CHAPTER 9 BIORETENTION SYSTEMS

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9.1 INTRODUCTION

This Chapter provides bioretention systems in term of functions, components and design methods to best serve stormwater quality treatment objectives while promoting a pleasant and green living environment in the urban setting. Bioretention systems are a form of stormwater best management practices (BMPs) that use biological uptake and porous media filtration processes, combined, to treat stormwater runoff. The systems integrate vegetation, such as trees, shrubs and grasses, and layered media using soil, sand and mulches. These structural controls capture, temporarily detain and treat runoff from small rainstorms before release it back to the receiving waters. Runoff shall be pretreated and diverted into the systems that can be constructed from a shallow excavated site along a proposed drainage channel or swale.

9.1.1 System Components

Bioretention systems can be designed as permeable or impermeable systems (DOW, 2007). The permeable system (Figure 9.1) drains the water through the filtration media and sand bed layer before spreading to the surrounding native soil and finally recharging groundwater. The impermeable system (Figure 9.2) similarly drains the water from the filtration media through transition layers, however, intercepted by a subsoil pipe/underdrain located in the drainage layer. In an area where native soils have relatively low infiltration capacity or higher rainfall intensity is frequently experienced, such underdrain is required to carry excess water away from the site so that its storage capacity is available for the next storm. The components of a bioretention system consist of pre-treatment, inlet, an excavated basin area with plant and underlying mulch layer, soil bed, sand bed and drainage and outlet structure.

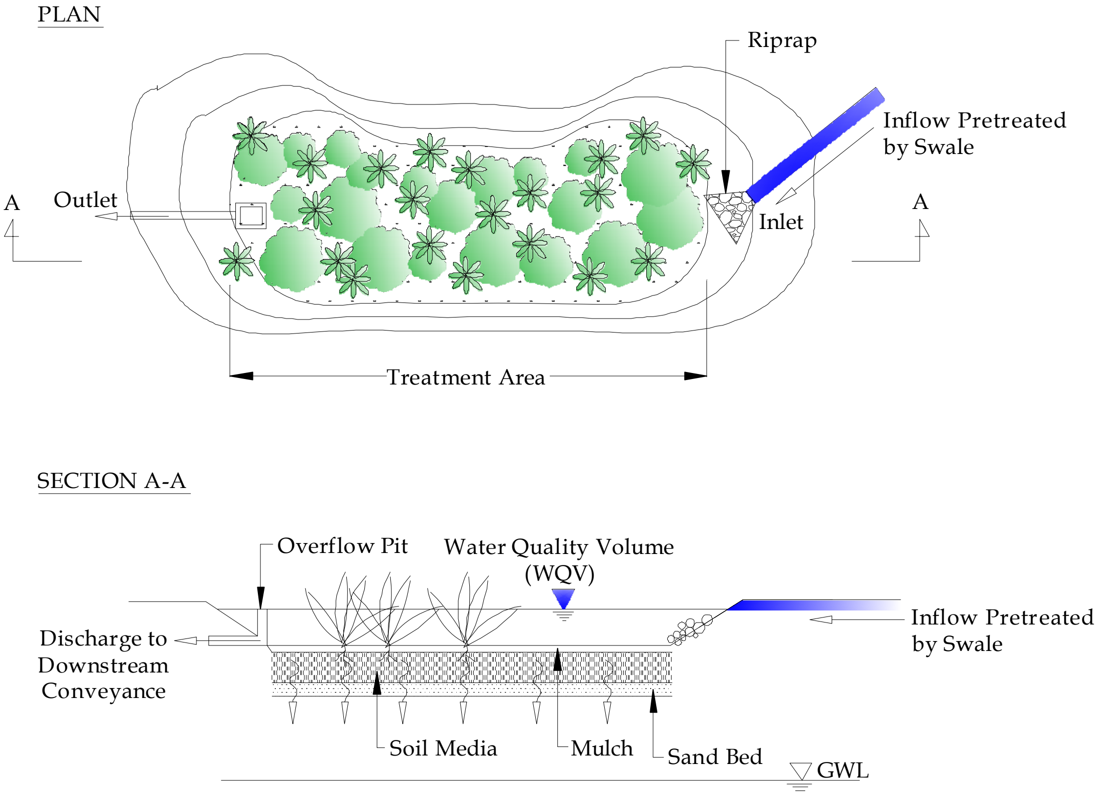


Figure 9.1: Permeable Bioretention Basin

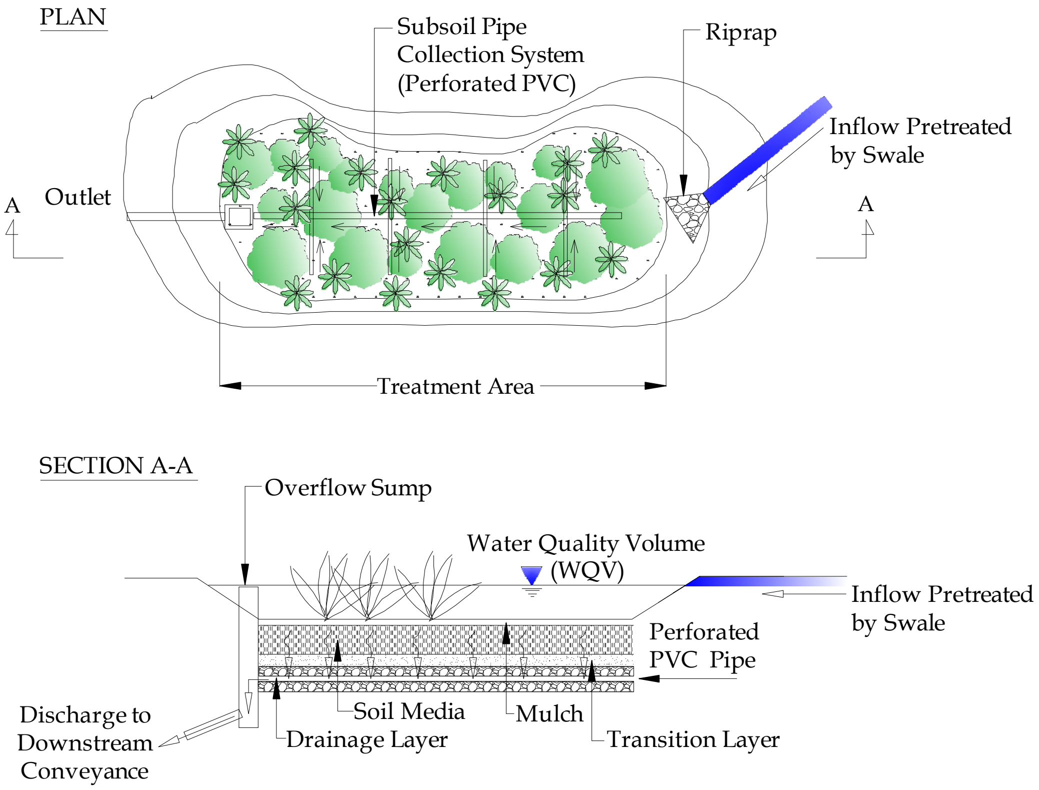


Figure 9.2: Impermeable Bioretention Basin

The selection of plant species can provide for a wide variety of landscape designs. The plants, soils, and organic matter such as compost and a mulch layer all play an important role in treating runoff by naturally breaking down pollutants. The underlying gravel beds (drainage layer) serve to temporarily store and infiltrate treated stormwater after percolating through the organic soil layer (filter media) or finally discharge treated water through under drains. They provide water quality treatment by removing fine sediment, trace metals, nutrients, bacteria and organics through a variety of pollutant removal mechanisms, including:

- Filtration, extended detention treatment;
- Adsorption to soil particles, denitrification; and
- Biological uptake by plants.

