Bioretention Swales

Chapter 3

3.1 Introduction

Bioretention swales provide stormwater treatment and conveyance functions, combining a bioretention system installed in the base of a swale that is designed to convey stormwater as part of a minor and/ or major drainage system. The swale component (refer also to Chapter 2 - Swales) provides pre-treatment of stormwater to remove coarse to medium sediments while the bioretention system removes finer particulates and associated contaminants. Bioretention swales provide flow retardation for frequent storm events and are particularly efficient at removing nutrients.

The bioretention swale treatment process operates by filtering stormwater runoff through surface vegetation associated with the swale and then percolating the runoff through a prescribed filter media, forming the bioretention component which provides treatment through fine filtration, extended detention treatment and some biological uptake. Rain patterns in the Dry Tropics mean that bioretention systems will receive reduced rainfall during the dry season and large volumes of fairly consistent rainfall during the wet season. Plant species selected for bioretention systems must therefore be able to tolerate free draining sandy soils and be capable of withstanding long dry periods as well as periods of inundation. Evidence from experimental trials conducted by the Facility for Advancing Water Biofiltration (FAWB) has shown that by including a saturated zone at the base of the bioretention system, soil moisture can be maintained to sustain vegetation for 2 to 3 months without rainfall/stormwater inflows (by drawing from this saturated zone over the dry season) (Zinger *et al* 2007a). This research also indicates that these saturated zones have potential nitrogen removal rates of 70% compared with 45% in bioretention systems with no saturated zone (Zinger *et al* 2007b).

Bioretention swales also 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 3-1 or can be provided as a continuous "trench" along the full length of a swale).

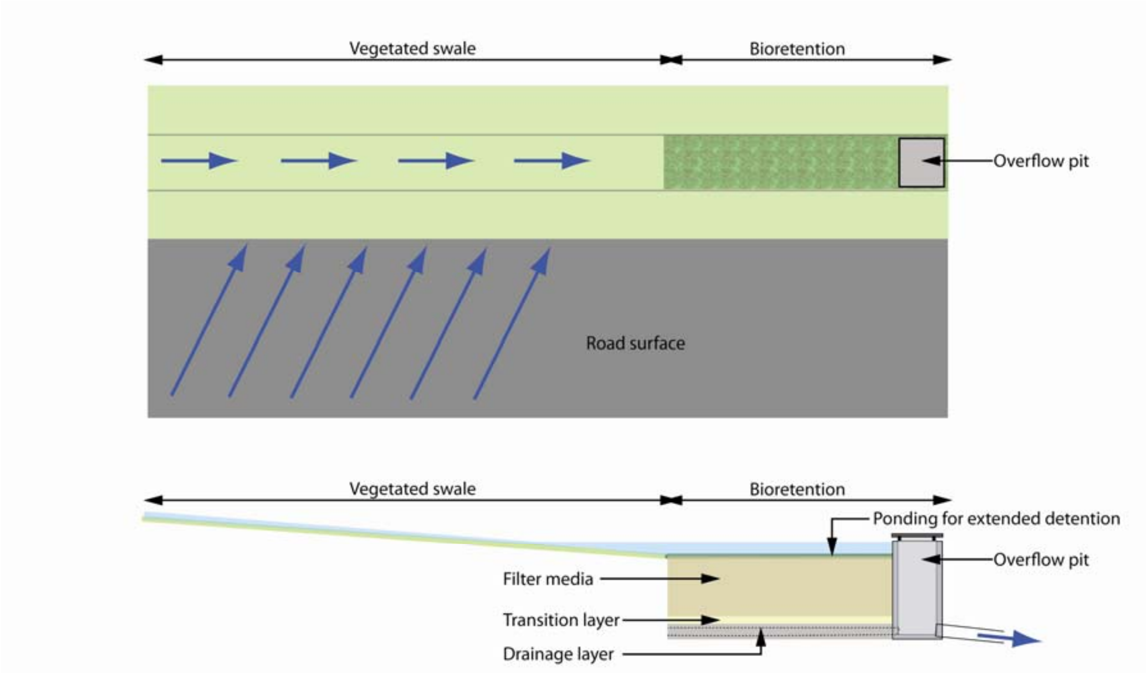


Figure 3-1 Bioretention Swale Conceptual Layout

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.

Bioretention swales are not intended to be 'infiltration' systems in that the intent is typically not to have the stormwater exfiltrate from the bioretention filter media to the surrounding in-situ soils. Rather, the typical design intent is to recover the percolated stormwater runoff at the base of the filter media, within perforated under-drains, for subsequent discharge to receiving waterways or for storage for potential reuse. In some circumstances however, where the in-situ soils allow and there is a particular design intention to recharge local groundwater, it may be desirable to permit the percolated stormwater runoff to infiltrate from the base of the filter media to the underlying in-situ soils.

3.2 Design Considerations for Bioretention Swales

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.

3.2.1 Landscape Design

Bioretention swales may be located within parkland areas, easements, carparks 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.

3.2.2 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.

3.2.3 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. When considering ex-filtration to surrounding soils, the designer must consider site terrain, hydraulic conductivity of the in-situ soil, soil salinity, groundwater and building setback. Further guidance in this regard is provided in Chapter 7 Infiltration Measures.

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 dependant on the characteristics of the local soils and the saturated hydraulic conductivity of the bioretention filter media (see Section 3.2.5). Typically, if the selected saturated hydraulic conductivity of the filter media is one to two orders of magnitude (i.e. 10 to 100 times) greater than that of the native surrounding soil profile, then the preferred flow path for stormwater runoff will be vertically through the bioretention filter media and into the perforated under-drains at the base of the filter media. As such, there will be little if any ex-filtration to the native surrounding soils.

However, 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 Section 3.2.5) 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.

3.2.4 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. However, grassed bioretention swales need to be mown to protect the conveyance capacity of the swale component and therefore repeated mowing of the grass over a continuous bioretention trench can result in long term compaction of the filter media and reduce its treatment performance. 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).

Dense vegetation planted along the swale component can also offer improved sediment retention by reducing flow velocity and providing vegetation enhanced sedimentation for deeper flows. However, densely vegetated swales have higher hydraulic roughness and therefore require a larger area and/ or more frequent use of swale field inlet pits to convey flows compared to grass swales. Densely vegetated bioretention swales can become features of an urban landscape and once established, require minimal maintenance and are hardy enough to withstand large flows.

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.

Appendix A (Plant Selection for WSUD Systems) provides more specific guidance on the selection of appropriate vegetation for bioretention swales.

3.2.5 Bioretention Filter Media

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

- Saturated hydraulic conductivity required to optimise the treatment performance of the bioretention component given site constraints on available filter media area.
- Depth of extended detention provided above the filter media.
- 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 3-2 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.

3.2.6 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). This research also revealed the benefit of saturated zones to plant health by maintaing soil moisture during extended dry periods (Zinger *et al.* 2007a). Evidence from trials of such systems in Victoria have shown that vegetation can be sustained for 2 to 3 months without rainfall/stormwater inflows by drawing from this saturated zone over the dry period.

Research on the effectiveness of saturated zones for nitrogen removal conducted by the Facility for Advancing of Water Biofiltration (FAWB) indicate nitrogen removal rates up to 55% higher than in bioretention systems with no saturated zone. To achieve the benefit of enhanced nitogen removal the saturated zone should be composed of clean (i.e. free of fines) medium to coarse sand, gravel or small rock (upto 50mm diameter) and must contain a long term carbon source (such as hardwood woodchips) to promote conditions suitable for denitrification.

Denitrifying bacteria occur in a thin anaerobic layer around the surface of the carbon source (woodchips) and transform nitrate into nitrogen gas as stormwater passes through the system. While anaerobic microsites are present (to support denitrification processes), the bulk of the stormwater within the saturated zone does not become anaerobic. Therefore, there is minimal risk of anoxic water discharging from bioretention systems with saturated zones. It should be noted however, that saturated zones can result in reduced die-off for some pathogens and therefore if treated water from the bioretention system is to be harvested and reused a disinfection treatment element should be installed (e.g. UV sterilisation).

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.

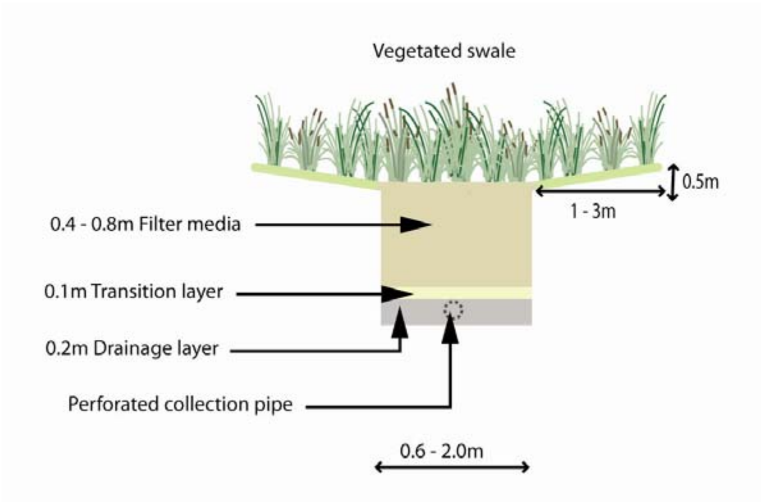


Figure 3-2: Typical Section of a Bioretention Swale

3.2.7 Traffic Controls

Another design consideration is keeping traffic and building material deliveries off swales, particularly during the building phase of a development. If bioretention swales are used for parking, then the surface will be compacted and vegetation damaged beyond its ability to regenerate naturally. Compacting the surface of a bioretention swale will reduce the infiltration into the filter media and lead to early bypass and reduced treatment. Vehicles driving on swales can cause ruts that can create preferential flow paths that diminish the water quality treatment performance as well as creating depressions that can retain water and potentially become mosquito breeding sites.

A staged construction and establishment method (Section 3.5) affords protection to the sub-surface elements of a bioretention swale from heavily sediment ladened 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 constractors of the purpose and function of the swales. Management of traffic onto the swales after completion of the allotment building phase can be achieved in a number of ways such as planting the interface to the road carriageway with dense vegetation that will discourage the movement of vehicles onto the swale or, if dense vegetation cannot be used, by providing physical barriers such as kerb and channel (with breaks to allow distributed water entry to the swale) or bollards and/ or street tree planting.

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

Where bollards/road edge guide posts are used, consideration should be given to intermixing mature tree plantings with the bollards to break the visual monotony created by a continuous row of bollards. Bollards and any landscaping (soft or hard) must comply with Townsville City Council guidelines.

