Bioretention
Technical Design Guidelines
Version 1.1, October 2014

waterbydesign
Healthy Waterways Initiative

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Healthy Waterways

Healthy Waterways is a not-for-profit, non-government organisation working to protect and improve waterway health in South East Queensland (SEQ). We facilitate careful planning and coordinated efforts among a network of member organisations from government, industry, research, and the community to achieve our shared vision for healthy waterways. For more information, visit www.healthywaterways.org.

Queensland Government

Australian Government

Bioretention Technical Design Guidelines

Version 1.1, October 2014

Water by Design is a program of Healthy Waterways Ltd

CONTENTS

LIST OF ACRONYMS AND ABBREVIATIONS

AASS	Actual Acid Sulphate Soil
ARI	Average Recurrence Interval
ASS	Acid Sulphate Soil
FAWB	Facility for Advancing Water Biofiltration
IPWEAQ	Institute of Publics Works Engineering Australia Queensland Division
MUSIC	Model for Urban Stormwater Improvement Conceptualisation
NATA	National Association of Testing Authorities
PASS	Potential Acid Sulphate Soil
QUDM	Queensland Urban Drainage Manual
WSUD	Water Sensitive Urban Design

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ONE **INTRODUCTION**

Waterways and other aquatic environments are valued by the community for their social, cultural, economic and environmental benefits. Urban runoff, contaminated with nutrients, sediment and other pollutants adversely impacts these valued resources. Water Sensitive Urban Design (WSUD) is a holistic approach to the planning and design of urban landscapes that minimises these negative impacts. Using this approach, designers select the treatment technology that considers the civil, landscape and ecological aspects of the site. Owing to flexible design, space efficiency and application at a variety of scales, bioretention systems (also called biofilters, bioretention basins, bioinfiltration systems, bioswales and raingardens) are the most commonly used treatment technology.

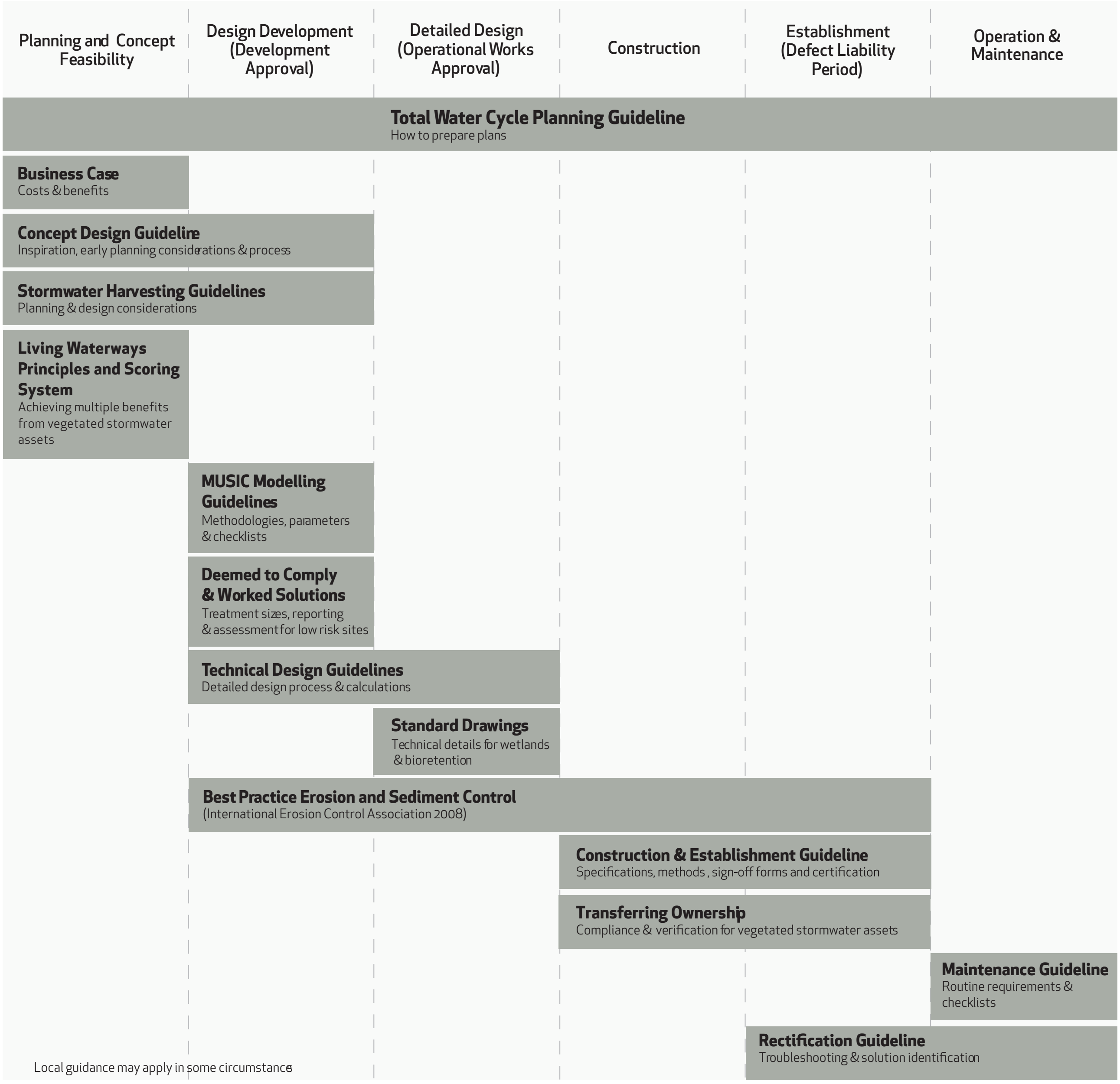
The key function of bioretention systems is to remove pollutants from stormwater. They achieve this by filtering the stormwater through a densely vegetated and biologically active sand and loam filter media. As the water percolates through the filter media, pollutants are captured by fine filtration, adsorption and biological processing by both soil microbes and plants. Treated water discharges to groundwater or is conveyed to downstream drainage systems such as waterways, channels or pipes. Bioretention systems also contribute to managing hydrology by slowing the rate of discharge of stormwater to the receiving environment and reducing volume through evapotranspiration.

Through careful integration and a collaborative design approach, bioretention systems must also provide multiple benefits. These benefits include:

- conserving water through the passive irrigation of landscape features by stormwater which reduces the demand on alternative water sources for irrigation
- creating or enhancing green spaces within the urban landscape
- providing amenity and aesthetic values for the community.

When multiple benefits are achieved they assist in maximising the social, cultural, economical and environmental outcomes for the community and our waterways.

Figure 1 The WSUD timeline and supporting guidelines



1.1 History and context of the guidelines

A comprehensive suite of tools and guidelines developed by Water by Design are available to support the planning, design and implementation of WSUD in Queensland. Figure 1 illustrates these tools and how they can be used in the context of a typical urban development process.

The *Water Sensitive Urban Design Technical Design Guidelines for South East Queensland (Water by Design)* were first released in June 2006. They provide guidance on the design, construction, establishment and maintenance of various stormwater management systems, including both bioretention swales and bioretention basins. Since the *Technical Design Guidelines* (Water by Design) were first published, the design of bioretention systems has evolved significantly.

The *Technical Design Guidelines* (Water by Design) addressed bioretention systems in several chapters. These included:

- Chapter 1 – Introduction
- Chapter 3 – Bioretention Swales
- Chapter 5 – Bioretention Basins
- Appendix A – Plant Selection for WSUD Systems.

With the release of version 1 of the *Bioretention Technical Design Guidelines*, all bioretention references in the *Water Sensitive Urban Design Technical Design Guidelines for South East Queensland* (Water by Design) were superseded by either that document, or another Water by Design publication. This revision (version 1.1) provides further information on drought resilience and additional guidance on plant selection.

1.2 Structure of the guidelines

Each of the five chapters of this guideline describes a particular aspect of the detailed design of bioretention systems. Table 1 outlines the content of each chapter.

Table 1 Structure and content of the *Bioretention Technical Design Guidelines*

Chapter 1 – Introduction	Introduces bioretention systems and the concept of WSUD. Provides the history, context and structure of this guideline.
Chapter 2 – Background	Provides background information critical to designing and managing bioretention systems. It describes the key features, possible configurations and drainage profiles of bioretention systems as well as outlining how and in what situation they can be applied. The concepts and nomenclature introduced are used throughout the document.
Chapter 3 – Design Process	Documents a design process that is proven to apply across the broad scales and configurations of bioretention systems available, and the contexts in which they can be applied. Each component of a bioretention system is addressed individually. Design details provided are divided into 'performance outcomes' and 'recommended approach'. The 'performance outcomes' outline the outcome to be achieved in designing each component of a bioretention system, while the 'recommended approach' is one approach which is proven to achieve the performance outcome. This delineation is to ensure that the essential aspects of bioretention design are incorporated, while also encouraging innovative approaches to design.
Chapter 4 – Specification Guide	Provides standard specifications for typical bioretention systems to assist in ensuring they are constructed correctly. The specifications can be used as an example, or where appropriate copied directly into tender packages.
Chapter 5 – Worked Example	Provides a worked example of the design of a bioretention system. The reader is guided through the process of designing a bioretention system in accordance with the recommended approach outlined in Chapter 3.

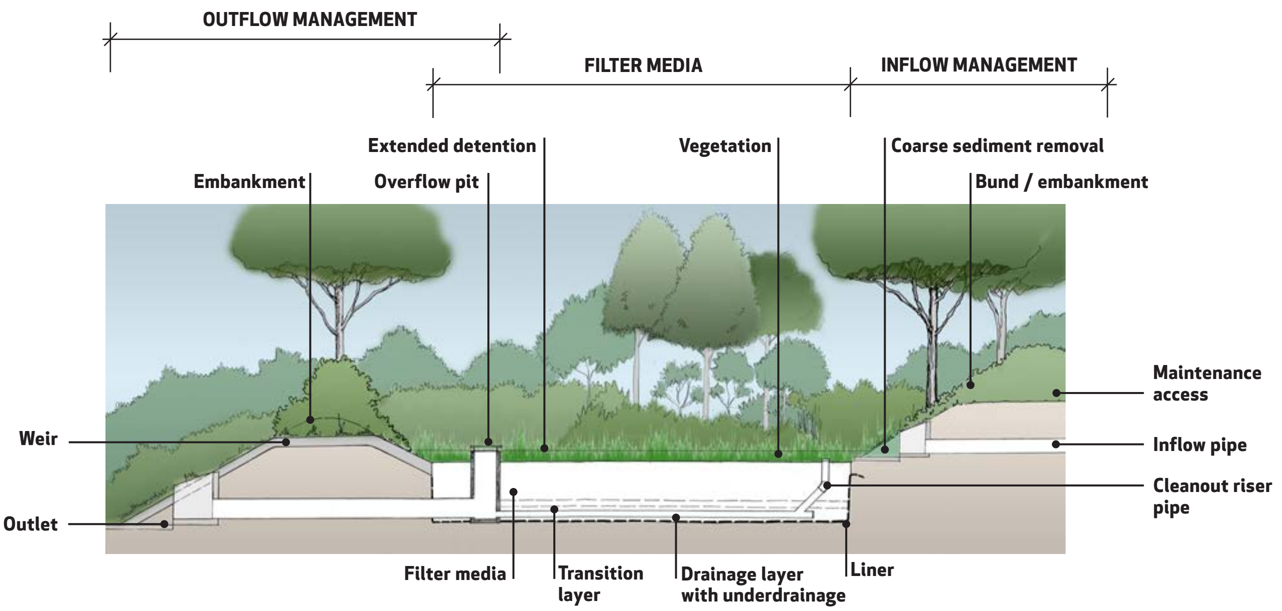
TWO **BACKGROUND**

2.1 What are bioretention systems?

Bioretention systems are shallow depressions in the urban landscape designed to collect and treat stormwater. Figure 2 depicts a typical bioretention system. Stormwater conveyed to a bioretention system is treated by filtering the stormwater through a densely vegetated, biologically active sand and loam filter media. As the water percolates through the filter media, pollutants are captured by fine filtration, adsorption and biological processing by both soil microbes and plants. Treated water discharges to groundwater or is conveyed via slotted or perforated pipes to downstream drainage systems such as waterways, channels or pipes.

As well as removing pollutants, bioretention systems also help manage changes in hydrology that occur as a result of urbanisation. For example, runoff from small rainfall events is captured above the filter media surface, in the extended detention zone, and slowly percolates through the bioretention system's filter media. By delaying the release of stormwater, bioretention systems can mimic aspects of pre-development hydrology such as baseflow regimes and reduce pressures on urban streams. The volume of runoff is also reduced through evapotranspiration or infiltration into the surrounding soil.

Figure 2 Components of a typical bioretention system



The main components of a bioretention system are:

- **Filter Media** - a sand and loam mix that supports vegetation and removes stormwater pollutants. Filter media is typically 500–1000 mm deep. The minimum recommended filter media depth to support vegetation is 400 mm; however, this depth should only be considered in exceptional circumstances. The filter media surface is generally flat, except for bioretention swales.
- **Transition Layer**- coarse sand located under the filter media as a 'bridging' layer to prevent finer filter media particles migrating into the drainage layer, perforated underdrainage pipes, downstream waterway and the surrounding soil.
- **Underdrainage** – a combination of fine aggregate and slotted or perforated underdrainage pipes that allows treated stormwater to leave the bioretention system. The exact configuration of the underdrainage depends on the type of bioretention system being designed (see Section 2.4).
- **Liner** – a layer surrounding either or both the base and sides of bioretention systems. Liners can be either permeable or impermeable. The need for a liner is dependent on the type of bioretention system being designed (see Section 2.4).
- **Hydraulic Structures** – typically an inflow pipe, overflow pit, outlet and weir, hydraulic structure serve to convey stormwater into the bioretention system, and discharge it after treatment.
- **Bunds and Embankments** – earthen structures necessary to integrate bioretention systems within the surrounding topography. They vary in size and slope depending on the location, size and context of the system, and serve to detain water prior to filtration.
- **Extended Detention** - a 100–300 mm layer above the bioretention system's surface that temporarily stores stormwater before it infiltrates into the filter media. The extended detention is created by raised pits, weirs, or other hydraulic structures. Its purpose is to spread flows over the surface of the filter media and increase the volume of stormwater runoff that can be treated.
- **Vegetation** – in conjunction with soil biology, is the 'biological' component of bioretention systems. Vegetation is critical for stormwater treatment. Vegetation takes up nutrients, supports biological growth (critical for pollutant removal), maintains and enhances the porosity of soil, and continuously breaks up the surface of the filter media to help to prevent surface clogging. Vegetation in bioretention systems (grasses, sedges, shrubs and trees) must be tolerant to extended dry periods and periodic inundation.
- **Coarse Sediment Removal** – a dedicated area to capture and store coarse sediment. Coarse sediment removal is comprised of either a coarse sediment forebay or an inlet pond. It also helps dissipate energy and protect against scour around inlets.
- **Maintenance Access** – a dedicated access to the bioretention system which allows for easy and cost effective maintenance.
- **Cleanout Riser Pipe** – an unperforated upright pipe connected to the ends of each underdrainage pipe to allow inspection and cleaning of the underdrainage.

2.2 Context in the landscape

Bioretention systems are flexible in size, shape and appearance. They can be readily integrated into a range of landscapes including individual development sites, allotments, streetscapes, civic spaces and forecourts, parklands and adjacent to riparian and bushland settings. Bioretention systems can be designed to seamlessly integrate with the local landscape or they can be a prominent landscape feature. The following categories of bioretention system are provided to showcase the range of applications, locations and contexts within which bioretention systems can be applied.

2.2.1 Within allotments

Bioretention systems may be located within allotments, on private land. Figure 3 depicts a bioretention system located within an allotment. Bioretention systems within allotments can take the form of raingardens on individual residential lots or small bioretention basins on commercial, industrial and multi-unit developments. They have shallow surfaces, usually less than 750mm below their surroundings, and accept stormwater via surface flow and shallow, small diameter pipes. They typically have a total filter media surface area of 5–200 m^2.

Figure 3 Examples of bioretention systems within allotments

Photo: Shaun Leinster, DesignFlow

Photo: Jack Mullaly, Healthy Waterways

Photo: Robin Allison, DesignFlow

Photo: Jack Mullaly, Healthy Waterways

2.2.2 In the streetscape

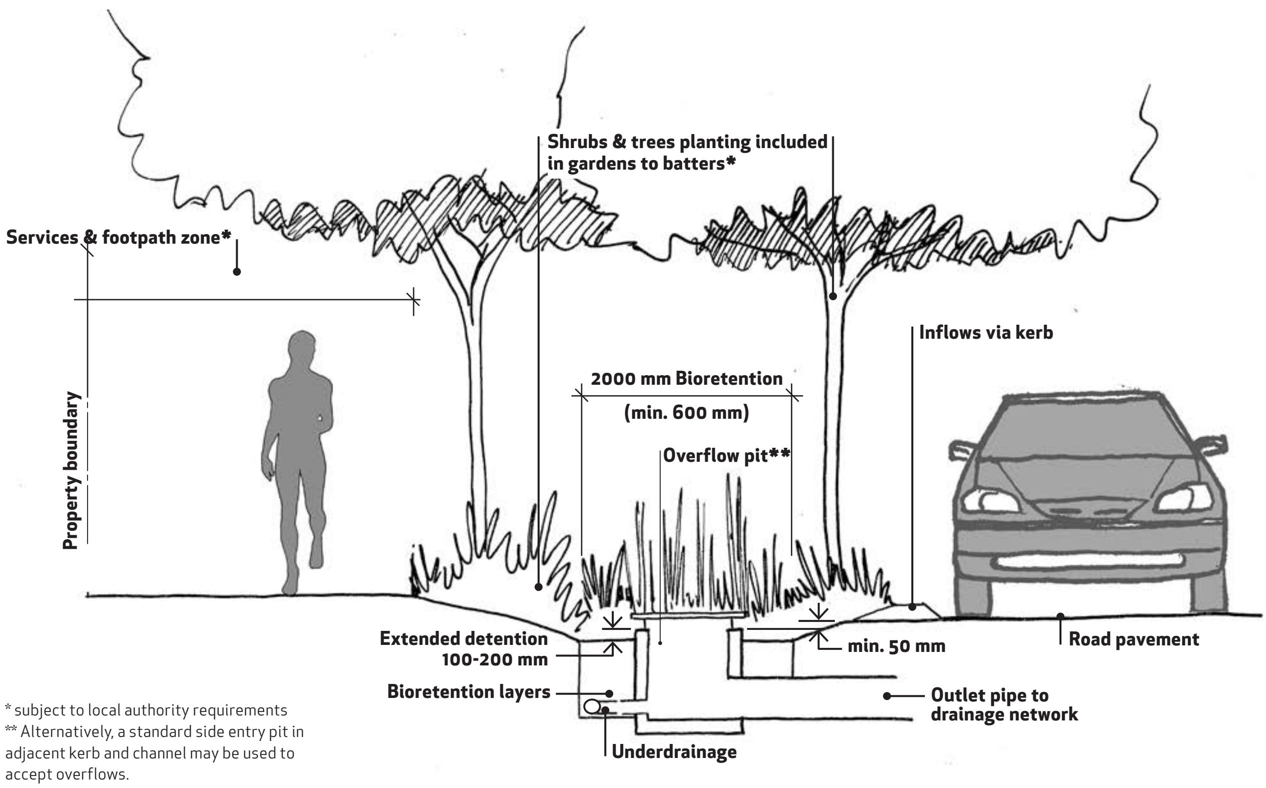
The streetscape is an effective and attractive location for a bioretention system. Streetscape bioretention systems are integrated into road reserve verges or traffic calming 'build-outs' from the kerb (Figure 4 and Figure 5). They receive and treat stormwater before it enters underground drainage systems. This allows them to be implemented on flat topography where end-of-pipe treatments are often not feasible due to level constraints.

Streetscape bioretention systems are often located where conventional side-entry pits would usually go (e.g. road low points and road intersections). Bioretention layers can generally fit within the depth needed to accommodate the minor drainage pit (with appropriate cover). As such, bioretention systems in the streetscape do not dictate the depth of the minor drainage system. The layout and size of streetscape systems is however restricted by other streetscape components such as footpaths, road pavements, and underground services corridors, which are defined by local authorities

Streetscape bioretention systems typically have a total filter media surface area of 5-50 m^2. The filter media surface is not substantially lower than the adjacent road surface and verges (< 500 mm).

The *Concept Design Guidelines for Water Sensitive Urban Design* (Water by Design) provides a model streetscape bioretention layout.

Figure 4 Streetscape bioretention cross-section



* subject to local authority requirements
** Alternatively, a standard side entry pit in adjacent kerb and channel may be used to accept overflows.

Figure 5 Examples of bioretention systems in the streetscape

Photo: Shaun Leinster, DesignFlow

Photo: Jack Mullaly, Logan City Council

Photo: Shaun Leinster, DesignFlow

2.2.3 Within civic space

Bioretention systems can be integrated into civic spaces as an attractive feature (Figure 6). They can also be combined with stormwater harvesting for non-potable uses such as landscape irrigation, topping up water features or within buildings for flushing toilets. The plant species and planting densities chosen for civic space bioretention systems should complement the surrounding urban space. Often this includes mass planting of a small number of plant species with low to medium vegetation height.

Civic space bioretention systems are designed with the filter media surface level close to the level of adjacent urban spaces. A difference of less than 500 mm between the two levels is recommended. Flows can be directed onto the bioretention surface through small, shallow drains (e.g. grated trenches). The total filter media surface area of civic space bioretention systems is typically 5-100m^2.

Figure 6 Examples of bioretention systems within civic space

Photo: Jack Mullaly, Logan City Council

Photo: Shaun Leinster, DesignFlow

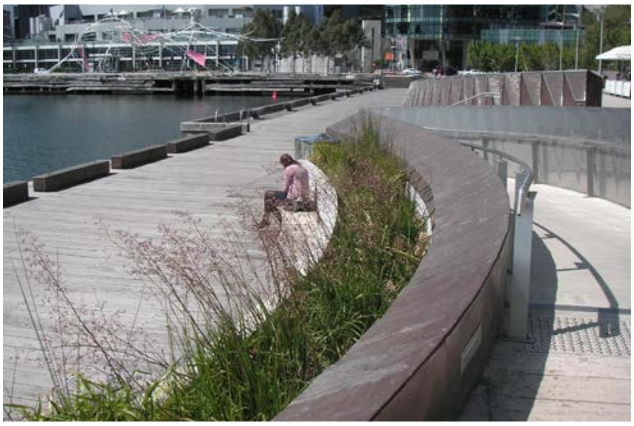


Photo: Robin Allison, DesignFlow

2.2.4 Within and adjacent parkland

Bioretention systems can be easily integrated within or adjacent to parkland (Figure 7). This has the benefits of increasing continuity of green space, engaging the community with the water cycle and providing opportunities to reuse stormwater. Planting of parkland bioretention systems should complement surrounding landscape space and include a diverse number of species, preferably trees and shrubs, including planting on batters.

Parkland bioretention systems are typically end-of-pipe systems, receiving inflows from a piped network. However some are designed as at-source systems to receive overland flow from hardstand areas, and some can do be designed to function as both end-of-pipe and at-source systems. Parkland bioretention systems can be sited within flood detention infrastructure. The filter media area of parkland bioretention systems is typically 50 – 800m^2.

Figure 7 Examples of bioretention systems within and adjacent to parkland

Photo: Shaun Leinster, DesignFlow

Photo: Jack Mullaly, Logan City Council

Photo: Jack Mullaly, Healthy Waterways

Photo: Jack Mullaly, Healthy Waterways

2.2.5 Adjacent to natural areas

Locating bioretention systems adjacent to natural areas such as bushland or riparian corridors is an easy way to achieve benefits above and beyond traditional stormwater management requirements. Bioretention systems located next to natural areas enhance the overall green space and provide for wildlife habitat and movement (Figure 8). They also have the potential to reduce maintenance costs through reducing edge effects and shading weeds.

Bioretention systems adjacent to natural areas are integrated with their surrounding landscape. This creates systems with informal shapes and gentle batter slopes, rather than hard edges. Planting in such systems should complement surrounding landscape and involve a well-structured and diverse landscape including grasses, sedges, shrubs and trees.

Bioretention systems adjacent to natural areas are typically end-of-pipe systems, receiving inflows from a piped network. They can be sited within flood detention infrastructure. Their filter media surface area is typically 50–800 m^2.

Figure 8 Examples of bioretention systems adjacent to natural areas

Photo: Jack Mullaly, Logan City Council

Photo: Jack Mullaly, Healthy Waterways

Photo: Jack Mullaly, Healthy Waterways

Photo: Jack Mullaly, Healthy Waterways

2.3 Configurations

The multiple contexts that bioretention basins are used in (see Section 2.2) require bioretention configurations that can adapt to the nature of the site in which they are located. Selecting the appropriate configuration for the site is important to ensure it integrates into the surrounding landscape, functions effectively and allows for easy and cost effective maintenance. There are four main configurations of bioretention system:

- Bioretention Basins
- Bioretention Swales
- Biopods
- Bioretention Street Trees.

2.3.1 Bioretention basins

Bioretention basins are an end-of-pipe bioretention system. They can vary in size greatly, typically from 100-800m^2 of filter media surface area. Bioretention basins are often located adjacent to parkland or natural areas (Figure 9). The vegetation used reflects the location. For example, bioretention basins located adjacent to parkland include vegetation compatible with other landscaping in the parkland, while bioretention basins adjacent to natural areas use species which reflect the ecosystem of that natural area.

Figure 9 Examples of bioretention basins

Photo: Shaun Leinster, DesignFlow

Photo: Shaun Leinster, DesignFlow

Photo: Paul Dubowski, BMT WBM

Photo: Jack Mullaly, Logan City Council

2.3.2 Bioretention swales

Bioretention swales are a type of bioretention system that both treats and conveys stormwater. A bioretention swale is comprised of all the main components of a bioretention system (see Section 2.1) co-located within the base of a swale (Figure 10 and Figure 11). For bioretention swales, the surface of the filter media follows the grade of the swale's surface (> 0.5% and < 2% slope) and is generally 600–2000 mm wide. The swale component of a bioretention swale conveys and pre-treats stormwater to remove coarse to medium-sized sediment. The bioretention filter media removes finer particulates and contaminants.

Bioretention swales are typically located within road reserves, parklands, and drainage easements with small catchments less than 2 ha. They can receive lateral flows across grassed or vegetated batters (1 in 4 or flatter) or directly from pipe outlets where there is adequate protection from scour. Bioretention swales are densely planted with sedges and rushes and may include trees to form a canopy.

Figure 10 Bioretention swale section

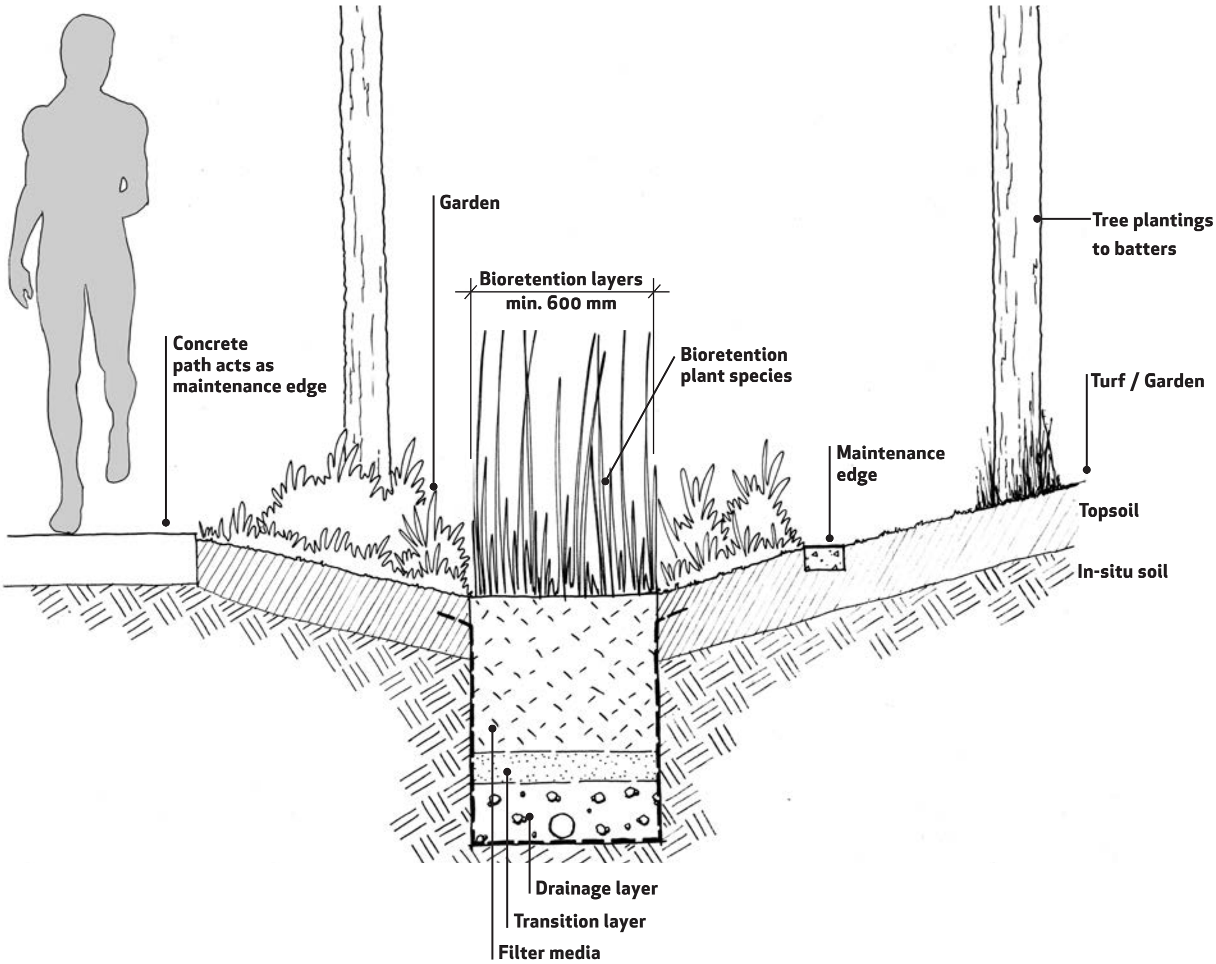


Figure 11 Examples of bioretention swales

Photo: Jack Mullaly, Healthy Waterways

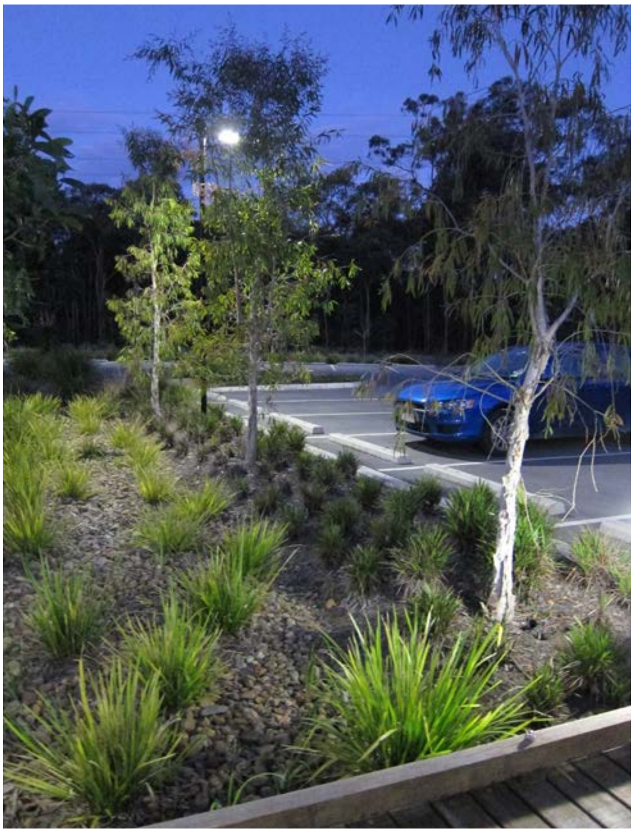


Photo: Jack Mullaly, Logan City Council

Photo: Jack Mullaly, Logan City Council

2.3.3 Biopods

Biopods are a form of at-source bioretention system. They receive stormwater runoff as overland flow from hardstand areas. Biopods are commonly used in the streetscape, but also have applications in commercial, industrial and multi-unit developments (Figure 12). They are typically less than 50m^2, but can be larger. Biopods provide visual amenity to streetscapes, similar to the outcomes of traditional streetscape landscaping. An advantage of biopods compared to traditional landscaping is that biopods are passively irrigated by stormwater inflows. Shrubs, grasses and sedges are the most commonly used types of vegetation, although trees are not precluded.

2.3.4 Bioretention street trees

Bioretention street trees are a combination of a bioretention system and a traditional street tree (Figure 13). They are located at-source and receive overland flow from adjacent hardstand areas. They are small systems, typically only a few square meters in size. The main type of vegetation used in this type of bioretention system are trees suitable for use in the streetscape, but shrubs, grasses and sedges can also be used for both aesthetic reasons, and to assist in maintaining the permeability of the filter media. If grasses, sedges and ground covers are not used, then much of the bioretention street tree's footprint may be covered by a solid surface (Figure 13).

Figure 12 Examples of biopods

Photo: Robin Allison, DesignFlow

Photo: Shaun Leinster, DesignFlow

Photo: Brad Dalrymple, BMT WBM

Figure 13 Examples of bioretention street trees

Photo: Brad Dalrymple, BMT WBM

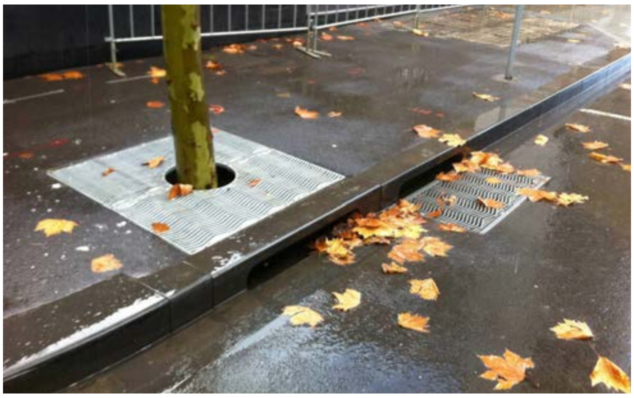


Photo: Brad Dalrymple, BMT WBM

Photo: Brad Dalrymple, BMT WBM

2.4 Drainage profiles

The term 'drainage profile' is the name given to how the filter media, transition layer, underdrainage and hydraulic structures are designed in order to discharge treated water from the system. There are four drainage profiles in common use (Figure 14), however the flexible nature of bioretention systems mean that other drainage profiles can be created. The four in common use are:

- Type 1 saturated zone
- Type 2 sealed
- Type 3 conventional
- Type 4 pipeless.

A description of these profiles is provided in Sections 2.4.1 to 2.4.4. Section 3.2.1 details how to select the most suitable drainage profile for the application.

2.4.1 Saturated zone bioretention systems

Type 1 saturated zone bioretention systems integrate a water storage (wet sump) in the transition and drainage layer. The water storage allows the vegetation to access water during dry periods, facilitates plant and soil biological health, and helps maintain ongoing treatment performance. Type 1 saturated zone bioretention systems have:

- an impermeable liner to ensure water is retained in the base of the system
- an outlet structure that holds water at a defined level within the transition and drainage layer, only able to be drawn down further through evapotranspiration
- a transition layer (transition layer depth varies, see Section 3.2.2.4)
- a drainage layer (drainage layer depth varies, see Section 3.2.2.3 and Section 3.2.2.4)
- a flat base beneath the drainage layer.

2.4.2 Sealed bioretention systems

Type 2 sealed bioretention systems drain via slotted or perforated underdrainage pipes and do not have a saturated zone. Sealed bioretention systems have:

- an impermeable liner around the base and sides
- a transition layer that is at least 100 mm deep
- a drainage layer that is at least 150 mm deep that grades towards the outlet, preferably at a slope of ≥ 0.5%, to ensure treated stormwater drains freely from the base of the bioretention system
- slotted or perforated underdrainage pipes within the drainage layer with ≥ 50 mm aggregate above them.

2.4.3 Conventional bioretention systems

Type 3 conventional bioretention systems encourage infiltration into the surrounding soils to manage frequent stormwater flows, and have slotted or perforated underdrain pipes for drainage when the infiltration capacity of the soil is exceeded. Conventional bioretention systems have:

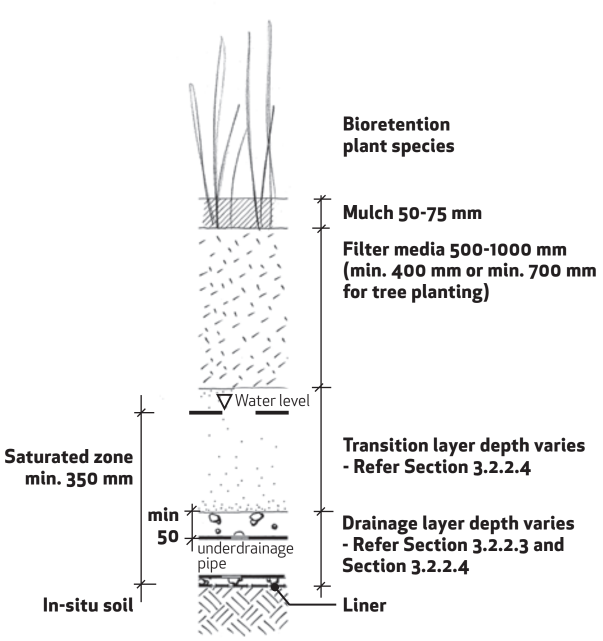
- a permeable geotextile liner around their sides (no liner along the base);
- a transition layer that is at least 100 mm deep
- a drainage layer that is at least 300 mm deep with a slotted or perforated pipe that has at least 50 mm aggregate above it and at least 150 mm aggregate below it
- a flat base under the drainage layer.

2.4.4 Pipeless bioretention systems

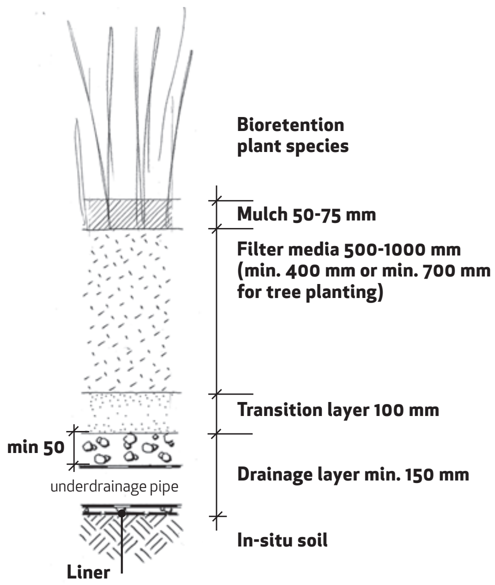
Type 4 pipeless bioretention systems allow all the treated stormwater to infiltrate into the surrounding soil. Pipeless bioretention systems have:

- a permeable geotextile liner around their sides (no liner along the base)
- a transition layer that is at least 100 mm deep
- no drainage layer or slotted or perforated underdrainage pipes
- a flat base under the transition layer.

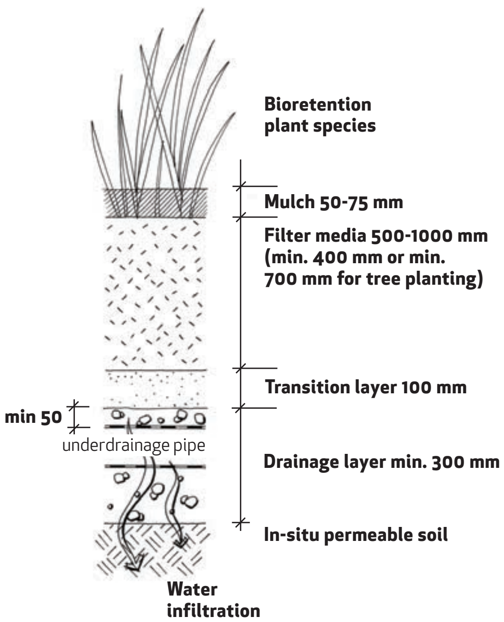
Figure 14 Bioretention drainage profiles



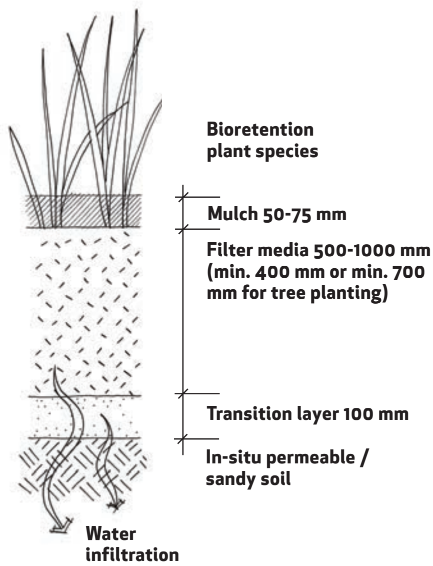
TYPE 1 SATURATED ZONE



TYPE 2 SEALED



TYPE 3 CONVENTIONAL



TYPE 4 PIPELESS

2.5 Site suitability

Bioretention systems are permanent; therefore, it is important that their size and location are appropriate for function, aesthetics, constructability, and maintenance requirements. Tables 2 and 3 outline a range of bioretention applications. They highlight important design characteristics for each application.

Table 2 When to use bioretention systems

Situation	Why bioretention is suitable
For managing litter, sediment, nutrients, metals and hydrocarbons transported by stormwater	Bioretention systems are effective at removing anthropogenic and organic litter, fine sediment, phosphorus, nitrogen, metals and hydrocarbons from stormwater. Where litter or coarse sediment loads are high, pre-treatment is recommended.
For managing stormwater flows	Bioretention systems can be used to manage urban hydrology, particularly frequent stormwater flows. They can also be combined with flood storage for large events, although bioretention systems are not designed specifically for this purpose.
For urban or civic landscapes, residential parkland and riparian and bushland landscapes	Bioretention systems have a flexible design and their vegetated finish allows them to be easily incorporated into a range of landscapes, from hard edge civic spaces to more natural residential parkland, bushland, or riparian settings.
For small catchments or where space is constrained	Bioretention systems are small (typically < 3% of the catchment area) allowing them to be used in small and constrained spaces.
For large catchments	Bioretention systems can manage runoff from large catchments if design solutions specifically developed for large systems are used (e.g. suitable distribution system).
On moderate to steep topography	Through careful design, bioretention systems can be readily integrated into relatively steep topography.
On flat topography	Bioretention systems can be located at-source or within streetscapes directing runoff onto the surface of the bioretention system before it enters an underground drainage network.
For stormwater harvesting	Bioretention systems can treat stormwater to a level suitable for some forms of re-use. It is important to account for any potential water losses through bioretention systems when estimating yields for stormwater harvesting systems.

Table 3 When not to use bioretention systems

Situation	Why bioretention is not suitable
For sites with insufficient elevation	Bioretention systems will not drain adequately if there is insufficient elevation from the surface of the system to the receiving drainage system. This will cause the filter media to remain inundated, and affect both the health of plants and the functioning of the bioretention system.
For sites with tidal influence	Saline water compromises the biological function of bioretention systems.
For sites with continuous inflow (i.e. constantly wet)	Moss or algae can form thick surface biofilms (or slimes) in continuously wetted bioretention systems, which reduce the rate of infiltration into the filter media. Periodic drying of bioretention systems is necessary to reduce the risk of blockages due to surface biofilm growth.
For swales with high velocities	High-flow velocities (> 1 m/s) are likely to scour the surface of bioretention systems.
For sites subject to toxic runoff	When the system is likely to be exposed to toxic substances (e.g. herbicides, solvents or industrial contaminants), biological function will be compromised. Structural separation should be used to exclude contaminants from the stormwater system.
When the system cannot be easily accessed for maintenance	Bioretention systems require periodic maintenance to ensure optimal function. As such, it is essential that easy access for maintenance is available.

2.6 Function over time

Bioretention systems provide a range of functions including managing hydrology, removing pollutants and enhancing amenity. Some of these functions are provided as long as the bioretention system remains in place while others vary over time. Most functions remain high while the porosity of the filter media is maintained and suitable plants are retained within the system. Careful selection of desirable plant species can aid in maintaining filter media porosity.

Hydrologic function – Bioretention systems designed for hydrologic benefits such as reducing stormwater volumes entering waterways will perform this function indefinitely while the hydraulic conductivity of the filter media remains close to the design rate.

Sediment removal – Sediment removal is a relationship between filter media grading and the porosity of the filter media. Sediment removal will remain constant while the hydraulic conductivity of the filter media remains close to the design rate.

Phosphorous removal – Phosphorus occurs in stormwater in particulate (attached to sediments) and soluble (dissolved) forms. Bioretention systems remove particulate sediment from stormwater via physical filtration within the filter media. Soluble phosphorous is removed by sorption onto fine particles within the filter media and to a lesser extent biological uptake by plants. Filter media has a finite capacity to retain dissolved phosphorous; however this capacity may be replenished over time due to new sediment entering the bioretention system and uptake by plants. After a given time, when the capacity of the filter media to retain dissolved phosphorous is exhausted, phosphorous removal within the bioretention system will decrease to a lower rate, comprised of filtration of particulate phosphorous and biological uptake of soluble phosphorous. About 40% of total phosphorous is associated with particles greater than 50 micron (Vaze and Chiew 2004). It is reasonable to expect this phosphorus to be removed in a bioretention system even after sorption capacity in the system has been exhausted. The time at which this occurs is driven by the amount of filter media (surface area and depth) in the bioretention system compared to total catchment area.

Nitrogen removal – Nitrogen occurs in stormwater in particulate, organic or soluble forms. Nitrogen processing in bioretention systems occurs through a combination of mineralisation, nitrification and denitrification. These processes change the form of the nitrogen. Nitrogen is ultimately removed from the stormwater by either plant uptake or by being released to the atmosphere as nitrogen gas. For this to occur, the bioretention system must contain a suitable amount of desirable plants (see Section 3.6.4). The plants in turn support microbial communities which facilitate this nitrogen processing. Newly constructed bioretention systems may see an initial lag in nitrogen removal until plants establish during the first growing season. Once plants are established, nitrogen removal in bioretention systems should remain relatively constant over time, so long suitable plants remain in the system and the filter media porosity is maintained.

Heavy metal removal – Heavy metals occur in stormwater in particulate (attached to sediments) and soluble (dissolved) forms. Bioretention systems remove particulate metals from stormwater via physical filtration within the filter media. Much like phosphorous, soluble metals are removed by sorption onto fine particles within the filter media and to a lesser extent biological uptake by plants. Filter media has a finite capacity to retain dissolved metals; however this capacity may be replenished over time due to new sediment entering the bioretention system and uptake by plants. After a given time, when the capacity of the filter media to retain dissolved metals is exhausted, metals removal within the bioretention system will decrease to a lower rate comprised of filtration of particulate metals and biological uptake of soluble metals. The time at which this occurs is driven by the amount of filter media (surface area and depth) in the bioretention system compared to total catchment area.