The systems provide a high degree of treatment as the increase in the organic content of soils used in bioretention cell promotes removal of pollutants in the water and also absorption of runoff. The organic soils act as a sponge to retain water, providing more storage capacity in the cell. The removal efficiency of a bioretention system for selected stormwater pollutants is given in Table 9.1 (ARC, 2001 & DOW, 2007).

Table 9.1: Removal Efficiency of Bioretention System

Pollutant	Removal Efficiency (%)
Total Suspended Solids (TSS)	80 (High)
Total Phosphorous (TP)	60 (Medium)
Total Nitrogen (TN)	50 (Medium)
Metals	80 (High)

The treated stormwater, filtered through the vegetation and soil media, is collected either in an underdrain system or allowed to infiltrate into the ground. Stormwater runoff higher than the design storm ARIs by passes the bioretention system.

9.1.2 Application

Bioretention systems are generally applied to small sites and ideally suited to many ultra urban areas, such as parking lots. They can fit into existing built up areas and provide visual enhancements to the urban landscape. The systems are typically placed close to runoff sources. They include use as off-line BMPs facilities located adjacent to parking lots, along highway and road drainage swales, around buildings and within landscaped islands in impervious or high-density environments. General form of bioretention systems can be very flexible, including as linear systems, basins and planter boxes (Figure 9.3).

Other application is at stormwater hotspot areas where landuse activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater. A typical example is a gas station or factory lot. Bioretention system can be used to treat stormwater hotspots as long as an impermeable liner is used at the bottom of the filter bed. The pollutant loading need to be considered for successful use in hotspot areas, as it is likely that the plants will not survive in some of the hotspots if the pollutant loads are high.

a) Residential - Basin

b) Road Side - Planter Box

c) Parking Lot - Linear

d) Factory (Hot Spot) - Basin

Figure 9.3: Typical Bioretention Application Sites

Bioretention can be used as a stormwater retrofit, by modifying existing landscaped areas, or if a parking lot is being resurfaced. In highly urbanised areas, they are one of the few retrofit options that can be employed. Bioretention systems have some limitations that they are used to treat runoff from small drainage areas. Although the systems itself do not consume a large amount of space, incorporating multiple bioretention systems into a high density or congested urban area may reduce the available space uses. Additionally, the construction and cumulative maintenance costs of bioretention systems are relatively high compared with other stormwater treatment BMPs.

9.2 DESIGN CONSIDERATIONS

9.2.1 General

Considerations for selecting the BMPs are the drainage area, landuse practices, slope, soil and subsurface conditions including the depth of the seasonally high groundwater table and the nearest impermeable layer below it.

Designers need to detail conditions and suitability at the site level and must incorporate design features to improve the longevity and performance of the device, while minimizing the maintenance cost.

9.2.1.1 Siting

Generally, the siting of a bioretention system should consider the followings:

- Closeness of placement of the facilities to the source of runoff generation, such as areas upstream from outfalls that receive sheet flow from graded areas.
- Site with land surface that permits the dispersion of flows relatively uniform.
- Space availability for easy installation considering setback requirements on residential subdivision lots and commercial lots.
- The systems should not be located near building areas (unless the design incorporates adequate waterproofing measures and are approved by a geotechnical engineer), well heads, and septic systems. Minimum setback distances from structures and property boundaries are shown in Table 9.2 for different soil type.
- Needs of stormwater management retrofit and redevelopment opportunities especially in areas where total stormwater management control is not feasible.
- The sites to be excavated or cut is suitable for the bioretention system construction.
- Existing wooded areas or other significant natural features should be avoided if possible.

Table 9.2: Minimum Setback Distances (Institute of Engineers Australia, 2006)

Soil Type	Saturated Hydraulic Conductivity (mm/hr)	Minimum Setback (m)
Sands	>180	3.0
Sandy Loam	36 to 180	3.0
Sandy Clay	3.6 to 36	4.0
Medium to Heavy Clay	0.0 to 3.6	5.0

9.2.1.2 Drainage Area

An individual bioretention system should usually be used to capture and treat runoff from small catchments, limited to less than 1.0 ha of impervious area. When used to treat larger areas, the systems tend to clog in shorter time. In addition, it is difficult to convey flow from a large area to a bioretention system. Generally, commercial or residential drainage areas, exceeding 0.5-1.0 ha in size, will discharge flows greater than the 5-year ARI storm event. When flows exceed this level, the designer should evaluate the potential for erosion to stabilized areas. Typically, flows greater than the 5-year ARI storm event will require channel/pipe enclosure across developed lots. However, by employing drainage runoff dispersion techniques and retaining existing contours, concentrated quantities of flow can be reduced below these thresholds, eliminating or reducing the need for a channel/pipe conveyance system. This may be accomplished by runoff dispersing larger drainage areas based on land grading design to multiple bioretention systems. This runoff dispersion of flow technique can reduce the cost of engineering design and site construction. In addition to reducing the need for drainage channel/pipe conveyance systems, runoff dispersion techniques can also eliminate the need for surface drainage easements or reserves.

9.2.1.3 Slope

Bioretention systems are best located on relatively small slopes (usually less than 5%). Sufficient grade is needed at the site to ensure that the runoff that enters a bioretention system can be connected to the storm drain system. It is important to note, however, that bioretention systems are most often located adjacent to parking lots or residential landscaped areas, which generally have gentle slopes.

9.2.1.4 In-Situ Soils

In an area where in situ soil is sandy and well drained it should be used for locating the permeable bioretention systems. For clayey and poorly drained soils impermeable system shall be used. Saturated hydraulic conductivity for typical soil types is shown in Table 9.3.

Table 9.3: Typical Soil Types and Associated Hydraulic Conductivity (Institute of Engineers Australia, 2006)

Typical Soil Types	Saturated Hydraulic Conductivity	
	(m/s)	(mm/hr)
Coarse Sand	$>1\times10^{-4}$	>360
Sand	$5\times10^{-5} - 1\times10^{-4}$	180 - 360
Sandy Loam	$1\times10^{-5} - 5\times10^{-5}$	36 - 180
Sandy Clay	$1\times10^{-6} - 1\times10^{-5}$	3.6 - 36
Medium Clay	$1\times10^{-7} - 1\times10^{-6}$	0.36 - 3.6
Heavy Clay	$< 1\times10^{-7}$	< 0.36

The permeable bioretention systems are recommended to be sited on in situ soils with saturated hydraulic conductivities of higher than 13mm/hr. The used of permeable bioretention system with lower saturated hydraulic conductivity of less than 13mm/hr results into prohibitively large bioretention area. In addition, soils with lower hydraulic conductivities will be more susceptible to clogging and will therefore require enhanced pretreatment.

9.2.1.5 Groundwater

Bioretention systems should be located above the groundwater table to ensure that groundwater never intersects with the bottom of the bioretention system, which prevents possible groundwater contamination and system failure. The minimum vertical distance between seasonal high water table and bottom of bioretention system should be 0.6m. Sites with shallow groundwater are not recommended as infiltration will not work effectively. Similarly, the organic absorption infiltration layer of a bioretention system is beneficial in pollutant removal where bedrock or impermeable layer is shallow.

9.2.2 System Design

9.2.2.1 Pre-treatment Area

Grass buffer strips or vegetated swales are commonly used as pretreatment devices. They are required where a significant amount of debris or suspended material is anticipated, such as from parking lots and commercial areas. Runoff enters the bioretention area as sheet flow after passing through grass buffer strips with reduced velocity and less particulate.

9.2.2.2 Inlet Controls

The flows may enter the system either through subsurface pipe, open channel/swale or as surface sheet flow contributed from an upstream catchment area. Scour protection such as light riprap with 6 to 12mm D50 is recommended to be used at the inlet into the system, to reduce localised flow velocities and to avoid erosion. The flow around the inlet should be non-erosive flow with velocity below 0.5m/s. Level spreader may be located to evenly distribute the incoming runoff onto the basin surface/cells for effective percolation.

