University of Southern Queensland

Faculty of Engineering and Surveying

Performance of Water Sensitive Urban Design Bioretention Installations on the Gold Coast

Preliminary project report submitted by

Ms Julia McLeod

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towards the degree of

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Nomenclature and Acronyms

AHD	Australian Height Datum
ARI	Average Recurrence Interval
ASS	Acid Sulfate Soils
City	City of Gold Coast
CRC	Cooperative Research Centre
IPWEAQ	Institute of Public Works Engineering Australasia Queensland
MUSIC	Model for Urban Stormwater Improvement Conceptualization
QUDM	Queensland Urban Drainage Manual
SEQ	South East Queensland
SEQ RP	South East Queensland Regional Plan
SPA	Sustainable Planning Act
TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
WBD	Water By Design
WSUD	Water Sensitive Urban Design

Chapter 1 Introduction

1.1 Outline of the Study

Water Sensitive Urban Design (WSUD) techniques have been used for the last few decades to manage and treat stormwater runoff and protect urban infrastructure and aquatic ecosystems. Bioretention systems are one such technique that involve a depression or basin where stormwater collects and is then filtered through dense vegetation and a filtration layer reducing sediments and contaminants and slowly releasing runoff into stream systems. This research project proposes investigating existing bioretention systems on the Gold Coast to discover trends in design, construction and maintenance that are affecting their performance.

1.2 Background

1.2.1 Water Sensitive Urban Design

Stormwater runoff in urban areas can cause significant damage to downstream aquatic ecosystems due to high levels of sediments and contaminants. Water By Design (2006) highlight that untreated urban stormwater can be a key contributor to reductions in water quality and ecosystem health in waterways. Traditional stormwater management dealt with quantity of runoff, designing drainage systems that sought to convey runoff quickly and efficiently into natural waterways, with little opportunity for treatment or reuse (Water By Design 2006). Figure 1.2.1 below shows a traditional concrete stormwater channel. With increased urban development the quantity of stormwater discharged into local waterways increased, causing problems with erosion and flooding (Wong 2006). In addition, a rise in public concern for environmental issues developed, with a new focus on the quality of stormwater runoff and its impact on important aquatic ecosystems. Water Sensitive Urban Design (WSUD) is a holistic approach to management of the water cycle that aims to minimise negative impacts and protect aquatic ecosystems (Water By Design 2006). WSUD techniques gained interest in the early 1990s as they provided a valuable role in the management and treatment of stormwater to protect downstream infrastructure and environments. Furthermore, WSUD systems can enhance the aesthetic appeal of public areas and can have other side benefits in terms of climate and public health and wellbeing.

Figure 1.2.1 Traditional stormwater management

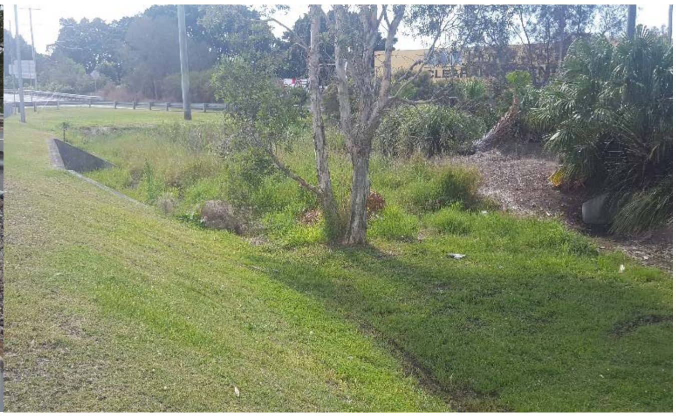


Figure 1.2.2 WSUD approach to stormwater management

WSUD changes the approach to urban planning and design by considering a site's natural features and how the opportunities and constraints can be individually designed for. Water is viewed as a precious resource and its use optimised. Water By Design (2006) lists the following six principles of WSUD:

- Protecting existing natural features and ecological processes;
- Maintain the natural hydrologic behaviour of catchments;
- Protect water quality of surface and ground waters;
- Minimise demand on the reticulated water supply system;
- Minimise sewage discharges to the natural environment;
- Integrate water into the landscape to enhance visual, social, cultural and ecological values.

The focus of this project addresses the principles above with the exception of minimising sewage discharges to the natural environment.

