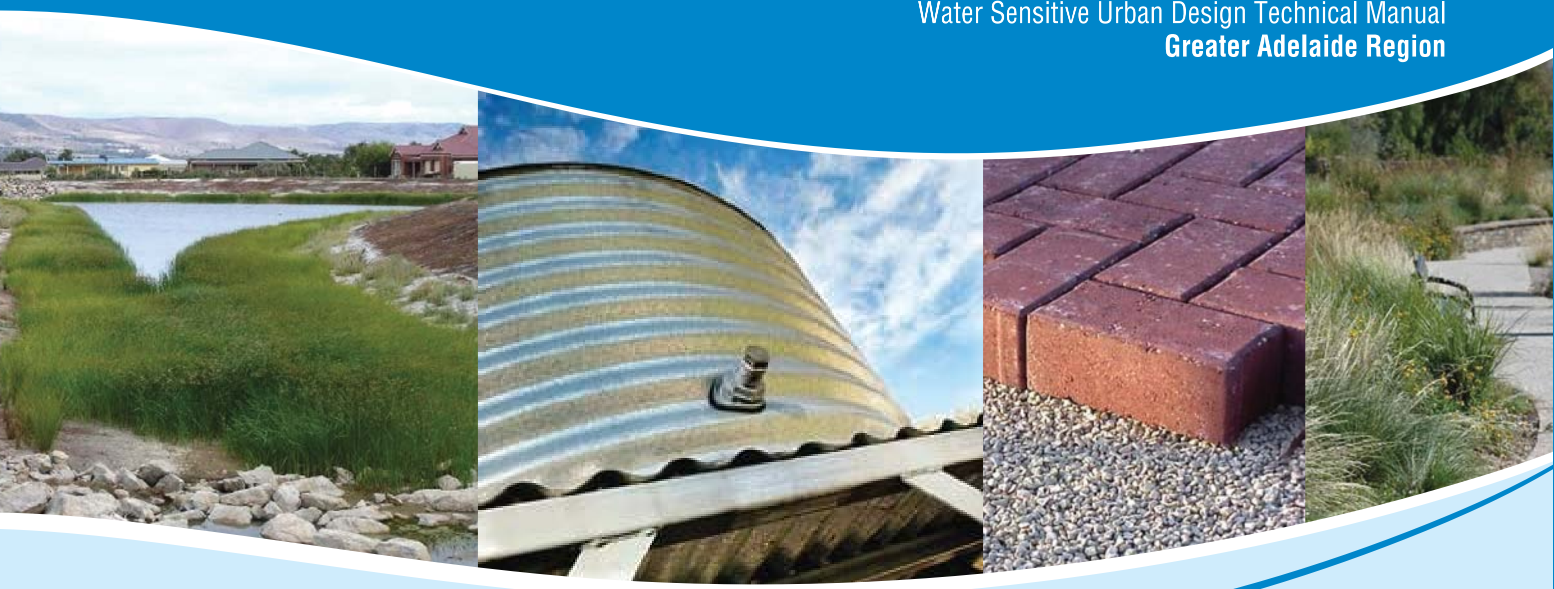
December 2010

Chapter 10

Bioretention Systems for Streetscapes

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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10.1 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). Bioretention systems are one of those measures.

This chapter of the Technical Manual for the Greater Adelaide Region is aimed at providing an overview of bioretention systems and how they can be utilised to assist in achieving the objectives and targets of Water Sensitive Urban Design (WSUD).

Description

Broadly speaking, bioretention systems are WSUD measures that involve some treatment by vegetation prior to the filtration of runoff through a prescribed media. Following treatment, water may be infiltrated to the subsoil or collected in subsoil pipes for retention, further treatment or disposal. A bioretention system is most commonly implemented as a bioretention swale or bioretention basin.

Bioretention Swales

Bioretention swales (or biofiltration trenches) are bioretention systems that are located within the base of a swale (see **Figure 10.1**). They may involve a continuous component of bioretention along the length of the swale, or a portion of bioretention prior to the outlet of the swale.

Figure 10.2 shows a bioretention swale at the Mawson Lakes Campus of the University of South Australia. This swale connects an upstream permeable pavement to a downstream wetland. The wetland provides a storage volume where treated stormwater harvested by both the permeable pavement system and bioretention swale can be deposited. This water is later retrieved from the wetland and is used to irrigate the plants in the bioretention swale during the extended interstorm dry periods that are commonly experienced in Adelaide. This bioretention swale is not connected to the municipal water supply system and has been designed to be solely reliant on the stormwater harvested by the WSUD system itself.

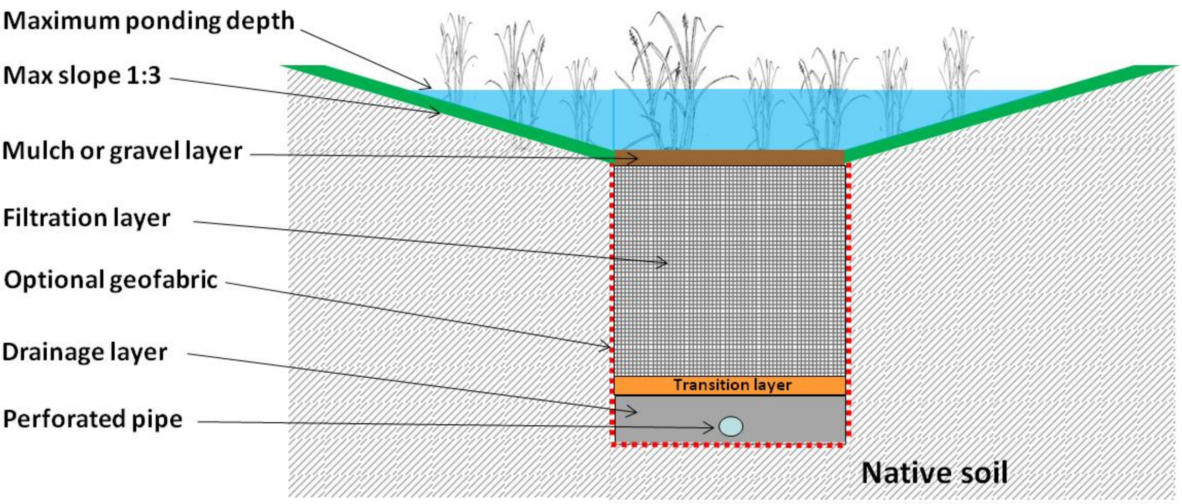


Figure 10.1 Cross Section through a Bioretention Swale

Figure 10.2 Bioretention Swale at Mawson Lakes Campus, University of South Australia (the swale also collects runoff filtered through a permeable paving system located in the carpark at the top of the picture)

Bioretention Basins

Bioretention basins provide flow control and water quality treatment functions. A bioretention basin is characterised by the ability to detain runoff in a depression storage (or ponded area) above the bioretention system (see **Figure 10.3**).

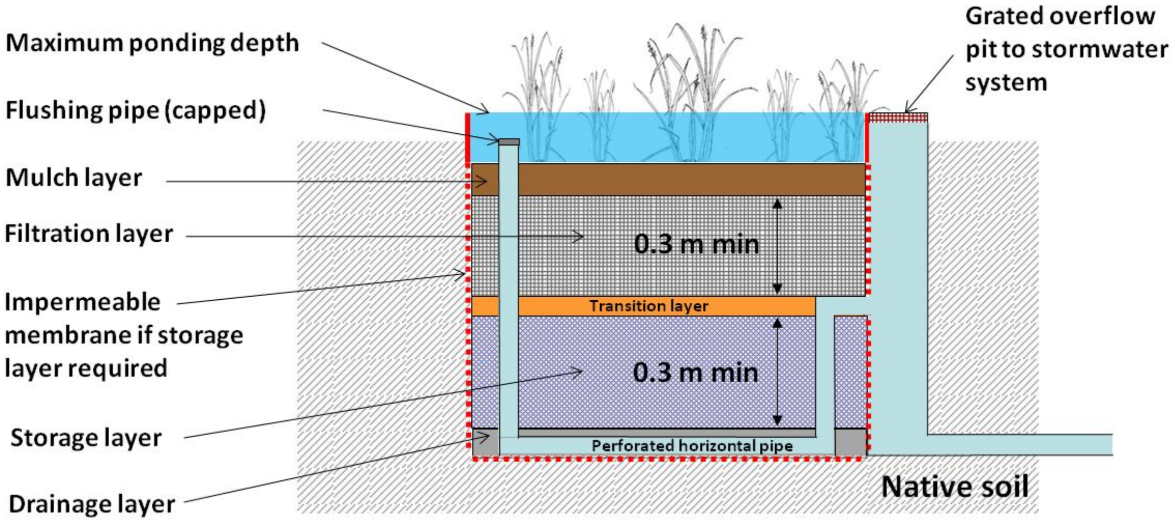


Figure 10.3 Bioretention Basin (incorporating Underground Storage Layer)

Because of the long dry summer periods that are commonly experienced in Adelaide, it is generally required to incorporate addition water storage below bioretention basins. **Figure 10.3** shows how such a storage layer can be readily incorporated into a streetscale bioretention basin.