9.2.2.3 Basin/Ponding Area

The ponding area provides surface storage of stormwater runoff before it filters through the soil bed. The ponding area also allows for evaporation and settling sediment. The ponding is typically limited to a depth of 150-300mm. A maximum 150mm additional freeboard depth should be provided for online systems to allow surcharge above the overflow outlet during larger storm events (> 3 month ARI). The ponding area is required to drain within 24 hours (MPCA, 2008 and CFWP & MDE, 2000). This is within the general practice of 72 hours maximum drain time of ponding to minimise mosquito breeding and other disease vectors. The 24 hours drain time is chosen based on the following consideration:

- The need to optimise the cost of the bioretention system as a shorter drain time of ponding area will lead to a bigger system.
- The pollutant removal based on 40mm of design storm is considered adequate for water quality control objective.

9.2.2.4 Mulch Layer

The organic mulch layer has several functions. It protects the soil bed from erosion, retains moisture in the plant root zone, provides a medium for biological growth and decomposition of organic matter, and provides some filtration of pollutants mainly larger sediment particles. The mulch layer should consist of 50-100mm depth of commercially-available fine shredded hardwood mulch or shredded hardwood chips.

9.2.2.5 Planting Soil Bed

The planting soil bed provides water and nutrients to support plant life in the bioretention system. Stormwater filters through the planting soil bed where pollutants are removed. The total depth of the planting soil bed should be between 450 to 1000mm.

Planting soils should be sandy loam, loamy sand, or loam texture with clay content ranging from 10 to 25%. The natural soil profile of silt loam with design hydraulic conductivity of 13mm/hr can be used for a planting bed. A much higher design hydraulic conductivity can be obtained with engineered soil mixture of sandy loam. The in-situ base soil is either mixed with loose non-angular sand (to increase saturated hydraulic conductivity) or conversely with loose non-dispersive soft clay (to reduce saturated hydraulic conductivity), to achieve the desired design saturated hydraulic conductivity of required engineered soil media. The engineered soil media should provide an organic matter contents that facilitates good plant root systems; and permeable substrata of around 25% porosity. Designer should strive for composition of organic matter content 15% and clay content of the mixture ≤25%. The recommended composition of engineered soil media for planting bed is given in Table 9.4 (CFWP & MDE, 2000). The pH of the planting soil bed should be 5.5 to 6.5.

Table 9.4: Engineered Soil Media Composition

Soil Mixture	Contents by Volume (%)
Top Soil (Sandy/Silt loam)	20-25
Medium Sand	50-60
Organic Leaf Compost	12-20

The maximum saturated hydraulic conductivity for engineered soil media should not be higher than 200 mm/hr. This is to ensure that the engineered soil media can retain sufficient soil moisture for sustaining vegetation growth. An appropriate saturated hydraulic conductivity is required to optimise the treatment performance of the bioretention system given site constraints and available engineered soil media surface area. The design infiltration rate (f_d) must be one-half the infiltration rate (f_c) found from soil textural analysis ($f_d = 0.5f_c$).

9.2.2.6 Sand Bed in Permeable System

In permeable systems where the underlying native soil has sufficient infiltration capacity to drain the water from the planting soil bed, the sand bed underlies the planting soil bed and allows water to drain into the underlying soil. The sand bed also provides additional filtration and allows for aeration of the planting soil bed. The sand bed should be 200-300mm thick. The sand should be clean and have less than 15% silt or clay content.

9.2.2.7 Drainage Layer in a Impermeable System

In impermeable systems, a drainage layer is used to convey treated flows into the subsoil/underdrain pipes. This layer is generally constructed using coarse sand or fine gravel (2mm to 5mm particle size). The layer should surround the subsoil pipe and is typically 200-400mm thick.

9.2.2.8 Transition Layer in a Impermeable System

A granular transition layer that is typically 100-150mm thick or a suitable geotextile fabric should be included between the planting soil bed and the drainage layer to prevent the filtration media from washing into the drainage layer and the subsoil pipes. This is desirable if the drainage layer is constructed using fine gravel. The material size differential should be approximately 10 between layers to avoid fine material being washed through the voids of a lower layer. The addition of a transition layer increases the overall depth of the bioretention area. This may be an important consideration for some sites and hence pipes with smaller perforations may be preferable. The material for transition layers must be sand/coarse sand material with typical specification given in Table 9.5.

Table 9.5: Typical Particle Size Distribution for Transition Layer
(Moreton Bay Waterways & Catchments Partnership, 2006)

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

9.2.2.9 Plants

Plants are an important component of a bioretention system. They remove pollutants and nutrient through uptake. The plant species selected are designed to replicate a forested ecosystem and to survive stresses such as frequent periods of inundation during runoff events and drying during inter-event periods. The use of native plant species or plants harmonised to the area is recommended (Annex 1).

In addition to providing for treatment of stormwater, bioretention facilities, when properly maintained, can be aesthetically pleasing. More often local regulations frequently require site plans to incorporate a certain percentage of reserved open landscaped area, for incorporation of bioretention facilities. The layout of bioretention facilities can be very flexible, and the selection of plant species can provide for a wide variety of landscape designs. However, it is important that a landscape architect with adequate experience in designing bioretention areas be consulted prior to construction to ensure that the plants selected can tolerate the maturing conditions present in bioretention area.

9.2.2.10 Outlet Controls

The design flow of 3 month ARI from the catchment area will be retained in the ponding area of bioretention system. The ponding water will then infiltrate through the filtration media and for permeable system deep infiltrate will take place within the surrounding soil before it reached the ground water. In the case of impermeable system, the water will be discharged through the primary outlet consists of perforated pipe provided in the drainage layer and will be conveyed to the road reserve and/or by connection to an underground drainage system.

A secondary outlet should be incorporated into the design of a bioretention system to safely convey excess stormwater higher than 3 month ARI. This includes the flow diversion structure or overflow weir to bypass major storm discharge where applicable.

9.2.2.11 Design for Maintenance

The system design should incorporate features to reduce the long term maintenance. This include such as easy accessibility for maintenance. Like any other BMPs, bioretention systems will need regular maintenance and eventual rehabilitation as it degrades over a number of years (Annex 2).

9.2.2.12 Landscaping

Landscaping is critical to the function and appearance of bioretention system. It is preferred that native vegetation is used for landscaping, where possible. Plants should be selected that can withstand the hydrologic regime they will experience (i.e., plants must tolerate both wet and dry conditions). At the edges, which will remain primarily dry, upland species will be the most resilient. In general, it is best to select a combination of trees, shrubs, and herbaceous materials (Annex 1).

9.3 SIZING PROCEDURE

The sizing of a bioretention facility requires a consideration of various factors including:

- Purposes and function of the bioretention system;
- Site requirements for water quality controls;
- Design storm that is required to meet the stormwater management criteria;
- Capabilities of the bioretention system to be used for water quality controls; and
- Use of bioretention system independently of other BMP's, or to be installed along with other devices within a treatment train.

9.3.1 Filter Bed Area

The filtering treatment criteria should be as follows:

- The entire treatment system (including pretreatment) should temporarily hold the Water Quality Volume (WQ_v) derived as runoff from 40mm (i.e., 3 month ARI) design rainfall, prior to infiltration.
- The bioretention system must conform to the accepted specification shown in Figure 9.4 and Figure 9.5. Table 9.6 presents the physical specification and geometry of a bioretention system while Table 9.7 gives the coefficient of permeability (k) for various types of filter media.

