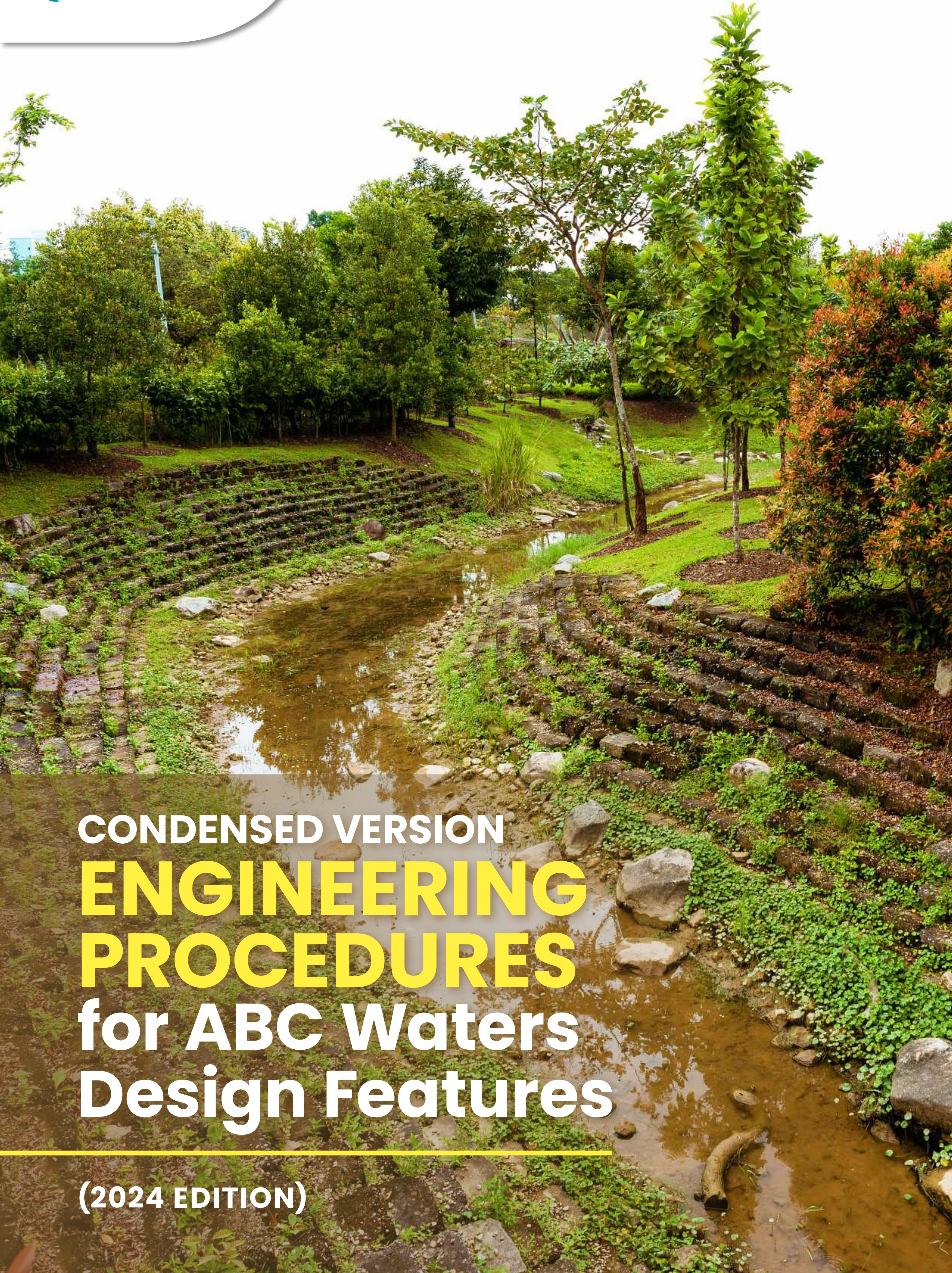
PUB SINGAPORE'S NATIONAL WATER AGENCY



CONDENSED VERSION

ENGINEERING PROCEDURES for ABC Waters Design Features

(2024 EDITION)

CONDENSED BOOKLET ON ENGINEERING PROCEDURES

This booklet contains 3 chapters of “Engineering Procedures for ABC Waters design features (2024 edition)” on Vegetated swales, Bioretention swales and Bioretention Basins. These 3 chapters concern the most commonly used ABC Waters design features in Singapore.

This booklet aims to serve as a handy reference for architects, engineers and landscape architects for designing, construction supervision and drawing up maintenance plans for these commonly used ABC Waters design features.

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Chapter 5 Swales and Buffer Strips

5.1 Introduction

Vegetated swales are used to remove coarse and medium sediments and convey stormwater in lieu of or with underground pipe drainage systems. They are commonly combined with buffer strips and bioretention systems (refer Chapter 6 - Bioretention Swales). Swales utilise overland flow and mild slopes to convey water slowly downstream. They protect waterways from damage by erosive flows from frequent storm events because swale flow velocities are slower than concrete drains.

The interaction between stormwater flow and vegetation within swale systems facilitates pollutant settlement and retention. Even swales with relatively low vegetation height (such as mown grass) can achieve significant sediment deposition rates provided flows are well distributed across the full width of the swale and the longitudinal grade of the swale is kept low enough (typically less than 4 % grade) to maintain slower flow conditions.

Swales alone cannot provide sufficient treatment to meet current stormwater treatment/ water quality objectives but can enable water quality objectives to be met by providing an important pretreatment function for other ABC Waters Design Features in a treatment train. Swales are particularly good at coarse sediment removal and can provide the necessary pretreatment for downstream treatment systems such as wetlands and bioretention basins. Some examples of swales are provided in Figure 5.1.

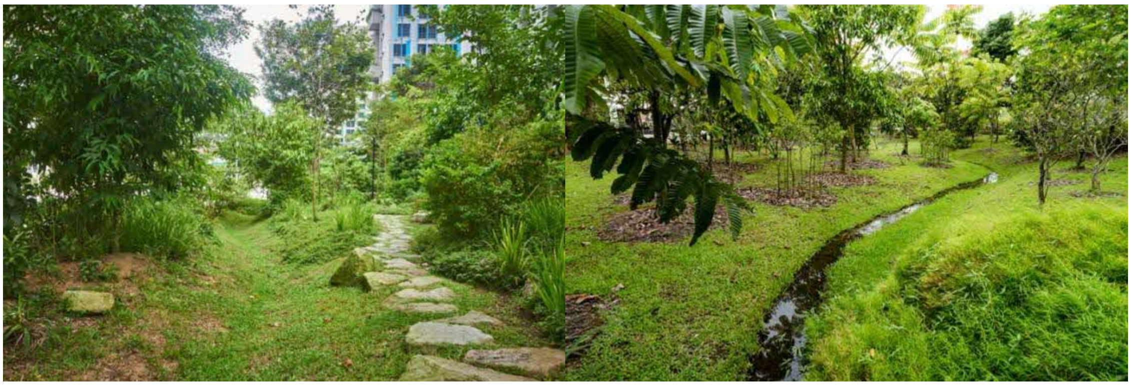


Figure 5.1 Swales in Singapore

Buffer strips (or buffers) are areas of vegetation through which runoff flows (as overland flow) to a discharge point. Sediment is deposited as flow passes through vegetation over a shallow depth. Effective treatment relies upon well distributed sheet flow. Vegetation slows flow velocities, encouraging coarse sediments to settle out of the water column. With the requirement for uniformly distributed flow, buffer strips are suited to treat road runoff in situations where road runoff is discharged via flush kerbs or through regular kerb ‘cut-outs’ or slotted kerbs. In these situations, buffer strips (located in the swale batter) can form part of a roadside swale system that receives the distributed inflows from the adjoining road pavement. The coverage of buffer strips in this chapter is limited to their application as part of a roadside swale system only. The reader is referred to *Australian Runoff Quality* (Engineers Australia 2006) for additional discussion on buffer strip design and for worked examples.

5.2 Design Considerations for Swales

5.2.1 Landscape Design

Swales may be located within parkland areas, easements, car parks or along road verges or centre medians. Landscape design of swales and buffer strips along the road edge can assist in defining the boundary of road or street corridors as well as enhancing landscape character. The landscape design of swales and buffers must address stormwater quality objectives whilst also incorporating landscape functions. As such, it is important that swales and buffers are carefully designed to integrate with the surrounding landscape character.

5.2.2 Hydraulic Design

Typically, swales are applicable for smaller scale contributing catchments. For larger catchments, dimension of swales may become too big for most urban areas in Singapore. Also, flow depths and velocities are such that the water quality improvement function of the swale, and its long-term function may be compromised. For water quality improvement, swales need only focus on ensuring frequent storm flows (typically up to the 3 month ARI flow) are conveyed within the swale profile. In most cases, however, a swale will also be required to provide a flow conveyance function as part of a minor drainage and/or major drainage system. In particular, swales located within road reserves must also allow for safe use of adjoining roadway, footpaths and bike paths by providing sufficient conveyance capacity to satisfy current engineering infrastructure design requirements as defined by PUB's Code of Practice on Surface Water Drainage. It may also be necessary to augment the capacity of the swale with underground drainage to satisfy the drainage requirements. This can be achieved by locating overflow pits (field inlet pits) along the invert of the swale that discharge into an underlying pipe drainage system. Careful attention should be given to the design of overflow pits to ensure issues of public safety (particularly when raised grates are being used) and aesthetic amenity are taken into account.

The longitudinal slope of a swale is another important hydraulic design consideration. Swales generally operate best with longitudinal slopes of between 1 % and 4 %. Slopes milder than this can become waterlogged and have stagnant ponding. However, the use of subsoil drains beneath the invert of the swale can alleviate this problem by providing a pathway for drainage of any small depressions that may form along the swale. For longitudinal slopes steeper than 4 %, check banks (e.g. small rock walls) along the invert of the swale, or equivalent measures, can help to distribute flows evenly across the swales, as well as reduce velocities and potential for scour. Check dams are typically low level rock weirs (e.g. 100 mm) that are constructed across the base of a swale. It is also important to protect the vegetation immediately downstream of check dams. Rock pitching can be used to avoid erosion.

A rule of thumb for locating check dams is for the crest of a downstream check dam to be at 4 % grade from 100 mm below the toe of an upstream check dam (refer Figure 5.2). The impact of check dams on the hydraulic capacity of the swale must be assessed as part of the design process.

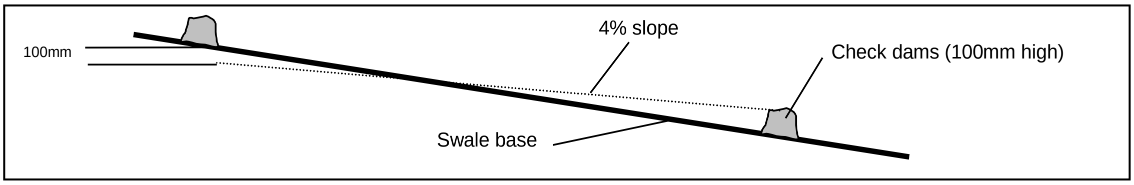


Figure 5.2 Location of Check Dams in Swales

Velocities within swales must be kept low to avoid scouring of collected pollutants and vegetation, preferably less than 0.5 m/s for minor flood flows (up to 10 year ARI events) and not more than 2.0 m/s for major flood flows (up to 100 year ARI events). Similar checks should also be undertaken to assess depth x velocity within the swale, at crossings and adjacent to pedestrian and bicycle pathways to ensure public safety criteria are satisfied. These are:

- depth x velocity < 0.6 m^2/s for low risk locations and 0.4 m^2/s for high risk locations (e.g. where pedestrian traffic is expected to be high)
- maximum flow depth on driveway crossings = 0.3 m.

5.2.3 Vegetation Types

Swales can use a variety of vegetation types including turf, sedges and tufted grasses. Vegetation is required to cover the whole width of the swale, be capable of withstanding design flows and be of sufficient density to prevent preferred flow paths and scour of deposited sediments (Figure 5.3).

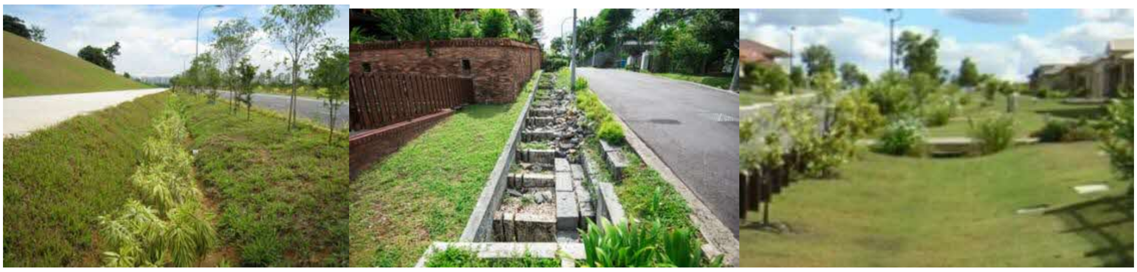


Figure 5.3 Swale systems: heavily vegetated (left), use of check dams (centre), grass swale with elevated crossings (right)

Turf swales are commonly used in residential areas. Turf swales should be mown and well maintained in order for the swale to operate effectively over the long term. Swales that are densely vegetated with tall vegetation offer improved sediment retention by slowing flows more and providing enhanced sedimentation for deeper flows. However, densely vegetated swales have higher hydraulic roughness and therefore require a larger area and/ or more frequent use of swale field inlet pits to convey flows compared to turf swales. Densely vegetated swales can become features of the urban landscape and once established, require minimal maintenance and are hardy enough to withstand larger flows.

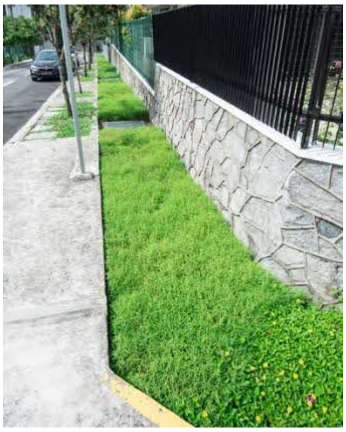


Figure 5.4 Swale incorporated into road reserve

The reader should consult the National Parks Board of Singapore for more specific guidance on the selection of appropriate vegetation for swales and buffers located within road reserves.

5.2.4 Driveway Crossings

A key consideration when designing swales along roadways is the requirement for provision of driveway crossings (or crossovers). 'Elevated' crossings are common in Singapore and raised above the invert of the swale (e.g. like a bridge deck or culvert, see Figure 5.5).

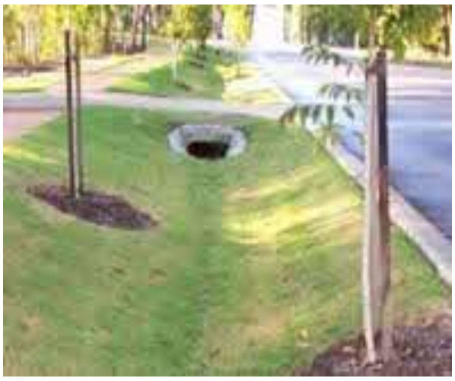


Figure 5.5 Elevated driveway crossings to allow vehicle access across swales (right)

'Elevated' crossings are applicable in Singapore. Where appropriate, they can be designed as streetscape features. They also provide an opportunity for locating check dams (to distribute flows) or to provide temporary ponding above a bioretention system (refer Chapter 6 – Bioretention Swales). A major limitation with 'elevated' crossings can be their high life cycle costs due to the need for on-going maintenance. Safety concerns with traffic movement adjacent to 'elevated' crossings and the potential for blockages of small culvert systems beneath the crossing are other possible limitations. These limitations can be overcome by careful design through the use of spanning crossings rather than using small culverts and through the use of durable decking materials in place of treated timber.

5.2.5 Traffic Controls

Another design consideration is keeping traffic and building materials off swales (particularly during the building phase of a development). If swales are used for parking, then the topsoil will be compacted and the swale vegetation may be damaged beyond its ability to regenerate naturally. In addition, vehicles driving on swales can cause ruts along the swale that can create preferential flow paths that will diminish the swale's water quality treatment performance as well as creating depressions that can retain water and potentially become mosquito breeding sites.

To prevent vehicles driving on swales and inadvertent placement of building materials, it is necessary to consider appropriate traffic control solutions as part of the swale design. These can include planting the swale with dense vegetation that will discourage the movement of vehicles onto the swale or, if dense vegetation cannot be used, providing physical barriers such as kerb and channel (with breaks to allow distributed water entry to the swale) or bollards and/ or street tree planting.

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

5.2.6 Roof Water Discharge

Roof water should be discharged onto the surface of the swale for subsequent conveyance and treatment by the swale (and downstream treatment measures) before being discharged to receiving aquatic environments. Depending on the depth of the roof water drainage system and the finished levels of the swale, this may require the use of a small surcharge pit located within the invert of the swale to allow the roof water to surcharge to the swale. Any residual water in the surcharge pit can be discharged to the underlying subsoil drainage by providing perforations in the base and sides of the surcharge pit. If a surcharge pit is used, an inspection chamber along the roof water drainage line is to be provided within the property boundary. Surcharge pits are discussed further in Section 5.3.4.3.

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

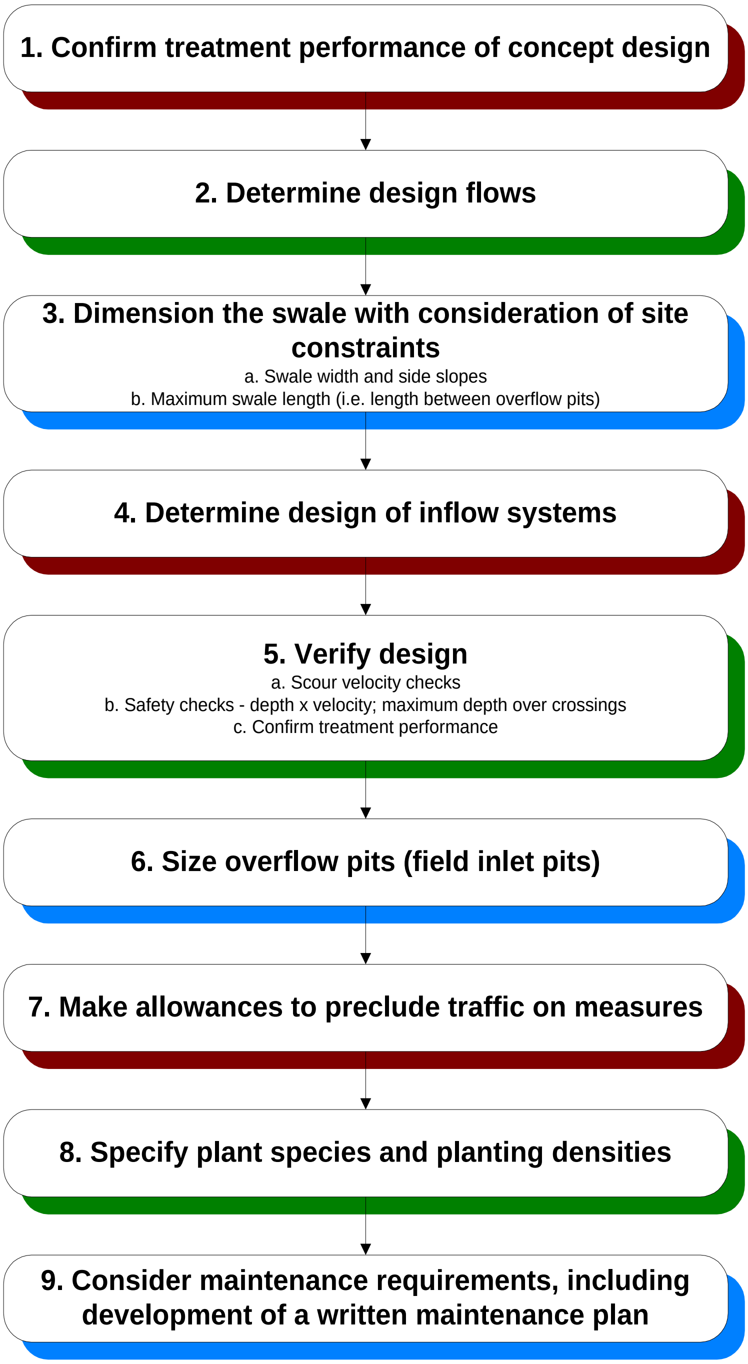
5.2.7 Services

Swales located within standard road reserves are to have services located within the services corridors in accordance with government requirements. Care should be taken to ensure the service conduits do not compromise the performance of the swale. Consideration will also need to be given to access to services for ongoing maintenance without the need to regularly disrupt or replace the swale.

5.3 Swale Design Process

The design process for swales involves in the first instance designing the swale to meet flow conveyance requirements and then ensuring the swale has the necessary design features to optimise its stormwater quality treatment performance.

The key design steps are:


1. Confirm treatment performance of concept design
2. Determine design flows
3. Dimension the swale with consideration of site constraints
a. Swale width and side slopes
b. Maximum swale length (i.e. length between overflow pits)
4. Determine design of inflow systems
5. Verify design
a. Scour velocity checks
b. Safety checks - depth x velocity; maximum depth over crossings
c. Confirm treatment performance
6. Size overflow pits (field inlet pits)
7. Make allowances to preclude traffic on measures
8. Specify plant species and planting densities
9. Consider maintenance requirements, including development of a written maintenance plan

Each of these design steps is discussed in the following sections. A worked example illustrating application of the design process on a case study site is presented in Section 5.7.

5.3.1 Step 1: Confirm Treatment Performance of Concept Design

Before commencing detailed design, the designer should first undertake a preliminary check to confirm the swale outlined on the concept design is adequate to deliver the level of stormwater quality improvement inferred within the concept design documentation. The swale treatment performance curves shown in Figure 5.6 to Figure 5.8 can be used to undertake this verification check.

The curves in Figure 5.6 to Figure 5.8 were derived using the Model for Urban Stormwater Improvement Conceptualisation (MUSIC), assuming the swale is a stand alone system (i.e. not part of a treatment train). The curves show the total suspended solid (TSS), total phosphorus (TP) and total nitrogen (TN) removal performance for a typical swale design, being:

- Top width 4.5 m
- Base width 1 m
- Side slopes 1 in 9

The curves in Figure 5.6 to Figure 5.8 are generally applicable to swale applications within residential, industrial and commercial land uses.

If the configuration of the swale concept design is significantly different to that described above, then a stormwater quality model such as MUSIC or equivalent should be used in preference to the curves in Figure 5.6 to Figure 5.8. The detailed designer should also use the stormwater quality model to verify swale concept designs that are part of a “treatment train”.

Swales should form part of the stormwater ‘treatment train’ as they will not achieve load-based pollutant reduction objectives on their own. Therefore, other stormwater quality best management practices should be incorporated into the surrounding catchment to augment the stormwater treatment performance of any proposed swale system.

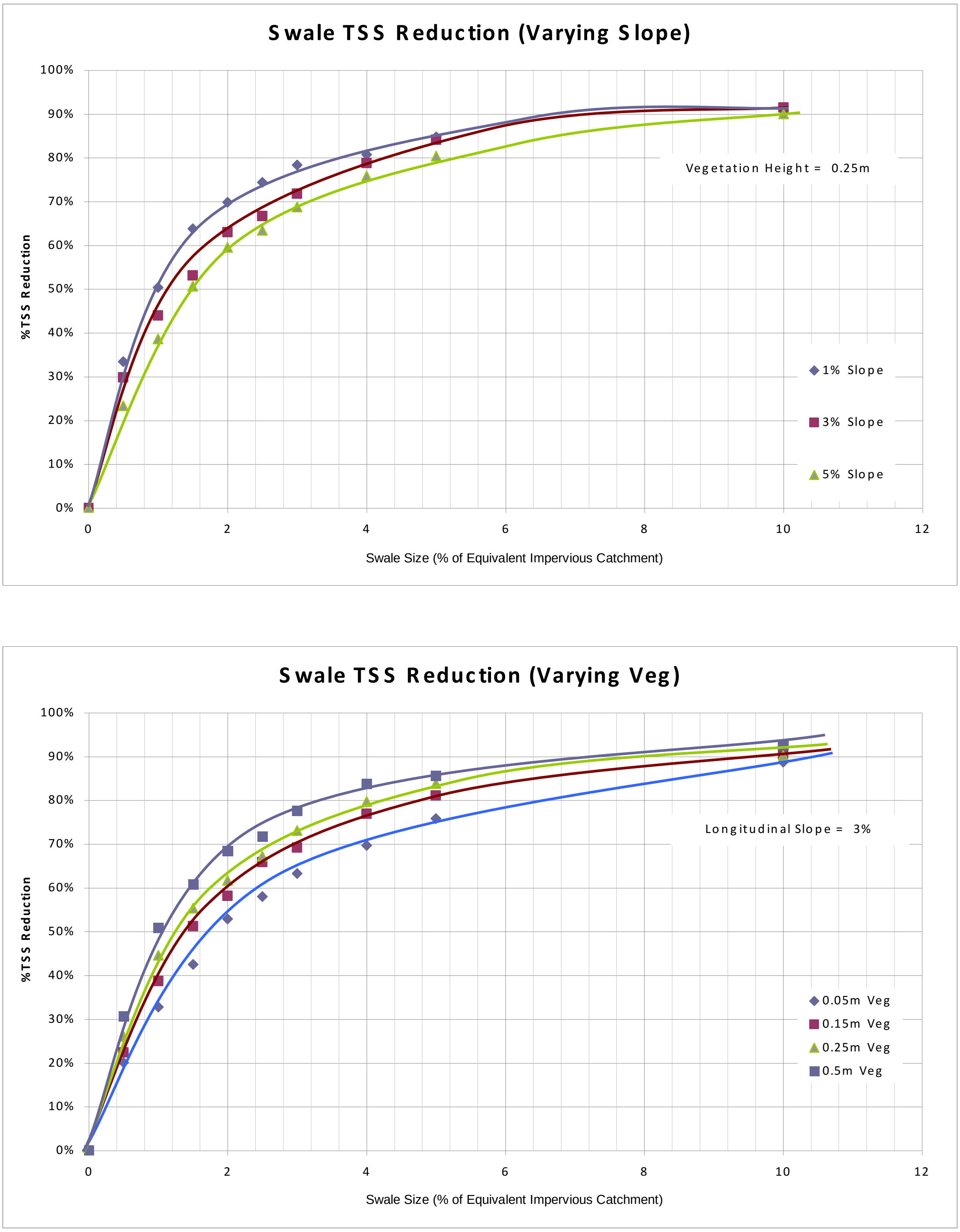
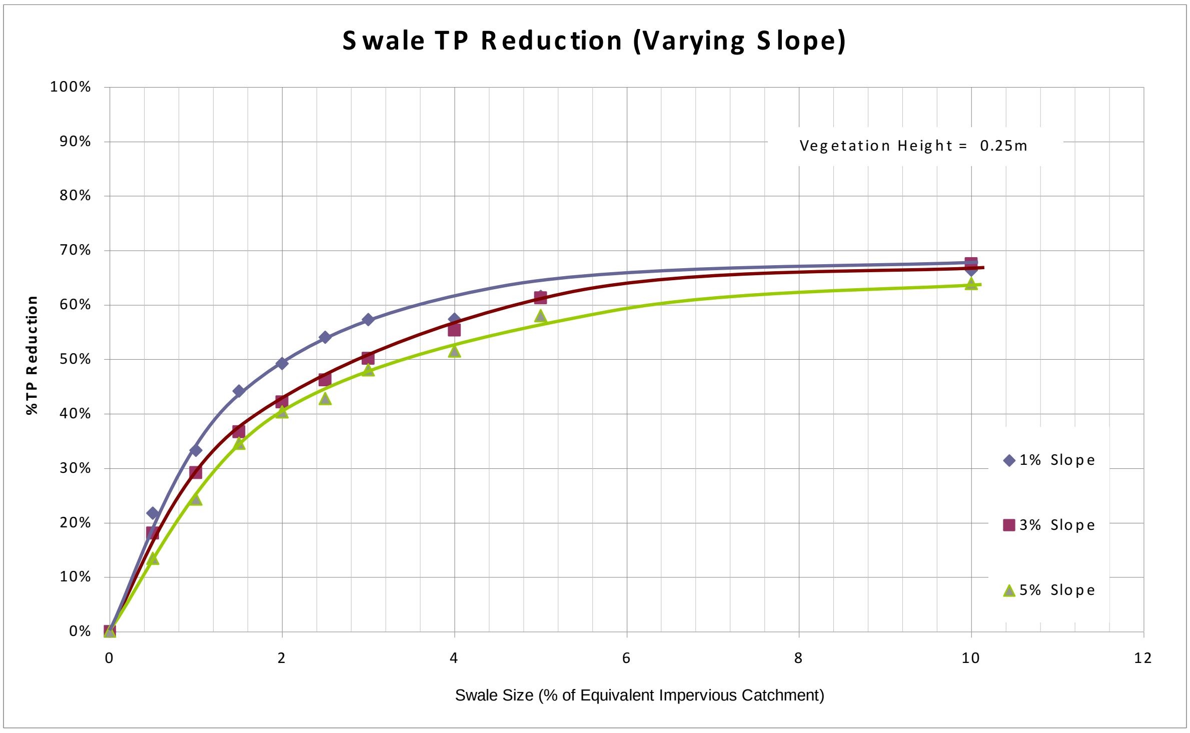


Figure 5.6 Swale TSS Removal Performance



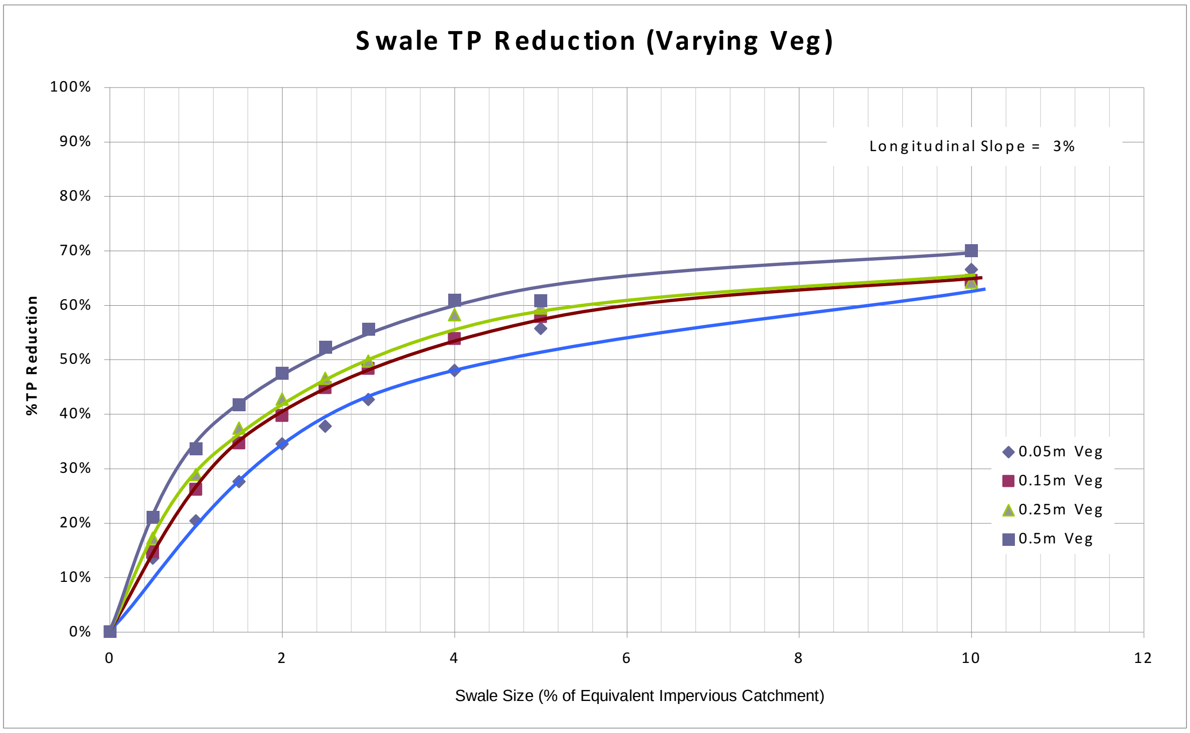
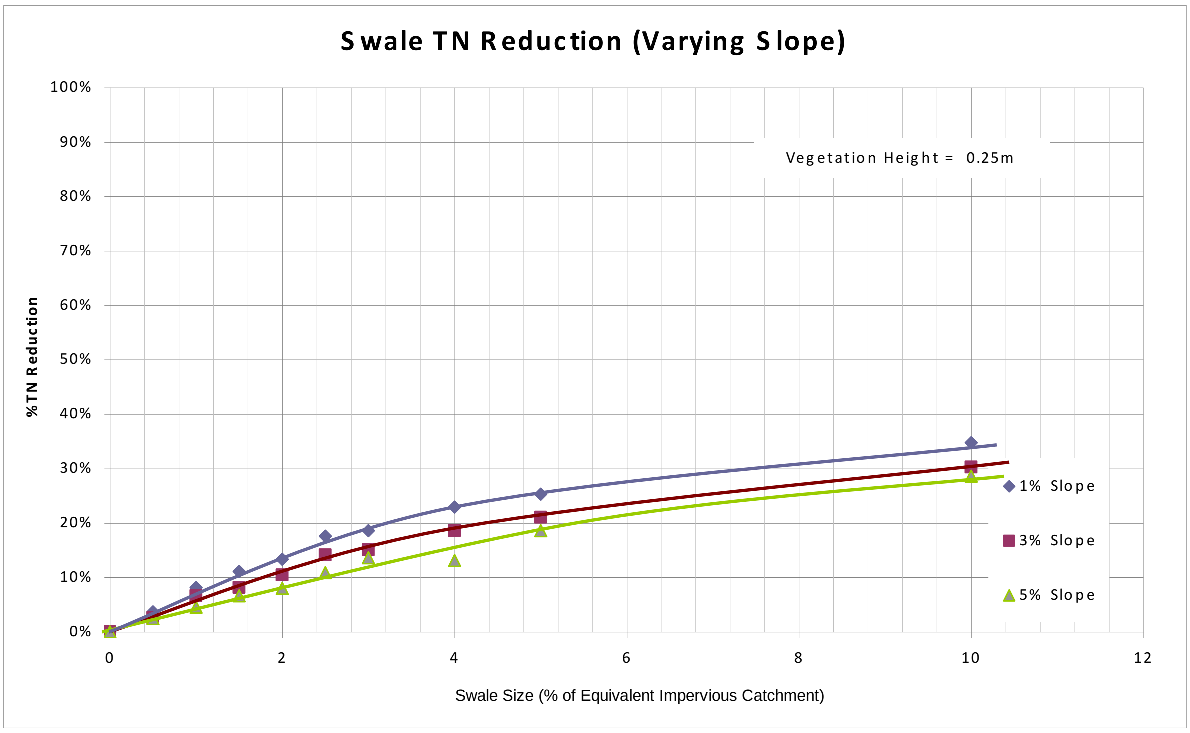


Figure 5.7 Swale TP Removal Performance



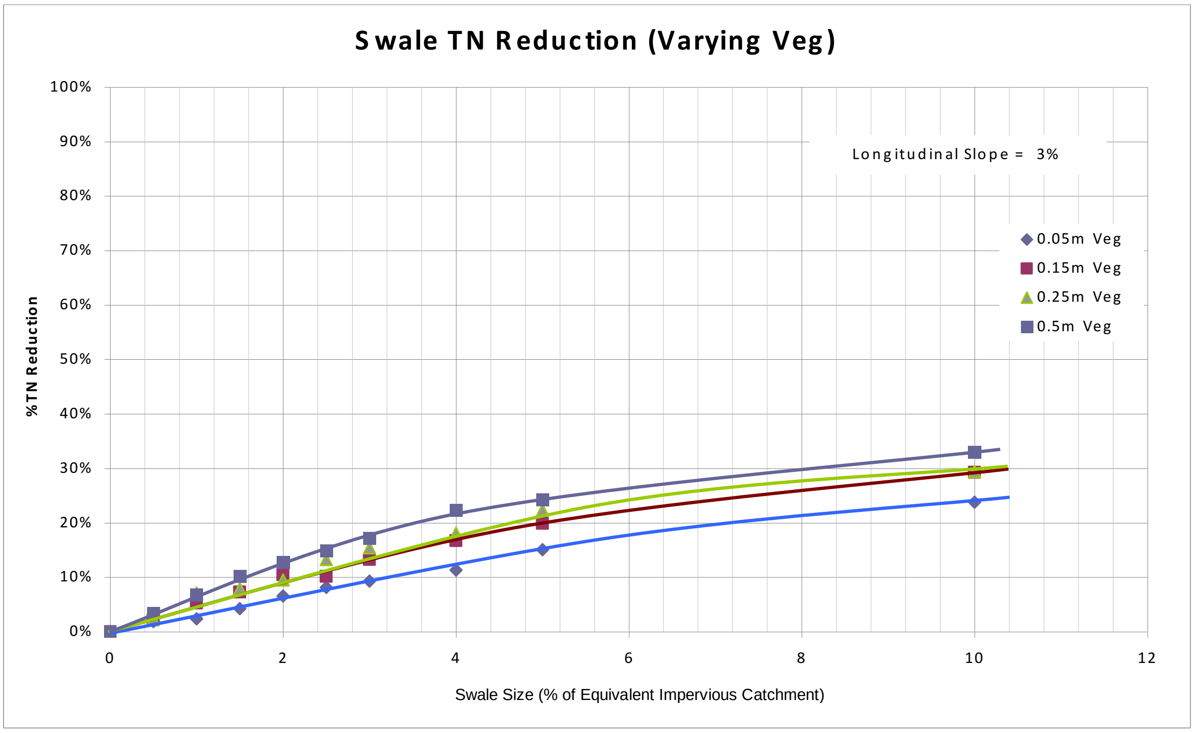


Figure 5.8 **Swale TN Removal Performance**

5.3.2 Step 2: Determine Design Flows

Two design flows are required to be estimated for the design of a swale, particularly where they are designed within a road reserve. These are to size the swale for conveyance of flows rather than treatment:

- minor flood flow (2-10 year ARI; typically the 10 year ARI peak discharge) to allow minor floods to be safely conveyed
- major flood flow (10-100 year ARI) to check flow velocities, velocity depth criteria, conveyance within road reserve, and freeboard to adjoining property.

The *Code of Practice on Surface Water Drainage* (PUB 2018) identifies the Rational Method as the procedure most commonly used to estimate peak flows from small catchments in Singapore.

5.3.3 Step 3: Dimension the Swale with Consideration of Site Constraints

Factors to consider are:

- Contributing catchment area
- Allowable width given the proposed road reserve and/ or urban layout
- How flows will be delivered into a swale (e.g. cover requirements for pipes or kerb details)
- Vegetation height
- Longitudinal slope
- Maximum side slopes and base width
- Provision of crossings
- Other requirements in accordance with the latest version of Code of Practice on Surface Water Drainage (PUB).

Depending on which of the above characteristics are fixed, other variables may be adjusted to derive the optimal swale dimensions for the given site conditions. The following sections outline some considerations in relation to configuring a swale.

5.3.3.1 Swale Width and Side Slopes

The maximum swale width needs to be identified early in the design process as it dictates the remaining steps in the swale design process. The maximum width of swale is usually determined from an urban layout and at the concept design stage. Where the swale width is not constrained by an urban layout (e.g. when located within a large open space area), then the width of the swale may be selected based on consideration of landscape objectives, maximum side slopes for ease of maintenance and public safety, hydraulic capacity required to convey the desired design flow, and treatment performance requirements.

Selection of an appropriate side slope for swales located in parks, easements or median strips is heavily dependent on-site constraints, and swale side slopes are typically between 1 in 10 and 1 in 4.

The maximum swale side slopes will be established from ease of maintenance and public safety considerations. Where ‘elevated’ crossings are used, swale side slopes would typically be between 1 in 6 and 1 in 4. ‘Elevated’ crossings will require provision for drainage under the crossings with a culvert or similar.

5.3.3.2 Maximum Length of a Swale

Provided the water quality function of the swale is met, the maximum length of a swale is the distance along a swale before an overflow pit (field inlet pit) is required to drain the swale to an underlying drainage system.

The maximum length of a swale is calculated as the distance along the swale to the point where the flow in the swale from the contributing catchment (for the specific design flood frequency) exceeds the bank full discharge capacity of the swale. For example, if the swale is to convey the minor flood flow without overflowing, then the maximum swale length would be determined as the distance along the swale to the point where the minor flood flow from the contributing catchment is equivalent to the bank full flow capacity of the swale (bank full flow capacity is determined using Manning's equation as discussed below).

5.3.3.3 Swale Capacity – Manning's Equation and Selection of Manning's *n*

Manning's equation is used to calculate the flow capacity of a swale. This allows the flow rate and flood levels to be determined for variations in swale dimensions, vegetation type and longitudinal grade. Manning's equation is given by:

$$Q = \frac{A \cdot R^{2/3} \cdot S^{1/2}}{n^{n}} \qquad \text{Equation 5.1}$$

Where: Q = flow in swale (m^3/s)

A = cross section area (m^2)

R = hydraulic radius (m)

S = channel slope (m/m)

n = roughness factor (Manning's n)

Manning's *n* relates to the roughness of the channel and is a critical variable in Manning's equation. It varies with flow depth, channel dimensions and the vegetation type. For constructed swale systems, recommended values are between 0.15 and 0.3 for flow depths shallower than the vegetation height (preferable for treatment) and significantly lower for flows with depth greater than the vegetation (e.g. 0.03 – 0.05 at more than twice the vegetation depth i.e. 50-100 year ARI). It is considered reasonable for Manning's *n* to have a maximum at the vegetation height and then to sharply reduce as depths increase.

