Bioretention Basins

Chapter 5

5.1 Introduction

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

Bioretention basins operate by filtering stormwater runoff through densely planted surface vegetation and then percolating runoff through a prescribed filter media. During percolation, pollutants are retained through fine filtration, adsorption and some biological uptake. The vegetation in a bioretention system is a vital functional element of the system providing a substrate for biofilm growth within the upper layer of the filter media. Vegetation facilitates the transport of oxygen to the soil and enhances soil microbial communities which enhance biological transformation of pollutants.

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

Bioretention basins can be installed at various scales, for example, as landscape planter boxes, in streetscapes integrated with traffic calming measures, in suburban parks and in retarding basins. In larger applications, it is considered good practice to have pretreatment measures (e.g. swales) upstream of the basin to reduce the maintenance frequency of the bioretention basin. Figure 5-1 shows examples of a basin integrated into a local streetscape and into a car park. Figure 5-1 also illustrates the key elements of bioretention basins, namely surface vegetation, extended detention, filter media, drainage layer and overflow pit.

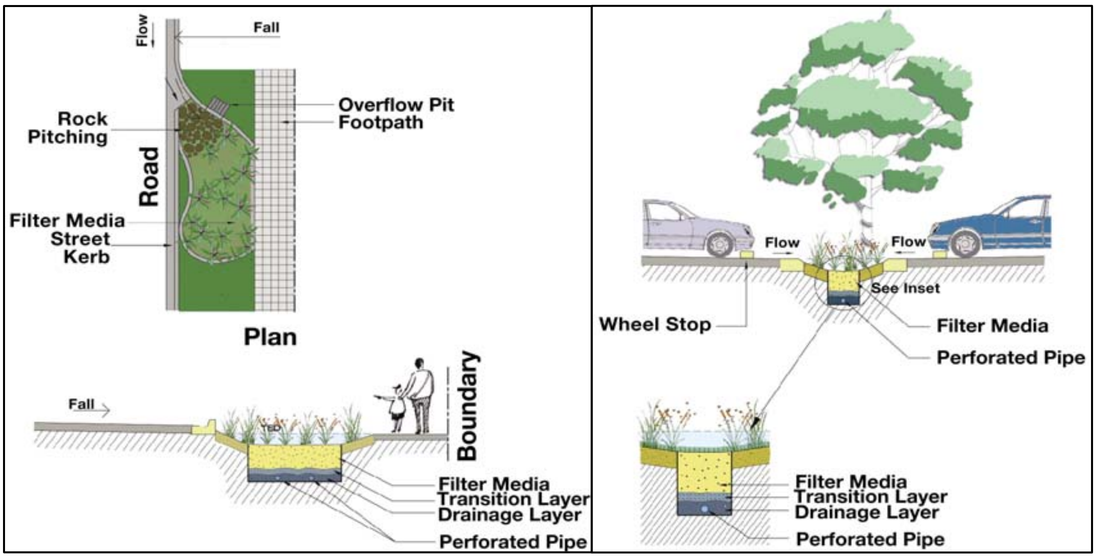


Figure 5-1: Bioretention basin integrated into a local streetscape (left) and a car park (right). (TED = top of extended detention)

5.2 Design Considerations

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

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

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

5.2.1 Landscape Design

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

Plate 5-1: Bioretention basin within roundabout at Kalynda Chase Development, Bohle Plains

5.2.2 Hydraulic Design

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

- The finished surface of the bioretention filter media must be horizontal (i.e. flat) to ensure even flow dispersion across the filter media surface (i.e. full engagement of the filter media by stormwater flows) and to prevent concentration of stormwater flows within depressions and ruts resulting in potential scour and damage to the filter media.
- Temporary ponding (i.e. extended detention) of up to 0.3 m depth over the surface of the bioretention filter media created through the use of raised field inlet pits (overflow pits) can assist in managing flow velocities over the surface of the filter media as well as increase the overall volume of stormwater runoff that can be treated by the bioretention filter media.
- Where possible, the overflow pit or bypass channel should be located near the inflow zone (refer to Figure 5-1(left)) to prevent high flows passing over the surface of the filter media. If this is not possible, then velocities during the minor (2-10 year ARI) and major (50-100 year ARI) floods should be maintained sufficiently low (preferably below values of 0.5 m/s and not more than 1.5 m/s for major flood) to avoid scouring of the filter media and vegetation.
- Where the field inlets in a bioretention system is required to convey the minor storm flow (i.e. is part of the minor drainage system), the inlet must be designed to avoid blockage, flow conveyance and public safety issues.
- For streetscape applications, the design of the inflow to the bioretention basin must ensure the kerb and channel flow requirements are preserved as specified in the Queensland Urban Drainage Manual (QUDM) (DNRW, IPWEA & BCC 1998)

5.2.3 Ex-filtration to In-Situ Soils

Bioretention basins can be designed to either preclude or promote ex-filtration of treated stormwater to the surrounding in-situ soils depending on the overall stormwater management objectives established for the given project. When considering ex-filtration to surrounding soils, the designer must consider site terrain, hydraulic conductivity of the in-situ soil, groundwater and building setback. 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 basin needs to be provided with an impermeable liner. The amount of water lost from bioretention basins 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 5.2.5). 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. shallow groundwater or close proximity to significant structures).

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

The greatest pathway of ex-filtration is through the base of a bioretention basin, as gravity and the difference in hydraulic conductivity between the filter media and the surrounding native soil would typically act to minimise ex-filtration through the walls of the trench. If lining is required, it is likely that only the base and the sides of the *drainage layer* (refer Section 5.2.5) will need to be lined.

Where ex-filtration of treated stormwater to the surrounding in-situ soils is promoted by the bioretention basin 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 basins promoting ex-filtration do not require perforated under-drains at the base of the filter media or a drainage layer (refer to Section 5.2.5).

5.2.4 Vegetation Types

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

Plate 5.2 : Established Vegetation

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

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

Appendix A provides more specific guidance on the selection of appropriate vegetation for bioretention basins. It should be noted that turf is not considered to be suitable vegetation for bioretention basins. The stem and root structure of turf is not suitably robust and rapid growing to ensure the surface of the bioretention filter media is continuously broken up to prevent clogging.

5.2.5 Bioretention Filter Media

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

- Saturated hydraulic conductivity required to optimise the treatment performance of the bioretention basin given site constraints and available filter media area.
- Depth of extended detention provided above the filter media.
- Surface area of the filter media
- Suitability as a growing media to support vegetation (i.e. retains sufficient soil moisture and organic content).

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

As shown in Figure 5-2 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.

5.2.6 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 (see Figure 5-2 below). The saturated zone holds water and therefore provides a source of water to maintain soil moisture for plant uptake during dry periods.

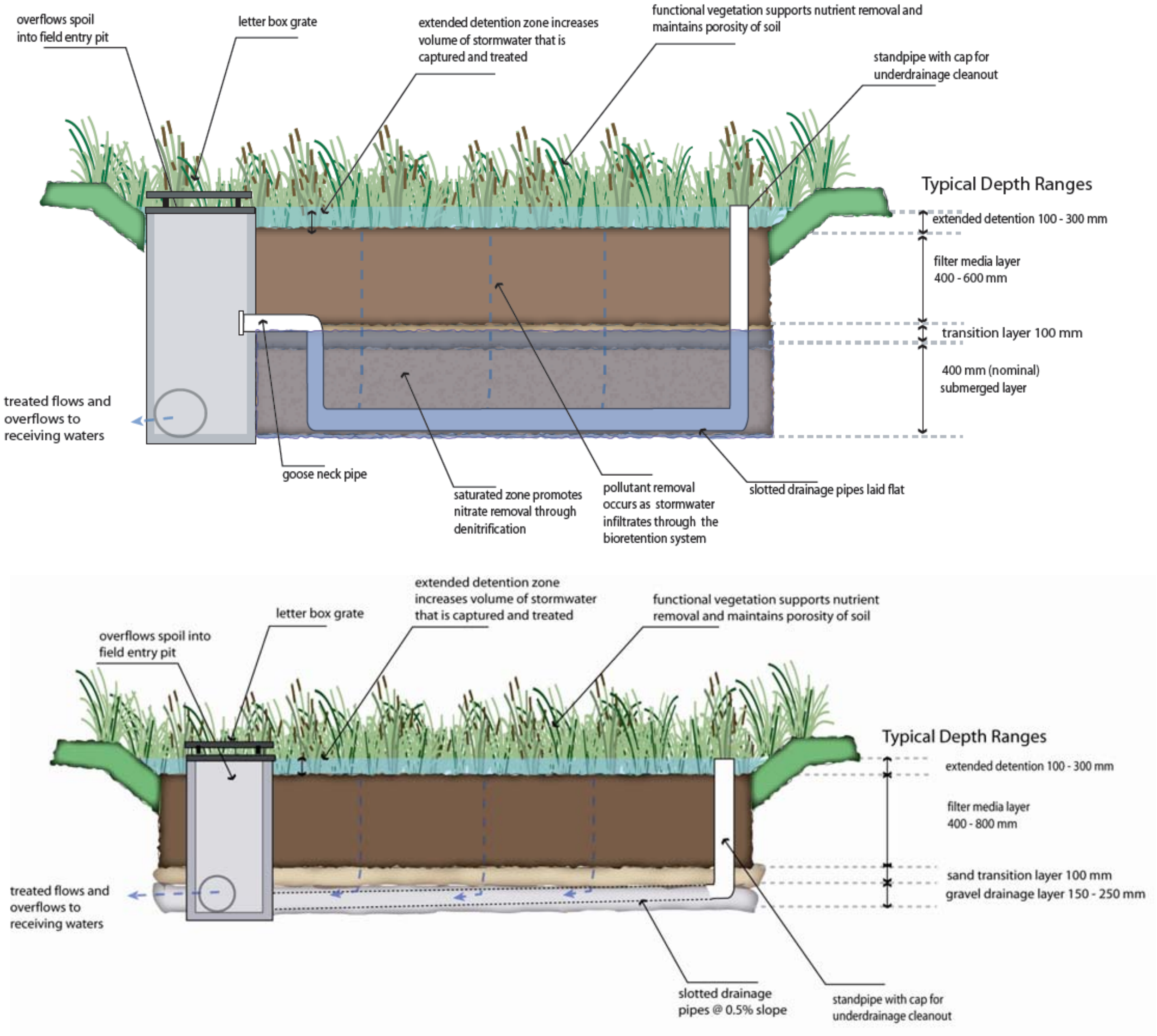


Figure 5-2: Cross Section of Bioretention Basins (top- with a saturated zone; below- without a saturated zone)

5.2.7 Traffic Controls

Another design consideration is keeping traffic and building material deliveries off bioretention basins (particularly during the construction phase of a development). If bioretention basins are driven over or used for parking, the filter media will become compacted and the vegetation damaged. As they can cause filter media blockages, building materials and wash down wastes should also be kept out of the bioretention basin. To prevent vehicles driving on bioretention basins, and inadvertent placement of building materials, it is necessary to consider appropriate traffic control solutions as part of the design. These can include dense vegetation planting that will discourage the movement of vehicles onto the bioretention basin or providing physical barriers such as bollards and/ or tree planting.