Purpose

The main functions of bioretention systems are water quality control, water conservation and increased amenity. They provide limited flood control, mainly because of their small volume.

Bioretention systems can provide both runoff treatment and conveyance functions including:

- The removal of coarse to medium sediments and associated pollutants (such as nutrients, free oils/grease and metals) by filtration through surface vegetation and groundcover (during conveyance, especially in a swale);
- The removal of fine particulates and associated contaminants by infiltration through the underlying filter media layers. This provides treatment by filtration, extended detention treatment and some biological uptake;
- A disconnection of impervious areas from downstream waterways and protection to natural receiving waterways from frequent storm events by delaying runoff peaks, providing retention capacity and a reduction in peak flow velocities. Swale components can be designed to convey runoff as part of a minor and/or major drainage system;
- Potential aesthetic benefits due to surface vegetation being able to be incorporated into streetscape and general landscape features; and

- The provision of quality habitat conditions for wildlife, contributing positively to biodiversity enhancement in urban areas.

Bioretention systems are generally not intended to be 'infiltration' systems – the design does not typically include runoff exfiltrating from the bioretention filter media to the in-situ soil environment. Rather, the most common application of bioretention systems is to recover the percolated runoff at the base of the filter media using perforated underdrains for subsequent discharge to receiving waterways. The water may also be directed to storage for potential reuse. Bioretention systems are therefore well suited to a wide range of soil conditions including areas affected by soil salinity and saline groundwater.

However, in some circumstances where the in-situ soils allow, and there is a design intention to recharge local groundwater, it is possible to permit the percolated runoff to infiltrate from the filter media to the underlying in-situ soils (after considering the in-situ soil properties).

The low void ratios of soils used in these systems (a typical value is 0.2) and their limited infiltration rates (typically 150 to 350 mm/h) 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 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 bioretention surface, velocities should be kept preferably below 0.5 m/s to avoid scour.

Scale and Application

Bioretention systems are best suited to small (i.e. less than 5 ha) catchments in residential, commercial and industrial developments with high percentages of impervious areas. Bioretention systems can be appropriate in areas where runoff is insufficient or unreliable, evaporation rates are too high, or soils are too pervious to sustain the use of constructed wetlands.

Bioretention systems can be installed at various scales, for example, in local streets or on large highways.

They can be located within:

- Parkland areas;
- Carparks;
- Along roadway corridors within footpaths (i.e. road verges); and
- Centre medians.

Performance Efficiency

Bioretention systems can improve the water quality of runoff through several treatment mechanisms. These include, but are not restricted to:

- Coarse filtration through surface vegetation;
- Sedimentation occurring while detained water infiltrates;
- Biological uptake of organic and inorganic pollutants by vegetation;
- Biological uptake of pollutants by subsoil biota;
- Sorption of pollutants to filter media; and
- Filtration through filter media.

Correctly designed and maintained bioretention systems have been shown to retain pollutants in numerous studies. Pollutant removal efficiencies of bioretention systems that are available in the literature are summarised in **Table 10.1**.

Table 10.1 Bioretention System Performance Efficiencies

Gross Pollutants*	Coarse Sediment*	Medium Sediment	Fine Sediment	Free Oil and Grease	Nutrients**	Metals
-	80-100%	50-80%	30-50%	30-50%	30-50%	30-50%

**Assumes gross pollutant pre-treatment provided*
***Bound to sediments and some dissolved nutrients*

Source: Upper Parramatta River Catchment Trust (2004)

Figure 10.4 Bioretention Swale as a Median Strip

Source: Courtesy of University of South Australia

10.2 Legislative Requirements and Approvals

Before undertaking a concept design of a bioretention system it is important to check whether there are any planning regulations, building regulations or local health requirements that apply to bioretention systems in your area.

The legislation which is most applicable to the design and installation of bioretention systems in the Greater Adelaide Region includes, but may not be restricted to:

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

Development Act 1993

Installing bioretention systems will generally be part of a larger development (for new developments), however whenever bioretention systems 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 bioretention systems on site.

Environment Protection Act 1993

Any development, including the installation of bioretention systems, 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 planning on installing bioretention systems are discussed below.

Water Quality

Water quality in South Australia is protected using 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 potential for environmental impact during construction. Guidance can be found in the *EPA Handbook for Pollution Avoidance on Building Sites* (see **Section 10.8**).

Measures also need to be taken to ensure that erosion and subsequent water quality impacts do not result after the installation of a bioretention system.

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* (see **Section 10.8**).

Noise

The issue of noise has the potential to cause nuisance during any construction works of bioretention systems. The noise level at the nearest sensitive receiver should be at least 5 dB(A) below the Environment Protection (Industrial Noise) Policy 1994 allowable noise level when measured and adjusted in accordance with that policy.

Reference should be made to the EPA Information Sheets on Construction Noise and Environmental Noise respectively to assist in complying with this policy (see **Section 10.8**).

Air Quality

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

Figure 10.5 Bioretention Swale at Mawson Lakes Campus at the University of South Australia

Source: Courtesy of University of South Australia

10.3 Design Considerations

As with other WSUD measures based on soil filtration of runoff, bioretention systems require due consideration of the site conditions. In the situation where water may permeate through the base of the bioretention media, the potential for contamination of the receiving soil and groundwater environment should be considered.

Design issues that need to be considered for the bioretention component of these systems, before detailed design, are addressed in this section.

The design considerations and design process for the swale component (where relevant) should be taken into account in conjunction with the information contained in this section (see **Chapter 11**).

These design considerations include:

- Landscape design;
- Vegetation types;
- Hydraulic design;
- Use as an infiltration system;
- Prevention of infiltration;
- Bioretention filter media;
- Traffic controls;
- Services; and
- Limitations.

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

Landscape Design

Bioretention systems are a combined solution that can involve treatment by extended detention and some biological uptake through the planted bioretention component. While the landscaping for either the swale (or basin) and bioretention parts is essentially similar to the treatments for the stand-alone components, consideration of the landscape interface between the vegetated swale (or basin) and bioretention is important.

As bioretention swales have the potential to perform a valuable landscape function it is important that the design is sensitive to landscape requirements. For example, landscape design of bioretention swales along the road edge can assist in defining the boundary of road or street corridors as well as providing landscape character and amenity.

Objectives

Landscape design for bioretention systems has some key objectives. These include:

- Ensuring surface treatments and planting designs address runoff quality objectives by incorporating appropriate plant species for treatment of runoff (particularly those with a biologically active root zone) while enhancing the overall natural landscape;
- Integrating planning and design of bioretention systems within their surrounding built and landscape environments;
- Incorporating Crime Prevention Through Environmental Design (CPTED) principles and road, driveway and footpath visibility safety standards;
- Creating landscape amenity opportunities that enhance community areas. This involves improvements to visual aesthetics, provision of shade and screening, view framing, and way finding; and
- Consideration of urban ecological and biodiversity value and promotion of the potential of the systems to serve as wildlife corridors.

Design

Bioretention systems can provide a relatively maintenance free finish if the planting is designed well. Key landscape considerations when designing bioretention systems are:

- Type and size of inorganic mulch;
- Density and types of plantings;
- Locations of trees and shrubs;
- Type of garden (mowing) edges to turf areas that allows unimpeded movement of runoff;
- Overall alignment of swale or basin within the streetscape;
- Timing of the planting of the vegetation;
- Provision of access for maintenance of the vegetation; and
- Water requirements, particularly considering the current drought conditions and watering restrictions.

Vegetation Types

The vegetation in a bioretention system enhances the treatment process of runoff and helps maintain the permeability of the filter media. The bioretention filter media is usually the plant growing material, which may comprise a mixture of soil, gravel, sand and/or peat.

Vegetation that grows in the filter media enhances its function by trapping and absorbing physical pollutants and preventing erosion of the filter medium. It also improves the performance of the system by continuously breaking up the soil through plant growth to prevent clogging of the system and providing biofilms on plant roots that pollutants can absorb or otherwise adhere to. While the type of vegetation varies depending on landscape requirements and climate, the filtration process generally improves with denser and higher vegetation.

Figure 10.6 Bioretention Swale Integrated into the Design of an Urban Park

Source: Courtesy of University of South Australia

The vegetation is required to:

- Cover the whole width of the system and bioretention filter media surface to encourage the trapping of suspended solids;
- Be capable of withstanding design flows; and
- Be of sufficient density to prevent the development of preferred flow paths and scour of deposited sediments.

