Chapter 6 **Bioretention basins**

Bioretention basin in Richmond, Victoria.

6.1 Introduction

Bioretention basins use ponding above a bioretention surface to maximise the volume of runoff treated through the **filtration media**. Their operation for treatment is in the same way as for **bioretention swales**, but typically they convey above design flows through overflow pits or bypass paths, and are not required to convey flood flows over the filtration surface. This has the advantage for the bioretention basins of not being subjected to high velocities that can dislodge collected pollutants or scour vegetation.

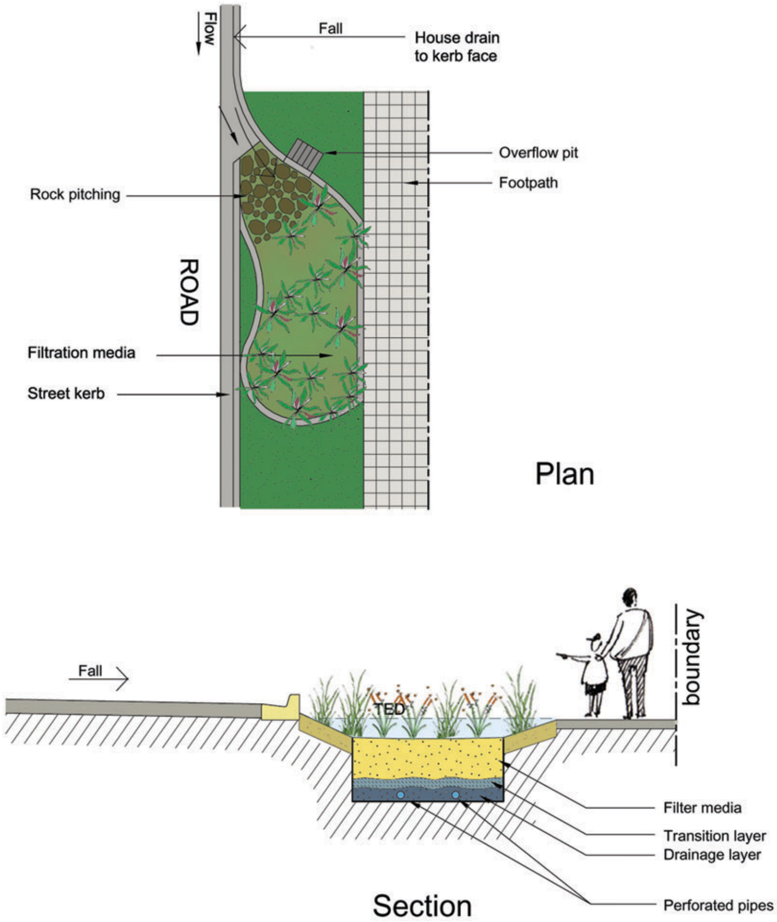
Bioretention basins can be installed at various scales, for example, in planter boxes, in retarding basins or in streetscapes integrated with traffic calming measures. In larger applications, it is considered good practice to have pretreatment measures upstream of the basin to reduce the maintenance frequency of the bioretention basin. For small systems this is not required.

Bioretention basins operate by passing runoff through prescribed filtration media, commonly planted with vegetation that provides treatment through fine filtration, **extended detention** and some **biological uptake**. They also provide flow retardation and are particularly efficient at removing nutrients.

Figure 6.1 shows an example of a basin integrated into a local streetscape and a car park.

They can be designed to either encourage infiltration (where reducing volumes of **stormwater** runoff is important) or as conveyance systems that do not allow infiltration (where soils are not suitable for infiltration or are close to surrounding structures).

a



b

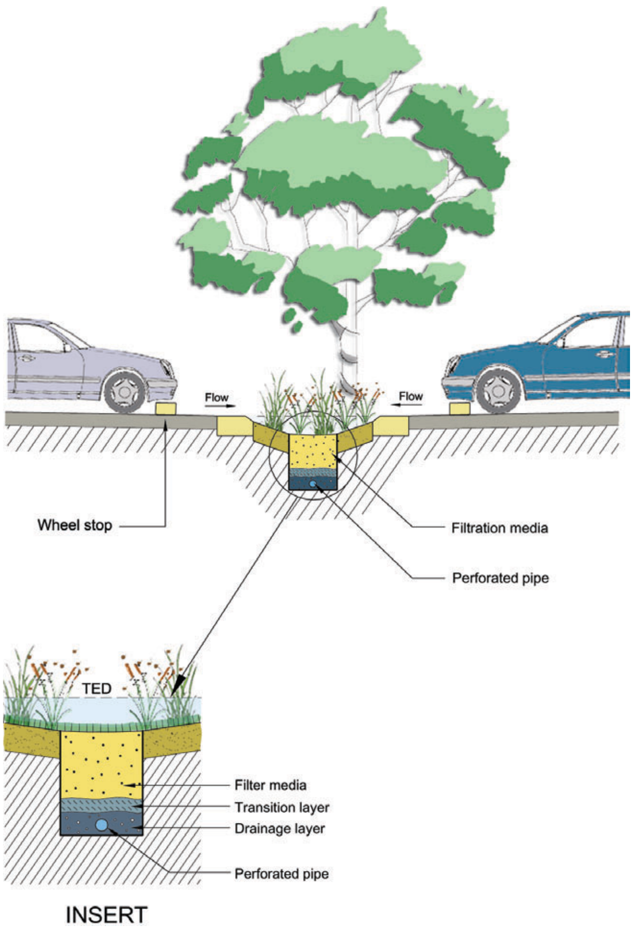


Figure 6.1 Bioretention basin integrated into: (a) a local streetscape and (b) a car park.

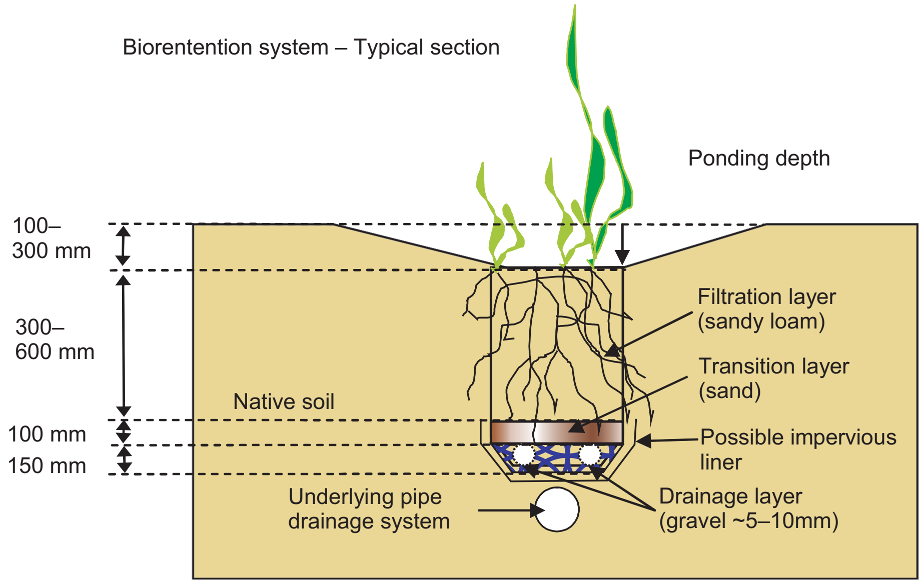


Figure 6.2 Section of a typical bioretention basin.

Where bioretention systems are not intended to be infiltration systems, the dominant pathway for water is not via **discharge** into groundwater. Rather, they convey collected water to downstream waters (or collection systems for reuse) with any loss in runoff mainly attributed to maintaining soil moisture of the filter media itself (which is also the growing media for the vegetation).

Where bioretention systems perform a pretreatment for infiltration, they are designed to facilitate infiltration by removing the collection system at the base of the filtration media allowing contact with surrounding soils.

Vegetation that grows in the filter media enhances its function by preventing erosion of the filter medium, continuously breaking up the soil through plant growth to prevent clogging of the system and providing **biofilms** on plant roots that pollutants can adsorb to. The type of vegetation varies depending on landscaping requirements. Generally the denser and higher the vegetation the better the filtration process. Vegetation is critical to maintaining porosity of the filtration layer.

Selection of an appropriate filtration media is a key issue that involves a trade-off between providing sufficient hydraulic conductivity (i.e. passing water through the filtration media as quickly as possible) and providing sufficient water retention to support vegetation growth (i.e. retaining sufficient moisture by having low hydraulic conductivities). Typically a sandy loam type material is suitable; however, the soils can be tailored to a vegetation type.

A drainage layer is required. This material surrounds the perforated underdrainage pipes and can be either coarse sand (1 mm) or fine gravel (2–5 mm). Should fine gravel be used, it is advisable to install a **transition layer** of sand or a geotextile fabric to prevent any filtration media being washed into the perforated pipes.

The design process for a bioretention basin is slightly different to bioretention **swales**, as they do not need to be capable of conveying large floods (e.g. five-year ARI flows) over their surface and an alternative route for flood flows is required.