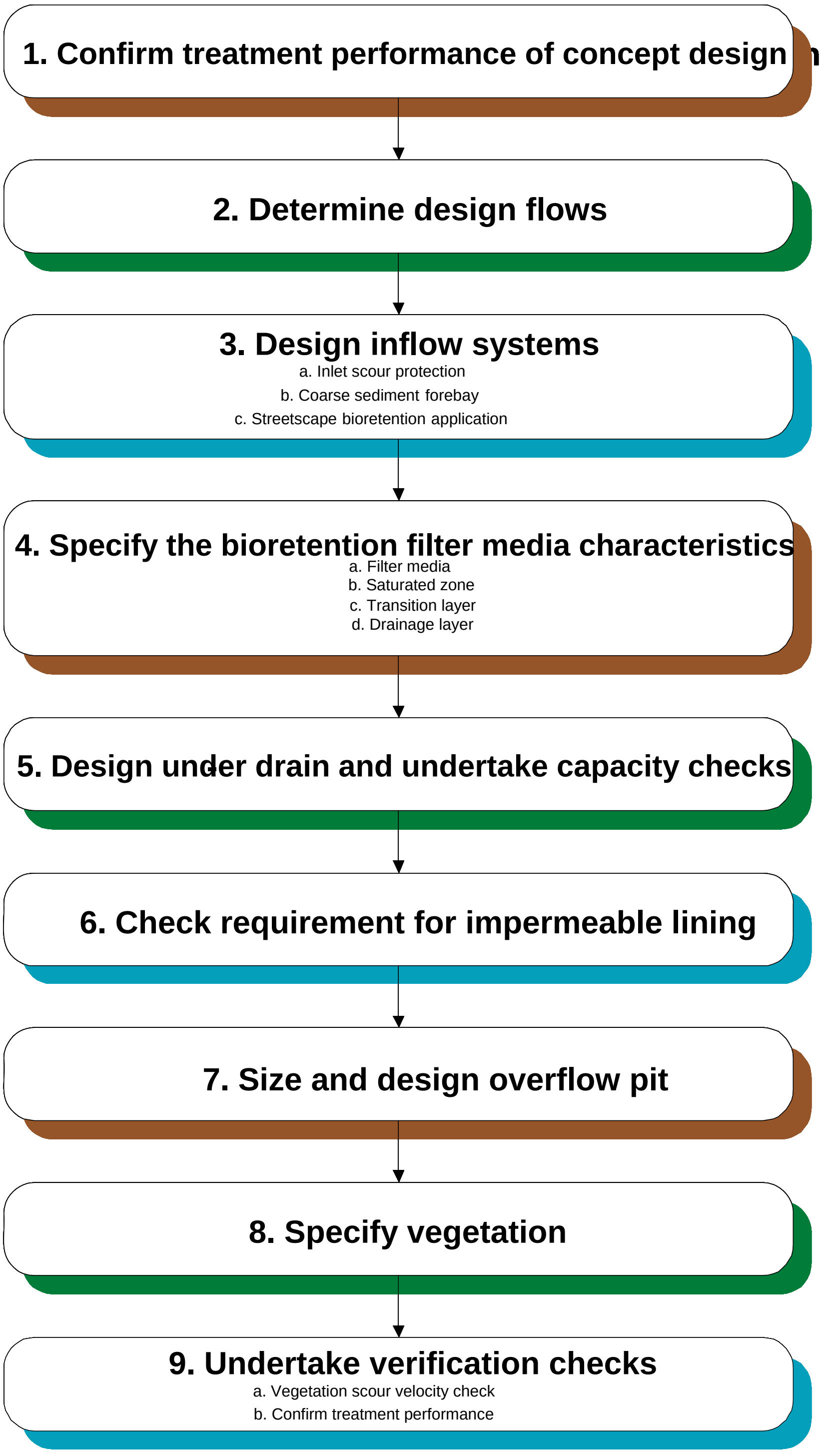
Streetscape bioretention systems must be designed to satisfy local authority requirements with respect to traffic calming devices within particular street or road reserve widths. Where bioretention is incorporated into traffic calming or control devices, or directly adjacent to mountable kerbs, consideration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

5.2.8 Services

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

5.3 Design Process

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



5.3.1 Step 1: Check Treatment Performance of Concept Design

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

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

5.3.2 Step 2: Determine Design Flows

5.3.2.1 Design Flows

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

- 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.

5.3.2.2 Design Flow Estimation

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

5.3.3 Step 3: Design Inflow Systems

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

- Scour protection – In most bioretention applications stormwater flows will enter the bioretention basin as concentrated flow (piped, channel or open channel) and as such is it important to slow and spread flows using appropriate scour (rock) protection.
- Coarse sediment forebay – Where stormwater runoff from the catchment is delivered directly to the bioretention basin without any coarse sediment management (through vegetated swale or buffer treatment) a coarse sediment forebay is to be included in the design. The forebay is to remove coarse sediment (1mm +) from stormwater to minimise the risk of vegetation in the bioretention basin being smothered.
- Street hydraulics (streetscape applications only) – In streetscape applications, where stormwater is delivered directly from the kerb and channel to the bioretention basin, it is important to ensure the location and width of the kerb opening is designed such that flows enter the bioretention basin without adversely affecting trafficability of the road (QUDM, Table 7.04.1).

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

5.3.3.1 Inlet Scour Protection

Erosion protection should be provided for concentrated inflows to a bioretention basin. Typically, flows will enter the bioretention basin from either a surface flow system (i.e. roadside kerb, open channel) or a piped drainage system. Rock beaching is a simple method for dissipating the energy of concentrated inflow. Where the bioretention basin is receiving stormwater flows from a piped system (i.e. from larger catchments), the use of impact type energy dissipation may be required to prevent scour of the filter media. In most cases this can be achieved with rock protection and by placing several large rocks in the flow path to reduce velocities and spread flows as depicted in Figure 5-3 (with the 'D' representing the pipe diameter dimension). The rocks can form part of the landscape design of the bioretention component.

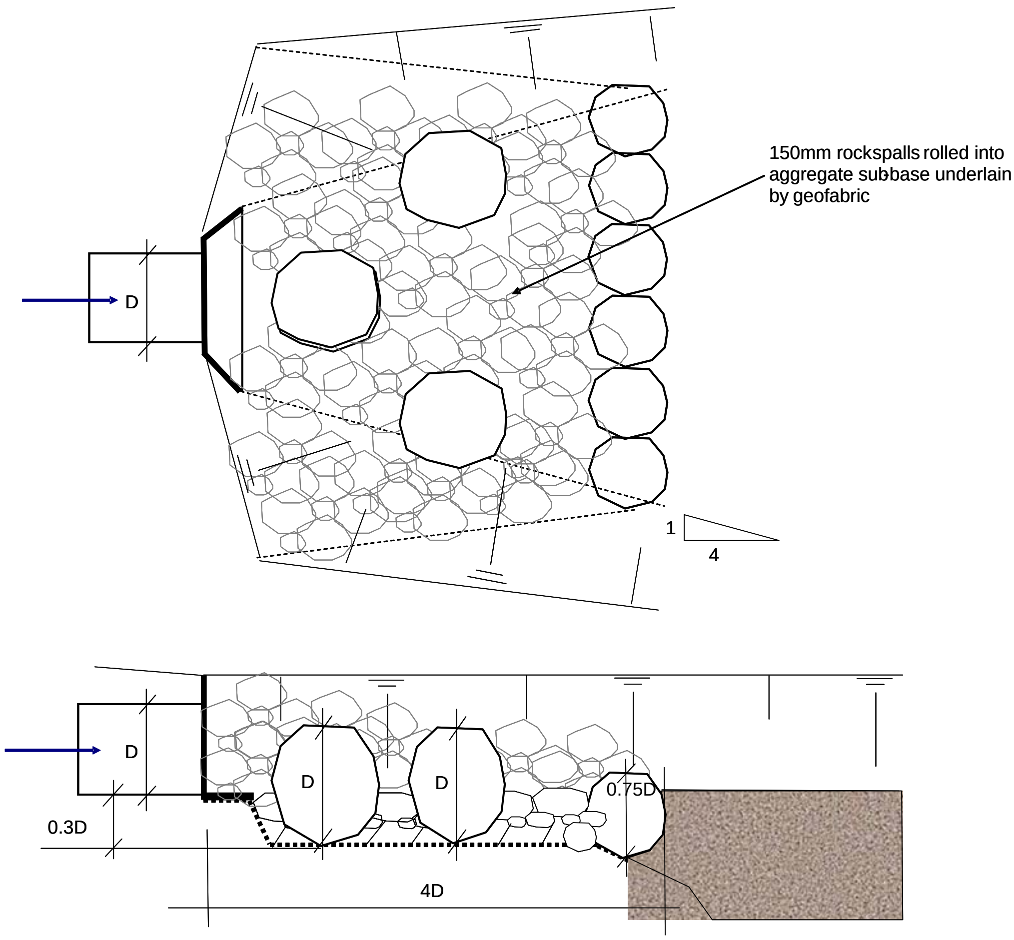


Figure 5-3: Typical Inlet Scour Protection Detail for Bioretention Basins Receiving Piped Flows

5.3.3.2 Coarse Sediment Control

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

- Remove particles that are 1mm or greater in diameter from the 3 month ARI storm event.
- Provide appropriate storage for coarse sediment to ensure desilting is required no more than once per year.

