Chapter 5 **Bioretention swales**

Bioretention swale in Zetland, NSW

5.1 Introduction

Bioretention swales provide both **stormwater** treatment and conveyance functions. A bioretention system is installed in the base of a **swale** that is designed to convey minor floods. The swale component provides pretreatment of stormwater to remove coarse to medium sediments while the bioretention system removes finer particulates and associated contaminants. Figure 5.1 shows the layout of a bioretention swale.

A bioretention system can be installed in part of a swale, or along the full length of a swale, depending on treatment requirements. Typically, these systems should be installed with slopes of between 1% and 4 %. In steeper areas, **check dams** are required to reduce flow velocities. For milder slopes, adequate drainage needs to be provided to avoid nuisance ponding (a bioretention system along a full length of the swale will provide this drainage).

Runoff can be directed into bioretention swales either through direct surface runoff (e.g. with flush kerbs) or from an outlet of a pipe system. In either case traffic needs to be kept away from the filter media as compaction can change the filter media functions substantially.

To design the bioretention swale, separate calculations are performed to design the swale and the bioretention system, with iterations to ensure appropriate criteria are met in each section. Depending on the length of the swale and steepness of the terrain, check dams can be used to manage steep slopes and also to provide ponding over a bioretention surface. In this way increased volumes of runoff can be treated through a bioretention system prior to bypass.

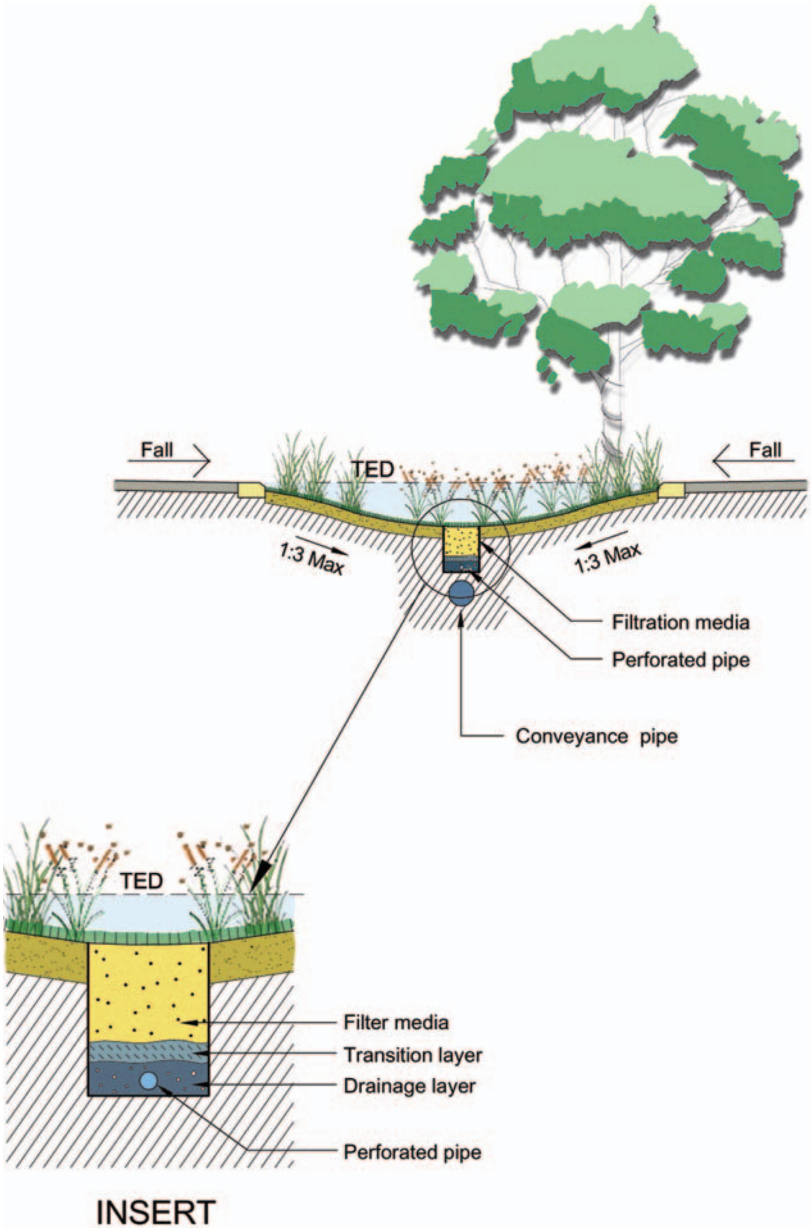

Figure 5.1 Bioretention swale as a centre road median

In many urban situations, the width available for a swale system will be fixed (as well as the longitudinal slope); therefore, the length of the swale to convey a minor storm safely will also be fixed. A common way to design these systems is as a series of discrete 'cells' (e.g. Figure 5.2). Each cell has an overflow pit that **discharges** flow to an underground pipe system. Bioretention systems can then be installed directly upstream of the overflow pits. This also allows an area for ponding over the **filtration media**.

As flood flows are conveyed along the bioretention surface, velocities need to be kept low to avoid scouring of collected pollutants and vegetation.

Bioretention swales can be installed at various scales, for example, in local streets or on large highways.

The treatment system operates by filtering surface flows through surface vegetation and then percolating runoff through prescribed filtration media that provide treatment through fine filtration, **extended detention** and some **biological uptake**. These media also provide flow retardation for frequent storm events and are particularly efficient at removing nutrients.

Bioretention systems 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 in close proximity to surrounding structures).

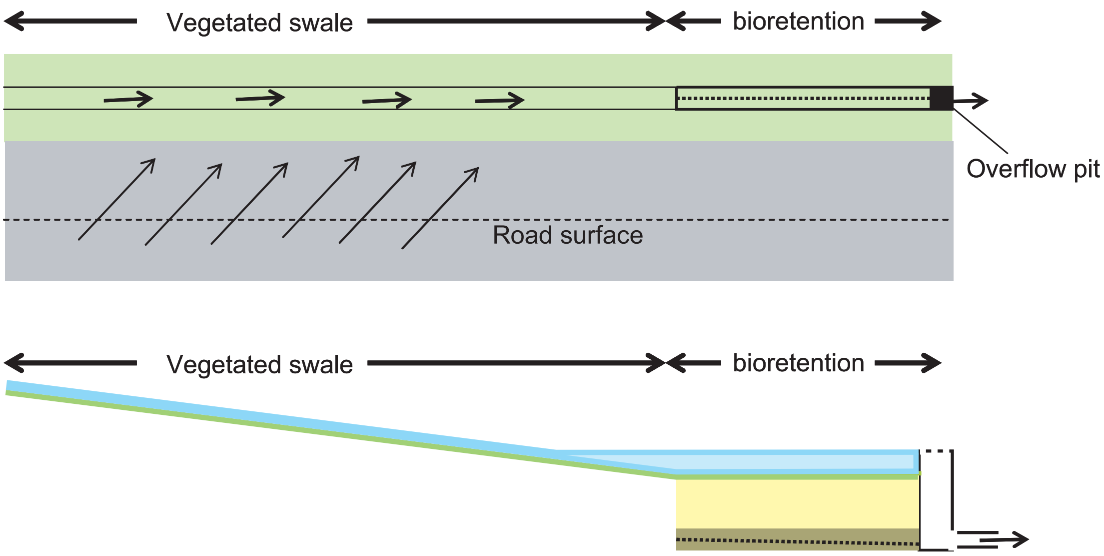

Figure 5.2 Bioretention swale example layout

Where bioretention systems are not intended to be infiltration systems, the dominant pathway for water is not via discharge into groundwater. Rather, these systems 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.

Runoff is filtered through a fine media layer as it percolates downwards. It is then collected via perforated pipes and flows to downstream waterways or storages for reuse (e.g. Figure 5.3).

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. Vegetation is critical to maintaining porosity of the filtration layer. Selection of an appropriate filtration media is a key issue. Sufficient hydraulic conductivity (i.e. passing water through the filtration medium as quickly as possible) needs to be balanced with stormwater detention for treatment and provision of a suitable growing medium to support vegetation growth (i.e. retaining sufficient soil moisture and organic content). Typically a sandy loam is suitable, but soils can be tailored to a vegetation type.

