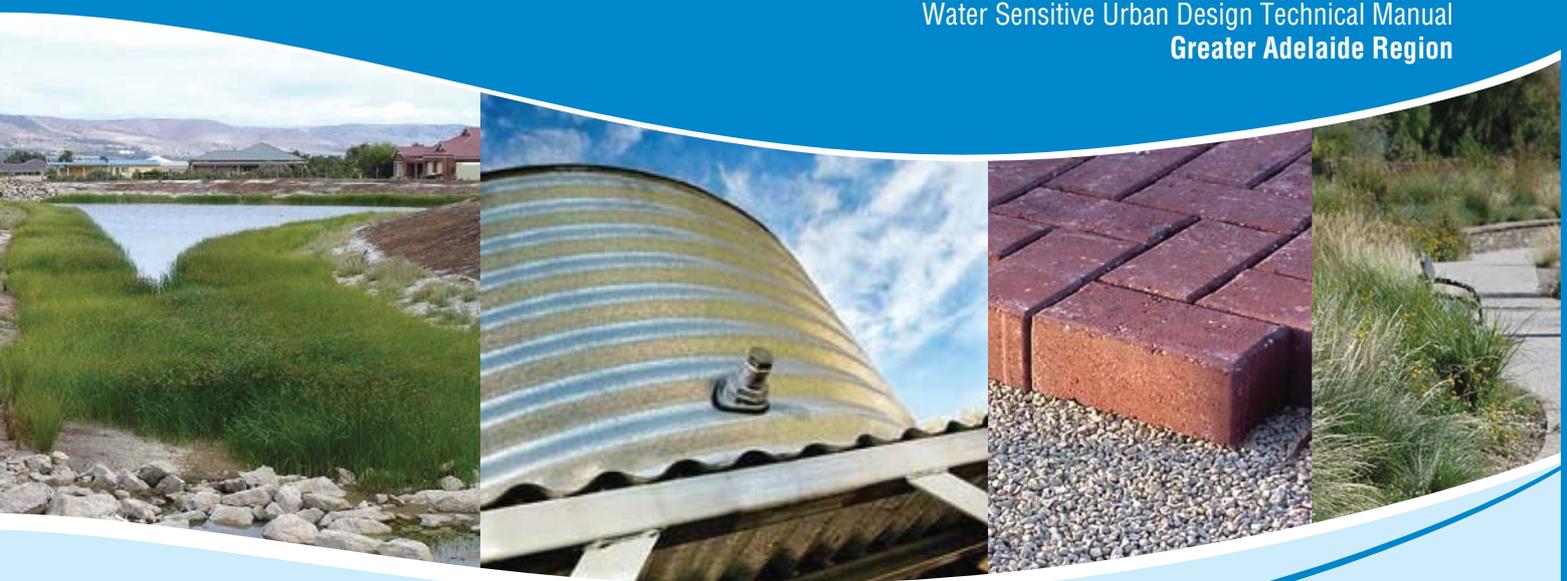


December 2010

Chapter 11

Swales and Buffer Strips

Water Sensitive Urban Design Technical Manual
Greater Adelaide Region



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The Water Sensitive Urban Design documents can be downloaded from the following website:

www.planning.sa.gov.au/go/wsud

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ISBN 978-1-876702-99-1

Preferred way to cite this publication

Department of Planning and Local Government, 2010, *Water Sensitive Urban Design Technical Manual for the Greater Adelaide Region*, Government of South Australia, Adelaide

Disclaimer

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Appropriate design procedures and assessment must be applied to suit the particular circumstances under consideration.

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.

Acknowledgments

Funding for preparation of the Water Sensitive Urban Design Technical Manual for the Greater Adelaide Region was provided by the Australian Government and the South Australian Government with support from the Local Government Association (SA).

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

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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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Chapter 11

Swales and Buffer Strips

11.1 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). Swales and buffer strips are two of those measures.

This chapter of the Technical Manual for the Greater Adelaide Region is aimed at providing a general overview of the benefits of swales and buffer strips, and how they can be utilised to achieve water quality and water quantity objectives and targets.

Further detailed design information can be obtained from the references included in the Useful Resources and Further Information section (see [Section 11.10](#)).

Description

Swales are formed, vegetated depressions (or channels) that are utilised for the conveyance of runoff from impervious areas. They are typically linear, shallow and wide. Swales can become features of a landscape, require minimal maintenance once established and are hardy enough to withstand large flows.

Buffer zones or strips, also known as filter strips, are grassed or vegetated areas that treat shallow overland flow before it enters the drainage network (or a discharge point). Buffer strips are broad, sloped open vegetated areas that accept shallow runoff from impervious areas as distributed or sheet flow.

Interaction with the vegetation tends to slow velocities, with a subsequent retention of coarse sediments. However, water quality treatment is generally limited to sediment trapping as noted by Yousef et al. (1987) who described water quality analyses at two locations alongside an interstate highway in the United States. They concluded by saying that *'swales alone should not be used for management of highway runoff based upon quality improvement and should be used as a transport channel to a more appropriate treatment process'*.

For filter strips, following extensive experimental work, Yu and Benelmouffok (1990) recommended a minimum width of 22m for filter strip design. Eight storm events were sampled and the pollutant removal efficiencies reported were for suspended solids 71%; zinc 51%; lead 25%; total phosphorus 38%; and nitrate-nitrite 10%. The

density and height of the grass were stated as important factors in pollutant removal (Pratt, 2004).

Purpose

Swales

Swales are used to convey runoff in lieu of, or in conjunction with, underground pipe drainage systems.

Swales provide a number of functions including:

- The removal of coarse to medium sized sediments (and attached pollutants) by filtration through the vegetated surface;
- Reducing runoff volumes (by promoting some infiltration to the subsoils) and even more so when coupled with an infiltration trench (see [Chapter 6](#));
- Delaying runoff peaks by reducing flow velocities;
- Accommodating pedestrian movement across and along them; and
- Providing pre-treatment for other runoff treatment measures, such as bioretention and infiltration systems, sedimentation basins and constructed wetlands.