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

$$V_s = A_c \cdot R \cdot L_o \cdot F_c \qquad \text{Equation 5.1}$$

Where V_s = volume of forebay sediment storage required (m^3)

A_c = contributing catchment area (ha)

R = capture efficiency (assume 80 %)

L_o = sediment loading rate (m^3/ha/year)

F_c = desired cleanout frequency (years)

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

$$A_s = \frac{V_s}{D_s}$$ Equation 5.2

Where *D* = depth of sediment forebay (max 0.3m below filter media surface)

The sediment forebay area should be checked to ensure it captures the 1mm and greater particles using the following expression (modified version of Fair and Geyer (1954)):

$$R = 1 - \left[1 + \frac{1}{n} \cdot \frac{v_s}{Q/A}\right]^{-n}$$ Equation 5.3

Where:

R = fraction of target sediment removed (80 %)

v_s = settling velocity of target sediment (100 mm/s or 0.1 m/s for 1 mm particle)

Q/A = applied flow rate divided by 'forebay' surface area ($m^3/s/m^2$)

n = turbulence or short-circuiting parameter (adopt 0.5)

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

5.3.3.3 Kerb Opening Configuration (Streetscape Applications)

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

- The location of the kerb opening must be designed to ensure flows in the channel do not exceed the maximum allowance widths as defined by QUDM Table 7.04.1 (DNRW, IPWEA & BCC 1998) and the relevant local authority requirements.
- The width of the kerb opening is designed to allow the design flow to enter the bioretention basin.

<u>Channel flow width at kerb opening</u>

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

<u>Design kerb opening width (where kerb and channel is used)</u>

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

$$Q = C_w \cdot L \cdot h^{3/2}$$ Equation 5.4

Where *Q* = flow (m^3/s)

C_w = weir coefficient (= 1.66)

L = length of opening (m)

h = depth of flow (m)

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

5.3.4 Step 4: Specify the Bioretention Filter Media Characteristics

Up to four types of media are required in bioretention basins (refer Figure 5.2).

5.3.4.1 Filter Media

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

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

- Organic carbon levels < 5%
- pH between 5.5 and 7.5.
- Electrical conductivity < 1.2 dS/m
- Saturated hydraulic conductivity between 100-500 mm/hr. The saturated hydraulic conductivity of the filter media is established by optimising the treatment performance of the bioretention system given site constraints of the particular site (using a continuous simulation model such as MUSIC).
- The filter media must also be structurally sound and not prone to structural collapse as this can result in a significant reduction in saturated hydraulic conductivity. The risk of structural collapse can be reduced by ensuring the soil has a well graded particle size distribution with a combined clay and silt fraction of < 3%.

5.3.4.2 Transition Layer (if required)

The purpose of the transition layer is to prevent the filter media from migrating down into the drainage layer (or the saturated zone). It also acts as a buffer between the permanently saturated zone (if required) and the filter media. This buffer is necessary to ensure the filter media is not saturated for prolonged periods during rainfall events due to increases in water levels in the saturated zone. To 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 the saturated zone) is more than one order of magnitude. If a transition layer is required then the material must be a clean, well-graded sand/coarse sand material containing little or no fines.

The transition layer is recommended to be 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 (or saturated zone particles) 'bridging' with the smallest 15% of the sand particles. This results in smaller voids, which prevent the migration of the filter media particles into the sand particles. The following equation is taken from the United States Golf Association's recommendations for golf course construction:

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

The addition of a transition layer increases the overall depth of the bioretention system and may be an important consideration for some sites where total depth of the bioretention system may be constrained. In such cases, the use of a sand drainage layer and/ or perforated pipes with smaller slot sizes may need to be considered (Section 5.3.5).

5.3.4.3 Saturated Layer (if required)

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.

5.3.4.4 Drainage Layer (if required)

The drainage layer is used to convey treated flows from the base of the filter media layer (or the saturated zone) into the perforated under-drainage system. The composition of the drainage layer is to be considered in conjunction with the selection and design of the perforated under-drainage pipes (refer to Section 5.3.5) as the slot sizes in the perforated pipes may determine the minimum drainage layer particle size to avoid washout of the drainage layer into the perforated pipe system. Coarser material (e.g. fine gravel aggregate) is to be used for the drainage layer if the slot sizes in the perforated pipes are too large for use of a sand based drainage layer. The drainage layer is to provide a minimum of 50mm cover above the perforated under-drainage pipes and have a minimum saturated hydraulic conductivity of 1000mm/hr.

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

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

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

5.3.5 Step 5: Design Under-Drain and Undertake Capacity Checks (if required)

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

In bioretention systems without saturated zones, perforated pipes are to grade at a minimum of 0.5% towards the overflow pit to ensure effective drainage. This is best achieved by grading the base of the bioretention system towards the pit and placing the perforated pipes (and the drainage layer) on this grade. In bioretention systems with saturated zones, perforated pipes should be laid flat (i.e. at 0% grade) to avoid preferential flow paths forming vertically through the filter media closer to the outlet.

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

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

- Ensure the slots in the pipes are not so large that sediment will freely flow into the pipes from the drainage layer. This is also a consideration when specifying drainage layer media.
- Minimise the potential for tree roots to enter the pipes in search of water. Generally, this is only a concern when the filter media has a low water holding capacity, or trees are planted in filter media whose depth is too shallow. In general, trees are not recommended if the filter media depth is less than 800 mm. Flexible 'ribbed' pipes are more likely, than PVC pipes, to retain 'beads' of moisture due to the small corrugations on the inside of the pipe. Therefore, a smooth surface perforated/slotted pipe system is recommended for use in bioretention basins exhibiting any of these characteristics.

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

- Ensure the perforations are adequate to pass the maximum filtration rate.
- Ensure the pipe itself has sufficient capacity.
- Ensure that the material in the drainage layer will not be washed into the perforated pipes (consider a transition layer).

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

$$Q_{max} = K_{sat} \cdot L \cdot W_{base} \cdot \frac{h_{max} + d}{d}$$ Equation 5.5

Where Q_{max} = maximum filtration rate (m^3/s)

K_{sat} = saturated 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 filtration rate to ensure the filter media drains freely and 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 rather than the perforated under-drainage system).

To ensure the perforated under-drainage system has sufficient capacity to collect and convey the maximum filtration rate, it is necessary to determine the capacity for flows to enter the under-drainage system via the perforations in the pipes. To do this, orifice flow can be assumed and the sharp edged orifice equation used. 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, with the maximum driving head being the depth of the filter media if no extended detention is provided. If extended detention is provided in the design, then the maximum driving head is to the top of extended detention depth. It is conservative, but reasonable to use a blockage factor to account for partial blockage of the perforations by the drainage layer media. A 50% blockage of the perforations should be used.

The flow capacity of the perforations is thus:

$$Q_{perf} = B \cdot C_d \cdot A\sqrt{2 \cdot g \cdot h}$$ Equation 5.6

Where Q_{perf} = flow through perforations (m^3/s)

C_d = orifice discharge coefficient (0.6)

A = total area of the orifice (m^2)

g = gravity (9.80665 m/s^2)

h = maximum depth of water above the pipe (m)

B = blockage factor (0.5)

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

After confirming the capacity of the under-drainage system to collect the maximum filtration rate, it is necessary to confirm the conveyance capacity of the underdrainage system is sufficient to convey the collected runoff. To do this, Manning's equation can be used (which assumes pipe full flow but not under pressure). The Manning's roughness used will be dependant on the type of pipe used (refer to QUDM Table 7.16.3 (DNRW, IPWEA & BCC 1998)). When a saturated zone is incorporated into the design, the underdrainage pipes are laid flat however the conveyance capacity can be calculated using the Manning's equation with an assumed friction slope of 0.5%.

Under-drains should be extended vertically to the surface of the bioretention system to allow inspection and maintenance when required. The vertical section of the under-drain should be unperforated and capped to avoid short-circuiting of flows directly to the drain. Reference is made to the drawings following the worked example (Section 5.9) for further guidance.

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

5.3.6 Step 6: Check Requirement for Impermeable Lining

The saturated hydraulic conductivity of the natural soil profile surrounding the bioretention system should be tested together with depth to groundwater, chemical composition and proximity to structures and other infrastructure. This is to establish if an impermeable liner is required at the base (only for systems designed to preclude ex-filtration to in-situ soils) and/or sides of the bioretention basin (refer also to discussion in Section 5.2.3). 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. Bioretention systems constructed in sodic soils do not require a impermeable liner as they are not at risk of exporting salt from the in-situ soil (Deletic and Mudd, 2006).

5.3.7 Step 7: Size Overflow Pit

The intention of the overflow pit design is to safely convey the minor floods to the same level of protection that a conventional stormwater system would provide. Bioretention basins are typically served with either grated overflow pits or conventional side entry pits located downstream of an inlet. The location of the overflow pit is variable but must ensure that above design flows do not pass through the length of the bioretention system.

In bioretention basins, the overflow pit is designed with the pit crest raised above the level of the bioretention filter media, to establish the design extended detention depth (i.e. maximum ponding depth). Typically, grated pits are used. 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 minimum freeboard requirements as defined in the *QUDM* and the relevant Council design guidelines. Depending on the location of the bioretention basin, the design flow to be used to size the overflow pit could be the minor flood flow (streetscape) or the major flood flow. There should be a minimum of 50 mm head over the overflow pit crest to facilitate discharge of the design flow into the overflow pit.

In streetscape bioretention applications, a level of conservatism is built into the design of grated overflow pits by placing their inverts at least 50 mm below the invert of the street channel (and therefore setting the maximum ponding depth). The head over the overflow pit crest is the sum of the 50 mm and the maximum ponding in the street channel under the minor storm (see Section 5.3.3.3). The overflow pit can be located near the inflow zone, and where designed for the minor storm, may be used in lieu of a traditional road gully pit. The overflow pit can also be external to the bioretention basin, potentially in the kerb and channel immediately downstream of the inlet to the basin in streetscape applications. In this way, the overflow pit can operate in the same way as a conventional side entry pit, with flows entering the pit only when the bioretention basin is at maximum ponding depth.