The following points provide general information on the selection of plants for a bioretention system:

- The preferred vegetation for the bioretention component of bioretention swales is sedges and tufted grasses (with potential occasional tree plantings) that do not require mowing. Repeated mowing over a bioretention swale can result in long-term compaction of the filter media and reduce its treatment performance. The use of turf is not encouraged;
- Drought tolerant plant species with spreading growth forms are preferable to clumping growth form plant species as they provide improved water quality performance and reduce the potential for scouring;
- Perennials with deep fibrous root systems provide enhanced infiltration performance over annuals with shallow root systems;

- Avoid invasive plant species that will smother the surface and eliminate other plant types in the bioretention system;
- The more dense and tall the vegetation planted in the bioretention filter media, the better the treatment provided, especially during extended detention. Taller vegetation has better interaction with temporarily stored runoff during ponding. Dense vegetation reduces flow velocity. Both enhance sedimentation of suspended sediments and associated pollutants;
- Densely vegetated bioretention systems can become features of an urban landscape and, once established, require minimal maintenance and are hardy enough to withstand large flows.

Plant selection should also be based on pollutant removal performance relative to locality. In general, for biodiversity enhancement purposes in urban green spaces, it is important to provide a range of shade, canopy heights and variety of habitat elements. This is best achieved using a range of vegetation types rather than a single plant species.

Figure 10.7 Bioretention Basin at Palmer Street, Aldinga Beach

Source: Courtesy of City of Onkaparinga

Hydraulic Design

A key hydraulic design consideration for bioretention systems is the delivery of runoff onto the surface of a bioretention filter media. Flow must not scour the bioretention surface and needs to be uniformly distributed over the full surface area of the filter media.

It is therefore important to ensure that velocities in the bioretention systems are kept low. Flow velocities should be preferably below 0.5 m/s in a minor flood event and not more than 1.0 m/s for a major flood event (IEAust 2006).

Reduced flow velocities can also be achieved by creating shallow temporary ponding (i.e. extended detention) over the surface of the bioretention filter media through the use of raised field inlet pits. This may also increase the overall volume of runoff that can be treated by the bioretention filter media.

With regards to a bioretention swale, typically, when used as a continuous trench along the full length of a swale, the desirable maximum longitudinal grade of the swale is 4%. For other applications, the desirable grade of the bioretention zone is either horizontal or as close as possible to horizontal to encourage uniform distribution of runoff over the full surface area of bioretention filter media and allowing temporary storage of flows for treatment before bypass occurs.

In steeper areas, where a swale is utilised, check dams may be required along the swale to reduce flow velocities discharged onto the bioretention filter media.

A check dam is used to prevent scouring and slow down water. It is a simple structure or mechanism that can consist of anything from an area on an existing slope where water can temporarily pond before proceeding further, to a small weir device that ponds water and spreads its flow.

It should be noted that check dams may inhibit ease of maintenance i.e. they can be a hindrance to mowing.

Use as an Infiltration System

Bioretention systems can be designed to either preclude or promote exfiltration of runoff to surrounding in-situ soils. In the latter case, the bioretention system acts as an enhanced infiltration system. The incorporation of an infiltration component in the design is dependent on the runoff management objectives of the project.

Before using a bioretention system as an enhanced infiltration system in the design, the following should be considered:

- Site terrain;
- Hydraulic conductivity of the in-situ soil;
- Soil salinity;
- Groundwater; and
- Building setback.

For further guidance on infiltration systems, please refer to **Chapter 6** (Rain Gardens, Green Roofs and Infiltration Systems) of the WSUD Technical Documents for the Greater Adelaide Region.

Preventing Infiltration

In some cases it may be necessary to take measures to ensure water does not enter the soil beneath a bioretention system. The amount of water lost from bioretention systems to surrounding in-situ soils is largely dependent on the characteristics of the local soils and the saturated hydraulic conductivity of the filter media.

If the selected saturated hydraulic conductivity of the filter media is one to two orders of magnitude (i.e. 10 to 100 times) greater than that of the local soils, then the preferred flow path for runoff will be vertically through the filter media and into underdrains at the base of the filter media. However, if the selected saturated hydraulic conductivity of the bioretention filter media is less than 10 times that of the local soils, it may be necessary to provide an impermeable liner. Flexible membranes or a concrete casting are commonly used. This is particularly applicable for surrounding soils that are very sensitive to any exfiltration (e.g. sodic soils and reactive clays in close proximity to significant structures such as roads).

The greatest pathway of exfiltration is through the base of a bioretention system. The gravity and the difference in hydraulic conductivity between the filter media and the local soil would typically act to minimise exfiltration through the walls of the system. If lining is required, it is likely that only the base and the sides of the drainage layer will need to be lined.

It may be necessary to provide an impermeable liner to the sides of the filter media to prevent horizontal exfiltration and subsequent short-circuiting of the treatment provided by the bioretention system.

Bioretention Filter Media

Selection of an appropriate bioretention filter media is a key design step involving consideration of three inter-related factors:

- The saturated hydraulic conductivity required to optimise the treatment performance of the bioretention component given site constraints on available filter media area;
- The depth of extended detention provided above the filter media; and
- The suitability as a growing media to support vegetation growth (i.e. retaining sufficient soil moisture and organic content).

The maximum saturated hydraulic conductivity should not exceed 500 millimetres/hour (and should preferably be in the range 150-350 millimetres/hour) in order to sustain vegetation growth.

During the conceptual design stage, the optimal combination of filter media, saturated hydraulic conductivity and extended detention depth can be established using a continuous simulation modelling approach (e.g. MUSIC, see **Section 10.5** and **Chapter 15**). Any adjustment of these design parameters during the detailed design stage will require the continuous simulation modelling to be re-run to assess the potential impact on the overall treatment performance.

A bioretention filter media can consist of up to three layers:

- The filter media required for treatment of runoff;
- The drainage layer required to convey treated water from the base of the filter media into perforated underdrains; and
- The drainage layer, which surrounds perforated underdrains and can be either coarse sand (1 mm) or fine gravel (2-5 millimetres).

If fine gravel is used for the drainage layer, it is advisable to install a transition layer of sand or a geotextile fabric (with a mesh size equivalent to the sand size) to prevent migration of the base filter media into the drainage layer and into the perforated underdrains.

To prevent the mixing of filter media into indiscreet layers, reference must be made to soil filter criteria.

Traffic Controls

Another design consideration is keeping traffic and building material deliveries off bioretention systems, particularly during the construction phase of a development. Consequences of vehicle movement and parking on bioretention systems include:

- The compaction of the surface and damage to vegetation beyond its ability to regenerate naturally;
- Reduction in infiltration into the filter media and early bypass, and reduced treatment.;
- Ruts which can create preferential flow paths that diminish the water quality treatment performance as well as creating depressions that can retain water and potentially become mosquito breeding sites.

A staged construction and establishment method affords protection to the subsurface elements of a bioretention system from runoff with a heavy sediment load during the construction and building phases.

To prevent vehicles driving on bioretention systems and inadvertent placement of building materials on the surface of a bioretention system, it is necessary to consider appropriate traffic control solutions as part of the system design. These can include:

- Temporary fencing of the system during the construction and building phases;
- Signage erected to alert builders and contractors of the purpose and function of the system;

- Planting the interface to the road carriageway with dense vegetation that will discourage the movement of vehicles onto the system once the construction phase has been completed;
- Providing physical barriers such as kerb and channel (with breaks to allow distributed water entry to the system) or bollards and/or street tree planting.

Kerb and channel should be used at all corners, intersections, cul-de-sac heads and at traffic calming devices to ensure the correct driving path is taken. For all of these applications, the kerb and channel should extend 5 metres beyond tangent points. The transition from barrier or lay back type kerb to flush kerbs and vice versa is to be done in a way that avoids creation of low points that cause ponding onto the road pavement.

Where bollards/road edge guide posts are used, consideration should be given to intermixing mature tree plantings with the bollards to break the visual monotony created by a continuous row of bollards.

The construction stage is also discussed in **Section 10.6**.

Services

Bioretention systems located within road verges must consider the standard location for services within the verge and ensure access for maintenance of services. It is generally acceptable to have water and sewer services located beneath the batters of the system. Surface finishing from water and sewerage services should not be located within the designated water flow area of the system.

Essentially, the design must ensure:

- No services are located below the system invert;
- Enough space is provided to access services for maintenance without affecting the system invert; and
- There is no compromise to the width provided in the road verge for services.

Limitations

Site limitations that may preclude the use of bioretention systems include:

- High headloss due to vertical filtration;
- A requirement for adequate sunlight for vegetation growth;
- The potential for filter clogging if upstream pre-treatment of litter and coarse sediments does not occur; and
- The need for regular inspections and maintenance required during the vegetation establishment period.

10.4 Design Process

Overview

The design process for bioretention systems consists of a number of steps including:

- Assess site suitability;
- Determine the design objectives and targets;
- Consult with council and other relevant authorities;
- Select the type of bioretention system;
- Design of the swale components (where applicable);
- Determine the design flows;
- Size the bioretention system;
- Determine the design of kerb inlets;
- Design the bioretention system components;
- Check the design objectives;
- Specify plant species and planting densities; and
- Develop a maintenance schedule.