Figure 5.9 shows a plot of Manning's *n* versus flow depth for a grass swale with longitudinal grade of 5 %. It is reasonable to expect the shape of the Manning's *n* relation with flow depth to be consistent with other swale configurations, with the vegetation height at the boundary between low flows and intermediate flows on the top axis of the diagram. The bottom axis of the plot has been modified from Barling and Moore (1993) to express flow depth as a percentage of vegetation height.

Further discussion on selecting an appropriate Manning's *n* for a swale is provided in Appendix F of the *MUSIC User Guide* (eWater Ltd 2014).

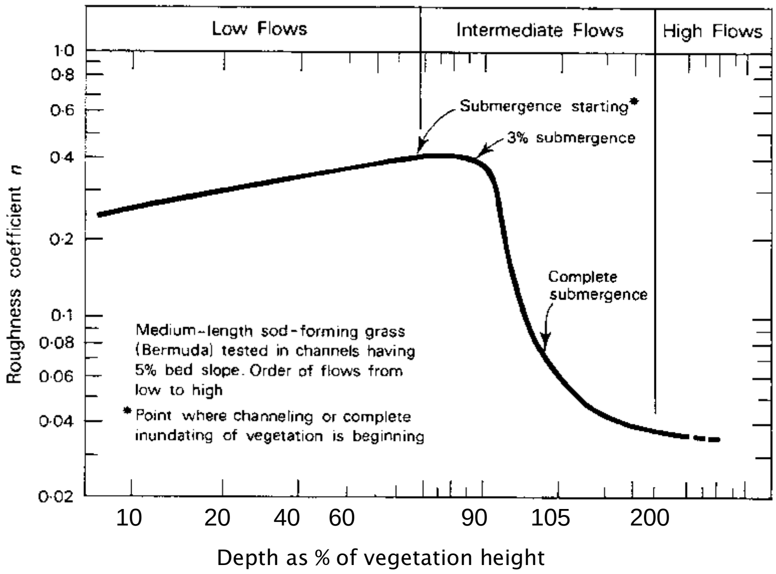


Figure 5.9 **Impact of Flow Depth on Hydraulic Roughness (adapted from Barling & Moore (1993))**

5.3.4 Step 4: Determine Design of Inflow Systems

Inflows to swales can be via distributed runoff (e.g. from flush kerbs or slotted kerbs along a road) or point outlets such as pipe culverts. Combinations of these two inflow pathways can also be used.

5.3.4.1 Distributed Inflow

An advantage of flows entering a swale system in a distributed manner (i.e. entering perpendicular to the direction of the swale) is that flow depths are kept as shallow sheet flow, which maximises contact with the swale vegetation on the batter receiving the distributed inflows. This swale batter is often referred to as a buffer. To ensure the function of the buffer, flow depths must be shallow (below the vegetation height) and erosion must be avoided. The buffer provides good pre-treatment through coarse sediment removal prior to flows being conveyed along the swale.

Distributed inflows can be achieved either by having a flush kerb or by using kerbs with regular breaks in them to allow for even flows across the buffer surface (Figure 5.10).

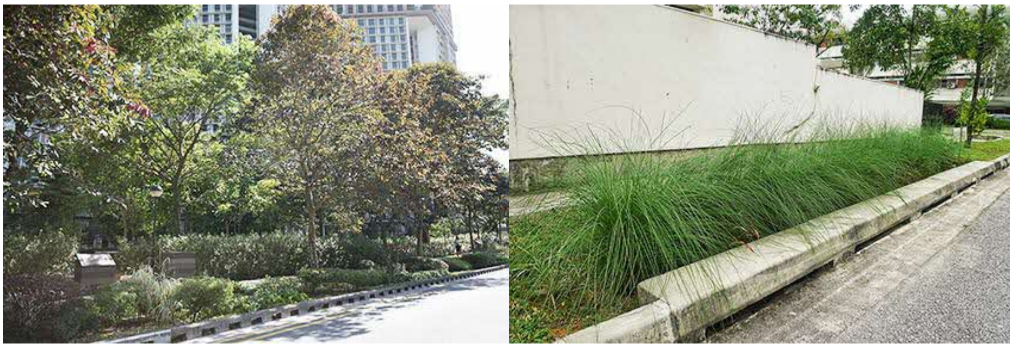


Figure 5.10 **Kerb arrangements to promote distributed flow into swales**

5.3.4.2 Buffer Requirements

There are several design guides that may to be applied to ensure buffers operate to improve water quality and provide a pretreatment role. Key design parameters of buffer systems are:

- Providing distributed rather than concentrated flows onto a buffer to avoid erosion and channelled flows
- Maintaining flow depths less than vegetation heights. This may require flow spreaders, or check dams.
- Minimising the slope of the buffer. It is best if slopes can be kept below 5 %, however buffers can still perform well with slopes up to 20 % provided flows are well distributed. The steeper the buffer the more likely flow spreaders will be required to avoid rill erosion.

Maintenance of buffers is required to remove accumulated sediment and debris. Therefore access is an important consideration. Sediments will accumulate mostly immediately downstream of the pavement surface and then progressively further downstream as sediment builds up.

It is important to ensure coarse sediments accumulate off the road surface at the start of the buffer or green verge. To avoid accumulation of sediments on the carriageway or just before the kerb openings, slotted kerbs with a level drop should be used so that the top of the vegetation is set 60 mm below the edge of pavement. This requires the finished topsoil surface of the swale (i.e. before turf is placed) to be approximately 100 mm below the edge of pavement level. Sediments can then accumulate off any trafficable surface.

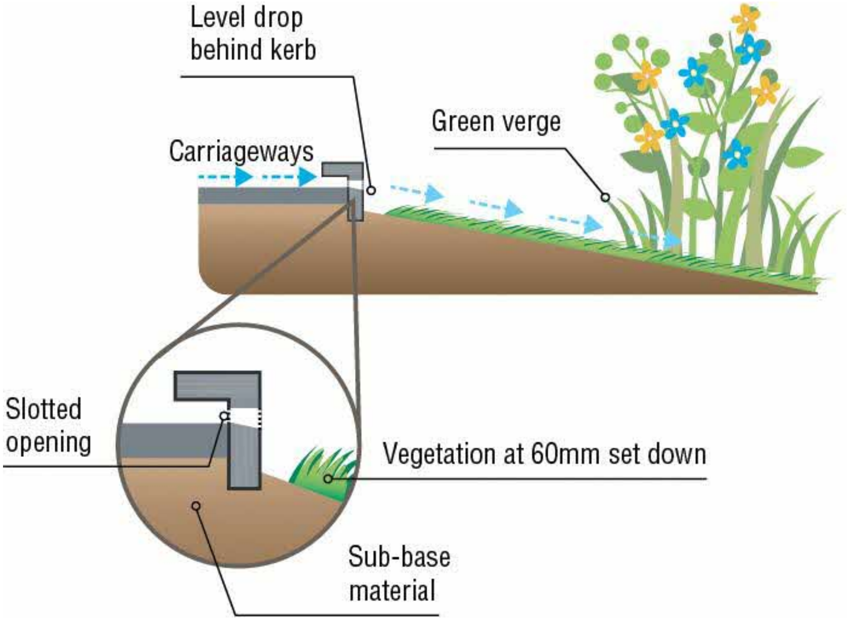


Figure 5.11 Slotted kerb with set-down to allow sediment to flow into the vegetated area

5.3.4.3 Concentrated Inflow

Concentrated inflows to a swale can be in the form of a concentrated overland flow or a discharge from a pipe drainage system. For all concentrated inflows, energy dissipation at the swale inflow location is an important consideration to minimise any erosion. This can usually be achieved with rock benching and/ or dense vegetation (Figure 5.12).

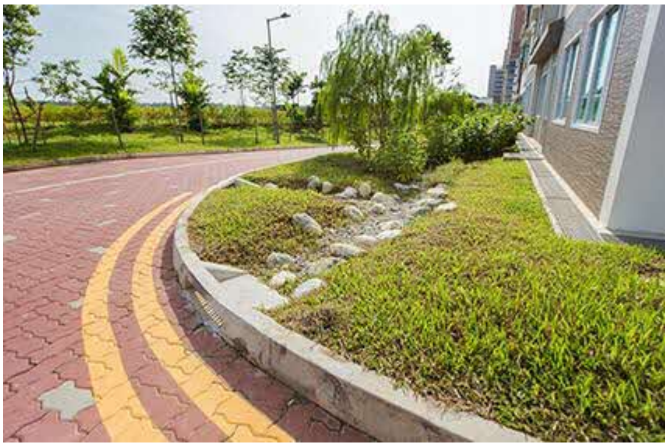
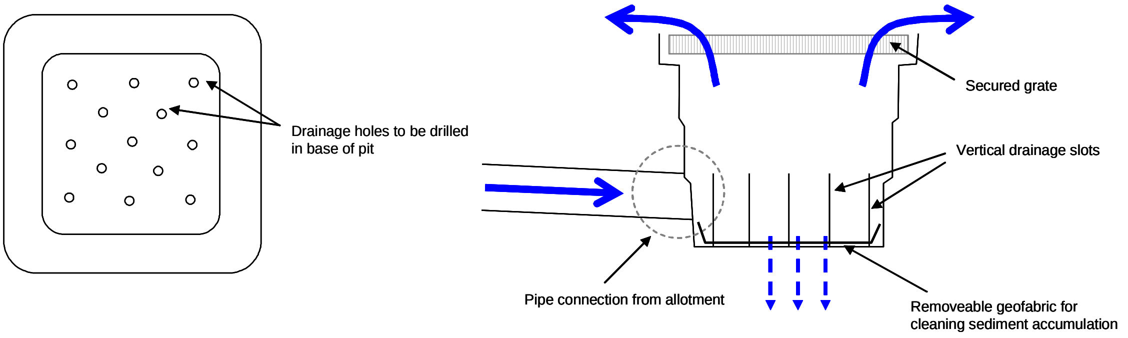


Figure 5.12 Energy Dissipator at swale inlet

The most common constraint on pipe systems discharging to swales is bringing the pipe flows to the surface of a swale. In situations where the swale geometry does not permit the pipe to achieve ‘free’ discharge to the surface of the swale, a ‘surcharge’ pit may need to be used. Surcharge pits should be designed so that they are as shallow as possible and have pervious bases to avoid long term ponding in the pits (this may require under-drains to ensure it drains, depending on local soil conditions). The pits need to be accessible so that any build up of coarse sediment and debris can be monitored and removed if necessary.

Figure 5.13 shows an example of a typical surcharge pit discharging into a swale. Surcharge pits are not considered good practice, due to additional maintenance issues and mosquito breeding potential and should therefore be avoided where possible. The design of surcharge pits shown here is for reference only. The actual design needs to be approved by the relevant agencies and the party that will take over the maintenance.


Drainage holes to be drilled
in base of pit
Secured grate
Vertical drainage slots
Pipe connection from allotment
Removeable geofabric for
cleaning sediment accumulation

PLAN

ELEVATION

Figure 5.13 Example of Surcharge Pit for Discharging Concentrated Runoff into a Swale

Surcharge pits are most frequently used when allotment runoff is required to cross a road into a swale on the opposite side of the road or for allotment and roof runoff discharging into shallow profile swales. Where allotment runoff needs to cross under a road to discharge into a swale it is preferable to combine the runoff from more than one allotment to reduce the number of crossings required under the road pavement.

5.3.5 Step 5: Verify Design

5.3.5.1 Vegetation Scour Velocity Check

Potential scour velocities are checked by applying Manning's equation to the swale design to ensure the following criteria are met:

- less than 0.5 m/s for minor flood (2 to 10 year ARI; typically the 10 year ARI) discharge
- less than 2.0 m/s and typically less than 1.0 m/s for major flood (100 year ARI) discharge.

5.3.5.2 Velocity and Depth Check – Safety

As swales are generally accessible by the public, it is important to check that depth x velocity within the swale, at crossings and adjacent to pedestrian and bicycle pathways, satisfies the following public safety criteria:

- depth x velocity of < 0.4 m^2/s is not exceeded for all flows up to the major design event, as defined in relevant local government guidelines
- maximum depth of flow over 'at-grade' crossings = 0.3 m

5.3.5.3 Confirm Treatment Performance

If the previous two checks are satisfactory then the swale design is adequate from a conveyance function perspective and it is now necessary to reconfirm the treatment performance of the swale by reference back to the information presented in Section 5.3.1.

5.3.6 Step 6: Size Overflow Pits (Field Inlet Pits)

To size a swale field inlet pit, two checks should be made to test for either drowned or free flowing conditions. A broad crested weir equation can be used to determine the length of weir required (assuming free flowing conditions) and an orifice equation used to estimate the area between openings required in the grate cover (assuming drowned outlet conditions). The smaller of the two pit configurations would normally suffice although other consideration such as the required pit to fit the stormwater pipe conveying overflows to the receiving waters need also to be considered. In addition, a blockage factor is to be used, that assumes the field inlet is 50 % blocked.

For free overfall conditions (weir equation):

$$Q_{weir} = B \cdot C_w \cdot L \cdot h^{3/2} \qquad \text{Equation 5.2}$$

Where Q_{weir} = flow over weir (pit) (m^3/s)

B = blockage factor (0.5)

C_w = weir coefficient (1.66)

L = length of weir (m)

h = depth of water above weir crest (m)

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

For drowned outlet conditions (orifice equation):

$$Q_{orifice} = B \cdot C_d \cdot A\sqrt{2 \cdot g \cdot h} \qquad \text{Equation 5.3}$$

Where
$Q_{orifice}$ = flow into drowned pit (m^3/s)
B = blockage factor (0.5)
C_d = discharge coefficient (0.6)
A = total area of orifice (openings) (m^2)
g = 9.80665 m/s^2
h = depth of water above centre of orifice (m)

When designing grated field inlet pits reference should be made to the procedure described in the latest version of Code of Practice on Surface Water Drainage (PUB)

5.3.7 Step 7: Make Allowances to Preclude Traffic on Measures

Refer to Section 5.2.5 for discussion on traffic control options.

5.3.8 Step 8: Specify Plant Species and Planting Densities

For planting within road verge, the National Parks Board should be consulted for guidance of appropriate plant species and planting densities applicable for roadside swales in Singapore.

5.3.9 Step 9: Consider Maintenance Requirements

Consider how maintenance is to be performed on the swale (e.g. how and where is access available, where is litter likely to collect etc.). A specific maintenance plan and schedule should be developed for the swale, either as part of a maintenance plan for the whole treatment train, or for each individual asset. Guidance on maintenance plans is provided in Section 5.5.

5.3.10 Design Calculation Summary

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

SWALES – DESIGN CALCULATION SUMMARY SHEET

	Calculation Task		CALCULATION SUMMARY	
			Outcome	Check
	Catchment Characteristics			
		Catchment Area	ha	
		Catchment Land Use (i.e. residential, Commercial etc.)		
		Catchment Slope	%	
	Conceptual Design			
		Swale Top Width	m	
		Swale Length	m	
		Swale Location (road reserve/ park/other)		
		Road Reserve Width	m	
1	**Confirm Treatment Performance of Concept Design**			
		Swale Area	m^2	
		TSS Removal	%	
		TP Removal	%	
		TN Removal	%	
2	**Determine Design Flows**			
	Time of concentration		minutes	
	Identify Rainfall intensities			
		Minor Storm ($I_{10\ \text{year ARI}}$)	mm/hr	
		Major Storm ($I_{100\ \text{year ARI}}$)	mm/hr	
	Design Runoff Coefficient			
		Minor Storm ($C_{10\ \text{year ARI}}$)		
		Major Storm ($C_{100\ \text{year ARI}}$)		
	Peak Design Flows			
		Minor Storm (10 year ARI)	m^3/s	
		Major Storm (100 year ARI)	m^3/s	
3	**Dimension the Swale**			
	Swale Width and Side Slopes			
		Base Width	m	
		Side Slopes – 1 in		
		Longitudinal Slope	%	
		Vegetation Height	mm	
	Maximum Length of Swale			
		Manning's *n*		
		Swale Capacity		
		Maximum Length of Swale		
4	**Design Inflow Systems**			
		Swale Kerb Type		
		60 mm set down to Buffer/ Swale Vegetation	Yes/ No	
		Adequate Erosion and Scour Protection (where required)		
5	**Verification Checks**			
		Velocity for 10 year ARI flow (< 0.25 - 0.5 m/s)	m/s	
		Velocity for 100 year ARI flow (< 2 m/s)	m/s	
		Velocity x Depth for 100 year ARI (< 0.4 m^2/s)	m^2/s	
		Depth of Flow over Driveway Crossing for 100 year ARI (< 0.3 m)	m	
		Treatment Performance consistent with Step 1		
6	**Size Overflow Pits (Field Inlet Pits)**			
		System to convey minor floods (10 year ARI)	L x W	

5.3.10.1 Typical Design Parameters

Table 5.1 provides typical values for a number of key swale design parameters.

Table 5.1: Typical Design Parameters

Design Parameter	Typical Values
Swale longitudinal slope	1 % to 4 %
Swale side slope (for areas not requiring access, e.g. parks, easements, median strips)	1 in 4 to 1 in 10
Swale side slope for trafficability (for footpaths with ‘at-grade’ crossings)	Maximum 1 in 9
Swale side slope (elevated driveway crossings)	1 in 4 to 1 in 10
Manning’s *n* (with flow depth less than vegetation height) (Refer)	0.15 to 0.3
Manning’s n (with flow depth greater than vegetation height)	0.03 to 0.05
Maximum velocity to prevent scour in minor event (e.g. Q_{10})	0.25 - 0.5 m/s
Maximum velocity for Q_{100}	1.0 - 2.0 m/s

5.4 Construction advice

This section provides general advice for the construction of swales. It is based on observations from construction projects around Australia.

5.4.1 Building phase damage

Protection of soil and vegetation is important during building phase, uncontrolled building site runoff is likely to cause excessive sedimentation, introduce weeds and litter and require replanting following the building phase. Can use a staged implementation - i.e. during building use geofabric, soil (e.g. 50mm) and instant turf (laid perpendicular to flow path) to provide erosion control and sediment trapping. Following building, remove and revegetate possibly reusing turf at subsequent stages.

5.4.2 Traffic and deliveries

Ensure traffic and deliveries do not access swales during construction. Traffic can compact the soil and cause preferential flow paths, deliveries can smother vegetation. Wash down wastes (e.g. silt, concrete) can disturb vegetation and cause uneven slopes along a swale. Swales should be protected during construction phase and controls implemented to avoid wash down wastes.

5.4.3 Inlet erosion checks

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

5.4.4 Timing for planting

Timing of vegetation is typically after completion of construction activities in the surrounding area and dependent on timing in relation to the phases of development too. For example temporary planting during construction for sediment control (e.g. with turf) then remove and plant out with long term vegetation upon completion of construction.

5.5 Maintenance Requirements

Swale treatment relies upon good vegetation establishment and therefore ensuring adequate vegetation growth is the key maintenance objective. In addition, they have a flood conveyance role that needs to be maintained to ensure adequate flood protection for local properties.

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

Typical maintenance of swale elements will involve:

- Routine inspection of the swale profile to identify any areas of obvious increased sediment deposition, scouring of the swale invert from storm flows, rill erosion of the swale batters from lateral inflows or damage to the swale profile from vehicles.
- Routine inspection of inlet points (if the swale does not have distributed inflows), surcharge pits and field inlet pits to identify any areas of scour, litter build up and blockages.
- Removal of sediment where it is impeding the conveyance of the swale and/ or smothering the swale vegetation and if necessary re-profiling of the swale and re-vegetating to original design specification.
- Repairing damage to the swale profile resulting from erosion or vehicle damage.
- Clearing of blockages to inlet or outlets.
- Regular watering/ irrigation of vegetation until plants are established and actively growing.
- Mowing of turf or slashing of vegetation (if required) to preserve the optimal design height for the vegetation.
- Removal and management of invasive weeds.
- Removal of plants that have died and replacement with plants of equivalent size and species as detailed in the plant schedule.
- Pruning to remove dead or diseased vegetation material and to stimulate new growth.
- Litter and debris removal.
- Vegetation pest monitoring and control.

Inspections are also recommended following large storm events to check for scour. All maintenance activities must be specified in a maintenance plan (and associated maintenance inspection forms) to be developed as part of the design procedure. Maintenance personnel and asset managers will use this plan to ensure the swales continue to function as designed. Maintenance plans and forms must address the following:

- inspection frequency
- maintenance frequency
- data collection/ data storage requirements
- detailed cleanout procedures (main element of the plans) including:
    - equipment needs

    - maintenance techniques
    - occupational health and safety
    - public safety
    - environmental management considerations
    - disposal requirements (of material removed)
    - access issues
    - stakeholder notification requirements
    - data collection requirements (if any)
- design details

An example of an operation and maintenance inspection form is provided in the checking tools provided in Section 5.6.3.

5.6 Checking tools

This section provides a number of checking aids for designers and approval authorities. In addition, advice on construction techniques and lessons learnt from building swale systems are provided.

Checklists are provided for:

- Design assessments
- Construction (during and post)
- Maintenance and inspections
- Asset transfer (following defects period).

5.6.1 Design assessment checklist

The Design Assessment Checklist on the following page presents the key design features that are to be reviewed when assessing a design of a swale. These considerations include configuration, safety, maintenance and operational issues that need to be addressed during the design phase. If an item receives an ‘N’ when reviewing the design, referral is made back to the design procedure to determine the impact of the omission or error. In addition to the checklist, a proposed design is to have all necessary permits for installation.

5.6.2 Construction Checklist

The Construction Checklist on the following page presents the key items to be reviewed when inspecting the swale during and at the completion of construction. The checklist is to be used by Construction Site Supervisors and compliance inspectors to ensure all the elements of the swale have been constructed in accordance with the design. If an item receives an ‘N’ in satisfactory criteria then appropriate actions must be specified and delivered to rectify the construction issue before final inspection sign-off is given.

5.6.3 Operation and Maintenance Inspection Form

The Operation and Maintenance forms on the following pages should be used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time. Inspections should occur every 1 to 6 months depending on the size and complexity of the swale system, and the stage of development (i.e. inspections should be more frequent during building phase and until the swale landform has stabilised).

SWALE DESIGN ASSESSMENT CHECKLIST

Asset I.D.		**Assessed by:**	Date:
Swale Location:			
Hydraulics:	Minor Flood (m^3/s):	Major Flood (m^3/s):	
Area:	Catchment Area (ha):	Swale Area (m^2):	

TREATMENT	**Y**	**N**
Treatment performance verified?		
INFLOW SYSTEMS	**Y**	**N**
Inlet flows appropriately distributed?		
Swale/ buffer vegetation set down of at least 60 mm below kerb invert incorporated?		
Energy dissipation (rock protection) provided at inlet points to the swale?		
SWALE CONFIGURATION/ CONVEYANCE	**Y**	**N**
Longitudinal slope of invert >1% and <4%?		
Manning's n selected appropriate for proposed vegetation type?		
Determine maximum width of swale		
Overall flow conveyance system sufficient for design flood event?		
Overflow pits provided where flow capacity exceeded?		
Velocities within swale cells will not cause scour?		
Maximum ponding depth and velocity will not impact on public safety (V x d < 0.4 m/s)		
Maintenance access provided to invert of conveyance channel?		
LANDSCAPE	**Y**	**N**
Plant species selected can tolerate periodic inundation and design velocities?		
Planting design conforms to acceptable sight line and safety requirements?		
Street trees conform to Land Development Guidelines		
Top soils are a minimum depth of 300mm for plants and 100 mm for turf		
Existing trees in good condition are investigated for retention?		
Swale and buffer strip landscape design integrates with surrounding natural and/ or built environment?		
OTHER NOTES		

SWALE CONSTRUCTION INSPECTION CHECKLIST

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

Items Inspected	**Checked**		**Satisfactory**		**Items Inspected**	**Checked**		**Satisfactory**	
	Y	**N**	**Y**	**N**		**Y**	**N**	**Y**	**N**
DURING CONSTRUCTION & ESTABLISHMENT									
A. FUNCTIONAL INSTALLATION					**Structural Components**				
Preliminary Works					13. Location and levels of pits as designed				
1. Erosion/ sediment control plan adopted					14. Safety protection provided				
2. Traffic control measures					15. Location of check dams as designed				
3. Location same as plans					16. Swale crossings located/ built as designed				
4. Site protection from existing flows					17. Pipe joints/ connections as designed				
5. Critical root zones (0.5 m beyond drip line) of nominated trees are protected					18. Concrete and reinforcement as designed				
					19. Inlets appropriately installed				
Earthworks					20. Inlet erosion protection installed				
6. Existing topsoil is stockpiled for reuse					21. Set down to correct level for flush kerbs				
7. Bed of swale level?					**B. EROSION AND SEDIMENT CONTROL**				
8. Batter slopes as plans					22. Silt fences and traffic control in place				
9. Longitudinal slope in design range					23. Stabilisation immediately following earthworks				
10. Provision of sub-soil drainage for mild slopes (<1%)					**C. OPERATIONAL ESTABLISHMENT**				
11. Compaction process as designed					**Vegetation**				
12. Appropriate topsoil on swale					24. Test and ameliorate topsoil, if required				
					25. Planting as designed (species/ densities)				
					26. Weed removal and watering as required				
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 sediment removed				
5. Vegetation as designed					10. Evidence of local surface ponding				

COMMENTS ON INSPECTION
ACTIONS REQUIRED:
Inspection officer signature:

SWALE (AND BUFFER) MAINTENANCE CHECKLIST

Asset I.D.:			
Inspection Frequency:	Weekly to monthly	**Date of Visit:**	
Location:			
Description:			
Site Visit by:			

INSPECTION ITEMS	**FREQUENCY**	**Y**	**N**	**ACTION REQUIRED (DETAILS)**
Sediment accumulation at inflow points?	Weekly			
Litter within swale?	Weekly			
Erosion at inlet or other key structures (e.g. crossovers)?	Weekly			
Traffic damage present?	Weekly			
Evidence of dumping (e.g. building waste)?	Weekly			
Vegetation condition satisfactory (density, weeds etc)?	Monthly			
Replanting required?	Monthly			
Mowing required?	Fortnightly			
Sediment accumulation at outlets?	Weekly			
Clogging of drainage points (sediment or debris)?	Weekly			
Evidence of ponding?	Weekly			
Set down from kerb still present?	Monthly			
Soil additives or amendments required?	Monthly			
Pruning and/ or removal of dead or diseased vegetation required?	Monthly			
Inspect swale cross-section profile according to Drawing No. XXXXX				
Inspect swale longitudinal profile according to Drawing No. YYYYY				
COMMENTS				

1) Cross-Section Plan – Drawing No. XXXXX
2) Longitudinal-Section Plan – Drawing No. YYYYY
3) Location Plan of Swale No. – Drawing No. ZZZZZ

ASSET TRANSFER CHECKLIST

Asset Description:			
Asset I.D.:			
Asset Location:			
Construction by:			
DLP Period:			
TREATMENT		**Y**	**N**
System appears visually to be working as designed?			
No obvious signs of under-performance?			
MAINTENANCE		**Y**	**N**
Maintenance plans and indicative maintenance costs provided for each asset?			
Vegetation establishment period completed?			
Inspection and maintenance undertaken as per maintenance plan?			
Inspection and maintenance forms provided?			
Asset inspected for defects?			
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?			
COMMENTS			

5.7 Swale Worked Example

5.7.1 Worked example introduction

As part of a development, runoff from allotments and a street surface is to be collected and conveyed in a vegetated swale system to downstream treatments. The swale will be vegetated with turf (100mm tall). An additional exercise in this worked example is to investigate the consequences on flow capacity of using a taller species such as sedges in the swale (vegetation height equal to 300mm).

A concept design for the development proposed this system as part of a treatment train. The street will have a one-way cross fall (to the high side) with flush kerbs, to allow for distributed flows into the swale system across a buffer zone.

The swale is to convey minor flood events, including all flows up to a ten-year ARI storm. However, the width of the swale is fixed at 5.0 m and there will be a maximum catchment area the swale can accommodate, above which an underground pipe will be required to preserve the conveyance properties of the downstream swale.

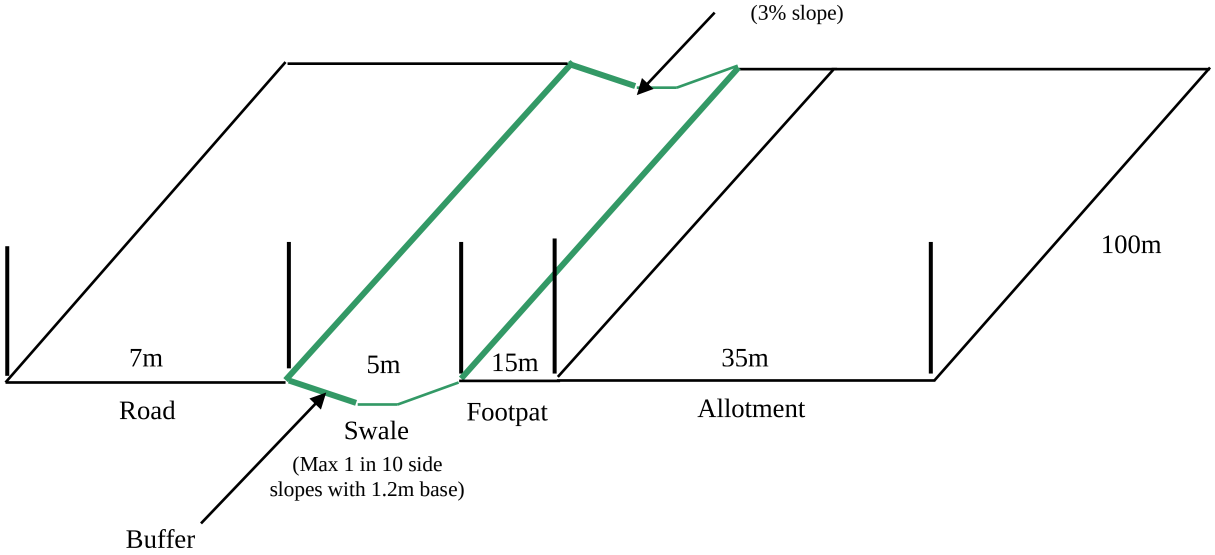


Figure 5.14 Cross section of proposed buffer/swale system

The contributing catchment area includes 35 m width and 100m length residential allotments on one side, a 7m wide road pavement surface and a 1.5 m footpath and 5.0 m swale and services easement (depicted in Figure 5.14, examples of similar systems are illustrated in Figure 5.15). The area is 100 m long with a 3 % slope.

Allotment runoff is to be discharged under a footpath via a conventional stormwater pipe directly into the swale system with appropriate erosion control.

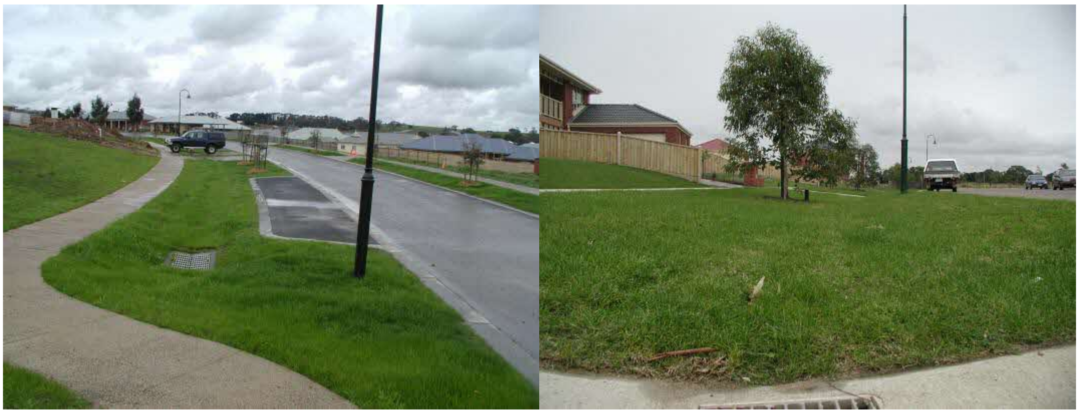


Figure 5.15 Similar buffer swale system for conveying runoff

Design criteria for the buffer/ swale system are to:

- Promote sedimentation of coarse particles through the buffer by providing for an even flow distribution and areas for sediment accumulation (i.e. set down at kerb edge);
- Provide traffic management measures that will preclude traffic damage (or parking) within the buffer or swale (e.g. bollards or parking bays);
- Provide check dams to control velocities and spread flows (potentially using crossings);
- Provide driveway access to lots within side slope limits and
- Convey 10-year ARI flows within the swale and underground pipe system.

This worked example focuses on the design of the buffer strip and vegetated swale conveyance properties. Analyses to be undertaken during the detailed design phase include the following:

- Design the swale system to accommodate driveway crossovers and check dams where required
- Select vegetation such that the hydraulic capacity of the swale is sufficient
- Determine maximum length of swale to convey 10-year flows before an underground pipe is required
- Check velocities are maintained to acceptable levels
- Overflow structure from swale to underground pipe (if required).

Additional design elements will be required, including:

- Configure the street kerb details such that sheet flow is achieved through the buffer strip
- Configure house lot drainage so that erosion control is provided
- Buffer strip vegetation
- Swale vegetation (integral with hydraulic design of the system).

5.7.1.1 Design Objectives

The design objectives are summarised as follows:

- Swale shall convey at least all flows up to the peak 10-year ARI storm event.

- Sedimentation of coarse particles will be promoted within the buffer by providing an even flow distribution.
- Prevent traffic damage to the buffer swale system.
- Flow velocities to be controlled to prevent erosion.

5.7.1.2 Site Characteristics

Catchment area:	3,500 m^2	(lots)
	850 m^2	(roads and concrete footpath)
	500 m^2	(swale and services easement)
	Total = 4,850 m^2	

Land use/surface type Residential lots, roads/concrete footpaths, swale and service easement.

Overland flow slope:

Total main flow path length = 100m @ 3% slope

Soil type: Clay

Fraction impervious:

- lots f = 0.65
- roads/footpath f = 1.00
- swale/service easement f = 1.0

Vegetation height of 100 mm

5.7.2 Step 1: Confirm Treatment Performance of Concept Design

Interpretation of Figure 5.6 to Figure 5.8 with the input parameters below is used to estimate the reduction performance of the swale system to ensure the design will achieve target pollutant reductions. To interpret the graphs the area of swale base to the impervious catchment needs to be estimated. For a base width of 1.2 m, the area of swale base as percentage of the contributing impervious catchment area:

$$1.2 \times 100 / [(0.65 \times 3500) + (1.0 \times 850) + (1.0 \times 500)] = 3.3\ \%$$

From the figures using an equivalent area in the reference site, it is estimated that, depending on the height of the vegetation, pollutant reductions are between 68% and 80% for TSS, 45% to 57% for TP and 10% to 20% for TN respectively.

5.7.3 Step 2: Determine Design Flows

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

5.7.3.1 Major and minor design flows

Time of concentration (t_c)

The time of concentration is estimated assuming overland flow across the allotments and along the swale and is determined to be 10 minutes.

Design rainfall intensities

Adopt from IDF table[1] for Singapore for a time of concentration (t_c) of 10 minutes

ARI	Intensity
10yr	190 mm/hr
100yr	275 mm/hr

Design runoff coefficient

Apply the Rational Formula method outlined in Code of Practice on Surface Water Drainage (PUB).

$Q = 0.002788 \times C \times I \times A$

$C_{10} = 0.65$

$C_{100} = 0.65$

Peak design flows

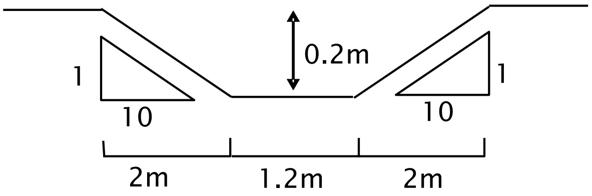
$Q_{10} = 0.002788 \times 0.65 \times 190 \times 0.485 = 0.17\ m^3/s$

$Q_{100} = 0.002788 \times 0.65 \times 275 \times 0.485 = 0.24\ m^3/s$

5.7.4 Step 3: Configuring the Swale

5.7.4.1 Swale Width and Side Slopes

The following cross section is proposed:



5.7.4.2 Maximum Length of Swale

The capacity of the swale is firstly estimated at the most downstream point. It is considered to be the critical point in the swale as it has the largest catchment and has the mildest slope. Flow velocities will also need to be checked at the downstream end of the steep section of swale.

The worked example firstly considers the swale capacity using a turf grass surface with a vegetation height of 100 mm. An extension of the worked example is to investigate the consequence of using 300mm tall vegetation (e.g. sedges) instead of grass.

A range of Manning's *n* values are selected for different flow depths appropriate for grass. It is firstly assumed that the flow height for a 10-year ARI storm will be above

---

[1] Please refer to Code of Practice for Surface Water Drainage

the vegetation and therefore Manning's *n* is quite low. A figure of 0.04 is adopted. The flow depth will need to be checked to ensure it is above the vegetation.

- Adopt slope 3% (minimum longitudinal slope)
- Manning's *n* = 0.04 (at 0.2m depth)
- Side slopes 1(v):10(h)

From Manning's equation: $Q = (AR^{2/3}S_o^{1/2})/n$

$Q_{cap} = 0.683\ m^3/s >> Q_{10}\ (0.17\ m^3/s)$ ………………OK

The nominated swale has sufficient capacity to convey the required peak Q_{10} flow without any requirement for an additional piped drainage system (i.e. slope = 3%, n = 0.07, $Q_{10} = 0.17\ m^3/s$), solving Manning's equation for depth, $d_{10\text{-year}} = 0.13$ m.

The capacity of the swale ($Q_{cap} = 0.683m^3/s$) is also sufficient to convey the entire peak Q_{100} flow of $0.24m^3/s$ without impacting on the adjacent road and footpath (i.e. slope = 3%, n = 0.04, $Q_{100} = 0.2425\ m^3/s$) and solving Manning's equation for depth gives $d_{100\text{-year}} = 0.143$ m.

The flow depths of both the minor (0.13 m) and major (0.143 m) event flows are less than the depth of the swale (0.2 m), indicating that all flow is contained within the swales.

Based on this result, the maximum permissible length of swale is also much longer than the 'actual' length of the swale (i.e. 100 m) and as such no overflow pits are required except at the downstream end of the swale to facilitate discharge to the trunk underground pipe drainage system (see Chapter 6 for design of overflow pits).

To investigate flow rates at depths lower than the height of vegetation, Manning's *n* is varied according to the flow depth relating to the vegetation height. This can be performed simply in a spreadsheet application. The values adopted here are:

Table 5.2 Manning's n and flow capacity variation with flow depth – turf

Flow Depth (m)	Manning's n	Flow (m^3/s)
0.05	0.30	0.006
0.1	0.08	0.149
0.15	0.06	0.252
0.2	0.04	0.674

From the table of Manning's equation output (Table 5.2) it can be seen that the 10-year ARI flow depth is above the vegetation height and therefore the adopted Manning's *n* value of 0.07 is reasonable. The boundary layer effect created by the turf significantly decreases between a flow depth of 0.05 m and 0.1 m with Manning's *n* decreasing from 0.3 to 0.08. This is due to the weight of the water flowing over the grass causing it to 'yield over' creating a 'smoother' surface with less resistance to flow. Once the water depth has reached twice the vegetation height (0.2 m), the Manning's n roughness coefficient has been further reduced to 0.04.

For the purposes of this worked example, the capacity of the swale is also estimated when using 300mm tall vegetation (e.g. sedges). The taller vegetation will increase the roughness of the swale (as flow depths will be below the vegetation height) and therefore a higher Manning's *n* should be adopted. The table below presents the adopted Manning's *n* values and the corresponding flow capacity of the swale for different flow depths.

Table 5.3 Manning's n and flow capacity variation with flow depth – sedges

Flow Depth (m)	Manning's n	Flow (m^3/s)
0.05	0.35	0.004
0.1	0.32	0.002
0.15	0.30	0.05
0.2	0.30	0.09

It can be seen in Table 5.3 that the swale with current dimensions is not capable of conveying a 10-year discharge of 0.17 m^3/s if sedges are to be planted. Either the swale depth would need to be increased or overflow pits provided to allow excess water to bypass the swale.

This worked example continues using 100mm turf for the remainder.

5.7.5 Step 4: Design Inflow Systems

There are two ways for flows to reach the swale, either directly from the road surface or from allotments via an underground 100mm pipe.

Direct runoff from the road enters the swale via a buffer (the grass edge of the swale). The pavement surface is set 60 mm higher than the start of the swale and has a taper that will allow sediments to accumulate off the pavement surface in the first section of the buffer. Flows from allotments will discharge into the base of the swale and localised erosion protection is provided with grouted rock at the outlet point of the pipe.

5.7.6 Step 5: Verification Checks

5.7.6.1 Vegetation scour velocity checks

Two velocity checks are performed to ensure vegetation is protected from erosion at high flow rates. 10-year and 100-year ARI flow velocities are checked and need to be kept below 0.5m/s and 2.0 m/s respectively.

Velocities are estimated using Manning's equation:

Firstly, velocities are checked at the most downstream location for the 10-year ARI (i.e. slope = 3%, n = 0.07, $Q_{10} = 0.17\ m^3/s$)

$d_{10\text{-year}} = 0.13$ m

$V_{10\text{-year}} = 0.46$ m/s < 0.5 m/s therefore OK

Secondly, velocities are checked at the most downstream location for the 100-year ARI (i.e. slope = 3%, n = 0.04, $Q_{100} = 0.24\ m^3/s$)

$d_{100\text{-year}} = 0.143$ m

$V_{100\text{-year}} = 0.645$ m/s < 2.0 m/s therefore OK

5.7.6.2 Velocity and Depth Checks - Safety

Check at critical points (bottom of entire swale) that velocity depth product is less than 0.4 during a 100-year ARI flow.

At bottom of swale:

V= 0.645 m/s, d= 0.143m; therefore V.d = 0.092 m^2/s <0.4 therefore OK.