3.2.8 Roof Water Discharge

Roof runoff can contain a range of stormwater pollutants including nitrogen washed from the atmosphere during rainfall events. Rainfall is consistently the major source of nitrogen in urban stormwater runoff (Duncan 1995) and inorganic nitrogen concentrations in rainfall often exceed the threshold level for algal blooms (Weibel et al. 1966). 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 Section 3.3.4.2.

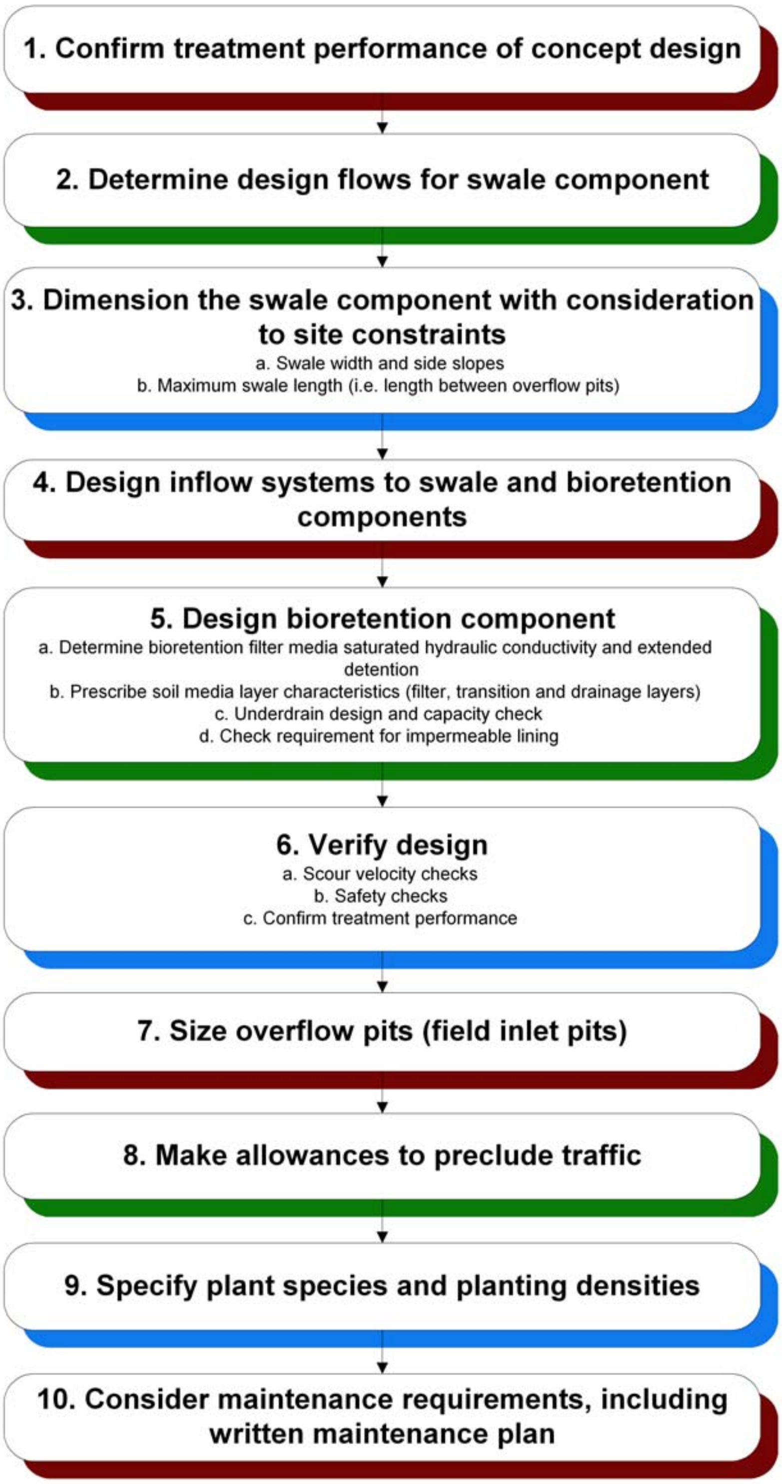
Roof water should only be directly connected to an underground pipe drainage system if an appropriate level of stormwater treatment is provided along (or at the outfall of) the pipe drainage system.

3.2.9 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.

3.3 Bioretention Swale Design Process

To create bioretention swales, separate calculations are performed to design the swale and the bioretention system, with iterations to ensure appropriate criteria are met in each section. The calculations and decisions required to design the swale component are presented in detail in Chapter 2 (Swales) and are reproduced in this chapter. This is to allow designers and Council development assessment officers to consult with this chapter only for designing and checking bioretention swale designs. The key design steps are:



Each of these design steps is discussed below, followed by a worked example illustrating application of the design process on a case study site.

3.3.1 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. 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.

The performance of the swale component for nitrogen removal is typically only minor and thus the sizing of the bioretention component will typically be driven by achieving compliance with best practice load reduction targets for Total Nitrogen.

3.3.2 Step 2: Determine Design Flows for the Swale Component

3.3.2.1 Design Flows

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

- 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.
- major flood flow (50 year ARI) to check flow velocities, velocity depth criteria, conveyance within road reserve, and freeboard to adjoining property.

3.3.2.2 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.

3.3.3 Step 3: Dimension the Swale Component with Consideration to Site Constraints

Factors to consider are:

- allowable width given the proposed road reserve and/ or urban layout
- how flows are delivered into a swale (e.g. cover requirements for pipes or kerb details)
- vegetation height
- longitudinal slope
- maximum side slopes and base width
- provision of crossings (elevated or at grade)
- requirements of QUDM and Townsville City Council.

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.

3.3.3.1 Swale Width and Side Slopes

The maximum width of swale is usually determined from an urban layout and at the concept design stage and should be undertaken in accordance with relevant local authority guidelines or standards. Brisbane City council's Standard Drawing UMS 151 presents examples of swale profiles that can be provided within typical residential road reserves and can be used as a reference for swale design in lieu of any local equivalent. 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 side slopes for swales in parks, easements or median strips is heavily dependant 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 from 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. The selection of crossing type should be made in consultation with urban and landscape designers.

3.3.3.2 Maximum Length of a Swale

The maximum length of a swale is the distance along a swale before an overflow pit (or field inlet pit) is required to drain the swale to an underlying pipe drainage system.

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 section 3.3.3.3).

The maximum length of a swale located along a roadway is calculated as the distance along the swale to the point where flow on the adjoining road pavement (or road reserve) no longer complies with the local standards for road drainage (for both the minor and major flood flows) or in lieu of any specific standrds then in compliance with the relevant design standards presented in QUDM.

3.3.3.3 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.

$$Q = \frac{A \cdot R^{2/3} \cdot S^{1/2}}{n} \qquad \text{Equation 3.1}$$

Where A = cross section area of swale (m^2)

R = hydraulic radius (m)

S = channel slope (m/m)

n = roughness factor (Manning's n)

Manning's *n* is a critical variable in Manning's equation relating to roughness of the channel. It varies with flow depth, channel dimensions and vegetation type. For constructed swale systems, values are recommended to be between 0.15 and 0.4 for flow depths shallower than the vegetation height (preferable for treatment) and significantly lower for flows with greater depth than the vegetation (e.g. 0.03 for flow depth more than twice the vegetation height). It is considered reasonable for Manning's *n* to have a maximum at the vegetation height and then to sharply reduce as depths increase.

Figure 3-3 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 3-3) 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).

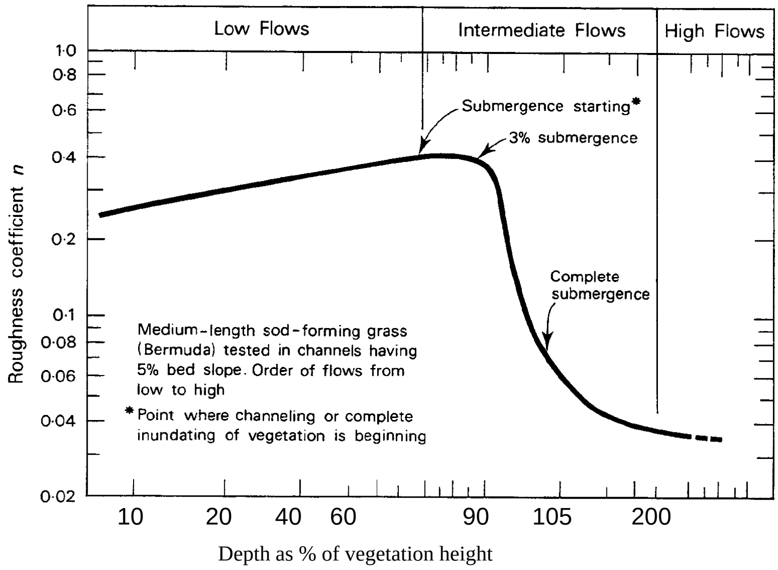


Figure 3-3: Impact of Flow Depth on Hydraulic Roughness (adapted from Barling and Moore (1993))

3.3.4 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.

3.3.4.1 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 3-4). 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 pretreatment (i.e. significant coarse sediment removal) prior to flows being conveyed along the swale.

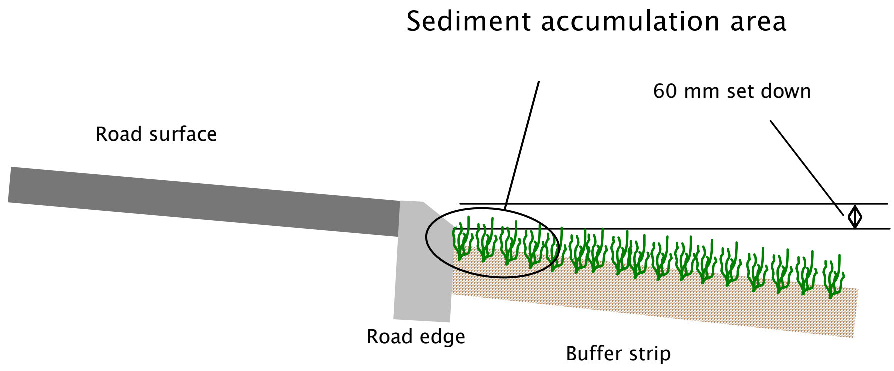


Figure 3-4: Flush Kerb with 60 mm Setdown to allow Sediment to Flow into Vegetated Area

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 (Plate 3-1).