A number of elements of the design process are discussed briefly below. Further details regarding the detailed design process are contained in **Appendix A** and a range of checklists is provided in **Appendix B**.

A general design process for WSUD measures is contained in **Chapter 3** of the Technical Manual.

Site Suitability

Careful selection of placement of the bioretention system is important and is not only a matter of appearance. An assessment of site conditions is necessary to identify what measures, if any, are required to ensure that the bioretention system will perform for the entire design lifetime.

Careful site analysis and integrated design with engineers, landscape architects and urban designers will ensure that a bioretention system meets functional and aesthetic outcomes.

Assessment of the groundwater should be undertaken to define existing water quality, potential uses (both current and future) and suitability for recharge.

Bioretention systems show a decline in permeability with exposure to sediment and organic matter through their lifetime. To ensure adequate performance of these systems, it may be necessary to design the system to utilise only a portion of their 'as new' capacity.

Figure 10.8 Bioretention Bed, Star of Greece Car Park

Source: Courtesy of the City of Onkaparinga

Bioretention systems should be located in areas to 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).

Design Objectives and Targets

The design objectives and targets will vary from one location to another and will depend on the characteristics of the site, form of the development 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 authority (i.e. council) prior to commencing the engineering design.

The design approach for bioretention systems is generally based on achieving the following broad objectives:

- For infiltration 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; and
- 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.

The design approach for bioretention systems is also based on achieving the following objectives:

- Providing an adequate hydraulic residence (filtration) time through the system to enable sediments and attached pollutants to be retained; and
- Selection of suitable planting filter media to provide required hydraulic residence (filtration) time through the system.

Bioretention 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;
- Enhancing groundwater recharge or preserving pre-development groundwater recharge; and
- Removing some sediment and attached pollutants by passing runoff through an underlying media layer.

Consult with Council and Other Relevant Authorities

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

- The bioretention system will not result in water damage to existing services or structures;
- Access to existing services is not compromised for maintenance and other works; and
- No conflicts arise between the location of services and WSUD devices.

The council will also be able to advise whether development approval is required and whether any other approving authorities should be consulted.

Asset ownership and transfer, including long-term maintenance requirements, should also be discussed at this initial meeting.

Select Type of Bioretention System

Selection of the type of bioretention system for a particular application must occur as part of the conceptual design process by assessing the site conditions, runoff management requirements, desired amenity and existing built environment/local character requirements against the functional types of bioretention systems. The two types of bioretention systems, bioretention basins and bioretention swales, are discussed in **Section 10.1**.

The selection of a bioretention system will depend on the nature of the available space. A bioretention basin will be used in cases where water is to be detained and treated in a single location. Surface runoff will be directed to the basin where it will pond, before passing through the bioretention media.

A bioretention swale is used in cases where periods of 'ponding' would be unacceptable, but where long stretches of land are available – road medians and carpark areas are prime examples of the type of applications. In a bioretention swale, runoff should be conveyed away from the area of the catchment where ponding will cause a hazard to the public.

Size Bioretention System

Factors to consider when sizing a bioretention system are:

- The allowable width, given the proposed road reserve and/or urban layout;
- The need to allow for services;
- Delivery of flows into the system (e.g. cover requirements for pipes or kerb details);
- The vegetation height;
- The longitudinal slope;
- The maximum side slopes and base width; and
- The provision of crossings (elevated or at grade).

Depending on which of the above factors are fixed, the other variables can be adjusted to derive the optimal dimensions for the given site conditions.

Design of Kerb Inlets

Kerb inlet design on a bioretention system is an important consideration, especially in the case of a bioretention basin. It is important to allow water to enter the bioretention system in a manner that will not scour the surface of the bioretention system and not compromise the safety of road users and pedestrians.

The design of kerb inlets for bioretention swales and basins is discussed below.

Bioretention Swale

In most instances, it is necessary to have some form of kerb along the length of a bioretention swale to delineate the adjacent roadway and/or parking area from the bioretention system. This is an important consideration to control traffic as traffic can damage both vegetation and the effective infiltration rate of bioretention soil media by compaction.

Kerbs with gaps tend to be the most common way of delineating trafficable and non-trafficable areas when applying a bioretention swale. Although there is no strict guideline for the design of kerbing with gaps, it is recommended that 0.5 m gaps or 'cutaways' be used between reformed kerb sections approximately 1-2 metres in length. Some practitioners have undertaken more decorative kerbing styles, as shown in Error! Reference source not found..

Figure 10.9 Kerb Inlet Design for a Bioretention Swale

Source: Courtesy of University of South Australia

Bioretention Basin

Advice from current practitioners is a valuable resource with respect to kerb inlet design for bioretention basins. The council of the City of Kingston, Victoria, prefers the use of depressed kerb inlet pits fitted with rock and concrete 'dispersion trays'. This kerb inlet design is also prescribed by Brisbane City Council documentation.

The following images illustrate possible inlet designs. Note that the rock and concrete structure is offset from the road itself where it may present a hazard to cycle traffic at the road edge.

Figure 10.10 Kerb Inlet Design for Bioretention Basin

Source: Courtesy of the University of South Australia

Figure 10.11 Alternative Pit Inlet Design for Depressed Bioretention Basin at Quinliven Road, Aldinga

Source: Courtesy of Martin Ely

Design of Bioretention System Components

Bioretention systems must be designed as two separate entities. The first step in any decision making process is to determine whether the primary purpose of the bioretention system will be:

- Conveyance; or
- Infiltration

Bioretention systems designed for *conveyance* should be designed with reference to the requirements for a **vegetated swale** in **Appendix A**. Note that these systems are not typically incorporating the 'retention' component as a primary aim in their design.

Bioretention systems that are designed for the *detention and subsequent filtration and collection or infiltration* of runoff should be designed in accordance with the design procedure for a **bioretention basin** in **Appendix A**.

Bioretention systems that are designed to achieve both *conveyance* and *infiltration* (for example, where a swale includes a significant area of infiltration) should be designed with reference to the design procedure for a **bioretention swale** in **Appendix A**.

Check the Design Objectives

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

Specify Plant Species

Refer to **Sections 10.3** and **10.8** for advice on selecting suitable plant species for bioretention systems in the Greater Adelaide Region. Consultation with landscape architects is recommended when selecting vegetation to ensure that the treatment system complements the landscape design of the area. Consideration also needs to be given to how maintenance is to be performed on the bioretention system (e.g. how and where access is provided, where litter and sediment will collect etc.) and the water requirements of the species given the current water restrictions.

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

Maintenance Plan

A specific maintenance plan and schedule should be developed for the bioretention system.

If the bioretention system is not maintained frequently, the entire filter media may need to be replaced due to clogging of the media material with fine particles. This can result in frequent maintenance being more cost effective in the long-term.

Bioretention swales have a flood conveyance role that needs to be maintained to ensure adequate flood protection for local properties.

Vegetation plays a key role in maintaining the permeability of the soil media of the bioretention system and a strong healthy growth of vegetation is critical to its performance.

The most intensive period of maintenance is during the plant establishment period (over the first two years) when weed removal and replanting may be required. The following critical items should be monitored every one to three months during this period:

- Ponding, clogging and blockage of the filter media;
- Establishment of desired vegetation/plants and density; and
- Blockage of the outlet from the bioretention system.

It is also the time when large loads of sediments could impact on plant growth, particularly in developing catchments with an inadequate level of erosion and sediment control.

Typical maintenance of bioretention swale elements will involve:

- Routine inspection of the swale profile to identify any areas of obvious increased sediment deposition, scouring of the swale invert from storm flows, rill erosion of the swale batters from lateral inflows, damage to the swale profile from vehicles and clogging of the bioretention trench (evident by a 'boggy' swale invert);
- Routine inspection of inlet points (if the swale does not have distributed inflows), surcharge pits and field inlet pits to identify any areas of scour, litter build up and blockages;
- Removal of sediment where it is impeding the conveyance of the swale and/or smothering the swale vegetation and, if necessary, reprofiling of the swale and revegetating to original design specification;
- Repairing any damage to the swale profile resulting from scour, rill erosion or vehicle damage;
- Tilling of the bioretention trench surface if there is evidence of clogging;
- Clearing of blockages to inlets or outlets;
- Inspections of inlet and outlet points to ensure structural integrity;
- Regular watering/irrigation of vegetation until plants are established and actively growing (for the swale component), in accordance with water restrictions;
- Mowing of turf or slashing of vegetation (if required) to preserve the optimal design height for the vegetation (although heavy machinery for mowing/slashing should be avoided);
- Removal and management of invasive weeds;
- Removal of plants that have died and replacement with plants of equivalent size and species as detailed in the plant schedule;
- Pruning to remove diseased vegetation material and to stimulate new growth;
- Litter and debris removal; and
- Vegetation pest monitoring and control.

