SC6.4.3.9 Water sensitive urban design guidelines

SC6.4.3.9.1 Introduction

(1) Water By Design's *Water Sensitive Urban Design Technical Design Guidelines for South East Queensland*, Version 1, 2006 (or as amended), are adopted, with the following exclusions:

(a) Chapter 1 Introduction

(b) Chapter 6 Constructed Stormwater Wetlands.

Note—Chapter 3 Bioretention Swales, Chapter 5 Bioretention Basins, and Appendix A Plant Selection for WSUD Systems, which formed part of the original version of the Technical Design Guidelines, have been superseded by Healthy Waters' *Bioretention Technical Design Guidelines (Version 1, October 2012)*. The *Bioretention Technical Design Guidelines* are **not** being adopted.

(2) The following sections – Introducing water sensitive urban design, Bioretention swales, Bioretention basins, Constructed stormwater wetlands, and Appendix A Plant selection for water sensitive urban design systems - have been developed specifically for the coastal dry tropic conditions found in the Townsville area, and replace those equivalent sections in the *Water Sensitive Urban Design Technical Design Guidelines for South East Queensland* (and the superseded parts that form the *Bioretention Technical Design Guidelines*).

(3) References to chapters and sections in this sub-section refer to the chapters and sections in the *Water Sensitive Urban Design Guidelines for South East Queensland*.

SC6.4.3.9.2 Introducing water sensitive urban design

(1) Water sensitive urban design (WSUD) is an internationally recognised concept that offers an alternative to traditional development practices. WSUD is a holistic approach to the planning and design of urban development that aims to minimise negative impacts on the natural water cycle and protect the health of aquatic ecosystems. It promotes the integration of stormwater, water supply and sewage management at the development scale.

The key principles of WSUD are to:

(a) protect existing natural features and ecological processes;

(b) maintain the natural hydrologic behaviour of catchments;

(c) protect water quality of surface and ground waters;

(d) minimise demand on the reticulated water supply system;

(e) minimise sewage discharges to the natural environment; and

(f) integrate water into the landscape to enhance visual, social, cultural and ecological values.

These guidelines are not intended to limit innovation in design or construction of WSUD elements by restricting alternative approaches to those presented here. Alternative designs should be considered where potential improvements in performance, constructability or maintenance requirements can be demonstrated. However, the design procedures and recommendations given in these guidelines are based on contemporary best practice, incorporating lessons from local experience, and are regarded as appropriate for the coastal dry tropics region.

(2) Design objectives for stormwater management

The adopted design objectives for the coastal dry tropics in mean annual pollutant load leaving a development site, compared to traditional urban design where stormwater is not treated:

(a) >= 80% reduction in total suspended solids load

(b) >= 65% reduction in total phosphorus load

(c) >= 40% reduction on total nitrogen load

(d) >= 90% reduction in gross pollutant load.

Editor's note—this sub-section contains illustrations and photographs of stormwater treatment devices. These are intended as examples only and should not be regarded as acceptable solutions. Unless specifically indicated, all drawings are not to scale.

(3) Selection of appropriate stormwater management measures

(a) Not all of the stormwater management measures presented in this sub-section are suitable for any given site. Appropriate measures should be selected by matching device characteristics to target pollutants and the physical constraints of the site.

(b) These guidelines are not intended to provide detailed advice on selection of stormwater treatment devices. However, the following tables provide an indication of:

(i) the scale at which various treatment measures are typically applied (Table SC6.4.3.9.1);

Table SC6.4.3.9.1 Scale of WSUD application in urban catchments

WSUD Measure	Allotment Scale	Street Scale	Precinct or Regional Scale
Swales and buffer strips		✓	
Bioretention Swales		✓	✓
Sedimentation basins			✓
Bioretention basins	✓	✓	✓
Constructed wetlands		✓	✓
Infiltration measures	✓	✓	
Sand filters	✓	✓	
Aquifer storage and recovery			✓

(ii) the effectiveness of these treatment measures in removing pollutants, attenuating peak flow rates and reducing runoff volume (Table SC6.4.3.9.2); and

Table SC6.4.3.9.2 Effectiveness of WSUD measures for runoff quality and quantity management

WSUD Measure Water	Quality Treatment			Peak Flow Attenuation*	Reduction in Runoff Volume*
	TSS	TP	TN		
Swales and buffer strips	H	M	L	L	L
Bioretention Swales	H	H	H	M	L
Sedimentation basins	H	M	L	M	L
Bioretention basins	H	H	H	M	L
Constructed wetlands	H	H	H	H	L
Infiltration measures**	-	-	-	H	H
Sand filters	H	M	L	L	L
Aquifer storage and recovery**	-	-	-	H	H

H – High; M – Medium; L – Low * Frequent events only ** Water quality treatment is not a primary function of these devices

(iii) site conditions that may affect the suitability of different treatment measures (Table SC6.4.3.9.3).

Table SC6.4.3.9.3 Site constraints for WSUD measures

WSUD Measure	Steep site (>5%)	Shallow bedrock	Acid Sulfate Soils	Low permeability soil (eg. Clay)	High permeability soil (eg. sand)	High water table	High sediment input	Land availability
Swales and buffer strips	C	D	D	✓	✓	D	D	D
Bioretention Swales	C	C	C	✓	✓	C	D	D
Sedimentation basins	C	✓	✓	✓	✓	D	✓	D
Bioretention basins	D	D	D	✓	✓	C	C	D
Constructed wetlands	C	D	C	✓	D	D	D	D
Infiltration measures	C	C	C	C	✓	C	C	D
Sand filters	D	✓	✓	✓	✓	D	C	✓
Aquifer storage and recovery	C	C	C	C	✓	C	C	D

C – Constraint may preclude use; D – Constraint may be overcome through appropriate design; ✓ – Generally not a constraint

(4) Safety and risk management

(a) WSUD aims to protect the environmental assets of a site and enhance liveability through greater integration of built and natural features. This approach may introduce some risks to the urban environment that are greater than or different to those encountered in traditional land development practice. The more obvious of these risks relate to the presence of open water bodies and the introduction of street-scape elements that may alter lines of sight or other aspects of traffic safety.

(b) Whilst this sub-section makes occasional comment on various aspects of safety, they are not intended to provide comprehensive advice on appropriate risk management strategies. Designers are responsible for providing an appropriate level of public safety in their designs and for ensuring that risk management procedures, in accordance with relevant standards and guidelines, are followed. Further information on risk management for water-related urban infrastructure is provided in the *Queensland Urban Drainage Manual*.

SC6.4.3.9.3 Bioretention swales

(1) Bioretention swales act to disconnect impervious areas from downstream waterways and provide protection to natural receiving waterways from frequent storm events by reducing flow velocities compared with piped systems. The bioretention component is typically located at the downstream end of the overlying swale "cell" (i.e. immediately upstream of the swale overflow pit(s) as shown in Figure SC6.4.3.9.1.

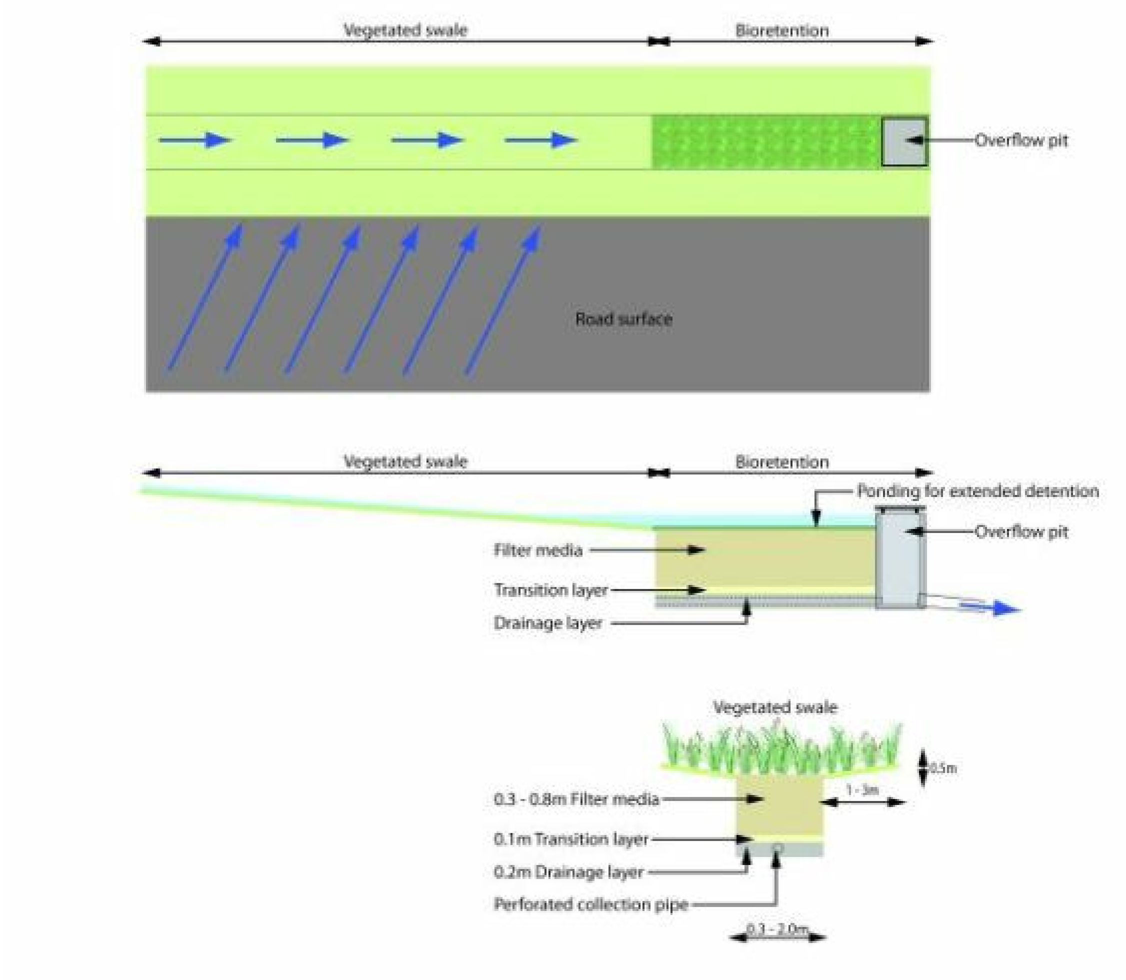

Figure SC6.4.3.9.1 Bioretention swale conceptual layout

The choice of bioretention location within the overlying swale will depend on a number of factors, including area available for the bioretention filter media and the maximum batter slopes for the overlying 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 encourage uniform distribution of stormwater flows over the full surface area of bioretention filter media and allowing temporary storage of flows for treatment before bypass occurs.

(2) Design considerations for bioretention swales

(a) This section outlines some of the key design considerations for bioretention swales that the detailed designer should be familiar with before applying the design procedure presented later in this chapter. Standard design considerations for the swale component of bioretention swales are discussed in detail in Chapter 2 (Swales) and are not reproduced here. However, other swale design considerations that relate specifically to the interactions between the swale and bioretention components are presented in the following sections together with design considerations relating specifically to the bioretention component.

(i) Landscape design

Bioretention swales may be located within parkland areas, easements, car parks or along roadway corridors within footpaths (i.e. road verges) or centre medians. 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. It is therefore important that the landscape design of bioretention swales addresses stormwater quality objectives whilst also being sensitive to these other important landscape functions. It is also necessary to adequately address potential aesthetics issues such as weeds and sustaining perennial plants during the dry season.

(i) Hydraulic design

A key hydraulic design consideration for bioretention swales is the delivery of stormwater runoff from the swale 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. In steeper areas, check dams may be required along the swale to reduce flow velocities discharged onto the bioretention filter media.

It is important to ensure that velocities in the bioretention swale from both minor (2-10 year ARI) and major (50-100 year ARI) runoff events are kept sufficiently low (preferably below 0.5 m/s and not more than 2.0 m/s for major flood) to avoid scouring. This can be achieved by ensuring the slope and hydraulic roughness of the overlying swale reduce flow velocities by creating shallow temporary ponding (i.e. extended detention) over the surface of the bioretention filter media via the use of a check dam and raised field inlet pits. This may also increase the overall volume of stormwater runoff that can be treated by the bioretention filter media.

(iii) Ex-filtration to in-situ soils

Bioretention swales can be designed to either preclude or promote ex-filtration of treated stormwater to the surrounding in-situ soils depending on the overall stormwater management objectives established for the given project.

Where the concept design specifically aims to preclude ex-filtration of treated stormwater runoff it is necessary to consider if the bioretention swale needs to be provided with an impermeable liner. The amount of water lost from bioretention trenches to surrounding in-situ soils is largely dependent on the characteristics of the local soils and the saturated hydraulic conductivity of the bioretention filter media (see SC6.4.3.9.3(2)(a)(iii)).

If the selected saturated hydraulic conductivity of the bioretention filter media is less than 10 times that of the native surrounding soils, it may be necessary to provide an impermeable liner. Flexible membranes or a concrete casting are commonly used to prevent excessive ex-filtration. This is particularly applicable for surrounding soils that are very sensitive to any ex-filtration (e.g. sodic soils and reactive clays in close proximity to significant structures such as roads).

The greatest pathway of ex-filtration is through the base of a bioretention trench, as gravity and the difference in hydraulic conductivity between the filter media and the surrounding native soil would typically act to minimise ex-filtration through the walls of the trench. If lining is required, it is likely that only the base and the sides of the drainage layer (refer to SC6.4.3.9.3(2)(a)(iii)) will need to be lined.

Where ex-filtration of treated stormwater to the surrounding in-situ soils is promoted by the bioretention swale concept design, it is necessary to ensure the saturated hydraulic conductivity of the in-situ soils is at least equivalent to that of the bioretention filter media, thus ensuring no impedance of the desired rate of flow through the bioretention filter media. Depending on the saturated hydraulic conductivity of the in-situ soils it may be necessary to provide an impermeable liner to the sides of the bioretention filter media to prevent horizontal ex-filtration and subsequent short-circuiting of the treatment provided by the filter media. Bioretention trenches promoting ex-filtration do not require perforated under-drains at the base of the filter media or a drainage layer.

A subsurface pipe is often used to prevent water intrusion into a road sub-base. This practice is to continue as a precautionary measure to collect any water seepage from bioretention swales located along roadways.

(iv) Vegetation types

Bioretention swales can use a variety of vegetation types including turf (swale component only), sedges and tufted grasses. Vegetation is required to cover the whole width of the swale and bioretention filter media surface, be capable of withstanding design flows and be of sufficient density to prevent preferred flow paths and scour of deposited sediments.

Grassed (turf) bioretention swales can be used in residential areas where a continuous bioretention trench approach is used. The preferred vegetation for the bioretention component of bioretention swales is therefore sedges and tufted grasses (with potential occasional tree plantings) that do not require mowing.

The denser and taller 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 stormwater during ponding, which results in enhanced sedimentation of suspended sediments and associated pollutants. The vegetation that grows in the bioretention filter media also acts to continuously break up the surface of the media through plant root growth and wind induced agitation, which prevents surface clogging. Vegetation also provides a substrate for biofilm growth in the upper layer of the filter media which facilitates biological transformation of pollutants (particularly nitrogen).

To maintain aesthetics in highly visible areas supplemental irrigation may be required to sustain vegetation. The incorporation of saturated zones beneath the bioretention filter media can help to sustain soil moisture and is beneficial for nitrogen removal from stormwater. The ability to sustain dense perennial vegetation is important for long term weed management.

SC6.4.3.9.6 Plant selection for WSUD systems in the coastal dry tropics provides more specific guidance on the selection of appropriate vegetation for bioretention swales.

(v) Bioretention filter media

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

(A) saturated hydraulic conductivity required to optimise the treatment performance of the bioretention component given site constraints on available filter media area;

(B) depth of extended detention provided above the filter media; and

(C) suitability as a growing media to support vegetation growth (i.e. retaining sufficient soil moisture and organic content).

The area available for bioretention swales in an urban layout is often constrained by factors such as the available area within the footpaths of standard road reserves. Selecting bioretention filter media for bioretention swale applications in the coastal dry tropics will often require careful consideration of saturated hydraulic conductivity and extended detention depth to ensure the desired minimum volume of stormwater runoff receives treatment. This must also be balanced with the requirement to also ensure the saturated hydraulic conductivity does not become too high such that it can no longer sustain healthy vegetation growth. The maximum saturated hydraulic conductivity should not exceed 500 mm/hr (and preferably be between 50 - 200 mm/hr) in order to sustain vegetation growth.

The concept design stage will have established the optimal combination of filter media saturated hydraulic conductivity and extended detention depth using a continuous simulation modelling approach (such as MUSIC). Any adjustment of either of these two design parameters during the detailed design stage will require the continuous simulation modelling to be re-run to assess the impact on the overall treatment performance of the bioretention system.

As shown in Figure SC6.4.3.9.2 below, bioretention media can consist of three or four layers. In addition to the filter media required for stormwater treatment, a saturated zone can also be added to enhance nitrogen removal and to provide a source of water for vegetation over the dry season. A drainage layer is also required to convey treated water from the base of the filter media or saturated zone into the perforated under-drains. The drainage layer surrounds the perforated under-drains and can be either coarse sand (1 mm) or fine gravel (2-5 mm). If fine gravel is used, a transition layer of sand must also be installed to prevent migration of the filter or saturated zone media into the drainage layer and subsequently into the perforated under-drains.

(vi) Saturated zone

The saturated zone design involves a relatively simple modification to a conventional bioretention system. An additional layer located below the filter media is designed to retain stormwater providing a saturated zone at the base of the bioretention system. A saturated zone can be formed by using a riser pipe with the outlet level higher than the drainage layer or by incorporating a weir within the outlet pit. The saturated zone holds water and therefore provides a source of water to maintain soil moisture for plant uptake during dry periods.

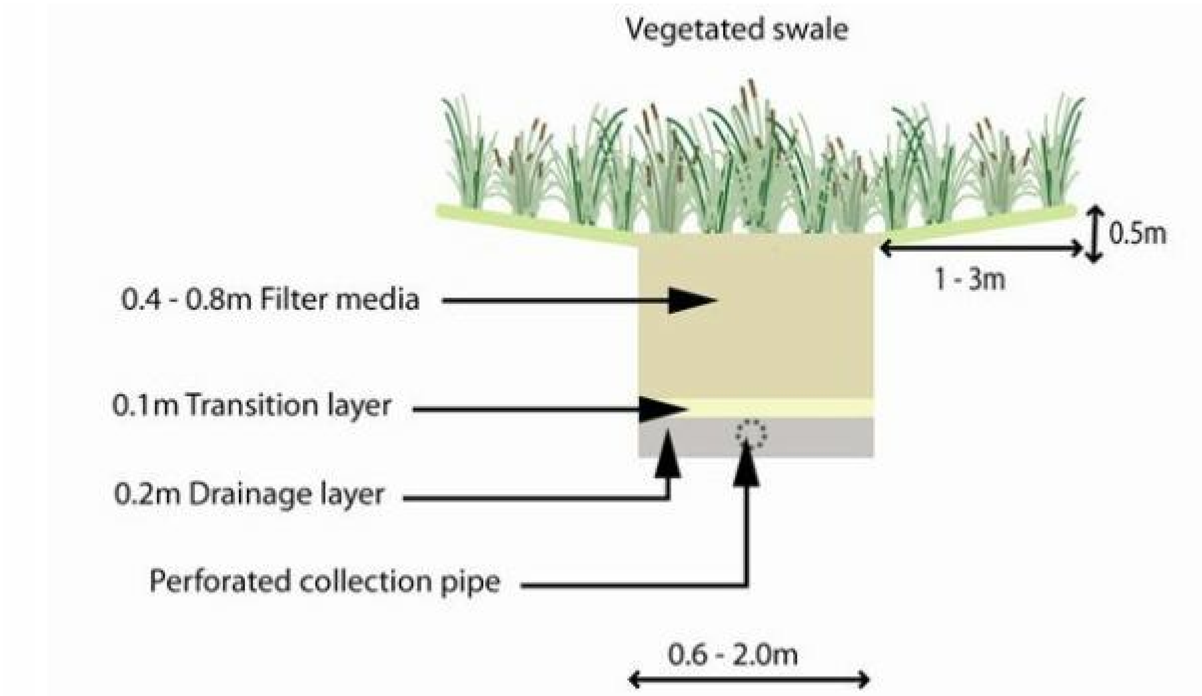

Figure SC6.4.3.9.2 Typical section of a bioretention swale

(vii) Traffic controls

Another design consideration is keeping traffic and building material deliveries off swales, particularly during the building phase of a development.

A staged construction and establishment method (SC6.4.3.9.3(5) Construction and establishment - bioretention swales) affords protection to the sub-surface elements of a bioretention swale from heavily sediment laden runoff during the subdivision construction and allotment building phases. However, to prevent vehicles driving on bioretention swales and inadvertent placement of building materials, it is necessary to consider appropriate traffic control solutions as part of the system design. These can include temporary fencing of the swale during the subdivision construction and allotment building phases with signage erected to alert builders and contractors of the purpose and function of the swales. Kerb and channel should be used at all corners, intersections, cul-de-sac heads and at traffic calming devices to ensure correct driving path is taken. For all of these applications, the kerb and channel is to extend 5 m beyond tangent points.

(viii) Roof water discharge

Roof runoff can contain a range of stormwater pollutants including nitrogen washed from the atmosphere during rainfall events. Roof water should be discharged onto the surface of the swale for subsequent conveyance and treatment by the swale (and downstream treatment measures) before being discharged to receiving aquatic environments. Depending on the depth of the roof water drainage system and the finished levels of the bioretention swale, this may require the use of a small surcharge pit located within the invert of the swale to allow the roof water to surcharge to the swale. Any residual water left in the surcharge pit can be discharged to the underlying subsoil drainage by providing perforations in the base and sides of the surcharge pit. If a surcharge pit is used then an inspection chamber along the roof water drainage line is to be provided within the property boundary. Surcharge pits are discussed further in SC6.4.3.9.3(3)(d)(ii) Concentrated inflow.

(ix) Services

Bioretention swales located within footpaths (i.e. road verges) must consider the standard location for services within the verge and ensure access for maintenance of services. Typically it is acceptable to have water and sewer services located beneath the batters of the swale with any sewers located beneath bioretention swales to be fully welded polyethylene pipes with rodding points.

(3) Bioretention swale design process

(a) Step 1: Confirm treatment performance of concept design

This design process assumes a conceptual design has been undertaken. Before commencing detailed design, the designer should first undertake a preliminary check to confirm the bioretention swale treatment area from the concept design is adequate to deliver the required level of stormwater quality improvement. This assessment should be undertaken by a WSUD specialist and can be achieved by modelling expected treatment performance in an appropriate quantitative modelling program. This modelling must be based on local rainfall data, the proposed configuration of the system, and based on local stormwater treatment performance data.

(b) Step 2: Determine design flows for the swale component

(i) Design flows

Two design flows are required for the design of a swale:

(A) minor flood flow (2 year ARI) to allow minor floods to be safely conveyed. For commercial and industrial areas the design flow requirement for minor flows is a 5 year ARI event.

(B) major flood flow (100 year ARI) to check flow velocities, velocity depth criteria, conveyance within road reserve, and freeboard to adjoining property.

(ii) Design flow estimation

A range of hydrologic methods can be applied to estimate design flows. As the typical catchment area should be relatively small (<50 ha) the Rational Method design procedure is considered to be a suitable method for estimating design peak flows.

(c) Step 3: Dimension the swale component with consideration to site constraints

Factors to consider are:

(i) allowable width given the proposed road reserve and/ or urban layout;

(ii) how flows are delivered into a swale (e.g. cover requirements for pipes or kerb details);

(iii) vegetation height;

(iv) longitudinal slope;

(v) maximum side slopes and base width;

(vi) provision of crossings (elevated or at grade); and

(vii) requirements of QUDM and Townsville City Plan.

Depending on which of the above factors are fixed, the other variables can be adjusted to derive the optimal swale dimensions for the given site conditions. The following sections outline some considerations in relation to dimensioning a swale.

(i) Swale width and side slopes

Where the swale width is not constrained by an urban layout (e.g. when located within a large parkland area) then the width of the swale can be selected based on consideration of landscape objectives, maximum side slopes for ease of maintenance and public safety, hydraulic capacity required to convey the desired design flow, and treatment performance requirements. The maximum swale width needs to be identified early in the design process as it dictates the remaining steps in the swale design process. Selection of appropriate sideslopes for swales in parks, easements or median strips is heavily dependent on site constraints, and swale side slopes are typically between 1 in 10 and 1 in 4.

For swales located adjacent to roads, the types of driveway crossing used will typically dictate batter slopes. Where there are no driveway crossings, the maximum swale side slopes will be established for ease of maintenance and public safety considerations. Generally “at-grade” crossings, are preferred which require the swale to have 1:9 side slopes with a nominal 0.5 m flat base to provide sufficient transitions to allow for traffic movement across the crossing. Flatter swale side slopes can be adopted but this will reduce the depth of the swale and its conveyance capacity. Where “elevated” crossings are used, swale side slopes would typically be between 1 in 6 and 1 in 4. “Elevated” crossings will require provision for drainage under the crossings with a culvert or similar.

(ii) Maximum length of a swale

The maximum length of a swale located within parkland areas and easements is calculated as the distance along the swale to the point where the flow in the swale from the contributing catchment (for the specific design flood frequency) exceeds the bank full capacity of the swale. For example, if the swale is to convey the minor flood flow (1-5 year ARI) without overflowing, then the maximum swale length would be determined as the distance along the swale to the point where the 1-5 year ARI flow from the contributing catchment is equivalent to the bank full flow capacity of the swale (bank full flow capacity is determined using Manning’s equation as discussed in SC6.4.3.9.3(3)(c)(iii) Swale capacity).

(iii) Swale capacity – Manning’s Equation and selection of Manning’s *n*

To calculate the flow capacity of a swale, use Manning’s equation. This allows the flow rate and flood levels to be determined for variations in swale dimensions, vegetation type and longitudinal grade.

$$Q = \frac{A \cdot R^{2/3} \cdot S^{1/2}}{n}$$

Where A = cross section area of swale (m^2)
R = hydraulic radius (m)
S = channel slope (m/m)
N = roughness factor (Manning’s n)

Figure SC6.4.3.9.3 shows a plot of Manning’s *n* versus flow depth for a grass swale with longitudinal grade of 5 %. It is reasonable to expect the shape of the Manning’s n relation with flow depth to be consistent with other swale configurations, with the vegetation height at the boundary between low flows and intermediate flows (Figure SC6.4.3.9.3) on the top axis of the diagram. The bottom axis of the plot has been modified from Barling and Moore (1993) to express flow depth as a percentage of vegetation height.

Further discussion on selecting an appropriate Manning’s n for a swale is provided in Appendix E of the MUSIC User Guide (CRCCH 2005).

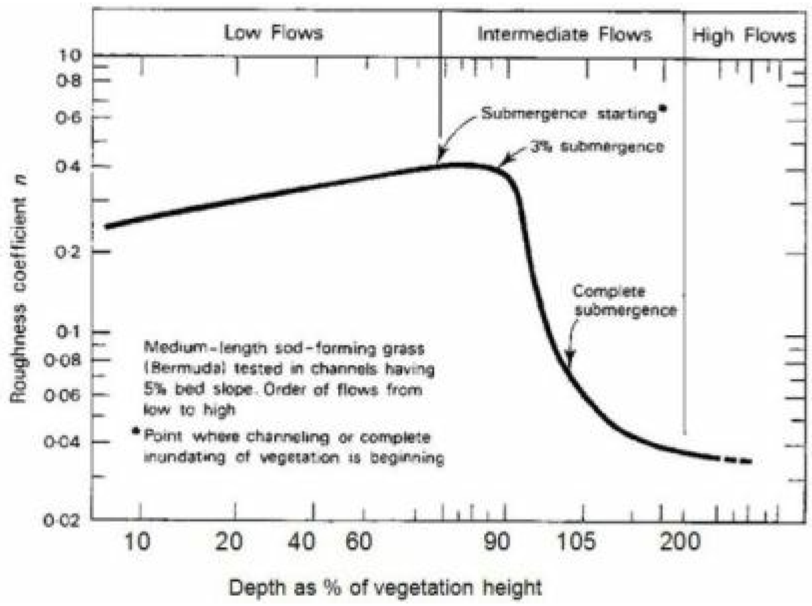

Figure SC6.4.3.9.3 Impact of flow depth on hydraulic roughness (adapted from Barling and Moore (1993))

(d) Step 4: Design inflow systems to swale and bioretention components

Inflows to bioretention swales can be via distributed runoff (e.g. from flush kerbs on a road) or point outlets such as pipe outfalls. Combinations of these inflow pathways can also be used.

(i) Distributed inflow

An advantage of flows entering a bioretention swale system in a distributed manner (i.e. entering perpendicular to the direction of the swale) is that flow depths are kept as shallow sheet flow, which maximises contact with the swale and bioretention vegetation, particularly on the batter receiving the distributed inflows. This swale and bioretention batter is often referred to as a buffer (see Figure SC6.4.3.9.4). The requirement of the buffer is to ensure there is dense vegetation growth, flow depths are shallow (below the vegetation height) and erosion is avoided. The buffer provides good pre-treatment (i.e. significant coarse sediment removal) prior to flows being conveyed along the swale.

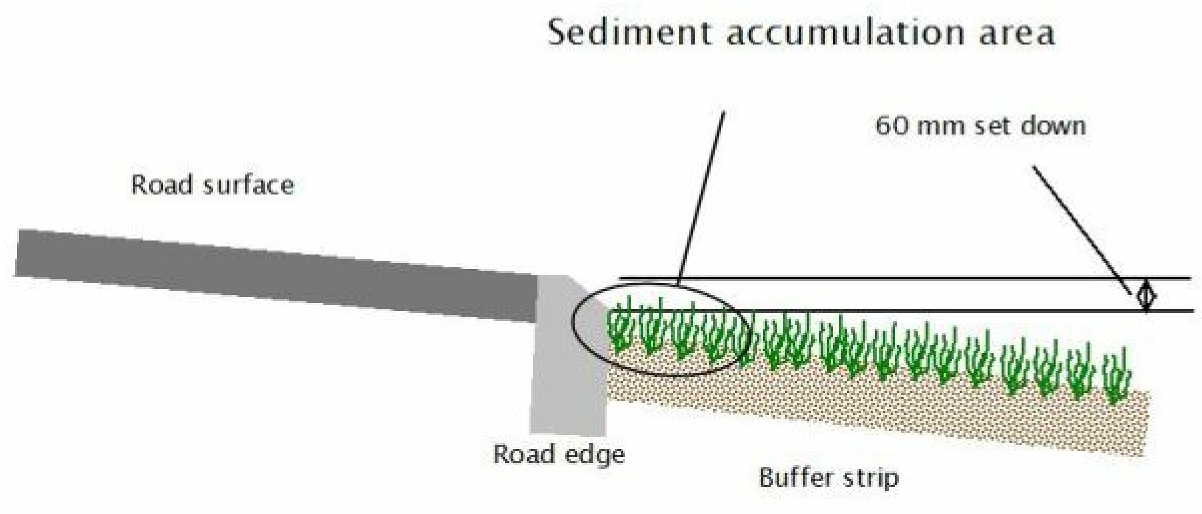

Figure SC6.4.3.9.4 Flush kerb with 60 mm setdown to allow sediment to flow into vegetated area

Distributed inflows can be achieved either by having a flush kerb or by using kerbs with regular breaks in them to allow for even flows across the buffer surface (Figure SC6.4.3.9.5).

Figure SC6.4.3.9.5 Kerb arrangements with breaks and flush kerbs to distribute inflows on to bioretention swales and prevent vehicle access

Key design parameters of buffer systems are:

(A) providing distributed flows into a buffer (potentially spreading stormwater flows to achieve this);

(B) avoiding rilling or channelised flows;

(C) maintaining flow heights lower than vegetation heights (this may require flow spreaders, or check dams); and

(D) minimising the slope of buffer, best if slopes can be kept below 5%.

Maintenance of buffers is required to remove accumulated sediment and debris therefore access is important. It is important to ensure coarse sediments accumulate off the road surface at the start of the buffer. Figure SC6.4.3.9.6 shows sediment accumulating on a street surface where the vegetation is the same level as the road. To avoid this accumulation, a tapered flush kerb must be used that sets the top of the vegetation 60 mm which requires the top of the ground surface (before turf is placed) to be approximately 100 mm below the road surface. This allows sediments to accumulate off any trafficable surface.

Figure SC6.4.3.9.6 Flush kerb without setdown, showing sediment accumulation on road

(ii) Concentrated inflow

Concentrated inflows to a bioretention swale can be in the form of a concentrated overland flow or a discharge from a piped drainage system (e.g. allotment drainage line). For all concentrated inflows, energy dissipation at the inflow location is required to minimise any erosion potential. This can usually be achieved with rock benching and/ or dense vegetation.

The most common constraint on pipe systems discharging to bioretention swales is bringing the pipe flows to the surface of a swale. In situations where the swale geometry does not allow the pipe to achieve “free” discharge to the surface of the swale, a “surcharge” pit may be used but should be avoided where possible.

Surcharge pit systems are most frequently used when allotment runoff is required to cross a road into a swale on the opposite side of the road or for allotment runoff discharging into shallow profile swales. Where allotment runoff needs to cross under a road to discharge to a swale, it is preferable to combine the runoff from more than one allotment to reduce the number of crossings required under the road pavement. Figure SC6.4.3.9.7 illustrates a typical surcharge pit discharging into a swale.

Another important form of concentrated inflow in a bioretention swale is the discharge from the swale component into the bioretention component, particularly where the bioretention component is located at the downstream end of the overlying swale and receives flows concentrated within the swale. Depending on the grade, its top width and batter slopes, the resultant flow velocities at the transition from the swale to the bioretention filter media may require the use of energy dissipation to prevent scour of the filter media (if flow velocities > 0.5 m/sec). For most cases, this can be achieved by placing several large rocks in the flow path to reduce velocities and spread flows. Energy dissipaters located within footpaths must be designed to ensure pedestrian safety.