Plate 3-1: Kerb Arrangements with Breaks and Flush Kerbs to Distribute Inflows on to Bioretention Swales and Prevent Vehicle Access

No specific design rules exist for designing buffer systems, however there are several design guides that are to be applied to ensure buffers operate to improve water quality and provide a pre-treatment role. Key design parameters of buffer systems are:

- providing distributed flows into a buffer (potentially spreading stormwater flows to achieve this)
- avoiding rilling or channelised flows
- maintaining flow heights lower than vegetation heights (this may require flow spreaders, or check dams)
- minimising the slope of buffer, best if slopes can be kept below 5 %, however buffers can still perform well with slopes up to 20 % provided flows are well distributed. The steeper the buffer the more likely flow spreaders will be required to avoid rill erosion.

Maintenance of buffers is required to remove accumulated sediment and debris therefore access is important. Most sediments will accumulate immediately downstream of the pavement surface and then progressively further downstream as sediment builds up.

It is important to ensure coarse sediments accumulate off the road surface at the start of the buffer. Plate 3-2 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 (refer Figure 3.4), 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.

Plate 3-2: Flush Kerb without Setdown, showing Sediment Accumulation on Road

3.3.4.2 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 an important consideration 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 need to be used. Surcharge pits should be designed so that they are as shallow as possible and have pervious bases to avoid long term ponding in the pits (this may require under-drains to ensure it drains, depending on local soil conditions). The pits need to be accessible so that any build up of coarse sediment and debris can be monitored and removed if necessary. It is noted that surcharge pits are generally not considered good practice (due to additional maintenance issues and mosquito breeding potential) and should therefore 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 3-5 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 > 0.5m/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.

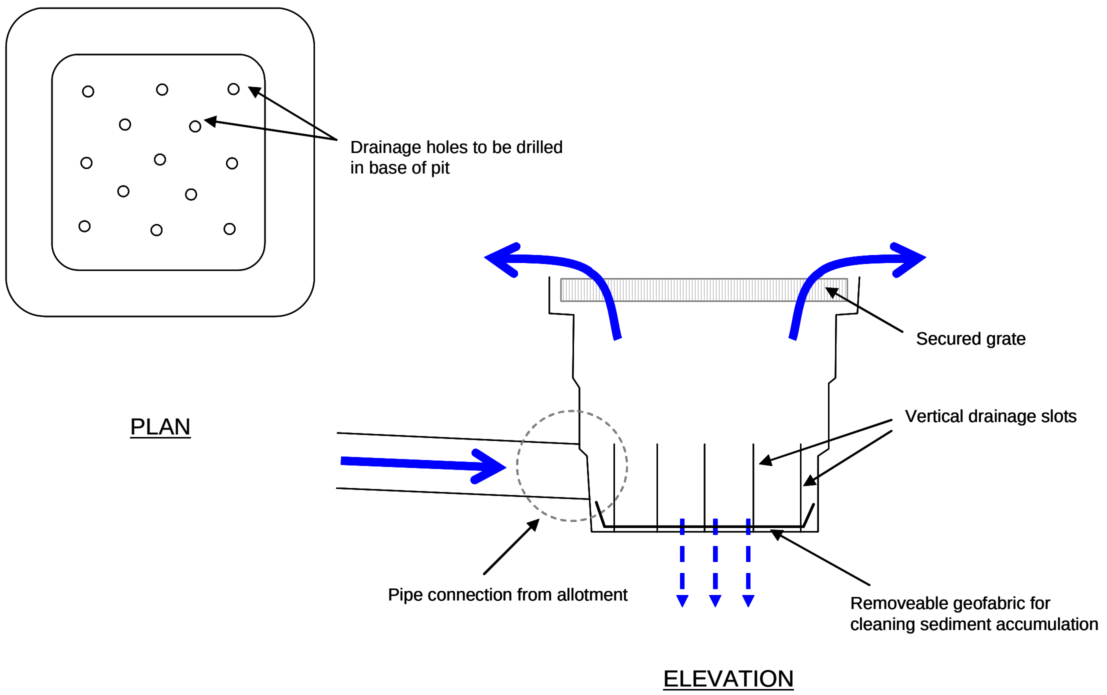


Figure 3-5: Example of Surcharge Pit for Discharging Allotment Runoff into a Swale

3.3.5 Step 5: Design Bioretention Component

3.3.5.1 Select Filter Media Saturated Hydraulic Conductivity and Extended Detention

Where design Steps 2 and 3 (Section 3.3.2 and 3.3.3) 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.

3.3.5.2 Specify the Bioretention Filter Media Characteristics

Three to four types of media can be required in the bioretention component of bioretention swales (refer Figure 3-2 in Section 3.2.5).

<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 300mm 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:

- 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%.
- 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.
- To amend the base soil to achieve the desired design saturated hydraulic conductivity either mix in a loose non-angular sand (to increase saturated hydraulic conductivity) or conversely a loose soft clay (to reduce saturated hydraulic conductivity).
- 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.

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

<u>Transition Layer (if required)</u>

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 acheive 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 100mm thick and have a minimum saturated hydraulic conductivity of 1000mm/hr.

A recent particle size distribution for the transition layer sand will need to be obtained to esnure 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 (Section 5.3.5).

<u>Saturated Layer (if required)</u>

Research in Australia (Zinger *et al.* 2007b) and in the USA (Kim *et al.* 2003) indicates that the presence of saturated zones can increase nitrate removal in bioretention systems. Microbial denitrification (i.e. the transformation of nitrate to nitrogen gas) is promoted in this saturated zone by providing a long term carbon source (such as hardwood chips). Denitrifying bacteria occur on a thin anaerobic layer surrounding the surface of the carbon source. Stormwater passing through the system does not become anoxic.

The saturated layer should be about 400mm 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 (50mm diameter maximum) together with a long term carbon source. Hardwood wood chips, 5mm to 40mm 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 400mm 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
- 3.3 m^3 hardwood wood chips, well graded 5mm-40mm

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)	656 kg/carbon
Safety Factor (x 2)	1313 kg/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 >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.

<u>Drainage Layer (if required)</u>

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 Section 3.3.5.3) 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.

3.3.5.3 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.
- 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:

$$Q_{max} = K_{sat} \cdot L \cdot W_{base} \cdot \frac{h_{max} + d}{d}$$ Equation 3.2

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.

$$Q_{perf} = B \cdot C_d \cdot A\sqrt{2 \cdot g \cdot h}$$ Equation 3.3

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 100mm. This is important to limit increase in the saturated zone depth and avoid prolonged saturation of the filter media.

3.3.5.4 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 Section 3.2.3). 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.

3.3.6 Step 6: Verify Design

3.3.6.1 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:

- less than 0.5 m/s for minor flood (2-10 year ARI) discharge
- less than 2.0 m/s for major flood (50-100 year ARI) discharge.

3.3.6.2 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:

- 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
- maximum depth of flow over crossing = 0.3 m.

3.3.6.3 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 Section 3.3.1.

3.3.7 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):

$$Q_{weir} = B \cdot C_w \cdot L \cdot h^{3/2}$$ Equation 3.4

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):

$$Q_{orifice} = B \cdot C_d \cdot A\sqrt{2 \cdot g \cdot h}$$ Equation 3.5

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 & BCC, 1998). Refer to relevant local authority guidelines or standards for grate types for inlet pits. In the absence of local guidelines designers can refer to Brisbane City Council's Standard Drawings UMS 157 and UMS 337 which provide examples of grate types for overflow pits located in bioretention systems.

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 5-2). The saturated zone would hold water rather than draining freely, and would therefore provide a source of water to the plants during dry periods.

3.3.8 Step 8: Make Allowances to Preclude Traffic on Swales

Refer to Section 3.2.7 for discussion on traffic control options.

3.3.9 Step 9: Specify Plant Species and Planting Densities

Refer to Sections 3.4 and Appendix A 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.

3.3.10 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 Section 3.6.

3.3.11 Design Calculation Summary

The following design calculation table can be used to summarise the design data and calculation results from the design process.

BIORETENTION SWALES DESIGN CALCULATION SUMMARY

	Calculation Task		CALCULATION SUMMARY Outcome		Check
	Catchment Characteristics				
		Catchment Area		ha	☐
		Catchment Land Use (i.e. residential, Commercial etc.)			
	Conceptual Design				
		Bioretention area		m^2	☐
		Filter media saturated hydraulic conductivity		mm/hr	
		Extended detention depth		mm	
1	**Confirm Treatment Performance of Concept Design**				
		Bioretention area to achieve water quality objectives		m^2	☐
		TSS Removal		%	
		TP Removal		%	
		TN Removal		%	
2	**Estimate Design Flows for Swale Component**				
		Time of concentration – QUDM		minutes	☐
	Identify Rainfall intensities				
		$I_{2\text{-}10\ year\ ARI}$		mm/hr	☐
		$I_{50\text{-}100\ year\ ARI}$		mm/hr	
	Design Runoff Coefficient				
		$C_{2\text{-}10\ year\ ARI}$			☐
		$C_{50\text{-}100\ year\ ARI}$			
	Peak Design Flows				
		2-10 year ARI		m^3/s	☐
		50-100 year ARI		m^3/s	
3	**Dimension the Swale Component**				
	Swale Width and Side Slopes				
		Base Width		m	☐
		Side Slopes – 1 in			
		Longitudinal Slope		%	
		Vegetation Height		mm	
	Maximum Length of Swale				
		Manning's *n*			☐
		Swale Capacity			
		Maximum Length of Swale			
4	**Design Inflow Systems to Swale & Bioretention Components**				
		Swale Kerb Type			☐
		Adequate Erosion and Scour Protection (where required)			
5	**Design Bioretention Component**				
		Filter media hydraulic conductivity		mm/hr	☐
		Extended detention depth		mm	
		Filter media depth		mm	
		Saturated zone required			
		Saturated zone depth		mm	
		Drainage layer media (sand or fine screenings)			
		Drainage layer depth		mm	
		Transition layer (sand) required			
		Transition layer depth		mm	
	Under-drain Design and Capacity Checks				
		Flow capacity of filter media (maximum infiltration rate)		m^3/s	☐
		Perforations inflow check			
		Pipe diameter		mm	☐
		Number of pipes			
		Capacity of perforations		m^3/s	
		CHECK PERFORATION CAPACITY > FILTER MEDIA CAPACITY			
		CHECK SATURATED ZONE WEIR/UP-TURNED PIPE CAPACITY > FILTER MEDIA CAPACITY			
	Perforated pipe capacity				
		Pipe capacity		m^3/s	☐
		CHECK PIPE CAPACITY > FILTER MEDIA CAPACITY			
	Check requirement for impermeable lining				
		Soil hydraulic conductivity		mm/hr	☐
		Filter media hydraulic conductivity		mm/hr	
		MORE THAN 10 TIMES HIGHER THAN IN-SITU SOILS?			
5	**Verification Checks**				
		Velocity for 2-10 year ARI flow (< 0.5 m/s)		m/s	☐
		Velocity for 50-100 year ARI flow (< 2 m/s)		m/s	
		Velocity x Depth for 50-100 year ARI (< 0.4 m^2/s)		m^2/s	
		Treatment Performance consistent with Step 1			
6	**Overflow Pit Design**				
		System to convey minor floods		L x W	☐

3.3.12 Typical Design Parameters

Table 3-1 shows typical values for a number of key bioretention swale design parameters.