A bioretention trench could consist of three layers (Figure 5.3). In addition to the filtration media, a drainage layer is required to convey treated water into the perforated underdrains. This

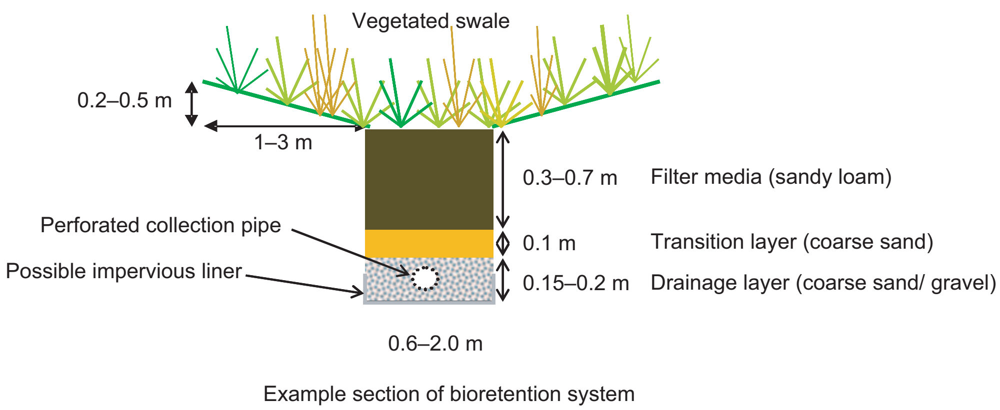

Figure 5.3 Typical section of a bioretention swale.

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 (with a mesh size equivalent to sand size) to prevent any filtration media being washed into the perforated pipes.

Another design component is keeping traffic and deliveries off bioretention swales. Traffic tends to ruin the vegetation, provide ruts that cause preferential flow paths that do not offer filtration and compact the filter media, thus reducing treatment flows. Traffic can be controlled by selecting vegetation that discourages the movement of traffic or by providing physical barriers. For example, barrier kerbs with breaks in them (to allow distributed water entry, albeit with reduced uniformity of flows compared with flush kerbs) or bollards along flush kerbs can be used to prevent vehicle movement onto swales.

The design process for a bioretention swale involves designing the system for treatment and then ensuring the system can convey a minor flood.

Key design issues to be considered are:

1 verifying size and configuration for treatment
2 determining design capacity and treatment flows
3 calculating dimensions of the swale
4 specifying details of the filtration media
5 checking above-ground components:
   - velocities
   - design of inlet zone and overflow pits
   - above design flow operation
6 checking below-ground components:
   - soil media layer characteristics (filter, transition and drainage layers)
   - underdrain design and capacity
   - requirements for bioretention lining
7 recommending plant species and planting densities
8 providing maintenance.

5.2 Verifying size for treatment

The curves (Figures 5.4–5.6) show the pollutant removal performance expected for bioretention systems (either swales or basins) with varying depths of ponding. An important consideration with bioretention swales is to estimate an average ponding depth as the average depth is less than the maximum depth if the surface of the bioretention system is sloped with the swale.

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
- filter media particle size (d_{50}) 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). The X-axis is the area of bioretention expressed as a percentage of the bioretention area of the *impervious* contributing **catchment** area.

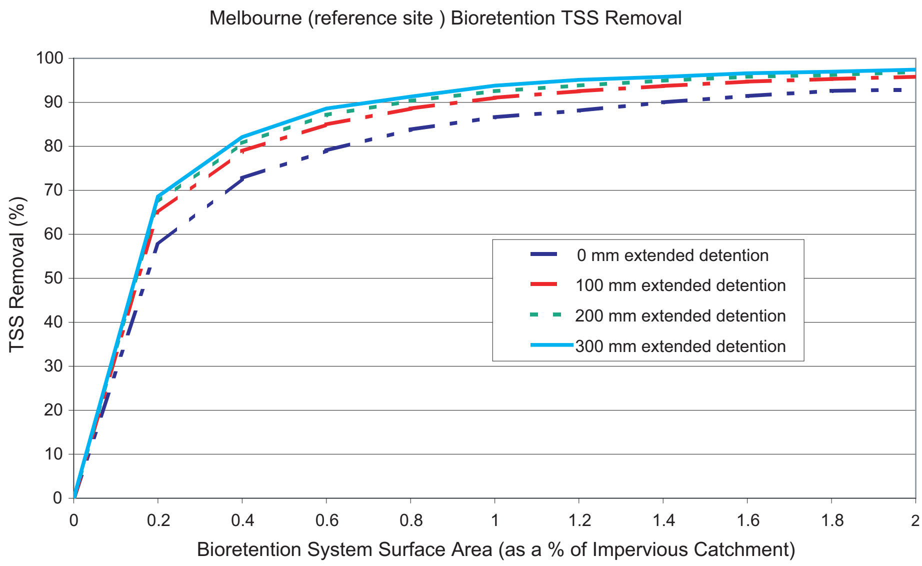

Figure 5.4 Performance of a bioretention system in removing Total Soluble Solids (TSS) in Melbourne.

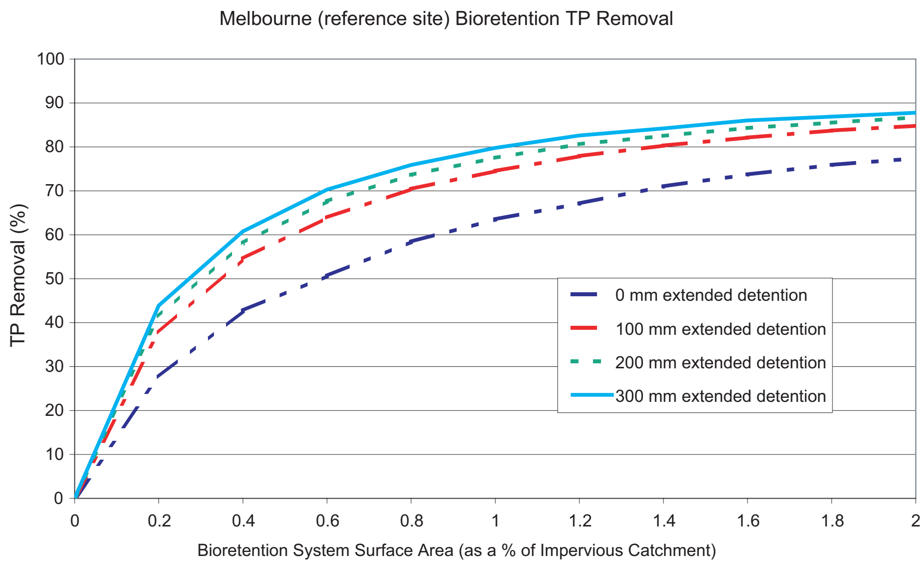

Figure 5.5 Performance of a bioretention system in removing Total Phosphorus (TP) in Melbourne.

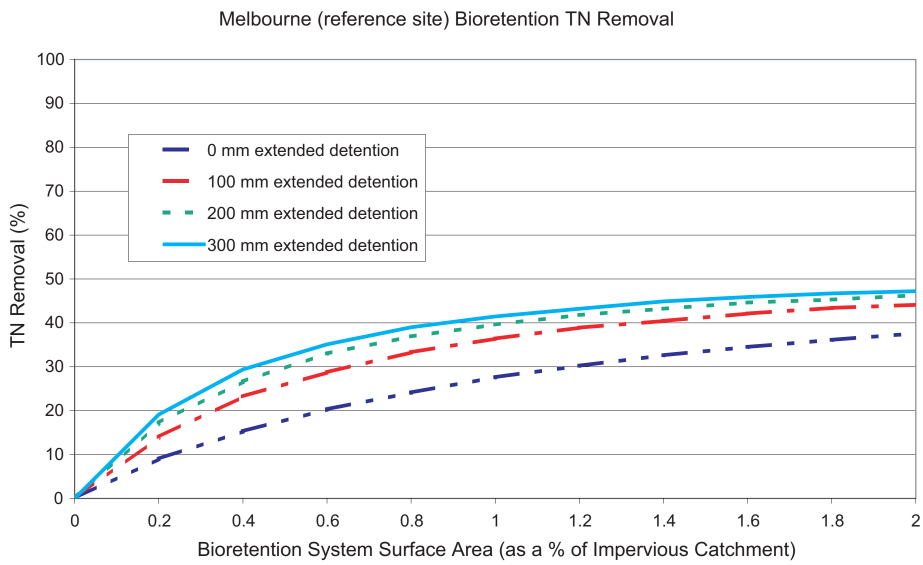

Figure 5.6 Performance of a bioretention system in removing Total Nitrogen (TN) in Melbourne.