1.2.2 Bioretention Systems

Bioretention systems are one of the techniques used in WSUD. They consist of a shallow depression designed to collect and treat stormwater. The depression is densely vegetated with a biologically activated filtration layer underneath, usually a sandy loam (Wong 2006). The combination of oxygen from the plants that encourages microbial growth, plant uptake and the filtration layer reduce sediment loads and treat contaminants. Stormwater is temporarily detained in the depression and slowly filters through the filtration layer providing a slow release of treated runoff into stream systems (City of Gold Coast 2007).

Bioretention systems are commonly used by local governments in public areas and flooding reserves and by urban developers to meet local government stormwater management objectives. While extensive research is available on WSUD, there is limited research on actual field performance of these systems. This project aims to look at the functionality of existing bioretention systems on the Gold Coast. A review of design and as constructed documentation, onsite analysis and modelling of bioretention systems will be performed in order to discover trends in the effectiveness of these installations and ways to improve future designs.

Figure 1.2.3 Bioretention garden - Informal design (Photo: Jack Mullaly (Water by Design 2014))

Figure 1.2.4 Bioretention garden - Formal design (City of Gold Coast 2007)

1.2.3 WSUD Organisations

As well as local, state and federal government there are significant organisations that are driving the promotion of WSUD in Australia. In South East Queensland (SEQ) the main organisation is Healthy Land and Water, a not-for-profit organisation that partners with local leaders, government at all levels and community members. Their aim is to preserve natural assets for communities today and in the future (Healthy Land & Water 2017). The Water By Design team of Healthy Land and Water have produced extensive publications that include technical guidelines for design, construction, maintenance and rectification of WSUD assets that are referenced by SEQ local government in their WSUD policies.

Engineers Australia in 2006 released the Australian Runoff Quality Guide to Water Sensitive Urban Design edited by Tony Wong. Griffith University on the Gold Coast, particularly Professor Margaret Greenway, has produced significant research that has contributed to the development of WSUD. Also Monash University's Water for Liveability Centre and Cooperative Research Centre for Water Sensitive Cities contribute extensively to research aimed at living in harmony with natural water environments. These research centres have evolved from previous Monash facilities called the Institute for Sustainable Water Resources and the Facility for Advancing Water Biofiltration that, similarly to Healthy Land & Water, have produced valuable technical guidelines.

1.2.4 Gold Coast

This project focuses on bioretention systems within the City of Gold Coast (City) local government area shown in Figure 1.2.5. The Gold Coast is Australia's largest non-capital city, with around 12 million visitors each year and a population of more than 550,000 residents, expected to increase by 320,000 in the next 20 years (City of Gold Coast 2016). In fact the draft South East Queensland Regional Plan expects the population of South East Queensland increasing by two million people by 2041 and points out the importance of managing such growth sustainably (Department of Infrastructure 2016). City of Gold Coast

(2016) has long had a focus on development, with a current shift from large developments on the fringe of the city, to redevelopment of urban centres with higher density and smaller lot size development. A strategic framework is in place for the Gold Coast to become a world class city with six key themes of:

- Creating liveable places;
- Making modern centres;
- Strengthening and diversifying the economy;
- Improving transport outcomes;
- Living with nature; and
- A safe, well designed city.

WSUD addresses the themes of creating liveable places and living with nature. Rapid population growth and expansion on the Gold Coast has placed stress on our natural waterways leading to degradation of our prized water assets. City has adopted WSUD practices as part of stormwater management under the City Plan to minimise these impacts on our waterways.

