Land and Water Constructions

Kingston City Council
and
Better Bays and Waterways - Institutionalising Water Sensitive Urban Design and Best Practice Management Project

Review of Street Scale WSUD in Melbourne

Study Findings

City of KINGSTON

Melbourne Water

Victoria The Place To Be

Department of Sustainability and Environment

clearwater

Australian Government

Executive Summary

In order to better understand factors which contribute to the successful implementation of street scale Water Sensitive Urban Design (WSUD) inspections were undertaken at 22 sites across Melbourne. The inspections were undertaken in response to concerns regarding poor plant growth at a number of sites.

The inspections found civil works and maintenance (weed and litter control) were generally undertaken well. Some issues identified with civil works include the use of inappropriate mulches and loss of extended detention storage due to overfilling of filters.

The most common issue identified in the site inspections was poor filter function, with many filters having infiltration rates below that specified in the design. Infiltration rates of filters were quantified via in-situ and laboratory methods and found most had infiltration rates of less than 80 mm/h. Systems with low infiltration rates will be achieving lower than intended pollutant removal rates as systems bypass more frequently.

The low hydraulic conductivity of the filters was due to inappropriately selected filter materials, with topsoil material being used in many rain gardens. Topsoil contains too high a proportion of fine grade materials. The fines clog soil pores and reduce the infiltrative capacity of the soil.

Plant growth was variable across the sites, with poor growth often linked to poor filter function water logging soils. In this regard terrestrial plants, e.g. Dianella species, were found to offer an advantage as they demonstrated poor growth if the filter had low infiltration rates. Where semi-aquatic plants were used in filters with low infiltration rates, the plants did not demonstrate poor growth. It is considered that the use of plants which prefer well drained conditions is preferable, as they will indicate poor filter function.

No plants were found to be suffering stress from a lack of water despite the drought conditions during the study. This indicates that the direction of additional runoff to rain gardens contributes to their long term health.

In recognition that many filters are not meeting their specification a new filter specification was developed. The specification includes details for all layers that make up rain gardens, i.e:

- Mulch
- Filter
- Transition Layer
- Drainage Layer

The approach assumes that a washed sand product will be used for the filter layer rather than a topsoil. As a result amelioration of the top layer of the filter will be required to support the initial plant growth.

Maintenance inputs and costs were reviewed and found maintenance costs are in the order of $3.80 to $20 per square metre of landscape per annum. The range of costs reflects the profile of the site to be maintained, with higher profile sites requiring greater maintenance intervention.

A typical maintenance regime was developed and costed and is contained in Table 5.2. Two maintenance regimes are proposed, reflecting the profile of various sites. The annual costs are \$8.76 and \$13.25/m^2, respectively, for low and high maintenance levels. Much of the maintenance cost is associated with annual inspections and litter pick up. If reductions in maintenance inputs are desired it is recommended that savings be made in these areas, rather than weed control and replanting. The coordination of the maintenance of rain gardens with adjacent landscapes will reduce the costs.

Table 1.1 Estimated annual maintenance costs per square meter of rain garden

Activities	Lower Cost	Upper Cost
Aesthetics	$ 4.80	$ 7.20
Vegetation	$ 3.00	$ 4.13
Damage		
Inspections	$ 0.96	$ 1.92
	$ 8.76	**$ 13.25**

Recommendations

A number of areas were identified for further work through this study and are summarised below:

- Knowledge Gaps
    - Jute mat – the infiltrative capacity of jute mat is unknown, given its widespread use in the landscape industry its infiltrative capacity should be better defined;
    - The effectiveness of turf grass systems – in many of the systems reviewed the use of turf grasses may have been appropriate and would result in reduced maintenance costs. The suitability of turf grasses is not known, with some turf systems e.g. golf greens, suffering from reduced infiltrative capacities over time. To allow turf systems to be adopted research is required into the long term behaviour of turf systems, for both pollutant removal and hydraulic conductivity; and
    - Maintenance Costs – it is recommended that more data be gathered regarding maintenance costs. Data should be collected by the relevant asset manager. Another agency will be required to take the lead on collating maintenance data and distributing it to the industry. The required data include for each site:

        - Physical description of the site, e.g, area and number of plants.
        - Number of visits and duration (man hours) for activities such as weed control and litter removal
        - Time and materials devoted to re-mulching and re-planting
        - Time spent on inspections.
- Existing Systems
    - Many of the systems reviewed have deficiencies that can be readily fixed. Some sites will require replacement of filter media and replanting. Other sites require regrading to provide adequate extended storage depth. Border planting or edge strips would be useful additions at some sites. All sites require regular ongoing maintenance to be undertaken.
    - Detailed recommendations of remedial works at each site are contained within Volume 2.
- Proposed Systems
    - Many of the findings of this study are suitable for application to new systems. It is recommended that when current design guidelines are reviewed that the findings of this study be reviewed and adopted, where appropriate.

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Client Contact	Max Pfitzner and Matthew Potter
Client Reference	
Authors	Dr Nicholas Somes and Joe Crosby
Synopsis	Twenty two sites of street scale WSUD were inspected to identify key areas where design practice could be improved. The study developed guidelines for the design, construction and maintenance of street scale WSUD.

REVISION/CHECKING HISTORY

REVISION NUMBER	DATE	CHECKED BY		ISSUED BY	
0	7/11/06	Joe Crosby		Nicholas Somes	
1	1/1/07	Nicholas Somes		Nicholas Somes	
2	13/1/01	Anthony Farrow		Nicholas Somes	

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FAWB Facility for Advancing Water Biofiltration

Fieldwork undertaken for this project was a joint venture between Land and Water Constructions and the Facility for Advancing Water Biofiltration.

Cover image courtesy of Bayside City Council

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Contents

1. Introduction

1.1. What is Street Scale Water Sensitive Urban Design (WSUD)?

Since the early 1990s a number of activities have been undertaken to reduce the impact of urban stormwater on the environment in greater Melbourne. As a result many regional scale end-of-pipe treatments, such as wetlands were constructed. By the late 1990s attention was also being focused on existing areas of development, to identify methods by which stormwater could be treated. Due to space constraints within urban areas opportunities for end of pipe treatment are often limited and as a result designers looked upstream into the catchment to seek opportunities to retrofit treatments at the street-scale.

Street-scale treatments face a number of design pressures not present in regional scale measures. In response to these design pressures many street-scale devices have the following characteristics:

- They generally do not contain areas of permanent water;
- Treatment is via filtration through a soil media;
- They need to be incorporated into the streetscape; and
- They tend to have a formal design in keeping with the urban environment.

The most common form of street-scale water sensitive urban design (WSUD) elements are biofiltration pits, commonly referred to as rain gardens. Rain gardens operate by filtering runoff through a soil media prior to discharge into the drainage system. The major pollutant removal pathways within rain gardens are:

- Event processes
    - Sedimentation in the extended detention storage, primary sediments and metals;
    - Filtration by the filter media, fine sediments and colloidal particles; and
    - Nutrient uptake by biofilms.
- Inter-event processes
    - Nutrient adsorption and pollutant decomposition by soil bacteria; and
    - Adsorption of metals and nutrients by filter particles.

To retain the filter media within the rain garden and aid drainage, one or more layers are used at the bottom of the filter. The surface of most rain gardens is planted with a range of vegetation. Figure 1-1 provides a sketch of a typical rain garden showing the key elements and water flow paths.

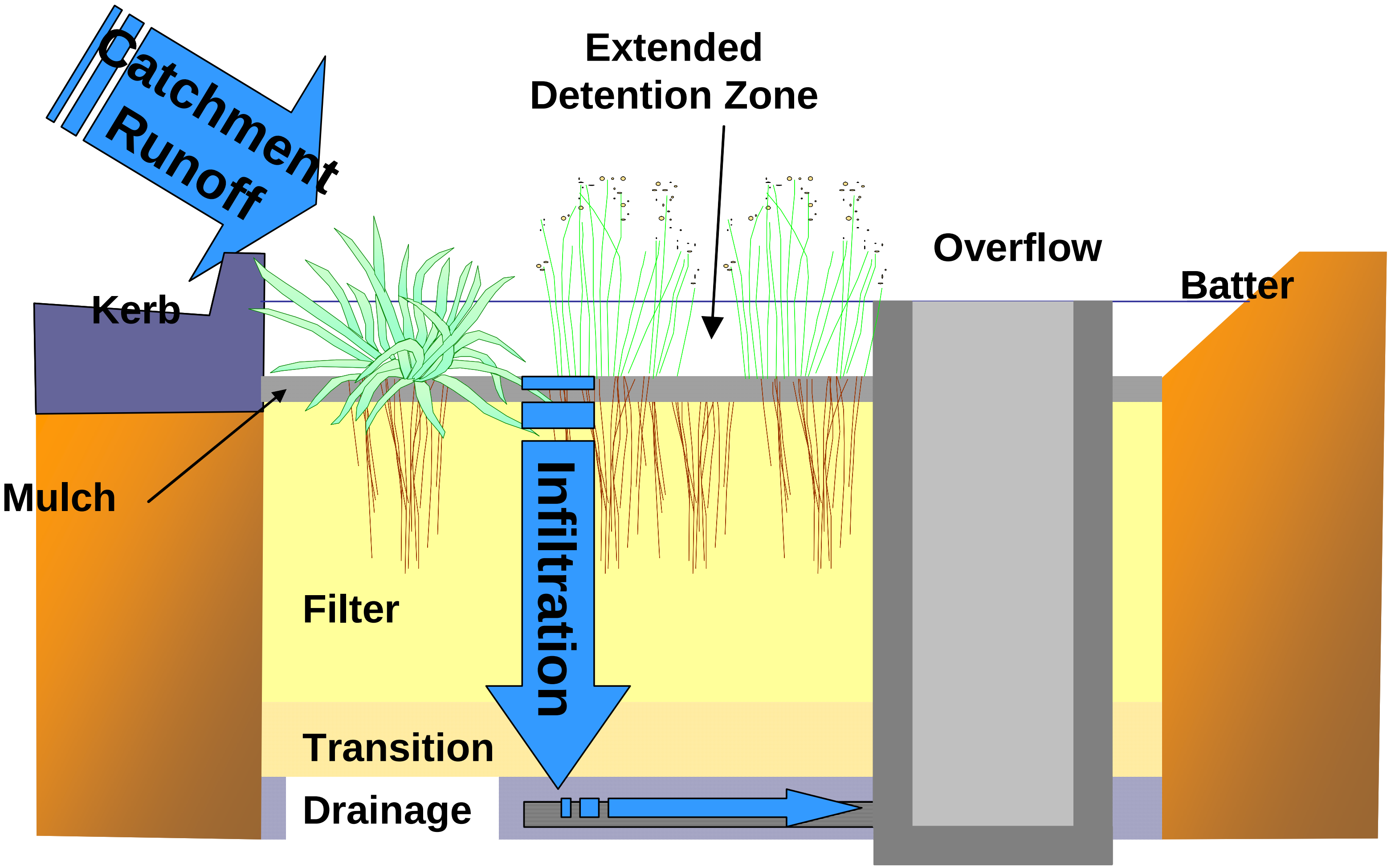

Figure 1-1 A cross section of typical rain garden

1.2. Study Objectives

The objectives of the study are to:

- Review stormwater treatments that have been retrofitted in Melbourne to determine the factors that contribute to the successful implementation of street-scale WSUD and identify the factors that have impeded successful implementation;
- Use these findings to develop recommendations for use in future projects to improve the implementation of street-scale WSUD.

In addition to the rain garden described in Figure 1-1 other treatment devices are reviewed as part of this project and include gravel infiltration trenches and small wetlands. The sites are distributed throughout Melbourne, with over half within the City of Kingston. The comments and recommendations in this report are focussed on rain gardens as they represent the majority of the sites.

2. Methodology

2.1. Site Inspections

Site selection was based on street-scale stormwater quality treatments that had been constructed in developed environments i.e. retrofit situations. Site inspections were undertaken over an eight week period in the winter of 2006. During each site visit, a series of observations was made regarding the design, construction, establishment and maintenance of each system. Where available, construction plans were compared with on-ground works to confirm if design dimensions and landscape treatments had been constructed as designed.

2.2. Design Review

Available design data was reviewed for each project. The design data was either conceptual or construction drawings, with limited design reports available. It should be noted that design data was limited to that available on drawings, with no detailed specifications reviewed.