Key design issues to be considered are:

1. verifying size and configuration for treatment
2. determining design capacity and treatment flows
3. specifying details of the filtration media
4. checking above-ground design:
   - velocities
   - design of **inlet zone** and overflow pits
   - above design flow operation
5. checking below-ground design:

- soil media layer characteristics (filter, transition and drainage layers)
- underdrain design and capacity
- requirement for bioretention lining

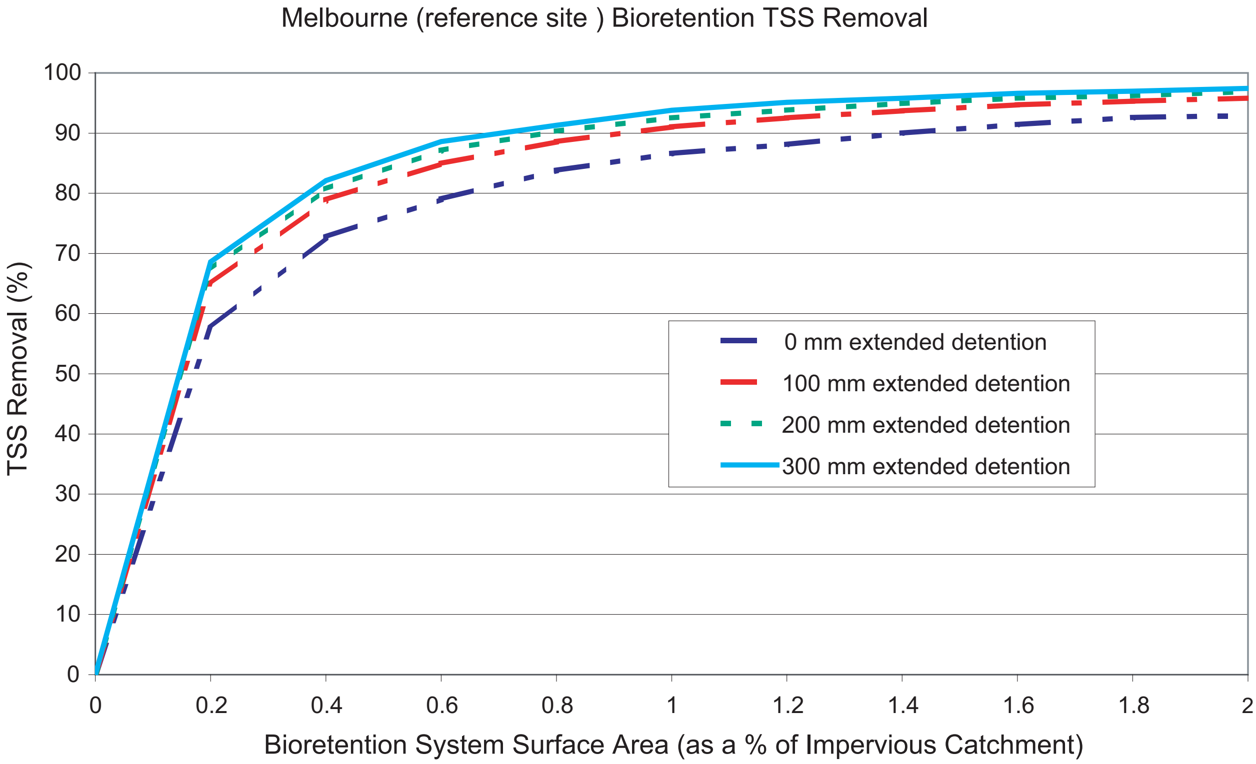


Figure 6.3 Performance of a bioretention system in removing Total Soluble Solids (TSS) in Melbourne.

6. recommending plant species and planting densities
7. providing maintenance.

6.2 Verifying size for treatment

The curves below (Figures 6.3–6.5) show the pollutant removal performance expected for bioretention basins with varying depths of ponding. The curves are based on the performance of the system in Melbourne and were derived using the Model for Urban Stormwater Improvement Conceptualisation (**MUSIC**) (Cooperative Research Centre for Catchment Hydrology 2003). To estimate an equivalent performance at other locations in Victoria, the hydrologic design region relationships should be used to convert the treatment area into an equivalent treatment area in Melbourne (reference site) (see Chapter 2). In preference to using the curves, local data should be used to model the specific treatment performance of the system.

The curves were derived assuming the systems receive direct runoff (i.e. no pretreatment) and have the following characteristics:

- hydraulic conductivity of 180 mm/hr
- filtration media depth of 600 mm
- particle size of 0.45 mm.

These curves can be used to check the expected performance of the bioretention system for removal of Total Soluble Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN).

6.3 Design procedure: bioretention basins

The following sections describe the design steps required for bioretention basins.

6.3.1 Estimating design flows

Three design flows are required for bioretention basins:

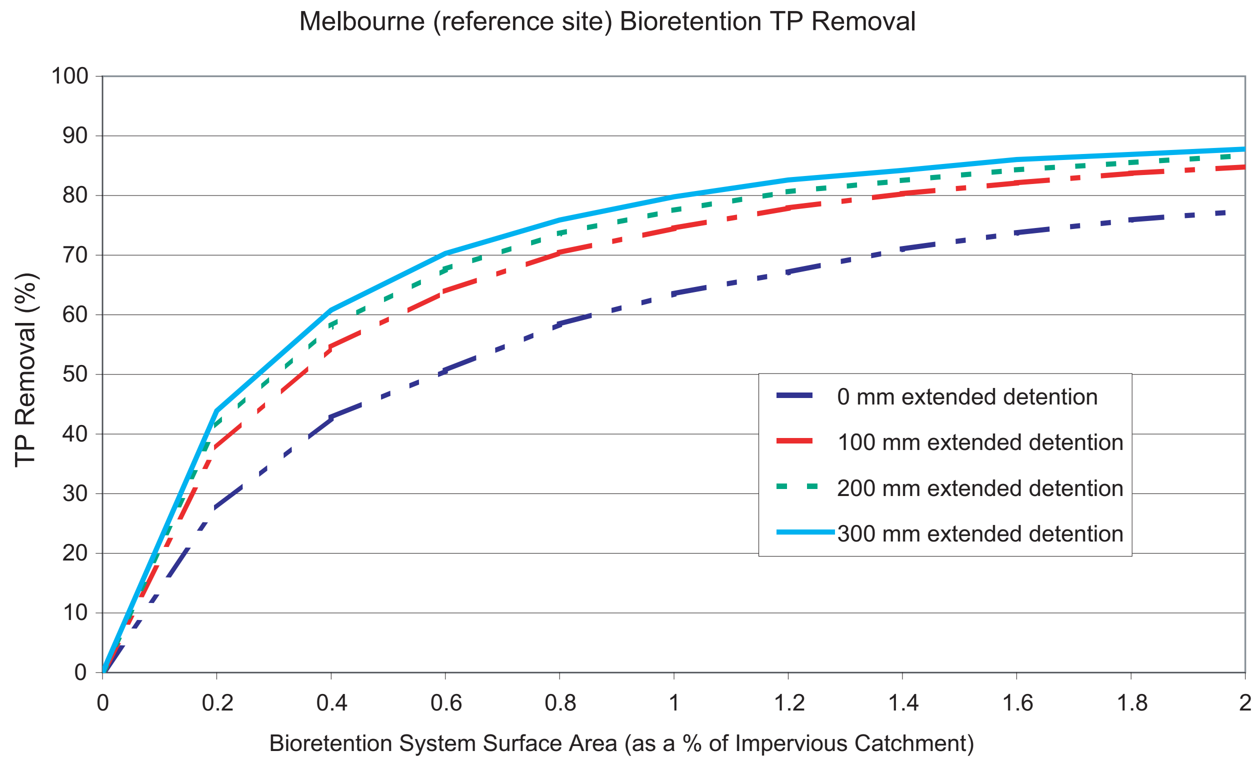


Figure 6.4 Performance of a bioretention system in removing Total Phosphorus (TP) in Melbourne.