Hydrocarbon removal – Bioretention systems remove hydrocarbons from stormwater by volatilisation and processing by microorganisms. While filter media porosity remains close to its design rate, hydrocarbon removal should remain constant.

Amenity – Bioretention systems provide amenity through the quality of design and plant selection. Amenity will increase as plants establish, and then remain relatively constant over time, varying seasonally, with climate and maintenance regime.

THREE **DESIGN PROCESS**

Designing bioretention systems requires the civil, landscape and ecological aspects of the site to be considered to ensure systems are functional, well integrated with the urban landscape, and that they complement local ecology.

Bioretention design involves multiple stages and iterations as illustrated in Figure 15. The concept design phase involves selecting the most appropriate treatment measure, and identifying the location, size and indicative shape of the treatment system within the site. The *Concept Design Guidelines for Water Sensitive Urban Design* (Water by Design) should be used to guide the concept design phase. These concepts form the basis of detailed design, described in this document.

There are two approaches that are commonly used when designing bioretention systems. The first is a linear process. In this model, background investigations (Section 3.1) inform the spatial location of the bioretention system via specifying layers, depths and levels (Section 3.2) and finalizing the layout (Section 3.3). Inlet (Section 3.4), outlet (Section 3.5) and vegetation design (Section 3.6) are then be completed, design checks (Section 3.7) undertaken and the design documented (Section 3.8). While this approach can achieve acceptable outcomes for very simple designs, it does not allow for complexity, collaboration and achieving multiple design objectives. The second approach is highly collaborative and iterative. The design team works together throughout the process and is cognisant of all design objectives at all times. This ensures that the optimum outcome is achieved and time consuming repetition of design steps avoided. It is recognised that there are perceived additional costs for collaborative design; however this process ultimately results in significant cost savings and the delivery of assets that are integrated with the landscape and accepted by the local community.

DESIGN NOTE: Bioretention design teams

The design process for bioretention systems should be:

- **Collaborative** between stormwater engineers, ecologists, landscape architects, and urban designers to ensure optimal functional, ecological, and aesthetic outcomes. Ideally the same design team should be involved in the concept design and the detailed design to ensure continuity and avoid misinterpretations.
- **Iterative** to ensure the design is responsive to changes in constraints, opportunities, and urban design.

The outcome of detailed design is a design report, a set of engineering and landscape drawings and construction specifications, which clearly communicate the design in sufficient detail for assessment (if required) and construction.

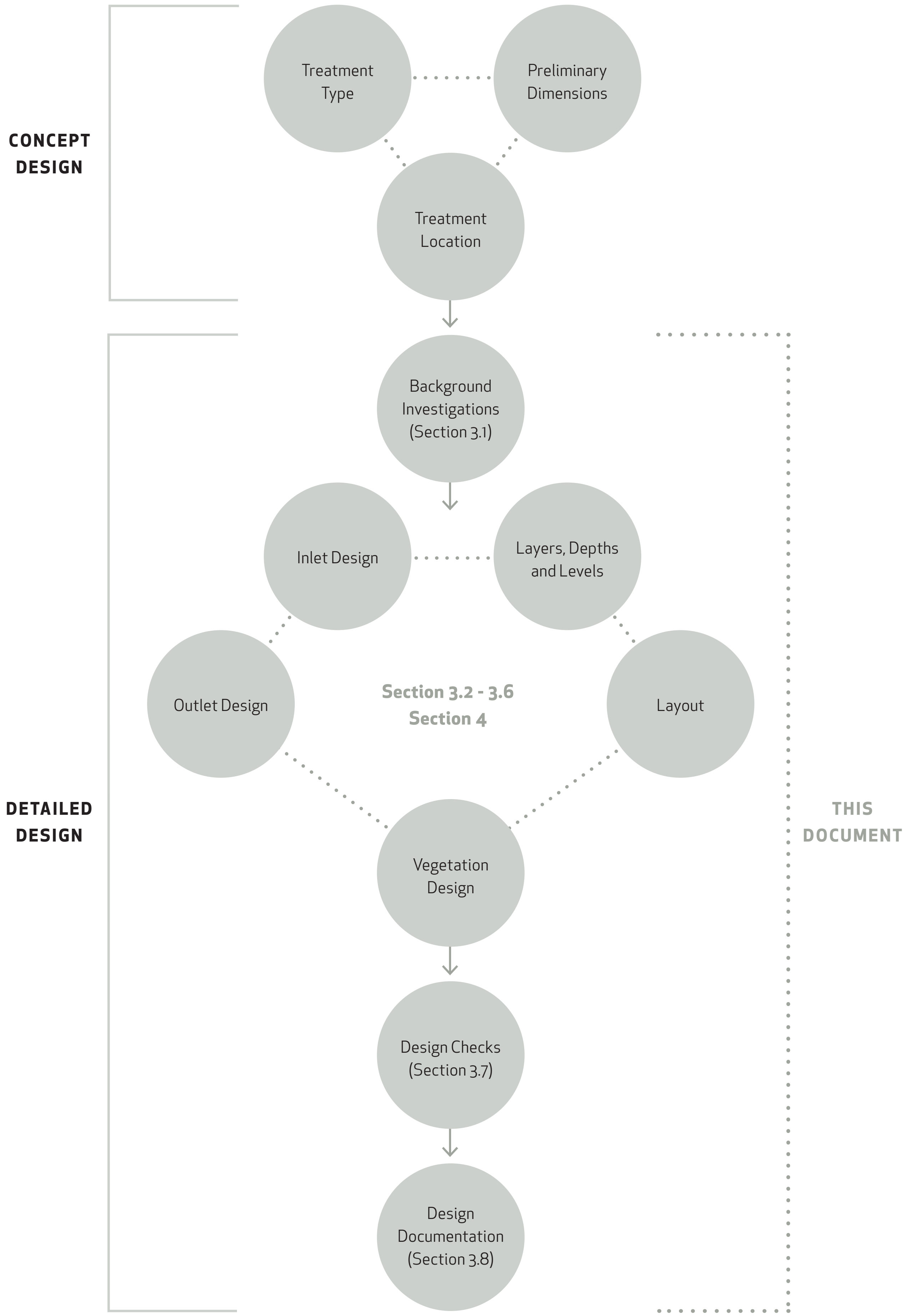
This section details the bioretention system design process. The design of each component of a bioretention system is addressed individually. Design details provided are divided into 'performance outcomes' and 'recommended approach'. The 'performance outcomes' outline the aim to be achieved in designing each component of a bioretention system, while the 'recommended approach' is one approach which is proven to achieve the performance outcome. This delineation is to ensure that the essential aspects of bioretention design are incorporated, while also encouraging innovative approaches to design.

In situations where the design of one element of a bioretention system is closely related to the design of another, cross references are provided.

DESIGN NOTE:
Local authority and service provider requirements

The design process and guidance provided in this document is based on a process that has been proven to work across many projects and locations. However individual local authorities and service providers may have standards and requirements which differ to those provided in this document. It is important to consult with the local authority and service providers early in the design process (see Section 3.1.3) and where specific requirements exist, defer to them.

Figure 15 Bioretention design process



3.1 Background investigations

Background investigations are required to ensure that site specific opportunities and constraints are identified early in the design process, and incorporated into the bioretention system's design. Undertaking the necessary background investigations streamlines the design process, reduces delays and mitigates risk during design, construction, establishment and operation. The background investigations required are:

- Analysis of the site
- Defining design objectives
- Consulting with the local authority.

3.1.1 Site analysis

PERFORMANCE OUTCOMES

Site analysis must:

- understand the site's constraints and opportunities
- test any assumptions made during concept design.

RECOMMENDED APPROACH

Site information should be obtained using desktop analysis and site inspections. All members of the design team should visit the site. Team members are likely to have visited the site during concept development; however, a site visit is still recommended at the start of the detailed design phase, to verify the suitability of the concept and to collect more detailed information. Ideally, the whole design team should attend an initial site inspection to develop a clear understanding of the intent of the bioretention system's design, within context of the site.

The amount and quality of information required for detailed design will vary between projects. Table 4 summarises the information typically required for detailed design. This information should be collected digitally and presented on an annotated plan.

Table 4 Site information requirements

Information	Requirements	Primary responsibility
Topographical site survey	Survey the site and external areas (where applicable) to assess existing flow pathways.	Surveyor
Boundaries	Determine boundaries of existing and proposed road reserves and allotments and any access routes that may cross the bioretention system. Consider if boundaries or routes are fixed or if there is scope to amend them.	Surveyor
Catchments	Determine the catchment area from: • a topographic survey for bioretention systems receiving surface flows • drainage network plans for bioretention systems receiving piped flows.	Stormwater specialist
Hydrology and drainage infrastructure	Inspect the site, waterways, bioretention catchment and receiving drainage during and after rainfall to verify: • flow direction and behaviour • presence of baseflow • ponded water zones. Survey the size, location, and levels of existing drainage and waterway features upstream, within, and downstream of the site. Importantly, invert levels of drainage systems that will receive outflows from the bioretention system should be collected as well as the levels of any existing upstream contributing drainage. If water is ponding in these drainage systems, survey the water level after rainfall. Confirm seasonal variation in water levels, particularly in low-lying areas. Where the bioretention system will connect with or abut future drainage infrastructure, the latest infrastructure design plans should be consulted in lieu of a survey.	Stormwater specialist, civil engineer, surveyor

Table 4 Site information requirements continued

Information	Requirements	Primary responsibility
Services	Where the bioretention system will be retrofitted into a site, identify existing services by undertaking a 'Dial Before you Dig' search (www.dialbeforeyoudig.com.au). Include the depths of underground services on the site survey plans. Physical detection of underground services may be required.	Civil engineer
Flora and fauna	If a site contains individual plants or vegetation communities that are to be preserved, survey their size, location, level and drip zone. Review any flora and fauna reports for the site and receiving waterways. Identify locally occurring native plant species that are performing well in similar conditions to the conditions of the proposed bioretention system. Identify the extent and location of invasive weeds that may influence design as well as any planting combinations that are successfully suppressing weeds.	Ecologist, surveyor
Soil	Identify details of the site's soils (type, chemistry and structure) through previous investigations (concept design stage), a review of soil maps, or a soil assessment in accordance with AS/NZS 1547:2000 Clause 4.1.3. Where a permeable base or sides are proposed for the bioretention system (Type 3 or 4 drainage profile), test in-situ hydraulic conductivity and assess groundwater to confirm whether water will infiltrate into in-situ soils from the bioretention base. Undertake a preliminary desktop assessment for acid sulphate soils (ASS) or contamination. If there is a potential risk, further geotechnical investigations are required to ensure these soils are avoided or appropriately managed. Management plans for ASS or contaminated soils should be developed by a suitably qualified professional.	Stormwater specialist and soil scientist
Groundwater	Determine the general characteristics of the local groundwater: • ensure the bioretention system will not cause adverse impacts (i.e. draining local groundwater, acid sulphate impacts) • determine whether infiltration of filtered flows into surrounding soil can occur. Preliminary assessment of groundwater should be undertaken at the same time as the soil assessment. Where elevated or acidic groundwater is detected, further groundwater investigations may be required to ensure the bioretention system does not interact with the groundwater (i.e. liner requirements). This work should be undertaken by a suitably qualified engineer or hydrogeologist.	Stormwater/ WSUD specialist, soil scientist, hydrogeologist.
Landscape features and integration issues	Interpret existing landscape features and, where relevant, survey these features. Features may include: • pedestrian and vehicle circulation and access points • view corridors • the character and nature of any adjacent development and land use.	Landscape architect
Other	Other information may also be required, such as: • aerial photos (current and historical) • site history and contamination to understand potential issues during excavation • tidal information • cultural and heritage information • local or regional flood levels (additional flood modelling is often required as part of overall project).	Stormwater specialist

3.1.2 Design objectives

PERFORMANCE OUTCOMES

The design objectives for bioretention systems must :

- be clear, align with local policy, and be agreed to by project team
- cover landscape, engineering, and ecological considerations.

RECOMMENDED APPROACH

Design objectives should be confirmed and agreed to by the design team, the client, and the local authority.

Each bioretention system will generally have a primary design objective and one or more secondary design objectives. Design objectives often form part of land development approval conditions. Example of bioretention system design objectives are:

- improve stormwater quality (typically the primary objective, in line with state or local government policies for the environmental protection of receiving waters)
- manage the rate and frequency of minor stormwater flows
- introduce a landscape feature into an urban setting
- enhance ecological values, (i.e. increase local biodiversity)
- buffer or integrate with an existing bushland or riparian corridor to enhance degraded conditions
- facilitate passive landscape irrigation
- engage and educate the community.

Objectives will dictate or influence particular design details. For example, if the primary objective of the bioretention system is stormwater quality and a secondary objective is linking it to an existing riparian zone, then the system will have shrubs and trees that integrate with the existing riparian vegetation communities.

3.1.3 Local authority consultation

PERFORMANCE OUTCOMES

The local authority's requirements and preferences for bioretention design, construction, and maintenance must be understood and incorporated into the design process.

RECOMMENDED APPROACH

Local authorities should be consulted early in the design process to discuss the intent and purpose of the bioretention system. Local authorities will often be the ultimate owners of bioretention systems that are, for example, handed over to the local authority by developers as contributed assets. Therefore, it is important that issues such as maintenance requirements are understood from the start.

The following information should be discussed with the local authority:

- relevant standard drawings
- formal or informal policies relating to bioretention
- biodiversity issues and opportunities
- bioretention flood immunity requirements
- maintenance approach
- access requirements
- physical constraints on maintenance techniques (e.g. excavator reach length)
- level of service
- budget
- problems with existing systems.

DESIGN NOTE: Development staging and asset handover impacts on bioretention design

It is important to identify the local authority requirements for accepting contributed stormwater assets as part of development. Authorities will generally not accept poorly constructed, unfinished, damaged, or unestablished vegetated stormwater assets that are still subject to significant disturbance by construction and building activities in the catchment.

Therefore, the design of bioretention systems in large developments should take account of the proposed staging and desired timing for compliance and asset handover processes. Multiple smaller bioretention systems rather than a single, larger system may avoid potential issues associated with multi-stage developments.

3.2 Layers, depths and levels

In order to operate effectively, adequate elevation must be provided for each of the bioretention system's layers. The design of layers, depths and levels are dictated by site constraints (see Section 3.1.1), design objectives (see Section 3.1.2) and the preferred drainage profile of the bioretention system (see Section 3.2.1). Several iterations of a layer profile design may be needed to satisfy all engineering and landscape requirements.

When setting bioretention system layers, depths and levels, the following should be specified:

- drainage profile type
- filter media depth and level
- transition layer depth and level
- drainage layer depth and level
- saturated zone depth and level
- outlet pipe levels
- base level and liner type
- outlet pit level
- overflow weir level
- extended detention depth and level
- maximum water level
- batter and embankment levels
- inlet levels
- coarse sediment forebay levels.

When setting levels, the risks associated with shallow groundwater and tidal influences should be considered (refer Section 3.2.3.2). Where possible, bioretention systems should avoid any actual acid sulphate soils (AASS) or potential acid sulphate soils (PASS). If it is not possible to avoid AASS or PASS, expert advice should be sought to manage the risks.

DESIGN NOTE: Estimating preliminary levels

It is important to carefully consider bioretention levels early in the design process and to make appropriate allowances for any constraints that may be encountered as the design progresses. Constraints in bioretention levels can impact development earthwork levels. Allow for a contingency in preliminary estimates of bioretention levels to avoid problems associated with raising development levels late in the design process. It is generally easier to convince a client to reduce development levels than increase them.

3.2.1 Drainage profile selection

PERFORMANCE OUTCOMES

The selected drainage profile must:

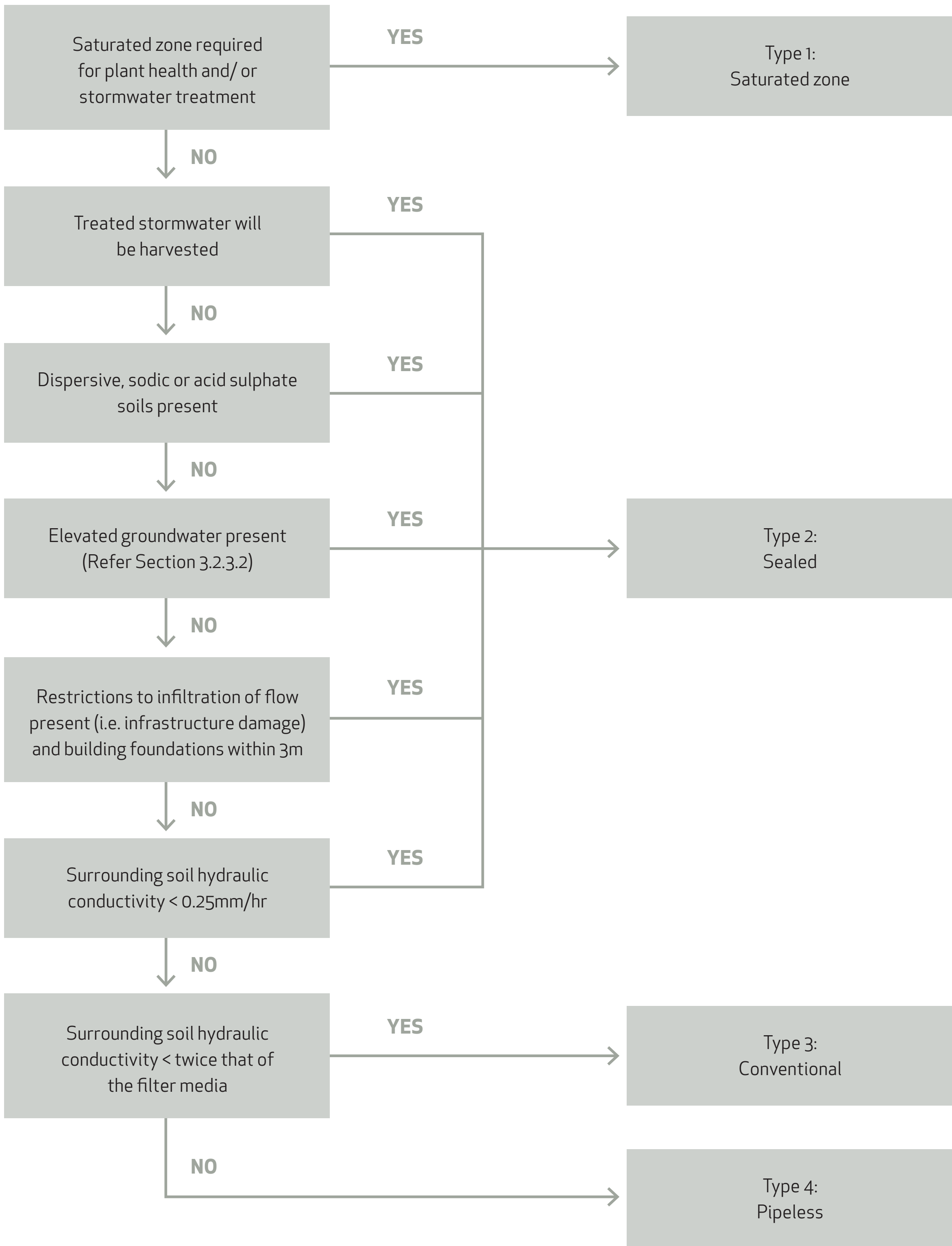
- provide suitable growing conditions
- ensure bioretention drainage does not adversely affect adjacent assets
- be appropriate for the given design objectives.

RECOMMENDED APPROACH

The drainage profile type influences bioretention depths and levels. Selecting a drainage profile is dictated by design objectives, site conditions, and climatic influences on vegetation. A decision tree for determining the most suitable drainage profile based on site conditions is shown in Figure 16. The following are attributes of each drainage profile that assist in selecting the most appropriate drainage profile:

- Type 1 saturated zone bioretention systems are recommended for systems containing trees as their roots are particularly effective at accessing water from wet sumps. There is also a lower risk of tree roots cogging underdrainage pipes that are submerged.
- Type 1 saturated zone bioretention systems are recommended for dry climates and climates with seasonal dry periods. Type 1 saturated zone systems will assist to support vegetation between rainfall events. Testing of bioretention systems with and without saturated zones showed that the filter media moisture content was consistently higher in systems with saturated zones (Zinger, et al. 2007).
- Type 1 saturated zone bioretention systems are recommended for large bioretention systems where evenly distributing flow across the filter media surface may be problematic, because the saturated zone will provide a water source for all the plants
- Type 2 sealed bioretention systems are the least effective at reducing flow volumes and meeting associated design objectives.
- Type 3 conventional bioretention systems promote infiltration to in-situ soils and assist in re-establishing the natural water cycle where in-situ hydraulic conductivity is not high enough to allow the use of Type 4 pipeless bioretention systems.
- Type 4 pipeless bioretention systems have higher total losses of flow volume than the other three types due to infiltration and evapotranspiration. Therefore, they are effective at managing frequent stormwater flows, assisting in re-establishing the natural water cycle, and reducing level constraints.

Figure 16 Drainage profile selection decision tree



3.2.2 Media layers and depths

The functional layers and depths described in this section and shown previously in Figure 14 are used for setting key bioretention levels.

3.2.2.1 Filter media

PERFORMANCE OUTCOMES

Filter media must:

- support bioretention vegetation
- infiltrate water sufficiently to enable design objectives to be met
- not migrate downwards through the transition layer, drainage layer, underdrainage or in-situ soil.

RECOMMENDED APPROACH

Filter media in bioretention systems is a sand and loam mix that supports vegetation and is integral removing stormwater pollutants. Filter media is typically 500–1000 mm deep (see Figure 14)

A minimum depth of 400 mm may be used for bioretention systems that only contain groundcover plants. Note that 400 mm is recommended as an absolute minimum depth and should only be used in exceptional circumstances at the discretion of the local authority.

A minimum depth 700 mm is recommended for bioretention with trees. A deeper filter media is recommended for trees as they have deeper roots.

The composition of filter media is critical to the correct function of bioretention systems and is detailed in Section 4.3.1.

3.2.2.2 Transition layer

PERFORMANCE OUTCOMES

Transition layers must:

- ensure the filter media does not migrate downwards
- not migrate downwards themselves through the drainage layer, underdrainage or in-situ soil
- not restrict flow rate through the filter media.

RECOMMENDED APPROACH

Transition layers are typically included in all bioretention drainage profiles. The transition layer composition is outlined in the Section 4.3.2.

For drainage profile Types 2 to 4, transition layers are typically at least 100 mm deep.

For drainage profile Type 1, the transition layer depth is strongly related to the configuration of the saturated zone. See Section 3.2.2.4 for the design of transition layers in Type 1 saturated zone systems.

For drainage profiles Types 2 and 3 where levels are constrainted, the transition layers can be omitted providing the top of the drainage layer is at least 100 mm above the top of the pipe and the specification requires the filter media and drainage layer material to comply with all parts of the specific criteria defined in the *Drainage of Subsurface Water from Roads – Technical Bulletin No 32* (VicRoads):

- D_{15} (drainage layer) $\leq 5 \times D_{85}$ (filter media)
- D_{15} (drainage layer) $= 5$ to $20 \times D_{15}$ (filter media)
- D_{50} (drainage layer) $< 25 \times D_{50}$ (filter media)
- D_{60} (drainage layer) $< 20 \times D_{10}$ (drainage layer).

3.2.2.3 Drainage layer

PERFORMANCE OUTCOMES

Drainage layers must:

- ensure overlying media does not migrate downwards
- not restrict flow through filter media.

RECOMMENDED APPROACH

The recommended drainage layer parameters for each bioretention drainage profile type are shown in Table 5, noting that the design of the drainage layer in Type 1 saturated zone bioretention systems is highly dependent on the configuration of the saturated zone (see Section 3.2.2.4) Specification details for drainage layer material are provided in Section 4.3.3.

Table 5 Recommended drainage layer parameters

Bioretention drainage profile type	Drainage layer parameters
Type 1 saturated zone	• ⩾ 50 mm of drainage layer material above all slotted or perforated underdrainage pipes. • Base does not need to slope.
Type 2 sealed	• ⩾ 50 mm of drainage layer material above all slotted or perforated underdrainage pipes. • Base slopes towards outlet (recommended grade is 0.5%).
Type 3 conventional	• ⩾ 50 mm of drainage layer material above all slotted or perforated underdrainage pipes. • ⩾ 200 mm of the drainage layer material is below the slotted or perforated pipes. • Base does not need to slope.
Type 4 pipeless	• No drainage layer required.

3.2.2.4 Saturated zone

This section only applies to Type 1 saturated zone bioretention systems.

PERFORMANCE OUTCOME

Saturated zones must support plant health and stormwater treatment.

RECOMMENDED APPROACH

Saturated zones are a water storage integrated into the transition and drainage layers of Type 1 saturated zone bioretention systems. The water level in saturated zones is generally controlled by a piped outlet (or similar) that enables water to spill into an overflow pit when it exceeds the top of the saturated zone. During dry weather the water level in the saturated zone is slowly drawn down by evapotranspiration.

The top of the saturated zone (i.e. the water level when the saturated zone is full to capacity) must be located within the transition layer (see Figure 14), at least 100mm below the bottom of the filter media. The top of the saturated zone should not be located within the filter media as this may lead to leaching of nutrients, nor within the drainage layer as this may prevent capillary action making moisture available to plants.

The recommended minimum saturated zone depth is 350 mm (see Figure 14). In dry climates that experience no rain for more than six continuous weeks in a typical year, the *Stormwater Biofiltration Systems Adoption Guidelines* (FAWB, 2009) recommend two options:

- Increase the saturated zone depth in accordance with Equation 1. For example, if a bioretention is likely to experience eight weeks of dry weather, the ideal depth would be 450 mm.
- Make the saturated zone as deep as possible and allow it to be replenished at defined intervals during the dry period via surface irrigation or direct filling via inspection risers. For example, if a bioretention with a 350 mm deep saturated zone is likely to experience eight weeks of dry weather, the saturated zone would need to be filled after approximately six weeks to avoid it drying out.

Equation 1

$D = 8mm/day \times t$

Where: D = depth of saturated zone (mm)
t = average of the longest annual dry period for the last 10 years (days)

3.2.3 Design levels (outlet, surface and water levels)

Critical bioretention levels are defined relative to the level of inlet and outlet inverts, and the surrounding landscape. Setting the design levels is typically an iterative process.

DESIGN NOTE: Inlet level constrained sites

In some cases, bioretention systems' surface levels are dictated by inflow levels, for example when sites are being retrofitted and the inflow level is fixed. Where inflow levels are fixed and not suitably elevated above the receiving drainage system, the following options should be investigated:

- draining the bioretention to a lower downstream outlet
- designing the bioretention at a higher level and surcharging flows onto the filter surface. Due to the increased hydraulic and maintenance implications with this option, confirm that the local authority is satisfied with this solution.

3.2.3.1 Outlet pipe level

This section only applies to bioretention drainage profiles Types 1 to 3 because Type 4 pipeless bioretention systems do not have an outlet pipe.

PERFORMANCE OUTCOMES

Outlet pipe levels must:

- be sufficient so that accumulated sediment does not block outlet pipe connection with receiving drainage system
- allow bioretention filter media to drain freely.

RECOMMENDED APPROACH

Bioretention system outlets should drain freely to receiving drainage systems as outlined in Table 6 The recommended pipe grade is at least 0.3% (preferably ≥ 0.5%). The outlet level is defined as the invert of the outfall pipe or channel where it discharges into receiving drainage system.

Table 6 Outlet pipe level recommendations

Receiving drainage system	Minimum recommended level
Ephemeral waterway	300 mm above waterway invert or 100 mm above wet season water level, whichever is highest
Perennial waterway	300 mm above dry weather water level or 100 mm above wet season water level, whichever is higher
Natural wetland	100 mm above the maximum of the ground level or wet season standing water level
Natural ground	100 mm above the maximum of the ground level or wet season standing water level
Pipe drainage system	50 mm above invert of downstream pit or pipe system and above wet season baseflow levels

3.2.3.2 Bioretention system levels relative to groundwater and tidal levels

PERFORMANCE OUTCOMES

With respect to groundwater and tidal levels, bioretention systems must:

- ensure bioretention biota is not harmed by water infiltrating from the surrounding soil into bioretention system
- ensure groundwater is not drawn down by bioretention underdrainage.

RECOMMENDED APPROACH

Allowing groundwater or tidal water to enter bioretention layers can be detrimental to biota (plants, bacteria, fungi etc.) within the system. Plants can be affected by the quality of the water (e.g. salinity) or from having saturated roots for an excessively long time. Prolonged wetting of the filter media can detrimentally affect its ability to retain stormwater pollutants. Bioretention systems may also artificially lower the local groundwater level or discharge poor quality sub-surface water if they are left open to groundwater intrusion.

The recommended bioretention system levels to ensure that adequate protection for biota and groundwater are outlined in Table 7. The allowance for 300 mm above the highest astronomical tide (HAT) accounts for potential sea level rise as a result of climate change and is in accordance with advice in the *Queensland Urban Drainage Manual* (QUDM) (DEWS, 2013).

3.2.3.3 Extended detention

PERFORMANCE OUTCOMES

The extended detention must:

- have sufficient temporary storage to enable design objectives to be met
- not harm vegetation through excessive inundation.

RECOMMENDED APPROACH

The recommended maximum extended detention depth is 300mm as shown in Figure 17. The overflow level (i.e. typically the overflow pit crest) is set at the top of extended detention. Extended detention depths greater than 300 mm can impact plant health and potentially cause overloading of the filter media. This can reduce the operational life expectancy of the system due to surface clogging or release of bound pollutants.

Table 7 Recommended bioretention levels relative to groundwater or tidal levels

Drainage profile type	Level relative to wet season groundwater level (WSGL)	Level relative to highest astronomical tide (HAT)
Type 1 saturated zone	Impermeable liner extends ≥ 300 mm above WSGL	Impermeable liner extends ≥ 300 mm above HAT
Type 2 sealed	System will be completely sealed (see Section 2.4). No further restrictions	Base of transition layer ≥ 300 mm above HAT
Type 3 conventional	Base of underdrainage pipes ≥ 300 mm above WSGL	
Type 4 pipeless	Base of transition layer ≥ 300 mm above WSGL	

3.2.3.4 Maximum water level

PERFORMANCE OUTCOMES

The maximum water level must inform the minimum embankment height and flood conveyance.

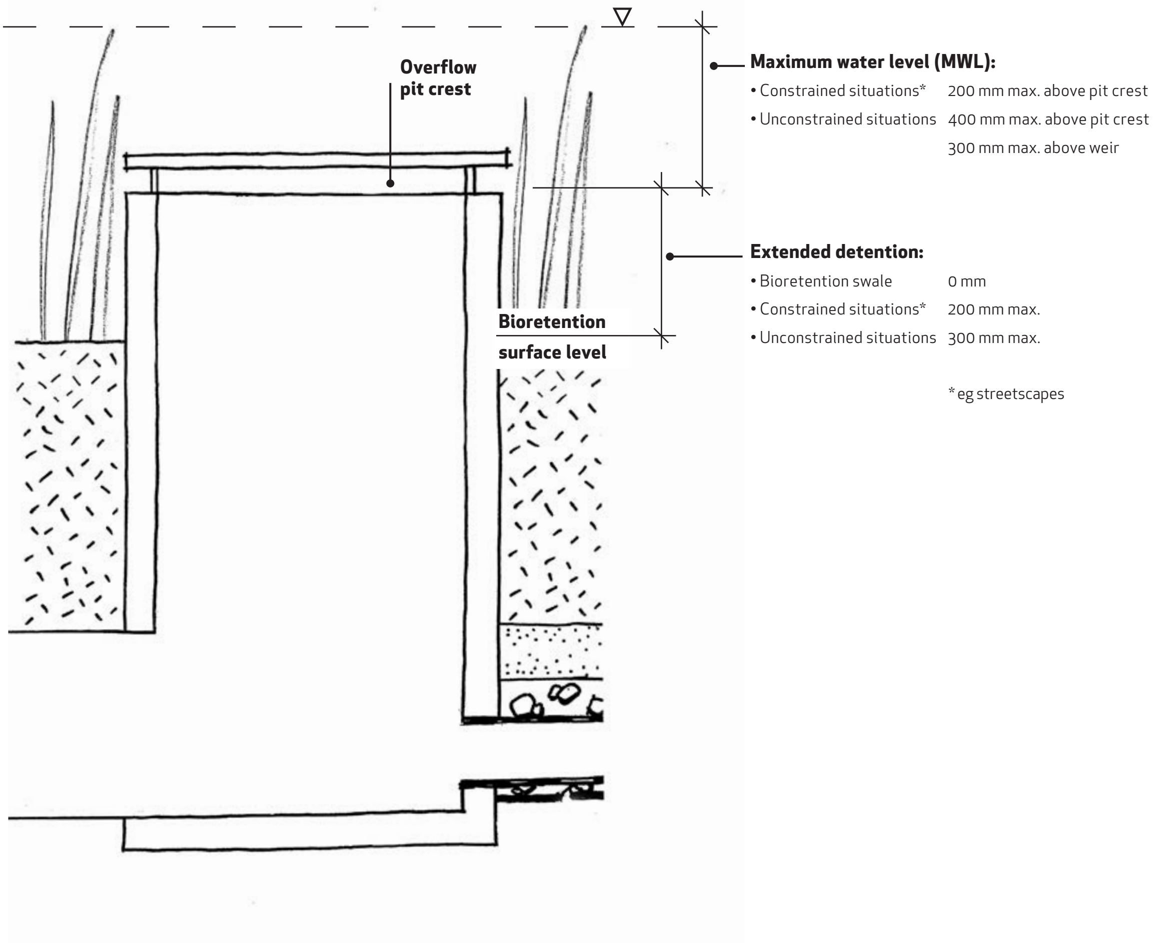
RECOMMENDED APPROACH

The maximum water level above the bioretention filter media surface will be influenced by the design storm entering the system and the overflow configuration. The maximum water level can be initially defined based on Figure 17 and refined as part of the outlet design (Section 3.5). Where bioretention systems lie within a flood detention basin, the maximum water level will be dictated by flood storage requirements. The maximum water level will influence the minimum design levels for embankments around the bioretention perimeter.

DESIGN NOTE: Maximum water level for streetscape bioretention systems

In streetscape bioretention systems, the maximum allowable water level is defined by the maximum allowable flow depth in the adjacent street kerb and channel. This depth is defined by local standards such as QUDM (DEWS, 2013) to ensure road traffic and safety standards are met.

Figure 17 Extended detention depth and maximum water level requirements



3.2.3.5 Filter surface level relative to surrounding surface

PERFORMANCE OUTCOMES

Relative to the surrounding landscape the filter media surface level must:

- ensure accumulated sediment does not block inlet pipe
- provide safe and stable bioretention system edges
- ensure the bioretention system forms an attractive landscape feature.

RECOMMENDED APPROACH

It is recommended that inflow pipe or channel inverts are at, or above, the bioretention system's surface (preferably 200 mm above the surface) to prevent silt or debris accumulating in pipes.

Bioretention system levels should be complementary to their surrounds and avoid creating significant depressions within the urban landscape. The elevation difference between the filter media and surrounding surface is referred to as the bioretention system surface set down.

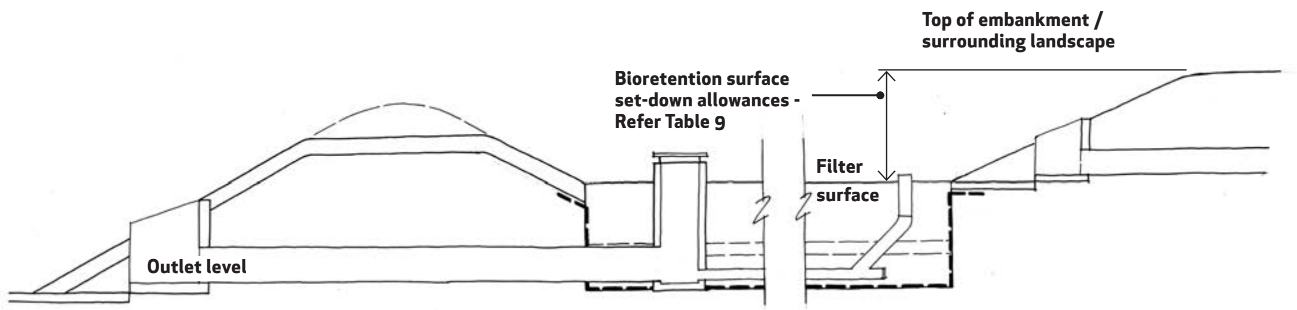
The recommended maximum bioretention surface set-down is outlined in Table 8 and shown in Figure 18.

Table 8 Recommended maximum bioretention system surface set-down

Bioretention application	Bioretention system surface set down
Allotment bioretention	≤ 500 mm
Streetscape bioretention	≤ 200 mm below kerb invert at bioretention inlets
Civic space bioretention	≤ 500 mm
Parkland bioretention	≤ 2000 mm*
Bioretention adjacent natural areas	≤ 2000 mm*

* the 2000 mm surface set down for bioretention systems adjacent parkland and natural areas assumes a large bioretention system which requires a deep set down (e.g. because of large inlet pipes requiring cover). Smaller bioretention systems adjacent parkland and natural areas can and should be designed with smaller surface set downs. Doing so has additional benefits such as reducing the overall footprint of the bioretention system.

Figure 18 Bioretention system surface set-down for landscape integration



DESIGN NOTE: Topsoil level on batters and embankments

Design levels for batters and embankments refer to the finished topsoil level. Therefore, earthworks design should account for a minimum of 200 mm topsoil placement to meet the finished design level. This is an important design note to include on detailed design drawings and specifications. Refer to Section 4.4.1 for specification details.

3.2.3.6 Minimum embankment height

PERFORMANCE OUTCOMES

Bioretention system embankments must:

- contain the maximum water level with appropriate freeboard
- prevent the bioretention system from being damaged by flows from external catchments.

RECOMMENDED APPROACH

It is recommended that embankment height provides for freeboard that is at least equal to the greater of:

- 20% of the elevation difference between the filter surface and maximum water level
- 50 mm.

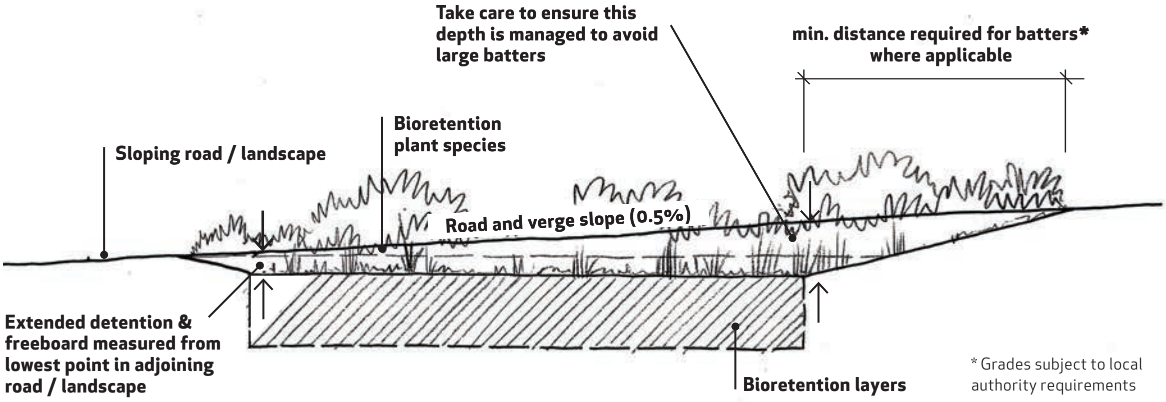
This freeboard recommendation aligns with a recommendation on the maximum water level around stormwater inlets described in QUDM (DEWS, 2013).

Local authorities may require bioretention embankments to be higher than local or regional flood levels (i.e. provide flood immunity for the bioretention system). Flood immunity requirements should be identified early in the design process as part of background investigations (refer to Section 3.1).

As discussed in Section 3.2.3.4, the maximum water level in streetscape bioretention systems may encroach into the road pavement. Local authority freeboard requirements for the major flow levels in streetscapes should be applied in these situations.

When proposing a new bioretention system within a sloping landscape (Figure 19), minimum bund height and freeboard requirements should be considered at the lowest point in the surrounding landscape or bund. This may require cut and fill techniques to avoid significant batters at one end of the system. Designers should ensure these types of configurations do not compromise the landscape amenity or space requirements for the system. Developing an earthworks model in conjunction with a landscape plan is useful to assist locating bunds and achieving freeboards.

Figure 19 Typical bioretention system embankment



3.2.3.7 Level constrained sites

PERFORMANCE OUTCOMES

Bioretention systems in level constrained sites must:

- adapt to the constraints of the site
- be robust and resilient
- demonstrate that they are the most appropriate solution for the site.

RECOMMENDED APPROACH

In level-constrained situations a number of design options may be feasible, subject to discussion with, and approval from, the local authority:

- adopting a saturated zone that can only be drained (e.g. for maintenance) via pumping
- reducing the buffer between the bioretention outlet pipe invert and the receiving drainage level and ensuring the bioretention base conforms to the specifications shown previously in Table 6. Very accurate survey and seasonal water level information provided to local authorities to demonstrate that the bioretention will freely drain.
- removing the transition layer by ensuring the drainage layer meets the particle size grading requirements set out in Section 3.2.2.2.
- using one or more other technologies that meet the design objectives more appropriately within the level constraints.

3.2.4 Liners

Bioretention systems often require a liner. The need for and nature of the liner required depends the bioretention system drainage profile and site conditions. Liners can be either impermeable or permeable.

3.2.4.1 Impermeable liners

PERFORMANCE OUTCOMES

Impermeable liners must ensure water cannot be exchanged between the bioretention system and the surrounding soil.

RECOMMENDED APPROACH

Impermeable liners are used for Type 1 saturated zone bioretention systems and Type 2 sealed bioretention systems. The liner should have a hydraulic conductivity of less than 1 x 10-9 m/s and can be made from compacted clay or a manufactured material.

For Type 1 saturated zone bioretention systems, the impervious liner should extend to at least the top of the saturated zone. The liner may need to be extended higher to prevent ingress of groundwater (refer Section 3.2.3.2).

For Type 2 sealed bioretention systems, the impervious liner should extend to the top of drainage layer or as required by Section 3.2.3.2.

The recommended impermeable liner is 300 mm deep compacted non-dispersive clay. Where suitable clays are available onsite, they should be used to create the liner.

Manufactured products, such as bentonite liners or HDPE membranes, can also be used to create an impermeable liner. Given that bioretention systems often have a complex shape and have at least one pipe connection through the liner, the seal between liner sheets and around perforations (e.g. around pipes and structures) must be robust.

Proprietary liners and membranes should be 'keyed' into bioretention batters by extending them at least 500 mm beyond the edge of the filter media (i.e. up the batter) then pinned to the in-situ soil and covered with at least 200 mm of topsoil. Refer to the IPWEAQ Standard Drawings for details. Where an embankment bounds the system, the liner should extend over the embankment for reinforcement (Figure 20).

Figure 20 Bioretention system liner extended over embankments

Photo: Shaun Leinster, DesignFlow

3.2.4.2 Permeable liners

PERFORMANCE OUTCOMES

Permeable liners must prevent in-situ soils from contaminating filter media or the underdrainage network.

RECOMMENDED APPROACH

Permeable liners (e.g. geotextile) are used to line the sides of Type 3 conventional bioretention systems and Type 4 pipeless bioretention systems to manage in-situ soil migration into the various layers. It is recommended that liners extend at least 300 mm onto the bioretention base to allow the liner to be held in place by pins or the lowest bioretention layer.

Permeable liners should be used around the sides of Type 1 saturated zone bioretention systems if the impermeable liner does not extend to the top of the filter media.

Permeable liners should be 'keyed' into bioretention batters by extending at least 500 mm beyond the edge of the filter media (i.e. up the batter) then pinned to in-situ soil and covered with at least 200 mm of topsoil. Refer to the IPWEAQ Standard Drawings for details. Where bioretention systems are bounded by an embankment, liners should extend over the embankment for reinforcement (Figure 20).

3.3 Bioretention system layout

The layout of the bioretention system should ensure that sufficient space is allocated for all elements of the system, that the location and design of these elements does not compromise the amenity or function of the surrounding spaces and infrastructure. The layout of the bioretention system should consider the:

- development of an earthworks model to assist in determining the optimum layout
- filter media size
- shape and location of the bioretention system
- inlet and outlet locations
- bioretention system edge and landscape interface
- maintenance access
- underground services
- road reserves
- flood storage requirements.

DESIGN NOTE: Timing of development within the catchment

During the design process, it is important to consider the timing of development within a bioretention system's catchment. Refer to the *Construction and Establishment Guidelines: Swales, Bioretention Systems and Wetlands* (Water by Design) to identify construction staging options and any methods for ensuring bioretention systems are resilient while the catchment is being developed. Key considerations include:

- location of inflow and outflow points
- protection of filter media from high sediment loads
- management of overland flow paths into or around the system
- use of the system (without media installed) as a sediment basin during construction
- delivery of large systems whose catchment will have building and construction activity occurring over several years or more.

If the implications of a bioretention system's location, construction technique and initial sediment load protection and management options are not considered during the design, major constraints can occur during the construction phase. Poorly designed, poorly constructed or damaged bioretention systems may not be accepted by a local authority at the post-development asset handover stage.

3.3.1 Earthworks model

PERFORMANCE OUTCOMES

The earthwork model must demonstrate the bioretention system's earthworks can be accommodated relative to vertical and horizontal constraints.

RECOMMENDED APPROACH

Developing a digital three-dimensional earthworks model of the proposed bioretention system can help to test the design layout. Having an accurate digital model of the system early in the design process can reduce the number of design iterations by identifying critical level and footprint issues. This digital model can gradually increase in detail as subsequent design elements are resolved. The final digital model can be used to produce design documents such as plans and cross-sections. For small or simpler bioretention systems, scale drawings and two-dimensional CAD designs may suffice.

3.3.2 Filter media area

PERFORMANCE OUTCOMES

The filter media area must:

- be sufficient to achieve the bioretention system's design objectives
- not detrimentally affect the lifespan of the bioretention system.

RECOMMENDED APPROACH

The required filter media area should be confirmed using catchment information collated in Section 3.1. One of the following sizing options should be used:

- **Confirming concept design size**. The filter media area should have been determined during the concept design phase (e.g. using MUSIC software or the *Deemed to Comply Solutions – Stormwater Quality Management* (Water by Design)). If the catchment and bioretention system's properties (e.g. catchment area and land use, filter media depth, extended detention depth) have not changed since conceptual design, then the filter media size should remain valid.
- **MUSIC modelling**. Where catchment or bioretention system layer properties have changed since conceptual design, MUSIC software can be used to confirm the filter area needed to achieve relevant stormwater management objectives.
- **Maximising size (retrofit)**. Where the available space for a bioretention system is constrained (i.e. less than required to meet relevant stormwater objectives), the design team should investigate options to maximise the filter media area within the given constraints. This requires consideration of surroundings and an iterative approach to designing the bioretention system's layout and levels.