2.3. Infiltration Rate Quantification

The function of rain gardens relies on polluted storm water infiltrating into the filter media. To confirm the operation of the rain gardens tests of infiltration rates were undertaken using laboratory and in-situ tests at selected sites. The sites were selected to gain a representative sample of the sites investigated in the study. A number of sites were excluded from the tests as they were either considered too small, had gravel filters, or did not rely on infiltration to treat runoff, e.g. wetlands.

Laboratory tests of filter media were undertaken for two sites by Sportsturf using a test that complied with AS4419 tests for landscape soils. In this test an uncompacted soil sample is placed in a tube with a constant head of water applied over it and the infiltration rate recorded when the soil column is saturated. This rate is considered to be the saturated hydraulic conductivity of the soil sample.

In-situ tests were used to provide an onsite assessment of infiltration and to develop a method that could be applied by Council Officers onsite. In-situ methods also avoid the need to disturb the filter media, preserving the as-constructed characteristics of the filter.

The in-situ test method used a steel collar that was driven into the filter profile to the drainage layer. A constant head was maintained within the steel tube and topped up on a regular basis, with the timing and volumes of additions recorded. The head used for the test was matched to the operating head of the rain garden, i.e. the test water level was equivalent to the maximum extended detention depth. Tests were run for between 1 and 2 hours depending on the infiltration rate, with tests suspended early when infiltration rates were low, i.e. less than 10mm/hour. The tests were conducted by Land and Water Constructions and the Facility for Advanced Water Biofiltration (FAWB) with results pooled.

Figure 2-1 Infiltration rate test rig

Figure 2-2 Infiltration rate test rig installed on site

It should be noted that in-situ tests are considered to measure infiltration rate not saturated hydraulic conductivity. The in-situ measurement of saturated hydraulic conductivity requires free draining media at the invert of the soil column to achieve atmospheric pore pressures. Many of the systems reviewed as part of this study were two layer systems, with the lower layer or drainage layer consisting of coarse sand. Concerns were raised by FAWB that this layer may not have sufficient pore spacings to attain atmospheric pore pressures. As a result saturated conductivity results are not quoted. Whilst the infiltration rates obtained in this study are not considered to be saturated hydraulic conductivity measurements, they are indicative of system function and are considered to be a reasonable assessment of filter function.

2.4. Maintenance Costs

A review of maintenance costs was undertaken as part of the study. Asset owners were approached and asked to define the maintenance regime and amounts spent on maintenance at their site(s). The available data was limited, with very few organisations having an accurate estimate of maintenance costs available. This is largely due to Councils not collecting maintenance data for individual sites. From the discussions it was clear that many Councils allocate maintenance resources on an as-required basis, with expenditure limited by available resources or contractual limitations. A summary of the available maintenance data is provided in Section 3.8.1.

As a result of the lack of accurate site based data, maintenance cost estimates quoted in this report are based on the study team's estimate of required maintenance activities, a range of frequencies and estimates of labour and material costs. Estimates of the time and materials required were made for high and low maintenance regimes. The estimates of time and materials were combined with a cost estimate of labour and materials to provide an annual cost estimate. The details of the cost estimate and all assumptions are outlined in Section 4.6.2.

3. Results

3.1. Site Inspections

A list of the sites visited and a summary of investigation results for each site is contained in Table 3.1. Individual inspection records for each site are contained in Volume 2.

The site inspections have considered the design, construction and maintenance of each site. The design review was based on available plans and site inspections. The construction review was based on discussions with Council Officers and site inspections. Each site review concludes with a series of recommendations for design, construction and maintenance of the system.

The findings for design construction and maintenance are summarised in the following sections. Individual site reports in Volume 2 were provided to the relevant site managers.

3.2. Master Planning

Designs were reviewed for both functional and detailed performance. The functional review considered how well the treatment element fitted into the streetscape and impacts of the surrounding use on its function, i.e. how well is the site master planned. A successful master plan is considered important for the overall success of a project as it largely defines the public perception of the project.

Master planning considers issues such as pedestrian access and safety, traffic movements, placement of bins for collections, vehicle parking and passenger movement, service access including street sweeping and waste management and site context. In planning the retrofitting of rain gardens, consideration should be given to the local community and the use of the street. For example, in one inner city case, rain gardens have been placed adjacent to car parks and bus stops, with people alighting from vehicles having to cross the rain garden to reach the footpath.

In a number of cases, rain gardens have suffered from being in pedestrian or traffic paths. For example the rain garden in Figure 3-1 is located in front of a school in an area of high foot traffic. Despite being fenced, pedestrians walk across the rain garden, eroding the surface and compacting the filter media. In another example, the rain gardens in Cremorne Street, Richmond (Figure 3-2) have been fenced to separate pedestrians and traffic from the rain garden areas. Damage to the fences by accidents and vandalism however, reduce the aesthetics significantly.

Table 3.1 Summary of Investigations and Inspections

No.	Location	Suburb	Type	Soil Test	Infiltration Test	Detailed Design Drawings
1	Wells Rd- Stage 1	Chelsea Heights	Wetland & swales		NA	Y
2	Riviera St	Mentone	Infiltration trenches		NA	Y
3	Railway Walk car park	Cheltenham	Infiltration trenches		NA	Y
4	Fowler St	Bonbeach	Rain gardens		NA	Y
5	Stawell St	Mentone	Rain gardens		L&W	Y
6	Wells Rd- Stage 2	Patterson Lakes	Rain gardens	Y	L&W	Y
7	Brisbane Tce	Parkdale	Rain gardens		L&W	Y
8	Peter Scullin car park	Mordialloc	Rain gardens		L&W	Y
9	Mernda Ave	Bonbeach	Rain garden		NA	Y
10	Alleyene Ave	Chelsea	Rain gardens	Y	FAWB	Y
11	Voltri St	Cheltenham	Rain garden		NA	Y
12	Cremorne St	Richmond	Rain gardens		FAWB	Y
13	Howe Parade	Port Melbourne	Rain gardens	Y	Lab	Y
14	Doncaster Park and Ride	Doncaster	Rain garden		NA	Y
15	Ricketts Point car park	Beaumaris	Rain gardens		L&W	N
16	Docklands street tree biopits	Docklands	Tree bio pits		NA	N
17	Docklands Point Park car park	Docklands	Rain gardens		FAWB	N
18	Rowville Community Centre car park	Knox	Biofiltration trench		NA	Y
19	Parker St	Pascoe Vale	Rain gardens		FAWB	Y
20	Hamilton St	Brunswick West	Rain gardens		FAWB	Y
21	Inkerman D'Lux	St Kilda	Mini wetland		NA	Y
22	Wittons Reserve	Warrandyte	Rain garden		NA	Y

Note: lab test undertaken by Sportsturf Consultants

A number of design actions can be undertaken to reduce conflicts between pedestrians or traffic and rain gardens. Simple measures include clear delineation of the bed via methods such as mulch and edge strips. These measures clearly define the rain garden as different from the surrounding area and discourage access. Vegetation can also be successfully used to create a barrier that discourages entry and defines the space. It was observed that many of these measures had been implemented on more recent projects. For example, Kingston City Council rain gardens have moved from systems such as Figure 3-1 where the treatment element was placed within a conventional nature strip, to a standard design that includes features such as mulch and edge strips. The newer systems also tend to be larger with batter areas and grade changes incorporated into the bed. Alleyne Avenue is a good example of this approach (Figure 3-3).

Delineation of rain gardens and the impact on system function and maintenance is discussed in later sections.

Figure 3-1 A rain garden in front of a school suffering damage from pedestrian traffic, Fowler Street, Bonbeach

Figure 3-2 Damage to fences, Cremorne Street, Richmond

3.3. Vertical Geometry

One of the key challenges when integrating rain gardens into existing streetscapes is the management of the vertical geometry. Rain gardens require an extended detention storage depth of 100 to 200mm, which is located below the level of the kerb invert. The required depth is determined by the catchment size draining to the pit and the surface area of the pit. This drop typically translates to a 200 to 400mm drop where the rain garden abuts the footpath or nature strip. Figure 3-3 is an example of the grade changes to be accommodated.

There are two methods to address the level difference, i.e. to use a sloping batter or construct hard vertical edges. Figure 3-4 and 3-5 provide examples of two treatments where sloping batters are used. The batters can be grassed, planted or paved. Issues observed with battered treatments are summarised as follows:

- Batter slopes that are considered safe e.g. a slope of 1 vertical to 4 horizontal require a large amount of space.
- Batters steeper than 1:4 can present a trip hazard and are difficult to maintain as mulch slips off the surface or they are difficult to mow.

These issues can be addressed through raised barriers or flat buffer strips (minimum width 300mm) adjacent to pedestrian paths. The buffer strip provides separation of pedestrians from the batter and allows an area for plants to be grown to further delineate the edge.

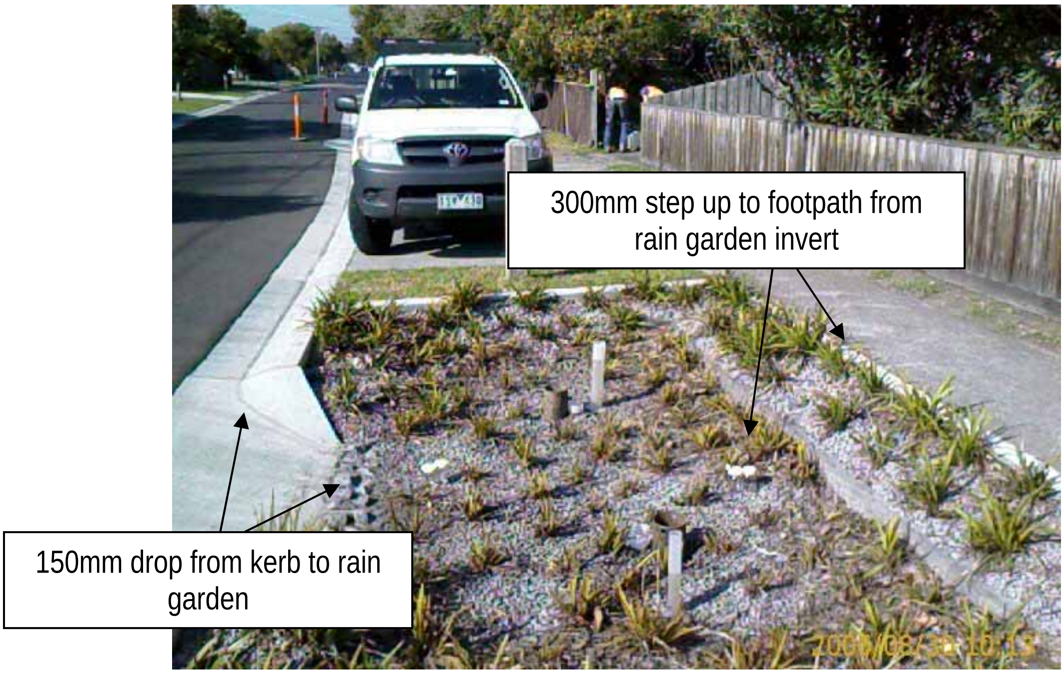

Figure 3-3 An example of the grade change to be accommodated across a rain garden, Alleyne Avenue, Chelsea

Figure 3-4 Grassed batters within a rain garden, Riviera Street, Mentone

Figure 3-5 Mulched and planted batters, Voltri Street, Cheltenham

The alternative to batters is the use of hard edges to take up the change of grade. Hard edges are typically well constructed and provide a low maintenance edge. A number of methods and materials were observed including:

- Timber retaining walls, Figure 3-3;
- Bluestone and paving, Figure 3-6; and
- Concrete edge beam, Figure 3-7.

Figure 3-6 Rain garden with a blue stone edge, Hamilton Street, Brunswick West

Figure 3-7 Rain garden with concrete edge beam, Ricketts Point, Beaumaris

A concern with the use of hard edges is the management of trip hazards. As discussed earlier, it is necessary to take up grade changes of up to 400mm across a rain garden. The treatment of these grade changes varies, with some examples, such as Cremorne Street, taking up grade changes in a single step and using fencing as edge protection. A disadvantage of the use of fences in urban environments is the resulting maintenance load created by vandalism and accidental damage, with many of the fences at Cremorne Street exhibiting damage.