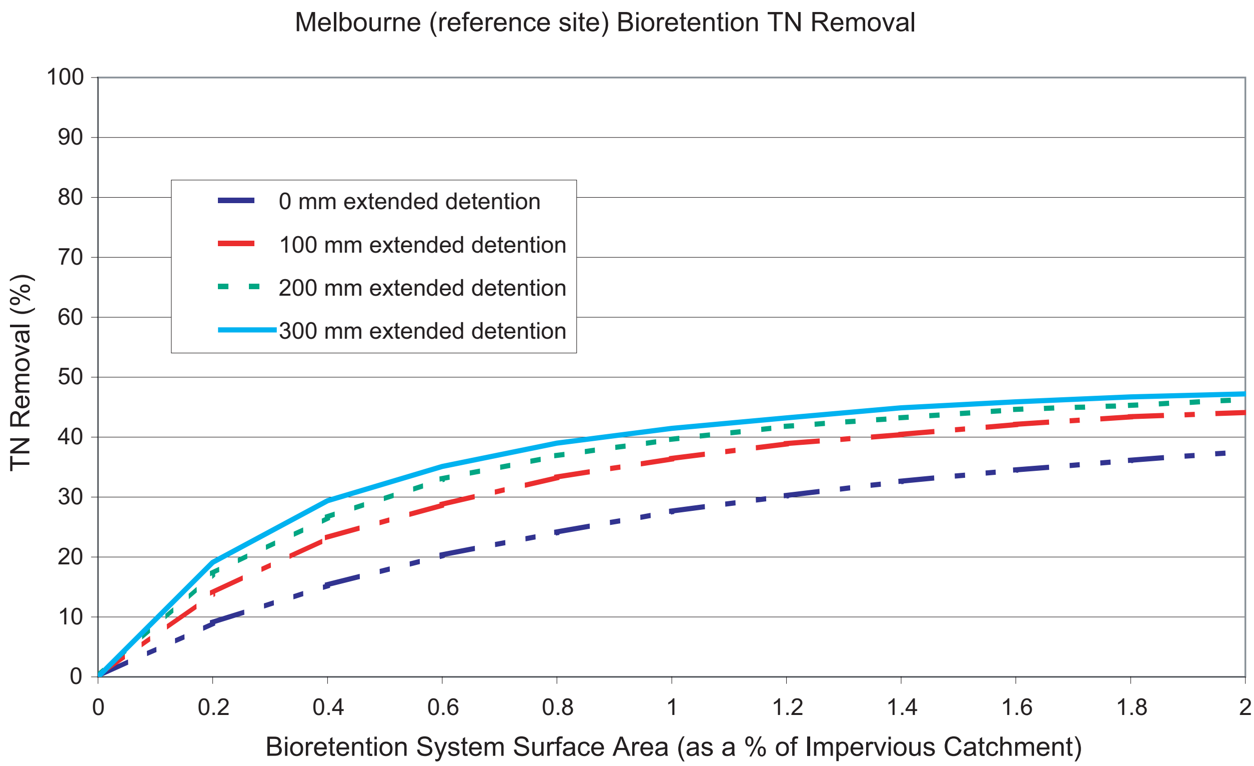


Figure 6.5 Performance of a bioretention system in removing Total Nitrogen (TN) removal in Melbourne.

- minor flood rates (typically five-year ARI) to size the overflows to allow minor floods to be safely conveyed and not increase any flooding risk compared to conventional stormwater systems
- major flood rates (typically 100-year ARI) to check that flow velocities are not too large in the bioretention system, which could potentially scour pollutants or damage vegetation
- maximum infiltration rate through the filtration media to allow for the underdrainage to be sized, such that the underdrains will allow the filter media to freely drain.

6.3.1.1 Minor and major flood estimation

A range of hydrologic methods can be applied to estimate design flows. With typical **catchment** areas being relatively small, the **Rational Method** Design Procedure is considered to be a suitable method for estimating design flows.

6.3.1.2 Maximum infiltration rate

The maximum infiltration rate represents the design flow for the underdrainage system (i.e. the slotted pipes at the base of the filter media). The capacity of the underdrains needs to be greater than the maximum infiltration rate to ensure the filter media drains freely and does not become a 'choke' in the system.

A maximum infiltration rate (Q_{max}) can be estimated by applying Darcy's equation (Equation 6.1):

$$Q_{max} = k \times L \times W_{base} \frac{h_{max} + d}{d} \qquad \text{(Equation 6.1)}$$

where k is the hydraulic conductivity of the soil filter (m/s)
W is the average width of the ponded cross section above the sand filter (m)
L is the length of the bioretention zone (m)
h_{max} is the depth of pondage above the sand filter (m).

6.3.2 Inlet details

Two checks of inlet details are required for bioretention basins: checking the width of flow in the gutter at the inlet (so traffic is not affected); and checking velocities to ensure scour does not occur at the entry for both minor and major storms.

6.3.2.1 Flow widths at entry

The width of flow at the entry during a minor storm event (typically five-year ARI) needs to be checked. This can be done by applying **Manning's equation** and ensuring that flows do not exceed local council regulations (e.g. maintaining at least one trafficable lane during a five-year ARI storm).

6.3.2.2 Kerb opening width at entry

To determine the width of the inlet slot in the kerb into the bioretention basin, Manning's equation can be used with the kerb, gutter and road profile to estimate flow depths at the entry point. Once the flow depths for the minor storm (e.g. five-year ARI) is estimated, this can be used to calculate the required width of opening in the kerb by applying a broad-crested **weir** equation (Equation 6.2). This ensures free-draining flows into the bioretention basin. The opening width is estimated by applying the flow depth in the gutter (as H) and solving for L (opening width).

$$Q = C \times L \times H^{3/2} \text{ with } C = 1.7 \qquad \text{(Equation 6.2)}$$

where C = weir coefficient

6.3.2.3 Inlet scour protection

It is considered good practice to provide erosion protection for flows as they enter a bioretention basin. Typically velocities will increase as flows drop from the kerb invert into the top of the bioretention soil media. **Rock beaching** is a simple method for managing these velocities.

6.3.3 Vegetation scour velocity check

Scour velocities over the vegetation are checked through the bioretention basin by assuming the system flows at a depth equal to the ponding depth across the full with of the system. Then by dividing the design flow rate by the cross-sectional area, flow velocity can be estimated. It is a conservative approach to assume that all flows pass through the bioretention basin (particularly for a 100-year ARI); however, this will ensure the integrity of the vegetation.

Velocities for discharges should be kept below:

- 0.5 m/s for five-year ARI
- 1.0 m/s for 100-year ARI.

6.3.4 Size of slotted collection pipes

The slotted collection pipes at the base of bioretention filter media collect treated water for conveyance downstream. They should be sized so that the filtration media are freely drained and the collection system does not become a 'choke' in the system.

Treated water that has passed through the filtration media is directed into slotted pipes via a 'drainage layer' (typically fine gravel or coarse sand, 1 mm–5 mm diameter). To convey water from the filtration media and into the perforated pipe, flows must pass through the drainage layer. The purpose of the drainage layer is to efficiently convey treated flows into the perforated pipes while preventing any of the filtration media from being washed downstream.

If gravel is used around the perforated pipes, it is recommended to install an additional 'transition' layer to prevent the fine filtration media being washed into the perforated pipes. Typically this is sand to coarse sand (0.7 mm–1.0 mm). Alternatively, a geotextile fabric could be used above the drainage layer to prevent finer material from reaching the perforated pipes; however, caution should be taken to ensure this material is not too fine as if it becomes blocked, the whole system will require resetting.

Considerations for the selection of a drainage layer include the slot widths in the perforated pipes as well as construction techniques. In addition, where the bioretention system can only have limited depth (e.g. maximum depth to perforated pipe < 0.5 m) it will be preferable to install just one drainage layer.

The maximum spacing of the perforated pipes should be 1.5 m (centre to centre) so that the distance water needs to travel through the drainage layer does not hinder drainage of the filtration media.

Installing parallel pipes is a means to increase the capacity of the perforated pipe system. A 100 mm diameter is considered a maximum size for the perforated pipes. Either flexible perforated pipe (e.g. AG pipe) or slotted polyvinyl chloride (PVC) pipes can be used; however, care needs to be taken to ensure the slots in the pipes are not so large that sediment would freely flow into the pipes from the drainage layer. This should also be a consideration when specifying the drainage layer media.

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

- the perforations are adequate to pass the maximum infiltration rate
- the pipe itself has sufficient capacity
- the drainage layer has sufficient hydraulic conductivity and will not be washed into the perforated pipes (consider a transition layer)

6.3.4.1 Perforations inflow check

To estimate the capacity of flows through the perforations, orifice flow conditions are assumed and a sharp-edged orifice equation (Equation 6.3) can be used. First, the number and size of perforations needs to be determined (typically from manufacturer's specifications) and used to estimate the flow rate into the pipes using a head of the filtration media depth plus the ponding depth. Second, it is conservative but reasonable to use a blockage factor (*B*) to account for partial blockage of the perforations by the drainage layer media. A factor of two is considered adequate.

$$Q_{\text{perforations}} = C \times A\sqrt{2gh}/B \qquad \text{(Equation 6.3)}$$

where $Q_{\text{perforations}}$ = flow through the perforation
g = acceleration due to gravity (9.81 m/s^2)
A = total area of the orifice (m)
h = maximum depth of water above the pipe (m)
C = orifice coefficient

6.3.4. Perforated pipe capacity

The Colebrook-White equation (Equation 6.4) can be applied to estimate the flow rate in the perforated pipe. Manning's equation could be used as an alternative. The capacity of this pipe needs to exceed the maximum infiltration rate.

$$Q = [-2(2gDS_f)^{0.5}\log_{10}(k/(3.7D) + 2.51\nu/D(2gDS_f)^{0.5})] \times A \quad \text{(Equation 6.4)}$$

6.3.4.3 Drainage layer hydraulic conductivity

The drainage layer is specified with the other soil media used in bioretention systems; however, it should be considered when selecting the perforated pipe system, in particular the slot sizes. Coarser material (e.g. fine gravel) should be used if the slot sizes are large enough for sand to be washed into the slots. If fine gravels are used, then a transition layer is recommended to prevent the filtration media from washing into the perforated pipes. The addition of a transition layer increases the overall depth of the bioretention system and may be an important consideration for some sites (therefore pipes with smaller perforations may be preferable).