DESIGN NOTE: Coarse sediment removal areas

Space for a coarse sediment removal system should be included in the overall bioretention system's layout (e.g. a coarse sediment forebay or inlet pond). The area required for these elements is in addition to the filter media area. Methods for sizing forebays and inlet ponds are provided in Section 3.4.3.

3.3.3 Shape and location

PERFORMANCE OUTCOMES

The shape and location of bioretention systems must:

- ensure the system is suitably integrated with the landscape and considers the site's constraints
- allow the system to be easily constructed with commonly available equipment, without compromising the system's ability to meet its design objectives.

RECOMMENDED APPROACH

Bioretention systems are permanent additions to the public landscape. There are many factors that influence enjoyment of public space. Bioretention designers need to understand and respect these factors throughout the design process to ensure positive impacts on public landscapes.

For bioretention systems in road space, the factors to consider include safety, legibility and ease of movement. For systems in parks, the factors to consider include scenic views, picnic areas, passive recreation areas and open kick-around spaces. For systems in civic spaces, factors to consider include shade, seating and ease of movement for large groups of people.

Visual and land use integration issues need to be carefully considered when determining bioretention shape and location.

Visual issues include:

- aesthetics of engineering and maintenance infrastructure such as headwalls, inlets, outlets, weirs, access tracks bunds and batters (Figure 21 and Figure 22)
- blocking scenic views and important pedestrian and vehicle sight lines with trees and shrubs (Figure 23)
- ensuring the shape of the bioretention system is appropriate for the site, for example an organic, curved shape is generally suitable for natural settings while a more rigid, angular shape is better suited to built up areas (Figure 24).

Land use issues include:

- impacts from overflows, overshadowing from tall trees
- space requirements – bunds, batters, maintenance tracks & resultant reduction in open park/grass verge area
- location of bioretention - implications on park circulation and use patterns.

Figure 21 Visual integration of bioretention systems

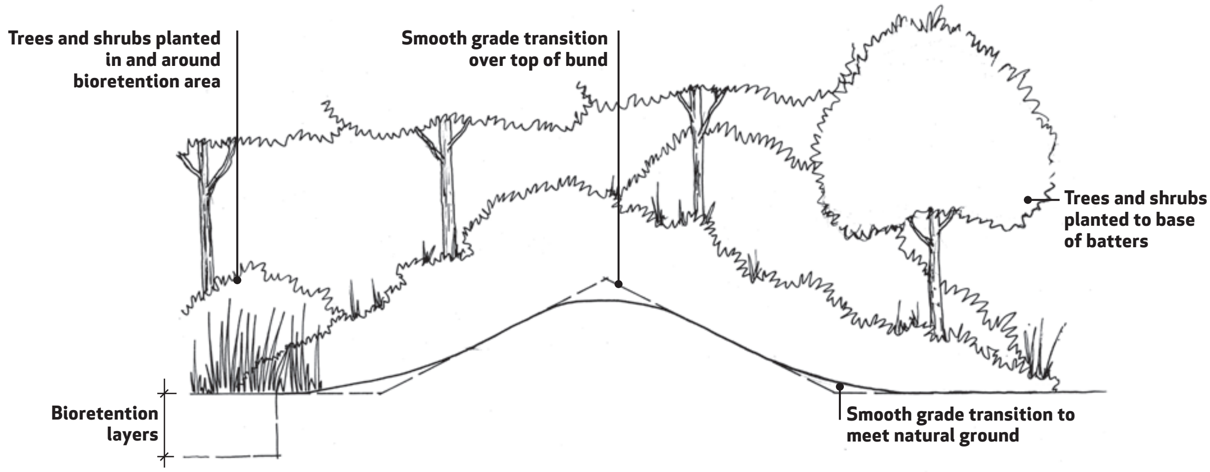


Figure 22 Visual integration of bioretention systems with existing park uses

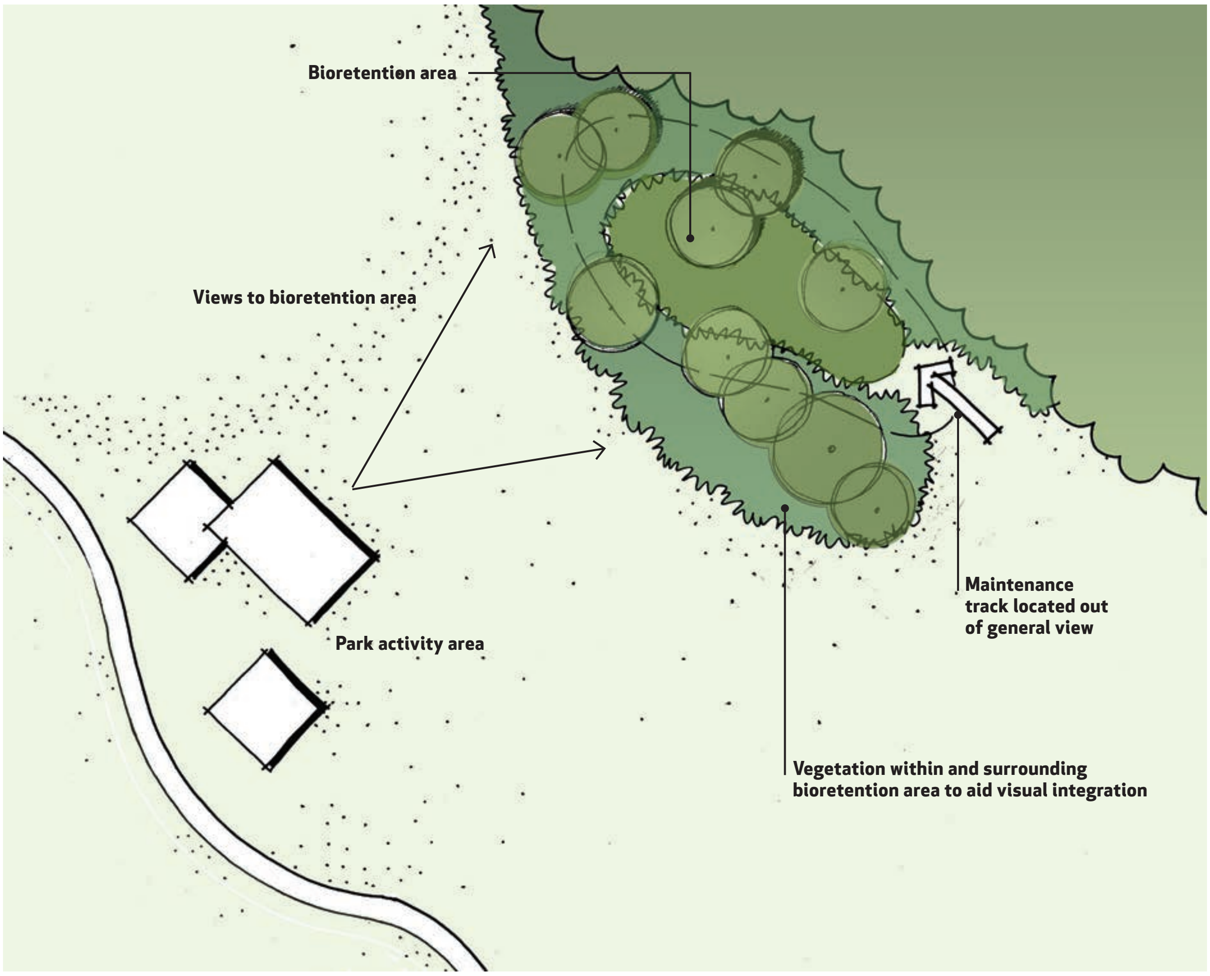
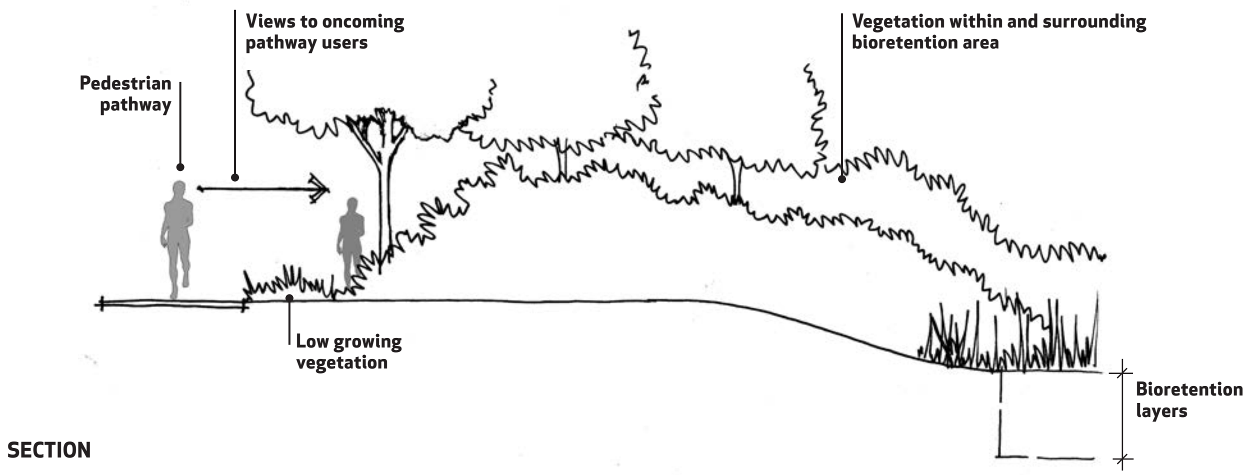


Figure 23 Integration of bioretention systems with pathways



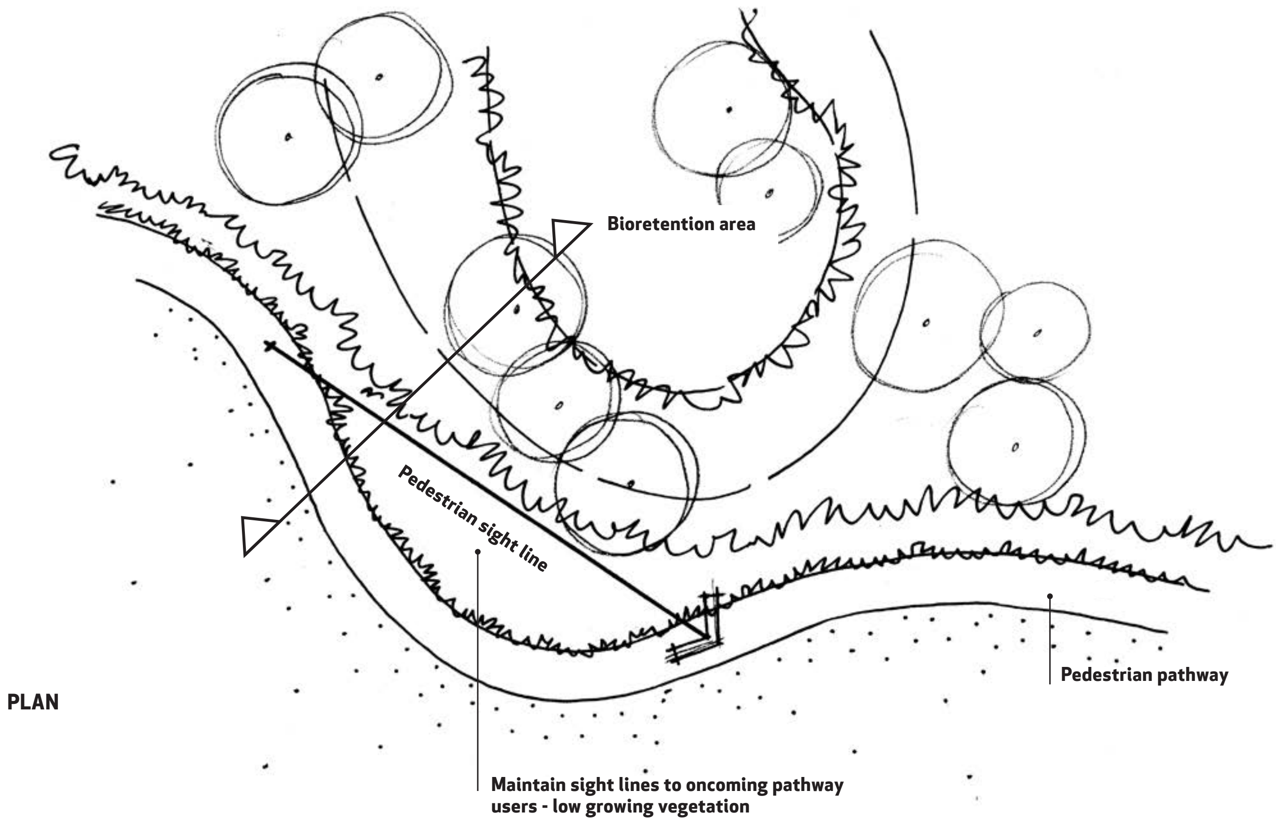
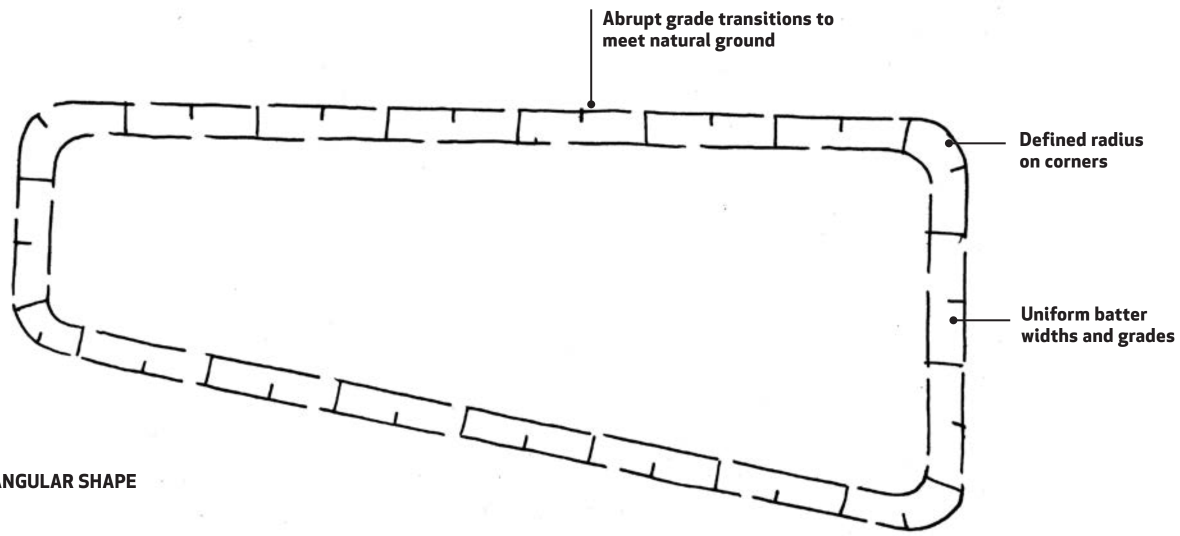
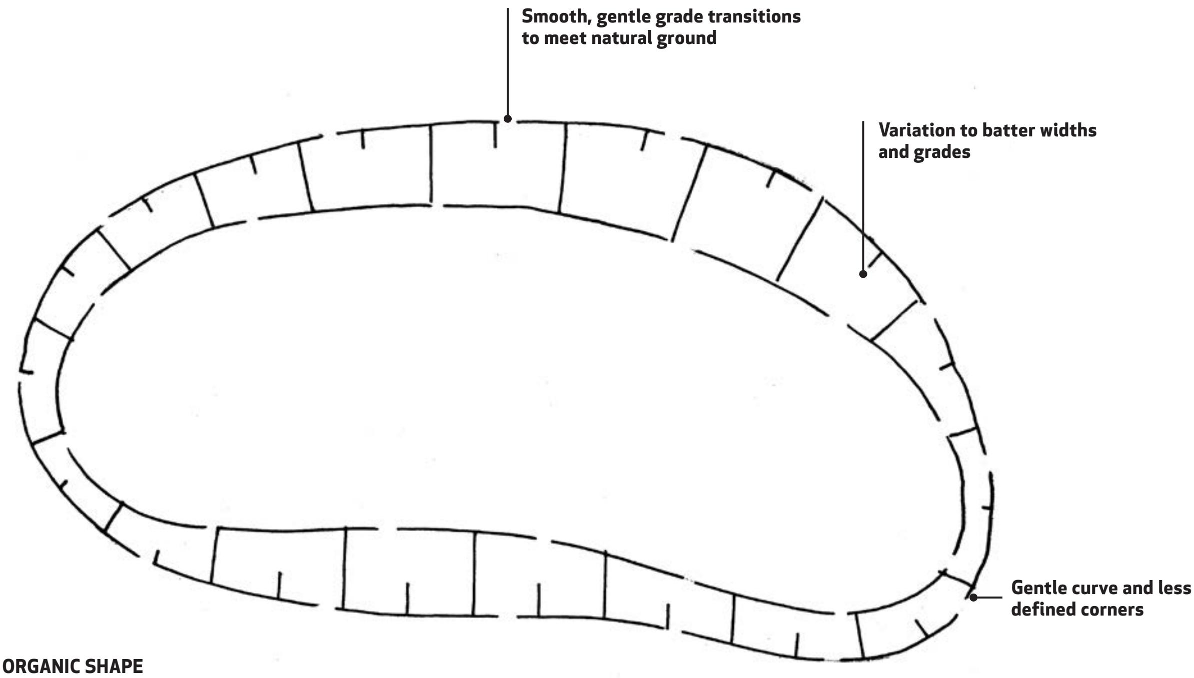


Figure 24 Bioretention system shapes



FORMAL, ANGULAR SHAPE



INFORMAL, ORGANIC SHAPE

The filter media area can be formed into almost any shape provided the overall system can be feasibly constructed and maintained and does not result in unacceptable hydraulic performance. The interaction of visual and land use elements should be carefully considered when determining the shape and location of bioretention systems.

To ensure construction and maintenance of the bioretention system is feasible, filter media should:

- be a maximum width of 600mm as narrower bioretention systems are difficult to construct
- where construction access is available from both sides of the filter media, be a maximum width of 15m (20m at an absolute maximum) to ensure the system can be constructed and maintained from the edge using typical construction equipment and machinery (Figure 25)
- where construction access is available from only one side of the filter media, be a maximum width of 10m to ensure the system can be constructed and maintained from the edge using typical construction equipment and machinery (Figure 25)
- a maximum length of 40m to minimise the risk of uneven distribution of stormwater over the surface, limit the length of underdrainage, and in the case of Type 2 sealed bioretention systems, limit the depth increase within the graded drainage layer.

To manage these risks, large bioretention systems with a total filter media area greater than 800 m^2 should be split into cells of no larger than 800 m^2. As depicted in Figure 26, large systems should also incorporate:

- inlet pond (sediment basin)
- high flow bypass from the inlet pond to the receiving drainage
- distribution system that connects the inlet pond to the bioretention cells and distributes flow evenly across the bioretention system's surface
- construction and maintenance access between and around bioretention cells.

Where dimensions outside these recommendations are used, designers should provide the local authority with details and justification of the proposed design and construction method.

Figure 25 Bioretention width limitations

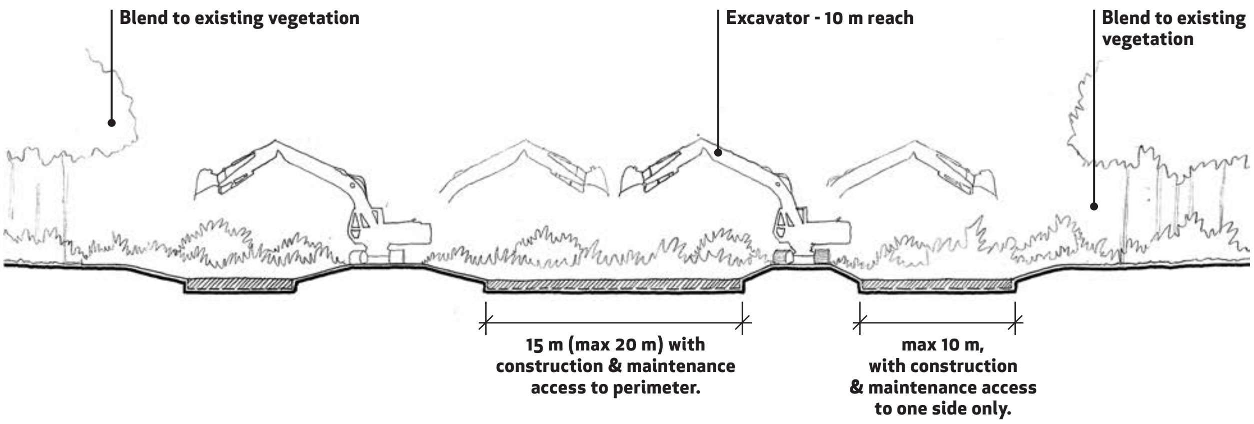
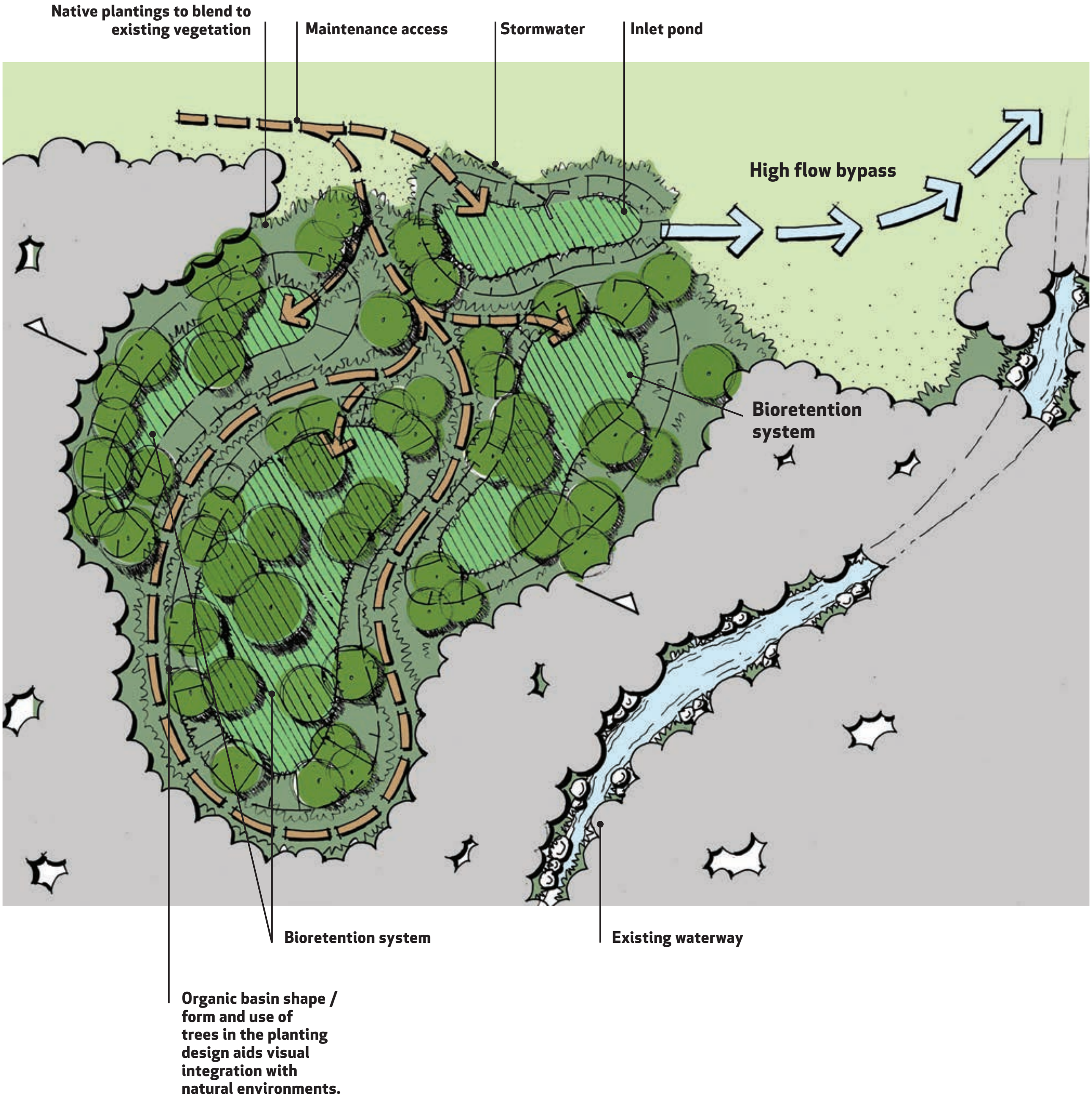


Figure 26 Layout of large bioretention systems



3.3.4 Inlet and outlet locations

PERFORMANCE OUTCOMES
Inlet and outlet locations must:

- allow inflows and outflows to be efficiently managed without damaging the bioretention systems or surrounding areas
- ensure hydraulic structure locations are sympathetic to landscape considerations.

RECOMMENDED APPROACH
When locating inlets and outlets, consider:

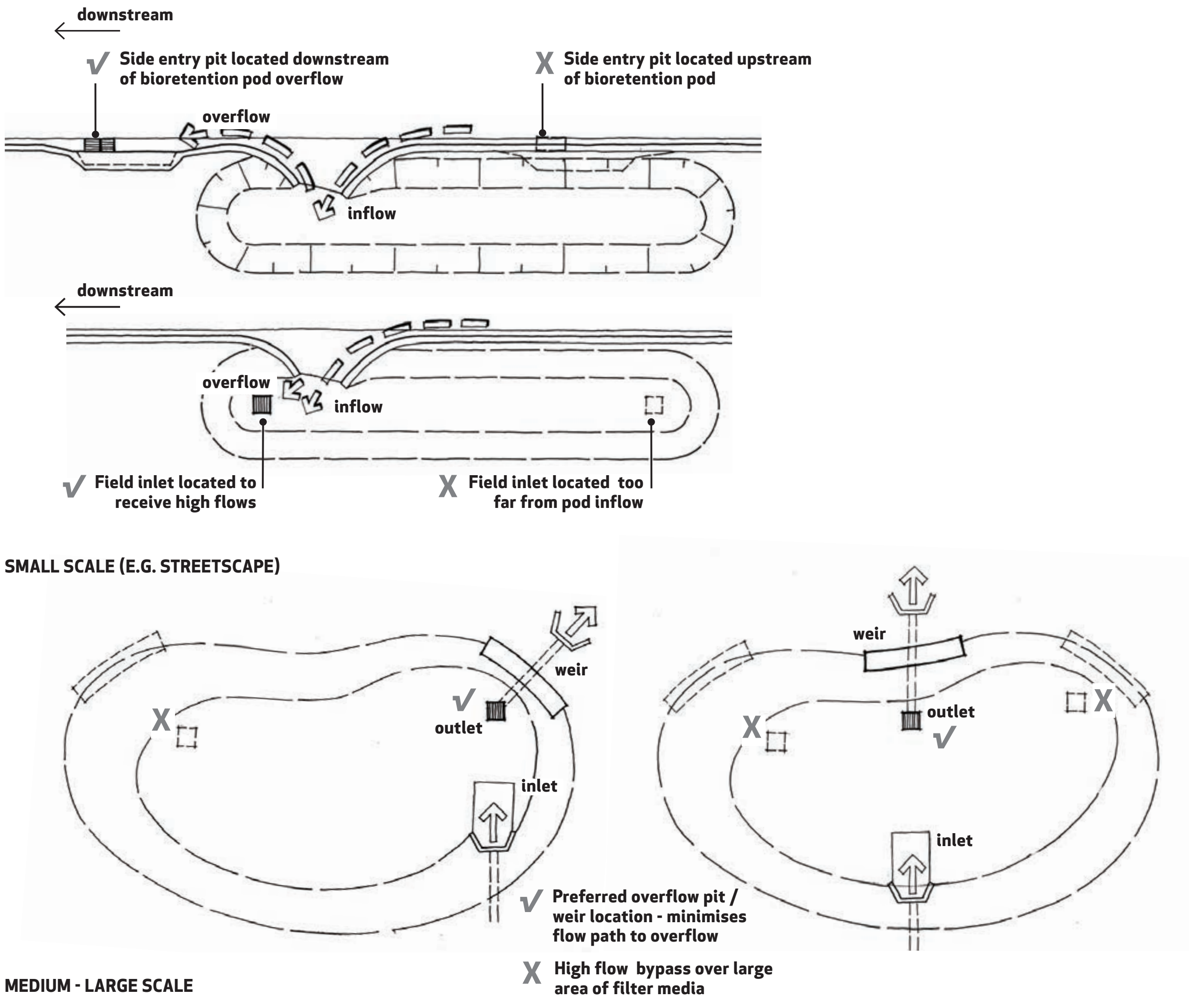
- filter media area (i.e. large bioretention systems may require inlet ponds)
- outlet structure type (overflow pit, side entry pit, weir or a combination of these)
- underdrainage design that may dictate where and how many overflow pits are required
- landscape aesthetic of inlets and outlets (these structures can be obvious, and often dominant, landscape features. Locating outlet pits out of direct or prominent view lines or planting shrubs adjacent to pits should be considered)
- local authority requirements.

Inflow and outflow structures should preferably be located close to each other (Figure 27) to:

- ensure high flows can reach the outlet without scouring vegetation or filter media
- allow bioretention systems to be partitioned off and flows bypassed around the filter media while activities such as building and house construction take place within the catchment. This protects vegetation and the filter media surface, as discussed in the *Construction and Establishment Guidelines: Swales, Bioretention Systems and Wetlands* (Water by Design).

Inflow and outflow system design is discussed in Sections 3.4 and 3.5.

Figure 27 Bioretention inflow and outflow locations



3.3.5 Edge and landscape interface (batters, embankments and walls)

Designs should consider visual amenity and the safety of any transitions from a depressed bioretention system surface to the surrounding landform and landscape. Batter slopes, embankments, and walls have a significant influence on the overall footprint of bioretention systems, as well as the interaction with adjoining landscape. This section includes important design considerations about designing the edges of bioretention systems.

3.3.5.1 Surrounding landscape

PERFORMANCE OUTCOMES

The layout of bioretention systems must not impact unacceptably on surrounding landscape features.

RECOMMENDED APPROACH

Features surrounding bioretention systems have an important role in defining the overall shape and edge design of the system. Existing features often need to be preserved and are therefore an important constraint to the layout of bioretention systems. Features in the surrounding area that will be created or modified in the future also need to be considered. These features may include:

- vegetation or trees
- local topography
- waterway and associated riparian zone
- pedestrian paths or roads
- residential dwellings
- playgrounds and active parks.

DESIGN NOTE: Existing vegetation

Bioretention earthworks should avoid the critical root zone (typically defined as 500 mm beyond the vegetation's drip line) of any retained vegetation (e.g. trees). Advice should be sought from an arborist regarding earthworks close to trees.

3.3.5.2 Public access and safety

PERFORMANCE OUTCOMES

The layout of bioretention systems must

- integrate with adjacent public spaces
- enhance public access and safety.

RECOMMENDED APPROACH

The shape and form of bioretention systems should integrate with adjacent active and passive public spaces. Interaction with pedestrian and vehicle pathways, and Crime Prevention Through Environmental Design principles should guide landscape design for bioretention systems in these situations.

Pathway crossings over bioretention systems allow the public to interact with and develop an appreciation of such systems, but can be expensive. Solid embankment crossings with culverts to allow water to pass underneath are generally cheaper to construct than boardwalk or bridge style crossings. Edge safety considerations recommended for batters and walls in Sections 3.3.5.3 and 3.3.5.5 also apply to path edges.

Bioretention systems should be safe to construct, consistent with requirements of the Work Health and Safety Act 2011 (QLD).

3.3.5.3 Batters

PERFORMANCE OUTCOMES

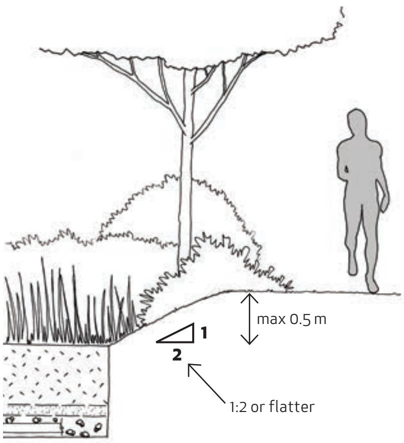
Bioretention batters must:

- be safe and stable
- be low maintenance
- not create unacceptable visual impacts.

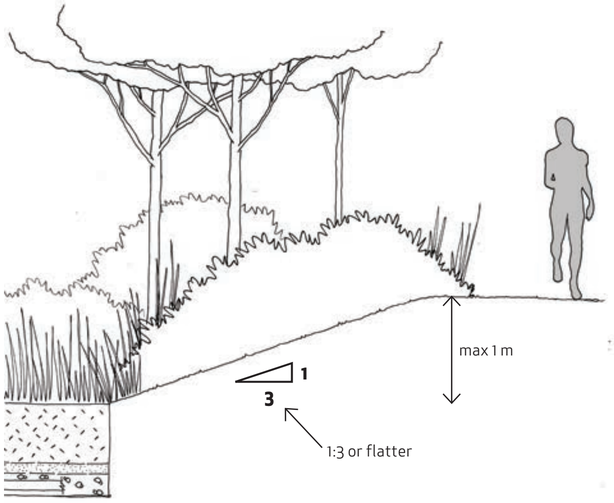
RECOMMENDED APPROACH

Figure 28 outlines batter design for bioretention systems. Generally, 1 in 4 batters or flatter are recommended. Batters and embankments should be densely vegetated and mulched to manage weed ingress. Groundcover coverage of 90% is recommended for all batters, which requires a planting density of around six plants per square metre. Lower planting densities may be applicable for certain plant species subject to local authority approval. Lateral flows down batters that are 1 in 3 or steeper should be avoided by creating designated inflow points with adequate erosion protection (swales/rock lined channel).

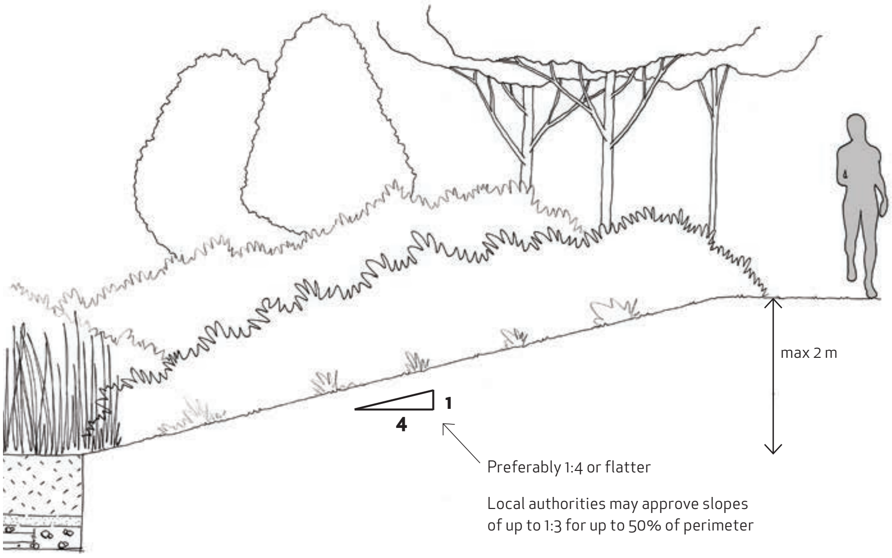
Figure 28 Batter design and guidance



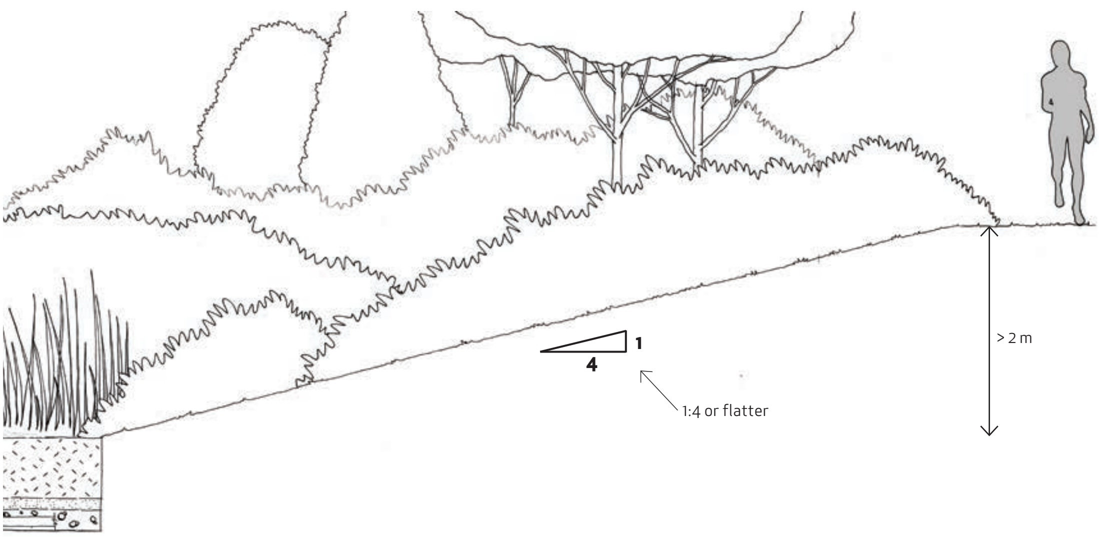
BATTER HEIGHT TO 0.5 M



BATTER HEIGHT 0.5 M TO 1 M



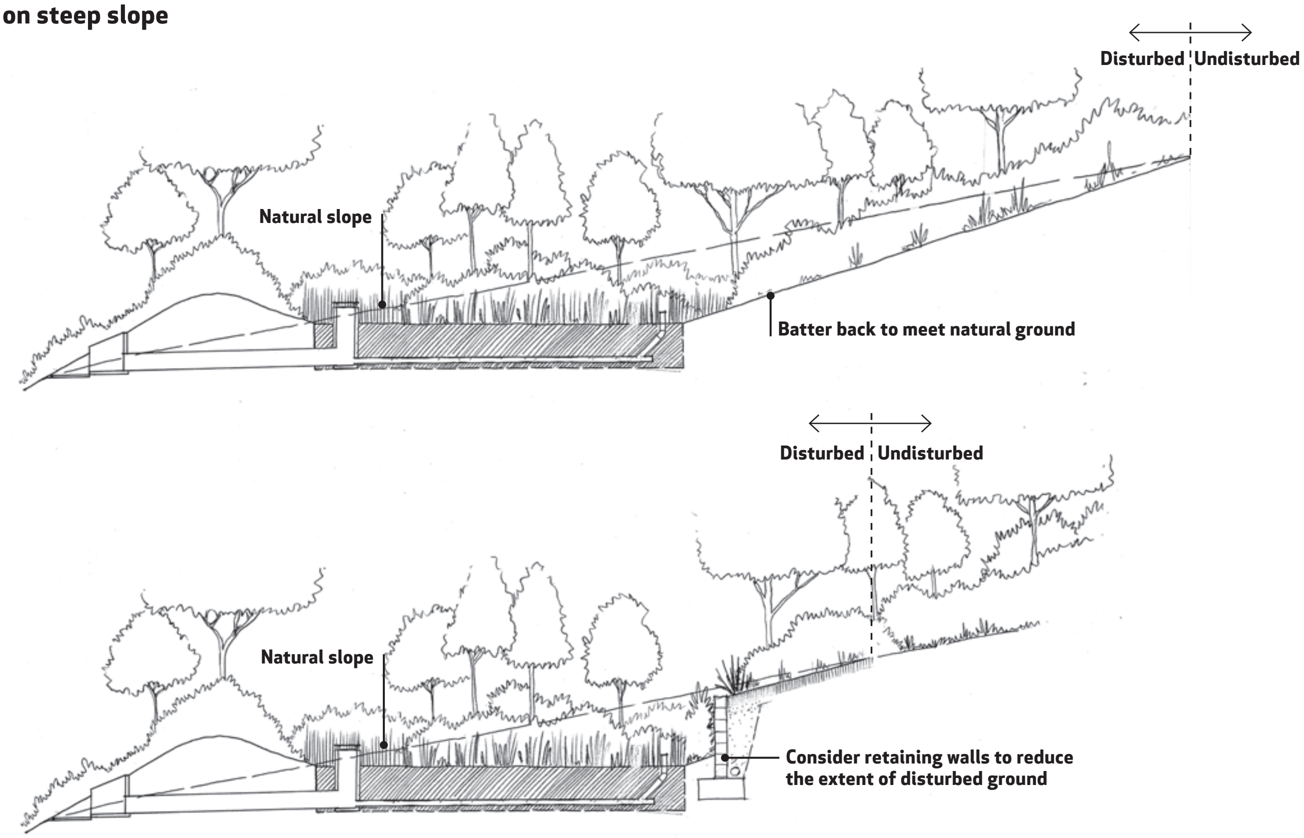
BATTER HEIGHT 1 M TO 2 M



BATTER HEIGHT TO 2 M

When designing bioretention systems on steep topography, care should be taken to manage the total footprint of the bioretention system as batter slopes can extend significant distance from the filter edge when tying into natural surfaces. Features such as retaining walls can alleviate this issue as illustrated in Figure 29. Aligning the long axis of bioretention systems to natural contours can also help to minimise the total bioretention system footprint and better integrate into the landscape.

Figure 29 Bioretention system edge design on steep slope



3.3.5.4 Embankments

PERFORMANCE OUTCOMES
Bioretention embankments must:

- be safe and stable
- be low maintenance
- not create unacceptable visual impacts
- provide for construction and maintenance of the system.

RECOMMENDED APPROACH
Bioretention embankments serve the multiple roles of retaining design stormwater flows, providing access for construction and maintenance and providing pedestrian access. The recommended approach for designing embankments around bioretention systems is shown in Figure 30.

3.3.5.5 Walls

PERFORMANCE OUTCOMES
Walls around bioretention systems must:

- be safe and stable
- not create unacceptable visual impacts
- allow the system to be easily constructed and maintained.

RECOMMENDED APPROACH
Bioretention systems should be designed without walls, where possible, because they present a potential safety hazard. However, walls may be acceptable in steep terrain, to preserve existing vegetation, or for aesthetic reasons. Local authorities should be consulted when walls are being proposed for bioretention systems. Specialist geotechnical advice should be sought for designing retaining walls.

Well-designed walls can provide interesting landscape finishes adjacent to a bioretention system (Figure 31). However, badly designed and high walls result in poor landscape outcomes, maintenance difficulties and public safety problems. It is recommended that walls around bioretention systems are in accordance with Figure 32 and Table 9.

The limits recommended in Figure 32 and Table 9 will help to manage the visual impact of the walls, include safety considerations and allow the wall to interact with the edge of the bioretention system. Where vertical drops are greater than 800 mm, it is recommended that more than one wall (each ≤ 800 mm high) are used. The walls should be separated by a vegetated strip that is at least 3 m wide and planted with trees. Where a wall is only used for part of the system perimeter, batters in accordance with Section 3.3.5.3 should be used for the rest of the perimeter of the bioretention system.

Walls should not be used for streetscape bioretention systems unless the walls are integrated with seating (Figure 31). Walls are not recommended around bioretention systems within flood storage areas.

Figure 30 Embankment width requirements

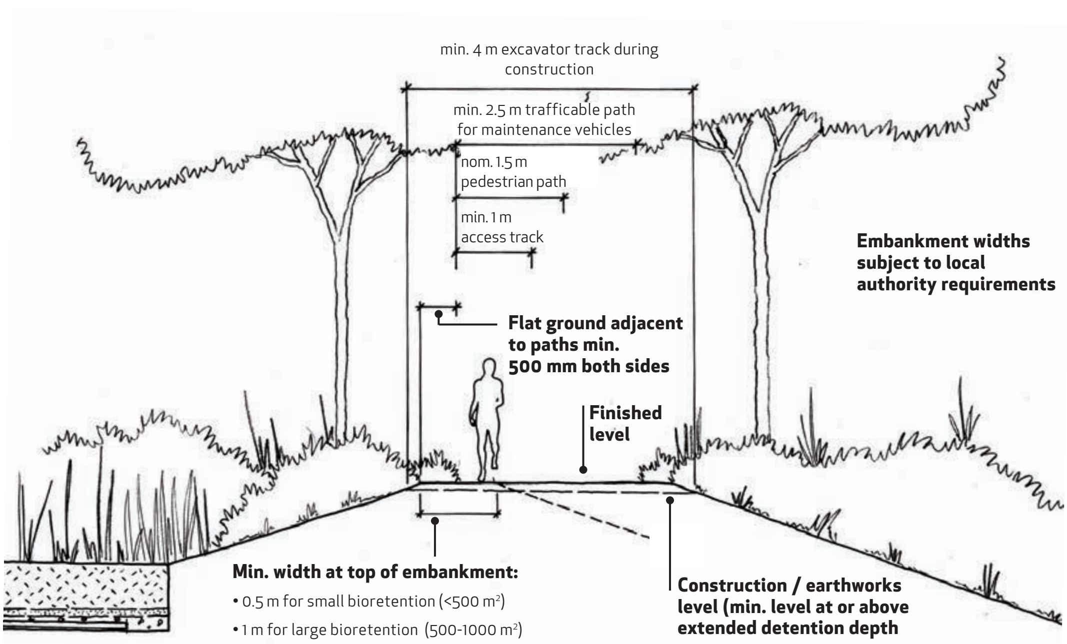


Table 9 Bioretention wall design guidance

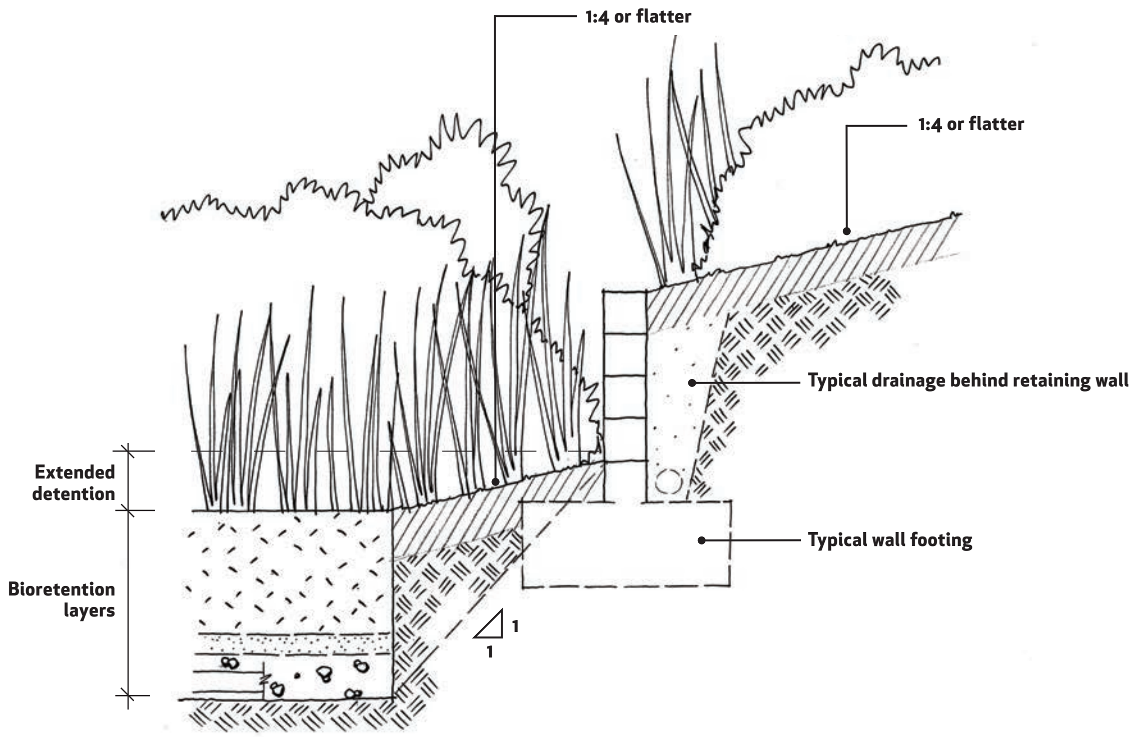
Wall details	Design response
Vertical drop ≤ 150 mm	Wall can surround entire bioretention system.
150 mm > vertical drop ≤ 300 mm	Wall around up to 75% of bioretention perimeter.
300 mm > vertical drop ≤ 800 mm	Wall around up to 50% of bioretention perimeter.