5.3 Design procedure: bioretention swales

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

5.3.1 Estimating design flows

Three design flows are required for bioretention swales:

- minor flood rates (typically five-year ARI (Average Recurrance Interval)) 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 filter media to drain freely.

5.3.1.1 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.

5.3.1.2 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 5.1):

$$Q_{max} = k \times L \times W_{base} \times \frac{h_{max} + d}{d} \qquad \text{(Equation 5.1)}$$

where k is the hydraulic conductivity of the soil filter (m/s);
W_{base} is the base width of the ponded cross section above the soil filter (m);
L is the length of the bioretention zone (m);
h_{max} is the depth of pondage above the soil filter (m);
d is the depth of filter media.

5.3.2 Swale design

The swale design of a bioretention swale needs to be determined first to set the broad dimensions of the system. Typically the swale will be trapezoidal in shape with side slopes ranging from 1:9 to 1:3 (gradient) depending on local council regulations and any requirements for driveway crossings. The base of the swale is where a bioretention system can be installed. A minimum base width of 300 mm is suggested; however, this would more typically be 600–1000 mm.

The swale design either involves determining the width of swale required to pass the design flow for the minor drainage system if the catchment areas are known or determining the maximum length of swale prior to discharge into an overflow pit (i.e. maximum length of each cell) for a given width of swale.

Manning's equation is used to size the swale given the site conditions. Selection of an appropriate **Manning's *n*** is a critical consideration (see Section 5.3.2.2) and this will vary depending on the vegetation type. Consideration of landscape and maintenance elements of vegetation will need to be made before selecting a vegetation type.

5.3.2.1 Slope considerations

Two considerations are required for the swale component of a bioretention swale: side slopes and longitudinal slopes.

Selection of an appropriate side slope depends on local council regulations and will relate to traffic access and the provision of driveway crossings (if required). The provision of driveway

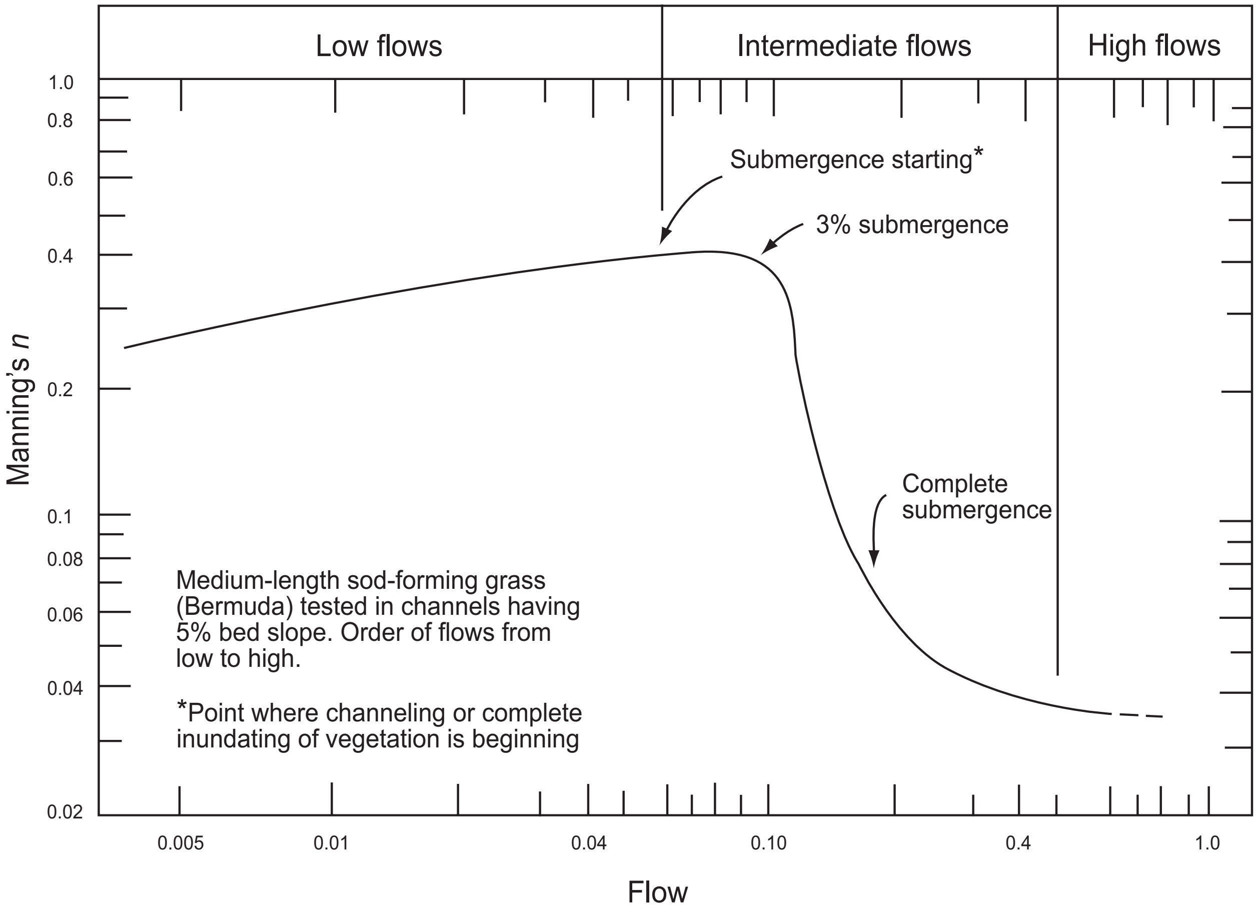

Figure 5.7 The effect of flow depth on hydraulic roughness (after Barling and Moore 1993).

crossings can significantly affect the required width of the swale/bioretention system. Driveway crossings can either be 'elevated' or 'at-grade'. Elevated crossings provide a culvert along the swale to allow flows to continue downstream, whereas at-grade crossings act as small fords and flows pass over the crossings. The slope of at-grade crossings (and therefore the swale) are governed by the trafficability of the change in slope across the base of the swale. Typically 1:9 side slopes, with a small flat base, will provide sufficient transitions to allow for suitable traffic movement.

Where narrower swales are required, elevated crossings can be used (with side slopes typically of 1:5) which will require provision for drainage under the crossings with a culvert or similar structure.

Crossings can provide good locations for promoting extended detention within the bioretention swale and also for providing overflow points in the bioretention swale that can also be used to achieve ponding over a bioretention system (e.g. Figure 5.2). The distance between crossings will determine the feasibility of having overflow points at each one.

Selection of an appropriate crossing type should be made in consultation with urban and landscape designers.

5.3.2.2 Selection of Manning's *n*

Manning's *n* is a critical variable in the Manning's equation relating to roughness of the channel. It varies with flow depth, channel dimensions and the vegetation type. For constructed swale systems, the values are recommended to be between 0.15 and 0.4 for flow depths shallower than the vegetation height (preferable for treatment) and significantly lower (e.g. 0.03) for flows with greater depth than the vegetation. It is considered reasonable for Manning's *n* to have a maximum at the vegetation height and then sharply reduce as depths increase. Figure 5.7 shows a plot of varying Manning's *n* with flow depth for a grass swale. It is reasonable to expect the shape of the Manning's *n* relation with flow depth to be consistent with other swale configurations, with the vegetation height at the boundary between 'Low flows' and

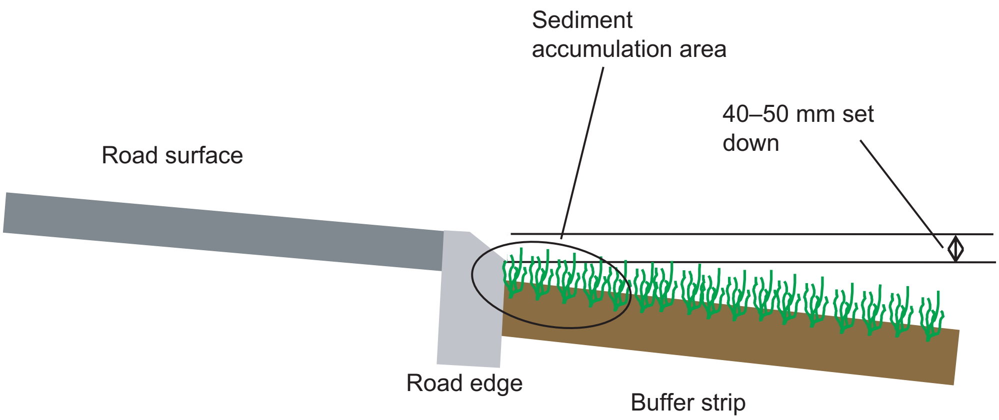

Figure 5.8 A flush kerb without setdown (photograph), edge detail showing setdown.