6.3.4.4 Impervious liner requirement

When infiltration is not to be encouraged, stormwater is treated via filtration through a specified soil media with the filtrate collected via a subsurface drainage system to be either discharged as treated surface flow or collected for reuse. The amount of water lost to surrounding soils depends largely on local soils and the hydraulic conductivity of the filtration media in the bioretention system. Typically the hydraulic conductivity of filtration media (sandy loam) is 1–2 orders of magnitude greater than the native surrounding soil profile therefore the preferred flow path is into the perforated underdrainage system.

Where bioretention basins are installed near to significant structures care should be taken to minimise any leakage from the bioretention system. The surrounding soils should be tested and the expected hydraulic conductivity estimated (see Chapter 11 of Engineers Australia 2003).

During a detailed design it is considered good practice to provide an impervious liner where the saturated hydraulic conductivity of the surrounding soils is less than one order of magnitude less than the filtration media. This is only expected to be required in sandy loan to sandy soils and where infiltration is expected to create problems.

In many roadside applications, a drainage trench runs parallel with the road and will collect any seepage from a bioretention system.

If surrounding soils are very sensitive to any exfiltration from the bioretention basin (e.g. sodic soils, shallow groundwater or close proximity to significant structures), an impervious liner can be used to contain all water within the bioretention system. The liner could be a flexible membrane or a concrete casing.

The intention of the lining is to eliminate the risk of exfiltration from a bioretention system. The lining of the whole bioretention system in some terrain can be problematic. Fully lined bioretention systems could create subsurface barriers to shallow groundwater movements. In areas of shallow groundwater any interruption to groundwater movements could increase groundwater levels.

The greatest risk of exfiltration is through the floor of the bioretention trench. Gravity and the difference in hydraulic conductivity between the filtration media and the surrounding native soil would act to minimise exfiltration through the walls of the trench. To minimise the likelihood of exfiltration from the floor of the bioretention basin, the floor of the basin should be lined and shaped to ensure itsmost efficient drainage.

6.3.5 High-flow route and bypass design

The intention of the high flow design is to convey safely the minor floods (e.g. five-year ARI flows) to the same level of protection that a conventional stormwater system provides. Bioretention basins are typically served with either grated overflow pits or conventional side entry pits (located downstream of an inlet) to transfer flows into an underground pipe network (the same pipe network that collects treated flows).

The location of the overflow pit is variable but it is desirable to ensure that flows do not pass through extended length of vegetation. Grated pits can be located near the inlet to minimise the flow path length for above-design flows. A level of conservatism is built into the design grated overflow pits by placing their inverts at least 100 mm below the invert of the street gutter (and therefore the maximum ponding depth). This allows the overflow to convey a minor flood prior to any **afflux** effects in the street gutter. The overflow pit should be sized to pass a five-year ARI storm with the available head below the gutter invert (i.e. 100 mm).

Overflow pits can also be located external to bioretention basins, potentially in the kerb and gutter immediately downstream of the inlet to the basin. In this way the overflow pit can operate in the same was as a conventional side entry pit, with flows entering the pit only when the bioretention system is at maximum ponding depth.

To size a grated overflow pit, two checks should be made to estimate either drowned or free-flowing conditions. A broad-crested weir equation (Equation 6.5) can be used to determine the length of weir required (assuming free-flowing conditions) (*L*) and an orifice equation (Equation 6.6) used to estimate the area between opening required (assumed drowned outlet conditions). The larger of the two pit configurations should be adopted. In addition, a blockage factor (*B*) is to be used that assumes the orifice is 50% blocked.

For free overfall conditions (weir equation) (solving for *L*):

$$Q_{\text{minor}} = B \times C \times L \times H^{3/2} \qquad \text{(Equation 6.5)}$$

with B = blockage factor (0.5), C = 1.7 and H = available head above the weir crest

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

For drowned outlet conditions (orifice equation) (Equation 6.6):

$$Q_{\text{minor}} = B \times C \times A\sqrt{2gh} \qquad \text{(Equation 6.6)}$$

with B = blockage factor (0.5), C = 0.6 and H = available head above weir crest.

6.3.6 Soil media specification

At least two and possibly three types of soil media are required for bioretention basins.

A filter media layer provides most of the treatment function, through fine filtration and by supporting the vegetation that enhances filtration. The vegetation helps to keep the filter media porous and provides some nutrient uptake of contaminants in stormwater. The filter media is required to have sufficient depth to support vegetation, and is usually between 300 mm and 1000 mm.

A drainage layer is used to convey treated flows into the perforated underdrainage pipes. Either coarse sand or fine gravel can be used. The layer should surround the perforated pipes and be 150 mm or 200 mm thick. Should fine gravel be used, a 100 mm transition layer is recommended that will prevent finer filter media being washed into the perforated pipes.

Materials similar to those described in the following Sections should provide adequate substrate for vegetation to grow in and sufficient conveyance of stormwater through the bioretention system.

6.3.6.1 Filter media specifications

The filter media material can be of siliceous or calcareous origin. The material will be placed and then lightly compacted. Compaction is only required to avoid subsistence and uneven drainage. The material will be completely saturated and completely drained periodically. The bioretention system will operate so that water will infiltrate into the sediment and move down through the profile. Maintaining the prescribed hydraulic conductivity is crucial.

The material shall meet the geotechnical requirements set out below:

- **Material** – Sandy loam or equivalent material (ie similar hydraulic conductivity, 50–200 mm/hr) free of rubbish and deleterious material.
- **Particle size** – Soils with infiltration rates in the appropriate range typically vary from sandy loams to loamy sands. Soils with the following composition are likely to have an infiltration rate in the appropriate range: clay 5%–15 %, silt < 30 %, sand 50%–70 %, assuming the following particle sizes ranges (clay < 0.002 mm, silt 0.002 mm–0.05 mm, sand 0.05 mm–2.0 mm).

  Soils with most particles in this range would be suitable. Variation in large particle size is flexible (i.e. an approved material does not have to be screened). Substratum materials should avoid the lower particle size ranges unless tests can demonstrate an adequate hydraulic conductivity (1–5 × $10^{[-]5}$ m/s).

- **Organic content** – between 5% and 10%, measured in accordance with AS1289 4.1.1.
- **pH** – is variable, but preferably neutral, nominal pH 6.0 to pH 7.5 range. Optimum pH for denitrification, which is a target process in this system, is pH 7–8. Siliceous materials may have lower pH values.

Any component or soil found to contain high levels of salt, clay or silt particles (exceeding the particle size limits set above), extremely low levels of organic carbon or any other extremes which may be considered retardant to plant growth and denitrification should be rejected.

6.3.6.2 Transition layer specifications

Transition layer material shall be sand/coarse sand material. A typical particle size distribution (per cent of particles passing through different sieve sizes) is provided below:

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

This grading is based on a Unimin 16/30 FG sand grading.

The transition layer is recommended to be a minimum of 100 mm thick. Hydraulic conductivities are shown for a range of media sizes (based on d_{50} sizes) that can be applied in either the transition or drainage layers (Table 6.1).

Table 6.1 Hydraulic conductivity for a range of media particle sizes (d_{50})
Engineers Australia (2003)

Soil type	Particle size	Saturated hydraulic conductivity	
	(mm)	(mm/hr)	(m/s)
Gravel	2	36000	1×10^{-2}
Coarse Sand	1	3600	1×10^{-3}
Sand	0.7	360	1×10^{-4}
Sandy Loam	0.45	180	5×10^{-5}
Sandy Clay	0.01	36	1×10^{-5}

6.3.6.3 Drainage layer specifications

The drainage layer specification can be either coarse sand (similar to the transition layer) or fine gravel, such as a 2 mm or 5 mm screenings.

This layer should be a minimum of 150 mm and preferably 200 mm thick.

6.3.7 Vegetation specification

Table A.1 (see Appendix A) provides lists of plants that are suitable for bioretention basins. Consultation with landscape architects is recommended when selecting vegetation, to ensure the treatment system complements the landscape of the area.

6.3.8 Design calculation summary

Bioretention basins		CALCULATION CHECKLIST		
	CALCULATION TASK	**OUTCOME**	**CHECK**	
1	**Identify design criteria**			☐
	Conveyance flow standard (ARI)		year	
	Area of bioretention		m^2	
	Maximum ponding depth		mm	
	Filter media type		mm/hr	
2	**Catchment characteristics**			☐
			m^2	
			m^2	
	Slope		%	
	Fraction impervious			☐
3	**Estimate design flow rates**			
	Time of concentration			
	Estimate from flow path length and velocities		minutes	☐
	Identify rainfall intensities			
	Station used for IFD data:			
	100-year ARI		mm/hr	
	5-year ARI		mm/hr	
	Peak design flows			
	Q_5		m^3/s	
	Q_{100}		m^3/s	
	Q_{infil}		m^3/s	☐
4	**Slotted collection pipe capacity**			
	Pipe diameter		mm	
	Number of pipes			
	Pipe capacity		m^3/s	
	Capacity of perforations		m^3/s	
	Soil media infiltration capacity		m^3/s	
	CHECK PIPE CAPACITY > SOIL CAPACITY			☐
5	**Check flow widths in upstream gutter**			
	Q_5 flow width		m	
	CHECK ADEQUATE LANES TRAFFICABLE			☐
6	**Kerb opening width**			
	Width of break in kerb for inflows		m	☐
7	**Velocities over vegetation**			
	Velocity for 5-year flow (<0.5 m/s)		m/s	
	Velocity for 100-year flow (<1.0 m/s)		m/s	☐
8	**Overflow system**			
	System to convey minor floods			☐
9	**Surrounding soil check**			
	Soil hydraulic conductivity		mm/hr	
	Filter media		mm/hr	
	MORE THAN 10 TIMES HIGHER THAN SOILS?			☐
10	**Filter media specification**			
	Filtration media			
	Transition layer			
	Drainage layer			☐
11	**Plant selection**			☐

6.4 Checking tools

Checking aids are included for designers and referral authorities. In addition, advice on construction techniques and lessons learnt from building bioretention systems are provided.