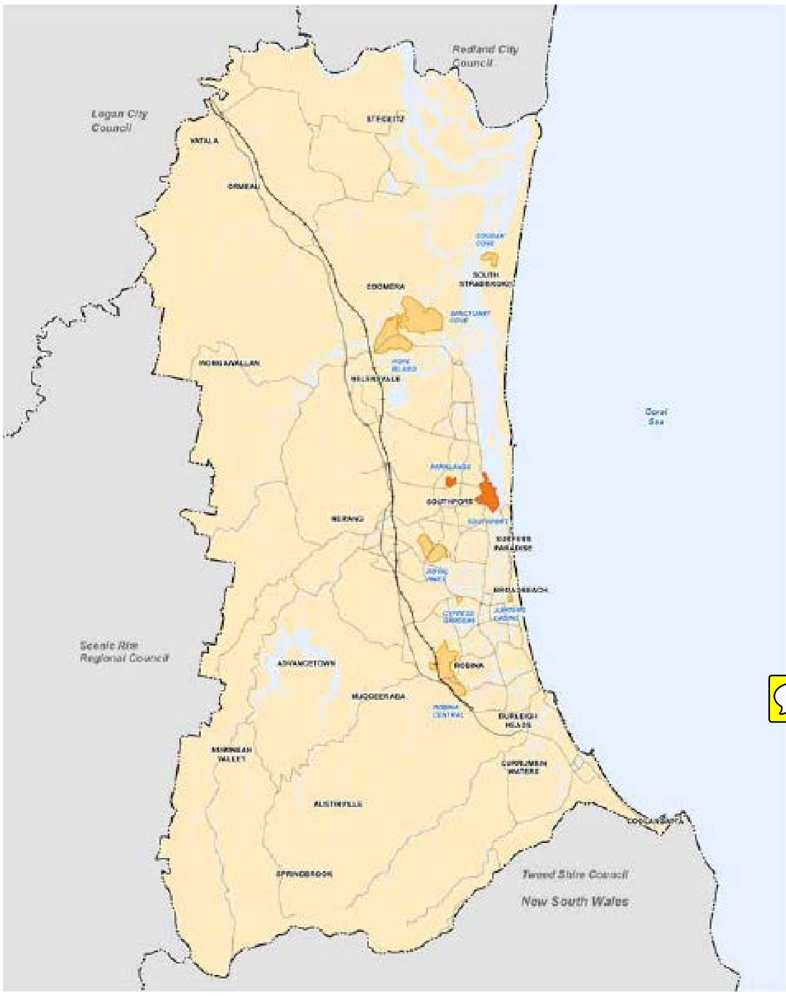


Figure 1.2.5 City of Gold Coast extent (City of Gold Coast 2016)

1.2.5 The Problem

When used appropriately, bioretention systems have been demonstrated to provide effective treatment of stormwater quality to meet management objectives and to ease the effects of the hydrologic cycle in urban environments including runoff peaks, volumes and frequencies. Despite these proven benefits, poor outcomes can still result due to inappropriate use, or poor construction, operation and maintenance practices (FAWB 2009). Bioretention gardens are a permanent fixture and will provide benefits long term as long as they are correctly designed and constructed for the local catchment and environment and maintenance ensures that the filter media and vegetation continue to operate effectively. This study aims to investigate whether design, construction and maintenance of bioretention systems are ensuring that bioretention systems are performing the role intended and meeting objectives.

1.3 Idea Development

This topic idea was developed from discussions with an environmental scientist with Calibre Consulting in Perth called Brendan Oversby. Brendan had recently helped with the research of a Master of Engineering student named Dean Huizinga, who had investigated the status and performance of bioretention systems in and around Perth. His intention was to look at the design, construction and maintenance of bioretention systems to determine common trends affecting the performance of these systems in the treatment of stormwater, flood protection and aesthetics. The aim of the research was to provide insight to help improve future design of bioretention systems.

Brendan suggested that a similar study on the Gold Coast would be interesting to determine if the trends found were backed up by a study of the Gold Coast or whether different trends were discovered. A meeting with Dean was arranged to discuss his project and methodology. A brief discussion with Dr Ian Brodie (USQ School of Engineering and Surveying) also highlighted the need to look at the unique characteristics of the Gold Coast that would affect bioretention systems.

1.4 Research Aims and Objectives

Although the use of Water Sensitive Urban Design is widespread, research into the actual field performance of these systems is limited. A field study by Le Coustumer et al. (2008) looked at the hydraulic performance of biofilter systems, particularly their hydraulic conductivity and how that affected performance. Also a thesis by QUT student Nathan Parker looked at hydrolic mitigation and stormwater quality effectiveness in a wetland and bioretention system. The aim of this research is to identify trends in the design, construction and maintenance of bioretention systems that can be used to improve future design outcomes.

The following are a list of objectives for the research project:

- Discover whether bioretention systems are being constructed as per the design documentation;
- Discover whether bioretention systems are in accordance with current local, state and federal government guidelines and regulations;
- Identify issues for existing bioretention systems that could be remediated to improve performance; and
- Identify broader trends affecting the performance of bioretention systems in order to improve future design outcomes.

The scope of this project limits the analysis of WSUD installations to bioretention systems. Other WSUD installations such as swales, sediment ponds and constructed wetlands are outside of the scope. The geographical location of the bioretention systems will be limited to the City of Gold Coast boundaries. This will limit the local government WSUD guidelines to the City Plan Version 3 (City of Gold Coast 2016).