'Intermediate flows' (Figure 5.7) on the top axis of the diagram. The bottom axis of the plot has been modified from Barling and Moore (1993) to express flow depth as a percentage of vegetation height.

Further discussion on selecting an appropriate Manning's *n* for swales is provided in Appendix E of the MUSIC modelling manual (Cooperative Research Centre for Catchment Hydrology 2003).

5.3.3 Inlet details

Stormwater inflow to bioretention swales can be uniformly distributed (e.g. from flush kerbs along a road) or directly from pipe outlets. Combinations of these two entrance pathways can be used.

5.3.3.1 Distributed inflows

An advantage of flows entering a swale system in a distributed manner (i.e. entering perpendicular to the direction of the swale) is that inflows are distributed and inflow depths are shallow which maximises contact with vegetation. This provides good pretreatment prior to flows entering the bioretention system. Creating distributed inflows can be achieved either by having flush kerbs or by using kerbs with regular breaks (Figure 5.9).

For distributed inflows, an area off the road surface is needed for coarse sediments to accumulate.. Sediment can accumulate on a street surface where the vegetation is at the same level as the road (Figure 5.8, photograph). To avoid this accumulation, a tapered flush kerb can be used that sets the top of the vegetation between 40 mm and 50 mm lower than the road surface (Figure 5.8), which requires the top of the ground surface (before turf is placed) to be between 80 mm and 100 mm below the road surface. This allows sediments to accumulate off any trafficable surface.

Figure 5.9 Kerbs with breaks to distribute inflows.

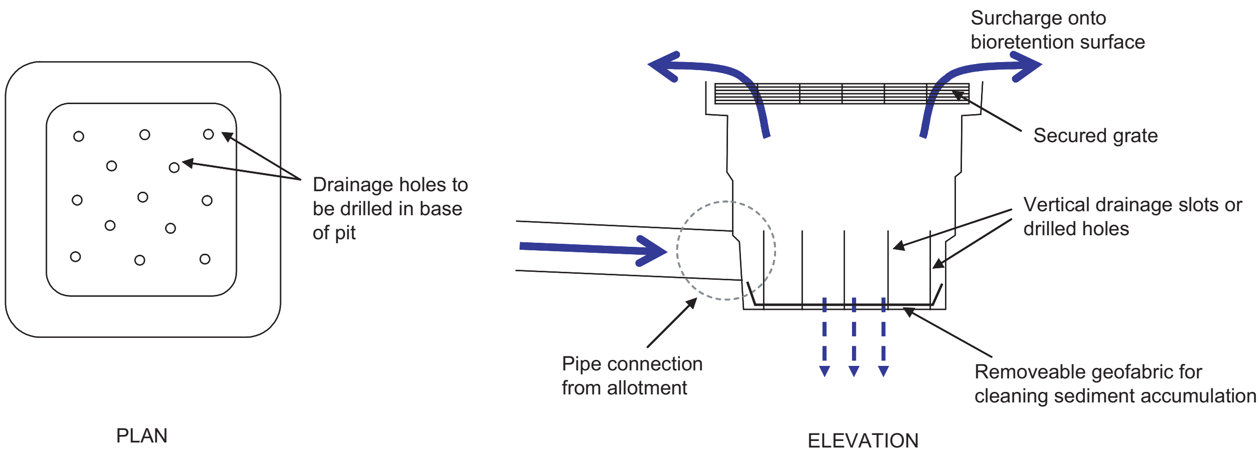

Figure 5.10 A surcharge pit for discharging allotment runoff into a bioretention swale.

5.3.3.2 Direct entry points

Direct entry of flows can be either through a break in a kerb or from a pipe system. Entrances through kerb breaks may cause some level of water ponding around the entry points. The width of the flow inundation on the road prior to entry will need to be checked and the width of the required opening determined to meet Council requirements (see Chapter 6, Section 6.3.2.1).

For piped entrances into bioretention swales, energy dissipation at the pipe outlet point is an important consideration to minimise any erosion potential. This can usually be achieved with rock beaching and dense vegetation or pipe outlet structures with specific provision for energy dissipation.

The most common constraint on this system is bringing the outlet pipe to the surface of the bioretention swale within the available width. Generally the maximum width of the system will be fixed, as will maximum **batter slopes** along the swale (1:5 is typical; however, 1:3 may be possible for shallow systems with bollards). Further constraints are the cover required for a pipe that crosses underneath a road, as well as the required grade of the pipe. These constraints need to be considered carefully.

In situations where geometry does not permit the outlet pipe to reach the surface, a surcharge pit can be used to bring flows to the surface. This is considered preferable to discharging flows below the surface directly into the bioretention filter media because of blockage potential and inability to monitor operation.

Surcharge pits should be designed so that they are as shallow as possible and they should also have pervious bases to avoid long term ponding in the pits and to allow flows from within the pits to drain through the bioretention media and receive treatment. The pits need to be accessible so that any build-up of coarse sediment and debris can be monitored and removed if necessary.

These systems are most frequently used when allotment runoff is required to cross a road into a swale on the opposite side. Several allotments can usually be combined prior to crossing the road to minimise the number of road crossings. Figure 5.10 shows an example of a surcharge pit discharging into a bioretention swale.

5.3.4 Vegetation scour velocity check

Scour velocities over the vegetation along the swale need to be checked. Manning's equation is used to estimate the mean velocity in the swale. An important consideration is the selection of an appropriate Manning's *n* that suits the vegetation height (see Section 5.3.2.2).

Manning's equation should be used to estimate flow velocities and ensure that they are below:

- 0.5 m/s for flows up to the design discharge for the minor drainage system (e.g. five-year ARI)
- 1.0 m/s for flows up to the 100-year ARI.

5.3.4.1 Velocity check – safety

As swales are generally accessible by the public, the combined depth and velocities product needs to be from a public risk perspective. To avoid people being swept away by flows along swales, a velocity–depth product check should be performed for design flow rates (see Institution of Engineers 2001, Book VIII Section 1.10.4). Thus, the following standard needs to be met:

$$\text{Velocity (m/s)} \times \text{depth (m)} < 0.4\ \text{m}^2/\text{s}$$

Note: 0.35 m^2/s is used in the Melbourne Water region.

5.3.5 Size perforated collection pipes

Perforated or slotted collection pipes at the base of bioretention systems collect treated water for conveyance downstream. The collection pipes (there may need to be multiple pipes) 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 perforated pipes via a 'drainage layer' (typically fine gravel or coarse sand, 1–5 mm diameter). To convey water from the filtration media 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.

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 with a geotextile fabric providing the function of the transition layer.If gravel is used around the perforated pipes and the filtration media is finer than sand, 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.

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

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.

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

These checks can be performed using the equations outlined in the following sections, or alternatively manufacturers' design charts can be adopted to select appropriately sized pipes. Product information may be available from suppliers (e.g. from manufacturer's websites). Vinidex, www.vinidex.com.au; or Iplex, www.iplex.com.au).

5.3.5.1 Perforations inflow check

To estimate the capacity of flows through the perforations ($Q_{perforations}$), orifice flow conditions are assumed and a sharp-edged orifice equation can be used (Equation 5.2). 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 recommended.

$$Q_{perforations} = C \times A\sqrt{2gh}/B \qquad \text{(Equation 5.2)}$$

where g = Acceleration due to gravity (9.81 m/s^2)
A = total area of the orifice
h = maximum depth of water above the pipe
C = orifice coefficient
B = blockage factor

5.3.5.2 Perforated pipe capacity

The Colebrook-White equation (Equation 5.3) 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.

$$Q = [-2(2gDS_f)^{0.5}\log_{10}(k/(3.7D) + 2.51\nu/D(2gDS_f)^{0.5})] \times A \qquad \text{(Equation 5.3)}$$

Where Q = flow (m^3/s)
D = pipe diameter (m)
A = area of the pipe
S_f = pipe slope
k = wall roughness
ν = viscosity
g = gravity constant.