Checklists are provided for:

- design assessments
- construction (during and post)
- operation and maintenance inspections
- asset transfer (following defects period).

6.4.1 Design assessment checklist

The *Bioretention Basin Design Assessment Checklist* presents the key design features that should be reviewed when assessing a design of a bioretention basin. These considerations include configuration, safety, maintenance and operational issues that should be addressed during the design phase.

Where an item results in an 'N' when reviewing the design, the design procedure should be assessed to determine the effect of the omission or error.

In addition to the *Checklist*, a proposed design should have all necessary permits for its installations. The referral agency should ensure that all relevant permits are in place. These can include permits to clear vegetation, to dredge, create a waterbody, divert flows or disturb fish or platypus habitat.

Land and asset ownership are key considerations prior to construction of a stormwater treatment device. A proposed design should clearly identify the asset owner and who is responsible for its maintenance. The proposed owner should be responsible for performing the *Asset Handover Checklist* (see Section 6.4.4).

6.4.2 Construction advice

General advice is provided for the construction of bioretention basins. It is based on observations from construction projects around Australia.

Building phase damage

It is important to protect filtration media and vegetation during the building phase as uncontrolled building site runoff is likely to cause excessive **sedimentation**, introduce weeds and litter and require replanting after building. A staged implementation can be used [i.e. during building use geofabric, some soil (e.g. 50 mm) and instant turf (laid perpendicular to flow path)] to provide erosion control and sediment trapping. Following building, remove the interim measures and revegetate, possibly reusing turf at subsequent stages.

Traffic and deliveries

Ensure traffic and deliveries do not access bioretention basins during construction. Traffic can compact the filter media and cause preferential flow paths, deliveries can block filtration media. Washdown wastes (e.g. concrete) can cause blockage of filtration media. Bioretention areas should be fenced off during the building phase and controls implemented to avoid washdown wastes.

Inlet erosion checks

It is good practice to check the operation of inlet erosion protection measures following the first few rainfall events. These need to be checked early in the systems life, to avoid continuing problems. If problems occur in these events, then erosion protection should be enhanced.

Sediment build-up on roads

Where flush kerbs are to be used, a set-down from the pavement surface to the vegetation should be adopted. This allows a location for sediments to accumulate that is off the pavement surface. Generally a set down from kerb of 50 mm to the top of vegetation (if turf) is adequate. Therefore, total set down to the base soil is about 100 mm (with 50 mm turf on top of base soil).

Timing for planting

Timing of planting vegetation depends on a suitable time of year (and potential irrigation requirements) as well as timing in relation to the phases of development. For example,

Bioretention Basin Design Assessment Checklist					
Bioretention location:					
Hydraulics	Minor flood: (m^3/s)		Major flood: (m^3/s)		
Area	Catchment area (ha):		Bioretention area (ha)		
Treatment				**Y**	**N**
Treatment performance verified from curves?					
Inlet zone/hydraulics				**Y**	**N**
Station selected for IFD appropriate for location?					
Overall flow conveyance system sufficient for design flood event?					
Maximum upstream flood conveyance width does not impact on traffic amenity?					
Velocities at inlet and within bioretention system will not cause scour?					
Bypass sufficient for conveyance of design flood event?					
Bypass has set down of at least 100 mm below kerb invert?					
Collection system				**Y**	**N**
Slotted pipe capacity > infiltration capacity of filter media?					
Maximum spacing of collection pipes <1.5 m?					
Transition layer/geofabric barrier provided to prevent clogging of drainage layer?					
Basin				**Y**	**N**
Maximum ponding depth will not impact on public safety?					
Selected filter media hydraulic conductivity > 10x hydraulic conductivity of surrounding soil?					
Maintenance access provided to base of bioretention (where reach to any part of a basin >6 m)?					
Protection from gross pollutants provided (for larger systems)?					
Vegetation				**Y**	**N**
Plant species selected can tolerate periodic inundation?					
Plant species selected integrate with surrounding landscape design?					
Detailed soil specification included in design?					

temporary planting during construction for sediment control (e.g. with turf) can then be removed and the area planted out with long-term vegetation.

Planting strategy

A planting strategy for a development depends on the timing of the building phases as well as marketing pressure. For example, it may be desirable to plant out several entrance bioretention systems to demonstrate long-term landscape values, and use the remainder of bioretention systems as building phase sediment controls (to be planted out following building).

Perforated pipes

Perforated pipes can be either a Polyvinyl Chloride (PVC) pipe with slots cut into its length it or a flexible ribbed pipe with smaller holes distributed across its surface (an AG pipe). Both can be suitable. PVC pipes have the advantage of being stiffer with less surface roughness and therefore greater flow capacity; however, the slots are generally larger than for flexible pipes and this may cause problems with filter or drainage layer particle ingress into the pipe. Stiff PVC pipes, however, can be cleaned out easily using simple plumbing equipment. Flexible perforated pipes have the disadvantage of roughness (therefore lower flow capacity); however, they have smaller holes and are flexible which can make installation easier. Blockages within the flexible pipes can be harder to dislodge with standard plumbing tools.

Inspection openings

It is good design practice to have inspection openings at the end of the perforated pipes. The pipes should be brought to the surface and have a sealed capping. This allows inspection of sediment build-up and water level fluctuations when required and allow easy access for maintenance. The vertical component of the pipe should not be perforated otherwise short circuiting can occur.

Clean filter media

Ensure drainage media is washed prior to placement to remove fines.

6.4.3 Construction checklist

CONSTRUCTION INSPECTION CHECKLIST

Bioretention basins

INSPECTED BY:	
DATE:	
TIME:	
WEATHER:	
CONTACT DURING VISIT:	

SITE: ____________________

CONSTRUCTED BY: ____________________

DURING CONSTRUCTION

Items inspected	Checked		Satisfactory	Unsatisfactory		Checked		Satisfactory	Unsatisfactory
Preliminary works	Y	N			**Structural components**	Y	N		
1. Erosion and sediment control plan adopted					15. Location and levels of pits as designed				
2. Traffic control measures					16. Safety protection provided				
3. Location same as plans					17. Pipe joints and connections as designed				
4. Site protection from existing flows					18. Concrete and reinforcement as designed				
Earthworks					19. Inlets appropriately installed				
5. Bed of basin correct shape					20. Inlet erosion protection installed				
6. Batter slopes as plans					21. Set down to correct level for flush kerbs				
7. Dimensions of bioretention area as plans					**Vegetation**				
8. Confirm surrounding soil type with design					22. Stablisation immediately following earthworks				
9. Provision of liner									
10. Perforated pipe installed as designed					23. Planting as designed (species and densities)				
11. Drainage layer media as designed									
12. Transition layer media as designed					24. Weed removal before stabilisation				
13. Filter media specifications checked									
14. Compaction process as designed									

FINAL INSPECTION

1. Confirm levels of inlets and outlets					6. Check for uneven settling of soil				
2. Traffic control in place					7. Inlet erosion protection working				
3. Confirm structural element sizes					8. Maintenance access provided				
4. Check batter slopes					9. Construction generated sediment removed				
5. Vegetation as designed									

COMMENTS ON INSPECTION

ACTIONS REQUIRED

1.
2.
3.
4.
5.
6.

6.4.4 Asset handover checklist

Asset Handover Checklist		
Asset location:		
Construction by:		
Defects and liability period		
Treatment	**Y**	**N**
System appears to be working as designed visually?		
No obvious signs of under-performance?		
Maintenance	**Y**	**N**
Maintenance plans provided for each asset?		
Inspection and maintenance undertaken as per maintenance plan?		
Inspection and maintenance forms provided?		
Asset inspected for defects?		
Asset information	**Y**	**N**
Design Assessment Checklist provided?		
As constructed plans provided?		
Copies of all required permits (both construction and operational) submitted?		
Proprietary information provided (if applicable)?		
Digital files (e.g. drawings, survey, models) provided?		
Asset listed on asset register or database?		

6.5 Maintenance requirements

Bioretention basins treat runoff by filtering it through vegetation and then passing the runoff vertically through a filtration media which filters the runoff. Besides vegetative filtration, treatment relies upon infiltration of runoff into an underdrain.Vegetation is key in maintaining the porosity of the surface of the filter media and a strong healthy growth of vegetation is critical to its performance.