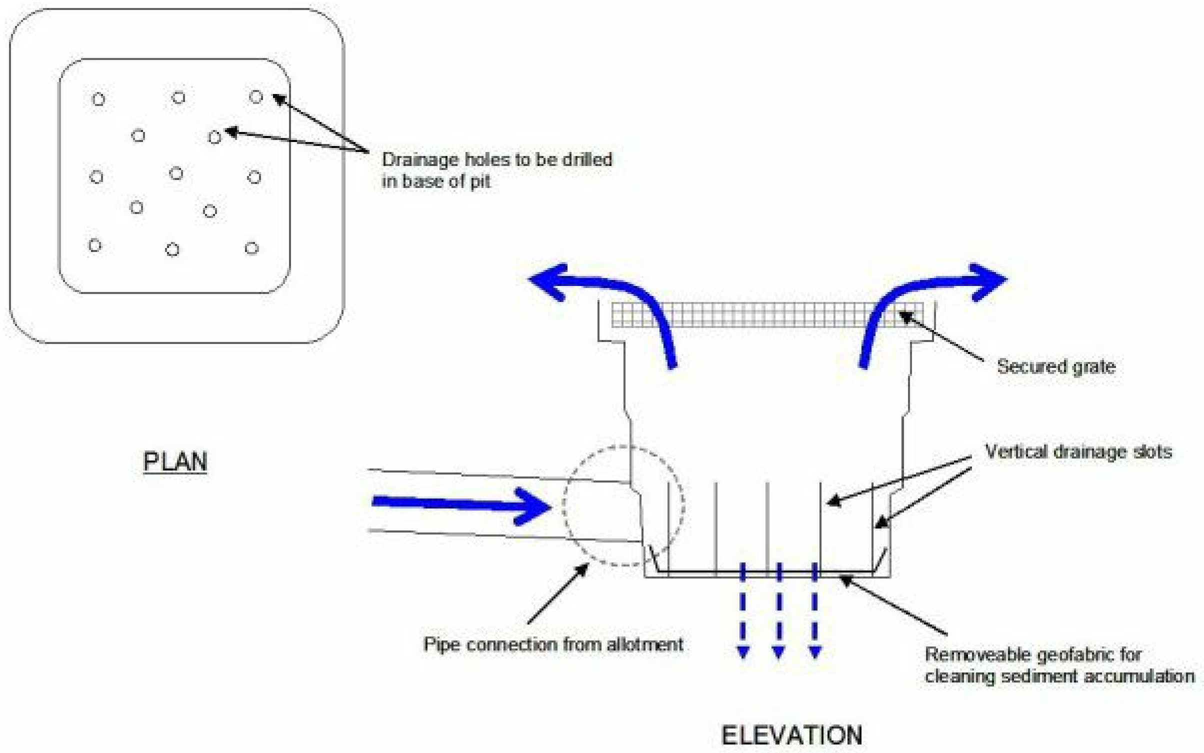

Figure SC6.4.3.9.7 Example of surcharge pit for discharging allotment runoff into a swale

(e) Step 5: Design bioretention component

(i) Select filter media saturated hydraulic conductivity and extended detention

Where design Steps 2 and 3 (SC6.4.3.9.3(3)(b) and SC6.4.3.9.3(3)(c)) reveal that the swale geometry derived during the concept design stage does not comply with the relevant local road drainage design standards and/or the standards established in QUDM for minor flood and major flood flows on adjoining road pavements and minimum freeboard requirements to adjoining properties, it is necessary to revise the swale geometry. As such, an alternative dimension for the surface area of the bioretention component may result and this may require further quantitative modelling to determine the "new" optimal combination of filter media saturated hydraulic conductivity and extended detention depth to maximise the water quality treatment function of the bioretention component.

(ii) Specify the bioretention filter media characteristics

Three to four types of media can be required in the bioretention component of bioretention swales (refer Figure SC6.4.3.9.2).

<u>Filter media</u>
The filter media layer provides the majority of the pollutant treatment function, through fine filtration and also by supporting vegetation. The vegetation enhances filtration, keeps the filter media porous, provides substrate for biofilm formation and provides some uptake of nutrients and other stormwater pollutants. As a minimum, the filter media is required to have sufficient depth to support vegetation. Typical depths are between 600-1000 mm with a minimum depth of 300 mm accepted in depth constrained situations. It is important to note that if deep rooted plants such as trees are to be planted in bioretention swales, the filter media must have a minimum depth of 800 mm to avoid roots interfering with the perforated under-drain system.

The saturated hydraulic conductivity of the filter media is established by optimising the treatment performance of the bioretention system given site constraints of the particular site (using a continuous simulation model). Saturated hydraulic conductivity should remain between 50-200 mm/hr (saturated hydraulic conductivity of greater than 500 mm/hr would not be accepted by most councils). Once the saturated hydraulic conductivity of the filter media has been determined for a particular bioretention swale, the following process can then be applied to derive a suitable filter media soil to match the design saturated hydraulic conductivity:

(A) identify available sources of a suitable base soil (i.e. topsoil) capable of supporting vegetation growth such as a sandy loam or sandy clay loam. In-situ topsoil should be considered first before importing a suitable base soil. Any base soil found to contain high levels of salt (see last bullet point), extremely low levels of organic carbon (< 5%), or other extremes considered retardant to plant growth and denitrification should be rejected. The base soil must also be structurally sound and not prone to structural collapse as this can result in a significant reduction in saturated hydraulic conductivity. The risk of structural collapse can be reduced by ensuring the soil has a well graded particle size distribution with a combined clay and silt fraction of < 12%;

(B) using laboratory analysis, determine the saturated hydraulic conductivity of the base soil using standard testing procedures (AS 4419-2003 Appendix H Soil Permeability). A minimum of five samples of the base soil should be tested. Any occurrence of structural collapse during laboratory testing must be noted and an alternative base soil sourced;

(C) the required content of sand or clay (by weight) to be mixed to the base soil will need to be established in the laboratory by incrementally increasing the content of sand or clay until the desired saturated hydraulic conductivity is achieved. The sand or clay content (by weight) that achieves the desired saturated hydraulic conductivity should then be adopted on-site. A minimum of five samples of the selected base soil and sand (or clay) content mix must be tested in the laboratory to ensure saturated hydraulic conductivity is consistent across all samples. If the average saturated hydraulic conductivity of the final filter media mix is within ± 20% of the design saturated hydraulic conductivity then the filter media can be adopted and installed in the bioretention system. Otherwise, further amendment of the filter media must occur through the addition of sand (or clay) and retested until the design saturated hydraulic conductivity is achieved;

(D) the base soil must have sufficient organic content to establish vegetation on the surface of the bioretention system. If the proportion of base soil in the final mix is less than 50%, it may be necessary to add organic material. This should not result in more than 10% organic content (measured in accordance with AS 1289.4.1.1-1997) and should not alter the saturated hydraulic conductivity of the final filter media mix;

(E) the pH of the final filter media is to be amended (if required) to between 6 and 7. If the filter media mix is being prepared off-site, this amendment should be undertaken before delivery to the site; and

(F) the salt content of the final filter media (as measured by EC1:5) must be less than 0.63dS/m for low clay content soils like sandy loam. (EC1:5 is the electrical conductivity of a 1:5 soil/ water suspension).

Transition layer (if required)

The purpose of the transition layer is to prevent the filter media from migrating down into the drainage layer (or saturated layer). It also acts as a buffer between the permanently saturated zone and the filter media. This buffer is necessary to ensure the filter media is not saturated for prolonged periods during rainfall events due to increases in water levels in the saturated zone. To achieve this, the transition layer depth must be greater than the head created by flows over the saturated zone outlet weir.

It is required if the particle size difference between the filter media and the drainage layer (or saturated layer) is more than one order of magnitude. If a transition layer is required then the material must be a clean, well-graded sand/coarse sand material containing little or no fines.

The transition layer is recommended to be 100 mm thick and have a minimum saturated hydraulic conductivity of 1000 mm/hr.

A recent particle size distribution for the transition layer sand will need to be obtained to ensure that it meets the required grading/"bridging" criteria outlined below. The "bridging" criteria is based on the engineering principles that rely on the largest 15% of the filter media particles "bridging" with the smallest 15% of the sand particles. This results in smaller voids, which prevent the migration of the filter media particles into the sand particles. The following equation is taken from the United

States Golf Association's recommendations for golf course construction:

Bridging Factor: **D15 (transitional layer sand) ≤ 8 x D85 (filter media)**

The addition of a transition layer increases the overall depth of the bioretention system and may be an important consideration for some sites where total depth of the bioretention system may be constrained. In such cases, the use of a sand drainage layer and/ or perforated pipes with smaller slot sizes may need to be considered (SC6.4.3.9.4(2)(e) Step 5: Design under-drain and undertake capacity checks (if required)).

Saturated layer (if required)

The saturated layer should be about 400 mm deep (but may deeper depending on the specific application) and composed of clean (i.e. free from fines) medium-coarse washed sand, gravel or small rock (50 mm diameter maximum) together with a long term carbon source. Hardwood wood chips, 5 mm to 40 mm in size, are recommended as the carbon source because they breakdown slowly to provide a long term carbon source yet have a decomposition rate that should not limit the denitrification process.

The total mass of carbon/electron donor that is required for denitrification must be calculated based on the expected stormwater influent TN mass over the desired life span of the system (e.g. 25 years). The calculation is based on the stoichiometry of the denitrification reaction (shown below).

Denitrification reaction:

NO_3- + 1.25 (CH_2O) + H+ (10^7M) → 0.5N_2 (g) + 1.75H_2O + 1.25CO_2 (g)

Based on a 400 mm deep saturated zone and the modelled annual TN runoff mass (for Townsville) for a bioretention system that is 2% of the contributing 1ha catchment, the saturated zone media would have the following composition:

- 76.7 m^3 washed coarse sand, gravel or small rock; and
- 3.3 m^3 hardwood wood chips, well graded 5 mm-40 mm.

This is equivalent to an organic carbon content of approximately 4-5% by volume. If the saturated zone depth changed, or the bioretention system to catchment area ratio changed, the hardwood proportion would need to be recalculated using the denitrification stoichiometry.

Calculating Carbon Source for Saturated Zone with safety factor (x2)	
Catchment Area	1 ha
Treatment Area Required	2%
Bioretention Surface Area	200 m^2
Saturated Zone Depth	400 mm
Total volume of Saturated Zone	80 m^3
TN load 1 year	12.5 kg/yr
TN load 25 years	312.5 kg/25yrs
Stoichiometry:	
N:C ratio = 1:1.25 (mol), which equates to 14:15(g) [Mw: N = 14g/mol, C = 12g/mol]	
Average total carbon content of hardwood woodchips is 50%, therefore	
N:C (woodchip) = 14:30 (g)	
N:C (woodchip) = 1:2.1	
Woodchips (312.5 x 2.1)	656 kg/carbon
Safety Factor (x 2)	1313kg/carbon
Density of wood chips	400 kg/m^3 (approx.)
Hardwood Wood Chips	**3.3 m^3**
Clean Coarse Sand	**76.7 m^3**

The saturated media must have a hydraulic conductivity of >1000 mm/hr (the ASTM F1815-06 test method is to be used to measure hydraulic conductivity).

The saturated zone should be lightly compacted (e.g. with one pass of a smooth drum lawn roller) during installation to stabilise the structure. Under no circumstances should heavy compaction or multiple-passes be made.

Drainage layer (if required)

The drainage layer is used to convey treated flows from the base of the filter media layer (or saturated zone) into the perforated under-drainage system. The composition of the drainage layer is to be considered in conjunction with the selection and design of the perforated under-drainage system (refer to SC6.4.3.9.3(e)(iii)) as the slot sizes in the perforated pipes may determine the minimum drainage layer particle size to avoid washout of the drainage layer into the perforated pipe system. Coarser material (e.g. fine gravel) is to be used for the drainage layer if the slot sizes in the perforated pipes are too large for use of a sand based drainage layer. Otherwise, sand is the preferred drainage layer media as it is likely to avoid having to provide a transition layer between the filter media and the drainage layer (if there is no saturated zone). The drainage layer is to be a minimum of 200 mm thick.

Bridging Factor:

D15 (drainage gravel/sand) ≤ 8 x D85 (filter media/saturated zone/transition layer)

Ensure drainage media is washed prior to placement in bioretention system to remove any fines.

(iii) Under-drain design and capacity checks

The maximum spacing of the perforated pipes in wide bioretention trenches is 1.5 m (centre to centre) so that the distance water needs to travel (horizontally) through the drainage layer does not hinder drainage of the filtration media.

By installing parallel pipes, the capacity of the perforated pipe under-drain system can be increased. The recommended maximum size for the perforated pipes 100 mm to minimise the required thickness of the drainage layer. Either flexible perforated pipe (e.g. ag pipe) or slotted

PVC pipes can be used, however care needs to be taken to ensure that the slots in the pipes are not so large that sediment would freely flow into the pipes from the drainage layer. This is also a consideration when specifying the drainage layer media.

To ensure the slotted pipes are of adequate size, several checks are required:

- ensure perforations are adequate to pass the maximum infiltration rate;
- ensure the pipe itself has capacity to convey the design flow/ infiltration rate; and
- ensure that the material in the drainage layer will not be washed into the perforated pipes (consider a transition layer).

The maximum infiltration rate represents the maximum rate of flow through the bioretention filter media and is calculated by applying Darcy's equation (Equation 3.2) as follows:

$$Q_{max} = K_{sat} \cdot L \cdot W_{base} \cdot \frac{h_{max} + d}{d}$$

Where	Q_{max}	=	maximum infiltration rate (m^3/s)
	K_{sat}	=	hydraulic conductivity of the soil filter (m/s)
	W_{base}	=	base width of the ponded cross section above the soil filter (m)
	L	=	length of the bioretention zone (m)
	h_{max}	=	depth of pondage above the soil filter (m)
	d	=	depth of filter media (m)

The capacity of the perforated under-drains need to be greater than the maximum infiltration rate to ensure the filter media drains freely and the pipe(s) do not become the hydraulic "control" in the bioretention system (i.e. to ensure the filter media sets the travel time for flows percolating through the bioretention system rather than the perforated under-drainage system).

To ensure the perforated under-drainage system has sufficient capacity to collect and convey the maximum infiltration rate, it is necessary to determine the capacity for flows to enter the under-drainage system via perforations in the pipes. To do this, orifice flow can be assumed and the sharp edged orifice equation can be used. Firstly, the number and size of perforations needs to be determined (typically from manufacturer's specifications) and used to estimate the flow rate into the pipes using the maximum driving head (being the depth of the filtration media if no extended detention is provided or if extended detention is provided in the design then to the top of extended detention). It is conservative but reasonable to use a blockage factor to account for partial blockage of the perforations by the drainage layer media. A 50% blockage of the perforation is recommended.

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

Where	Q_{perf}	=	flow through perforations (m^3/s)
	B	=	blockage factor (0.5)
	C_d	=	orifice discharge coefficient (assume 0.61 for sharp edge orifice)
	A	=	total area of the orifice (m^2)
	g	=	gravity (9.79 m/s^2)
	h	=	head above the perforated pipe (m)

If the capacity of the drainage system is unable to collect the maximum infiltration rate then additional under- drains will be required.

After confirming the capacity of the under-drainage system to collect the maximum infiltration rate is it then necessary to confirm the conveyance capacity of the underdrainage system is sufficient to convey the collected runoff. To do this, Manning's equation (Equation 3.1) can be used (which assumes pipe full flow (in place of channel flow) but not under pressure). The Manning's roughness used will be dependent on the type of pipe used. When a saturated zone is incorporated into the design, the underdrainage pipes are laid flat however the conveyance capacity can be calculated using the Manning's equation with an assumed friction slope of 0.5%.

The under-drains should be extended vertically to the surface of the bioretention system to allow inspection and maintenance when required. The vertical section of the under-drain should be unperforated and capped to avoid short circuiting of flows directly to the drain.

In bioretention systems with a saturated zone, the capacity of the weir or up-turned pipe (maintaining the water level within the saturated zone) must also be checked to ensure it does not become the hydraulic "control" in the bioretention system (i.e. to ensure the filter media sets the travel time for flows percolating through the bioretention system). A broad crested weir equation can be used to determine the length of weir required (assuming free flowing conditions) to convey the maximum flow/filtration rate. The maximum depth of flow over the weir is to be 100 mm. This is important to limit increase in the saturated zone depth and avoid prolonged saturation of the filter media.

(iv) Check requirement for impermeable lining

The saturated hydraulic conductivity of the natural soil profile surrounding the bioretention system should be tested together with depth to groundwater, chemical composition and proximity to structures and other infrastructure. This is to establish if an impermeable liner is required at the base (only for systems designed to preclude ex-filtration to in-situ soils) and/or sides of the bioretention system (refer also to discussion in SC6.4.3.9.3(2)(a)(iii) Ex-filtration to in-situ soils). If the saturated hydraulic conductivity of the filter media in the bioretention system is more than one order of magnitude (10 times) greater than that of the surrounding in-situ soil profile, no impermeable lining is required.

(f) Step 6: Verify design

(i) Vegetation scour velocity check

Potential scour velocities are checked by applying Manning's equation (Equation 3.1) to the bioretention swale design to ensure the following criteria are met:

(A) less than 0.5 m/s for minor flood (2-10 year ARI) discharge; and

(B) less than 2.0 m/s for major flood (50-100 year ARI) discharge.

(ii) Velocity and depth check – safety

As bioretention swales are generally accessible by the public, it is important to check that depth x velocity within the bioretention swale, at any crossings and adjacent pedestrian and bicycle pathways, satisfies the following public safety criteria:

(A) depth x velocity < 0.6 m^2/s for low risk locations and 0.4 m^2/s for high risk locations as defined in QUDM; and

(B) maximum depth of flow over crossing = 0.3 m.

(iii) Confirm treatment performance

If the previous two checks are satisfactory then the bioretention swale design is satisfactory from a conveyance function perspective and it is now necessary to confirm the treatment performance of the bioretention swale by reference to the performance information presented in SC6.4.3.9.3(3)(a)).

(g) Step 7: Size overflow pit (field inlet pits)

In a bioretention swale system, an overflow pit can be provided flush with the invert of the swale and/ or bioretention system filter media (i.e. when no extended detention is provided in the design) or it can be provided with the pit crest raised above the level of the bioretention filter media to establish the design extended detention depth (if extended detention is provided for in the design).

Grated pits are typically used and the allowable head for discharges into the pits is the difference in level between the pit crest and the maximum permissible water level to satisfy the local council's minimum freeboard requirements. Depending on the location of the bioretention swale, the design flow to be used to size the overflow pit could be the maximum capacity of the swale, the minor flood flow (2-5 year ARI) or the major flood flow (50 year ARI). There should be a minimum of 100 mm head over the overflow pit crest to facilitate discharge of the design flow into the overflow pit.

To size an overflow pit, two checks should be made to test for either drowned or free flowing conditions. A broad crested weir equation can be used to determine the length of weir required (assuming free overflowing conditions) and an orifice equation used to estimate the area between openings required in the grate cover (assuming drowned outlet conditions). The larger of the two pit configurations should be adopted (as per Section 7.05 QUDM). In addition, a blockage factor is to be used, that assumes the grate is 50% blocked.

For free overfall conditions (weir equation):

$$Q_{weir} = B \cdot C_w \cdot L \cdot h^{3/2}$$

Where	Q_{weir}	=	Flow into pit (weir) under free overfall conditions (m^3/s)
	B	=	Blockage factor (= 0.5)
	C_w	=	Weir coefficient (= 1.66)
	L	=	Length of weir (perimeter of pit) (m)
	h	=	Flow depth above the weir (pit) (m)

Once the length of weir is calculated, a standard sized pit can be selected with a perimeter at least the same length of the required weir length.

For drowned outlet conditions (orifice equation):

$$Q_{orifice} = B \cdot C_d \cdot A\sqrt{2 \cdot g \cdot h}$$

Where *B*, *g* and *h* have the same meaning as in Equation 3.4

$Q_{orifice}$	=	flow rate into pit under drowned conditions (m^3/s)
C_d	=	discharge coefficient (drowned conditions = 0.6)
A	=	area of orifice (perforations in inlet grate) (m^2)

When designing grated field inlet pits, reference is also to be made to the procedure described in QUDM Section 7.05.4 (DNRW, IPWEA and BCC, 1998).

When a saturated zone is included in the design of a bioretention system, additional components must be incorporated into the outlet design. A saturated zone can be formed at the base of a bioretention system by using a riser pipe with the outlet level set at the top of the desired saturation depth (i.e. top of the saturated zone) or by incorporating a weir/overflow structure within the outlet pit (see Figure SC6.4.3.9.22). The saturated zone would hold water rather than draining freely, and would therefore provide a source of water to the plants during dry periods.

(h) Step 8: Make allowances to preclude traffic on swales

Refer to SC6.4.3.9.3(a)(vii) for discussion on traffic control options.

(i) Step 9: Specify plant species and planting densities

Refer to SC6.4.3.9.3(4) Landscape design notes - bioretention swales and SC6.4.3.6 Landscape policy for advice on selecting suitable plant species for bioretention swales in the coastal dry tropics. Consultation with landscape architects is recommended when selecting vegetation to ensure the treatment system compliments the landscape design of the area.

(j) Step 10: Consider maintenance requirements

Consider how maintenance is to be performed on the bioretention swale (e.g. how and where is access available, where is litter likely to collect etc.). A specific maintenance plan and schedule should be developed for the bioretention swale in accordance with SC6.4.3.9.3(6) Maintenance requirements - bioretention swales.

(k) Design calculation summary

The following design calculation table (Table SC6.4.3.9.4) can be used to summarise the design data and calculation results from the design process.

Click here to view **Table SC6.4.3.9.4 Bioretention swales design calculation summary**

(l) Typical design parameters

Table SC6.4.3.9.5 shows typical values for a number of key bioretention swale design parameters.

Table SC6.4.3.9.5 Typical design parameters for bioretention swales

Design Parameter	Typical Values
Swale longitudinal slope	1% to 4%
Swale side slope for trafficability (with “at grade” crossover)	Maximum 1 in 9
Swale side slope (with elevated driveway crossover)	1 in 4 to 1 in 10
Manning’s *n* (with flow depth lower than vegetation height)	0.15 to 0.3
Manning’s *n* (with flow depth greater than vegetation height)	0.03 to 0.05
Maximum velocity for scour in minor event (e.g. 2-10yr ARI)	0.5 m/s
Maximum velocity for 50-100yr ARI	2.0 m/s
Perforated pipe size	100 mm (maximum)
Drainage layer average material diameter (typically fine gravel or coarse sand)	1-5 mm diameter
Transition layer average material diameter typically sand to coarse sand	0.7 – 1.0 mm diameter

(4) Landscape design notes - bioretention swales

Bioretention swales are a combined solution that involves integrating a swale with the filtration function of a bioretention basin/trench. These can involve an extended detention treatment and some biological uptake through the planted bioretention component. The landscaping for both the swale and bioretention parts are essentially similar to the treatments for the stand alone components however consideration of the interface landscape between the vegetated swale and bioretention is important.

(a) Objectives

Landscape design for bioretention swales has four key objectives:

(i) ensure surface treatments and planting designs address stormwater quality objectives by incorporating appropriate plant species for stormwater treatment (biologically active root zone) whilst enhancing the overall natural landscape. This includes requirements for maintaining dense perennial vegetation throughout the dry season to maintain aesthetics and to minimise weed growth;

(ii) integrated planning and design of bioretention swales within the built and landscape environments;

(iii) incorporating crime prevention through environmental design (CPTED) principles and road, driveway and footpath visibility safety standards; and

(iv) create landscape amenity opportunities that enhance community and environmental needs, such as visual aesthetics, shade, screening, view framing, and way finding.

(b) Streetscape bioretention systems

When using bioretention swales in road reserves it is important to understand how the swale landscape can be used to define the visual road space. Creative landscape treatments may be possible given that the bioretention swale element will typically be a minimum of 4 m in width. Design responses may range from informal “natural” planting layouts to regimented avenues of trees along each external and internal edge of the bioretention swale element. Bioretention swales can be incorporated into a typical streetscape landscape using either a central splitter median or using one side of the road reserve.

Bioretention swale surface treatments are generally a vegetated swale that integrates into a densely planted bioretention component. The use of turf for the bioretention parts of the system is discouraged as mowing and public use of these areas will compact the upper filter media and limit the amount of filtration.

Vegetated bioretention swales can provide a relatively maintenance free finish if the planting and invert treatment are designed well. Key considerations when detailing are density and types of plantings, locations of trees and shrubs, type of garden (mowing) edges to turf areas that allows unimpeded movement of stormwater flow and overall alignment of swale invert within the streetscape.

(i) Centre median

Generally, the central median swale will provide a greater landscaped amenity, allowing planting and shade trees to enhance the streetscape more effectively, whilst verges remain constraint free. This swale configuration is however confined to roads requiring larger corridors for increased traffic.

This can be seen in Figure SC6.4.3.9.8 and Figure SC6.4.3.9.9.

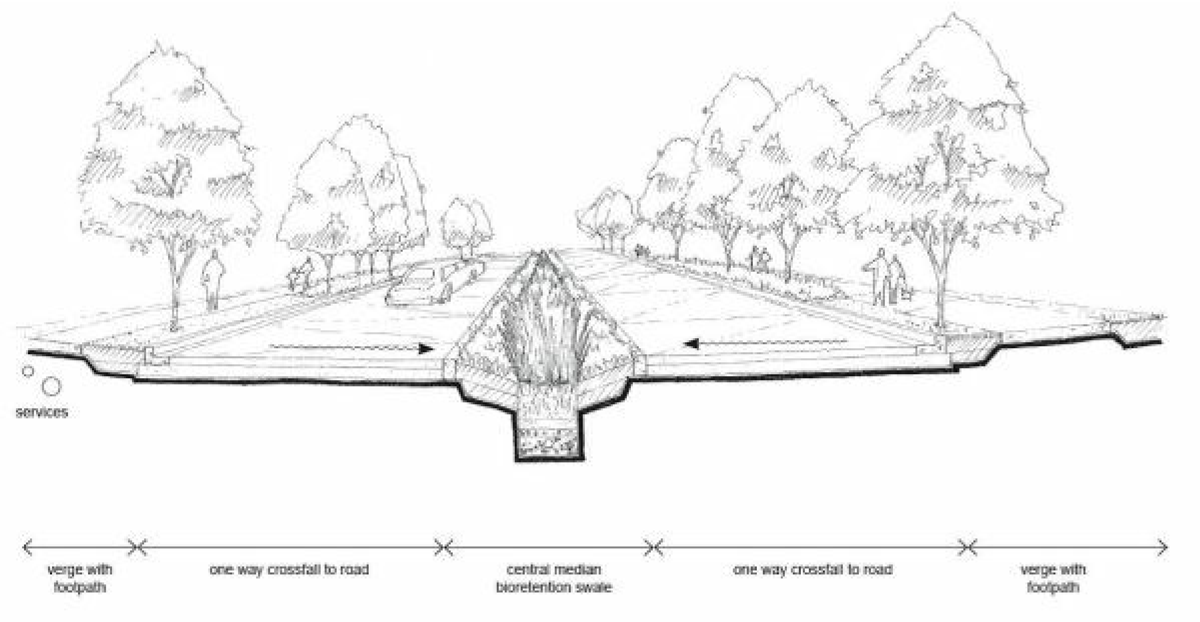

Figure SC6.4.3.9.8 Bioretention swale in centre median

Figure SC6.4.3.9.9 Median strip bioretention applications

(ii) Side of road

In smaller minor roads, one side of the road can have a swale landscape to capture stormwater runoff from road pavements and house lots. To enhance the visual road space, creative landscape treatments to driveway cross-overs, general planting and invert treatments should be used. It is important in this swale arrangement that services and footpaths that are standard for road verges have been planned and located to avoid clashes of function. This can be seen in Figure SC6.4.3.9.10.

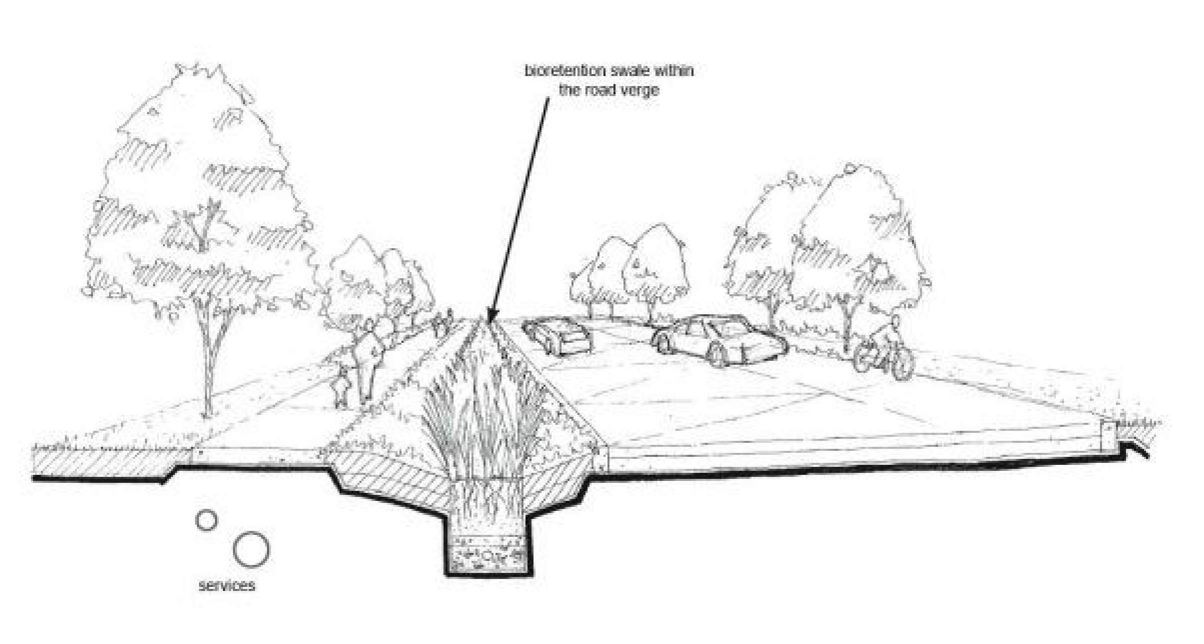

Figure SC6.4.3.9.10 Bioretention swale within road verge

(c) Civic and urban spaces

With increasing population growth in the coastal dry tropics, gentrification of urban areas is required to create more robust spaces that meet current environmental and social needs. Often constrained by existing infrastructure, landscape treatments of swales can have a dual role of providing functional stormwater quality objectives whilst creating landscapes that enhance the communities' perception of water sensitive design.

By creating hard useable edges to swales and using complimentary planting strategies, civic spaces can provide an aesthetic landscape that meets recreational uses and promotes water sensitive design to the community. Refer to Figure SC6.4.3.9.11 for an illustrative example.

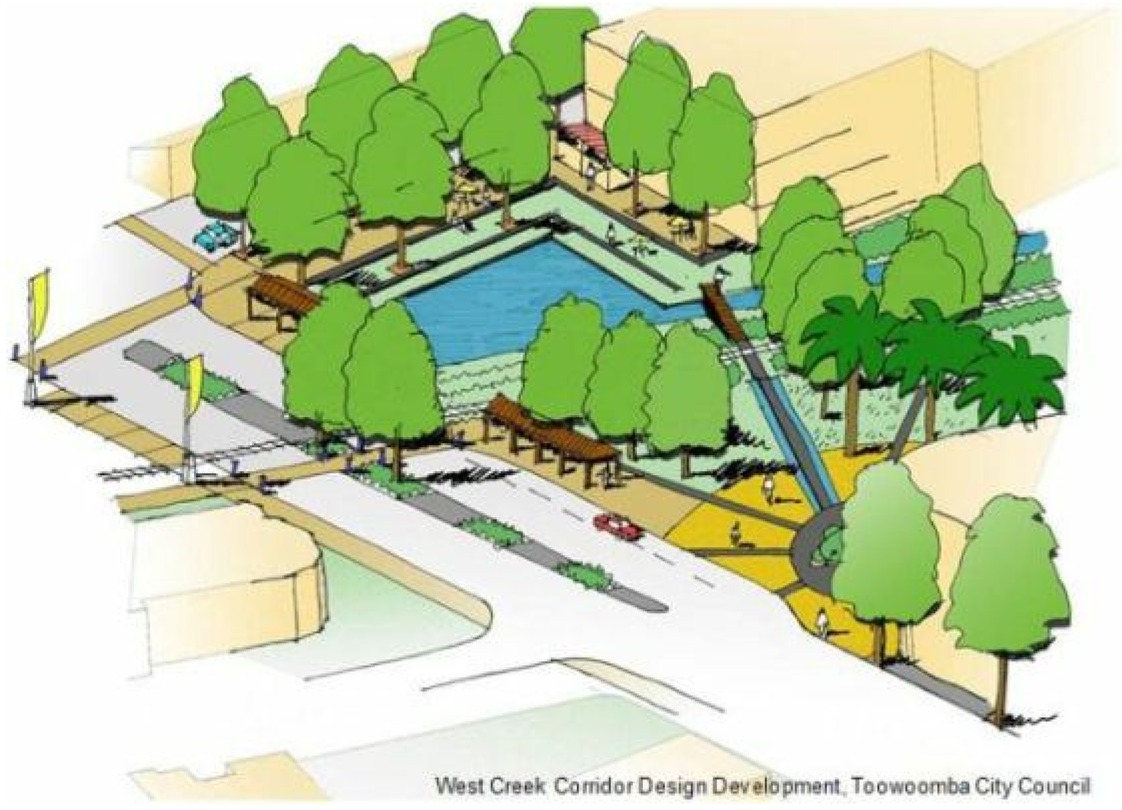

Figure SC6.4.3.9.11 Swale treatment in civic space

(d) Appropriate plant species

Planting for bioretention swale elements may consist of up to four vegetation types:

(i) groundcovers for stormwater treatment and erosion protection (required element);

(ii) shrubbery for screening, glare reduction, character, and other values;

(iii) street trees for shading, character and other landscape values; and

(iv) existing vegetation.

It is important to note that deep rooted plants such as trees are to be planted towards the top of the swale bank rather than near the bioretention trench, to avoid roots interfering with the underdrain system.

Where the landscape design includes canopy layers, more shade tolerant species should be selected for the groundcover layer. Trees and shrubbery should be managed so that the groundcover layer is not out-competed. If this does occur, replacement planting and possible thinning of the upper vegetation layers may be required.

(v) Groundcovers, shrubs and street trees

Refer to SC6.4.3.9.6 Plant selection for WSUD systems in the coastal dry tropics for guidance on selecting suitable plant (including turf) species and cultivars that meet the functional requirements of bioretention swales to deliver the desired stormwater quality objectives.

(vi) Existing vegetation

Existing vegetation, such as remnant native trees, within the bioretention swale alignment may be nominated for retention. In this case, the swale will need to be diverted or piped to avoid the vegetation's critical root zone (equivalent to 0.5 m beyond the vegetation's drip line).

(e) Safety issues

Bioretention swales within streetscapes and parks need to be generally consistent with public safety requirements for new developments. These include reasonable batter profiles for edges, providing adequate barriers to median swales for vehicle/pedestrian safety and safe vertical heights from driveways to intersecting swale inverts.

(i) Crime prevention through environmental design (CPTED)

Landscape design of bioretention swales need to accommodate the standard principles of informal surveillance, exclusion of places of concealment and open visible areas. Regular clear sightlines should be provided between the roadway and footpaths/ property. Where planting may create places of concealment or hinder informal surveillance, groundcovers and shrubs should not generally exceed 1 m in height.

(ii) Traffic sightlines

The standard rules of sightline geometry apply – planting designs should allow for visibility at pedestrian crossings, intersections, rest areas, medians, driveways and roundabouts. Refer to the *Road Landscape Manual* (DMR 1997) for further guidance.

(5) Construction and establishment - bioretention swales

This section provides general advice for the construction and establishment of bioretention swales and key issues to be considered to ensure their successful establishment and operation.

(a) Staged construction and establishment method

(i) Construction and establishment challenges

There exist a number of challenges that must be appropriately considered to ensure successful construction and establishment of bioretention swales. These challenges are best described in the context of the typical phases in the development of a greenfield or infill development, namely the subdivision construction phase and the building phase (see Figure SC6.4.3.9.13).

(A) Subdivision construction - the risks to successful construction and establishment of the WSUD systems during this phase of work have generally related to the following:

- construction activities which can generate large sediment loads in runoff which can smother vegetation and clog bioretention filter media; and

- construction traffic and other works can result in damage to the bioretention swales. Importantly, all works undertaken during Subdivision Construction are normally "controlled" through the principle contractor and site manager. This means the risks described above can be readily managed through appropriate guidance and supervision.

(B) Building phase - the allotment building phase (see Figure SC6.4.3.9.12) represents the greatest risk to the successful establishment of bioretention swales.

Figure SC6.4.3.9.12 Example of building phase

(ii) Staged construction and establishment method

To overcome the challenges associated within delivering bioretention swales a staged construction and establishment method should be adopted (see Figure SC6.4.3.9.13).

(A) Stage 1: Functional installation - construction of the functional elements of the bioretention system at the end of subdivision construction (i.e. during landscape works) and the installation of temporary protective measures.

(B) Stage 2: Sediment and erosion control – during the building phase the temporary protective measures preserve the functional infrastructure of the bioretention swales against damage whilst also providing a temporary erosion and sediment control facility throughout the building phase to protect downstream aquatic ecosystems.

(C) Stage 3: Operational establishment - at the completion of the building phase, the temporary measures protecting the functional elements of the bioretention swales can be removed along with all accumulated sediment and the system planted in accordance with the design planting schedule.