5.3.5.3 Drainage layer hydraulic conductivity

The composition of the drainage layer should be considered when selecting the perforated pipe system, as the slot sizes in the pipes may determine a minimum size of drainage layer particles. Coarser material (e.g. fine gravel) should be used if the slot sizes are large enough for sand to be washed into the slots.

The material size differential should be an order of magnitude between layers to avoid fine material being washed through the voids of a lower layer. Therefore, 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).

5.3.5.4 Impervious liner requirement

When bioretention systems are used as conveyance filtration devices (i.e. infiltration is not an objective) it is important to contain flows in the bioretention system. Stormwater is treated via filtration through a specified soil media with the filtrate collected by 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 largly on local soils and the hydraulic conductivity of the filtration media in the bioretention system. Typically the hydraulic conductivity of filtration media should be selected such that it is 1–2 orders of magnitude greater than the native surrounding soil profile to ensure that the preferred flow path is into the perforated underdrainage system.

During detailed design, it is good practice to provide an impervious liner when infiltration is not desired and where the saturated hydraulic conductivity of the surrounding soils is more than one order of magnitude lower than the filtration media (see chapter 11 of Engineers Australia 2003). This is only expected to be required in sandy loam to sandy soils and where infiltration is expected to create problems.

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

Should surrounding soils be very sensitive to any exfiltration from the bioretention system (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 the bioretention trench. The greatest risk of exfiltration is through the base of a 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. It is recommended that if lining is required, only the base and the sides of the *drainage layer* be lined. Furthermore, it is recommended that the base of the bioretention trench be shaped to promote a more defined flow path of treated water towards the perforated pipe.

5.3.6 High-flow route and overflow design

The design for high flows must safely convey flows up to the design storm for the minor drainage system (e.g. five-year ARI flows) to the same level of protection that a conventional stormwater system provides. Flows are to be contained within the bioretention swale. Where the capacity of the swale system is exceeded at a certain point along its length, an overflow pit is required. This discharges excess flows into an underground drainage system for conveyance downstream. The frequency of overflow pits is determined in the swale design (see Section 5.3.2 for a method to dimension the overflow pits).

Locations of overflow pits are variable, but it is desirable for them to be placed at the downstream end of the bioretention system and to have their inverts higher than the filter media to allow ponding and therefore more treatment of flow before bypass occurs.

Typically, grated pits are used and the allowable head for discharges is the difference in level between the invert and the nearby road surface. This should be at least 100 mm, but preferably more.

To size a grated overflow pit, two checks should be made to estimateeither drowned or free flowing conditions. A broad-crested **weir** equation (Equation 5.4) can be used to determine the length of weir required (assuming free-flowing conditions) (L) and an orifice equation (Equation 5.5) 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):

$$Q_{\text{minor}} = B \times C \times L \times H^{3/2} \qquad \text{(Equation 5.4)}$$

where Q_{minor} represents the flow through the minor drainage system (m^3/s), B = blockage factor (0.5), C = 1.7 and H = available head above the weir crest, and L = length of weir (m).

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 5.5):

$$Q_{\text{minor}} = B \times C \times A\sqrt{2gh} \qquad \text{(Equation 5.5)}$$

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

5.3.7 Soil media specification

At least two and possibly three types of soil media are required for the bioretention component of the system.

A filter media layer provides most of the treatment function, through fine filtration and also by supporting vegetation that enhances filtration. The vegetation also helps to keep the filter media porous and provides some uptake of nutrients and other contaminants in the 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 from 150 mm to 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.

5.3.7.1 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 subsidence 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 filter media 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 (i.e. similar hydraulic conductivity, 36–180 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 (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 hydraulic conductivity tests can demonstrate an adequate hydraulic conductivity (36–180 mm/hr).
- **Organic content** – between 5% and 10%, measured in accordance with AS1289 4.1.1.
- **pH** – is variable, but preferably neutral, with 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 a retardant to plant growth and denitrification should be rejected.

5.3.7.2 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 5.1).

Table 5.1 Saturated hydraulic conductivity for a range of media particle sizes (d_{50})
Engineers Australia (2003)

Soil type	Particle size (mm)	Saturated hydraulic conductivity (mm/hr)(m/s)	
Gravel	2	36 000	1×10^{-2}
Coarse sand	1	3 600	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}

5.3.7.3 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. Alternative material can also be used (such as recycled glass screenings) provided it is inert and free draining.

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

5.3.8 Vegetation specification

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

5.3.9 Design calculation summary

Bioretention Swales	CALCULATION CHECKLIST		
CALCULATION TASK	OUTCOME		CHECK
1 Identify design criteria			
Conveyance flow standard (ARI)		year	
Area of bioretention		m²	
Maximum ponding depth		mm	
Filter media type		mm/hr	☐
2 Catchment characteristics			
Cell A		m²	
Cell B		m²	
Slope		%	
Fraction impervious			
Cell A			
Cell B			☐
3 Estimate design flow rates			
Time of concentration			
Estimate from flow path length and velocities		minutes	☐
Identify rainfall intensities			
Station used for IFD data:			
Major flood – 100 year ARI		mm/hr	
Minor flood – 5 year ARI		mm/hr	
Peak design flows	Cell A, Cell B		
Q_{minor}		m^3/s	
Q_{100}		m^3/s	
Q_{infil}		m^3/s	☐
3 Swale design			
Appropriate Manning's *n* used?			☐
4 Inlet details			
Adequate erosion and scour protection?			☐
5 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	
Safety: Vel x Depth (<0.4)		m/s	☐
6 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	☐
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			

5.4 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).

5.4.1 Design assessment checklist

The *Bioretention Swale Design Assessment Checklist* presents the key design features that should be reviewed when assessing a design of a **bioretention swale**. 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).

5.4.2 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. After building, remove the interim measures and revegetate, possibly reusing turf at subsequent stages. Also divert flows around swales during building (i.e. divert to sediment controls).

Traffic and deliveries

Ensure traffic and deliveries do not access bioretention swales during construction. Traffic can compact the filter media and cause preferential flow paths. Deliveries (such as sand or gravel) can cause clogging if placed onto the surface of the bioretention system. Washdown wastes (e.g. concrete) can also cause blockage of filtration media and damage vegetation. Bioretention areas should be fenced off during the building phase and controls implemented to avoid washdown wastes.

Management of traffic during the building phase is particularly important and poses significant risks to the health of the vegetation and functionality of the bioretention system. Measures such as those proposed in the previous Section (e.g. staged implementation of final landscape) should be considered.

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 system's life, to avoid continuing problems. If problems occur in these events, then erosion protection should be enhanced.

Bioretention Swale Design Assessment Checklist					
Bioretention location:					
Hydraulics	Minor flood: (m³/s)		Major flood: (m³/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?					
Longitudinal slope of invert >1% and <4%?					
Mannings '*n*' selected appropriate for proposed vegetation type?					
Overall flow conveyance system sufficient for design flood event?					
Maximum flood conveyance width does not impact on traffic amenity?					
Overflow pits provided where flow capacity exceeded?					
Inlet flows appropriately distributed?					
Energy dissipation provided at inlet?					
Velocities within bioretention cells will not cause scour?					
Set down of at least 50 mm below kerb invert					
Collection system				Y	N
Slotted pipe capacity > infiltration capacity of filter					
Transition layer/geofabric barrier provided to prevent clogging of drainage layer?					
Cells				Y	N
Maximum ponding depth and velocity will not impact on public safety (V x D <0.4)?					
Selected filter media hydraulic conductivity > 10x hydraulic conductivity of surrounding soil?					
Maintenance access provided to invert of conveyance channel?					
Protection from gross pollutants provided (for larger systems)?					
Vegetation				Y	N
Plant species selected can tolerate periodic inundation and design velocites?					
Plant species selected integrate with surrounding landscape design?					
Detailed soil specification included in design?					

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).