Figure 31 Well-designed bioretention system walls

Photo: Shaun Leinster, DesignFlow

Photo: Robin Allison, DesignFlow

Figure 32 Preferred configurations of walls around bioretention systems



If a wall forms the edge of the filter media, it should have a flat surface and the filter media should be compacted against the surface to minimise the risk of scouring (Figure 33).

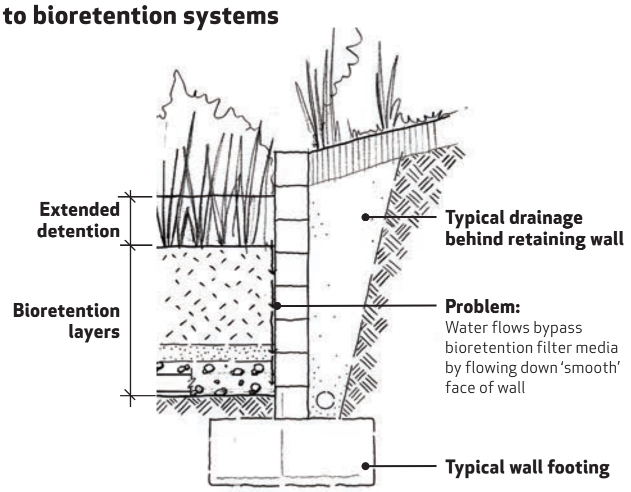
Where uneven rock walls are adopted, the wall should be set back from the bioretention filter media, retaining at least 1 m of in-situ soil. The separation should be wide enough to ensure the base of the rock wall is well founded, that is at a 45 degree angle from the base of the filter media.

3.3.6 Maintenance access

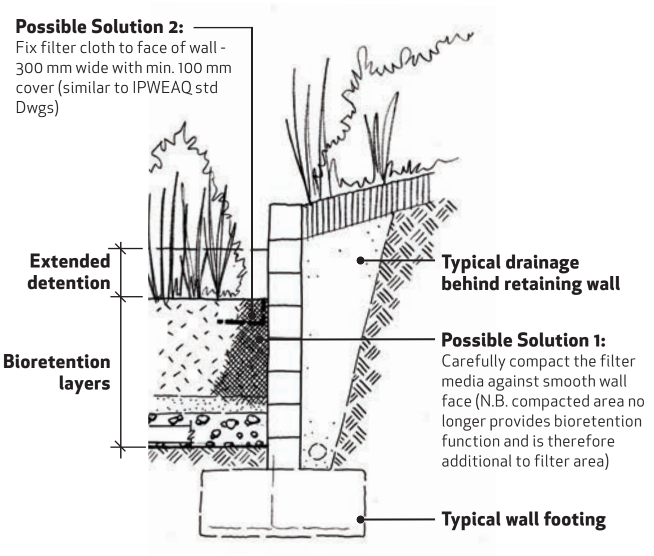
Bioretention systems require regular, proactive but simple maintenance to ensure their effective long term operation and to minimise lifecycle costs. Typical maintenance activities involve weeding, litter collection, sediment removal, repair of localized scour and inspection of hydraulic structures. To ensure this can happen, it is vital that bioretention design:

- provides access for sediment removal
- provides access to the filter media and vegetation
- appropriately delineates the edge of the bioretention system.

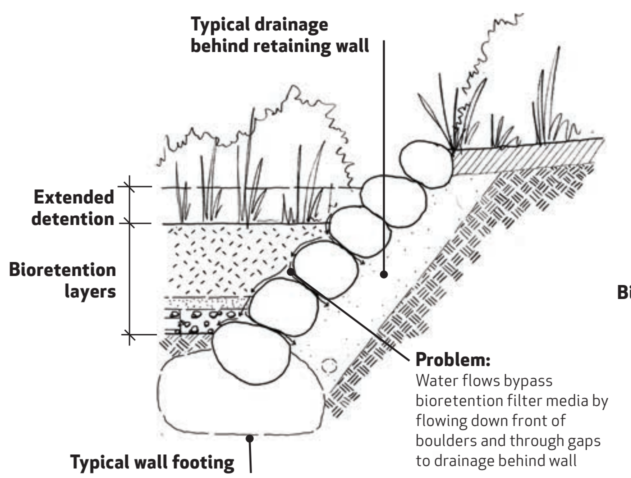
Figure 33 Design guidance for walls in and adjacent to bioretention systems



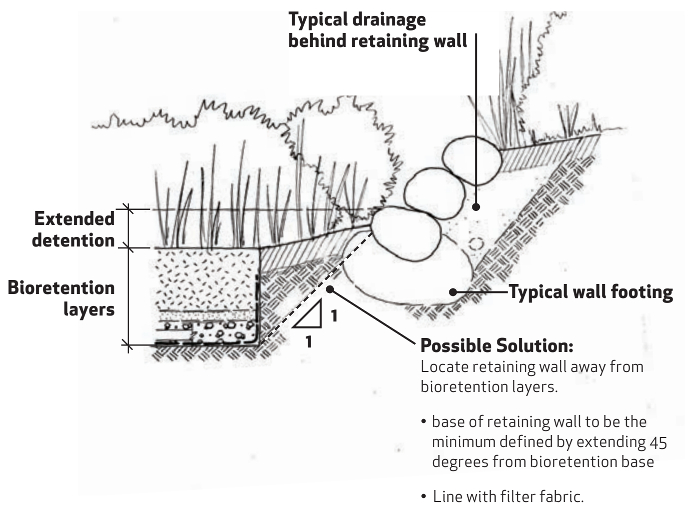
BLOCK RETAINING WALL - TYPICAL PROBLEM



BLOCK RETAINING WALL - POSSIBLE SOLUTIONS



BOULDER RETAINING WALL - TYPICAL PROBLEM



BOULDER RETAINING WALL - POSSIBLE SOLUTION

3.3.6.1 Sediment cleanout access

PERFORMANCE OUTCOMES

Access for sediment cleanout must ensure accumulated sediment can be easily removed using commonly available equipment.

RECOMMENDED APPROACH

Removing sediment from bioretention systems will typically involve machinery and vehicles such as mini excavators, bobcats, trucks, tippers or utilities. Maintenance paths should meet an access point (road or car park) for vehicles to be able to access the bioretention system. These access points should preferably be located away from high-use pedestrian areas. Consideration should be given to preventing public vehicle access to maintenance tracks by using lockable gates or bollards.

Access requirements for cleaning sediment from inlet ponds and coarse sediment forebays are outlined in Figure 34. Local authorities should be consulted to confirm their requirements as part of the design process.

Maintenance access should be provided to the invert of coarse sediment forebays. For inlet ponds, a suitable area for dewatering extracted sediments should be provided. The dewatering area should be approximately a quarter of the inlet pond area (at normal water level) and drain towards the pond.

Figure 34 Recommended sediment maintenance access track parameters

COARSE SEDIMENT CAPTURE TYPE	ACCESS TRACK SLOPE	RECOMMENDED PATH MATERIAL AND WIDTH
Coarse sediment forebay	1 in 4 or flatter	Concrete, gravel or reinforced turf path ≥ 2.5m wide
	1 in 3 to 1 in 4	Reinforced concrete path ≥ 2.5m wide
Inlet pond < 100m²	1 in 4 or flatter	Reinforced concrete path ≥ 2.5m wide from inlet pond base to 0.5m above standing water level Concrete, gravel or reinforced turf path ≥ 2.5m wide, higher than 0.5m above standing water level
Inlet pond > 100m²	1 in 4 or flatter	Reinforced concrete path ≥ 3.0m wide from inlet pond base to 0.5m above standing water level Concrete, gravel or reinforced turf path ≥ 3.0m wide, higher than 0.5m above standing water level
Other (e.g. GPT)	Determine in consultation with local authority	

3.3.6.2 Filter and vegetation maintenance access

PERFORMANCE OUTCOMES

Access for filter and vegetation must allow access for regular inspections and maintenance.

RECOMMENDED APPROACH

Maintenance access is required for weeding, replanting and regular inspections. All maintenance access tracks/paths should allow appropriate entry and exit connections with a road or car park. Local authority requirements for access paths and lockable gates apply. Maintenance access can be combined with pedestrian pathways in accordance with local authority requirements.

The recommended maintenance access to bioretention systems' perimeters is outlined in Table 10.

3.3.6.3 Outlet pipe access

PERFORMANCE OUTCOMES

Access must allow for maintenance to ensure the outlet pipe drains freely.

RECOMMENDED APPROACH

Outlet pipes discharging to low lying, inundated areas are at risk of becoming blocked by vegetation or sediment. A maintenance access track, trafficable by small earthmoving equipment such as a dingo or small bobcat (e.g. gravel, reinforced turf or other) should be provided from an appropriate access point (e.g. road or carpark) to outlet pipes discharging to low lying, inundated areas. Other outlet pipes (e.g. those discharging to the stormwater drainage network or parkland) should be provided with maintenance access in line with local authority requires for similar outlets not from bioretention systems.

3.3.6.4 Maintenance edges

PERFORMANCE OUTCOMES

Maintenance edges must:

- minimise the risk of turf and weeds encroaching into the bioretention system
- provide for easy maintenance of the bioretention system
- delineate the bioretention system from surrounding land uses if required.

Figure 35 Maintenance edge to bioretention system

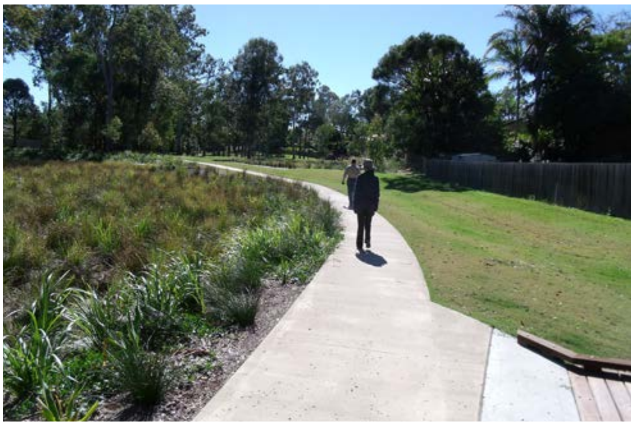


Photo: Shaun Leinster, DesignFlow

Photo: Shaun Leinster, DesignFlow

RECOMMENDED APPROACH

Maintenance edges minimise the risk of turf and weeds encroaching into the bioretention system. They separate different landscape types, create clean edges to the batter planting, and permit easy maintenance of adjacent landscapes. Maintenance edges are not recommended for bioretention systems located next to bushland or riparian vegetation. Maintenance edges (Figure 35) should be located at the perimeter of bioretention planting and consist of:

- pedestrian pathways or un-vegetated maintenance access tracks
- concrete landscape maintenance edge in line with local authority standards.

Table 10 Bioretention perimeter maintenance access

Filter media area	Recommended perimeter maintenance access
< 500 m^2	Access path along one side of the bioretention system (≥ 40% of perimeter) to allow easy access on foot. Turf, gravel or concrete path ≥ 1 m wide.
> 500 m^2	Trafficable path (≥ 2.5 m wide) suitable for small utilities or tractors (reinforced turf, gravel or other) along ≥ 40% of perimeter of each cell. Path (≥ 1.0 m wide) suitable for foot traffic (turf, gravel or other) around remaining perimeter

3.3.7 Underground services

PERFORMANCE OUTCOMES

Where underground services are located in proximity to a bioretention system, the design of the system must:

- ensure the operation of the bioretention system does not compromise the function of the service and vice versa
- ensure common maintenance and checking activities undertaken on the service do not compromise any component (e.g. filter media) or function of the bioretention system, or vice versa.

RECOMMENDED APPROACH

Underground services should be located outside the filter media area, but may be incorporated into bioretention system batters. Where this is not possible (e.g. in retrofit or in streetscape), how to access services for maintenance without regularly disrupting the bioretention should be considered.

Interactions between services and the bioretention systems are detailed in Table 11; however, the requirements of local authorities and service providers take precedence over the advice in Table 11.

3.3.8 Road reserves (streetscape bioretention systems)

PERFORMANCE OUTCOMES

The layout of streetscape bioretention systems must:

- not compromise other streetscape functions
- integrate with the aesthetics of the streetscape.

RECOMMENDED APPROACH

Placing bioretention systems within road reserves requires careful consideration of the functions that streetscapes perform, including:

- services corridors, crossings, and connections to dwellings
- road pavement and trafficable lane widths
- road base and kerb support
- pedestrian paths, access, and safety
- landscape design intent and street tree locations
- street lighting
- drainage (location of stormwater pits)
- vehicle site lines
- postal delivery services
- access to parked cars.

Table 11 Bioretention system interface with underground services

Service	Acceptable location relative to bioretention system
Electrical, telephone, gas	Electrical, telephone and gas services should not be located in the bioretention system's filter media. They can be installed under batters. If in a difficult situation or at service crossings within the road reserve one or more of these services is passed is passed through the filter media, a suitable conduit must be installed. Detection tape and kerb markers should be used to show service locations. Service connections (electrical pillars etc.) in bioretention systems are not recommended.
Water, sewer, stormwater	Water, sewer and stormwater services should not be located in the bioretention system's filter media. They can be installed under batters. In difficult or constrained situations, it may be possible to: • locate sewers or stormwater infrastructure under the filter media • pass water through the filter media via a conduit. Detection tape and kerb markers should be used to show service locations. Service connections (water meters etc.) in filter media are not recommended.

Road reserve cross sections need to support all these functions, as well as provide space for bioretention systems. Some local authorities have developed standard road reserve cross sections for streetscape bioretention systems. Local authorities should be consulted to determine if any standards exist and if not, how one may be developed for the subject site.

Refer to the *Concept Design Guidelines for Water Sensitive Urban Design* (Water by Design) and *Deemed to Comply Solutions — Stormwater Quality Management* (Water by Design) for more guidance and examples of streetscape bioretention systems and road sections. The following design responses should be considered when locating bioretention systems within road reserves. These responses must be approved by the local authority:

- localised widening of road reserves by indenting property boundaries (e.g. 15 m wide road reserves may widen to 18 m in the vicinity of bioretention systems (Figure 36)
- offsetting the road carriageway centreline if additional space on one side of the road is needed
- integrating bioretention within traffic calming 'build-outs' from the kerb
- developing street networks with low design speeds to reduce the need for footpaths
- locating parking bays to accommodate bioretention (retrofit situation).

3.3.9 Bioretention within flood storage

PERFORMANCE OUTCOMES

When bioretention systems are combined with flood storage, they must ensure that:

- flood storage outcomes are achieved
- flood storage design does not rely on extended detention volumes
- bioretention system design objectives are not compromised during or after flood events.

RECOMMENDED APPROACH

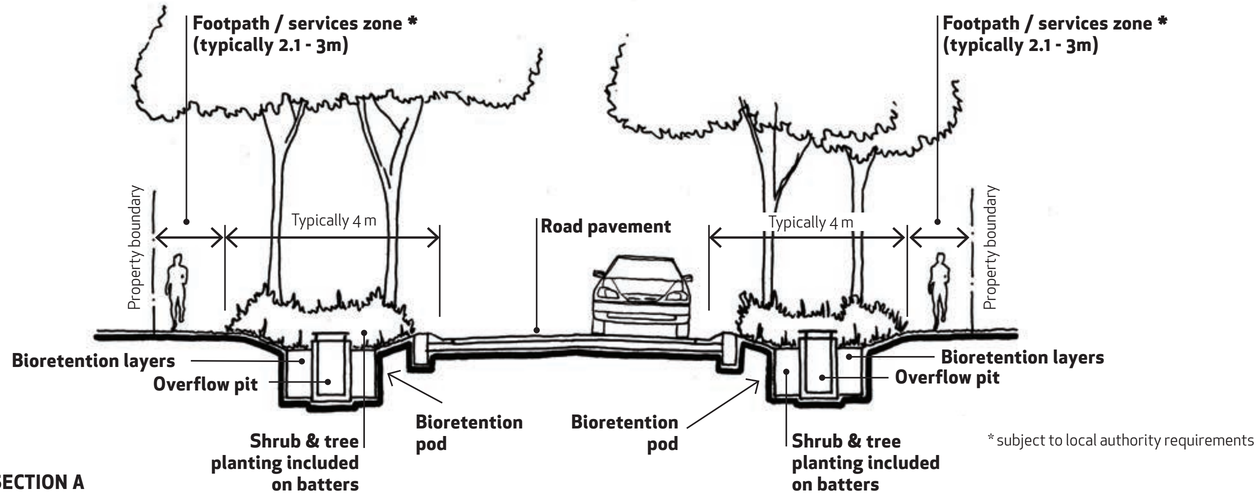
Bioretention systems may be integrated into the base of flood storage, effectively reducing the overall land required for managing stormwater quality and quantity. Where bioretention systems can be integrated into the base of flood storage, they will infrequently become inundated to greater depths than the extended detention depth. The duration of any inundation should be relatively short (hours) and is unlikely to affect the vegetation in the bioretention system if the water can drain after flood events without scouring the filter media and batters and does not deposit excessive sediment on the surface of the filter media.

The footprint to meet flood attenuation requirements is generally larger than that needed for bioretention systems. The size and configuration of the flood storage should therefore be carefully defined and integrated with the broader landscape. The flood storage area outside the bioretention system can be flat or sloped, depending on the site characteristics and proposed vegetation. The flood storage size should be established using modelling and calculations in accordance with local authority standards.

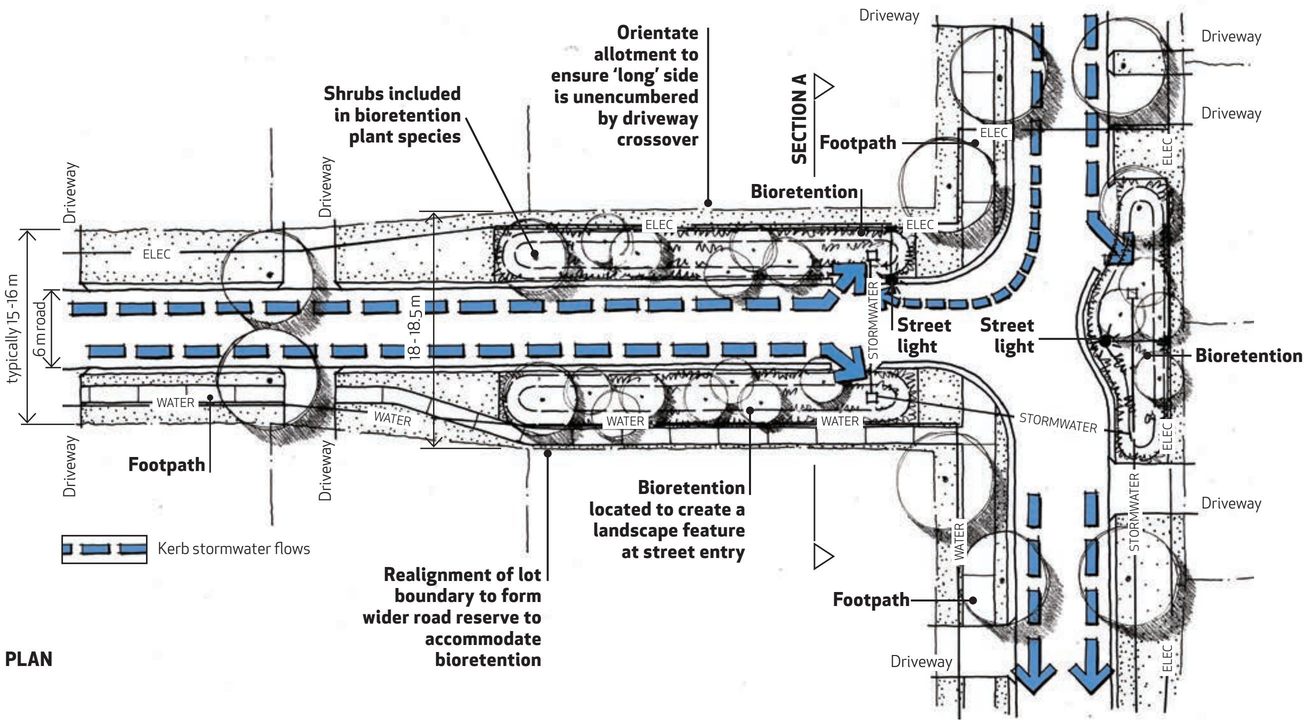
A number of issues should be considered when combining flood storage with bioretention systems:

- Extended detention volume should not be included in the storage volume used to assess the performance of flood attenuation. The extended detention is drawn down via the filter media at a slower rate than the dedicated flood storage volume. This means the extended detention volume is not available for flood storage if a flood event closely follows a smaller rainfall event.
- Where a bioretention system is sized to meet the objectives for a catchment that is smaller than the total flood storage catchment, flows from the additional flood storage catchment greater than the peak one-year Average Recurrence Interval (ARI) event should bypass the filter media. This will avoid overloading the filter media with sediment or excessive wetting.
- To minimise the risk of scour, the spread of flows greater than the peak one-year ARI should be controlled by the flood storage outlet (i.e. backwater).
- To manage public safety risks, the peak 20-year ARI inundation depth should be no more than 1.2 m above the surface of the filter media in accordance with QUDM (DEWS, 2013).
- Walls should not be used around the perimeter of the bioretention system to avoid a vertical drop that will be hidden when the flood storage is engaged.
- The surface of the flood storage that will be inundated by the peak one-year ARI water level should be vegetated with appropriate plant species (i.e. not turf) as it will be frequently wet and mowing is likely to be difficult.

Figure 36 Road reserve widening to accommodate bioretention systems



SECTION A



PLAN

3.4 Inlet design

The design of the bioretention system inlet dictates the amount of water that enters the bioretention system, how and when this occurs, whether the system will be prone to either sediment accumulation or scour and whether flows will be evenly distributed across the filter media surface. Bioretention inlet design requires careful consideration to ensure that these elements do no compromise the long term operation of the bioretention system. Bioretention inlet design should consider:

- the design inflows
- the inlet type
- coarse sediment removal
- energy dissipation and scour protection
- flow distribution in large bioretention systems.

3.4.1 Design inflows

PERFORMANCE OUTCOMES

Design inflow estimates must be accurate as they inform the design of both inlet and outlet components.

RECOMMENDED APPROACH

It is recommended that a number of different design inflows are used for sizing hydraulic structures and coarse sediment removal measures for bioretention systems. Table 12 defines each design inflow and sets out its uses.

For small catchment areas of ≤ 10 ha, the Rational Method as described in QUDM (DEWS, 2013) is generally appropriate for determining design inflows. However, local authority requirements for rainfall-runoff assessment should be adopted where available. Where detailed hydrologic modelling is available, it should be used to estimate flows.

For large catchment areas of > 10 ha or where a bioretention system forms part of a flood detention basin, a runoff routing model should be used to estimate peak flow rates, using an appropriate method of validation against simplified methods (such as the Rational Method) as required by the local authority.

Flood modelling should be used to ensure design criteria in Section 3.3.9 are satisfied for bioretention systems located within a flood detention basin.

DESIGN NOTE: Design flows in pipe drainage network

When designing bioretention basins at the outlet from a pipe drainage network, it is important to check if the pipe drainage has been designed to the local authority 'minor' drainage requirements or if it has been upsized to carry a portion of the major storm flow also (i.e. where surface flow depth or width is exceeded during the major storm, the underground pipe drainage may have been increased to alleviate this). Actual drainage design capacity (and discharge velocities) should be used in the design of inlet/outlet structures and scour protection in bioretention basins.

DESIGN NOTE: Drainage network upstream of bioretention systems

When designing new or retrofit bioretention systems, consideration should be given to the effect of the bioretention system's extended detention depth and maximum water level on the hydraulic grade line within the upstream drainage network.

Table 12 Design inflows and their uses

Design inflow	Uses
Maximum flow that will enter the bioretention system during the peak major storm event as defined by local authority (e.g. 50-year ARI)	Overflow weir design Setting embankment levels Scour velocity check
Maximum flow that will enter the bioretention system during the peak minor storm event as defined by local authority (e.g. 2-year ARI)	Overflow pit design Setting overflow weir height Scour velocity check
Peak 1-year ARI	Inlet pond design
Peak 3-month ARI	Coarse sediment forebay design

3.4.2 Inflow type

The site layout, levels and adjoining land use will dictate the most appropriate method for delivering stormwater to a bioretention system. Stormwater may be discharged directly from a drainage network (e.g. end-of-pipe system) or as a low-flow diversion from a nearby drainage system or kerb. Inflows to bioretention systems mainly come from:

- pipe flow
- concentrated surface flow
- distributed surface flow.

This section provides design guidance for inflows from the above inflow types. The performance outcomes detailed below apply to all three inflow types. The recommended approach for each inlet type is specified in Sections 3.4.2.1 to 3.4.2.3.

Stormwater may also be directed to bioretention systems via diversion or surcharge structures. Diversion or surcharge structures are often associated with retrofitting bioretention systems where pipe or surface inflow to a bioretention system is not feasible. The design of diversion and surcharge structures should comply with local authority drainage design standards. The design should also take into account upstream hydraulic impacts within existing drainage; accumulation of sediment, litter and debris; maintenance access; and dewatering following runoff events.

PERFORMANCE OUTCOMES

The inlet of bioretention systems must:

- convey a sufficient proportion of the catchment run-off onto the surface of the bioretention system to enable performance objectives to be met
- be unlikely to block with debris
- not cause inappropriate upstream inundation
- ensure the filter media does not get clogged with excessive algal growth.

DESIGN NOTE: Baseflow into bioretention systems

Continual baseflows through either piped or surface drainage networks can lead to excessive algal biofilm growth on the filter media, which can clog the surface preventing infiltration. This effect has been observed on installed systems.

Where site analysis (see Section 3.1) finds a baseflow 10 days or more after rainfall, one of the following approaches should be used:

- bypass the baseflow around the filter media, only if the baseflow is good quality water or will be treated in another way
- find and eliminate the source of the baseflow (e.g. fix a leaking pipe or remove a cross-connection)
- use an alternative treatment option (e.g. a constructed wetland).

If none of these options are possible, designers can consider using multiple bioretention cells and directing the baseflows to alternating cells. This approach requires expert advice on suitable resting frequency and the duration and commitment required from the long-term asset owner to manage the flow diversion infrastructure.

3.4.2.1 Concentrated surface or pipe inflow

RECOMMENDED APPROACH

Recommended design outcomes for concentrated inflows are:

- a sediment forebay, inlet pond or another form of pre-treatment (e.g. gross pollutant trap) unless the bioretention system only receives roof runoff or its catchment is less than 2ha, (further design discussion on coarse sediment removal is in Section 3.4.3)
- energy dissipation and scour protection at the inflow point or sediment forebay designed to prevent concentrated inflows from damaging the bioretention system
- inflow pipe or channel invert at, or above, the surface of the bioretention system (preferably 200 mm above) to prevent siltation or debris accumulation in pipes
- for a coarse sediment forebay, the inflow pipe invert should be at the top of the sediment accumulation depth (100–300 mm above the forebay invert)
- where an inlet pond is used, the inflow pipe invert should ideally be at the normal water level; the local authority should be consulted if the pipe invert is submerged below or elevated above the normal water level.

Structural elements such as forebays and rock protection can impact on the landscape amenity of the bioretention systems and they should be concealed where possible.

3.4.2.2 Concentrated kerb inflow (streetscape)

RECOMMENDED APPROACH

Concentrated inflow to streetscape bioretention systems typically occurs via kerb inlets formed as cut-outs from the kerb alignment. The kerb opening size will be determined by the location of the stormwater outlet, which can be either:

- **Side entry pit within the kerb and channel (preferred).** Where the bioretention overflows enter a conventional side entry pit, immediately downstream of the inflow point, kerb openings to the bioretention system only need to be sized to convey the treatment flow (e.g. less than one-year ARI). When the bioretention extended detention is full to the kerb invert level, stormwater bypasses the kerb opening to the downstream side entry pit. This bypass requires kerb openings immediately upstream of side entry pits. The minimum suggested opening width is 500 mm to minimise the risk of opening becoming blocked by debris. The side entry pit should be designed in accordance with IPWEAQ SEQ D-063 or equivalent. An example of a kerb inlet and a side entry pit within the kerb and channel is shown in Figure 37.
- **Overflow pit within the bioretention.** Where an overflow pit is located within a streetscape bioretention system, the overflow pit will typically form part of the minor drainage for the roadway. The kerb opening will, therefore, need to be sufficiently sized to convey the flow from a minor storm (2–10 year ARI, depending on local authority standards) to the overflow pit, while meeting the flow depth and width requirements on the adjacent roadway, which are determined by the local authority.

To promote flow from the kerb, the slope of an apron extending from the kerb invert into the bioretention system should be between 1 in 10 and 1 in 4. The flow can be further enhanced by locally depressing the kerb invert (in longitudinal profile) at a kerb opening, designed in accordance with local authority requirements and take vehicle and bicycle safety into account.

KERB OPENING IN SAG

To size the kerb opening width for sag locations and very low grade streets of < 1%:

- determine for the design flow required to enter the bioretention system, the depth and width of flow in the kerb at the inlet, using either Izzard's equation as described in QUDM (DEWS, 2013) or road flow capacity charts where available
- confirm that the flow depth and width limitations required by the local authority at the kerb opening location are met
- determine for the flow depth in the kerb, the length of kerb opening based on the broad-crested weir equation (Equation 2).

Equation 2

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

Where: Q_{weir} = design flow through kerb opening (m^3/s)

C_w = weir coefficient (1.66)

L = length of kerb opening (m)

h = depth of flow in kerb (m)

KERB OPENING ON-GRADE

Where the overflow pit is located within the bioretention system and the inlet is on-grade, rather than in sag, the kerb openings should be located and sized using the same procedure for sizing on-grade minor drainage pit openings, as described in QUDM (DEWS, 2013) or equivalent. Poorly designed streetscape bioretention systems can result in local flooding.

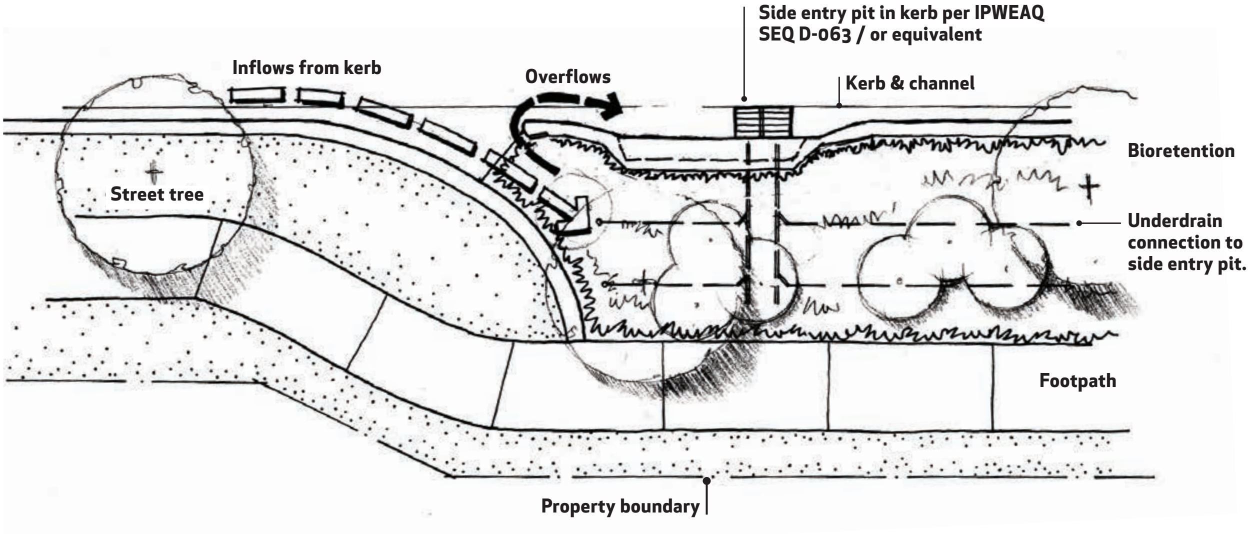
3.4.2.3 Distributed surface inflow (flush kerb or kerb breaks)

RECOMMENDED APPROACH

Flows may enter a bioretention system in a distributed manner via a flush kerb or regular kerb breaks (Figure 38). Distributed surface flows are typically associated with bioretention swales in road reserves and parkland areas where pavement runoff (from roads, paths or hardstand areas) directly enters a bioretention system as sheet flow over vegetated batters.

Standard drawings for flush kerbs are available from the IPWEAQ and many local authorities.

Figure 37 Kerb cut-out to streetscape bioretention



A number of issues should be considered when designing streetscape bioretention systems with distributed surface inflows:

- Promote lateral flow at the inlet to ensure that coarse sediment does not accumulate on the road or block the kerb breaks. Lateral flow should be achieved by using a minimum 1 in 6 concrete batter or a set down of 60 mm from the kerb edge to the top of turf or mulch. This requires the finished batter topsoil surface (i.e. before turf or mulch) to be approximately 100 mm below the edge of pavement level to allow for turf or topsoil.
- To ensure an even distribution of flow, kerb breaks should be at least 500 mm wide and have a maximum spacing of 5 m. Scour protection may be required at the inflow points of kerb breaks.
- Suitable traffic management should be provided around flush kerbs.

Figure 38 Flush kerb to promote distributed flow into the bioretention system

Photo: Robin Allison, DesignFlow

3.4.3 Coarse sediment removal

To ensure that the deposition of coarse sediment on the filter media surface does not affect bioretention system function, bioretention systems should be designed with pre-treatment to limit the amount of coarse sediment reaching the filter media. Accumulating sediment in a dedicated area also makes maintenance simpler and more cost effective. The following sections detail how to select the most appropriate pre-treatment method for the site as well as methods for sizing both sediment forebays and inlet ponds.

3.4.3.1 Selecting the pre-treatment type

PERFORMANCE OUTCOMES

Selecting the pre-treatment type for the site and catchment must:

- ensure that deposition of coarse sediment on the filter media does not affect the performance of the bioretention system
- ensure the bioretention system integrates with the surrounding landscape
- allow for the bioretention system to be easily maintained.

RECOMMENDED APPROACH

Table 13 outlines the most appropriate coarse sediment removal methods for various catchment types and sizes. Consideration should be given to local authority requirements when specifying the coarse sediment removal method as maintenance regimes or other requirements may prevent local authorities from accepting certain types of coarse sediment removal.

3.4.3.2 Sediment forebay design

PERFORMANCE OUTCOMES

Forebays must be designed to:

- remove 80% of particles that are 1 mm or larger in diameter from the peak three-month ARI flow
- provide appropriate storage for coarse sediment to ensure desilting is required no more than once per year
- provide energy dissipation of incoming flows (refer to Section 3.4.4).

RECOMMENDED APPROACH

Forebays should be designed in accordance with Figure 39 and by referencing local standards, such as the IPWEAQ Standard Drawings.

Sizing of coarse sediment forebays is undertaken in three steps:

- determining the sediment forebay volume
- determining the sediment forebay area
- determining the sediment forebay depth.

The minimum sediment forebay volume should be determined using Equation 3:

Equation 3

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

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

A_c = contributing catchment area (ha)

R = capture efficiency (0.8 recommended)

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

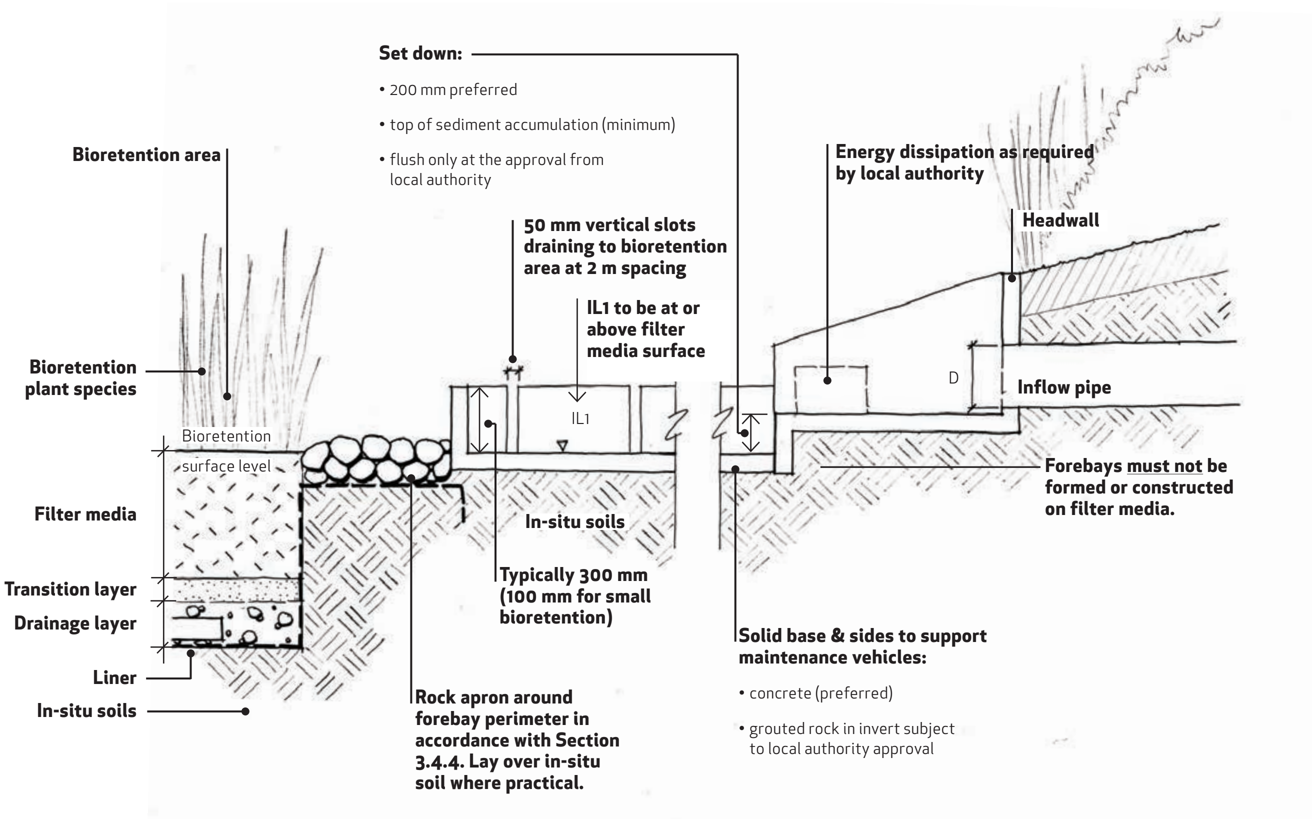
F_c = desired cleanout frequency (years)

Table 13 Recommended coarse sediment removal methods

Catchment scenario	Coarse sediment removal methods
Roof runoff only	None
Catchment ≤ 2 ha	None*
Catchment > 2 ha and ≤ 5 ha	Vegetated swale, coarse sediment forebay, inlet pond or gross pollutant trap
Catchment > 5 ha	Inlet pond or gross pollutant trap

*Sediment accumulation at the point of inflow should be regularly assessed and accumulated sediment cleared if it is blocking inlet or it is impeding infiltration.

Figure 39 Coarse sediment forebay requirements



If local data is unavailable, a catchment loading rate (Lo) of 0.6 m^3/ha/year is recommended. This rate is based on a review of sediment removal from gross pollutant traps (GPTs) in stable urban catchments in Brisbane. This review was commissioned by the South East Queensland Healthy Waterways Partnership in 2011.

The minimum forebay area for capturing the target sediment size (1 mm) can be determined using Equation 4 (modified from Fair and Geyer (1954)):

Equation 4

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

Where: R = fraction of target sediment removed (0.8 recommended)

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

Q = 3-month ARI flow rate (m^3/s)

A_f = minimum forebay area for sediment capture (m^2)

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

Preliminary depth for forebays can be established by dividing the minimum volume by the minimum area (see Equation 5). Forebays should be no more than 300 mm deep. Small forebays of <10 m^2 should preferably be 100–200 mm deep. If using the minimum forebay area from Equation 3 results in a depth greater than these maximums, the forebay area should be increased to provide the required storage volume and an acceptable depth.

Equation 5

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

Where: V_s = minimum forebay volume for sediment storage (m^3) from Equation 3

A_f = minimum forebay area for sediment capture (m^2)
D_s = forebay depth ($\leq$ 0.3 m)

To allow the forebay to freely drain, 50 mm wide vertical slots should be provided at 2 m spacing around the forebay wall. Where practical, slots should be located away from the primary flow path, preferably orientated at a right angle to the direction of flow, to prevent high flows flushing sediment through slots. Circular weep holes are not recommended as they are prone to blockage.

3.4.3.3 Inlet pond design

PERFORMANCE OUTCOMES

Inlet ponds to bioretention systems must be designed to:

- remove coarse sediment by using a permanent water column to reduce flow velocities and promote settling
- regulate flows entering the bioretention filter media
- dissipate inflow energy
- allow for high flows to bypass the bioretention filter media
- provide appropriate storage for coarse sediment to ensure desilting is only required infrequently
- minimise safety risk
- provide visual amenity.

RECOMMENDED APPROACH

Inlet ponds should be designed in accordance with the sediment basin chapter of the *Water Sensitive Urban Design Technical Design Guidelines for South East Queensland* (Water by Design) and should include:

- high-flow bypass weir and channel
- connection from inlet pond to a bioretention system for small events only e.g. less than one-year ARI
- a system which ensures even distribution of flow to the bioretention system surface (e.g. by using multiple pipes or distribution channels along the edge of bioretention cells)
- maintenance access.

Inlet ponds should be used for large bioretention systems (> 800 m^2) and for contributing catchments greater than 5 ha. Inlet ponds are also recommended for systems where:

- large diameter inlet pipes may compromise sediment capture within a forebay (pipes > 600 mm diameter)
- multiple pipes discharge to a single bioretention cell to avoid multiple forebays and access points or
- improved flow distribution to multiple bioretention cells is required.

3.4.4 Inlet energy dissipation and scour protection

Bioretention inlets require energy dissipation and scour protection to avoid damage to the filter media from inflows, and to minimise the re-suspension of coarse sediment collected near the inlet. The method by which this is achieved varies depending on whether the inlet is via a pipe, openings in the kerb or from distributed surface flow. The following performance outcomes apply to all three inlet types. The recommended approach for each inlet type is specified in Sections 3.4.4.1 to 3.4.4.3.

PERFORMANCE OUTCOMES

Energy dissipation and scour protection must:

- prevent filter media from scouring during a major storm event
- minimise re-suspension of coarse sediment collected near the inlet.

3.4.4.1 Pipe inlets

RECOMMENDED APPROACH

Inflows to bioretention systems and inlet ponds will usually require some form of energy dissipation or scour protection to ensure that concentrated flow paths do not damage or destabilize vegetated batters or the filter media.

For inlet ponds, scour protection is typically limited to a rock apron at the headwall. Energy will dissipate as flows enter the deep water and velocities decrease. Incoming pipe inverts should be set as close as possible to the normal standing water level of the sediment pond to limit turbulence and re-suspension of sediment, and to maximise energy dissipation. Rock aprons and energy dissipaters should be designed in accordance with local authority requirements.

For discharge directly from pipes into bioretention systems, protection against scour is required. This may require a combination of a rock outlet pad, a sediment forebay and energy dissipating rock or concrete structures.

Where a sediment forebay is present, it will provide some protection against scour of the filter media. A rock apron around the downstream perimeter of the forebay (see Figure 39) should help to protect further against scour. It should be designed in accordance with the advice on rock outlet pads in QUDM (DEWS, 2013) or equivalent. The length of the forebay can be included in the total apron length. Where the pipe outlet velocity is high, there is a risk of re-suspension of coarse sediment collected near the inlet. Where pipe outlet velocity exceeds 3m/s, energy dissipating rock or concrete structures should be used at the pipe headwall upstream of the forebay. QUDM (DEWS, 2013) provides advice on the design of energy dissipaters.

Where no sediment forebay is present (i.e. for catchments <2ha as per Table 13), a rock apron and energy dissipation designed in accordance with the advice provided in QUDM (DEWS, 2013) will be required.

3.4.4.2 Kerb openings

RECOMMENDED APPROACH

Kerb openings, or cut-outs, are typically used for streetscape bioretention systems, with small catchments and low gradient, and therefore low velocity, surface drainage.

The size and length of the rock protection should be determined in accordance with advice on rock outlet pads in QUDM (DEWS, 2013) or equivalent using the peak one-year ARI flow depth at the entry, in lieu of the inlet pipe diameter.

3.4.4.3 Distributed surface flow

RECOMMENDED APPROACH

Distributed surface flow typically has low flow velocities and, therefore, minimal requirements for energy dissipation or scour protection. Stabilised turf or densely vegetated zones are likely to provide sufficient protection.

3.4.5 Filter media scour velocity check

PERFORMANCE OUTCOMES

Bioretention system design must ensure that flows across the filter media surface do not cause scouring of the filter media or damage to plants.

RECOMMENDED APPROACH

In addition to scour at the interface of the inlet and the filter media as discussed in Section 3.4.4, scour of the filter media can occur at other locations in bioretention systems.

A check of maximum velocities passing over the filter media surface should be undertaken by assuming inflows pass through the full width of the system at its narrowest point, and dividing the flow rate by the area in accordance with Equation 6. Given the outlet will generally be located near the inlet, this is a conservative approach, but it allows for a simple calculation method.

Equation 6

$$v = \frac{Q}{w \times d}$$

Where: v = velocity of flow over filter media surface (m/s)

Q = flow rate in the design storm event (m^3/s)

w = bioretention basin width at narrowest point (m)

d = depth of flow in accordance with Table 14 (m)

The bioretention system should be configured so that the maximum velocities across the filter media, under minor and major storms, calculated using the flow depths in Table 14, is less than 1 m/s. This velocity limit is based on advice in Fischenich (2001) for surfaces covered in 'short native and bunch grasses'. Where more detailed information on flow depth in given design storms is available, this information can be used in lieu of the flow depths in Table 14.