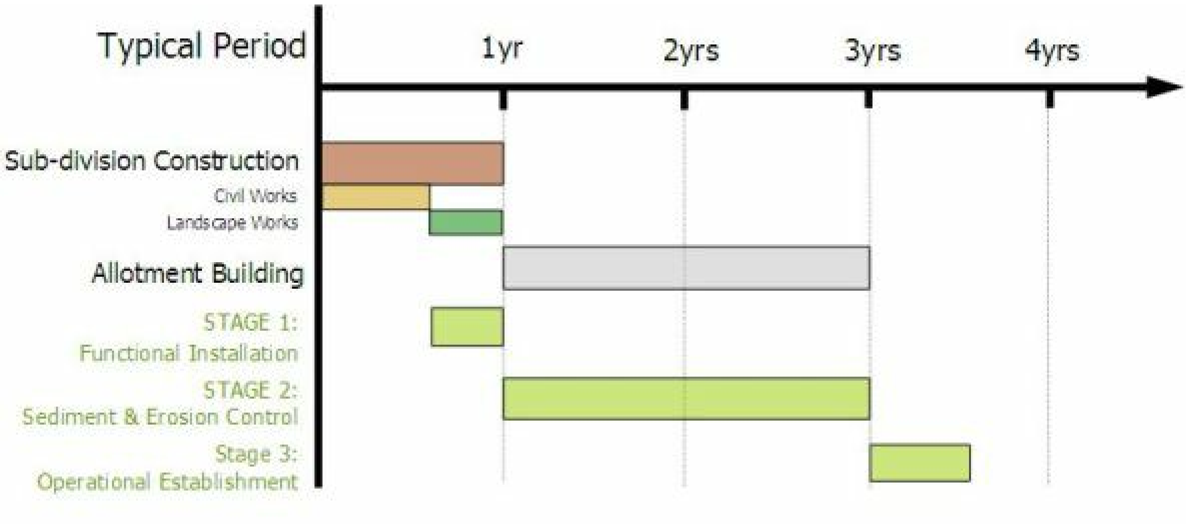

Figure SC6.4.3.9.13 Staged construction and establishment method

(iii) Functional installation

Functional installation of bioretention swales (see Figure SC6.4.3.9.14) occurs at the end of subdivision construction as part of landscape works and involves:

(A) bulking out and trimming;

(B) installation of the outlet structures;

(C) placement of liner and installation of drainage layer (i.e. under-drains and drainage layer);

(D) placement of filter media;

(E) placement of a temporary protective layer - covering the surface of filtration media with geofabric and placement of 25 mm topsoil and turf over geofabric. This temporary geofabric and turf layer will protect the bioretention system during construction (subdivision and building phases) ensuring sediment/litter laden waters do not enter the filter media causing clogging; and

(F) place silt fences around the boundary of the bioretention swale to exclude silt and restrict access.

Figure SC6.4.3.9.14 Bioretention swale functional installation

(iv) Sediment and erosion control

The temporary protective layers are left in place through the allotment building phase to ensure sediment laden waters do not clog the filtration media and allotment building traffic does not enter the bioretention swale (see Figure SC6.4.3.9.15). Importantly the configuration of the bioretention swale and the turf vegetation allow the system to function effectively as a shallow sedimentation basin reducing the load of coarse sediment discharging to the receiving environment. Using this approach, WSUD systems can operate effectively to protect downstream ecosystems immediately after construction.

Figure SC6.4.3.9.15 Bioretention swale sediment and erosion control

(v) Operational establishment

At the completion of the allotment building phase the temporary measures are removed with all accumulated sediment and the bioretention swale re-profiled and planted in accordance with the proposed landscape design. Establishment of the vegetation to design condition can require more than two growing seasons, depending on the vegetation types, during which regular watering and removal of weeds will be required.

(b) Sourcing bioretention vegetation

The minimum recommended lead time for ordering is 3-6 months. This usually allows enough time for plants to be grown to the required size. The following pot sizes are recommended as the minimum:

(i) viro tubes 50 mm wide x 85 mm deep;

(ii) 50 mm tubes 50 mm wide x 75 mm deep; and

(iii) native tubes 50 mm wide x 125 mm deep.

(c) Vegetation establishment

The following weed control measures and watering schedule are recommended to ensure successful plant establishment. Regular general maintenance as outlined in SC6.4.3.9.3(6) Maintenance requirements - bioretention swales will also be required.

(i) Weed control

Conventional surface mulching of bioretention swales with organic material like tanbark, should not be undertaken. Most organic mulch floats and runoff typically causes this material to be washed away with the risk of blockage of drains occurring. Weed management will need to be done manually until such time that the design vegetation is established with sufficient density to effectively prevent weed propagation.

(ii) Watering

Regular watering of bioretention swale vegetation is essential for successful establishment and healthy growth and weed reduction. 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. The following watering program is generally adequate but should be adjusted (increased) to suit the site conditions:

(A) Week 1-2 3 visits/ week;

(B) Week 3-6 2 visits/ week; and

(C) Week 7-12 1 visit/ week.

After this initial three month period, temporary, supplementary irrigation will be required in bioretention swales without submerged zones and may be required in bioretention swales with submerged zones (particularly during the 2 year plant establishment period). Watering requirements to sustain healthy vegetation should be determined during ongoing maintenance site visits.

(6) Maintenance requirements - bioretention swales

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 porosity of the soil media of the bioretention system and a strong healthy growth of vegetation is critical to its performance.

(a) Typical maintenance of bioretention swale elements will involve:

(i) 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);

(ii) 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;

(iii) 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;

(iv) repairing any damage to the swale profile resulting from scour, rill erosion or vehicle damage;

(v) tilling of the bioretention trench surface if there is evidence of clogging;

(vi) clearing of blockages to inlet or outlets;

(vii) regular watering/ irrigation of vegetation until plants are established and actively growing (see SC6.4.3.9.3(5)(c) Vegetation establishment);

(viii) mowing of turf or slashing of vegetation (if required) to preserve the optimal design height for the vegetation;

(ix) removal and management of invasive weeds;

(x) removal of plants that have died and replacement with plants of equivalent size and species as detailed in the plant schedule;

(xi) pruning to remove dead or diseased vegetation material and to stimulate new growth;

(xii) litter and debris removal; and

(xiii) vegetation pest monitoring and control.

(b) Additional maintenance required if a saturated zone is included in the design:

(i) check weir/up-turned pipe is clear of debris; and

(ii) check water level in the saturated zone is at the design level.

(c) 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. Inspections are also recommended following large storm events to check for scour.

(d) All maintenance activities must 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 swales continue to function as designed. The maintenance plans and forms must address the following:

(i) inspection frequency;

(ii) maintenance frequency;

(iii) data collection/ storage requirements (i.e. during inspections);

(iv) detailed cleanout procedures (main element of the plans) including:

(A) equipment needs;

(B) maintenance techniques;

(C) occupational health and safety;

(D) public safety;

(E) environmental management considerations;

(F) disposal requirements (of material removed);

(G) access issues;

(H) stakeholder notification requirements; and

(I) data collection requirements (if any); and

(v) design details.
An example operation and maintenance inspection form is included in the checking tools provided in SC6.4.3.9.3(7).

(7) Checking tools - bioretention swales

A number of checking aids have been developed for designers and council development assessment officers. In addition, advice on construction techniques and lessons learnt from building bioretention swale systems are provided.

(a) Design assessment

The checklist at Table SC6.4.3.9.6 presents the key design features to be reviewed when assessing design of a bioretention swale. These considerations include configuration, safety, maintenance and operational issues that need to be addressed during the design phase. Where an item results in an “N” when reviewing the design, referral is to be made back to the design procedure to determine the impact of the omission or error.

In addition to the checklist, a proposed design is to have all necessary permits for its installations. Council development assessment officers need to ensure that all relevant permits are in place. These can include permits to clear vegetation, to dredge, create a waterbody, divert flows or disturb fish or platypus habitat.

Click here to view Table SC6.4.3.9.6 Bioretention swale design assessment checklist

(b) Construction (during and post)

The checklist at Table SC6.4.3.9.7 presents the key items to be reviewed when inspecting the bioretention swale during and at the completion of construction. The checklist is to be used by construction site supervisors and compliance inspectors to ensure all the elements of the bioretention system have been constructed in accordance with the design. If an item receives an “N” in Satisfactory criteria then appropriate actions must be specified and delivered to rectify the construction issue before final inspection sign-off is given.

Click here to view Table SC6.4.3.9.7 Bioretention swale construction inspection checklist

(c) Operation and maintenance inspection

The form at Table SC6.4.3.9.8 is to be used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time.

Click here to view Table SC6.4.3.9.8 Bioretention swale maintenance checklist

(d) Asset transfer (following defects period)

Land ownership and asset ownership are key considerations prior to construction of a stormwater treatment device. A proposed design is to clearly identify the ultimate asset owner and who is responsible for its maintenance. Local authorities will use the asset transfer checklist at Table SC6.4.3.9.9 when the asset is to be transferred to the local authority.

Click here to view Table SC6.4.3.9.9 Bioretention swale asset transfer checklist

(8) Engineering drawings - bioretention swales

The relevant local authority should be consulted to source standard drawings applicable to bioretention swales. These drawings may provide example dimensions for a number of different road reserve configurations. Standard drawings are not intended to be prescriptive drawings which must be adhered to, rather they are intended to provide detailed examples of swales which can be incorporated into commonly used urban subdivision layouts. Designers are encouraged to develop alternative bioretention swale designs to suit site specific conditions.

In the absence of locally specific guidelines, Brisbane City Council (BCC) standard drawings applicable to swales and bioretention systems are UMS 151-158. These may also be used as reference standards for swale design. BCC Standard drawings are available online.

(9) References - bioretention swales

Barling RD & Moore ID 1993, 'The Role of Buffer Strips in the Management of Waterway Pollution', in Woodfull J et al. (eds), *The Role of Buffer Strips in the Management of Waterway Pollution from Diffuse Urban and Rural Sources*, LWRRDC Occasional Paper No. 01/93, Canberra

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DMR (Queensland Department of Main Roads) 1997, *Road Landscape Manual*, prepared by EDAW (Aust) Pty Ltd for DMR, Brisbane

Duncan HP 1995, *A Review of Urban Storm Water Quality Processes*, Cooperative Research Centre for Catchment Hydrology, Report 95/9, Melbourne, Australia

Engineers Australia 2006, *Australian Runoff Quality*, Engineers Australia, ACT, http://www.arq.org.au/

Leinster, S 2006, *Delivering the Final Product – Establishing Water Sensitive Urban Design Systems*, 7th International Conference on Urban Drainage Modelling and 4th International Conference on Water Sensitive Urban Design Book of Proceedings, Volume 2, A Deletic and T Fletcher (eds), Melbourne.

LHCCREMS (Lower Hunter and Central Coast Regional Environmental Management Strategy) 2002, *Water Sensitive Urban Design in the Sydney Region: 'Practice Note 2 – Site Planning'*, LHCCREMS, NSW.

DNRW, IPWEA and BCC (Department of Natural Resources and Water, Institute of Public Works Engineering Australia – Qld Division & Brisbane City Council) 1998, *Queensland Urban Drainage Manual (QUDM) Second Edition*, prepared by Neville Jones & Associates and Australian Water Engineering for DNRW, IPWEA & BCC, Brisbane.

Standards Australia 1997, AS 1289.4.1.1-1997: *Methods of testing soils for engineering purposes - Soil chemical tests - Determination of the organic matter content of a soil - Normal method,* Standards Australia

Standards Australia 2003, AS 4419-2003: *Soils for landscaping and garden use*, Standards Australia

Townsville City Council, *Water sensitive urban design for the coastal dry tropics (Townsville): Technical design guidelines for stormwater management*, 2011

Weibel SR, Weidner RB, Cohen JM & Christianson AG, 1996, "Pesticides and Other Contaminants in Rainfall and Runoff", *Journal American Water Works Association*, vol. 58, no. 8, August 1966, pp. 1075-1084

SC6.4.3.9.4 Bioretention basins

(1) Bioretention basins are vegetated areas where runoff is filtered through a filter media layer (e.g. sandy loam) as it percolates downwards. It is then collected via perforated under-drains and flows to downstream waterways or to storages for reuse. Bioretention basins often use temporary ponding above the filter media surface to increase the volume of runoff treated through the filter media. They treat stormwater in the same way as bioretention swales; however, "above design" flows are conveyed through overflow pits or bypass paths rather than over the filter media. This has the advantage of protecting the filter media surface from high velocities that can dislodge collected pollutants or scour vegetation.

Bioretention basins are generally not intended to be "infiltration" systems that discharge from the filter media to surrounding in-situ soils. Rather, the typical design intent is to recover stormwater at the base of the filter media in perforated under-drains and discharge to receiving waterways or to storages for potential reuse.

Figure SC6.4.3.9.16 shows examples of a basin integrated into a local streetscape and into a car park. Figure SC6.4.3.9.16 also illustrates the key elements of bioretention basins, namely surface vegetation, extended detention, filter media, drainage layer and overflow pit.

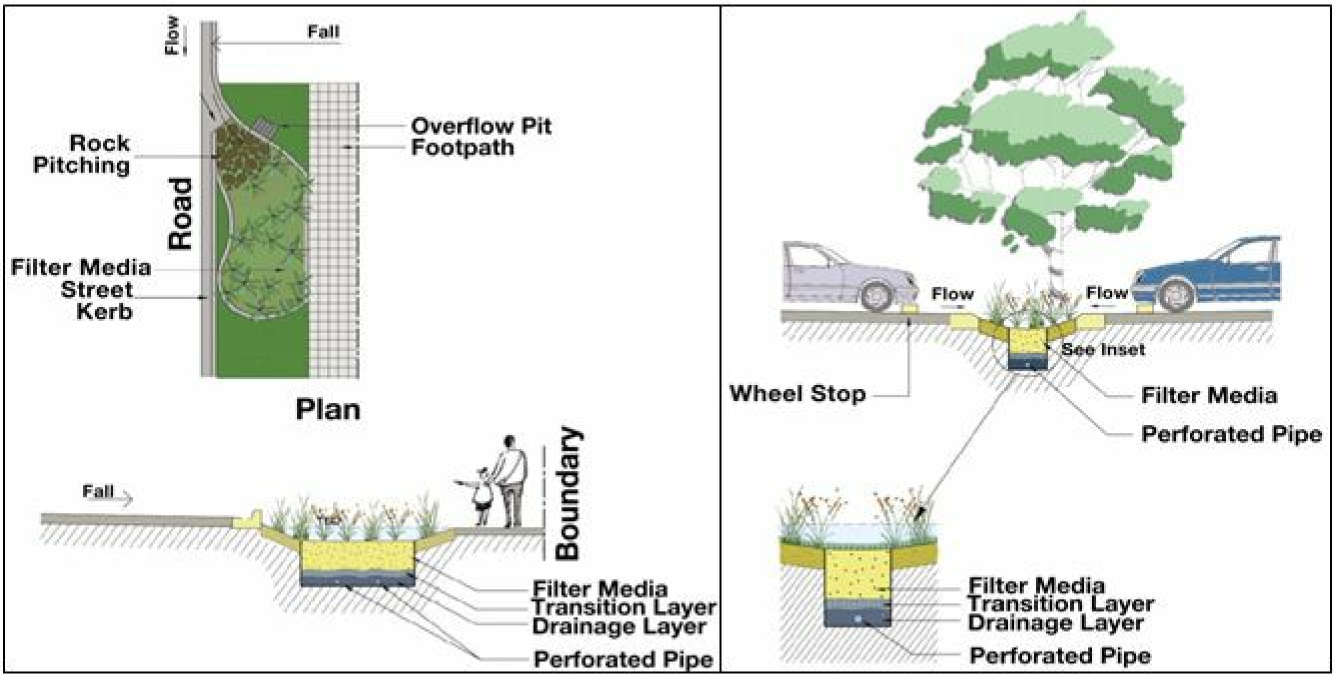


Figure SC6.4.3.9.16 Bioretention basin integrated into a local streetscape (left) and a car park (right).

(2) Design considerations – bioretention basins

This section outlines some of the key design considerations for bioretention basins that the detailed designer should be familiar with before applying the design procedure presented later in this chapter.

Rain patterns in the dry tropics mean that bioretention systems will receive large volumes of consistent rainfall during the wet season and are likely to remain dry for extended periods during the dry season. Therefore, bioretention basin design will need to be adapted to incorporate the following elements:

- controls to ensure the bioretention basin is not compromised by sediment smothering;
- a saturated zone beneath the filter media to increase soil moisture and help sustain vegetation during dry periods; or
- supplemental temporary irrigation to sustain vegetation and maintain aesthetics in highly visible areas (e.g. bioretention pods within road verges).

(a) Landscape design

Bioretention basins are predominantly located within public areas, such as open space or within streets, which provide a primary setting for people to experience their local community and environment. It is therefore necessary for bioretention basins to be given an appropriate level of landscape design consideration to compliment the surrounding landscape character and to adequately address potential aesthetics issues such as weeds and sustaining perennial plants during the dry season. The landscape design of bioretention basins must address stormwater quality objectives whilst also being sensitive to other important landscape objectives such as road visibility, public safety and community character and habitat. To achieve this, the design process requires close collaboration between landscape architects, urban designers, ecologists and WSUD engineers (see example at Figure SC6.4.3.9.17).

Figure SC6.4.3.9.17 Bioretention basin within roundabout at Kalynda Chase Development, Bohle Plains

(b) Hydraulic design

The correct hydraulic design of bioretention basins is essential to ensure effective stormwater treatment performance, minimise damage by storm flows, and to protect the hydraulic integrity and function of associated minor and major drainage systems. The following aspects are of key importance:

(i) the finished surface of the bioretention filter media must be horizontal (i.e. flat) to ensure even flow dispersion across the filter media surface (i.e. full engagement of the filter media by stormwater flows) and to prevent concentration of stormwater flows within depressions and ruts resulting in potential scour and damage to the filter media;

(ii) temporary ponding (i.e. extended detention) of up to 0.3 m depth over the surface of the bioretention filter media created through the use of raised field inlet pits (overflow pits) can assist in managing flow velocities over the surface of the filter media as well as increase the overall volume of stormwater runoff that can be treated by the bioretention filter media;

(iii) where possible, the overflow pit or bypass channel should be located near the inflow zone (refer to Figure SC6.4.3.9.16 (left)) to prevent high flows passing over the surface of the filter media. If this is not possible, then velocities during the minor (2-10 year ARI) and major (50-100 year ARI) floods should be maintained sufficiently low (preferably below values of 0.5 m/s and not more than 1.5 m/s for major flood) to avoid scouring of the filter media and vegetation;

(iv) where the field inlets in a bioretention system is required to convey the minor storm flow (i.e. is part of the minor drainage system), the inlet must be designed to avoid blockage, flow conveyance and public safety issues; and

(v) for streetscape applications, the design of the inflow to the bioretention basin must ensure the kerb and channel flow requirements are preserved as specified in the Queensland Urban Drainage Manual (QUDM) (DNRW, IPWEA and BCC 1998).

(c) Ex-filtration to in-situ soils

Bioretention basins can be designed to either preclude or promote ex-filtration of treated stormwater to the surrounding in-situ soils depending on the overall stormwater management objectives established for the given project. When considering ex-filtration to surrounding soils, the designer must consider site terrain, hydraulic conductivity of the in-situ soil, groundwater and building setback. Where the concept design specifically aims to preclude ex-filtration of treated stormwater runoff it is necessary to consider if the bioretention basin needs to be provided with an impermeable liner. If the selected saturated hydraulic conductivity of the bioretention filter media is less than 10 times that of the native surrounding soils, it may be necessary to provide an impermeable liner. Flexible membranes or a concrete casting are commonly used to prevent excessive ex-filtration. This is particularly applicable for surrounding soils that are very sensitive to any ex-filtration (e.g. shallow groundwater or close proximity to significant structures).

Bioretention systems constructed in sodic soils without an impermeable lining are not at risk of exporting salt from in-situ soil into local streams or groundwater. Even after six months of intensive flushing under controlled, laboratory conditions, bioretention systems (constructed in sodic soils) did not leach salt from the surrounding soils (Deletic and Mudd, 2006).

The greatest pathway of ex-filtration is through the base of a bioretention basin, as gravity and the difference in hydraulic conductivity between the filter media and the surrounding native soil would typically act to minimise ex-filtration through the walls of the trench. If lining is required, it is likely that only the base and the sides of the drainage layer will need to be lined.

(d) Vegetation types

Vegetation is required to cover the whole bioretention filter media surface, be capable of withstanding minor and major design flows, and be of sufficient density to prevent preferred flow paths, scour and re-suspension of deposited sediments. Additionally, vegetation that grows in the bioretention filter media functions to continuously break up the surface of the filter media through root growth and wind induced agitation, which prevents surface clogging. The vegetation also provides a substrate for biofilm growth within the upper layer of the filter media, which facilitates biological transformation of pollutants (particularly nitrogen).

Ground cover vegetation (e.g. sedges and tufted grasses) is an essential component of bioretention basin function. Generally, the greater the density and height of vegetation planted in bioretention filter media, the better the treatment provided especially when extended detention is provided for in the design. Contact between stormwater and vegetation results in enhanced sedimentation of suspended sediments and adsorption of associated pollutants.

Plant species selected for bioretention systems must be able to tolerate free draining sandy soils and be capable of withstanding long dry periods as well as periods of inundation. To maintain aesthetics in highly visible areas (e.g. bioretention pods within road verges) temporary supplemental irrigation may be required to sustain vegetation. The incorporation of saturated zones beneath the filter media can help to sustain soil moisture and is beneficial for nitrogen removal from stormwater. The ability to sustain dense perennial vegetation is important for long term weed management.

SC6.4.3.9.6 Plant selection for WSUD systems in the coastal dry tropics provides more specific guidance on the selection of appropriate vegetation for bioretention basins. It should be noted that turf is not considered to be suitable vegetation for bioretention basins. The stem and root structure of turf is not suitably robust and rapid growing to ensure the surface of the bioretention filter media is continuously broken up to prevent clogging.

(e) Bioretention filter media

Selection of an appropriate bioretention filter media is a key design step that involves consideration of the following four inter-related factors:

(i) saturated hydraulic conductivity required to optimise the treatment performance of the bioretention basin given site constraints and available filter media area;

(ii) depth of extended detention provided above the filter media;

(iii) surface area of the filter media; and

(iv) suitability as a growing media to support vegetation (i.e. retains sufficient soil moisture and organic content).

The concept design stage will have established the optimal combination of filter media saturated hydraulic conductivity and extended detention depth using a continuous simulation modelling approach (i.e. MUSIC). Any adjustment of either of these two design parameters during the detailed design stage will require the continuous simulation modelling to be re-run to assess the impact on the overall treatment performance of the bioretention basin.

As shown in Figure SC6.4.3.9.18 below, bioretention media can consist of three or four layers. In addition to the filter media required for stormwater treatment, a saturated zone can also be added to enhance nitrogen removal and to provide a source of water for vegetation over the dry season. A drainage layer is also required to convey treated water from the base of the filter media or saturated zone into the perforated under-drains. The drainage layer surrounds the perforated under-drains and can be either coarse sand (1 mm) or fine gravel (2-5 mm). If fine gravel is used, a transition layer of sand must also be installed to prevent migration of the filter or saturated zone media into the drainage layer and subsequently into the perforated under-drains.

(f) Saturated zone

The incorporation of a saturated zone into bioretention design has evolved from research demonstrating improved nitrate removal through denitrification processes (Kim et al. 2003 and Zinger et al. 2007b).

The saturated zone design involves a relatively simple modification to a conventional bioretention system. An additional layer located below the filter media is designed to retain stormwater providing a saturated zone at the base of the bioretention system. A saturated zone can be formed by using a riser pipe with the outlet level higher than the drainage layer or by incorporating a weir within the outlet pit (see Figure SC6.4.3.9.18 below). The saturated zone holds water and therefore provides a source of water to maintain soil moisture for plant uptake during dry periods.

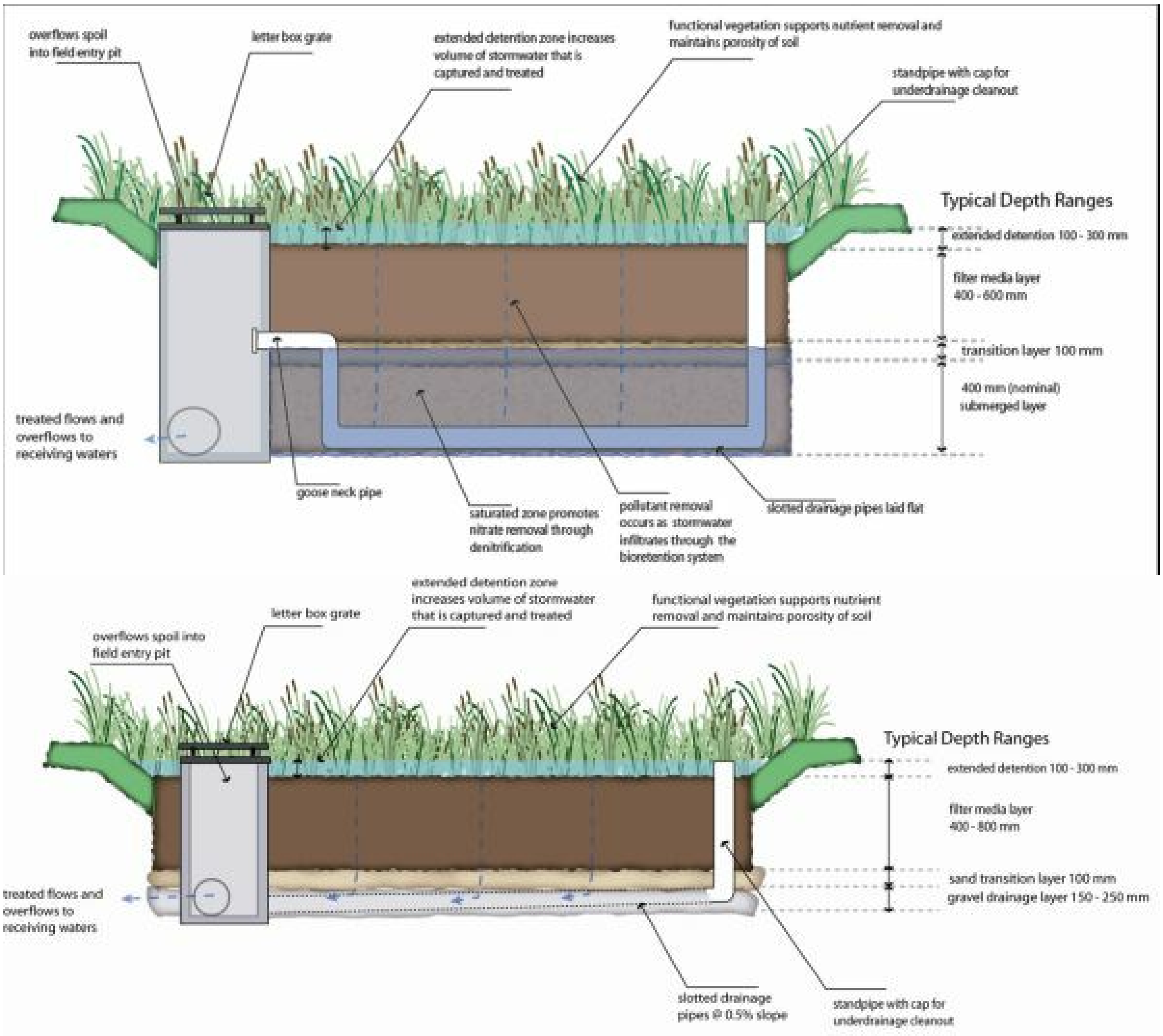


Figure SC6.4.3.9.18 Cross section of bioretention basins (top- with a saturated zone; below- without a saturated zone)

(g) Traffic controls

Another design consideration is keeping traffic and building material deliveries off bioretention basins (particularly during the construction phase of a development). If bioretention basins are driven over or used for parking, the filter media will become compacted and the vegetation damaged.

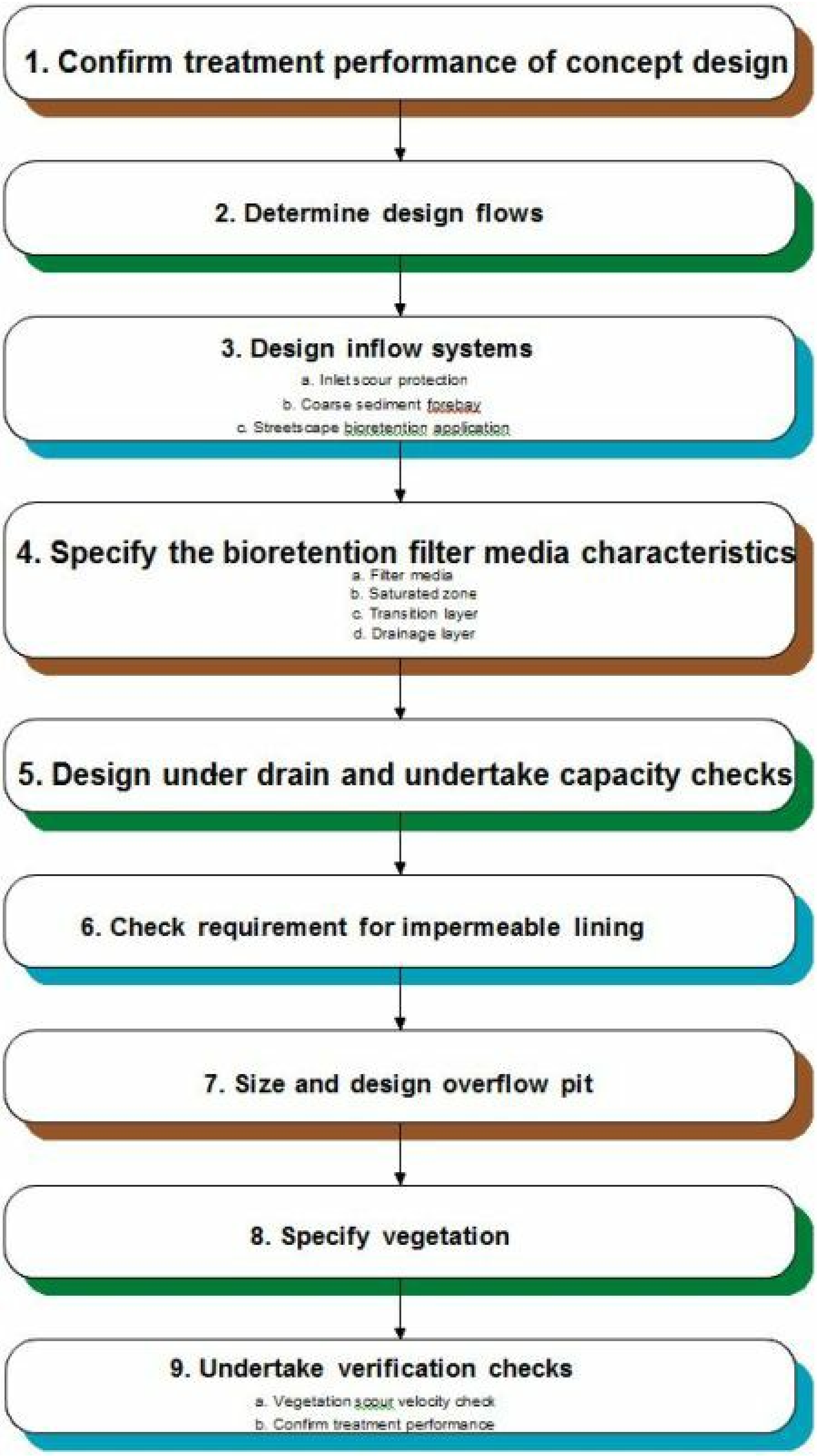
Streetscape bioretention systems must be designed to satisfy local authority requirements with respect to traffic calming devices within particular street or road reserve widths. Where bioretention is incorporated into traffic calming or control devices, or directly adjacent to mountable kerbs, consideration should be given to protection of the area immediately behind the kerb where vehicles are likely to mount the kerb.

(h) Services

Bioretention basins or cells located within road verges or within footpaths must consider the standard location for services within the verge and ensure access for maintenance of services without regular disruption or damage to the bioretention system.

(3) Design process – bioretention basins

The following sections detail the design steps required for bioretention basins. Key design steps are:



(a) Step 1: Check treatment performance of concept design

Before commencing detailed design, the designer should first undertake a preliminary check to confirm the bioretention basin treatment area (i.e. the surface area of the filter media) from the concept design is adequate to deliver the required level of stormwater quality improvement. This design process assumes a conceptual design has been undertaken.

This assessment should be undertaken by a WSUD specialist and can be achieved by modelling expected treatment performance in an appropriate quantitative modelling program. Where possible, this modelling should be based on local rainfall data, the proposed configuration of the system, and based on local stormwater treatment performance data.

(b) Step 2: Determine design flows

(i) Design flows

The hydraulic design of the bioretention basin should be based on the following design flows:

(A) minor flood flow (2 year ARI) to allow minor floods to be safely conveyed. For commercial and industrial areas the design flow requirement for minor flows is a 5 year ARI event; and

(B) major flood flow (100 year ARI) to check flow velocities, velocity depth criteria, conveyance within road reserve, and freeboard to adjoining property.

(ii) Design flow estimation

A range of hydrologic methods can be applied to estimate design flows. If the typical catchment areas are relatively small, the Rational Method design procedure is considered to be a suitable method for estimating design flows. However, if the bioretention system is to form part of a retention basin or if the catchment area to the bioretention system is large, then a full flood routing computation method needs to be used to estimate design flows.

(c) Step 3: Design inflow systems

(i) The design of the inflow systems to bioretention basins needs to consider a number of functions:

(A) scour protection – In most bioretention applications stormwater flows will enter the bioretention basin as concentrated flow (piped, channel or open channel) and as such is it important to slow and spread flows using appropriate scour (rock) protection;

(B) coarse sediment forebay – Where stormwater runoff from the catchment is delivered directly to the bioretention basin without any coarse sediment management (through vegetated swale or buffer treatment) a coarse sediment forebay is to be included in the design. The forebay is to remove coarse sediment (1 mm +) from stormwater to minimise the risk of vegetation in the bioretention basin being smothered;

(C) constant low base flows have to be taken into account and dealt with as they can blind the filter material and promote weed growth within permanently saturated areas; and

(D) street hydraulics (streetscape applications only) – In streetscape applications, where stormwater is delivered directly from the kerb and channel to the bioretention basin, it is important to ensure the location and width of the kerb opening is designed such that flows enter the bioretention basin without adversely affecting trafficability of the road (QUDM, Table 7.04.1).

(ii) Each of these functions and the appropriate design responses are described in the following sections.

(iii) Inlet scour protection

Erosion protection should be provided for concentrated inflows to a bioretention basin. Typically, flows will enter the bioretention basin from either a surface flow system (i.e. roadside kerb, open channel) or a piped drainage system. Rock beaching is a simple method for dissipating the energy of concentrated inflow, as depicted in Figure SC6.4.3.9.19 (with the “D” representing the pipe diameter dimension). The rocks can form part of the landscape design of the bioretention component.