Tolerances

Tolerances are very important in the construction of bioretention swales (e.g. base, longitudinal and batters) – having flat surfaces is particularly important for well-distributed flow paths and even ponding over the surfaces. Generally plus or minus 50 mm is acceptable.

Erosion control

Immediately following earthworks it is good practice to revegetate all exposed surfaces with sterile grasses (e.g. hydroseed). These will stabilise soils, and prevent weed invasion but not future plantings from establishing.

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, temporary planting set up during construction for sediment control (e.g. with turf) can then be removed and the area planted out with long-term vegetation. Alternatively temporary (e.g. turf or sterile grass) can be used until a suitable season for 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). Other important considerations include the time of year and whether irrigation will be required during establishment.

Perforated pipes

Perforated pipes can be either a Polyvinyl Chloride (PVC) pipe with slots cut into its length 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.

Clean filter media

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

5.4.3 Construction checklist

CONSTRUCTION INSPECTION CHECKLIST

Bioretention swales

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					16. Location and levels of pits as designed				
2. Traffic control measures					17. Safety protection provided				
3. Location same as plans					18. Location of check dams as designed				
4. Site protection from existing flows					19. Swale crossings located and built as designed				
Earthworks									
5. Level bed of swale					20. Pipe joints and connections as designed				
6. Batter slopes as plans					21. Concrete and reinforcement as designed				
7. Dimensions of bioretention area as plans					22. Inlets appropriately installed				
8. Confirm surrounding soil type with design					23. Inlet erosion protection installed				
9. Provision of liner					24. Set down to correct level for flush kerbs				
10. Perforated pipe installed as designed					**Vegetation**				
11. Drainage layer media as designed					25. Stablisation immediately following earthworks				
12. Transition layer media as designed									
13. Filter media specifications checked					26. Planting as designed (species and densities)				
14. Compaction process as designed									
15. Appropriate topsoil on swale					27. Weed removal before stabilisation				
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.

5.4.4 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?		

5.5 Maintenance requirements

Bioretention swales treat runoff by filtering it through vegetation and then passing the runoff vertically through a filtration media which filters the runoff. In addition, they are used for flood conveyance and need to be maintained to ensure adequate flood protection for local properties.

Besides vegetative filtration, treatment relies upon detention, soil filtration and collection of runoff into an underdrain. Vegetation is key in maintaining the porosity of the soil media of the bioretention system and a strong healthy growth of vegetation is critical to its performance. The potential for rilling and erosion along the swale component of the system needs to be carefully monitored during establishment stages of the system.

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 affect plant growth, particularly in developing catchments with poor building controls.

Other components of the system that require careful consideration are the inlet points (if the system does not have distributed inflows). These inlets can be prone to scour and build-up of litter and surcharge pits, in particular, will require routine inspections. Occasional litter removal and potential replanting may be required.

Maintenance is primarily concerned with:

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

Vegetation maintenance will include:

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

Sediment accumulation at the inlet points needs to be monitored. Depending on the catchment activities (e.g. building phase) the deposition of sediment can tend to smother plants and reduce the available ponding volume. Should excessive sediment build-up, it will affect plant health and require removal before it reduces the infiltration rate of the filter media.

Similar to other types of stormwater 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.

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

5.5.1 Operation and maintenance inspection form

The *Bioretention Swale 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.

5.6 Bioretention swale worked example

5.6.1 Worked example introduction

Modelling using MUSIC was undertaken in developing a stormwater quality treatment system for a residential estate in Melbourne. The bioretention system makes up part of a larger system including downstream reuse. Because of the downstream treatment, TSS is the limiting pollutant for the bioretention system itself. This worked example describes the detailed design of a grass swale and bioretention system located in a median separating an arterial road and a local road within the residential estate. The layout of the catchment and bioretention swale is shown in Figure 5.11. A photograph of a similar bioretention swale in a median strip is shown in Figure 5.12 (although the case study is all turf).

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

Three crossings of the median are required and the raised access crossings can be designed as the separation mounds between the swale and bioretention treatment system, thus resulting in a two-cell system.

Each bioretention swale cell will treat its individual catchment area. Runoff from the arterial road is conveyed by the conventional kerb and gutter system into a stormwater pipe and discharged into the surface of the swale at the upstream end of each cell. Runoff from the local street can enter the swale as distributed inflow (sheet flow) along the length of the swale.

As runoff flows over the surface of the swale, it receives some pretreatment and coarse to medium-sized particles are trapped by vegetation on the swale surface. During runoff, flow is temporarily impounded in the bioretention zone at the downstream end of each cell. Filtered runoff is collected via a perforated pipe in the base of the bioretention zone. Flows in excess of the capacity of the filtration medium pass through the swale as surface flow and overflow into the piped drainage system at the downstream end of each bioretention cell.

Simulation using MUSIC found that the required area of the bioretention system to achieve a 80% reduction in TSS from values typically generated from urban catchments is approximately 61 m^2 and 22 m^2 for Cell A and B, respectively. The filtration medium used is sandy loam with a notional saturated hydraulic conductivity of 180 mm/hr. The required area of the filtration zone is distributed to the two cells according to their catchment area.

Bioretention Swale 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 swale?			
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?			
Set down from kerb still present?			
Damage/vandalism to structures present?			
Surface clogging visible?			
Drainage system inspected?			
Resetting of system required?			
Comments:			

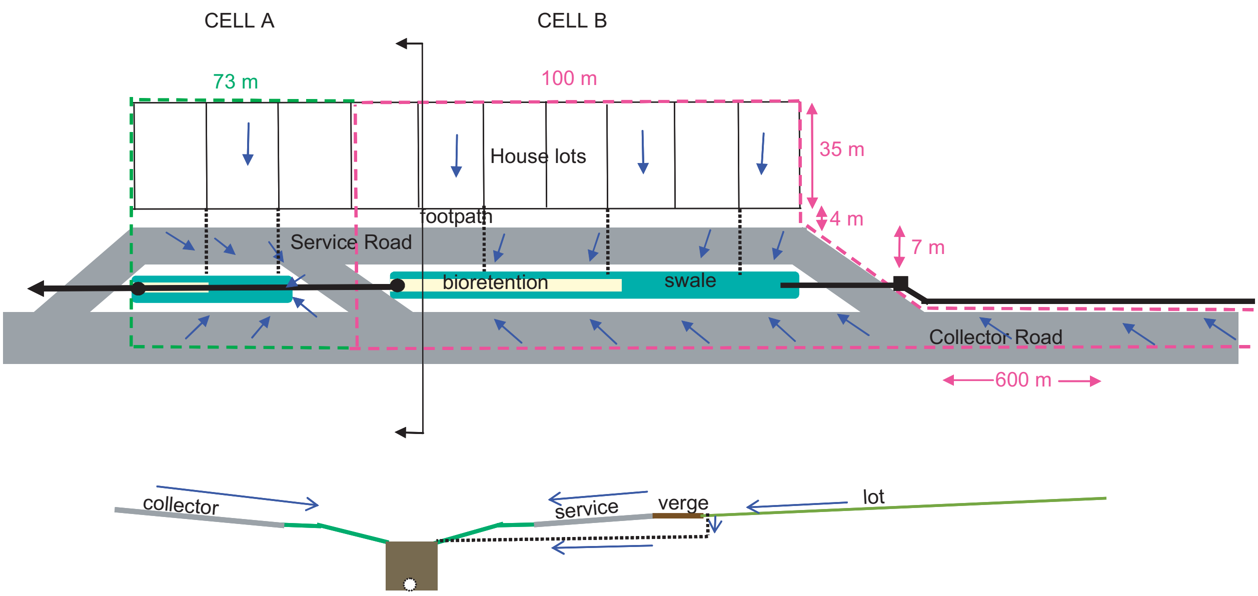

Figure 5.11 Catchment area layout and section for worked example of a stormwater quality treatment system for a residential estate in Melbourne.

5.6.1.1 Design objectives

The design objectives of the bioretention swale are to:

- use treatment to achieve a 80% reduction of TSS
- design the subsoil drainage pipe to ensure that the capacity of the pipe exceeds the saturated infiltration capacity of the filtration media (both inlet and flow capacity)

Figure 5.12 A bioretention swale.