Table 3-1: 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. 2-10 yr ARI)	0.5 m/s
Maximum velocity for 50-100 yr 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

3.4 Landscape Design Notes

Bioretention swales are a combined solution that involves integrating a swale (Chapter 2) with the filtration function of a bioretention basin/trench (Chapter 5). 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.

3.4.1 Objectives

Landscape design for bioretention swales has four key objectives:

- 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.
- Integrated planning and design of bioretention swales within the built and landscape environments.
- Incorporating Crime Prevention through Environmental Design (CPTED) principles and road, driveway and footpath visibility safety standards.
- Create landscape amenity opportunities that enhance community and environmental needs, such as visual aesthetics, shade, screening, view framing, and way finding.

3.4.2 Context and Site Analysis

When designing for bioretention swales as part of a WSUD strategy, the overall concept layout needs to consider:

- possible road profiles and cross-sections
- building and lot layout
- possible open space and recreational parks
- existing natural landforms
- location of services

Slope and soil type will also determine if swales are appropriate to the site and which swale type and swale location will be the most effective.

Careful site analysis and integrated design with engineers, landscape architects and urban designers will ensure the bioretention swales meet functional and aesthetic outcomes. A balanced approach to alignments between roads, footpaths and lot boundaries will be required early in the concept design of new developments to ensure swales are effective in both stormwater quality objectives and built environment arrangements. This is similar to concept planning for parks and open space where a balance is required between useable recreation space and WSUD requirements.

Comprehensive site analysis should inform the landscape design as well as road layouts, civil works and maintenance requirements. Existing site factors such as roads, driveways, 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)

3.4.3 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.

3.4.3.1 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 3-6.

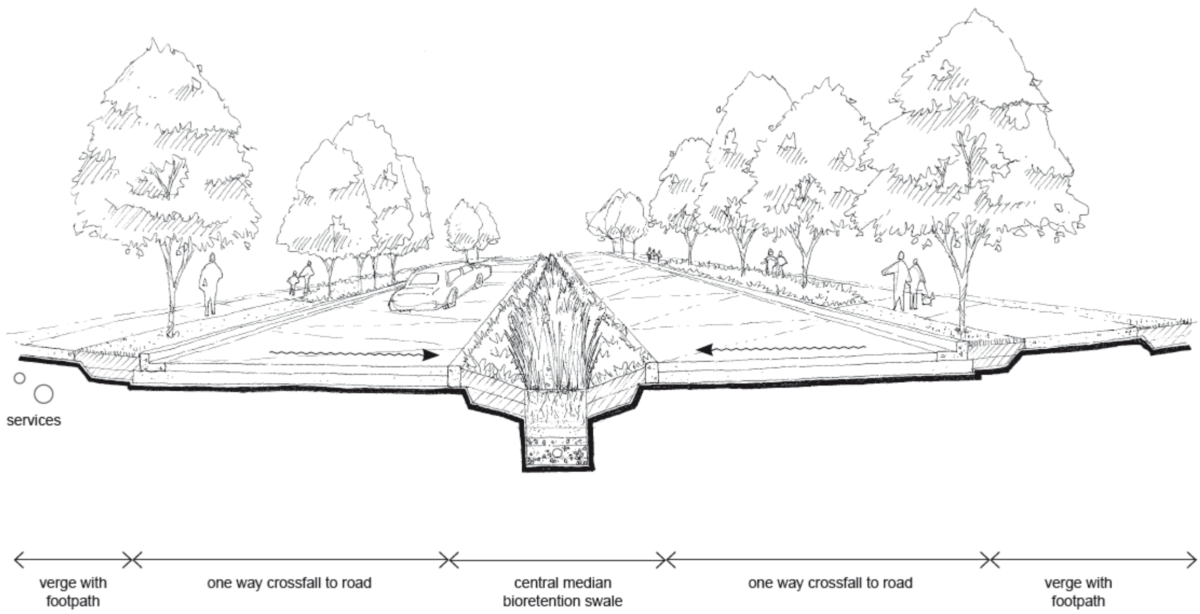


Figure 3-6: Bioretention swale in centre median

Plate 3-3: Median Strip Bioretention applications

3.4.3.2 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 3-7.

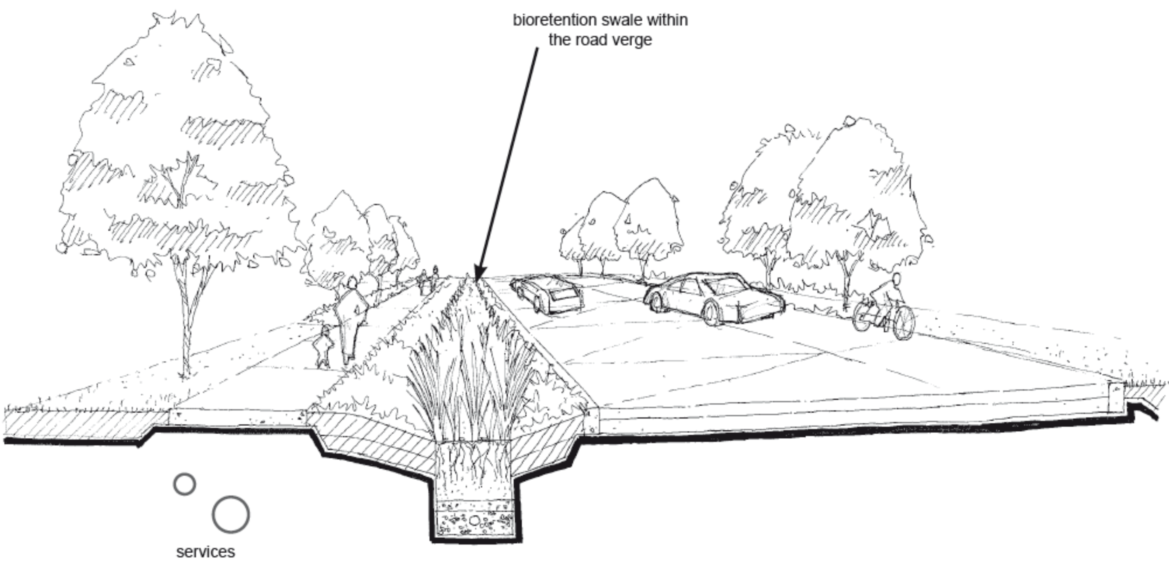


Figure 3-7: Bioretention swale within road verge

3.4.4 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 3-6 for an illustrative example.

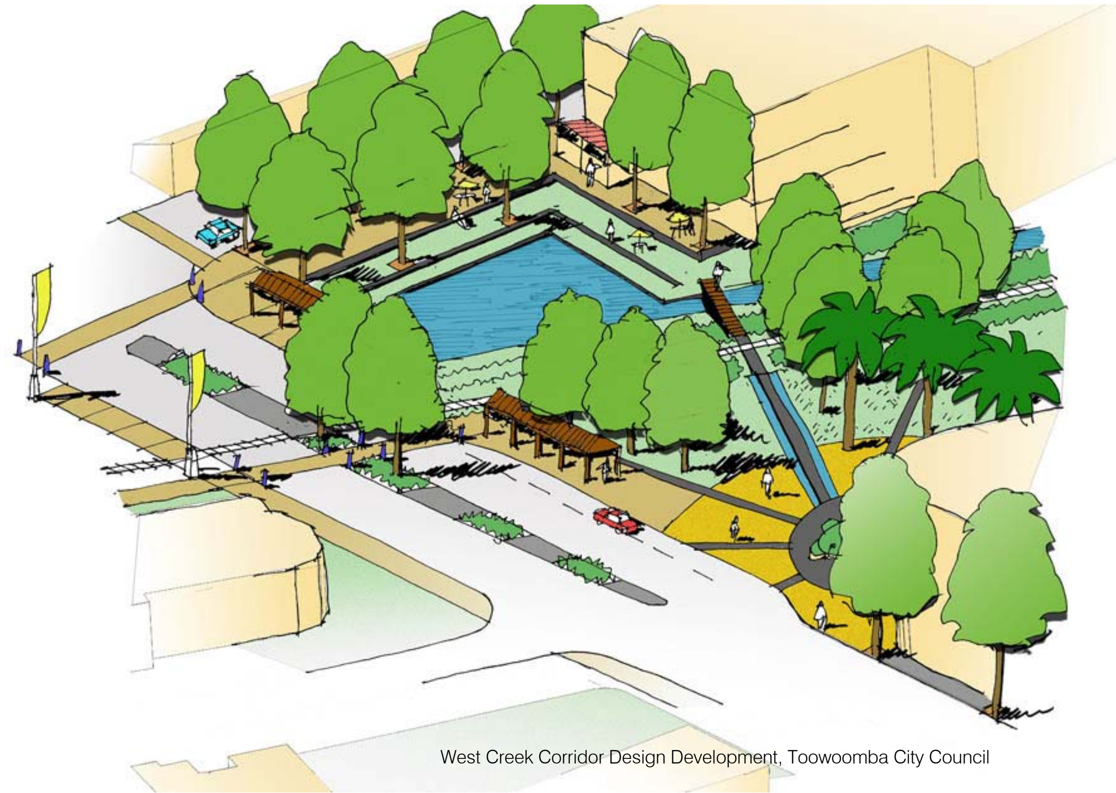


Figure 3-6: Swale treatment in Civic Space

3.4.5 Open Space Bioretention Swales

Design and siting of parks/open space swales allows for greater flexibility in sectional profile, treatments and alignments. It is important however for careful landscape planning, to ensure that spaces for particular recreational uses are not encumbered by stormwater management devices including swales.