A Geographical Information System (GIS) will be developed to collect research results for each site and the analysis of this research data will make up the deliverables for this research project, providing information on the above listed objectives. The GIS will contain the following information for each site:

- Catchment size and characteristics;
- Site specific data;
- System specific data;
- Flow observations;
- Maintenance conditions;
- Filter media condition and performance;
- Vegetation condition and cover;
- Underdrainage and outflow;
- MUSIC modelling results;
- Comparison of current conditions with design documentation; and
- Comparison of current conditions with design guidelines and standards.

1.5 Project Feasibility Analysis

Treatment of urban stormwater increasingly relies upon WSUD and especially bioretention systems to achieve performance outcomes. However there is limited research available about the actual field performance of such systems and concerns about the possibility of decreases in performance long term (Le Coustumer et al. 2008). Researching the success of existing working bioretention systems will provide information that may help improve the design and performance of future installations. Extensive research exists into the potential benefits of WSUD in managing and treating stormwater runoff and design of these installations has become widespread and sophisticated. This study will look at existing bioretention systems on the Gold Coast and investigate the unique conditions that affect whether they are successful. The results of the investigation will provide feedback on issues for existing installations that can be remediated, as well as potentially providing an information base for improvement in the design of bioretention systems.

The research part of the project will be provided by field work investigating the performance of individual bioretention systems. The aim is to locate as many bioretention systems local to the Gold Coast as possible, then select sites for testing that will give a broad range of location, size and type. A GIS will be set up to record the collected information.

Analysis of the success of the installations will be provided by comparing results to performance objectives and outcomes as well as design standards and guidelines.

Hydraulic soil conductivity will be tested on site using a single ring test. The results will be recorded in the GIS. It is expected that gaining access to design documentation and maintenance regimes for all sites may be difficult. As constructed documentation may be available online from the site approvals process. The existence of regular maintenance regimes should be apparent from the state vegetation and sediment traps. Modelling of the sites will be undertaken using MUSIC and will convert the collected data into information that is comparable with performance objectives.

Gold Coast weather patterns consist of extended periods of heavy rains over the summer months and extended dry periods over winter and autumn. It would be worthwhile if time permits to visit the sites twice to record data, for field testing during dry conditions and during a rain event to observe water flow. There may also be a difference in observations such as vegetation and maintenance conditions.

1.6 Expected Outcomes and Benefits

This project has been designed to provide information on the performance of bioretention systems on the Gold Coast. The outcomes of the research are expected to be:

- Provide information on issues with existing bioretention systems; and
- Provide insights into trends in design, construction and maintenance of bioretention systems that may affect performance of bioretention systems.

The benefit of these outcomes will be in the ability to design, construct and maintain bioretention systems with improved performance.

Chapter 2 Literature Review

2.1 Introduction

This chapter examines the current research associated with WSUD, particularly bioretention systems. The review will start by looking at background information on WSUD and bioretention systems. Current standards and guidelines will be investigated for the design, construction and maintenance of bioretention systems. Specific areas of interest will then be considered such as local performance objectives for bioretention systems, filter media performance, vegetation cover and condition, modelling using MUSIC software and developing a graphical information system (GIS) to capture, store and display the collected research data. The literature review has been designed to offer background information for bioretention systems and their design, construction and maintenance and will provide a basis for the project methodology outlined in the following chapter.

2.2 Water Sensitive Urban Design

WSUD offers an alternative approach to planning and design that views the natural water cycle holistically, integrating stormwater, water supply and sewage management and seeking to minimise the negative impacts of urban hydrology on the environment. WSUD looks at ways that the natural opportunities and constraints of a site can be incorporated into planning and design to optimise the use of water as an important resource (Water By Design 2006).