5.7.6.3 Confirm Treatment Performance

As there has been no requirement to alter the swale geometry established for Swales 1 and 2 in Step 3, the same treatment performance identified in Step 1 still applies. Where modifications to the swale geometry occur during the previous design steps, a check of the new configuration with procedures identified in Step 1 is required to ensure treatment performance is adequate.

5.7.7 Step 6: Size Overflow Pits

As the swale can carry a ten-year ARI discharge, overflow structures are not required for this worked example. See Chapter 6 for an example including the design of an overflow pit.

5.7.8 Step 7: Traffic Control

Traffic control in the worked example is achieved by using kerbs mixed with street trees.

5.7.9 Step 8: Vegetation specification

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

5.7.10 Calculation summary

The sheet overleaf shows the results of the design calculations.

SWALES – DESIGN CALCULATION SUMMARY SHEET

	Calculation Task		CALCULATION SUMMARY		
			Outcome		**Check**
	Catchment Characteristics (Swale 1)				
		Catchment Area	0.485	ha	✓
		Catchment Land Use (i.e. residential, Commercial etc.)	Res		
		Catchment Slope	3	%	
	Conceptual Design				
		Swale Top Width	5	m	✓
		Swale Length	100	m	
		Swale Location (road reserve/ park/other)	Road res		
		Road Reserve Width	13.5	m	
1	**Confirm Treatment Performance of Concept Design**				
		Swale Area	125	m^2	✓
		TSS Removal	68	%	
		TP Removal	45	%	
		TN Removal	10	%	
2	**Determine Design Flows**				
	Time of concentration				
	Swale 1				
		10 year ARI	10	minutes	✓
		100 year ARI	10	minutes	
	Swale 2				
		10 year ARI		minutes	✓
		100 year ARI		minutes	
	Identify Rainfall intensities				
	Swale 1				
		$I_{10\text{ year ARI}}$	190	mm/hr	✓
		$I_{100\text{ year ARI}}$	275	mm/hr	
	Swale 2				
		$I_{10\text{ year ARI}}$		mm/hr	✓
		$I_{100\text{ year ARI}}$		mm/hr	
	Design Runoff Coefficient				
		$C_{10\text{ year ARI}}$	0.65		✓
		$C_{100\text{ year ARI}}$	0.65		
	Peak Design Flows				
		10 year ARI	0.17	m^3/s	✓
		100 year ARI	0.24	m^3/s	
3	**Dimension the Swale**				
	Swale Width and Side Slopes				
		Base Width	1.0	m	✓
		Side Slopes – 1 in	10		
		Longitudinal Slope	3	%	
		Vegetation Height	100	mm	
	Maximum Length of Swale				
		Manning's *n*	0.04		✓
		Swale Capacity	0.63	m^3/s	
		Maximum Length of Swale	<100	m	
4	**Design Inflow Systems**				
		Swale Kerb Type	Flush		✓
		60 mm set down to Buffer/ Swale Vegetation	Yes	Yes/ No	
		Adequate Erosion and Scour Protection (where required)	N/A		
5	**Verification Checks**				
		Velocity for 10 year ARI flow (< 0.5 m/s)	0.46	m/s	✓
		Velocity for 100 year ARI flow (< 2 m/s)	0.65	m/s	
		Velocity x Depth for 100 year ARI (< 0.4 m^2/s)	0.09	m^2/s	
		Depth of Flow for 100 year ARI (< 0.3 m)	0.143	m	
		Treatment Performance consistent with Step 1	Yes		
6	**Size Overflow Pits (Field Inlet Pits)**				
		System to convey minor floods – Swale 1		L x W	✓
		System to convey minor floods – Swale 2		L x W	

5.8 References

Barling RD & Moore ID 1993, 'The Role of Buffer Strips in the Management of Waterway Pollution', in Woodfull J *et al*. (eds), *The Role of Buffer Strips in the Management of Waterway Pollution from Diffuse Urban and Rural Sources*, LWRRDC Occasional Paper No. 01/93, Canberra

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Public Utilities Board (PUB), Code of Practice on Surface Water Drainage, Seventh Edition

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Bioretention Swales 6

6

Chapter 6 **Bioretention Swales**

6.1 Introduction

Bioretention swales provide both stormwater treatment and conveyance functions. These systems consist of both components of a vegetated swale and a bioretention system. These components are subtly different in functions. The main function of the swale element is for conveyance of stormwater, while the primary function of the bioretention component is the promotion of soil filtration of stormwater. Typically, a bioretention swale would consist of a vegetated swale when the bioretention system is installed in the base of a swale. The swale may have a discharge capacity to convey stormwater flow for design events (i.e. up to the 10 year ARI event in accordance to the Singapore Code of Practice on Surface Water Drainage) or have overflow provision sized to by-pass design events to a drain with sufficient capacity.

The swale component provides pretreatment of stormwater to remove coarse to medium sediments while the bioretention system underneath removes finer particulates and associated contaminants. Figure 6.1 shows the cross-section of a bioretention swale. Bioretention swales provide flow retardation for frequent storm events and are particularly efficient at removing nutrients.

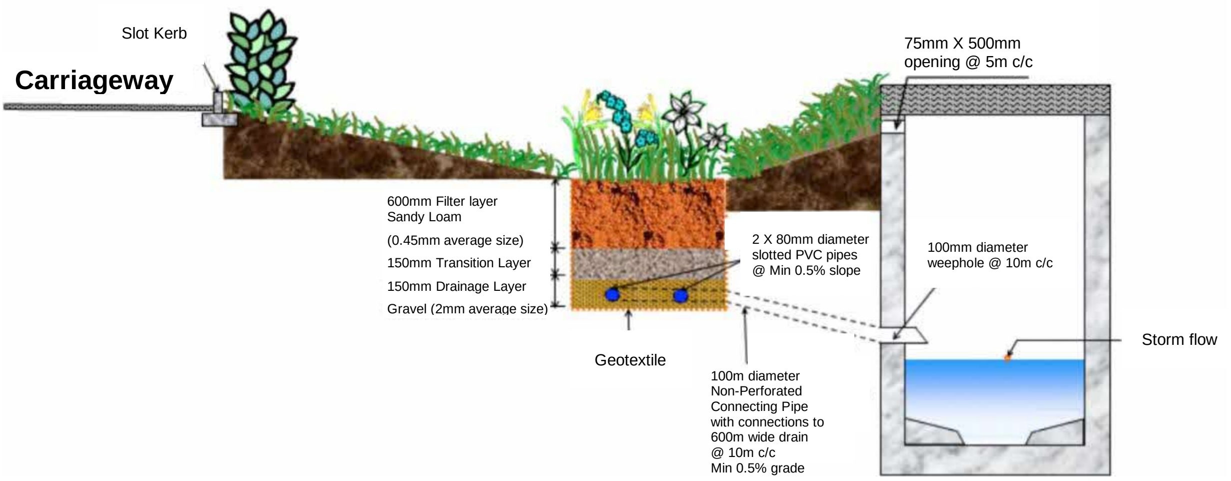

Figure 6.1 A typical Bioretention swale

The bioretention swale treatment process operates by firstly filtering stormwater runoff through surface vegetation associated with the swale. The bioretention component then operates by percolating the runoff vertically through a prescribed filter media, which provides treatment through fine filtration, extended detention treatment and biological uptake.

Bioretention swales also act to reduce flow velocities compared with concrete drains and thus provide protection to natural receiving waterways from frequent storm events. The bioretention component is typically located at the downstream end of the overlying swale ‘cell’ (i.e. immediately upstream of the swale overflow pit(s) as shown in Figure 6.2 or can be provided as a continuous “trench” along the full length of a swale).

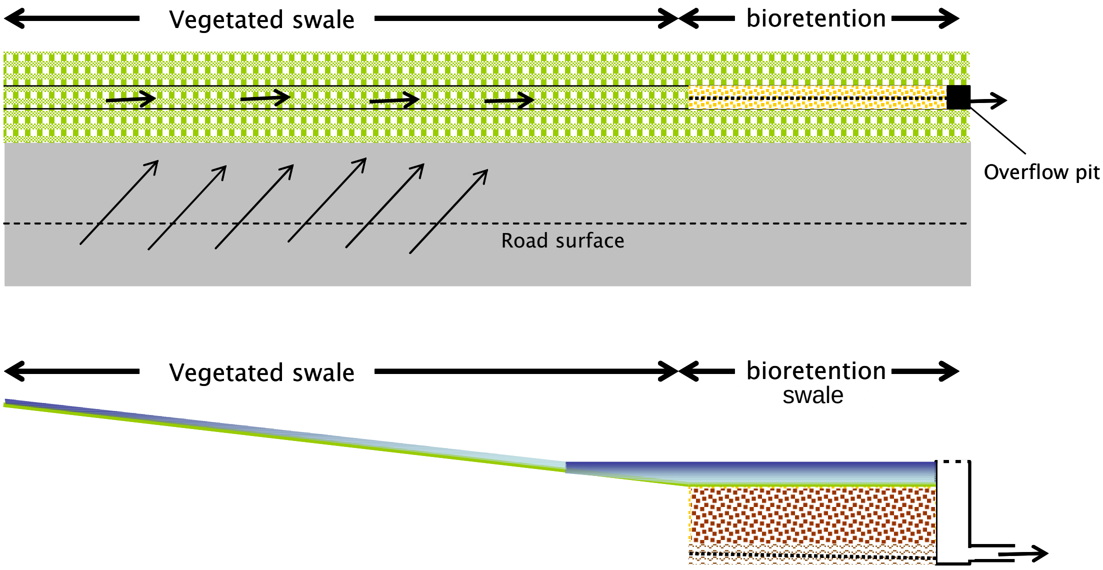

Figure 6.2 Bioretention Swale used downstream of vegetated swale

The choice of bioretention location within the overlying swale will depend on a number of factors, including available area for the bioretention filter media and the maximum batter slopes for the overlying swale. Typically, when used as a continuous trench along the full length of a swale, the desirable maximum longitudinal grade of the swale is 4%. For other applications, the desirable longitudinal slope of the bioretention zone is close to horizontal to encourage uniform distribution of stormwater flows over the full surface area of bioretention filter media and allowing temporary storage of flows for treatment.

Bioretention swales should not be used as an ‘infiltration’ system to prevent excessive stormwater exfiltrate from the bioretention filter media to the surrounding in-situ soils. Rather, the typical design intent is to recover the percolated stormwater runoff at the base of the filter media, within perforated under-drains, for subsequent discharge to receiving waterways or to a storage facility for potential reuse. Thus these systems are suited even when close to structures as long as steps are taken to prevent exfiltration to surround soils through the use of a impervious liner where necessary.

In some circumstances however, where the in-situ soils are appropriate (i.e. have suitable permeability to avoid water stagnation) and there is a particular design intention to recharge local groundwater, it may be desirable to permit the percolated stormwater runoff to exfiltrate from the base of the filter media to the underlying in-situ soils.

6.2 Design Considerations for Bioretention Swales

This section outlines some of the key design considerations for bioretention swales that the designer should be familiar with. Standard design considerations for the swale component of bioretention swales are discussed in detail in Chapter 5 (Swales and Buffers) and are not reproduced here. However, swale design considerations that relate specifically to the interactions between the swale and bioretention components are presented in this chapter so as to provide sufficient clarity of these interactions with design considerations that are specifically related to the bioretention component.

Design considerations for the bioretention system are similar to that presented in Chapter 7 Bioretention Basins and are presented in both chapters for ease of reference with the exception of submerged zones which may be incorporated in bioretention swales to maximise treatment performance. Refer to Chapter 7.2 Key design configurations for further detail.

6.2.1 Landscape Design

Bioretention swales may be located within parkland areas, residential areas, carparks or along roadway corridors within footpaths (i.e. road verges) or centre medians etc. Landscape design of bioretention swales along the road edge can assist in defining the boundary of road or street corridors as well as providing landscape character and amenity. It is therefore important that the landscape design of bioretention swales addresses stormwater quality objectives and accommodates these other important landscape functions.

6.2.2 Hydraulic Design

A key hydraulic design consideration for bioretention swales is the delivery of stormwater runoff from the swale onto the surface of a bioretention filter media. Flow must not scour the bioretention surface and needs to be uniformly distributed over the full surface area of the filter media. In steeper areas, check dams may be required along the swale to reduce flow velocities discharged onto the bioretention filter media.

It is important to ensure that velocities in the bioretention swale are kept below 0.5 m/s for frequent runoff events (10 year ARI) and below 2.0 m/s for major (100 year ARI) runoff events to avoid scouring. This can be achieved by ensuring the slope and hydraulic roughness of the overlying swale reduce flow velocities by creating shallow temporary ponding (i.e. extended detention) over the surface of the bioretention filter media via the use of a check dam. This may also increase the overall volume of stormwater runoff that can be treated by the bioretention filter media.

6.2.3 Preventing Exfiltration to In-situ Soils

Bioretention swales can be designed to generally preclude exfiltration of treated stormwater to the surrounding in-situ soils. The amount of water potentially lost from bioretention trenches to surrounding in-situ soils is largely dependent on the characteristics of the surrounding soils and the saturated hydraulic conductivity of the bioretention filter media (see Section 6.2.5).

If the saturated hydraulic conductivity of the filter media is one to two orders of magnitude (i.e. 10 to 100 times) greater than that of the surrounding soil profile, the preferred flow path for stormwater runoff will be effectively contained within the bioretention filter media and into the perforated under-drains at the base of the filter media. As such, there will be little exfiltration to the surrounding soils.

If the selected saturated hydraulic conductivity of the bioretention filter media is less than 10 times that of the surrounding soils, it may be necessary to provide an impermeable liner. Flexible membranes or a concrete casting are commonly used to prevent excessive exfiltration. The greatest pathway of exfiltration is through the base of a bioretention trench. If lining is required, it is likely that only the base and the sides of the *drainage layer* (refer Section 6.2.5) will need to be lined.

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

Bioretention system built on highly porous landscape may suitably promote exfiltration to surrounding soils. In such circumstances, the designer must consider site terrain, hydraulic conductivity of the in-situ soil, soil salinity, groundwater and building setback.

6.2.4 Vegetation Types

Bioretention swales can use a variety of vegetation types including turf (swale component only), sedges and tufted grasses. Vegetation is required to cover the whole width of the swale and bioretention filter media surface, be capable of withstanding design flows and be of sufficient density to prevent preferred flow paths and scour of the media surface. Grass species that do not have fibrous or shallow roots should ideally be avoided as shallow rooted systems with inadequate penetration to the full depth of the filter media will not help to keep the permeability of filter media. Therefore it is preferred that the vegetation for the bioretention component of bioretention swales is sedges. A list of plants for use in the filtration area of bioretention systems is in 6.7 for reference. A CUGE (NParks) publication on “A selection of plants for bioretention systems in the tropics” can also be consulted for plant selection. The publication can be downloaded at https://www.cuge.com.sg/research/download.php?product=47.

Dense vegetation planted along the swale component can also offer improved sediment retention by reducing flow velocity and providing enhanced sedimentation for deeper flows. However, densely vegetated swales have higher hydraulic roughness and this will need to be considered in assessing their discharge capacity. Densely vegetated bioretention swales can become features of an urban landscape and once established, require minimal maintenance and can help to maintain soil porosity.

6.2.5 Bioretention Filter Media

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

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

The high rainfall intensities experienced in Singapore is expected to result in bioretention treatment areas being larger in Singapore than comparable systems overseas in Australia and the United States. The area available for bioretention swales in an urban layout is often constrained by factors such as the available area within the footpaths of standard road reserves.

Selecting bioretention filter media for bioretention swale applications in Singapore will often require careful consideration of saturated hydraulic conductivity and extended detention depth to ensure the desired minimum volume of stormwater runoff receives treatment. This must also be balanced with the requirement to ensure the saturated hydraulic conductivity does not become too high such that it can no longer sustain healthy vegetation growth.

The maximum saturated hydraulic conductivity (k_f) should not exceed 500 mm/hr (and preferably be between 100 - 300 mm/hr) in order to sustain vegetation growth. k_f less than 100 mm/hr (>50 mm/hr) could be accepted with caution.

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

As shown in Figure 6.3, a bioretention system can consist of three layers. The filter media is the primary soil layer consisting typically of sandy-loam material. In addition to the filter media, a drainage layer is also required to convey treated water from the base of the filter media to the outlet via a perforated under-drains unless the design intent is to allow the filtered water to discharge (exfiltrate) into insitu soil. The drainage layer surrounds perforated under-drains and consist typically of fine gravel of 2-5 mm particle size. In between the filter media layer and the drainage layer is the transition layer consisting of clean sand (1mm) to prevent migration of the base filter media into the drainage layer and into the perforated under-drains.

[Refer to the Bioretention Media Guidelines produced by FAWB[1] (2009) for more information.]

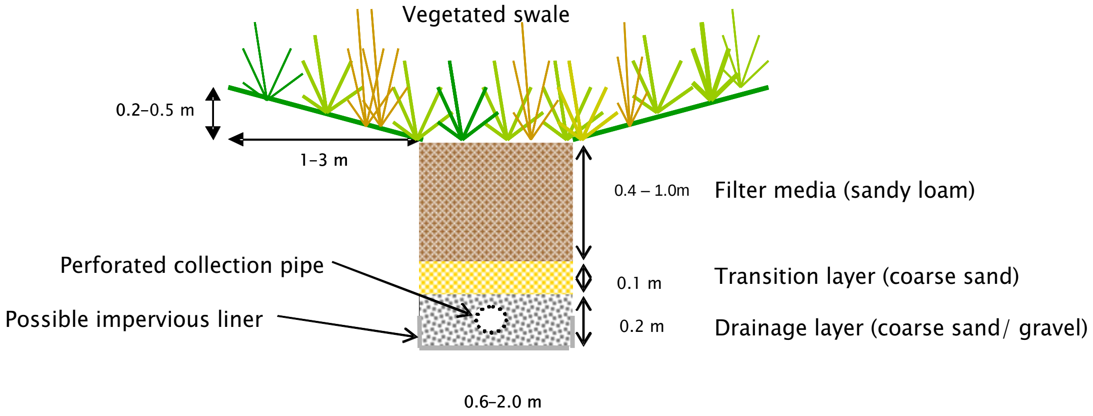
Vegetated swale
0.2–0.5 m
1–3 m
0.4 – 1.0m
Filter media (sandy loam)
Perforated collection pipe
0.1 m
Transition layer (coarse sand)
Possible impervious liner
0.2 m
Drainage layer (coarse sand/ gravel)
0.6–2.0 m

Figure 6.3 Typical Section of a Bioretention Swale

6.2.6 Traffic Controls

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

A staged construction and establishment method (see Section 6.4.2) affords protection to the sub-surface elements of a bioretention swale from heavily sediment laden runoff during the subsequent construction phases. However, to prevent vehicles driving on bioretention swales and inadvertent placement of building materials, it is necessary to consider appropriate traffic control solutions as part of the system design. These can include temporary fencing of the swale during the construction and allotment building

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[1] Facility for Advancing Water Biofiltration – http://www.monash.edu.au/fawb/

phases with signage erected to alert builders and contractors of the purpose and function of the swales. Management of traffic near swales can be achieved in a number of ways such as planting the interface to the road carriageway with dense vegetation that will discourage the movement of vehicles onto the swale or, if dense vegetation cannot be used, by providing physical barriers such as kerb and channel (with breaks to allow distributed water entry to the swale) or bollards and/ or street tree planting.

Kerb with slots or drop inlet chambers should be used to convey road runoff to the bioretention swales. The transition from barrier type kerb to flush kerbs and vice versa is to be done in a way that avoids creation of low points that cause ponding onto the road pavement.

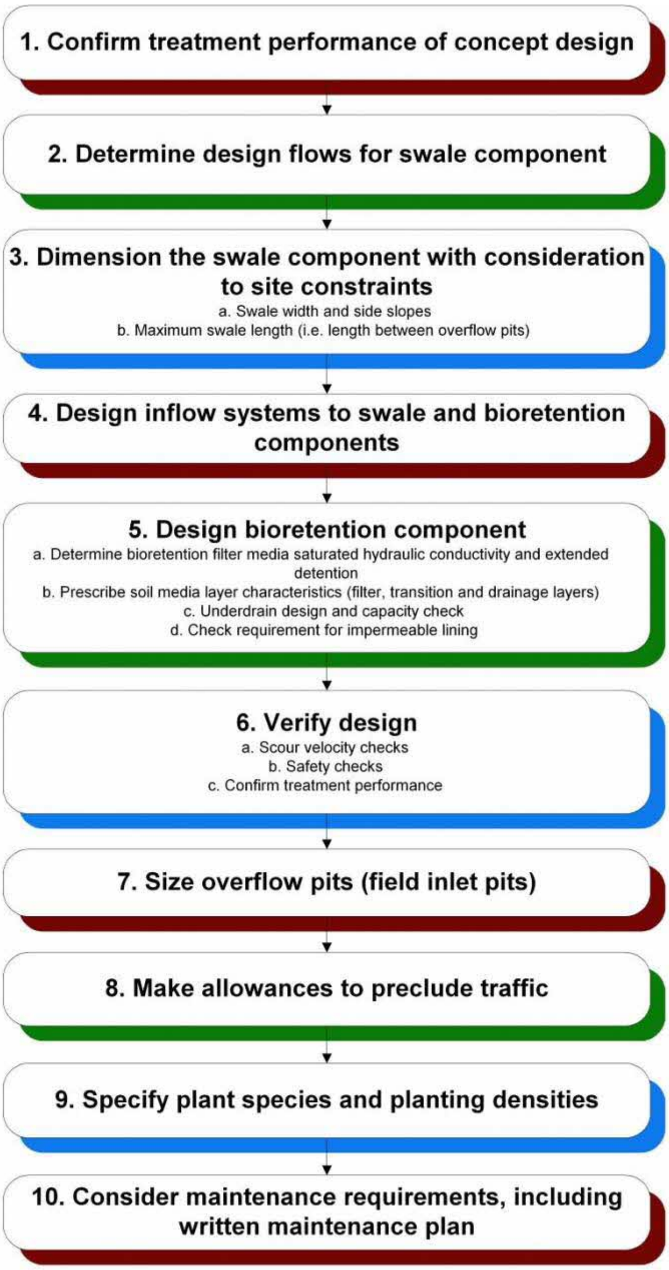
Where bioretention systems are used in road verge, the use of bioretention basins can allow for tree planting in between them.

6.2.7 Services

It is good to have bioretention systems not affected by any services. However, if this is not possible, selected services could locat beneath the batter of the bioretention swale, without affecting the filter layers and sub-soil pipes.

6.3 Bioretention Swale Design Process

To create bioretention swales, separate calculations are performed to design the swale and the bioretention system, with iterations to ensure appropriate criteria are met in each section. The calculations and decisions required to design the swale component are presented in detail in Chapter 5 Swales and Buffers and are reproduced in this chapter. This is to allow designers and assessors to consult with this chapter only for designing and checking bioretention swale designs. The key design steps are:


1. Confirm treatment performance of concept design
2. Determine design flows for swale component
3. Dimension the swale component with consideration to site constraints
a. Swale width and side slopes
b. Maximum swale length (i.e. length between overflow pits)
4. Design inflow systems to swale and bioretention components
5. Design bioretention component
a. Determine bioretention filter media saturated hydraulic conductivity and extended detention
b. Prescribe soil media layer characteristics (filter, transition and drainage layers)
c. Underdrain design and capacity check
d. Check requirement for impermeable lining
6. Verify design
a. Scour velocity checks
b. Safety checks
c. Confirm treatment performance
7. Size overflow pits (field inlet pits)
8. Make allowances to preclude traffic
9. Specify plant species and planting densities
10. Consider maintenance requirements, including written maintenance plan

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

6.3.1 Step 1: Confirm Treatment Performance of Concept Design

Before commencing detailed design, the designer should first undertake a preliminary check to confirm the bioretention swale treatment area from the concept design is adequate to deliver the required level of stormwater quality improvement. A conceptual design of a bioretention basin is normally typically undertaken prior to detailed design. The performance of the concept design must be checked to ensure that stormwater treatment objectives will be satisfied.

The treatment performance curves shown in Figure 6.4 to Figure 6.6 reflect the treatment performance of the bioretention component only and will be conservative as they preclude the sediment and nutrient removal performance of the overlying swale component. Notwithstanding this, the performance of the swale component for nitrogen removal is typically only minor and thus the sizing of the bioretention component will typically be driven by achieving compliance with best practice load reduction targets for Total Nitrogen. Therefore, by using the performance curves below, the designer can be confident that the combined performance of the swale and bioretention components of a bioretention swale will be similar to that shown in the curves for total Nitrogen and will exceed that shown for Total Suspended Sediment and total Phosphorus.

These curves are intended to provide an indication only of appropriate sizing and do not substitute the need for a thorough conceptual design process. Nevertheless, it is a useful visual guide to illustrate the sensitivity of bioretention treatment performance to the ratio of bioretention treatment area and contributing catchment area. The curves allow the designer to make a rapid assessment as to whether the bioretention trench component size falls within the “optimal size range” or if it is potentially under or over-sized.

The curves in Figure 6.4 to Figure 6.6 show the total suspended solid (TSS), total phosphorus (TP) and total nitrogen (TN) removal performance for a typical bioretention basin design with the following configurations:

- Filter media saturated hydraulic conductivity (k) = 180 mm/hr (0.5 x 10^{-4} m/s) and 360mm/hr (1 x 10^{-4} m/s)
- Filter Media average particle size = 0.5mm
- Filter Media Depth = 0.6m
- Extended Detention Depth = from 0 mm to 300 mm

The curves in Figure 6.4 to Figure 6.6 are generally applicable to bioretention swale applications within residential, industrial and commercial land uses.

If the characteristics of the bioretention component of the bioretention swale concept design are significantly different to that described above, then the curves in Figure 6.4 to Figure 6.6 may not provide an accurate indication of treatment performance**.** In these cases, the detailed designer should use MUSIC or equivalent software to verify the performance of the bioretention swale.

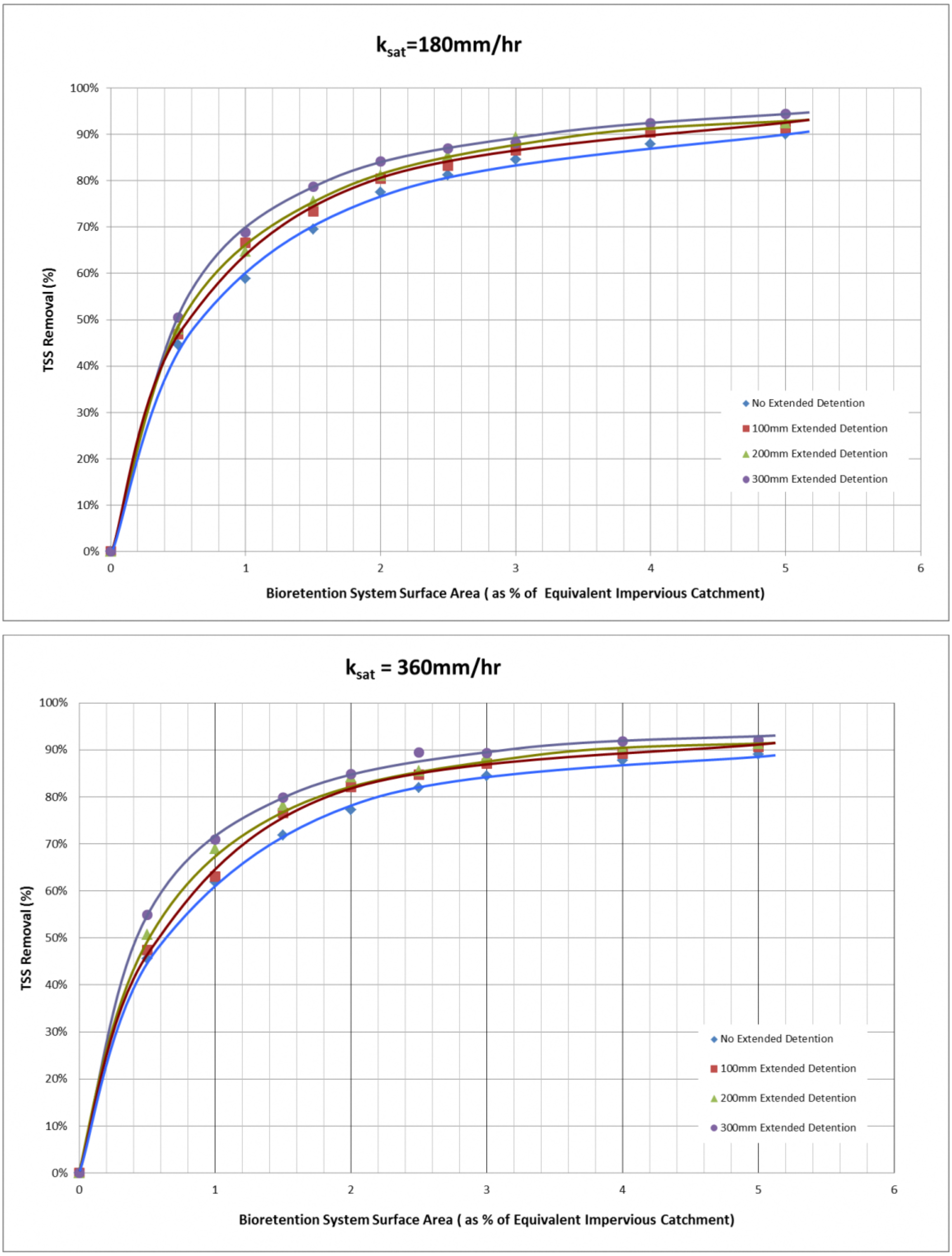
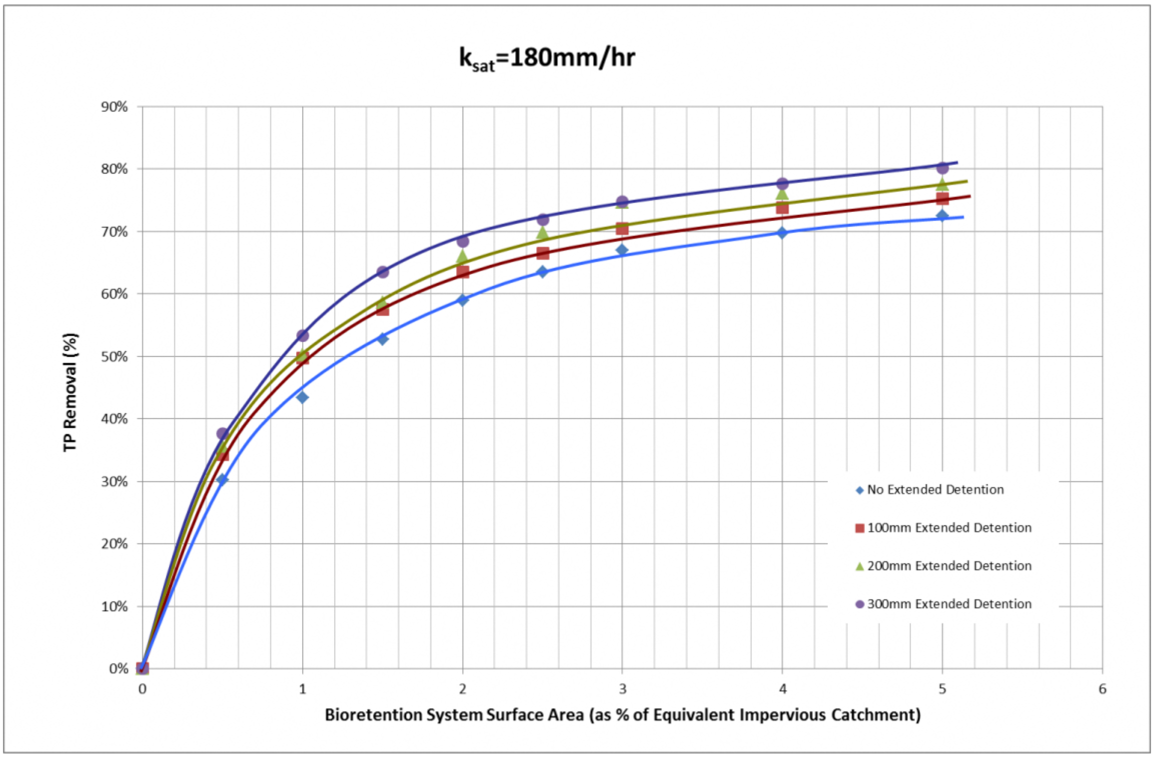


Figure 6.4 Bioretention system TSS removal performance (Reference: Station 43)



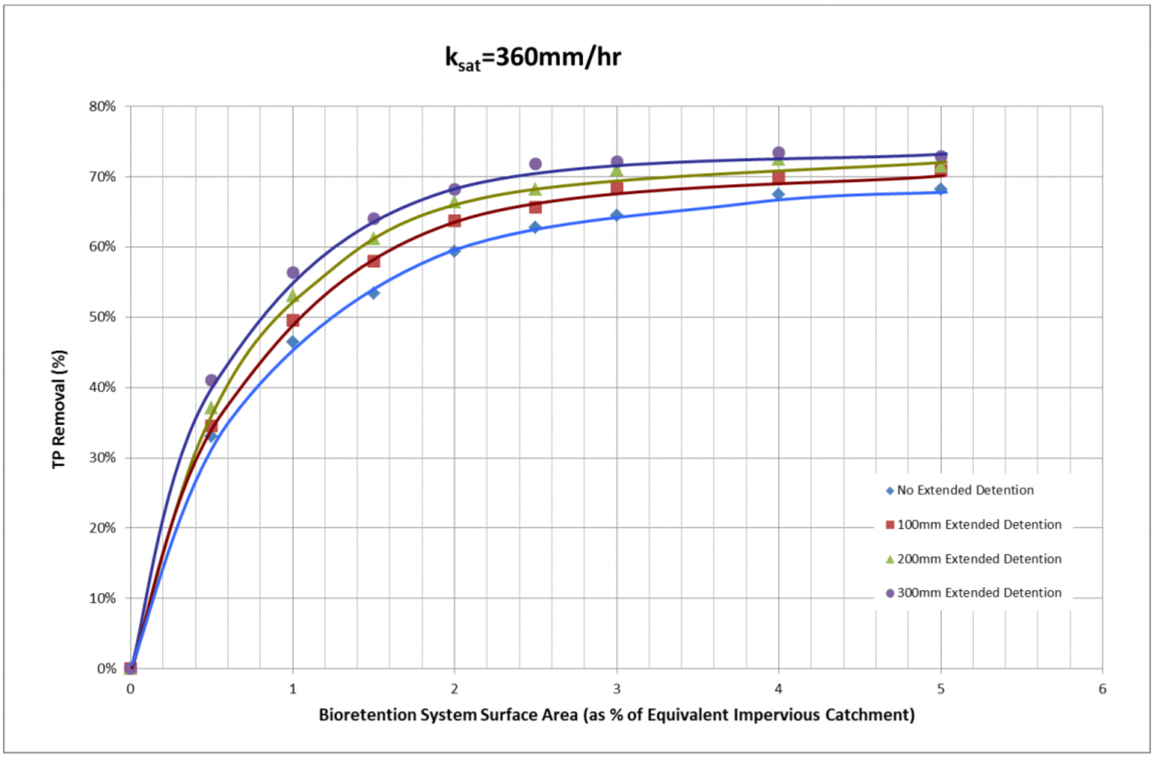
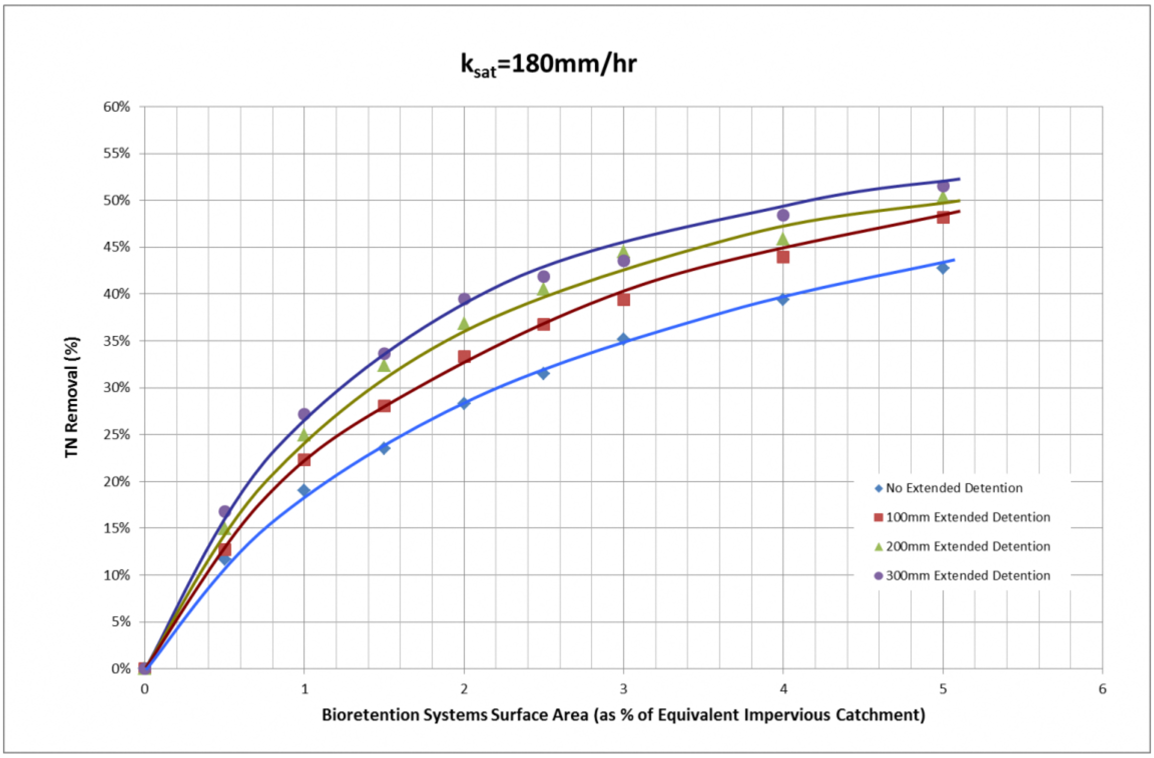


Figure 6.5 Bioretention system TP removal performance (Reference: Station 43)



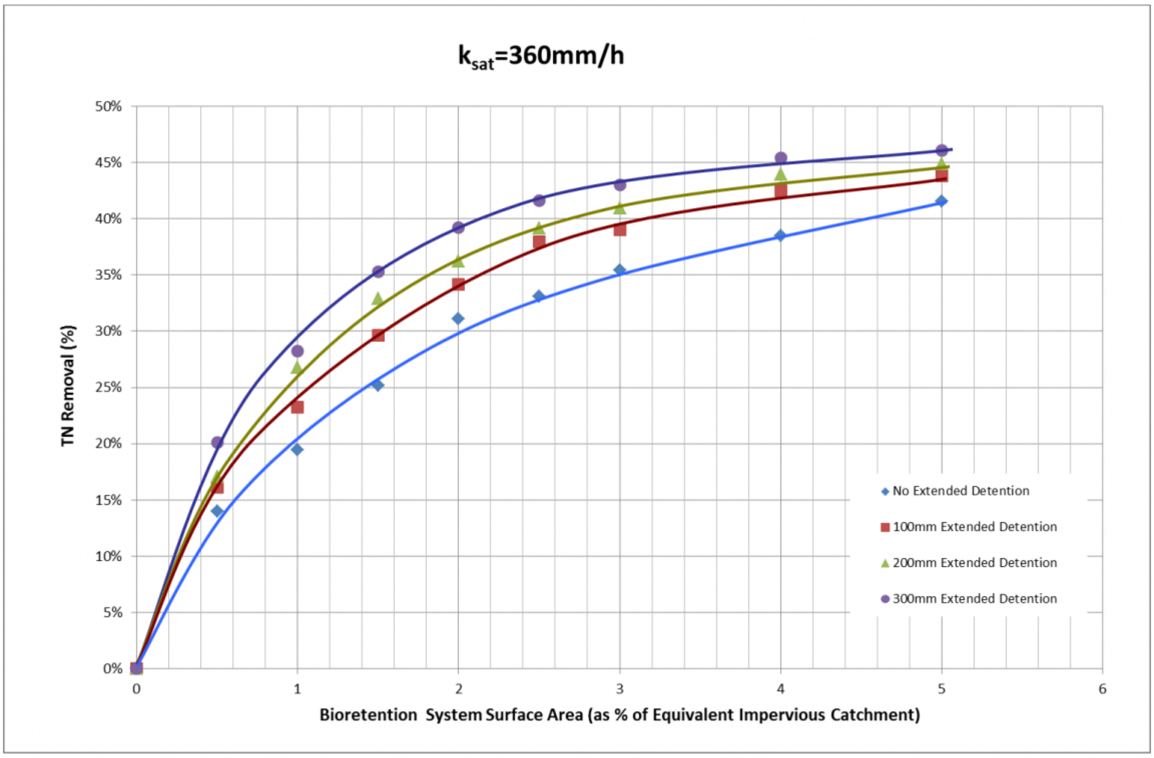


Figure 6.6 Bioretention system TN removal performance (Reference: Station 43)

6.3.2 Step 2: Determine Design Flows for the Swale Component

6.3.2.1 Design Flows

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

- Minor (frequent) storm conditions (typically 10 year ARI) to size the hydraulic structures to safely convey storm flows of frequent/minor events within the swale and not increase any flooding risk compared to conventional stormwater systems
- Major flood flow (100 year ARI) to check flow velocities, velocity depth criteria, conveyance within road reserve, and freeboard to adjoining property.

6.3.2.2 Design Flow Estimation

A range of hydrologic methods can be applied to estimate design flows. As the typical catchment area should be relatively small (<50 ha) the Rational Method design procedure is considered to be a suitable method for estimating design peak flows.