Other sites take up the grade change in one or more steps, e.g. Point Park car park. The Point Park car park (Figure 3-8) uses a concrete edge beam and a gabion basket to take up a grade change of approximately 200mm. This approach is considered to be very successful as the grade change is incorporated into the design and it provides no greater risk than the surrounding streetscape. The Point Park car park site has a large footprint due to the width of the gabion, a smaller footprint may be achieved by limiting the step tread to a minimum width of 200mm.

Figure 3-8 Edge details at Point Park car park, Docklands

The final method reviewed to protect rain garden edges is the use of street furniture. The street tree biopits in the Docklands precinct provide a good example of this type of treatment, Figure 3-9.

Figure 3-9 Seating used to accommodate the grade change at a rain garden, Docklands

3.4. Edge Treatments

A range of edge treatments have been adopted across the sites that were reviewed. Many of the edge treatments are integral to the geometry of the system and have been discussed previously. Edge strips are also provided to delineate the rain gardens from the surrounding landscape, in particular grassed areas. Kingston City Council uses concrete edge strips in newer systems to facilitate maintenance. The strips provide an edge along which weeds and grass can be controlled and delineate areas maintained by Council. If the rain garden is to be located within a grassed area it is recommended that edge strips be adopted to facilitate maintenance. Figure 3-10 provides an example of an edge strip used to delineate a garden bed. As discussed earlier, edge strips also delineate the bed indicating to the public that it is different to surrounding landscape.

Figure 3-10 Concrete edge strip used to delineate a rain garden, Stawell Street, Mentone

In systems where landscape beds are not delineated from the surrounding landscape it was often observed that maintenance of the rain garden was compromised. For example at a number of Kingston sites, e.g. Fowler Street and Riviera Street, rain gardens are located within grassed nature strips with no edge strip. At each of these sites management of the rain garden vegetation is compromised as the surrounding grass is growing into the garden bed requiring control by trimming and herbicide. Figure 3-11 shows an example of where herbicide control of the grassed areas has resulted in overspray of the rain garden vegetation, the creation of unsightly bare areas and damage to the rain garden vegetation.

Figure 3-11 An example of the lack of edge strip and the effects of maintenance to keep grass clear of rain garden

3.5. Filter Specifications

As outlined previously, the filter is the key functional component of any rain garden as it is responsible for much of the pollutant removal and supports plant growth. Filter specification is an area of ongoing development, with the specifications changing significantly over the last 5 years. It is expected that more development will occur over the coming years.

Filters are typically defined via one or more of the following parameters:

- Number and composition of layers, e.g. filter, transition and drainage;
- Filter depth;
- Filter material and grading;
- Infiltration rate; and
- Horticultural properties.

Older systems, e.g. Park and Ride or Riviera Street, have a single layer of 5 to 7mm aggregate (gravel) for filter material. Features of this approach are:

- The material is rapidly draining;
- Provides limited water quality improvement due the rapid infiltration rate and limited surface area; and

- The media does not support plant growth, and where plants are required soil is placed in geofabric containers within the filter.

In older systems, filter media was usually defined in terms of a particle size grading alone and the systems appeared to be constructed in accordance with the design. The high degree of compliance between the design and as-built details, reflects the simplicity of the designs. An example of this type of system is shown in Figure 3-12. In some of these systems, e.g. Doncaster Park and Ride, the filter media is wrapped in geofabric. Since this system was constructed, it has been demonstrated that a geofabric layer within the filter is likely to clog over time, reducing the system's infiltrative capacity. Older systems that have been constructed in this manner will require monitoring to determine their infiltrative capacity and may require remedial works, i.e. re-setting of the filter.

Figure 3-12 A single layer system that includes an area where the planter bed has been inserted, Riviera Street, Mentone

Since the first systems were constructed changes to design practices have resulted in the adoption of systems with a finer graded filter media and multiple layers. To separate the filter from the sub-surface drain it has been necessary to add one or more layers underneath the filter layer. It is now common practice to construct two or three layer systems. The number of layers or the composition of the layers below the filter was not found to impact performance of rain gardens in this study.

More recent systems have been specified with a finer grading of material, e.g. sandy loam materials for the filter layer. These materials are significantly finer than early systems, with a median particle diameter in the range of 0.2 to 1.0mm.

Filters were frequently specified in the following manner:

- A material description e.g. sandy loam;
- A desired hydraulic conductivity, typically in the range of 80 to 180mm/h; and
- In some cases, a required grading was also provided.

In many cases the specifications were in conflict or were contradictory. The description of soils, e.g. sandy loam, includes a relatively wide grading range and can contain up to 20% of clay material (AS 4419-2003 Table I1). This proportion of clay material is considered to be too high to maintain the required hydraulic conductivity.

In addition to functional characteristics, sandy loam is a poor term to use in specifications as it is widely used in the landscape construction industry to describe topsoil sold for landscaping purposes. Soils for landscaping purposes are selected on their horticultural properties rather than drainage and in many cases will have infiltration rates of less than 25mm/h. The material is not processed apart from screening to remove over-sized particles and particle size distributions will vary from supplier to supplier. The material properties of sandy loam are inherently variable as it is sourced from a range of sites. In particular it is very difficult to control the proportion of fines, which can have a significant impact on the infiltration rate. Throughout the study it was found that many of the construction contractors have used sandy loam material and not confirmed its hydraulic conductivity or particle size distribution. This has led to many filters having lower than desired hydraulic conductivities.

It is recommended that the practice of using material descriptions such as sandy loam be discontinued. This will reduce the opportunity for contractors to use materials that have not been tested.

A case was also found where documentation of hydraulic conductivity did not match the material delivered to site. It is appropriate to conduct an infiltration test on site to confirm that the material is suitable.

In the early stages of the study, poor infiltrative capacities were identified as the likely cause of poor vegetation growth in a number of systems. To determine the infiltrative capacity of the soils, 46 infiltration tests were undertaken across 12 sites by FAWB and Land and Water using the method outlined in Section 2. The results of the infiltration tests are summarised in Figure 3-13, which plots the distribution of samples into a range of infiltration rates. The results demonstrate that most of the sites (55%) have an infiltration rate below the desired minimum rate of 80mm/h, with 45% below 40mm/h. This data indicates that most of the rain gardens reviewed during this study are not functioning correctly. This is generally the result of clogging due to fines in the mulch or filter media. These issues can be remedied through replacement of mulch and media, where required.

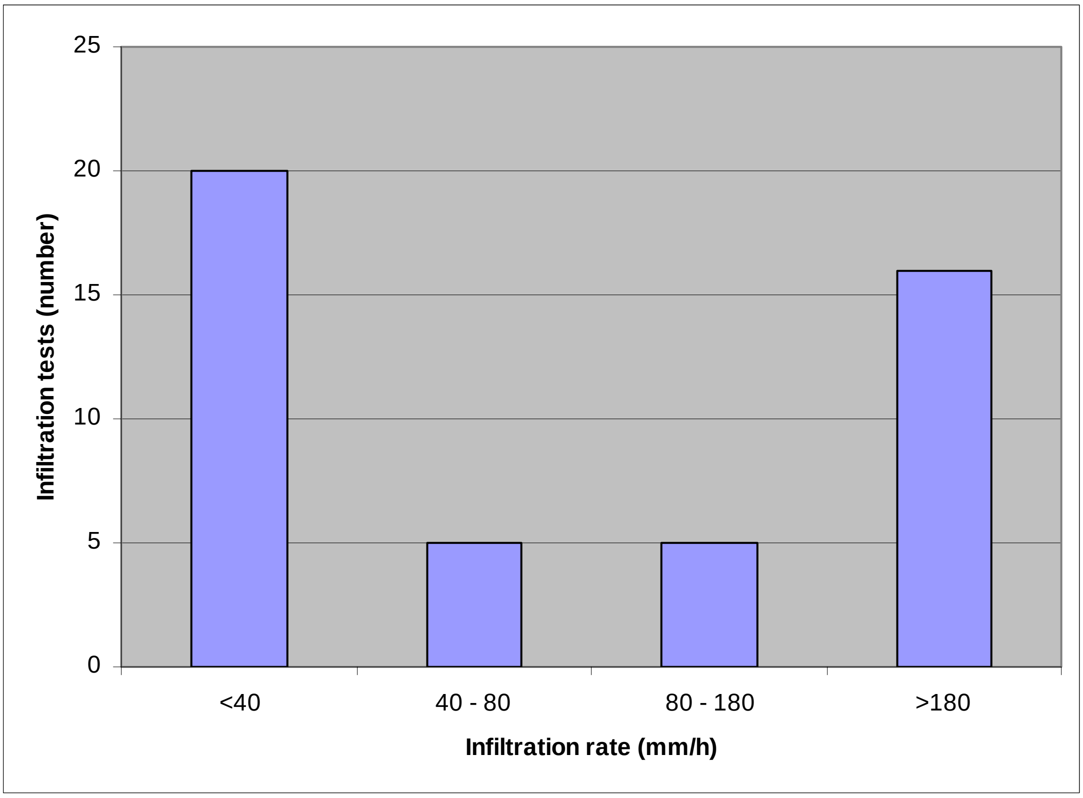

Figure 3-13 Distribution of infiltration rates measured

(Please note: graph includes data from FAWB and Land and Water Constructions.)

The effect of infiltration rate on pollutant removal is demonstrated in Figure 3-14, which plots the nitrogen removal estimate from a simulation of a rain garden performance with a range of infiltration rates. Simulations were undertaken using the Model for Urban Stormwater Conceptualisation (MUSIC). In this example, the rain garden was designed to meet best practice with an infiltration rate of 180mm/h. The infiltration rate was then varied to quantify its impact on pollutant removal. As the infiltration rate decreases, the proportion of nitrogen removal decreases, this is largely due to the increased rate of bypass as a result of decreased infiltration. The results suggest that many of the rain gardens reviewed in this study, which have lower than specified infiltration rates, would have the design pollutant removal effectiveness reduced by 10 to 15%.

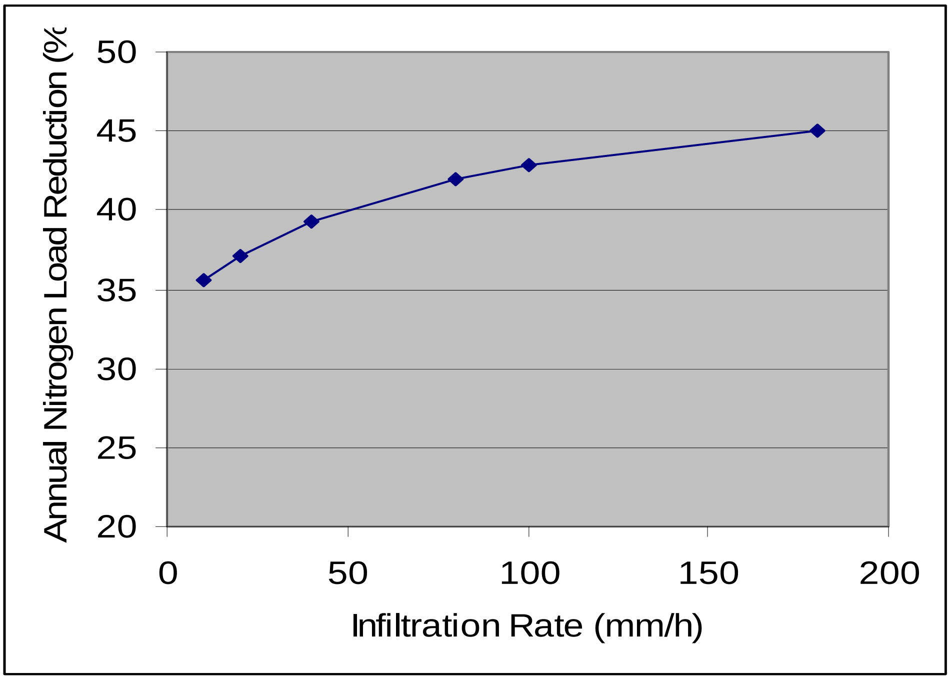

Figure 3-14 Effect of infiltration rate on rain garden performance as indicated from MUSIC modelling results

Soil fertility tests were undertaken at two sites exhibiting poor plant growth. The results indicated that the samples had reasonable levels of nutrients and would support plant growth. Both sites were subsequently found to have very low infiltration rates and the poor plant growth was due to saturated soil conditions not soil fertility. The soil test identified that topsoil had been used at both sites.

At least one site was inspected (Howe Parade) where a washed sand was used for the filter and low soil fertility had been identified as an issue during the defects liability period, requiring the amelioration of the filter to support plant growth.