Swales utilise overland flow and mild slopes to convey water slowly downstream. They provide a means of disconnecting impervious areas from downstream waterways, which assists in protecting waterways from damage by frequent storm events, by reducing flow velocity compared with piped systems.

To convey flood flows along swales, in excess of treatment design flow, pits draining to underground pipes can be used. This is particularly useful in areas that have narrow verges, where a swale can only accommodate flows associated with the minor drainage system.

In practice, swales are generally designed as conveyance devices. They do slow down (or attenuate) flood flows because of their increased hydraulic roughness which has a beneficial effect on downstream flooding. During low intensity rainfall events, swales also act to filter the flow and therefore have some water treatment functionality.

Buffer Strips

Buffer strips are primarily intended to remove sediment, as well as some nutrients and hydrocarbons. Buffer strips can be used as edges to swales, particularly where flows are distributed along the banks of the swale, as an alternative to kerb and gutter drainage systems.

Buffer strips provide a number of functions including:

- The removal of sediments by filtration through the vegetation;

- A reduction in runoff volumes (by promoting some infiltration to the subsoils);
- A delay in runoff peaks by reducing flow velocities;
- With appropriate vegetative cover and diversity, buffer strips can form part of a multi-use habitat (i.e. provide a habitat corridor for wildlife); and
- Effective pre-treatment for other WSUD measures such as bioretention and infiltration systems.

Buffer strips initially immobilise pollutants by binding them to organic matter and soil particles. Ultimate pollutant removal is achieved by settling, filtration and infiltration into the subsoil. Certain pollutants, such as nutrients and hydrocarbons, may be digested and processed by the soil microorganisms in the filter strip. Consequently, adequate contact time between the runoff and the vegetation and soil surface is required to optimise pollutant removal.

Scale and Application

Swales

Most swales are practical and cost effective when serving catchment areas up to 2 hectares and typically should not be used in catchments over 4 hectares in area. Larger than this, flow depths and velocities are such that the water quality improvement function of the swale, and its long-term function, may be compromised.

Swales are most applicable at the subdivision scale (i.e. along median strips or through parks) but can be applied at allotment level, depending on catchment area. Swales are generally most suited to areas with very low density housing with wide roadway verges, or overland flows in open space.



Figure 11.1 Palmer Street Swale Retrofit, Aldinga Beach

Source: Courtesy of City of Onkaparinga

Swales are often used in low density residential developments as an alternative to kerb and gutter, or as a pre-treatment to other measures. These are similar in many ways to buffer strips, but are used to convey runoff. They can also be used in:

- Road medians and verges;
- Carpark runoff areas; and
- Parks and recreation areas to convey stormwater flows.

Swales are best placed in central median strips rather than on the edge of a road where driveways and services are required. However, driveways and services can be accommodated with swales as needed.

Swales are commonly combined with bioretention systems (refer to [Chapter 10](#)) and used to convey runoff to sedimentation basins (refer to [Chapter 12](#)) and/or constructed wetlands (refer to [Chapter 13](#)).

In Adelaide, without irrigation it can be difficult to maintain vegetation in grass-lined swales during the hot dry periods commonly experienced in summer. Vegetation die-off can lead to exposed topsoils that are readily eroded during subsequent storm events.

Buffer Strips

While buffer strips are most applicable at the subdivision scale, with catchment areas less than 2 hectares, they can be applied at allotment level (e.g. buffering runoff from driveways, overflows from rainwater tanks etc) depending on the catchment area. Buffer strips are also worth considering where there are opportunities to make multiple uses of existing tracts of undeveloped land. For example, sport fields can serve as effective buffer strips where circumstances permit. However, some large tracts of land, such as golf courses, will be unsuitable where nutrient addition such as fertiliser may have a negative effect on the quality of runoff.

Removal Efficiencies

While essentially a conveyance based system, one of the major roles of swales is to provide disconnection from the receiving environment. Research and past experience suggest that swales represent a practical and potentially effective technique for controlling urban runoff (quantity and quality). While limited local Greater Adelaide Region performance data exists for swales, it is known that riffles, gentle slopes, permeable soil, dense vegetation cover and slow velocity all contribute to successful pollutant removal by the swale system.

The interaction between stormwater flow and vegetation within swale systems facilitates pollutant settlement and retention. Even swales with relatively low vegetation height can achieve significant sediment deposition rates provided flows travel at a 'low' velocity and are well distributed across the full width of the swale.

Swales can provide an important pre-treatment function for other WSUD measures in a treatment train, enabling water quality objectives to be met. Swales are particularly good at coarse sediment removal as a pre-treatment for tertiary treatment systems such as constructed wetlands and bioretention systems.

In Australia, vegetated swales are becoming a common feature of water sensitive urban design, but there is still somewhat limited, rigorous information available on performance in relation to design parameters. Fletcher et al. (2002) established controlled experiments on a newly constructed swale in Brisbane. The treatment performance diminished with increasing flow rate for suspended solids, reflecting the importance of sedimentation and infiltration in their removal. The results of Fletcher et al. (2002) with regard to total phosphorus (TP) are in contrast to those reported by Rushton (2002), who reported raised TP after flow along swales, but did suggest landscaping practices could explain this (Pratt, 2004).

The estimated removal efficiencies for swales is summarised in **Table 11.1**.

Table 11.1 Estimated Removal Efficiency for Swales

Gross Pollutants*	Coarse Sediment*	Medium Sediment	Fine Sediment	Free Oil and Grease	Nutrients	Metals
-	50-80%	30-50%	10-50%	10-50%	10-50%	10-50%

* Assumes gross pollutant pre-treatment provided

Source: Upper Parramatta River Catchment Trust, (2004)

It should be noted that actual swale performance will vary depending on individual design parameters such as temporal variation in flow and pollutant input concentration, vegetation height, infiltration capacity, length of swale and detention (contact) time.

11.2 Legislative Requirements and Approvals

Before undertaking a concept design of a swale or buffer strip it is important to check whether there are any planning regulations, building regulations or local health requirements that apply to swales or buffer strips in your area.