The most intensive period of maintenance is during plant establishment (first two years) when weed removal and replanting may be required. It is also when large loads of sediments could affectplant growth particularly in developing catchments with poor building controls.

Maintenance is primarily concerned with:

- flow to and through the bioretention basin
- maintaining vegetation
- preventing undesired overgrowth vegetation from taking over the bioretention basin
- removal of accumulated sediments
- litter and debris removal.

Vegetation maintenance will include:

- fertilising plants
- removal of noxious plants or weeds
- re-establishment of plants that die

Sediments accumulation at the inlets needs to be monitored. Depending on the catchment activities (e.g. building phase) the deposition of sediment can tend to smother plants and reduce

Bioretention Basin Maintenance Checklist			
Inspection frequency: 3 monthly	Date of visit:		
Location:			
Description:			
Site visit by:			
Inspection items	Y	N	Action required (details)
Sediment accumulation at inflow points?			
Litter within basin?			
Erosion at inlet or other key structures (e.g. crossovers)?			
Traffic damage present?			
Evidence of dumping (e.g. building waste)?			
Vegetation condition satisfactory (density, weeds etc.)?			
Replanting required?			
Mowing required?			
Clogging of drainage points (sediment or debris)?			
Evidence of ponding?			
Damage/vandalism to structures present?			
Surface clogging visible?			
Drainage system inspected?			
Resetting of system required?			
Comments:			

the available ponding volume. Should excessive sediment build-up, it will affepact plant health and require removal before it reduces the infiltration rate of the filter media.

Similar to other types of practices, debris removal is an ongoing maintenance function. Debris, if not removed, can block inlets or outlets, and can be unsightly. Inspection and removal of debris should be done regularly, but debris should be removed whenever it is observed on the site.

6.5.1 Operation and maintenance inspection form

The *Bioretention Basins Maintenance Checklist* is designed to be used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time.

6.6 Bioretention basin worked example

6.6.1 Worked example introduction

A series of bioretention basins, designed as street traffic parking 'out-stands' is to be retrofitted into a local street to treat road runoff. The local street is in inner Melbourne. A proposed layout of the bioretention system is shown in Figure 6.6 and an image of a similar system to that proposed is shown in Figure 6.7.

The contributing catchment areas to each of the individual bioretention basins consist of 300 m^2 of road and footpath pavement and 600 m^2 of adjoining properties. Runoff from adjoining properties (about 60% impervious) is discharged into the road gutter and, together with road runoff, is conveyed along a conventional roadside gutter to the bioretention cell.

The aim of the design is to facilitate effective treatment of stormwater runoff while maintaining a five-year ARI level of flood protection for the local street. Analysis during the concept design of the system has found that a bioretention basin area of 6 m^2 with an extended detention depth of 200 mm, and consisting of a sandy loam soil filtration medium, would treat

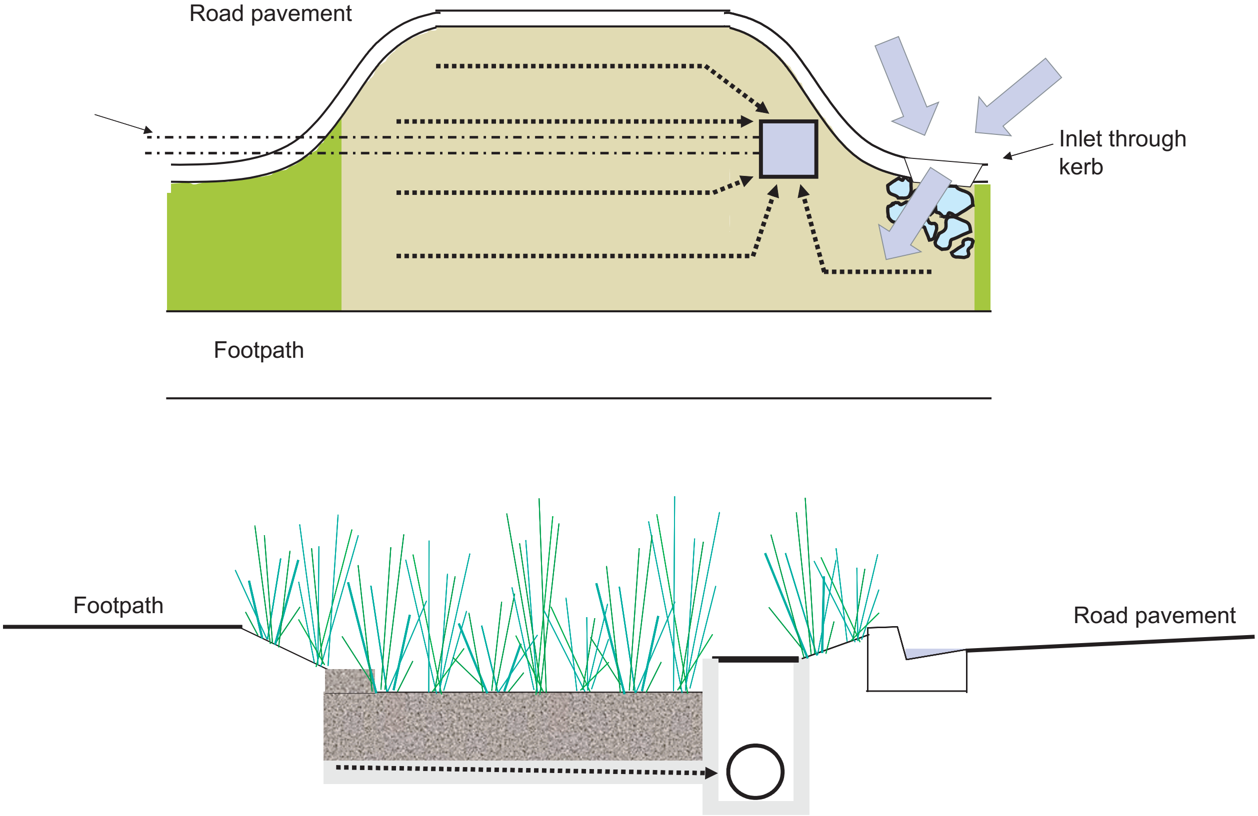


Figure 6.6 General layout and cross section of proposed bioretention system in inner Melbourne.

Figure 6.7 Retrofitted bioretention system in a street.

stormwater runoff adequately to best practice objectives. The actual size of the cell may, however, be increased to suit other streetscape objectives. The maximum width (measured perpendicular to the alignment of the road) of the bioretention basin is to be 2 m. Analyses to detail the operation of the bioretention basin are shown below and demonstrate the design procedures. The analyses include:

- road and gutter details to convey water into the basin
- detailing inlet conditions to provide for erosion protection
- configuring and designing a system for above-design operation that will provide the required five-year ARI flood protection for the local street
- sizing of below-ground drainage system
- specification of the soil filtration medium
- landscape layout and details of vegetation.

6.6.1.1 Design objectives

The design objectives of the bioretention basin are to:

- maximise reductions of TSS, TP and TN, respectively, while maintaining a five-year ARI level of flood protection for the local street.

6.6.1.2 Constraints and concept design criteria

Analyses during a concept design determined the following criteria:

- bioretention basin area of 6 m^2 (minimum) is required to achieve the water quality objectives
- maximum width of the bioretention basin is to be 2m.
- extended detention depth is 200 mm.
- filter media shall be a sandy loam.

6.6.1.3 Site characteristics

The site characteristics for the bioretention basin are:

- urban, paved carpark and footpaths, lots land use.
- typical overland flow slope of 1%.
- clay soil assumed
- catchment area: carpark, 300 m^2; lots, 600 m^2
- fraction impervious is: carpark, 0.90; lots, 0.60.

6.6.2 Confirm size for treatment

Interpretation of Figures 6.3 to 6.5 with the input parameters below is used to estimate the reduction performance of the bioretention basin for the three pollutants.

- Melbourne location
- 200 mm extended detention
- treatment area to impervious area ratio: 6 m^2/ $[(0.9 \times 300) + (0.6 \times 600)]m^2 = 0.95\%$

From the graphs, the expected pollutant reductions are 92%, 75% and 38% for TSS, TP and TN respectively, and exceed the design requirements of 80%, 45% and 45%.

6.6.3 Estimating design flows

6.6.3.1 Major and minor design flows

With a small catchment the Rational Method Design Procedure is considered an appropriate approach to estimate the five- and 100-year ARI peak flow rates. The steps in these calculations follow.

Time of concentration (t_c)

- Lot, flow path length, is 15 m
  adopt Horton's n (roughness coefficient) = 0.030 (grassed surface)
  slope (S) = 1%

$$\text{Friend's equation } t = \frac{107 \times nL^{0.333}}{S^{0.2}} \qquad \text{(Equation 6.7)}$$

$$t = (107 \times 0.03 \times 15^{\,0.333})/1^{0.2} = 7.9 \text{ min}$$

- Gutter flow: adopt flow path length of 50 m to bioretention.
  Velocity = 1 m/s
  Flow time = 50 m / 1 m/s = 50 s
  Adopt t_c = 7.9 + 0.8 = 8.7 min, say 8 min.