3.6. Landscape Treatments

3.6.1. Mulch

Mulch is used in the establishment of landscape areas to control weeds and assist moisture retention within the soil profile. Most of the rain gardens reviewed had mulch of one form or another. The most common materials used as mulch within the rain gardens are jute mat and gravel. Organic mulch comprising recycled timber was used in one case and is not recommended as it floats and is therefore washed off during storm events.

Jute mat was used in a number of cases and provides effective cover in the short term. Over the longer term its effectiveness is questionable as it degrades over a three to five year period. The impact of jute on infiltration rates is not well understood, with concerns raised over its ability to maintain sufficient hydraulic conductivity to ensure the filter receives adequate flow. Research is required to determine the effective infiltrative capacity of jute mat and its variability over time.

The effective life of jute mat is considered to be less than 5 years, however at the end of this period plants should have sufficient coverage to no longer need the matting as mulch. Jute mat has the disadvantage of potentially being perceived as unsightly in the early years, prior to good plant coverage being achieved. This perception arises as the jute can be lifted at the edges due to plant growth and the colour of the material is distinctive and fades over time (Figure 3-15). If jute mat is to be used, the plant list should include ground cover species that will cover the jute mat, creating a self mulching organic layer. Recommendations of suitable groundcover species are contained in Section 4.4.

Figure 3-15 An example of jute mat that has been laid for 18 months

Gravel or stone mulch is considered to be the most effective treatment for rain gardens. Its advantages include that it will not float and it does not degrade. A range of stones and sizes are used, with stone sizes in the range of 4 to 13mm appropriate. Figure 3-16 shows an example of fine gravel. Gravel mulches should not contain fines as these will allow the material to compact, forming a crust and limiting infiltration. An absence of fines will prevent materials compacting and maintain infiltration rates.

The depth of stone mulch was variable with depths within the range of 50mm to 75mm considered appropriate. The grading of the material impacts the required layer thickness, with finer materials requiring thinner layers. Systems should be designed to have the appropriate extended detention depth of 100 – 200mm accommodated above the mulch layer.

Figure 3-16 An example of fine gravel mulch, Inkerman D'Lux, St Kilda

Stone mulch was usually specified by rock type, grading and layer thickness. Compliance with specifications was generally good. However, at several sites materials containing fines were used as mulches. The fines allowed the material to compact and form impermeable crusts, e.g. Peter Scullin car park and Ricketts Point. From discussions with Council Officers, the decision to change materials from those specified had been made on-site and reflected officers' inexperience with rain gardens and the requirements for their correct function.

The impact of using inappropriate gravel is demonstrated in Figure 3-17, which outlines the results from an infiltration test conducted at Ricketts Point. The infiltration tests shown in Figure 3-17 were conducted with the mulch in place and removed. Where the mulch is in place the measured infiltration rate was an order of magnitude lower than where it was removed. The biofiltration swale at Ricketts Point has been mulched with a granitic sand material, which is frequently used in the construction of paths. Figure 3-18 shows a sample of granitic sand and demonstrates its structural integrity.

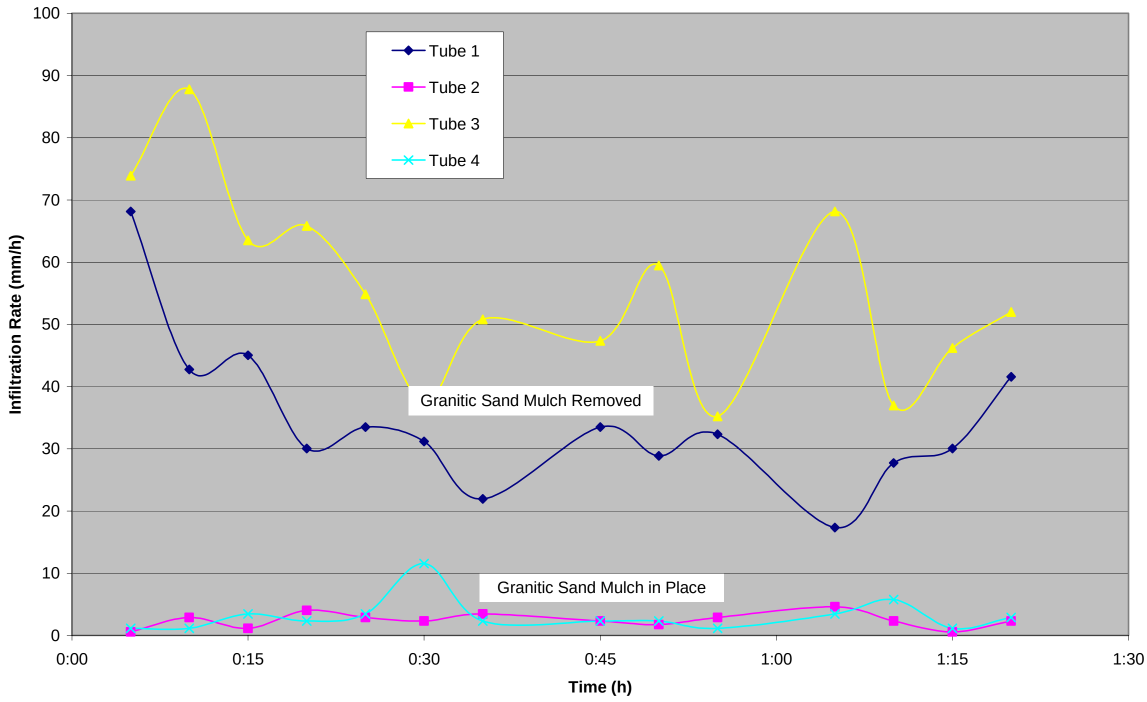

Figure 3-17 Infiltration test results from Ricketts Point demonstrating the impact of inappropriate mulch on system performance

Figure 3-18 A sample of granitic sand, demonstrating its structural properties

3.6.2. Plants

Plants have an important role in the function and aesthetics of rain gardens. Key design parameters in the selection of vegetation are:

- Plant species;
- Pot size; and
- Planting density.

A wide variety of species are used within rain gardens, with grasses and sedges used most often. The most commonly used plants were:

- Dianella revoluta (Black Anther Lily);
- Dianella tasmanica (Tasman Flax-lily);
- Lomandra longifolia (Spiny Headed Matt-rush);
- Ficinea nodosa (Knobby Club-rush);
- Carex species (sedges); and
- Juncus species (tussocks).

An example of each of the plants is outlined in Figure 3-19.

Each of these plants form tussocks and have foliage of varying widths. The plants are widely used in the commercial landscape industry and have demonstrated the ability to perform in a wide variety of climates and soil conditions. The first three on the list are considered to be terrestrial plants, while the remainder are often used in terrestrial and wetland applications.

The observed performance of plants was variable for the Dianella species, with growth typically poor where the infiltration rate of the media was low and the plant was in a moist environment.

For example, Wells Road contains five rain gardens, four of which have healthy stands of Dianella tasmanica and one with poor vegetation (refer Figure 3-20). The beds with healthy growth had infiltration rates of 87mm/h and 136mm/h respectively. The bed with poor growth had an infiltration rate of 5mm/h and 19mm/h, indicating it was likely to be water logged. Similar results were also found at Alleyne Avenue and Stawell Street. These results reflect the experience of the authors with Dianella species in a range of applications, which has shown that Dianella species prefer well drained environments.

The other widely used plants, Ficinea nodosa, carex species and juncus species have demonstrated success in a number of the rain gardens. These plants are able to grow well in variety of conditions, including water logged sites. For example, Hamilton Street in Brunswick (Figure 3-6), which has an infiltration rate of less than 15mm/h, is planted with Ficinea nodosa, which are growing well.

Figure 3-19 Examples of plants commonly used in rain gardens

(a)

(b)

Figure 3-20 Examples of well (a) and poorly (b) performing rain gardens planted with Dianella tasmanica, Wells Road, Chelsea Heights

Based on these results, it is an advantage to use some plants in the planting list that exhibit visible distress when planted in saturated conditions. If plants die or exhibit poor health when the filter is saturated, i.e. it has low hydraulic conductivity, it is likely to prompt investigations to determine why the plants are growing poorly. This was the case at Wells Road where one filter had a very low infiltration rate resulting in poor plant growth, the poor plant growth prompted investigation which revealed the filter was clogged. Use of species adapted to growing in wet conditions, e.g. juncus species, will not provide a method of indicating poor plant growth.

In the Kingston City Council examples, poor plant growth led to Council undertaking investigations into the design and function of the rain gardens. These investigations will result in the rain gardens being modified to meet best practice. Several sites with healthy vegetation, e.g. Hamilton Street, were found to have very poor infiltration rates as part of this study. Without these investigations, the poor performance of the treatment systems would have not been identified as the plants are adapted to sites with saturated soils and appear healthy.

Other plants used within stormwater treatment measures include shrubs and trees. Doncaster Park and Ride and Docklands Point car park use shrubs in the landscape and they are attractive and provide cover over the rain garden surface. Similarly the tree pits at Docklands provide a variation to the use of sedges and grasses. An advantage of having street trees within rain gardens is the regular watering that occurs from rainfall events. It is likely that regular watering from rainfall events will reduce or avoid the need for watering following planting as is often required with tress planted conventionally.

Some of the systems use grass as the cover, e.g. Rowville Community Centre and Doncaster Park and Ride. In both cases the grass is growing well but current infiltration rates are not known. They are likely to be low as topsoil was used as the filter media in both cases. In general little is known of the suitability of grass systems for use in rain gardens, with most research to date focussed on planted beds. A concern with grass systems is the potential loss of infiltrative capacity due to thatching. Thatching describes a process in turf systems, e.g. golf greens, where a build up of organic material in the soil profile reduces infiltrative capacity. Techniques such as soil coring and scarifying are required to reduce the thatch and maintain infiltration rates. Thatching may not be an issue in stormwater treatment systems as the systems do not have the heavy fertiliser application and frequent mowing that occurs in turf systems, therefore grass grown will not be as intense. It is suggested that on-going research be undertaken to determine the long term behaviour of infiltrative capacity and pollutant removal of grassed systems.

A range of plant formats are used to establish rain gardens, the most common formats being 150mm pots and tube stock. Figure 3-21 shows an example of a hiko tube, forestry tube and 150mm pot. The 150mm pot is significantly larger, with both greater shoot and root growth. Larger stock is typically used to provide an immediate impact at the time of construction. In the long term, there is no difference in the mature size of plants regardless of their container size at planting. The use of 150mm stock will typically reduce the plant establishment period by 12 months. The reduced plant establishment period comes at an increased maintenance cost as larger plants suffer a greater degree of transplant shock and will require more frequent watering. Larger plants are also more expensive, an issue which is explored in Section 4. It may be appropriate to use 150mm stock for border planting and tube stock within gardens.

Figure 3-21 A comparison of a hiko tube, forestry tube and 150mm container-grown plant

A variety of plant densities was observed on site. In most cases the plant densities were within the range of 4 to 6 plants per square metre. This density is considered appropriate for landscape construction as it allows the plants room for growth and maintains competition at a reasonable level. A number of recent guidelines have suggested plant densities should be greater than 8 per square metre and as high as 15. These densities are recommended to control weed growth, achieve cover sooner and encourage competition. It is considered that densities greater than 8 plants per square metre are excessive and will adversely impact the long term health of plants due to overcrowding and competition. The most effective form of weed control is considered to be the correct application of mulch and regular maintenance. This approach is not only more effective from a horticultural perspective, it is also a lower cost approach, which is demonstrated in Section 4. If ground covers are included appropriate planting densities are 4 - 6 per m for plant and 1 - 2 per m^2 for ground covers.

Many of the rain gardens are planted with a monoculture planting. Where the landscape has worked successfully, e.g. Wells Road Stage 2, the effect is striking (refer Figure 3-20 a). Other plant designs use a variety of species. There does not appear to be any significant advantage or disadvantage to establishing a monoculture.

A common observation made regarding vegetation was the lack of ground covers. Where mulch is used, it is less of an issue, as the mulch stabilised the soil surface and retains moisture. In systems with jute mat, the inclusion of groundcovers into the plant mix would help to provide a cover to stabilise the soil and retain moisture after the jute mat had degraded. Groundcovers would also increase the aesthetic appearance of pits more quickly if designed to complement other vegetation types.