The legislation which is most applicable to the design and construction of sedimentation basins includes:

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

Development Act 1993

While installation of a swale or buffer strip will generally be part of a larger development, whenever a swale or buffer strip is planned it is advised that the local council be contacted to determine whether development approval is required under the *Development Act 1993*.

Environment Protection Act 1993

Any development, including the construction of swales or buffer strips, 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 or installing a swale or buffer strip 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, construction 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 of a swale or buffer strip.

Noise

Noise has the potential to cause nuisance during any construction works of swales or buffer strips. 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 which will assist with complying with this policy (see **Section 11.10**).

Air Quality

Air quality may be affected during the construction of a swale or buffer strip. 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.

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 11.10**).

11.3 Design Considerations

The operation of swales and buffer strips involves the interaction between runoff, vegetation and hydraulic structures, and the successful implementation of swales and buffer strips requires appropriate integration into the landscape design.

A number of the design considerations for swales and buffer strips include:

- Services
- Gradient
- Capacity
- Flow velocity
- Public safety
- Water source
- Catchment characteristics
- Driveway crossings
- Edge treatment
- Traffic control
- Landscape design
- Vegetation selection
- Maintenance
- Land and asset ownership

The following provides an overview of the key design issues that should be considered when conceptualising and designing swales and buffer strips.

Services

Swales located within road verges or within footpaths must consider the standard location for services (such as sewers and underground electricity). In general, a swale should not be in the line of other services, as these services will need regular maintenance. Therefore, it should be ensured that access for maintenance of services is possible without regular disruption or damage to the swale.

Gradient

The most important design consideration for a swale is the longitudinal slope. It is important to ensure flow velocities along a swale are kept sufficiently low to avoid scouring of vegetation and collected pollutants.

Swales typically operate best between longitudinal slopes of 1-4%, given that slopes milder than this can become waterlogged and have stagnant ponding (which can be remedied with subsoil drains) and steeper slopes can result in scour (which can be potentially prevented through check dams or equivalent measures).

Capacity

For water quality improvement, swales and buffer strips need only focus on treating/conveying frequent storms (typically up to the 3 month ARI). However, many swales may be required to provide a flow conveyance function as part of a minor and/or major drainage system, and it may be necessary to augment the capacity of the swale with overflow pits along the invert of the swale that discharge to the underground pipe drainage.

Flow Velocity

Velocities within swales should be kept low. IEAust (2006) recommends a flow velocity of less than 0.5 metres/second for the 1 year ARI flood flow to ensure adequate treatment up to this level of flow. A flow of less than 1.0 metres/second for the 100 year ARI is recommended to avoid scouring of collected pollutants and surface vegetation.

Public Safety

Swales located within road reserves must allow for the safe use of adjoining roadway, footpaths and bike paths by providing sufficient conveyance capacity to satisfy local infrastructure design requirements.

Checks should be undertaken to assess depth and velocity within the swale, at crossings and adjacent to pedestrian and bicycle pathways to ensure public safety.



Figure 11.2 Grass Swale in Rymill Park

Water Sources

Consideration should be given to the possible sources of water that could be directed to the swale or buffer strip.

Runoff directly from roof areas or overflow from rainwater tanks etc should be discharged to swales (if possible), which may require the use of a small surcharge pit (with perforations allowing drainage to the surrounding subsoil) in the invert of the swale to allow roof water to surcharge to the swale.

Catchment Characteristics

Silt build up can create difficulties for swale management as it impacts on gradients, creates flow channels, smothers vegetation and can destroy vegetation during the process of removing the silt. Off-site management of silt loads should be part of the design, assessment, establishment and management process.

Driveway Crossings

Driveway crossings for swales along roadways can be 'at grade' or 'elevated' and their applicability will be dependent on a number of factors (e.g. aesthetics, cost, requirement for ponding, public safety and traffic movement).

'At grade' crossings follow the profile of the swale (e.g. like a ford), while 'elevated' crossings are raised above the invert of the swale (e.g. like a bridge deck or culvert).

Crossings constructed 'at grade' require the maximum slopes to be approximately one in 10 to ensure vehicles can traverse the crossing without bottoming out. This means the entire swale will have a shallow profile, reducing its flow conveyance capacity.

'At grade' crossings are typically cheaper to construct than 'elevated' crossings, however they need to be constructed at the same time as the swale to avoid damaging the swale. This imposes a fixed driveway location on each allotment, which can potentially constrain future development of the site.

Elevated driveway crossings create a major impediment to verge maintenance mowing due to the disruption to mower paths and the necessity for careful manoeuvring to avoid infrastructure. This can add a considerable amount of time to the mowing/slashing program.

Edge Treatment

In order to avoid sediment accumulation on the edge of any impervious areas adjacent to buffer strips, a flush kerb aris (or drop down) should be used that sets the top of the vegetation 60 millimetres below the pavement edge. This requires the finished topsoil surface of the buffer strip (i.e. before turf is placed) to be approximately

100 millimetres below the pavement edge level.

Traffic Control

Traffic on swales can have an adverse influence on the long-term viability in street systems. This is an important design consideration, and could be an issue when on-street parking is intended.

To prevent vehicles driving on buffer strips and swales (and reducing treatment performance etc) appropriate traffic control measures should be considered (e.g. dense vegetation or physical barriers).

Kerb and channel should be used at all corners, intersections, cul-de-sac heads and at traffic calming devices to ensure a correct driving path is taken.

Wider road corridors may be required to incorporate swales, limiting off-street parking.



Landscape Design

Swales and buffer strips can be successfully integrated into a landscape such that functional runoff objectives, landscape aesthetics, biodiversity and amenity are achieved.

Landscape design of swales and buffer strips along the road edge can assist in defining the boundary of the road or street corridors as well as enhancing landscape character.

Consultation with landscape architects is recommended when designing a swale or buffer strip to ensure the treatment system complements the landscape of the area.

Vegetation Selection

Plant species selection needs to consider both aesthetic and functional requirements. The long dry periods in the Greater Adelaide Region are not conducive to vegetated swale establishment without additional irrigation, which is an important consideration in terms of viability.