Design rainfall intensities

Adopt the values from from IFD (Intensity–Frequency Duration) table for Melbourne (Table 6.2).

Table 6.2 Design rainfall intensities

	100 yr	5 yr	1 yr
Intensity (mm/hr)	150	72	39.3

Design runoff coefficient

To calculate the design runoff coefficient, apply the method outlined in ARR (Institution of Engineers 2001, Book VIII, 5.1.5.5 iii)

$C^1{}_{10} = 0.1 + 0.0133({}^{10}I_1 - 25)$, where $C^1{}_{10}$ is the pervious year runoff coefficient

$C_{10} = 0.9f + C^1{}_{10}(1-f)$, where f is the fraction impervious.

$${}^{10}I_1 = 28.6 \text{ mm/hr}$$

$$C^1{}_{10} = 0.15$$

$$f = 0.06 \times 0.6 + 0.03 \times [0.90/(0.06 + 0.03)] = 0.70.$$

$$C_{10} = 0.67$$

$$C_5 = 0.95 \times C_{10} = 0.64$$

$$C_{100} = 1.2 \times C_{10} = 0.81$$

$$C_{3\text{ Month}} = C_1 = 0.8 \times C_{10} = 0.54.$$

Peak design flows

The peak design flows are calculated by using the Rational Method as follows:

$$Q = CIA/360$$

$$Q_5 = 0.012 \text{ m}^3\text{/s}$$

$$Q_{100} = 0.030 \text{ m}^3\text{/s}$$

6.6.3.2 Maximum infiltration rate

The maximum infiltration rate reaching the perforated pipe at the base of the soil media is estimated by using the hydraulic conductivity of the media (k) and head above the pipes (h_{max}) and applying Darcy's equation (Equation 6.1):

Saturation permeability = 180 mm/hr
Flow capacity of the infiltration media (assume no blockage)
Assume $\Upsilon = 0$ (no blockage – maximise infiltration)

Maximum infiltration rate = $(0.18 \times 6)/3600 \times (0.2 + 0.6/0.6) = 0.0004$ m^3/s.

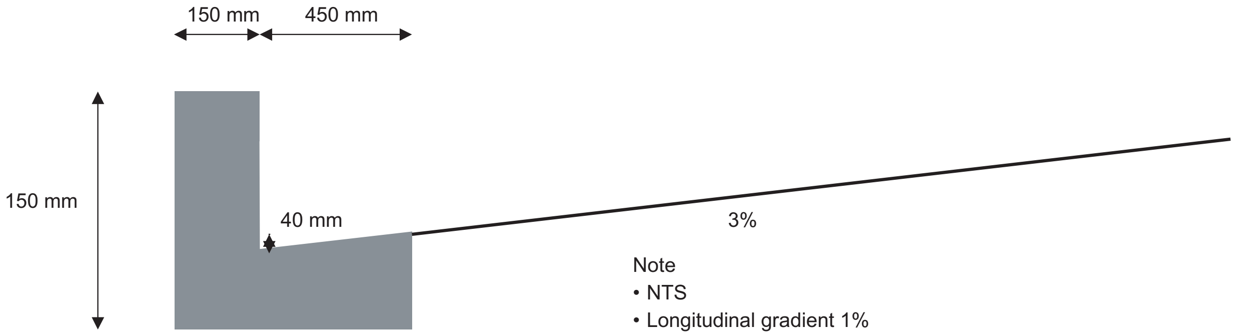


Figure 6.8 Gutter details

6.6.3.3 Inlet details

Flow width at entry

A check of the flow capacity of the system and the width of the flow across the road needs to be performed to ensure the road is protected to council standards for a minor (five-year ARI) flood. In this case the council has a criterion of having less than 2 m wide flow in the gutter, which facilitates one trafficable lane during a minor flood.

Adopt the following kerb, gutter and road profile, with a longitudinal gradient of 1% along the gutter. The following flow and depth estimates can be made using Manning's equation.

- Check flow capacity and width of flow
- Assume uniform flow conditions, estimate by applying Manning's equation:

$$Q_{5\text{-year}} = 0.012\ \text{m}^3/\text{s, depth of flow} = 0\ 55\ \text{mm}$$

$$\text{width of flow} = 900\ \text{mm (within gutter)}$$

$$\text{velocity} = 0.6\ \text{m/s (within gutter).}$$

The estimated peak flow width during the $Q_{5\text{-year}}$ storm is appropriate for the development (< 2.0 m during minor storm flow).

$$Q_{100} = 0.030\ \text{m}^3/\text{s, depth of flow} = 70\ \text{mm}$$

$$\text{width of flow} = 1.45\ \text{m (within gutter)}$$
$$\text{velocity} = 0.8\ \text{m/s (within gutter).}$$

Kerb opening at entry

The flow depth in the gutter estimated in the previous Section is used to determine the required width of opening in the kerb to allow for flows to freely flow into the bioretention system.

$$Q_5 = 0.012\ \text{m}^3/\text{s.}$$

Assume broad-crested weir flow conditions (Equation 6.5) through the slot

$$Q = C.L.H^{3/2}$$

Adopt $C = 1.7$.
Flow depth (Q_5) = 55 mm, adopt $H = 0.055$ m
Therefore,

$$L = Q_5/(CH^{3/2}) = (0.012)/(1.7 \times 0.055^{3/2}) = 0.55\ \text{m.}$$

Therefore, adopt a 0.6m wide opening in the kerb at the inlet.

Inlet scour protection

Rock beaching is to be provided at the inlet to manage flow velocities from the kerb and into the bioretention system. This detail is shown on Figure 6.6.

6.6.4 Vegetation scour velocity check

Assume Q_5 and Q_{100} will be conveyed through the bioretention system. Check for scouring of the vegetation by checking that velocities are below 0.5 m/s during Q_5 and 1.0 m/s for Q_{100}.

Width of bioretention = 2 m
Extended detention depth = 0.2 m
Area = 2 m x 0.2 m= 0.4 m^2

Q_5 average velocity = 0.012 m^3/s / 0.4 m^2 = 0.03 m/s, which is < 0.5 m/s – therefore OK.

Q_{100} average velocity = 0.03 m^3/s / 0.4 m^2 = 0.08 m/s, which is < 1.0 m/s – therefore OK.

Hence, the bioretention system can satisfactorily convey the peak five-year and 100-year ARI flood, minimising the potential for scour.

6.6.5 Sizing of perforated collection pipes

6.6.5.1 Perforations inflow check

Estimate the inlet capacity of subsurface drainage system (perforated pipe) to ensure it is not a choke in the system. To build in conservatism, it is assumed that 50% of the holes are blocked. A standard perforated pipe was selected that is widely available. To estimate the flow rate, an orifice equation (Equation 6.3) is applied using the following parameters:

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

Assume subsurface drains with half of all pipes blocked:
Clear opening = 2100 mm^2/m, hence blocked openings are 1050 mm^2/m
Slot width is 1.5 mm
Slot length, 7.5 mm
No. of rows, 6
Diameter = 100 mm,
Number of slots per metre = (1050)/(1.5 × 7.5) = 93.3
Assume orifice flow conditions – $Q = CA\sqrt{2gh}$
C = 0.61 (assume slot width acts as a sharp-edged orifice, see Equation 6.3).
Inlet capacity per metre of pipe =

$$[0.61 \times (0.0015 \times 0.0075) \times \sqrt{2 \times 9.88 \times 0.85}] \times 93.3 = 0.0025 \text{ m}^3/\text{s}$$

Inlet capacity per metre × total length = 0.0025 × (6/2) = 0.008 m^3/s, which is > 0.004 (maximum infiltration rate), hence OK.

6.6.5.2 Perforated pipe capacity

The Colebrook-White equation (Equation 6.4) is applied to estimate the flow rate in the perforated pipe. Manning's equation could be used as an alternative. A slope of 0.5% is assumed and a 100 mm perforated pipe (as above) was used. Should the capacity not be sufficient, either a second pipe could be used or a steeper slope. The capacity of this pipe needs to exceed the maximum infiltration rate.

Estimate applying the Colebrook-White equation (see Equation 6.4):

$$Q = [-2(2gDS_f)^{0.5}\log_{10}(k/(3.7D) + 2.51\nu/D(2gDS_f)^{0.5})] \times A$$

Adopt D = 0.15 m
S_f = 0.005 m/m
g = 9.81 m^2/s
k = 0.007 m

$\nu = 1.007 \times 10^{-6}$

$Q_{cap} = 0.004\ m^3/s$ (for one pipe), which is > $0.004\ m^3/s$, and is hence OK.

Adopt 1 × ϕ (diameter) 100 mm perforated pipe for the underdrainage system.

6.6.5.3 Drainage layer hydraulic conductivity

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

6.6.5.4 Impervious liner requirement

In this catchment the surrounding soils are clay to silty clays with a saturated hydraulic conductivity of about 3.6 mm/hr. The sandy loam media that is proposed as the filter media has a hydraulic conductivity of 50–200 mm/hr. Therefore, the conductivity of the filter media is > 10 times the conductivity of the surrounding soils and an impervious liner is not considered to be required.