Bioretention strips can form convenient edges to pathway networks, frame recreational areas, create habitat adjacent to existing waterways/vegetation and provide landscape interest. Important issues to consider as part of the open space landscape design are maintenance access and CPTED principles which are further discussed in following sections.

3.4.6 Appropriate Plant Species

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

- groundcovers for stormwater treatment and erosion protection (required element)
- shrubbery for screening, glare reduction, character, and other values
- street trees for shading, character and other landscape values
- 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.

3.4.6.1 Groundcovers

Groundcover vegetation is an essential functional component of bioretention swales. Appendix A provides 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. Other species may be considered to aid in providing a visually aesthetic landscape. A table of recommended species is provided in Appendix A. Generally species selection should aim to ensure:

- a high leaf surface density within the design treatment depth to aid efficient stormwater treatment
- a dense and uniform distribution of vegetation to prevent stormwater flows from meandering between plants and to create a uniform root zone within the bioretention filter media.

3.4.6.2 Shrubs

Shrubs provide an important role in allowing for visual screening, providing interest and should compliment the design and siting of the bioretention swale. Some species are outlined in Appendix A that are useful in urban and residential landscapes, however it should be noted that these lists are guides only. Other species and cultivars may be appropriate given the surrounding natural and/ or built environment of the bioretention swale. Designers should ensure that the proposed planting schedule is suitable for the specific site. Local authorities may also provide guidance on choosing suitable shrub and tree species.

3.4.6.3 Street Trees

Trees for systems located on roadsides should conform with the local authority's relevant policy and landscape design guidelines. Also refer to Appendix A for further guidance on tree species selection.

It is important when considering planting trees within the bioretention swale system that deep rooting species are planted to the top of the bioretention zone batter to reduce roots impacting upon the filter media. If planting trees in the bioretention zone is important to the overall landscape design then creating a deeper filter media zone (min of 800mm) that further separates invasive roots from the lower drainage system is important.

3.4.6.4 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).

3.4.7 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.

3.4.7.1 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.

3.4.7.2 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.

3.5 Construction and Establishment

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. 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.

3.5.1 Staged Construction and Establishment Method

It is important to note that bioretention swale systems, 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 bioretention swales and establishing vegetation can be a challenging task. Therefore, bioretention swales require a careful construction and establishment approach to ensure the system establishes in accordance with its design intent. The following sections outline a recommended staged construction and establishment methodology for bioretention swales (Leinster, 2006). For a detailed construction sequence for bioretention systems, including key milestones requiring inspection and sign off by either the superintendent or the design team, refer to section 5.5.1.6 - Chapter 5 (Bioretention Basins).

3.5.1.1 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 3-7).

- 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 vegetation and clog bioretention filter media
  - 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.

- 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 bioretention swales.

Plate 3-4: Example of Building Phase

3.5.1.2 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 3-7):

- 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. For example, temporary protection of bioretention swales can been achieved by using a temporary arrangement of a suitable geofabric covered with shallow topsoil (e.g. 25mm) and instant turf, in lieu of the final basin planting.
- 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.
- 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.

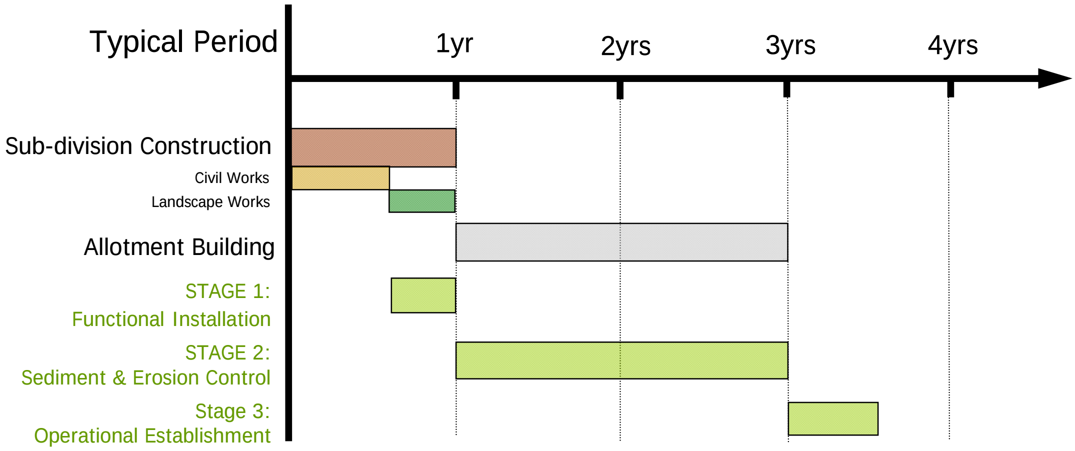


Figure 3-7: Staged Construction and Establishment Method

3.5.1.3 Functional Installation

Functional installation of bioretention swales occurs at the end of Subdivision Construction as part of landscape works and involves:

- Bulking out and trimming
- Installation of the outlet structures
- Placement of liner and installation of drainage layer (i.e. under-drains and drainage layer)
- Placement of filter media
- Placement of a temporary protective layer - Covering the surface of filtration media with geofabric and placement of 25mm 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.

Plate 3-5: Bioretention Swale Functional Installation

- Place silt fences around the boundary of the bioretention swale to exclude silt and restrict access.

3.5.1.4 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. 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.

Plate 3-6: Bioretention Swale Sediment & Erosion Control

3.5.1.5 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 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.

3.5.2 Construction Tolerances

It is important to emphasise the significance of tolerances in the construction of bioretention swales (e.g. profiling of swale and bioretention trench base and surface grades). Ensuring the base of the filtration trench and surface of the bioretention filter media is free from localised depressions resulting from construction is particularly important to achieve even distribution of stormwater flows across the surface and to prevent localised ponding on the surface, which may cause mosquito problems. In addition, to enable the perforated sub-surface drainage pipes to drain freely, the base of the trench should be sloped towards the outlet pit (min 0.5% longitudinal grade). Generally an earthworks tolerance of plus or minus 50 mm is considered acceptable.

3.5.3 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 swale 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 Appendix A 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:

- Viro Tubes — 50 mm wide x 85 mm deep
- 50 mm Tubes — 50 mm wide x 75 mm deep
- Native Tubes — 50 mm wide x 125 mm deep

3.5.4 Vegetation Establishment

The following weed control measures and watering schedule are recommended to ensure successful plant establishment. Regular general maintenance as outlined in Section 3.6 will also be required. October and November are considered the most ideal time 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.

3.5.4.1 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.

3.5.4.2 Watering

Regular watering of bioretention swale vegetation is essential for successful establishment and healthy growth. The frequency of watering to achieve successful plant establishment is dependent upon rainfall, maturity of planting stock and the water holding capacity of the soil. The following watering program is generally adequate but should be adjusted (increased) to suit the site conditions:

- Week 1-2 3 visits/ week
- Week 3-6 2 visits/ week
- Week 7-12 1 visit/ week

After this initial three month period, 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.

3.6 Maintenance Requirements

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.

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

The potential for rilling and erosion down the swale component of the system needs to be carefully monitored during establishment stages of the system. Other components of the system that will require careful consideration are the inlet points (if the system does not have distributed inflows) and surcharge pits, as these inlets can be prone to scour and the build up of litter and sediment. Bioretention swale field inlet pits also require routine inspections to ensure structural integrity and that they are free of blockages with debris. Debris removal is an ongoing maintenance requirement. Debris can block inlets or outlets and can be unsightly, particularly in high visibility areas. Inspection and removal of debris should be done regularly.

Typical maintenance of bioretention swale elements will involve:

- Routine inspection of the swale profile to identify any areas of obvious increased sediment deposition, scouring of the swale invert from storm flows, rill erosion of the swale batters from lateral inflows, damage to the swale profile from vehicles and clogging of the bioretention trench (evident by a 'boggy' swale invert).
- Routine inspection of inlet points (if the swale does not have distributed inflows), surcharge pits and field inlet pits to identify any areas of scour, litter build up and blockages.
- Removal of sediment where it is impeding the conveyance of the swale and/ or smothering the swale vegetation, and if necessary, reprofiling of the swale and revegetating to original design specification.
- Repairing any damage to the swale profile resulting from scour, rill erosion or vehicle damage.
- Tilling of the bioretention trench surface if there is evidence of clogging.
- Clearing of blockages to inlet or outlets.

- Regular watering/ irrigation of vegetation until plants are established and actively growing (see section 3.5.4).
- Mowing of turf or slashing of vegetation (if required) to preserve the optimal design height for the vegetation.
- Removal and management of invasive weeds.
- Removal of plants that have died and replacement with plants of equivalent size and species as detailed in the plant schedule.
- Pruning to remove dead or diseased vegetation material and to stimulate new growth.
- Litter and debris removal.
- Vegetation pest monitoring and control.

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

- Check weir/up-turned pipe is clear of debris.
- Check water level in the saturated zone is at the design level.

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.

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:

- inspection frequency
- maintenance frequency
- data collection/ storage requirements (i.e. during inspections)
- detailed cleanout procedures (main element of the plans) including:
  - equipment needs
  - maintenance techniques
  - occupational health and safety
  - public safety
  - environmental management considerations
  - disposal requirements (of material removed)
  - access issues
  - stakeholder notification requirements
  - data collection requirements (if any)
- design details

An example operation and maintenance inspection form is included in the checking tools provided in Section 3.7.

3.7 Checking Tools

The following sections provide a number of checking aids for designers and Council development assessment officers. In addition, advice on construction techniques and lessons learnt from building bioretention swale systems are provided. Checklists are provided for:

- Design Assessment

- Construction (during and post)
- Operation and Maintenance Inspections
- Asset Transfer (following defects period).

3.7.1 Design Assessment Checklist

The checklist on page 3-35 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.

3.7.2 Construction Checklist

The checklist on page 3-36 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.

3.7.3 Operation and Maintenance Inspection Form

The form on page 3-37 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.

3.7.4 Asset Transfer Checklist

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 on page 3-38 when the asset is to be transferred to the local authority.