Vegetation is required to:

- Cover the whole width of the swale and/or buffer strip;
- Be capable of withstanding design flows;
- Be of sufficient density to prevent preferred flow paths and scour of deposited sediments; and
- Be resilient to long periods of dry weather, commonly experienced in Adelaide.

Plant species should have the following features:

- A capability to tolerate short periods of inundation punctuated by longer dry periods;
- Spreading rather than clumped growth forms;
- A perennial rather than annual capability; and
- Drought tolerant.

Denser vegetated swales can offer improved sediment retention by slowing flows more and providing enhanced sedimentation for deeper flows.

Swales and buffer strips can use a variety of vegetation types including turf, sedges, and tufted grasses. Vegetated swales should be planted with local native plant species to enhance biodiversity, reduce the need for watering and reduce the spread of weed species to receiving environments via runoff.

Consideration should also be given to:

- Other WSUD objectives such as landscape, aesthetics, biodiversity, conservation and ecological value;
- Region, climate, soil type and abiotic factors;
- Roughness of the channel (Manning's n roughness factor);
- Establishment period for vegetation growth (and hence timing of planting);
- Access for maintenance of the vegetation; and
- Adequate sunlight for vegetation growth.

Maintenance

Regular inspections and maintenance are required during the establishment period of swales and buffer strips. Detailed information regarding the maintenance requirements are contained in **Section 11.7**.

The design should ensure that adequate access is available for maintenance of all aspects of the system.

Land and Asset Ownership

Land and asset ownership issues are key considerations prior to construction of a WSUD measure, including swales and buffer strips. A proposed design should clearly identify the asset owner and who is responsible for maintenance.

11.4 Design Process

The design process for swales and buffer strips includes the following steps:

- Site analysis (including determining any site constraints);
- Determine the design objectives;
- Meet with council and relevant authorities;
- Undertake a concept design:
 - Topographical survey of the site
 - Preliminary geotechnical survey
 - Design criteria based on water quality and quantity objectives
 - Design flows based on catchment characteristics
 - Consideration of gross pollutants
 - Verification of design performance (e.g. water quality or hydraulic modelling)
 - Maintenance and access
 - Identify and propose mitigation of environmental issues on site
 - Allowances to preclude traffic on swales or buffer strips
 - Selection of plant species
 - Cost estimate (including life cycle costing);
- Approvals process:
 - Local government
 - Environment Protection Authority
 - Natural Resources Management Board
 - Department of Water Land and Biodiversity Conservation;
- Detailed design:
 - Detailed design of civil works
 - Additional geotechnical/hydrogeological study
 - Detailed design drawings
 - Detailed design of relocation of services
 - Detailed cost estimate and schedule of quantities
 - Procurement plan
 - Planting plan
 - Maintenance plan
 - Design report;
- Check design objectives;
- Vegetation specification;
- Develop a maintenance plan.

It should be noted that not all of the steps detailed above will be required for each swale or buffer strip design.

Detailed swale and buffer strip design process information is contained in various publications (see **Section 11.10**) which will need to be adapted for the Greater Adelaide Region. However, a number of the design process elements are discussed briefly below.

The design process is also discussed in general in **Chapter 3** of the Technical Documents.

Site Analysis

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

Factors which should be considered when undertaking a site suitability assessment include:

- Open space and landscape;
- Flora and fauna;
- Services;
- Catchment characteristics;
- Potential for site contamination; and
- Gradient.

Objectives and Targets

Before the commencement of the design process, the objectives and targets for the swale or buffer strip should be established. Objectives include environmental benefits (such as water quality improvement, detention and erosion control), habitat value (enhancing biodiversity and conservation), or aesthetic and recreational values.

If the objectives for designing a swale or buffer strip are clearly defined, the task is simplified.

The design approach for swales and buffer strips is generally based on achieving the following objectives:

- Providing sufficiently low flow velocities through the swale or buffer strip to limit surface erosion and scouring;
- Limiting the flow depth through the swale or buffer strip to maximise contact and filtration through the vegetation; and

- Meeting conveyance requirements for minor and major flow events.

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

Meet with Council

Before designing or installing a swale or buffer strip, it is important to check whether there are any planning regulations, building regulations or local health requirements that apply to swales or buffer strips in your area. A meeting with your local development assessment officer at council is therefore recommended.

The council will be able to advise whether:

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

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

Concept Design

A detailed design process and example calculation for swale design is included in **Appendix B** of this chapter. Key points to consider in this design process are highlighted below. The design process outlined covers only the numerical calculations to ensure the swale operates effectively. The qualitative design aspects of buffer strips and swales is equally, if not more, important and should be addressed with reference to the rest of this chapter, and checked off using the design calculation sheets in **Appendix A** of this chapter.

Design Flows

Design of swales needs to consider two types of storm events:

- Minor storm flows (typically a 1 year ARI) for conveyance of nuisance flooding and applicability of water quality treatment functions. Design should be checked to ensure that flow velocity is less than 0.5 metres/second; and
- Major flood flows (typically the 100 year ARI) to check flow velocities, velocity depth criteria, conveyance within the road reserve and freeboard to the adjoining properties. Design should be checked to ensure that the maximum flow velocity is less than 1 metres/second.

Design Criteria

The following design criteria for swales should be met:

- Flow depths of less than 200 millimetres for a 1:10 year rainfall event;
- Ponding for no more than one hour after rainfall cessation is unlikely;
- Turf used is tolerant of submersion and resistant to scour and erosion; and
- Depth to width ratio of greater than 1:10.

Swale Geometry

The swale's geometrical design is an iterative process that needs to take into consideration the site's constraints including topography, development layout and density, how flow reaches the swale and available reserve width. The iterative process involves solving the Manning's equation and can be undertaken using a simple spreadsheet procedure.

Manning's n Value Selection

The selection of an appropriate Manning's n value is established by example in **Appendix B** of this document. Designers are also advised to take into account the reduction in Manning's n coefficient at high flow depths (i.e. at the 100 year ARI event) where the influence of roughness is reduced.