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

Factors to consider in defining the dimensions of the bioretention swale are:

- allowable width given the proposed road reserve and/ or urban layout
- how flows are delivered into a swale (e.g. cover requirements for pipes or kerb details)
- vegetation height
- longitudinal slope
- maximum side slopes and base width
- provision of crossings (elevated or at grade)
- requirements of the Public Utilities Board Code of Practice on Surface Water Drainage (latest edition).

Depending on which of the above factors are fixed, the other variables can be adjusted to derive the optimal swale dimensions for the given site conditions. The following sections outline some considerations in relation to dimensioning a swale.

6.3.3.1 Swale Width and Side Slopes

The maximum width of swale is usually determined from an urban layout and at the concept design stage, and should be in accordance with relevant local guidelines or standards of the Public Utilities Board. Where the swale width is not constrained by an urban layout (e.g. when located within a large parkland area) then the width of the swale can be selected based on consideration of landscape objectives, maximum side slopes for ease of maintenance and public safety, hydraulic capacity required to convey the desired design flow, and treatment performance requirements. Swale side slopes are typically between 1 in 10 and 1 in 4. The maximum swale width needs to be identified early in the design process as it dictates the remaining steps in the swale design process.

For swales located adjacent to residential roads, the types of driveway crossing used will typically dictate batter slopes. Where there are no driveway crossings, the maximum swale side slopes will be established from ease of maintenance and public safety considerations. Generally ‘at-grade’ crossings, are preferred which require the swale to have 1:9 side slopes with a nominal 0.5 m flat base to provide sufficient transitions to allow for traffic movement across the crossing. Flatter swale side slopes can be adopted but this will reduce the depth of the swale and its conveyance capacity. Where ‘elevated’ crossings are used, swale side slopes would typically be between 1 in 6 and 1 in 4. ‘Elevated’ crossings will require provision for drainage under the crossings with a culvert or similar. The selection of crossing type should be made in consultation with urban and landscape designers.

6.3.3.2 Maximum Length of a Swale

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

The maximum length of a swale located along a roadway is calculated as the distance along the swale to the point where flow on the adjoining road pavement (or road reserve) no longer complies with the local standards for road drainage (for both the minor and major flood flows). This is often related to the discharge capacity of the swale and is calculated as the distance along the swale to the point where the flow in the swale (for the specific design flood frequency) exceeds the bank full capacity of the swale. For example, if the swale is to convey the minor flood flow (typically the 10 year ARI event in accordance to the Singapore Code of Practice for Surface Drainage) without overflowing, then the maximum swale length would be determined as the distance along the swale to the point where the 10 year ARI flow from the contributing catchment is equivalent to the bank full flow capacity of the swale (bank full flow capacity is determined using Manning’s equation as discussed section 6.3.3.3).

6.3.3.3 Swale Capacity – Manning’s Equation and Selection of Manning’s *n*

The flow capacity of a swale can be calculated using Manning’s equation. This allows the flow rate (and flood levels) to be determined for variations in swale dimensions, vegetation type and longitudinal slope.

$$Q = \frac{A \cdot R^{2/3} \cdot S^{1/2}}{n} \qquad \text{Equation 6.1}$$

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

R = hydraulic radius (m)

S = channel slope (m/m)

n = roughness factor (Manning’s n)

Q = flow (m^3/s)

Manning’s *n* is a critical variable in Manning’s equation relating to roughness of the channel. It varies with flow depth, channel dimensions and vegetation type. For constructed swale systems, typical Manning’s n values are between 0.15 and 0.4 for flow depths shallower than the vegetation height (preferable for treatment) and significantly lower for flows with greater depth than the vegetation (e.g. 0.03 for flow depth more than twice the vegetation height).

Figure 6.7 shows a plot of Manning’s *n* versus flow depth for a grass swale with longitudinal grade of 5 % which is also applicable for other swale configurations. The bottom axis of the plot has been modified from Barling and Moore (1993) to express flow depth as a percentage of vegetation height. Further discussion on selecting an appropriate Manning’s *n* for a swale is provided in Appendix F of the *MUSIC User Guide* (eWater Ltd 2014).

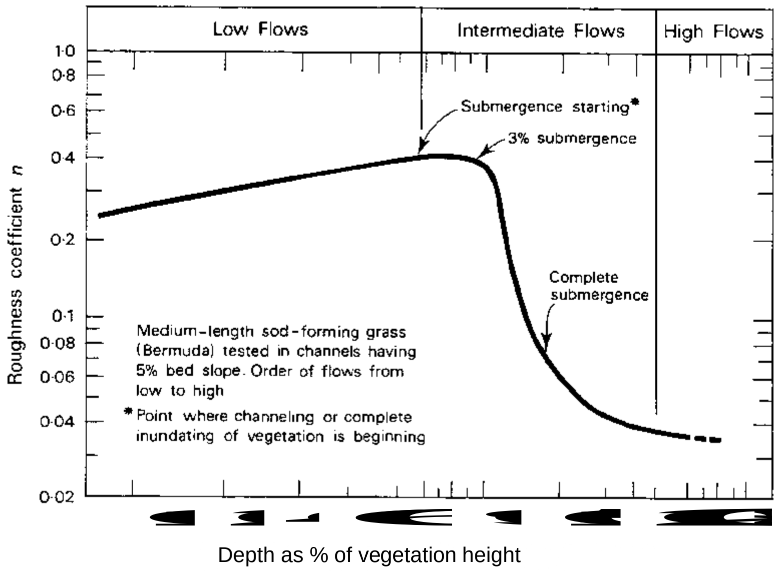


Figure 6.7 **Impact of Flow Depth on Hydraulic Roughness (adapted from Barling and Moore (1993)**

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

Inflows to bioretention swales can be via distributed runoff (e.g. from flush kerbs on a road) or point outlets such as pipe outfalls. Combinations of these inflow pathways can also be used. Uniform distribution of inflow would generally provide better operating conditions of bioretention swales owing to their long linear configuration.

6.3.4.1 Distributed Inflow

An advantage of flows entering a bioretention swale system in a distributed manner (i.e. entering perpendicular to the direction of the swale) is that flow depths are kept as shallow owing to sheet flow conditions. This maximises contact with the swale and bioretention vegetation, particularly on the batter (buffer strip) receiving the distributed inflows (see Figure 6.8). The buffer strip provides good pretreatment (i.e. significant coarse sediment removal) prior to flows being conveyed along the swale.

Distributed inflows can be achieved either by having a flush kerb or by using kerbs with regular breaks in them to allow for even flows across the buffer surface (Figure 6.9).

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

- providing distributed flows into a buffer (potentially spreading stormwater flows to achieve this)
- avoiding rilling or channelised flows
- maintaining flow heights lower than vegetation heights (this may require flow spreaders, or check dams)
- minimising the slope of buffer, best if slopes can be kept below 5 %, however buffers can still perform well with slopes up to 20 % provided flows are well distributed. The steeper the buffer the more likely flow spreaders will be required to avoid rill erosion (i.e. the removal of soil by concentrated water flow, and it occurs when the water forms small channels in the soil as it flows off site).

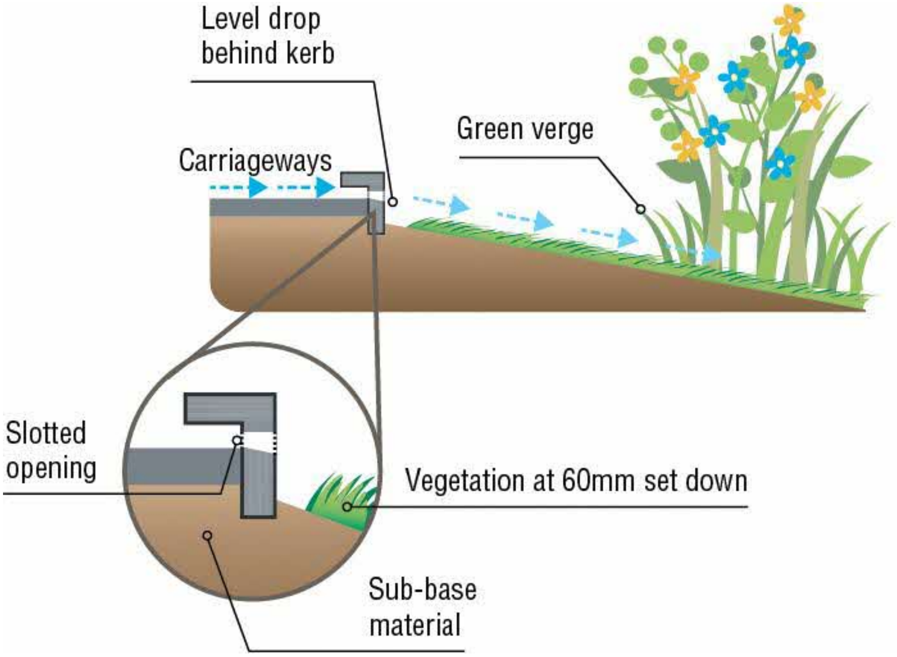


Figure 6.8 **Slotted Kerbs with level drop or set-down allow Sediments to Flow into Vegetated Area**

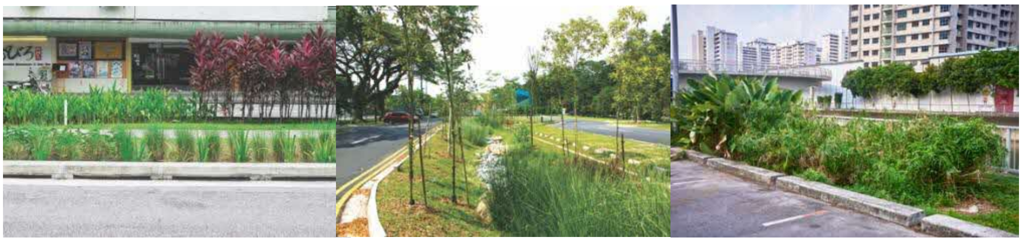


Figure 6.9 **Kerb Arrangements with Breaks to Distribute Inflows on to Bioretention Swales and Prevent Vehicle Access**

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

It is important to ensure coarse sediments accumulate off the road surface at the start of the buffer. Figure 6.10 shows sediment accumulating on a street surface where the vegetation is the same level as the road. To avoid this accumulation, a tapered flush kerb must be used that sets the top of the vegetation at approximately 60 mm below the road surface, which requires the top of the ground surface (before turf is placed) to be approximately 100 mm below the road surface. This allows sediments to accumulate off any trafficable surface.

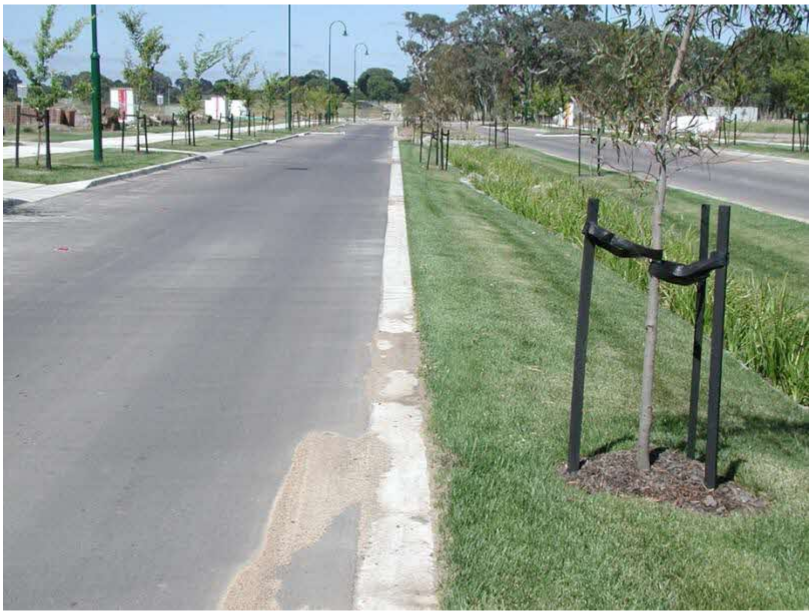


Figure 6.10 Flush Kerb without Setdown, showing Sediment Accumulation on Road

6.3.4.2 Concentrated Inflow

Concentrated inflows to a bioretention swale can be in the form of a concentrated overland flow or a discharge from a piped drainage system (e.g. allotment drainage line). For all concentrated inflows, energy dissipation at the inflow location is an important consideration to minimise any erosion potential. This can usually be achieved with rock benching and/ or dense vegetation.

The most common constraint on pipe systems discharging to bioretention swales is bringing the pipe flows to the surface of a swale. In situations where the swale geometry does not allow the pipe to achieve ‘free’ discharge to the surface of the swale, a ‘surcharge’ pit may need to be used. Surcharge pits should be designed so that they are as shallow as possible and have pervious bases or weep-holes to avoid long term ponding in the pits (this may require under-drains to ensure it drains, depending on local soil conditions). The pits need to be accessible so that any build up of coarse sediment and debris can be monitored and removed if necessary. Surcharge pits are not considered good practice due to additional maintenance issues and mosquito breeding potential and should therefore be avoided where possible.

Surcharge pit systems are most frequently used when allotment runoff is required to cross a road into a swale on the opposite side of the road or for allotment runoff discharging into shallow profile swales. Where allotment runoff needs to cross under a road to discharge to a swale, it is preferable to combine the runoff from more than one allotment to reduce the number of crossings required under the road pavement. Figure 6.11 illustrates a typical surcharge pit discharging into a swale. The design of the surcharge pit is for reference only. The actual design needs to be approved by relevant agencies and the party who will take over the maintenance.

Another important form of concentrated inflow in a bioretention swale is the discharge from the swale component into the bioretention component, particularly where the bioretention component is located at the downstream end of the overlying swale and receives flows concentrated within the swale. Depending on the grade, its top width and batter slopes, the resultant flow velocities at the transition from the swale to the bioretention filter media may require the use of energy dissipation to prevent scour of the filter media. For most cases, this can be achieved by placing several large rocks in the flow path to reduce velocities and spread flows. Energy dissipaters located within footpaths must be designed to ensure pedestrian safety.

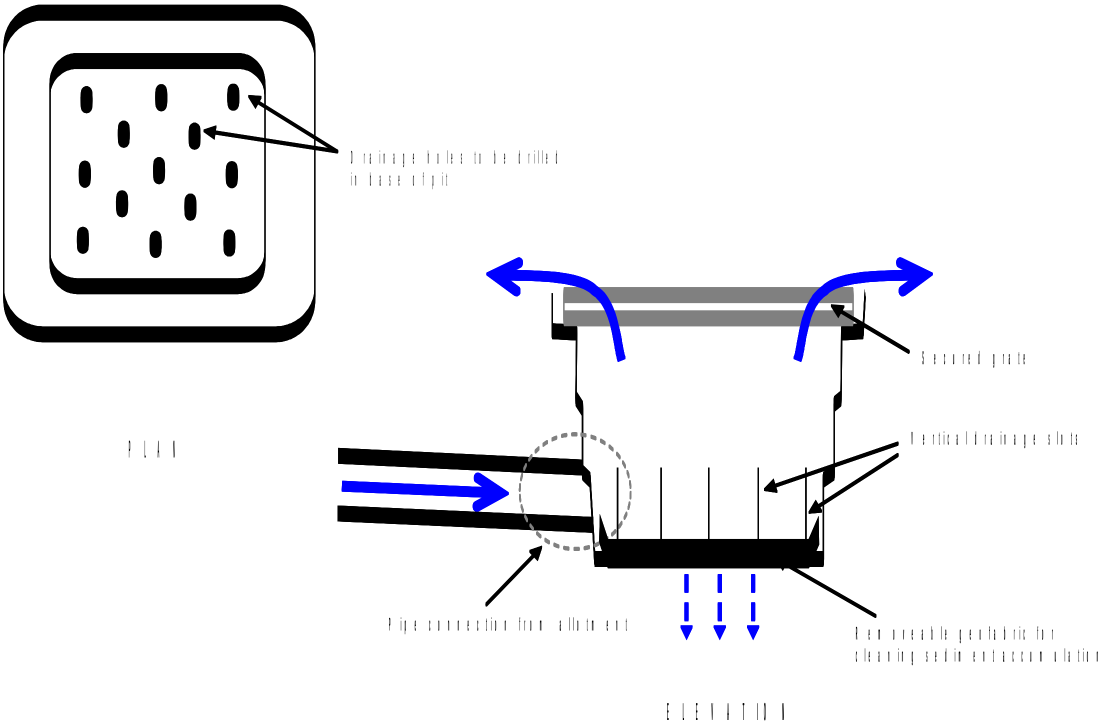

Drainage holes to be drilled
in base of pit
PLAN
Secured grate
Vertical drainage slots
Pipe connection from allotment
Removable geofabric for
cleaning sediment accumulation
ELEVATION

Figure 6.11 Example of Surcharge Pit for Discharging Allotment Runoff into a Swale

6.3.5 Step 5: Design Bioretention Component

6.3.5.1 Specify the Bioretention Filter Media Characteristics

Generally, three types of media are required in the bioretention component of bioretention swales (refer Figure 6.3 in Section 6.2.5).

<u>Filter Media</u>

The filter media layer provides the majority of the pollutant treatment function, through fine filtration and also by supporting vegetation. The vegetation enhances filtration, keeps the filter media permeable, provides substrate for biofilm formation that is important for the uptake and removal of nutrients and other stormwater pollutants. It is important to have a good plant density on filter media. As a minimum, the filter media is required to have sufficient depth to support vegetation. Typical depths are between 600-1000 mm with a minimum depth of 400mm accepted in depth constrained situations. It is important to note that if deep rooted plants such as trees are to be planted in bioretention swales, the filter media must have a minimum depth of 1000 mm to provide sufficient plant anchoring depth.

Saturated hydraulic conductivity should be between 100-300 mm/hr (and should not be greater than 500 mm/hr). Saturated hydraulic conductity between 50 and 100 mm/hr can be accepted with caution. The following procedure is recommended in determining the appropriate soil filter media to match the design saturated hydraulic conductivity:

- Identify available sources of a suitable base soil (i.e. topsoil) capable of supporting vegetation growth such as a sandy loam or sandy clay loam. In-situ topsoil should be considered first before importing soil. Any soil found to contain high levels of salt (see last bullet point), extremely low levels of organic carbon (< 3%), or other extremes considered retardant to plant growth and microbial activity should be rejected. The base soil must also be free from pollutants like heavy metals, excessive nutrient and organic pollutants that may affect water quality of the filtrate.
- Using laboratory analysis, determine the saturated hydraulic conductivity of the base soil using standard testing procedures. (In Australia, reference is made to AS 4419-2003 Appendix H Soil Permeability or refer to Constant head method BS1377-5:1990 for Singapore). A minimum of five samples of the base soil should be tested. Any occurrence of structural collapse during laboratory testing must be noted and an alternative base soil sourced.
- To amend the base soil to achieve the desired design saturated hydraulic conductivity either mix in a loose non-angular sand (to increase saturated hydraulic conductivity) or conversely a loose loam (to reduce saturated hydraulic conductivity).
- The required content of sand or clay (by weight) to be mixed to the base soil will need to be established in the laboratory by incrementally increasing the content of sand or clay until the desired saturated hydraulic conductivity is achieved. The sand or clay content (by weight) that achieves the desired saturated hydraulic conductivity should then be adopted on-site. A minimum of five samples of the selected base soil and sand (or clay) content mix must be tested in the laboratory to ensure saturated hydraulic conductivity is consistent across all samples. If the average saturated hydraulic conductivity of the final filter media mix is within ± 20% of the design saturated hydraulic conductivity then the filter media can be adopted and installed in the bioretention system. Otherwise, further amendment of the filter media must occur through the addition of sand (or clay) and retested until the design saturated hydraulic conductivity is achieved.
- The filter media must be structurally sound and not prone to structural collapse as this can result in a significant reduction in saturated hydraulic conductivity. The risk of structural collapse can be reduced by ensuring the soil has a well graded particle size distribution with a combined clay and silt fraction of < 12%.
- The base soil must have sufficient organic content to establish vegetation on the surface of the bioretention system. If the proportion of base soil in the final mix is less than 3%, it may be necessary to add organic material. This should not result in more than 10% organic content and should not alter the saturated hydraulic conductivity of the final filter media mix.
- The pH of the final filter media is to be amended (if required) to between 5.5 and 7.5. If the filter media mix is being prepared off-site, this amendment should be undertaken before delivery to the site.
- The salt content of the final filter media (as measured by EC1:5) must be less than 0.63 dS/m for low clay content soils like sandy loam. (EC1:5 is the electrical conductivity of a 1:5 soil/ water suspension).
- Testing of this soil property should be undertaken prior to their placement during construction. It should also be noted that soil hydraulic conductivity will vary after placement and is expected to initially decrease due to hydraulic compaction during operation. With maturity of plant growth, the

soil hydraulic conductivty canbe expected to recover to asymptote to an equilibrium level comparable to its original value.

The selection of suitable soil filter media is a topic of continuing research. Further information can also be obtained from “Guidelines for Filter Media for Biofiltration System by FAWB (Facility for Advancing Water Biofiltration).

Transition Layer

The particle size difference between the filter media and the underlying drainage layer should be not more than one order of magnitude to avoid the filter media being washed through the voids of the drainage layer. Therefore, with fine gravels being used for the drainage layer (which will be at least two orders of magnitude coarser than the likely average particle size of the filter media), a transition layer is recommended to prevent the filter media from washing into the perforated pipes. The material for the transition layer is sand/coarse sand. An example particle size distribution (% passing) is provided below (typical specification only):

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

The transition layer is recommended to be 100 mm thick.

The addition of a transition layer increases the overall depth of the bioretention system and may be an important consideration for some sites where total depth of the bioretention system may be constrained. In such cases, two options are available to reduce the overall depth of the system, ie.

- the use of a sand drainage layer and/or perforated pipes with smaller slot sized may need to be considered (Section **Error! Reference source not found.**).
- use a geotextile layer with a mesh size specified to be between 0.7 to 1mm. (This option should be an option of last resort as the risk of installing inappropriate liner is high).

Drainage Layer

The drainage layer is used to convey treated flows to the outlet via a perforated under-drainage system. The composition of the drainage layer is to be considered in conjunction with the selection and design of the perforated under-drainage system (refer to Section **Error! Reference source not found.**) as the slot sizes in the perforated pipes may determine the minimum drainage layer particle size to avoid washout of the drainage layer into the perforated pipe system.

Gravel is the preferred media for the drainage layer to match with the typical slot size of typical perforated or slotted under-drains.

However, there may be circumstances where site conditions constraint the depth of the bioretention system. In such cases, it may be possible to use sand as the drainage layer media to avoid having to provide a transition layer between the filter media and the drainage layer. The drainage layer is to be a minimum of 200 mm thick and it is advisable that the drainage media is washed prior to placement in bioretention system to remove any fines.

6.3.5.2 Under-drain Design and Capacity Checks

The maximum spacing of the perforated pipes in wide bioretention trenches is 1.5 m (centre to centre) to ensure effective drainage of the bioretention system.

By installing parallel pipes, the capacity of the perforated pipe under-drain system can be increased. The recommended maximum diameter of the perforated pipes is 100 mm to minimise the required thickness of the drainage layer. Either flexible perforated pipe (e.g. agricultural pipe) or slotted PVC pipes can be used, however care needs to be taken to ensure that the slots in the pipes are not too large that sediment would freely flow into the pipes from the drainage layer. This is also a consideration when specifying the drainage layer media.

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

- Ensure perforations are adequate to pass the maximum filtration rate of the media.
- Ensure the pipe itself has capacity to convey the design flow (ie. the maximum filtration rate multiplied by the surface area).
- Ensure that the material in the drainage layer will not be washed into the perforated pipes.

6.3.5.3 Maximum filtration rate

The maximum filtration rate represents the maximum rate of flow through the bioretention filter media and is calculated by applying Darcy's equation (Equation 6.2) as follows:

$$Q_{max} = K_{sat} \cdot L \cdot W_{base} \cdot \frac{h_{max} + d}{d} \qquad \text{Equation 6.2}$$

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

K_{sat} = hydraulic conductivity of the soil filter (m/s)

W_{base} = base width of the ponded cross section above the soil filter (m)

L = length of the bioretention zone (m)

h_{max} = depth of pondage above the soil filter (m)

d = depth of filter media (m)

The capacity of the perforated under-drains need to be greater than the maximum filtration rate to ensure the filter media drains freely and the pipe(s) do not become the hydraulic 'control' in the bioretention system (i.e. to ensure the filter media sets the travel time for flows percolating through the bioretention system rather than the flow through the perforated under-drainage system).

To ensure the perforated under-drainage system has sufficient capacity to collect and convey the maximum infiltration rate, it is necessary to determine the inflow capacity of combined slotted area or perforation area of the under-drainage system. To do this, the sharp edged orifice equation can be used, i.e.

- the number and size of perforations is determined (typically from manufacturer's specifications)
- the maximum driving head (being the depth of the filtration media plus the depth of extended detention).
- it is conservative but reasonable to use a blockage factor to account for partial blockage of the perforations by the drainage layer media. A 50 % blockage of the perforation is recommended. The orifice equation is expressed as follows:-

$$Q_{perf} = B \cdot C_d \cdot A\sqrt{2 \cdot g \cdot h} \qquad \text{Equation 6.3}$$

Where

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

B = blockage factor (0.5)

C_d = orifice discharge coefficient (0.61 for sharp edge orifice)

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

g = gravity (9.81 m/s^2)

h = head above the perforated pipe (m)

It is essential that adequate inflow capacity is provided to enable the filtered water to drain freely into the drainage layer.

After confirming the capacity of the under-drainage system to collect the maximum filtration rate, it is then necessary to confirm the conveyance capacity of the under-drainage system is sufficient to convey the collected runoff. To do this, Manning's equation (Equation 6.1) can be used assuming pipe full flow conditions and a nominal friction slope of 0.5%. The Manning's roughness used will be dependent on the type of pipe used.

One end of the under-drains should be extended vertically to the surface of the bioretention system to allow inspection and maintenance when required. The vertical section of the under-drain should be a non-perforated or slotted pipe and capped to avoid short circuiting of flows directly to the drain.

6.3.5.4 Check Requirement for Impermeable Lining

The saturated hydraulic conductivity of the natural soil profile surrounding the bioretention system should be tested together with depth to groundwater, chemical composition and proximity to structures and other infrastructure. This is to establish if an impermeable liner is required at the base (only for systems designed to preclude exfiltration to in-situ soils) and/or sides of the bioretention basin (refer also to discussion in Section 6.2.5). If the saturated hydraulic conductivity of the filter media in the bioretention system is more than one order of magnitude (10 times) greater than that of the surrounding in-situ soil profile, no impermeable lining is required.

6.3.6 Step 6: Verify Design

6.3.6.1 Vegetation Scour Velocity Check

Potential scour velocities are checked by applying Manning's equation (Equation 6.1) to the bioretention swale design to ensure the following criteria are met:

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

6.3.6.2 Velocity and Depth Check – Safety

As bioretention swales are generally accessible by the public, it is important at any crossings and adjacent pedestrian and bicycle pathways to check that, the product of flow depth and flow velocity within the bioretention swale satisfies the following recommended public safety criteria:

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[2] This is consistent with the recommendation in the Singapore Code of Practice for Surface Drainage which stipulates that the maximum velocity for an earth drain and concrete-lined drain should not exceed 1.5 m/s and 3 m/s respectively.

- depth x velocity < $0.6.m^2/s$ for low risk locations and $0.4\ m^2/s$ for high risk locations
- maximum depth of flow over crossing = 0.3 m

6.3.6.3 Confirm Treatment Performance

If the previous two checks are satisfactory then the bioretention swale design is satisfactory from a conveyance function perspective and it is now necessary to confirm the treatment performance of the bioretention swale by reference to the performance information presented in Section 6.3.1

6.3.7 Step 7: Size Overflow Pit

In a bioretention swale system, overflow pits are used to control innundation depth. The crest of the pit is set raised above the surface of the bioretention filter media to establish the design extended detention depth.

Grated pits are typically used and the allowable head for discharges into the pits is the difference in level between the pit crest and the maximum permissible water level to satisfy the minimum freeboard requirements of the Public Utilities Board. Depending on the location of the bioretention swale, the design flow to be used to size the overflow pit could be the maximum capacity of the swale, the minor flood flow (10 year ARI) or the major flood flow (100 year ARI).

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

For free overfall conditions (weir equation):

$$Q_{weir} = B \cdot C_w \cdot L \cdot h^{3/2}$$ Equation 6.4

Where Q_{weir} = Flow into pit (weir) under free overfall conditions (m^3/s)

B = Blockage factor (= 0.5)

C_w = Weir coefficient (= 1.7)

L = Length of weir (perimeter of pit) (m)

h = Flow depth above the weir (pit) (m)

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

For drowned outlet conditions (orifice equation):

$$Q_{orifice} = B \cdot C_d \cdot A\sqrt{2 \cdot g \cdot h}$$ Equation 6.5

Where B, g and h have the same meaning as in Equation 6.4

$Q_{orifice}$ = flow rate into pit under drowned conditions (m^3/s)

C_d = discharge coefficient (drowned conditions = 0.6)

A = area of orifice (perforations in inlet grate) (m^2)

When designing grated field inlet pits, refer to relevant guidelines or standards for grate types for inlet pits.

6.3.8 Step 8: Make Allowances to Preclude Traffic on Swales

Refer to Section 6.2.6 for discussion on traffic control options.

6.3.9 Step 9: Specify Plant Species and Planting Densities

Refer to Section 6.2.4 and the National Parks Board of Singapore for advice on selecting suitable plant species for bioretention swales in Singapore. Consultation with landscape architects is recommended when selecting vegetation to ensure the treatment system compliments the landscape design of the area. It is also good to check with the party who will take over the landscape maintenance (e.g. Town Councils) regarding plant species selection.

6.3.10 Step 10: Consider Maintenance Requirements

Consider how maintenance is to be performed on the bioretention swale e.g. how and where is access available, where is litter likely to collect etc. A specific maintenance plan and schedule should be developed for the bioretention swale in accordance with Section 6.5, and hand over to the party who will take over the maintenance.

6.3.11 Design Calculation Summary

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

BIORETENTION SWALES DESIGN CALCULATION SUMMARY

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

6.3.12 Typical Design Parameters

Table 6.1 shows typical values for a number of key bioretention swale design parameters.

Table 6.1: Typical Design Parameters for Bioretention Swales

Design Parameter	Typical Values
Swale longitudinal slope	1% to 4 %
Swale side slope for trafficability (with ‘at grade’ vehicular crossover)	Maximum 1 in 9
Swale side slope	Maximum 1 in 3
Manning’s *n* (with flow depth lower than vegetation height)	0.15 to 0.3
Manning’s *n* (with flow depth greater than vegetation height)	0.03 to 0.05
Maximum velocity for scour in minor event (e.g. 10 yr ARI)	0.5 m/s
Maximum velocity for 100 yr ARI	2.0 m/s
Perforated pipe diameter	100 mm (maximum)
Drainage layer average material diameter (typically fine gravel or coarse sand)	2-5 mm diameter
Transition layer average material diameter typically sand to coarse sand	0.7 – 1.0 mm diameter

6.4 Construction advice and checking tools

This section provides a number of checking aids 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)
- Maintenance and inspections
- Asset transfer (following defects period).

6.4.1 Design Assessment Checklist

The checklist overleaf below 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, referral should be made back to the design procedure to determine the impact 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 habitat.

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

BIORETENTION SWALE DESIGN ASSESSMENT CHECKLIST

Asset I.D.		Assessed by:	Date:
Bioretention Location:			
Hydraulics:	Minor Flood (m^2/s):	Major Flood (m^2/s):	
Area:	Catchment Area (ha):	Bioretention Area (m^2):	

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

6.4.2 Construction Advice

This section provides general advice for the construction of bioretention basins.

6.4.2.1 Clean filter media

Ensure sand and gravel media is washed to remove fines prior to placement.

6.4.2.2 Perforated Pipes

Suitable perforated pipes can be either a PVC pipe with slots cut into the length of it or a flexible corrugated HDPE pipe with holes or slots distributed across its surface. PVC pipes have the advantage of being stiffer with less surface roughness therefore greater flow capacity; however the slots are generally larger than 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 may have the disadvantage of roughness (therefore lower flow capacity) but 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.

6.4.2.3 Tolerances

It is importance to stress the importance of tolerances in the construction of bioretention swales (e.g base, longitudinal and batters) – having flat surfaces is particularly important for a well distributed flow path and even ponding over the surfaces. Generally, a tolerance of 50mm in surface levels is acceptable.

6.4.2.4 Building Phase Damage

Protection of filtration media and vegetation is important during the building phase. Uncontrolled building site runoff is likely to cause excessive sedimentation, introduce weeds and litter and require replanting following the building phase. Where possible, a staged implementation should be adopted, i.e. during the site development/construction phase, use geofabric and some soil and instant turf (lay perpendicular to flow path) to provide erosion control and sediment trapping. Following the building phase, temporary measures and sediments would be removed and bioretention swale is revegetated in accordance with design planting schedule. It is also possible to reuse the instant turf in the subsequent stages.

If these systems are not staged to be part of the sediment control system during construction, it is advisable that stormwater flow during the site construction phases be diverted around the bioretention swales to sediment controls system to avoid smothering of planted vegetation by sediment loads from the construction site.

6.4.2.5 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) that can block filtration media is delivered onto the surface of the bioretention filter media. Washdown wastes (e.g. concrete) can also cause blockage of filtration media and damage vegetation. Bioretention areas should be fenced off during 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 above (e.g. staged implementation of final landscape) should be considered.

6.4.2.6 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 60mm to the top of vegetation (if turf) is adequate. Therefore, total set down to the base soil is approximately 100 mm (with approximately 40mm turf on top of base soil).

6.4.2.7 Inlet Erosion Checks

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

6.4.2.8 Erosion Control

Immediately following earthworks, it is good practice to revegetate all exposed surfaces with sterile grasses (e.g. hydro-seed). These will stabilise soils, prevent weed invasion yet not prevent future planting from establishing.

6.4.2.9 Timing for Planting

Timing of vegetation is dependent on the timing in relation to the phases of development. For example, temporary planting during construction for sediment control (e.g. with turf) is removed and the bioretention system planted out with long term vegetation. Alternatively, temporary planting (eg. turf or sterile grass) can be used until a suitable season for appropriate long-term vegetation. Ideally, long term vegetation should be planted when the surrounding soil has been stabilised.

6.4.2.10 Weed Control

Conventional surface mulching of bioretention swales with organic material like tanbark, should not be undertaken. Most organic mulch floats and runoff typically causes this material to be washed away with the risk of blockage of drains occurring. Weed management will need to be done manually until such time that the design vegetation is established with sufficient density to effectively prevent weed propagation.

6.4.2.11 Watering

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

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

After this initial three-month period, watering may not be required anymore, except during dry period. Watering requirements to sustain healthy vegetation should be determined during ongoing maintenance site visits.

6.4.3 Construction checklist

BIORETENTION SWALE CONSTRUCTION INSPECTION CHECKLIST

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

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

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

COMMENTS ON INSPECTION

ACTIONS REQUIRED

1.

2.

Inspection officer signature:

6.4.4 Asset transfer checklist

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

6.5 Maintenance Requirements

Bioretention swales have a flood conveyance role that needs to be maintained to ensure adequate flood protection for local properties. In this regard, a key maintenance requirement is ensuring that the shape of the swale is maintained and that the swale is not subject to erosion or excessive deposition of debris that may impede the passage of stormwater or increase its hydraulic roughness from that assumed.

Vegetation plays a key role in maintaining the porosity of the soil media of the bioretention system and a strong healthy growth of vegetation is critical to its performance.

The most intensive period of maintenance is during the plant establishment period (first 3-6 months) when weed removal and replanting may be required. It is also the time when large loads of sediments could impact on plant growth, particularly in developing catchments with an inadequate level of erosion and sediment control.

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

Typical maintenance of bioretention swale elements will involve:

- Routine inspection of the swale profile to identify any areas of obvious increased sediment deposition, scouring of the swale invert from storm flows, rill erosion of the swale batters from lateral inflows, damage to the swale profile from vehicles and clogging of the bioretention trench (evident by a ‘boggy’ swale invert).
- Routine inspection of inlet points (if the swale does not have distributed inflows), surcharge pits and field inlet pits to identify any areas of scour, litter build up and blockages.
- Removal of sediment where it is impeding the conveyance of the swale and/ or smothering the swale vegetation, and if necessary, reprofiling of the swale and revegetating to original design specification.
- Repairing any damage to the swale profile resulting from scour, rill erosion or vehicle damage.
- Tilling of the bioretention trench surface if there is evidence of clogging.
- Clearing of blockages to inlet or outlets.
- Regular watering/ irrigation of vegetation until plants are established and actively growing (see section 6.4.2.11).
- Mowing of turf or slashing of vegetation (if required) to preserve the optimal design height for the vegetation.
- Removal and management of invasive weeds.
- Removal of plants that have died and replacement with plants of equivalent size and species as detailed in the plant schedule.
- Pruning to remove dead or diseased vegetation material and to stimulate new growth.

- Litter and debris removal.
- Vegetation pest monitoring and control.

Resetting (i.e. complete reconstruction) of bioretention elements will be required if the available flow area of the overlying swale is reduced by 25 % (due to accumulation of sediment) or if the bioretention trench fails to drain adequately after tilling of the surface. Inspections are also recommended following large storm events to check for scour.

All maintenance activities must be specified in a maintenance plan (and associated maintenance inspection forms) to be developed as part of the design procedure. Maintenance personnel and asset managers will use this plan to ensure the bioretention swales continue to function as designed. The maintenance plans and forms must address the following:

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

An example of operation and maintenance inspection form is included in the checking tools provided in Section 6.5.1.

6.5.1 Operation & Maintenance Inspection Form

The form below summarises the basic maintenance items and suggested frequencies for Bioretention Swales. The ABC Waters Professional should customise the items and frequencies according to their design and project requirements. The customised form should be used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time.

BIORETENTION SWALE MAINTENANCE CHECKLIST

Asset I.D.			
Inspection Frequency:	Weekly to monthly	**Date of Visit:**	
Location:			
Description:			
Site Visit by:			

INSPECTION ITEMS	**FREQUENCY**	**Y**	**N**	**ACTION REQUIRED (DETAILS)**
Sediment accumulation at inflow points?	Weekly			
Litter within swale?	Weekly			
Erosion at inlet or other key structures (eg crossovers)?	Weekly			
Traffic damage present?	Weekly			
Evidence of dumping (eg building waste)?	Weekly			
Clogging of drainage points (sediment or debris)?	Weekly			
Evidence of ponding?	Weekly			
Drainage system inspected?	Weekly			
Surface clogging visible?	Weekly			
Vegetation condition satisfactory (density, weeds etc)?	Monthly			
Replanting required?	Monthly			
Keeping the maximum plant height at _ mm.	Fortnightly			
Set down from kerb still present?	Monthly			
Damage/vandalism to structures present?	Monthly			
Soil additives or amendments required?	Monthly			
Pruning and/ or removal of dead or diseased vegetation required?	Monthly			
Flushing of sub-soil pipes.	Half-yearly			
Resetting of system required?	Monthly			
Maintaining the cross section profile and longitudinal profile/slope.	Monthly			

COMMENTS

Name of ABC Waters Professional: _______________

Registration No. of ABC Waters Professional: _______________

Signature: _______________

Name of Maintenance Agency: _______________

Handing Over Date (TOP or Completion of DLP): _______________

Drawing No. for Location Plan and Sectional Plans (X-section and long section) for All Bioretention Swales:

1. _______________
2. _______________
3. _______________

6.6 Bioretention swale worked example

6.6.1 Worked Example Introduction

Modelling using MUSIC was undertaken in developing a stormwater quality treatment system for a residential estate. 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 6.12. A photograph of a similar bioretention swale in a median strip is shown in Figure 6.13 (although in that example the vegetation cover of the swale and bioretention system is all grass).

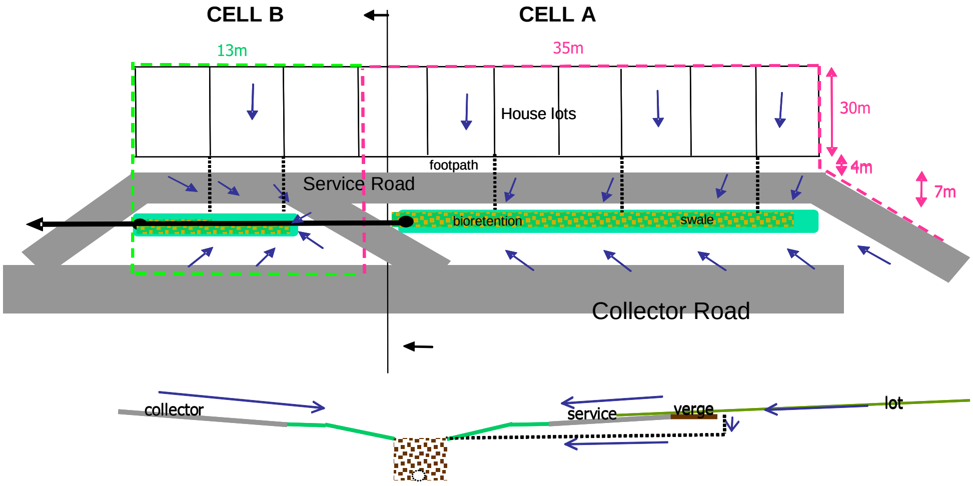

Figure 6.12 Catchment area layout and section for worked example

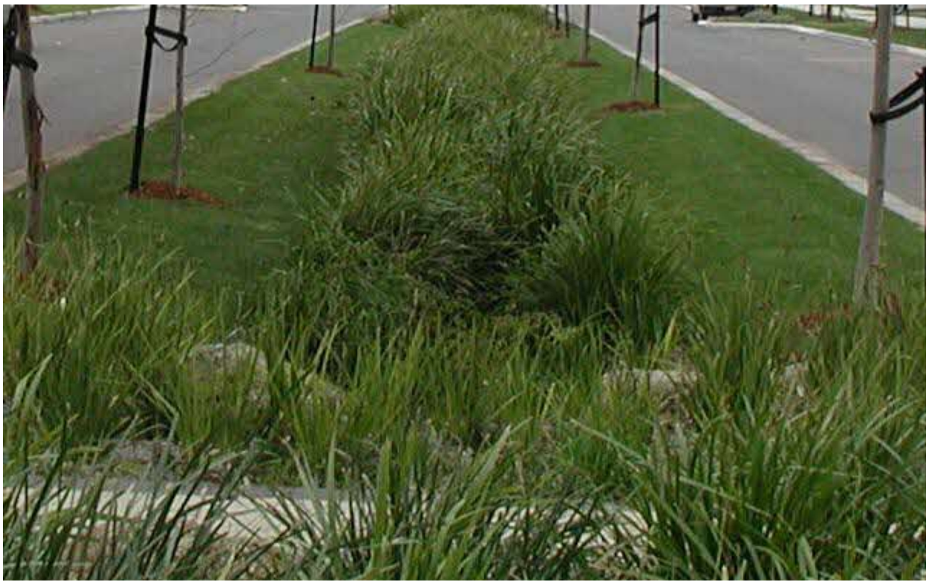

Figure 6.13 Photograph of bioretention swale

6.6.1.1 Site Description

The site comprised of the arterial road and a service road separated by a median of some 6m width. The median area offers the opportunity for a local treatment measure. The area available is relatively large in relation to the catchment and is elongated in shape. The catchment area for the swale and bioretention area includes the road reserve and the adjoining allotment (of approximately 30m 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 a 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 can be expected to be trapped by vegetation on the swale surface. Stormwater inflow exceeding the filtration rate of the soil media in the bioretention system will temporarily pond on 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 overflow into the piped drainage system at the downstream end of each bioretention cell.