Many of the systems reviewed for this study were installed during a drought period. None of them appeared to be suffering from a lack of water. This is due to them being directly to impervious surfaces, which deliver runoff to them.

The systems reviewed in this study also use indigenous plants that are adapted to Melbourne’s climatic regime, which has always included extended dry periods. In planning for drought in the establishment of landscape systems, consideration needs to be given to the duration of the planting season, which is usually confined to winter and early spring, and the requirement for additional follow up watering post planting. Given their relatively small size and connection to impervious surfaces, rain gardens are considered to be a relatively easy system to establish in a period of drought, as they will be relatively wet compared to similar terrestrial landscapes and receive more regular wetting events.

3.7. Construction Issues

The most common construction issue is the implementation of the specified filter media, which has been discussed previously. Another issue was the absence of extended detention storage due to the system not being constructed to design levels. A number of the systems had virtually no extended detention storage, which results in the system bypassing water when the extended detention storage volume is exceeded. This reduces its treatment effectiveness, as bypassed water receives no treatment. The design was often altered to reduce drops at the edge of the rain garden or around overflow pits. This is largely due to poor supervision of the works.

Construction supervisors are generally well skilled in installation of civil works and the changes to designs at the construction stage reflects a lack of understanding of the operation of the systems. Adequate supervision of biofiltration construction requires a sound understanding of critical design issues including correct filter media, use of mulch, correct levels for inlet, extended detention storage, and overflow point.

An unexpected issue observed during this study was the high number of sites where the staff responsible for the supervision of the works were no longer employed. This loss of staff and their knowledge made it very difficult to resolve issues that arose several years after the systems had been constructed as knowledge on the construction period was lacking. This loss of knowledge contributes to a limited capacity to have a successful regime of ongoing maintenance.

3.8. Maintenance Issues

Maintenance is related to the condition of the civil works and landscape. Civil works generally require minimal maintenance apart from checks to ensure drainage function.

Landscape areas require ongoing maintenance to:

- Control weeds;
- Remove litter and sediment;
- Trim and de-thatch plants;
- Replace plant losses; and
- Maintain design levels.

The level of maintenance required also varies throughout the life of a project with more maintenance required in the two years immediately following construction (establishment period). This review has considered longer term maintenance costs as these will be of more interest to landscape managers in local government. The costs of post-construction maintenance are discussed in Chapter 4.

Of the sites inspected two had excessive weed growth. In each case it was not thought to be as a result of poor maintenance technique but rather a lack of maintenance activity. In one case, it is understood to be due to a community group not undertaking maintenance and in another poor hand over of an asset from the construction phase to maintenance. The only other sites with weeds were where mulch had not been used or it had been displaced, i.e. timber mulch had been used and it had floated away. The lack of mulch allowed weed germinants to establish on the bare ground.

Vegetated rain gardens tend to trap litter within the vegetation, with much of the litter being leaves. The rain gardens also collected differing amounts of street litter depending on the surrounding land use. Sites near schools, e.g. Fowler Street, or in inner city industrial areas, e.g. Cremorne Street, were collecting more litter. Some rain gardens in Cremorne Street were also collecting large sediment loads, which is thought to be due to construction works within the street. These works required the removal of a large volume of soil from the construction site, with some being transported onto the road and subsequently into the rain gardens.

Inappropriate maintenance of the vegetation had resulted in damage to plants and plant deaths in some cases. The most common form of maintenance damage was excessive trimming of plants (Figure 3-22). Whilst some plants, such as the poa species, require regular trimming and de-thatching to maintain vigour, most do not. It is recommended that the condition of the plants be monitored and they be cut back and de-thatched when they have built up large quantities of dead organic material. Other than poas, it is unlikely that the most common suite of plants used as described in section 3.6.2 would require trimming in the first 5 years of their life and in many cases it would be more than 10 years.

Plant deaths had also occurred from herbicide overspray. When herbicides are used to control weeds, poor technique or inaccurate application often leads to plant deaths or impacts. The sites where overspray occurred were also where there was poor delineation between the rain garden and surrounding landscape, i.e. where there was no edge strip. The lack of edge strip requires spraying immediately adjacent to the plants, increasing the risk of overspray.

Little replanting had occurred across the sites. This is considered to be largely due to sites being less than 5 years old and not requiring replanting. Replanting should be a part of regular maintenance, as all sites will eventually suffer some plant losses.

Figure 3-22 An example of plants that have been trimmed excessively

3.8.1. Maintenance Costs

Well functioning rain gardens require a maintenance regime similar to that required for other gardens beds. As a result many new rain garden areas have been assimilated into Councils' maintenance regimes. Based on this finding it is recommended that any estimate of future landscape maintenance cost be based on current maintenance costs for similar landscapes within the municipality.

For rain garden beds the quoted maintenance costs vary from $3.80 to $20 per square metre of garden bed per year, with an average value of $11.16/m^2/year. The high degree of variability reflects the location of different sites and the maintenance input required. It should also be noted that some maintenance costs were estimated rates and may not reflect what was occurring.

The maintenance regime of sites varied from a weekly visit for a high profile site to a 13 week cycle for a residential street. It is considered that the maintenance frequency is a reflection of the surrounding landscape's maintenance requirements as much as the maintenance requirements of the rain garden. For example, a site in a high profile location such as a foreshore reserve will require more frequent visits than a residential street.

One grassed system was reviewed and had an estimated maintenance cost $0.50/m^2/year. This very low maintenance cost reflects the low cost of mowing large grassed areas.

4. Discussion

4.1. Master Planning

Successful projects demonstrated that a master planned approach had been adopted to the design, construction and maintenance. Master planning is considered to include all aspects of the project, not just how the system will be fitted into the street. A number of projects were reviewed that had difficulties because they were developed and implemented in one part of Council and then transferred to another for maintenance at a later date.

Prior to commencing a project it is recommended that all groups within Council responsible for the implementation and operation be identified and consulted. A consultation strategy for these interest groups should be developed and implemented throughout the project to ensure all groups benefit from the lessons learned in completing the project and institutional capacity is increased.

By encouraging participation across the organisation an integrated set of skills will inform the outcomes. These participants should include but not be limited to civil and water quality engineers, landscape architects, urban designers and a traffic engineer, where applicable. Experience in the current water quality programs at Melbourne Water have identified this collaboration as an important phase to the success of master planning water quality projects.

In terms of design, projects are more successful when the treatment measures form part of a master plan for a street or precinct. This approach avoids conflicts between existing and proposed land uses and desired outcomes. During the master planning process, decisions regarding issues of vertical geometry, layout and plant selection need to be made, with design, construction and maintenance staff likely to have varying views on each aspect.

4.2. Civil Design

A large amount of design development has occurred over the duration of the projects reviewed during this study, with lessons being transferred from early adopters to others. Key findings and recommendations are:

- Correct sizing to meet best practice objectives requires use of modelling software such as MUSIC;
- Grade changes are most efficiently accommodated via vertical steps, rather than batters; and
- Delineation of the garden beds via edge strips and mulched areas defines the beds and eases maintenance.

4.3. Filter Specifications

As was demonstrated in the results section, many of the rain gardens have infiltration rates below the desired design range. This is largely due to inappropriate filter materials and mulch being used. These materials were used for the following reasons:

- Specifications either being insufficiently detailed or being incorrectly interpreted; and
- Lack of testing by contractors or Council supervisors to confirm filter media met the specification.

In many cases the filter is specified via an infiltration rate and a descriptor, typically sandy loam. In many cases a sandy loam material has been sourced and used without testing its infiltrative capacity. Therefore it should be common practice for all filter materials to be tested prior to use to confirm their infiltrative capacity meets specifications and the required horticultural properties.

In light of these findings the following guidelines have been developed to aid in the development of recommendations. The guidelines have been developed with input from Sportsturf Consultants and a review of the United States Golf Association (USGA) document "Recommendations for the Establishment of Putting Greens" and the guidelines recently published by the Facility for Advanced Water Biofiltration (FAWB). This combination of documents has been reviewed to provide a specification that is robust and can be readily implemented. It is acknowledged that it may appear overly prescriptive, but the experience of the review of existing systems has demonstrated that a greater degree of prescription is required to achieve appropriate outcomes.

The rain garden specification consists of the following layers:

- Mulch – to suppress weeds and retain moisture within the underlying filter media;
- Filter – soil layer which acts as a pollutant filter and supports plant growth;
- Transition Layer – layer to separate filter layer from the drainage layer to avoid clogging of drainage pipe; and
- Drainage Layer – relatively free draining layer containing perforated drainage pipe.

The following sections provide a background to the specification and outline the key parameters of the specification. A stand alone specification is contained within the report Appendices.

4.3.1. Mulch

It is recommended that the top layer of the filter should be covered with a 50 to 75mm thick layer of stone mulch. Stone aggregate is recommended as it will not be displaced by water and will not adversely affect hydraulic conductivity of the system. Stone aggregate should be screened and contain no fine material. 100% of the particles should be in the size range 5 – 13mm. Stone may be of granite or basalt origin and should be clean and sound.

The choice of aggregate source should give consideration to the aesthetics of the rain garden and the source of the mulch. It has been assumed that quarried material will be used in most cases, as it is readily available and can be easily specified. The source of materials should also be considered as some materials, e.g. river pebbles, may not be considered to be sustainable. The use of recycled materials has not been investigated, however care should be taken in using recycled concrete due the potential for high levels of alkalinity, which could adversely affect plant growth.

Mulch is to be installed in a 50mm to 75mm layer across the surface of the filter. Mulch shall be raked to a clean, even, neat appearance and kept clear of plant stems to avoid collar rot.

Jute mat is not recommended as there is concern regarding its hydraulic conductivity and aesthetics. If designers wish to use jute they need to confirm it will have sufficient hydraulic conductivity to not impede infiltration into the filter. It is also recommended that designers include groundcovers in the plant mix to provide a natural cover for the filter as the jute degrades.

4.3.2. Filter Media

The filter has two requirements:

- Drain at an appropriate rate to ensure desired pollutant removal is achieved; and
- Support plant growth.

The material can be of siliceous or calcareous origin. To meet the hydraulic conductivity and grading specification, the filter material is likely to be a quarry product that has been mined and processed (washed). Washing is required to remove fines from the quarried material. Natural soils or topsoils are not considered suitable due to their variable physical characteristics and potential to contain weed seeds. It is also unlikely that site soils will be suitable for filter construction.

Filter materials shall have a saturated hydraulic conductivity in the range of 100 – 200mm/h. This is a critical element for a bioretention system. Hydraulic conductivities higher than this will not allow adequate time in the filter for pollutant uptake, while hydraulic conductivities below this range are more susceptible to clogging over time and regular bypass due to detention capacity being exceeded.

Hydraulic conductivity testing should be conducted to ensure the material has an appropriate hydraulic conductivity prior to accepting the material. The filter material is required to support plant growth, therefore its horticultural properties need to be assessed prior to planting. This study recommends the use of washed products for the filter. Washed products have low fertility and require amelioration to support plant growth. The recommendations provided here are general recommendations that will be suitable for most washed sands.

The testing of horticultural properties is required to ensure the soil will not inhibit plant growth. In many cases the soil supplier will be able to supply this data. As a minimum the following should be defined prior to the material being used:

- pH: The pH of washed sands are typically in the range of 4 – 7, with a desired range of 5.5 to 7.5. The rate of addition will need to be defined by a soils laboratory.

- Electrical conductivity (< 0.17mS/cm)
- Total Salts (<500ppm)

To support plant growth the top layer (75mm) of the filter will need to be ameliorated prior to planting. Amelioration includes addition of a range of fertilisers and trace elements and mixing into the top 75mm of the filter prior to planting. It is important to note that the addition of nutrients is a one-off occurrence and is extremely important to the successful establishment of the plants.

The following is an example of a soil amelioration that has been used successfully in recent rain garden projects.

- Agricultural lime - rate to be determined depending on pH of selected soil
    - o 10- 30kg/100m^2 (indicative range).
- Granulated chicken manure at 50kg/100m^2
- Superphosphate at 2kg/100 m^2
- Magnesium Sulphate 3kg/100 m^2
- Potassium Sulphate 2kg/100 m^2
- Trace Element Mix 1kg/100 m^2
- Fertiliser NPK 16.4.14 at 4kg/100 m^2

In considering the appropriateness of soil amelioration, concerns are often raised regarding the impact of adding nutrients, i.e. phosphorus (P) and nitrogen (N), to a system that is intended to remove them. The ameliorants above result in the addition 19 grams and 26 grams of P and N, respectively to each square metre of the filter surface. By comparison, a filter designed to meet best practice captures 26 and 110 grams of P and N per year per square metre of filter. Thus the impact of the amelioration is a very small proportion of the load captured by the filter during its lifetime.