11.5 Design Tools

A range of design tools is available for the concept and detailed design of swales and buffer strips as detailed in [Chapter 15](#). The modelling tools which are able to assist include:

- MUSIC;
- EPA SWMM;
- XP-SWMM;
- Hec-Ras; and
- E2.

In addition, design flows for particular storm events can be estimated using a range of hydrologic methods with varying complexity. For small simplistic catchments, the rational method is suitable for peak flow estimation, while for larger, more complex catchments, use of hydrologic/hydraulic models may be more appropriate for design.

Previous methods of sizing of a swale were based purely on hydraulic requirements and did not take into account the subsequent water quality effects. The parameters from the hydraulic calculations can be directly transferred to MUSIC to determine the water quality effect that the swale will have in the treatment train.

11.6 Construction Process

There are numerous challenges that must be appropriately considered to ensure successful construction and establishment of swales and buffer strips.

Protection During Construction

The risks to successful construction and establishment of swales or buffer strips are generally related to the construction activities which can generate large sediment loads in runoff which can smother vegetation. Construction traffic and other works can also result in damage to the swale or buffer strip.

If the swale or buffer strip is to be used during the development of other aspects of a site, the swale or buffer strip should be constructed well in advance of development to provide enough time for the swale vegetation to establish. Depending on the site runoff sediment loads and flow rates, swales may need to be restored once construction of the adjacent development site is complete.

If the swale (or buffer strip) is to be constructed for use after completion of the entire development, it should be protected from construction site runoff and should be fenced during the construction period to prevent damage from heavy plant and vehicles.

Temporary protection of swales and buffer strips can be achieved by using an arrangement of a suitable geofabric covered with shallow topsoil (e.g. 50 mm) and instant turf (laid perpendicular to flow path). This will allow the swale to function as a temporary erosion and sediment control facility throughout the building phase. At the completion of the building phase these temporary measures should be removed with all accumulated sediment and the swale reprofiled (if necessary) and planted in accordance with the proposed swale design. It may be possible to reuse the instant turf as part of the final planting if this is consistent with the proposed landscape design.

Landscaping

Topsoils

The preparation and installation of horticultural soils should follow environmental best practices and include:

- Preparation of soil survey reports including maps and test results at the design phase;
- Stripping and stockpiling of existing site topsoils prior to commencement of civil works for possible reuse as a plant growth medium;

- Testing of the quality of the local topsoil to determine the soil's suitability for reuse as a plant growth medium;
- Deep ripping of subsoils using a non-inversion plough;
- Reapplication of stockpiled topsoils;
- Remedial works, if necessary, to improve the soil's capacity to support plant growth and to suit the intended plant species; and
- Addition, where necessary, of imported topsoils (certified to AS 4419-2003 – Soils for Landscaping and Garden Use).

Soils applied must also be free from significant weed seed banks as labour intensive weeding can incur large costs in the initial plant establishment phase. On some sites, topsoils may be non-existent and material will need to be imported.

Sourcing Vegetation

Notifying nurseries early for contract growing is essential to ensure the specified species are available in the required numbers and of adequate maturity in time for swale (or buffer strip) planting. When this is not done and the planting specification is compromised (because of sourcing difficulties), poor vegetation establishment and increased initial maintenance costs may occur.

To ensure the planting specification can be accommodated, the minimum recommended lead time for ordering is three to six months.

Timing for Planting

Construction planning and phasing should endeavour to correspond with suitable planting months wherever possible. In some circumstances it may be appropriate to leave temporary planting in place (if this is used to protect the swale or buffer strip during the building phase (e.g. turf over geofabric)) and then remove this at a suitable time to allow the final swale planting to occur at the preferred time of year.

Weed Control

To combat weed invasion and reduce costly maintenance requirements for weed removal, high planting density rates should be adopted. A suitable biodegradable erosion control matting or a heavy application of seedless hydromulch can also be applied to swale batters (where appropriate) for short-term erosion and weed control.

Conventional surface mulching of swale (or buffer strip) systems with organic material should not be undertaken (for weed or moisture control). Most organic mulch floats and runoff typically causes this material to be washed away with a risk of causing drain blockage.

Watering

Regular watering of swale vegetation is essential for successful establishment and healthy growth. The frequency of watering to achieve successful plant establishment is dependent upon rainfall, maturity of planting stock and the water holding capacity of the soil.

After an initial three month period, watering may still be required. Watering requirements to sustain healthy vegetation should be determined during ongoing maintenance site visits.

However, water restrictions should be considered and the design should be undertaken to ensure that there are minimal water requirements and only species that can survive long dry periods are selected.

11.7 Maintenance Requirements

As the functionality of swales and buffer strips relies upon good vegetation establishment, adequate vegetation growth is a key maintenance objective. In addition, swales and buffer strips have a flood conveyance role that needs to be maintained to ensure adequate flood protection for local properties.

The most intensive period of maintenance is during the plant establishment period (first two years) when weed removal and replanting may be required. It is also the time when large loads of sediments may impact on plant growth, particularly in developing catchments with an inadequate level of erosion and sediment control.

It is good practice to check the operation of inlet erosion protection measures following the first few rainfall events in order to avoid any long-term issues. Should problems be identified in these events, the erosion protection should be enhanced.

Following construction, swales and buffer strips should be inspected every one to three months (or after each major rainfall event) for the initial establishment period to determine whether or not the swale (or buffer strip) surface and vegetation requires immediate maintenance.

Swales and buffer strips require ongoing maintenance such as mowing, watering (in accordance with water restrictions), weeding, sediment and litter removal, and scour and erosion repair.

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 that the swale or buffer strip continues to function as designed. An example Maintenance and Inspection Checklist for swales and buffer strips is contained in **Appendix A**.