Table 14 Scour velocity limits over the surface of the bioretention system

Design flow	Depth of flow over surface
Minor storm (2–10 year ARI)	Extended detention depth + 0.1 m
Major storm (50–100 year ARI)	Lesser of the bypass weir level + 0.1 m or the maximum water level

3.4.6 Flow distribution

PERFORMANCE OUTCOMES

Flow must be evenly distributed across the bioretention filter media surface.

RECOMMENDED APPROACH

Maintaining an even distribution of flow across the entire filter media area during small inflow events is a challenge for large bioretention systems. In large bioretention systems fed by a single inflow point, the area immediately downstream of the inlet will be wet more frequently than the area at the opposite end of the system, which may remain dry for extended periods. Therefore:

- the filter media closest to the inlet is likely to support healthy plant growth, due to frequent wetting, but it will be continuously loaded with stormwater pollutants that may result in filter media blockage or pollutant saturation
- the filter media furthest from the inlet will be dryer and vegetation may die back, leading to reduced treatment in larger rainfall events.

To alleviate this situation, medium to large bioretention systems with a filter media area of > 400 m^2 should have a flow distribution comprised of either:

- multiple inflow points
- a distribution channel along the edge of the bioretention system (e.g. inverted box culvert with weir cut-outs at 5 m spacing).

3.5 Outlet design

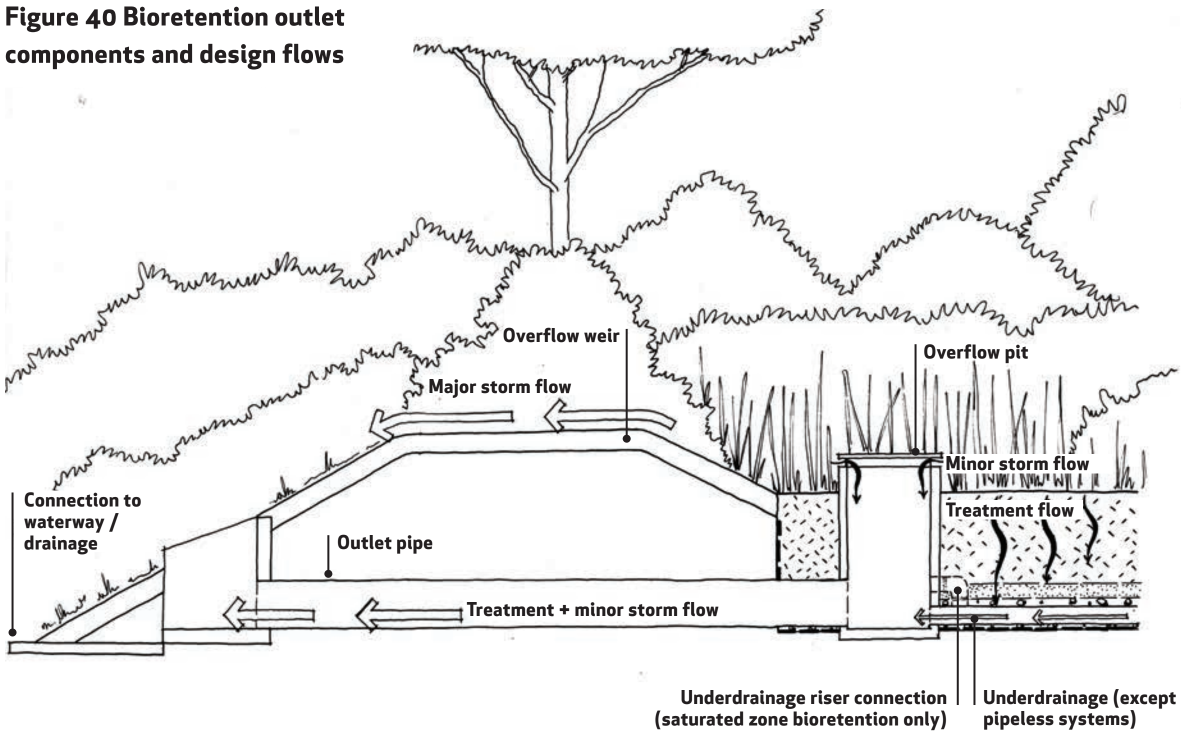
Bioretention system outlets serve multiple purposes including setting the extended detention depth, discharging treated flows via the underdrainage and conveying above design flows to the receiving environment. Outlets should also ensure that the bioretention system does not exacerbate flooding nor allow stormwater to overtop bioretention system bunds and embankments. They must be able to manage a range of flow rates.

Bioretention outlet design must consider:

- bioretention outlet components
- underdrainage pipe layout, material and sizing
- overflow pit design
- overflow weir design
- outlet pipe design
- connection of the bioretention system to the receiving environment
- flood storage objectives.

Bioretention system outlet components and their associated stormwater flows are shown in Figure 40 and detailed in Sections 3.5.1 to 3.5.6.

Figure 40 Bioretention outlet components and design flows



3.5.1 Underdrainage pipes

This section outlines the methods to design bioretention system underdrainage pipes. It does not apply to Type 4 pipeless bioretention systems as they do not have underdrainage pipes.

The design of bioretention system underdrain pipes involves:

- specifying the underdrainage network components and layout
- selecting the pipe material
- designing the saturated zone underdrainage riser
- sizing the underdrainage pipes.

It should be noted that two methods for sizing underdrainage pipes are provided in the following sections. The general approach to sizing underdrainage pipes (Section 3.5.1.4) can be used for Type 1 to 3 bioretention systems. It sizes underdrainage pipes based on a detailed calculation of head losses through the underdrainage network. A simplified conservative approach to sizing underdrainage pipes is outlined in Section 3.5.1.5. It can be used for Type 2 sealed bioretention systems.

PERFORMANCE OUTCOMES

Underdrainage pipes must:

- meet local authority requirements
- not restrict flow rates through filter media
- ensure access for inspection and cleaning
- prevent drainage layer material entering slots.

3.5.1.1 Underdrainage pipe network components and layout

RECOMMENDED APPROACH

Underdrainage pipes collect treated stormwater from a gravel drainage layer at the base bioretention systems and convey it to the outlet or overflow pit. Key components of underdrainage pipe networks are illustrated in Figure 41.

Underdrainage pipe layouts need to consider:

- location of the outlet pit (refer Section 3.3.4)
- maximum length of the slotted or perforated underdrainage
- use of collector pipes
- inspection and cleanout points.

Figure 42 illustrates various underdrainage pipe configurations. The most appropriate underdrainage pipe design for a specific site often requires multiple iterations to optimise the layout and hydraulic conveyance.

Vertical solid pipe sections should be used to create inspection or cleanout points at the end of every slotted or perforated pipe and at least every 20 m for pipes longer than 20 m. The vertical pipes should be the same diameter as the slotted or perforated pipe and extend at least 150 mm above the surface of the filter media to ensure they can be found when vegetation is established. A screw cap should be placed on the end of riser pipes and, where vandalism is a concern, a locking mechanism should be attached to ensure caps are not removed. Refer to local standards, such as IPWEAQ Standard Drawings when designing inspection and cleanout points.

Figure 41 Underdrainage components

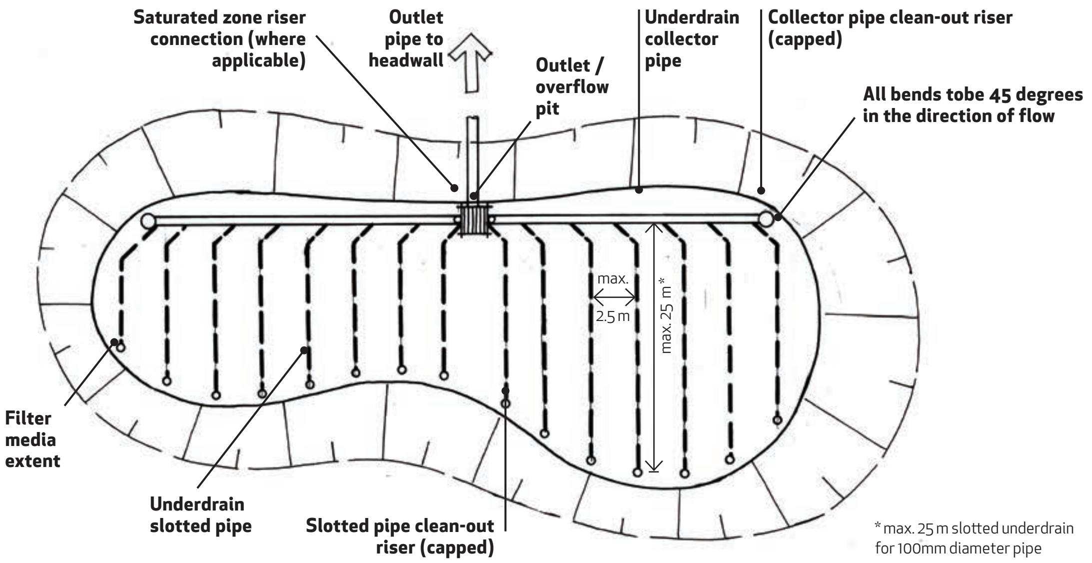
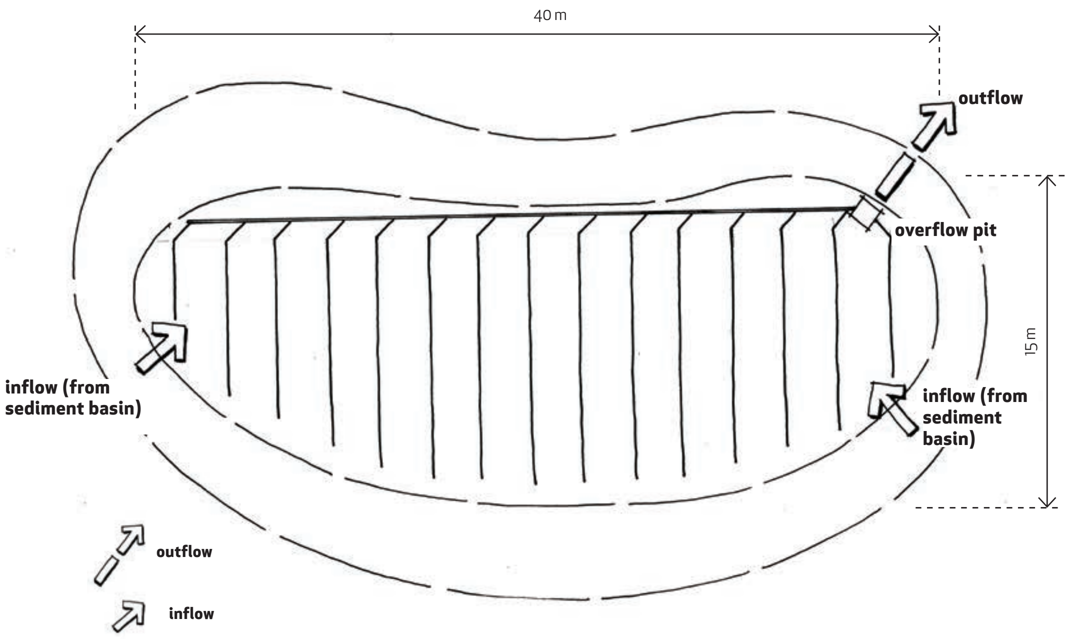


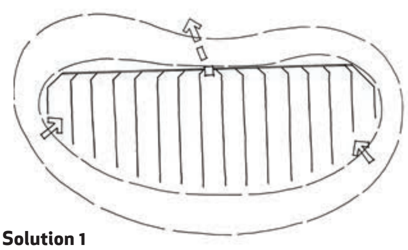
Figure 42 Underdrainage layout variations



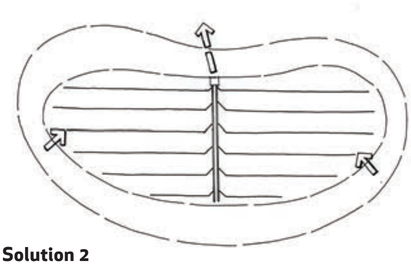
INITIAL LAYOUT

PROBLEMS:

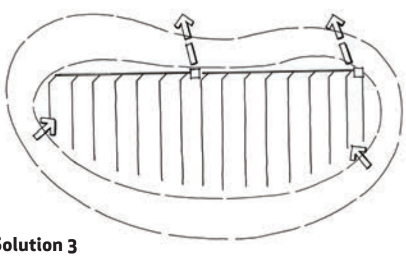
- underdrain headlosses exceed available hydraulic head
- collector pipe diameter excessively large



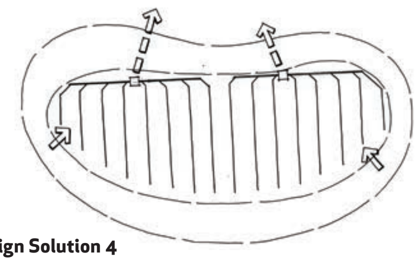
Design Solution 1



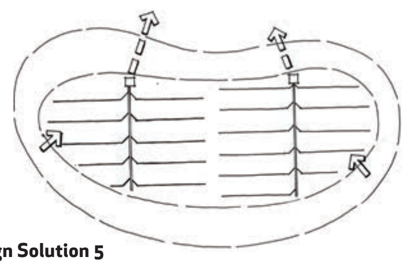
Design Solution 2



Design Solution 3



Design Solution 4



Design Solution 5

DESIGN SOLUTIONS:

- reduce pipe lengths (collector or underdrains)
- minimise pipe lengths to reduce elevation change and / or headloss
- increase number of overflow pits / connection points

The optimum arrangement can only be determined through checking design levels and hydraulic calculations

3.5.1.2 Pipe material selection

RECOMMENDED APPROACH

Either slotted rigid pipe or flexible perforated corrugated pipe can be used for underdrainage. Table 15 summarises the features of slotted rigid pipes and flexible corrugated pipes. Flexible pipe may be more appropriate where the shape of the bioretention system requires the pipe to turn a number of times. Pipes should not be wrapped in a filter sock (or equivalent) because it poses a clogging risk. For example, ag-pipe is often supplied with filter sock that should be removed.

Table 15 Underdrainage materials

Feature	Slotted rigid pipe	Flexible corrugated pipe
Rigidity	Pipe grade is not affected by local depressions in the bioretention base. This makes it easy to achieve a 0.5% grade towards the overflow pit.	Pipes tend to follow the final profile of the base of the bioretention system, which includes local depressions, making it difficult to create a constant grade to the overflow pit. There is also a risk of local ponding within the pipe.
Ease of connection and sealing	Standard plumbing for rigid pipes makes connecting and sealing pipes simple.	Connecting flexible corrugated pipe can be more difficult and may require a substantial amount of sealant.
Internal pipe surface	The smooth surface is free draining and does not hold water for a significant period after rain, minimising the potential for tree roots to enter the pipes in search of water. The smooth surface is less resistant to flow. At a 0.5% grade, a 100 mm diameter slotted rigid pipe can convey up to 3 L/s.	The corrugated surface is more likely to retain beads of moisture inside the pipe, increasing the potential for tree roots to enter the pipes in search of water (in Type 2 sealed or Type 3 conventional bioretention systems*). The corrugated surface is more resistant to flow. At a 0.5% grade, a flexible 100 mm diameter corrugated pipe can convey up to 1.5 L/s.
Maintenance	There is little resistance to flushing accumulated sediment and debris from the rigid pipe.	Corrugations and the flexibility of pipe make it harder to dislodge and flush sediment and debris.
Slot size	Wider slots are less likely to block.	More slots, but narrower perforations can block easily.
Resilience	Brittle so damage is irreversible.	Flexible so more resilient to rough handling.
Cost	More expensive.	Cheaper and easier to handle.

* A video inspection of underdrainage in a 10-year old bioretention system with extensive tree planting found a negligible amount of tree roots in the flexible corrugated underdrainage pipes. The base and sides of this system are lined with a permeable liner. The drainage profile operates in a similar way to a Type 3 conventional bioretention system. The video can be viewed at www.waterbydesign.com.au/pipecam.

3.5.1.3 Saturated zone underdrainage riser

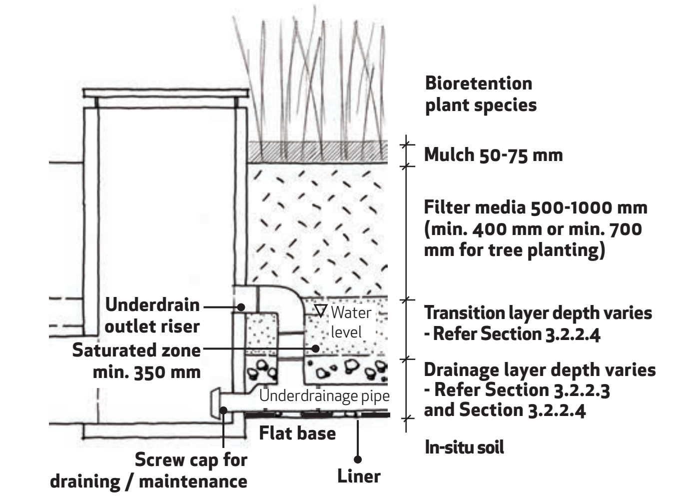
RECOMMENDED APPROACH

The method for connecting the saturated zone underdrainage pipes to the outlet pit is critical for maintaining saturated zone water levels. Three underdrainage connection options for saturated zones are shown in Figure 43. All options include a riser to create the reservoir in the saturated zone and a watertight seal through the pit. A maintenance drain at the saturated zone base (e.g. pipe with a screw cap) will allow dewatering for maintenance. Screw caps are recommended on maintenance flushing pipes because they are significantly cheaper than sluice valves.

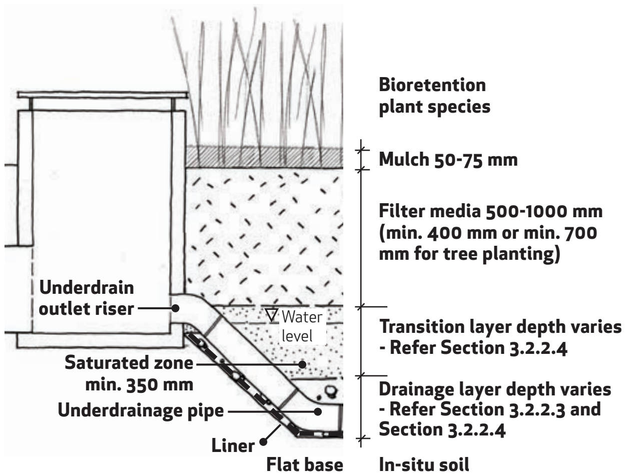
Saturated zones can be drained without collection pipes (Option 4 - pipeless in Figure 43). However, the risk of clogging at transition points should be considered in the hydraulic design of these transition points (e.g. by using a blockage factor of 0.5).

All saturated zone outlet options will have a small area of potential mosquito breeding habitat, but the potential for breeding at the outlet is insignificant compared to other habitat typically found in urban areas.

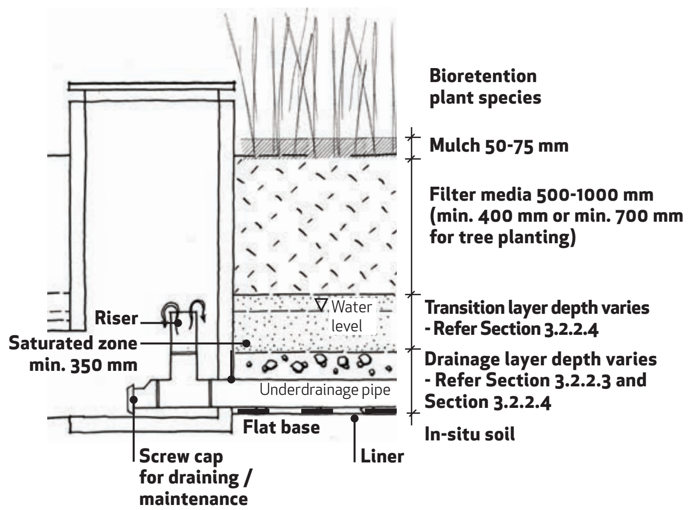
Figure 43 Saturated zone underdrainage riser connection options



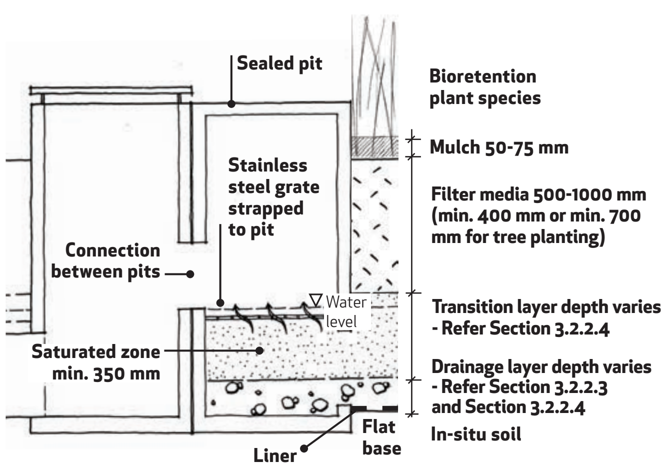
OPTION 1



OPTION 3 - LEVEL CONSTRAINED

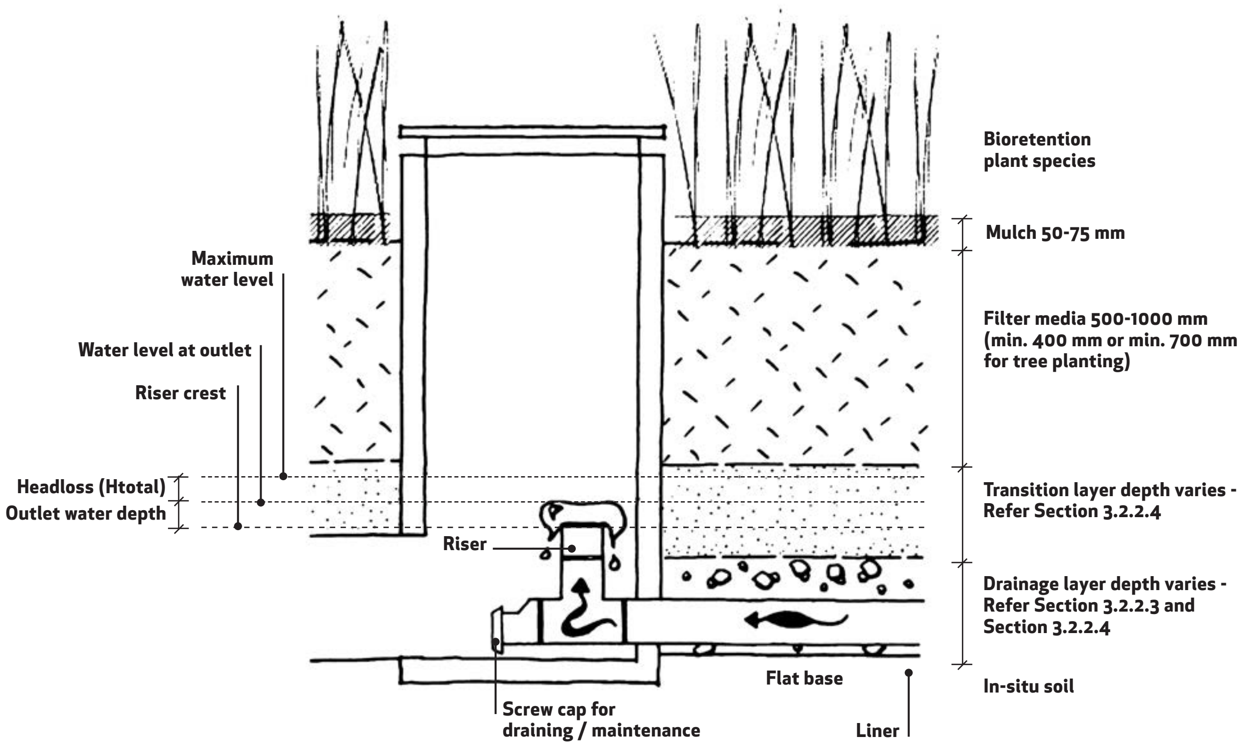


OPTION 2



OPTION 4 - PIPELESS

Figure 44 Hydraulics of bioretention system underdrainage



3.5.1.4 General approach to sizing underdrainage pipes

RECOMMENDED APPROACH

A hydraulic head is required to drive water through underdrainage pipes. Underdrainage pipes should be sized such that they:

- allow the filter media to drain at its designed hydraulic conductivity or greater
- allow the bioretention systems performance outcomes to be met.

Poorly designed or undersized underdrainage can cause water to back up within the bioretention profile and reduce the effectiveness of the system.

Figure 44 demonstrates how for a given outlet riser crest level, the depth (and duration) of water temporarily held above the defined level of the saturated zone is controlled by:

- the depth of water spilling from the riser
- headloss through the underdrainage

If either of these factors are too excessive (i.e. from undersized pipes), the system will not drain efficiently.

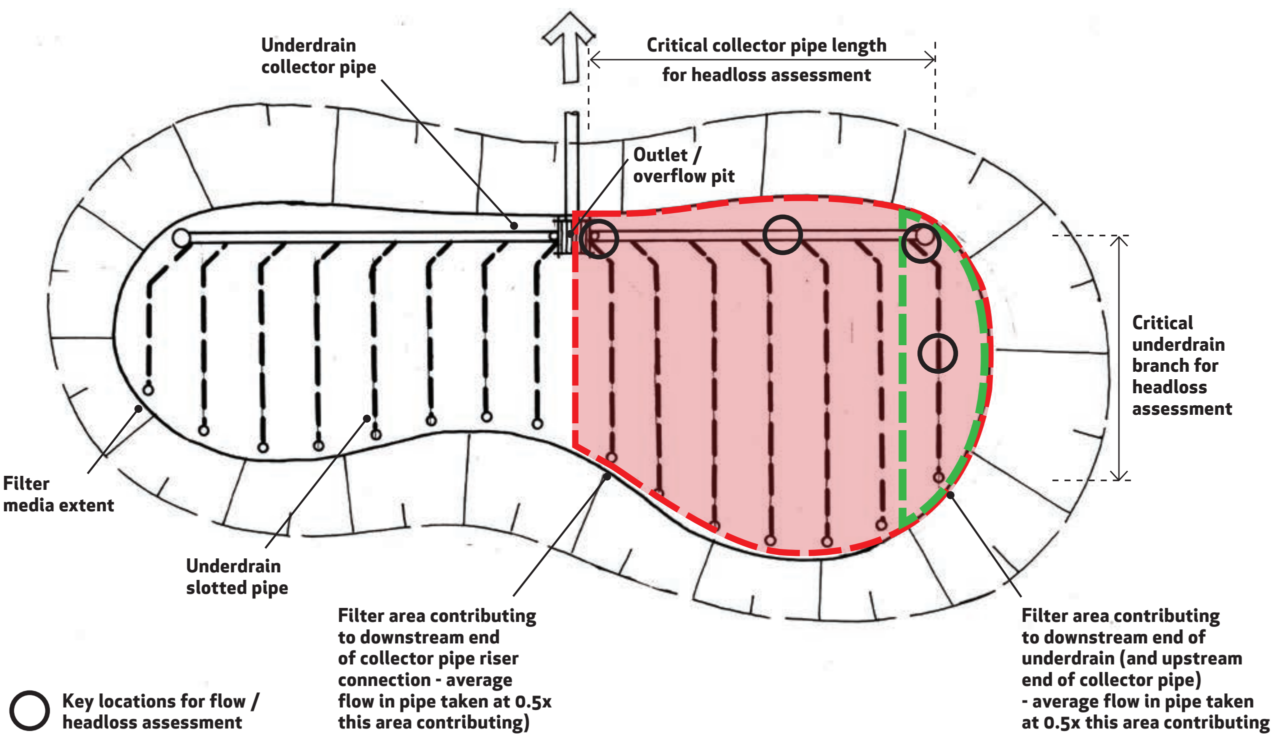
The general approach to sizing underdrainage pipes therefore aims to ensure that the hydraulic head required to drive water through the underdrainage (i.e. the depth of water spilling from the riser plus the headloss through the underdrainage) is less than the difference in elevation between the riser crest level and the base of the filter media (known as the allowable head loss). This approach may be used for Type 1 to 3 bioretention systems. Note that underdrainage for Type 2 sealed bioretention systems may be sized using either this method or the conservative, simplified method presented in Section 3.5.1.5.

The general approach to sizing underdrainage pipe is as follows:

1. Develop an initial underdrainage layout and pipe sizing in accordance with Section 3.5.1.1.
2. For Type 1 saturated zone bioretention systems, define the riser connection to the overflow pit. Refer to Section 3.5.1.3 for details.
3. Calculate the maximum infiltration rate through media.
4. Determine the maximum water level at the outlet when it is passing the maximum infiltration rate, assuming free drainage from outlet. Note that underdrain discharge from saturated zone risers may occur either as simple spilling from a vertical riser pipe (as weir flow) or as part full pipe flow from horizontal riser connection (elbow from top of vertical riser) (see Figure 43).
5. Select the longest underdrainage pipe run (slotted underdrainage plus collection pipe) from the initial underdrainage layout (Figure 45) and calculate the total hydraulic head loss. Hydraulic head losses that should be considered include:
   a. friction losses along slotted or perforated pipes
   b. bend losses at the transition from slotted pipes to collection pipes
   c. friction losses along collection pipes
   d. fitting losses from lateral inflows into collector pipes at slotted pipe connections
   e. any bend losses (e.g. at end of collection pipe or riser connection).
6. Ensure the combined hydraulic head loss through the longest underdrain pipe run is less than the distance between the base of the filter media and the maximum water level exiting the outlet (from step 3).
7. Where step 6 is not satisfied, revise the underdrainage layout in one of more of the following ways and repeat the hydraulic head loss assessment:
   a. increase the slotted or collector pipe size and ensure there is at least 50 mm of drainage layer gravel above the slotted or perforated pipe
   b. change number or type of bends and fittings
   c. use multiple underdrainage pipe collection networks (see Figure 42)
   d. decrease the elevation of the outlet level relative to the base of the filter media (i.e. increase allowable head loss).

Relevant calculations for each component of the head loss assessment are provided on the following pages.

Figure 45 Underdrainage capacity assessment using head loss equations



Maximum infiltration rate

The maximum infiltration rate for the filter media is defined by Darcy's equation (Equation 7):

Equation 7

$$Q_{max} = K_{sat} \times A \times \frac{h_{max} + d}{d}$$

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

K_{sat} = saturated hydraulic conductivity of the soil filter (m/s). Note that hydraulic conductivity is often expressed in mm/hr and so a conversion may be required.

A = filter media area (m^2)

h_{max} = extended detention depth (above filter) (m)

d = depth of filter media (m)

Maximum water level at the outlet

The method for calculating the maximum water level at the outlet varies depending on how the underdrainage pipes connect into the outlet pit (see Section 3.5.1.3). An example of how to calculate the maximum water level at the outlet for one particular configuration is provided in Section 5.7.1.2. A hydraulics text book should be consulted when using other configurations.

Friction losses (slotted and collector pipes)

The friction loss for slotted underdrainage and collector pipes are calculated separately. Average pipe flow should be used to estimate total friction loss along a pipe (see Figure 45). An estimate of this average flow rate can be derived from the area of filter media contributing to the mid-point of the subject pipe, multiplied by the maximum flow per square metre of filter media calculated previously. This flow rate should be applied over the total length of pipe. Pipe friction loss is determined from flow resistance charts that plot a relationship between pipe size, velocity, discharge, and head loss per length of pipe. This calculation is based on the Colebrook-White and Darcy friction factor equations. Alternatively, the rearranged Hazen-Williams equation (Equation 8) can be used:

Equation 8

$$h_f = L \left(\frac{10.67 \times Q_a^{1.85}}{C^{1.85} \times D^{4.87}} \right)$$

Where: h_f = head loss in pipe due to friction (m)

L = total length of pipe section (m)

Q_a = flow at mid-point of pipe length (m^3/s)

C = roughness coefficient (typically 150 for rigid plastic pipes)

D = pipe diameter (m)

Fitting, bend and outlet losses

Head loss at each fitting, bend, and junction (structure losses) can be defined by Equation 9:

Equation 9

$$h_s = K \frac{V^2}{2g}$$

Where: h_s = head loss at structure (m)

K = pressure change coefficient

V = velocity in pipe section (m/s) (defined as flow / pipe area)

g = gravity (9.81 m/s^2)

Structure losses should be calculated using the maximum flow (not the average flow) at the location of the fitting, bend, or outlet (see Figure 45).

Pressure change coefficients, K (or structure loss coefficients), vary considerably between fitting types and bend angle and can often be sourced from local design standards such as QUDM (DEWS, 2013), pipe manufacturers, or hydraulic text books.

The total head loss over the critical underdrain or collector pipe run (typically the longest run) is therefore shown in Equation 10:

Equation 10

$$H_{total} = h_{f(slotted)} + h_{f(collector)} + \sum h_{s(slotted)} + \sum h_{s(collector)} + \sum h_{s(riser)}$$

Where: H_{total} = total head loss (m)

h_f = friction losses in pipes (m)

h_s = structure losses in pipe sections (m)

3.5.1.5 Simple conservative approach for sizing underdrainage pipes for Type 2 sealed bioretention systems

RECOMMENDED APPROACH

Underdrainage pipes in Type 2 sealed bioretention systems should slope towards the outlet pit. This can be achieved by grading the bioretention base towards the pit and placing the perforated pipes and the drainage layer on this grade. Underdrainage pipes can be sized using the following steps:

1. Develop an initial underdrainage layout and sizing in accordance with Section 3.5.1.1.
2. Calculate the maximum infiltration rate of filter media (see Section 3.5.1.4).
3. Check the flow capacity for the overall slotted underdrain pipe system (i.e. confirm overall slotted underdrainage conveyance is greater than filter media infiltration flow).
4. Undertake capacity checks on the collector pipes as required.
5. Where capacity issues are identified in any part of the underdrainage network, revise the layout, increase pipe size, increase pipe numbers, or undertake a combination of these.

Underdrainage capacity

Manning's equation or pipe capacity charts (see QUDM (DEWS, 2013)) can be used to calculate the slotted underdrainage flow capacity ($Q_{slotted}$) assuming the pipe is flowing full, but not under pressure. Equation 11 should then be satisfied.

Equation 11

$$Q_{slotted} \times \textit{no. pipes} > 1.2 \times Q_{max}$$

Where: $Q_{slotted}$ = maximum conveyance of a single slotted pipe (m^3/s)

no.pipes = number of parallel slotted underdrains

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

1.2 = 20% blockage factor (in case pipe is partially blocked)

Collector pipe capacity

Slotted underdrains can feed into a larger diameter collector pipe (as the spine to the branched underdrain network), which is typically non-slotted. In large bioretention systems, multiple collector pipes may be required. Collector pipes need to be able to convey the maximum filter infiltration rate as shown in Equation 12.

Equation 12

$$Q_{collector} > 1.2 \times Q_{max}$$

Where: $Q_{collector}$ = maximum conveyance of the collector pipe (from Manning's eq.) (m^3/s)

Q_{max} = maximum filtration rate of area being serviced by collector (m^3/s)

1.2 = allows 20% blockage factor (in case pipe is partially blocked)

3.5.2 Overflow pit

Overflow pits are the most common minor flow outlet structure used in bioretention systems. The crest of the pit is raised above the surface of the filter media to create the extended detention. The pits accept overflows when the extended detention depth is exceeded. Underdrainage commonly discharges into the base of the overflow pit.

Field inlet pits (Section 3.5.2.1) and side entry pits (Section 3.5.2.2) are commonly used for bioretention overflows.

PERFORMANCE OUTCOMES

Overflow pits (or equivalent) must:

- pass the peak minor flow with acceptable upstream inundation
- have a low risk of being blocked with debris.

3.5.2.1 Raised field inlet

RECOMMENDED APPROACH

The field inlet (i.e. grated) overflow pits should have a raised grate (typically 100 mm above the pit crest) to minimise the risk of blockage (Figure 46). Flush grates should not be used. Refer to IPWEAQ standard drawing SEQ D-050 for typical pit details, excluding the surrounding apron for bioretention system overflow pits.

Sufficient hydraulic ponding depth should be provided above the pit crest to enable the design flow to enter it. The design flow will typically be for the minor design storm; however, the pit can be designed to accept higher or lower flow rates depending on site constraints, design objectives and local drainage standards.

Raised field inlet pits can be sized using manual hydraulic calculations. The pit capacity in free overflow conditions should be estimated using the weir equation and checked against drowned outlet conditions using the orifice equation. The lower of the two capacity estimates is adopted.

Figure 46 Overflow pit with raised grate

Photo: Andrew O'Neill, DesignFlow

DESIGN NOTE: Designing for saturated zone outlet risers within pits

Where the saturated zone underdrainage discharges to an overflow pit, an assessment is needed to ensure that underdrainage outlet risers, control valves, maintenance drains, and access ladders can be accommodated within the pit without compromising either their function or accessibility for maintenance. The pit dimensions may be determined by accommodating these components, rather than by the capacity to pass the design fl ow. Alternatively, multiple pits may be required.

For free overfall conditions, the weir equation (Equation 13) is used:

Equation 13

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

Where: Q_{weir} = flow over weir (pit perimeter) (m³/s)

B = blockage factor (0.5 is recommended for raised grates and 0.25 for flush grates)

C_w = weir coefficient (1.66 is recommended)

L = length of weir (m)

h = depth of water above weir crest (m)

For drowned outlet conditions (orifice equation) use Equation 14:

Equation 14

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

Where: $Q_{orifice}$ = flow into drowned pit (m^3/s)

B = blockage factor (0.5 is recommended for raised grates and 0.25 for flush grates)

C_d = discharge coefficient (0.6 recommended)

A = total area of pit (m^2)

g = 9.81 m/s^2

h = depth of water above centre of orifice (m)

DESIGN NOTE: Replacing overflow pit with a weir

If a weir rather than an overflow pit is being considered for minor flows, a landscape and cost assessment should be undertaken to assess the benefits of this approach. Underdrainage needs to connect through the weir embankment (or via a dedicated underdrain connection pit) to the receiving drainage system. Designers should ensure that the underdrainage outlet can be easily located and accessed for maintenance.

3.5.2.2 Side entry pit

RECOMMENDED APPROACH

Side entry pits within the kerb and channel can accept minor design flows in conjunction with streetscape bioretention (Figure 47). This option relies on flows entering the bioretention system through a kerb cut-out upstream of the pit (see Section 3.4.2.2), filling the extended detention, then backwatering to the kerb invert level, allowing flows to bypass the bioretention and enter the pit.

This option allows the surface of the filter media to be as high as possible relative to the adjacent road or kerb level because the surcharge depth required above the pit inlet occurs within the kerb and channel external to the bioretention system. Bioretention underdrainage can be connected to the side entry pit.

Side entry pits should be designed in accordance with local authority requirements.

Figure 47 Streetscape bioretention system with side entry pit

Photo: Robin Allison, DesignFlow

3.5.3 Outlet pipe

PERFORMANCE OUTCOMES

The outlet pipe (or equivalent) must convey the peak minor flow to the receiving drainage system taking into account tailwater conditions.

RECOMMENDED APPROACH

Outlet pipes from overflow pits should be designed in accordance with local authority standard drainage requirements. Outlet pipes need to convey the relevant design flow from the pit considering tailwater conditions. All pipe outlets through embankments should be appropriately backfilled, compacted, and have an anti- seepage collar, cut-off walls, or filter collars to prevent seepage paths developing along the pipe. Failure to appropriately account for seepage can result in serious structural issues for embankment walls.

Scour protection is required at pipe outfalls and along overland flow paths in line with local authority design standards.

3.5.4 Overflow weir

PERFORMANCE OUTCOMES

Overflow weirs (or equivalent) must:

- be able to pass the peak major flow with acceptable upstream inundation
- have a low risk of being blocked with debris
- ensure the embankment does not scour during a peak major flow.

RECOMMENDED APPROACH

A safe and stable route for discharging peak major flows from the bioretention system is required. This is generally achieved by using an overflow weir as well as an overflow pit.

The weir level is generally set above an overflow pit. A suitable freeboard is required between the maximum water level above the weir during the peak major flow event and the embankment level (see Section 3.2.3.6). The drop from the crest of the weir to the downstream finished surface level should be as low as possible to minimise scour and reduce costs.

Overflow weirs are generally large concrete and rock structures. Weirs should be configured in accordance local standards such as the IPWEAQ Standard Drawings. They should be positioned away from highly visible areas and masked with planting. Appropriate scour protection, and where required energy dissipation, should be provided around all weirs. Rock protection on the downstream side of weirs should be designed in accordance with local authority requirements.

Weirs should not be used where they will pass flows over vegetated embankments more than once per year. Vegetated embankments are susceptible to scour from high flows if they are frequently wet.

Weir capacity can be estimated using Equation 15:

Equation 15

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

Where: L = weir width (m)

h = allowable hydraulic head over the weir (preferably < 0.3 m, refer to local authority requirements)

Q_{weir} = major design flow minus the overflow pit flow (m^3/s)

C_w = weir coefficient (1.74 recommended for sharp crested, 1.66 for broad crested)

DESIGN NOTE: Replacing overflow weir with a pit

Where site constraints such as space, steep slopes, unstable soils, or retaining walls limit the use of weirs, an appropriately sized overflow pit and pipe can provide an outlet for major storm events; however, some form of overland flow or spillway will still be required for extreme flood events.

3.5.5 Connection to waterways

PERFORMANCE OUTCOMES
The connection of the bioretention system to the receiving drainage system must prevent scour during peak major flows.

RECOMMENDED APPROACH
When discharging bioretention outflows to waterways:

- pipes and weirs should be angled downstream
- pipes or drains should be free draining (i.e. no backwatering into pipe from waterway).

Scour protection (e.g. rock drop structure) should be used to transition from a bioretention outlet to a waterway. Where a transition includes a vertical drop of greater than 400 mm, major grade control and scour protection is recommended. For guidance on outlet design, energy dissipation, and stabilisation refer to local design guidelines and standards such as QUDM (DEWS, 2013).

3.5.6 Flood storage outlets

PERFORMANCE OUTCOMES
Flood storage outlets must allow both bioretention and flood attenuation design objectives to be met.

RECOMMENDED APPROACH
Where bioretention systems form part of a flood detention basin, bioretention system outflow structures (pits and weirs) may either be:

- combined with the flood discharge control outlet
- independent to, and upstream of, the main flood control outlet.

Where outlets are combined, hydraulic modelling required for designing the detention basin should ensure that any proposed outlet structures (pits, pipes and weirs) meet design requirements for both the bioretention and detention functions.

Section 3.3.9 provides advice on combining bioretention and flood detention basins. The design of flood detention basins and outlets needs to comply with local authority requirements.

3.6 Vegetation design

Bioretention systems should have a dense cover of healthy, actively growing plants that help to remove pollutants and help the long-term performance of the filter media. The function of vegetation in bioretention systems is summarised in Table 16.

The key plant attributes that influence pollutant uptake and the plant's long-term survival in bioretention systems include:

- **Root structure** – Plants with fibrous root systems are more effective in bioretention systems than those with tap root systems. A mix of shallow and deep-rooted plants will maximise the bioretention systems' capacity to remove pollutants at all depths.
- **Growth rate and plant size** – Both fast and slow growing plant species are required in bioretention systems. Fast growing plants tend to be smaller with high nutrient demands, allowing rapid establishment and pollutant uptake. They also provide full coverage of the filter media, which is important to protect the filter media from scour and weeds. Their short growing cycles replenish organic material in the filter media. Slow growing plants are typically larger with well-developed root systems and gradually increase pollutant uptake and storage capacity.
- **Tolerance to wetting and drying cycles** – To maintain year-round vegetative cover, plants must be able to tolerate prolonged dry periods as well as periodic inundation. Semi-aquatic plant species adapted to longer periods of inundation should not be used because they are generally not suited to the dry conditions between rainfall events.

Successful bioretention systems contain a variety of vegetation that:

- has the attributes identified above
- integrates with surrounding landscapes (existing natural or created)
- suppresses weed growth
- thrives in the local climate
- enhances biodiversity, where required.

Designing a planting plan to meet these objectives requires consideration of vegetation types, planting style, species diversity, planting density, planting set-out, and the type of mulch to be applied. This section contains recommendations for each of these aspects.

Table 16 The function of vegetation in bioretention system

Functional process	Role of vegetation
Aesthetics	Vegetation can reduce visual impacts of a modified landscape, such as cut batters and bund formations. Tree plantings can ensure that the existing tree canopy remain unbroken. Shrubs can screen and filter negative views to bioretention infrastructure, including maintenance tracks, headwalls, and weirs.
Physical	Vegetation reduces stormwater velocity and therefore protects filter surface from scour. Root growth and decay provides micro-pathways for water infiltration and oxygen movement and limit the potential for the filter media to become clogged.
Chemical	Organic acids and sugars released from plant roots stimulate microbial activity within the root zone, which is essential for pollutant transformation. Some species of vegetation enhance soil aeration by diffusing oxygen from their roots into the surrounding media.
Biological	Plants uptake nutrients and, in some cases, incorporate metals into their tissue. Root decay provides a continuous source of carbon used by denitrifying bacteria. Organic material also enhances filter media moisture retention capacity. Plant roots provide a substrate for microbial growth. Soil microbes facilitate decomposition and mineralisation of organic matter, nutrient uptake, nitrogen processing and heavy metal uptake.
Ecological	Planting design and species selection can enhance local biodiversity. Bioretention planting zones can create faunal services (i.e. habitat and food). Dense vegetation suppresses weed growth.

3.6.1 Vegetation types

3.6.1.1 Groundcovers

Groundcovers are most often used in bioretention systems because they typically have fibrous root systems, are fast growing, and are highly effective at removing pollutants from stormwater. Suitable groundcovers include tall grasses, sedges, and rushes. Many herb and scrambling groundcovers species are not recommended for bioretention systems due to their undesirable root structures. Turf has traditionally not been recommended for long term use in bioretention systems because it is not effective at stormwater treatment due to its shallow root systems and short shoot length. Where there is an overriding landscape amenity objective, turf may be used in conjunction with functional tree species, avoiding a dense canopy.

3.6.1.2 Shrubs

Shrubs are commonly used in bioretention systems. Shrubs generally have medium-sized fibrous root systems, are relatively slow growing, and can take several months to establish. Shrubs may have limited effect on nutrient uptake before they are established; however, their large root biomass, compared to groundcovers, has a greater capacity to retain nutrients in the plant tissues in the long term (Parke, et al. 2009).

Shrubs can shade the surface of filter media, reducing weeds and filter surface temperature during summer. They can also enhance the visual amenity, increase biodiversity, screen concrete structures, and provide dense vegetative barriers to deter public access.