BIORETENTION SWALE DESIGN ASSESSMENT CHECKLIST			
Asset I.D.			
Bioretention Location:			
Hydraulics:	Minor Flood (m^2/s):	Major Flood (m^2/s):	
Area:	Catchment Area (ha):	Bioretention Area (m^2):	

TREATMENT	Y	N
Treatment performance verified?		
SWALE COMPONENT	**Y**	**N**
Longitudinal slope of invert >1% and <4%?		
Manning's 'n' selected appropriate for proposed vegetation type?		
Overall flow conveyance system sufficient for design flood event?		
Maximum flood conveyance width does not impact on traffic requirements?		
Overflow pits provided where flow capacity exceeded?		
Energy dissipation provided at inlet points to the swale?		
Velocities within bioretention cells will not cause scour?		
Set down of at least 60mm below kerb invert to top of vegetation incorporated?		
BIORETENTION COMPONENT	**Y**	**N**
Design documents bioretention area and extended detention depth as defined by treatment performance requirements?		
Overflow pit crest set at top of extended detention?		
Maximum ponding depth and velocity will not impact on public safety (v x d <0.4)		
Bioretention media specification includes details of filter media, saturated zone (if required), drainage layer and transition layer (if required)?		
Design saturated hydraulic conductivity included in specification?		
Design of saturated zone included in specification?		
Transition layer provided where drainage layer or saturated zone consists of gravel (rather than coarse sand)?		
Perforated pipe capacity > infiltration capacity of filter media?		
Saturated zone outflow weir/up-turned pipe capacity > infiltration capacity of filter media?		
Selected filter media hydraulic conductivity > 10 x hydraulic conductivity of surrounding soil?		
Maximum spacing of collection pipes <1.5m?		
Collection pipes extended to surface to allow inspection and flushing?		
Liner provided if selected filter media hydraulic conductivity > 10x hydraulic conductivity of surrounding soil?		
Maintenance access provided to invert of conveyance channel?		
LANDSCAPE & VEGETATION	**Y**	**N**
Plant species selected can tolerate periodic inundation and design velocities?		
Bioretention swale landscape design integrates with surrounding natural and/ or built environment?		
Planting design conforms with acceptable sight line and safety requirements?		
Top soils are a minimum depth of 300 mm for plants and 100 mm for turf?		
Existing trees in good condition are investigated for retention?		
Detailed soil specification included in design?		
COMMENTS		

BIORETENTION SWALE CONSTRUCTION INSPECTION CHECKLIST

Asset I.D.		Inspected by:	
Site:		Date:	
		Time:	
Constructed by:		Weather:	
		Contact during site visit:	

Items inspected	Checked		Satisfactory		Items inspected	Checked		Satisfactory	
	Y	N	Y	N		Y	N	Y	N
DURING CONSTRUCTION & ESTABLISHMENT									
A. FUNCTIONAL INSTALLATION					Structural components				
Preliminary Works					17. Location and configuration of inflow systems as designed				
1. Erosion and sediment control plan adopted					18. Location and levels of overflow pits as designed				
2. Temporary traffic/safety control measures					19. Under-drainage connected to overflow pits as designed				
3. Location same as plans					20. Concrete and reinforcement as designed				
4. Site protection from existing flows					21. Set down to correct level for flush kerbs (streetscape applications only)				
Earthworks and Filter Media					22. Kerb opening width as designed				
5. Bed of swale correct shape and slope					23. Level of saturated zone weir/up-turned pipe as designed (if required)				
6. Batter slopes as plans									
7. Dimensions of bioretention area as plans					B. SEDIMENT & EROSION CONTROL (IF REQUIRED)				
8. Confirm surrounding soil type with design					24. Stabilisation immediately following earthworks and planting of terrestrial landscape around basin				
9. Confirm filter media specification in accordance with Step 4					25. Silt fences and traffic control in place				
9. Provision of liner (if required)					26. Temporary protection layers in place				
10. Under-drainage installed as designed									
11. Drainage layer media as designed					C. OPERATIONAL ESTABLISHMENT				
12. Transition layer media as designed (if required)					27. Temporary protection layers and associated silt removed				
14. Extended detention depth as designed					Vegetation				
15. Weir/up-turned pipe is clear of debris (if required)					28. Planting as designed (species and densities)				
16. Water level in saturated zone as designed (if required)					29. Weed removal and watering as required				

FINAL INSPECTION									
1. Confirm levels of inlets and outlets					6. Check for uneven settling of banks				
2. Confirm structural element sizes					7. Under-drainage working				
3. Check batter slopes					8. Inflow systems working				
4. Vegetation as designed					9. Maintenance access provided				
5. Bioretention filter media surface flat and free of clogging									

COMMENTS ON INSPECTION

ACTIONS REQUIRED
1.
2.
3.

Inspection officer signature:

BIORETENTION SWALE MAINTENANCE CHECKLIST			
Asset I.D.			
Inspection Frequency:	1 to 6 monthly	Date of Visit:	
Location:			
Description:			
Site Visit by:			

INSPECTION ITEMS	Y	N	ACTION REQUIRED (DETAILS)
Sediment accumulation at inflow points?			
Litter within swale?			
Erosion at inlet or other key structures (eg crossovers)?			
Traffic damage present?			
Evidence of dumping (eg building waste)?			
Vegetation condition satisfactory (density, weeds etc)?			
Replanting required?			
Mowing required?			
Clogging of drainage points (sediment or debris)?			
Evidence of ponding?			
Set down from kerb still present?			
Damage/vandalism to structures present?			
Surface clogging visible?			
Drainage system inspected?			
Remulching of trees and shrubs required?			
Soil additives or amendments required?			
Pruning and/ or removal of dead or diseased vegetation required?			
Resetting of system required?			
Weir/up-turned pipe is clear of debris (if required)?			
Water level in saturated zone as designed (if required)?			

COMMENTS

BIORETENTION SWALE ASSET TRANSFER CHECKLIST		
Asset I.D.:		
Asset Location:		
Construction by:		
Defects and Liability Period:		
TREATMENT	Y	N
System appears to be working as designed visually?		
No obvious signs of under-performance?		
MAINTENANCE	Y	N
Maintenance plans and indicative maintenance costs provided for each asset?		
Vegetation establishment period completed?		
Inspection and maintenance undertaken as per maintenance plan?		
Inspection and maintenance forms provided?		
ASSET INSPECTED FOR DEFECTS AND/OR MAINTENANCE ISSUES AT TIME OF ASSET TRANSFER		
Sediment accumulation at inflow points?		
Litter within swale?		
Erosion at inlet or other key structures?		
Traffic damage present?		
Evidence of dumping (e.g. building waste)?		
Vegetation condition satisfactory (density, weeds)?		
Watering of vegetation required?		
Replanting required?		
Mowing/slashing required?		
Clogging of drainage points (sediment or debris)?		
Evidence of ponding?		
Damage/vandalism to structures present?		
Surface clogging visible?		
Drainage system inspected?		
Weir/up-turned pipe is clear of debris (if required)?		
Water level in saturated zone as designed (if required)?		
COMMENTS/ACTIONS REQUIRED FOR ASSET TRANSFER		
ASSET INFORMATION	Y	N
Design Assessment Checklist provided?		
As constructed plans provided?		
Copies of all required permits (both construction and operational) submitted?		
Proprietary information provided (if applicable)?		
Digital files (eg drawings, survey, models) provided?		
Asset listed on asset register or database?		

3.8 Engineering Drawings

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, 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 at http://www.brisbane.qld.gov.au/planning-building/planning-building-rules/standard-drawings/index.htm.

3.9 Bioretention Swale Worked Example

Quantitative modelling was undertaken to develop a stormwater quality treatment system for the concept design stage of a new greenfield residential estate. This worked example describes the detailed design of a vegetated swale and bioretention system located in a median separating an arterial road and a local road within the residential estate. The layout of the catchment and bioretention swale is shown in Figure 3-8. A photograph of a similar bioretention swale in a median strip is shown in Plate 3-7.

The site is comprised of the arterial road and a service road separated by a median approximately 6 m wide. The median area offers the opportunity for a local stormwater treatment measure. The area available is relatively large in relation to the catchment; however, it is elongated in shape. The catchment area for the swale and bioretention area includes the road reserve and the adjoining allotment (approximately 35 m in depth and with a fraction impervious of 0.6).

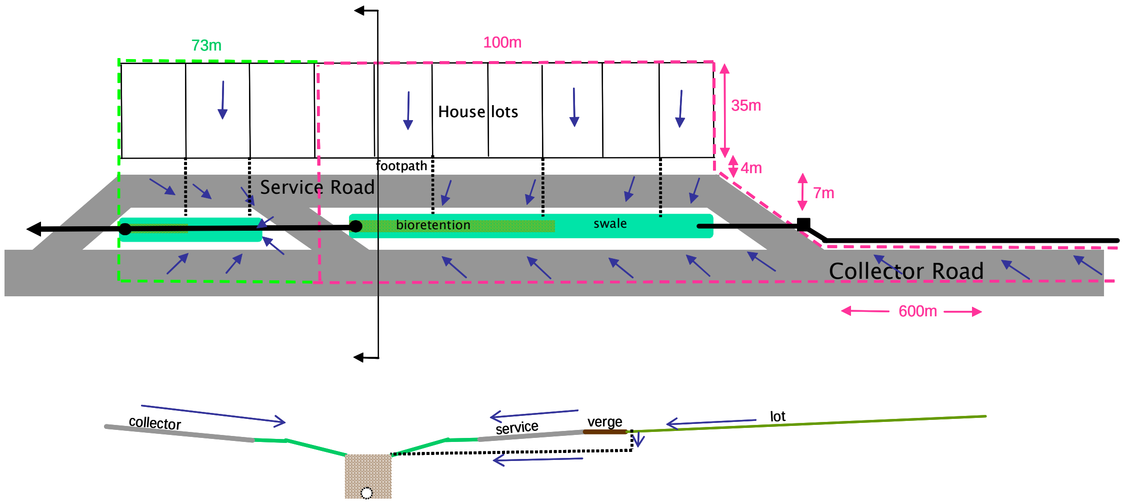


Figure 3-8: Catchment Area Layout and Section for Worked Example

Plate 3-7: Bioretention Swale Located Between a Main Road and Local Road

Three crossings of the median are required and the raised access crossings can be designed as the separation mounds between the swale and bioretention treatment system, thus resulting in a two-cell system. Each bioretention swale cell will treat its individual catchment area. Runoff from the arterial road is conveyed by the conventional kerb and gutter system into a stormwater pipe and discharged into the surface of the swale at the upstream end of each cell. Runoff from the local street can enter the swale as distributed inflow (sheet flow) along the length of the swale.

As runoff flows over the surface of the swale, it receives some pre-treatment and coarse to medium sized particles are trapped by vegetation on the swale surface. During runoff events, flow is temporarily impounded in the bioretention zone at the downstream end of each cell. Filtered runoff is collected via a perforated pipe in the base of the bioretention zone. Flows in excess of the capacity of the filtration medium pass through the swale as surface flow and overflow into the piped drainage system (via inlet pits) at the downstream end of each bioretention cell with a 2 year ARI capacity (the minor storm for the hypothetical worked example).