Resetting (i.e. complete reconstruction) of bioretention elements will be required if the available flow area of the overlying swale is reduced by 25% (due to accumulation of sediment) or if the bioretention trench fails to drain adequately after tilling of the surface and other maintenance/corrective actions are taken. Inspections are also recommended following large storm events to check for scour.

All maintenance activities should be specified in a maintenance plan (and associated maintenance inspection forms) to be developed as part of the design procedure. Maintenance personnel and asset managers will use this plan to ensure the bioretention system continues to function as designed. The maintenance plan and forms should address the following:

- Inspection frequency;
- Maintenance frequency;
- Data collection/storage requirements (i.e. during inspections);
- Detailed cleanout procedures (main element of the plan) including:
  - Equipment needs
  - Maintenance techniques
  - Occupational health and safety
- Public safety;
- Environmental management considerations;
- Disposal requirements (of material removed);
- Access issues;
- Stakeholder notification requirements;
- Data collection requirements (if any); and
- Design details.

An example Operation and Maintenance Checklist is included in **Appendix B**.

10.5 Design Tools

Various design tools are available for the concept and detailed design of bioretention systems as detailed in **Chapter 15** and listed below:

Water treatment:

- Music; and
- SWMM.

Runoff conveyance for surface flow management:

- SWMM; and
- DRAINS.

10.6 Construction Process

There are numerous challenges that must be appropriately considered to ensure successful construction and establishment of bioretention systems. These include:

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

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

Further details are contained in **Section 10.3**.

Figure 10.12 Preliminary Stages of Construction of a Bioretention Swale at Mawson Lakes Campus at the University of South Australia

Source: Courtesy of the University of South Australia

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

10.7 Approximate Costs

The construction cost for bioretention systems depend on the surface area/width, depth, type of surface vegetation and the inlet/outlet structures. The estimated unit rate construction costs for a 3 m wide x 1 m nominal deep, online bioretention trench is summarised in **Table 10.2** below.

The unit cost for a 3 m wide x 1 m nominal deep bioretention trench is approximately $410/metre by length, or approximately $137/metre of trench surface area. However, costs , will tend to differ as a result of the type of surface landscaping, and the sand and gravel type and source location.

Long-term maintenance costs for bioretention systems are largely unknown but are likely to be dominated by activities similar to those of swales, i.e. $1.5 to $2.5/square metre for landscaped systems (Upper Parramatta River Catchment Trust, 2004).

Table 10.2 Estimated Costs for a Biofiltration Trench

Work Description	Quantity	Unit	Rate	Cost ($/m)
Excavated trench (3m x1.5m) and stockpile	4.8	m^3/m	20	96
Supply and install geofabric liner	6.2	m^2/m	5	31
Supply and place under-drainage pipe (100 diameter)	1.0	m/m	13	13
Supply and place gravel drainage layer	0.7	m^3/m	45	31.5
Supply and place filter media (sand/gravel soil)	0.5	m^3/m	55	165
Supply and place graded filter sand layer (150 nom thick)	3.0	m^3/m	45	22.5
Supply and place topsoil layer (100 nom thick)	0.5	m^3/m	7.0	21
Supply established vegetation ground cover including planting, fertiliser and watering	3.0	m^2/m	10	30
TOTAL				410

Source: Upper Parramatta River Catchment Trust (2004)

Note: Based on 2003 financial data

10.8 Useful Resources and Further Information

Fact Sheets

www.melbourne.vic.gov.au/Environment/SavingWater/Documents/WSUD_part3.pdf

Bioretention Systems fact sheet – Water Sensitive Urban Design Guidelines Fact Sheets, City of Melbourne

www.brisbane.qld.gov.au/bccwr/lib184/wsud%20practice%20note%2003%20bioretention%20swales.pdf

WSUD Practice Note 3: Bioretention Swales, Brisbane City Council

www.brisbane.qld.gov.au/bccwr/lib184/wsud%20practice%20note%2005%20bioretention%20basins.pdf

WSUD Practice Note 5: Bioretention Basins, Brisbane City Council

Regulations and Legislation

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

EPA Information – Environmental Noise

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

EPA Information – Construction Noise

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

EPA Industrial Noise Policy

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

EPA Handbook for Pollution Avoidance on Building Sites

Design Information

www.wsud.org/tools-resources/

Water Sensitive Urban Design Technical Information for Western Sydney

http://waterbydesign.com.au/TechGuide/

Water Sensitive Urban Design Technical Design Guidelines for South East Queensland

www.brisbane.qld.gov.au/BCC:STANDARD:369665131:pc=PC_1898

Water Sensitive Urban Design Engineering Guidelines: Stormwater

(Websites current at August 2010)

10.9 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.

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

IEAust (1987). *Australian Rainfall and Runoff - A Guide to Flood Estimation*. Barton, ACT. **www.ncwe.org.au/arq/**.

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

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

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
Bioretention System Design Process

Bioretention System Design Process Details

The design process for a bioretention system will depend on whether the system functions as a bioretention swale or bioretention basin, as these systems are described in Section 10.1. Essentially, a bioretention swale will require two separate design steps to consider the swale and the basin components. The design process for a bioretention basin system only requires consideration for the effectiveness of the basin.

Design for Vegetated Swales

The following design procedure for a swale has been adapted from IEAust (2006).

Determine the Dimensions

Dimensions of a swale can be determined using Manning's equation, below. This allows the flow rate and flood levels within the swale to be determined for variations in the dimensions of the swale.

$$Q = \frac{AR^{\frac{2}{3}}S^{\frac{1}{2}}}{n}$$

$$\text{Where } R = \frac{A}{P}$$

Where:	Q	=	Flow in the swale (m^3/s)
	A	=	Cross sectional area of the swale (m^2)
	P	=	Hydraulic perimeter (m)
	R	=	Hydraulic radius (m)
	S	=	Channel slope (m/m)
	n	=	Roughness coefficient (or Manning's n) ($m^{-1}/^{3}s$)

Flow in the swale should be determined according to the:

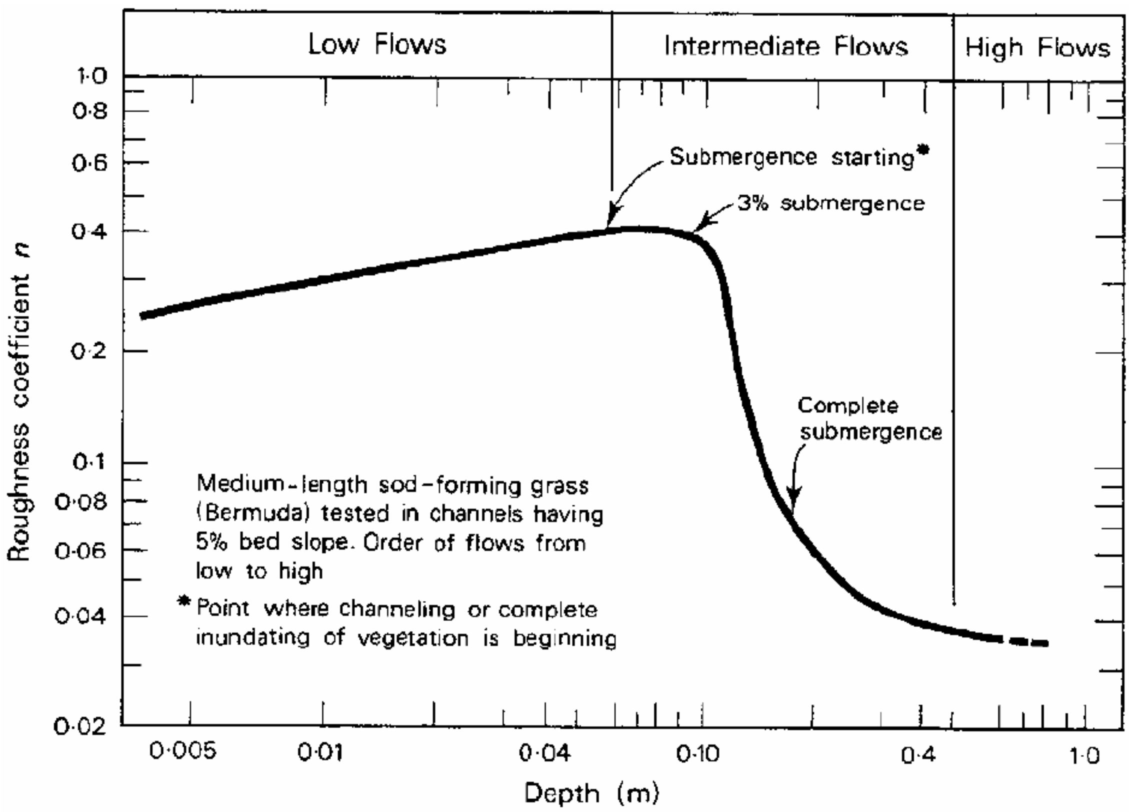
- Design 1 year ARI peak discharge; and
- Design 100 year ARI peak discharge.