To size an overflow pit, two checks must be made to test for either drowned or free flowing conditions. A broad crested weir equation can be used to determine the length of weir required (assuming free flowing conditions) and an orifice equation used to estimate the area between openings required in the grate cover (assuming drowned outlet conditions). The larger of the two pit configurations should be adopted (as per Section 7.05 QUDM (DNRW, IPWEA & BCC 1998)). In addition, a blockage factor that assumes the grate is 50% blocked is to be used.

For free overfall conditions (weir equation):

$$Q_{weir} = B \cdot C_w \cdot L \cdot h^{3/2} \qquad \text{Equation 5.7}$$

Where	Q_{weir}	=	flow over weir (pit) (m^3/s)
	B	=	blockage factor (= 0.5)
	C_w	=	weir coefficient (= 1.66)
	L	=	Length of weir (m)
	h	=	flow depth above the weir (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):

$$Q_{orifice} = B \cdot C_d \cdot A\sqrt{2 \cdot g \cdot h} \qquad \text{Equation 5.8}$$

Where *B*, *g* and *h* have the same meaning as above

$Q_{orifice}$	=	flow rate 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.

In terms of the actual grate, letter box or dome type grates must be used in bioretention basins. An example of acceptable letter box solutions is provided in Brisbane City Council's Standard Drawings UMS 157 and UMS 337.

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.

5.3.8 Step 8: Specify Vegetation

Refer to Section 5.4 and Appendix A for advice on selecting vegetation for bioretention basins in the Coastal Dry Tropics. Consultation with landscape architects is recommended when selecting vegetation to ensure the treatment system also compliments the landscape of the area.

5.3.9 Step 9: Undertake Verification Checks

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

5.3.9.1 Vegetation Scour Velocity Check

Scour velocities over the vegetation in the bioretention basin are determined by assuming the system flows at a depth equal to the maximum ponding depth across the full width of the system. By dividing the minor and major storm design flow rates by this cross sectional flow area, an estimate of flow velocity can be made. It is a conservative approach to assume that all flows pass through the bioretention basin (particularly for a major storm), however this will ensure the integrity of the vegetation.

Velocities should be kept below:

- 0.5 m/s for minor flood (2-5 year ARI) discharges.
- 2.0 m/s for major flood (50 year ARI) discharges.

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

5.3.9.2 Confirm Treatment Performance

If, during the course of undertaking detailed design of the bioretention basin, the basic design parameters established by the conceptual design phase have changed (e.g. area, filter media depth, etc.) then the designer should verify that the current design meets the required water quality improvement performance.

This can be done by re-modelling expected treatment performance determined in the conceptual design based on the revised configuration of the system.

5.3.10 Design Calculation Summary

A calculation summary sheet for the key design elements of a bioretention basin is provided below.

BIORETENTION BASIN DESIGN CALCULATION SUMMARY

	Calculation Task		CALCULATION SUMMARY Outcome		Check
	Catchment Characteristics				
		Catchment area		Ha	
		Catchment land use (i.e residential, commercial etc.)			
		Storm event entering inlet		yr ARI	
	Conceptual Design				
		Bioretention area		m^2	
		Filter media saturated hydraulic conductivity		mm/hr	
		Extended detention depth		mm	
1	Verify size for treatment				
	Bioretention area to achieve water quality objectives				
		Total suspended solids		% of catchment	
		Total phosphorus)		% of catchment	
		Total nitrogen		% of catchment	
		Bioretention area		m^2	
		Extended detention depth		m	
2	Determine design flows				
	Time of concentration				
	Refer to relevant local authority guidelines and QUDM			minutes	
	Identify rainfall intensities				
		Minor Storm ($I_{1\text{-}5\ year\ ARI}$)		mm/hr	
		Major Storm ($I_{50\ year\ ARI}$)		mm/hr	
	Design runoff coefficient				
		Minor Storm ($C1_{\text{-}5\ year\ ARI}$)			
		Major Storm($C_{50\ year\ ARI}$)			
	Peak design flows				
		Minor Storm (1-5 year ARI)		m^3/s	
		Major Storm (50 year ARI)		m^3/s	
3	Design inflow systems				
	Adequate erosion and scour protection?				
	Coarse Sediment Forebay Required?				
		Volume (V_s)		m^3	
		Area (A_s)		m^2	
		Depth (D)		m	
*	Check flow widths in upstream channel				
		Minor storm flow width		m	
		CHECK ADEQUATE LANES TRAFFICABLE			
*	Kerb opening width				
		Kerb opening length		m	
4	Specify bioretention media characteristics				
		Filter media hydraulic conductivity		mm/hr	
		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	
5	Under-drain design and capacity checks				
		Flow capacity of filter media		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			

BIORETENTION BASIN DESIGN CALCULATION SUMMARY

		CALCULATION SUMMARY		
	Calculation Task	Outcome		Check
6	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?			
7	Size overflow pit			
	System to convey minor floods (2-5yr ARI)		L x W	
8	Verification Checks			
	Velocity for Minor Storm (<0.5m/s)		m/s	
	Velocity for Major Storm (<2.0m/s)		m/s	
	Treatment performance consistent with Step 1			

* Relevant to streetscape application only

5.4 Landscape Design Notes

5.4.1 Objectives

Landscape design for bioretention basins has four key objectives:

- Addressing stormwater quality objectives by incorporating appropriate groundcover plant species for sediment removal, erosion protection, stormwater treatment (biologically active root zone) and preventing filter media blockages.
- Ensuring that the overall landscape design for the bioretention basin integrates with its surrounding environment. This includes requirements for maintaining dense perennial vegetation throughout the dry season to maintain aesthetics and to minimise weed growth.
- Incorporating Crime Prevention through Environmental Design (CPTED) principles and traffic visibility safety standards for roadside systems. This objective also needs to incorporate public safety.
- Providing other landscape values such as shade, amenity, character, buffers, glare reduction, place making and habitat.

Landscape treatments to bioretention basins will largely depend on their context and size. For example, planter box type systems in urban areas will require a different approach than larger systems located in open space areas. Comprehensive site analysis should inform the landscape design as well as road layouts, civil works and maintenance access 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)

5.4.2 Bioretention Basin Vegetation

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

- Groundcovers for stormwater treatment and erosion protection
- Shrubbery for screening, glare reduction and character
- Trees for shading, character and other landscape values.

For specific guidance on plant species the designer is initially directed to Appendix A and relevant guidelines provided by the local authority. In the absence of local guidance the designer can refer to Appendix A Plant Selection for WSUD Systems which outlines plant species suitable for the Coastal Dry Tropics Region.

The plant species listed in Apendix A tolerate free draining sandy soils and are capable of withstanding long dry periods as well as periods of inundation. However, because the dry periods in the Coastal Dry Tropics can be severe, bioretention systems must have supplemental irrigatation or include a saturated zone. These measures ensure dense perennial vegetation can be sustained to maintain aesthetics, stormwater treatment capacity and to minimise weed growth

The following sections describe the functional requirements of the different types of vegetation that can be applied to bioretention basins.

5.4.2.1 Groundcovers

Groundcover vegetation (e.g. sedges and tufted grasses) is an essential functional component of bioretention basins. Generally, the greater the density and height of vegetation planted in bioretention filter media, the better the treatment provided especially when extended detention is provided for in the design. This occurs when stormwater is temporarily stored and the contact between stormwater and vegetation results in enhanced sedimentation of suspended sediments and adsorption of associated pollutants.

Additionally, groundcover vegetation plays the primary role of continuously breaking up the surface of the bioretention filter media through root growth and wind induced agitation, which prevents surface clogging. The vegetation also provides a substrate for biofilm growth within the upper layer of the filter media, which facilitates biological transformation of pollutants (particularly nitrogen).

In general ground cover vegetation should:

- Cover the whole bioretention filter media surface.

- Possess high leaf density within the design extended detention depth to aid efficient stormwater treatment.
- A dense and uniform distribution to prevent preferred flow paths, to prevent scour/resuspension and to create a uniform root zone within the bioretention filter media.
- Where appropriate, be endemic to the area and as a minimum be local to the Coastal Dry Tropics. Species (including natives) that have the potential to become invasive weeds should be avoided.
- Tolerate short periods of inundation (and water logged soils) punctuated by longer dry periods.

5.4.2.2 Shrubs and Trees

Shrubs and trees are not a functional requirement for bioretention basins but can be designed into the systems to ensure integration within the wider landscape (streetscape or parkscape) and to provide amenity, character and habitat. When incorporating trees and shrubs into bioretention systems appropriate space should be allowed between the systems to promote an open canopy that allows sunlight to penetrate to groundcover plants. Additionally, trees and shrubs must be accompanied by shade tolerant groundcover species.

In general, trees and shrubs planted into bioretention basins should have the following features:

- Able to tolerate short periods of inundation (and water logged soils) punctuated by longer dry periods.
- Have relatively sparse canopies to allow light penetration to support dense groundcover vegetation.
- Root systems that are relatively shallow and are not known to be adventurous 'water seekers' to reduce the risk of root intrusion into under-drainage pipes.
- Preferably native to the Coastal Dry Tropics region and not exotic or deciduous.
- Be relatively fast growing.

5.4.3 Other specific Landscape considerations

5.4.3.1 Planter Boxes

Planter boxes are relatively small WSUD elements that are most applicable to highly urbanised contexts. In well used areas, planter boxes are likely to be highly visible elements that could become local features. The urban landscape design principles of form, colour, texture and massing should apply to both plantings and raised containers. An irrigation system may be required to provide supplementary watering.

5.4.3.2 Parkland Bioretention Basins

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

- opportunities and constraints presented by various siting options.
- if the device is to be visually prominent (perhaps for educational value) or merged with the surrounding parkland space using a consistent planting layout in the basin, embankment and parkland.
- a formal or informal style dependent on the setting and surrounding open space and urban design.

5.4.4 Safety Issues

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

5.4.4.1 Crime Prevention Through Environmental Design (CPTED)

Where planting may create places of concealment or hinder informal surveillance, groundcovers and shrubs should not generally exceed 1 m in height. For specific guidance on CPTED requirements the designer is initially directed to relevant guidelines provided by the local authority, however, in the absence of local guidance the designer can refer to BCC's CPTED Planning Scheme Policy in *Brisbane City Plan 2000* (BCC 2000b, vol. 2, app. 2, pp. 68a – 68f) and associated references.