4.3.3. Transition Layer

A transition layer is required when the drainage layer is fine gravel. A transition layer is not recommended when the drainage layer is coarse sand. The transition layer should be a sand/coarse sand material with a higher hydraulic conductivity than the filter layer, generally applied in a 100mm layer. A suitable product is VicRoads A2 filter sand (VicRoads) with 90% of particles retained above 0.25mm.

Geotextiles or other filter fabrics are not recommended for separating the filter layer from the drainage layer, as they are prone to clogging.

4.3.4. Drainage Layer

The drainage layer should be 150mm to 200mm in thickness. Suitable materials include coarse sand (coarser than transition layer) or fine gravel in the range of 4mm – 7mm. A typical particle size distribution for a gravel based system is tabulated below.

Table 4.1 Recommended particle size distribution for drainage layer

Particle size (mm)	% Retained
Greater than 7.0	0
4.0 - 7.0	greater than 70
2.0 - 4.0	less than 20
Less than 2.0	0

When specifying the source of gravel for the drainage layer, the use of scoria should be avoided as scoria has the potential to break down, creating fines which will block the drainage layer.

The agricultural pipe is to be placed on an even bed of 20mm depth of aggregate over the base and to be surrounded and covered with a minimum 20mm depth of aggregate over the pipe. Depending on the size of the drainage pipe and thickness of the drainage layer, some localised mounding over the top of the drain may be required. The pipe diameter should be sized appropriately relative to inflow. Oversized pipes increase drainage layer depth and reduce the thickness of overlying layers.

Agricultural pipe can either be slotted HDPE pipe or flexible agi pipe. Agi drains should not be installed with filter socks as these are prone to blocking.

4.4. Vegetation Selection

When functioning well, rain gardens can support a wide variety of grasses, lilies, shrubs and trees. As with many urban landscapes, issues of water logging, foot traffic, rubbish/debris, maintenance, and weed invasion were found to be the principal factors affecting plant performance.

Infiltration beds that function within the ideal range – (i.e. draining at 100mm to 200mm per hour) will support most terrestrial plants found in free draining to moist soils. The recommended plant list provided below was selected using the following criteria:

- Indigenous to the Melbourne area (check references such as *The Flora of Melbourne* for localised detail);
- Ornamental value, i.e. form, growth habit and colour;
- Proven durability in the landscape;
- Habit of growth conducive to dealing with debris and sediment from stormwater; and
- Fast growth to close out weeds and have quick visual impact.

Plants naturally occurring in sandy soils, and with the ability to deal with short periods of inundation were favoured (for example Spinifex, Leucophyta and Ficinea). Deep rooted, rhizomous or spreading plants were also given preference as these are features which aid the function of infiltration systems by providing sites of microbe activity and aerating filter media.

Dianella tasmanica at Wells Road, Dianella caerula at Railway Walk and Correa mass plantings at Docklands Point Park are three successful landscapes where plants usually found in free draining soils are growing well in rain gardens. Moreover these species can act as indicators of system function. The use of sedges and rushes *Carex, Juncus* and other semi-aquatic species has been quite successful (for example Cremorne Street) however, these plants will still perform as infiltration rates drop and will not act as indicators of poor system function (i.e. clogging of filter media).

The use of shrubs in rain gardens can act as a border around the edge of the plot to minimize foot traffic and protect pedestrians against the drop off into the bed. Shrubs are long lived and when used correctly will require less maintenance than sedges or tussocks as they do not require trimming of de-thatching.

Feature trees in rain gardens increase the aesthetic appeal of such measures when executed well, and can tie the WSUD into the streetscape.

The majority of the sites within the study area are monoculture plantings, many resulting in a positive impact on the landscape. Some of the groundcovers listed in Table 4.3 could be used to fill the gaps between tussock style group plantings. These groundcovers are flowering and will break up the thick leafy appearance of sedges and tussocks with annual flowers as well as reduce the opportunity for weed infestation.

Mixed species plantings provide some contingency for plant die-off. All species may establish, but if some species do not cope with the site conditions their position is soon taken up by those species that are coping well. On the other hand, if a monoculture planting does not cope with site conditions, then the entire landscape of that stormwater measure may fail.

With appropriate filter media a large range of indigenous, native and exotic plants will be successful in rain gardens. Plants not listed in the recommended list may be appropriate for planting in rain gardens. It is advisable to seek horticultural advice when selecting plants.

Table 4.2 Recommended sedges, grasses and rushes

SPECIES	COMMON NAME	SIZE	COMMENTS
Gahnia sieberiana	Red fruited Saw-sedge	1m to 2m	Thick attractive foliage with flowers held on stalks above leaves. Used successfully in landscapes, including Cremorne St, Richmond and Hallam Bypass. Tolerates free draining to wet soils.
Carex fascicularis		Up to 1m x 1m	Requires moisture. Grows fast, producing lush green foliage.
Carex appressa	Tall sedge	Up to 1m x 1.2m	Tolerates dry periods better than most other Carex species. Forms thick tussocks.
Carex tereticaulis	Common Sedge	Up to 1.5 m, generally 0.8m	Long lived. Erect fast growing sedge preferring wetter sites.
Carex gaudichaudiana	Tufted Sedge	Up to 80cm generally 50cm tall and spreading	Creeping Carex with attractive foliage. Performing very well at Cremorne St.
Juncus spp. amabilis, gregiflorus, pallidus, krausii	Rush	From 30cm to 1.5m	A large group of species, some tolerating dry periods or fast draining soils better than others. Growing in tussocks and responding to pruning with new flushes of growth.
Ficinia / Isolepis nodosa	Knobby club-rush	70cm x 70cm	Generally grows well under a wide variety of conditions. Responds well to pruning. Successfully used in many landscapes, including Ricketts Point

Table 4.2 Recommended sedges, grasses and rushes - continued

SPECIES	COMMON NAME	SIZE	COMMENTS
Lomandra longofolia	Spiny headed mat-rush	Up to 1 x 1m	Used widely across many landscapes. Tolerates harsh conditions once established, forming thick swarms when the tussocks are planted in groups.
Dianella tasmanica	Tasman Flax-lily	Up to 1m	Proven success in WSUD where drainage is adequate.
Dianella revoluta	Black Anther or Spreading Flax-lily	0.5m and spreading	Tolerant of shade and dry periods. Does not like water logging or heavy pruning.
Dianella longifolia	Pale or Smooth Flax-lily	0.6m	Tolerates conditions damper than D. revoluta but does not spread with rhizomes, instead forms tussocks with attractive purple flowers.
Dianella caerulea	Paroo Lily	Up to 1.2m	Successful at Railway Walk, Cheltenham. Spreading and tolerating deep shade and wet soils.
Distichlis distichphylla	Australian Salt grass	5 – 20cm high and spreading	Forms a thick mat with long creeping rhizomes. Naturally occurring in moist, saline and sandy soils.
Spinifex sericeus	Spinifex	60cm high and long creeping	Fast growing and spreading grass, native to coastal Melbourne. Naturally occurring in sand.

Table 4.3 Recommended ground covers

SPECIES	COMMON NAME	SIZE	COMMENTS
Myoporum parvifolium broad leaf form	Creeping Boobialla	To 20cm high and spreading	Ornamental and vigorous ground cover with a good display of flowers. Suitable for a monoculture planting.
Calocephalus lacteus	Milky Beauty-heads	To 20cm high and spreading	White daisy flowers held on short stalks. Forms a thick mat. Tolerates water-logging and drying out once established. Attractive fragrant foliage. Suitable for a monoculture planting.
Carpobrotus modestus	Inland Noon-flower or Pigface	Prostrate, spreading 1 to 3m	A spreading succulent perennial with immense purple flowers. Salt and drought tolerant. Occurs naturally in sandy soils Suitable for a monoculture planting.
Mentha australis	River Mint	About 50cm high and spreading	Requires moist soils. Spreads fast and will quickly fill in gaps between grasses and sedges.
Whalenbergia spp	Bluebells	15 to 40cm high and spreading	Attractive flower, useful for quickly filling gaps between tussocks. Self-seeds readily.
Pratia perdunculata	Matted Pratia	Prostrate 2 to 3m	Likes short periods of inundation. Flowers well in full sun.

Table 4.4 Recommended small shrubs

There are many shrubs that could be used either as a feature in a rain garden or as a mass planting. The list below has been selected as they are small ornamental shrubs, with proven ability to perform in streetscapes.

SPECIES	COMMON NAME	SIZE	COMMENTS
Leucophyta brownii	Cushion Bush	0.2 – 1.2m x 0.5 – 2m wide	Dense rounded shrub with whitish grey leaves. Responds well to pruning and maintains a neat dense form.
Correa spp	Correa	0.2 to 1.5m x 0.8 to 2m wide	Small shrubs with attractive flowers and compact ornamental habit. Working very well at Docklands Point Park.
Senna artmisioides	Desert Cassia	1 – 3m x 1m wide	Small to medium shrub with bright yellow flowers responding well to pruning if required.
Goodenia ovata	Hop Goodenia	1– 2.5m x 1–3m wide	Used widely in many landscapes. Bright green and appreciates moisture in free draining soils.
Spyridium parvifolium	Dusty Miller	1 – 3m x 1 – 2m wide	This compact small shrub flowers for most of the year, preferring free draining soils.

Table 4.5 Recommended small trees

SPECIES	COMMON NAME	SIZE	COMMENTS
Allocasurina verticillata	Coast or Drooping She oak	4 – 11m	Erect tree with drooping branchlets.
Acacia melanoxylon	Blackwood	5 – 30m	Lush green foliage with a bulky canopy on a straight trunk
Acacia implexa	Lightwood Wattle	5 – 15m	Fast growing small erect tree, often used as a street tree and in landscapes.
Bursaria spinosa var spinosa	Sweet Bursaria	2 – 6m	A long lived small tree with fragrant flowers.
Allocasurina littoralis	Black She oak	4 – 8m	Erect small tree with attractive deeply fissured bark.

4.4.1. Landscape Construction Costs

The review of landscape construction costs is provided as it is thought that many Councils will require this data. In reviewing design costs it is recommended that implementation costs be considered as they can provide guidance on the most efficient way to proceed. For example market rates for supply and installation of common items are:

- Mulch
  - Jute $6.50/m^2
  - Rock Mulch $6.00/m^2 (50mm depth)
- Plants
  - 150mm $7.00 each
  - Tube stock $2.00 each

At the densities recommended in the design section, costs associated with establishing a square metre of garden bed is as follows:

- 150mm pots
  - 4 plants per square metre 4 @ $7 each $28/m^2
  - Mulch $6/m^2
  - Total Cost $34/m^2
- Tubestock
  - 6 plants per square metre 6 @ $2 each $12/m^2
  - Mulch $6/m^2
  - Total Cost $18/m^2

These cost estimates indicate that significant savings can be made if large plants are not required immediately. Large plants in an urbanised setting contribute to the protection of the system from traffic as well as provision of barriers for safety. A combination of larger plants for borders and tube stock for plantings may be appropriate.

Similarly recommendations of planting tube stock at high densities e.g. 8 to 12 per square metre are not recommended as the cost of additional plants is more than offset by providing mulch. As outlined earlier, mulch is also more effective at retaining moisture and suppressing weeds than high density planting.

The pricing of civil works is considered to be relatively simple as much of the work (e.g. kerb and channel and drainage construction) is regularly undertaken by Councils. The only new element is the construction of the filter. For large scale systems the construction cost is approximately $75 to $100 per square metre.

Many of the systems outlined in this study are very small and due to the complicated nature of the works and the additional costs associated with doing works by hand and deliveries of small quantities of materials, the costs will rise. It is recommended that a cost of $150 - $200 per square metre be adopted when estimating the cost of a four layer system. This includes all materials and labour to construct the filter.

4.5. Construction

Appropriate supervision is essential to ensure a well implemented outcome in any constructed element. In most of the projects reviewed as part of this study the implementation of the works was supervised by Council Officers who were usually responsible for civil works. Their experience is reflected in the civil works in nearly all cases being constructed to a high standard. However, the landscape works, in particular filters, have been implemented poorly, with very few of the rain gardens performing adequately. In most cases the poor implementation has been as a result of the specification being partially adopted or incorrectly adopted.