Cross sectional area and hydraulic radius are variables that the designer must determine (according to the area available for the swale). This can then be calculated and trialled to determine its fitness for use.

Slope of the swale will usually be dependent on the adjacent infrastructure (road, rail, pathway etc). Slope is recommended to be between 2 and 4%. Lower slopes will require underdrains to prevent ponding, while larger slopes will require flow spreading to ensure uniform flow occurs across the swale (IEAust 2006). High slopes may also require velocity reduction measures such as check dams.

Manning's *n* is a critical variable in the Manning equation that relates to the roughness of the channel. It varies with flow depth, channel dimensions and vegetation type. For constructed swale systems, values are recommended to be between 0.15 and 0.3 for flow depths shallower than the vegetation height (preferable for treatment) and significantly lower for flows with greater depth than the vegetation (e.g. 0.03 for flow depth more than twice the vegetation height).

It is considered reasonable for Manning's *n* to have a maximum value at the vegetation height and then to sharply reduce as depths increase. The graph below is adapted from Barling and Moore (1993) and provides a useful reference for determining the Manning's *n* of a channel using the depth of flow.



Flow Velocity in the Swale

As a final check to ensure the integrity of the swale as a water quality treatment measure, flow velocity should be checked to determine that:

- 1 year ARI peak velocity does not exceed 0.5 metres per second; and
- 100 year ARI peak velocity does not exceed 1 metre per second.

Design of Bioretention Basins

A bioretention basin can be designed in much the same manner as a rain garden by using pre-determined hydrological effectiveness curves (see **Chapter 6**). It should be noted that an alternative, concise design procedure is provided in the document *Australian Runoff Quality* (IEAust 2006).

The performance of storage systems can be described in terms of hydrological effectiveness. Hydrological effectiveness takes account of EIA (equivalent impervious area), historical rainfall series, storage, infiltration (outflow), bypass and overflow characteristics, as illustrated in **Figure A1**.

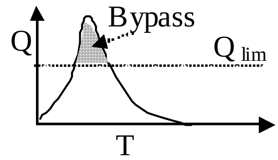
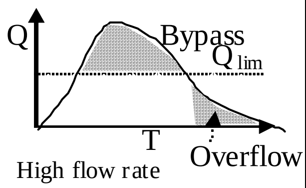
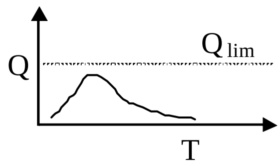
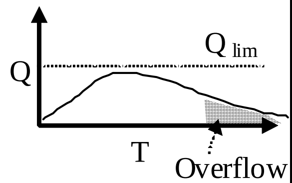
Runoff event type	**Loss mode :** bypass and/or overflow
 High flow rate Low runoff volume	**BYPASS and NO OVERFLOW***
 High flow rate High runoff volume	**BYPASS and OVERFLOW ****
 Low flow rate Low runoff volume	**NO BYPASS and NO OVERFLOW ***
 Low flow rate High runoff volume	**NO BYPASS and** *OVERFLOW***

Figure A1 Hydrological Event Processes

Hydrological effectiveness, R, is the ratio:

$$R = \frac{\text{Unshaded area in hydrographs}}{\text{Area under each hydrograph expressed as a percentage}}$$

Note: hydrological effectiveness is identical to the term retention efficiency, R used in Argue (Ed., 2009).

The equivalent impervious area, A_{EIA} is estimated by an adjusted runoff coefficient that is significantly less than that used in flood control design. The reason for this is the assessment needs to focus on the regular runoff events that usually flow through the bioretention system as a result of "normal" rainfall events rather than flood flows. Recordings indicate that these regular events have greater (relative) losses than a flood flow and hence the runoff coefficient needs to be less when assessing these smaller more regular events. A_{EIA} should therefore be calculated for use in the hydrological effectiveness graphs applying a factor of 0.83 to the conventional C10 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).

A set of hydrological effectiveness curves has been generated for the Greater Adelaide Region and this is presented in **Appendix B**. The curves allow the user to assess the approximate performance of basic systems such as rain gardens.

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

- Equivalent impervious catchment area, $A_{EIA,}$ is determined incorporating an appropriate volumetric runoff coefficient. Typically, A_{EIA} includes those areas which are connected to the bioretention system;
- 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 bioretention swale is contained in the design example below.

Design of Bioretention Swales

The design of bioretention swales must incorporate the design aspects of both vegetated swales for the conveyance component of the bioretention swale, and the storage/discharge requirements of the basin component of the bioretention swale. An example calculation is included below to familiarise the reader with the design of bioretention swales.

Example: Design for a Bioretention Swale

The following example is adapted in part from IEAust (2006).

Task

Determine characteristics of a 100 m length trapezoidal channel needed to manage stormwater from a road catchment with the following characteristics:

- The channel is to have a bioretention system capable of filtering, by infiltration, 95% of the average annual runoff;
- The swale is vegetated up to a height of 0.3 m;
- The hydraulic conductivity of the bioretention media is equal to 50 mm/hr;
- An underlying pipe system is to collect water from the base of the bioretention system. Infiltration is to be discouraged on this site;
- The bioretention system is located in Adelaide, near the city centre, with an average annual rainfall of 545 mm/yr.;
- Soil is a prescribed sandy loam, k_h = 50 mm/hr, with a moderation factor, U = 1.0. The moderation factor is a factor introduced by Argue (Ed., 2009).

  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 (Argue, 2004):

  Clay soils - U = 2.0

  Sandy clay soils - U = 1.0

  Sandy soils - U = 0.5

  For more information refer to Section 11.3.2 of Argue (Ed., 2009).
- Contributing catchment includes
  - Roof area A_{EIA} = 2000 m^2
  - Paved area A_{EIA} = 1400 m^2
- Storage is to be considered only as surface ponding, where porosity (e_S) = 1.
- Length of swale = 100 m
- Maximum width of swale = 6 m
- Average depth of bioretention component of swale is equal to 0.52 m

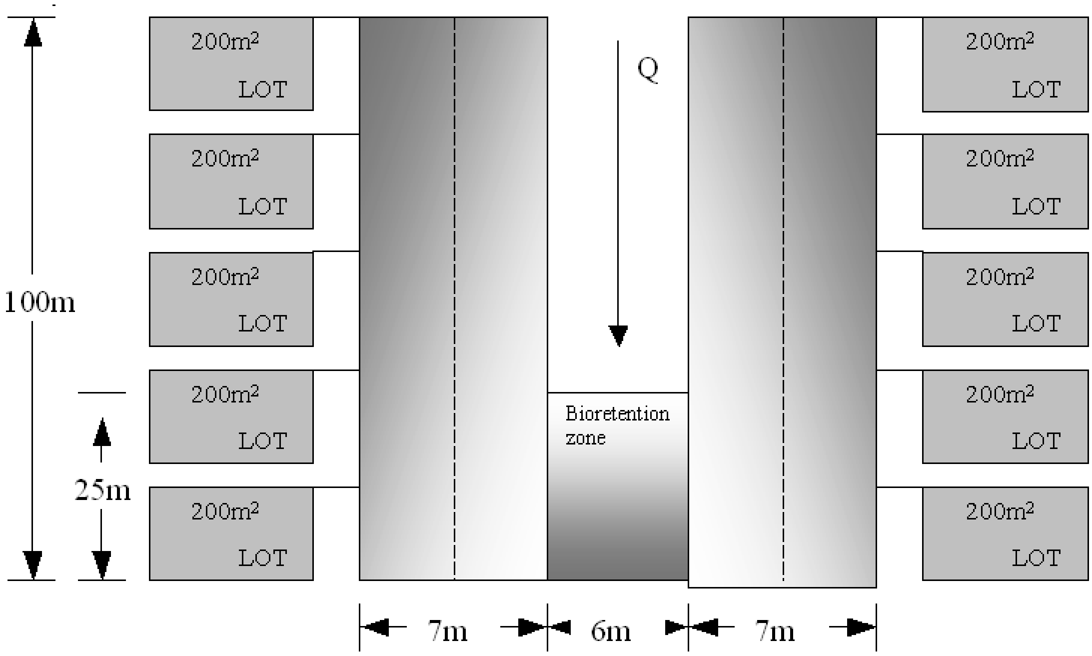


Figure A2 The Bioretention Swale Plan (not to scale)

Determine the Swale Dimensions

For the swale component, trial a trapezoidal channel of base width 2 m and side slopes 1(v):3(h). A slope of 2% will be used as the initial slope calculation. Assume that the annual peak discharge from the catchment is 0.3 m^3/s, and the 100 year ARI peak discharge is equal to 1.2 m^3/s. The procedures for determining these peak discharge figures are found in the document *Australian Rainfall and Runoff* (IEAust 1987). A Manning's n value of 0.2 is adopted for these calculations.