5.4.4.2 Traffic Sightlines

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

5.5 Construction and Establishment

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

5.5.1 Staged Construction and Establishment Method

It is important to note that bioretention basin 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 basins and establishing vegetation can be a challenging task. Therefore, bioretention basins require a careful construction and establishment approach to ensure the basin establishes in accordance with its design intent. The following sections outline a recommended staged construction and establishment methodology for bioretention basins (Leinster, 2006).

5.5.1.1 Construction and Establishment Challenges

There exist a number of challenges that must be appropriately considered to ensure successful construction and establishment of bioretention basins. 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 5-3).

- 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 basins.

  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 basins.

Plate 5-3: Example of Building Phase destruction

5.5.1.2 Staged Construction and Establishment Method

To overcome the challenges associated within delivering bioretention basins a Staged Construction and Establishment Method should be adopted (Figure 5-4):

- Stage 1: Functional Installation - Construction of the functional elements of the bioretention basin at the end of Subdivision Construction (i.e. during landscape works) and the installation of temporary protective measures. For example, temporary protection of bioretention basins 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 basins 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 basins can be removed along with all accumulated sediment and the system planted in accordance with the design planting schedule.

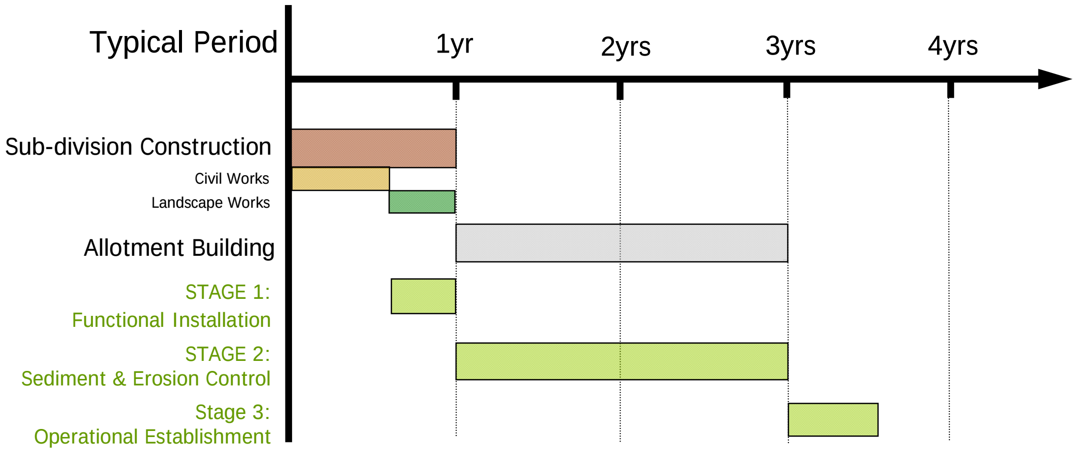


Figure 5-4: Staged Construction and Establishment Method

5.5.1.3 Functional Installation

Functional installation of bioretention basins 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 basin during construction (Subdivision and Building Phases) ensuring sediment/litter laden waters do not enter the filter media causing clogging.
- Place silt fences around the boundary of the bioretention basin to exclude silt and restrict access.

Plate 5-4: Bioretention Basin Functional Installation

5.5.1.4 Sediment and Erosion Control

Many soils within the Coastal Dry Tropics region are dispersive, highlighting the critical importance of appropriate sediment and erosion control. All development and land disturbance activities must employ best practice sediment and erosion control practices to minimise the impact on receiving environments (refer to relevant local government and/or regional sediment and erosion control guidelines). In relation to bioretention systems, temporary protective layers (Section 5.5.1.3) must be installed are left in place throughout the allotment building phase to ensure sediment laden waters do not clog the filtration media and allotment building traffic does not enter the bioretention system. Importantly the configuration of the bioretention basin and the turf vegetation allow the system to function effectively as a shallow sedimentation basin reducing the load of sediment discharging to the receiving environment. Using this approach, WSUD systems can operate effectively to protect downstream ecosystems immediately after construction.

5.5.1.5 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 system re-profiled and planted in accordance with the proposed landscape design. Establishment of the vegetation to design condition can require more than two growing seasons, depending on the vegetation types, during which regular watering and removal of weeds will be required.

Plate 5-5 : Bioretention Basin Sediment & Erosion Control

5.5.1.6 Quality Control during Construction

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

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

- Prior to commencement of civil works;
- Prior to commencement of landscape works;
- At the completion of works.

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

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

1. Survey bioretention basin location.
2. Undertake bulking out, including construction of bunds surrounding basin. Construct outflow headwall(s) and install section(s) of stormwater reinforced concrete pipes (RCP) that runs underneath bund. Terminate pipe at interface of bund and bioretention basin.
3. Excavate surrounding landform to design subsoil level (achieving surrounding level at this stage reduces the need for earthworks adjacent to the basins after they have been constructed).
4. Install overflow pit(s) and ensure pit crest(s) is at design level. The pit crest(s) will then be used as a datum from which other levels within the basin will be measured. The pit requires holes for pipe connections and these should be drilled at this stage.
5. Detailed excavation, trimming and profiling of sides and base of basin, ensuring base has minimum 0.5% grade (0% slope when saturated zones are included in the designs) towards pit. Ensure base of basins are free from debris. 'As constructed' survey is required at this time and should include the base and bunds of the system and all hard structures (i.e. overflow pit, overflow weir and pipe connection punch-out holes).
6. Install silt fences around basin to prevent sediment entering system and to keep construction vehicles off the basin.

SUPERINTENDENT INSPECTION AND SIGN OFF REQUIRED BEFORE PROCEEDING

7. Line basin with geofabric, ensuring geofabric extends beyond top of bioretention basin side walls, up to the sediment control fence. This ensures that exposed earth on the bunds won't wash into basins during construction.
8. Install remaining RCP stormwater pipe connecting overflow pit(s) to existing RCP stormwater pipe installed as part of Step 2.
9. Install slotted PVC under-drainage pipes and PVC collector pipes in specified layout. Ensure all pipes are laid at min 0.5% slope (0% slope when saturated zones are included in the designs) with no localized depressions verified using level or string line. Arrange slots so that they are not directly on top of the pipe (to minimise fine particles blocking the slots). Seal junctions and connections (i.e. slotted PVC pipes to PVC collector pipes; slotted PVC pipes/PVC collector pipes to overflow pits) using sealant to prevent sand/gravel/soil passing into drainage network. Connect clean out points ensuring top of clean out points will ultimately sit 200 mm below overflow pit crest.

SUPERINTENDENT INSPECTION AND SIGN OFF REQUIRED BEFORE PROCEEDING

10. Install drainage, transition and saturated zones as required and as detailed in the design drawings.
11. Place prescribed bioretention filter media to design surface level of bioretention basin. Spread material using excavator bucket, hand tools, or a small 'pozitrack' bobcat. Do not drive over filter media with any vehicle other than a 'pozitrack' bobcat and only if agreed to by civil superintendent. In order to remove air pockets within the filter media, apply light and even compaction by making a single pass with a 'pozitrack' bobcat (or similar). If required, apply additional filter media to ensure

final surface level is correct. Use a spreader bar to flatten the surface of the filter media. Ultimately, the surface of the filter media must be level (horizontal) and free from local depressions and set at 300 mm below pit crest.

12. Construct coarse sediment forebay utilising large, flat rocks to form base of forebay and interface between forebay and bioretention area.
13. Install temporary protective covering over bioretention surface. This involves covering the surface of filtration media with geofabric and placement of 50mm topsoil and turf over the geofabric. This geofabric/turf layer is a temporary measure to protect the filter media from being clogged with construction sediment while allotment building is being undertaken. Once a majority of the allotment building is complete and the construction sediment load is minimal, this protective layer will be removed, and the system will be planted out with the vegetation as per designs.
14. Place landscaping topsoil on top of geofabric covering the bunds and around basin as per designs.
15. Flush under-drainage pipes to remove any initial ingress of material.
16. Undertake as constructed survey of the basin surface and surrounding bunds, picking up at least one spot level per 100m^2 on the basin surface and at least one spot level every 10m along the top of the bunds.

FINAL SUPERINTENDENT INSPECTION AND SIGN OFF

5.5.2 Construction Tolerances

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

5.5.3 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 basin planting. When this is not done and the planting specification is compromised, poor vegetation establishment and increased initial maintenance costs may occur. The species listed in 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

5.5.4 Vegetation Establishment

The following weed control measures and watering schedule are recommended to ensure successful plant establishment. Regular general maintenance as outlined in Section 5.6 will also be required.

5.5.4.1 Weed Control

Conventional surface mulching of bioretention basins with organic material like tanbark, should not be undertaken. Most organic mulch floats and runoff typically causes this material to be washed away with a risk of blocking

Plate 5-6: Plant Establishment Period in Bioretention

drains. Adopting high planting densities (e.g. 8-10 plants per square metre) and if necessary, applying a suitable biodegradable erosion control matting to the basin batters will help to combat weed invasion and reduce labour intensive maintenance requirements for weed removal. A heavy application of seedless hydro-mulch or hydro-mulch seeded with a sterile annual grass (e.g. Sterile Rye Grass) to create an anchored mulch can also provide short term erosion and weed control prior to planting with nursery stock. No matting or hydro-mulch is to be applied to the surface of the bioretention basin following the construction phase (i.e. in its final design form, vegetated as per planting schedule), as this will hinder filtration of stormwater through the filter media.

5.5.4.2 Watering

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

- 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 basins without submerged zones and may be required in bioretention basins with saturated zones (particularly during the 2 year plant establishment period). Watering requirements to sustain healthy vegetation should be determined during ongoing maintenance site visits.