Table 9.6: Physical Specification and Geometry

Parameter	Specification
Minimum Size	3m wide by 6m long
Length and Width ratio (optional)	2:1
Maximum Emptying Time	≤24 hours
Permeability of Planting Bed	≥13mm/hr
Ponding Depth	150mm – 300mm
Depth to Groundwater Table (below drainage layer)	0.60m (min)

Table 9.7: Coefficient of Permeability (*k*) for Various Types of Filter Media

Media Type	*k* (m/day)
Sand	1.00
Peat	0.60
Leaf Compost	2.65
Bioretention Soil	≥0.312

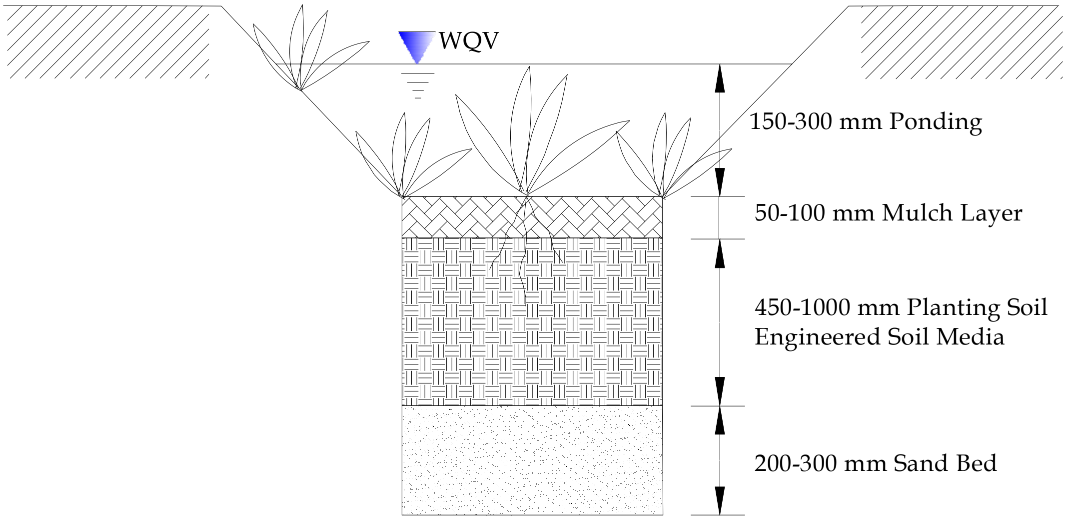


Figure 9.4: Specification for Permeable Bioretention System

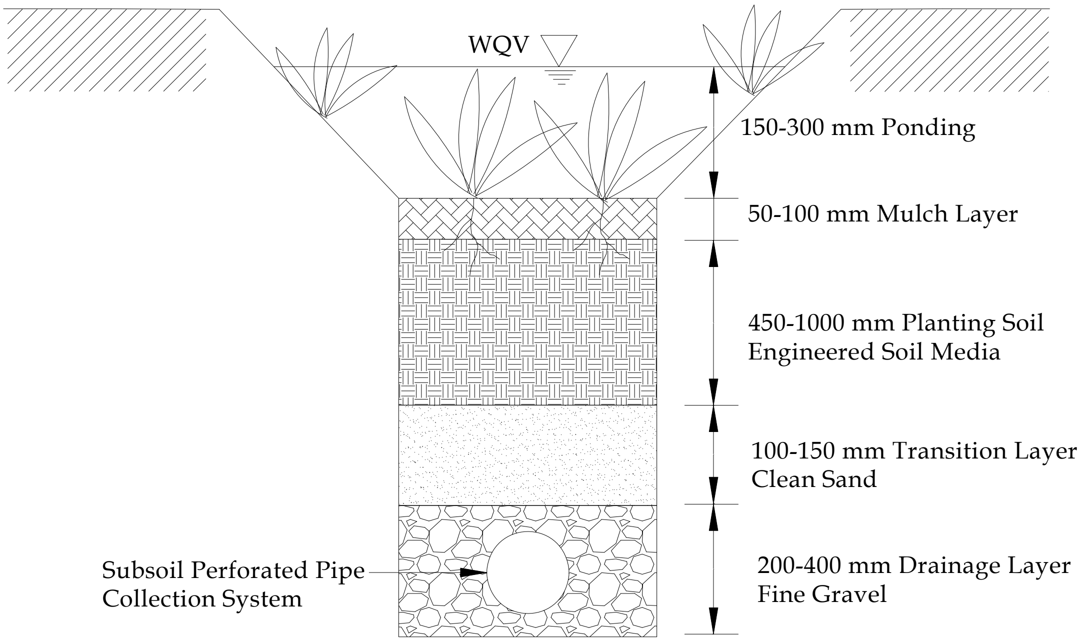


Figure 9.5: Specification for Impermeable Bioretention System

The required filter bed area (A_f) is computed based on the Darcy's Law. For those practices that are designed with an under drain (impermeable system), the following equation is used:

$$A_f = \frac{(WQ_v)(d_f)}{[(k)(h_f+d_f)(t_f)]} \tag{9.1}$$

where,

A_f = Surface area of filter bed (m^2);
WQ_v = Water quality volume (m^3);
d_f = Filter bed depth (m) (Figure 9.6);
k = Coefficient of permeability of filter media (m/day);
h_f = Average height of water above filter bed (m); and
t_f = Design filter bed drain time (day) – (1 day maximum).

For those systems that are designed without an under drain (permeable system), the area is estimated by:

$$A_f = \frac{(WQ_v)(d_f)}{[(i)(h_f+d_f)(t_f)]} \tag{9.2}$$

where,

A_f = Surface area of filter bed (m^2);
WQ_v = Water quality volume (m^3);
d_f = Filter bed depth (m);
i = Infiltration rate of underlying soils (m/day);
h_f = Average height of water above filter bed (m); and
t_f = Design filter bed drain time (day) – (1 day maximum).

9.3.2 Maximum Infiltration Rate

In the case of impermeable bioretention system, the maximum infiltration rate through the filtration media must be considered to allow for the subsoil drain to be sized. The capacity of the subsoil drain, when installed, must exceed the maximum infiltration rate to ensure free draining conditions for the filter media (Figure 9.6). The maximum infiltration rate reaching the perforated pipe at the base of the soil media is estimated applying the equation:

$$Q_{max} = kL_bW_b\frac{h_f+d_f}{d_f} \tag{9.3}$$

where,

Q_{max} = Maximum infiltration rate (m^3/s);
k = Hydraulic conductivity of the filter bed (m/s);
W_b = Base width of the ponded cross section above the filter bed (m);
L_b = Base length of the bioretention zone (m);
h_f = Height of water above the filter bed (m); and
d_f = Depth of filter media (m).

The suitability of the above formula for design purposes will need to be assessed for each individual site, considering the influence of both the annual maximum groundwater level and infiltration capacity of surrounding natural soils on bioretention system infiltration, particularly for permeable bioretention systems.

9.3.3 Subsoil/Underdrain Pipes

Subsoil pipes are perforated pipes placed at the base of impermeable bioretention systems to collect treated water for conveyance downstream. These collection pipes are sized to allow free draining of the filtration layer and prevent 'choking' of the system. Typically, subsoil pipes should be limited to approximately 150mm in diameter so that the thickness of the drainage layer does not become excessive. Where the maximum infiltration rate is greater than the capacity of the pipe consideration should be given to using multiple pipes. To ensure the subsoil pipes are of adequate size:

- Perforations must be adequate to pass the maximum infiltration rate into the pipe;
- The pipe itself must have adequate hydraulic capacity to convey the required design flow; and
- The material in the drainage layer must not be washed into the perforated pipes.