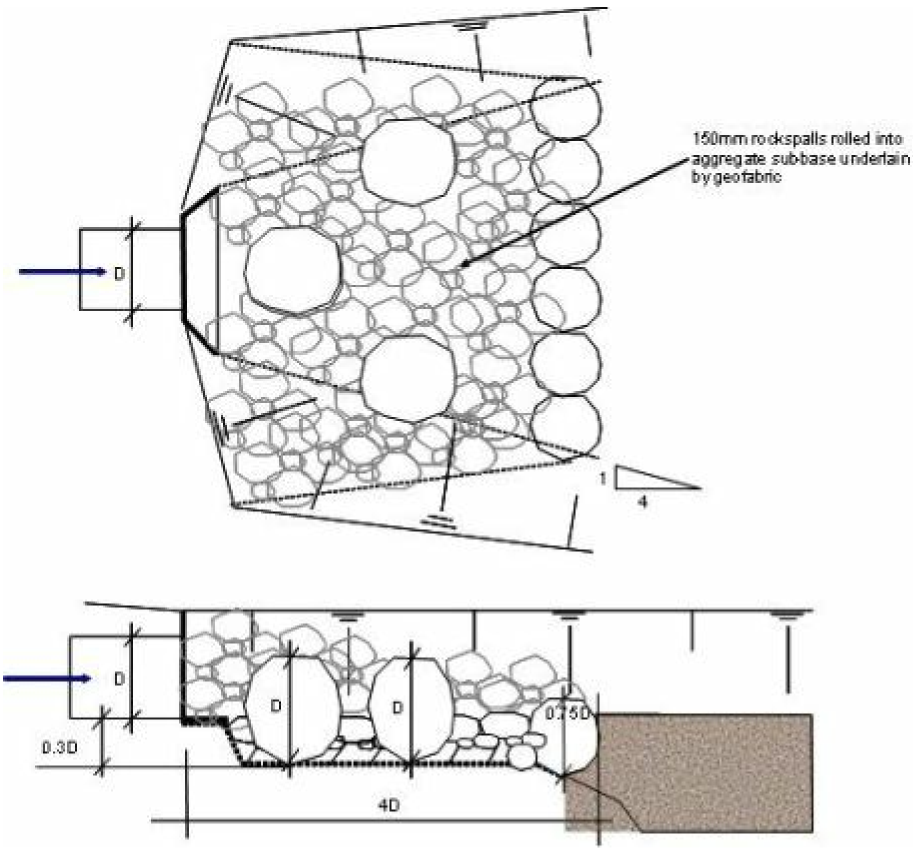


Figure SC6.4.3.9.19 Typical inlet scour protection detail for bioretention basins receiving piped flows

(iv) Coarse sediment control

Where stormwater runoff from the catchment is delivered directly to the bioretention basin without pre-treatment (through vegetated swale or buffer treatment), coarse sediment may accumulate near the basin inflow. This sediment may smother vegetation and reduce infiltration to the filter media. To mitigate these effects, either a sedimentation basin (see Chapter 4) is to be located upstream or the bioretention basin inflow system is to incorporate a coarse sediment forebay. The forebay should be designed to:

(A) remove particles that are 1 mm or greater in diameter from the 3 month ARI storm event; and

(B) provide appropriate storage for coarse sediment to ensure desilting is required no more than once per year.

The size of the sediment forebay is established using the following equation:

$$V_s = A_c \cdot R \cdot L_o \cdot F_c$$

Where	V_s	= volume of forebay sediment storage required (m^3)
	A_c	= contributing catchment area (ha)
	R	= capture efficiency (assume 80%)
	L_o	= sediment loading rate (m^3/ha/year)
	F_c	= desired cleanout frequency (years)

A catchment loading rate (L_o) of 1.6 m^3/ha/year for developed catchments can be used to estimate the sediment loads entering the basin. The area of the forebay is established by dividing the volume by the depth. The depth of the forebay should not be greater than 0.3 m below the surface of the filter media.

$$A_s = \frac{V_s}{D_s}$$

Where D = depth of sediment forebay (max 0.3 m below filter media surface).
The sediment forebay area should be checked to ensure it captures the 1 mm and greater particles using the following expression (modified version of Fair and Geyer (1954).

$$R = 1 - \left[1 + \frac{1}{n} \cdot \frac{v_s}{Q/A}\right]^{-n}$$

Where:	R	=	fraction of target sediment removed (80%)
	v_s	=	settling velocity of target sediment (100 mm/s or 0.1 m/s for 1 mm particle)
	Q/A	=	applied flow rate divided by forebay surface area ($m^3/s/m^2$)
	n	=	turbulence or short-circuiting parameter (adopt 0.5)

The coarse sediment forebays will contain large rocks for energy dissipation and be underlain by filter material to promote drainage following storm events.

(v) Kerb opening configuration (streetscape applications)

In streetscape applications where stormwater is delivered directly from a kerb and channel to a bioretention basin, the following design issues must be considered:

(A) the location of the kerb opening must be designed to ensure flows in the channel do not exceed the maximum allowance widths as defined by QUDM Table 7.04.1 (DNRW, IPWEA & BCC 1998); and

(B) the width of the kerb opening is designed to allow the design flow to enter the bioretention basin.

Channel flow width at kerb opening

The width of channel flow at the kerb opening during a minor storm event (2 10 year ARI) needs to be checked to ensure it does not exceed the maximum allowable channel flow widths defined by QUDM Table 7.04.1 (DNRW, IPWEA & BCC 1998) and the local authority requirements. This check can be undertaken by applying Manning's equation or Izzard's equation and ensuring the flow depth does not exceed either the crest of the road or the top of kerb (whichever is lowest).

Design kerb opening width (where kerb and channel is used)

To determine the width of the opening in the kerb to allow flows to enter the bioretention basin, Manning's equation or Izzard's equation (QUDM Section 7.04.2) can be used with the kerb, channel and road profile to estimate the flow depth in the kerb and channel at the entry point. Once the flow depth for the minor storm (e.g. 2-10 year ARI) is known, this can then be used to calculate the required width of the opening in the kerb by applying a broad crested weir equation. The opening width is estimated by applying the flow depth in the channel (as h) and solving for L (opening width).

$$Q = C_w \cdot L \cdot h^{3/2}$$

Where	Q	= flow (m^3/s)
	Cw	= weir coefficient (= 1.66)
	L	= length of opening (m)
	h	= depth of flow (m)

This method ensures the kerb opening does not result in an increase in the upstream channel flow depth, which in turn ensures the bioretention basin does not impact on the trafficability of the adjoining road pavement as required by the QUDM. To ensure the kerb opening width is adequate, additional width factors may be required to account for slope of the kerb and channel, and the angle at which flow meets the kerb opening. This will depend on the location and position of the bioretention system in relation to the kerb and channel. Design of the inflow system within the kerb and channel will need to consider maximising flow into the bioretention system. The kerb opening can be made more effective by lowering the kerb opening below the channel, increasing the cross fall at the kerb opening or by providing deflectors at the kerb opening.

(d) Step 4: Specify the bioretention filter media characteristics

Up to four types of media are required in bioretention basins (refer Figure SC6.4.3.9.18 Cross section of bioretention basins (top—with a saturated zone; below—without a saturated zone)).

(i) Filter media

As a minimum, the filter media is required to have sufficient depth to support vegetation, typically between 400-600 mm (or as specified in the engineering design). It is important to note that if deep rooted plants such as trees are to be planted in bioretention basins, the filter media must have a minimum depth of 800 mm to avoid roots interfering with the perforated under-drain system.

In general, the media should be a loamy sand with an appropriately high permeability under compaction and should be free of rubbish, deleterious material, weed seeds, toxicants, and should not be hydrophobic. The filter media should contain some organic matter for increased water holding capacity but be low in nutrient content. To ensure a proposed soil is suitable as filter media, a testing regime is required. The *Guidelines for Soil Filter Media in Bioretention Systems*: Version 2.01 (FAWB, March 2008) (refer to http://www.monash.edu.au/fawb/products/index.html) provides best practice guidance on filter media selection and testing. It is recommended that soils used for bioretention filter media fulfil the requirements outlined in the FAWB Guideline. In summary, these requirements include:

(A) organic carbon levels < 5%;

(B) pH between 5.5 and 7.5;

(C) electrical conductivity < 1.2 dS/m;

(D) saturated hydraulic conductivity between 100-500 mm/hr. The saturated hydraulic conductivity of the filter media is established by optimising the treatment performance of the bioretention system given site constraints of the particular site (using a continuous simulation model such as MUSIC); and

(E) the filter media must also be structurally sound and not prone to structural collapse as this can result in a significant reduction in saturated hydraulic conductivity. The risk of structural collapse can be reduced by ensuring the soil has a well graded particle size distribution with a combined clay and silt fraction of < 3%.

(ii) Transition layer (if required)

The purpose of the transition layer is to prevent the filter media from migrating down into the drainage layer (or the saturated zone). It also acts as a buffer between the permanently saturated zone (if required) and the filter media. This buffer is necessary to ensure the filter media is not saturated for prolonged periods during rainfall events due to increases in water levels in the saturated zone. To achieve this, the transition layer depth must be greater than the head created by flows over the saturated zone outlet weir.

It is required if the particle size difference between the filter media and the drainage layer (or the saturated zone) is more than one order of magnitude. If a transition layer is required then the material must be a clean, well-graded sand/coarse sand material containing little or no fines.

The transition layer is recommended to be 100 mm thick and have a minimum saturated hydraulic conductivity of 1000 mm/hr.

A recent particle size distribution for the transition layer sand will need to be obtained to ensure that it meets the required grading/"bridging" criteria outlined below. The "bridging" criteria is based on the engineering principles that rely on the largest 15% of the filter media particles (or saturated zone particles) "bridging" with the smallest 15% of the sand particles. This results in smaller voids, which prevent the migration of the filter media particles into the sand particles. The following equation is taken from the United States Golf Association's recommendations for golf course construction:

Bridging Factor: **D15 (transitional layer sand) ≤ 8 x D85 (filter media)**

The addition of a transition layer increases the overall depth of the bioretention system and may be an important consideration for some sites where total depth of the bioretention system may be constrained. In such cases, the use of a sand drainage layer and/ or perforated pipes with smaller slot sizes may need to be considered.

(iii) Saturated layer (if required)

The saturated layer should be about 400 mm deep (but may deeper depending on the specific application) and composed of clean (i.e. free from fines) medium-coarse washed sand, gravel or small rock (50 mm diameter maximum) together with a long term carbon source. Hardwood wood chips, 5 mm to 40 mm in size, are recommended as the carbon source because they breakdown slowly to provide a long term carbon source yet have a decomposition rate that should not limit the denitrification process.

The total mass of carbon/electron donor that is required for denitrification must be calculated based on the expected stormwater influent TN mass over the desired life span of the system (e.g. 25 years). The calculation is based on the stoichiometry of the denitrification reaction (shown below).

Denitrification reaction:

$NO_3^- + 1.25\ (CH_2O) + H^+\ (10^{-7}\ M) \rightarrow 0.5N_2\ (g) + 1.75H_2O + 1.25CO_2\ (g)$

Based on a 400 mm deep saturated zone and the modelled annual TN runoff mass (for Townsville) for a bioretention system that is 2% of the contributing 1 ha catchment, the saturated zone media would have the following composition:

(A) 76.7 m^3 washed coarse sand, gravel or small rock; and

(B) 3.3 m^3 hardwood wood chips, well graded 5 mm-40 mm.

This is equivalent to an organic carbon content of approximately 4-5% by volume. If the saturated zone depth changed, or the bioretention system to catchment area ratio changed, the hardwood proportion would need to be recalculated using the denitrification stoichiometry.

Calculating carbon source for saturated zone with safety factor (x2)	
Catchment Area	1 ha
Treatment Area Required	2%
Bioretention Surface Area	200 m^2
Saturated Zone Depth	400 mm
Total volume of Saturated Zone	80 m^3
TN load 1 year	12.5 kg/yr
TN load 25 years	312.5 kg/25 yrs
Stoichiometry:	
N:C ratio = 1:1.25 (mol), which equates to 14:15 (g) [Mw: N = 14g/mol, C = 12g/mol]	
Average total carbon content of hardwood woodchips is 50%, therefore	
N:C (woodchip) = 14:30 (g)	
N:C (woodchip) = 1:2.1	
Woodchips (312.5 x 2.1)	656kg/carbon
Safety Factor (x 2)	1313kg/carbon
Density of wood chips	400kg/m^3 (approx.)
Hardwood Wood Chips	**3.3 m^3**
Clean Coarse Sand	**76.7 m^3**

The saturated media must have a hydraulic conductivity of >1000mm/hr (the ASTM F1815-06 test method is to be used to measure hydraulic conductivity).

The saturated zone should be lightly compacted (e.g. with one pass of a smooth drum lawn roller) during installation to stabilise the structure. Under no circumstances should heavy compaction or multiple-passes be made.

(iv) Drainage layer (if required)

The drainage layer is used to convey treated flows from the base of the filter media layer (or the saturated zone) into the perforated under-drainage system. The composition of the drainage layer is to be considered in conjunction with the selection and design of the perforated under-drainage pipes as the slot sizes in the perforated pipes may determine the minimum drainage layer particle size to avoid washout of the drainage layer into the perforated pipe system. Coarser material (e.g. fine gravel aggregate) is to be used for the drainage layer if the slot sizes in the perforated pipes are too large for use of a sand based drainage layer. The drainage layer is to provide a minimum of 50 mm cover above the perforated under-drainage pipes and have a minimum saturated hydraulic conductivity of 1000 mm/hr.

A particle size distribution for the gravel will need to be obtained to ensure that it meets the “bridging” criteria outlined below:

Bridging Factor:
D15 (drainage gravel/sand) ≤ 8 x D85 (filter media/saturated zone/transition layer)

Ensure drainage media is washed prior to placement in bioretention system to remove any fines.

(e) Step 5: Design under-drain and undertake capacity checks (if required)

The maximum spacing of the perforated under-drains in bioretention basins located in streetscape zones and small public zones (i.e. bioretention < 100 m^2) is 1.5 m (centre to centre). This ensures that the distance water needs to travel horizontally toward the perforated pipes through the drainage layer does not hinder drainage of the filter media. The maximum spacing of the perforated pipes in bioretention basins located in local parks and large open space areas (i.e. bioretention > 100 m^2) can be increased to 2.5 – 3 m.

In bioretention systems without saturated zones, perforated pipes are to grade at a minimum of 0.5% towards the overflow pit to ensure effective drainage. In bioretention systems with saturated zones, perforated pipes should be laid flat (i.e. at 0% grade) to avoid preferential flow paths forming vertically through the filter media closer to the outlet.

Perforated pipes should not use a geofabric wrapping, as this is a potential location for blockage and would require a complete resetting of the bioretention system. Where perforated pipes are supplied with geofabric wrapping, it is to be removed before installation.

Installing parallel pipes is a means to increase the capacity of the perforated pipe system. 100 mm diameter is recommended as the maximum size for the perforated pipes to minimise the thickness of the drainage layer. Either slotted PVC pipes or flexible perforated pipes (e.g. Ag pipe) can be used; however, care needs to be taken when selecting the type of pipe to consider the following:

(i) ensure the slots in the pipes are not so large that sediment will freely flow into the pipes from the drainage layer. This is also a consideration when specifying drainage layer media; and

(ii) minimise the potential for tree roots to enter the pipes in search of water. Generally, this is only a concern when the filter media has a low water holding capacity, or trees are planted in filter media whose depth is too shallow. In general, trees are not recommended if the filter media depth is less than 800 mm. Flexible “ribbed” pipes are more likely, than PVC pipes, to retain “beads” of moisture due to the small corrugations on the inside of the pipe. Therefore, a smooth surface perforated/slotted pipe system is recommended for use in bioretention basins exhibiting any of these characteristics.

(iii) To ensure slotted pipes are of adequate size, several checks are required:

(A) ensure the perforations are adequate to pass the maximum filtration rate;

(B) ensure the pipe itself has sufficient capacity; and

(C) ensure that the material in the drainage layer will not be washed into the perforated pipes (consider a transition layer).

The maximum filtration rate represents the maximum rate of flow through the bioretention filter media and is calculated by applying Darcy's equation as follows:

$$V_s = A_c \cdot R \cdot L_o \cdot F_c$$

Where	V_s	= volume of forebay sediment storage required (m^3)
	A_c	= contributing catchment area (ha)
	R	= capture efficiency (assume 80%)
	L_o	= sediment loading rate (m^3/ha/year)
	F_c	= desired cleanout frequency (years)

To ensure the perforated under-drainage system has sufficient capacity to collect and convey the maximum filtration rate, it is necessary to determine the capacity for flows to enter the under-drainage system via the perforations in the pipes. To do this, orifice flow can be assumed and the sharp edged orifice equation used. It is conservative, but reasonable to use a blockage factor to account for partial blockage of the perforations by the drainage layer media. A 50% blockage of the perforations should be used.

The flow capacity of the perforations is thus:

$$A_s = \frac{V_s}{D_s}$$

If the capacity of the drainage system is unable to collect the maximum filtration rate additional under-drains will be required.

The Manning's roughness used will be dependent on the type of pipe used (refer to QUDM Table 7.16.3 (DNRW, IPWEA & BCC 1998)). When a saturated zone is incorporated into the design, the underdrainage pipes are laid flat however the conveyance capacity can be calculated using the Manning's equation with an assumed friction slope of 0.5%.

Under-drains should be extended vertically to the surface of the bioretention system to allow inspection and maintenance when required. The vertical section of the under-drain should be unperforated and capped to avoid short-circuiting of flows directly to the drain. Reference is made to the drawings following the worked example (Section SC6.4.3.9.4(3)(i) Step 9: Undertake verification checks) for further guidance.

In bioretention basins with a saturated zone, the capacity of the weir or up-turned pipe (maintaining the water level within the saturated zone) must also be checked to ensure it does not become the hydraulic "control" in the bioretention system (i.e. to ensure the filter media sets the travel time for flows percolating through the bioretention system). A broad crested weir equation can be used to determine the length of weir required (assuming free flowing conditions) to convey the maximum flow/filtration rate. The maximum depth of flow over the weir is to be 100 mm. This is important to limit increase in the saturated zone depth and avoid prolonged saturation of the filter media.

(f) Step 6: Check requirement for impermeable lining

The saturated hydraulic conductivity of the natural soil profile surrounding the bioretention system should be tested together with depth to groundwater, chemical composition and proximity to structures and other infrastructure. This is to establish if an impermeable liner is required at the base (only for systems designed to preclude ex-filtration to in-situ soils) and/or sides of the bioretention basin (refer also to discussion in SC6.4.3.9.4(2)(c) Ex-filtration to in-situ soils). If the saturated hydraulic conductivity of the filter media in the bioretention system is more than one order of magnitude (10 times) greater than that of the surrounding in-situ soil profile, no impermeable lining is required.

(g) Step 7: Size overflow pit

There should be a minimum of 50 mm head over the overflow pit crest to facilitate discharge of the design flow into the overflow pit.

In streetscape bioretention applications, a level of conservatism is built into the design of grated overflow pits by placing their inverts at least 50 mm below the invert of the street channel (and therefore setting the maximum ponding depth). The head over the overflow pit crest is the sum of the 50 mm and the maximum ponding in the street channel under the minor storm (see SC6.4.3.9.4(3)(c)(v) Kerb opening configuration). To size an overflow pit, two checks must be made to test for either drowned or free flowing conditions. A broad crested weir equation can be used to determine the length of weir required (assuming free flowing conditions) and an orifice equation used to estimate the area between openings required in the grate cover (assuming drowned outlet conditions). The larger of the two pit configurations should be adopted (as per Section 7.05 QUDM (DNRW, IPWEA & BCC 1998)). In addition, a blockage factor that assumes the grate is 50% blocked is to be used.

For free overfall conditions (weir equation):

$$R = 1 - \left[1 + \frac{1}{n} \cdot \frac{v_s}{Q/A}\right]^{-n}$$

Where:

Where:	R	=	fraction of target sediment removed (80%)
	v_s	=	settling velocity of target sediment (100 mm/s or 0.1 m/s for 1 mm particle)
	Q/A	=	applied flow rate divided by forebay surface area ($m^3/s/m^2$)
	n	=	turbulence or short-circuiting parameter (adopt 0.5)

Once the length of weir is calculated, a standard sized pit can be selected with a perimeter at least the same length of the required weir length.

For drowned outlet conditions (orifice equation):

$$Q = C_w \cdot L \cdot h^{3/2}$$

Where	Q	= flow (m^3/s)
	Cw	= weir coefficient (= 1.66)
	L	= length of opening (m)
	h	= depth of flow (m)

When designing grated field inlet pits, reference is also to be made to the procedure described in QUDM Section 7.05.4.

In terms of the actual grate, letter box or dome type grates must be used in bioretention basins.

When a saturated zone is included in the design of a bioretention system, additional components must be incorporated into the outlet design. A saturated zone can be formed at the base of a bioretention system by using a riser pipe with the outlet level set at the top of the desired saturation depth (i.e. top of the saturated zone) or by incorporating a weir/overflow structure within the outlet pit (see Figure SC6.4.3.9.18). The saturated zone would hold water rather than draining freely, and would therefore provide a source of water to the plants during dry periods.

(h) Step 8: Specify vegetation

Refer to SC6.4.3.9.4(4) Landscape design notes and SC6.4.3.9.6 Plant selection for WSUD systems in the coastal dry tropics for advice on selecting vegetation for bioretention basins in the coastal dry tropics.

Editor's note—applicants will also need to address 9.4.3 Landscape Code and sub-section SC6.4.3.6 Landscape policy.

(i) Step 9: Undertake verification checks

Once the detailed design is complete, a final check should be undertaken to confirm that vegetation will be protected from scour during flood events and that the final design will achieve the required treatment performance.

(i) Vegetation scour velocity check

Velocities should be kept below:

(A) 0.5 m/s for minor flood (2-5 year ARI) discharges; and

(B) 2.0 m/s for major flood (50 year ARI) discharges.

If the inlet to the bioretention basin “controls” the maximum inflow to the basin then it is appropriate to use this maximum inflow to check velocities. In this case, velocities should be maintained below 0.5 m/s.

(ii) Confirm treatment performance

If, during the course of undertaking detailed design of the bioretention basin, the basic design parameters established by the conceptual design phase have changed (e.g. area, filter media depth, etc.) then the designer should verify that the current design meets the required water quality improvement performance. This can be done by re-modelling expected treatment performance determined in the conceptual design based on the revised configuration of the system.

(j) Design calculation summary

A calculation summary sheet for the key design elements of a bioretention basin is provided in Table SC6.4.3.9.10.

Click here to obtain a copy of **Table SC6.4.3.9.10**

(4) Landscape design notes – bioretention basins

(a) Objectives

Landscape design for bioretention basins has four key objectives:

(i) addressing stormwater quality objectives by incorporating appropriate groundcover plant species for sediment removal, erosion protection, stormwater treatment (biologically active root zone) and preventing filter media blockages;

(ii) ensuring that the overall landscape design for the bioretention basin integrates with its surrounding environment. This includes requirements for maintaining dense perennial vegetation throughout the dry season to maintain aesthetics and to minimise weed growth;

(iii) incorporating crime prevention through environmental design (CPTED) principles and traffic visibility safety standards for roadside systems. This objective also needs to incorporate public safety; and

(iv) providing other landscape values such as shade, amenity, character, buffers, glare reduction, place making and habitat.

For further guidance refer to the *South East Queensland WSUD Conceptual Design Guidelines* (Healthy Waterways Partnership, 2008)

(b) Bioretention basin vegetation

Planting for bioretention basin elements may consist of up to three vegetation types:

(i) groundcovers for stormwater treatment and erosion protection;

(ii) shrubbery for screening, glare reduction and character; and

(iii) trees for shading, character, breaking up filter material and other landscape values.

The plant species listed in SC6.4.3.9.6 Plant selection for WSUD systems in the coastal dry tropics tolerate free draining sandy soils and are capable of withstanding long dry periods as well as periods of inundation. However, because the dry periods in the coastal dry tropics can be severe, bioretention systems must have supplemental temporary irrigation or include a saturated zone. These measures ensure dense perennial vegetation can be sustained to maintain aesthetics, stormwater treatment capacity and to minimise weed growth.

(c) Parkland bioretention basins

Once the general location has been determined, it will be necessary to investigate how the elements of the bioretention system will be arranged within the open space including:

(i) opportunities and constraints presented by various siting options;

(ii) if the device is to be visually prominent (perhaps for educational value) or merged with the surrounding parkland space using a consistent planting layout in the basin, embankment and parkland; and

(iii) a formal or informal style dependent on the setting and surrounding open space and urban design.

(d) Safety issues

The standard principles of informal surveillance, exclusion of places of concealment and open visible areas apply to the landscape design of bioretention basins. Regular clear sightlines should be provided between the roadway and footpaths/ property. Safety measures in accordance with the requirements of the relevant local authority should also be installed around structural components of bioretention basins where safety hazards exist.

(i) Crime prevention through environmental design (CPTED)

Where planting may create places of concealment or hinder informal surveillance, groundcovers and shrubs should not generally exceed 1 m in height.

(ii) Traffic sightlines

The standard rules of sightline geometry apply. Planting designs should allow for visibility at pedestrian crossings, intersections, rest areas, medians and roundabouts.

(5) Construction and establishment – bioretention basins

This section provides general advice for the construction and establishment of bioretention basins and key issues to be considered to ensure their successful establishment and operation (see Figure SC6.4.3.9.20).

Figure SC6.4.3.9.20 Bioretention basin functional installation

(a) Staged construction and establishment method

(i) Sediment and erosion control

Many soils within the coastal dry tropics region are dispersive, highlighting the critical importance of appropriate sediment and erosion control. All development and land disturbance activities must employ best practice sediment and erosion control practices to minimise the impact on receiving environments (refer to the Development manual planning scheme policy SC6.4.3.8 Stormwater management plans for development).

In relation to bioretention systems, temporary protective layers must be installed and left in place throughout the allotment building phase to ensure sediment laden waters do not clog the filtration media and allotment building traffic does not enter the bioretention system (see Figure SC6.4.3.9.21). Importantly the configuration of the bioretention basin and the turf vegetation allow the system to function effectively as a shallow sedimentation basin reducing the load of sediment discharging to the receiving environment. Using this approach, WSUD systems can operate effectively to protect downstream ecosystems immediately after construction.

Figure SC6.4.3.9.21 Bioretention basin sediment and erosion control

(ii) Operational establishment

At the completion of the allotment building phase the temporary measures (i.e. geofabric and turf) are removed with all accumulated sediment and the bioretention system re-profiled and planted in accordance with the proposed landscape design. Establishment of the vegetation to design condition can require more than two growing seasons, depending on the vegetation types, during which regular watering and removal of weeds will be required.

(iii) Quality control during construction

The primary responsibility for supervision of the construction of WSUD elements lies with the site superintendent. Key milestones requiring inspection and sign off by either the superintendent or the design team are detailed in the suggested construction sequence below.

Meetings between the design team and contractors should also take place at the commencement of each phase of works, i.e.:

- prior to commencement of civil works;
- prior to commencement of landscape works; and
- at the completion of works.

Regular site inspections by a member of the design team are also recommended to ensure the bioretention basins are constructed as per the design intent and to provide ongoing construction and establishment advice to the contractors.

The suggested construction sequence for the bioretention basins are as follows:

(A) survey bioretention basin location;

(B) undertake bulking out, including construction of bunds surrounding basin. Construct outflow headwall(s) and install section(s) of stormwater reinforced concrete pipes (RCP) that runs underneath bund. Terminate pipe at interface of bund and bioretention basin;

(C) excavate surrounding landform to design subsoil level (achieving surrounding level at this stage reduces the need for earthworks adjacent to the basins after they have been constructed);

(D) install overflow pit(s) and ensure pit crest(s) is at design level. The pit crest(s) will then be used as a datum from which other levels within the basin will be measured. The pit requires holes for pipe connections and these should be drilled at this stage;

(E) detailed excavation, trimming and profiling of sides and base of basin, ensuring base has minimum 0.5% grade (0% slope when saturated zones are included in the designs) towards pit. Ensure base of basins are free from debris. As constructed survey is required at this time and should include the base and bunds of the system and all hard structures (i.e. overflow pit, overflow weir and pipe connection punch-out holes);

(F) install silt fences around basin to prevent sediment entering system and to keep construction vehicles off the basin;

SUPERINTENDENT INSPECTION AND SIGN OFF REQUIRED BEFORE PROCEEDING

(G) line basin with geofabric, ensuring geofabric extends beyond top of bioretention basin side walls, up to the sediment control fence. This ensures that exposed earth on the bunds won't wash into basins during construction;

(H) install remaining RCP stormwater pipe connecting overflow pit(s) to existing RCP stormwater pipe installed as part of Step 2;

(I) install slotted PVC under-drainage pipes and PVC collector pipes in specified layout. Ensure all pipes are laid at min 0.5% slope (0% slope when saturated zones are included in the designs) with no localized depressions verified using level or string line. Arrange slots so that they are not directly on top of the pipe (to minimise fine particles blocking the slots). Seal junctions and connections (i.e. slotted PVC pipes to PVC collector pipes; slotted PVC pipes/PVC collector pipes to overflow pits) using sealant to prevent sand/gravel/soil passing into drainage network. Connect clean out points ensuring top of clean out points will ultimately sit 200 mm below overflow pit crest;

SUPERINTENDENT INSPECTION AND SIGN OFF REQUIRED BEFORE PROCEEDING

(J) install drainage, transition and saturated zones as required and as detailed in the design drawings;

(K) place prescribed bioretention filter media to design surface level of bioretention basin. Spread material using excavator bucket, hand tools, or a small "pozitrack" bobcat. Do not drive over filter media with any vehicle other than a "pozitrack" bobcat and only if agreed to by civil superintendent. In order to remove air pockets within the filter media, apply light and even compaction by making a single pass with a "pozitrack" bobcat (or similar). If required, apply additional filter media to ensure final surface level is correct. Use a spreader bar to flatten the surface of the filter media. Ultimately, the surface of the filter media must be level (horizontal) and free from local depressions and set at 300 mm below pit crest;

(L) construct coarse sediment forebay utilising large, flat rocks to form base of forebay and interface between forebay and bioretention area;

(M) install temporary protective covering over bioretention surface. This involves covering the surface of filtration media with geofabric and placement of 50 mm topsoil and turf over the geofabric. This geofabric/turf layer is a temporary measure to protect the filter media from being clogged with construction sediment while allotment building is being undertaken. Once a majority of the allotment building is complete and the construction sediment load is minimal, this protective layer will be removed, and the system will be planted out with the vegetation as per designs;

(N) place landscaping topsoil on top of geofabric covering the bunds and around basin as per designs;

(O) flush under-drainage pipes to remove any initial ingress of material; and

(P) undertake as constructed survey of the basin surface and surrounding bunds, picking up at least one spot level per 100m² on the basin surface and at least one spot level every 10m along the top of the bunds.

FINAL SUPERINTENDENT INSPECTION AND SIGN OFF

(b) Construction tolerances

It is important to emphasise the significance of tolerances in the construction of bioretention basins (e.g. profiling of trench base and surface grades). Ensuring the surface of the bioretention filter media is free from localised depressions is particularly important to achieve even distribution of stormwater flows across the surface. In bioretention systems without saturated zones, the base of the trench should be sloped towards the outlet pit (min 0.5% longitudinal grade) to enable the perforated sub-surface drainage pipes to drain freely. Generally an earthworks tolerance of plus or minus 50 mm is considered acceptable.

(c) Sourcing bioretention 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 bioretention basin planting. When this is not done and the planting specification is compromised, poor vegetation establishment and increased initial maintenance costs may occur. The species listed in SC6.4.3.9.6 Plant selection for WSUD systems in the coastal dry tropics are generally available commercially from local native plant nurseries. Availability is, however, dependent upon many factors including demand, season and seed availability. To ensure planting specification can be accommodated, the minimum recommended lead time for ordering is 3-6 months. This usually allows enough time for plants to be grown to the required size. The following pot sizes are recommended as the minimum:

(i) viro tubes - 50 mm wide x 85 mm deep;

(ii) 50 mm tubes - 50 mm wide x 75 mm deep; and

(iii) native tubes - 50 mm wide x 125 mm deep.

(d) Vegetation establishment

The following weed control measures and watering schedule are recommended to ensure successful plant establishment. Regular general maintenance as outlined in SC6.4.3.9.4(5) will also be required.

(i) Weed control

Conventional surface mulching of bioretention basins with organic material like tanbark, should not be undertaken. Most organic mulch floats and runoff typically causes this material to be washed away with a risk of blocking drains. Adopting high planting densities (e.g. 8-10 plants per square metre) and if necessary, applying a suitable biodegradable erosion control matting to the basin batters will help to combat weed invasion and reduce labour intensive maintenance requirements for weed removal. A heavy application of seedless hydro-mulch or hydro-mulch seeded with a sterile annual grass (e.g. Sterile Rye Grass) to create an anchored mulch can also provide short term erosion and weed control prior to planting with nursery stock. No matting or hydro-mulch is to be applied to the surface of the bioretention basin following the construction phase (i.e. in its final design form, vegetated as per planting schedule), as this will hinder filtration of stormwater through the filter media.

(ii) Watering

Regular watering of bioretention basin 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. The following watering program is generally adequate but should be adjusted (increased) to suit the site conditions:

(A) week 1-2 3 visits/ week;

(B) week 3-6 2 visits/ week; and

(C) week 7-12 1 visit/ week.

After this initial 3 month period, supplementary irrigation will be required in bioretention basins without submerged zones and may be required in bioretention basins with saturated zones (particularly during the 2 year plant establishment period (see Figure SC6.4.3.9.22)). Watering requirements to sustain healthy vegetation should be determined during ongoing maintenance site visits.

Figure SC6.4.3.9.22 Plant establishment period in bioretention basin

(6) Maintenance requirements – bioretention basins

Vegetation plays a key role in maintaining the porosity of the filter media of a bioretention basin and a strong healthy growth of vegetation is critical to its performance. Therefore the most intensive period of maintenance is during the plant establishment period (first 2 years) when weed removal and replanting may be required.

Inflow systems and overflow pits require careful monitoring, as these can be prone to scour and litter build up. Debris can block inlets or outlets and can be unsightly, particularly in high visibility areas. Inspection and removal of debris should be done regularly, and debris should be removed whenever it is observed on a site. Where sediment forebays are adopted, regular inspection of the forebay is required (3 monthly) with removal of accumulated sediment undertaken as required.

For larger bioretention basins, a maintenance access track for maintenance vehicles (e.g. 4WD ute) should be provided to the full perimeter of the system for maintenance efficiency and ease.

(7) Checking tools – bioretention basins

A number of checking aids have been developed for designers and council development assessment officers. In addition, SC6.4.3.9.4(5) Construction and establishment - bioretention basins provides general advice for the construction and establishment of bioretention basins and key issues to be considered to ensure their successful establishment and operation based on observations from construction projects around Australia.

(a) Design assessment

The checklist at Table SC6.4.3.9.11 presents the key design features that are to be reviewed when assessing the design of a bioretention basin. These considerations include configuration, safety, maintenance and operational issues that need to be addressed during the design phase. If an item receives an "N" when reviewing the design, referral is made back to the design procedure to determine the impact of the omission or error. A copy of the completed design calculation summary from Table SC6.4.3.9.10 should be provided as part of the application to assist in the design assessment. In addition to the checklist, a proposed design is to have all necessary permits for its installation. Council development assessment officers will require all relevant permits to be in place prior to accepting a design.

Click here to view **Table SC6.4.3.9.11 Bioretention basin design assessment checklist**

(b) Construction (during and post)

The checklist at Table SC6.4.3.9.12 presents the key items to be reviewed when inspecting the bioretention basin during and at the completion of construction. The checklist is to be used by Construction Site Supervisors and local authority Compliance Inspectors to ensure all the elements of the bioretention basin have been constructed in accordance with the design. If an item receives an "N" in Satisfactory criteria then appropriate actions must be specified and delivered to rectify the construction issue before final inspection sign-off is given.

Click here to view **Table SC6.4.3.9.12 Bioretention basin construction inspection checklist**

(c) Operation and maintenance inspection

The example form at Table SC6.4.3.9.13 should be developed and used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time. Inspections should occur every 1 - 6 months depending on the size and complexity of the system. More detailed site specific maintenance schedules should be developed for major bioretention basins and include a brief overview of the operation of the system and key aspects to be checked during each inspection.