5.6 Maintenance Requirements

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

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

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

Typical maintenance of bioretention basin elements will involve:

- Routine inspection of the bioretention basin profile to identify any areas of obvious increased sediment deposition, scouring from storm flows, rill erosion of the batters from lateral inflows, damage to the profile from vehicles and clogging of the bioretention basin (evident by a 'boggy' filter media surface).
- Routine inspection of inflows systems, overflow pits and under-drains to identify and clean any areas of scour, litter build up and blockages.
- Removal of sediment where it is smothering the bioretention basin vegetation.
- Where a sediment forebay is adopted, removal of accumulated sediment.
- Repairing any damage to the profile resulting from scour, rill erosion or vehicle damage by replacement of appropriate fill (to match onsite soils) and revegetating.
- Tilling of the bioretention basin surface, or removal of the surface layer, if there is evidence of clogging.
- Regular watering/ irrigation of vegetation until plants are established and actively growing (see Section 5.5.4.2).
- Removal and management of invasive weeds (herbicides should not be used).
- 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 growth.

- 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 the bioretention basin will be required if the system fails to drain adequately after tilling of the surface. Maintenance should only occur after a reasonably rain free period when the soil in the bioretention system is dry. Inspections are also recommended following large storm events to check for scour and other damage.

All maintenance activities must be specified in an approved Maintenance Plan (and associated maintenance inspection forms) to be documented and submitted to Council as part of the Development Approval process. Maintenance personnel and asset managers will use this Plan to ensure the bioretention basins continue to function as designed. An example operation and maintenance inspection form is included in the checking tools provided in Section 5.7.3. These forms must be developed on a site-specific basis as the nature and configuration of bioretention basins varies significantly.

5.7 Checking Tools

This section provides a number of checking aids for designers and Council development assessment officers. In addition, Section 5.5 provides general advice for the construction and establishment of bioretention basins and key issues to be considered to ensure their successful establishment and operation based on observations from construction projects around Australia. The following checking tools are provided:

- Design Assessment Checklist
- Construction Inspection Checklist (during and post construction)
- Operation and Maintenance Inspection Form
- Asset Transfer Checklist (following 'on-maintenance' period).

5.7.1 Design Assessment Checklist

The checklist on page 5-30 presents the key design features that are to be reviewed when assessing the design of a bioretention basin. These considerations include configuration, safety, maintenance and operational issues that need to be addressed during the design phase. If an item receives an 'N' when reviewing the design, referral is made back to the design procedure to determine the impact of the omission or error. A copy of the completed Design Calculation Summary from Section 5.3.10 should be provided as part of the application to assist in the design assessment. In addition to the checklist, a proposed design is to have all necessary permits for its installation. Council development assessment officers will require all relevant permits to be in place prior to accepting a design.

5.7.2 Construction Checklist

The checklist on page 5-31 presents the key items to be reviewed when inspecting the bioretention basin during and at the completion of construction. The checklist is to be used by Construction Site Supervisors and local authority Compliance Inspectors to ensure all the elements of the bioretention basin have been constructed in accordance with the design. If an item receives an 'N' in Satisfactory criteria then appropriate actions must be specified and delivered to rectify the construction issue before final inspection sign-off is given.

5.7.3 Operation and Maintenance Inspection Form

The example form on page 5-32 should be developed and used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time. Inspections should occur every 1 - 6 months depending on the size and complexity of the system. More detailed site specific maintenance schedules should be developed for major bioretention basins and include a brief overview of the operation of the system and key aspects to be checked during each inspection.

5.7.4 Asset Transfer Checklist

Land ownership and asset ownership are key considerations prior to construction of a stormwater treatment device. A proposed design should clearly identify the asset owner and who is responsible for its maintenance. The proposed owner should be responsible for performing the asset transfer checklist. For details on asset transfer to specific to each Council, contact the relevant local authority. The table on page 5-33 provides an indicative asset transfer checklist.

BIORETENTION BASIN DESIGN ASSESSMENT CHECKLIST			
Asset I.D.		DA No.	
Basin Location:			
Hydraulics:	Minor Flood (m^3/s):	Major Flood (m^3/s):	
Area:	Catchment Area (ha):	Bioretention Area (ha):	

TREATMENT	Y	N
Treatment performance verified from curves?		
BIORETENTION MEDIA AND UNDER-DRAINAGE	**Y**	**N**
Design documents bioretention area and extended detention depth as defined by treatment performance requirements.		
Overall flow conveyance system sufficient for design flood event(s)?		
Where required, bypass sufficient for conveyance of design flood event?		
Where required scour protection provided at inflow point to bioretention?		
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?		
Liner provided if 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?		
*Maximum upstream flood conveyance complies with QUDM?		
*Overflow pit has set down of at least 50mm below kerb invert? (where conventional gully/lintel used downstream of bioretention then no overflow pit required)		
BASIN	**Y**	**N**
Bioretention area and extended detention depth documented to satisfy treatment requirements?		
Overflow pit crest set at top of extended detention?		
Maximum ponding depth will not impact on public safety?		
Maintenance access provided to surface of bioretention system (for larger systems)?		
Protection from coarse sediments provided (where required) with a sediment forebay?		
Protection from gross pollutants provided (where required)?		
LANDSCAPE	**Y**	**N**
Plant species selected can tolerate extended dry periods, periodic inundation and design velocities?		
Bioretention design and plant species selected integrate with surrounding landscape or built environment design?		
*Planting design conforms with acceptable sight line and safety requirements?		
COMMENTS		

*Streetscape application only

BIORETENTION BASIN CONSTRUCTION INSPECTION CHECKLIST

Asset I.D.		Inspected By:	
Site:		Date:	
		Time:	
Constructed By:		Weather:	
		Contact During 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 basin 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
Inspection officer signature:

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

INSPECTION ITEMS:	Y	N	Action Required (details)
Sediment accumulation at inflow points?			
Litter within basin?			
Erosion at inlet or other key structures?			
Traffic damage present?			
Evidence of dumping (e.g. building waste)?			
Vegetation condition satisfactory (density, weeds etc)?			
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?			
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 BASIN ASSET TRANSFER CHECKLIST		
Asset I.D.		
Asset Location:		
Construction by:		
'On-maintenance' 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 (2 years)?		
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	Y	N
Sediment accumulation at inflow points?		
Litter within basin?		
Erosion at inlet or other key structures?		
Traffic damage present?		
Evidence of dumping (e.g. building waste)?		
Vegetation condition satisfactory (density, weeds etc)?		
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 (e.g. drawings, survey, models) provided?		
Asset listed on asset register or database?		

5.8 Example Engineering Drawings

Where the relevant local authority has standard drawings appropriate to a bioretention basin application, these should be used to guide the design and construction of a bioretention basin. In the absence of local standards, BCC have developed a set of Standard Drawings (UMS 155, 156 and 337) that can be readily applied to bioretention basin applications in the Coastal Dry Tropics. These drawings relate specifically to inlet pits and sub-surface drains for bioretention swales but may be used to guide design for bioretention basins. These are not intended to be prescriptive drawings which must be adhered to, rather they are intended to provide detailed examples of bioretention system configurations. Standard drawings are available online at http://www.brisbane.qld.gov.au/planning-building/planning-building-rules/standard-drawings/index.htm.

5.9 Bioretention Basin Worked Example

A series of bioretention basins, designed as landscaped 'out-stands', are to be retrofitted into a minor road in the greater Townsville area. The street has a longitudinal grade of 1% and the adjacent allotments have an average slope of 8%. A proposed layout for the bioretention basins is shown in Figure 5-5 with an image of a similar system to that proposed shown in Plate 5.7.

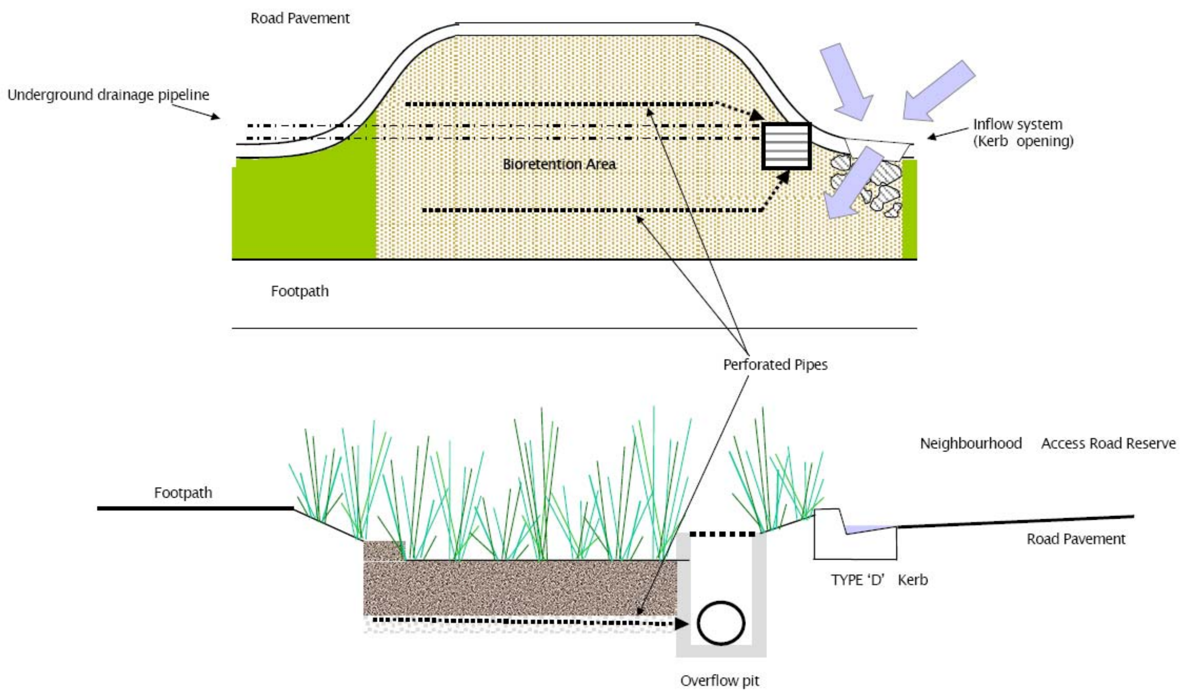


Figure 5-5: General Layout and Cross Section of Proposed Bioretention System

Plate 5-6: Retrofitted Bioretention System in a Street

The contributing catchment areas to each of the individual bioretention basins consist of 200 m^2 of road and footpath pavement and 400 m^2 of adjoining properties. Runoff from adjoining properties (approximately 60 % impervious) is discharged into the road channel and, together with road runoff, is conveyed along a conventional roadside channel to the bioretention basin.