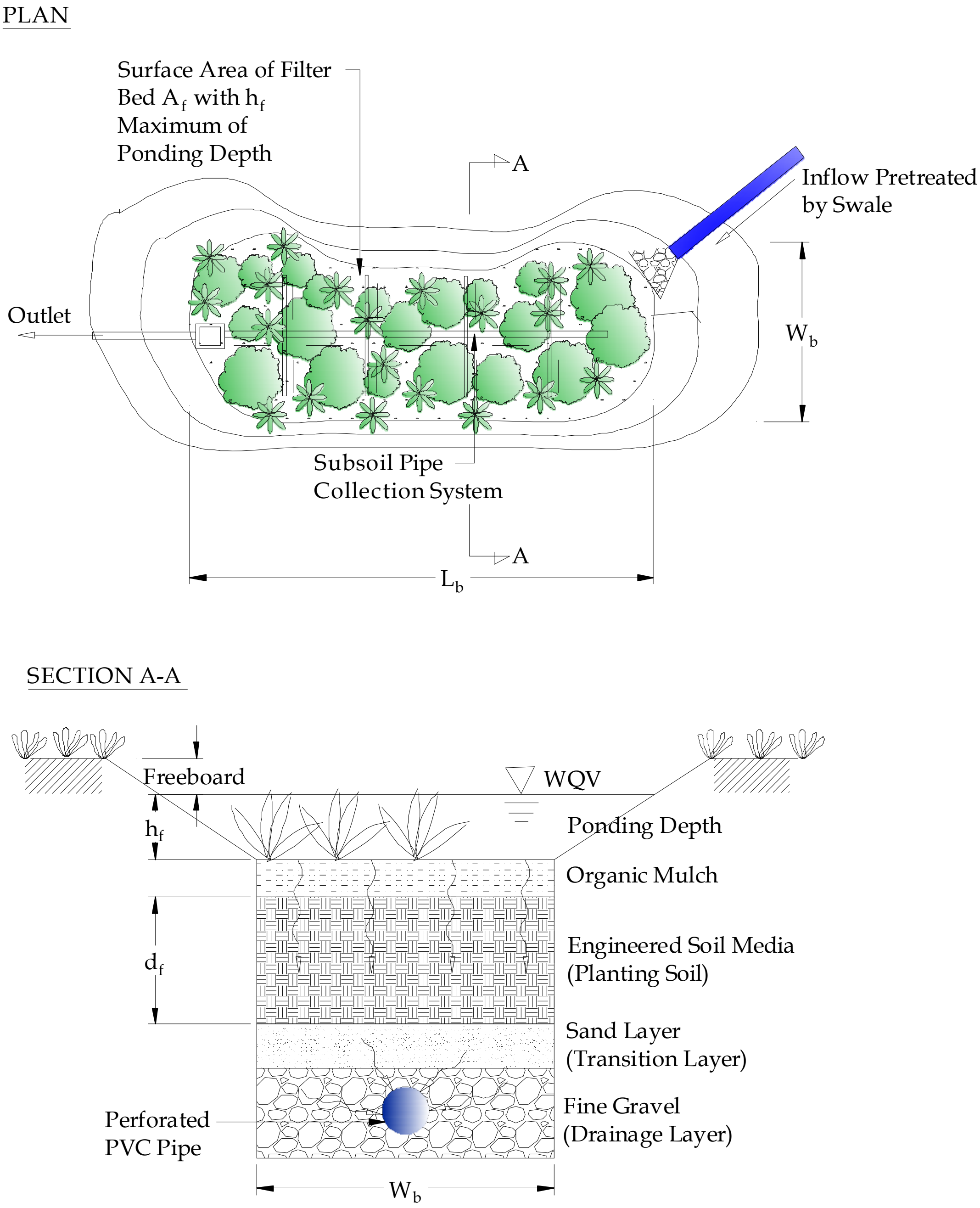


Figure 9.6 Hydraulic Variables for Subsoil Drainage

These requirements can be assessed using the Equation 9.4 and 9.5, or alternatively using manufacturers' design charts. To estimate the capacity of flows through the perforations, orifice flow conditions are assumed and a sharp edged orifice equation can be used. The number and size of perforations need to be determined (typically from manufacturers' specifications) and used to estimate the total flow rate into the pipe. It is conservative but reasonable to use a blockage factor to account for partial blockage of the perforations by the drainage layer media. Flow per perforation is therefore estimated by:

$$Q_{perf} = \frac{C\,.A\sqrt{2gh}}{\Psi} \tag{9.4}$$

where,

Q_{perf} = Flow per perforation (m^3/s);
A = Total area of orifice (m^2);
h = Maximum head of water above the pipe (m) (filtration media depth plus ponding depth);
C = Orifice coefficient;
Ψ = Blockage factor (Ψ = 2 is recommended); and
g = Gravity constant (9.81 m^2/s).

For circular perforated pipes flowing full, using Manning Equation the flow in pipe (Q_{pipe}) is given by:

$$Q_{pipe} = \left(\frac{0.312}{n}\right) D^{2.67} S_o^{0.5} \tag{9.5}$$

where,

n = Manning Coefficient;
D = Pipe diameter (m); and
S_o = Slope of hydraulic grade line (m/m).

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

9.3.4 Outlet Structure

The excess flow of the ponding area of bioretention system, which is greater than design flow, will be conveyed to downstream drainage system via overflow pit and subsequently by the road reserve and/or by connection to an underground drainage system. To size a grated overflow pit, two checks should be made for either drowned or free flowing conditions:

- The broad crested weir equation to determine the length of weir required (assuming free conditions); and
- The orifice equation to estimate the area of opening required (assuming drowned outlet conditions).

The larger of the two pit configurations should then be adopted for design purposes. The weir flow equation for free overfall conditions is:

$$Q_{oflow} = C\,.L.H^{3/2} \tag{9.6}$$

where,

Q_{oflow} = Overflow (weir) discharge (m^3/s);
C = 1.7;
H = Head above weir crest (m); and
L = Length of 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. It is considered likely that standard pit sizes will accommodate flows for most situations. The orifice flow equation for drowned outlet conditions is:

$$Q_{oflow} = C\,.A\sqrt{2gh} \qquad (9.7)$$

where,

Q_{oflow} = Overflow (orifice) discharge (m^3/s);
C = 0.6;
h = Available head above weir crest (m);
A = Orifice area (m^2); and
g = Gravity constant ($9.81m^2/s$).

9.3.5 Scour Velocity of Inflows

It is recommended where possible, the overflow pit or bypass channel should be located near the inflow zone to prevent high flows from passing over the surface of the filter media. If this is not possible, then velocities during the minor storms (2-10 year ARI) and major storms (50-100 year ARI) should be maintained sufficiently low (preferably below values of 0.5m/s and not more than 1.5m/s for major storm) to avoid scouring of the filter media and vegetation.

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

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

9.3.6 Inlet Structure

Erosion protection should be provided for concentrated inflows to a bioretention system. Flows will enter the system from either surface flow system or a piped drainage system. Rock beaching is a simple method for dissipating the energy of concentrated inflow. The use of impact type energy dissipation may be required to prevent scour of the filter media.

This can be achieved with rock protection and by placing several large rocks in the in the flow path to reduce velocities and spread flow as shown in Figure 9.7 (Moreton Bay Waterways & Catchment Partnership, 2006). The detailing of the inlet structure is based on the hydraulic diameter, *DH* which is given as follows:

$$DH = \frac{4A}{P} \qquad (9.8)$$

where,

A = Cross-section area; and
P = Wetted Perimeter.

For Trapezoidal channel the hydraulic diameter is

$$DH = \frac{4H(mH+BW)}{BW+2H\sqrt{1+m^2}} \qquad (9.9)$$

where,

1:m (V:H) = Side slope;
BW = Bottom width (m) ; and
H = Depth (m).