Simulation using MUSIC found that the required area of bioretention system to meet a desired target of 80% reduction in TSS and 45% reduction in TP and TN 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.

6.6.1.2 Design Objectives

The design treatment objectives for the bioretention swale are as follows:-

- To meet the desired target of 80%, 45% and 45% reductions of TSS, TP and TN respectively
- Sub-soil drainage pipe to be designed to ensure that the capacity of the pipe exceeds the saturated infiltration capacity of the filtration media (both inlet and flow capacity)
- Design flows within up to 10-year ARI range are to be safely conveyed into a piped drainage system without any inundation of the adjacent road.
- The hydraulics for the swale need to be checked to confirm flow capacity for the 10-year ARI peak flow.
- The flow conditions are to attain acceptable safety and scouring behaviour for 100 year ARI peak flow.

6.6.1.3 Constraints and Concept Design Criteria

The constraints and design criteria are as follows:-

- Depth of the bioretention filter layer shall be a maximum of 600mm
- Maximum ponding depth (extended detention) allowable is 200mm
- Width of median available for constructing the bioretention system is 6m
- The filtration media available is a sandy loam with a saturated hydraulic conductivity of 180mm/hour.

6.6.1.4 Site Characteristics

Key site characteristics are summarised as follows:-

Land use	Urban, low density residential
Overland flow slopes	Cell A and B =1.3%
Soil	Clay
Catchment areas:	Summarised in Table below

	Allotments	Collector road	Local road	Footpath	Swale	Total
Cell A	35m x 30m	35m x 7m	35m x 7m	35m x 4m	103m x 7.5m	1680m^2
Cell B	13m x 30m	13m x 7m	13m x 7m	13m x 4m	44m x 7.5m	624m^2

6.6.2 Step 1: Confirm Treatment Performance of Concept Design

Nominated bioretention areas for Cell A and Cell B are 61m^2 and 22m^2 respectively. The equivalent imperious area for cell A is 1344m^2 (0.8 x 1680) and for Cell B is 499m^2 (0.8 x 624). Interpretation of Figure 6.4 to Figure 6.6 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.

- 200mm extended detention
- treatment area to impervious area ratio:
- Cell A - 61m^2/ 1344 m^2 = 4.5%
- Cell B - 22m^2/ 499 m^2 = 4.4%

From the graphs, the expected pollutant reductions are 93%, 77% and 49% for TSS, TP and TN respectively and exceed the design requirements of 80%, 45% and 45%.

6.6.3 Step 2: Estimate Design Flows for Swale Component

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

Time of concentration (t_c)

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 concluded the flow along the collector road was the longest and was adopted for t_c.
- Cell B – the t_c calculations include overland flow across the lots and road and swale/bioretention flow time.

The following t_c values are estimated:

t_c Cell A: 10 mins

t_c Cell B: 8 mins

Design rainfall intensities

Adopted from IDF Chart for Singapore

Design ARI	Cell A (10 min t_c)	Cell B (8 min t_c)
10	190 mm/hr	200 mm/hr
100	275 mm/hr	283 mm/hr

Runoff Coefficient

The runoff coefficients adopted were in accordance to those for a densely built-up urban area, as outlined in Code of Practice on Surface Water Drainage (Public Utilities Board 2013).

Design ARI	Cell A	Cell B
10	0.8	0.8
100	0.8	0.8

Design Flows

The design flows for the two cells, computed using the Rational Method (Q = 0.00278. C.I.A) are summarised below:

Design ARI	Cell A (m^3/s)	Cell B (m^3/s)
10	0.071	0.026
100	0.10	0.04

6.6.4 Step 3: Dimensions of Swale

The swales need to be sized such that they can convey the 10 year ARI peak discharge without water encroaching on the road. Manning's equation is used to compute the discharge capacity of the swale.

In determining the dimensions of the swale, the depth of the swale was determined by the requirement for it to enable allotment drainage to be discharged to the surface of the swale. Given the cover requirements of the allotment drainage pipes as they flow under the service road (600 mm minimum cover), it set the base of the bioretention systems at 0.76m below road surface. The following are the characteristics of the proposed swale:-

- Base width of 1m with 1:3 side slopes, max depth of 0.76m
- Grass vegetation mown to height of 0.1m (assume n = 0.045 for 10 year ARI with flows above grass height)
- 1.3% longitudinal 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 (Q_{cap}) is estimated adopting a 110mm freeboard[3] (i.e. maximum depth is 0.65m).

$Q_{cap} = 2.19 \text{ m}^3/\text{s} >> 0.10 \text{ m}^3/\text{s}$

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

With a base width of 1 m, the lengths of the bioretention system in Cells A and B will need to be 61 m and 22 m respectively to attain the required areas to meet the water quality objectives.

6.6.5 Step 4: Design of Swale Inlet

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

Flush kerbs with a 60 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.

6.6.6 Step 5: Design of bioretention component

6.6.6.1 Soil Media Specification

Three layers of soil media are to be used. A sandy loam filtration media (600mm), a medium to coarse sand transition layer (100mm) and a gravel drainage layer (200mm).

6.6.6.2 Filter Media Specifications

The filter media is to be a sandy loam with the following criteria (mainly from FAWB 2009):

The material shall meet the geotechnical requirements set out below:

Hydraulic conductivity between 100-300 mm/hr

Particle sizes of between**:** clay 2 – 4 %, silt 4 – 8 %, sand < 85 %

Organic content between 3% and 10%

pH 5.5 – 7.5

6.6.6.3 Transition Layer Specifications

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

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

6.6.6.4 Drainage Layer Specifications

The drainage layer is to be 2 - 5 mm screenings.

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[3] The Singapore Code of Practice for Surface Drainage would normally stipulate a freeboard of 15% of the depth of the drain, ie. 0.15 x 760 = 110mm

6.6.6.5 Maximum Filtration Rate of Bioretention Media

The maximum filtration rate reaching the perforated pipe at the base of the soil media is estimated by using the hydraulic conductivity of the media and the head above the pipes and applying Darcy’s equation.

Saturated hydraulic conductivity = 180 mm/hr = 5 x 10^{-5} m/s

Flow capacity of the filtration media = (1-ϒ) As k_h

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

$$Q_{\max} = 5 \cdot 10^{-5} \cdot L \cdot W_{base} \left(\frac{0.2 + 0.6}{0.6} \right)$$

where:

k = hydraulic conductivity of the soil filter (m/s)

W_{base} = base width of the filtration area (m) – 1 m width adopted

L = length of the bioretention zone (m); 61 m (Cell A) and 22 m (Cell B)

h_{max} = depth of pondage above the soil filter (m)

d = depth of filter media

Maximum filtration rate Cell A = 0.0041 m^3/s

Maximum filtration rate Cell B = 0.0015 m^3/s

6.6.6.6 Sizing of Slotted Collection Pipes

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

Assuming drainage layer is saturated, driving head is half the depth of the drainage layer – H = 0.1m

Assume sub-surface drains with half of all pipes blocked

Product specification Clear Opening = 2100 mm^2/m

Assumed unblocked opening = 1050mm^2/m

Slot Width = 1.5 mm

Slot Length = 7.5 mm

Diameter = 100 mm

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

Assume orifice flow conditions – Q = CA $\sqrt{2gh}$

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

Inlet capacity /m of pipe = [0.61x (0.0015 x 0.0075) x $\sqrt{2x9.81x0.1}$] x 93.3

= 0.0009 m^3/s

Inlet capacity/m x total length =

Cell A = 0.0009 x 61 = 0.055 m^3/s >> 0.0041 m^3/s (max infiltration rate), hence 61 m of pipe has sufficient perforation capacity to pass flows into the perforated pipe.

Cell B = 0.0009 x 22 = 0.020 m^3/s >> 0.0015 m^3/s (max infiltration rate), hence 22m of pipe is sufficient.

6.6.6.7 Slotted Pipe Capacity

The Colebrook-White equation is applied to estimate the flow rate in the perforated pipe. A slope of 0.5%[4] is assumed and a 100mm perforated pipe (as above) was used. Should the capacity not be sufficient, additional pipes would be required. The capacity of this pipe needs to exceed the maximum filtration rate of the media.

Estimate applying the Colebrook-White Equation

$$Q = \left[-2\left(2gDS_f\right)^{0.5}\log\left(\frac{k}{3.7D}\right) + \frac{2.51v}{D(2gDS_f)^{0.5}}\right] * A$$

Adopt

D = pipe internal diameter (0.10m)

S_f = slope (0.005m/m)

g = gravitational acceleration ($9.81m^2/s$)

k = hydraulic roughness (0.007m)

v = velocity (1.007×10^{-6} m/s)

A = cross-sectional area of pipe

Q_{cap} = 0.01 m^3/s[5] (for one pipe) > 0.0041 m^3/s (Cell 1); 0.0015 m^3/s (Cell 2), and hence 1 pipe is sufficient to convey the maximum infiltration rate for both Cell A and B.

Adopt 1 x ϕ 100 mm slotted pipe for the underdrainage system in both Cell A and Cell B.

6.6.6.8 Drainage Layer Hydraulic Conductivity

Typically flexible perforated pipes are installed using fine gravel media to surround them. In this case study, 2-5mm 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.

6.6.6.9 Impervious Liner Requirement

In this catchment the surrounding soils are clay to silty clays with a saturated hydraulic conductivity of approximately 3.6 mm/hr. The sandy loam media that is proposed as the filter media has a hydraulic conductivity of 100 - 300 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.

6.6.7 Step 6: Verification checks

6.6.7.1 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 0.5m/s during Q_{10} and 2.0 m/s for Q_{100}.

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[4] A slope of 0.5% is adopted simply for convenience. In reality, the discharge capacity is reached when the soil is saturated and water ponded to the full extended detention depth. Bioretention systems can operate equally effectively with the underdrain laid at near-zero (but positive) slopes.

[5] Per manufacturer data

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

Q_{10} = 0.071 m^3/s, depth = 0.12 (with n = 0.06), velocity = 0.38m/s < 0.5m/s – therefore, OK

Q_{100} = 0.103 m^3/s, depth = 0.14m (with n = 0.045), velocity = 0.52m/s < 2.0m/s – therefore, OK

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

6.6.7.2 Safety Velocity Check

Check velocity – depth product in Cell A during peak 100-year ARI flow for pedestrian safety criteria.

V = 0.52m/s (calculated previously)

D = 0.14m

V.D = 0.52 x 0.14 = 0.07 < 0.4m^2/s

Therefore, velocities and depths are OK.

6.6.8 Step 7: Overflow pit 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.

There are standard pit sizes to accommodate connection to the underground stormwater pipe. For a minimum underground pipe of 300 mm diameter, a 450 mm x 450 mm pit will be required for both Cell A and Cell B.

To check the adequacy of this pit to convey the 10 year ARI peak discharge, two flow conditions need to be check. The assumed water level above the crest of the pit is the depth of water from the road surface, less freeboard and the extended detention (i.e. 0.76 – (0.11 + 0.2) = 0.45m).

First check using a weir equation

Q_{weir} = B.C.L.$H^{3/2}$ with B = 0.5, C = 1.7, L = 1.8 and H = 0.45

= 0.4 m^3/s > 0.071 m^3/s …….OK

Now check for drowned conditions:

$Q_{orifice}$ = B.C.A $\sqrt{2gh}$ with B = 0.5, C = 0.6, A = 0.20 and H = 0.45

= 0.17 m^3/s > 0.071 m^3/s……OK

6.6.9 Step 8: Allowances to preclude traffic on swales

Traffic control is achieved by using traffic bollards.

6.6.10 Step 9: Vegetation specification

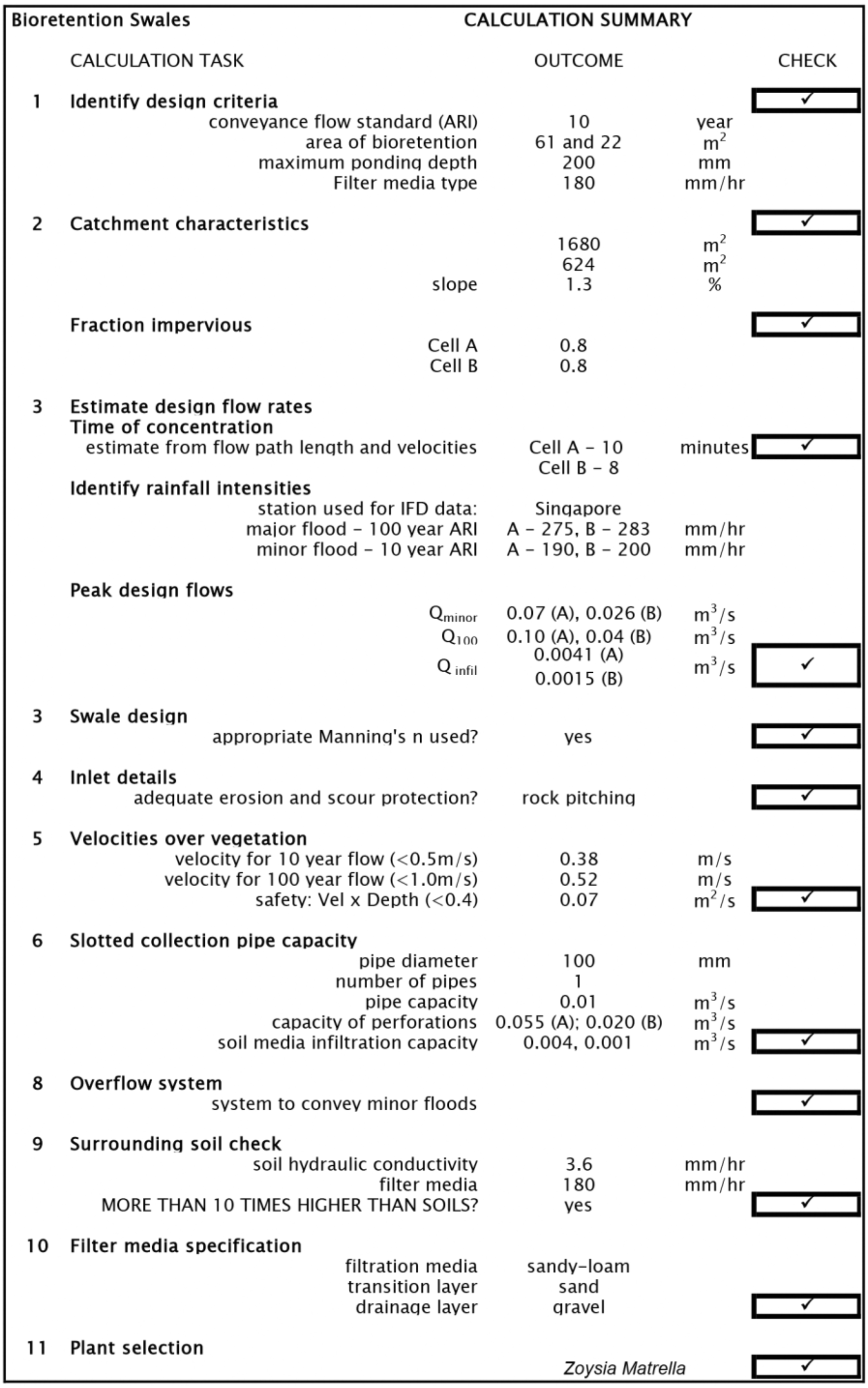
Plants may be selected from the reference list in 6.7. Also check with the party who is going to take over the maintenance of the bioretention swales.

6.6.11 Step 10: Maintenance Plan

A maintenance plan for Swales 1 and 2 is to be prepared by the ABC Waters Professional in accordance with the requirements of the Code of Practice on Surface Water Drainage.

6.6.12 Calculation summary

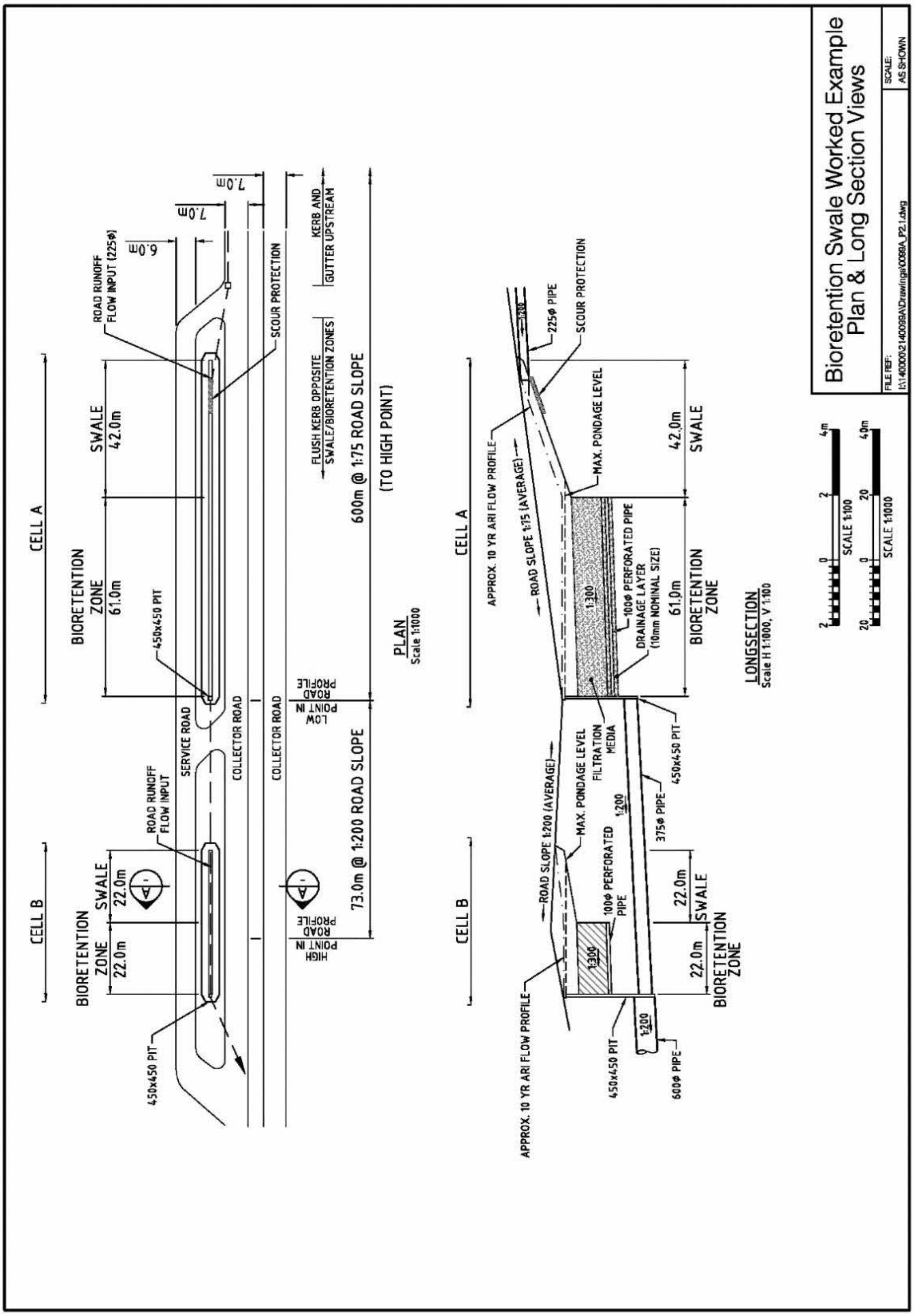
The sheet below summarises the results of the design calculations.

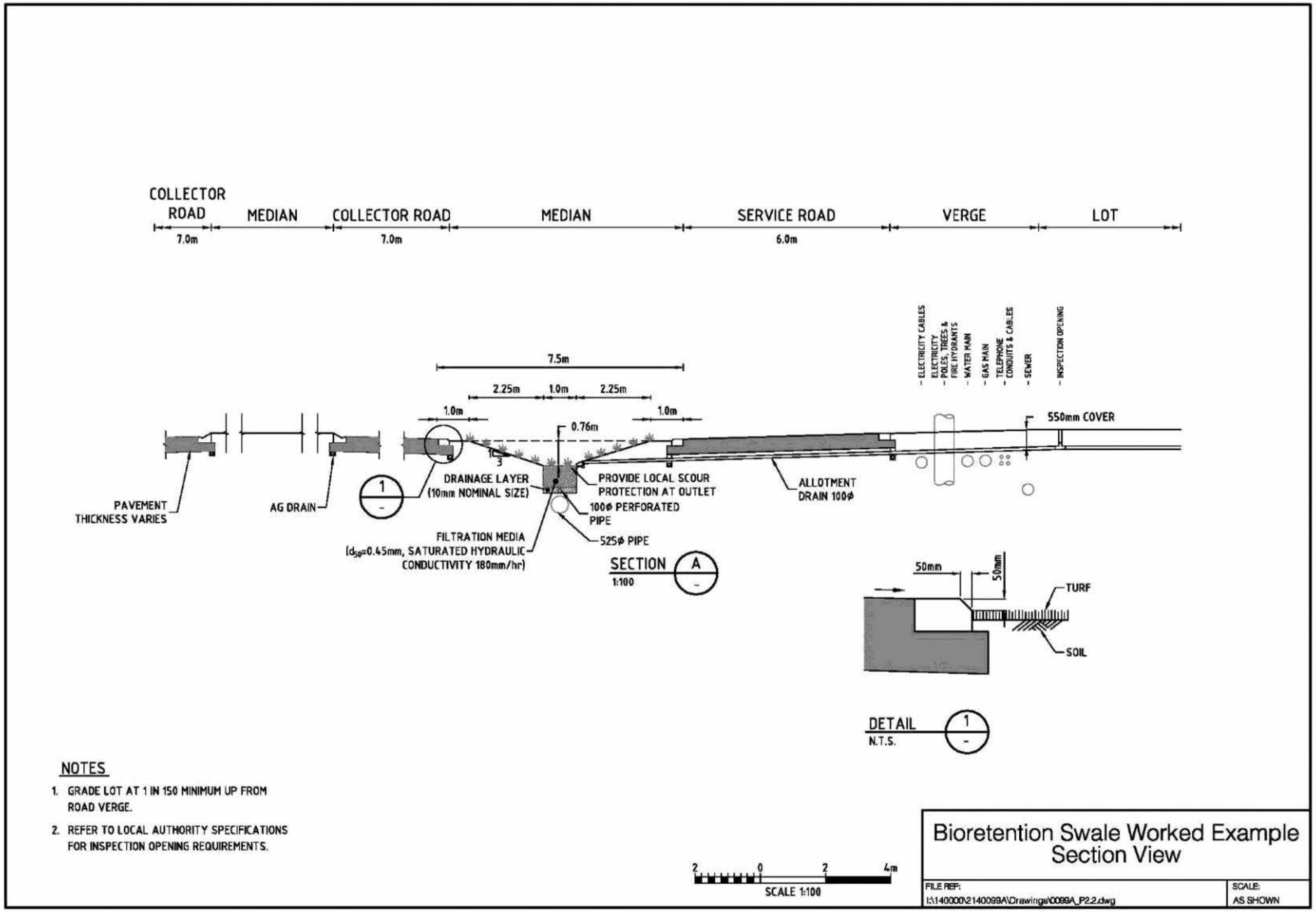


Bioretention Swales CALCULATION SUMMARY

	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**			✓
		1680	m^2	
		624	m^2	
	slope	1.3	%	
	Fraction impervious			✓
	Cell A	0.8		
	Cell B	0.8		
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:	Singapore		
	major flood - 100 year ARI	A - 275, B - 283	mm/hr	
	minor flood - 10 year ARI	A - 190, B - 200	mm/hr	
	Peak design flows			
	Q_{minor}	0.07 (A), 0.026 (B)	m^3/s	
	Q_{100}	0.10 (A), 0.04 (B)	m^3/s	
	Q_{infil}	0.0041 (A) 0.0015 (B)	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 10 year flow (<0.5m/s)	0.38	m/s	
	velocity for 100 year flow (<1.0m/s)	0.52	m/s	
	safety: Vel x Depth (<0.4)	0.07	m^2/s	✓
6	**Slotted collection pipe capacity**			
	pipe diameter	100	mm	
	number of pipes	1		
	pipe capacity	0.01	m^3/s	
	capacity of perforations	0.055 (A); 0.020 (B)	m^3/s	
	soil media infiltration capacity	0.004, 0.001	m^3/s	✓
8	**Overflow system**			
	system to convey minor floods			✓
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**	*Zoysia Matrella*		✓

6.6.13 Construction drawings





NOTES

1. GRADE LOT AT 1 IN 150 MINIMUM UP FROM ROAD VERGE.
2. REFER TO LOCAL AUTHORITY SPECIFICATIONS FOR INSPECTION OPENING REQUIREMENTS.

Bioretention Swale Worked Example
Section View

6.7 Reference List of Plants for Filtration Area in Bioretention System

Asystasia sp.
Calathea lutea
Canna generalis, hybrids
Canna indica
Cyathula prostrata
Cymbopogon citratus
Cyperus alternifolius
Cyperus papyrus
Dianella ensifolia
Dissotis rotundifolia
Excoecaria cochinchinensis
Galphimia glauca
Heliconia psittacorum
Leea indica
Leucophyllum frutescens
Loropetalum chinense
Murraya paniculata
Osmoxylum lineare
Pandanus amaryllifolius
Pandanus pygmaeus
Pennisetum alopecuroides
Pennisetum setaceum
Pennisetum x advena 'Rubrum'
Phyllanthus cochichinensis
Phyllanthus myrtifolius
Pogonantherum paniceum
Ruellia brittoniana
Russelia equisetiformis
Schefflera arboricola
Serissa japonica
Sphagneticola trilobata
Thalia geniculata
Zoysia matrella

6.8 References

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Institution of Engineers Australia 2001. Australian Rainfall and Runoff - A Guide to Flood Estimation. Barton, ACT, Engineers Australia. Editor in Chief – Pilgram, D.H.

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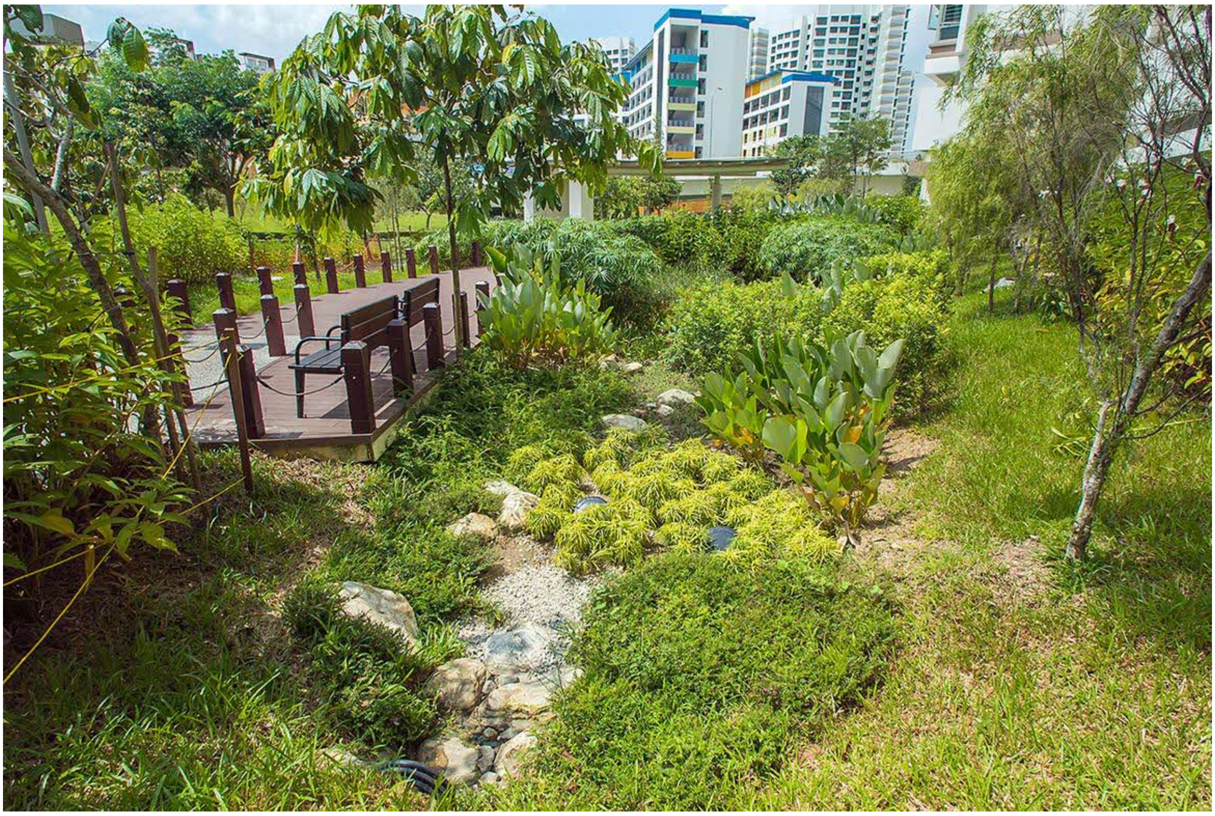
Bioretention Basins 7



7

Chapter 7 Bioretention Basins

7.1 Introduction

Bioretention basins use ponding above a bioretention surface to maximise the volume of runoff treated through the filtration media. Their treatment processes are the same as that for bioretention swales. However, they are predominantly detention systems designed for frequent storms (like 3 month ARI storms) with flood flows bypassing the filtration surface into stormwater drains or detention tanks.

Bioretention basins operate by filtering stormwater runoff through densely planted surface vegetation as a means of pre-treatment before they infiltrate/percolate through a prescribed filter media. During percolation, pollutants are retained through fine filtration, adsorption and some biological uptake. The vegetation in a bioretention system is a vital functional element of the system both in terms of maintaining the hydraulic conductivity of the filter media and the improving soil capacity for chemical and biological removal of stormwater contaminants. Vegetation facilitates the transport of oxygen to the soil and enhances soil microbial communities which enhance biological transformation of pollutants.

Bioretention basins are generally not intended to be ‘infiltration’ systems that discharge from the filter media to surrounding in-situ soils. Rather, the typical design intent is to recover stormwater at the base of the filter media in perforated under-drains and discharge to receiving waterways or to storages for potential reuse. In some circumstances however, where the in-situ soils allow infiltration or when there is a particular design intention to recharge local groundwater, it may be desirable to allow stormwater to infiltrate from the base of a filter media to underlying in-situ soils. This type of Bioretention basin is termed as Soak-away rain gardens.

Bioretention basins can be installed at various scales, ranging from planter boxes, to streetscape raingardens integrated with traffic calming measures, to system contained within retarding basins. 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 system this is not required. Example applications are given in Figure 7.1

This chapter describes the design, construction and maintenance of a bioretention basins.

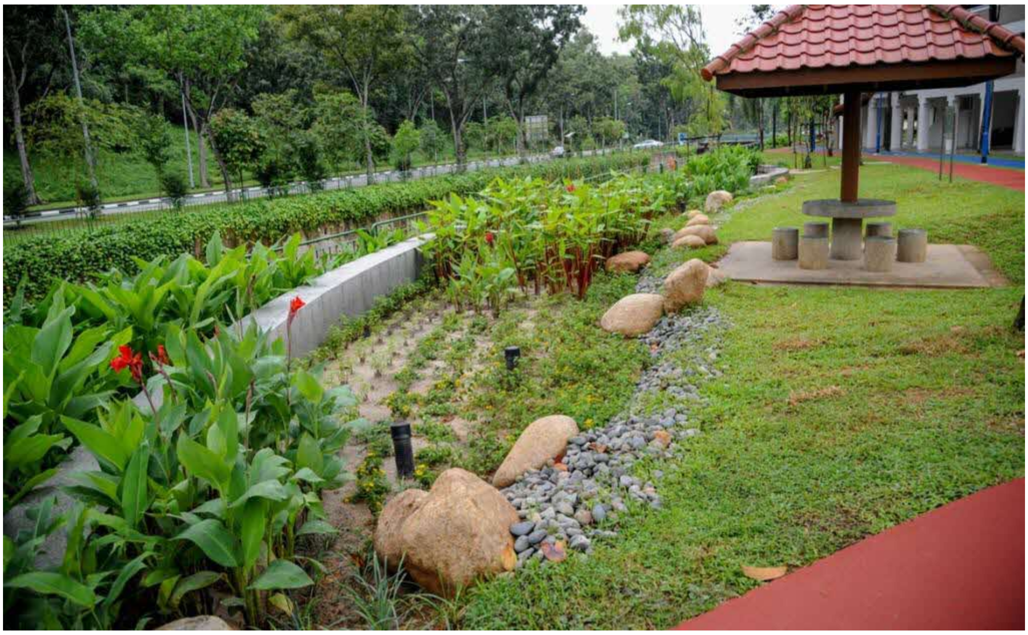


Figure 7.1 Example of bioretention basin in Sungei Tampines

7.2 Key Design Configurations

There are many possible design variations for bioretention systems and these may be grouped into five core design configurations. The features of each of these configurations are described below.

It is strongly recommended that bioretention systems which include submerged zones should be used wherever possible. It has been shown that the treatment performance of bioretention systems is significantly reduced after extended dry periods. The presence of a submerged, permanent pool of water at the bottom of the systems acts as a buffer against drying and helps maintain a healthy plant community throughout long dry spells.

Illustrations in this section are for demonstration purposes only. Outlet structures may be any combination of raised pits or more complex outflow structures as described in chapter 7.4 Design Process.

7.2.1 Lined bioretention system

A standard lined bioretention system (Figure 7.2) prevents exfiltration and minimises losses through the system. This type of bioretention basin is optimal in the following situations.

- Sites where exfiltration is not possible. This may arise where there is a need to protect built infrastructure or whereby interactions with shallow groundwater are undesirable.
- Climates that do not experience long dry spells.
- If systems are designed for NO_x removal or if receiving waters are highly sensitive to Cu or Zn.

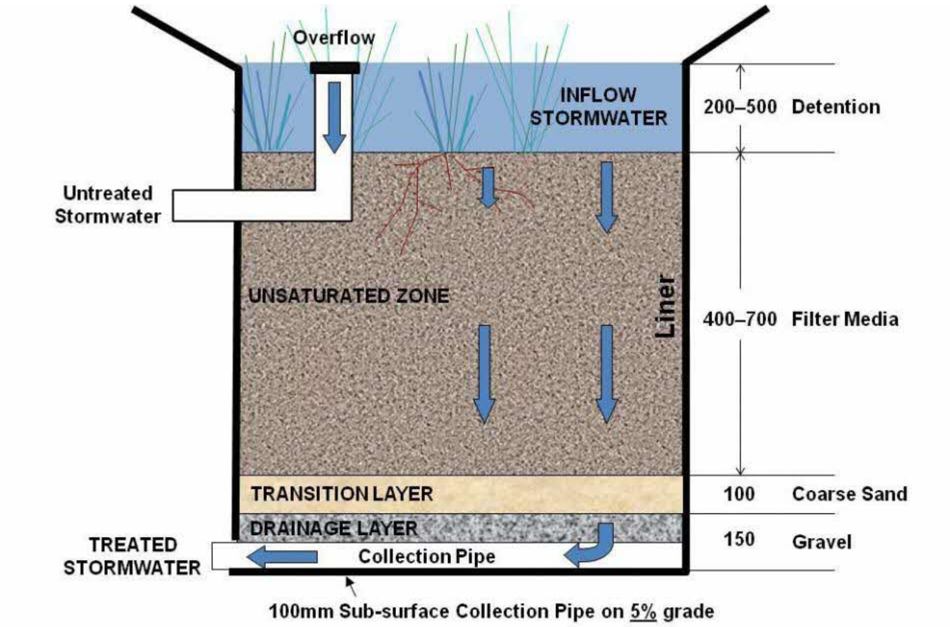


Figure 7.2 Lined standard bioretention system [source: FAWB, 2009]

A lined bioretention system may also be designed to include a submerged zone with the submerged zone comprising of sand (Figure 7.3) or gravel. This type of bioretention basin should be used for the following situations;

- Sites where exfiltration is not possible. This may arise where there is a need to protect built infrastructure or whereby interactions with shallow groundwater are undesirable.
- Climates that have very long dry spells. The submerged zone is able to act as a water source for up to five weeks, supporting the plants and microbial community.
- If systems are designed for NO_x removal or if receiving waters are highly sensitive to Cu or ZN.

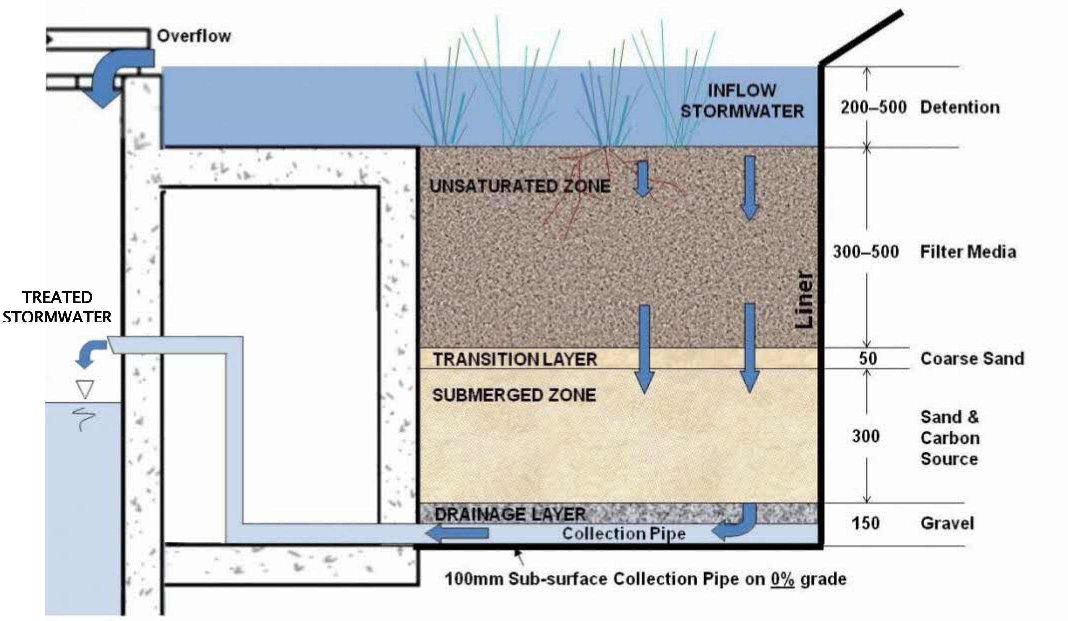


Figure 7.3 **Lined bioretention system with submerged zone comprised of gravels and hardwood chips [modified from: FAWB, 2009]**

7.2.2 Unlined bioretention system

A standard unlined bioretention system (Figure 7.4) is the simplest configuration of bioretention system to design and build. These systems are suited for

- Sites where minimal infiltration is allowed. (The hydraulic conductivity of the surrounding soils should be an order of magnitude lower than the filter media to ensure minimal infiltration.
- Climates that do not experience long dry spells.
- Systems that are not designed for stormwater harvesting.