- be able to convey safely design flows within up to 10-year ARI range into a piped drainage system without any inundation of the adjacent road
- check the hydraulics for the swale to confirm flow capacity for the 10-year ARI peak flow.
- create acceptable safety and scouring behaviour for an 100-year ARI peak flow.

5.6.1.2 Constraints and concept design criteria

The constraints and concept design criteria for the bioretention swale are that:

- depth of the bioretention filter layer shall be a maximum of 600 mm
- maximum ponding depth allowable is 200 mm
- width of median available for siting the system is 6 m
- the filtration medium available is a sandy loam with a saturated hydraulic conductivity of 180 mm/hr.

5.6.1.3 Site characteristics

The site characteristics for the bioretention swale are:

- urban, low density residential land use
- a 1.3% overland flow slopes for Cell A and B
- soil is clay
- fraction impervious is: 0.60 (lots); 0.90 (roads); 0.50 (footpaths); 0.0 (swale)
- catchment areas are as shown in Table 5.2.

Table 5.2 Catchment areas for the worked example of the bioretention swale
All measurements are in metres (length x width)

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

5.6.2 Confirm size for treatment

Interpretation of Figures 5.4 to 5.6 with the input parameters below is used to estimate the reduction performance of the bioretention system to ensure the design will achieve target pollutant reductions.

- Melbourne location
- 200 mm extended detention
- treatment area to impervious area ratio: Cell A – 61 m^2/ 6710 m^2 = 0.89%; Cell B – 22 m^2/ 2599 m^2 = 0.85%.

From the TSS graph, the expected pollutant reduction is 92% for TSS which exceeds the design requirement of 80%.

5.6.3 Estimating design flows

With a small catchment the Rational Method Design Procedure is considered an appropriate approach to estimate the 10-year and 100-year ARI peak flow rates. The steps in these calculations follow.

5.6.3.1 Major and minor design flows

Time of concentration (t_c)

Approach: Cell A and Cell B are effectively separate elements for the purpose of sizing the swales for flow capacity and inlets to the piped drainage system for a 10-year ARI peak flow event. Therefore, the t_c are estimated separately for each cell.

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

Following the procedures in *Australian Rainfall and Runoff* (Institution of Engineers 2001), the following t_c values are estimated:

t_c – Cell A : 10 min
t_c – Cell B: 8 min.

Design rainfall intensities

Adopt the values from IFD (Intensity–Frequency Duration) table for Melbourne (Table 5.3).

Table 5.3 Rainfall intensities for selected catachments

	t_c	100 yr	10 yr
Cell A	10 min	135	77
Cell B	8 min	149	85

Design runoff coefficient

To calculate the design runoff coefficient, apply the method outlined in ARR (Institution of Engineers 2001, Book VIII, Section 1.5.5 iii):

$C^1_{10} = 0.1 + 0.0133\ ({}^{10}I_1 - 25)$, where C^1_{10} is the pervious runoff coefficient
$C_{10} = 0.9f + C^1_{10}\ (1\ [-]\ f)$, where f is the fraction impervious.
The fraction impervious is calculated using the following f values:

- roads, f = 0.90
- footpaths, f = 0.5
- swales, f = 0.0
- lots, f = 0.6.

Therefore, for Cell A (area weighted), f = 0.70
For Cell B (area weighted), f = 0.61
C_{10} for Cell A = 0.67

C_{10} for Cell B = 0.61
$C_y = F_y\ C_{10}$ (F_y from Table 1.6 Institution of Engineers 2001 Book VIII)

Table 5.4 Design runoff coefficients and flows

	C_{10}	C_{100}
Cell A	0.67	0.80
Cell B	0.61	0.73

Peak design flows

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

$$Q = 0.00278.\ CIA\ (\text{m}^3/\text{s})$$

	Q_{10}	Q_{100}
Cell A	0.14	0.29
Cell B	0.06	0.11

5.6.3.2 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 (k) of the media and the head above the pipes (h_{max}) and applying Darcy's equation (see Equation 5.1):
Hydraulic conductivity = 180 mm/h
Flow capacity of the infiltration media, Q_{max} (assuming no blockage)

$$Q_{max} = k \times L \times W_{base} \times \frac{h_{max} + d}{d}$$

$$Q_{max} = 5E10^{-5} \times L \times W_{base}\left(\frac{0.2 + 0.6}{0.6}\right) \qquad \text{(Equation 5.6)}$$

Therefore, completing the above calculations gives a result of maximum infiltration rate Cell A = 0.004 m^3/s, and maximum infiltration rate Cell B = 0.001 m^3/s.

5.6.4 Swale design

The swales need to be sized such that they can convey 10-year ARI flows into the underground pipe network without water encroaching on the road. Manning's equation is used with the following parameters. Note the depth of the swale (and hence the side slopes) were determined by the requirement of discharging allotment runoff onto the surface of the bioretention system. Given the cover requirements of the allotment drainage pipes as they flow under the service road (550 mm minimum cover), it set the base of the bioretention systems at 0.76 m below the road surface.

- Base width of 1 m with 1:3 side slopes, maximum depth of 0.76 m
- Grass vegetation (assume n = 0.045 for 10-year ARI with flows above grass height)
- 1.3% slope.

The approach taken is to size the swale to accommodate flows in Cell A and then adopt the same dimension for Cell B for aesthetic reasons (Cell B has lower flow rates).

The maximum capacity of the swale (Equation 5.7) is estimated by adopting a 150 mm freeboard (i.e. maximum depth is 0.61 m).

$$Q_{cap} = 2.1\ \text{m}^3/\text{s} > 0.14\ \text{m}^3/\text{s} \qquad \text{(Equation 5.7)}$$

Q_{cap} = flow capacity of the swale

Therefore, there is adequate capacity given the relatively large dimensions of the swale to accommodate allotment runoff connection.

5.6.5 Inlet details

There are two mechanisms for flows to enter the system: underground pipes (either from the upstream collector road into cell 1 or from allotment runoff); and direct runoff from the road and footpaths.

Flush kerbs with a 50 mm set down are intended to be used to allow for sediment accumulation from the road surfaces.

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

5.6.6 Vegetation scour velocity check

Assume Q_{10} and Q_{100} will be conveyed through the swale/bioretention system. Check for scouring of the vegetation by checking that velocities are below 0.5 m/s during Q_{10} and 1.0 m/s for Q_{100}.

Using Manning's equation (to solve for depth for Q_{10} and Q_{100} gives the following results:

Q_{10} = 0.14 m^3/s, depth = 0.15 m (with n = 0.3), velocity = 0.09 m/s < 0.5 m/s – therefore, OK.

Q_{100} = 0.29 m^3/s, depth = 0.32 m (with n = 0.05), velocity = 0.49 m/s < 1.0 m/s – therefore, OK.

Hence, the swale and bioretention system can satisfactorily convey the peak 10-year and 100-year ARI flood, with minimal risk of vegetation scour.

5.6.6.1 Velocity check – safety

The velocity–depth product in Cell A during peak 100-year ARI flow must be checked for pedestrian safety criteria (Equation 5.8). As v = 0.49 m/s (calculated in Section 5.6.6), and d = 0.32 m, then:

$$v \times d = 0.49 \times 0.32 = 0.16 < 0.4\, m^2/s \qquad \text{(Equation 5.8)}$$

(Institution of Engineers 2001 Book VIII Section 1.10.4)

Therefore, velocities and depths are OK.

5.6.7 Sizing of perforated collection pipes

5.6.7.1 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 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 [x] 7.5) =93.3

Assume orifice flow conditions – $Q = CA\sqrt{2gh}$ (see Equation 4.6)

C = 0.61 (assume slot width acts as a sharp-edged orifice, see Equation 5.2).

Inlet capacity per metre of pipe =

$$[0.61 \times (0.0015 \times 0.0075) \times \sqrt{2} \times 9.81 \times 0.85] \times 93.3$$
$$= 0.0025\ \text{m}^3/\text{s}$$

Inlet capacity per metre × total length for each of Cells A and B:
Cell A = 0.0025 × 61 = 0.15 m^3/s > 0.003 (max infiltration rate), hence one pipe has sufficient perforation capacity to pass flows into the perforated pipe.
Cell B = 0.0025 × 22 = 0.05 m^3/s > 0.001 (max infiltration rate), hence 1 pipe is sufficient.