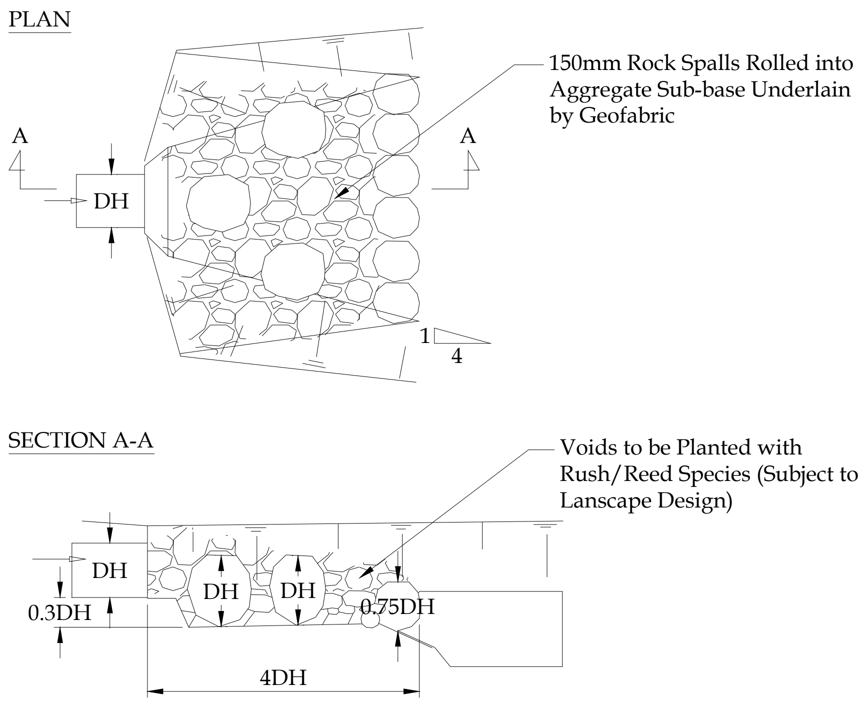


Figure 9.7: Typical Inlet Scour Protection Detail

9.4 DESIGN STEPS

Step 1: Site Evaluation

Make a preliminary judgment as to whether site conditions are appropriate for the use of a bioretention system, and identify the function of the practice in the overall BMPs treatment system. Consider these basic parameters in the site evaluation:

- Drainage area;
- Topography and slopes;
- Soil infiltration capacity (Chapter 8);
- Depth to ground water and bedrock;
- Location/minimum setbacks.

Determine how the bioretention system will fit into the overall stormwater treatment train system and decide whether bioretention is the only BMP to be employed, or if are there other BMPs addressing some of the treatment requirements. Decide on the site where the bioretention system is most likely to be located.

Step 2: Field Verification of Site Suitability

If the initial evaluation indicates that a bioretention system would be a good BMP choice for the site, it is recommended that soil borings or pits be carried out (in the same location as the proposed bioretention system) to verify soil types and infiltration capacity characteristics and to determine the depth to groundwater and bedrock. The number of soil borings should be selected as needed to determine local soil conditions. It is recommended that the minimum depth of the soil borings or pits be 1.5m below the bottom elevation of the proposed bioretention system.

It is recommended that soil profile descriptions be recorded and include the following information for each soil horizon or layer:

- Thickness;
- Feature colour; abundance; size and contrast;
- USDA soil textural class (Chapter 8);
- Soil structure, grade size and shape;
- Soil consistency; root abundance and size;
- Soil boundary; and
- Occurrence of saturated soil; impermeable layers/lenses; ground water; bedrock or disturbed soil.

Step 3: Estimating Design Flow

Calculate the design stormwater volume to be treated through bioretention system. If part of the overall design stormwater volume is to be treated by other BMPs, subtract that portion from the total design volume to determine the part of the design volume to be treated by the bioretention system. The design techniques adopted are meant to maximize the volume of stormwater being infiltrated. If the site layout and underlying soil conditions permit, a design water quality volume derived from 40mm of rainfall depth (i.e. 3 month ARI) may be adopted.

Step 4: Inlet Structure

The flows may enter the system either through subsurface pipe, open channel/swale or as surface sheet flow contributed from an upstream catchment area. Scour protection such as light riprap with 6 to 12mm D50 is recommended to be used at the inlet into the system, to reduce localised inflow velocities. The flow should be non-erosive to the basin with velocity below 0.5m/s.

Bioretention system which receives flows from larger catchment may require an impact type energy dissipator that can be achieved with rock protection and by placing several large rocks in the flow path to reduce the velocities and spread the flows.

Step 5: Select the Bioretention Type

The selection of design variant shall be based on the location of naturally occurring permeable soils, the depth to the water table, bedrock or other impermeable layers, and the contributing drainage area. The bottom of a bioretention system must have a minimum 0.6m height above the local water table. While the initial step in sizing a bioretention system is selecting the type of design variant for the site, the basic design procedures for each type of bioretention system are similar.

Information collected during the field verification of site suitability (Step 2) should be used to explore the potential for multiple bioretention systems application or in integration with other stormwater BMPs in a treatment train.

Step 6: Determine Site Infiltration Rates (Saturated Hydraulic Conductivity)

If the infiltration rate is not measured, select the design infiltration rate from Table 9.3 based on the least permeable soil horizon within the first 1.5m below the bottom elevation of the proposed bioretention system. The infiltration capacity of natural basins is inheritably different from constructed systems.

In the event that a natural depression is proposed to be used as a bioretention system, the designer must assess the followings: the infiltration capacity of the soil under existing conditions (mm/hr), the existing drawdown time for water at the maximum basin water level and the natural overflow elevation. The designer should also demonstrate that the operation of the natural depression under post-development conditions mimics the hydrology of the system under pre-development conditions.

If the infiltration rates are to be measured, the tests shall be conducted at the proposed bottom elevation of the bioretention system. If the infiltration rate is measured with a double-ring infiltrometer the requirements of standard practice should be used for the field test.

Step 7: Determine the Size of Bioretention Area

The size of bioretention area is determined using Darcy's equation (Equation 9.1 for impermeable system and Equation 9.2 for permeable system). The corresponding equation is applied depending on whether the system is impermeable or permeable. The composition of filter media is designed to achieve a minimum coefficient of permeability of 13mm/hr.

Step 8: Sizing of Perforated Collection Pipes

The inlet capacity of the underdrain system (perforated pipe) is estimated by assuming that 50% of the holes are blocked. To estimate the flow rate, an orifice equation is applied using the identified parameters for optimum performance. The Manning equation is applied to estimate the flow rate in the perforated pipe. The capacity of this pipe needs to exceed the maximum infiltration rate.

Step 9: Determine the Size of Outlet Structure

It is required that a secondary outlet or spillway be incorporated into the design of a bioretention system to safely convey excess stormwater. This includes the flow diversion structure to bypass major storm where applicable.

Step 10: Landscaping Design

The performance of the bioretention system is dependent on the selection of plant species. Native plant species should be considered for stormwater treatment and optimum maintenance (Annex 1).

REFERENCES

1. ARC (2001). *Georgia Stormwater Management Manual, Vol. 2,* Technical Handbook, First Edition, August 2001, Atlanta Regional Commission.

2. CFWP & MDE (2000). *Maryland Stormwater Design Manual, Vol. I & II*, Centre for Watershed Protection (CFWP), Ellicot City, Maryland and Maryland Department of the Environment (MDE), Water Management Administration, Baltimore Maryland.

3. DOW (2007). *Stormwater Management Manual for Western Australia: Structural Controls,* Department of Water, Government of Western Australia.