1 year ARI flow condition:

Trial y = 0.2m; A = 0.52 m^2; P = 3.26m

Q = 0.14 m^3/s

Trial y = 0.3m; A = 0.87 m^2; P = 3.90m

Q = 0.30 m^3/s ~ 1 year ARI peak flow

Where y = trial flow depth

100 year ARI flow condition:

Trial y = 0.5 m; A = 1.75 m²; P = 5.16 m

Q = 0.80 m³/s

Trial y = 0.60 m; A = 2.28 m²; P = 5.79 m

Q = 1.15 m³/s

Trial y = 0.65 m; A = 2.57 m²; P = 6.11 m

Q = 1.35 m³/s ~ 100 year ARI peak flow

Check Flow Velocities

1 year ARI event; v = 0.30/0.87 = 0.34 m/s

< 0.5 m/s, OK

100 year ARI event; v = 1.35/2.57 = 0.52 m/s

<1 m/s, OK

Therefore, a channel should be designed with a base width of 2 m, minimum depth 0.65 m, side slopes 1(v):3(h), and vegetation height roughly equivalent to 0.3 m.

Note that the swale has been designed for the entire 100 m length. In some cases, it may be necessary to design a swale in sections, with intermediate overflow zones.

Design of Bioretention Basin Component

The bioretention basin is located in the lower half of the swale.

Determine infiltration rate and unit discharge rate.

Moderated hydraulic conductivity:

The design infiltration media is characterised with the following hydraulic conductivity:

$$
\begin{aligned}
k_h &= 50 \text{ mm/hr} \times U \\
&= 50/3600 \text{ m/s} \times U \\
&= (5 \times 10^{-2}) \times U \\
&= 5.5 \times 10^{-2} \times 1.0 \\
&= 5.5 \times 10^{-2} \text{ m/s}
\end{aligned}
$$

Infiltration discharge unit rate, q,

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

A_{EIA} = (6 x 50) m² + (6 x 50) m² + (10 x 200) m² + (2 x 100 x 7) m²

= 4000 m²

A_{avail} = 2m x 25m

= 50 m²

q = 5.5 × 10⁻² × 1.0 x 50 /4000

= 6.9 × 10⁻⁴ L/s/ m²

Determine Mean Annual Runoff Volume (MARV)

Locate q on **Figure A3:**

The value of q corresponds to a % mean annual rainfall volume (MARV) value equal to 1.1%. Therefore, the storage volume of the bioretention component of the swale must be equal to 1.1% of the MARV.

Mean annual runoff volume (MARV) is 545mm/yr

= 0.545 x 4000m²

= 2180 m³

Therefore, the storage required to treat 95% of runoff must be equal to *at least* 24.0 m³. Using geometry, the volume of the storage, including swale channel, is equal to

21.1 m³ and hence the hydrological efficiency is lower than 95% with the first trial design.

There are several ways to increase the hydrological effectiveness, such as using soil with a higher hydraulic conductivity rate, extending the length of the bioretention zone (with check dams, if necessary) or deepening the invert to increase the storage. To increase the storage of the bioretention system in this example, an extra 0.15 m³ per linear metre will be added over the length of the 25 m bioretention system.

This yields a storage volume of 24.9 m³, which is adequate for ensuring 95% of stormwater runoff passes through the bioretention system.

When using the hydrological effectiveness approach it is important to ensure that the unit discharge rate ‘q’ refers to the lowest flow capacity in the bioretention system, i.e. either at the surface or at the subsurface outlet.

In cases where the subsurface outlet discharge rate is less the surface infiltration rate, the total storage volume may include the voids space in the bioretention soil media.

Design of Base Pipe

The next step requires one to calculate the nature of the pipe collecting water from the base of the infiltration system. It is assumed that an insignificant amount will infiltrate to the in-situ soil for this step. The required flow rate within the subsoil pipe is:

q_{pipe} = 6.9×10^{-4} L/s/ m² x (EIA)

Q_{pipe} = 6.9×10^{-4} L/s/ m² x 4000

= 2.76 L/s

Water will exit the system in the sub-base pipe via perforations in the pipe(s). The pipe size required to discharge from such a pipe is determined using the sharp edged orifice equation:

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

Where:
- Q_{perf} = Flow through perforations, m³/s
- B = Blockage factor, usually 0.5
- C_d = Orifice discharge coefficient – use 0.61 for a sharp edge orifice
- A = Total area of orifice (m²)
- g = Acceleration due to gravity
- h = head above the perforated pipe

The number and size of perforations in the pipe must be found. These can be acquired from the pipe manufacturer and used to estimate the maximum flow rate into the pipes assuming a maximum value of head (depth from the top of the pipe to the surface of the bioretention system, plus any further storage depth).

The average *vertical* depth of the bioretention system over the 25 m length is:

Depth (d) ~ 0.52 m.

Here it is assumed that there is a commonly available slotted pipe in the base of the system with the following characteristics:

- The pipe has a clear opening 2100 mm²/m;
- Slot width is equal to 1.5 mm;
- Slot length is equal to 7.5 mm;
- Number of rows – 6;
- Diameter of pipe – 100 mm.

Number of slots per metre = 2100/(1.5 x 7.5)

= 186.7

Using the orifice flow equation:

Q_{pipe} = (0.5)(0.61)(0.0075x0.0015)x(2x9.81x0.52) $^{1/2}$x186.7 $m^3/s/m$

= 2.04 x 10^{-3} $m^3/s/m$

= 2.04 x 10^{-3} (25)

= 5.1 x 10^{-2} m^3/s

= 51 L/s

Therefore, the sub-base pipe is adequate for the system. If there was any discrepancy, additional pipe(s) would be placed to increase the flow capacity in the base of the system.

Solution

According to the design calculations, a swale channel is to be designed and constructed with a height of 0.65 m, with an extra depth of 0.075 m over the last 25 m of the swale, over the top of the bioretention section, to achieve the requirements stormwater detention and treatment.

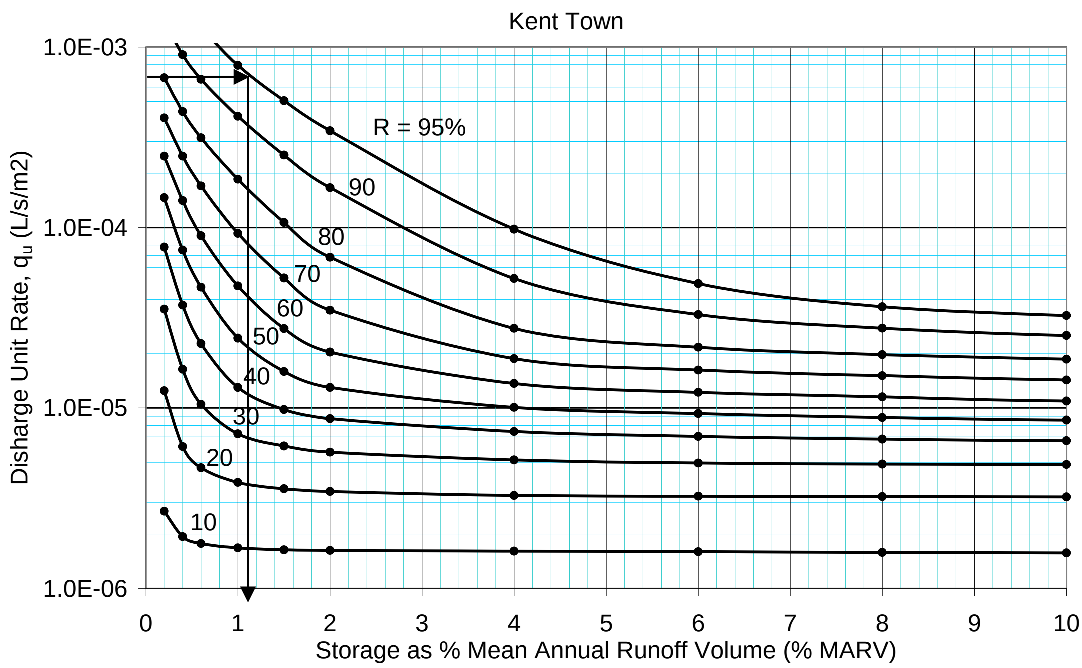


Figure A3 Hydrological Effectiveness Graph, Adelaide (Kent Town)

Appendix B
Checklists

Bioretention Swale

Design Calculation Summary

Calculation Task	Outcome	Units
Catchment Characteristics		
1. Catchment area		ha
2. Catchment land use (i.e. residential, commercial etc)		
Conceptual Design		
3. Bioretention area		m^2
4. Filter media saturated hydraulic conductivity		mm/hr
5. Extended detention depth		mm
Confirm Concept Design		
6. Bioretention area required to achieve water quality objectives		m^2
7. TSS removal (forecast)		%
8. TPP removal (forecast)		%
9. TN removal (forecast)		%
Estimate Design Flows for Swale Component (where applicable)		
10. Time of concentration		minutes
11. Identify rainfall intensities		
12. $I_{1\ year\ ARI}$		mm/hr
13. $I_{100\ year\ ARI}$		mm/hr
Design Runoff Coefficient		
14. $C_{1\ year\ ARI}$		
15. $C_{100\ year\ ARI}$		
Peak Design Flows		
16. One year ARI		m^3/s