Quantitative modelling undertaken during the concept design stage found that the area of bioretention to meet the required water quality objectives is approximately 65 m^2 and 25 m^2 for Cell A and B respectively. The filter media saturated hydraulic conductivity derived from the treatment performance modelling was 180 mm/hr based on 200 mm of extended detention and dense plantings of sedges and tufted grasses in the bioretention filter media.

Design Objectives

- Treatment to achieve 75 %, 45 % and 25 % reductions of mean annual loads of TSS, TP and TN respectively, with these reductions having been defined by earlier treatment performance modelling that indicated such standards were required in order for the stormwater treatment train proposed for the site to comply with the relevant local water quality objectives.
- Perforated under-drainage to be designed to ensure that the capacity of the perforated pipes exceeds the saturated hydraulic conductivity of the filter media.
- Design flows up to 2 year ARI range are to be safely conveyed into a piped drainage system with acceptable inundation of the adjacent road.
- The hydraulics for the swale and road system need to be checked to confirm flow capacity for the 2 year and 50 year ARI peak flows, in accordance with the road drainage standards for the local Council.
- Acceptable safety and scouring behaviour for 2 year and 50 year ARI peak flows.
- Integration of the bioretention swale landscape design with the surrounding natural and built environment.

Constraints and Concept Design Criteria

- Depth of the bioretention filter layer shall be a maximum of 600 mm.
- Maximum extended depth allowable is 200 mm.
- Width of median available for siting the system is 6 m.
- The filter media available is a sandy loam top soil stripped from the site and amended by mixing in a loose non-angular sand to achieve the design saturated hydraulic conductivity of 180 mm/hour determined to be the optimal saturated hydraulic conductivity by the treatment performance modelling undertaken at the concept design stage.
- As the site is located in a landscaped area which receives supplemental irrigation to sustain the vegetation, a saturated zone within the bioretention system is not required.

Site Characteristics

- Land use: urban, low density residential
- Overland flow slopes: Cell A and B = 1.3 %
- Soil: Clay
- Fraction impervious, f_i: 0.60 (lots); 0.90 (roads); 0.50 (footpaths); 0.0 (Swale)
- Catchment areas:

	Allotments	Collector road	Local road	Footpath	Swale
Cell A	100 m x 35 m	600 m x 7 m	100 m x 7 m	100 m x 4 m	103 m x 7.5 m
Cell B	73 m x 35 m	73 m x 7 m	73 m x 7 m	73 m x 4 m	44 m x 7.5 m

3.9.1 Step 1: Confirm Treatment Performance of Concept Design

Quantitative modelling of treatment performance with the input parameters below is used to estimate the reduction performance of the bioretention system to ensure the design will achieve target pollution reductions.

- Location is within the Coastal dry Tropics Region
- 200 mm extended detention
- treatment area to catchment area ratio:
  - Cell A: $65\ m^2 / 6710\ m^2 = 0.97\ \%$
  - Cell B: $25\ m^2 / 2599\ m^2 = 0.96\ \%$

From quantitative modelling of treatment performance in the concept design phase, the expected pollutant reductions are 76 %, 59 % and 25 % for TSS, TP and TN respectively, and exceed the design requirements of 75 %, 45 % and 25 %.

3.9.2 Step 2: Estimating Design Flows for Swale Component

With a small catchment, the Rational Method is considered an appropriate approach to estimate peak flow rates. The steps in these calculations follow below.

3.9.2.1 Major and Minor Design Flows

Time of concentration (t_c)

Approach:

Cell A and Cell B are effectively separate elements for the purpose of sizing the swales. Therefore, t_c values are estimated separately for each cell.

- Cell A - the t_c calculations include consideration of runoff from the allotments as well as from gutter and pipe flow along the collector road. Comparison of these travel times concluded the flow along the collector road was the longest and was adopted for t_c.
- Cell B – the t_c calculations include overland flow across the lots and road and swale/ bioretention flow time.

Following procedures in QUDM, the following t_c values are estimated:

- t_c Cell A : 8 mins (5 min inlet time and 3 min pipe flow time (assuming a pipe flow velocity of 3 m/s)
- t_c Cell B: 15 mins (inlet time from QUDM for land with a slope of $< 3\%$)

Design rainfall intensities (refer *Handbook for Drainage: Design Criteria (TCC 2004)*)

Design ARI	Cell A (8 min t_c)	Cell B (15 min t_c)
2	129 mm/hr	101 mm/hr
50	265 mm/hr	208 mm/hr

Design runoff coefficient

- Fraction impervious

Cell A:	Area (m^2)	f_i	Impervious Area (m^2)
Allotments	3500	0.6	2100
Roads	4900	0.9	4410
Footpath	400	0.5	200
Swale	772.5	0.0	-
TOTAL	9572.5	-	6710

Hence effective $f_i = 0.7$

Cell B:	Area (m^2)	f_i	Impervious Area (m^2)
Allotments	2555	0.6	1533
Roads	1022	0.9	919.8
Footpath	292	0.5	1467
Swale	330	0.0	-
TOTAL	4199	-	2599

Hence effective $f_i = 0.62$

- Runoff coefficients, as per QUDM (DNRW, IPWEA & BCC, 2008)

Design ARI	Cell A	Cell B
2	0.70	0.70
50	0.94	0.94

Peak Design flows

- Rational Method

$$Q = CIA/360 \text{ (m}^3\text{/s)}$$

Design ARI	Cell A (m^3/s)	Cell B (m^3/s)
2	0.24	0.08
50	0.66	0.23

3.9.3 Step 3: Dimension the Swale Component

3.9.3.1 Swale Width and Side Slopes

The swale component of Cell A and B need to be sized such that they can convey the 2 year and 50 year ARI flows with acceptable amount of water encroaching on the road. Manning's equation (Equation 3.2) is used with the following parameters. Note the depth of the swale (and hence the side slopes) was determined by the requirement of discharging allotment runoff onto the surface of the bioretention system. The cover requirements of the allotment drainage pipes as they flow under the service road set the surface of the bioretention system. In this example, a Class 4 pipe is adopted and as such requires 300 mm cover. Allowing for this cover, a 100 mm diameter pipe and 100 mm fall with passage across the service road, the surface level of the bioretention systems must be 0.5 m below the edge of road pavement surface level.

The adopted swale dimensions for both Cell A and Cell B were:

- swale base width of 1 m with 1:5 side slopes, max depth of 0.5 m
- moderate vegetation height 200 mm (assume Manning's $n = 0.04$ for flows above vegetation height)
- 1.3% slope

3.9.3.2 Maximum Length of Swale

The approach taken is to first determine the maximum length of the swale component of Cell A and then assume this same maximum length also applies to the swale component of Cell B (which has lower flow rates than Cell A).

To determine the maximum length of swale for the swale component of Cell A, it is necessary to calculate the maximum capacity of the swale using Manning's equation (Equation 3.1) and the design parameters presented above. This equates to:

$Q_{cap} = 2.17 \text{ m}^3/\text{s} >> 0.66 \text{ m}^3/\text{s}$ (Q_{50}) and $0.24 \text{ m}^3/\text{s}$ (Q_2)

Therefore, there is adequate capacity in the swale to convey all flows up to and well in excess of the Q_{50} with no flow required to be conveyed on the adjacent road pavement. This result indicates that the maximum length of swale for the swale component of Cell A (and therefore Cell B) is much longer than the 'actual' length of the swale components of Cell A and B. As such, no additional calculations are required to check flow widths and depths on the adjacent road pavements to confirm compliance with the minor flood and major flood criteria outlined in Section 7.04 of QUDM

Freeboard to adjoining property must also be checked and comply with the relevant local requirements. Given, in this instance, that Q_{50} is contained within the swale, the freeboard requirements are satisfied.

3.9.4 Step 4: Design Inflow Systems to Swale and Bioretention Components

There are two mechanisms for flows to enter the bioretention swale systems Cell A and Cell B. Firstly, underground pipes (either from the upstream road into Cell A or from allotment runoff) and secondly, off road surfaces.

Flush kerbs with a 60 mm set down are intended to be used to allow for sediment accumulation off the road surfaces.

Grouted rock is to be used for scour protection for the pipe outlets into the system. The intention of these is to reduce localised flow velocities to avoid erosion.

3.9.5 Step 5: Design Bioretention Component

3.9.5.1 Select Filter Media Saturated Hydraulic Conductivity and Extended Detention

The calculations undertaken for Steps 2 and 3 show that the dimensions of the swale component are sufficient to satisfy flow conveyance criteria and therefore there is no requirement for the bioretention component's saturated hydraulic conductivity or extended detention depth to be altered from what was determined by the treatment performance modelling undertaken at the concept design stage.

3.9.5.2 Specify the Bioretention Filter Media Characteristics (Filter, Transition and Drainage Layers)

The specification of the filter media and drainage layers requires consideration of the perforated under-drainage system. In this case, a perforated pipe with a slot width of 1.5 mm has been selected, meaning there is a risk that sand (typically 1 mm diameter and less) could wash into the pipe. Therefore, in this case, three layers are to the used, an amended sandy loam as the filter media (600 mm), a coarse sand transition layer (100 mm) and a fine gravel drainage layer (200 mm).

<u>Filter media specifications</u>

The filter media is to be a sandy loam, formed through the procedure documented in Section 3.3.5.2. The filter media will generally meet the following geotechnical requirements:

- saturated hydraulic conductivity of 180 mm/hr determined from appropriate laboratory testing (see section 3.3.5.2)
- less than 5 % organic content, measured in accordance with AS 1289.4.1.1-1997
- pH between 5.5 and 7.5.

<u>Transition layer specifications</u>

Transition layer material shall be coarse sand material. A typical particle size distribution is:

% passing	1.4 mm	100 %
	1.0 mm	80 %
	0.7 mm	44 %
	0.5 mm	8.4 %

<u>Drainage layer specifications</u>

The drainage layer is to be 5 mm screenings.

3.9.5.3 Under Drainage Design and Capacity Checks

<u>Maximum infiltration rate</u>

The maximum infiltration rate reaching the perforated pipe system at the base of the bioretention filter media is estimated by using the hydraulic conductivity of the media and the head above the pipes and applying Darcy's equation (Equation 3.2).