Click here to view **Table SC6.4.3.9.13 Bioretention basin maintenance checklist**

(d) Asset transfer (following on maintenance period)

Land ownership and asset ownership are key considerations prior to construction of a stormwater treatment device. A proposed design should clearly identify the asset owner and who is responsible for its maintenance. The proposed owner should be responsible for performing the asset transfer checklist. For details on asset transfer to specific to each council, contact the relevant local authority. Table SC6.4.3.9.14 provides an indicative asset transfer checklist.

Click here to view **Table SC6.4.3.9.14 Bioretention basin asset transfer checklist**

(8) Example engineering drawings – bioretention basins

Where council has standard drawings appropriate to a bioretention basin application, these should be used to guide the design and construction of a bioretention basin. In the absence of local standards, Brisbane City Council have developed a set of Standard Drawings (UMS 155, 156 and 337) that can be readily applied to bioretention basin applications in the coastal dry tropics. These drawings relate specifically to inlet pits and sub-surface drains for bioretention swales but may be used to guide design for bioretention basins.

Editor's note—these are not intended to be prescriptive drawings which must be adhered too; rather they are intended to provide detailed examples of bioretention system configurations.

(9) References and additional information – bioretention basins

BCC 2000a (with revisions 2004), *Subdivision and Development Guidelines*.

BCC 2000b, *Brisbane City Plan 2000*, BCC, Brisbane.

BCC, DMR & PRSC (Brisbane City Council, Queensland Department of Main Roads & Pine Rivers Shire Council) 2001, *Preferred Species Manual: Green Routes Program*, prepared for the Green Routes Program by BCC, DMR & PRSC, Brisbane Deletic, A. and G. Mudd (2006). Preliminary results from a laboratory study on the performance of bioretention systems built in Western Sydney saline soils, Facility for Advancing Water Biofiltration.

DMR (Queensland Department of Main Roads) 1997, *Road Landscape Manual*, prepared by EDAW (Aust) Pty Ltd for DMR, Brisbane

DNRW, IPWEA & BCC (Department of Natural Resources and Water, Institute of Public Works Engineering Australia – Qld Division & Brisbane City Council) 1998, Q*ueensland Urban Drainage Manual (QUDM)* Second Edition, prepared by Neville Jones & Associates and Australian Water Engineering for DNRW, IPWEA & BCC, Brisbane.

Kim, H., E.A Seagren and A.P. Davis. (2003) Engineered Bioretention for Removal of Nitrate from Stormwater Runoff. *Water Environment Research*, 75(4), 355-367

Leinster, S 2006, *Delivering the Final Product – Establishing Water Sensitive Urban Design Systems*, 7th International Conference on Urban Drainage Modelling and 4th International Conference on Water Sensitive Urban Design Book of Proceedings, Volume 2, A Deletic and T Fletcher (eds), Melbourne.

LHCCREMS (Lower Hunter and Central Coast Regional Environmental Management Strategy) 2002, *Water Sensitive Urban Design in the Sydney Region: 'Practice Note 2 – Site Planning*', LHCCREMS, NSW, http://www.wsud.org/downloads/Planning%20Guide%20&%20PN%27s/02-Site%20Planning.pdf

McFarlane A 1997, *Successful Gardening in Warm Climates*, Kangaroo Press, Sydney

Standards Australia 2003, AS 4419-2003: *Soils for landscaping and garden use*, Standards Australia

Townsville City Council, *Water sensitive urban design for the coastal dry tropics (Townsville): Technical design guidelines for stormwater management*, 2011

Zinger, Y., A. Deletic and T. D. Fletcher (2007a). *The effect of various intermittent wet-dry cycles on nitrogen removal capacity in biofilters systems. 13th International Rainwater Catchment Systems* Conference and 5th International Water Sensitive Urban Design Conference, Sydney, Australia.

Zinger, Y., T. D. Fletcher, A. Deletic, G. T. Blecken and M. Viklander (2007b). *Optimisation of the nitrogen retention capacity of stormwater biofiltration systems.* Novatech 2007, 6th International Conference on Sustainable Techniques and Strategies in Urban Water Management, Lyon, France.

SC6.4.3.9.5 Constructed stormwater wetlands

Editor's note—due to the different climatic conditions, the design of constructed wetlands in the coastal dry topics differs from the design of wetlands in south east Queensland and southern states. The following design considerations and criteria outlined below are specific to the coastal dry topics and are intended to address key requirements such as maintaining perennial wetland vegetation during the dry season; managing the potential for weed ingress and providing natural means of managing mosquito populations.

(1) Constructed wetland systems are densely vegetated water bodies that use enhanced sedimentation, fine filtration and biological uptake processes to remove pollutants from stormwater. Water levels rise during rainfall

events and outlets are configured to slowly release flows, typically over two to three days, back to dry weather water levels. In addition to treating stormwater, constructed wetlands can also provide habitat, passive recreation and improved landscape amenity.

Constructed wetlands in the coastal dry tropics will generally consist of an inlet zone (sedimentation basin to remove coarse sediments, deep pools, a deep marsh macrophyte zone (i.e. a heavily vegetated area to remove fine particulates and uptake soluble pollutants) and a high flow bypass channel (to protect the macrophyte zone from scour and vegetation damage). Figure SC6.4.3.9.23 Schematic layout of a constructed wetland system and Figure SC6.4.3.9.24 Wet and dry season conditions in a constructed freshwater wetland show the key elements of constructed stormwater wetland systems.

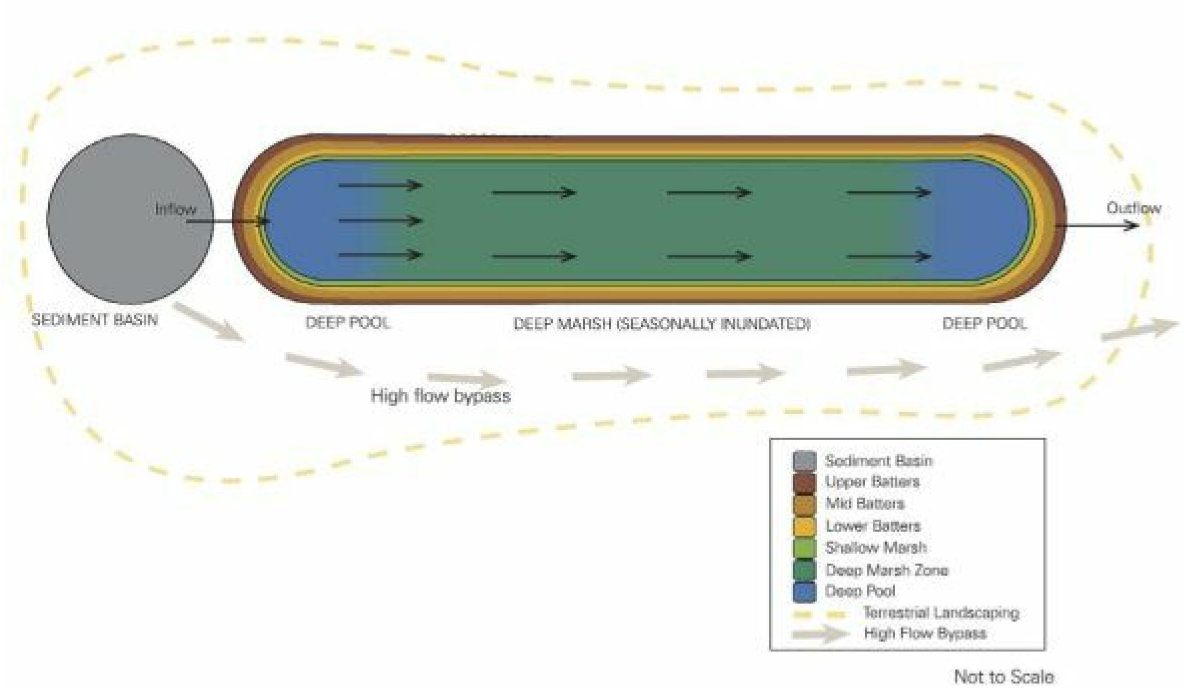


Figure SC6.4.3.9.23 Schematic layout of a constructed wetland system

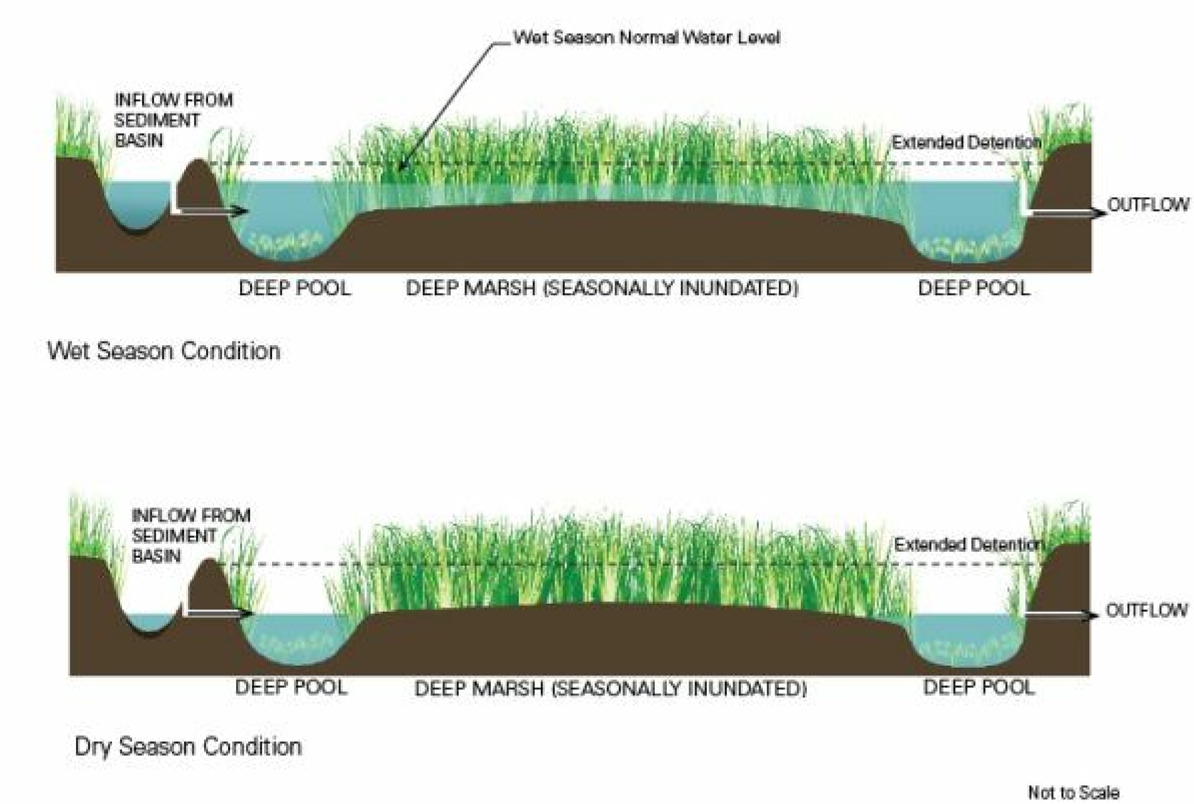


Figure SC6.4.3.9.24 Wet and dry season conditions in a constructed freshwater wetland

Constructed wetlands treat stormwater by capturing runoff and slowly passing it horizontally through a densely vegetated macrophyte zone. Soluble and colloidal (fine particles held in suspension) pollutants are mostly removed by sorption (absorption – "into" and adsorption – "onto") to biofilms on stems of wetland plants (Figure SC6.4.3.9.25). For this reason, dense vegetation is important for effective treatment and vegetation with a large stem surface area provides greatest treatment (i.e. plants with many small diameter stems are able to support more biofilms than plants with fewer, thicker stems). Emergent macrophytes are also important for:

(a) transferring oxygen to the sediments (oxygen pumps) thereby facilitating the processing and/or immobilising of pollutants captured and held within wetland sediments;

(b) aiding in the treatment of nutrient and heavy metal concentrations, either through direct uptake, or through providing a surface for biofilms and epiphytes that assist with the removal of pollutants;

(c) influencing sediment deposition and physically filtering sediment particles from the water column;

(d) influencing hydrology and hydraulics by promoting even flow distribution through the wetland;

(e) providing shade, decreasing light availability for algal synthesis;

(f) decreasing erosion by reducing wave action and flow velocities while binding soil particles with their root systems; and

(g) providing a basis for wetland food chains and supplying shelter for mosquito predators such as macroinvertebrates and fish.

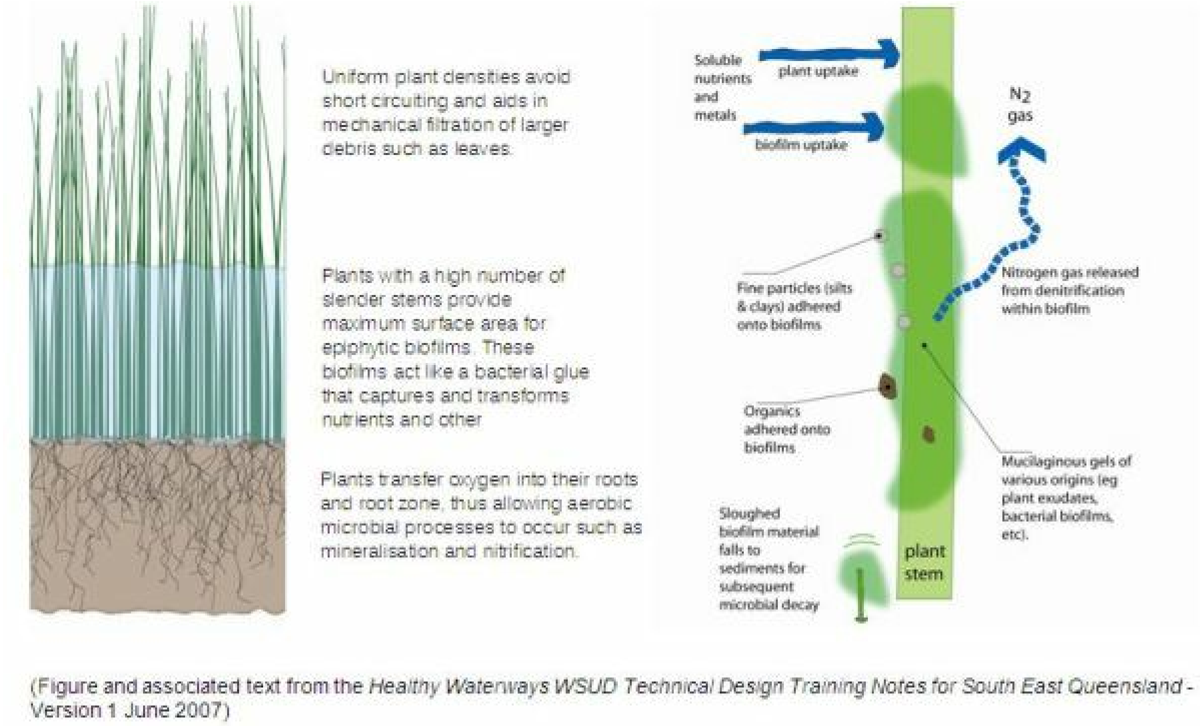


Figure SC6.4.3.9.25 Dense emergent macrophytes and biofilms on the plant stems play an important role in nutrient removal in constructed stormwater wetlands

Source—Figure and associated text from the *Healthy Waterways WSUD Technical Design Training Notes for South East Queensland* - Version 1 June 2007.

(2) Design considerations - constructed wetlands

Due to the different climatic conditions, the design of constructed wetlands in the coastal dry topics differs from the design of wetlands in south-east Queensland and southern states. The following design considerations and criteria outlined below are specific to the coastal dry topics and are intended to address key requirements such as maintaining perennial wetland vegetation during the dry season; managing the potential for weed ingress and providing natural means of managing mosquito populations. Constructed wetlands in the form detailed below have not yet been constructed in the Townsville region. Therefore it is recommended that demonstration projects adopting the design guidelines detailed below are constructed and revisions/updates of this clause made, where deemed appropriate, to reflect practical learnings and understanding of the performance and sustainability of constructed stormwater treatment wetlands in the coastal dry tropics.

Community acceptance of constructed wetlands will be driven by their aesthetics and landscape amenity value. Poorly designed and/or maintained wetlands are unlikely to gain community support; therefore, it is essential to address potential issues such as pests and weeds starting at conceptual design and continuing through implementation and long-term maintenance.

The operation of constructed wetlands involves the interaction between stormwater runoff, vegetation and hydraulic structures and the successful implementation of constructed wetlands requires appropriate integration into the landscape design. In this regard, the following sections provide an overview of the key design issues that must be considered when conceptualising and designing constructed wetlands.

(a) Landscape design

Constructed wetlands are often located within accessible open space areas and can become interesting community features. Landscape design aims to ensure that macrophyte planting fulfils the intended stormwater treatment function as well as integrating with their surrounds. Opportunities to enhance public amenity and safety with viewing areas, pathway links, picnic nodes and other elements should be exploited. Community education through signage and public art can also be explored. It is important that the landscape of constructed wetlands addresses stormwater quality objectives whilst being sensitive to these other important landscape aims.

Terrestrial landscaping provides a visual buffer and framework for the wetland system within the community and native habitat. Native trees can encourage recreational elements such as walking and bird watching. These recreational elements, as well as education in the form of descriptive panels and signs, can increase acceptance of these systems within the community.

Figure SC6.4.3.9.26 Boardwalk and public viewing area on the edge of a landscaped wetland

(b) Invasive weed control

To protect landscape amenity and the stormwater treatment efficiency of the wetland it is important to maintain, throughout the year, the design vegetation communities to avoid excessive colonisation of the wetland by weeds. Weed infestation is a major problem in the dry tropics, particularly within ephemeral waterways and stormwater treatment facilities. The wetland design presented in this chapter is based on an ephemeral wetland (i.e. it will dry periodically) and therefore, the design and management of the wetland to manage weed infestation takes on high importance. Management of weeds is achieved as follows:

(i) designing the macrophyte zone as predominately a deep marsh system (i.e. water depth 0.5 m - 0.7 m) to maintain the macrophyte vegetation by minimising the frequency and duration of wetland drying, thus permanently occupying the habitat and restricting weed colonisation opportunities;

(ii) planting dense littoral vegetation around the perimeter of the wetland to avoid the ingress of weed species. To maintain dense perennial littoral vegetation, irrigation is likely to be required, particularly during the dry season; and

(iii) during the establishment and ongoing maintenance of the wetland, prompt removal of weeds before they spread and/or set seed is of critical importance.

(c) Detention time and hydrologic effectiveness

Detention time is the time taken for each “parcel” of water entering the wetland to travel through the macrophyte zone assuming “plug” flow conditions. In highly constrained sites, simulations using quantitative computer models, such as the Model for Urban Stormwater Improvement Conceptualisation (MUSIC, CRCCH 2005), are often required to optimise the relationship between wetland detention time1 and wetland hydrologic effectiveness to maximise treatment performance. Hydrologic effectiveness is a measure of the mean annual volume of stormwater runoff captured and treated within the wetland and is expressed as a percentage of the mean. It is recommended that a notional detention time should preferably be around 48 hours to remove nutrients effectively from urban stormwater. Optimal hydrologic effectiveness in the coastal dry tropics Region is a balance between minimising overflows in the wet season and sustaining vegetation in the dry season (i.e. sizing the wetland to treat the majority of stormwater runoff while not being too large as to result in water level drawdown and drying in excess of 60–70 days in the dry season). Further discussion on hydrologic effectiveness and sizing of wetlands in the coastal dry tropics is provided in the following sections of this clause.

Editor’s note—it should be noted that detention time is rarely a constant and the term notional detention time is used throughout this chapter to provide a point of reference in modelling and determining the design criteria for riser outlet structures.

(d) Hydrodynamic design

Poor wetland hydrodynamics is often identified as a major contributor to wetland operational and management problems. A summary of desired hydrodynamic characteristics and design considerations is presented in Table SC6.4.3.9.15.

Table SC6.4.3.9.15 Desired wetland hydrodynamic characteristics and associated design considerations

Hydrodynamic Characteristics	Design Considerations	Remarks
Uniform Distribution of flow velocity	Wetland shape, inlet and outlet placement and bathymetrical design of wetland to eliminate short-circuit flow paths and poorly mixed zones.	Poor flow pattern within a wetland will lead to zones of stagnant pools which promote litter, oil and scum accumulation as well as potentially supporting mosquito breeding. Short circuit flow paths of high velocities will lead to the wetland being ineffective in water quality improvement.

Inundation depth, wetness gradient, base flow and hydrologic regime	Selection of wetland size and design of outlet control to ensure compatibility with the hydrology and size of the catchment draining into the wetland. Bathymetry layout and outlet control design to compliment the botanical design and the hydrology of the wetland.	Wetland area and outlet design is critical to achieve the WSUD Objectives (e.g. target pollutant load reduction) as well as ensuring the size is adequate to sustain wetland vegetation (i.e. not too large as to result in excessive water level drawdown and drying in excess of 60 days in the dry season). Inadequate attention to the inundation depth, wetness gradient of the wetland and the frequency of inundation at various depth ranges would lead to sparse vegetation cover and/or dominance of certain plant species (especially weed species over time). This results in a deviation from the intended botanical layout of the wetland and reduced stormwater treatment performance.
Uniform vertical velocity profile	Selection of plant species and location of inlet and outlet structures to promote uniform vertical velocity profile.	Preliminary research findings have indicated that certain plant species have a tendency to promote stratification of flow conditions within a wetland leading to ineffective water pollution control and increasing the potential for algal blooms.
Scour protection	Design of inlet structures and erosion protection of banks.	Owing to the highly dynamic nature of stormwater inflows, measures are to be taken to “protect” the wetland from erosion during periods of high inflow rates.

(e) Inlet zone design considerations

The inlet zone of a constructed stormwater wetland is designed as a sedimentation basin and has two key functional roles. The primary role is to remove coarse to medium sized sediment (i.e. 125 µm or larger) prior to flows entering the macrophyte zone. This ensures the vegetation in the macrophyte zone is not smothered by coarse sediment and allows the macrophyte zone to target finer particulates, nutrients and other pollutants.

The second role of the inlet zone is the control and regulation of flows entering the macrophyte zone and bypass of flows during “above design flow” conditions. The outlet structures from the inlet zone (i.e. sedimentation basin) are designed such that flows up to the “design flow” (typically the 1 year ARI) enter the macrophyte zone whereas “above design flows” are bypassed around the macrophyte zone. In providing this function, the sedimentation basin protects the vegetation in the macrophyte zone against scour during high flows (see Figure SC6.4.3.9.27).

When the available space for a constructed wetland is constrained, it is important to ensure that the size of the inlet zone (i.e. sedimentation basin) is not reduced. This ensures the larger sediments are effectively trapped and prevented from smothering the macrophyte zone. When the site constrains the size of the constructed wetland it is the macrophyte zone of the wetland that should be reduced accordingly.

Large wetland systems usually require a gross pollutant trap (GPT) as part of the inlet zone to protect the wetland from litter and debris. The decision of whether a GPT is required or not, depends on the presence of upstream GPT measures and catchment size. The relevant local authority should be consulted to determine if a GPT is required.

Figure SC6.4.3.9.27 Inlet zone bypassing major design flows around wetland.

(f) Macrophyte zone design considerations

The layout of the macrophyte zone needs to be configured such that system hydraulic efficiency is optimised and healthy vegetation sustained. Design considerations include:

(i) the preferred extended detention depth is 0.5 m. Deeper extended detention depths, up to a maximum of 0.75 m, may be acceptable where the wetland has a high hydrologic effectiveness and where the botanic design uses plant species tolerant to greater depths of inundation;

(ii) the longitudinal bathymetry of the macrophyte zone should grade (min 0.5% grade) smoothly from 0.7 m in depth (based on design normal water level) up to a central crest 0.5 m in depth and then back down to a maximum of 0.7 m in depth. This ensures that isolated pools of water are not created within the macrophyte zone during the dry season when the normal water level slowly draws down due to evapotranspiration;

(iii) the macrophyte zone is to have a flat cross sectional bathymetry only grading up at the edge batters. This facilitates the even distribution of flows to avoid short circuiting, creates a uniform hydraulic conveyance and maximises stormwater contact with macrophyte stems and biofilms;

(iv) the bathymetry of the macrophyte zone should be designed so that the macrophyte zone is connected to deeper open water pools (located at the inlet and outlet of the macrophyte zone) to allow mosquito predators to seek refuge in the deeper open water zones during periods of extended dry weather;

(v) the deep open water pools should be 2 m in depth to ensure that a permanent pool of water is sustained throughout the dry season. This ensures habitat is retained for fish, macroinvertebrates (mosquito predators) and submerged macrophytes;

(vi) the surface area of deep refuge pools (excluding the sediment basin) within the wetland should be between 20% and 30% of the total macrophyte area;

(vii) the constructed wetland is required to retain water permanently and therefore the base must be of suitable material to retain water (e.g. clay). If in-situ soils are unsuitable for water retention, a clay liner (e.g. compacted 300 mm thick) must be used to ensure there will be permanent water for vegetation and habitat;

(viii) particular attention should be given to the placement of the inlet and outlet structures, the length to width ratio of the macrophyte zone and flow control features to promote a high hydraulic efficiency within the macrophyte zone;

(ix) dense littoral vegetation around the perimeter of the wetland is required to avoid the ingress of weed species. To maintain dense perennial littoral vegetation, irrigation is likely to be required, particularly during the dry season. During extended dry periods (e.g. in excess of 60 days) wetland macrophytes may also require irrigation to sustain dense foliage and prevent habitat opportunities for weed species;

(x) provision to drain the macrophyte zone for water level management during the plant establishment phase should also be considered; and

(xi) the macrophyte zone outlet structure needs to be designed to provide a notional detention time (usually48 hours) for a wide range of flow depths. The outlet structure should also include measures to exclude debris to prevent clogging.

(g) Wetlands constructed within retention (or detention) basins

In many urban applications, wetlands can be constructed in the base of retention basins, thus reducing the land required for stormwater treatment. In these situations, wetland systems will occasionally become inundated to greater depths than the extended detention depth; however, the inundation duration is usually relatively short (hours) and is unlikely to affect the wetland vegetation provided there is a safe pathway to drain the wetland following flood events which avoids scour of the wetland vegetation and banks.

When designing a wetland within a retention basin, the outlet control structure of the retention basin (typically culverts) should be placed at the end of the wetland bypass channel. This ensures flood flows “backwater” across the wetland thus protecting the macrophyte vegetation from scour by high velocity flows.

(h) Vegetation types

Vegetation planted in the macrophyte zone has an important functional role in treating stormwater flows, as well as adding aesthetic value. A dense cover of perennial emergent macrophytes is essential for both stormwater treatment function and for the control of weeds. It is necessary for the macrophytes to permanently occupy the wetland habitat to limit weed colonisation opportunities. Dense perennial littoral vegetation is also important to avoid the ingress of weed species into the wetland macrophyte zone. Dense planting of the littoral zone will inhibit public access to the macrophyte zone, minimising potential damage to wetland plants and reducing the safety risks posed by water bodies.

The reader is referred to SC6.4.3.9.6 Plant selection for WSUD systems in the coastal dry tropics for a list of suggested plant species suitable for constructed wetland systems in the coastal dry tropics. The planting densities recommended in the list should ensure that 70 - 80% cover is achieved within two growing seasons (2 years). The distribution of the species within the wetland will relate to their structure, function, relationship and compatibility with other species. The plant species in SC6.4.3.9.6 Plant selection for WSUD systems in the coastal dry tropics are listed in accordance with the wetland zone/water depth in which they should be planted. The wetland zones are: deep marsh, shallow marsh (wetland edge), lower littoral and upper littoral.

(i) Designing to avoid mosquitoes

To reduce the risk of high numbers of mosquitoes, there are a number of design features that can be considered. Not all of these will be feasible in any one situation, but they include:

(i) providing access for mosquito predators, such as fish and predatory insects, to all parts of the water body (avoid stagnant isolated areas of water);

(ii) providing a deep permanent pool (for long dry periods or for when water levels are artificially lowered) so that mosquito predators can seek refuge and maintain a presence in the wetland;

(iii) where possible, incorporating a steep slope into the water, preferably greater than 300 or 3:1 horizontal to vertical. Note that steep edges may be unacceptable for public safety reasons, and a slope of up to 8:1 horizontal to vertical is generally used;

(iv) wave action from wind over open water will discourage mosquito egg laying and disrupt the ability of larvae to breathe;

(v) providing a bathymetry such that water draws down evenly so isolated pools are avoided;

(vi) providing sufficient gross pollutant control at the inlet such that human derived litter does not accumulate and provide breeding habitat;

(vii) providing ready access for field operators to monitor and treat mosquito larvae if required;

(viii) ensuring maintenance procedures do not result in wheel rut and other localised depressions that create isolated pools when water levels fall; and

(ix) ensuring overflow channels don’t have depressions that will hold water after a storm event.

(j) Designing for maintenance access

Access to all areas of a constructed wetland is required for maintenance. In particular inlet zones and gross pollutant traps require a track suitable for heavy machinery for removal of debris and desilting as well as an area for dewatering removed sediments. If sediment removal requires earthmoving equipment to enter the basin, then a stable ramp suitable for heavy plant will be required into the base of the inlet zone (maximum slope 1:10).

To aid maintenance, it is recommended that the inlet zone is constructed with a hard (i.e. rock) bottom. This is important if maintenance is performed by driving into the basin. It also serves an important role by allowing excavator operators to detect when they have reached the base of the inlet zone during desilting operations.

Macrophyte zones require access to the areas for weeding and replanting as well as regular inspections. Commonly, these access tracks can be incorporated with walking paths around a wetland system. Maintenance access to constructed wetland needs to be considered when determining the layout of a wetland system.

(3) Technical note: saline/brackish constructed wetlands

Urban communities in the dry tropics are often located near large estuarine river systems. In some locations it may be useful to have an optional estuarine stormwater treatment system. While estuarine systems are typically lower nutrient environments than freshwater stormwater treatment systems, a modified salt marsh community would still have considerable nutrient processing capability and could potentially provide a stormwater treatment capacity in some locations. This is a new concept that has not yet been tested and therefore should only be considered if other design solutions are not possible or practical.

If an estuarine stormwater treatment system was to be trialled/ constructed as a demonstration project, it is recommended that the model would need to consider the following list of features/design elements:

(a) drain a large stormwater runoff event over several tidal cycles;

(b) during a runoff event, extended detention depth should not exceed 0.5 m, but preferably be lower;

(c) the wetland should consist of a series of cells that would progressively fill and spill during a runoff event;

(d) the initial cell would be a sedimentation pond;

(e) surrounding the sedimentation pond and throughout the subsequent cells would support salt marsh communities (ranging from herbaceous to woody);

(f) a dry weather drainage system would allow complete drainage over a single tide cycle;

(g) the wetland would be drained by a series of runnels that would be capable of completely draining the system on a low tide sequence, thus managing potential mosquito breeding habitat;

(h) high tides (exceeding mean high tide) would be allowed to penetrate the entire system;

(i) a salinity gradient would be maintained through the system for most seasons;

(j) a series of berms and chokes would be included to ensure cells progressively fill and spill and that a salinity gradient is created and maintained;

(k) in high tidal range environments particular care will be needed in the design of the hydraulic connection between the perched salt marsh treatment system and the larger and deeper estuarine drainage channels (these environments are highly susceptible to erosion particularly after catchment development); and

(l) an important element in a estuarine system will be the wetting and drying sequence in that this will heighten the capacity to process nitrogen pollutants which are critical pollutants to near shore marine ecosystems.

The illustrations on the following page (Figure SC6.4.3.9.28 Possible design features of saline/brackish constructed wetlands), demonstrate how a saline/brackish wetland may be configured to achieve the above design criteria.