4. Institute of Engineers Australia (2006). *Australia Runoff Quality*, Engineers Australia, ACT.

5. MPCA (2008). *Minnesota Stormwater Manual*, Minnesota Pollution Control Agency, Version 2 January 2008.

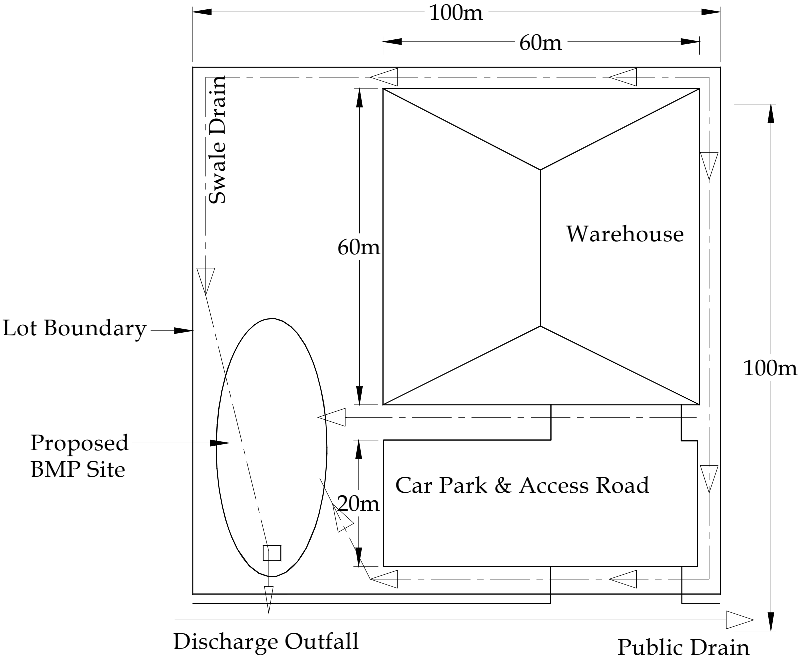
6. Moreton Bay Waterways & Catchments Partnership (2006). *Water Sensitive Urban Design*, Technical Design Guidelines for Southeast Queenslands, Moreton Bay Waterways and Catchments Partnership, Version 1 June 2006.

APPENDIX 9.A EXAMPLE - IMPERMEABLE BIORETENTION SYSTEM

Problem:

An industrial area located in Bukit Tengah, Seberang Perai Tengah, Pulau Pinang, has been adopted for the warehouse development with lot area of 1 ha (100m x 100m), floor area 60m x 60m and parking area 60m x 20m. The stormwater runoff from the impervious areas will be directed to the vegetated filter strip around the perimeter of the building and parking areas. The distributed stormwater runoff from vegetated filter strip will be collected in the grassed swale to be conveyed downstream of the lot area and treated by a bioretention facility of impermeable type. For such runoff quality treatment an appropriate sizing of the facility is required.

a) Site Plan



b) Warehouse and Drainage Layout

Figure 9.A1: Development Site

Solution:

Reference	Calculation	Output
	Design Rainfall Duration	
Figure 9.A1	Development Project Area	
	Catchment area, A =	1.0ha
	The time of flow in the channel (t_d) is derived based on the velocity (V) and length (L) of flow in the swale.	
	Given that:	
	Velocity, V =	0.25m/s
	Length, L =	175m
	Then, $t_d = L/V = 175/0.25$ =	11.7min
	=	12min
	Assume the overland flow time (t_o) is 5 minutes	
	Then, the time of concentration, $t_c = t_o + t_d = 5 + 12$ =	17min
	Design Rainfall Intensity	
Equation 2.2	$i = \frac{\lambda T^{\kappa}}{(d + \theta)^{\eta}}$	
	Where,	
	i = Rainfall Intensity (mm/hr) T = Average Recurrence Interval (year) d = Storm Duration (hr)	
	λ, K, θ, η = Coefficients	
	Given that,	
	Average Recurrence Interval, T =	5 yr
	Storm Duration, D =	17min
Table 2.B2	$\lambda = 52.771$, $\kappa = 0.203$, $\theta = 0.095$ & $\eta = 0.717$	
	Then,	
Equation 2.2	$i=\frac{52.771\times5^{0.203}}{(0.283+0.095)^{0.717}}$ =	146.88mm/hr
	Water Quality Volume	
	The water quality volume is estimated based on 40 mm of 3 month ARI rainfall.	
Table 2.6	Permeable area: Open spaces grass cover with runoff coefficient value, C =	0.40
Table 2.6	Impermeable area: Impervious roofs, concrete and roads with runoff coefficient value, C =	0.95

Reference	Calculation	Output

Landuse	C	P (mm)	A (m^2)	WQ$_v$ (m^3)
Permeable	0.40	40	5200	83.2
Impermeable	0.95	40	4800	182.4

Reference	Calculation	Output
	The water quality volume, WQv	= 265.6m^3
	<u>Soil Mixture of Planting Bed</u>	
	Specification of Planting Bed:	
	Depth	= 750mm
	Porosity	= 25%
	Maximum Clay Content	= 5%
	Coefficient of Permeability, k	= 26mm/hr = 0.624m/day
	Recommended composition of planting bed is specified in Table 9.4.	
	<u>Surface Area of Filter Bed</u>	
	Given that:	
	Water Quality Volume, WQ$_v$	= 265.6m^3
	Planting Bed Depth, d_f	= 0.75m
	Saturated Hydraulic Conductivity, k = 0.5×0.624m/day	= 0.312m/day
	Average height of Water above Filter Bed, h_f	= 0.3m
	Design Filter Bed Drain Time, t	= 1.0day
	The surface area of filter bed for impermeable system is given as:	
Equation 9.1	$A_f = \frac{(265.6)(0.75)}{(0.312)(0.3+0.75)(1.0)}$	= 608.1m^2
	<u>Maximum Infiltration Rate</u>	
	Given that,	
	Saturated Hydraulic Conductivity, k	= 7.222×10^{-6}m/s
	Base Width of the Ponded Cross Section above the Filter Bed, W_b	= 15.00m
	Base Length of the Bioretention Zone, L_b	= 41.00m
	Average height of water above the filter bed, h_f	= 0.30m
	Depth of Planting Bed, d_f	= 0.75m
	Therefore, the maximum infiltration rate reaching the perforated pipe at the base of the soil media is given as:	
Equation 9.3	$Q_{max} = (7.222 \times 10^{-6})41 \times 15 \left(\frac{0.30 + 0.75}{0.75}\right)$	= 6.22 × 10^{-3}m^3/s

Reference	Calculation	Output
	Sub-Soil Pipe	
	The impermeable bioretention system employs a UPVC perforated sub-soil pipe to convey the stormwater runoff to the downstream conveyance.	
	Given that,	
	Diameter of Perforated Pipe =	100mm
	Diameter of Perforations =	5mm
	Spacing of Perforations =	25mm c/c
	Circumference of Perforated Pipe =	314.2mm
	Number of Rows (of Perforations) =314.2/25 =	12.57
	Number of Column (of Perforation/m) =1000/25 =	40.00
	Number of Perforations = 12.57 × 40.00 =	502.72
	Number of Perforations (assume 50% blockage) = 502.72/2 =	251.36
	Area of each Perforation =	$19.63 mm^2$
	And so,	
	Total Area of the Orifices, A = $19.63 \times 251.36 \times 10^{-6}$ =	$0.0049 m^2$
	Maximum Head of Water above the Pipe (m) (filtration media depth plus ponding depth), h =	1.4m
	Orifice Coefficient, C =	0.60
	Blockage Factor (Ψ = 2 is recommended), Ψ =	2.00
	Gravity Constant, g =	$9.81 m^2/s$
	Note that, the maximum head of water above the pipe (h) is given as: 300 mm (ponding depth) + 100 mm (mulch layer) + 750 mm (planting bed) + 100 mm (transition layer) + 100 mm (part of drainage layer above the pipe) + 50 mm (radius of perforated pipe) = 1400 mm	
	The flow per perforation is given as:	
Equation 9.4	$Q_{perf}=\frac{0.60 \times 19.63 \times 251.36 \times 10^{-6} \sqrt{2 \times 9.81 \times 1.4}}{2.0}$ =	$0.0078 m^3/s/m$
	Inlet capacity per meter × total length: 0.0078 × 41 = 0.318 m^3/s > 0.0062 m^3/s (maximum infiltration). Hence, a single pipe of 100 mm diameter is sufficient to pass the flow into the perforation.	
	The Manning equation can then be applied to estimate the flow rate in the perforated pipe.	
	Given that,	
Table 2.3	Manning Roughness, n =	0.01
	Diameter of the Perforated Pipe, D =	0.1m
	Slope HGL, S_o =	0.01m/m
	The flow rate in the perforated pipe is given as:	
Equation 9.5	$Q_{pipe}=\left(\frac{0.312}{0.01}\right)0.1^{2.67}0.01^{0.5}$ =	$0.0067 m^3/s$

Reference | Calculation | Output

This is higher than the maximum infiltration capacity; hence the single 100 mm diameter perforated pipe is adequate for the bioretention system.