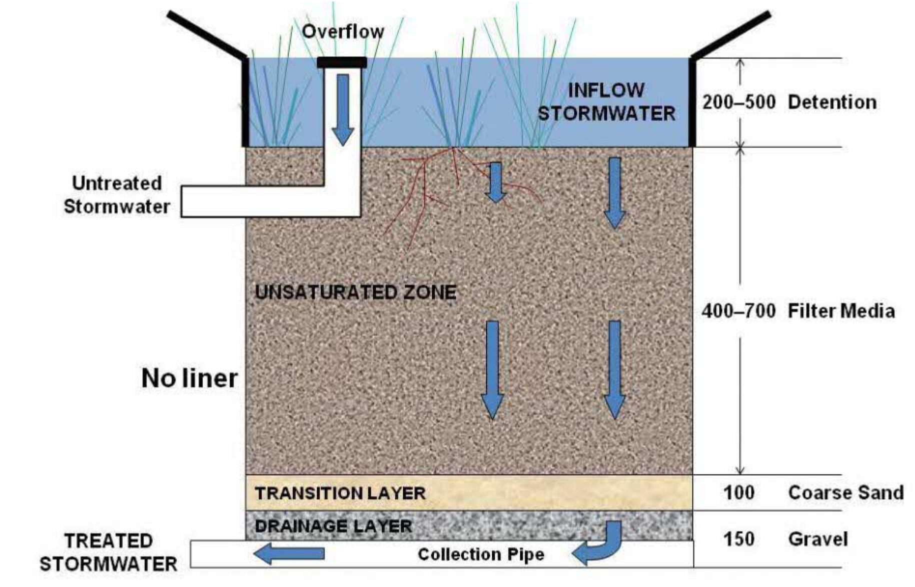


Figure 7.4 Unlined standard bioretention system [source: FAWB, 2009]

Unlined bioretention systems may also include a submerged zone (Figure 7.5). The addition of a submerged zone is appropriate whereby exfiltration is permissible and the local climate yields long dry spells. These systems have unlined sides, however the submerged zone must be lined to maintain saturation.

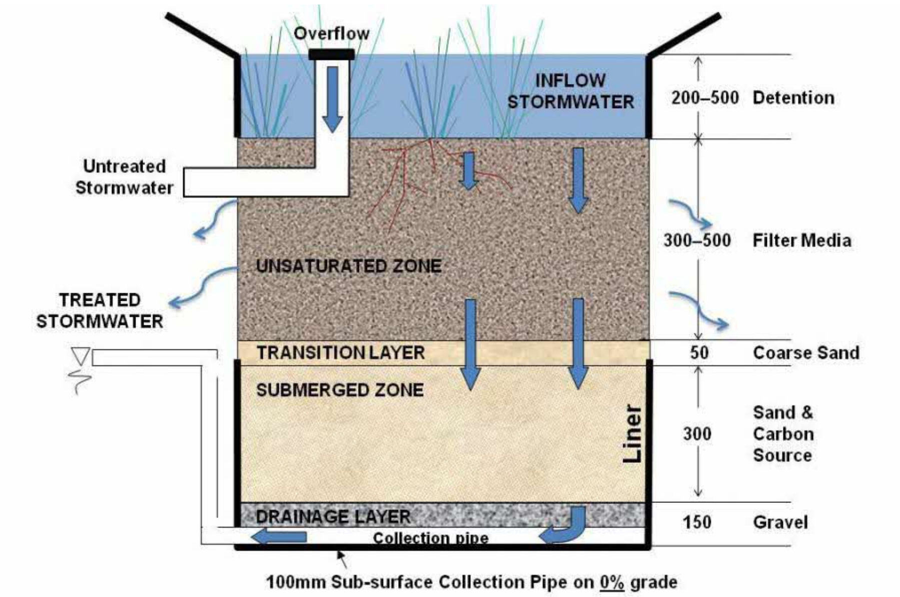


Figure 7.5 Unlined bioretention system with submerged zone [source: FAWB, 2009]

7.2.3 Unlined bio-infiltration system

An unlined bioretention system is a hybrid system, combining a standard bioretention system and an infiltration system, which is also referred to as a bio-infiltration system. Unlined bio-infiltration systems are recommended for;

- Sites where exfiltration is allowed.
- Whereby both water quality improvements and runoff reduction are required.
- Systems that are not designed for stormwater harvesting.

Unlined bioretention systems do not contain collection pipes in the drainage layer. Where possible, unlined bioretention systems are preferable to standard, non-vegetated infiltration systems due to the increased nutrient removal and are therefore highly recommended whereby appropriate.

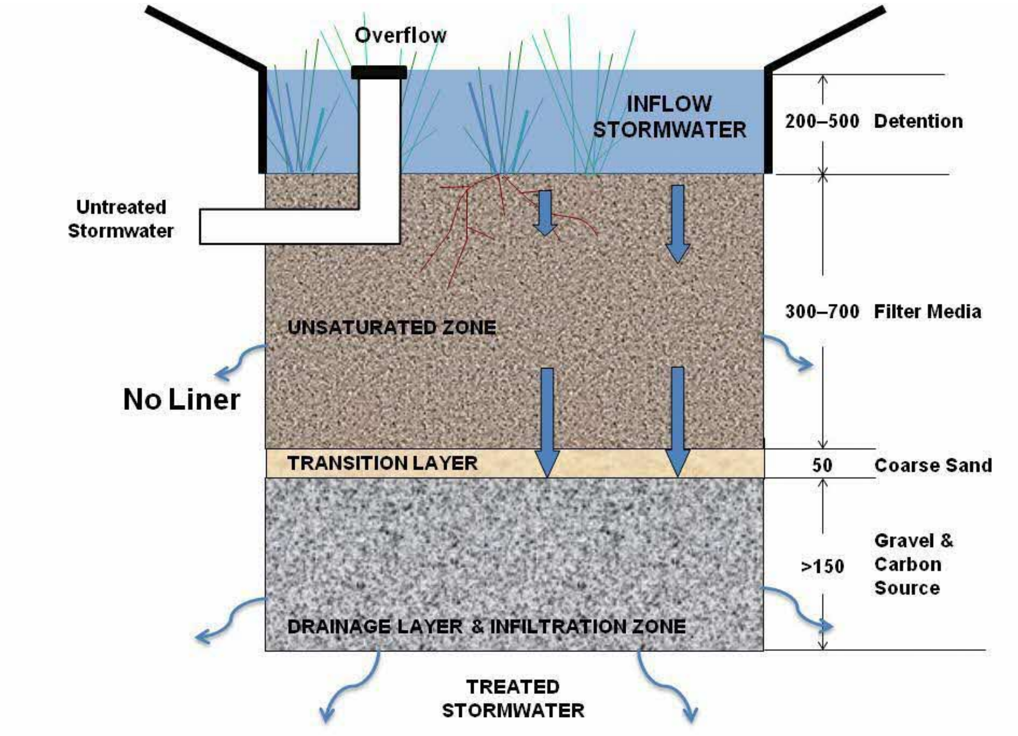


Figure 7.6 A hybrid bioretention and infiltration system [source: FAWB, 2009]

7.3 Design Considerations for Bioretention Basins

A typical design for a bioretention basin is given in Figure 7.7. Key to the design is the hydraulic operation, the filter media, the vegetation and the interaction of the basin within the urban space. These design considerations are discussed further in the following sections. Design considerations are similar to that presented in Chapter 6 Bioretention Swales and are presented in both chapters for ease of reference.

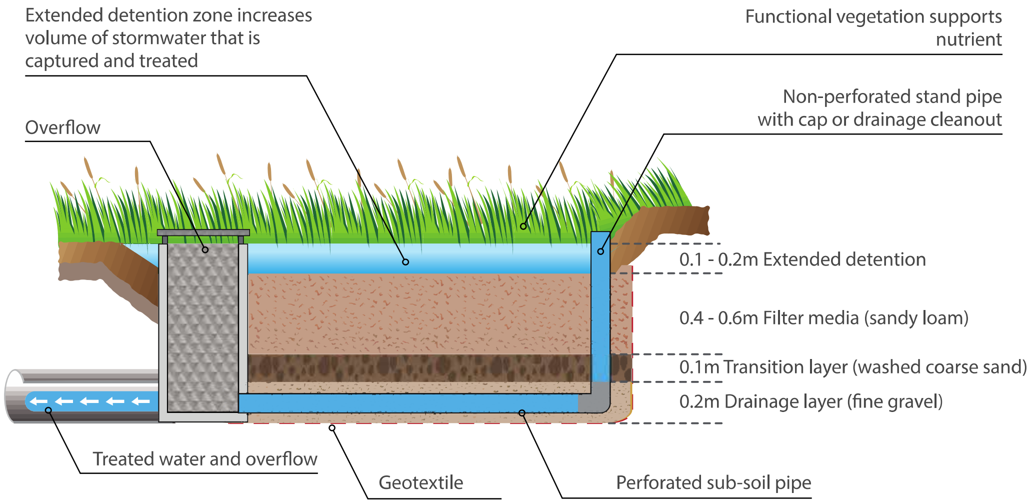

Extended detention zone increases volume of stormwater that is captured and treated
Functional vegetation supports nutrient
Non-perforated stand pipe with cap or drainage cleanout
Overflow
0.1 - 0.2m Extended detention
0.4 - 0.6m Filter media (sandy loam)
0.1m Transition layer (washed coarse sand)
0.2m Drainage layer (fine gravel)
Treated water and overflow
Geotextile
Perforated sub-soil pipe

Figure 7.7 Typical cross section of a bioretention basin

7.3.1 Landscape Design

Bioretention basins, sometimes referred to as bioretention pods and rain gardens, may be located within parkland areas, easements, carparks or along roadway corridors as 'standalone' soil filtration systems. Landscape design of bioretention basins along the road edge can assist in defining traffic islands and intersections as well as providing landscape character and amenity. It is therefore important that the landscape design of bioretention basins addresses stormwater quality objectives and accommodates these other important landscape functions.

7.3.2 Hydraulic Design

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

- The finished surface of the bioretention filter media must be horizontal (i.e. flat) to ensure full engagement of the filter media by stormwater flows and to prevent concentration of stormwater flows within depressions.
- Temporary ponding or extended detention, typically of up to 0.3m depth over the surface of the soil filter media created through the use of raised inlet pits (overflow pits) can assist in increasing the overall volume of stormwater runoff that can be treated by the bioretention filter media.
- Where possible, the overflow pit or bypass pathway should be located near the inflow zone to prevent high flows passing over the surface of the filter media. If this is not possible, then velocities during the minor (10 year ARI) and major (100 year ARI) floods should be maintained sufficiently low (preferably below values of 0.5 m/s and not more than 2.0 m/s for major flood) to avoid scouring of the filter media and vegetation.

- Where the inlet to a bioretention system is required to convey the minor storm flow (i.e. is part of the minor drainage system), the inlet must be designed to avoid blockage, flow conveyance and public safety issues.
- For streetscape applications, the design of the inflow to the bioretention basin must ensure the kerb and channel flow requirements are preserved.

7.3.3 Preventing Exfiltration to In-Situ Soils

Bioretention basins can be designed to generally preclude exfiltration of treated stormwater to the surrounding in-situ soils. The amount of water potentially lost from bioretention trenches to surrounding in-situ soils is largely dependent on the characteristics of the surrounding soils and the saturated hydraulic conductivity of the bioretention filter media (see Section 7.3.5).

If the saturated hydraulic conductivity of the filter media is one to two orders of magnitude (i.e. 10 to 100 times) greater than that of the insitu soil, the flow path of stormwater percolation will be effectively contained within the bioretention filter media and through to the drainage layer. As such, there will be little exfiltration to the surrounding soils.

If the selected saturated hydraulic conductivity of the bioretention filter media is less than 10 times that of the surrounding soils, it may be necessary to provide an impermeable liner. Flexible membranes or a concrete casting are commonly used to prevent excessive exfiltration.

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

7.3.4 Vegetation Specification

Vegetation is a key component of a bioretention basin, servicing the following processes:

- Scour protection
- Maintaining the porosity of filtration layer
- Enhancing pollutant adsorption to biofilms in roots within the filter media

Generally, the greater the density and height of vegetation planted in a bioretention basin the better will be the treatment especially when extended detention is provided in the design. When the extended detention is engaged, the contact between stormwater and vegetation results in enhanced sedimentation of suspended sediments and some adsorption of associated pollutants.

Bioretention basins should be planted to cover the whole bioretention filter media surface. Vegetation should be of sufficient density to prevent preferred flow paths, scour and re-suspension of deposited sediments. Turf grasses should ideally be avoided as these are shallow rooted systems with inadequate penetration to the full depth of the filter media and the turf stems inadequately prevent clogging at the surface of the filter media.

A list of commonly used plants for Bioretention Systems is in Section 6.7. A CUGE (NParks) publication on “A selection of plants for bioretention systems in the tropics” can also be consulted for plant selection. The publication can be downloaded at https://www.cuge.com.sg/research/download.php?product=47.

7.3.5 Bioretention Filter Media

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

- Saturated hydraulic conductivity of the filter media.
- Depth of extended detention provided above the filter media.
- Suitability as a growing media to support vegetation (i.e. retains sufficient soil moisture and organic content).

The high rainfall intensities experienced in Singapore is expected to result in bioretention treatment areas being larger in Singapore than comparable systems overseas in Australia and the United States. The area available for bioretention basins in an urban layout is often constrained by factors such as the available area within the footpaths of standard road reserves.

Selecting bioretention filter media for bioretention basin applications in Singapore will often require careful consideration of saturated hydraulic conductivity and extended detention depth to ensure the desired minimum volume of stormwater runoff receives treatment. This must also be balanced with the requirement to also ensure the saturated hydraulic conductivity does not become too high such that it can no longer sustain healthy vegetation growth.

The maximum saturated hydraulic conductivity (k_f) should not exceed 500 mm/hr (and preferably be between 100 - 300 mm/hr) in order to sustain vegetation growth. k_f less than 100 mm/hr (>50 mm/hr) could be accepted with caution.

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

As shown in Figure 7.7, a bioretention system can consist of three layers. The filter media is the primary soil layer consisting typically of sandy-loam material. In addition to the filter media, a drainage layer is also required to convey treated water from the base of the filter media to the outlet via a perforated under-drains, unless the design intent is to allow the filtered water to discharge (exfiltrate) into insitu soil. The drainage layer surrounds perforated under-drains and consists typically of fine gravel of 2-5 mm particle size. In between the filter media layer and the drainage layer is the transition layer consisting of clean sand (1mm) to prevent migration of the base filter media into the drainage layer and into the perforated under-drains.

[Refer to the Bioretention Media Guidelines produced by FAWB[1] (2009) for more information.]

7.3.6 Maintenance and Access

The performance of a bioretention system will be affected by impeded flow. Driving over or storing construction material on the bioretention basin can cause the filter media to become impacted (compacted) and the vegetation damaged. The design of a bioretention system should consider means of preventing or discouraging the bioretention basin as becoming a trafficable and/or storage area.

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[1] Facility for Advancing Water Biofiltration – http://www.monash.edu.au/fawb/

7.4 Design Process

The following sections detail the design steps required for bioretention basins. Key design steps following the site planning and concept development stages are:

1. **Confirm treatment performance of concept design**
2. **Determine design flows**
3. **Design inflow systems**
    - a. Inlet scour protection
    - b. Coarse sediment forebay
    - c. Streetscape bioretention application
4. **Specify the bioretention filter media characteristics**
    - a. Filter media
    - b. Drainage layer
    - c. Transition layer
5. **Design under-drain and undertake capacity checks**
6. **Check requirement for impermeable lining**
7. **Size overflow pit**
8. **Specify vegetation**
9. **Undertake verification checks**
    - a. Vegetation scour velocity check
    - b. Confirm treatment performance

7.4.1 Step 1: Confirm treatment size given in conceptual design

A conceptual design of a bioretention basin is normally typically undertaken prior to detailed design. The performance of the concept design must be checked to ensure that stormwater treatment objectives will be satisfied.

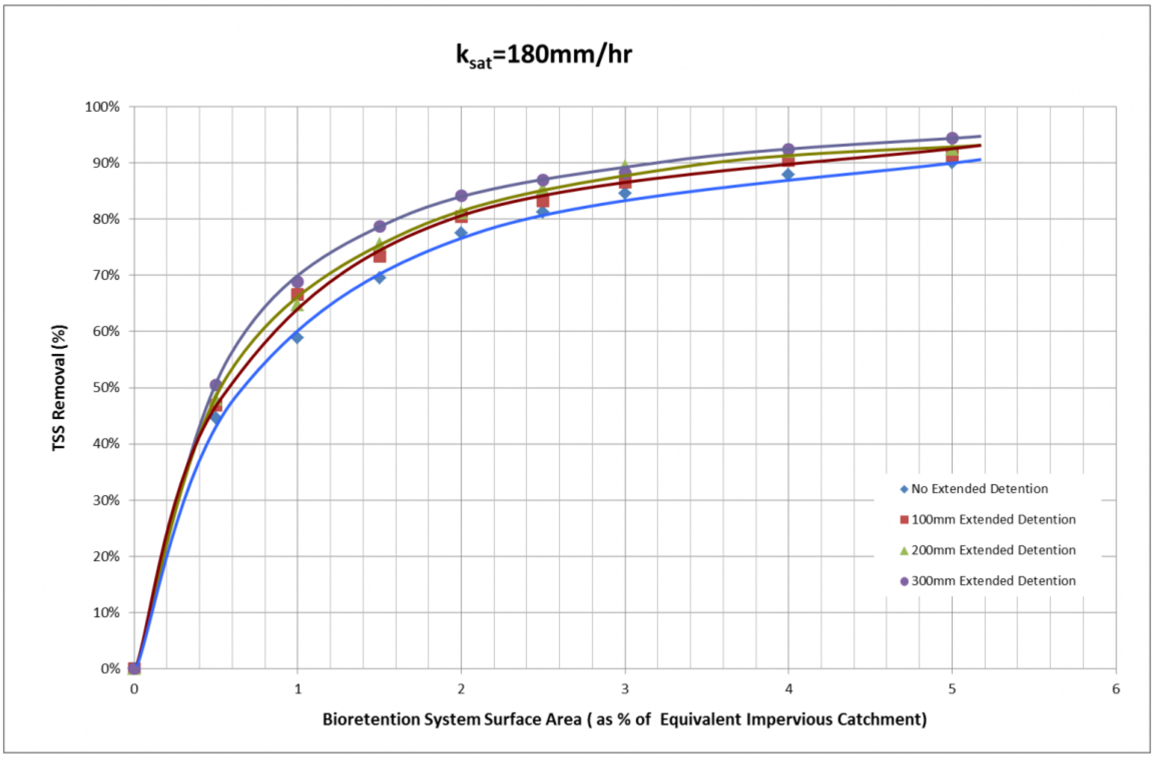
The treatment performance curves shown in Figure 7.8 to Figure 7.10 reflect the treatment performance of the bioretention basin. The performance curves provide an indication only of appropriate sizing and do not substitute the need for a thorough conceptual design process. Nevertheless, it is a useful visual guide to illustrate the relationship of bioretention treatment performance to the ratio of bioretention treatment area and contributing catchment area. The curves allow the designer to make a rapid assessment as to whether the bioretention basin size falls within the “optimal size range”.

The curves in Figure 7.8 to Figure 7.10 show the total suspended solid (TSS), total phosphorus (TP) and total nitrogen (TN) removal performance for a typical bioretention basin design with the following configurations:

- Filter media saturated hydraulic conductivity (k) = 180 mm/hr and 360mm/hr or 0.5 x 10^{-4} m/s and 1 x 10^{-4} m/s
- Filter Media average particle size = 0.5mm
- Filter Media Depth = 0.6m
- Extended Detention Depth = from 0 mm to 300 mm

The curves in Figure 7.8 to Figure 7.10 are generally applicable to bioretention basin applications within residential, industrial and commercial land uses. Please take note that “Equivalent Imperious Catchment” is used in the curves. Equivalent Imperious Catchment is the product of total catchment area and the runoff coefficient (C).

If the characteristics of the bioretention component of the bioretention swale concept design are significantly different to that described above, then the curves in Figure 7.8 to Figure 7.10 may not provide an accurate indication of treatment performance. In these cases, the detailed designer should use MUSIC to verify the performance of the bioretention swale.



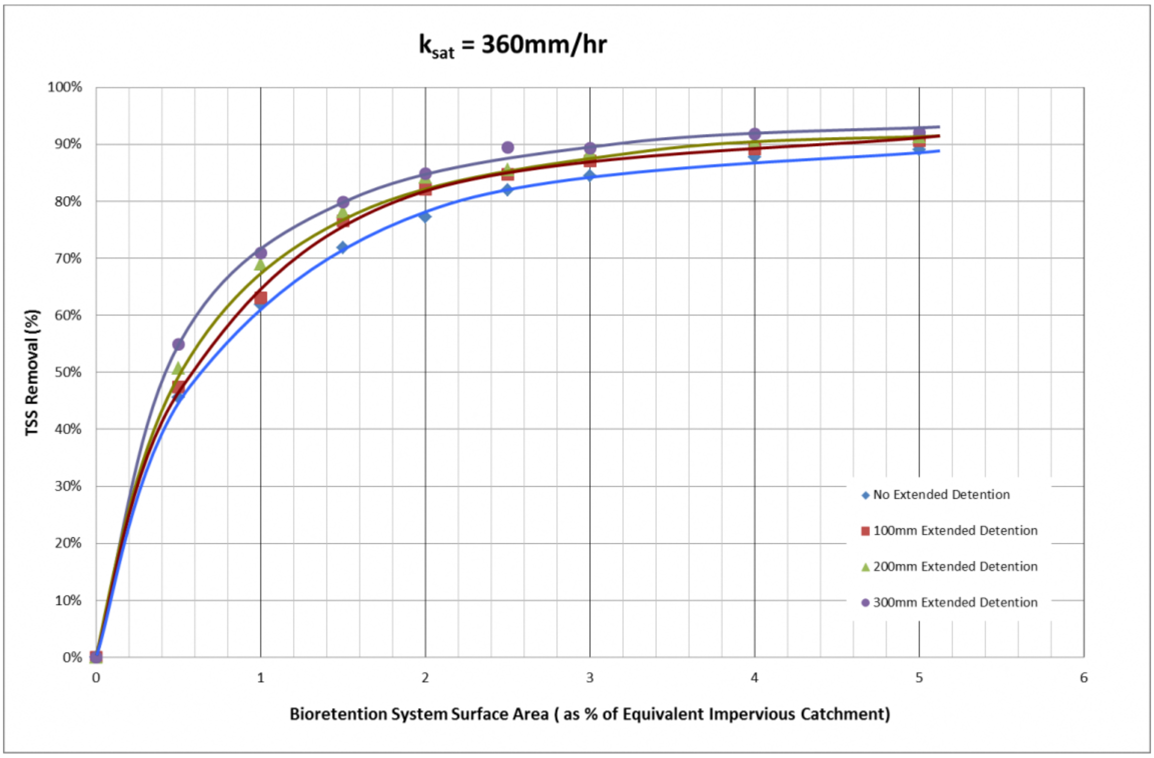
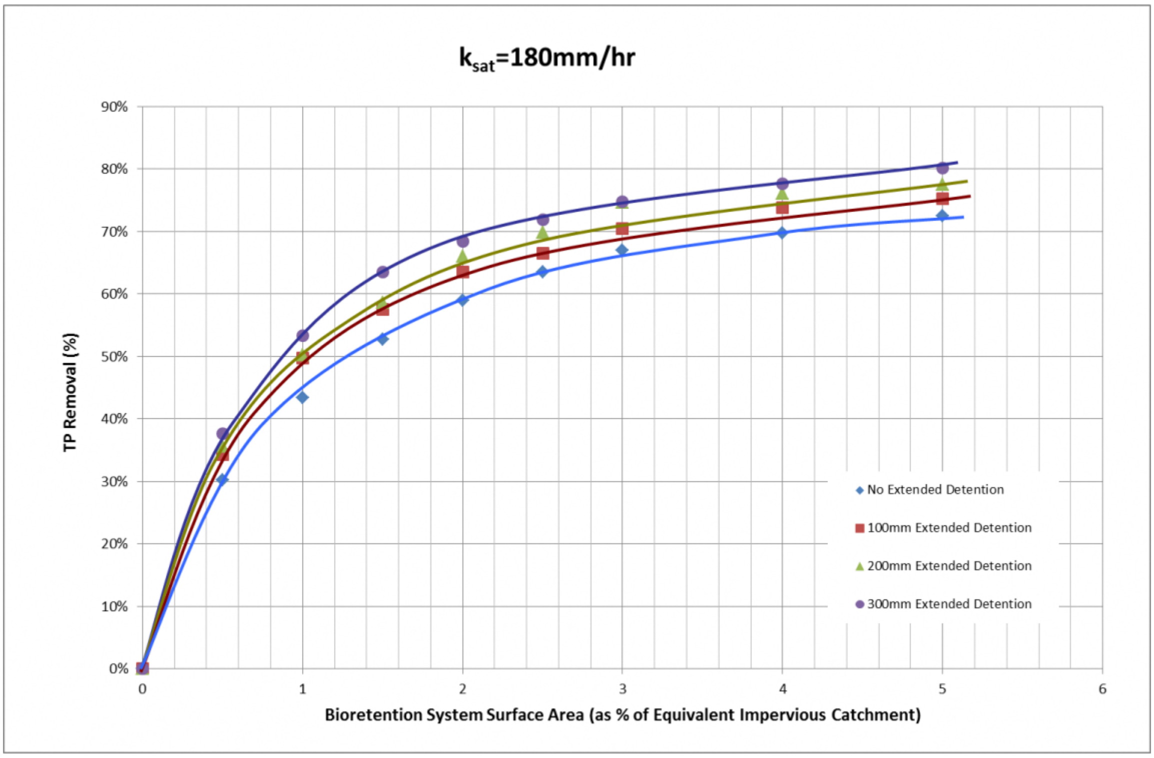


Figure 7.8 Bioretention system TSS removal performance (Reference: Station 43)



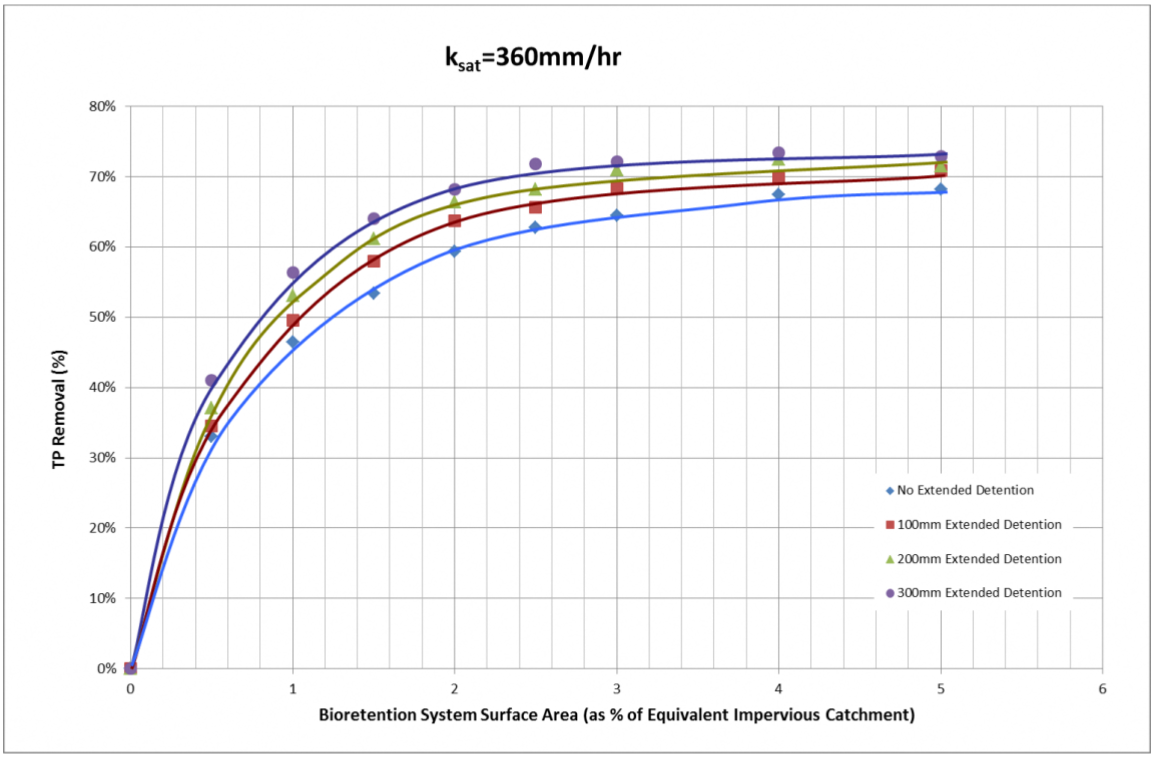
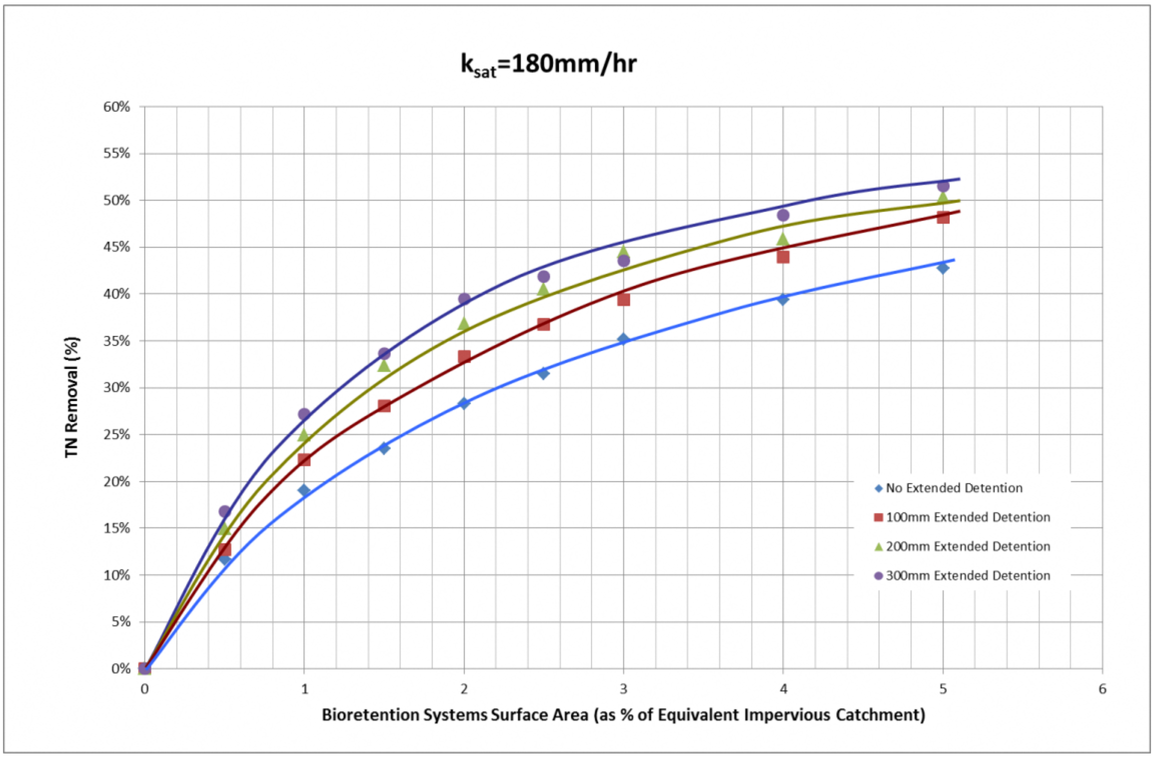


Figure 7.9 Bioretention system TP removal performance (Reference: Station 43)



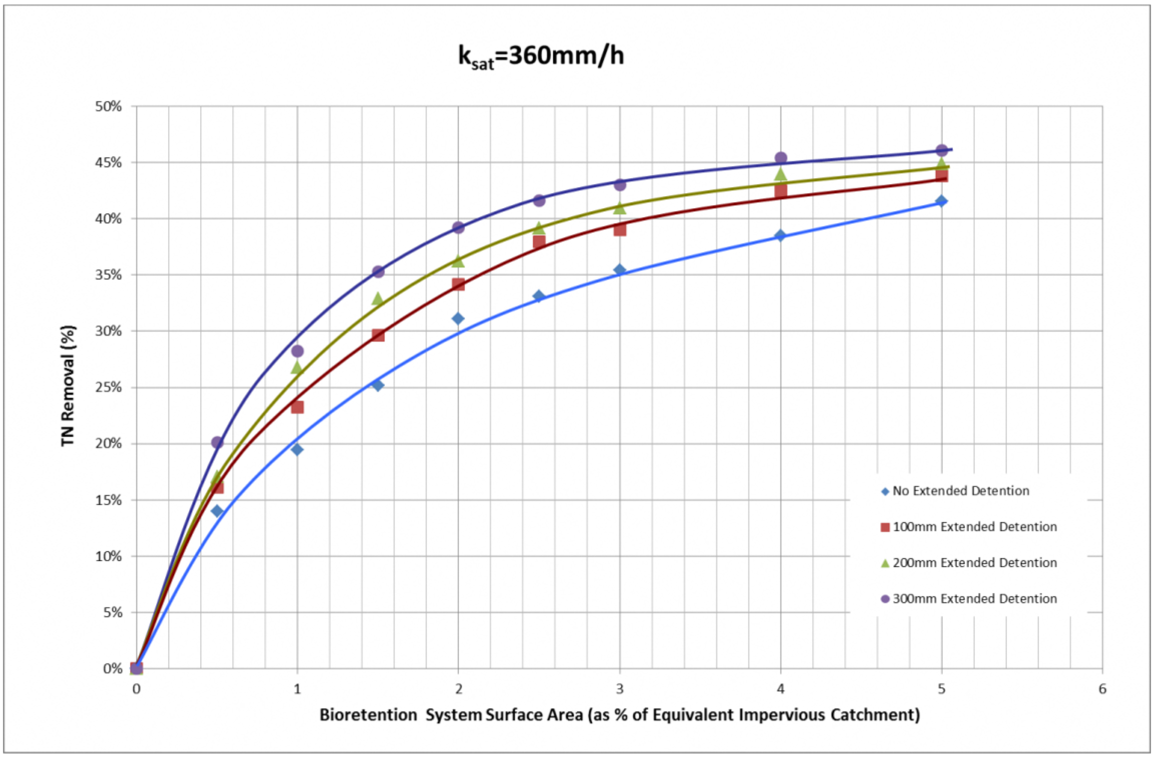


Figure 7.10 Bioretention system TN removal performance (Reference: Station 43)

7.4.2 Step 2: Determine design flows

7.4.2.1 Design Flow

Two design flows are required for bioretention basins:

- Minor (frequent) storm conditions (typically 10 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 conditions (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

7.4.2.2 Design Flow 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.

7.4.3 Step 3: Design Inflow System

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

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

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

7.4.3.1 Inlet Scour Protection

Erosion protection should be provided for concentrated inflows to a bioretention basin. Typically, flows will enter the bioretention basin from either a surface flow system (i.e. roadside kerb, open channel) or a piped drainage system. Rock beaching is a simple method for dissipating the energy of concentrated inflow. Where the bioretention basin is receiving stormwater flows from a piped system (i.e. from larger catchments), the use of impact type energy dissipation may be required to prevent scour of the filter media. In most cases this can be achieved with rock protection and by placing several large rocks in the flow path to reduce velocities and spread flows as depicted in Figure 7.11 (with the ‘D’ representing the pipe diameter dimension). The rocks can form part of the landscape design of the bioretention component.

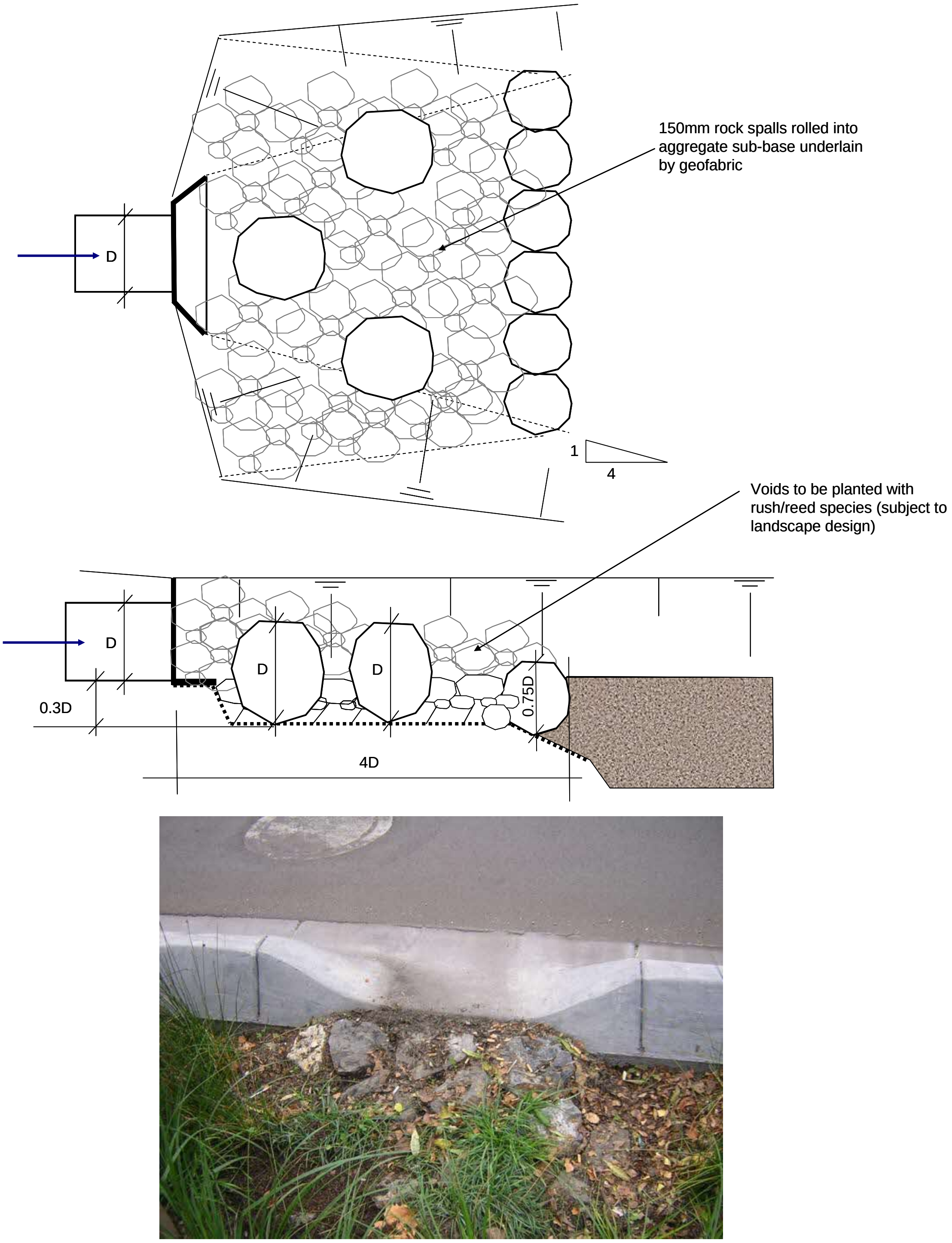

150mm rock spalls rolled into aggregate sub-base underlain by geofabric
D
1
4
Voids to be planted with rush/reed species (subject to landscape design)
D
D
D
0.75D
0.3D
4D

Figure 7.11 Typical Inlet Scour Protection Detail for Bioretention Basins Receiving Piped Flows

7.4.3.2 Coarse Sediment Forebay

Coarse sediment may accumulate near the basin inflow where stormwater runoff from the catchment is delivered directly to the bioretention basin without pre-treatment (through vegetated swale or buffer treatment). To mitigate these effects, it is recommended that a coarse sediment forebay be incorporated into the design of a bioretention basin. The forebay should be designed to:

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

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

The area of the sediment forebay (A_S) is calculated by solving the following expression (modified version of Fair and Geyer (1954)):

$$R = 1 - \left[1 + \frac{1}{n} \cdot \frac{v_s}{Q/A_S}\right]^{-n} \qquad \text{Equation 7.1}$$

Where

R = fraction of target sediment removed (adopt 80% or higher)

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

Q = Design flow (3 month ARI peak discharge calculate from the Rainfall Intensity – Duration – Frequency curve for Singapore in Figure 7.12.

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

A_S = The area of the sediment forebay

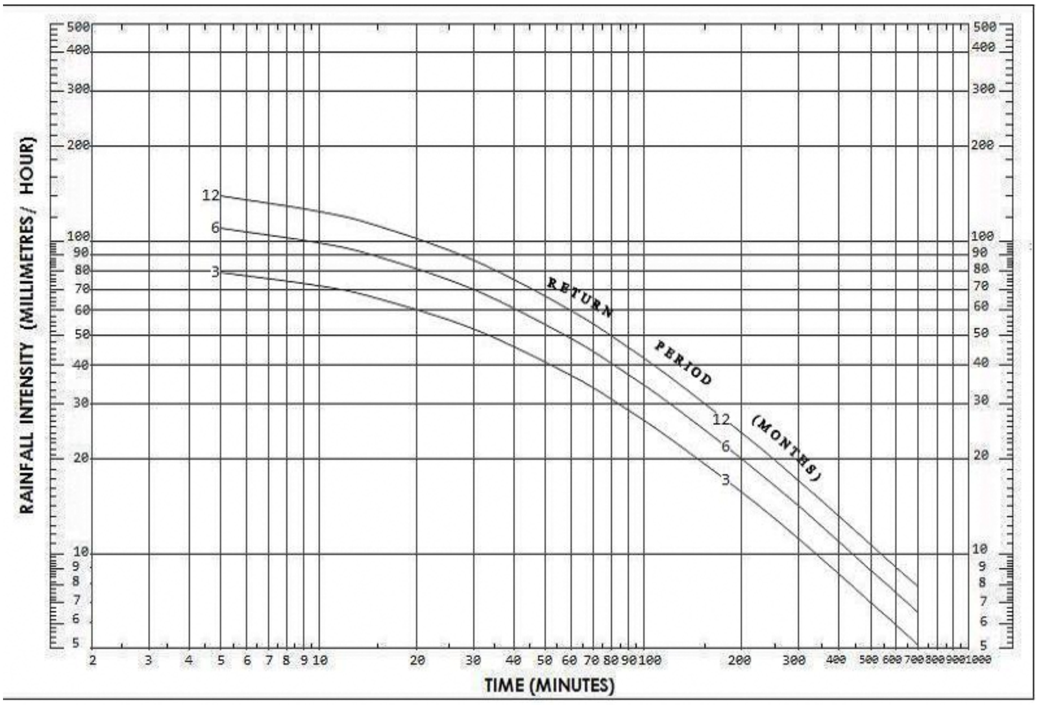


Figure 7.12 IDF Curves for 3-month, 6-month, & 12-month ARI storms

A catchment sediment loading rate (L_o) of 3m^3/ha/year for developed catchments in Singapore may be used to estimate the total sediment loads entering the basin (see Chapter 4 Sedimentation Basin). This volume represents the full range of sediment sizes. In the absence of local sediment particle size distribution, it is not possible to accurately estimate the volume captured at the forebay. A conservative approach is to multiply the capture efficiency (R) by the sediment load estimated applying the catchment loading rate (L_o).