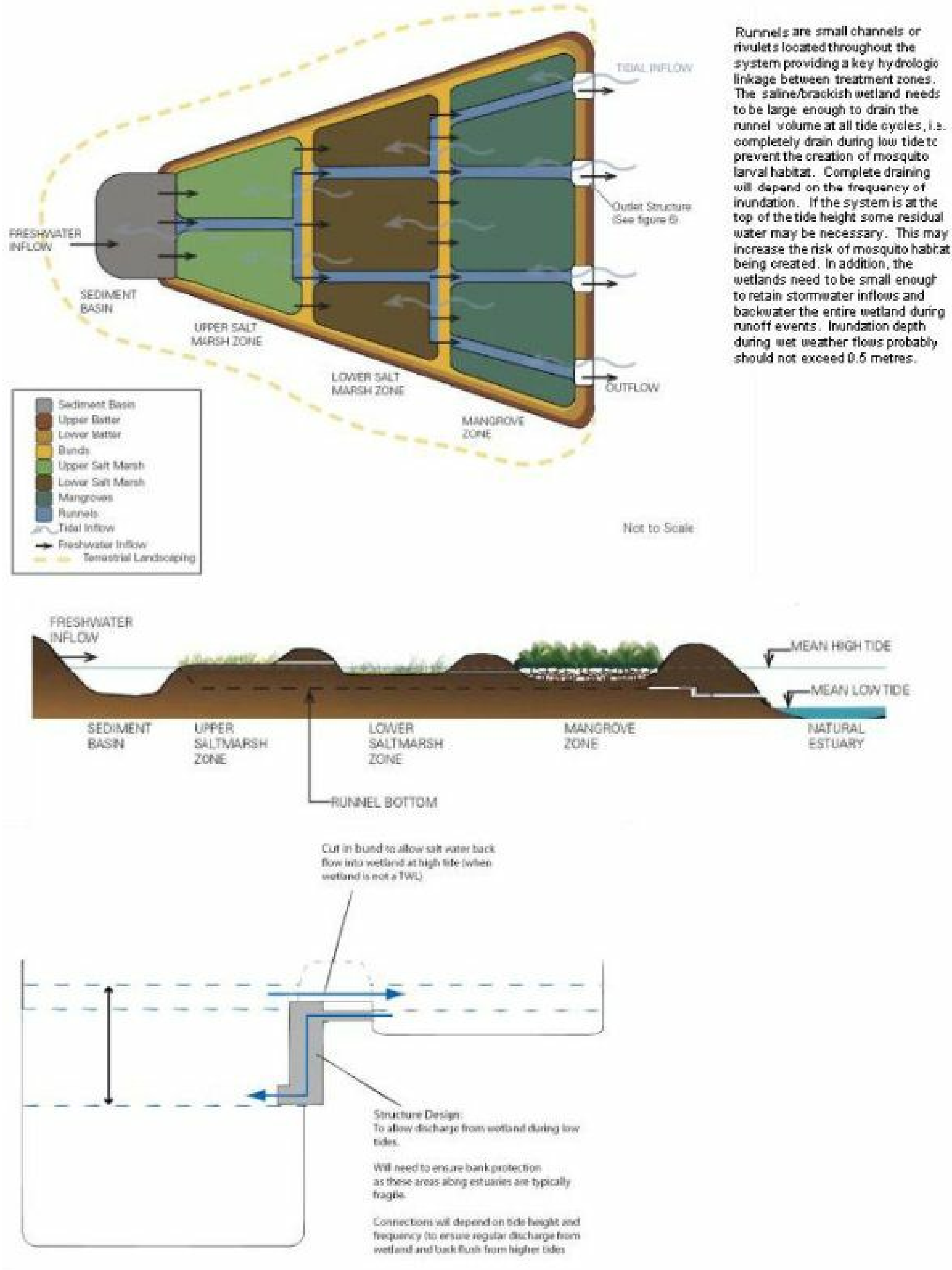
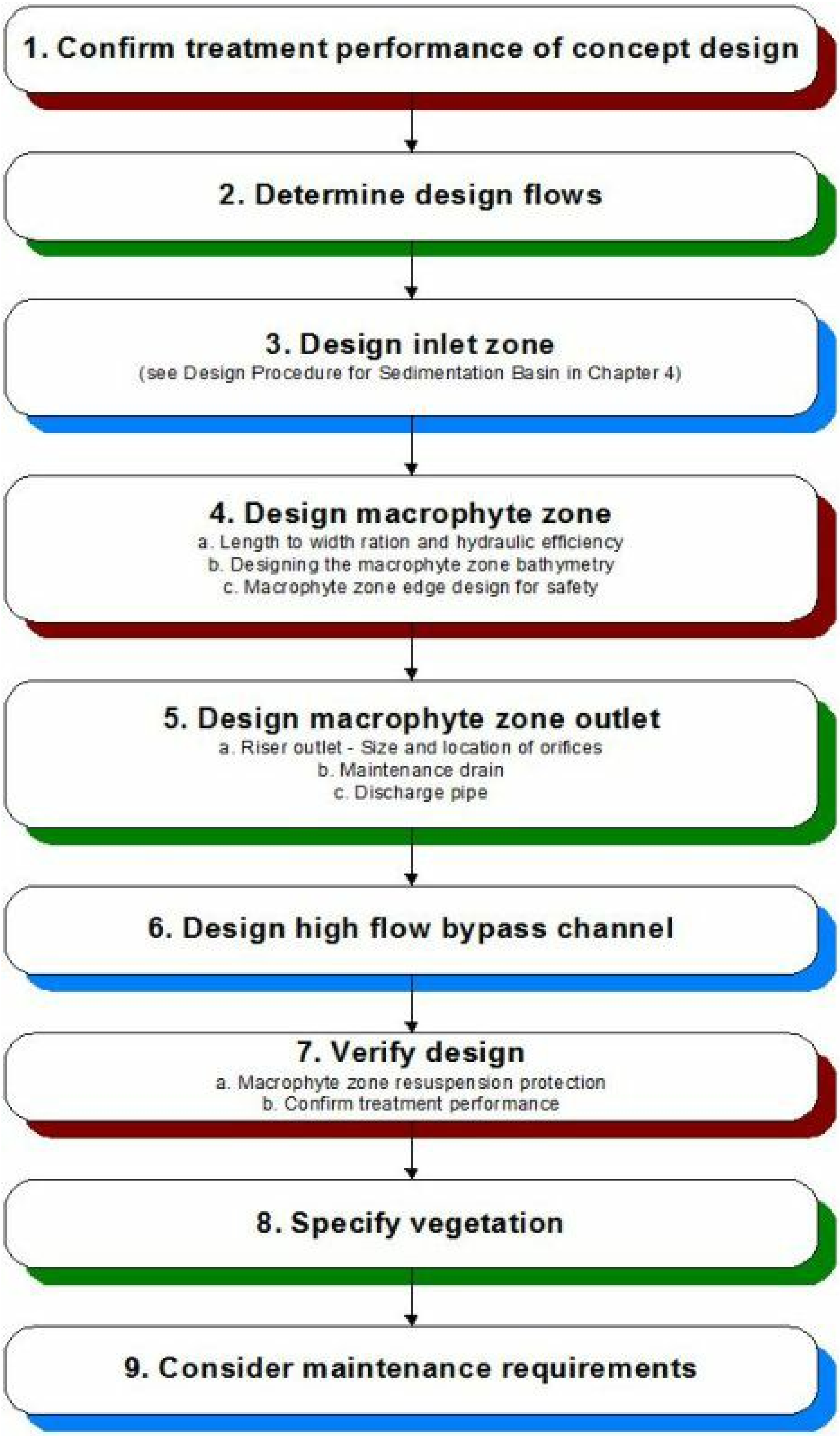


Figure SC6.4.3.9.28 Possible design features of saline/brackish constructed wetlands

(4) Wetland design process

The key design steps following the site planning and concept development stages are:



(a) Step 1: Confirm treatment performance of concept design

Before commencing detailed design, the designer should first undertake a preliminary check to confirm the constructed wetland area (i.e. the macrophyte zone surface area) from the concept design is adequate to deliver the required level of stormwater quality improvement. This assessment should be undertaken by a WSUD specialist and can be achieved by modelling expected treatment performance in an appropriate quantitative modelling program. Where possible, this modelling should be based on local rainfall data, the proposed configuration of the system, and based on local stormwater treatment performance data.

(b) Step 2: Determine design flows

(i) Design discharges

To configure the inlet zone and high flow bypass elements of a constructed wetland the following design flows apply:

(A) design operation flow (1 year ARI) for sizing the inlet zone (i.e. sedimentation basin) and the "control" outlet structure (i.e. overflow pit and pipe connection) discharging to macrophyte zone; and

(B) above design flow for design of the high flow bypass around the macrophyte zone. The discharge capacity for the bypass system may vary depending on the particular situation but will typically correspond to one of the following:

- minor design flow (2 year ARI) – for situations where only the minor drainage system is directed to the inlet zone; and
- major flood flow (100 year ARI) – for situations where both the minor and major drainage system discharge into the inlet zone.

(ii) Design flow estimation

A range of hydrologic methods can be applied to estimate design flows. If the typical catchment areas are relatively small, the Rational Method design procedure is considered to be a suitable method for estimating design flows. However, if the constructed wetland is to form part of a retention basin (refer to SC6.4.3.9.5(2)(g) Wetlands constructed within retention (or detention) basins) or if the catchment area to the wetland is large (> 50 ha), then a full flood routing computation method needs to be used to estimate design flows.

(c) Step 3: Design inlet zone

As outlined in SC6.4.3.9.5(2)(e) Inlet zone design considerations, the inlet zone (see example in Figure SC6.4.3.9.29 Inlet zone of a constructed wetland in Brisbane) of a constructed stormwater wetland is designed as a sedimentation basin and serves two functions: (1) pretreatment of inflow to remove coarse to medium sized sediment; and (2) the hydrologic control of inflows into the macrophyte zone and bypass of floods during "above design" operating conditions. As depicted in Figure SC6.4.3.9.30 Example of inlet zone connection to macrophyte, the inlet zone consists of the following elements:

(i) sedimentation basin "pool" to capture coarse to medium sediment (125μm or larger).

(ii) inlet zone connection to the macrophyte zone (or "control" structure as defined in normally consisting of an overflow pit within the inlet zone connected to one or more pipes through the embankment separating the inlet zone and the macrophyte zone.

(iii) high flow bypass weir (or "spillway" outlet structure to deliver "above design" flood flows to the high flow bypass channel.

Figure SC6.4.3.9.29 Inlet zone of a constructed wetland in Brisbane

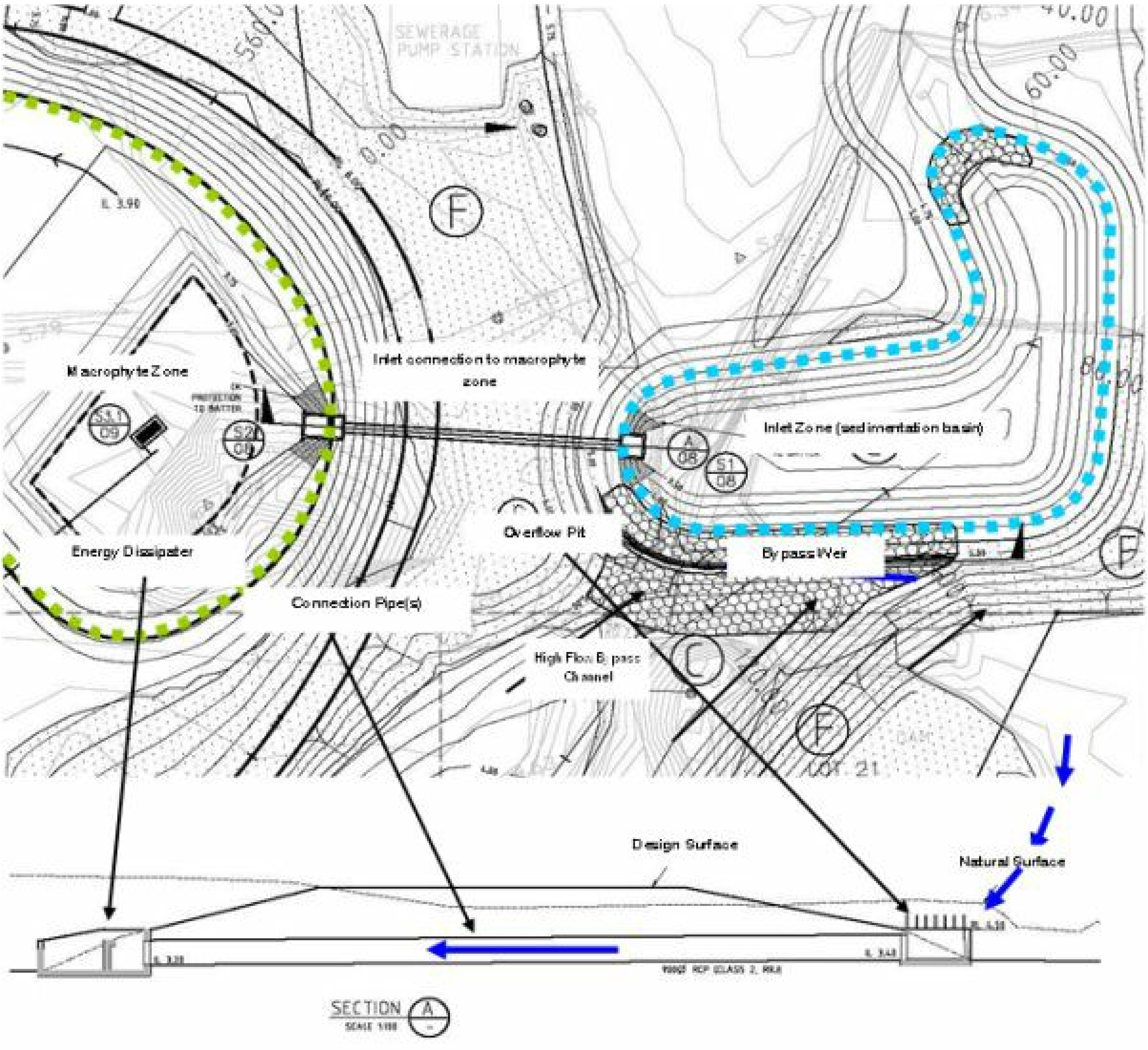


Figure SC6.4.3.9.30 Example of inlet zone connection to macrophyte zone

(iv) For more information and design guidance for each of the inlet zone elements listed above, the reader is referred to Chapter 4 Sedimentation Basins. When applying the design procedure outlined in Chapter 4, the following should be used as a guide:

(A) the inlet zone typically must comprise a deep open water body that operates essentially as a sedimentation basin designed to capture coarse to medium sized sediment (i.e. 125 µm or larger);

(B) it may be necessary for a GPT to be installed such that litter and large debris can be captured at the interface between the incoming waterway (or pipe) and the open water of the inlet zone;

(C) the crest of the overflow pit must be set at the normal water level of the inlet zone (which is typically set 0.3 m above the normal water level of the macrophyte zone);

(D) the pipe that connects the sedimentation basin to the macrophyte zone needs to have sufficient capacity to convey a 1 year ARI flow, assuming the macrophyte zone is at the normal water level and without resulting in any flow over the high flow bypass weir;

(E) the obvert of the connection pipe can be set below the normal water level of the wetland to conceal the pipe (below the normal water level) during the dry season;

(F) an energy dissipater is usually required at the end of the pipes to reduce velocities and distribute flows into the macrophyte zone;

(G) the inlet zone is to have a structural base (e.g. rock) to define the base when desilting and provide support for maintenance plant/ machinery when entering the basin for maintenance; and

(H) the high flow bypass weir ("spillway" outlet) is to be set at the same level as the top of extended detention in the macrophyte zone.

(d) Step 4: Designing the macrophyte zone

(i) Length to width ratio and hydraulic efficiency

To optimise wetland performance, it is important to avoid short circuit flow paths and poorly mixed regions within the macrophyte zone. One way to minimise this is to adopt a high length to width ratio not less than 5 to 1 for the macrophyte zone. Length to width ratios less than this can lead to poor hydrodynamic conditions and reduced water quality treatment performance.

Persson et al. (1999) used the term hydraulic efficiency (λ) to define the expected hydrodynamic characteristics for a range of configurations of stormwater detention systems (Figure SC6.4.3.9.31). Engineers Australia (2006) recommend that constructed wetland systems should not have a hydraulic efficiency (λ) less than 0.5 and preferably should be greater than 0.7.

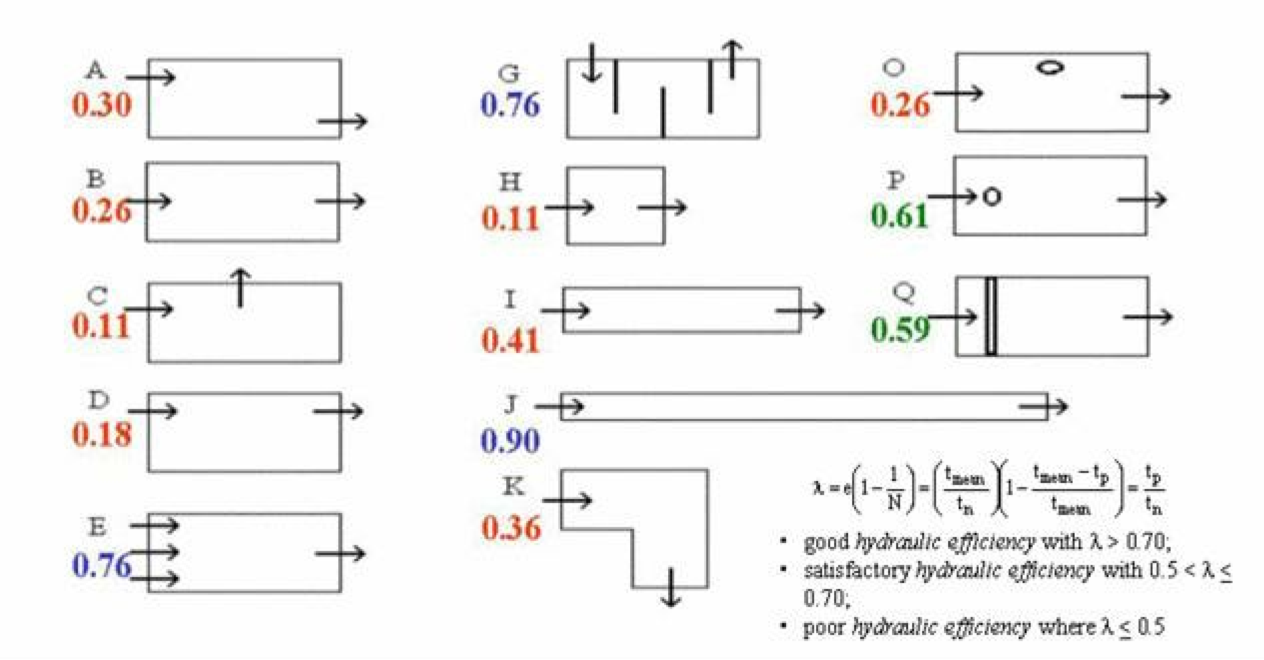


Figure SC6.4.3.9.31 Hydraulic effiency (λ) ranges

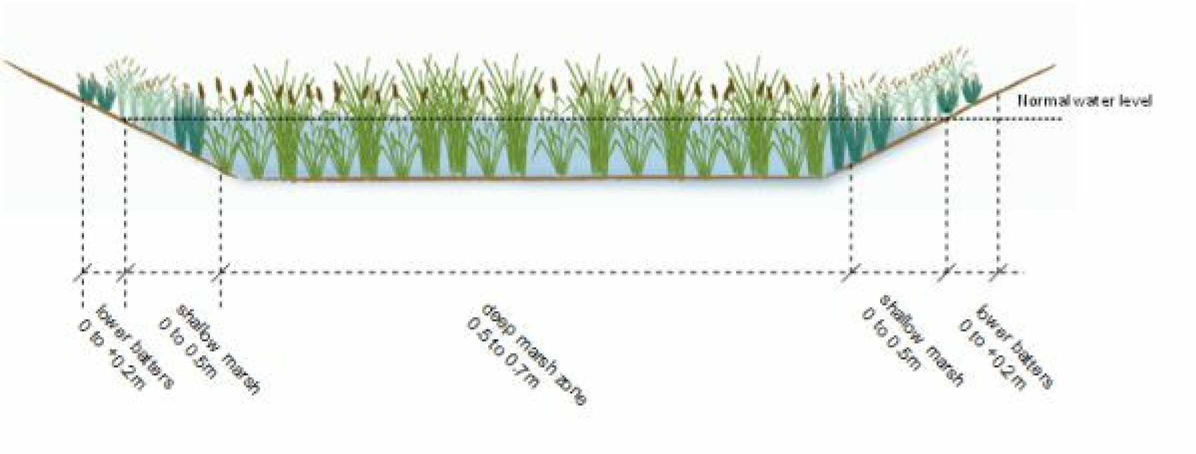
Hydraulic efficiency ranges from 0 to 1, with 1 representing the best hydrodynamic conditions for stormwater treatment. The o in diagrams O and P represent islands in the waterbody and the double line in diagram Q represents a weir structure to distribute flows evenly (Persson et al. 1999).

(ii) Designing the macrophyte zone bathymetry

The bathymetry of constructed wetlands in the coastal dry tropics are to be designed to ensure that macrophytes can provide adequate pollutant removal during the wet season and also be sustained during the dry season. To achieve this, the longitudinal bathymetry of the macrophyte zone should gently grade (min 0.5% grade) from 0.7 m in depth (based on design normal water level) up to a central crest 0.5 m in depth and then back down to a maximum of 0.7 m in depth. This ensures that isolated pools of water are not created during the dry season when the normal water level slowly draws down due to evapotranspiration. Smaller deep open water permanent pools at the inlet and outlet of the wetland are required to provide habitat for mosquito predators during the dry season (Refer to Figure SC6.4.3.9.23 Schematic layout of a contructed wetland system and Figure SC6.4.3.9.24 Wet and dry season conditions in a constrcted freshwater wetland). For large wetlands, this bathymetry could be repeated in series (i.e. a deep pool located between two macrophyte zones).

The macrophyte zone is to have a flat cross sectional bathymetry only grading up at the edge batters (Figure SC6.4.3.9.32). This facilitates the even distribution of flows to avoid short circuiting, creates a uniform hydraulic conveyance and maximises stormwater contact with macrophyte stems and biofilms. This is also assisted by providing banded macrophyte planting perpendicular to the direction of flow (Figure SC6.4.3.9.33).

The deep open water pools should be 2 m in depth to ensure that a permanent pool of water is sustained throughout the dry season. This ensures habitat is retained for fish, macroinvertebrates (mosquito predators) and submerged macrophytes. Submerged macrophytes are important to provide habitat and for maintaining dissolved oxygen levels and therefore deeper pools (i.e. >2 m) should be avoided. A balance pipe connection between the deep pools is necessary to allow inflows in dry conditions to benefit and sustain the deep permanent pools. The surface area of deep refuge pool (excluding the sediment basin) within the wetland should be between 20% and 30% of the total macrophyte area. This ensures the volume of water within the pools is sufficient to maintain permanent water during the dry season but not so large that the macrophyte zone is likely to experience dry periods of greater than 60 days (due to larger inflows required to fill the pools before wetting the macrophyte zone).



Note—refer to SC6.4.3.9.6 Plant selection for WSUD systems in the coastal dry tropics for more detail on planting zones and suitable macrophyte species.

Figure SC6.4.3.9.32 Typical cross section of a constructed wetland system showing preferred bathymetry and planting zones.

Figure SC6.4.3.9.33 Macrophyte zone banded planting (direction of flow is from left to right)

(iii) Macrophyte zone edge design for safety

Consideration of public safety is required when wetlands are located in parklands/public open space or any areas readily accessible. Reducing public safety risk can be achieved in a number of ways and the measures adopted should respond to the level of perceived risk given the particular site characteristics.

One method of reducing the risk posed by water bodies is to design batter slopes on approaches and immediately under the normal water level (refer Figure SC6.4.3.9.34). It is recommended that a gentle slope to the water edge and extending below the water line be adopted before the batter slope steepens into deeper areas.

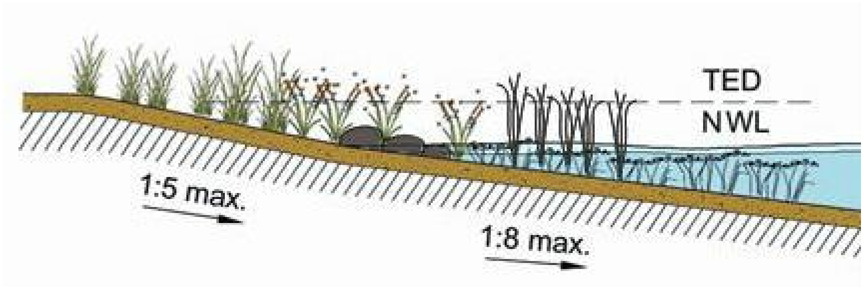


Figure SC6.4.3.9.34 Example of a wetland edge design for public safety

The safety requirements for individual wetlands will vary from site to site and requires careful consideration. The following requirements from the *Sediment Basin Design, Construction and Maintenance Guidelines* (BCC 2001) can be applied to constructed wetland systems:

- for water depths greater than 150 mm and maximum batter slope of 5:1 (H:V) or less, no fencing is required; and
- for water depths greater than 150 mm and maximum batter slope greater than 5:1 (H:V) fencing may be required.

In some cases, vertical edges are used for wetlands (refer to SC6.4.3.9.5(5) Landscape design notes). When vertical edges are used, a safety fencing/ barrier should be considered on top of concrete or stone walls where:

(A) there is a risk of serious injury in the event of a fall (over 0.5 m high and too steep to comfortably walk up/down or the lower surface has sharp or jagged edges);

(B) there is a high pedestrian or vehicular exposure (on footpaths, near bikeways, near playing/ sporting fields, near swings and playgrounds);

(C) where water ponds to a depth of greater than 300 mm on a constructed surface of concrete or stone;

(D) where the water is expected to contain concentrated pollutants; and

(E) where mowed grassed areas abut the asset.

The type of fence/ barrier to be considered should be a:

- dense vegetation at least 2 m wide and 1.2 m high (minimum) may be suitable; or
- pool fence (or similar) when there is a chance of drowning and the surrounding area is specifically intended for use by small children (swings, playgrounds, sporting fields etc.).

(iv) Macrophyte zone soil testing

Constructed wetlands are permanent water bodies and therefore the soils in the base must be capable of retaining water. Geotechnical investigations of the suitability of the in-situ soils are required to establish the water holding capacity of the soils. Where the infiltration rates are too high for permanent water retention, tilling and compaction of in-situ soils may be sufficient to create a suitable base for the wetland. Where in- situ soils are unsuitable for water retention, a compacted clay liner may be required (e.g. 300 mm thick). Specialist geotechnical testing and advice must be sought.

Wetland plants must be planted into suitable topsoil with a minimum depth of 200 mm (see SC6.4.3.9.5(6)(d) Topsoil specification and preparation). Most terrestrial topsoils provide a good substratum for wetlands, nonetheless laboratory soil testing (using Australian Standard testing procedures, e.g. AS 4419-2003: Soils for landscaping and garden use) of topsoil is necessary to ensure the topsoil will support plant and microbial growth and have a high potential for nutrient retention. Careful consideration should be given to the topsoil source and its propensity to contain weed seeds which may be viable in an ephemeral wetland habitat.

(e) Step 5: Design macrophyte zone outlet

A macrophyte zone outlet has two purposes: (1) hydrologic control of the water level and flows in the macrophyte zone to achieve the design detention time; and (2) to allow the wetland permanent pool to be drained for maintenance.

(i) Riser outlet – size and location of orifices

The riser outlet is designed to provide a uniform notional detention time in the macrophyte zone over the full range of the extended detention depths. The target maximum discharge ($Q_{max\ riser}$) may be computed as the ratio of the volume of the extended detention to the notional detention time as follows

$$Q_{max\ riser} = \frac{\text{extended detention storage volume } (m^3)}{\text{notional detention time } (s)}$$

The placement of orifices along the riser and determining their appropriate diameters is an iterative process. The orifice equation (Equation 6.2) is applied over discrete depths along the length of the riser starting at the normal water level and extending up to the riser maximum extended detention depth.

$$A_o = \frac{Q}{C_d\sqrt{2 \cdot g \cdot h}} \qquad \text{(Small orifice equation)}$$

Where	C_d	=	orifice discharge coefficient (0.67)
	h	=	depth of water above the centroid of the orifice (m)
	A_o	=	orifice area (m^2)
	Q	=	required flow rate to achieve notional detention time (m^3/s) at the *given h*
	g	=	9.79 m/s^2

As the outlet orifices can be expected to be small, it is important that they are prevented from clogging by debris. Some form of debris guard is recommended as illustrated in Figure SC6.4.3.9.35 below. An alternative to using a debris guard is to install a riser in a pit located in the embankment surrounding the wetland macrophyte zone (thus reducing any visual impact). A riser within the pit can also be configured with a weir plate (by drilling holes through the plate). An advantage of using a weir plate is that it provides an ability to drain the wetland simply by removing the weir plate entirely. Additionally, shorter weir plates may also be used during the vegetation establishment phase, thus providing more flexibility for water level manipulation.

Figure SC6.4.3.9.35 Example outlet riser assemblies with debris guards

The pit is connected to the deep pool of the macrophyte zone via a submerged pipe culvert. The connection should be adequately sized such that there is minimal water level difference between the water within the pit and the water level in the macrophyte zone. With the water entering into the outlet pit being drawn from below the normal water level (i.e. pipe obvert a minimum 0.3 m below normal water level), floating debris is generally prevented from entering the outlet pit, while heavier debris would normally settle onto the bottom of the wetland. The riser pipe should be mounted upright on a socketed and flanged tee with the top of the pipe left open to allow overtopping of waters if any of the riser orifices become blocked. Figure SC6.4.3.9.36 and Figure SC6.4.3.9.37 show one possible configuration for a riser outlet pit.

Figure SC6.4.3.9.36 Macrophyte zone outlet arrangement

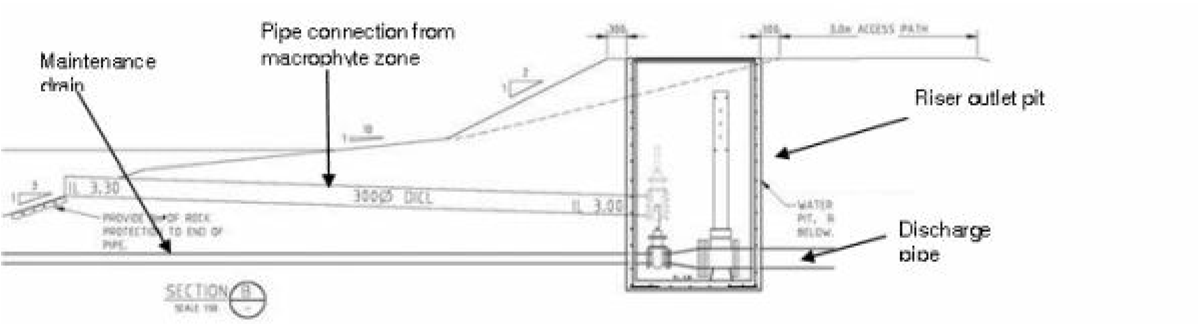


Figure SC6.4.3.9.37 Typical macrophyte zone outlet arrangement

(ii) Maintenance drains

To allow access for maintenance, the wetland should have appropriate allowance for draining. A maintenance drainage pipe should be provided that connects the low points in the macrophyte zone bathymetry to the macrophyte zone outlet. A valve is provided on the maintenance drainage pipe (typically located in the outlet pit as shown in Figure SC6.4.3.9.37), which can be operated manually. The maintenance drainage pipe should be sized to draw down the permanent pool within 12 hours (i.e. overnight). If a weir plate is used as a riser outlet, provision should be made to remove the weir plate and allow drainage for maintenance.

(iii) Discharge pipe

The discharge pipe of the wetland conveys the outflow of the macrophyte zone to the receiving waters (or existing drainage infrastructure). The conveyance capacity of the discharge pipe is to be sized to match the higher of the two discharges (i.e. maximum discharge from the riser or the maximum discharge from the maintenance drain).

(iv) Balance pipe

A balance pipe connection between the deep permanent pools in the wetland is necessary to allow inflows in dry conditions to benefit and sustain all deep pools rather than just the pool located at the inlet. The deep pools are generally 2 m in depth and may experience up to 1m of draw down during the dry season. The invert of the balance pipe should therefore be located approximately 1 m below the normal water level. A 300 mm diameter pipe is typically sufficient for a balance pipe.

(f) Step 6: Design high flow bypass channel

The bypass channel accepts “above design flow” from the inlet zone (sediment pond) of the wetland via the bypass weir (SC6.4.3.9.5(4)(c)) and conveys these flows downstream around the macrophyte zone of the wetland. The bypass channel should be designed using standard methods (i.e. Manning’s Equation) to convey the “above design flow” (SC6.4.3.9.5(4)(b)) and to avoid bed and bank erosion (see Chapter 2). Typically, a turf finish will provide appropriate protection for most bypass channel applications (but velocities need to be checked). Dense planting can be applied when appropriately designed for in terms of design roughness and management of velocities. Figure SC6.4.3.9.38 shows typical high flow bypass channel configurations.

Figure SC6.4.3.9.38 Turfed constructed wetland high flow bypass weir configuration.

(g) Step 7: Verify design

(i) Macrophyte zone resuspension protection

The principle pathway for biological uptake of soluble nutrients in wetlands is through biofilms (epiphytes) attached to the surface of the macrophyte vegetation. The biofilms, being mostly algae and bacteria, are susceptible to wash out under high flow conditions. Further, wetland surveys indicate that up to 90% of the total nutrients are stored in the sediments, therefore, the key to effective retention of pollutants is managing high velocity flows that could potentially resuspend and remobilise these stored pollutants.

A velocity check is to be conducted for design conditions, when the wetland water level is at the top of the extended detention level and the riser is operating at design capacity, to ensure velocities are less than 0.05 m/s through all zones of the wetland. The following condition must be met:

$$\frac{Q_{max\ riser}}{A_{section}} < 0.05 m/s$$

Where $Q_{max\ riser}$ = target maximum discharge (defined in Equation 6.1) (m^3/s)

Asection = minimum wetland cross-section area* (m^2) x 0.5 vegetation blockage factor**

*measured from top of extended detention

**blockage due to tall dense vegetation

(ii) Confirm treatment performance

If the basic wetland parameters established by the conceptual design phase have changed during the course of undertaking detailed design (e.g. macrophyte zone area, extended detention depth, etc.) then the designer should verify that the current design meets the required water quality improvement performance. This can be done by simulating the current design using a suitable quantitative modelling program.

(h) Step 8: Specify vegetation

Refer to SC6.4.3.9.5(5) Landscape design notes and SC6.4.3.9.6 Plant selection for WSUD systems in the coastal dry tropics for advice on selecting suitable plant species for constructed wetlands.

(i) Step 9: Consider maintenance requirements

Consider how maintenance is to be performed on the wetland (e.g. how and where is access available, where is litter likely to collect etc.). A specific maintenance plan and schedule should be developed for the wetland, either as part of a maintenance plan for the whole treatment train, or for each individual asset. Guidance on maintenance plans is provided in SC6.4.3.9.5(7) Maintenance requirements - constructed wetlands.

(j) Design calculation summary

Following is Table SC6.4.3.9.16 Constructed wetlands design calculation summary, for the key design elements.

Click here to view **Table SC6.4.3.9.16 Constructed wetlands design calculation summary**

(5) Landscape design notes - constructed wetlands

Whilst constructed wetlands play a significant role in delivering stormwater quality objectives, they can also play an important role in creating a community landscapes and urban ecology. The following sections outline some of the landscape design issues that should be considered when designing constructed wetland systems.

(a) Objectives

Landscape design of wetlands generally requires consideration of the following objectives:

(i) integrated planning and design of constructed wetlands within the built and landscape environments ensuring that the overall landscape design for the wetland integrates with its host natural and/ or built environment;

(ii) achieving dense perennial littoral vegetation around the perimeter of the wetland to avoid the ingress of weed species. To maintain dense perennial littoral vegetation, irrigation is likely to be required, particularly during the dry season;

(iii) ensuring that the wetland planting strategy is based on the wetland design depths/zones, achieves dense perennial emergent macrophyte cover and has the structural characteristics to perform particular treatment processes (e.g. well distributed flows, enhance sedimentation, maximise surface area for the adhesion of particles and provide a substratum for algal epiphytes and biofilms);

(iv) providing maintenance access to allow for the prompt removal of weeds before they spread and/or set seed;

(v) incorporating crime prevention through environmental design (CPTED) principles; and

(vi) providing other landscape values, such as shade, amenity, character and place making.

Comprehensive site analysis should inform the landscape design as well as road layouts, maintenance access points and civil works. Existing site factors such as roads, buildings, landforms, soils, plants, microclimates, services and views should be considered. For further guidance refer to the *South East Queensland WSUD Conceptual Design Guidelines* (Healthy Waterways Partnership, 2008).

(b) Wetland siting and shapes

Constructed wetlands need to be arranged to meet hydrological and stormwater quality requirements, but also to integrate effectively into the surrounding existing landscape. The arrangement of wetland, basin and high flow bypass should be designed early in the concept design phase, to ensure that amenity of open space is enhanced.

The final shape of a wetland should provide landscape opportunities to create alternate useable spaces/recreation areas (see Figure SC6.4.3.9.39). Often different shapes to wetland edges can make pathway connections through and around these recreation areas more convenient and enhances the community perception of constructed wetlands. Pathways and bridges across planted earth bunds can be the best way of getting across or around wetlands (see Figure SC6.4.3.9.40). The materials on the bridge and pathways are important to be low maintenance and do not impede hydrological flows. Ease of access to the inlet basin for sediment and trash removal is also important to consider.

The area required for the high flow bypass can be manipulated to provide open spaces that only periodically convey stormwater flows. Further discussion of high flow bypass configuration is provided in SC6.4.3.9.5(5)(c)(iii) High flow bypass channel.

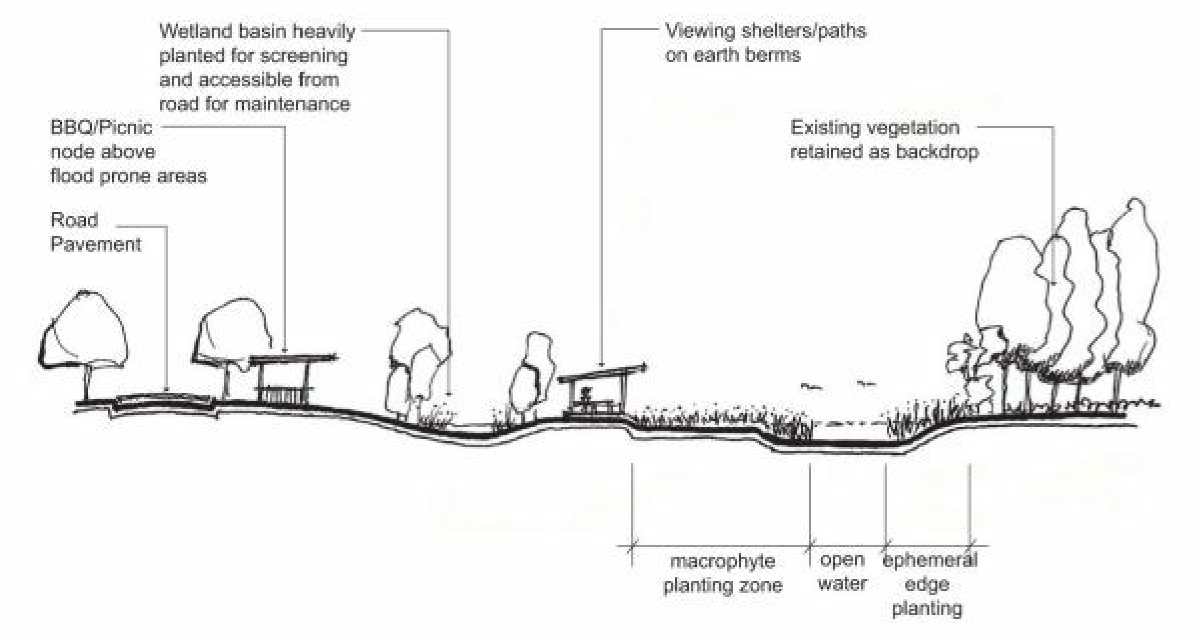


Figure SC6.4.3.9.39 Typical landscape treatments to constructed wetlands in open space areas

Figure SC6.4.3.9.40 Boardwalk treatment over wetland (left) and integration of urban art with wetland setting (right)

(c) Specific landscape considerations

Numerous opportunities are available for creative design solutions for specific elements. Close collaboration between landscape designer, hydraulic designer, civil/structural engineer and maintenance personnel is essential. In parklands and residential areas, the aim is to ensure elements are sympathetic to their surroundings and are not overly engineered or industrial in style and appearance. Additionally, landscape design to specific elements should aim to create places that local residents and visitors will come to enjoy and regard as an asset.