3.6.1.3 Trees

In combination with shrubs, trees in bioretention systems can increase planting diversity and structure, provide additional habitat opportunities, and enhance the amenity value of bioretention systems. An established tree canopy provides shade to suppress weed growth within bioretention systems, minimising maintenance costs. It also influences local microclimates.

DESIGN NOTE: Bioretention profile with trees

When including trees in bioretention systems, a minimum filter media depth of 700 mm is recommended to support the additional depth of root growth. Saturated zone bioretention systems should also be used to limit the risk of tree roots blocking underdrainage pipes.

3.6.2 Planting style

PERFORMANCE OUTCOMES

The planting style of a bioretention system must:

- be suitable for the local landscape and ecology
- not interfere with sight lines
- be suitable for the available maintenance regime.

RECOMMENDED APPROACH

Planting design will be guided by the size or location of the system within the urban environment.

Table 17 outlines the characteristics of the planting styles that are commonly adopted for arrange of landscape settings.

Examples of the planting styles described in Table 17 are shown in Figures 48 to 50.

Table 17 Bioretention system planting styles

Planting style	Landscape setting	Dominant planting	Characteristics
Small scale urban	Streetscape, civic spaces, urban centres and forecourts	Low diversity groundcovers	• Enhances, or is sympathetic to the surrounding urban built form and landscape design. • Low profile (plant height). • Higher maintenance (weed control).
Medium–large scale urban	Open space, parklands and drainage corridors (typically residential areas)	Diverse and structured mix of exotic or native groundcovers, shrubs, and occasionally trees (particularly in large systems)	• Creates new landscape and amenity for surrounding areas. • Low maintenance. • Plants are readily available from local nurseries and are not necessarily endemic.
Bushland	Interface of urban areas with natural bushland and riparian corridors.	Densely planted native vegetation community comprising groundcovers, shrubs, and trees, including locally occurring and core plant species	• Planting theme based on principles of bush reconstruction (Henderson and Blanch, 2009). • Replicates structure and composition of existing local bushland and riparian vegetation communities. • Enhances aesthetic appeal of site. • Increases local biodiversity. • Provides fauna habitat. • Resilient to changes in local conditions. • Resistant to disease and insect attack. • Self-maintaining, suppresses weeds, low maintenance.

Figure 48 Small scale urban planting style

Photo: Shaun Leinster, DesignFlow

Figure 49 Medium-large scale urban planting style

Photo: Shaun Leinster, DesignFlow

Photo: Shaun Leinster, DesignFlow

Figure 50 Bushland planting style

Photo: Jack Mullaly, Healthy Waterways

3.6.3 Species diversity

PERFORMANCE OUTCOMES

The selected species must:

- meet local authority requirements
- have 90% plant cover within two growing seasons.

RECOMMENDED APPROACH

A diverse range of plant types and species, including core plant species known to be successful in bioretention systems, will ensure a higher likelihood of successful plant establishment, as well as long-term resilience to changing conditions.

The recommended minimum number of plant species for each planting style is in Table 18.

3.6.4 Species selection

PERFORMANCE OUTCOMES

The plant species chosen for a bioretention system must:

- be suitable for the local landscape and ecology
- enable bioretention performance objectives to be met
- be suitable for the predicted wetting and drying regime.

RECOMMENDED APPROACH

Table 19 shows plant species that are particularly suitable for bioretention planting. Using these core plant species ensures that a minimum level of bioretention performance will be achieved. At least 50% of the filter area should be planted with the core plant species identified in Table 19. The remainder of the filter media area should be planted with the supplemental species shown in Table 20, or species with the attributes listed in Section 3.6. The batters should be planted with species with the attributes listed in Section 3.6.

If a lower coverage of core plant species is proposed, a suitably qualified ecologist or landscape architect should confirm that the plant species conform to the functional plant attributes outlined in Section 3.6.

Local climatic variations mean that some plant species may be more or less suited to certain locations within the regions identified in Tables 19 and 20. The local authority should be consulted to determine if any plant species are unlikely to survive in a particular location.

Where a bushland planting style is proposed, plant species should preferably be of local origin to preserve local biodiversity and to use plants that are suited to local climatic conditions. The selection of plant species that form natural associations in local bushland ecosystems also ensures that many subtle components of the ecosystem are preserved, such as food and habitat resources for insects and birds that are specific to particular plant species associations.

Regional ecosystem descriptions should be consulted for guidance on plant species selection. Local government landscape strategies or plant selection guidelines may help with choosing suitable species. Refer to Parke et al. (2009) for examples of how to select plant species with attributes suitable for bioretention systems from a range of different vegetation communities.

In a dry climate, or climates with prolonged dry periods, locally occurring drought resistant plant species should be used to increase the resilience of the system to climatic variables and other stressors. Trees and shrubs can be installed in and around bioretention systems to produce a canopy which cools the system and reduces evapotranspiration. Plant survival in dry climates will be supported by using Type 1 saturated zone bioretention systems.

Trees with an open canopy that will not completely shade underlying plants are recommended for all climatic regions. Trees with dense canopies should only be used where suitable shade tolerant species can be planted under them.

Selecting species for batters may be influenced by functional and landscape considerations such as providing borders (edge plantings); screening; maintaining view lines; public access; weed suppression; or facilitating maintenance access. Core plant species listed in Table 19 and supplemental plant species listed in Table 20 are also suitable for batter planting.

DESIGN NOTE: Use of other plant species

Up to 50% of the bioretention area may also include plant species that are not listed in Table 19, provided they are suitable for the site conditions. Additional species may include more commercially available varieties or amenity plant species. For example, varieties of *Melaleuca linariifolia* or other species of the *Callistemon* genus may be suitable.

Table 18 Minimum plant species diversity in bioretention systems and batters

Planting style	Minimum number of plant species
Small scale urban	Two if filter area < 100 m^2 Four if filter area ≥ 100 m^2
Medium–large scale urban	Six
Bushland	10

Table 19 Core functional bioretention plant species

Species name[1]	Common name	Type[3]	Region
Carex appressa	Tall Sedge	Groundcover sedge	ST, WT
Ficinia nodosa	Knobby club-sedge	Groundcover sedge	ST
Imperata cylindrica	Blady grass	Groundcover grass	All
Lepidosperma laterale	Variable sword-sedge	Groundcover sedge	All
Lomandra hystrix	River mat-rush	Groundcover herb	ST, DT, WT
Lomandra longifolia	Spiny-headed mat-rush	Groundcover herb	All
Lomandra leucocephala	Woolly Mat-Rush	Groundcover herb	DT, A
Pennisetum alopecuriodes[2]	Swamp foxtail grass	Groundcover grass	ST
Poa labillardieri	Common tussock grass	Groundcover grass	ST, A
Themeda australis	Kangaroo grass	Groundcover grass	All
Callistemon sieberi	River bottlebrush	Shrub	ST
Leptospermum liversidgei	Olive tea-tree	Shrub	ST
Melaleuca thymifolia	Thyme honey myrtle	Shrub	ST, DT
Banksia robur	Swamp banksia	Small tree	ST, DT, WT
Melaleuca linariifolia	Flax-leaved paperbark	Small tree	ST
Melaleuca viridiflora	Broad leaved tea-tree	Small tree	ST, WT, DT
Casuarina glauca	Swamp oak	Tree	ST, WT, DT
Casuarina cunninghamiana	River sheoak	Tree	ST
Lophostemon suaveolens	Swamp Mahogany	Tree	ST, WT, DT
Melaleuca bracteata	Black tea-tree	Tree	ST, WT, DT
Melaleuca quinquenervia	Broad-leaved paper bark	Tree	ST, WT, DT

1 The list of core plant species has been derived from research conducted by FAWB (http://www.monash.edu.au/fawb), it's successors, other research organisations and observations of healthy bioretention systems.

2 Pennisetum alopecuroides is strongly self-seeding. Local authority advice should be sought regarding its use.

3 WT = wet tropics; DT = dry tropics; ST = subtropics; A = arid zones; All = occurs in all regions

Table 20 Supplementary bioretention plant species

Supplimentary Species	Common name	Type	Region[2]
Cymbopogon refractus	Barbed wire grass	Groundcover grass	DT, WT, ST
Fimbristylis dichotoma	Common fringe sedge	Groundcover sedge	All
Fimbristylis ferruginea	Rusty fringe sedge	Groundcover sedge	All
Fimbristylis tristachya		Groundcover sedge	DT, WT, ST
Fuirena umbellata		Groundcover sedge	DT, WT, ST
Gahnia aspera	Saw sedge	Groundcover sedge	ST, DT, WT
Gahnia seiberiana	Red-fruit saw-sedge	Groundcover sedge	ST, WT, DT
Juncus polyanthemus	Striated rush	Groundcover sedge	DT, WT, ST
Juncus usitatus	Common rush	Groundcover sedge	DT, WT, ST
Lomandra confertifolia	Dwarf mat rush	Groundcover sedge	ST
Rhynchospora corymbosa	Matamat	Groundcover sedge	All
Scleria polycarpa	Many-fruited sedge grass	Groundcover sedge	DT, WT
Aidia racemosa	Archer Cherry	Shrub	DT, WT
Alphitonia excelsa	Red ash	Shrub	All
Atractocarpus fitzalanii	Native Gardenia	Shrub	DT, WT
Austromyrtus dulcis	Midgen berry	Shrub	ST
Breynia oblongifolia	False coffee bush	Shrub	All
Cordyline manners-suttoniae	Giant palm lily	Shrub	ST, WT
Hibiscus heterophyllus	Native rosella	Shrub	DT, WT, ST
Leptospermum polygalifolium	Wild May	Shrub	DT, WT, ST
Melastoma malabathricum	Blue tongue	Shrub	ST, WT
Myoporum acuminatum	Coastal boobialla	Shrub	All
Xanthorrhoea fulva	Swamp grass tree	Shrub	ST
Albizia canescens	Townsville siris	Tree	DT, WT
Casuarina equisetifolia	Coast She Oak	Tree	DT, WT, ST
Buckinghamia celsissima	Ivory curl flower	Tree	DT, WT
Callistemon viminalis	Weeping bottle brush	Tree	All
Chionanthus ramiflora	Native olive	Tree	DT, WT, ST
Colubrina asiatica	Latherleaf	Tree	DT, WT
Corymbia tesselaris	Moreton Bay Ash	Tree	DT, WT, ST
Cupaniopsis anacardioides	Beach tuckeroo	Tree	DT, WT, ST
Eucalyptus raveretiana	Black ironbox	Tree	DT
Eucalyptus tereticornis	River blue gum	Tree	DT, WT, ST
Eugenia reinwardtiana	Cedar Bay cherry	Tree	DT, WT, ST

Table 20 Supplementary bioretention plant species, continued

Supplimentary Species	Common name	Type	Region[2]
Ganophyllum falcatum	Scaly ash	Tree	DT, WT
Livistona decora	Weeping Cabbage Palm	Tree	DT, ST
Lophostemon grandiflorus	Northern Swamp Box	Tree	DT, WT
Melaleuca dealbata	Blue leaved paperbark	Tree	DT, WT, ST
Melaleuca fluviatilis	Weeping Tea Tree	Tree	DT, WT
Melaleuca leucadendra	Weeping Tea Tree	Tree	DT, WT
Mimusops elengi	Red Coondoo, Tanjong Tree	Tree	DT, WT
Waterhousea floribunda	Weeping Lily-pily	Tree	ST
Bothriochloa pertusa	Indian couch	Turf[1]	DT, ST
Paspalum distichum	Water couch	Turf[1]	DT, ST
Paspalum vaginatum	Salt water couch	Turf[1]	DT, ST, WT
Sporobolus virginicus	Marine Couch	Turf[1]	DT, WT, ST
Zoysia macrantha	Zoysia	Turf[1]	ST

1 Turf species are not as effective at stormwater treatment due to their shallower root systems and shoot length. If there is a landscape amenity objective that is driving this response, then plant with appropriate tree species (avoid dense canopies) for a deeper root distribution.

2 WT = wet tropics; DT = dry tropics; ST = subtropics; A = arid zones; All = occurs in all regions

3.6.5 Planting density

PERFORMANCE OUTCOMES

Planting densities must:

- provide rapid coverage to out-compete weeds
- have a uniform root zone through the filter media
- enable bioretention performance objectives to be met
- have 90% coverage in two growing seasons.

RECOMMENDED APPROACH

High plant density in bioretention systems is beneficial to:

- facilitate rapid establishment of vegetation cover
- exclude weeds
- ensure a uniform root zone throughout the filter media
- maintain filter media porosity
- maximise pollutant removal
- distribute flows evenly across the surface of the bioretention system
- prevent scour, establishment of preferred flow paths, and re-suspension of deposited sediments.

A suitable planting density should be used to ensure vegetation covers at least 90% of the bioretention surface after the establishment period (i.e. < 10% soil or mulch visible from above). The planting density to achieve this outcome will vary depending on the species used. Table 21 provides typical planting densities required to achieve 90% coverage rapidly. Over many years, as plants mature and expand, some plants may die. Densities may reduce, however the high initial densities will ensure that in the long term coverage is maintained.

Direct seeding may be a useful alternative to the use of seedlings, particularly in large bioretention systems where it is important to establish vegetation cover quickly to minimising weed ingress. Direct seeding is commonly used for establishing grass cover in bush reconstruction projects. It can also be used to establish shrubs and trees.

As the success rate of direct seeding cannot be guaranteed, direct seeding should be used to complement planting seedlings.

Table 21 Typical planting densities required to achieve 90% cover

Vegetation type	Planting density
Groundcovers (including grasses, herbs and sedges)*	Six to eight plants per m^2
Shrubs**	One plant per 2–20 m^2
Trees**	One plant per 20–100 m^2

* Groundcover densities of up to 12 plants per m^2 may be required for bushland layouts.
** Suitable planting densities for shrubs and trees depend on the size and form of individual plant species and the overall landscape objectives sought

Using seedlings is recommended over direct seeding because:

- seedlings have a higher survival rate compared to direct seeding
- seedlings guarantee accurate selection and layout of the plants; with direct seeding it is not possible to predict what species will germinate and in what quantities
- seedlings have faster growth rates, which is important where rapid growth is required for pollutant treatment and to rapidly establish mature vegetation across the surface of the bioretention system.

3.6.6 Planting set-out

PERFORMANCE OUTCOMES

The planting set-out must minimise the risk of bare patches developing if one species fails.

RECOMMENDED APPROACH

Groundcover species should be distributed across the surface of bioretention systems to minimise the risk of bare patches developing if one species fails. The distribution should be in small clumps of 5–10 plants of the same species to ensure propagation can readily occur. Where groundcovers are planted in large bands of a single species, the designer must be confident the species will survive.

The placement of trees and shrubs can involve:

- a random distribution to provide shade cover and weed suppression
- clumping of several trees and shrubs of the same species, as would occur naturally.

3.6.7 Mulch

PERFORMANCE OUTCOMES

Mulch must:

- ensure adequate soil moisture for plant health
- suppress weeds
- not hinder plant growth.

RECOMMENDED APPROACH

Lack of adequate soil moisture, particularly in areas that experience hot dry conditions, is often a major reason for vegetation failing. Mulch should be applied to bioretention surfaces until plants establish to help insulate and retain moisture within the filter media, and to suppress weeds. Mulch layers should be 50–75 mm deep to ensure that plants are not hindered.

For further information about selecting mulch material is in Section 4.4.4 and the *Construction and Establishment Guidelines: Swales, Bioretention Systems and Wetlands* (Water by Design).

3.6.8 Resilience to climatic variations

PERFORMANCE OUTCOME

Bioretention systems are installed in widely varying climatic regions. To ensure that bioretention systems function, and particularly that vegetation survives, bioretention design must be resilient and respond to local climatic conditions.

RECOMMENDED APPROACH

In dry climates, or climates with extended dry periods (those with low rainfall and/ or high evapotranspiration) bioretention systems should employ the following techniques to ensure plant survival.

- Installing Type 1 saturated zone bioretention systems (see Section 3.2.2.4).
- Installing locally relevant drought tolerant species (see Section 3.6.4).

Plant survival can also be enhanced by:

- Amending filter media to increase soil moisture content (see Section 4.3.1).
- Installing trees and/ or shrubs in and around the bioretention system to produce a canopy which cools the system and reduces evapotranspiration (see Section 3.6.4).

3.7 Design check and summary

Designing bioretention systems involves a number of design iterations and modifications. At the completion of the design process, it is important to ensure that the iterations have delivered a successful design. Therefore, it is important to undertake a final check of the design, preferably before the design drawings are completed.

Table 22 shows key design parameters that should be checked and documented. The completed summary should then be included with any reports submitted to local authorities in conjunction with the design drawings.

Table 22 Design check and summary

Item	Description	Detail	Recommendation
1. Treatment			
(a)	Catchment area	ha	
(b)	Filter media area (excluding batters)	m^2	Single or multiple cells < 800 m^2 each
(c)	Confirm water quality performance meets the design objectives		
(d)	Confirm hydrologic performance meets relevant frequent flow objectives		
2. Design inflows			
(a)	Minor design storm entering system	ARI	
(b)	Minor storm peak flow rate	m^3/s	
(c)	Major design storm entering system	ARI	
(d)	Major storm peak flow rate	m^3/s	
3. Depth profile			
(a)	Bioretention drainage profile type	Type	
(b)	Minimum drainage layer depth	mm	See Section 3.2.2.3 and 3.2.2.4 for "Type 1" ≥ 150 mm for "Type 2" ≥ 300 mm for "Type 3" Not needed for "Type 4"
(c)	Maximum drainage layer depth	mm	Same as minimum except for "Type 2"
(d)	Transition layer depth	mm	See Section 3.2.2.4 for "Type 1" ≥ 100 mm for "Type 2", "Type 3" and "Type 4"
(e)	Saturated zone depth for Type 1 bioretention systems	mm	See Section 3.2.2.4
(f)	Filter media layer depth	mm	≥ 400 mm (≥ 700 mm with trees)
(g)	Extended detention depth	mm	≤ 300 mm
(h)	Maximum water level depth above extended detention for major storm event	mm	
(i)	Freeboard to top of embankment	mm	Multiple, see Section 3.2.3.6
(j)	Total system profile depth [3(c)+3(d)+3(f)+3(g)+3(h)+3(i)]	mm	= 4(j)
(k)	Liner type (i) Permeable (ii) Impermeable (iii) None to base		Subject to drainage profile type and in-situ soils/groundwater (see Section 3.2.4)
(l)	AASS/PASS assessed and appropriately managed		
(m)	Presence of dispersive soils assessed and appropriately managed		

Item	Description	Detail	Recommendation
4. Design levels			
(a)	Outlet invert level	m AHD	
(b)	Overflow pit invert level	m AHD	
(c)	Minimum drainage layer level	m AHD	
(d)	Filter media surface level	m AHD	
(e)	Overflow pit crest level	m AHD	
(f)	Overflow weir level	m AHD	
(g)	Maximum design water level	m AHD	
(h)	Top of embankment/batter level	m AHD	
(i)	Inlet/inflow invert level	m AHD	
(j)	Total level difference [4(h)-4(c)]	m	= 3(j)
(k)	Highest astronomical tide level	m AHD	"Type 1" – impermeable liner extends ≥ 300 mm above HAT "Type 2", "Type 3" and "Type 4" – base of transition layer ≥ 300 mm above HAT
(l)	Groundwater level	m AHD	Varies with drainage profile type, see Table 7
5. Layout			
(a)	Maximum filter media length	m	≤ 40 m
(b)	Maximum filter media width	m	≤ 20 m (preferred ≤ 15 m)
(c)	Maximum batter slope	V: H	
(d)	Maximum wall height (where applicable)	m	
(e)	Provision for services (water, sewer, gas, telecommunications, stormwater)		
(f)	Maintenance access provided		
(g)	Flood storage volume above extended detention (where bioretention combined with flood storage)	m^3	
6. Inlet design			
(a)	Inlet/inflow type (i) pipe (ii) channel (iii) sheet flow (iv) other		
(b)	Diversion/surcharge type (where applicable)		
(c)	Coarse sediment removal (i) forebay (ii) inlet pond (iii) swale (iv) other		
(d)	Coarse sediment removal area	m^2	
(e)	Coarse sediment removal depth	m	
(f)	Coarse sediment clean-out frequency	/year	< once per year
(g)	Flow distribution type		Required if filter media area > 400 m^2

Item	Description	Detail	Recommendation
(h)	Confirm scour protection at inflow locations		
(i)	Minor storm flow velocity over filter	m/s	< 1.0 m/s
(j)	Major storm flow velocity over filter	m/s	< 1.0 m/s
7. Underdrainage (outlet design)			
(a)	Filter media saturated hydraulic conductivity	mm/hr	100 – 300 mm/hr
(b)	Maximum filter infiltration capacity	m^3/s	
(c)	Underdrain capacity (taking into account blockage factors)	m^3/s	> 7 (b)
8. Overflow design (outlet design)			
(a)	Overflow pit type		
(b)	Overflow pit dimensions		
(c)	Overflow weir length	m	
(d)	Overflow pit capacity (taking into account blockage factors)	m^3/s	> 2 (b)
(e)	Overflow pit plus overflow weir capacity (taking into account blockage factors)	m^3/s	> 2 (d)
(f)	Outlet pipe size	mm	
(g)	Appropriate outlet scour protection provided		
9. Vegetation design			
(a)	Planting style (i) small scale urban (ii) med–large scale urban (iii) bushland		
(b)	Trees and shrubs to be included (yes/no)		
(c)	Species diversity (number of species)		Refer Table 18
(d)	Species selection	(refer to plan:____)	≥ 50% coverage with plants from Table 19
(e)	Planting density	$/m^2$	May vary between plant species, refer to plan if required
(f)	Mulch type and depth		See Section 3.6.7 and Section 4.4.4

3.8 Detailed design documentation

At the completion of detailed design it is important to document the design, both for construction and for the development approvals process if required. There are three main detailed design documents that should be produced:

- Design report.
- Detailed design drawings.
- Specifications.

3.8.1 Design report

A bioretention design report documenting the analysis methods and assumptions made during the design process should be submitted to the approval authority, together with the design drawings. Design reports should include a description of any unique maintenance requirements and evidence that the ultimate asset owner is satisfied with these requirements. The design report should describe the erosion and sediment control measures to be used during the construction and establishment phases, if this information is not covered elsewhere.

The report should refer to local standards for any other specific reporting requirements such as the *Urban Stormwater Quality Planning Guidelines* (DERM, 2010).

The design report should include:

- description of design intent
- supporting calculations or modelling results
- a summary of key design parameters
- detailed design drawings
- proposed construction and establishment methodology
- design checklist.

3.8.2 Detailed design drawings

A set of engineering and landscape drawings suitable for design approval and construction tendering should be completed at the end of the design process. The drawings should clearly detail the design of the bioretention system, including all elements developed from the detailed design process.

The tendering package should also include a specification outlining construction methods, tolerances, and materials. An example of civil and landscape specifications for bioretention systems is provided in Section 4.

Final drawings should be suitably scaled and annotated, and include:

1. Plan view showing:

- filter media and batters and embankments relative to existing features, such as roads
- design levels and earthworks to illustrate profiles and relationships to surrounds (batters, contours, and spot heights)
- property boundaries, including road reserves
- location and details of the inflow and outflows
- coarse sediment removal layout
- maintenance access
- road pavement and pedestrian pathways
- all services
- tree protection zones or areas of existing vegetation to be retained

2. Cross sections of the bioretention profile and interaction with surrounds, illustrating:

- filter media surface level and depths of filter media, extended detention, transition layer and drainage layer, where applicable
- underdrainage and base profile and levels, where applicable
- batter and embankments
- top and bottom of liner and type, where applicable
- top and bottom of topsoil on batters
- inflow and outflow arrangements, including forebay or inlet pond
- vegetation at mature height
- all services

3. Details of:

- inflow
- outflow
- clean-out
- underdrainage layout, connections, and outlet riser, where applicable

4. Relevant references to standard drawings (e.g. IPWEAQ)

5. Set-out plan

6. Surface finishes plan, including:

- location of the bioretention system in relation to surrounding landscape (e.g. pathways, driveway cross-overs, inlet and outlet structures etc)
- details of maintenance edges (e.g. concrete edge strip)

7. A detailed planting layout, specifying:

- location and number of plant species
- specific planting zones

8. Planting schedule, specifying:

- planting zones that correlate with the planting plan
- a plant list for each zone, including scientific species and common name
- plant container size
- plant density (per m^2)
- mature plant size (optional)
- number of plants

9. Notes, including:

- specifications or reference to separate specification documents
- construction and establishment requirements.

3.8.3 Specifications

Design specifications (see Section 4) must be documented for assessment and construction. Typically this can be done by either including the specifications as notes on the detailed design drawings, producing a standalone specification document or a combination of both. The most important consideration is that anyone either assessing or constructing the system must be able to easily access the information contained within the specification. For this reason, even if a standalone specification document is produced, the detailed design drawings and design report must make mention of the specification document.

FOUR **SPECIFICATION GUIDE**

4.1 How to use this section

This section provides standard specifications for typical bioretention systems. Relevant sections of the specifications can be used as an example or copied directly into tender packages. When using the standard specifications, designers should ensure:

- the standard specification is relevant to their particular bioretention system design
- the final specification includes any information that is not covered in this standard specification.

Most of this specification is relevant to all bioretention systems; however, there are some differences for the four bioretention drainage profile types, as summarised in Table 23.

4.2 Civil construction

4.2.1 Tolerances

Bioretention systems must be constructed within the tolerances shown in Table 24 and Figure 51. Compliance with these requirements must be demonstrated using the survey standard shown in Table 24, or using a more accurate method agreed to by the superintendent.

Table 23 Bioretention types and relevant specifications

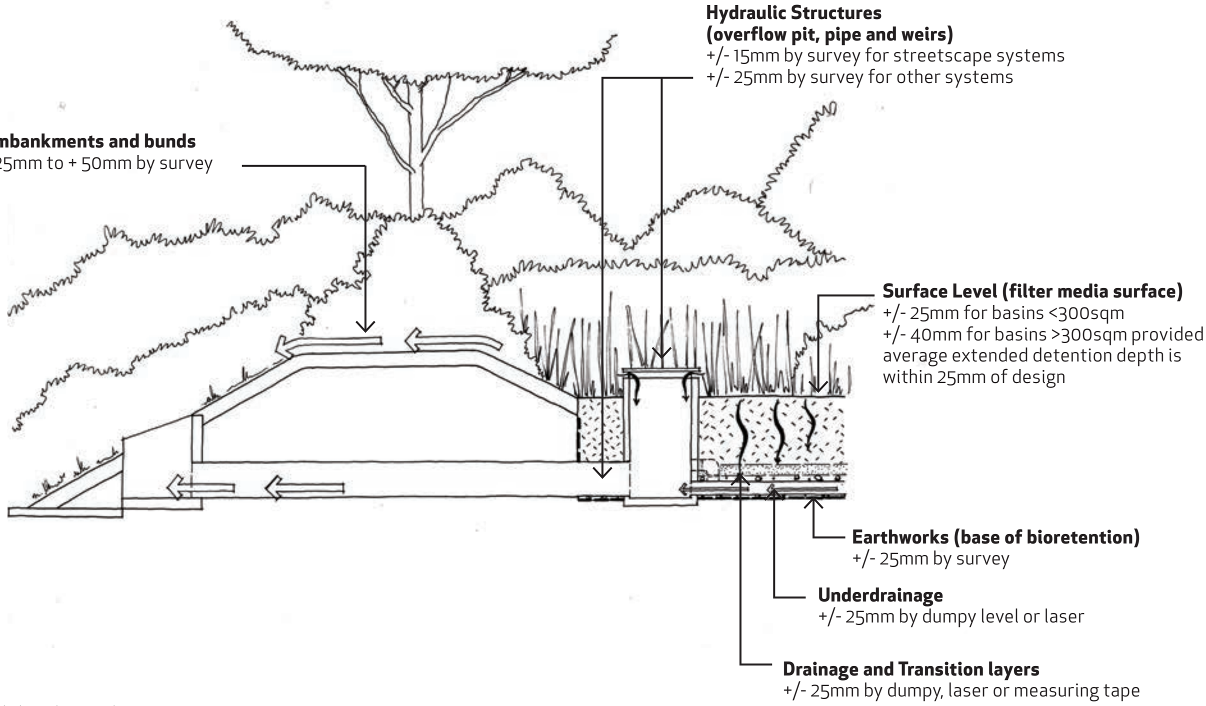
Bioretention construction element	**Specification guide reference section**			
	Type 1 saturated zone	**Type 2 sealed**	**Type 3 conventional**	**Type 4 pipeless**
Tolerances	4.2.1			
Hydraulic structures	4.2.2			
Liner	4.2.3.2	4.2.3.1 and 4.2.3.2	4.2.3.1 and 4.2.3.3	4.2.3.1 and 4.2.3.3
Underdrainage	4.2.4	4.2.4	4.2.4	none
Services	4.2.5			
Maintenance access	4.2.6			
Filter media	4.3.1			
Transition layer	4.3.2			
Drainage layer	4.3.3	4.3.3	4.3.3	none
Landscape and planting considerations	4.4			

Table 24 Bioretention system tolerances

Bioretention element	Construction considerations	Tolerance	Minimum survey standard
Hydraulic structures (overflow pit, pipe and weirs)	These structures control the movement of water through the system. Tolerances apply to: • inlet pipes • overflow pit crest level • pipe connections to overflow pit • outlet pipe invert (upstream and downstream) • weirs	± 15 mm for streetscape systems ± 25 mm for other systems	Survey*
Earthworks (base of the bioretention system)	The base of Type 2 bioretention systems must slope towards the outlet pit at a grade of ⩾ 0.5% in accordance with design drawings. The base of Type 1, Type 3 and Type 4 bioretention systems must be flat The base of bioretention system must be free from localised depressions.	± 0.2% ± 25 mm	Survey*
Underdrainage	The underdrainage in Type 2 bioretention systems must slope towards the outlet pit at a grade of ⩾ 0.5% to freely drain the base. The underdrainage in Type 1 and Type 3 bioretention systems must be flat Type 4 bioretention systems do not have underdrainage	± 0.2%	Dumpy level or laser
Drainage and transition layers	Must be ⩾ 50 mm of drainage layer material above underdrainage pipes. Must be ⩾ 100 mm of transition layer material above the drainage layer material.	+ 25 mm	Dumpy level, laser or measuring tape
Surface level (filter media surface)	Must be free from localised depressions to ensure even distribution of stormwater across the surface and prevent localised ponding. Achieving a flat surface on large bioretention systems can be challenging, so a separate tolerance is provided.	± 25 mm ± 40 mm for filter area > 300 m^2 provided 'average' extended detention depth is within 25 mm of design.	Dumpy level or laser for construction Survey for as-constructed*
Embankments and bunds	These contain water within the extended detention and when required, force runoff to the overflow structure.	- 25 mm + 50 mm Preference for bund to be higher rather than lower	Survey for as-constructed*

* Land or engineering survey by qualified surveyor

Figure 51 Typical bioretention system cross section showing construction tolerances and survey method



4.2.2 Hydraulic structures

A description of hydraulic structures and the corresponding construction requirements is in Table 25.

Table 25 Hydraulic structures in bioretention systems

Hydraulic structure	Description	Construction requirements
Overflow pit	Collects flows in excess the filter media's infiltration rate. Transfers collected flows to an outlet pipe that is connected to receiving drainage system.	Concrete construction. Refer to drawings, local authority standards, or the IPWEAQ Standard Drawings for details. Underdrainage pipes must be sealed into the overflow pit. Note: The crest is intentionally set higher than the surface of filter media and lower than the embankment or bund.
Outlet pipes	Transfer flows from overflow pit to receiving systems. Sized to convey the minor design storm.	Refer to drawings for location, size, levels, and class of pipe. Rock protection may be required at the outfall of the pipe (refer to drawings). Must be free draining, sealed to the overflow pit and include a seepage collar.
Overflow weir	Transfers large flood flows out of the bioretention system to the receiving overland flow drainage.	Mass concrete crest, typically 500 mm deep with reinforcing. Refer to drawings, local authority standards, or the IPWEAQ Standard Drawings for details. Grouted rock protection on both sides of crest to at least the base of the batters. Concrete and rock protection extending up batters and into bunds or batters at the ends of the weir. Refer drawings, local authority standards, or the IPWEAQ Standard Drawings for details.

4.2.3 Liner

4.2.3.1 Permeable liner

A permeable geotextile liner:

- enables treated stormwater to exfiltrate to the surrounding soils
- defines the edge of the media layers.

Permeable liners must be keyed into batters (refer to drawings or the IPWEAQ Standard Drawings. The liner must:

- extend along the bioretention batter at least 500 mm beyond the top of the sides (i.e. beyond the filter media)
- be pinned to the in-situ soil and be covered by at least 200 mm of topsoil placed extend over any embankment surrounding the system
- be resistant to all soil acids and alkalis and comply with the requirements of AS 3706.12
- be resistant to microorganisms (fungi and bacteria) within the soil and comply with the requirements of AS 3706.13.

4.2.3.2 Impermeable liner

Type 1 saturated zone and Type 2 sealed bioretention systems require an impermeable liner around the drainage layer, up to the top of the drainage layer or higher as shown on design plans. Care should be given to ensuring that liners create an impermeable seal around all relevant hydraulic connections. The liner must achieve a hydraulic conductivity of less than 1 x 10-9 m/s. Liners can be made of compacted clay or a range of proprietary products.

Clay liners can be made from suitable in-situ soil or from imported material. The clay should be tested and installed in accordance with specialist geotechnical advice.

Where synthetic liners are used, the following conditions must be met:

- The contractor must receive written assurance from the manufacturer that the product has a permeability of no greater than 1 x 10-9 m/s.
- Specific written advice on sealing the liner around protrusions (e.g. outlet pipes) must be obtained from the manufacturer.
- Liners must be installed and sealed in accordance with manufacturer's specifications and appropriately keyed into the batters and embankments to ensure the system is watertight.
- Certification that the liner has been installed in accordance with the manufacturer's specifications and that it is watertight must be obtained.

4.2.3.3 No liner (open base)

For Type 3 conventional and Type 4 pipeless bioretention systems, permeable geotextile liners should only line the sides of the bioretention system (see Section 4.2.3.1).

4.2.4 Underdrainage

4.2.4.1 Slotted pipes

Underdrainage pipes collect treated stormwater from the drainage layer (aggregate) at the base of the bioretention system and convey flows to the overflow pit. Type 4 pipeless bioretention systems do not have underdrainage pipes. The underdrainage must comply with the following:

- Slotted rigid pipes must comply with requirements of AS 2439.1 for Type 2 pipes.
- Ag-pipes must comply with requirements of AS 2439.1 for Type 1 pipes.
- For filter media surfaces of <100 m^2, the maximum underdrainage spacing is 1.5 m from centre to centre.
- For filter media surface >100 m^2, the maximum spacing of the underdrainage is 2.5 m from centre to centre.
- All pipe junctions and connections to the overflow pit must be sealed to prevent soil entering the pipe network.
- Y-connections (45^o angle) are to be used on all connections to allow easy access for cleaning devices.
- Underdrainage must not use a filter cloth wrapping or sock. Filter cloths may cause blockages that require a complete resetting of the bioretention system.

4.2.4.2 Cleanouts

Underdrains must extend vertically beyond the surface of the filter media by at least 150 mm for inspection and maintenance. The vertical section of the underdrain must not be perforated and must be capped to avoid short-circuiting flows. Caps should be secured with screws to reduce the risk of vandalism. Y-connections (45^o angle) should be used on all connections to allow easy access and clean-out. Refer to the IPWEAQ Standard Drawings.

4.2.5 Services

In accordance with Section 3.3.7, underground services should be located outside the filter media area, but may be incorporated into bioretention system batters. An impermeable barrier should separate the filter media and the service. Where there is no alternative to running services through a bioretention cell, services should be located in conduits running between pits at either end of the bioretention system, subject to approval from the local authority and from the service providers. The interface between the conduits and the edge of the bioretention system must be sealed to prevent flows migrating along the services trench. Detection tape must be placed above the conduits to clearly mark their location.

A 'Dial Before You Dig' search must be completed before the bioretention system is constructed to determine the presence of services. If services are present, then they need to be accurately located and the superintendent consulted about appropriate construction procedures.

4.2.6 Maintenance access

Refer to design drawings for location, width, slope, and surface finish of access tracks.

4.2.6.1 Concrete access tracks

All concrete access tracks, including the base of sediment basins, must meet the following requirements:

- Tracks must comply with local authority concrete access requirements.
- Concrete will consist of a mixture of ordinary Portland cement, coarse and fine aggregate, and water.
- Cement must comply with AS 3972.
- Aggregate must comply with AS 2758.
- Concrete must be normal class as defined by AS 1379, Class N25.
- Concrete must be sampled and tested in accordance with the provisions of AS 1012 (Method of Testing Concrete).
- Reinforcement will be deformed bars or welded wire fabric and comply with AS4671 as appropriate.
- Construction joints to be in accordance with the design drawings.

4.2.6.2 Gravel access tracks

All gravel access tracks must meet the following requirements.

- Gravel access tracks must be comprised of well-graded crushed or rock-soil aggregate that is free from deleterious materials with no more than two thirds of the percentage, by weight, being able to pass through a 0.425 mm sieve.
- Fill is to be compacted to 98% maximum dry density, using a modified compactive effort (in compliance with AS 1289-5.2.1) or 70% minimum density index (in compliance with AS 1289-1.2.1).
- Where any regular access by heavy vehicles is required, tracks should be comprised of a suitable depth (typically 200 mm) of larger ballast (75 mm diameter).

4.3 Bioretention media specification and certification

This section provides specifications for bioretention systems' filter media and guidance on the protocols for testing and certifying each type of filter media.

4.3.1 Filter media

The main role of the filter media in a bioretention system is to remove pollutants and support vegetation. The filter media must be at least 400 mm deep, with depth details provided in the design drawings. Filter media must also comply with the *Guidelines for Soil Filter Media in Biofiltration Systems* (FAWB Guidelines) (FAWB 2009) and meet the following specific requirements:

- Characteristics required for plant growth should be confirmed with soil analysis in consultation with a horticulturalist, as required by the FAWB Guidelines.
- The filter media should be free from AASS and PASS.
- The filter media must not be made from dispersive or erodible materials.

The contractor must arrange for the delivered filter media to be tested in accordance with the FAWB Guidelines at the following frequencies:

- For small to medium bioretention systems (< 500 m^2), one sample per 500 m^3 is to be tested to meet the FAWB Guideline specification tests
- For large bioretention systems (> 500 m^2), one sample per 2,000 m^3 is to be tested for the FAWB Guideline specification tests PLUS one sample per 500 m^3 is to be tested for the hydraulic conductivity test (e.g. one full FAWB test plus three hydraulic conductivity tests per 2000 m^3).

Written records of the testing results along with certification that the requirements are met must be provided to the superintendent for review and approval before the filter media is installed.

The surface of the filter media must be lightly compacted (e.g. using a single pass of a drum lawn roller).

The surface of the filter media must be flat and free from localised depressions. A spreader bar or equivalent should be used.

DESIGN NOTES: Clay and silt content in filter media

The FAWB Guidelines recommend that filter media has a clay and silt content of less than 3%. Industry experience has shown that filter media with a clay and silt content of less than 3% has resulted in poor plant establishment, and that bioretention system filter media with an initial clay and silt content as high as 6% can function appropriately. It is recommended that the minimum clay and silt content in filter media is 2%. It is also recommended that consideration be given to filter media with a clay and silt content as high as 6%, provided that the required saturated hydraulic conductivity is achieved and the media is well graded (i.e. the particle size distribution for particles greater than 0.05 mm is in accordance with FAWB Guidelines).

Filter media saturated hydraulic conductivity

The FAWB Guidelines recommend filter media with a saturated hydraulic conductivity of between 100mm/hr and 300mm/hr, but allow for it to be as high as 600mm/hr. Filter media with a saturated hydraulic conductivity greater than 300mm/hr can lead to poor plant establishment and survival, and may also result in leaching of pollutants. Filter media saturated hydraulic conductivity should be between 100mm/hr and 300mm/hr.

Commercial availability of filter media

The FAWB Guidelines and the requirements of this document allow for flexibility in the properties of bioretention filter media. This flexibility is not always reflected in commercially available filter media. It is recommended that the bioretention designer contact filter media suppliers to ensure that the filter media specifications can be met in a commercially available product.

Filter media in dry climates

Sustaining vegetation in bioretention systems in dry climates and climates with extended dry periods can be challenging. In such climates, filter media can be modified to increase soil water holding capacity, making more water available to plants for longer. The type and quantity of filter media additive used should be selected in conjunction with a suitably qualified professional, but may include:

- Composted garden waste
- Composted pine bark
- Coconut coir
- Composted wood chip fines
- Sugar cane bagasse
- Composted saw dust
- Diatomatous earth
- Zeolites
- Scoria
- Perlite
- Power station ash
- Crushed brick and tile

Some sources of the above additives may, due to their production or composition, have a detrimental effect on either the environment or the performance of bioretention systems (e.g. parameters such as hydraulic conductivity, particle size distribution and nutrient content). Care must be taken to ensure that additives used do not compromise outcomes of bioretention system performance.

4.3.2 Transition layer

Transition layers prevent filter media from migrating into the drainage layer. It is not present in bioretention systems that meet the requirements outlined in Section 3.2.2.2. The transition layer surface must be flat and free from localised depressions. A spreader bar or equivalent should be used.

Where present, the transition layer must:

- for Type 1 saturated zone bioretention systems meet the requirements of Section 3.2.2.4
- for Type 2 to 4 bioretention systems be at least 100mm deep.

The transition layer material must be a clean, well-graded sand containing less than 2% fines. To avoid migration of the filter media into the transition layer, the particle size distribution of the sand should be assessed to ensure it meets 'bridging criteria', that is, the smallest 15% of the sand particles bridge with the largest 15% of the filter media particles:

- D15 (transition layer) ≤ 5 x D85 (filter media) where: D15 (transition layer) is the 15th percentile particle size in the transition layer material (i.e., 15% of the sand is smaller than D mm), and D85 (filter media) is the 85th percentile particle size in the filter media.

4.3.3 Drainage layer

Drainage layers convey infiltrated flows horizontally across the base of the system into the slotted underdrainage pipes. It is not present in Type 4 pipeless bioretention systems

Drainage layers must:

- be at least 150 mm deep for Type 1 and 2 bioretention systems
- be at least 300 mm deep for Type 3 bioretention systems
- provide at least 50 mm of cover above the underdrainage pipes
- comprise fine gravel (2–5 mm) with less than 2% fines and a minimum saturated hydraulic conductivity of 4000 mm/hr. The drainage layer gravel must meet the following bridging criteria:
  - D15 (drainage layer) ≤ 5 x D85 (transition layer).

The surface of the drainage layer must be flat and free from localised depressions. A spreader bar or equivalent should be used.

Geotextile fabrics are not recommended for use between layers in bioretention systems due to the risk of clogging.

4.3.4 Saturated zone

Saturated zones must be at least 350 mm deep and contain:

- a drainage layer of fine gravel (2-5mm) installed at the base of the saturated zone which meets the depth requirements of Sections 3.2.2.3 and 3.2.2.4
- a transition layer of coarse double washed sand (i.e. twice before being installed) installed on top of the transition layer which also meets the depth requirements of Section 3.2.2.4.

4.4 Landscape considerations and specifications

4.4.1 Topsoil (batters and embankments)

The batters and embankments around bioretention systems must be covered with at least 200 mm topsoil.

Topsoil must be tested by a National Association of Testing Authorities (NATA)-accredited laboratory in accordance with AS 4419. The topsoil should be rejected if the proposed topsoil has high salt levels, extremely low levels of carbon (< 5%), or any other extreme characteristic that may restrict plant growth. The laboratory testing will identify any amelioration requirements. The results of the topsoil test must be given to the site superintendent and bioretention system designer for review before the topsoil is installed.

Bioretention system topsoil can be sourced from the in-situ topsoil or from soil suppliers. In-situ topsoils can be used for bioretention batters; however, laboratory soil testing in accordance with AS 4419 is required to ensure the topsoil will support plant growth. If the in-situ topsoil is unsuitable, new topsoil should be purchased from a soil supplier. Purchased soils must still comply with AS 4419.

Weed infested soils should be avoided, particularly soils containing aggressive pasture grasses tolerant of moist conditions. If these weeds are in in-situ soil, and no other sources of topsoil are available, a minimum of 50 mm should be scraped from the soil surface and discarded.

4.4.2 Plants

Planting densities and species must be consistent with the detailed design drawings. No substitutions should be made unless approved by the superintendent.

4.4.2.1 Plant procurement

For large orders, it is recommended that plant stock is periodically inspected at the nursery to ensure that suitable plants will be ready when required and to check:

- that plants are being grown in clean, weed, and pest-free conditions
- that roots of plants are fresh and white
- that plants are exposed to direct sunlight as a 'hardening off' phase before delivery and are not taken directly from a shade house to the construction site.

Plants used in bioretention systems are typically tube stock sourced from wholesale nurseries. Plant availability varies considerably between different regions and times of the year. Sufficient time must be allowed to order plants and up to six months lead-time may be required to ensure appropriate species are available. If provenance plant stock is required, up to 18 months may be required to collect seeds and propagate plants.

Some species are very difficult or slow to propagate. Advice should be sought from a knowledgeable nursery to avoid last minute substitutions due to species unavailability.

4.4.2.2 Maturity

Plant stock must be well developed, sun-hardened, and contain a fully established root ball that does not crumble when removed from its container. Height is important to enable plants to cope with inundation and not to be buried in mulch. Plant stock should be at least 200 mm high.

Immature plants and plants that are too old can be difficult to establish. Many species of sedges and other bioretention plants will struggle to develop once they are old and pot-bound. These plants may remain stunted, be susceptible to herbivory and disease and fail to provide the root cover required for optimal filtration.

The plant stock must:

- show no sign of pest and disease
- show no signs of nutrient deficiency
- show signs of new growth and general vigour
- be free from weeds
- be clearly labelled.

Plants must be supplied in a container that is at least:

- 90 mm high
- 50 mm wide.

4.4.3 Preparing filter media

Before planting, the filter media should be tested at a NATA-accredited laboratory for advice on whether additional nutrients are required for successful plant establishment. This advice must be followed.

If a laboratory analysis is not possible, each plant must receive at least 10 g of slow-release native fertiliser in granular or tablet form. After planting, the contractor must undertake monthly assessments of plant health to determine whether any species require additional fertiliser.

Plant stress and watering requirements can be reduced by increasing the water-holding capacity of the soil using water crystals. Water crystals should be applied when they are fully hydrated (to limit the potential for plants being pushed out of their holes as the crystals swell) at a rate of 2–3 g per plant.

4.4.4 Mulching

Mulching retains moisture around plants, as well providing a source of organic matter to help plants establish. Mulch must be:

- applied in accordance with design drawings
- applied before planting
- 50-75mm thick to ensure new vegetation shoots are not hindered
- kept clear of plant stems by at least 50 mm to avoid excessive moisture around stems.