Estimation of Peak Discharge

The computation of peak flow for 5 year ARI is tabulated below.

Landuse	C	I (mm/hr)	A (m^2)	Q (l/s)
Permeable	0.40	146.88	5200	84.9
Impermeable	0.95	146.88	4800	186.1

The peak flow for 5 year ARI contributed from the permeable and impermeable areas is estimated to be 271 l/s.

Size of Overflow Sump

Sizing an overflow structure to convey stormwater in the basin in excess of the 300 mm ponding depth from the bioretention system to the downstream conveyance.

The broad crested weir equation (Equation 9.6) is initially used to determine the length of weir required by assuming free overfall conditions.

Given that,

Overflow (weir) discharge, Q_5 = $0.271 m^3/s$
Flow Coefficient, C = 1.7
Head above weir crest, H = 0.15m

The length of weir crest is computed as,

Equation 9.6

$$L = \frac{0.271}{1.7 \times 0.15^{1.5}} = 2.74m$$

The required length of weir crest, L is equal to 2.74 m, which can be provided by 785 mm × 785 mm square overflow sump.

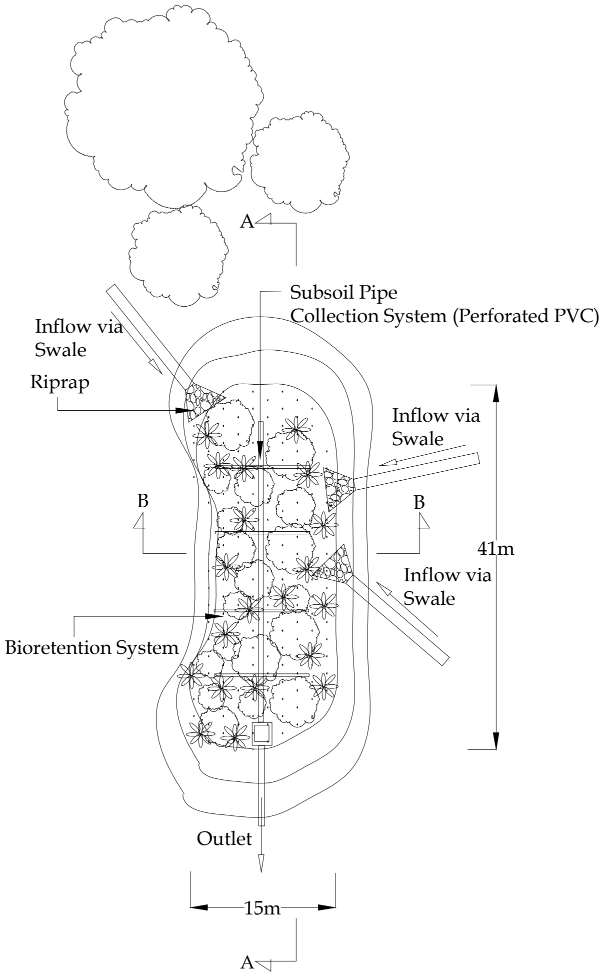
Secondly, checking for drowned outlet conditions using orifice equation (Equation 9.7):

Given that,

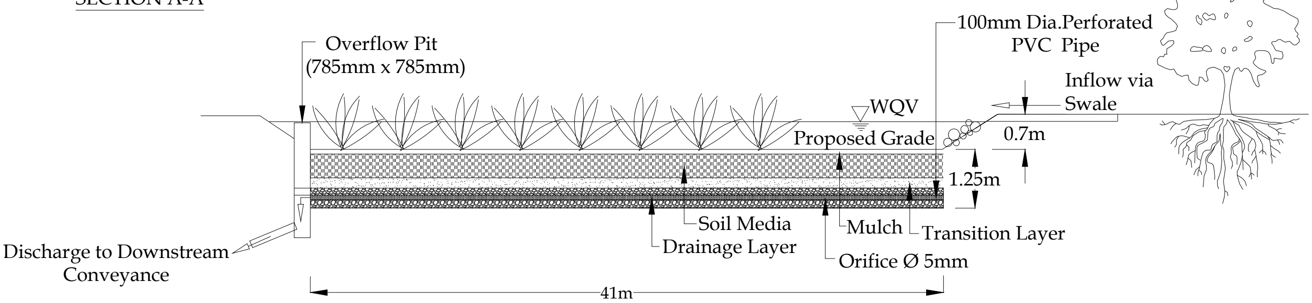
Overflow (Orifice) Discharge, Q_5 = $0.271 m^3/s$
Flow Coefficient, C = 0.6
Head above Weir Crest, h = 0.15m
Gravity Constant, g = $9.81 m^2/s$

Reference	Calculation		Output
	The area of orifice is given as,		
Equation 9.7	$A = \dfrac{0.271}{0.6 \times \sqrt{2 \times 9.81 \times 0.15}}$	=	0.263m^2
	The discharge area required is A = 0.263 m², which can be provided by 515 mm × 515 mm overflow sump. Hence, the free overfall conditions dominate the overflow design. A pit size of 785 × 785 mm is adopted. The size of the overflow sump needs also to consider an allowance for the grate bars, which will reduce the available perimeter and area.		
	<u>Details of the Inlet Structure</u>		
	Used the typical trapezoidal swale for design flow 5 year ARI as follows:		
	Bottom Width, *BW*	=	500mm
	Depth of the Swale, *H*	=	300mm
	Side Slope of 1:3 (*V*:*H*), *m*	=	3
	Then,		
	Cross-section Area, *A*	=	0.42m^2
	Wetted Perimeter, *P*	=	2.40m
	Hence,		
Equation 9.9	Hydraulic Diameter, *DH*	=	700mm

PLAN



SECTION A-A



SECTION B-B

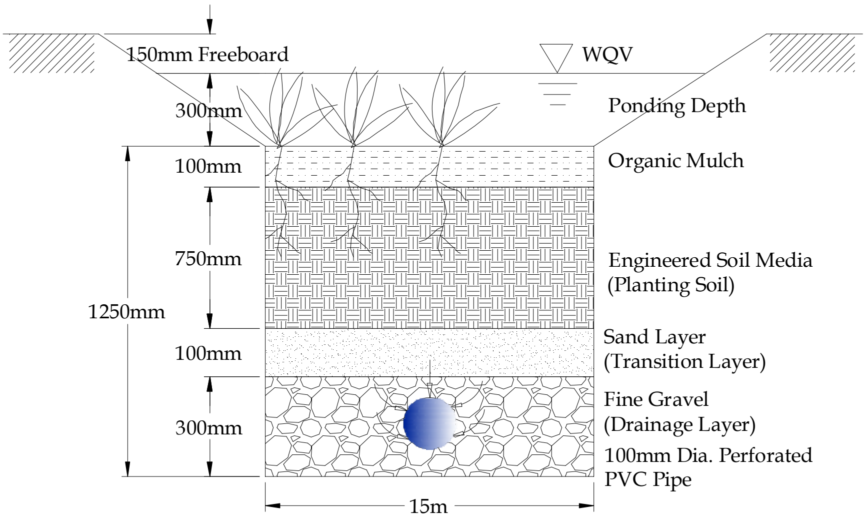


Figure 9.A2: Design Details of the Bioretention System

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