(i) Crossings

Given the size and location of wetland systems, it is important to consider if access is required across the wetland as part of an overall pathway network and maintenance requirement. Factors that should be considered include:

(A) the appropriateness of hardwood timber board walks given their life-cycle costs. Where walkway footings are in contact with water, council will not accept timber piers;

(B) if boardwalks are used, they should not be located near open water where they could encourage the public to feed wildlife; and

(C) earth bunds located between the sedimentation basin and macrophyte zone can be used as crossings and can be planted as a shaded walkways.

Figure SC6.4.3.9.41 illustrates a conceptual earth bund walkway.

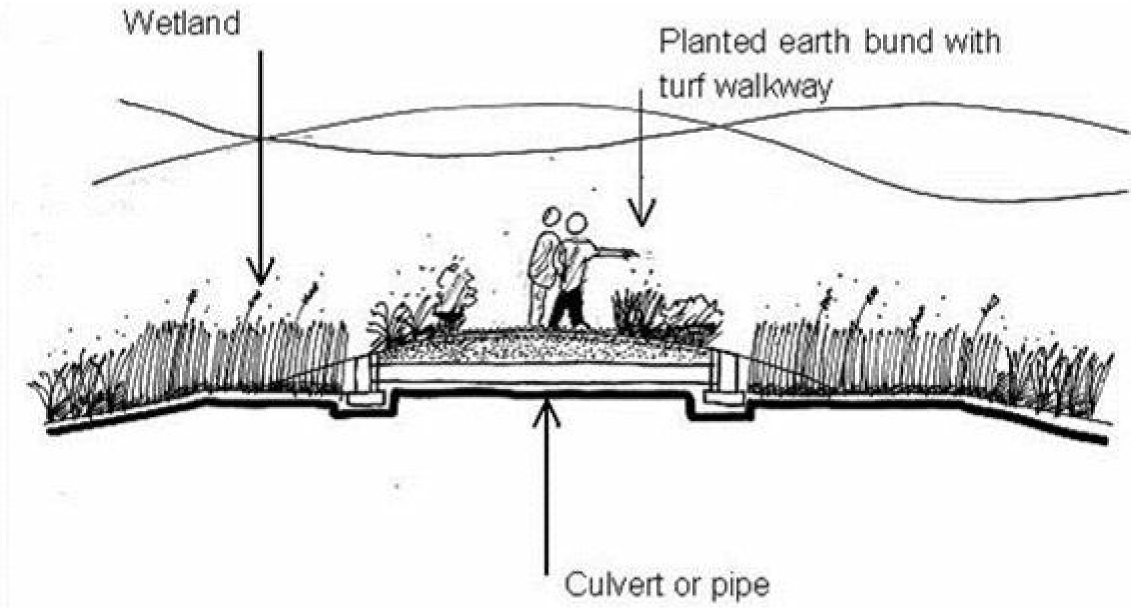


Figure SC6.4.3.9.41 Earth bund structure as wetland crossing

(ii) Wetland embankments

The landscape design approach for the wetland embankments is similar to the approach taken for embankments in sedimentation basins.

(iii) High flow bypass channel

The high flow bypass channel will convey stormwater during above design flow and in some situations can form a large element in the landscape. Therefore the design of the high flow bypass needs to be carefully considered to provide recreational and landscape opportunities during times outside of above design flow events.

The key considerations for design of the high flow bypass area are as follows:

(A) no major park infrastructure including playgrounds, barbeques and amenity buildings to be located within the high flow bypass areas. Passive recreation infrastructure including seating and picnic tables are suitable provided they are of robust design;

(B) in many cases, the high flow bypass will be formed through the use of turf and in these cases the opportunity for creating more active spaces should be investigated;

(C) designers should investigate the opportunities for locating trees and other vegetation types within the bypass channel. Provided hydraulic efficiencies can be accommodated, grassed mounds and landform;

(D) grading of the embankment edge could also be explored to add variation and interest;

(E) where groundcover species other than turf are adopted, plant species should be selected to ensure appropriate response after periodic flooding;

(F) areas of large revegetation or garden beds that cut through the high flow bypass zone should use thick matting mulch types that bind well to the surface to minimise loss; and

(G) the relationship between the high flow bypass channel and the permanent water bodies should be considered in order to create interesting spaces and forms within the open space. For example, after consideration of site constraints and hydraulic parameters, designers could investigate options to separate the elements from each other or to channel both elements alongside each other. Opportunities should also be sought to achieve balanced cut and fill earthworks. Figure SC6.4.3.9.42 provides an illustration of creation of open spaces through configuration of key wetland components.

(iv) Macrophyte zone outlet structure

Landscape design approach for the macrophyte outlet zone is similar to the approach taken for overflow pits in sedimentation basins. Refer to Chapter 4, Section 4.4.3.6 for further guidance.

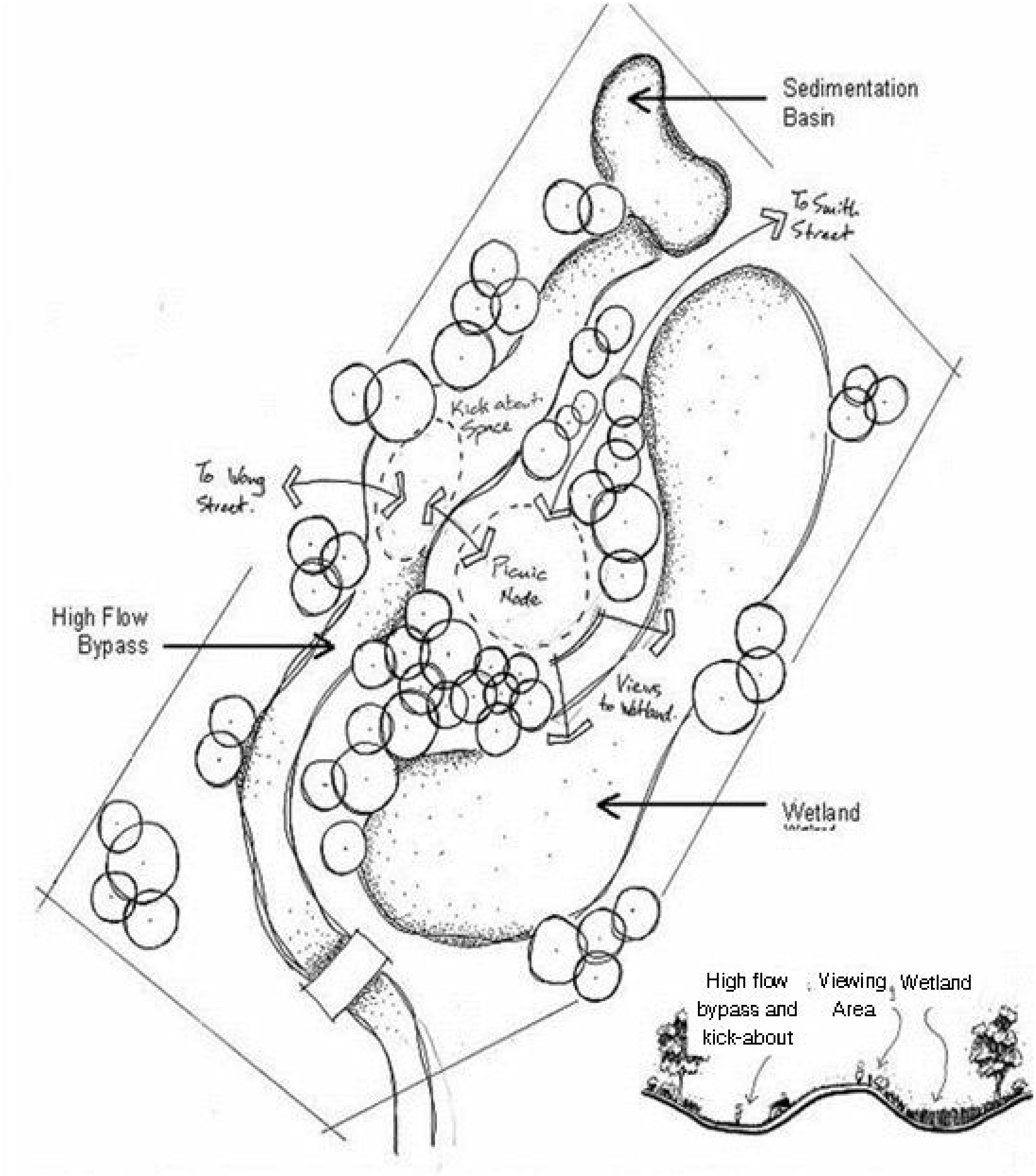
(v) Viewing areas

Refer to Chapter 4, Section 4.4.3.8 for guidance.

(vi) Fencing

Refer to Chapter 4, Section 4.4.3.9 for guidance.

Editor's note—these Chapter and Section references are to *Water Sensitive Urban Design Guidelines for South East Queensland*.



Landscape design should explore options for siting the bypass, wetland and basin and analyse the potential for enhanced amenity. This process should initially take place at the concept development phase and can be refined during the detailed design.

Figure SC6.4.3.9.42 Example relationship between high flow bypass wetland and basin and the creation of open space

(d) Constructed wetland vegetation

Planting for constructed wetlands systems may consist of up to three vegetation types:

(i) Macrophyte zone planting consisting of deep marsh (0.5 m – 0.7 m in depth at design normal water level) and shallow marsh (edges) (0.5 m – 0 m in depth at design normal water level);

Macrophyte zone planting (from 1.0 m below to 0.2 m above design water level) SC6.4.3.9.6 Plant selection for WSUD systems in the coastal dry tropics provides guidance on selecting suitable plant species and cultivars that deliver the desired stormwater quality objectives for constructed wetlands. Often the most effective way to meet those objectives with the macrophyte planting is to create large bands of planting perpendicular to flow that respond to designed depth zones and local biodiversity.

In general, macrophyte vegetation should provide:

(A) well distributed flows;

(B) enhanced sedimentation;

(C) maximum surface area for the adhesion of particles;

(D) a substratum for algal epiphytes and biofilms; and

(E) habitat and refuge for fauna, both terrestrial and aquatic.

This is achieved by selecting species with many small diameter vertical leaves or stems and planting the vegetation in bands. When selecting suitable species it is important to also note the ability of some species to be highly self-sustaining. Littoral planting should provide a dense buffer between the wetland and publicly accessible open space to discourage contact with the water.

(ii) Littoral vegetation (embankment) (above design normal water level) and parkland vegetation

Between the macrophyte zone and the top of the embankment, establishment of trees, shrubs and groundcovers can occur in consideration of the following:

(A) selecting groundcovers, particularly for slopes greater than 1 in 3, with matting or rhizomatous root systems to assist in binding the soil surface during the establishment phase;

(B) achieving dense perennial littoral vegetation around the perimeter of the wetland to avoid the ingress of weed species. To maintain dense perennial littoral vegetation, irrigation is likely to be required, particularly during the dry season;

(C) preventing macrophyte zone plants and ground covers from being shaded out by minimising tree densities at the water's edge and choosing species such as Melaleuca that allow sunlight to penetrate the tree canopy;

(D) locating vegetation to allow views of the wetland and its surrounds whilst discouraging the public from accessing the water body; and

(E) parkland vegetation may be of a similar species to the embankments littoral vegetation and layout to visually integrate the wetland with its surrounds. Alternatively, vegetation of contrasting species and/ or layout may be selected to highlight the water body as a feature within the landscape. Turf may be considered to achieve this goal.

(iii) Terrestrial plants, including existing vegetation, adjacent to the upper littoral edge.

(e) Safety issues

(i) General

Constructed wetlands need to be generally consistent with public safety requirements for new developments. These include reasonable batter profiles for edges to facilitate public egress from areas with standing water and fencing where water depths and edge profile requires physical barriers to public access. Fences can be substituted where possible by using dense edge plantings to deter public access to areas of open water. Dense littoral vegetation that can grow to around 2 m high and 1.5 m wide are effective in deterring public access.

(ii) Restricting access to open water

Fences or vegetation barriers to restrict access should be incorporated into wetland areas, particularly on top of concrete or stone walls where:

(A) there is a risk of serious injury in the event of a fall (over 0.5 m high and too steep to comfortably walk up/ down or the lower surface or has sharp or jagged edges);

(B) there is a high pedestrian or vehicular exposure (on footpaths, near bikeways, near playing/ sporting fields, near swings and playgrounds etc.);

(C) where water ponds to a depth of greater than 300 mm on a constructed surface of concrete or stone. Natural water features are exempt; and

(D) where grassed areas requiring mowing abut the asset.

Barriers that may be appropriate are:

- dense vegetation at least 2 m wide and 1.2 m high (minimum) may be suitable; and
- pool fence (or similar) when there is a chance of drowning and the surrounding area is specifically intended for use by small children (swings, playgrounds, sporting fields etc.).

Dense littoral planting around the wetland and particularly around the deeper open water pools of the sediment pond (with the exception of any maintenance access points), will deter public access to the open water and create a barrier to improve public safety. Careful selection of plant species (e.g. tall, dense or “spiky” species) and planting layouts can improve safety as well as preventing damage to the vegetation by trampling.

Dense vegetation (hedge) at least 2 m wide and 1.2 m high (minimum) may be suitable. A temporary fence may be required until the vegetation has established and becomes a deterrent to pedestrians.

An alternative to the adoption of a barrier/ fence is to provide a 2.4 m safety bench that is less than 0.2 m deep below the normal water level around the waterbody. This is discussed in Chapter 4 Section 4.3.3.3 with respect to appropriate batter slopes.

(6) Construction and establishment - constructed wetlands

This section provides general advice for the construction and establishment of constructed wetlands and key issues to be considered to ensure their successful establishment and operation. Some of the issues raised have been discussed in other sections of this chapter and are reiterated here to emphasise their importance based on observations from construction projects around Australia.

(a) Staged construction and establishment method

It is important to note that constructed wetlands, like most WSUD elements that employ soil and vegetation based treatment processes, require approximately two growing seasons (i.e. two years) before the vegetation in the systems has reached its design condition (i.e. height and density). In the context of a large development site and associated construction and building works, delivering constructed wetlands and establishing vegetation can be a challenging task. Therefore, constructed wetlands require a careful construction and establishment approach to ensure the wetland establishes in accordance with its design intent. The following sections outline a recommended staged construction and establishment methodology for constructed wetlands (Leinster, 2006).

(i) Construction and establishment challenges

There exist a number of challenges that must be appropriately considered to ensure successful construction and establishment of wetlands. These challenges are best described in the context of the typical phases in the development of a greenfield or infill development, namely the subdivision construction phase and the building phase.

(A) subdivision construction - involves the civil works required to create the landforms associated with a development and install the related services (roads, water, sewerage, power etc.) followed by the landscape works to create the softscape, streetscape and parkscape features. The risks to successful construction and establishment of the WSUD systems during this phase of work have generally related to the following:

- construction activities which can generate large sediment loads in runoff which can smother wetland vegetation; and
- construction traffic and other works can result in damage to the constructed wetlands.

Importantly, all works undertaken during subdivision construction are normally “controlled” through the principle contractor and site manager. This means the risks described above can be readily managed through appropriate guidance and supervision.

(B) building phase - once the subdivision construction works are complete and the development plans are sealed then the building phase can commence (i.e. construction of the houses or built form). This phase of development is effectively “uncontrolled” due to the number of building contractors and sub- contractors present on any given allotment. For this reason the allotment building phase represents the greatest risk to the successful establishment of constructed wetlands.

(ii) Staged construction and establishment method

To overcome the challenges associated within delivering constructed wetlands a staged construction and establishment method should be adopted (see Figure SC6.4.3.9.43):

(A) Stage 1: Functional installation - construction of the functional elements of the constructed wetland at the end of subdivision construction (i.e. during landscape works) and the installation of temporary protective measures.

(B) Stage 2: Sediment and erosion control – during the building phase the temporary protective measures preserve the functional infrastructure of the constructed wetland against damage whilst also providing a temporary erosion and sediment control facility throughout the building phase to protect downstream aquatic ecosystems.

(C) Stage 3: Operational establishment - at the completion of the building phase, the temporary measures protecting the functional elements of the constructed wetland can be removed along with all accumulated sediment.

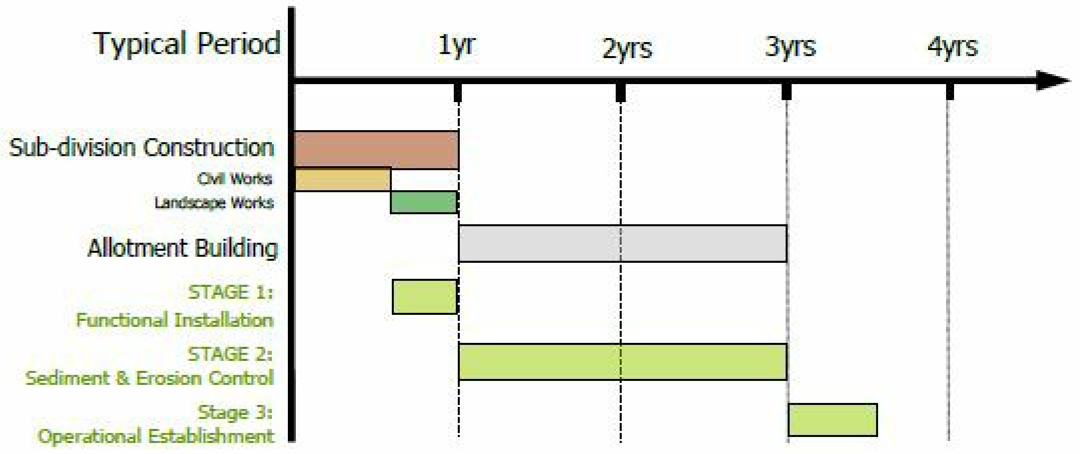


Figure SC6.4.3.9.43 Staged construction and establishment method

(iii) Functional installation

Functional installation of constructed wetlands occurs at the end of subdivision construction as part of landscape works and involves:

(A) earthworks to configure the bathymetry of the wetland;

(B) installation of the hydraulic control structures including inlet/outlet control and the high flow bypass weir;

(C) placement of topsoil, trimming and profiling;

(D) placement of turf in the High Flow Bypass channel to protect against erosion;

(E) disconnecting the Inlet Zone from Macrophyte Zone and allowing all stormwater to flow along High Flow Bypass. This effectively isolates the Macrophyte Zone from catchment flows and allows the establishment of wetland plants without the risk of being smothered with coarse sediment during the Subdivision Construction and Allotment Building Phases;

(F) planting of the Macrophyte Zone once the disconnection is in place;

(G) water level in the Macrophyte Zone can be varied as required by the rate of wetland plant maturity by opening the connection for short periods or opening the outlet control. Irrigation of edges may be required; and

(H) planting the littoral zone and providing irrigation to ensure fast establishment of dense vegetation to minimise weed growth.

Figure SC6.4.3.9.44 depicts the functional installation of a constructed wetland

(iv) Sediment and erosion control

During allotment building phases the sedimentation pond can be used to reduce the load of coarse sediment discharging to the receiving environment. The disconnection between the sediment pond and the macrophyte zone will remain in place to ensure the majority of flows from the catchment continue to bypass the macrophyte zone thus allowing the wetland plants to reach full maturity without the risk of being smothered with coarse sediment (see Figure SC6.4.3.9.45).

This means the macrophyte zone can be fully commissioned and made ready for operation once the allotment building phase is complete.

Figure SC6.4.3.9.45 Constructed wetland sediment and erosion control operation

(v) Operational establishment

At the completion of the allotment building phase the sediment pond is de-silted, the disconnection between the sediment pond and macrophyte zone is removed and the constructed wetland is allowed to operate in accordance with the design.

Figure SC6.4.3.9.46 Constructed wetland operational establishment

(b) Construction tolerances

It is important to emphasise the significance of tolerances in the construction of constructed wetland systems. Ensuring the relative levels of the control structures (inlet connection to macrophyte zone, bypass weir and macrophyte zone outlet) are correct is particularly important to achieve appropriate hydraulic functions. Generally control structure tolerance of plus or minus 5 mm is considered acceptable.

Additionally the bathymetry of the macrophyte zone must be free from localised depressions and low points resulting from earthworks. This is particularly important to achieve a well distributed flow path and to prevent isolated pools from forming (potentially creating mosquito habitat) when the wetland drains. Generally an earthworks tolerance of plus or minus 25 mm is considered acceptable.

(c) Sourcing wetland vegetation

To ensure the specified plant species are available in the required numbers and of adequate maturity in time for wetland planting, it is essential to notify nurseries early for contract growing. When early ordering is not undertaken, the planting specification may be compromised due to sourcing difficulties, resulting in poor vegetation establishment and increased initial maintenance costs. The species listed in SC6.4.3.9.6 Plant selection for WSUD systems in the coastal dry tropics are generally available commercially from local native plant nurseries but availability is dependent upon many factors including demand, season and seed availability. To ensure the planting specification can be accommodated the minimum recommended lead time for ordering is 3-6 months. This generally allows adequate time for plants to be grown to the required size. The following sizes are recommended as the minimum:

(i) viro tubes 50 mm wide x 85 mm deep;

(ii) 50 mm tubes 50 mm wide x 75 mm deep; and

(iii) native tubes 50 mm wide x 125 mm deep.

“Floral Edges”, a system of interlocking plants within one long container is recommended for wetland planting, particularly for the deep marsh zone. The series of plants (usually five) are grown together in a single “strip” container. Generally, these “floral edges” are supplied as more mature plants with developing rhizomes (for rhizomatous species) and interlocking roots. This has been used very successfully in wetland planting previously because the larger more mature plants, often with a thick rhizome system, can survive in deeper water and are more tolerant to fluctuations in water level. The structure of this system slows the movement of water and binds the substrate, helping to reduce erosion. The weight of the interlocking plants also prevents birds from removing them, a common problem encountered during wetland plant establishment. Nurseries require a minimum lead time of 6 months for supply of these systems.

(d) Topsoil specification and preparation

The provision of suitable topsoil in wetlands is crucial to successful macrophyte establishment and to the long term functional performance of the wetland. Wetland macrophytes typically prefer medium textured silty to sandy loams that allow for easy rhizome and root penetration. Although there are a few plants that can grow in in-situ heavy clays (e.g. phragmites), growth is slow and the resulting wetland system will have low species richness, which is undesirable. The wetland must therefore have a layer of topsoil no less than 200 mm deep and preferably 300 mm in depth for improved dry season moisture retention.

During the wetland construction process, topsoil is to be stripped and stockpiled for possible wetland reuse as a plant growth medium. Most terrestrial topsoils provide a good substratum for wetlands, nonetheless laboratory soil testing (using Australian Standard testing procedures, e.g. AS 4419-2003: *Soils for landscaping and garden use*) of the in-situ topsoil is necessary to ensure the topsoil will support plant and microbial growth and have a high potential for nutrient retention. Typically, standard horticultural soil analysis, which includes major nutrients and trace elements, is suitable for topsoils intended for wetland use. The laboratory report will indicate the soils suitability as a plant growth medium and if any amendments are required.

Careful consideration should be given to the topsoil source and its propensity to contain weed seeds which may be viable in an ephemeral wetland habitat. If a problematic weed bank is likely to be present within the topsoil then importing alternative topsoil should be considered. If the in-situ topsoil is found to contain high levels of salt, extremely low levels of organic carbon (<< 5%), or any other extremes that may be considered a retardant to plant growth, it should be rejected.

If the in-situ topsoil is not suitable and soil amendment is considered impractical or not cost effective, sandy loam topsoil should be purchased from a soil supplier. If the local topsoil is suitable but very shallow, mixing with an imported soil will be necessary to reach the required volume to ensure a minimum 200 mm deep topsoil for wetland planting.

Imported topsoils are generally suitable as wetland plant growth medium, however as for in-situ soils (above), testing is required to determine the appropriate gypsum or lime dosing rate. If the local topsoil was tested and found to be suitable but then mixed with an imported soil to meet the required volume, laboratory soil testing should be repeated.

(i) Topsoil treatments

The wetland topsoil should be tested in accordance with AS 4419-2003: *Soils for landscaping and garden use* to ensure it is appropriate for growth of vegetation. If testing finds the topsoil is not appropriate then an alternative source should be found.

Topsoils for wetlands generally do not require fertiliser treatment. Imported foreign loam will contain sufficient nutrients for vegetation growth and local terrestrial topsoil will release nutrients after the wetting process. Submersion of terrestrial soils in water causes a shift from aerobic to anaerobic processes, prompting mineralisation and decomposition of organic matter contained in the soil, thus increasing available nitrogen. When soils become anaerobic, reduction processes cause iron oxides to be released from the surface of soil particles leading to increased availability of phosphorus. The addition of nutrients (fertiliser application) can facilitate the growth of algae (including cyanobacteria (blue-green) algae), particularly when the competing macrophytes and submerged plants are in the early stages of development, increasing the likelihood of algal blooms.

The topsoil within the wetland (macrophyte zones and open water zones) may need to be treated with gypsum or lime. The application of gypsum is standard on most construction sites for the purpose of securing or flocculating dispersive soils if entrained in runoff. The use of gypsum in wetland should only occur within catchments with dispersive soils and applied at a maximum rate of 0.4 kg/m^2. The application of lime may be required where the AS4419 (2003) soil testing identifies a potential soil pH problem (pH < 5) or where acid sulfate soils (ASS) exist in the vicinity of the wetland. The rate of lime application should be guided by soil test results, an ASS Management Plan and water quality (pH) monitoring of the wetland and inflow.

Gypsum/ lime should be applied about one week prior to vegetation planting. Subsequent application may be required at intervals depending on water quality monitoring. Application of gypsum/ lime too far in advance of planting may lead to aquatic conditions that promote algal growth (i.e. clear water with no aquatic plants competing for resources).

(e) Vegetation establishment

(i) Timing for planting

Timing of vegetation planting is dependent on a suitable time of year (and potential irrigation requirements) as well as timing in relation to the phases of development. October and November are considered ideal times to plant vegetation in treatment elements. This allows for adequate establishment/ root growth before the heavy summer rainfall period but also allows the plants to go through a growth period soon after planting, resulting in quicker establishment. Planting late in the year also avoids the dry winter months, reducing maintenance costs associated with watering. Construction planning and phasing should endeavour to correspond with suitable planting months wherever possible. However, as lead times from earthworks to planting can often be long, temporary erosion controls (e.g. use of matting or sterile grasses to stabilise exposed batters) should always be used prior to planting.

(ii) Water level manipulation

To maximise the chances of successful emergent macrophyte establishment, the water level of the wetland system is to be manipulated in the early stages of vegetation growth. When first planted, vegetation in the deep marsh zone may be too small to be able to exist in their prescribed water depths (depending on the maturity of the plant stock provided). Macrophytes intended for the deep marsh sections will need to have half of their form above the water level, which may not be possible if initially planted at their intended depth. Similarly, if planted too deep, the young submerged plants will not be able to access sufficient light in the open water zones. Without adequate competition from submerged plants, phytoplankton (algae) may proliferate.

The water depth must be controlled in the early establishment phase. This can be achieved by closing off the connection between the sediment pond and the macrophyte zone (i.e. covering the overflow pit) and opening the maintenance drain. The deep marsh zones should have a water depth of approximately 0.2 m for at least the first 6 - 8 weeks. This will ensure the deep marsh zones of the wetland are inundated to shallow depth and the shallow marsh edges remain moist (muddy) providing suitable conditions for plant establishment. Seedlings planted in the littoral zones of the wetland will require ongoing watering at a similar rate as the terrestrial landscape surrounding the wetland (SC6.4.3.9.5(5)(e)(ii) Restricting access to open water). When it is evident that the plants are establishing well and growing actively, a minimum of 6 - 8 weeks following planting, the plants should be of sufficient stature to endure deeper water. At this time, the connection between the inlet pond and the macrophyte zone can be temporarily opened to allow slow filling of the wetland to the design operating water level.

(iii) Weed control

To protect landscape amenity and the stormwater treatment efficiency of the wetland it is important to maintain, throughout the year, the design vegetation communities to avoid excessive colonisation of the wetland by weeds. Weed infestation is a major problem in the dry tropics, particularly within ephemeral waterways and stormwater treatment facilities, therefore, the design and management of the wetland to manage weed infestation takes on high importance. Management of weeds is achieved as follows:

(A) designing the macrophyte zone as predominately a deep marsh system (i.e. water depth 0.5 m - 0.7 m) to maintain the macrophyte vegetation by minimising the frequency and duration of wetland drying, thus permanently occupying the habitat and restricting weed colonisation opportunities;

(B) planting dense littoral vegetation around the perimeter of the wetland to avoid the ingress of weed species. To maintain dense perennial littoral vegetation, irrigation is likely to be required, particularly during the dry season; and maintaining dense macrophyte vegetation in the wetland during prolonged dry conditions is necessary to avoid opening up habitat opportunities for weeds. When the macrophyte zone dries (i.e. the macrophyte zone sediments are exposed) for a period in excessive of 60 days, irrigation of the macrophyte zone may be required to achieve this.

During the establishment and ongoing maintenance of the wetland, prompt removal of weeds before they spread and/or set seed is of critical importance.

Conventional surface mulching of the wetland littoral berms with organic material like tanbark is not recommended. Most organic mulch floats and water level fluctuations and runoff typically causes this material to be washed into the wetland with a risk of causing blockages to outlet structures. Mulch can also increase the wetland organic load, potentially increasing nutrient concentrations and the risk of algal blooms. Adopting high planting density rates and if necessary applying a suitable biodegradable erosion control matting to the wetland batters (where appropriate), will help to combat weed invasion and will reduce maintenance requirements for weed removal. If the use of mulch on the littoral zones is preferred, it must be secured in place with appropriate mesh or netting (e.g. jute mesh).

(iv) Watering

Regular watering of the littoral vegetation during the plant establishment phase is essential for successful establishment and vigorous growth. The frequency of watering to achieve successful plant establishment is dependent upon rainfall, maturity of planting stock and the water level within the wetland. However, the following watering program is generally adequate but should be adjusted (i.e. increased) as required to suit site conditions:

(A) week 1-2 3 visits/ week;

(B) week 3-6 2 visits/ week; and

(C) week 7-12 1 visit/ week.

After this initial 3 month period, irrigation will still be required, particularly during the dry season. Watering requirements to sustain healthy dense vegetation should be determined during ongoing monitoring and maintenance site visits.

(v) Bird protection

During the early stages of wetland establishment, water birds can be a major nuisance due to their habit of pulling out recently planted species. Interlocking planting systems (i.e. where several plants are grown together in a single container such as “floral edges”) can be used, as water birds find it difficult to lift the interlocking plants out of the substrate unlike single plants grown in tubes.

(7) Maintenance requirements - constructed wetlands

Wetlands treat runoff by filtering it through vegetation and providing extended detention to allow sedimentation to occur. In addition, they have a flow management role that needs to be maintained to ensure adequate flood protection for local properties and protection of the wetland ecosystem.

Maintaining healthy vegetation and adequate flow conditions in a wetland are the key maintenance considerations. Weeding, planting, mowing and debris removal are the dominant tasks (but should not include use of herbicides as this affects water quality). In addition, the wetland needs to be protected from high loads of sediment and debris and the inlet zone needs to be maintained in the same way as sedimentation basins (see Chapter 4). Routine maintenance of wetlands should be carried out once a month.

(a) The most intensive period of maintenance is during plant establishment period (first two years) when weed removal and replanting may be required. It is also the time when large loads of sediments could impact on plant growth, particularly in developing catchments with poor building controls. Debris removal is an ongoing maintenance function. If not removed, debris can block inlets or outlets, and can be unsightly if in a visible location. Inspection and removal of debris should be done regularly. Typical maintenance of constructed wetlands will involve:

(i) irrigation of the littoral zone plants (especially during dry periods) to prevent the ingress of invasive weeds;

(ii) prompt removal of weeds before they spread and/or set seed is of critical importance;

(iii) desilting the inlet zone following the construction/ building period;

(iv) routine inspection of the wetland to identify any damage to vegetation, weed growth, scouring, formation of isolated pools, litter and debris build up or excessive mosquitoes;

(v) routine inspection of inlet and outlet points to identify any areas of scour, litter build up and blockages;

(vi) removal of litter and debris;

(vii) removal and management of invasive weeds;

(viii) repair to wetland profile to prevent the formation of isolated pools;

(ix) periodic (usually every 5 years) draining and desilting of the inlet pond;

(x) watering of wetland macrophytes during prolonged dry periods (in excess of 60 days);

(xi) water level control during plant establishment;

(xii) replacement of plants that have died (from any cause) with plants of equivalent size and species as detailed in the planting schedule; and

(xiii) vegetation pest monitoring and control.

Inspections are recommended following large storm events to check for scour and damage.

(b) All maintenance activities must be specified in a maintenance plan (and associated maintenance inspection forms) to be developed as part of the design procedure (SC6.4.3.9.5(4)(i) Step 9: Consider maintenance requirements). Maintenance personnel and asset managers will use this plan to ensure the wetlands continue to function as designed. To ensure maintenance activities are appropriate for the wetland as it develops, maintenance plans should be updated a minimum of every three years. The maintenance plans and forms must address the following:

(i) inspection frequency;

(ii) maintenance frequency;

(iii) data collection/ storage requirements (i.e. during inspections);

(iv) detailed clean-out procedures (main element of the plans) including:

(A) equipment needs;

(B) maintenance techniques;

(C) occupational health and safety;

(D) public safety;

(E) environmental management considerations;

(F) disposal requirements (of material removed);

(G) access issues;

(H) stakeholder notification requirements; and

(I) data collection requirements (if any); and

(v) design details.

An approved maintenance plan is required prior to asset transfer to the local authority. Refer to the guidelines or direction from the relevant local authority for more specific guidance on requirements for asset transfer.

An example operation and maintenance inspection form is included in the checking tools provided in SC6.4.3.9.5(8)(c) Operation and maintenance inspection form. These forms must be developed on a site specific basis as the configuration and nature of constructed wetlands varies significantly.

(8) Checking tools - constructed wetlands

A number of checking aids has been developed for designers and council development assessment officers. In addition, SC6.4.3.9.5(6) Construction and establishment provides general advice for the construction and establishment of wetlands and key issues to be considered to ensure their successful establishment and operation, based on observations from construction projects around Australia.

(a) Design assessment

The checklist in Table SC6.4.3.9.17 presents the key design features to be reviewed when assessing a design of a wetland. These considerations include configuration, safety, maintenance and operational issues that should be addressed during the design phase. Where an item results in an “N” when reviewing the design, referral should be made back to the design procedure to determine the impact of the omission or error. In addition to the checklist, a proposed design must have all necessary permits for its installations. Council development assessment officers will require supporting evidence/ proof from the developer that all relevant permits are in place.