At a minimum the following areas of the works should be checked or confirmed as works proceed:

- Connections to drainage system, including sub-surface drains and overflow pit;
- Levels of inlet, overflow pit, and extended detention area base;
- Filter details to confirm they comply with the specification;
- Placement of the filter to appropriate levels;
- That any amelioration required has been undertaken in accordance with the recommendations; and
- The grading of the extended detention area is in accordance with the design and appropriate storage volume has been provided.

The level of understanding of the technology by those responsible for its implementation should not be over-estimated, as it was frequently found that contractors and Council Superintendents did not understand the functional requirements of the rain garden. At the commencement of any project, particularly where the supervisor or contractor have not demonstrated they have experience in constructing rain gardens, an information session should be conducted to fully inform the contractor of the particulars of the project. Additional consultation is also required as the project proceeds.

4.6. Maintenance

Appropriate maintenance is essential for the long term viability and aesthetics of any landscape feature. Correctly established rain gardens, should require the same maintenance as adjacent garden beds.

4.6.1. Post Construction Maintenance

The period immediately following construction is essential for the successful establishment of landscape system. During this period a range of works will be required including:

- Watering - as required;

- Control of weeds – a monthly visit required;
- Removal of litter and sediment – as required; and
- Replacement of plant losses – 10% to 15% of initial plantings.

These costs are typically the responsibility of the contractor and will cost between 10% and 25% of the soft landscape (planting and mulching works) construction cost per annum. The higher cost is associated with small sites, which will often involve significant mobilisation costs.

The duration of post construction maintenance is generally two years for large projects. For smaller projects, a shorter maintenance period may be appropriate if Council has the resources to undertake maintenance. If Council takes over the site after an initial six month maintenance period, the cost of maintenance will be reduced as the landscape can be maintained using local resources with no additional travel costs. Commercial landscapers also have to make assumptions regarding the proportion of re-plants, watering and weed control. As a result establishment phase maintenance cost estimates provided by contractors generally include contingencies, as contractors need to recover costs for all works undertaken.

4.6.2. Long Term Maintenance

Long term maintenance is required to ensure the ongoing aesthetics and function of rain gardens. The long term maintenance functions for a rain garden are listed in Table 4.7, which lists the elements to be maintained and the approximate maintenance frequency. The maintenance activities are divided into the following key areas:

- Aesthetics;
- Horticulture;
- Damage; and
- Inspections.

These categories have been chosen, as they will need to be differentiated between sites to gain an understanding of the estimated maintenance cost. The review of existing rain gardens found significant variation in the estimate of maintenance costs.

For each activity within Table 4.6 a range of maintenance inputs is defined. The ranges reflect the findings of the site review for typical urban and industrial areas. It should noted that in some cases the maintenance regime will require a significantly higher frequency of visits due to the nature of the site, i.e. a high visitation local park.

Table 4.6 Recommended Maintenance Actions and Frequencies

Action	Frequency	Comment
Aesthetics		
Litter & Organics removal	As required, typical range 12 to 18 visits per year	Highly variable depending on landscape site.
Sediment removal	As required, would only be expected if new sediment source present in catchment, e.g. construction works	Works adjacent to rain gardens should be monitored and builders asked to desilt any rain gardens affected.
Vegetation		
Weed Control	6 to 8 visits per year	More spraying will be required for areas with poor mulch cover.
Replanting	5% per year after first two years of maintenance	The replanting regime assumes plants will be replaced progressively.
Mulching	Top up annually if required	Mulch should require minimal top up if installed correctly. Ensure levels are not modified from design.
Damage	Repair accidental and deliberate damage as required	Will vary from site to site, less than 10% of construction cost per annum.
Inspections		
Functional elements	Every 5 to 10 years and inspection of drainage elements is undertaken.	This should be similar to scope outlined in WSUD Engineering Procedures: Stormwater.
Landscape	Every 5 to 10 years and inspection of the landscape is undertaken.	A review of the aesthetics and physical condition.
Infiltration	Every 5 to 10 years, an in situ infiltration test should be undertaken.	Representative in-situ infiltration tests should be taken across the site to confirm infiltration rate. If the infiltration rate is below 50mm/h, the filter should be replaced.

To provide a guideline on the expected range of costs, estimates were made of the upper and lower range of maintenance costs. The cost estimates were based on the following assumptions:

- The cost of labour was $30 per hour including vehicle;
- The site had 150m^2 of rain gardens and landscaped areas;
- A maintenance visit was one hour with two staff, including travel, with frequency defined in Table 4.6;
- Re-planting used tube stock @ $2.00 each and replanting occurred during routine maintenance activities;
- Civil and landscape inspections were allocated four hours each. They were undertaken at 5 and 10 year intervals, depending on the level of maintenance. Costs were distributed on an annual basis; and
- Infiltration investigations were $1,600 each and undertaken at 10 and 5 year intervals, with costs distributed across each year, i.e. annualised.

Estimates of maintenance costs per square metre of rain garden are outlined in Table 4.7. The figures are based on activities and frequencies defined in Table 4.6 and indicate maintenance will be in the range of $8.76 to $13.25/m^2 per annum. The major costs are associated with maintenance of the aesthetics, i.e. litter pick up and annual inspections. If Councils are seeking to save money on maintenance it is suggested they review the level of visitation for litter pick up and the requirement for annual inspections. The frequency of inspections and infiltration tests could probably be reduced with little impact on the function of the system. The cost to maintain the vegetation is relatively low and is considered to be essential to the ongoing aesthetics and function of the system. If maintenance costs are to be cut, vegetation maintenance should be the last to have its frequency reduced. Failure to keep sites weed free will result in the loss of plants and require replanting of rain gardens at significantly higher cost than maintaining them.

Table 4.7 Estimated annual maintenance costs per square meter of rain garden

Activities	Lower Cost	Upper Cost
Aesthetics	$ 4.80	$ 7.20
Vegetation	$ 3.00	$ 4.13
Damage		
Inspections	$ 0.96	$ 1.92
Total	**$ 8.76**	**$ 13.25**

The estimated costs assume maintenance works occur independently of other landscape maintenance activities. In many cases, street scale WSUD devices are a component of a larger landscape and therefore the area to be maintained will be larger. This should reduce the overall maintenance cost as maintenance between the WSUD and adjacent landscape can be coordinated reducing time lost to travel.

5. Conclusions and Recommendations

5.1. Site Investigation Findings

Site inspections were undertaken at 22 street-scale water sensitive design sites across Melbourne. The objectives of the inspections were to:

- Review stormwater treatments that have been retrofitted to determine which factors contribute to the successful implementation of street-scale WSUD and factors which have impeded successful implementation; and
- Use these findings to develop recommendations for use in future projects to improve the implementation of street-scale WSUD.

The results of the site inspections are summarised in Table 5.1 which summarises the findings for all sites investigated. Green shading indicates good condition or function, orange moderate and red poor.

The results indicate that civil works were generally well constructed and weeds and litter were generally well managed. The cases of moderate civil construction were related to poor treatment of batter slopes and inadequate extended detention depth being provided. Another issue identified with civil construction was the selection of gravel mulches that contained fines, which formed a compacted and relatively impermeable crust over the surface of the rain garden.

The sites with moderate weed growth were considered due to a combination of insufficient maintenance and poor mulch coverage. The sites with poor weed condition were as a result of maintenance not being conducted.

The litter rating is reflective of land use, with the sites with poor or moderate litter ratings being in areas of naturally high litter loads, i.e. inner city areas and areas of high pedestrian traffic.

The biggest issue identified in the site inspections was poor filter function. Infiltration tests were conducted in-situ and in the laboratory across many of the sites to quantify infiltration rates. The infiltration tests were a collaboration between Land and Water Constructions and FAWB. The results of the infiltration tests are summarised in Figure 5-1 and show that more than half the sites tested had infiltration rates below 40mm/h. These results indicate that many rain gardens are not functioning appropriately and will not be achieving their intended design pollutant removal. The poor performance is thought to be due to inappropriately selected filter materials, with topsoil material being used in many rain gardens. Topsoils are likely to contain too high a proportion of fine grade materials, which leads to low infiltration rates and reduced system performance.

Table 5.1 Summary of site investigation findings

No.	Location	Civil Works	Plant Condition	Filter	Weeds	Litter
1	Wells Rd- Stage 1	Good	Good		Good	Good
2	Riviera St	Good	Moderate		Good	Good
3	Railway Walk car park	Good	Good		Good	Moderate
4	Fowler St	Good	Moderate	Poor	Moderate	Moderate
5	Stawell St	Good	Moderate	Poor	Good	Good
6	Wells Rd- Stage 2	Good	Moderate	Moderate	Good	Good
7	Brisbane Tce	Good	Moderate	Poor	Good	Good
8	Peter Scullin car park	Moderate	Good	Poor	Good	Good
9	Mernda Ave	Moderate	Poor		Good	Good
10	Alleyene Ave	Good	Poor	Poor	Good	Good
11	Voltri St	Good	Poor		Good	Good
12	Cremorne St	Good	Good	Good	Moderate	Poor
13	Howe Parade	Moderate	Moderate	Good	Poor	Moderate
14	Doncaster Park and Ride	Good	Good		Good	Good
15	Ricketts Point car park	Moderate	Good	Moderate	Good	Good
16	Docklands street tree biopits	Good	Good		Good	Good
17	Docklands Point Park car park	Good	Good	Good	Good	Good
18	Rowville Community Centre car park	Good	Good		Good	Good
19	Parker St	Moderate	Good	Poor	Good	Good
20	Hamilton St	Moderate	Good	Poor	Good	Good
21	Inkerman D'LUX	Good	Good		Good	Good
22	Wittons Reserve	Moderate	Poor		Poor	Moderate

Please note: Blank cells indicate not defined or not part of design.

	Good		Moderate		Poor

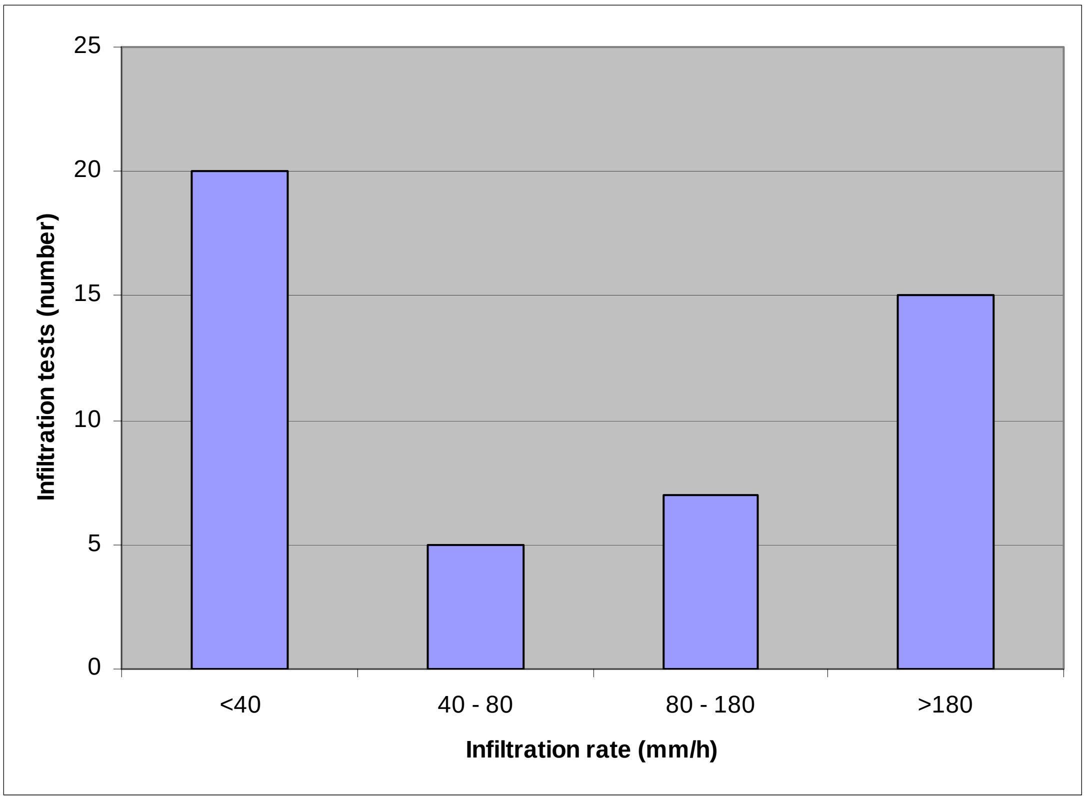

Figure 5-1 Distribution of infiltration rates measured

(Please note: graph includes data from FAWB and Land and Water Constructions.)