The coarse sediment forebays will contain large rocks for energy dissipation and be underlain by filter material to promote drainage following storm events. The depth of the forebay should not be greater than 0.3m below the surface of the filter media. As the sediment forebay will be filled with rocks and gravels, a porosity factor (ρ) should be applied to estimate the volume of voids within the sediment forebay that is available for deposition of sediments.

7.4.3.3 Streetscape Applications

As bioretention pods are not continuous systems, streetscape applications need to carefully consider the locations of inlets to the bioretention pods so as not to increase the width of channel flow along the street leading to the inflow to these systems.

7.4.4 Step 4: Specify the bioretention media characteristics

7.4.4.1 Specify the Bioretention Filter Media Characteristics

Generally, three types of media are required in the bioretention component of bioretention swales (refer Figure 7.1 and Figure 7.7).

Filter Media

The filter media layer provides the majority of the pollutant treatment function, through fine filtration and also by supporting vegetation. The vegetation enhances filtration, keeps the filter media porous, provides substrate for biofilm formation that is important for the uptake and removal of nutrients and other stormwater pollutants. As a minimum, the filter media is required to have sufficient depth to support vegetation. Typical depths are between 600-1000 mm with a minimum depth of 400mm accepted in depth constrained situations. It is important to note that if deep rooted plants such as trees are to be planted in bioretention swales, the filter media must have a minimum depth of 1000 mm to provide sufficient plant anchoring depth.

Saturated hydraulic conductivity should remain between100-300 mm/hr (and should not be greater than 500 mm/hr. Saturated hydraulic conductity less than 100 mm/hr (but higher than 50 mm/hr) shall be accepted with caution. The following procedure is recommended in determine the appropriate soil filter media to match the design saturated hydraulic conductivity:

- Identify available sources of a suitable base soil (i.e. topsoil) capable of supporting vegetation growth such as a sandy loam or sandy clay loam. In-situ topsoil should be considered first before importing soil. Any soil found to contain high levels of salt (see last bullet point), extremely low levels of organic carbon (< 3%), or other extremes considered retardant to plant growth and microbial activity should be rejected. The base soil must be free from pollutants like heavy metals, excessive nutrient and organic pollutants that may affect water quality of the filtrate.
- The base soil must also be structurally sound and not prone to structural collapse as this can result in a significant reduction in saturated hydraulic conductivity. The risk of structural collapse can be reduced by ensuring the soil has a well graded particle size distribution with a combined clay and silt fraction of < 12%.
- Using laboratory analysis, determine the saturated hydraulic conductivity of the base soil using standard testing procedures. (In Australia, reference is made to AS 4419-2003 Appendix H Soil Permeability or refer to Constant head method BS1377-5:1990 for Singapore). A minimum of five samples of the base soil should be tested. Any occurrence of structural collapse during laboratory testing must be noted and an alternative base soil sourced.
- To amend the base soil to achieve the desired design saturated hydraulic conductivity either mix in a loose non-angular sand (to increase saturated

hydraulic conductivity) or conversely a loose loam (to reduce saturated hydraulic conductivity).

- The required content of sand or clay (by weight) to be mixed to the base soil will need to be established in the laboratory by incrementally increasing the content of sand or clay until the desired saturated hydraulic conductivity is achieved. The sand or clay content (by weight) that achieves the desired saturated hydraulic conductivity should then be adopted on-site. A minimum of five samples of the selected base soil and sand (or clay) content mix must be tested in the laboratory to ensure saturated hydraulic conductivity is consistent across all samples. If the average saturated hydraulic conductivity of the final filter media mix is within ± 20% of the design saturated hydraulic conductivity, then the filter media can be adopted and installed in the bioretention system. Otherwise, further amendment of the filter media must occur through the addition of sand (or clay) and retested until the design saturated hydraulic conductivity is achieved.

- The base soil must have sufficient organic content to establish vegetation on the surface of the bioretention system. If the proportion of base soil in the final mix is less than 3%, it may be necessary to add organic material. This should not result in more than 10% organic content and should not alter the saturated hydraulic conductivity of the final filter media mix.

- The pH of the final filter media is to be amended (if required) to between 5.5 and 7.5. If the filter media mix is being prepared off-site, this amendment should be undertaken before delivery to the site.

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

- Testing of this soil property should be undertaken prior to their placement during construction. It should also be noted that soil hydraulic conductivity will vary after placement and is expected to initially decrease due to hydraulic compaction during operation. With maturity of plant growth, the soil hydraulic conductivty can be expected to recover to asymptote to an equilibrium level comparable to its original value.

The selection of suitable soil filter media is a topic of continuing research. Further information can also be obtained from “Guidelines for Filter Media for Biofiltration System by FAWB (Facility for Advancing Water Biofiltration).

Transition Layer

The particle size difference between the filter media and the underlying drainage layer should be not more than one order of magnitude to avoid the filter media being washed through the voids of the drainage layer. Therefore, with fine gravels being used for the drainage layer (which will be at least two orders of magnitude coarser than the likely average particle size of the filter media), a transition layer is recommended to prevent the filter media from washing into the perforated pipes. The material for the transition layer is sand/coarse sand. An example particle size distribution (% passing) is provided below (typical specification only):

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

The transition layer is recommended to be 100 mm thick.

The addition of a transition layer increases the overall depth of the bioretention system and may be an important consideration for some sites where total depth of the bioretention system may be constrained. In such cases, two options are available to reduce the overall depth of the system, ie.

- the use of a sand drainage layer and/or perforated pipes with smaller slot sized may need to be considered.
- use a geotextile layer with a mesh size specified to be between 0.7 to 1mm. (This option should be an option of last resort as the risk of installing inappropriate liner is high).

Drainage Layer

The drainage layer is used to convey treated flows to the outlet via a perforated under-drainage system. The composition of the drainage layer is to be considered in conjunction with the selection and design of the perforated under-drainage system (refer to Section 0) as the slot sizes in the perforated pipes may determine the minimum drainage layer particle size to avoid washout of the drainage layer into the perforated pipe system.

Gravel is the preferred media for the drainage layer to match with the typical slot size of typical perforated or slotted under-drains.

However, there may be circumstances where site conditions constraint the depth of the bioretention system. In such cases, it may be possible to use sand as the drainage layer media to avoid having to provide a transition layer between the filter media and the drainage layer. The drainage layer is to be a minimum of 200 mm thick and it is advisable that the drainage media is washed prior to placement in bioretention system to remove any fines.

Submerged Zone

The submerged zone should be comprised of a mix of medium to coarse sand and carbon, or a mix of fine gravel and carbon. The carbon source should be a mix of 5% mulch and 5% hardwood chips, by volume.

A depth of 450mm has been shown to be optimal (Zinger *et al*., 2007), however the feasibility of this will be determined by site conditions. A minimum of 300mm is required for this zone to be effective. A submerged zone of 300mm will protect against drying for up to five weeks of continuous null inflow. In climates where dry periods are likely to exceed five weeks, the submerged zone should be increased in depth by 120mm for every additional week of expected zero inflows. It is also important to note that a 50mm transition layer should separate the filter media and submerged zone. This will prevent the leaching of pollutant and nutrients by ensuring that the filter media does not become permanently saturated.

7.4.5 Step 5: Under-drain design and capacity checks

The slotted collection pipes at the base of bioretention filter media collect treated water for conveyance downstream. The collection pipes are sized to ensure flow through the filter media is not choked (or impeded) by the collection system.

The recommended maximum diameter of the perforated pipes is 100 mm to minimise the required thickness of the drainage layer. Either flexible perforated pipe (e.g. agricultural pipe) or slotted PVC pipes can be used, however care needs to be taken to ensure that the slots in the pipes are not too large that sediment would freely flow into the pipes from the drainage layer.

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

- Ensure the perforations are adequate to pass the maximum filtration rate of the media
- Ensure the pipe itself has sufficient capacity to convey the design flow (ie. the maximum filtration rate multiplied by the surface area).
- Ensure that the material in the drainage layer will not be washed into the perforated pipes.

7.4.5.1 Maximum filtration rate

The maximum filtration 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 filtration rate to ensure the filter media drains freely and does not 'choke' the system.

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

$$Q_{\max} = k \cdot L_b \cdot W_{base} \cdot \frac{h_{\max} + d}{d} \qquad \text{Equation 7.2}$$

Where

k = hydraulic conductivity of the soil filter (m/hr)

W_{base} = average width of the ponded cross section above the soil filter (m)

L_b = length of the bioretention zone (m)

h_{max} = depth of pondage above the sand filter (m)

d = depth of filter media (m)

There are two possible configurations for an underdrain in a bioretention system with a submerged zone:

1. Perforated collection pipe with riser outlet

In this configuration, the collection pipe(s) is placed in the drainage layer with an elbow to create a riser outlet to raise the invert. The collection pipe(s) does not need to be sloped as the outlet is elevated. Slotted PVC pipes are preferable to flexible perforated ag-pipe, as they are easier to clean and ribbed pipes are likely to retain moisture which may attract plant roots into pipes, however this necessitates a drainage layer to ensure that finer material from the filter media and transition layers are not washed into the collection pipe(s). The upstream end of the collection pipe should extend to the surface to allow inspection and maintenance; the vertical section(s) of the pipe should be unperforated and capped. Where more than one collection pipe is required, these should be spaced no further than 1.5 m apart.

The following need to be checked:

a) Perforations in pipe are adequate to pass the maximum infiltration rate.
b) Pipe has sufficient capacity to convey the treated water; this component should be oversized to ensure it does not become a choke in the system.
c) Material in the drainage layer will not wash into the perforated pipes.

2. Riser outlet only (no perforated pipe)

A collection pipe is not strictly necessary in a bioretention system with a submerged zone; inclusion of a riser outlet confines exit flow to be via this path and the drainage layer can act as a surrogate collection pipe. The riser outlet should extend to the surface to allow inspection and maintenance.

The following need to be checked:

a) Pipe has sufficient capacity to convey the treated water; this component should be oversized to ensure it does not become a choke in the system.
b) Material in the drainage layer will not wash into the riser outlet.

7.4.5.2 Spacing of perforated pipes

Spacing of perforated pipes should be sufficiently close together to ensure effective drainage of the bioretention system. With a smaller aspect ratio associated with bioretention basins compared with bioretention swales, the maximum spacing of the perforated pipes can be increased to 2.5 – 3 m, especially for large bioretention basins (> 100 m^2).

Where possible the perforated pipes are to grade at a minimum of 0.5% towards the overflow pit to ensure effective drainage. A slope of 0.5% is adopted simply for convenience. In reality, the discharge capacity of the perforated pipe is not dependent on this slope since maximum discharge condition is reached when the soil is saturated and water ponded to the full extended detention depth. Bioretention systems can operate equally effectively with the underdrain laid at near-zero (but positive) slope. Grading the base of the bioretention system towards the pit and placing the perforated pipes (and the drainage layer) on this grade is a recommended approach to ensuring that the pipes are laid on a positive slope.

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

7.4.5.3 Perforations inflow check

To ensure the perforated under-drainage system has sufficient capacity to collect and convey the maximum filtration rate, it is necessary to determine the capacity for flows to enter the under-drainage system via the perforations in the pipes. If the capacity of the drainage system is unable to collect the maximum filtration rate additional under-drains will be required.

To calculate the flow through the perforations, orifice flow can be assumed and the sharp edged orifice equation used as given in the following equation.

$$Q_{perf} = B \cdot C_d \cdot Ao\sqrt{2 \cdot g \cdot h} \qquad \text{Equation 7.3}$$

Where

Q_{perf} = Flow rate through perforations (m^3/s)

B = Blockage factor (= 0.5)

C_d = Orifice discharge coefficient (= 0.6)

A_o = Total area of the orifices (m^2)

h = Assuming drainage layer is saturated, driving head is half the depth of the drainage layer (m)

The total area of the orifice (A_o) is a function of the number of perforations in the pipe. This information is typically provided in the manufacturer's specifications. The maximum driving head is equal to the depth of the filter media plus the extended detention depth, if extended detention is provided.

It is conservative, but reasonable to use a blockage factor to account for partial blockage of the perforations by the drainage layer media. A blockage factor of 0.5 is considered adequate.

7.4.5.4 Perforated pipe capacity

After confirming the capacity of the under-drainage system to collect the maximum filtration rate, it is necessary to confirm the conveyance capacity of the under-drainage system is sufficient to convey the collected runoff. The Colebrook-White equation can be applied to estimate the flow rate in the perforated pipe.

$$Q_{pipe} = A_p \left[-2\left(2gD_pS_f\right)^{0.5} log\left(\frac{k}{3.7D} + \frac{2.51v}{D_p\left(2gD_pS_f\right)^{0.5}} \right) \right] \qquad \text{Equation 7.4}$$

Where

Q_{pipe} = Flow rate through the perforated pipe (m^3/s)

A_p = Pipe cross sectional area (m^2)

D_p = Pipe diameter (m)

S_f = Hydraulic gradient (m/m)

k = Hydraulic roughness

v = Kinematic viscosity of water (m^2/s)

One end of the under-drains should be extended vertically to the surface of the bioretention system to allow inspection and maintenance when required. The vertical section of the under-drain should be a non-perforated or slotted pipe and capped to avoid short-circuiting of flows directly to the drain.

7.4.6 Step 6: Check requirements for impermeable lining

The saturated hydraulic conductivity of the natural soil profile surrounding the bioretention system should be tested together with depth to groundwater, chemical composition and proximity to structures and other infrastructure. This is to establish if an impermeable liner is required at the base (only for systems designed to preclude ex-filtration to in-situ soils) and/or sides of the bioretention basin. If the saturated hydraulic conductivity of the filter media in the bioretention system is more than one order of magnitude (10 times) greater than that of the surrounding in-situ soil profile, no impermeable lining is required.

It is important to note that for unlined bioretention systems with submerged zones, the bottom and sides of the submerged zone will need to be lined in order to maintain a permanent pool of water.

7.4.7 Step 7: Size overflow pit

The intention of the high flow design is to convey safely the minor floods (eg. 10-year ARI flows) with 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 that flows do not pass through extensive section of the bioretention basin enroute to the overflow pit. Grated pits can be located near the inlet to minimize the flow path length for above design flows. A level of conservatism should be built into the design grated overflow pits by placing the crest of the pit at least 100 mm below the invert of the street gutter. This allows the overflow pit to convey a minor flood prior to any afflux effects in the street gutter. The overflow pit should be sized to pass a ten 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 form of convention side entry pits associated with the street kerb and gutter immediately downstream of the inlet to the basin. In this way the overflow pit can operate in the same way as a conventional drainage system, with flows entering the pit only when the bioretention system is at maximum ponding depth. This is illustrated in Figure 7.13.

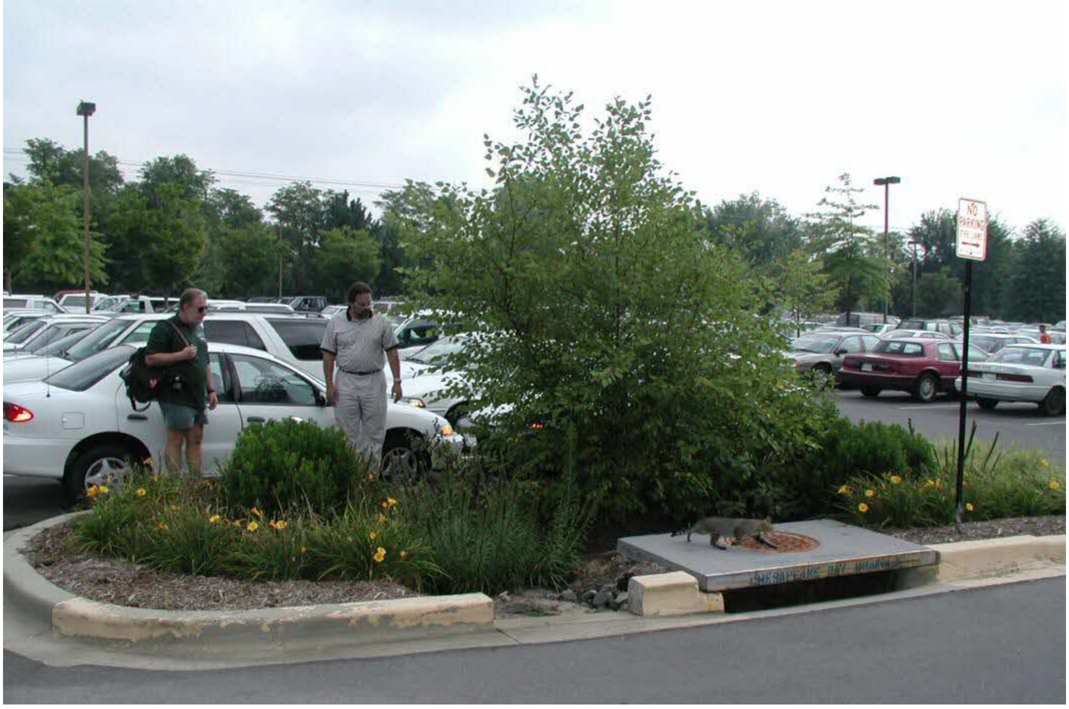


Figure 7.13 A conventional side entry pit for overflow from Bioretention Pod. Once inundated to street level, stormwater will no longer enter the bioretention raingarden but will instead be conveyed to the adjoining side entry pit.

A grated overflow pit is sized based on the governing flow condition; weir flow or submerged flow conditions. A weir equation can be used to determine the length of weir required (assuming free overfall conditions). An orifice equation is used to estimate the required area between openings in the grate cover (assuming drowned outlet conditions). The larger of the resulting required dimensions to accommodate the two flow conditions should be adopted. In sizing the overflow pit for both drowned and free flowing conditions, it is recommended that a blockage factor that assumes the orifice is 50% blocked be used.

The weir equation for free flowing conditions is given by:

$$Q_{\min or} = Q_{weir} = B \cdot C_w \cdot L \cdot h_w^{3/2} \qquad \text{Equation 7.5}$$

Where

Q_{weir} = Flow over weir pit (m^3/s)

B = Blocked factor (assumed to be 50%)

C_w = Weir coefficient (adopt 1.7)

L = Length of weir (m)

h_w = Flow depth above weir (m)

A standard sized pit can be selected with a perimeter at least the same length as the required weir length.

The orifice equation for drowned outlet conditions is given by:

$$Q_{\min or} = Q_{grate} = B.C_d.A_{grate}\sqrt{2gh_w} \qquad \text{Equation 7.6}$$

Where

Q_{grate} = Flow rate under drowned conditions (m^3/s)

A_{grate} = Area of perforations in inlet grate (m^2)

h_w = Flow depth above weir (m)

C_d = Discharge coefficient (0.6)

7.4.8 Step 8: Specify Vegetation

Advice from the party who will takeover the features for maintenance (e.g. NParks, Town Councils, MCST etc.) should be sought in determining the lists of plants suitable for bioretention basins. Consultation with landscape architects is recommended when selecting vegetation, to ensure the treatment system compliments the landscape design of the area.

7.4.9 Step 9: Verification Checks

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

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 width of the system. Dividing the design flow rate by the cross sectional area, an estimate of flow velocity can be made. It is a conservative approach to assume that all flows pass through the bioretention basin (particularly for a 100 year ARI) however this will ensure the integrity of the vegetation.

Velocities should be kept below 0.5 m/s for flows up to the 10-year ARI peak discharges and less than 2.0 m/s for events up to the 100-year ARI discharges.

If the design of the bioretention basin (i.e. the treatment area) changes to ensure the above criteria are met, the performance of the bioretention system given the new treatment area should be checked against the sizing curves given in Figure 7.8 to Figure 7.10.

7.4.10 Design Calculation Summary

A summary of the key design elements of a bioretention basin are presented in the following table.

Bioretention basins

	CALCULATION TASK			
	Catchment Characteristics			
	- Land Uses			
		Residential		m^2
		Commercial		m^2
		Roads		m^2
	- Fraction Impervious			
		Residential		-
		Commercial		-
		Roads		-
		Weighted average		
	Conceptual Design			
		Basin Area		m^2
		Maximum width		m
		maximum ponding depth (extended detention)		m
		Filter media type (hydraulic conductivity)		mm/hr
	Identify design criteria			
		Minor flood		year ARI
		Major flood		year ARI
1	**Confirm treatment performance and concept design**			
		Reduction in TSS		**%**
		Reduction in TP		**%**
		Reduction in TN		**%**
2	**Estimate design flow rates**			
	Time of concentration			
		Estimate from flow path length and velocities		minutes
	Identify rainfall intensities			
		Design Rainfall Intensity for minor flow		mm/hr
		Design Rainfall Intensity for major flow		mm/hr
	Design runoff coefficient			-
	refer to the Singapore Code of Practice on Surface Water Drainage(2000)			
	Peak design flows			
		Minor Storm (selected design storm ARI and flow)	ARI	m^3/s
		Major Storm (selected design storm ARI and flow)	ARI	m^3/s
		$Q_{\text{max infiltration}}$		m^3/s
3	**Design inflow system**			
	Adequate erosion and scour protection?			y/n
	Coarse Sediment Forebay Required?			
		Volume (V_s)		m^3
		Area (A_s)		m^2
		Depth (D)		m
	Check flow widths in upstream channel			
		Minor storm flow width		m
		CHECK ADEQUATE LANES TRAFFICABLE		
	Kerb opening width			
		Kerb opening length		m
4	**Specify bioretention media characteristics**			
		Filter media hydraulic conductivity		mm/hr
		Filter media depth		mm
		Drainage layer media (sand or fine screenings)		
		Drainage layer depth		mm
		Transition layer (sand) required		
		Transition layer depth		mm
5	**Under-drain design and capacity check**			
	- Perforations inflow check			
		Pipe diameter		mm
		Number of pipes		

	Capacity of perforations	m^3/s	
	CHECK PERFORATION CAPACITY > Filter media maximum infiltration rate		
6	**Check requirement for impermeable lining**		
	Soil hydraulic conductivity	mm/hr	
	Filter media hydraulic conductivity	mm/hr	
	MORE THAN 10 TIMES HIGHER THAN IN-SITU SOILS?		
7	**Size overflow pit**		
	System to convey minor floods	L x W	
	Flow capacity for the overflow pits	m^3/s	
8	**Vegetation Specification**		
9	**Verification Checks**		
	Velocity for Minor Storm (<0.5m/s)	m/s	
	Velocity for Major Storm (<2.0m/s)	m/s	

7.5 Checking Tools

The following sections provide a number of checking aids for designers and referral authorities. Additional advice on construction and maintenance is provided.

Checklists have been provided for:

- Design assessments
- Construction (during and post)
- Maintenance and inspections

7.5.1 Design Assessment Checklist

The checklist below 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, referral should be made back to the design procedure to determine the impact 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 downstream aquatic habitats.

7.5.2 Construction Advice

This section provides general advice for the construction of bioretention basins. It is based on observations from construction projects around Australia.

7.5.2.1 Building Phase Damage

Protection of filtration media and vegetation is important during the building phase. Uncontrolled building site runoff is likely to cause excessive sedimentation, introduce weeds and litter and require replanting following the building phase.

To minimise the impact of construction activities on the site, it is recommended that the bioretention system be installed in stages. For example, temporary protection of a bioretention basin can be achieved by using a temporary arrangement of a suitable geofabric covered with shallow topsoil (e.g. 25mm) and instant turf (laid perpendicular to flow path) (Leinster, 2006). Such a system will provide erosion and sediment control. At the completion of construction activities, the temporary protection can be removed (along with the collected sediment) and the system planted in accordance with the planting schedule.

It is also recommended that a silt fence be installed around the periphery of the basin to exclude silt and restrict access. The silt fence is removed once construction is completed.

7.5.2.2 Traffic and Deliveries

It is important to ensure traffic and deliveries do not access bioretention basins during construction. Traffic can compact the filter media and cause preferential flow paths, while deliveries can block filtration media (if placed above media). Washdown wastes (eg. concrete) can also cause blockages in the filtration media.

Bioretention areas should be fenced off during building phase and controls implemented to avoid washdown wastes.

Checklist 1: Bioretention basin design assessment checklist

BIORETENTION BASIN DESIGN ASSESSMENT CHECKLIST

Basin Location:		
Hydraulics:	Minor Flood (m^3/s):	Major Flood (m^3/s):
Area:	Catchment Area (ha):	Bioretention Area (ha):

TREATMENT	**Y**	**N**
Treatment performance verified from curves?		
BIORETENTION MEDIA AND UNDER-DRAINAGE	**Y**	**N**
Design documents bioretention area and extended detention depth as defined by treatment performance requirements.		
Overall flow conveyance system sufficient for design flood event(s)?		
Where required, bypass sufficient for conveyance of design flood event?		
Where required scour protection provided at inflow point to bioretention?		
Bioretention media specification includes details of filter media, drainage layer and transition layer (if required)?		
Design saturated hydraulic conductivity included in specification?		
Transition layer provided where drainage layer consists of gravel (rather than coarse sand)?		
Perforated pipe capacity > infiltration capacity of filter media?		
Selected filter media hydraulic conductivity > 10 x hydraulic conductivity of surrounding soil?		
Liner provided if selected filter media hydraulic conductivity < 10 x hydraulic conductivity of surrounding soil?		
Maximum spacing of collection pipes <1.5m?		
Collection pipes extended to surface to allow inspection and flushing?		
Maximum upstream flood conveyance complies with Singapore surface water drainage requirements?		
BASIN	**Y**	**N**
Bioretention area and extended detention depth documented to satisfy treatment requirements?		
Overflow pit crest set at top of extended detention?		
Maximum ponding depth will not impact on public safety?		
Maintenance access provided to surface of bioretention system (for larger systems)?		
Protection from coarse sediments provided (where required) with a sediment forebay?		
Protection from gross pollutants provided (where required)?		
LANDSCAPE	**Y**	**N**
Plant species selected can tolerate periodic inundation and design velocities?		
Bioretention design and plant species selected integrate with surrounding landscape or built environment design?		

COMMENTS

7.5.2.3 Inlet Erosion Checks

It is good practice to check the operation of inlet erosion protection measures following the first few rainfall events to ensure the system would not be affected by scour. Should problems occur in these events the erosion protection should be enhanced.

7.5.2.4 Timing for Planting

Timing of vegetation is dependent 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 during construction for sediment control (eg. with turf) were removed and plant out with long term vegetation.

7.5.2.5 Planting Strategy

A planting strategy for a development will depend on the timing of construction 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 control facilities (to be planted out following building).

7.5.2.6 Perforated Pipes

Corrugated perforated HDPE pipes are normally used as perforated subsoil pipes for Bioretention systems. Pipe fittings should be compatible in type and material. There should also be standpipes to facilitate flushing of subsoil pipes. The standpipes should be corrugated non-perforated HDPE pipes with removable end caps.

7.5.2.7 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 buildup and water level fluctuations when required and easy access for maintenance. The vertical component of the pipe should not be perforated otherwise short circuiting can occur.

7.5.2.8 Clean Filter Media

Ensure sand, gravels and other material used in the filter, transition, drainage and other layers are washed prior to placement to remove fines.

7.5.2.9 Construction Inspection Checklist

The following checklist presents the key items to be reviewed when inspecting the bioretention basin during and at the completion of construction. The checklist is to be used by Construction Site Supervisors and local authority Compliance Inspectors to ensure all the elements of the bioretention basin have been constructed in accordance with the design. If an item is ticked as unsatisfactory, appropriate actions must be specified and delivered to rectify the construction issue before final inspection sign-off is given.

Checklist 2: Construction Inspection Checklist

BIORETENTION BASIN CONSTRUCTION INSPECTION CHECKLIST

Site:		**Date:**	
		Time:	
Constructed By:		**Weather:**	
		Contact During Visit:	

Items inspected	**Checked**		**Adequate**		**Items inspected**	**Checked**		**Adequate**	
	Y	**N**	**Y**	**N**		**Y**	**N**	**Y**	**N**
DURING CONSTRUCTION & ESTABLISHMENT									
Preliminary Works					**Structural components**				
1. Erosion and sediment control plan adopted					15. Location and configuration of inflow systems as designed				
2. Temporary traffic/safety control measures					16. Location and levels of overflow pits as designed				
3. Location same as plans					17. Under-drainage connected to overflow pits as designed				
4. Site protection from existing flows					18. Concrete and reinforcement as designed				
Earthworks and Filter Media					19. Set down to correct level for flush kerbs (streetscape applications only)				
5. Bed of basin correct shape and slope					20. Kerb opening width as designed				
6. Batter slopes as plans									
7. Dimensions of bioretention area as per plans					**Vegetation**				
8. Confirm surrounding soil type with design					21. Planting as designed (species and densities)				
9. Confirm filter media specification in accordance with guidelines (Step 4)					22. Weed removal and watering as required				
9. Provision of liner (if required)					23. Stabilisation immediately following earthworks and planting of terrestrial landscape around basin				
10. Under-drainage installed as designed									
11. Drainage layer media as designed					**Sediment & Erosion Control (If Required)**				
12. Transition layer media as designed (if required)					24. Silt fences and traffic control in place				
14. Extended detention depth as designed					25. Temporary protection layers in place				

FINAL INSPECTION									
1. Confirm levels of inlets and outlets					6. Check for uneven settling of banks				
2. Confirm structural element sizes					7. Under-drainage working				
3. Check batter slopes					8. Inflow systems working				
4. Vegetation as designed					9. Maintenance access provided				
5. Bioretention filter media surface flat and free of clogging					10. Construction generated sediment removed				

COMMENTS ON INSPECTION
ACTIONS REQUIRED
Inspection officer signature:

7.5.3 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 plays a key role 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 the plant establishment period (first two years) when weed removal and replanting may be required. It is also the time when large loads of sediments could impact on plant growth particularly in developing catchments with poor building controls.

Maintenance is primarily concerned with:

- Maintenance of 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 the ponding volume available. Should excessive sediment build up it will impact on 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 if located in a visible location. Inspection and removal of debris should be done regularly, but debris should be removed whenever it is observed on the site.

7.5.3.1 Operation & Maintenance Inspection Form

The form below should be used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time.

Checklist 3: Bioretention basin maintenance checklist

BIORETENTION BASIN MAINTENANCE CHECKLIST					
Inspection Frequency:	Weekly to monthly (adjust according to site requirement)	**Date of Visit:**			
Location:					
Description:					
Site Visit by:					

INSPECTION ITEMS:	**FREQUENCY**	**Y**	**N**	**Action Required (details)**
Sediment accumulation at inflow points?				
Litter within basin?				
Erosion at inlet or other key structures?				
Evidence of dumping (e.g. building waste)?				
Watering of vegetation required?				
Clogging of drainage points (sediment or debris)?				
Evidence of ponding?	Weekly or After rain			
Surface clogging/ algae on filter media surface visible?	Bi-weekly			
Drainage system inspected?				
Vegetation condition satisfactory (density, weeds etc)?				
Trimming/thinning of overgrown vegetation as necessary and removal of weeds.	Monthly			
Damage/vandalism to structures present?				
Flushing of subsoil pipes.	Half-yearly			
Resetting of system required?				

COMMENTS

Name of ABC Waters Professional: _______________

Registration No. of ABC Waters Professional: _______________

Signature: _______________

Name of Maintenance Agency: _______________

Handing Over Date (TOP or Completion of DLP): _______________

7.6 Bioretention Basin Worked Example

7.6.1 Worked example introduction

A series of bioretention basins (pods), designed as street traffic parking “out-stands” is to be retrofitted into a local street to treat road runoff. The local street is in Singapore. A proposed layout of the bioretention system is shown in Figure 7.14 and an image of a similar system to that proposed is shown in Figure 7.15.

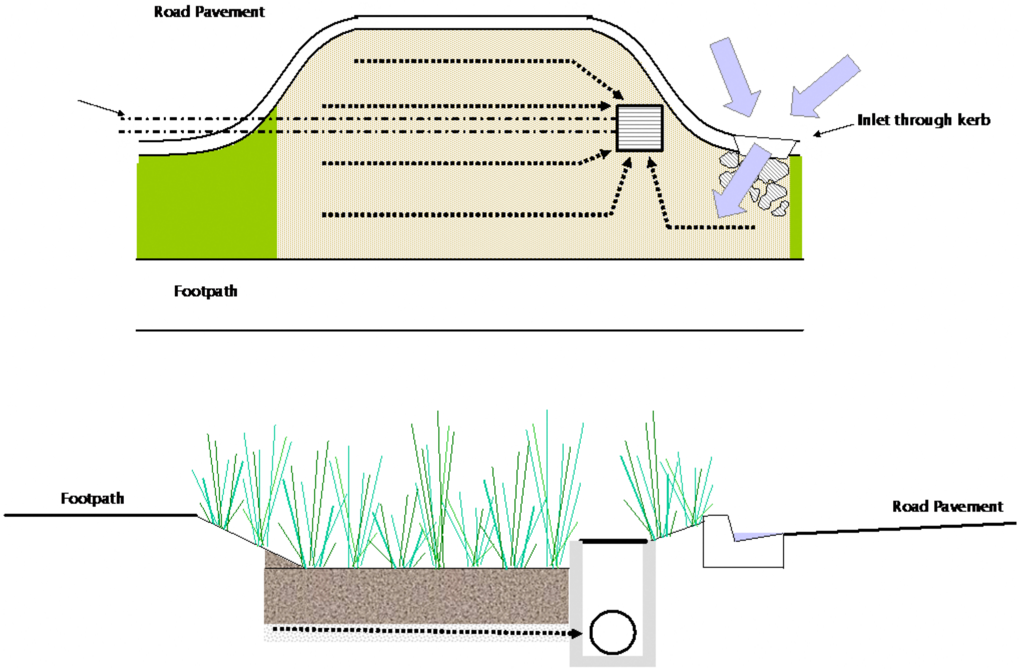


Figure 7.14 Layout of proposed bioretention system

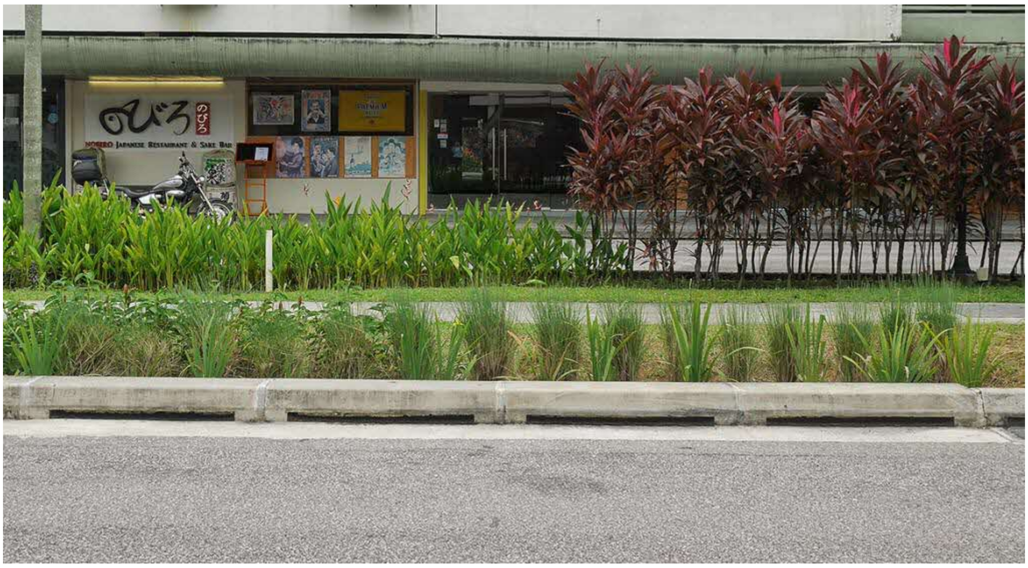


Figure 7.15 Example of a bioretention system in a street (Faber Hill Estate)

Catchment Description

Each of the individual bioretention basins (pods) has a contributing catchment of 100m^2 road and footpath pavement and 300m^2 of adjoining properties. Runoff from adjoining properties (approx. 60% impervious) is discharged into the road gutter and, together with road runoff, is conveyed along a conventional roadside gutter to the bioretention pod.

Table 7.1: Catchment properties

Catchment Land Uses	Area (m^2)	% Impervious
Car Park	100	0.9
Allotment	300	0.6
Total	400	0.68

Design Objectives

The aim of the design is to facilitate effective treatment of stormwater runoff while maintaining a level of flood protection for the local street during frequent storm events up to the 10yr ARI event. Effective stormwater quality treatment is described in terms of pollutant load reductions for total suspended solids (TSS), total phosphorous (TP) and total nitrogen (TN).

The key design elements for effective operation of the bioretention basins are:

- road and channel details to convey water into the basins
- detailing inlet conditions to provide for erosion protection
- configuring and designing a system for ‘above design’ operation that will provide the required 10year ARI flood protection for the local street
- detailing of the bioretention under-drainage system
- specification of the soil filter medium
- landscape layout and details of vegetation.

Constraints and Concept Design Criteria

The proposed site for the bioretention basin has the following characteristics:

Overland flow slope:	1% typical
Soil:	clay

A preliminary design was completed for the site. The specifications for the bioretention basins were determined as follows:

- A bioretention basin area of 14m^2 (minimum) is required to achieve the stipulated water quality objectives for this worked example (pollutant load reductions of 80%, 45% and 45% for TSS, TN and TP respectively)
- The maximum width of the bioretention basin is to be 2m.
- The extended detention depth is 200 mm.
- Filter media shall be a sandy loam.

7.6.2 Calculation Steps

The design of a bioretention system has been divided into the following 9 calculations steps:

Step 1 Confirm treatment size given in conceptual design
Step 2 Determine design flows
Step 3 Design inflow system
Step 4 Specify the bioretention media characteristics
Step 5 Under-drain design and capacity checks
Step 6 Check requirements for impermeable lining
Step 7 High flow route and by-pass design
Step 8 Vegetation Specification
Step 9 Verification Checks

Details for each calculation step are provided below. A design calculation summary has been completed for the worked example and is given at the conclusion of the calculation steps.

Step 1 Confirm treatment size given in conceptual design

The sizing of the bioretention system determined during conceptual design was verified using the sizing curves given in Figure 7.8 to Figure 7.10 The sizing curves, developed for Singapore conditions, give an estimate of the pollutant load reduction for a given treatment size (defined in terms of equivalent impervious treatment area). Verification using the sizing curves requires the following information:

- The extended detention depth (200mm)
- The ratio of treatment area to equivalent impervious area =

$$\frac{14m^2}{[(0.9\times 100)+(0.6\times 300)]}=5\%$$

The expected pollutant reductions given in the sizing curves for the above criteria are 93%, 77% and 49% for TSS, TP and TN respectively and exceed the design requirements of 80%, 45% and 45%.

Step 2 Determine design flows

<u>Minor and major flood estimation</u>

With a small catchment, the Rational Method is considered an appropriate approach to estimate the 10 and 100 year ARI peak flow rates. The calculation steps are given below.

a. Time of concentration (t_c)

The time of concentration is associated with overland flow and kerb and gutter travel times. In this worked example, the time of concentration is estimated to be approximately 10 minutes.

b. Design rainfall intensities

The rainfall intensity for the 10 year and 100 year ARI event is calculated from the Singapore IDF curve. Data for the 1year flow is extrapolated from the curve. Rainfall intensities for the 100year, 10year and 1year ARI event for 10min storm duration are given below.

	100yr	10yr	1yr
Intensity (mm/hr)	271	190	106

c. Design runoff coefficient

The runoff coefficients are taken from the Singapore Code of Practice on Surface Water Drainage (PUB, 2013). A runoff coefficient of 0.65 and 1.0 is recommended for residential areas (not densely built up) and road catchment, respectively. The weighted average for the catchment given the two land uses is 0.74.

d. Peak Design flows

Apply the Rational Method to determine the peak flows for 10year and 100year ARI events:

$$Q = \frac{CIA}{360}$$

$$Q_{10} = \frac{0.74 \times 190 \times 400 \times 10^{-4}}{360}$$

$$= 0.016 m^3 / s$$

$$Q_{100} = \frac{0.74 \times 271 \times 400 \times 10^{-4}}{360}$$

$$= 0.02 m^3 / s$$

The Intensity – Duration – Frequency (IDF) curve for 3 month ARI storms is in Figure 7.12. The 3 month ARI flow is calculated as:

$$Q_{3mth} = \left[\frac{0.74 \times 71 \times 400 \times 10^{-4}}{360} \right]$$

$$= 0.006 m^3 / s$$

Maximum filtration rate

The maximum filtration rate, or the flow reaching the perforated pipe in the drainage layer, is estimated by applying Darcy's equation (Equation 7.2) at the saturated hydraulic conductivity of the filter media (assuming no blockage of the media) and the head above the base of the filter media:

$$Q_{\max} = k \cdot L_b \cdot W_{base} \cdot \frac{h_{\max} + d}{d} \quad = 3.4 \text{ m}^3\text{/hr or } 0.0009 \text{ m}^3\text{/s}$$

Given

k = hydraulic conductivity of the soil filter (0.18m/hr)

$L_b \cdot W_{base}$ = average area of the ponded section above the sand filter (14m^2)

h_{max} = depth of pondage above the sand filter (0.2m)

d = Filter media depth (0.6m)

Step 3 Design inflow system

Inlet Scour Protection

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

Coarse Sediment Forebay

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

- Remove particles that are 1mm or greater in diameter from the 3mth ARI storm event.
- Provide appropriate storage for coarse sediment to ensure desilting is required once every year.