Typical maintenance will involve:

- Routine inspection of the swale profile to identify any areas of obvious increased sediment deposition, or scouring of the swale invert from a storm;
- Routine inspection of the swale profile to identify any damage from vehicles;
- Routine inspection of swale batters to identify any rill erosion caused by lateral inflows;
- 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 or 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 damage to the swale profile resulting from scour, rill erosion or vehicle damage;
- Clearing of blockages to inlets or outlets;
- Regular watering/irrigation of vegetation until plants are established and actively growing (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 (from any cause) and replacement with plants of equivalent size and species as detailed in the plant schedule;
- Pruning to remove dead or diseased vegetation material and to stimulate new growth;
- Litter and debris removal;
- Vegetation pest monitoring and control; and
- Addressing nuisance problems such as mosquitoes and boggy areas.

Vegetation should be maintained preferably above 100 to 150 millimetres in height for swales and above 75 millimetres in height for buffer strips (Upper Parramatta River Catchment Trust, 2004).

11.8 Education and Awareness

Any residents or employees located near a swale or buffer strip which has been constructed should be informed of the function of the WSUD measure and its benefits, to help prevent damage and/or misuse. The erection of signage near the swale or buffer strip is recommended to inform the public of its function and use.

11.9 Approximate Costs

Standard cost data for construction of swales and buffer strips in the Greater Adelaide Region is not readily available. The costs provided in this section have been obtained from a number of sources and are indicative only and may vary based on the region. It should also be noted that there may be additional costs associated with maintaining the swale or buffer strip during the construction and establishment phase.

Life cycle costing should be undertaken in the concept design phase.

Swales

The construction cost for swales depends on the surface area/width, type of vegetation and the steepness of the area (i.e. whether intermittent check dams are required). The essential unit rate construction for a nominal 3 metre wide swale is summarised in **Table 11.2**.

Table 11.2 Estimated Unit Rate Construction Cost for Swales

Works Description	Quantity	Unit	Rate	Cost (\$/m)
Excavate and profiling swale channel	3	m ² /m	2.0	6
Supply and place topsoil layer (at least 100 mm thick)	3	m ² /m	7.0	21
Supply and apply grass seed, fertiliser and watering	3	m ² /m	1.0	3
TOTAL				30

Source: Upper Parramatta River Catchment Trust (2004)

Based on the above, the unit cost is approximately \$30/metre length of swale or approximately \$10/square metres of swale. For swales with an underlying subsoil drain (i.e. for grades less than 2%), include an additional \$30/m for the construction of the subsoil drain, including excavation, perforated pipe, gravel and sand backfill and geofabric surround. If rolled turf is used instead of seed, the estimated unit cost of the swale would increase to approximately \$18/square metres (excluding subsoil drain) (Upper Parramatta River Catchment Trust, 2004).

Estimated swale maintenance costs are provided in **Table 11.3** and are derived from the Models Farm High School case study (Upper Parramatta River Catchment Trust, 2004).

Table 11.3 Estimated Swale Maintenance Costs

Component	Estimated Cost (\$)	Swale Size 1	Swale Size 2	Comments
		0.5 m deep, 0.3 m bottom, 3 m top width	1 m deep, 1 m bottom width, 7 m top width	
Mowing	1.62/100 m ²	264.6	440.1	Mow 2-3 times per year
General grass care	16.2/100 m ²	297	499.5	Grass maintenance area is top width + 3 m x length
Debris / litter removal	0.95/ m ²	170.1	170.1	
Reseeding / fertilisation	0.65/ m ²	10.8	18.9	Area revegetated is 1% of maintenance per area per year
Inspection and general administration	1.35/ m ²	421	421	Inspection once per year
TOTAL	3.13/ m ²	1164	1550	

Source: Upper Parramatta River Catchment Trust (2004)

Buffer Strips

The construction cost for buffer strips depends on the surface area and type of vegetation used. The construction cost for a buffer strip comprising surface preparation (grading, compacting and scarifying), topsoiling and seeding (with grasses) would be in the order of \$10 to \$15/square metres. The cost would increase to around \$20 to \$50/square metres if the area was planted with a ground cover of established and native grasses (Upper Parramatta River Catchment Trust, 2004).

Maintenance of buffer strips in the form of the removal of litter and mowing is approximately \$2.5/square metres (Upper Parramatta River Catchment Trust, 2004).

11.10 Useful Resources and Further Information

Fact Sheets

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

City of Melbourne fact sheets

Legislation Information

[www.legislation.sa.gov.au/LZ/C/POL/ENVIRONMENT%20PROTECTION%20\(WATER%20QUALITY\)%20POLICY%202003/CURRENT/2003.-.UN.PDF](http://www.legislation.sa.gov.au/LZ/C/POL/ENVIRONMENT%20PROTECTION%20(WATER%20QUALITY)%20POLICY%202003/CURRENT/2003.-.UN.PDF)

Environment Protection (Water Quality) Policy 2003

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

Environment Protection (Industrial Noise) Policy 1994

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

EPA information sheet on Construction Noise

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

EPA information sheet on Environmental Noise

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

EPA Handbook for Pollution Avoidance on Building Sites

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

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

Design Information

www.ewatercrc.com.au

Hydrological modelling and research information

www.toolkit.net.au/tools/

Provides eWater Toolkit which is a range of online modelling tools, including MUSIC, available for specific purposes.

www.wsud.org/tools-resources/

Water Sensitive Urban Design Guidelines in the Sydney Region

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

Water Sensitive Urban Design Technical Design Guidelines for South East Queensland

www.goldcoast.qld.gov.au/gcplanningscheme_policies/policy_11.html#guidelines

Water Sensitive Urban Design Guidelines – Gold Coast City Council

www.water.wa.gov.au/Managing+our+water/Stormwater+and+drainage/Stormwater+management+manual/default.aspx

Stormwater Management Manual for Western Australia – Structural Controls

(Websites current at August 2010)

11.11 References

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

Fletcher T.D.D., Peljo L., Fielding J., Wong T.H.F. and Weber T., 2002. The performance of vegetated swales for urban stormwater pollution control. Proc. 9th Int. Conf. on Urban Drainage, Global Solutions for Urban Drainage, Eds. E W Strecker and WC Huber, Portland, Oregon, USA. ISBN 0 7844 0644 8.