5.6.7.2 Perforated pipe capacity

The Colebrook-White equation 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 5.3):

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

Adopt: $D = 0.10$ 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) > 0.003 m^3/s (Cell 1) 0.001 m^3/s (Cell 2), and hence one pipe is sufficient to convey maximum infiltration rate for both Cells A and B.

Adopt 1 × ϕ (diameter) 100 mm perforated pipe for the underdrainage system in both Cell A and Cell B.

5.6.7.3 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 layer into the perforated pipe, a transition layer is to be used. This is to be 100 mm of coarse sand.

5.6.7.4 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 required.

5.6.8 Overflow design

The overflow pits are required to convey 10-year ARI flows safely from above the bioretention systems and into an underground pipe network. Grated pits are to be used at the downstream end of each 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, less freeboard (i.e. 0.76 – (0.2 + 0.15)= 0. 41 m).

First, check using a broad-crested weir equation (see Equation 5.4):

$$Q_{minor} = B \times C \times L \times H^{3/2}$$

where $B = 0.5$, $C = 1.7$ and $H = 0.41$, and solving for L

Gives $L = 0.62$ m of weir length required (equivalent to 155 × 155 mm pit).

Second, check for drowned conditions (see Equation 5.5):

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

$0.14 = 0.5 \times 0.6 \times A \times \sqrt{2g} \times 0.41$ gives $A = 0.16$ m^2 (equivalent to 400 × 400 pit).

Hence, drowned outlet flow conditions dominate, adopt pit sizes of 450 × 450 mm for both Cell A and Cell B as this is minimum pit size to accommodate underground pipe connections.

5.6.9 Soil media specification

Three layers 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 sectionsbelow.

5.6.9.1 Filter media specifications

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

- hydraulic conductivity between 50 mm/hr and200 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.

5.6.9.2 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 as follows: percentage passing 1.4 mm, 100%; 1.0 mm, 80%; 0.7 mm, 44%; 0.5 mm, 8.4%.

5.6.9.3 Drainage layer specifications

The drainage layer is to be 5 mm screenings.

5.6.10 Vegetation specification

To complement the landscape design of the area, a grass species is to be used. For this application a turf with maximum height of 100 mm has been assumed. The actual species will be selected by the landscape designer.

5.6.11 Calculation summary

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

Bioretention Swales	CALCULATION SUMMARY		
CALCULATION TASK	OUTCOME		CHECK
1 Identify design criteria			
Conveyance flow standard (ARI)	10	year	
Area of bioretention	61 and 22	m^2	
Maximum ponding depth	200	mm	
Filter media type	180	mm/hr	✓
2 Catchment characteristics			
Cell A	9600	m^2	
Cell B	4200	m^2	
Slope	1.3	%	
Fraction impervious			
Cell A	70		
Cell B	0.61		✓
3 Estimate design flow rates			
Time of concentration			
Estimate from flow path length and velocities	Cell A – 10 Cell B – 8	minutes	✓
Identify rainfall intensities			
Station used for IFD data:			
Major flood – 100 year ARI		mm/hr	
Minor flood – 5 year ARI		mm/hr	
Peak design flows	Cell A, Cell B		
Q_{minor}	0.14, 0.06	m^3/s	
Q_{100}	0.29, 0.11	m^3/s	
Q_{infil}	0.003, 0.001	m^3/s	✓
3 Swale design			
Appropriate Manning's *n* used?	yes		✓
4 Inlet details			
Adequate erosion and scour protection?	rock pitching		✓
5 Velocities over vegetation			
Velocity for 5-year flow (<0.5 m/s)	0.09	m/s	
Velocity for 100-year flow (<1.0 m/s)	0.49	m/s	
Safety: Vel x Depth (<0.4)	0.16	m/s	✓
6 Slotted collection pipe capacity			
Pipe diameter	100	mm	
Number of pipes	1		
Pipe capacity	0.004	m^3/s	
Capacity of perforations	0.15	m^3/s	
Soil media infiltration capacity	0.003	m^3/s	✓
8 Overflow system			
System to convey minor floods	grated pits 450 x 450		✓
9 Surrounding soil check			
Soil hydraulic conductivity	3.6	mm/hr	
Filter media	180	mm/hr	
MORE THAN 10 TIMES HIGHER THAN SOILS?	YES		✓
10 Filter media specification			
Filtration media	sandy loam		
Transition layer	sand		
Drainage layer	gravel		✓
11 Plant selection	turf		

5.6.12 Construction drawings

Figure 5.13 shows the construction drawing for the worked example.

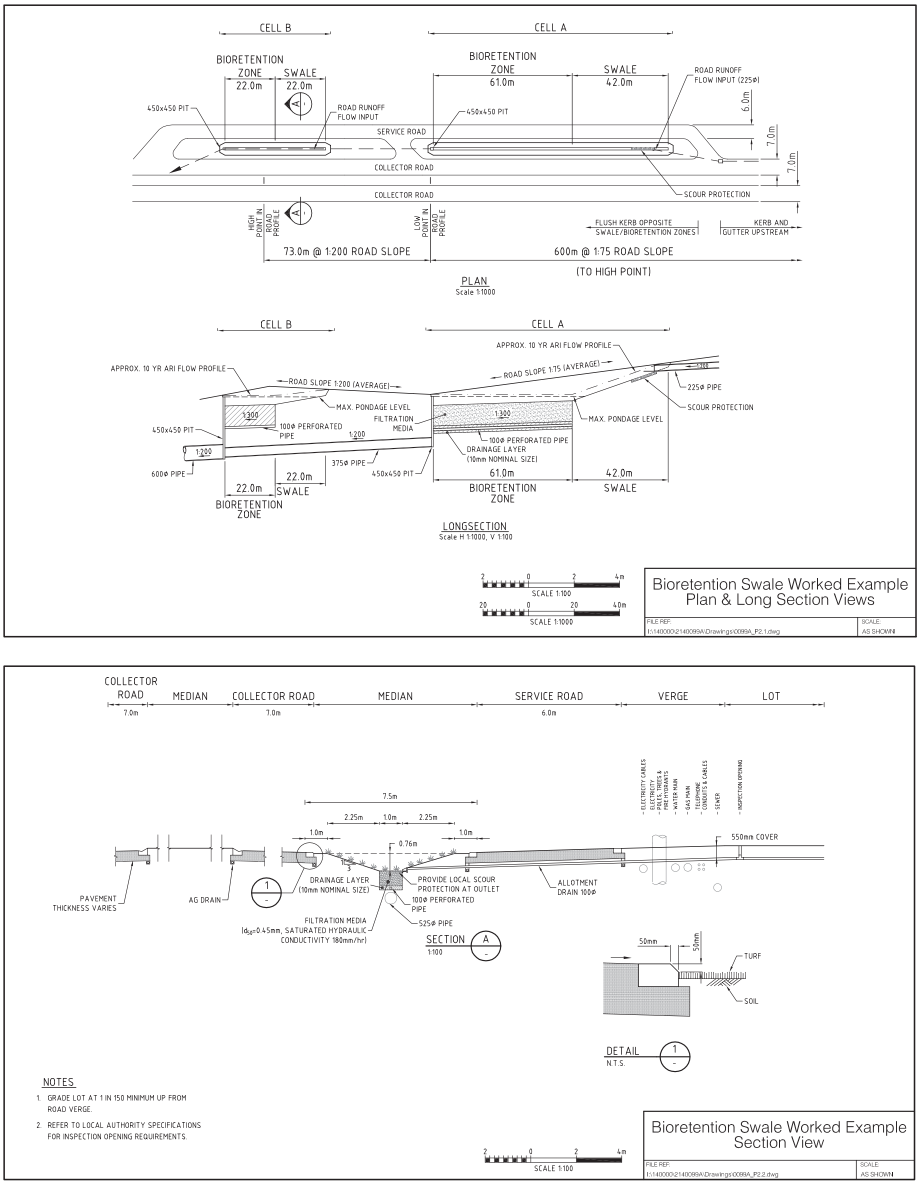

Figure 5.13 Construction drawing of the bioretention swale worked example, and a section view.

5.7 References

Barling, R.D. and Moore, I.D. (1993). The role of buffer strips in the management of waterway pollution. Paper presented at 'The role of buffer strips in the management of waterway pollution from diffuse urban and rural sources', The University of Melbourne.

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 2003.

Institution of Engineers, Australia (2001). *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.