The aim of the design is to facilitate effective treatment of stormwater runoff while maintaining a level of flood protection for the local street under the minor storm (2yr ARI). Conceptual design of the bioretention basins has been undertaken, with MUSIC used to ensure the stormwater discharges comply with Townville City Council water quality objectives (WQOs) of achieving best practice load reductions. The bioretention basins have an area of 12 m^2 to meet both the landscape and stormwater treatment objectives with an extended detention depth of 200 mm and consisting of a modified sandy loam soil filtration medium (saturated hydraulic conductivity = 100 mm/hr). The width (measured perpendicular to the alignment of the road) of the bioretention basins is 2 m. The key design elements to ensure effective operation of the bioretention basins are listed below:

- road and channel details to convey water into the basins
- detailing inlet conditions to provide for erosion protection
- configuring and designing a system for 'above design' operation that will provide the required 2 year ARI flood protection for the local street
- detailing of the bioretention under-drainage system
- specification of the soil filter medium
- landscape layout and details of vegetation.

Design Objectives

The design objectives are to achieve best practice load reduction targets which are 80% reduction in mean annual TSS load, 70% reduction in mean annual TP load and 45% reduction in mean annual TN load, whilst maintaining the minor event (i.e. 2 year ARI) level of flood protection for the local street.

Constraints and Concept Design Criteria

Analyses undertaken during a concept design established the following criteria:

- bioretention basin area of 12 m^2 required to achieve the landscape amenity and Dry Tropics WSUD Objectives (e.g. Best Practice Load Reduction Objectives)
- maximum width of each bioretention basin is to be 2 m
- extended detention depth is 200 mm
- filter media to have a saturated hydraulic conductivity of 100 mm/hr
- as the site is located in a landscaped area which receives supplemental irrigation to sustain the vegetation a saturated zone within the bioretention systems is not required.

5.9.1 Step 1: Confirm Treatment Performance of Concept Design

It is assumed conceptual design of the bioretention basins included an assessment of the basin performance using an appropriate water quality modelling program to ensure the configuration of the basins achieve the stated WQOs. 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 input parameters listed below provided an estimate of the reduction performance of the bioretention basin for the three key pollutants (TSS, TP and TN):

- 200 mm extended detention
- treatment area to catchment area ratio 2% (i.e. 12 m^2 bioretention basin with 600 m2 catchment area).

The expected pollutant reductions are 84%, 71% and 45% for TSS, TP and TN respectively, thus considered to meet the design objectives.

5.9.2 Step 2: Determine Design Flows

With a small catchment (in this case 600 m2), the Rational Method is considered an appropriate approach to estimate the design storm peak flow rates. The steps in this calculation follow below.

<u>Time of concentration (t_c)</u>

Adjacent allotment flow path length = 15 m

Time of concentration t_c = 10 mins (QUDM for land with 6 % < slope < 10 %)

<u>Design runoff coefficient</u>

Runoff Coefficients

C10 = 0.8 (from local authority guidelines)

	C Runoff		
ARI	2	10	50
QUDM Factor	0.85	1	1.15
C_{ARI}	0.60	0.88	1.01

Catchment Area, A = 600 m^2 (0.06 ha)

Rainfall Intensities, t_c = 10 mins

I_2 = 119 mm/hr

I_{50} = 244 mm/hr

Rational Method Q = CIA/360

$Q_{2yr\ ARI}$ = 0.012

m^3/s

$Q_{50yr\ ARI}$ = 0.041 m^3/s

5.9.3 Step 3: Design Inflow Systems

5.9.3.1 Inlet Scour Protection

Rock protection is to be provided in the bioretention basins to manage flow velocities entering from the kerb opening.

5.9.3.2 Coarse Sediment Forebay

A bioretention system such as the one proposed here should incorporate a coarse sediment forebay to remove coarse sediment from stormwater prior to flowing across the surface of the filter media. The forebay should be designed to:

- Remove particles that are 1mm or greater in diameter from the 3mth ARI storm event.

- Provide appropriate storage for coarse sediment to ensure desilting is required once every year.

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

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

Where V_s = volume of forebay sediment storage required (m^3)

A_c = contributing catchment area (0.06 ha)

R = capture efficiency (assume 80%)

L_o = sediment loading rate (1 m^3/ha/year)

F_c = desired cleanout frequency (2 years)

V_s = 0.06 * 0.8 * 1 * 2

= 0.096 m^3

The area of the forebay is established by dividing the volume by the depth. The depth of the forebay should not be greater than 0.3m below the surface of the filter media.

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

Where D = depth of sediment forebay (0.3)

A_s = *0.096 / 0.3*

= *0.32 m^2*

The sediment forebay area should be checked to ensure it captures the 1mm and greater particles using the following expression (modified version of Fair and Geyer (1954)):

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

Where

R = fraction of target sediment removed (80%)

v_s = settling velocity of target sediment (100mm/s or 0.1m/s for 1mm particle)

Q_{3mth} / A = applied flow rate divided by basin surface area ($m^3/s/m^2$)

n = turbulence or short-circuiting parameter (adopt 0.5)

Q_{3month} = 0.5 * Q_1 (approx)

I_1 = 91.9 mm/hr

Q_1 = C*I*A / 360

= 0.71 * 91.9 * 0.06 / 360

= 0.011 m^3/s

$Q_{3\text{-}month}$ = 0.5 * 0.011

= 0.006 m^3s

R = 1 - [1 + 1/0.5 * 0.1 / 0.006 / 0.3072]$^{-0.5}$

= 1 – [11.24]$^{-0.5}$

= 0.702

= 70 % of 1 mm particles

5.9.3.3 Kerb Opening Configuration (Streetscape Applications)

Channel flow width and kerb opening

The depth and width of channel flow at the locality of the kerb opening needs to be determined to establish the hydraulic head at the kerb opening. The kerb, channel (Figure 5-6) and road profile (Figure 5-7) is shown below as provided by the relevant local government guidelines. The longitudinal grade of the road is 1%.

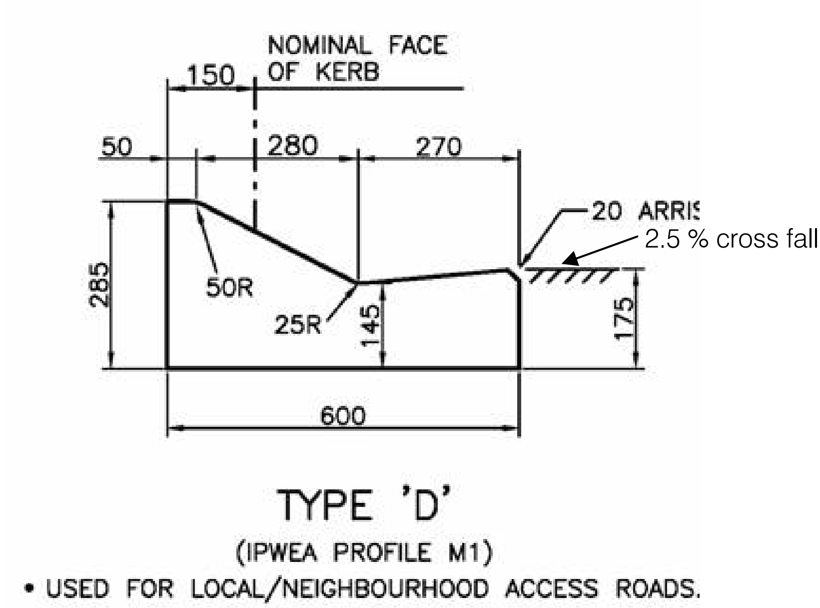


Figure 5-6: Typical Kerb and Channel Detail

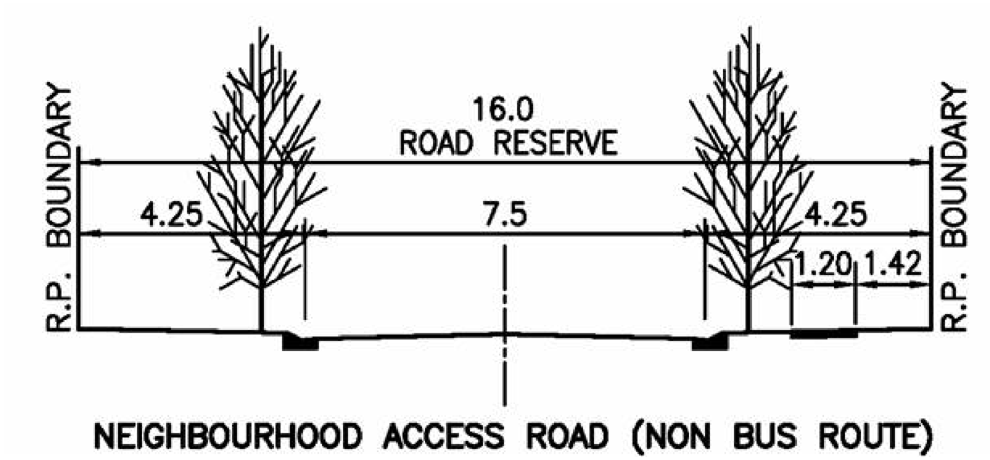


Figure 5-7: Typical Road Reserve Cross Section

The width and depth of channel flow is estimated using the procedure described in QDUM Section 7.04 with the 'Road Flow Capacity Chart Tables' provided in QUDM (DNRW, IPWEA & BCC 1998) allowing rapid calculation.

$Q_{2\ Year}$ = 0.012 m^3/s gives

Depth of Flow = 50 mm

Width of Flow = 1.3 m

Velocity = 0.57 m/s

The estimated channel flow width at the kerb opening during the $Q_{2\ Year}$ storm event is less than half road width during minor storm flow and thus complies with the relevant local government guidelines.

Kerb opening length

The flow depth in the channel estimated above is used to determine the required length of opening in the kerb to allow for the 2 year ARI flow to pass freely into the bioretention basin.