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.

Pratt C.J. (2004). *A Review of Published Material on the Performance of Various SUDS Components*, Prepared for The UK Environment Agency, Coventry University, Coventry, UK.

Rushton B. (2002). Enhanced parking lot design for stormwater treatment. Proc. 9th Int. Conf. on Urban Drainage, Global Solutions for Urban Drainage, Eds. E W Strecker and W C Huber, Portland, Oregon, USA. ISBN 0 7844 0644 8.

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/.

Yousef Y.A., Hvitved-Jacobsen T., Wanielista M.P. and Harper H.H. (1987). *Removal of contaminants in highway runoff flowing through swales*. Sci.Tot.Env., 59, pp391-399.

Yu S.L. and Benelmouffok D. (1990). *Field tests of urban best management practices for controlling stormwater pollution*. In: *Drainage Systems and Runoff Reduction*, Eds. Y. Iwasa and T. Sueishi, (Proc. 5th Int. Conf. on Urban Storm Drainage, Vol. 2), Osaka, Japan, pp. 805-808.

(Websites current at August 2010)

Appendix A

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.

Swales or Buffer Strips

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)

Swales or Buffer Strips

Design Assessment Checklist

Asset ID:	
Swale Location:	
Description:	
Major Flood - 100 yr ARI (m ³ /s):	
Minor Flood - 1 yr ARI (m ³ /s)	
Catchment Area (ha):	
Swale / Buffer Strip Area (m ²):	
Designed by:	
Checked by:	

Items Checked	Checked Y/N	Satisfactory Y/N
Concept Design		
1. Treatment performance verified		
2. Service location checked or appropriate allocation provided		
Inlet Zone / Hydraulics		
3. Station selected for IFD appropriate for location		
4. Longitudinal slope of invert > 1% and < 4%		
5. Manning's <i>n</i> selected appropriate for proposed vegetation type		
6. Overall flow conveyance width does not impact on traffic requirements		
7. Overflow pits provided where flow capacity exceeded		
8. Energy dissipation provided at inlet points to the swale and inlet flows appropriately distributed		
9. Velocities within swale cells will not cause scour		

Items Checked	Checked Y/N	Satisfactory Y/N
Cells		
10. Design states area and extended detention depth as defined by treatment performance requirements		
11. Overflow pit crest set at top of extended detention		
12. Maximum ponding depth and velocity will not impact on public safety		
13. Design saturated hydraulic conductivity included in specification		
14. Maintenance access provided to invert of conveyance channel		
Landscape and Vegetation		
15. Plant species selected can tolerate periodic inundation and design velocities		
16. Swale landscape design integrates with surrounding natural and/or built environment		
17. Planting design conforms with acceptable sight line safety requirements		
18. Existing trees in good condition are investigated for retention		
Comments on Design		
Actions Required		
1.		
2.		
3.		

Swales or Buffer Strips

Inspection and Maintenance Checklist

Asset ID:		Date of Visit:	
Inspection Frequency:	1 to 6 months	Time of Visit:	
Location:			
Description:			
Inspected by:			
Weather:			

Items Inspected	Checked Y/N	Action Required (Details) Y/N
Debris Cleanout		
1. Swale and contributing areas clear of debris		
2. Observed domestic litter / debris in swale channel		
3. Inlet and outlet structures clear of obstructions		
Swale Surface		
4. Evidence of erosion or scour		
5. Vegetation condition		
6. Sediment deposition		
7. Evidence of vehicle damage		
Swale Vegetation		
8. Vegetation trimming / mowing		
9. Fertilisation where required		
10. Weed infestation		
Ponding		
11. Evidence of ponding water		

Items Inspected	Checked Y/N	Action Required (Details) Y/N
Comments on Inspection		
Actions Required		
1.		
2.		
3.		
4.		
5.		

Appendix B

Design Procedure and Example for Determining Swale Capacity

The following design procedure for a swale has been adapted from IEAust (2006) and Gold Coast City Council (2007). Please note that this considers the quantitative design process only – qualitative design features must be kept in mind during the design procedure. To ensure these features are followed it is recommended that practitioners make use of the design checklists in **Appendix A**.

The design process for a swale is as follows:

Step 1: 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.

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

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

Where: Q = Flow in the swale (m³/s)
 A = Cross sectional area of the swale (m²)
 P = Hydraulic Perimeter (m)
 R = Hydraulic Radius (m)
 S = Channel Slope (m/m)
 n = Roughness coefficient (or Manning's *n*)

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.

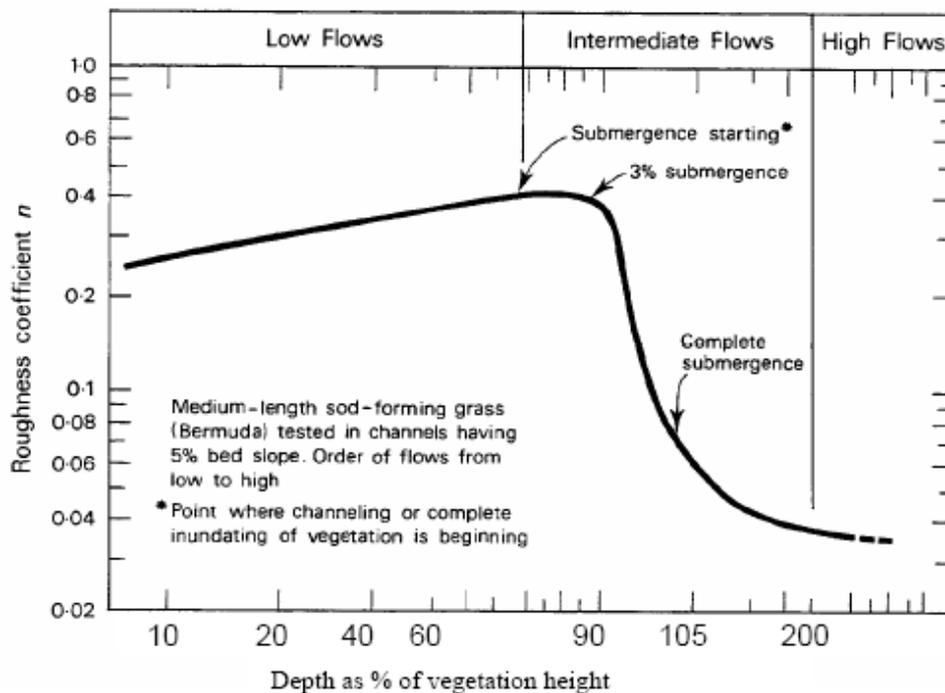
Slope of the swale will usually be dependent on the adjacent infrastructure (road, rail, pathway etc). Slope is recommended to be between 2-4%. Lower slopes will require underdrains to prevent ponding, while larger slopes will require flow spreading to ensure uniform flow occurs across the swale (IEAust 2006).