Saturated hydraulic conductivity = 180 mm/hr

Flow capacity of the infiltration media = (1-ϒ). As k_h – (Engineers Australia 2006)

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

$$Q_{max} = 5 \times 10^{-5} \cdot L \cdot W_{base} \cdot \frac{0.2 + 0.6}{0.6}$$

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

Maximum infiltration rate Cell A = 0.004 m^3/s

Maximum infiltration rate Cell B = 0.001 m^3/s

Perforations inflow check

Estimate the inlet capacity of sub-surface drainage system to ensure it is not a choke in the system. As a conservative approach, it is assumed that 50 % of the holes are blocked. A standard perforated pipe was selected that is widely available. To estimate the flow rate, an orifice equation (Equation 3.3) is applied using the following parameters:

Head above pipe (h)= 0.95 m [0.6 m (filter depth) + 0.1m (transition) + 0.1 (half drainage layer) + 0.2 m (max. pond level) + 0.05 (half of pipe diameter)]

Assume sub-surface drains with half of all pipes blocked.

Clear Opening	= 2100 mm^2/m, hence blocked openings
	= 1050 mm^2/m (50%)
Slot Width	= 1.5 mm
Slot Length	= 7.5 mm
Number of Rows	= 6
Diameter	= 100 mm

Number of slots per metre = (1050)/(1.5x7.5) = 93.3

Assume orifice flow conditions:

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

Where C_d = 0.61 (Assume slot width acts as a sharp edged orifice).

Note: Blockage Factor B (=0.5) has already been accounted for in the 'Clear Opening' calculation above

Inlet capacity /m of pipe:

$$Q_{perf} = [0.61 \times (0.0015 \times 0.0075)\sqrt{2 \times 9.81 \times 1.05}] \times 93.3$$

$$= 0.0029 \text{ m}^3/\text{s}$$

Inlet capacity/m x total length:

Cell A = 0.0029 x 61 = 0.18 m^3/s > 0.004 L/s (max infiltration rate), hence one pipe has sufficient perforation capacity to pass flows into the perforated pipe.

Cell B = 0.0029 x 22 = 0.06 m^3/s > 0.0014 L/s (max infiltration rate), hence one pipe is sufficient.

<u>Check perforated pipe capacity</u>

Manning's equation is applied to estimate the flow rate in the perforated pipe. A slope of 0.5 % is assumed and a 100 mm perforated pipe (as above) with Manning's *n* of 0.02 was used. Should the capacity not be sufficient, either a second pipe could be used or a steeper slope. The capacity of this pipe needs to exceed the maximum infiltration rate.

Estimate applying Manning's Equation:

Q = 0.0024 m^3/s

Therefore, will need two pipes for Cell A (0.004 m^3/s max. infiltration rate) and one pipe for Cell B (0.001 m^3/s max. infiltration rate).

<u>Check drainage layer hydraulic conductivity</u>

Typically, flexible perforated pipes are installed using fine gravel media to surround them. In this worked example, 5 mm gravel is specified for the drainage layer. This media is much coarser than the filtration media (sandy loam) therefore, to reduce the risk of washing the filtration layer into the perforated pipe, a transition layer is to be used. This is to be 100 mm of coarse sand as specified in previous sections.

3.9.5.4 Impervious Liner Requirement

In this catchment, the surrounding soils are clay to silty clays with a saturated hydraulic conductivity of approximately 3.6 mm/hr. The sandy loam media that is proposed as the filter media has a hydraulic conductivity of 180 mm/hr. Therefore, the conductivity of the filter media is greater than 10 times the conductivity of the surrounding soils and an impervious liner is not required.

3.9.6 Step 6: Verification Checks

3.9.6.1 Vegetation Scour Velocity Check

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

- Less than 0.5 m/s for minor flood (2 year ARI) discharge.
- Less than 2.0 m/s for major flood (50 year ARI) discharge.

Using Manning's equation to solve for depth for Q_2 and Q_{50} in Cell A gives the following results. Note, Manning's *n* used for Q_2 = 0.1 (flow below vegetation height) and for Q_{50} = 0.04 (flow above vegetation height) (Refer to Figure 3-3).

Q_2 = 0.24 m^3/s, velocity = 0.36 m/s < 0.5 m/s – therefore OK

Q_{50} = 0.66 m^3/s, velocity = 0.91 m/s < 2.0 m/s – therefore OK

Hence, the swale can satisfactorily convey the peak 2 year and 50 year ARI flood flows with minimal risk of vegetation scour.

3.9.6.2 Safety Velocity Check

The maximium velocity-depth product will be at the end of the swale in Cell A, as it is on a grade (the bioretention area is flat) and has the highest flow rate in a major storm design event of the two swales.

Check velocity *(V)* x depth *(d)* product in Cell A during peak 50 year ARI flow for pedestrian safety criteria.

V = 0.91 m/s

d = 0.29 m

$V \times d = 0.91 \times 0.32 = 0.27 < 0.6\ m^2/s$

Therefore, velocities and depths are OK.

3.9.7 Step 7: Overflow Pit Design

The overflow pits are required to convey 2 year ARI flows safely from the bioretention systems and into an underground pipe network. Grated pits are to be used at the downstream end of each bioretention system.

The sizes of the pits are calculated using a broad crested weir equation (Equation 3.4) with the height above the maximum ponding depth and below the road surface, less freeboard (i.e. 0.76 – (0.2 + 0.15) = 0.41 m).

First check using a broad crested weir equation (refer Section 7.05.4 from QUDM (DNRW, IPWEA & BCC 1998) and Equation 3.4):

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

Where B = Blockage factor (= 0.5)

C_w = Weir coefficient (= 1.66)

L = required length of weir (pit perimeter) (m)

h = Flow depth above the weir (0.41 m)

Solving for L gives L = 1.1 m of weir length required (equivalent to 300 x 300 mm pit).

Now check for drowned conditions (Equation 3.5):

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

with C_d = 0.6 and h = 0.41 m we have:

$$0.24 = 0.6 \times A\sqrt{2 \times 9.81 \times 0.41}$$

Gives $A = 0.14\ m^2$ (equivalent to 400 x 400 mm pit)

Hence, drowned outlet flow conditions dominate, a minimum pit size of 400 x 400 mm is required for both Cell A and Cell B. The minimum pit size to allow underdrainage pipe connections of 600 x 600 mm is adopted for both Cell A and Cell B.

3.9.8 Step 8: Allowances to Preclude Traffic on Swales

Traffic control is achieved by using traffic bollards.

3.9.9 Step 9: Vegetation Specification

To compliment the landscape design of the area a mix of tufted grass and sedges is to be used. For this application, species with the average height of 200 mm have been proposed. The actual species to be planted will be selected by the landscape designer.

3.9.10 Step 10: Maintenance Plan

A maintenance plan for Swales 1 and 2 is to be prepared in accordance with local authority requirements and the recommendation in Section 3.5.

3.9.11 Calculation summary

The sheet below summarises the results of the design calculations.

BIORETENTION SWALES DESIGN CALCULATION SUMMARY

	Calculation Task		Outcome (CALCULATION SUMMARY)		Check
	Catchment Characteristics				
		Catchment Area	0.671	Ha	✓
		Catchment Land Use (i.e. residential, Commercial etc.)	Res		
	Conceptual Design				
		Bioretention area	65	m^2	✓
		Filter media saturated hydraulic conductivity	180	mm/hr	
		Extended detention depth	200	mm	
1	Confirm Treatment Performance of Concept Design				
		Bioretention area to achieve water quality objectives	0.97	m^2	✓
		TSS Removal	76	%	
		TP Removal	59	%	
		TN Removal	25	%	
2	Estimate Design Flows for Swale Component				
		Time of concentration – QUDM or relevant local government guideline	8	minutes	✓
	Identify Rainfall intensities				
		$I_{2\ year\ ARI}$	129	mm/hr	✓
		$I_{50\ year\ ARI}$	265	mm/hr	
	Design Runoff Coefficient				
		$C_{2\ year\ ARI}$	0.70		✓
		$C_{50\ year\ ARI}$	0.94		
	Peak Design Flows				
		2 year ARI	0.24	m^3/s	✓
		50 year ARI	0.66	m^3/s	
3	Dimension the Swale Component				
	Swale Width and Side Slopes				
		Base Width	1	m	✓
		Side Slopes – 1 in	5		
		Longitudinal Slope	1.3	%	
		Vegetation Height	200	mm	
	Maximum Length of Swale				
		Manning's *n*	0.04		✓
		Swale Capacity	2.17		
		Maximum Length of Swale	Yes		
4	Design Inflow Systems to Swale & Bioretention Components				
		Swale Kerb Type	Flush		✓
		Adequate Erosion and Scour Protection (where required)	N/A		
5	Design Bioretention Component				
		Filter media hydraulic conductivity	180	mm/hr	
		Extended detention depth	200	mm	
		Filter media depth	600	mm	
		Saturated zone required			×
		Saturated zone depth	N/A	mm	
		Drainage layer media (sand or fine screenings)	Fine screenings		✓
		Drainage layer depth	200	mm	
		Transition layer (sand) required	Yes		
		Transition layer depth	100	mm	
	Under-drain Design and Capacity Checks				
		Flow capacity of filter media (maximum infiltration rate)	0.004	m^3/s	✓
		Perforations inflow check	Yes		
		Pipe diameter	100	mm	✓
		Number of pipes	2		
		Capacity of perforations	0.15	m^3/s	
		CHECK PERFORATION CAPACITY > FILTER MEDIA CAPACITY	Yes		
		CHECK SATURATED ZONE WEIR/UP-TURNED PIPE CAPACITY > FILTER MEDIA CAPACITY	N/A		
	Perforated pipe capacity				
		Pipe capacity	0.0024x2	m^3/s	✓
		CHECK PIPE CAPACITY > FILTER MEDIA CAPACITY	Yes		
		Check requirement for impermeable lining			
		Soil hydraulic conductivity	180	mm/hr	✓
		Filter media hydraulic conductivity	3.6 (clay)	mm/hr	
		MORE THAN 10 TIMES HIGHER THAN IN-SITU SOILS?	Yes		
5	Verification Checks				
		Velocity for 2 year ARI flow (< 0.5 m/s)	0.36	m/s	✓
		Velocity for 50 year ARI flow (< 2 m/s)	0.91	m/s	
		Velocity x Depth for 50 year ARI (< 0.4 m^2/s)	0.27	m^2/s	
		Treatment Performance consistent with Step 1	Yes		
6	Overflow Pit Design				
		System to convey minor floods	400x400	L x W	✓

3.10 References

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