The plants selected across the sites fell into two broad categories:

- Terrestrial plants that are normally used in well drained situations; and
- Semi aquatic plants that grow in periodically inundated areas.

Plant growth was variable across the sites, with poor growth often linked to poor filter function or water logged soils. In this regard terrestrial plants, e.g. Dianella species, were found to offer an advantage as they demonstrated poor growth if the filter had low infiltration rates. The poor growth prompted managers to investigate reasons for the poor growth, which subsequently led to the filter function being identified as being of concern. Where semi-aquatic plants were used in filters with low infiltration rates, the plants did not demonstrate poor growth. It is considered that the use of some plants which prefer well drained conditions is appropriate, as they will indicate poor filter function.

No plants were found to be suffering stress from a lack of water despite the drought conditions during the study. This indicates that the direction of additional runoff to rain gardens contributes to their long term health.

5.2. Rain Garden Construction

Appropriate construction requires construction supervisors to be informed of the critical design aspects of rain gardens and to undertake appropriate checks during construction regarding material and civil aspects.

5.2.1. Civil Works

Civil works were generally constructed well, with the exception of the extended detention storage areas. In many cases storage areas surrounding overflow pits and near the edges of the rain gardens had been filled. The loss of extended detention storage results in reduced treatment effectiveness, as systems will bypass more frequently. This is in line with common civil construction practice and reflects previous comments regarding the need for appropriate supervision.

5.2.2. Filter Specification

In recognition that many filters are not meeting their specification a new filter specification was developed. The specification is contained in the Appendices. The underlying assumptions used to develop the specification were:

- The filter would consist of four layers:
    1. Mulch
    2. Filter
    3. Transition Layer
    4. Drainage Layer
- The specification would be relatively prescriptive to provide Council Officers with a robust specification to ensure rain gardens could be constructed relatively simply.
- The approach assumes that a washed sand product will be used for the filter layer rather than a topsoil. As a result amelioration of the top layer of the filter will be required to support the initial plant growth.
- A testing regime is also provided to guide works supervisors on the appropriate test methods for all materials.

5.2.3. Plant Selection

As outlined earlier a wide variety of plants are suitable for use in rain gardens. Recommendations for a variety of plants varying from ground covers to trees are made in Section 4. The final species selection will be determined by the design requirements for landscape. It is not considered that any particular plants are better suited than others, if the filter meets the specification.

5.2.4. Construction Costs

Estimates of construction costs were made for both landscape and filter elements to aid in the costing of projects. The estimated costs are as follows:

- Landscape
    - 150mm pots - $28 per square metre (4 plants)
    - Tubestock - $12 per square metres (6 plants)
- Filter - $150 - $200 per square metre of filter, includes all layers and mulch

The potential savings of planting at a higher density were also reviewed and found to be inappropriate due the higher cost and impact on the long term health of the plants. The use of mulch is considered to be a better approach than high density planting.

5.3. Maintenance

In addition to reviewing the level of maintenance across the sites and its efficacy, the study also sought to provide a cost estimate of maintenance works. Limited data was obtained of the current level of maintenance inputs, with data provided suggesting maintenance costs are in the order of $3.80 to $20 per square metre of landscape. The range of costs reflects the profile of the site to be maintained, with higher profile sites requiring greater maintenance intervention.

A typical maintenance regime was developed and costed and is contained in Table 5.2. Two maintenance regimes are proposed, reflecting the profile of various sites. The annual costs are $8.76 and $13.25/m^2, respectively, for low and high maintenance levels. Much of the maintenance cost is associated with annual inspections and litter pick up. If reductions in maintenance inputs are desired it is recommended that savings be made in these areas, rather than weed control and replanting. The coordination of the maintenance of rain gardens with adjacent landscapes will reduce the costs.

Table 5.2 Estimated annual maintenance costs per square meter of rain garden

Activities	Lower Cost	Upper Cost
Aesthetics	$ 4.80	$ 7.20
Vegetation	$ 3.00	$ 4.13
Damage		
Inspections	$ 0.96	$ 1.92
	$ 8.76	**$ 13.25**

5.4. Recommendations

A number of areas were identified for further work through this study and are summarised below:

- Knowledge Gaps
    - Jute mat – the infiltrative capacity of jute mat is unknown, given its widespread use in the landscape industry its infiltrative capacity should be better defined;
    - The effectiveness of turf grass systems – in many of the systems reviewed the use of turf grasses may have been appropriate and would result in reduced maintenance costs. The suitability of turf grasses is not known, with some turf systems e.g. golf greens, suffering from reduced infiltrative capacities over time. To allow turf systems to be adopted research is required into the long term behaviour of turf systems, for both pollutant removal and hydraulic conductivity; and
    - Maintenance Costs – it is recommended that more data be gathered regarding maintenance costs. Data should be collected by the relevant asset manager. Another agency will be required to take the lead on collating maintenance data and distributing it to the industry. The required data include for each site:
        - Physical description of the site, e.g, area and number of plants.
        - Number of visits and duration (man hours) for activities such as weed control and litter removal
        - Time and materials devoted to re-mulching and re-planting
        - Time spent on inspections.
- Existing Systems
    - Many of the systems reviewed have deficiencies that can be readily fixed. Some sites will require replacement of filter media and replanting. Other sites require regrading to provide adequate extended storage depth. Border planting or edge strips would be useful additions at some sites. All sites require regular ongoing maintenance to be undertaken.
    - Detailed recommendations of remedial works at each site are contained within Volume 2.
- Proposed Systems
    - Many of the findings of this study are suitable for application to new systems. It is recommended that when current design guidelines are reviewed that the findings of this study be reviewed and adopted, where appropriate.

6. Appendix – Filter Specifications

Rain Garden (Bioretention) Filter Specification

Rain gardens (bioretention systems) are soil based systems that treat runoff via filtration through a soil media. Successful implementation of rain gardens requires careful consideration of the soils hydraulic and horticultural properties. Effective rain gardens require planting. Plant roots promote porosity maintenance and biofilm activity for nutrient take up.

Rain gardens typically consist of the following layers:

- Mulch – to suppress weeds and retain moisture within the underlying filter media;
- Filter – soil layer which acts as a pollutant filter and supports plant growth
- Transition Layer – layer to separate filter layer from the drainage layer to avoid clogging of drainage pipe
- Drainage Layer –relatively free draining layer containing perforated drainage pipe

In some cases it may be necessary to line the rain garden to prevent infiltration into the surrounding soil. The requirements for liners are not considered in this document. Decisions made regarding their use should be made in consultation with suitably qualified professionals.

The following sections contain guidance on the specification of each layer.

Test Methods

The following test methods are to be used when conducting tests associated with this specification:

- Hydraulic conductivity – AS4419
- Particle size distribution – AS1141.11

The horticultural properties of a soil will be determined by analysis of the following by a laboratory:

- pH, desired range 5.5 – 7.5, adjust with lime if too low
- Electrical conductivity less than < 0.17mS/cm
- Total Salts, less than 500ppm

Mulch

It is recommended that the top layer of the filter should be covered with a 50mm thick layer of mulch. Stone aggregate is preferable as it will not be displaced by water and will not adversely affect hydraulic conductivity of the system. Other materials may be displaced by water or impede hydraulic conductivity (e.g. jute mat). Stone aggregate should be screened and contain no fine material. 100% of the particles should be in the size range 4 – 13mm. Stone may be of granite or basalt origin and should be clean and sound.

A sample of the proposed mulch is to be provided to the Superintendent for approval prior to installation.

Mulch is to be installed in a 50mm layer across the surface of the filter prior to planting. Mulch shall be raked to a clean, even, neat appearance and kept clear of plant stems to avoid collar rot. The finish level of the mulch is to be equivalent to the finish grade of the top of the filter to preserve the extended detention storage volume.

Filter Media

Description

The material can be of siliceous or calcareous origin. The filter material shall preferably be a “washed sand” i.e. one that has been mined and processed. Natural soils or topsoils are not preferable due to their variable physical characteristics and potential to contain weed seeds.

Soils shall have a saturated hydraulic conductivity in the range of 100 – 200mm/h. This is a critical element for a bioretention system. Hydraulic conductivities higher than this will not allow adequate time in the filter for pollutant uptake and hydraulic conductivities below this range are more susceptible to clogging over time.

Filter materials which comply with the particle size grading outlined below will generally meet saturated hydraulic conductivity specifications of 100mm/h to 200mm/h.

Description	Maximum Proportion	Grading
Clay	2 - 4%	<0.002mm
Silt	4 - 8%	0.002 - 0.05mm)

Testing Requirements

To determine whether a soil is suitable, the following tests are to be undertaken on any soil prior to its delivery:

- Saturated Hydraulic Conductivity
- Particle size distribution (PSD)

Please note: saturated hydraulic conductivity is the critical performance factor and materials which fall outside the desired grading envelope may be appropriate. If a material drains at the appropriate rate and falls outside the desired grading envelope, it appropriateness should be reviewed by a suitably qualified soil scientist.

Any sample not meeting the hydraulic conductivity specification is not to be used and another sample is to be provided for testing.

A sample of the proposed mulch is to be provided to the Superintendent for approval prior to installation.

Horticultural Properties

The filter is required to support plant growth and will require testing to determine its horticultural properties and if amelioration is required. As washed sand products are recommended, that filter media will require amelioration to support plant growth. The preferred approach is that a sample of the soil is tested to determine its horticultural properties and recommendations made regarding its amelioration by a qualified horticulturalist.

In some cases, it will not be practical to test for nutrients, e.g. for small scale projects. In these cases, the following is recommended to be incorporated into the top 75mm of the filter media prior to planting.

- Agricultural lime - rate to be determined depending on pH of selected soil, 10-30 kg/100 sq.m. indicative range
- Granulated chicken manure at 50 kg/100 sq.m.

- Superphosphate at 2 kg/100 sq.m.
- Magnesium Sulphate 3 kg/100 sq.m.
- Potassium Sulphate 2 kg/100 sq.m.
- Trace Element Mix 1 kg/100 sq/m.
- Fertiliser NPK 16.4.14 at 4 kg/100 sq.m.

Transition Layer

A transition layer is required when the drainage layer is fine gravel. It is recommended when the drainage layer is coarse sand. The transition layer should be a sand/coarse sand material, generally applied in a 100mm layer. A suitable product is washed A2 filter sand (Vic Roads) with 90% particles retained above 0.25mm.

A sample of the proposed transition layer is to be provided to the Superintendent for approval prior to installation.

The superintended may require the transition layer to be tested to determine its hydraulic conductivity and particle size distribution.

Drainage Layer

The drainage layer should be a minimum of 100 mm thick. Suitable materials include coarse sand (coarser than transition layer) or fine gravel in the range 4mm – 7mm. A typical particle size distribution is:

Particle size (mm)	% Retained
Greater than 7.0	0
4.0 - 7.0	greater than 70
2.0 - 4.0	less than 20
Less than 2.0	0

Note: Scoria is not considered a suitable material for this application.

The agricultural pipe is to be placed on an even bed of 20mm depth of aggregate over the base and to be surrounded and covered with a minimum 20mm depth of aggregate over the pipe.

A sample of the proposed drainage layer is to be provided to the Superintendent for approval prior to installation.

The superintended may require the drainage layer to be tested to determine its hydraulic conductivity and particle size distribution.

Summary of specification and testing requirements

Layer	Material	Thickness	Sat hydraulic conductivity	Tests
Mulch	Stone aggregate 5 –13mm no fines	50mm	> filter media	Visual inspection to ensure no fines
Filter	washed sand with amelioration to top 75mm	300mm minimum	100-200mm/h sat. hydraulic conductivity	Saturated hydraulic conductivity Particle size distribution Horticultural properties
Transition layer	sand/coarse sand	100mm	>filter layer	Saturated hydraulic conductivity (optional) Particle size distribution optional)
Drainage layer	coarse sand or fine gravel 2mm – 7mm	100mm minimum	> transition layer	Visual inspection to ensure no fines