Manning's *n* is a critical variable in Manning's equation relating to 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) (Gold Coast City Council 2007).

It is considered reasonable for Manning's n to have a maximum at the vegetation height and then to sharply reduce as depths increase. The graph below is a useful reference for determining the Manning's n of a channel using the depth of flow as a percentage of the height of vegetation. Designers are also advised to take into account the reduction in Manning's n coefficient at high flow depths (i.e. at the 100 year ARI event) where the influence of roughness is reduced.

Further discussion on selecting an appropriate Manning's n for a swale is provided in Appendix E of the *MUSIC User Guide* (CRC for Catchment Hydrology 2005).



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 m/s; and
- 100 year ARI peak velocity does not exceed 1 m/s.

Sample Design for a 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 swale is vegetated up to a height of 0.3 m;
- The swale is located in Adelaide, near the city centre, with an average annual rainfall of 545 mm/yr;
- Contributing catchment includes:
 - Roof area $A_{EIA} = 2000 \text{ m}^2$
 - Paved area $A_{EIA} = 1400 \text{ m}^2$;
- Length of Swale = 100 m; and
- Maximum width of swale = 6 m.

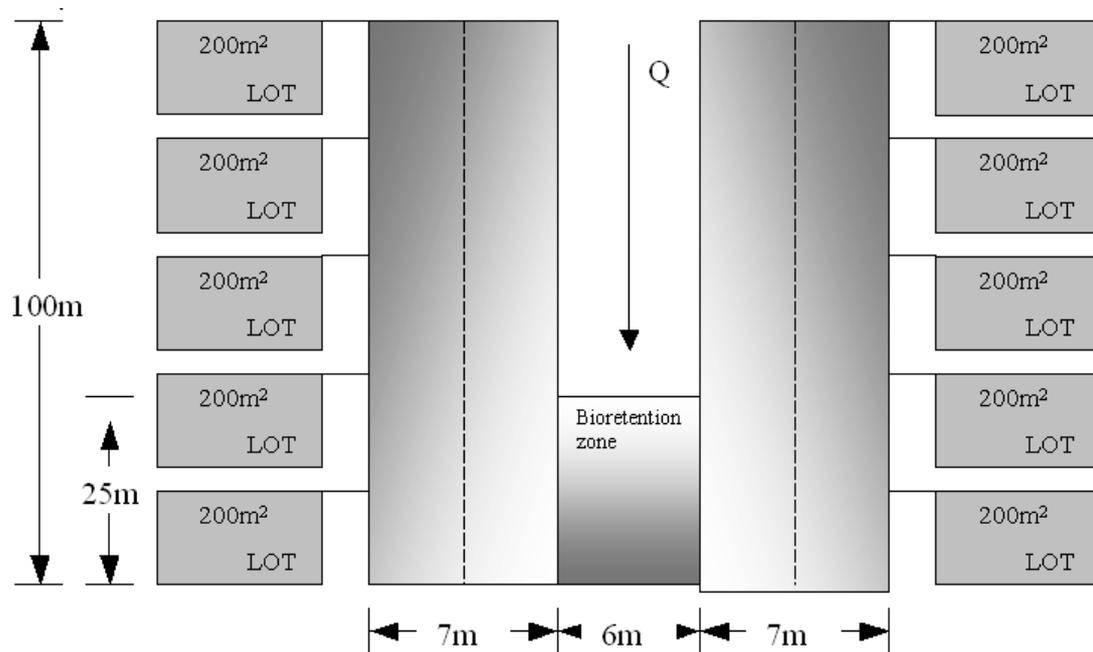


Figure B2 Bioretention Swale Plan (not to scale)

Determine Swale Dimensions

To start to design the swale, any values can be selected within the design limits. Here, we can 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 m³/s, and the 100 year ARI peak discharge is equal to 1.2 m³/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 $y = 0.2\text{m}$; $A = 0.52\text{ m}^2$; $P = 3.26\text{m}$

$Q = 0.14\text{ m}^3/\text{s}$

Trial $y = 0.3\text{m}$; $A = 0.87\text{ m}^2$; $P = 3.90\text{m}$

$Q = 0.30\text{ m}^3/\text{s} \sim 1\text{ year ARI peak flow}$

Where y = trial flow depth (m).

100 year ARI flow condition:

Trial $y = 0.5\text{ m}$; $A = 1.75\text{ m}^2$; $P = 5.16\text{ m}$

$Q = 0.80\text{ m}^3/\text{s}$

Trial $y = 0.60\text{ m}$; $A = 2.28\text{ m}^2$; $P = 5.79\text{ m}$

$Q = 1.15\text{ m}^3/\text{s}$

Trial $y = 0.65\text{ m}$; $A = 2.57\text{ m}^2$; $P = 6.11\text{ m}$

$Q = 1.35\text{ m}^3/\text{s} \sim 100\text{ year ARI peak flow.}$

Check Flow Velocities

1 year ARI event; $v = 0.30/0.87 = 0.34\text{ m/s}$

< 0.5 m/s, OK

100 year ARI event; $v = 1.35/2.57 = 0.52\text{ m/s}$

< 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 required to design a swale in sections, with intermediate overflow zones.