A range of mulches are suitable for bioretention systems:

- Organic friable mulches that degrade within six months such as fine sugar cane or tea tree mulch (to avoid the mulch being washed away during storms, it should be pinned down with an organic weed mesh (e.g. loose-weave jute), pinned at no more than 500 mm centres).
- Organic matting that is lightweight and degrades in less than six months; however maintenance will need to be undertaken as plants establish and expand to ensure that the matting does not strangle the plants.
- Bonded fibre matrix mulches.
- An inorganic mulch that does not float, such as small gravel or stone; however, the mulch must not inhibit plant growth (e.g. physically restrict plant growth, absorbing heat and transferring it to plant stems and/or reflecting heat onto the undersides of plant foliage).

River stones should be avoided because they are extracted from natural water courses.

The following should not be used as mulch for bioretention systems:

- Long-lasting organic mulches including tanbark or other hardwood.
- Organic mulch that is likely to contain weed seeds.
- Heavy-duty matting such as 800 gsm jute mat.
- Inorganic matting such as filter cloth.

4.4.5 Planting procedure

4.4.5.1 Plant set-out

Plant set-out is a critical part of landscape works and must be confirmed with the designer or landscape architect before landscape works start. It is essential to confirm the placement of species, particularly for trees or shrubs within the system, or if attempting to mimic a representative vegetation community.

Planting areas should be measured from design drawings and marked with stakes for ease of planting and to reduce the risk of incorrect placement.

Avoid creating large areas of monoculture. Contact the site superintendent if the design drawings indicate large monocultures.

4.4.5.2 Planting

Vegetation in bioretention systems is usually planted using hand tools or light machinery such as auger drills. Heavier equipment is not necessary as the filter media will be uncompacted. Planter holes should be twice the size of the tubestock. Plants should be carefully removed from the tube to ensure their stems do not break from the root ball. Plants should be placed in the filter media such that all roots are covered by at least 10–20 mm of soil.

4.4.5.3 Establishment

Given the importance of establishing plant cover within the bioretention system as quickly as possible; a pro-active and adaptive approach must be taken to landscape establishment, responding to any issues about the health of the plants as they arise. Responses can include watering or fertilising to deal with plant stress or weather patterns, and manual removal of weeds. Spreading seed can improve the seed bank and increase plant cover in bare areas.

Replanting must occur during the establishment period if less than 90% of plants survive.

4.4.6 Watering

Plants must be regularly watered during the establishment phase. The frequency of watering will depend on the time of year and weather. The watering program outlined below must be followed unless a variation is agreed by the superintendent.

- Week 1–6 Five waterings per week.
- Week 6–10 Three waterings per week.
- Week 11–15 Two waterings per week.

In the absence of rain, it is recommended that each plant receives 2.5–5 L of water per week during the first six weeks (40 mm of watering per week during establishment).

After an initial four-month period, watering may still be required, particularly during the first winter or dry period. Watering requirements for healthy vegetation can be determined by ongoing inspections.

4.4.7 Measures of successfully established plants

Planting in bioretention systems is considered to be 'established' when the plants are robust and self-sustaining. Growth and maturity must be recorded through three-monthly photo logs every 250 m^2 and the following criteria noted:

- Vegetation must cover at least 90% of the bioretention surface (< 10% soil/mulch visible from above).
- Any areas without established vegetation cover must be mulched.
- Minimum vegetation height is 500 mm.
- Plants must be healthy and free from disease.

FIVE **WORKED EXAMPLE**

The following worked example provides a practical application of the design process presented in Section 3 of this guideline within the context of a real site. The structure of the worked example aligns closely with Section 3 to allow quick reference from the design calculations back to supporting information. This example is intended to demonstrate concepts and calculations specific to bioretention functional design and therefore assumes that all supporting information (e.g. trunk drainage design, ecological assessments, flood studies) have been completed in accordance with industry standards. Where applicable, such information is simply stated in the example rather than calculated or described in detail. The worked example is not intended to provide prescriptive design solutions that are applicable to all situations. Designers must use experience and professional judgement as well as understand Local Authority requirements in order to undertake a suitable bioretention design.

5.1 Project overview

As part of a retrofit stormwater treatment strategy, a bioretention basin is to be integrated into an existing park beside a small creek in Brisbane. The aim of the project is to capture and treat stormwater prior to it entering the creek through the use of a bioretention system which integrates with both the existing residential area and the riparian corridor.

5.2 Concept design

Concept design was undertaken for the bioretention system and is summarised in Table 26 and Figure 52.

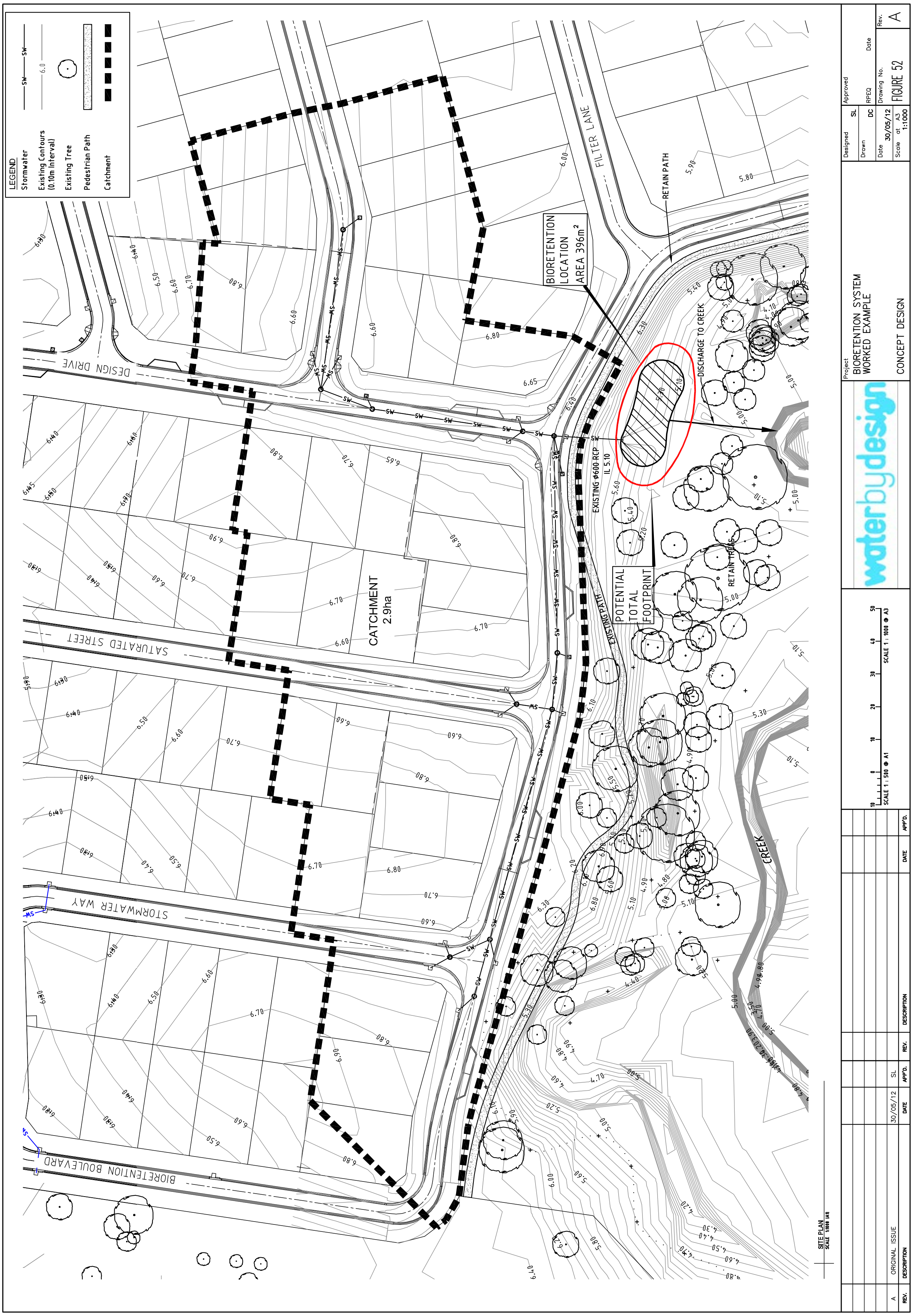
The bioretention basin will receive piped minor flows (2 year ARI) from a 2.9 hectare catchment and overland major flows (50 year ARI) from a 1.3 hectare catchment. The filter media area and extended detention depth were established using MUSIC. The proximity to both parkland and natural areas (creek) guided the overall configuration and proposed planting outcomes for the bioretention basin. The bioretention basin will not form part of any flood detention basin nor interact with the streetscape directly so specific design details relating to these types of bioretention systems are not required.

The following sections present detailed design completed for the bioretention system based on the concept design parameters summarised in Table 26.

Table 26 Concept design parameters

Catchment Parameter	Value adopted
Minor flow catchment (piped)	2.9 ha
Major flow catchment	1.3 ha
Houses (with rainwater tanks supplying non-potable uses)	8
Houses (with no rainwater tank)	21
Houses (total)	29
Impervious cover	55%
Bioretention Parameter	**Value adopted**
Filter media area	396 m^2
Total footprint (three times filter area)	~1,188 m^2
Extended detention depth	300 mm
Filter media depth	600 mm (min)
Drainage profile	Saturated zone
Filter media saturated hydraulic conductivity	100 mm/hr

Figure 52 Concept design



5.3 Background investigations

5.3.1 Site analysis

The following site characteristics were confirmed based on desktop analysis, site investigation, discussions with Council and input by specialist sub-consultants:

- Detailed topographical survey was completed for the entire catchment.
- Catchments for piped and overland flows were confirmed based on topography and drainage layout, including defining the location, size and invert of existing stormwater drainage infrastructure.
- All physical boundaries and constraints were identified, including the wet season water level (3.0 m AHD) in the downstream receiving waterway.
- Flood levels were provided by Council for the bioretention location as follows:
  - 5yr ARI = 5.3 m AHD
  - 50yr ARI = 5.8 m AHD
- Dial Before You Dig search was undertaken and indicated no services in the broad bioretention area
- Significant trees were identified along the riparian zone of the creek and ecological assessment of the representative indigenous flora undertaken. All trees to be retained are marked on the drawings.
- Geotechnical investigations were undertaken to determine if any PASS or dispersive clays were present on-site. Test pits were excavated and samples taken. PASS were found to be present and will be managed in accordance with a management plan. No dispersive soils were located.
- Groundwater monitoring was undertaken and indicated that the maximum wet season groundwater level is 3.6 m AHD.
- It was assumed that the bioretention will not receive baseflow as no flow was observed in the pipe during a site visit undertaken after five days without rainfall

The above site characteristics are shown in Drawing WSUD- P01 and WSUD-P02

5.3.2 Design objectives

The following design objectives were resolved by the design team:

- Meet best practice stormwater pollutant reductions (80% reduction in total suspended solids load, 60% reduction in total phosphorus load and 45% reduction in total nitrogen load).
- Provide integration between existing residential area and riparian corridor.

5.3.3 Consultation with local authority

The following design requirements were identified in consultation with Council:

- Vegetated batters to be no steeper than 1 in 4.
- The bioretention system and associated batters to be planted with groundcovers, shrubs and trees to complement the existing riparian vegetation and limit weed ingress.
- Access to the sediment forebay is required for cleaning annually at a minimum. Access must be at least 2.5 m wide and can be reinforced turf provided grade is 1 in 4 or flatter.
- The bioretention system embankments must be higher than the peak 5 year ARI water level from the waterway immediately south of the bioretention (i.e. 5.3 m AHD).
- Embankments and surrounding pathways require 200 mm or more freeboard above the peak water level during the major flow.

5.4 Layers, depths and levels

5.4.1 Bioretention profile selection

A saturated zone bioretention was selected for the following reasons:

- to sustain vegetation during dry periods
- to enable trees to be planted in the system
- because an impermeable liner will be required due to ASS, and thus the inclusion of saturated zone was considered an easy change to the design.

5.4.2 Media layers and depths

The saturated zone bioretention system will be created using an outlet riser configuration sited within the outlet pit (see Option 2 in Figure 43 and Figure 53). This will ensure the saturated zone can be periodically drained for maintenance purposes. To allow trees to be planted in the bioretention basin to improve integration with the riparian zone, the filter media will be 700 mm deep. The bioretention layers, depths and levels are presented in Figure 53.

5.4.2.1 Saturated zone depth

The saturated zone will be 400 mm deep. This exceeds both the minimum recommended depth of 350mm (see Section 3.2.2.4), and the minimum requirement to sustain plants during the average annual longest expected dry period in Brisbane (see Equation 1) as shown in Calculation 1 below.

Calculation 1

$D_{sz} = 8mm/day \times t_{dp}$

Where: D_{sz} = Ideal depth of saturated zone (mm)

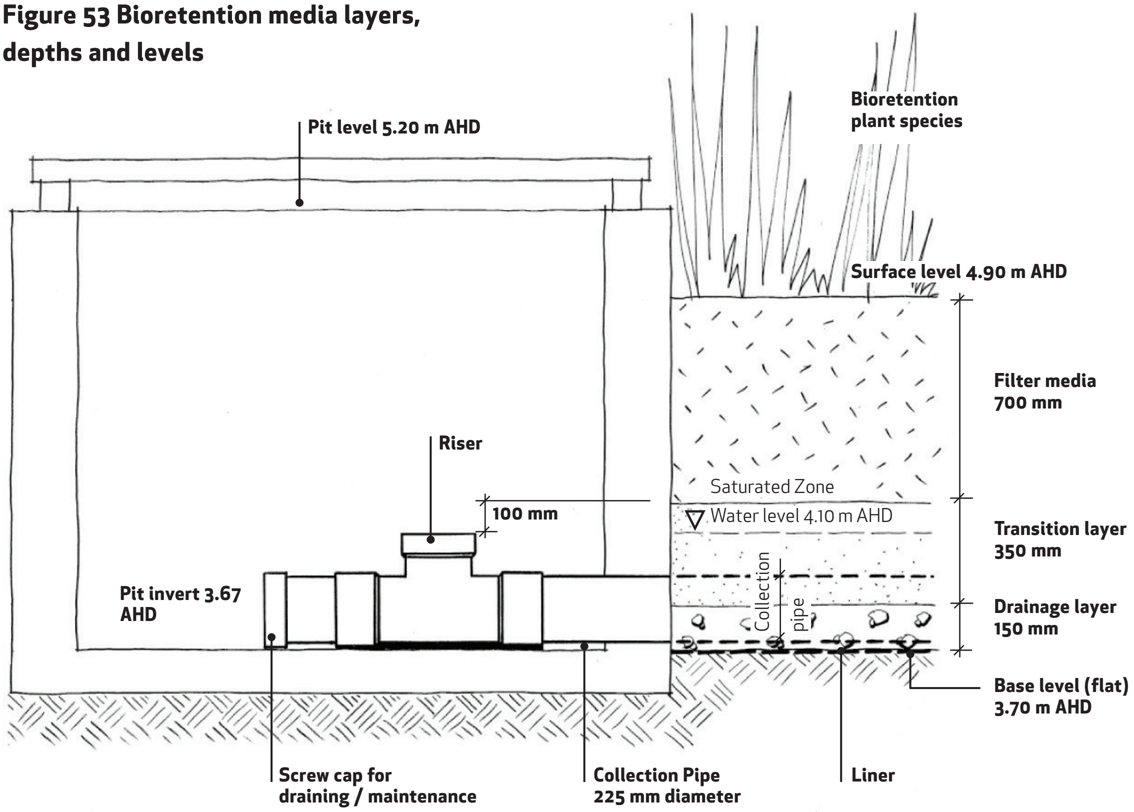
t_{dp} = average of the longest annual dry period for the last 10 years = 33 days

$D_{sz} = 8mm/day \times 33$

$D_{sz} = 264mm$

The drainage layer will be 150mm deep in order that 50mm of drainage layer is located above the top of the perforated underdrainage (see Table 5). This will ensure that the top of the saturated zone is not located within the drainage layer (see Section 3.2.2.4). To ensure the top of the saturated zone is located within the transition layer, and at least 100mm below the base of the filter media, the transition layer shall be 350mm deep.

Figure 53 Bioretention media layers, depths and levels



5.4.3 Design levels (outlet, surface and water levels)

The bioretention levels were established through an iterative design process considering layout, inlet design (existing pipes) and outlet design. In doing so, both the design objectives of this bioretention system (see Section 5.3.2) and the design requirements for layers, depths and levels specified in Section 3.2 were met. Further explanation of the method by which each level was calculated is provided in the following sections. The design levels are:

1. Outlet invert level = 3.26 m AHD which is 0.36 m, above the standing water level and 0.16 m above the 1 month ARI flow event in the receiving waterway/drain.
2. Pipe invert levels (established based on the outlet level and pipe grade of 1.2%):

   a. Downstream pipe invert = 3.26 m AHD

   b. Upstream pipe invert = 3.67 m AHD.
3. Outlet pit invert level = 3.67 m AHD.
4. Bioretention base level = 3.7 m AHD. The base of the saturated zone bioretention system is flat.
5. Drainage layer, transition layer and filter media surface levels:

   a. Drainage layer surface = 3.85 m AHD

   b. Transition layer surface = 4.2 m AHD

   c. Filter media surface = 4.9 m AHD.
6. Coarse sediment forebay invert is set at 5.0 m AHD (100mm above the filter media) with the incoming pipe invert at 5.1 m AHD.
7. Extended detention depth = 300 mm and overflow pit level = 5.2 m AHD.
8. Maximum water level = 5.60 m AHD (based on an overflow weir level of 5.5 m AHD – refer to Calculation 24 in Section 5.7.4).
9. Minimum embankment level = 5.8 m AHD. Note this is well above the 5 year ARI requirement of 5.3 m AHD by Council.
10. Maximum level difference from bioretention surface level to adjacent pathways will be 1.1 m.

5.4.4 Liner

A bentonite liner will be used for the bioretention base and side as no suitable clays were found on site during geotechnical investigations.

5.5 Bioretention system layout

5.5.1 Earthworks model

A digital earthworks model was created for the site using the topographical survey. The model defines the layout and level configuration for the bioretention system. This was also used in a broader flood plain model with the outcome showing no loss of floodplain storage or impacts on local stream hydraulics.

5.5.2 Filter media area

The bioretention filter media area of 396 m^2 was established during concept design using MUSIC modelling. The catchment area, land use and key bioretention parameters from the concept design remained unchanged, and hence this filter media area was retained.

5.5.3 Shape

The minimum width of the filter media will be 5 m and the maximum length 40 m (refer Drawing WSUD-P03). This is in accordance with the requirements of Section 3.3.3.

5.5.4 Inlet and outlet locations

In order to minimise the amount of new stormwater infrastructure required the existing pipe and headwall (refer Drawing WSUD-P01) will be retained as the inlet to the bioretention system. The pipe invert was used as a key design level for the overall system profile. Through careful site layout, and in accordance with the requirements of Section 3.3.4, the outlet pit will be located close to the inlet to ensure high flows can pass through the bioretention without engaging with the whole filter media surface. A coarse sediment forebay will be located at the inlet.

The layout and profile of the system will result in the bioretention outlet pipe discharging directly to the waterway (rather than further up the bank/flood plain). Careful design of this outlet and scour protection was therefore required to avoid adverse impacts on the local receiving waterway from concentrated outflows (see Section 5.7.5).

5.5.5 Edge and landscape interface (batters and embankments)

5.5.5.1 Surrounding landscape

The design considered the surrounding landscape by:

- retaining existing trees
- retaining the existing pathways to preserve bike and pedestrian movement
- forming the bioretention system in an organic shape to ensure integration with the natural riparian setting.

5.5.5.2 Public access and safety

There will be no pedestrian access to or across the filter media. The existing pathway connection will be retained and realigned where required towards the existing road allowing passive surveillance. No pedestrian movement will be encouraged to the creek side of the bioretention system where surveillance may not be possible.

5.5.5.3 Batters

The batters around the bioretention system will vary from 1 in 4 (maximum) to 1 in 8. The height of the batters varies from 0.9 m on the creek side of the bioretention system to 1.1 m on the road side of the bioretention. Shrubs and trees will be planted on the batters.

5.5.5.4 Embankments

The top of the embankment (5.8 m AHD) will be 1 m wide allowing for maintenance access (see Section 5.5.6).

5.5.5.5 Walls

The bioretention system will not include any walls or fences.

5.5.6 Maintenance access

5.5.6.1 Sediment cleanout access

A reinforced turf section of the bioretention batter with a maximum slope of 1 in 4 will form an access track for bobcats to enter the coarse sediment forebay for annual cleanout. The access track will be 2.5 m wide. Maintenance vehicles will be able to use the pedestrian path to get from the road to the reinforced turf access track.

5.5.6.2 Filter and vegetation maintenance

Due to the scale of the system (<500 m^2) the perimeter only needed to be accessed by maintenance staff on foot (i.e. vehicle access is not required).

The 2.5 m wide pedestrian path along the northern bioretention edge will make up 41% of the perimeter and will therefore be in accordance with Table 10 shown previously.

The top of the embankment along the south, east and west sides will be 1.0 m wide to provide an access route for maintenance staff if required. This is wider than the minimum 0.5 m requirement from Table 10.

5.5.6.3 Maintenance edges

The base of the bioretention embankment on the south, east and west edges will abut riparian vegetation so no maintenance edge is required. The pedestrian path will form a maintenance edge along the north side.

5.5.7 Underground services

Background investigations found no known services within the bioretention vicinity.

5.6 Inlet design

5.6.1 Design inflows

Design flows were estimated using the probabilistic rational method, in accordance with QUDM (DEWS, 2013) and Council standards (Table 27).

Table 27 Design inflows

Design flow	ARI	Flow (m^3/s)
Major	50 year	1.18
Minor	2 year	0.74
Coarse sediment management	3 month	0.22

5.6.2 Inflow type

Inflow to the system will be concentrated via the existing pipe and headwall (concentrated pipe inflow).

Observations made during the site visit indicate that the system will not receive a constant base flow.

5.6.3 Coarse sediment removal

Due to the scale of the catchment (2.9 ha) a coarse sediment forebay is required. The base of the concrete forebay will be at 5.0 m AHD. This will locate it 100 mm above the filter media surface and 100 mm lower than the invert of the inlet pipe. A 200 mm high concrete rim will form the interface between the forebay and bioretention system. Vertical slots (50 mm wide) at 2 m spacing will allow the forebay to drain to the filter media.

The sediment forebay was sized in accordance with Equations 3, 4 and 5 (see Section 3.4.3.2), ensuring:

- adequate removal of sediments greater than 1 mm particle size
- clean out is required no more regularly than once per year (i.e. Frequency, Fc = 1)
- sediment removal based on the 3 month ARI flow.

First, the minimum storage volume required was determined (Calculation 2). The contributing catchment area during the 3 month ARI flow will be 2.9 ha. A target removal efficiency of 0.8 was chosen in accordance with Section 3.4.3.2. No site specific sediment load data was available for the site so 0.6 m3/ha/yr was used in accordance with Section 3.4.3.2. A cleanout frequency of 1 was adopted because Council requires that the forebay be designed for desilting no more than once per year.

Calculation 2

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

Where: V_s = storage volume

A_c = catchment area = 2.9 ha

R = removal efficiency = 0.8

L_o = sediment loading rate = 0.6 m^3/ha/yr

F_c = cleanout frequency = 1 year

$$V_s = 2.9 \times 0.8 \times 0.6 \times 1$$
$$V_s = 1.4 m^3$$

Next, the minimum forebay area required to achieve the sediment storage volume was determined (Calculation 3). The sediment storage volume was obtained from Calculation 2. A maximum sediment storage depth of 0.1m was a key assumption when setting the bioretention basins depths and levels (see Section 5.4.3), and hence was adopted here.

Calculation 3

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

Where: A_s = storage area

V_s = storage volume = 1.4 m^3

D_s = maximum sediment storage depth = 0.1 m

$$A_s = \frac{1.4}{0.1}$$
$$A_s = 14 m^2$$

Third, the minimum forebay area required to achieve the target sediment removal efficiency of 80% was calculated (Calculation 4). A settling velocity of 0.1 m/s was adopted for the target 1mm sediment in accordance with Section 3.4.3.2. A turbulence factor of 0.5 also as recommended in Section X was adopted. The 3 month ARI design flow calculated in Section 5.6.1 (see Table 27) was used.

Calculation 4

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

Where: A_f = forebay area

R = target removal efficiency = 0.8

v_s = settling velocity of 1mm sediment = 0.1 m/s

Q = 3 month ARI design flow = 0.22 m^3/s

n = turbulence factor = 0.5

$$0.8 = 1 - \left[1 + \frac{1}{0.5} \times \frac{0.1}{0.22/A_f}\right]^{-0.5}$$

Solving for A_f gives

$$A_f = 26.4 m^2$$

The forebay must be large enough to achieve both the required removal efficiency and the storage volume. Therefore the larger of these two values (26.4m² from Calculation 4) was adopted as the forebay area. At this area, the annual sediment accumulation depth will be 53 mm. This means the coarse sediment forebay can be cleaned every 1.5 - 2 years.

5.6.4 Inlet energy dissipation and scour protection

An assessment of the inlet pipe discharge velocity was undertaken in accordance with QUDM (DEWS, 2013) to determine the requirements for energy dissipation and scour protection. The pipe velocity dictated the need for a rock apron with a length of approximately six times the pipe diameter (600 mm). As the total forebay length will be just over 7.0 m, no additional energy dissipation and scour protection was designed. However, in order to manage localised filter media scour from flows overtopping the sediment forebay wall, a 0.6 m wide rock apron will surround the sediment forebay. This will be nominally widened (in the direction of flow) to 1.2m between the forebay and overflow pit. The rock used will be between 100 and 150 mm nominal diameter.

5.6.5 Filter media scour velocity check

The velocity of water across the filter media surface in both the minor (Calculation 5) and major (Calculation 6) storms was calculated to check that the filter media would not be prone to scour. The flow rate previously determined for each design storm (see Table 27) was used. A width of 4m was used as this is the width of the bioretention basin at the narrowest point in the filter media (in this case the interface of the coarse sediment forebay rock protection and the filter media). The depth of flow was calculated in accordance with Section 3.4.5. In the minor storm calculation the depth was 0.4 m (the extended detention depth plus 100 mm). In the major storm calculation the depth was 0.65 m (the bypass weir level plus 100 mm).

Calculation 5

$$v = \frac{Q}{w \times d}$$

Where: v = velocity of flow over filter media surface (m/s)

Q = flow rate in the design storm event = 0.74 m^3/s

w = bioretention basin width at narrowest point = 4 m

d = depth of flow in accordance with Table 14 = 0.4 m

$$v = \frac{0.74}{4 \times 0.4}$$

$v = 0.46 m/s$

Calculation 6

$$v = \frac{Q}{w \times d}$$

Where: v = velocity of flow over filter media surface (m/s)

Q = flow rate in the design storm event = 1.18 m^3/s

w = bioretention basin width at narrowest point = 4 m

d = depth of flow in accordance with Table 14 = 0.65 m

$$v = \frac{1.18}{4 \times 0.65}$$

$v = 0.45 m/s$

The velocity in both the minor and major storms will be less than 1 m/s and will therefore be acceptable.

5.6.6 Flow distribution

A dedicated distribution system will not be required as the bioretention is not greater than 400 m^2. The saturated zone will ensure even soil moisture during dry weather.

5.7 Outlet design

5.7.1 Underdrainage pipes

5.7.1.1 Pipe material selection

Slotted 100 mm diameter HDPE underdrainage will be used. The slotted pipes will connect to a solid 225 mm diameter HDPE collector pipe with 45 degree 'Y' junctions to permit flushing.

5.7.1.2 Saturated zone bioretention underdrainage

As the bioretention system contains a saturated zone, the underdrainage was sized in accordance with the general approach to sizing underdrainage pipes detailed in Section 3.5.1.4.

1. **Underdrainage layout and pipe sizing**
   The proposed underdrainage arrangement is shown in Drawing WSUD-P03. The slotted pipes will be at 2 m spacing.
2. **Riser connection**
   The riser connection will be 225 mm in diameter with a crest level 100 mm below the top of the transition layer (4.1 m AHD).
3. **Maximum water level height at riser connection**

   a. Design flow through filter
   The maximum infiltration rate ($Q_{inf\,max}$) per square meter of filter media was determined (Calculation 7)

in accordance with Equation 7 (see Section 3.5.1.4). In accordance with the design, the filter media depth and extended detention depth used were 0.7m and 0.3m respectively. As the calculation was performed on a single square meter of filter media, the filter media area used was 1.0m². A saturated hydraulic conductivity of 2.78×10^{-5} m/s (i.e.100mm/hr in accordance with Table 26) was used.

Calculation 7

$$Q_{inf\,max} = K_{sat} \times A \times \frac{h_{max} + d}{d}$$

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

d = depth of filter media = 0.7 m

h_{max} = extended detention depth = 0.3 m

A = filter media area = 1.0 m^2

K_{sat} = saturated hydraulic conductivity of filter media = 2.78×10^{-5} m/s

$$Q_{inf\,max} = 2.78 \times 10^{-5} \times 1 \times \frac{0.3 + 0.7}{0.7}$$

$Q_{inf\,max} = 3.97 \times 10^{-5} m^3/s$ *per* m^2

$Q_{inf\,max} = 0.016 m^3/s$ *for the total filter area of 396* m^2

b. Maximum outlet riser water level

The maximum water level at the outlet from the underdrainage network (i.e. the depth of flow spilling from the vertical riser pipe) was calculated by rearranging the weir equation (Calculation 8). The weir equation was used because the outlet riser configuration chosen (see Figure 53) behaves as a weir. The length of weir used was 0.72m as this is the circumference of the 225m diameter outlet pipe. A weir coefficient of 1.66 was adopted. A flow rate through the outlet of 0.016m³/s was adopted as determined in Calculation 7.

Calculation 8

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

Where: C_w = weir coefficient = 1.66

L = length of weir = 0.72m

Q_{weir} = flow rate through outlet = 0.016m³/s

h = depth of flow above weir crest (m)

$0.016 = 1.66 \times 0.72 \times h^{3/2}$

hence,

$h = 0.056m$

The maximum water level using the weir equation was found to be 0.056 m, which corresponds to 4.156 m AHD.

c. Allowable head loss

The allowable head loss through the slotted pipe network was calculated as 0.044 m; that is the difference between the base of the filter layer (4.200 m AHD) and the maximum outlet water level (4.156 m AHD).

4. **Under-drainage head loss**

To check the combined head loss (H_{total}) of the underdrainage network will not exceed the allowable head loss identified above, the individual components contributing to head loss (i.e. friction (h_f) and structure (h_s) losses in the critical (typically longest) run of underdrainage network) were calculated then summed in accordance with Equation 10 (see Section 3.5.1.4), as shown again here.

$$H_{total} = h_{f(slotted)} + h_{f(collector)} + \sum h_{s(slotted)} + \sum h_{s(collector)} + \sum h_{s(riser)}$$

The calculations for each head loss component are shown below.

a. Head loss – slotted pipe friction

The friction head loss (h_f) in the longest slotted pipe was calculated using Equation 8 (see Section 3.5.1.4). To do this, the average flow rate for the pipe was required. This was determined as shown in Calculation 9. The contributing area for half the pipe was determined to be 10m² (i.e. 5 m long by 2.0 m wide). The maximum infiltration rate per square meter of filter media determined in Calculation 7 was used.

Calculation 9

$$Q = Q_{inf\,max} \times A$$

Where: Q = flow rate for subject portion of underdrainage (m³/s)

$Q_{inf\,max}$ = maximum infiltration rate per square meter of filter media = 3.97×10^{-5}m/s

A = contributing filter area = 10m²

$Q = 3.97 \times 10^{-5} \times 10$

$Q = 3.97 \times 10^{-4}$ m³/s

This value was then used to determine the friction loss in the longest slotted pipe (Calculation 10). The length of pipe was 10m, the coefficient of roughness 150 (as recommended in Section 3.5.1.4) and the pipe diameter 0.1m (see Section 5.7.1.1)

Calculation 10

$$h_{f\,(slotted)} = L\left[\frac{10.67 \times Q^{1.85}}{C^{1.85} \times D^{4.87}}\right]$$

Where: $h_{f\,(slotted)}$ = slotted pipe friction loss (m)

L = pipe length = 10 m

Q = flow rate for subject portion of underdrainage = $3.97\text{x}10^{-4}\,m^3/s$

C = roughness coefficient = 150

D = pipe diameter = 0.1 m

$$h_{f\,(slotted)} = 10\left[\frac{10.67 \times (3.97 \times 10^{-4})^{1.85}}{150^{1.85} \times 0.1^{4.87}}\right]$$

$$h_{f\,(slotted)} < 0.001m$$

b. Head loss – collector pipe friction

The friction loss in the collector pipe (35 m long) was also calculated using Equation 8 (see Section 3.5.1.4) based on the average pipe flow (i.e. at pipe midpoint). The contributing filter area at the pipe midpoint will be 200 m^2 (approximately half the filter). The flow rate for this portion of filter/underdrainage is therefore:

Calculation 11

$$Q = Q_{inf\,max} \times A$$

Where: Q = flow rate for subject portion of underdrainage (m^3/s)

$Q_{inf\,max}$ = maximum infiltration rate per square meter of filter media = $3.97\text{x}10^{-5}$ m/s

A = contributing filter media area = 200 m^2

$$Q = 3.97 \times 10^{-5} \times 200$$

$$Q = 7.94 \times 10^{-3}\ m^3/s$$

Collector pipe friction loss was then determined (Calculation 12).

Calculation 12

$$h_{f\,(collector)} = L\left[\frac{10.67 \times Q^{1.85}}{C^{1.85} \times D^{4.87}}\right]$$

Where: $h_{f\,(collector)}$ = collector pipe friction loss (m)

L =pipe length = 35 m

Q = flow rate for subject portion of underdrainage = $7.94\text{x}10^{-3}\,m^3/s$

C = roughness coefficient = 150

D = pipe diameter = 0.225 m

$$h_{f\,(collector)} = 35\left[\frac{10.67 \times (7.94 \times 10^{-3})^{1.85}}{150^{1.85} \times 0.225^{4.87}}\right]$$

$$h_{f\,(collector)} = 0.007m$$

c. Head loss – structural at slotted and collector pipe connection

The fitting loss where the slotted pipe connects to the collector pipe was calculated using Equation 9 (see Section 3.5.1.4). First, flow rate in the pipe upstream of the fitting was calculated based on 20 m^2 of contributing filter media area.

Calculation 13

$$Q = Q_{inf\,max} \times A$$

Where: Q = flow rate in pipe at the fitting (m^3/s)

$Q_{inf\,max}$ = maximum infiltration rate per square meter of filter media = $3.97\text{x}10^{-5}$ m/s

A = contributing filter media area = 20 m^2

$$Q = 3.97 \times 10^{-5} \times 20$$

$$Q = 7.94 \times {}^{-4}\ m^3/s$$

Next, velocity (V) at the fitting was calculated based on the flow in the pipe from Calculation 13 and the area of the pipe ($7.85\text{x}10^{-3}$m^2 for a 100mm diameter pipe).

Calculation 14

$$V = \frac{Q}{A}$$

Where: V = velocity at the fitting (m/s)

Q = flow rate in pipe upstream of the fitting = $7.94\text{x}10^{-4}\,m^3/s$

A = pipe area = $7.85\text{x}10^{-3}\,m^2$

$$V = \frac{7.94 \times 10^{-4}}{7.85 \times 10^{-3}}$$

$$V = 0.1m/s$$

Finally, head loss at the fitting was calculated using Equation 9 (see Section 3.5.1.4). A K value of 1.0 was obtained from a hydraulics text book (based conservatively on approximating the dual 45° elbow connection to the collector pipe as a line to branch flow in a junction).

Calculation 15

$$h_{s\,(slotted)} = K \frac{V^2}{2g}$$

Where: h_s = head loss at the fitting (m)

K = pressure change coefficient = 1.0

V = velocity at the fitting = 0.1 m/s

g = gravity = 9.81m/s²

$$h_{s\,(slotted)} = 1.0 \frac{0.10^2}{2 \times 9.81}$$

$$h_{s\,(slotted)} < 0.001m$$

d. Head loss – structural at lateral inflow points

Head loss along the collector pipe from the lateral slotted pipe inflows was also calculated using Equation 9.

From the collector pipe friction calculation (see Calculation 11), the flow rate at the midpoint is known to be 7.94 x 10-3 m³/s. Therefore, the velocity at this point was determined as shown in Calculation 16. The area of the 225mm diameter collector pipe is 0.040m².

Calculation 16

$$V = \frac{Q}{A}$$

Where: V = velocity at the fitting (m/s)

Q = flow rate in pipe upstream of the fitting = 7.94×10^{-3} m³/s

A = pipe area = 0.040 m²

$$V = \frac{7.94 \times 10^{-3}}{0.040}$$

$$V = 0.199\ m/s$$

Headloss was then determined using Equation 9 (see Section 3.5.1.4).

A K value of 0.2 was obtained from a hydraulics text book (based on energy loss coefficients at branch lines). To estimate the gradually increasing inflows along the collector pipe, the loss from the lateral inflow at the collector pipe midpoint was calculated and multiplied by the number of lateral inflows (21 in total).

Calculation 17

$$h_{s\,(collector)} = K \frac{V^2}{2g} \times \textit{number of connection}$$

Where: h_s = headloss at the fitting (m)

K = pressure change coefficient = 0.2

V = velocity at the fitting = 0.199 m/s

g = gravity = 9.81m/s²

no. of connections = 21

$$h_{s\,(collector)} = 0.2 \frac{0.199^2}{2 \times 9.81} \times 21$$

$$h_{s\,(collector)} = 0.008m$$

e. Head loss – structural at bend in riser

Head loss from the bend (riser) at the end of the collector pipe was also calculated using Equation 9 (see Section 3.5.1.4). Velocity in the pipe was calculated (Calculation 18) based upon the flow in the pipe. At the riser, the entire filter media contributes flow. Therefore flow in the pipe was 0.016m³/s (see Calculation 7). The area of a 225mm pipe is 0.040m².

Calculation 18

$$V = \frac{Q}{A}$$

Where: V = velocity at the bend (m/s)

Q = flow rate in pipe at the bend = 0.016m³/s

A = pipe area = 0.040 m²

$$V = \frac{0.016}{0.040}$$

$$V = 0.4\ m/s$$

Finally, headloss from the bend was calculated using Equation 9 (see Section 3.5.1.4). A K value of 1.0 was obtained from a hydraulics text book (for tee junction).

Calculation 19

$$h_{s\,(riser)} = K \frac{V^2}{2g}$$

Where: h_s = headloss at the bend (m)

K = pressure change coefficient = 1.0

V = velocity at the fitting = 0.4 m/s

g = gravity = 9.81 m/s²

$$h_{s\,(riser)} = 1.0 \frac{0.400^2}{2 \times 9.81}$$

$$h_{s\,(riser)} = 0.008m$$

f. Head loss – total

The individual head loss components (Calculations 10, 12, 15, 17 and 19) were substituted into Equation 10 (see Section 3.5.1.4) to calculate the total head loss (Calculation 20).

Calculation 20

$$H_{total} = h_{f(slotted)} + h_{f(collector)} + \sum h_{s(slotted)} + \sum h_{s(collector)} + \sum h_{s(riser)}$$

$$H_{total} = 0.001 + 0.007 + 0.001 + 0.008 + 0.008$$

$$H_{total} = 0.025\ m$$

The total head loss through the underdrainage at the maximum infiltration rate is therefore 0.025 m which is less than the 0.044 m available. Thus the underdrainage configuration adopted will operate effectively.

5.7.2 Overflow pit

Minor flows (2 year ARI) will overflow from the bioretention via a grated pit. The design intent is to manage the minor flows through the pit only (without engaging the high flow weir). A number of trial pit sizes and weir levels were assessed to determine an appropriate configuration to manage design flows and ponding depths. The pit was also checked against the underdrainage riser configuration to ensure the pipes and junctions could be adequately accommo dated within the pit (225 mm riser tee approximately 0.65m long x 0.45 m high plus allowance for pipe and screw cap connection and access).

The hydraulic calculations for the adopted pit size of 1200 mm by 1800 mm are shown below.

The crest of the pit will be at 5.2 m AHD (i.e. top of extended detention at 300 mm above the filter surface). The water depth above the pit crest during the peak minor flow ($Q = 0.74\ m^3/s$ from Table 27) was tested under weir (see Equation 13) and orifice (see Equation 14) conditions.

Calculation 21 shows the results under weir flow conditions. A blockage factor of 0.5 and a weir coefficient of 1.66 were used in accordance with Section 3.5.2.1. The pit perimeter (6.0 m) was adopted as the length of the weir.

Calculation 21

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

Where: Q_{weir} = flow rate during peak minor flow = $0.74\ m^3/s$

B = blockage factor = 0.5

C_w = weir coefficient = 1.66

L = pit perimeter length = 6.0 m

h = depth of flow over the pit (m)

$$0.74 = 0.5 \times 1.66 \times 6 \times h^{3/2}$$

$$h = 0.28m$$

Calculation 22 shows the results under orifice flow conditions. A blockage factor of 0.5 and an orifice coefficient of 0.6 were used in accordance with Section 3.5.2.1. The pit area was calculated to be $2.16m^2$.

Calculation 22

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

Where: $Q_{orifice}$ = flow rate during peak minor flow = $0.74\ m^3/s$

B = blockage factor = 0.5

C_d = orifice coefficient = 0.6

A = pit area = $2.16\ m^2$

g = gravity = $9.81\ m/s^2$

h = depth of flow over the pit (m)

$$0.74 = 0.5 \times 0.6 \times 2.16 \sqrt{2 \times 9.81 \times h}$$

$$h = 0.07\ m$$

Pit overflow discharge will therefore be controlled by weir flow for the minor design event (i.e. results in lower discharge for a given depth over pit). The maximum water level for the minor flow will therefore be 0.28m above the pit crest (i.e. 5.48 m AHD) which satisfies the design intent of being below the adopted high flow weir level (see Section 5.7.4)

5.7.3 Outlet pipe

The outlet pipe from the pit was sized to convey the minor flow ($0.74\ m^3/s$) based on the pipe flowing full (but not under pressure) using Manning's equation. The site layout and level constraints dictate that the pipe will be approximately 34 m in length at a grade of 1.2% (1 in 80). Based on the pipe flow capacity charts in QUDM (DEWS, 2013), the minimum standard pipe required to convey the minor event is a 675 mm diameter. The actual capacity of this pipe size will be $0.93\ m^3/s$ (based on Manning's equation).

5.7.4 Overflow weir

The overflow weir will manage discharge of major flows entering the bioretention basin. The weir was sized (Calculation 23) to convey the balance of the major flow (see Table 27) above the capacity of the minor pit / pipe overflow (conservatively calculated in Section 5.7.3 to be 0.93 m^3/s).

Calculation 23

$Q_{weir} = Q_{major} - Q_{pit/pipe}$

Where: Q_{weir} = flow conveyed by weir (m^3/s)

Q_{major} = flow in major storm = 1.18 m^3/s

$Q_{pit\,/\,pipe}$ = capacity of overflow pit and/or overflow pipe = 0.93 m^3/s

$Q_{weir} = 1.18 - 0.93$

$Q_{weir} = 0.25\ m^3/s$

The crest of the overflow weir will be at 5.5 m AHD. This is just above the minor design storm water level controlled by the pit (5.48 m AHD from Section 5.7.2). Assuming a flow depth of 100 mm over the weir and the adopted minimum embankment level of 5.8 m AHD, the 200 mm freeboard required by Council will be achieved. The length of weir required to achieve the discharge (Calculation 23) at 100mm flow depth was calculated by rearranging Equation 15 (Calculation 24).

Calculation 24

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

$$L = \frac{Q_{weir}}{C_w \times h^{3/2}}$$

Where: L = weir length (m)

Q_{weir} = flow conveyed by weir = 0.25 m^3/s

C_w = weir coefficient = 1.66

h = flow depth over the weir = 0.1 m

$$L = \frac{0.25}{1.66 \times 0.1^{3/2}}$$

$L = 4.76\ m$

Therefore a 4.8 m weir will be required.

The weir was also checked for the scenario where the overflow pit is completely blocked (Calculation 25) to ensure the weir can adequately convey the entire major storm flow without the bunds being overtopped, thus avoiding potential scour or failure of the bunds. This was done by rearranging the weir equation (Equation 15).

Calculation 25

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

$$h = \left(\frac{Q_{weir}}{C_w \times L}\right)^{2/3}$$

Where: h = flow depth over the weir (m)

Q_{weir} = flow conveyed by weir = 1.18 m^3/s

C_w = weir coefficient = 1.66

L = weir length = 4.8 m

$$h = \left(\frac{1.18}{1.66 \times 4.8}\right)^{2/3}$$

$h = 0.28m$ (i.e 5.78m AHD)

Therefore, under the worst case scenario that the overflow pit is fully blocked, a 4.8 m weir can manage the discharge of the entire major storm entering the bioretention basin while maintaining the water level just below the embankment (5.8 m AHD), avoiding the potential for erosion and scour of embankments from uncontrolled overflow.

DESIGN NOTE: Sizing overflow pits, pipes and weirs

The above design method for pits, pipes and weirs represents a conservative approach to sizing hydraulic structures. Where depth, pipe cover and/or levels are more constrained or where the local authority requirements dictate, a more detailed hydraulic analysis of the outlet structures (considering hydraulic grade line and head losses) may be required to optimise conservative sizing.

5.7.5 Connection to waterway

The bioretention basin outlet pipe will discharge directly to the receiving waterway due to the levels and layout of the retrofitted bioretention basin. In order to minimise the impact of discharges on the waterway and to protect the stormwater infrastructure from erosion:

- the headwall and rock apron will be recessed into the bank (out of the direct flow path in the watercourse) by a minimum of 6.8m (approximately 10 times the outlet pipe diameter) from the toe of bank
- the discharge pipe will be angled downstream in the direction of flow
- a rock apron 4.1 m (minimum) in length with a median (D50) rock size of 200mm (in accordance with QUDM (DEWS, 2013)) will be constructed on the base and sides of the recessed outlet
- the outlet pipe invert will be above the minor (1 month ARI) flowing water level in the creek to allow free drainage.

5.8 Vegetation design

5.8.1 Planting style

As required by Council, the bioretention vegetation design will attempt to replicate the bushland/riparian assemblage which exists adjacent to the creek.

5.8.2 Species diversity

The bioretention system planting will consist of 10 species of groundcover plus shrubs and trees. Ecological assessment of the existing vegetation was completed to inform the species selected.

5.8.3 Species selection

Five groundcover species were selected from the list of core functional bioretention plant species (Table 19).

The riparian community adjacent to the site comprises of regional ecosystem RE 12.3.7 – Fringing Riverine Wetland. The vegetation community is comprised of a Eucalyptus dominated overstory, with a grass and sedge dominated understory interspersed with medium to large shrubs.

A number of tree, shrub and groundcover species with desirable attributes were selected from the adjacent riparian community for use in the bioretention systems filter media and batters (Table 28).