Calculation Task	Outcome	Units
17. 100 year ARI		m^3/s
Dimension of Swale Component (where required)		
18. Swale width and side slopes		
19. Base width		m
20, Side slopes		
21. Longitudinal slope		%
22. Vegetation height		mm
23. Maximum length of swale		m
24. Manning's *n*		
25. Swale capacity		
Design Inflow Systems to Swale and Bioretention Components		
26. Swale kerb type		
27. Adequate erosion and scour protection (where required)		
Design of Bioretention Component		
28. Filter media hydraulic conductivity		mm/hr
29. Extended detention depth		
30. Filter media depth		
31. Drainage layer media (sand or fine screenings)		
32. Drainage layer depth		
33. Transition layer		
34. Transition layer depth		
Surrounding Soil for Infiltration Applications		
35. Hydraulic conductivity		m/s
36. Soil moderation factor		

Calculation Task	Outcome	Units
Hydrological Effectiveness		
37. Ave. annual rainfall		mm/yr
Underdrain Design and Capacity Checks		
38. Flow capacity of filter media (maximum infiltration rate)		m^3/s
39. Perforations inflow check		
40. Pipe diameter		mm
41. Number of pipes		
42. Capacity of perforations		m^3/s
Check Pipe > Filter Media Flow Capacity		
43. Perforated pipe capacity		
44. Pipe capacity		m^3/s
Check Pipe Capacity > Filter Media Capacity		
45. Check requirement for impermeable lining		
46. Soil hydraulic conductivity		mm/hr
47. Filter media hydraulic conductivity		mm/hr
48. More than 10 times higher than in-situ soils		
49. Verify design		
50. Velocity for 2-10 year ARI flows (<0.5m/s)		m/s
51. Velocity for 100 year ARI flows (<2 m/s)		m/s
52. Velocity x depth for 100 year ARI (<0.4 m^2)		m^2/s
53. Treatment performance consistent with Step 1		
54. Size overflow pits		
55. System to convey minor floods		L x W

Bioretention Swale

Design Assessment Checklist

Asset ID:		
Bioretention Location:		
Hydraulics:	Minor flood (m^3/s):	
	Major flood (m^3/s):	
Area:	Catchment area (ha):	
	Bioretention area (m^2):	

Concept Design	**Y/N**
1. Treatment performance verified	
2. Service location checked or appropriate allocation provided	
Swale Component (where applicable)	**Y/N**
3. Longitudinal slope of invert >1% and <4 %	
4. Manning's *n*; selected appropriate for proposed vegetation type	
5. Overall flow conveyance width does not impact on traffic requirements	
6. Overflow pits provided where flow capacity exceeded	
7. Energy dissipation provided at inlet points to the swale	
8. Velocities within bioretention cells will not cause scour	
9. Set down of a least 60 mm below kerb invert to top of vegetation incorporated	
Bioretention Component	**Y/N**
10. Design documents bioretention area and extended detention depth as defined by treatment performance requirements (i.e. MUSIC modelling performed is consistent with final design). Area approximately 1-3% of catchment. Extended detention depth up to 0.3m	
11. Overflow pit crest set at top of extended detention	
12. Maximum ponding depth and velocity will not impact on public safety (V x D < 0.4)	
13. Bioretention media specification includes details of filter media, drainage layer and transition layer (if required)	
14. Design saturated hydraulic conductivity included in specification	

15. Transition layer provided where drainage layer consists of gravel (rather than coarse sand)	
16. Perforated pipe capacity > infiltration capacity of filter media	
17. Selected filter media hydraulic conductivity > 10 x hydraulic conductivity of surrounding soil	
18. Maximum spacing of collection pipes <1.5m	
19. Collection pipes extended to surface to allow inspection and flushing	
20. Liner provided if selected filter media hydraulic conductivity > 10 x hydraulic conductivity of surrounding soil	
21. Maintenance access provided to invert of conveyance channel	
Landscape and Vegetation	**Y/N**
22. Plant species selected can tolerate periodic inundation and design velocities	
23. Bioretention swale landscape design integrates with surrounding natural and/or built environment	
24. Planting design conforms with acceptable sight line safety requirements	
25. Top soils are a minimum depth of 300 mm for plants and 100 mm for turf	
26. Existing trees in good condition are investigated for retention	
27. Detailed soil specification included in design	
28. Adequate access provided for maintenance of vegetation and filter material	
29. Timing of planting specified and appropriate	
Comments	

Source: Adapted from Gold Coast City Council (2007)

Bioretention Swale

Construction Inspection Form

Asset ID:		**Date of Visit:**	
Contact During Site Visit:		**Time of Visit:**	
Location:			
Description:			
Inspected by:			
Constructed by:			
Weather:			

Items Inspected	Checked Y/N	Satisfactory Y/N
A. During Construction		
Preliminary works		
1. Erosion and sediment control plan adopted		
2. Temporary traffic/safety control measures		
3. Location same as plans		
4. Site protection from existing flows		
Earthworks and Filter Media		
5. Bed of swale correct shape and slope		
6. Batter slopes as plans		
7. Dimensions of bioretention area as plans		
8. Confirm surrounding soil type with design		
9. Confirm filter media specification in accordance with Step 4		
10. Provision of liner (if required)		
11. Underdrainage installed as designed		
12. Drainage layer media as designed		
13. Transition layer media as designed (if required)		
14. Extended detention depth as designed		

Items Inspected	Checked Y/N	Satisfactory Y/N
Structural Components		
15. Location and configuration of inflow systems as designed		
16. Location and levels of overflow pits as designed		
17. Underdrainage connected to overflow pits as designed		
18. Concrete and reinforcement as designed		
19. Set down to correct level for flush kerbs (streetscape applications only)		
B. Sediment and Erosion Control (if required)		
20. Stabilisation immediately following earthworks and planting of terrestrial landscape and around basin		
21. Silt fences and traffic control in place		
22. Temporary protection layers in place		
C. Operational Establishment		
23. Temporary protection layers and associated silt removed		
Vegetation		
24. Planting as designed (species and densities)		
25. Weed removal and watering as required		
Comments on Inspection		
Actions Required		
1.		
2.		
3.		

Source: Adapted from Gold Coast City Council (2007)

Bioretention Swale

Final Inspection Form

Asset ID:		**Date of Visit:**	
Contact During Site Visit:		**Time of Visit:**	
Location:			
Description:			
Inspected by:			
Constructed by:			
Weather:			

Items Inspected	Checked Y/N	Satisfactory Y/N
1. Confirm levels of inlets and outlets		
2. Confirm structural element sizes		
3. Check batter slopes		
4. Vegetation as designed		
5. Bioretention filter media surface flat and free of clogging		
6. Check for uneven settling of banks		
7. Infiltration rate of filter media tested and verified as being between 150 and 350mm/hr		
8. Underdrainage installed as designed and working		
9. Inflow systems working (including erosion protection)		
10. Maintenance access provided		
11. Provision of liner (if required)		
12. Drainage layer media as designed		
13. Transition layer media as designed (if required)		
14. Extended detention depth as designed		
15. Traffic control in place		

Comments on Inspection
Actions Required
1.
2.
3.

Source: Adapted from Gold Coast City Council (2007) and Melbourne Water (2005)

Bioretention Swale

Maintenance Inspection Form

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

Items Inspected	Checked Y/N	Maintenance Needed Y/N	Inspection Frequency
Debris Cleanout			
1. Sediment/debris accumulation at inflow points			
2. Litter/debris in swale (or basin)			
3. Overflow clear of debris			
4. Evidence of dumping (e.g. building waste)			
5. Clogging of drainage points (sediment or debris)			
Dewatering			
6. Trench dewatering between storms (i.e. is there any evidence of ponding)			
7. Surface clogging visible			
8. Drainage system inspected			
9. Set down from kerb still present			
Trench Surface Vegetation			
10. Erosion at inlet or other key structures (e.g. crossovers)			
11. Traffic damage present			
12. Vegetation condition satisfactory (density, weeds etc)			
13. Replanting required			

Items Inspected	Checked Y/N	Maintenance Needed Y/N	Inspection Frequency
14. Mowing required			
15. Remulching of trees and shrubs required			
16. Soil additives or amendments required			
17. Pruning and/or removal of dead or diseased vegetation required			
18. Topsoil layer require replacing			
19. Resetting of system required (i.e. entire planting media require replacing)			
Outlet/Overflow Channel or Pit			
20. Pit/grate condition			
21. Evidence of cracking or spalling of concrete structures			
22. Evidence of erosion in downstream channel			
23. Damage/vandalism to structures present			
Comments			

Source: Adapted from Gold Coast City Council (2007), Melbourne Water (2005) and Upper Parramatta River Catchment Trust (2004)