Click here to view **Table SC6.4.3.9.17 Wetland design assessment checklist**

(b) Construction (during and post)

The checklist in Table SC6.4.3.9.18 presents the key items to be reviewed when inspecting the bioretention basin during and at the completion of construction. The checklist is to be used by Construction Site Supervisors and local authority Compliance Inspectors to ensure all the elements of the bioretention basin have been constructed in accordance with the design. If an item receives an “N” in Satisfactory criteria then appropriate actions must be specified and delivered to rectify the construction issue before final inspection sign-off is given.

Click here to view **Table SC6.4.3.9.18 Wetland construction inspection checklist**

(c) Operation and maintenance inspection

The example form in Table SC6.4.3.9.19 should be developed and used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time. Inspections should occur every 1 - 6 months depending on the size and complexity of the system. More detailed site specific maintenance schedules should be developed for major constructed wetland systems and include a brief overview of the operation of the system and key aspects to be checked during each inspection.

Click here to view **Table SC6.4.3.9.19 Wetland maintenance checklist**

(d) Asset transfer (following on maintenance period)

Land ownership and asset ownership are key considerations prior to construction of a stormwater treatment device. A proposed design should clearly identify the asset owner and who is responsible for its maintenance. The proposed owner should be responsible for performing the asset transfer checklist. Table SC6.4.3.9.20 provides an indicative asset transfer checklist.

Click here to view **Table SC6.4.3.9.20 Asset transfer checklist**

(9) References - constructed wetlands

BCC 2000 (with revisions 2004), *Subdivision and Development Guidelines*, BCC, Brisbane

BCC 2001, *Sediment Basin Design, Construction and Maintenance: Guidelines*, BCC, Brisbane

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GBLA (Graeme Bentley Landscape Architects) 2004, *Preliminary drawings for Mernda Wetland*, report for Stockland, GBLA, Victoria

Leinster, S 2006, *Delivering the Final Product – Establishing Water Sensitive Urban Design Systems, 7th International Conference on Urban Drainage Modelling and 4th International Conference on Water Sensitive*

Urban Design Book of Proceedings, Volume 2, A Deletic and T Fletcher (eds), Melbourne.

LHCCREMS (Lower Hunter and Central Coast Regional Environmental Management Strategy) 2002, *Water Sensitive Urban Design in the Sydney Region: 'Practice Note 2 – Site Planning'*, LHCCREMS, NSW

McFarlane A 1997, *Successful Gardening in Warm Climates*, Kangaroo Press, Sydney

DNRW, IPWEA & BCC (Department of Natural Resources and Water, Institute of Public Works Engineering Australia – Qld Division & Brisbane City Council) 1998, *Queensland Urban Drainage Manual* (QUDM) Second Edition, prepared by Neville Jones & Associates and Australian Water Engineering for DNRW, IPWEA & BCC, Brisbane.

Persson J, Somes NLG and Wong THF 1999, *Hydraulic efficiency and constructed wetland and ponds*, Water Science and Technology, vol. 40 no. 3, pp. 291–289

Standards Australia 2003, AS 4419-2003: *Soils for landscaping and garden use*, Standards Australia

Townsville City Council, *Water sensitive urban design for the coastal dry tropics (Townsville): Technical design guidelines for stormwater management*, 2011

SC6.4.3.9.6 Plant selection for WSUD systems in the coastal dry tropics

(1) This clause provides guidance on selecting appropriate plant species for water sensitive urban design (WSUD) systems where the plants have a functional role in stormwater treatment and/ or erosion protection. Selecting suitable plant species is critical to the long term landscape amenity, functional performance and structural integrity of WSUD systems.

Due to the strong seasonal rainfall patterns in the dry tropics, weed infestation is a major problem, particularly within ephemeral waterways and stormwater treatment facilities. The vegetation design to manage weed infestation takes on high importance and requires special consideration to achieve the following objectives:

- (a) maintain, throughout the year, a dense cover of the design vegetation to occupy habitat and avoid excessive colonisation by weeds;
- (b) manage potential weed ingress from edges by sustaining perennial littoral vegetation;
- (c) in bioretention systems the vegetation must be able to tolerate long dry periods, periodic inundation and free draining sandy soils;
- (d) provision of irrigation to wetland littoral zones; and
- (e) provision of irrigation to bioretention systems designed without saturated zones.

Careful selection of plant species and by adopting suitably high planting densities can significantly reduce costs associated with weed management.

(2) A list of recommended plant species for various WSUD systems, including appropriate planting densities, is provided in the following tables:

- (a) Table SC6.4.3.9.21 A1 Groundcover plant species list for swales (incorporating buffer strips), bioretention swales and bioretention basins and Table SC6.4.3.9.22 A2 Shrub and tree plant species list for bioretention basins:
  - (i) swales (incorporating buffer strips);
  - (ii) bioretention swales; and
  - (iii) bioretention basins; and
- (b) Table SC6.4.3.9.23 A3 Macrophyte and groundcover plant species list for wetlands and sedimentation basins and Table SC6.4.3.9.24 A4 Shrub and tree plant species list for wetlands and sedimentation basins:

(i) sedimentation basins; and

(ii) wetlands.

The plant species lists in Table SC6.4.3.9.21 A1 and Table SC6.4.3.9.22 A2 are not exhaustive and other plants may be used provided their physiological and structural characteristics match the characteristics of the plant species listed in the tables.

Non-indigenous natives and exotics should only be considered when there is a specific landscape need and the species has the appropriate growth form and habit. If non-indigenous natives and exotics are chosen, careful consideration should be given to the potential impacts on downstream receiving ecosystems. Species (including natives) that have the potential to become invasive weeds should be avoided.

(3) Swales (and buffer strips), bioretention swales and bioretention basins - plant selection

(a) Required plant characteristics

Planting for bioretention basin elements may consist of up to three vegetation types:

- groundcovers for stormwater treatment and erosion protection;
- shrubbery for screening, glare reduction and character; and
- trees for shading, character and other landscape values.

For specific guidance on plant species the designer is directed to Table SC6.4.3.9.21 A1 and Table SC6.4.3.9.22 A2 which outline plant species suitable for the coastal dry tropics. The designer should also refer to any relevant local guidelines.

(i) Groundcovers

The plant (groundcover) species listed in Table SC6.4.3.9.21 A1 have been specifically selected, based on their life histories, physiological and structural characteristics, to meet the functional requirements of swales, buffer strips and bioretention systems (i.e. bioretention swales and bioretention basins). Bioretention systems must have filter media with a minimum depth of 400 mm for groundcover plants to provide an adequate depth of aerobic soil for healthy root development.

Plant species selected for bioretention systems must be able to tolerate free draining sandy soils and be capable of withstanding long dry periods punctuated by short periods of temporary inundation. The addition of saturated zones in bioretention systems will help retain moisture during the dry season where supplemental irrigation is not provided. Suitable plants species are listed in Table SC6.4.3.9.21 A1. Where irrigation of bioretention systems is provided, a more diverse range of species may be selected to achieve the desired landscape aesthetic provided they are tolerant of the filter media conditions and have the required features to fulfil the functional roles of the WSUD element. In general, the plant species in Table SC6.4.3.9.21 A1 have the following features:

(A) they are able to tolerate short periods of inundation punctuated by longer dry periods. For bioretention systems these dry periods may be reasonably severe due to the free draining nature (relatively low water holding capacity) of bioretention filter media. In the dry tropics climate irrigation of bioretention vegetation will be required unless saturated zones are provided to maintain soil moisture;

(B) they generally have spreading rather than clumped growth forms;

(C) they are perennial rather than annual;

(D) they have deep, fibrous root systems;

(E) groundcover plants can be turf, prostrate or tufted;

(F) prostrate species would typically be low mat forming stoloniferous or rhizomatous plants; and

(G) tufted species would typically be rhizomatous plants with simple vertical leaves.

Most of the groundcovers listed in Table SC6.4.3.9.21 A1 are widespread, occurring throughout the coastal dry tropics. However, alternative locally occurring species that display the required features may be selected to tailor the species list to match the native vegetation associations of the area and to compliment surrounding vegetation communities.

(ii) Shrubs and trees

Shrubs and trees are not a functional requirement within swales, bioretention swales or bioretention basins, but can be integrated to provide amenity, character and landscape value. Planting trees and shrubs in bioretention systems requires the filter media to have a minimum depth of 800 mm to avoid root interference with the perforated subsurface drainage pipes. They must also be accompanied by densely planted shade tolerant groundcover species with the characteristics outlined above. Trees and shrubs are to be managed so that the ground cover layer is not out-competed. To avoid over-shading, trees and shrubs should be planted at low densities. Periodic thinning of the upper vegetation layers may also be required. In general, tree and shrub species that can be incorporated into bioretention systems have the following general features:

(A) trees need to be able to tolerate short periods of inundation punctuated by longer dry periods. These dry periods may be reasonably severe due to the free draining nature (relatively low water holding capacity) of bioretention filter media. In the dry tropics climate irrigation of bioretention vegetation will be required unless saturated zones are provided to maintain soil moisture;

(B) they need to have relatively sparse canopies to allow light penetration to support dense groundcover vegetation;

(C) have shallow root systems and root systems that are not known the be adventurous “water seekers” to reduce the risk of root intrusion into subsurface drainage pipes;

(D) trees must not be deciduous; and

(E) preferably native and occur naturally in the local area.

The shrubs and trees listed in Table SC6.4.3.9.22 A2 are recommended as they display the above features.

Most of the shrub and tree species listed in Table SC6.4.3.9.22 A2 are widespread, occurring throughout the coastal dry tropics. However, alternative locally occurring species that display the required features may be selected to tailor the species list to match the native vegetation associations of the area and to compliment surrounding vegetation communities.

(b) Plant species selection

Well established uniform groundcover vegetation is crucial to the successful operation of swale and bioretention system treatment elements. As a result, plant species selection needs to consider both the aesthetic and functional requirements. The functional plant traits required for effective water treatment are different for different devices. For example:

(i) swales – require plants with vigorous growth and a spreading habit to hold soil in place against flow. They should also be suited to growth in wet clay soils. Examples include turf grasses, tufted grasses and sedges;

(ii) bioretention swales - require plants with vigorous growth and a spreading habit to hold soil in place against flow. They should be drought tolerant and suited to growth in sandy soils. Examples include turf grasses, tufted grasses and sedges;

(iii) bioretention basins – plants should be drought tolerant and suited to growth in sandy soils. Examples include grasses, shrubs and trees. A diverse mix is recommended; and

(iv) when selecting plant species from Table SC6.4.3.9.21 A1, consideration must be given to the following factors:

(A) other WSUD objectives such as landscape, aesthetics, biodiversity, conservation and ecological value;

(B) region, climate, soil type and other abiotic factors;

(C) roughness of the channel (Manning’s *n* roughness factor) (for swales); and

(D) extended detention depth (for bioretention systems).

Typical heights of each plant species and comments relating to shade and salt tolerances and soil moisture requirements are provided in Table SC6.4.3.9.21 A1 and will help with the selection process.

The low growing and lawn species are suitable for swale elements that require a low hydraulic roughness. The treatment performance of bioretention systems, in particular, requires dense vegetation to a height equal to that of the extended detention depth. Therefore, a system with a 300 mm extended detention depth should have vegetation that will grow to at least 300 mm high. Turf is not considered to be suitable vegetation for bioretention basins. The stems do not grow high enough and the root structure of turf is not suitably robust to ensure the surface of the bioretention filter media is continuously broken up to prevent clogging.

Included in Table SC6.4.3.9.21 A1 is a recommended planting density for each plant species. The groundcover planting densities should ensure that 70-80 % cover is achieved after two growing seasons (2 years) given adequate irrigation and weed control. High density planting to avoid weed ingress is particularly important in the dry tropics due to the climatic conditions which favour opportunistic (colonising) seasonal weed species. High density planting also ensures runoff does not establish preferential flow paths around the plants and erode the swale/ bioretention surface. Dense vegetation is also required to ensure a uniform root zone, which is particularly important in bioretention systems.

If prostrate shrubs that form scrambling thickets are used (in place of or in conjunction with the plant species in Table SC6.4.3.9.21 A1) they should be planted at high densities (8-10 plants/m²) and may require pruning to ensure even plant cover and to maintain an even root distribution below ground.

(c) Vegetation establishment and maintenance

Swales, buffer strips and bioretention basins are living systems and require two years of establishment before the vegetation matures and reaches fully functional form. During this establishment period, regular site monitoring and maintenance is critical to the success of these systems. In addition, specific requirements for plant stock sourcing, topsoil selection and testing and vegetation establishment, as detailed in the relevant WSUD element chapters, are necessary to maximise successful vegetation establishment and system treatment performance. Particular reference is made to the sections titled “Landscape Design Notes”, “Maintenance Requirements” and “Construction and Establishment” for guidance on vegetation establishment and maintenance procedures. The “Construction and Establishment” section also details a staged implementation approach by which the functional elements of the WSUD system are protected from building site runoff and associated sedimentation, weeds and litter during the building phase.

Table SC6.4.3.9.21 A1 Groundcover plant species list for swales (incorporating buffer strips), bioretention swales and bioretention basins

S Swale,
BS Bioretention Swale,
BB Bioretention Basin
Strongly recommended – perennial, vigorously growing species with appropriate traits for good pollutant removal

Scientific Name	Common Name	Application	Form	Height (mm)	Planting Density[1] (Qty/m²)	Comments
Atriplex muelleri	Salt Bush	BB	Prostrate	100	2-3	Very common low prostrate mat in saline areas, silver foliage highly ornamental
Bacopa monnieri	Bacopa	BB	Prostrate	100	6-8	Not suitable for sandy soils with low water holding capacity, Native to region prostrate herb
Bothriochloa pertusa	Indian Couch	S, BS, BB	Turf		Seeded or rolled	Tolerates prolonged dry periods
Carex fascicularis	Tassel Sedge	S	Tufted	1000	6-8	Not suitable for sandy soils with low water holding capacity,
Carex polyantha	Creek Sedge	S	Tufted	To 900	6-8	Not suitable for sandy soils with low water holding capacity,

Scientific Name	Common Name	Application	Form	Height (mm)	Planting Density[1] (Qty/m[2])	Comments
Cymbopogon refractus	Barbed Wire Grass	S	Tufted	300	8-10	Does not tolerate prolonged dry periods
Cyperus haspan	Haspan Flatsedge	S	Tufted	400	8	Suitable for, sandy soils, perennial, native to region
Cyperus javanicus		S	Tufted	1400	8	Suitable for, sandy soils, perennial, native to region
Cyperus polystachyos	Bunchy Sedge	S	Tufted	600	8	Suitable for both sand and clay soils, perennial, native to region, tolerates salinity
Cyperus scariosis#		S		900	8	Suitable for, sandy soils, perennial, native to region, tolerates salinity levels may suppress *Urochloa mutica* (para grass)
Dianella longifolia var. longifolia	Pale Flax-lily	S, BS, BB,	Tufted	300-800	8	Shade tolerant, native to region
Eragrostis elongata	Lavender Grass	S, BS, BB			8	Annual or weak perennial, best in rockeries and roadsides
Fimbristylis dichotoma		BS, BB	Tufted	750	8	Suitable for, sandy soils, perennial, native to region
Fimbristylis ferruginea	Rusty Finger Rush	BS, BB	Tufted	650 -800	8	Suitable for, sandy soils, perennial, native to region, salt tolerant
Fimbristylis tristachya		BS, BB	Tufted	600	8	Suitable for, sandy soils, perennial, native to region
Gahnia aspera	Saw Sedge	S	Tufted	1000	6	Not suitable for sandy soils, native to region, difficult to propagate
Gahnia sieberiana	Red-fruited Sword Sedge	S	Tufted	1500-3000	6	Aesthetic, difficult to propagate
Imperata cylindrical#	Blady grass	S, BS, BB	Tufted	500	8	Only use when it occurs in natural surroundings, native to region,
Juncus usitatus#	Common Rush	S, BS, BB	Tufted	500	8-10	Not suitable for sandy soils
Lomandra hystrix	Creek Matt Rush	S, BS, BB	Tufted	1000	6	Shade tolerant, native to region
Lomandra longifolia	Matt Rush	S, BS, BB	Tufted	500-1000	6	Shade tolerant, native to region
Paspalum distichum	Water Couch	S, BS, BB	Turf	To 500	Seeded or rolled	Not suitable for sandy soils, native to region
Paspalum vaginatum cv 'Saltene'	Salt Water Couch	S, BS, BB	Turf	To 500	Seeded or rolled	Salt tolerant, native to region
Platyzoma microphyllum	Fern	BB	Fern	150-500	8	Not suitable in areas expecting prolonged dry periods , Native to region
Eragrostis spartinoides	Love Grass	S, BS, BB	Grass	600	8	Native to region
Sporobolus virginicus	Marine Couch	S, BS, BB	Turf	To 400	Seeded or rolled	Salt tolerant, Native to region
Themeda triandra	Kangaroo Grass	S, BS, BB	Tufted	300-500	6-8	

Note—planting density indicates the mean number of plants per square metre for the species spatial distribution within the zone. The planting densities recommended are suggested minimums. Any reduction in planting density has the potential to reduce the rate of vegetation establishment, increase the risk of weed invasion, and increase maintenance costs. S = Swale, BS = Bioretention Swale, BB= Bioretention Basin

Table SC6.4.3.9.22 A2: Shrub and tree plant species list for bioretention basins

Note—trees not suitable for systems requiring flow conveyance (i.e. swales and bioretention swales) due to shading reducing growth of ground cover.

Scientific Name	Common Name	Form	Height (m)	Planting Density[2] (Qty/m^2)	Comments
Breynia oblongifolia	False Coffee Bush	Shrub	1-2	2-4	Native to region
Corymbia tessellaris	Moreton Bay Ash	Tree	10-20		Suitable for sandy soils, native to region
Aidia racemosa		Shrub	10-15		Native to region, tolerates high winds
Atractocarpus fitzalanii	Ivory Curl Tree	Shrub	3-10		Native to region
Eugenia reinwardtiana	Cedar Bay Cherry	Tree	1-3		Native to region
Leptospermum polygalifolium	Wild May	Shrub	1-4	2-4	Sunny position, native to region
Myoporum acuminatum	Coastal Boobialla	Shrub	0.5-6	2-4	Sun or semi-shade, salt tolerant, native to region
Albizia canescens	Townsville Siris	Tree			Native to region, rare
Buckinghamia celsissima		Tree	20-30		Native to region
Chionanthus ramiflorus	Native Olive	Tree	6-8		Native to region
Colubrina asiatica		Tree			Salt tolerant
Cupaniopsis anacaroides	Beach Tuckeroo	Tree	8-15		Suitable for sandy soils, native to region
Callistemon(Melaleuca) viminalis	Weeping Bottle Brush	Tree	5-10	<1	Requires moist soils during establishment but tolerates dry periods once established
Eucalyptus raveretiana	Black Ironbox	Tree			Tolerates high winds
Eucalyptus tereticornis	River Blue Gum	Tree	20-50m		Native to region
Ganophyllum falcatum		Tree	10-25		Native to region
Lophostemon grandiflorus		Tree	8-12		Native to region, tolerates high winds, periods of flooding and fire
Melaleuca dealbata	Cloudy Tea Tree	Tree	5-15		Native to region, tolerates high winds, periods of flooding and fire
Melaleuca fluviatilis		Tree			Native to region, tolerates high winds and periods of flooding, forms a root mat good for erosion cotrol
Mimusops elengi		Tree	10-15		Suitable for all soil types, native to region, tolerates high winds

Note—planting density indicates the mean number of plants per square metre for the species spatial distribution within the zone. The planting densities recommended are suggested minimums. Any reduction in planting density has the potential to reduce the rate of vegetation establishment, increase the risk of weed invasion, and increase maintenance costs.

(4) Wetlands and sedimentation basins - plant selection

Due to the strong seasonal rainfall patterns in the dry tropics, weed infestation is a major problem, particularly within ephemeral waterways and stormwater treatment facilities such as wetlands and sediment basins. Therefore, the design and management of these systems to manage weed infestation takes on high importance. Management of weeds is achieved through the plant selection and landscape design as follows:

- planting dense littoral vegetation around the perimeter of the wetland to avoid the ingress of weed species. To maintain dense perennial littoral vegetation, irrigation is likely to be required, particularly during the dry season; and
- designing the macrophyte zone as predominately a deep marsh system (i.e. water depth 0.5 m - 0.7 m) to maintain the macrophyte vegetation by minimising the frequency and duration of wetland drying, thus permanently occupying the habitat and restricting weed colonisation opportunities.

During the establishment and ongoing maintenance of the wetland, prompt removal of weeds before they spread and/or set seed is of critical importance.

(a) Required plant characteristics

Planting for wetlands and sedimentation basins may consist of two vegetation types:

- macrophytes and groundcovers for stormwater treatment, erosion protection and weed management. The macrophytes are divided further into several different zones as outlined in Table SC6.4.3.9.23 A3; and
- shrubbery and trees for screening, shading, character and other landscape values.

For specific guidance on plant species the designer is directed to Table SC6.4.3.9.23 A3 and Table SC6.4.3.9.24 A4 which outline plant species suitable for the coastal dry tropics.

(i) Macrophytes and groundcovers

The plant species listed in Table SC6.4.3.9.23 A3 have been specifically selected based on their life histories and physiological and structural characteristics, to meet the functional requirements of wetland systems. Plant species suitable for wetlands will also be suitable for edge planting around sedimentation basins. The following sections address wetlands specifically as they have very defined vegetation requirements for stormwater treatment. This includes consideration of the wetland zone/ depth range, typical extended detention time (typically 48 hrs) and extended detention depth (typically 0.5 m).

Other species can be used to supplement the core species listed in Table SC6.4.3.9.23 A3 provided they have the required features to fulfill the functional roles of the wetland zone. Careful consideration of the water depth range and wetland hydrological regime (water depth and inundation period) is also required to assess the suitability of alternate species for constructed wetlands. Wetland plants in the dry tropics must be able to tolerate large water level variations and dry periods of up to 60 days. Short growing emergent macrophytes will not be suitable for the deep marsh zone as they will become over inundated. As a guide, emergent macrophytes require 1/3 of their foliage to extend above the water level 80% of the time. However, during the plant establishment phase emergent macrophytes require 50% of their foliage above the water level.

In general, the species in Table SC6.4.3.9.23 A3 have the following features:

(A) they grow in water as either submerged or emergent macrophytes, or they grow adjacent to water and tolerate periods of inundation (typically sedge, rush or reed species);

(B) they generally have spreading rather than clumped growth forms;

(C) they are perennial rather than annual;

(D) they generally have rhizomatous growth forms;

(E) they have fibrous root systems; and

(F) they are generally erect species with simple vertical leaves (e.g. Juncus spp, Baumea spp).

(ii) Shrubs and trees

Shrubs and trees are not a required element of wetlands or sedimentation basins but can be integrated to provide amenity, character and landscape value. Shrubs and trees (generally only planted in the littoral zones) should be accompanied by dense shade tolerant groundcover species as an understorey to occupy habitat and provide a weed ingress barrier. Table SC6.4.3.9.24 A4 provides a list of shrubs and trees that are natives to the coastal dry tropics and are suitable for planting in the littoral zone (i.e. on the batters) around wetlands and sedimentation basins.

Littoral zone vegetation is primarily for weed management (to avoid weed ingress into the macrophyte zone), batter stabilisation, aesthetics and to restrict public access, rather than for stormwater treatment. For this reason, species that do not have all of the above structural features, but fulfill the primary littoral zone requirements (e.g. weed management and erosion protection) and landscape objectives may still be acceptable for inclusion in this zone (refer to the “Landscape Design Notes” section in the relevant WSUD chapter).

(b) Plant species selection

Plant species listed in Table SC6.4.3.9.23 A3 are recommended as core species for wetland planting. These plant species have been grouped into a wetland macrophyte zone according to their preferred water depth and the hydrologic conditions of the zone. The perennial wetland plants must be able to tolerate large water level variations and periodic drying (potentially of up to 60 days duration). In general, the deep marsh emergent macrophytes must be capable of a standing water level of 0.5 m – 0.7 m punctuated with short episodes of extended detention (up to 1.2 m in total water depth) and seasonal drying.

While individual plant species can have very specific water depth requirements other species can be quite adaptive to growing across various zones over time. It is however, recommended that the suggested zones and plant groups are adhered to for planting purposes. Plant species listed against the shallow marsh and lower batters are only suited for edge planting in wetlands and sedimentation basins. Planting densities recommended should ensure that 70-80 % cover is achieved after two growing seasons (2 years). This is particularly important for weed management and therefore the recommended planting densities should not be reduced.

Suitable plant species for the littoral zone that surrounds wetlands and sedimentation basins have also been recommended in Table SC6.4.3.9.23 A3. The littoral zone relates to the berms, batters or embankments around the systems. Plants that have a drier habit should be planted towards the top of batters, whereas those that are adapted to more moist conditions should be planted closer to the water line. High density planting of the littoral zone is required to provide a barrier (by occupying habitat) to prevent weed ingress into the wetland or sediment basin.

(c) Vegetation establishment and maintenance

To maximise the success of plant establishment in wetland macrophyte zones specific procedures are required in site preparation, stock sourcing, vegetation establishment and maintenance. Reference is to be made to procedures detailed in SC6.4.3.9.5(5) Sourcing wetland vegetation as follows:

(i) sourcing plant stock (SC6.4.3.9.5(6)(c) Sourcing wetland vegetation):

   (A) lead times for ordering plants; and

   (B) recommended planting systems/ products;

(ii) topsoil specification and preparation SC6.4.3.9.5(6)(d) Topsoil specification and preparation):

   (A) sourcing, testing and amendment; and

   (B) top soil treatments (e.g. gypsum, lime, fertiliser); and

(iii) vegetation establishment (SC6.4.3.9.5(6)(e) Vegetation establishment):

   (A) weed control;

   (B) watering; and

   (C) water level manipulation.

Constructed wetlands are living systems and they require two years of establishment before the vegetation matures and reaches fully functional form. During this establishment period, regular site monitoring and maintenance is critical to the success of these systems. Reference must also be made to the SC6.4.3.9.5(7) Maintenance requirements – constructed wetlands and SC6.4.3.9.5(6) Construction and establishment – constructed wetlands for guidance on maintenance procedures and vegetation establishment.

Similarly, the vegetation planted in sedimentation basins require an equivalent vegetation establishment period (i.e. 2 years) and level of attention to site preparation, stock sourcing, vegetation establishment and maintenance to ensure success. Reference must be made to the sections entitled “Landscape Design Notes”, “Maintenance Requirements” and “Construction and Establishment” in Chapter 4.

(d) Vegetation selection for mosquito management

Species selected should have a stiff, thin, upright growth habit. This allows mosquito predators to access all wet areas and control mosquito larvae. Species with a spreading habit such as turf grasses or wide strappy leaves such as Typha can isolate pockets of water where mosquitoes can breed and avoid predation.

Table SC6.4.3.9.23 A3: Macrophyte and groundcover plant species list for wetlands and sedimentation basins

Key to Table SC6.4.3.9.22 A3:

Zone		Depth*(m)	Form	
P	Permanent Pool	2.0– 0.7	S	Submerged macrophyte
DM	Deep Marsh	0.7 – 0.35	E	Emergent macrophyte
SM	Shallow Marsh	0.35 – 0	Am	Amphibious
LB	Lower Batters	0 – +0.5**	A	Annual Groundcover
UB	Upper Batters	+0.5- +1.0**	Sh	Shrub
			Tr	Trees

* ‘Depth’ refers to depth below permanent pool water level

** ‘+’ denotes levels above permanent pool water level

Strongly recommended – perennial, vigorously growing species with appropriate traits for good pollutant removal.

Scientific name	Common name	Zone	Type	Perennial or Annual	Height (mm)	Planting Density[2] (Qty/m^2)	Comments
Isolepis inundata	Swamp Club-rush	SM	Emergent Macrophyte		To 300	6-8	High surface area; rapid growth
Oryza australiensis	Native Rice	SM	Emergent Grass	Perennial	2500		Attracts birds, native to region
Actinoscirpus grossus		DM	Emergent	Perennial	3000	6	Suitable for clay soils
Baumea articulataarticulate#	Jointed Twig-rush	DM	Emergent	Perennial	1000-2000	6-8	Slow growth, plant solo
Eleocharis sphacelata#	Tall Spike-rush	DM	Emergent	Perennial	500-2000	6-8	Plant solo, rhizomes can restrict growth of other plants; slow establishment, flow resistant,
Leersia hexandra	Swamp Ricegrass	DM	Emergent	Perennial	2000	6	Tolerates periods of flooding, fire resistant
Lepironia articulataarticulate#	Grey Rush	DM	Emergent	Perennial	600-2300	4-6	Tall grey sedge from Hidden Valley, very ornamental, popular in wetland plantings
Phragmites australis#	Common Reed	DM	Emergent	Perennial	5000	6	Native to region, forms dense swards
Phragmites karka (vallatoria)#	Spiny MudgrassTropical Reed	DM	Emergent	Perennial	1000-2000	6	Native to region

Scientific name	Common name	Zone	Type	Perennial or Annual	Height (mm)	Planting Density[2] (Qty/m^2)	Comments
Schoenoplectus litoralis	Shore Club-rush	DM	Emergent	Perennial	600-1500	4-6	Tolerates salinity
Schoenoplectus validus #	River Club-rush	DM	Emergent	Perennial	600-1600	4-6	
Scleria poiformis		DM	Emergent	Perennial	2200	6	Requires irrigation
Thoracostachyum sumatran	Sedge	DM	Emergent	Perennial	2500	6	
Eleocharis dulcis#	Water Chestnut	DM & SM	Emergent	Perennial	1000-1500	4-6	Plant solo, flow resistant
Oryza australiensis	Native Rice	DM & SM	Emergent	Perennial	2500	6	Attracts birds, native to region
Carex polyantha#	Creek Sedge	LB	Emergent Macrophyte	Perennial	To 900	6-8	
Cyperus digitatus	Sedge	LB	Amphibious Sedge	Wet Season Annual	500-1500	8	
Cyperus iria	Rice Flat Sedge	LB	Amphibious Sedge	Wet Season Annual	600	8	Tufted growth
Cyperus tenuispica		LB	Amphibious Sedge	Wet Season Annual	400	8	Suitable for sand and clay solids
Fimbristylis littoralis	Fimbry	LB	Amphibious Sedge	Wet Season Annual		8	Native to region
Juncus pristmatocarpus	Branching Rush	LB	Emergent Macrophyte	Perennial	300-600	6-8	
Phyla nodiflora		LB	Herb	Perennial	200		Native to region
Schoenoplectus lateriflorus		LB	Amphibious Sedge	Wet Season Annual	700	8	
Schoenoplectus praelongatus		LB	Amphibious Sedge	Wet Season Annual	350	8	
Ceratophyllum demersum	Hornwort	P	Submerged	Perennial	600		Native to region
Myriophyllum dicoccum	Water Milfoil	P	Submerged	Perennial or Annual	To 200	1	
Myriophyllum filiforme	Water Milfoil	P	Emergent Aquatic Herb	Dry Season Annual	150	1	
Myriophyllum verrucosum	Red Water-milfoil	P	Submerged	Perennial	100-1500	1	Native to region
Najas tenuifolia	Water Nymph	P	Submerged	Perennial	500	1	
Potamogeton crispus	Curly Pondweed	P	Submerged	Perennial	To 4500	1	Growth can be dense, native to region
Potamogeton octandrus	Pondweed	P	Submerged	Perennial	To 4500	1	
Potamogeton tricarinatus	Pondweed	P	Submerged	Perennial		1	

Scientific name	Common name	Zone	Type	Perennial or Annual	Height (mm)	Planting Density[2] (Qty/m^2)	Comments
Vallisneria gigantea	Ribbonweed	P	Submerged	Perennial	To 3000	1	Rapid growth; salt tolerant (1500 ppm),
Vallisneria nana	Ribbonweed	P	Submerged	Perennial	700	1	Native to region
Ischaemum australe	Zipper Grass	SM	Amphibious Grass	Perennial	1500	6	Forms dense swards
Ischaemum rugosum		SM	Amphibious Grass	Perennial	1200	6	Native to region
Schoenoplectus mucronatus#	Club Rush	SM		Perennial	0.35-1.0m	8	Native to region
Cyperus scariosis	Sedge	SM & LB	Amphibious Sedge	Perennial	800	8	Native to region, salt tolerant
Fimbristylis dichotoma#		SM & LB	Amphibious Sedge	Perennial	1000	8	Native to region
Juncus usitatus#	Common Rush	SM & LB	Emergent Macrophyte		300-1200	8-10	Rapid growth
Dianella longifolia var. longifolia	Pale Flax-lily	UB	GrassLily	Perennial	300-800	6-8	Aesthetic; shade tolerant
Lomandra filiformis spp. filiformis	Wattle Mat-rush	UB	Tufted	Perennial	150-500	6-8	Shade tolerant when established, native to region
Lomandra longifolia #	Spiny-headed Mat Rush	UB	Tufted	Perennial	500-1000	4-6	Shade tolerant, native to region
Sorghum plumosum	Plume Sorghum	UB	Grass		To 4000	6	Growth can be dense
Themeda triandra	Kangaroo Grass	UB	Grass	Perennial	750	8	Requires local propagation, does not tolerate water logged soils
Cyperus polystachyos#	Bunchy Sedge	UB & LB	Sedge	Perennial	To 600	6-8	Suitable for sand and clay soils, Native to region, salt tolerant
Gahnia siberiana	Red-fruited Sword Sedge	UB & LB	Tufted	Perennial	1500-3000	4-6	Aesthetic. difficult to germinate

Note—planting density indicates the mean number of plants per square metre for the species spatial distribution within the zone. The planting densities recommended are suggested minimums. Any reduction in planting density has the potential to reduce the rate of vegetation establishment, increase the risk of weed invasion, and increase maintenance costs.

Table SC6.4.3.9.24 A4: Shrub and tree plant species list for wetlands and sedimentation basins

Scientific name	Common name	Zone	Form	Height (mm)	Planting Density 3 (Qty/m^2)	Comments
Callistemon viminalis	Weeping Bottle Brush	UB	Tree	5.0-10.0	<1	Moist, medium to heavy soils, tolerates dry periods once established
Eucalyptus coolabah		UB	Tree		<1	
Livistona decora		UB	Tree		<1	Native to region
Lophostemon suaveolens	Swamp Box	UB	Tree	5.0-25.0	<1	Moist sandy soils
Melaleuca leucadendron	Weeping Paperbark	UB	Tree		2-4	
Melaleuca nodosa	Prickly-leafed Paperbark	UB	Tree	2.0-7.0	2-4	Deep sands and moist sandy soils
Melaleuca viridiflora		UB	Tree		2-4	Native to region
Nauclea orientalis	Leichardt Tree	UB	Tree		<1	Native to region, tolerates high winds and periods of flooding
Pandanus cookii	Screw Pine	UB	Tree		<1	Native to region, tolerates high winds, periods of flooding, fire resistant, will drop leaves
Myoporum acuminatum	Coastal Boobialla	UB	Shrub	0.5-6.0	2-4	Sun or semi-shade, salt tolerant Native to region

Note—planting density indicates the mean number of plants per square metre for the species spatial distribution within the zone. The planting densities recommended are suggested minimums. Any reduction in planting density has the potential to reduce the rate of vegetation establishment, increase the risk of weed invasion, and increase maintenance costs.

(5) References - plant selection

BCC 2005, *Growing Native Plants in Brisbane, BCC,* Brisbane, accessed 25th July 2005

BCC, DMR & PRSC (Brisbane City Council, Queensland Department of Main Roads and Pine Rivers Shire Council) 2001, *Preferred Species Manual: Green Routes Program*, prepared for the Green Routes Program by BCC, DMR and PRSC, Brisbane