6.6.6 High-flow route and bypass design

The overflow pit is required to convey five-year ARI flows safely from above the bioretention system into an underground pipe network. Grated pits are to be used at the upstream end of the bioretention system.

The size of the pits are calculated using a broad-crested weir equation with the height above the maximum ponding depth and below the road surface (i.e. 100 mm).

First, check using a broad-crested weir equation (Equation 6.2):

$Q_{minor} = B \times C \times L \times H^{3/2}$ with $B = 0.5$, $C = 1.7$ and $H = 0.1$ and solving for L

Gives $L = 0.44$ m of weir length required (equivalent to 115 × 115 mm pit).

Second, check for drowned conditions:

$$Q = \mathrm{B} \times \mathrm{C} \times \mathrm{A}\ \sqrt{2gh} \quad \text{with C} = 0.6$$

$$0.12 = 0.5 \times 0.6 \times A \times \sqrt{2g} \times 0.1 \text{ gives } A = 0.029\ \mathrm{m}^2 \text{ (equivalent to 170 x 170 pit)}$$

Hence, drowned outlet flow conditions dominate, adopt pit sizes of 600 × 600 mm for this system as this is minimum pit size to accommodate underground pipe connections.

6.6.7 Soil media specification

Three layer of soil media are to be used. A sandy loam filtration media (600 mm) to support the vegetation, a coarse transition layer (100 mm) and a fine gravel drainage layer (200 mm). The specifications for these are in the following sections.

6.6.7.1 Filter media specifications

The filter media is to be a sandy loam with the following criteria and meet the geotechnical requirements set out below:

- hydraulic conductivity between 50 mm/hr and 200 mm/hr
- particle sizes of between: clay 5%–15 %, silt < 30%, sand 50%–70 %
- between 5% and 10% organic content, measured in accordance with AS1289 4.1.1.
- pH neutral.

6.6.7.2 Transition layer specifications

Transition layer material shall be coarse sand material such as Unimin 16/30 FG sand grading or equivalent. A typical particle size distribution is provided as follows:

percentage passing 1.4 mm, 100%; 1.0 mm, 80%; 0.7 mm, 44%; 0.5 mm, 8.4%.

6.6.7.3 Drainage layer specifications

The drainage layer is to be 5 mm screenings.

6.6.8 Vegetation specification

With such a small system it is considered sufficient to have a single species of plants within the bioretention system. For this application a Tall Sedge (*Carrex appressa*) is proposed with a planting density of 8 plants/m^2. More information on maintenance and establishment is provided in Appendix A.

6.6.9 Calculation summary

The completed *Bioretention Basin Calculation Summary* shows the results of the design calculations.

Bioretention basins — CALCULATION SUMMARY

CALCULATION TASK	OUTCOME		CHECK
1 Identify design criteria			✓
Conveyance flow standard (ARI)	5	year	
Area of bioretention	6	m^2	
Maximum ponding depth	200	mm	
Filter media type	180	mm/hr	
2 Catchment characteristics			✓
Car park area	300	m^2	
Allotment area	600	m^2	
Slope	1	%	
Fraction impervious			✓
Car park	0.9		
Allotments	0.6		
3 Estimate design flow rates			
Time of concentration			
Estimate from flow path length and velocities	8	minutes	✓
Identify rainfall intensities			
Station used for IFD data:	Melbourne		
100-year ARI	150	mm/hr	
5-year ARI	72	mm/hr	
Peak design flows			
Q_5	0.012	m^3/s	
Q_{100}	0.030	m^3/s	
Q_{infil}	0.0003	m^3/s	✓
4 Slotted collection pipe capacity			
Pipe diameter	100	mm	
Number of pipes	1		
Pipe capacity	0.004	m^3/s	
Capacity of perforations	0.015	m^3/s	
Soil media infiltration capacity	0.004	m^3/s	
CHECK PIPE CAPACITY > SOIL CAPACITY	YES		✓
5 Check flow widths in upstream gutter			
Q_5 flow width	0.9	m	
CHECK ADEQUATE LANES TRAFFICABLE	YES		✓
6 Kerb opening width			
Width of break in kerb for inflows	0.6	m	✓
7 Velocities over vegetation			
Velocity for 5-year flow (<0.5 m/s)	0.03	m/s	
Velocity for 100-year flow (<1.0 m/s)	0.08	m/s	✓
8 Overflow system			
System to convey minor floods	grated pit 600 x 600		✓
9 Surrounding soil check			
Soil hydraulic conductivity	0.36	mm/hr	
Filter media	180	mm/hr	
MORE THAN 10 TIMES HIGHER THAN SOILS?	YES (no liner)		✓
10 Filter media specification			
Filtration media	sandy loam		
Transition layer	coarse sand		
Drainage layer	fine gravel		✓
11 Plant selection			
	Carex appressa		✓

6.6.10 Construction drawings

Figure 6.9 shows the construction drawing for the worked example.

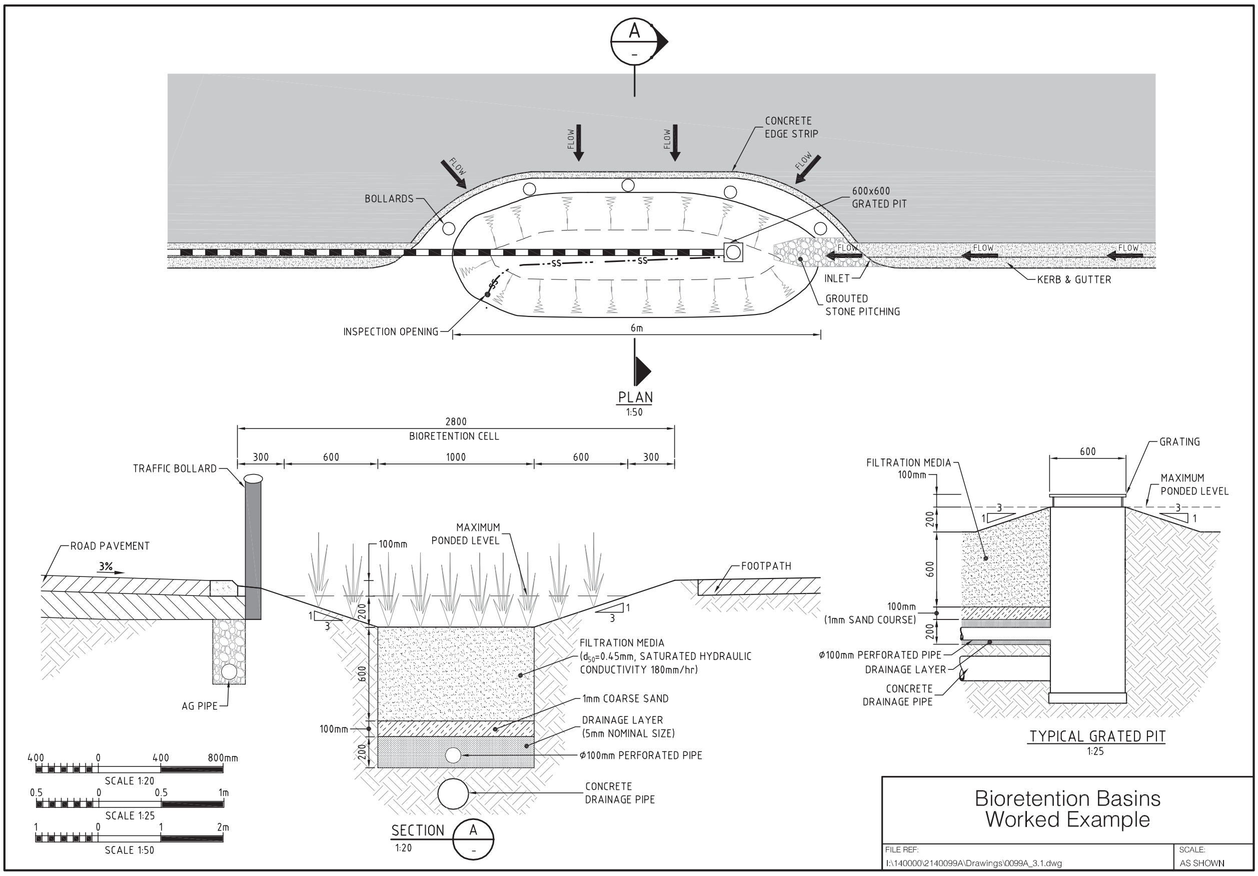


Figure 6.9 Construction drawing and a section view of the bioretention basin.

6.7 References

Cooperative Research Centre for Catchment Hydrology (CRCCH) (2003). *Model for Urban Stormwater Improvement Conceptualisation (MUSIC) User Guide*, Version 2.0, CRCCH, Monash University, Victoria.

Engineers Australia (2003). *Australian Runoff Quality Guidelines*, Draft, June.

Institution of Engineers, Australia (1997). *Australian Rainfall and Runoff – A Guide to Flood Estimation*, Revised edn, Pilgram, D.H. (Ed.), Institution of Engineers, Australia, Barton, ACT.

Standards Australia (1997). AS 1289.4.1.1: Methods of testing soils for engineering purposes – Soil chemical tests – Determination of the organic matter content of a soil – Normal method, Standards Australia, Sydney.