The size of the sediment forebay (A_s) is determined by solving Equation 7.1 for a capture efficiency of 80%, i.e.

$$A_s = \frac{nQ}{V_s}\left[(1-R)^{-1/n} - 1\right]$$

Where

R = fraction of target sediment removed (adopt 80% or higher)

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

Q = Design flow (3 month ARI peak discharge)

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

A_s = The area of the sediment forebay

ρ = Porosity (adopt 0.4 for gravel)

$$A_s = \frac{(0.5)(0.006)}{0.1}\left[(1 - 0.8)^{-1/0.5} - 1\right] = 0.72m^2$$

The volume of the sediment forebay is calculated by adopting a mean depth of 0.3 m, ie.

$$V_s = 0.72 \times 0.3 = 0.22m^3$$

Adopting a sediment loading rate of 3 m^3/ha/yr, the clean-out frequency of the sediment forebay is estimated to be 0.22 x 0.4(3 x 0.04) = 0.72 years.

Step 4 Specify the bioretention media characteristics

The bioretention system will have three layers:

- Sandy loam layer as the filter media (600mm)
- Coarse sand transition layer (100mm)
- Fine gravel drainage layer (200mm)

Filter Media Specifications

The filter media shall have the following properties:

- saturated hydraulic conductivity of approximately 180 mm/hr
- particle sizes ranging between: clay 5 – 15 %, silt <30 %, sand 50 – 70 %

- between 5% and 10% organic content
- pH neutral

Transition layer specifications

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

Particle Size	%Passing
1.4mm	100%
1.0mm	80%
0.7mm	44%
0.5mm	8.4%

Drainage layer specifications

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

Step 5 Under-drain design and capacity checks

A single under-drain is to be installed in the drainage layer. The perforated pipe is to be laid on the base of the bioretention system which grades at 0.5 % towards the overflow pit. A standard perforated pipe has the following specifications:

Openings per metre of pipe = 2100mm^2

Slot (opening) width = 1.5mm

Slot length = 7.5mm

No. of rows = 6

Pipe diameter = 100mm

Number of perforations (n) = 186

The flow capacity of the perforations and the pipe need to be checked against the maximum filtration rate (0.0009 m^3/s – determined in Step 2) to ensure the flow through the media is not impeded by the drainage system.

Perforations inflow check

The inlet capacity of a sub-surface drainage system (perforated pipe) is estimated to ensure it is not a choke in the system. To build in conservatism, it is assumed that 50% of the holes are blocked.

The flow capacity of the perforations is calculated using equation 7.3

$$Q_{perf} = B.C_d.nA\sqrt{2gh}$$

When

C_d = Discharge coefficient (0.6)

h = Assuming drainage layer is saturated, driving head is half the depth of the drainage layer – H = 0.1m

A = 1.125x10^{-5}m^2/hole

B = Blockage factor (adopt 0.5)

n = Numbers of holes

$$Q_{perf} = 0.5 \times 0.6 \times 186 \times 1.125 \times 10^{-5} \times \sqrt{2 \times 9.81 \times 0.1}$$

$$= 0.0009 m^3 / s / metre\ \ of\ \ \ pipe$$

Given the perforated pipe will be 3m in length, the perforated flow for the pipe system is 0.0027 m^3/s. As the perforation flow capacity of the pipe is greater than the maximum filtration rate the perforated pipe, it is adequate in transferring flows from the media.

Perforated pipe capacity

The Colebrook-White equation is applied to estimate the flow rate in the perforated pipe. A slope of 0.5% is assumed[2] and a 100mm perforated pipe (as above) was used. The capacity of this pipe needs to exceed the maximum infiltration rate.

Applying the Colebrook-White Equation (Equation 7.**4**) to calculate the capacity of the perforated pipe

$$Q = A_p \left[-2\left(2gD_pS_f\right)^{0.5} log\left(\frac{k}{3.7D_p} + \frac{2.51v}{Dp\left(2gD_pS_f\right)^{0.5}}\right)\right]$$

Where

D_p = 0.10m

S_f = 0.005m/m

g = 9.81m^2/s

k = 0.007m

v = 1.007 x 10^{-6}

A_p= 0.009m^2

The flow capacity of the pipe is 0.003 m^3/s, which is greater than the infiltration rate. Hence, the perforated pipe specified is adequate for the under-drainage system.

Step 6 Check requirements for impermeable lining

The soils found in Singapore are typically clay with the saturated hydraulic conductivity expected to be ~3.6mm/hr. The sandy loam media that is proposed as the filter media has a hydraulic conductivity of approximately 180 mm/hr. Therefore, the conductivity of the filter media is > 10times the conductivity of the surrounding soils and an impervious liner is not considered to be required.

Step 7 High flow route and by-pass design

The overflow pit (sump) is required to convey 10 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. There are standard pit sizes to accommodate connection to the underground stormwater pipe.

For the existing 450 mm diameter stormwater pipe, 600 x 600 mm pit will be required.

The size of the pit necessary to convey the overflow is computed assuming both free overfall weir flow and submerged flow conditions. For the free overflow condition, a weir equation is used with the maximum headwater depth (h) above the weir being set by the level difference between the crest of the overflow pit and the invert level of the inflow kerb opening (i.e. 100mm).

---

[2] A slope of 0.5% is adopted simply for convenience. In reality, the discharge capacity is reached when the soil is saturated and water ponded to the full extended detention depth. Bioretention systems can operate equally effectively with the underdrain laid at near-zero (but positive) slope.

The weir equation is

$$Q_{\min or} = Q_{weir} = B \cdot C_w \cdot L \cdot h_w^{3/2}$$

For the 10year ARI event, assuming a blockage factor (B) and weir coefficient (C) of 0.5 and 1.7, respectively, the weir length is

$$L = \frac{Q_{\min or}}{B.C_W.H^{\frac{3}{2}}} = \frac{0.016}{0.5\times1.7\times0.1^{\frac{3}{2}}} = 0.08m$$

A 0.08m weir length is equivalent to a 200mm by 200mm pit – smaller than the standard 600 mm by 600 mm pit.

For drowned outlet conditions, the orifice equation is used:

$$Q = B.C_d.A\sqrt{2gh}$$

For the minor flow event, given a discharge coefficient of 0.6, the required area of the pit is

$$A = \frac{0.016}{0.5\times0.6\times\sqrt{2\times9.81\times0.1}}$$
$$= 0.048m^2$$

The equivalent pit dimensions for the drowned outlet condition are 200mm by 200mm – smaller than the standard 600 mm by 600 mm pit.

Hence, the 600mm by 600mm pit is to be adopted.

Step 8 Vegetation Specification

Consultation with the maintenance party is required in determining the list of suitable plant species for the proposed bioretention basin. A list of the commonly used plants in bioretention basin is in Section 6.7.

Step 9 Verification Checks

Flows for the 10yr ARI (Q_{10}) and 100yr ARI (Q_{100}) storm events may be conveyed through the bioretention system. A check for vegetation scouring is completed by checking those velocities through the bioretention system are below 0.5m/s and 2.0 m/s for the 10yr ARI and 100yr ARI event, respectively. The scour check is performed using Equation 7.6.

Given the width of the basin is 2m and the extended detention is 0.2m, the susceptible flow area is 0.4m^2. Hence,

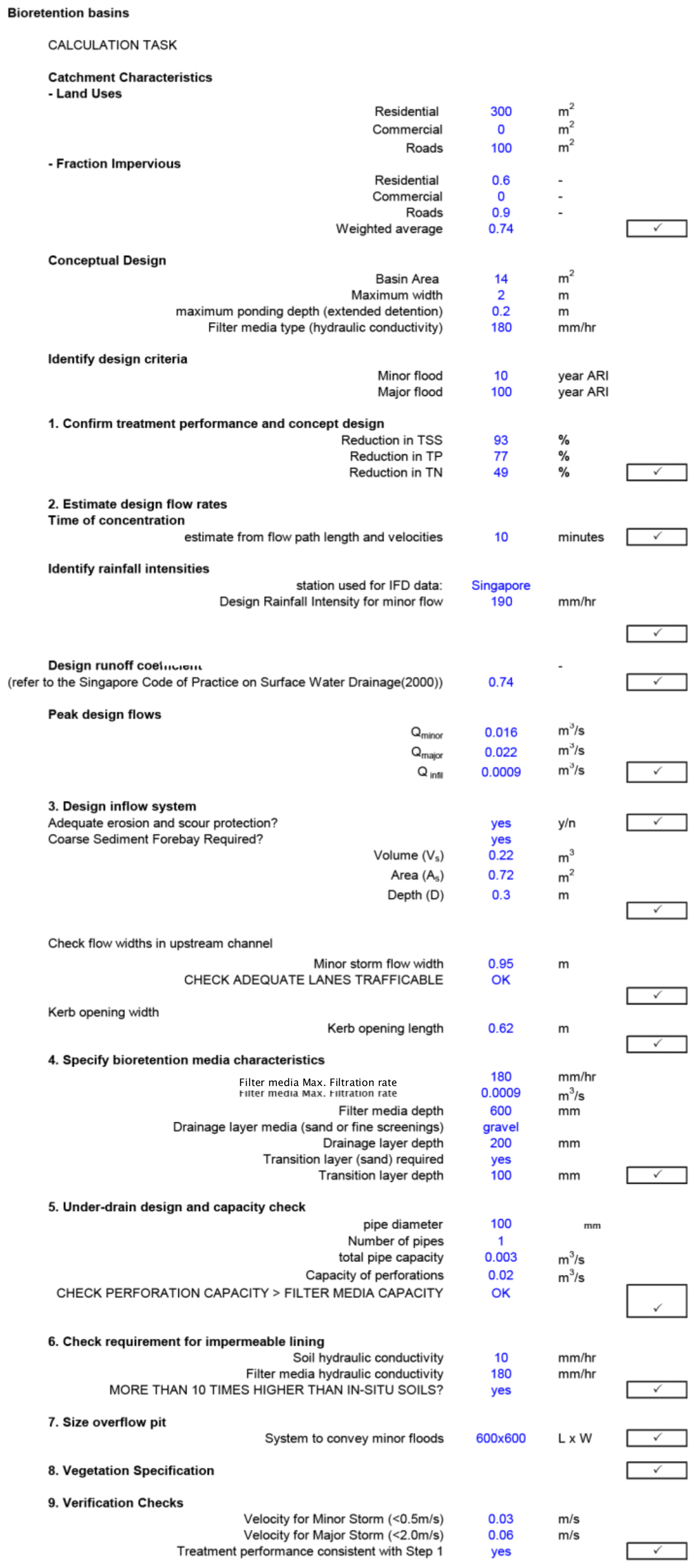
$$V_{10\ year} = \frac{Q_{10}}{A} = 0.04m/s < 0.5m/s$$

$$V_{100\ year} = \frac{Q_{100}}{A} = 0.05m/s < 2.0m/s$$

Hence, bioretention system can satisfactorily convey the peak 10yr and 100yr ARI flood, minimising the potential for scour.

7.6.3 Calculation summary

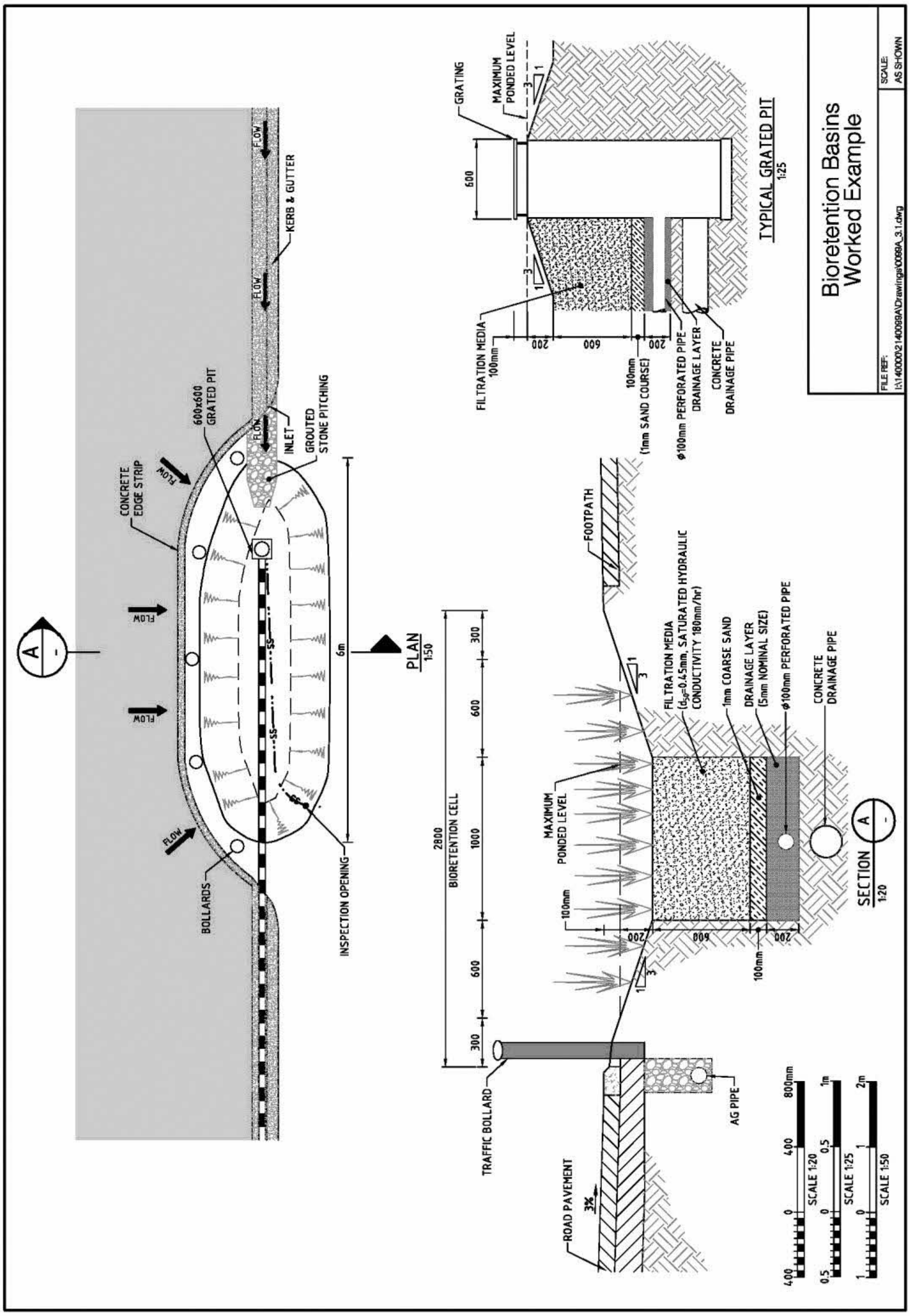
The sheet below shows the results of the design calculations.



Bioretention basins			
CALCULATION TASK			
Catchment Characteristics			
- Land Uses			
Residential	300	m^2	
Commercial	0	m^2	
Roads	100	m^2	
- Fraction Impervious			
Residential	0.6	-	
Commercial	0	-	
Roads	0.9	-	
Weighted average	0.74		✓
Conceptual Design			
Basin Area	14	m^2	
Maximum width	2	m	
maximum ponding depth (extended detention)	0.2	m	
Filter media type (hydraulic conductivity)	180	mm/hr	
Identify design criteria			
Minor flood	10	year ARI	
Major flood	100	year ARI	
1. Confirm treatment performance and concept design			
Reduction in TSS	93	%	
Reduction in TP	77	%	
Reduction in TN	49	%	✓
2. Estimate design flow rates			
Time of concentration			
estimate from flow path length and velocities	10	minutes	✓
Identify rainfall intensities			
station used for IFD data:	Singapore		
Design Rainfall Intensity for minor flow	190	mm/hr	
			✓
Design runoff coefficient		-	
(refer to the Singapore Code of Practice on Surface Water Drainage(2000))	0.74		✓
Peak design flows			
Q_{minor}	0.016	m^3/s	
Q_{major}	0.022	m^3/s	
Q_{infil}	0.0009	m^3/s	✓
3. Design inflow system			
Adequate erosion and scour protection?	yes	y/n	✓
Coarse Sediment Forebay Required?	yes		
Volume (V_s)	0.22	m^3	
Area (A_s)	0.72	m^2	
Depth (D)	0.3	m	
			✓
Check flow widths in upstream channel			
Minor storm flow width	0.95	m	
CHECK ADEQUATE LANES TRAFFICABLE	OK		
			✓
Kerb opening width			
Kerb opening length	0.62	m	✓
4. Specify bioretention media characteristics			
Filter media Max. Filtration rate	180	mm/hr	
Filter media Max. Filtration rate	0.0009	m^3/s	
Filter media depth	600	mm	
Drainage layer media (sand or fine screenings)	gravel		
Drainage layer depth	200	mm	
Transition layer (sand) required	yes		
Transition layer depth	100	mm	✓
5. Under-drain design and capacity check			
pipe diameter	100	mm	
Number of pipes	1		
total pipe capacity	0.003	m^3/s	
Capacity of perforations	0.02	m^3/s	
CHECK PERFORATION CAPACITY > FILTER MEDIA CAPACITY	OK		✓
6. Check requirement for impermeable lining			
Soil hydraulic conductivity	10	mm/hr	
Filter media hydraulic conductivity	180	mm/hr	
MORE THAN 10 TIMES HIGHER THAN IN-SITU SOILS?	yes		✓
7. Size overflow pit			
System to convey minor floods	600x600	L x W	✓
8. Vegetation Specification			✓
9. Verification Checks			
Velocity for Minor Storm (<0.5m/s)	0.03	m/s	
Velocity for Major Storm (<2.0m/s)	0.06	m/s	
Treatment performance consistent with Step 1	yes		✓

7.6.4 Construction drawings

The diagram below shows the construction drawing for the worked example.



7.7 Case Study

NUS SCHOOL OF DESIGN & ENVIROMENT

The bioretention system at the NUS School of Design and Environment is a component part of a stormwater management strategy to treat, detain, and harvest rainwater, and to showcase ABC Waters design. The bioretention system consists of a 4 cascading bioretention basins. Excess water from a basin overflow via a weir to the adjacent basin downstream. The first basin (B1) receives water from Water Feature Pond 1 while the last basin (B4) discharges excess water to the detention tank through an overflow sump. Filtrate from all 4 basins enters Water Feature Pond 2. Water Feature Pond 1 and 2 are showcase features that demonstrate the results of treatment through the bioretention system. The schematic diagram is in Figure 7.17 and the design calculation by ABC Waters Professionals is also given in Page 45-47.

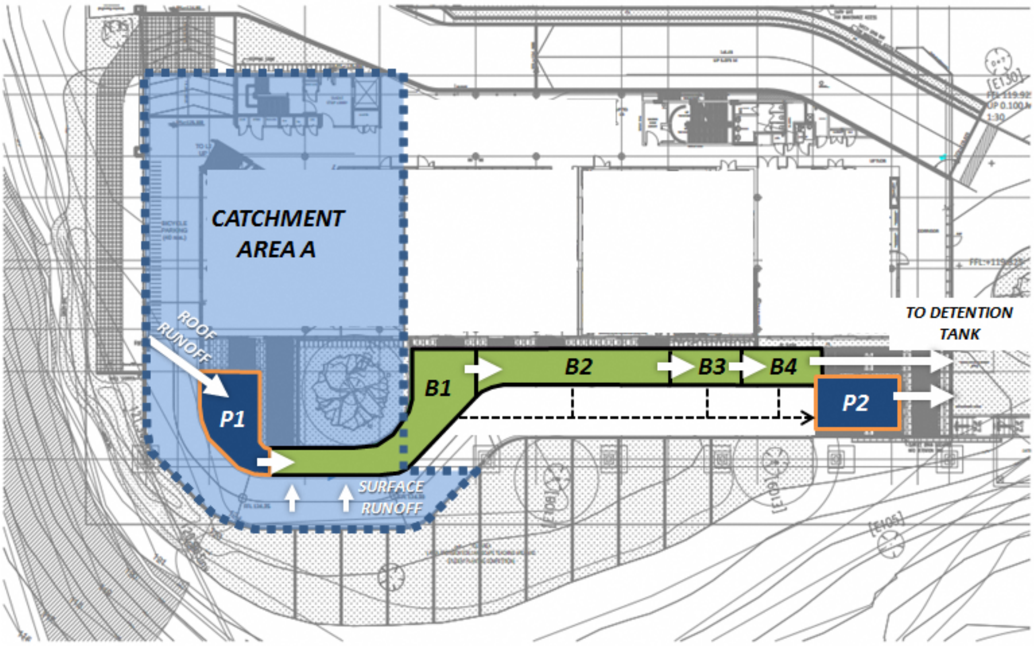


Figure 7.16 Site Plan

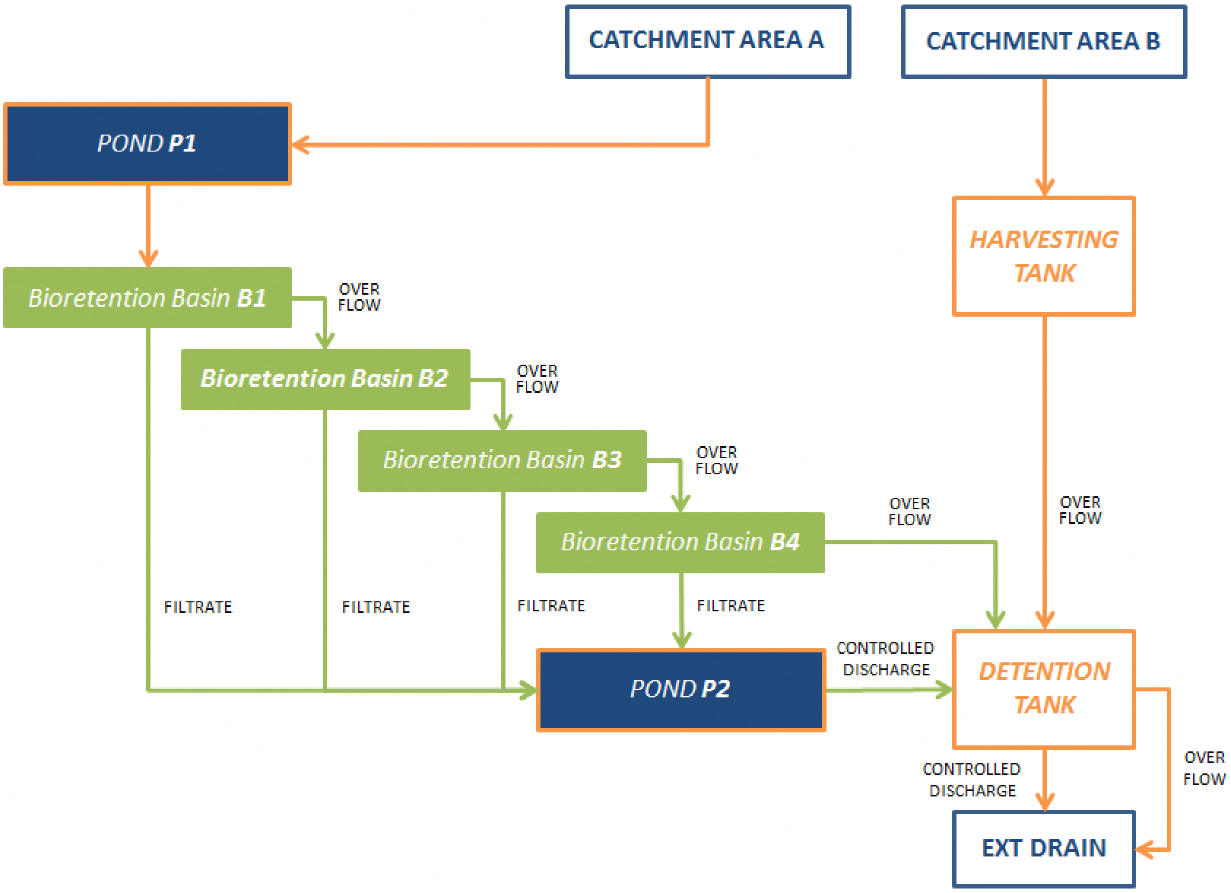


Figure 7.17 **Schematic diagram of the bioretention and pond system**

Credit is due to the following contributors for the case study:
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Surbana Jurong Pte Ltd
Kajima Overseas Asia Pte Ltd
Netatech Engineering Ptd Ltd.
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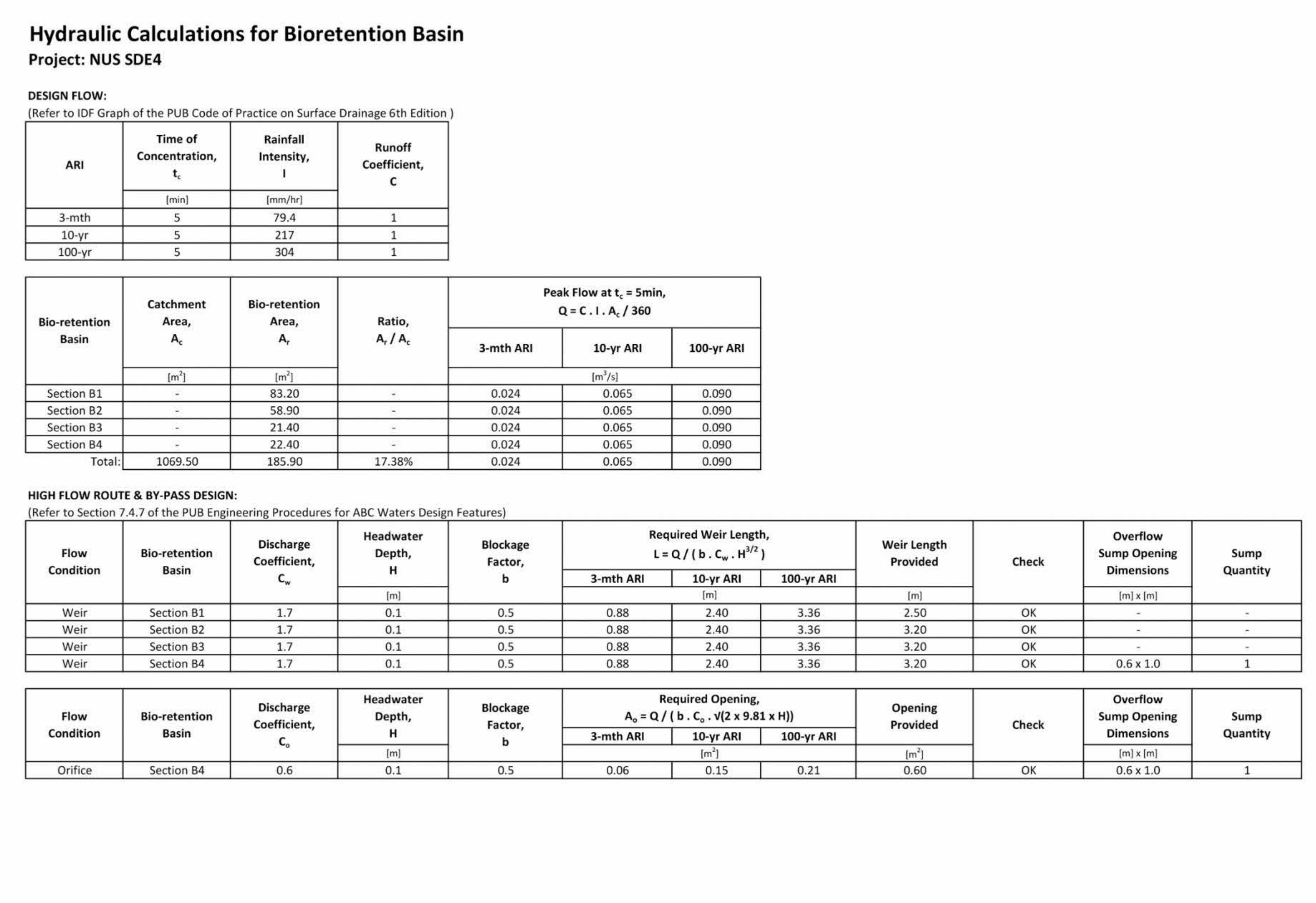


Hydraulic Calculations for Bioretention Basin

Project: NUS SDE4

DESIGN FLOW:
(Refer to IDF Graph of the PUB Code of Practice on Surface Drainage 6th Edition)

ARI	Time of Concentration, t_c	Rainfall Intensity, I	Runoff Coefficient, C
	[min]	[mm/hr]	
3-mth	5	79.4	1
10-yr	5	217	1
100-yr	5	304	1

Bio-retention Basin	Catchment Area, A_c	Bio-retention Area, A_r	Ratio, A_r / A_c	Peak Flow at t_c = 5min, Q = C . I . A_c / 360		
				3-mth ARI	10-yr ARI	100-yr ARI
	[m^2]	[m^2]		[m^3/s]		
Section B1	-	83.20	-	0.024	0.065	0.090
Section B2	-	58.90	-	0.024	0.065	0.090
Section B3	-	21.40	-	0.024	0.065	0.090
Section B4	-	22.40	-	0.024	0.065	0.090
Total:	1069.50	185.90	17.38%	0.024	0.065	0.090

HIGH FLOW ROUTE & BY-PASS DESIGN:
(Refer to Section 7.4.7 of the PUB Engineering Procedures for ABC Waters Design Features)

Flow Condition	Bio-retention Basin	Discharge Coefficient, C_w	Headwater Depth, H	Blockage Factor, b	Required Weir Length, L = Q / (b . C_w . $H^{3/2}$)			Weir Length Provided	Check	Overflow Sump Opening Dimensions	Sump Quantity
					3-mth ARI	10-yr ARI	100-yr ARI				
			[m]		[m]			[m]		[m] x [m]	
Weir	Section B1	1.7	0.1	0.5	0.88	2.40	3.36	2.50	OK	-	-
Weir	Section B2	1.7	0.1	0.5	0.88	2.40	3.36	3.20	OK	-	-
Weir	Section B3	1.7	0.1	0.5	0.88	2.40	3.36	3.20	OK	-	-
Weir	Section B4	1.7	0.1	0.5	0.88	2.40	3.36	3.20	OK	0.6 x 1.0	1

Flow Condition	Bio-retention Basin	Discharge Coefficient, C_o	Headwater Depth, H	Blockage Factor, b	Required Opening, A_o = Q / (b . C_o . √(2 x 9.81 x H))			Opening Provided	Check	Overflow Sump Opening Dimensions	Sump Quantity
					3-mth ARI	10-yr ARI	100-yr ARI				
			[m]		[m^2]			[m^2]		[m] x [m]	
Orifice	Section B4	0.6	0.1	0.5	0.06	0.15	0.21	0.60	OK	0.6 x 1.0	1

Hydraulic Calculations for Bioretention Basin

Project: NUS SDE4

VELOCITY CHECK:

(Refer to Section 5.7.6 of the PUB Engineering Procedures for ABC Waters Design Features)

Bio-retention Basin	Basin Width, W_{ch}	Extended Detention Depth, d	Channel Flow Area, $A_x = W_{ch} \cdot d$	Flow Velocity, $V = Q / A_x$		Scouring Check		Flow Depth, $d_{100\text{-}yr}$	$X = V_{100\text{-}yr} \cdot d_{100\text{-}yr}$	Velocity & Depth Check
				$V_{10\text{-}yr}$	$V_{100\text{-}yr}$	$V_{10\text{-}yr}$	$V_{100\text{-}yr}$			
	[m]	[m]	[m^2]	[m/s]				[m]	[m^2/s]	
Section B1	2.5	0.20	0.50	0.13	0.18	< 0.5 m/s, OK	< 1m/s, OK	0.3	0.054	X < 0.4, OK
Section B2	3.2	0.20	0.64	0.10	0.14	< 0.5 m/s, OK	< 1m/s, OK	0.3	0.042	X < 0.4, OK
Section B3	3.2	0.20	0.64	0.10	0.14	< 0.5 m/s, OK	< 1m/s, OK	0.3	0.042	X < 0.4, OK
Section B4	3.2	0.20	0.64	0.10	0.14	< 0.5 m/s, OK	< 1m/s, OK	0.3	0.042	X < 0.4, OK

OVERFLOW SUMP DISCHARGE PIPE FLOW CAPACITY:

Bio-retention Basin	Peak Discharge at 10yr ARI	Pipe Diameter, D_{op}	Pipe X-sectional Area, A_{op}	Pipe Slope, S_f	k	v	Flow Capacity of Single Pipe, $Q_{op} = A_{op} \cdot (-2(2g \cdot D_{op} \cdot S_f)^{0.5} \cdot \log(k/3.7D_{op} + (2.51v) / (D_{op} \cdot (2g \cdot D_{op} \cdot S_f)^{0.5}))$
	[m3/s]	[m]	[m^2]	[m/m]	[m]		[m^3/s]
Section B4	0.065	0.30	0.071	0.01	0.007	0.000001007	0.075

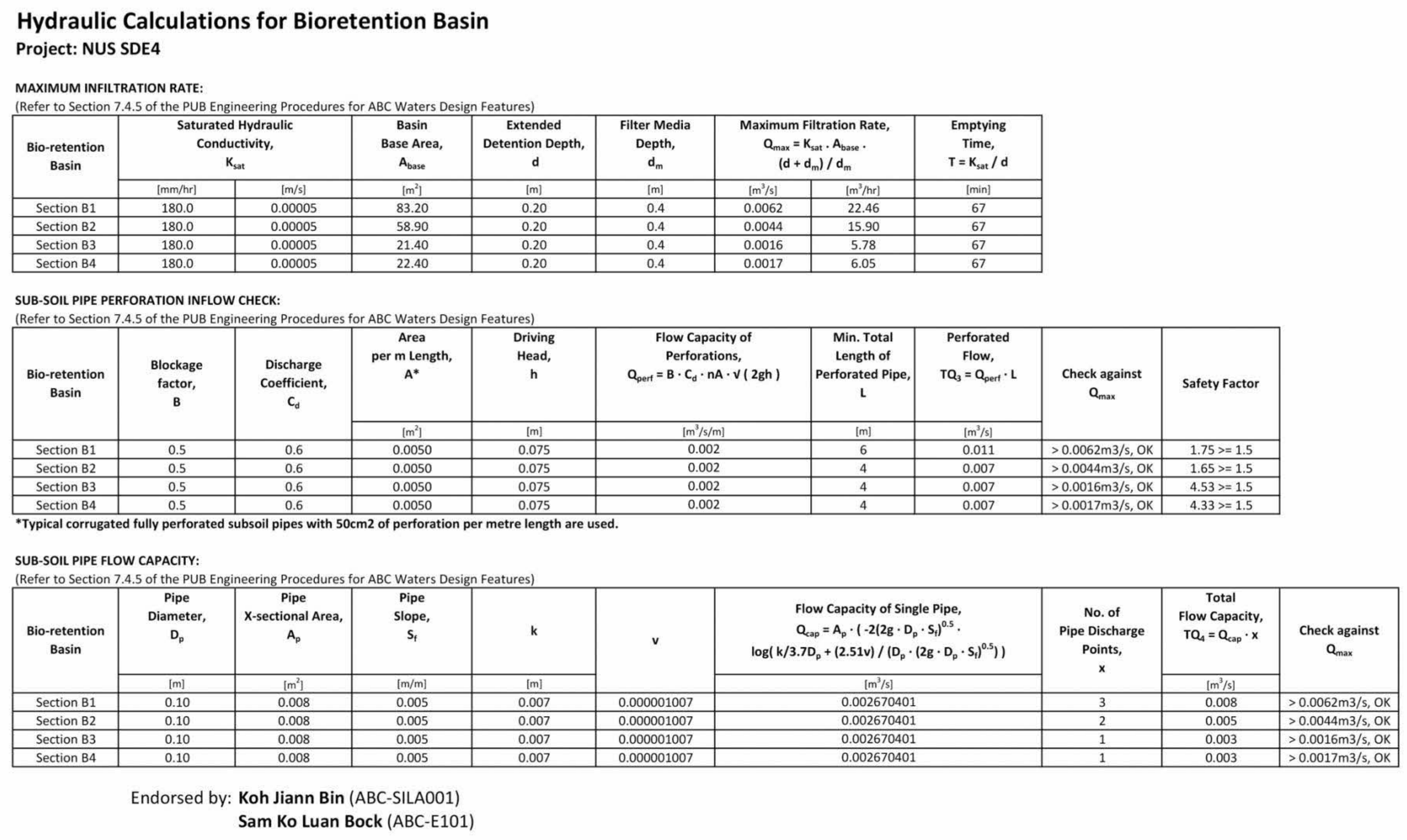
Bio-retention Basin	Pipe Quantity, X_{op}	Total Capacity, $TQ_2 = Q_{op} \cdot X_{op}$	Check against $Q_{peaktotal}$	Safety Factor
		[m^3/s]		
Section B4	2	0.151	> 0.065m3/s, OK	2.33 >= 1.5

SEDIMENT FOREBAY:

(Refer to Section 7.4.3.2 of the PUB Engineering Procedures for ABC Waters Design Features)

Bio-retention Basin	Catchment Area, A_c	Sediment Loading Rate, L_o	Desired Clean-out Frequency, F_c	Sediment Volume, $V_{sd1} = A_c \cdot L_o \cdot F_c$	Capture Efficiency, R	Settling Velocity, v_s	3mth ARI Design Flow, Q	Turbulence Parameter, n
	[m^2]	[m^3/ha/yr]	[yr]	[m^3]		[m/s]	[m^3/s]	
Section B1	1069.5	3	1	0.32	0.8	0.1	0.024	0.5

Bio-retention Basin	Min. Forebay Area Required, $A_s = n \cdot Q \cdot ((1-R)^{-1/n} - 1) / v_s)$	Forebay Depth Required, d_{fb}	Forebay Area Provided, A_{fb}	Forebay Depth Provided, D_{fb}	Assumed Porosity, P	Forebay Vol. Provided, $V_{fb} = P \cdot A_{fb} \cdot D_{fb}$	Check against V_{sd1}
	[m^2]	[m]	[m^2]	[m]		[m^3]	
Section B1	2.83	0.11	6	0.15	0.4	0.36	> 0.32m3, OK



Hydraulic Calculations for Bioretention Basin

Project: NUS SDE4

MAXIMUM INFILTRATION RATE:
(Refer to Section 7.4.5 of the PUB Engineering Procedures for ABC Waters Design Features)

Bio-retention Basin	Saturated Hydraulic Conductivity, K_{sat}		Basin Base Area, A_{base}	Extended Detention Depth, d	Filter Media Depth, d_m	Maximum Filtration Rate, $Q_{max} = K_{sat} \cdot A_{base} \cdot (d + d_m) / d_m$		Emptying Time, $T = K_{sat} / d$
	[mm/hr]	[m/s]	[m^2]	[m]	[m]	[m^3/s]	[m^3/hr]	[min]
Section B1	180.0	0.00005	83.20	0.20	0.4	0.0062	22.46	67
Section B2	180.0	0.00005	58.90	0.20	0.4	0.0044	15.90	67
Section B3	180.0	0.00005	21.40	0.20	0.4	0.0016	5.78	67
Section B4	180.0	0.00005	22.40	0.20	0.4	0.0017	6.05	67

SUB-SOIL PIPE PERFORATION INFLOW CHECK:
(Refer to Section 7.4.5 of the PUB Engineering Procedures for ABC Waters Design Features)

Bio-retention Basin	Blockage factor, B	Discharge Coefficient, C_d	Area per m Length, A*	Driving Head, h	Flow Capacity of Perforations, $Q_{perf} = B \cdot C_d \cdot nA \cdot \sqrt{(2gh)}$	Min. Total Length of Perforated Pipe, L	Perforated Flow, $TQ_3 = Q_{perf} \cdot L$	Check against Q_{max}	Safety Factor
			[m^2]	[m]	[m^3/s/m]	[m]	[m^3/s]		
Section B1	0.5	0.6	0.0050	0.075	0.002	6	0.011	> 0.0062m3/s, OK	1.75 >= 1.5
Section B2	0.5	0.6	0.0050	0.075	0.002	4	0.007	> 0.0044m3/s, OK	1.65 >= 1.5
Section B3	0.5	0.6	0.0050	0.075	0.002	4	0.007	> 0.0016m3/s, OK	4.53 >= 1.5
Section B4	0.5	0.6	0.0050	0.075	0.002	4	0.007	> 0.0017m3/s, OK	4.33 >= 1.5

***Typical corrugated fully perforated subsoil pipes with 50cm2 of perforation per metre length are used.**

SUB-SOIL PIPE FLOW CAPACITY:
(Refer to Section 7.4.5 of the PUB Engineering Procedures for ABC Waters Design Features)

Bio-retention Basin	Pipe Diameter, D_p	Pipe X-sectional Area, A_p	Pipe Slope, S_f	k	v	Flow Capacity of Single Pipe, $Q_{cap} = A_p \cdot (-2(2g \cdot D_p \cdot S_f)^{0.5} \cdot \log(k/3.7D_p + (2.51v) / (D_p \cdot (2g \cdot D_p \cdot S_f)^{0.5}))$	No. of Pipe Discharge Points, x	Total Flow Capacity, $TQ_4 = Q_{cap} \cdot x$	Check against Q_{max}
	[m]	[m^2]	[m/m]	[m]		[m^3/s]		[m^3/s]	
Section B1	0.10	0.008	0.005	0.007	0.000001007	0.002670401	3	0.008	> 0.0062m3/s, OK
Section B2	0.10	0.008	0.005	0.007	0.000001007	0.002670401	2	0.005	> 0.0044m3/s, OK
Section B3	0.10	0.008	0.005	0.007	0.000001007	0.002670401	1	0.003	> 0.0016m3/s, OK
Section B4	0.10	0.008	0.005	0.007	0.000001007	0.002670401	1	0.003	> 0.0017m3/s, OK

Endorsed by: **Koh Jiann Bin** (ABC-SILA001)
Sam Ko Luan Bock (ABC-E101)

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