Table 28 Species list for bioretention filter bed and batters

Plant species	Filter Media	Batter	Vegetation Type
Carex appressa *	✓	✓	Groundcover - sedge
Ficinia nodosa *	✓		Groundcover - sedge
Cymbopogon refractus		✓	Groundcover - grass
Dianella caerulea		✓	Groundcover - herb
Gahnia sieberiana	✓	✓	Groundcover- sedge
Imperata cylindrica * #	✓	✓	Groundcover - grass
Lomandra longifolia *	✓	✓	Groundcover - herb
Lomandra hystrix		✓	Groundcover - herb
Poa labillardieri *	✓		Groundcover - grass
Themeda triandra		✓	Groundcover - grass
Callistemon viminalis	✓	✓	Shrub/small tree
Banksia robur	✓	✓	Shrub/small tree
Melaleuca nodosa	✓	✓	Shrub
Eucalyptus tereticornis		✓	Tree
Waterhousia floribunda	✓	✓	Tree

* Denotes core functional bioretention plant species planted in filter media. # Imperata cylindrical exists in the adjacent creek riparian zone

Table 29 Total number of plants required.

Plant species	Density Plants/m²	Filter Media (396 m²)		Batter (500 m²)		Total
		% Cover	Number	% Cover	Number	
Carex appressa *	8	20	634	20	800	1434
Ficinia nodosa *	8	30	950	0		950
Cymbopogon refractus	10	0		10	500	500
Dianella caerulea	8	0		5	200	200
Gahnia sieberiana	6	10	238	5	150	388
Imperata cylindrica *	8	20	634	15	600	1234
Lomandra longifolia *	6	15	356	15	450	806
Lomandra hystrix	6	0		15	450	450
Poa labillardieri *	8	5	158	5	200	358
Themeda triandra	10			10	500	500
Callistemon viminalis	1/25m²		16		20	36
Banksia Robur	1/25m²		16		20	36
Melaleuca nodosa	1/25m²		16		20	36
Eucalyptus tereticornis	1/40m²				12	12
Waterhousia floribunda	1/40m²		10		12	22
	Total		**3028**		**3934**	**6962**

* Denotes core functional bioretention plant species planted in filter media.

5.8.4 Planting density

A range of groundcover planting densities were selected to facilitate the rapid establishment of vegetation cover on both the filter bed and batters (Table 29). The variation in planting densities between individual plant species reflects differences in growth rate, plant form and height.

Planting densities for shrubs and trees was guided by plant densities outlined in Table 29 and the structural composition of the adjacent riparian community.

5.8.5 Planting set-out

The total number of plants required was calculated from the percentage cover (per plant species); the overall planting area and planting densities (see Table 29). The planting zones for the filter bed and batters are shown on Drawing WSUD-P06.The planting set-out for individual shrub and tree species is detailed on the planting layout as the locations of these plants are integral to the final appearance and function of the bioretention vegetation.

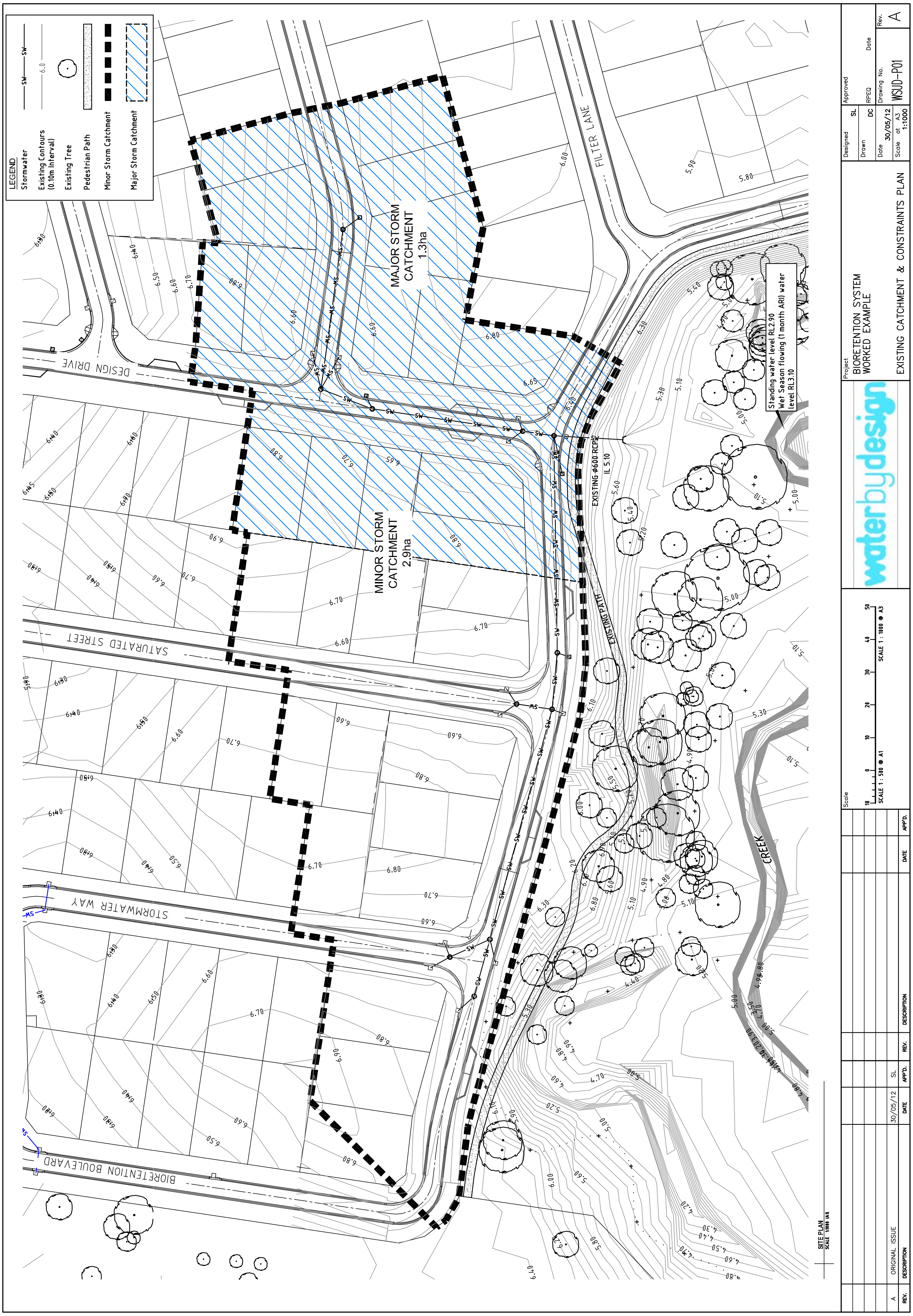
5.8.6 Mulch

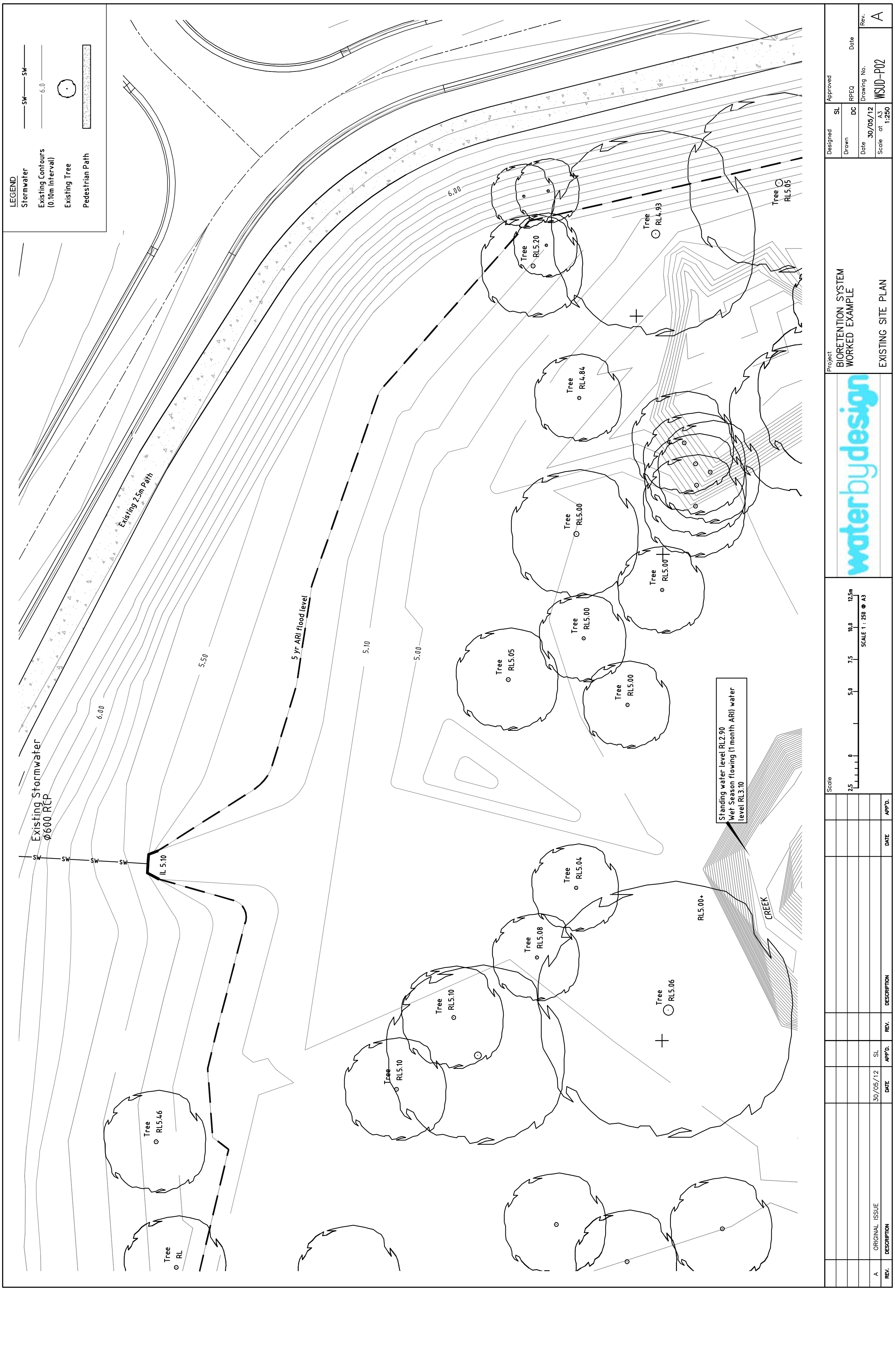
Sugar cane mulch will be applied to the bioretention filter media surface and 1.0m up the batters. The mulch will be pinned down with open weave jute net.

Locally sourced mulch with no fines, weeds or soil will be used on the upper batters and embankments.

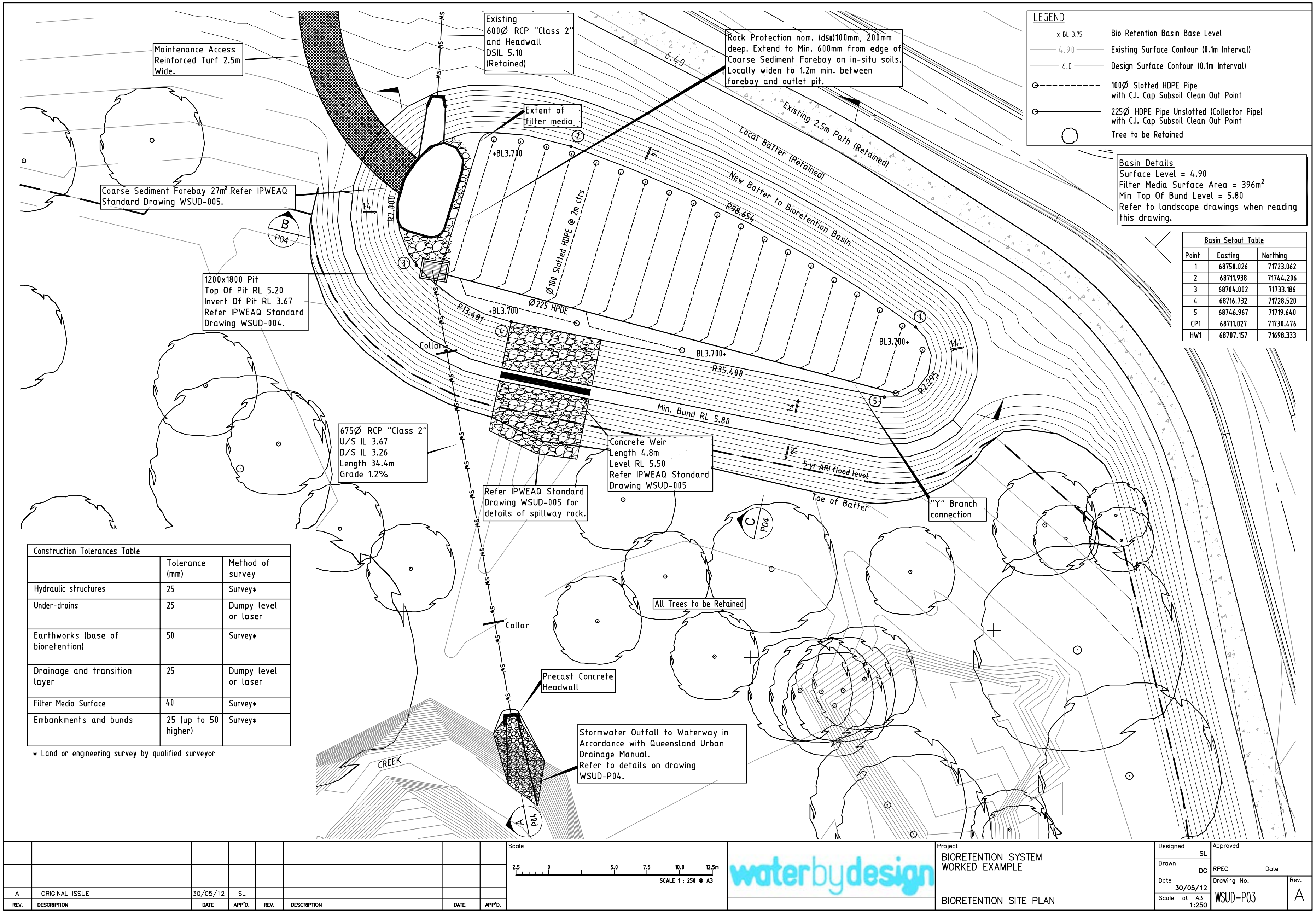
5.9 Detailed design documentation

Refer to Drawings WSUD-P01 to WSUD-P07 for detailed civil and landscape design drawings.


LEGEND
Stormwater
Existing Contours (0.10m Interval)
Existing Tree
Pedestrian Path
Minor Storm Catchment
Major Storm Catchment
MAJOR STORM CATCHMENT 1.3ha
MINOR STORM CATCHMENT 2.9ha
FILTER LANE
DESIGN DRIVE
SATURATED STREET
STORMWATER WAY
BIORETENTION BOULEVARD
EXISTING Ø600 RCP
IL 5.10
EXISTING PATH
CREEK
Standing water level RL2.90
Wet Season flowing (1 month ARI) water level RL3.10
SITE PLAN
SCALE 1:1000 (A3)
SCALE 1 : 500 @ A1
SCALE 1 : 1000 @ A3
Project
BIORETENTION SYSTEM WORKED EXAMPLE
EXISTING CATCHMENT & CONSTRAINTS PLAN
Designed SL
Drawn DC
Approved RPEQ
Date 30/05/12
Scale at A3 1:1000
Drawing No. WSUD-P01
Rev. A
A ORIGINAL ISSUE 30/05/12 SL
REV. DESCRIPTION DATE APP'D.



LEGEND
Stormwater
Existing Contours (0.10m Interval)
Existing Tree
Pedestrian Path
Existing 2.5m Path
Existing Stormwater Ø600 RCP
IL 5.10
5 yr ARI flood level
6.00
5.50
5.10
5.00
Tree RL5.20
Tree RL4.93
Tree RL5.05
Tree RL4.84
Tree RL5.00
Tree RL5.05
Tree RL5.46
Tree RL5.10
Tree RL5.08
Tree RL5.04
Tree RL5.06
Tree RL
RL5.00+
CREEK
Standing water level RL2.90
Wet Season flowing (1 month ARI) water level RL3.10
Scale
SCALE 1 : 250 @ A3
Project
BIORETENTION SYSTEM WORKED EXAMPLE
EXISTING SITE PLAN
Designed SL
Drawn DC
Date 30/05/12
Scale at A3 1:250
Approved
RPEQ
Date
Drawing No.
WSUD-P02
Rev.
A
A ORIGINAL ISSUE 30/05/12 SL
REV. DESCRIPTION DATE APP'D.



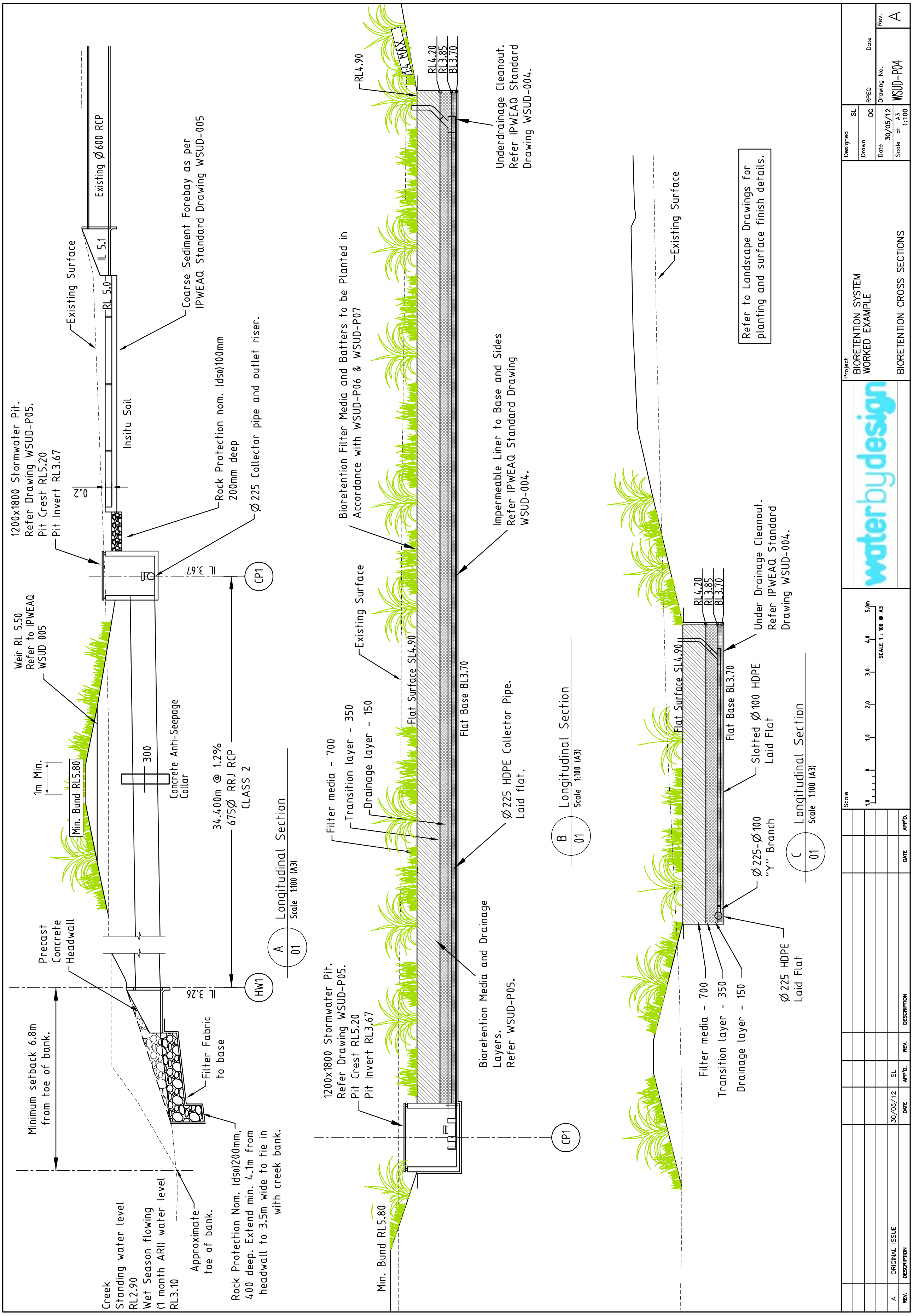
Basin Setout Table

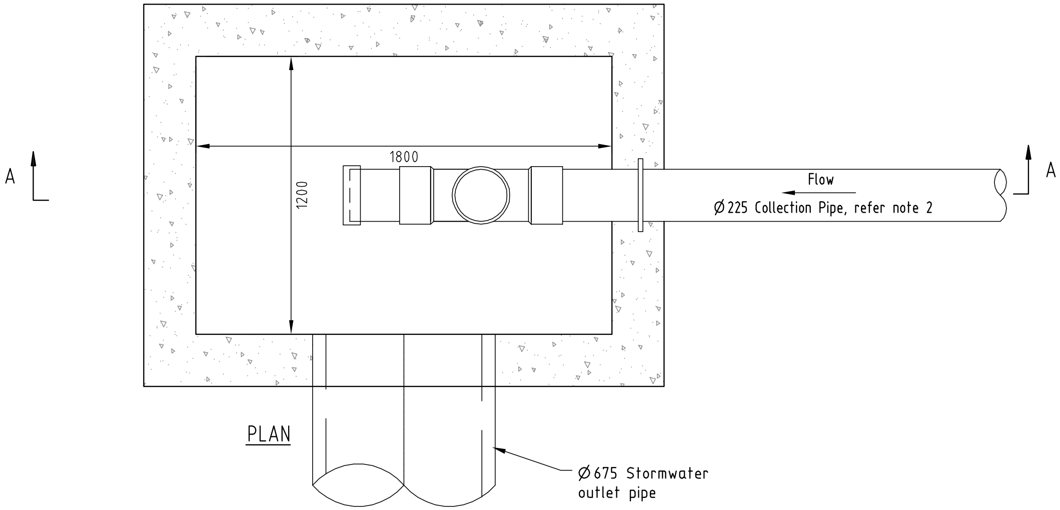
Point	Easting	Northing
1	68750.026	71723.062
2	68711.938	71744.206
3	68704.002	71733.186
4	68716.732	71728.520
5	68746.967	71719.640
CP1	68711.027	71730.476
HW1	68707.157	71698.333

Construction Tolerances Table

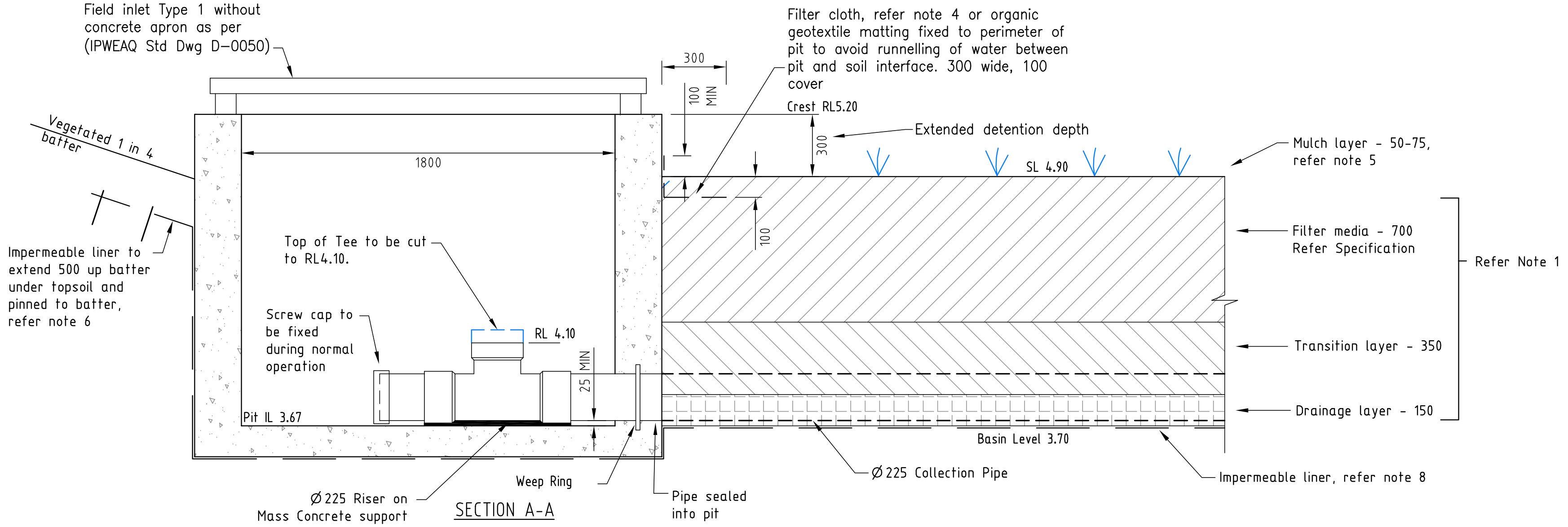
	Tolerance (mm)	Method of survey
Hydraulic structures	25	Survey*
Under-drains	25	Dumpy level or laser
Earthworks (base of bioretention)	50	Survey*
Drainage and transition layer	25	Dumpy level or laser
Filter Media Surface	40	Survey*
Embankments and bunds	25 (up to 50 higher)	Survey*

* Land or engineering survey by qualified surveyor


Creek
Standing water level
RL2.90
Wet Season flowing
(1 month ARI) water level
RL3.10
Approximate
toe of bank.
Rock Protection Nom. (d50)200mm,
400 deep. Extend min. 4.1m from
headwall to 3.5m wide to tie in
with creek bank.
Minimum setback 6.8m
from toe of bank.
Filter Fabric
to base
Precast
Concrete
Headwall
IL 3.26
HW1
Min. Bund RL5.80
1m Min.
Weir RL 5.50
Refer to IPWEAQ
WSUD 005
300
Concrete Anti-Seepage
Collar
34,400m @ 1.2%
675Ø RRJ RCP
CLASS 2
IL 3.67
CP1
1200x1800 Stormwater Pit.
Refer Drawing WSUD-P05.
Pit Crest RL5.20
Pit Invert RL3.67
0.2
Rock Protection nom. (d50)100mm
200mm deep
Ø225 Collector pipe and outlet riser.
Insitu Soil
Existing Surface
Coarse Sediment Forebay as per
IPWEAQ Standard Drawing WSUD-005
RL 5.0
IL 5.1
Existing Ø600 RCP
A
01
Longitudinal Section
Scale 1:100 (A3)
Min. Bund RL5.80
1200x1800 Stormwater Pit.
Refer Drawing WSUD-P05.
Pit Crest RL5.20
Pit Invert RL3.67
Bioretention Media and Drainage
Layers.
Refer WSUD-P05.
Filter media - 700
Transition layer - 350
Drainage layer - 150
Flat Surface SL4.90
Flat Base BL3.70
Existing Surface
Ø225 HDPE Collector Pipe.
Laid flat.
Bioretention Filter Media and Batters to be Planted in
Accordance with WSUD-P06 & WSUD-P07
Impermeable Liner to Base and Sides
Refer IPWEAQ Standard Drawing
WSUD-004.
RL4.90
1:4 MAX
RL4.20
RL3.85
BL3.70
Underdrainage Cleanout.
Refer IPWEAQ Standard
Drawing WSUD-004.
B
01
Longitudinal Section
Scale 1:100 (A3)
Filter media - 700
Transition layer - 350
Drainage layer - 150
Ø225 HDPE
Laid Flat
Ø225-Ø100
"Y" Branch
Slotted Ø100 HDPE
Laid Flat
Flat Surface SL4.90
Flat Base BL3.70
RL4.20
RL3.85
BL3.70
Under Drainage Cleanout.
Refer IPWEAQ Standard
Drawing WSUD-004.
C
01
Longitudinal Section
Scale 1:100 (A3)
Existing Surface
Refer to Landscape Drawings for
planting and surface finish details.
A ORIGINAL ISSUE 30/05/12 SL
REV. DESCRIPTION APP'D. DATE
Scale
SCALE 1 : 100 @ A3
waterbydesign
Project
BIORETENTION SYSTEM
WORKED EXAMPLE
BIORETENTION CROSS SECTIONS
Designed SL
Drawn DC
RPEQ
Date 30/05/12
Scale at A3 1:100
Drawing No. WSUD-P04
Rev. A



PLAN



SECTION A-A

NOTES:

1. Bioretention media specification, refer note 1 IPWEAQ WSUD-001
2. Underdrain, refer note 2 IPWEAQ WSUD-001.
3. Vegetated batter slopes, refer note 3 IPWEAQ WSUD-001.
4. Filter cloth, refer note 4 IPWEAQ WSUD-001,
5. Basin finished surface level, refer note 5 IPWEAQ WSUD-001.
6. Construction tolerances, refer note 6 IPWEAQ WSUD-001.
7. Landscape, refer note 7 IPWEAQ WSUD-001.
8. Impermeable Liner, bentonite or approved equivalent to base and sides, installed as per manufacturer's specification. Refer to the Bioretention Technical Design Guidelines (Water by Design) for details.
9. All dimensions are in millimetres unless otherwise noted.

REV.	DESCRIPTION	DATE	APP'D.	REV.	DESCRIPTION	DATE	APP'D.
A	ORIGINAL ISSUE	30/05/12	SL				

0.2 0 0.4 0.6 0.8 1.0m
SCALE 1 : 20 @ A3

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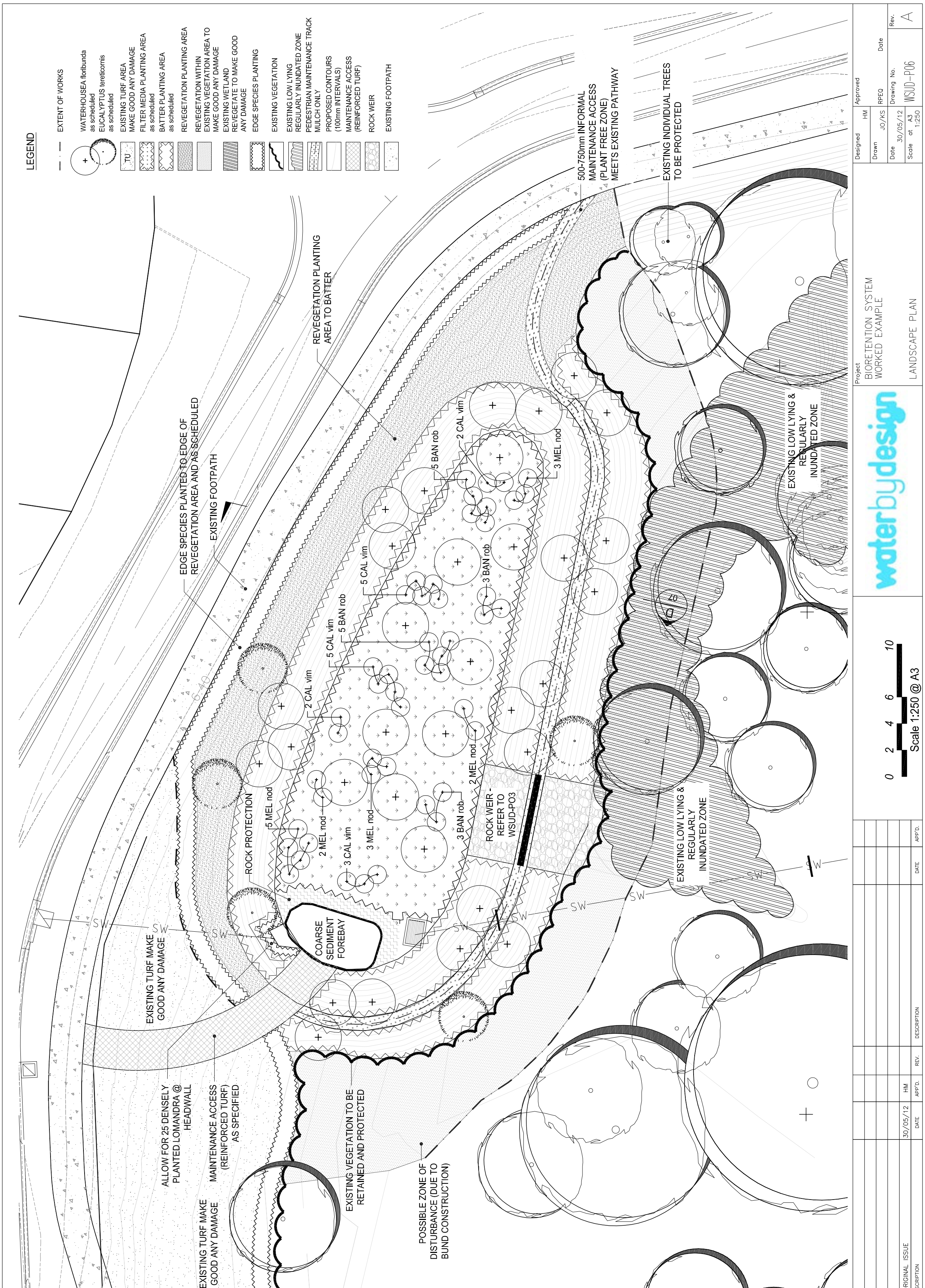
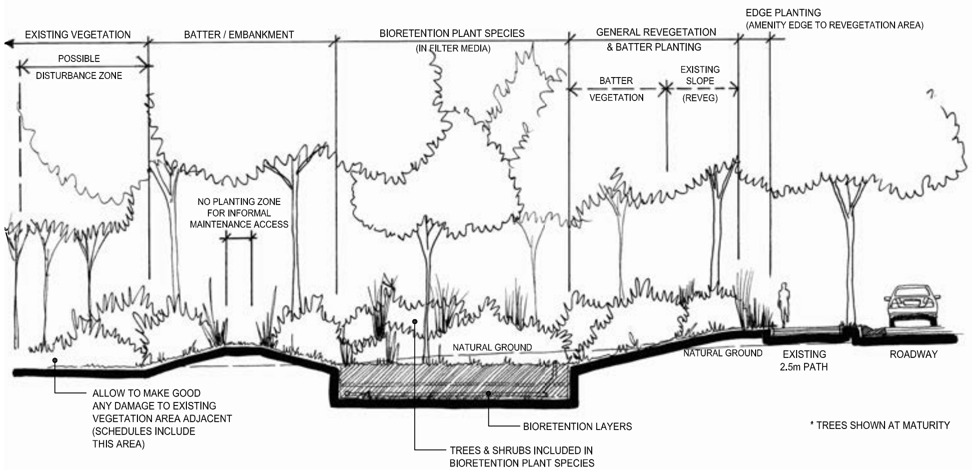
Project: BIORETENTION SYSTEM WORKED EXAMPLE

BIORETENTION OUTLET PIT (AMENDED FROM IPWEAQ WSUD-002)

Designed: SL | Drawn: ST | Date: 30/05/12 | Scale at A3: 1:20 | Approved: RPEQ | Date: | Drawing No.: WSUD-P05 | Rev.: A


LEGEND
EXTENT OF WORKS
WATERHOUSEA floribunda as scheduled
EUCALYPTUS tereticornis as scheduled
EXISTING TURF AREA MAKE GOOD ANY DAMAGE
FILTER MEDIA PLANTING AREA as scheduled
BATTER PLANTING AREA as scheduled
REVEGETATION PLANTING AREA
REVEGETATION WITHIN EXISTING VEGETATION AREA TO MAKE GOOD ANY DAMAGE
EXISTING WETLAND REVEGETATE TO MAKE GOOD ANY DAMAGE
EDGE SPECIES PLANTING
EXISTING VEGETATION
EXISTING LOW LYING REGULARLY INUNDATED ZONE
PEDESTRIAN MAINTENANCE TRACK MULCH ONLY
PROPOSED CONTOURS (100mm INTERVALS)
MAINTENANCE ACCESS (REINFORCED TURF)
ROCK WEIR
EXISTING FOOTPATH
500-750mm INFORMAL MAINTENANCE ACCESS (PLANT FREE ZONE) MEETS EXISTING PATHWAY
EXISTING INDIVIDUAL TREES TO BE PROTECTED
REVEGETATION PLANTING AREA TO BATTER
EDGE SPECIES PLANTED TO EDGE OF REVEGETATION AREA AND AS SCHEDULED
EXISTING FOOTPATH
EXISTING LOW LYING & REGULARLY INUNDATED ZONE
2 CAL vim
5 BAN rob
3 MEL nod
5 CAL vim
3 BAN rob
5 BAN rob
5 CAL vim
2 CAL vim
2 MEL nod
ROCK PROTECTION
5 MEL nod
2 MEL nod
3 CAL vim
3 MEL nod
3 BAN rob
ROCK WEIR - REFER TO WSUD-PO3
COARSE SEDIMENT FOREBAY
SW
EXISTING LOW LYING & REGULARLY INUNDATED ZONE
EXISTING TURF MAKE GOOD ANY DAMAGE
ALLOW FOR 25 DENSELY PLANTED LOMANDRA @ HEADWALL
MAINTENANCE ACCESS (REINFORCED TURF) AS SPECIFIED
EXISTING TURF MAKE GOOD ANY DAMAGE
EXISTING VEGETATION TO BE RETAINED AND PROTECTED
POSSIBLE ZONE OF DISTURBANCE (DUE TO BUND CONSTRUCTION)
0 2 4 6 10
Scale 1:250 @ A3
A ORIGINAL ISSUE 30/05/12 HM
REV. DESCRIPTION DATE APP'D. REV. DESCRIPTION DATE APP'D.
waterbydesign
Project
BIORETENTION SYSTEM WORKED EXAMPLE
LANDSCAPE PLAN
Designed HM
Drawn JO/KS
Date 30/05/12
Scale at A3 1:250
Approved RPEQ Date
Drawing No. WSUD-P06
Rev. A



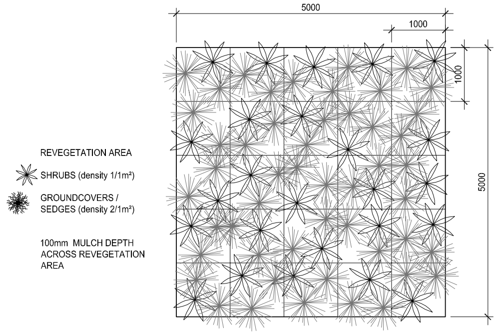
LD01 07 **SECTION D**
SCALE 1:200

REVEGETATION AREA AND EDGE PLANT SCHEDULE

Plant species	Density Plants/m²	No.
Edge Planting (125sqm)		
Carex appressa	3	190
Lomandra longifolia	2	125
Revegetation Planting (240sqm)		
Carex appressa	3	72
*Cymbopogon refractus**	2	48
Dianella caerulea	3	72
*Gahnia aspera**	2	48
*Gahnia seiberiana**	2	48
*Imperata cylindrica**	1	24
Lomandra longifolia	2	48
*Lomandra hystrix**	2	48
Poa labillardierei	2	48
Themeda triandra	3	72
*Callistemon salignus**	1	120
*Callistemon viminalis**	1	120
*Melaleuca linariifolia**	0.5 (1/2sqm)	120
*Melaleuca nodosa**	0.2 (1/5sqm)	120
Syzygium australe	0.1(1/10sqm)	24
Alphitonia excelsa	0.05 (1/20sqm)	12
*Eucalyptus tereticornis**	0.05 (1/20sqm)	12
Glochidium ferdinandi	0.05 (1/20sqm)	12
*Waterhousia floribunda**	0.05 (1/20sqm)	12

Use all of the the above species when making good any damage to existing vegetation areas.

**** use these species in low lying swamp area.***



LD02 07 **REVEGETATION MODULE**
SCALE 1:50

BIORETENTION BASIN AND BATTERS PLANT SCHEDULE

Plant species	Density Plants/m²	Filter Media (396 m2) %Cover	Filter Media (396 m2) Number	Batter (500 m²) %Cover	Batter (500 m²) Number	Total
Carex appressa *	8	20%	634	20%	800	1434
Ficinia nodosa *	8	30%	950			950
Cymbopogon refractus	10			10%	500	500
Dianella caerulea	8			5%	200	200
Gahnia seiberiana *	6	10%	238	5%	150	388
Imperata cylindrica *	8	20%	634	15%	600	1234
Lomandra longifolia	6	15%	356	15%	450	806
Lomandra hystrix	6			15%	450	450
Poa labillardierei *	8	5%	158	5%	200	358
Themeda triandra	10			10%	500	500
*Callistemon viminalis***	1/25m²		16		20	36
*Banksia robur***	1/25m²		16		20	36
*Melaleuca nodosa***	1/25m²		16		20	36
*Eucalyptus tereticornis***	1/40m²				12	12
*Waterhousia floribunda***	1/40m²		10		12	22
	Total		3028		3934	6962

* Denotes core functional bioretention plant species.

** Average densities only. Plant layout in accordance with planting plan.

REV.	DESCRIPTION	DATE	APP'D.	REV.	DESCRIPTION	DATE	APP'D.
A	ORIGINAL ISSUE	30/05/12	HM				

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Project: BIORETENTION SYSTEM WORKED EXAMPLE

BIORETENTION CROSS SECTION AND PLANT SCHEDULES

Designed: HM | Approved: RPEQ | Date
Drawn: JO/KS
Date: 30/05/12 | Drawing No.: WSUD-P07 | Rev.: A
Scale at A3: 1:200

5.10 Design check and summary

The key design parameters for the bioretention system are shown in Table 30.

Table 30 Worked example design check and summary

Item	Description	Detail	Recommendation
1. Treatment			
(a)	Catchment area	2.9 ha	
(b)	Filter media area (excluding batters)	396 m^2	Single or multiple cells < 800 m^2 each
(c)	Confirm water quality performance meets the design objectives	Yes	
(d)	Confirm hydrologic performance meets relevant frequent flow objectives	Yes	
2. Design inflows			
(a)	Minor design storm entering system	2 ARI	
(b)	Minor storm peak flow rate	0.74 m^3/s	
(c)	Major design storm entering system	50 ARI	
(d)	Major storm peak flow rate	1.18 m^3/s	
3. Depth profile			
(a)	Bioretention drainage profile type	Type 1	
(b)	Minimum drainage layer depth	150 mm	See Section 3.2.2.3 and 3.2.2.4 for "Type 1" ≥ 150 mm for "Type 2" ≥ 300 mm for "Type 3" Not needed for "Type 4"
(c)	Maximum drainage layer depth	150 mm	Same as minimum except for "Type 2"
(d)	Transition layer depth	350 mm	See Section 3.2.2.4 for "Type 1" ≥ 100 mm for "Type 2", "Type 3" and "Type 4"
(e)	Saturated zone depth for Type 1 bioretention systems	400 mm	See Section 3.2.2.4
(f)	Filter media layer depth	700 mm	≥ 400 mm (≥ 700 mm with trees)
(g)	Extended detention depth	300 mm	≤ 300 mm
(h)	Maximum water level depth above extended detention for major storm event	400 mm	
(i)	Freeboard to top of embankment	200 mm	Multiple, see Section 3.2.3.6
(j)	Total system profile depth [3(c)+3(d)+3(f)+3(g)+3(h)+3(i)]	2100 mm	= 4(j)
(k)	Liner type (i) Permeable (ii) Impermeable (iii) None to base	Impermeable	Subject to drainage profile type and in-situ soils/groundwater (see Section 3.2.4)
(l)	AASS/PASS assessed and appropriately managed	N/A	
(m)	Presence of dispersive soils assessed and appropriately managed	N/A	

Item	Description	Detail	Recommendation
4. Design levels			
(a)	Outlet invert level	3.20 m AHD	
(b)	Overflow pit invert level	3.67 m AHD	
(c)	Minimum drainage layer level	3.70 m AHD	
(d)	Filter media surface level	4.90 m AHD	
(e)	Overflow pit crest level	5.20 m AHD	
(f)	Overflow weir level	5.50 m AHD	
(g)	Maximum design water level	5.60 m AHD	
(h)	Top of embankment/batter level	5.80 m AHD	
(i)	Inlet/inflow invert level	5.10 m AHD	
(j)	Total level difference [4(h)-4(c)]	2.10 m	= 3(j)
(k)	Highest astronomical tide level	Non-tidal m AHD	"Type 1" – impermeable liner extends ≥ 300 mm above HAT "Type 2", "Type 3" and "Type 4" – base of transition layer ≥ 300 mm above HAT
(l)	Groundwater level	N/A m AHD	Varies with drainage profile type, see Table 7
5. Layout			
(a)	Maximum filter media length	35 m	≤ 40 m
(b)	Maximum filter media width	15 m	≤ 20 m (preferred ≤ 15 m)
(c)	Maximum batter slope	1:4 V: H	
(d)	Maximum wall height (where applicable)	N/A m	
(e)	Provision for services (water, sewer, gas, telecommunications, stormwater)	N/A	
(f)	Maintenance access provided	Yes	
(g)	Flood storage volume above extended detention (where bioretention combined with flood storage)	N/A m^3	
6. Inlet design			
(a)	Inlet/inflow type (i) pipe (ii) channel (iii) sheet flow (iv) other	Pipe	
(b)	Diversion/surcharge type (where applicable)	N/A	
(c)	Coarse sediment removal (i) forebay (ii) inlet pond (iii) swale (iv) other	Forebay	
(d)	Coarse sediment removal area	27 m^2	
(e)	Coarse sediment removal depth	0.2 m	
(f)	Coarse sediment clean-out frequency	0.5 /year	< once per year
(g)	Flow distribution type	N/A	Required if filter media area > 400 m^2

Item	Description	Detail	Recommendation
(h)	Confirm scour protection at inflow locations	Yes	
(i)	Minor storm flow velocity over filter	0.46 m/s	< 1.0 m/s
(j)	Major storm flow velocity over filter	0.45 m/s	< 1.0 m/s
7. Underdrainage (outlet design)			
(a)	Filter media saturated hydraulic conductivity	100 mm/hr	100 – 300 mm/hr
(b)	Maximum filter infiltration capacity	0.016 m^3/s	
(c)	Underdrain capacity (taking into account blockage factors)	>0.016 m^3/s	> 7 (b)
8. Overflow design (outlet design)			
(a)	Overflow pit type	Field inlet	
(b)	Overflow pit dimensions	1200 x 1800mm	
(c)	Overflow weir length	4.8 m	
(d)	Overflow pit capacity (taking into account blockage factors)	0.74 (at 5.48 m AHD) m^3/s	> 2 (b)
(e)	Overflow pit plus overflow weir capacity (taking into account blockage factors)	1.30 (at 5.57 m AHD) m^3/s	> 2 (d)
(f)	Outlet pipe size	675 Ø mm	
(g)	Appropriate outlet scour protection provided	Yes	
9. Vegetation design			
(a)	Planting style (i) small scale urban (ii) med–large scale urban (iii) bushland	Bushland	
(b)	Trees and shrubs to be included (yes/no)	Yes	
(c)	Species diversity (number of species)	15	Refer Table 18
(d)	Species selection	refer to plan: WSUD-P08	≥ 50% coverage with plants from Table 19
(e)	Planting density	6-10 /m^2	May vary between plant species, refer to plan if required
(f)	Mulch type and depth	Sugar cane mulch min. 75 mm	See Section 3.6.7 and Section 4.4.4

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