$Q_{2yr\ ARI} = 0.012\ m^3/s$

Assume broad crested weir flow conditions through the kerb opening and use Equation 5.1 to determine length of opening:

Hence

Where $Q = Q_{2yr\ ARI} = 0.012\ m^3/s$,

C_w = weir coefficient = 1.66

h = depth of (Q_2) flow (50mm) = 0.05 m

Solving gives L = 0.68 m, therefore adopt a 0.7 m long opening which ensures there will be no increase in channel flow depth and width upstream of the kerb opening.

5.9.4 Step 4: Specify the Bioretention Media Characteristics

As outlined in Section 5.3.4, 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 be 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).

5.9.4.1 Filter Media

The filter media is to be a sandy loam and will be formed through the procedure documented in Section 5.3.4.1. The filter media will generally meet the following geotechnical requirements:

- saturated hydraulic conductivity of 100 mm/hr determined from appropriate laboratory testing (see section 5.3.4.1)
- Organic carbon levels < 5%
- pH between 5.5 and 7.5.

5.9.4.2 Drainage Layer

The drainage layer is to be 200 mm of 5 mm screenings graded at 0.5% toward the overflow pit.

5.9.4.3 Transition Layer

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

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

5.9.5 Step 5: Under-drain Design and Capacity Checks

Two under-drains are to be installed in the drainage layer approximately 1 m apart. This will ensure the drainage layer does not hinder drainage of the filter media. A standard perforated pipe was selected for the under-drain that has a slot clear opening of 2100 mm^2/m with the slots being 1.5 mm wide. The perforated pipes are to be laid on the base of the bioretention system which grades at 0.5 % towards the overflow pit.

The maximum filtration rate, or the flow reaching the perforated pipe in the drainage layer, is estimated by using the saturated hydraulic conductivity of the filter media (assuming no blockage of the media) and head above the base of the filter media and applying Darcy's equation (Equation 5.5).

Saturated hydraulic conductivity	= 100 mm/hr	= 0.1 m/hr
Area of bioretention basin	= 12 m^2	
Maximum ponding depth (h_{max})	= 200 mm	
Filter media depth	= 0.6 m	

From Equation 5.5, the maximum filtration rate is:

Q_{max} = (0.1 m/hr x 12 m^2 x [0.2 m + 0.6 m]/0.6 m)/3600 s/hr = 0.00044 m^3/s

<u>Perforations inflow check</u>

Estimate the inlet capacity of sub-surface drainage system (perforated pipe) to ensure it is not a choke in the system. To build in conservatism, 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 is applied using the following parameters:

Head (h) = 0.85 m [0.6 m (filter depth) + 0.2 m (max. pond level) + 0.05 m (half of pipe diameter)]

Assume sub-surface drains with half of all slots blocked (B = 0.5)

Clear Opening	= 2100 mm^2/m,
Hence, blocked openings	= 1050 mm^2/m (50 %)
Slot Width	= 1.5 mm
Slot Length	= 7.5 mm
Pipe diameter	= 100 mm
Number of slots per metre	= (1050)/(1.5 x 7.5) = 93.3

Assume orifice flow conditions (Equation 5.6):

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

h = 0.85 m (from above)

A = area of slots (=1.5 mm x 7.5 mm x 93.3 slots = 0.00105 m^2)

(note: this already allows for blockage, so B can be ignored in this case)

Inlet capacity per metre length of pipe:

= 0.0026 m^3/s

Inlet capacity per m x total length (two lengths of 5.5 m)

= 0.0026 x (2 x 5.5m) = 0.029 m^3/s >> 0.00044 (max filtration rate), hence OK.

<u>Perforated pipe capacity</u>

Manning's equation is applied to estimate the flow rate in the perforated pipes to confirm the capacity of the pipes is sufficient to convey the maximum filtration rate. Two 100 mm diameter perforated pipes are to be laid in parallel and at a grade of 0.5 % towards the overflow pit.

Applying the Manning's Equation assuming a Manning's *n* of 0.02 gives:

Q (flow per pipe) = 0.0024 m^3/s

Then Q_{Total} = 0.0048 m^3/s (for two pipes) > 0.00044 m^3/s, and hence OK.

5.9.6 Step 6: Check Requirement for Impermeable Lining

In the 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 100 mm/hr, therefore the conductivity of the filter media is > 10 times (one order of magnitude) the conductivity of the surrounding soils and an impervious liner is not considered to be required.

5.9.7 Step 7: Size Overflow Pit

The overflow pit is required to convey 2 year ARI flows safely from above the bioretention system into an underground pipe network. Grated pits are to be used at the upstream end of the bioretention system. The sizes of the pits are established using two calculations for drowned and free overfall conditions. For free overfall conditions, a broad crested weir equation (Equation 5.4) is used with the maximum headwater depth (h) above the weir being set by the level difference between the crest of the overflow pit and the invert level of the kerb opening (i.e. 100 mm for this design):

Where $Q = Q_{2yr\ ARI}$ = 0.012 m^3/s, B = 0.5, C_w = 1.66 and h = 0.1m and solving for L

Gives L = 0.5 m of weir length required (equivalent to 125 x 125 mm pit)

Now check for drowned conditions using Equation 5.5:

Where $Q = Q_{2yr\ ARI}$ = 0.012 m^3/s, B = 0.5, C_d = 0.6 and h = 0.1m and solving for A

Gives A = 0.03 m^2 (equivalent to 175 x 175 mm pit)

Hence, drowned outlet flow conditions dominate and the pit needs to be greater than 175 x 175 mm. In this case, a 600 x 600 mm pit is adopted as this is minimum pit size to accommodate underground pipe connections.

5.9.8 Step 9: Vegetation Specification

With such a small system, it is appropriate to have vegetation of a single species within the bioretention system. For this application, *Carex fascicularis* is proposed with a planting density of 8 plants/m^2. Information on maintenance and establishment is provided in earlier sections of this chapter.

5.9.9 Step 8: Verification Checks

5.9.9.1 Vegetation Scour Velocity Checks

The location and sizing of the overflow pit precludes flows from minor and major storm events over the bioretention surface. Therefore, no scour velocity checks are required for this worked example.

5.9.9.2 Confirm Treatment Performance

The key functional elements of the bioretention basins developed as part of the conceptual design (i.e. area, filter media depth) were not adjusted as part of the detailed design. Therefore, the performance check undertaken in Step 1 (see Section 5.9.2) still applies.

5.9.10 Design Calculation Summary

The sheet below shows the results of the design calculations.

BIORETENTION BASIN DESIGN CALCULATION SUMMARY

	Calculation Task		Outcome (Calculation Summary)		Check
	Catchment Characteristics				
		Catchment area	0.06	Ha	✓
		Catchment land use (i.e residential, commercial etc.)	Residential		
		Storm event entering inlet	2yr ARI	yr ARI	
	Conceptual Design				
		Bioretention area	12	m^2	✓
		Filter media saturated hydraulic conductivity	100	mm/hr	
		Extended detention depth	200	mm	
1	Confirm Treatment Performance of Concept Design				
		Total suspended solids	84	% reduction	
		Total phosphorus	71	% reduction	
		Total nitrogen	45	% reduction	
		Bioretention area	12	m^2	✓
		Extended detention depth	0.2	m	
2	Determine design flows				
	Time of concentration				
	Refer to relevant local authority guidelines and QUDM		10	minutes	✓
	Identify rainfall intensities				
		Minor Storm ($I_{1\text{-}2\ year\ ARI}$)	119	mm/hr	✓
		Major Storm ($I_{50\ year\ ARI}$)	244	mm/hr	
	Design runoff coefficient				
		Minor Storm ($C_{1\text{-}5\ year\ ARI}$)	0.8		✓
		Major Storm($C_{50\ year\ ARI}$)	0.925		
	Peak design flows				
		Minor Storm (1-2 year ARI)	0.013	m^3/s	✓
		Major Storm (50 year ARI)	0.041	m^3/s	
3	Design inflow systems				
	Adequate erosion and scour protection?		Yes		✓
	Coarse Sediment Forebay Required?		Yes		
		Volume (V_s)	0.096	m^3	
		Area (A_s)	0.31	m^2	
		Depth (D)	0.3	m	
*	Check flow widths in upstream channel				
		Minor storm flow width	1.3	m	✓
		CHECK ADEQUATE LANES TRAFFICABLE			
*	Kerb opening width				
		Kerb opening length	0.7	m	✓
4	Specify bioretention media characteristics				
		Filter media hydraulic conductivity	100	mm/hr	✓
		Filter media depth	600	mm	
		Saturated zone required			×
		Saturated zone depth	N/A	mm	
	Drainage layer media (sand or fine screenings)				
		Drainage layer depth	200	mm	✓
		Transition layer (sand) required	Yes		
		Transition layer depth	100	mm	
5	Under-drain design and capacity checks				
		Flow capacity of filter media	0.00031	m^3/s	✓
	Perforations inflow check				
		Pipe diameter	100	mm	
		Number of pipes	2		
		Capacity of perforations	0.057	m^3/s	
		CHECK PERFORATION CAPACITY > FILTER MEDIA CAPACITY			
		CHECK SATURATED ZONE WEIR/UP-TURNED PIPE CAPACITY > FILTER MEDIA CAPACITY	N/A		
	Perforated pipe capacity				
		Pipe capacity	0.0048	m^3/s	✓
		CHECK PIPE CAPACITY > FILTER MEDIA CAPACITY			

BIORETENTION BASIN DESIGN CALCULATION SUMMARY					
			CALCULATION SUMMARY		
	Calculation Task		Outcome		Check
6	Check requirement for impermeable lining				
		Soil hydraulic conductivity	3.6	mm/hr	✓
		Filter media hydraulic conductivity	100	mm/hr	
		MORE THAN 10 TIMES HIGHER THAN IN-SITU SOILS?			
7	Size overflow pit				
		System to convey minor floods (2yr ARI)	600 x 600	L x W	✓
8	Verification Checks				
		Velocity for Minor Storm (<0.5m/s)	N/A	m/s	✓
		Velocity for Major Storm (<2.0m/s)	N/A	m/s	
		Treatment performance consistent with Step 1	Yes		

* Relevant to streetscape application only

5.9.11 Worked Example Drawing

Drawings 5.1 and 5.2 at the end of the chapter illustrate the worked example bioretention basin layout.

5.10 References and Additional Information

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