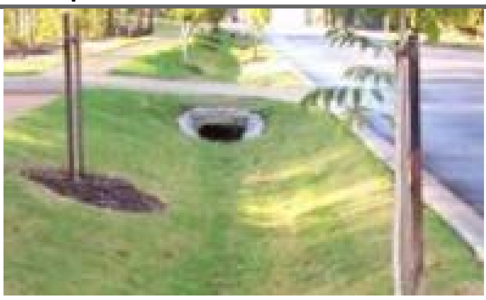
Water By Design (2006) lists the following as the key principles of WSUD:

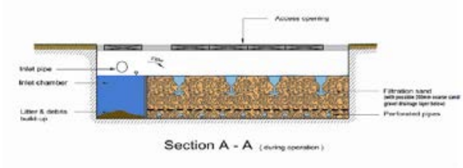
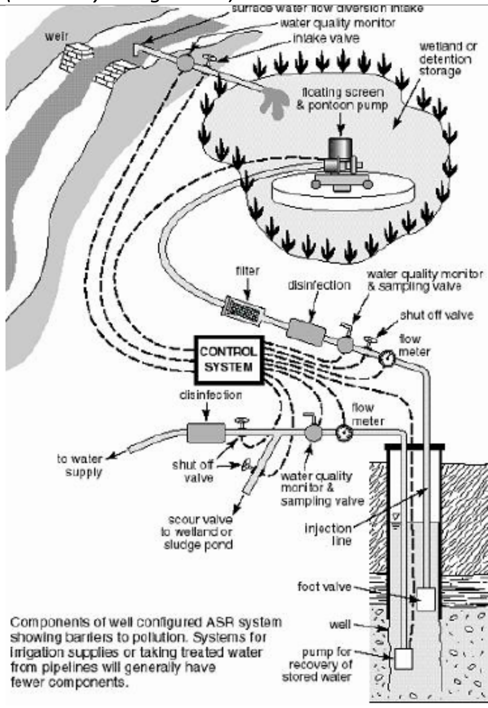
- Protect existing natural features and ecological processes.
- Maintain the natural hydrologic behaviour of catchments.
- Protect water quality of surface and ground waters.
- Minimise demand on the reticulated water supply system.
- Minimise sewage discharges to the natural environment.
- Integrate water into the landscape to enhance visual, social, cultural and ecological values.

This project involves all of these key principles to some extent except for minimising sewage discharges to the natural environment. The Queensland Urban Drainage Manual lists some of the likely benefits of WSUD systems as reduced runoff volume, rate, frequency, duration and pollutant loads, improved low-flow water quality, reduced impact of development on ecological systems, reduced waterway erosion (Department of Energy and Water Supply 2013). Table 2.2.1 below summarises the techniques used in

WSUD to address the principles listed and achieve these benefits. This project will be focusing on bioretention systems, including bioretention swales.

Table 2.2.1 WSUD techniques

Treatment Type	Typical Features	Example
Swales	• Shallow channel lined with vegetation • Treatment provided by infiltration into soil and coarse sediment removal	 *(Water By Design 2006)*
Buffer Strips	• Vegetated slope • Treatment provided by infiltration into soil and coarse sediment removal	
Bioretention Swales	• Vegetated infiltration trench with the invert of a swale • Treatment of sediments and nutrients as a result of biofiltration	 *(Water By Design 2006)*
Sedimentation Basins	• Small ponds designed to allow coarse to medium sediments to settle out of stormwater	
Bioretention Basins	• Shallow basin with vegetated filtration bed that captures stormwater runoff • Treatment of sediments and nutrients through filtration and biological plant uptake	 *(Water By Design 2006)*

Treatment Type	Typical Features	Example
Constructed Wetlands	• Shallow vegetated water bodies • Treatment by sedimentation, fine filtration and biological plant uptake	
Infiltration Measures	• Typically a holding pond or tank that allows infiltration of stormwater runoff into surrounding soils • Function is primarily runoff volume control rather than water quality treatment	 *(Water By Design 2006)*
Sand Filters	• Filters fine particles from stormwater	 *(Water By Design 2006)*
Aquifer Storage and Recovery	• Treated stormwater is pumped or gravity fed into underground aquifer recharging storage	 *(Water By Design 2006)*

Note: Table information summarised from (Water By Design 2006).

2.3 Bioretention Systems

Bioretention systems are a form of stormwater treatment that use physical, chemical and biological processes to slow urban runoff and provide water treatment. When designed, constructed and maintained appropriately they are an effective and sustainable form of stormwater treatment (FAWB 2009a). These systems typically consist of a vegetated depression with filtration, transition and drainage layers below. Stormwater runoff ponds temporarily in the surface of the system before slowly filtering through the system layers. Certain systems also have underdrainage pipes to convey treated runoff into the stormwater system while other systems rely on infiltration into surrounding soils or a combination of underdrainage and infiltration (FAWB 2009a). Examples of bioretention system layouts are provided as Figure 2.3.1 and Table 2.3.2 below.

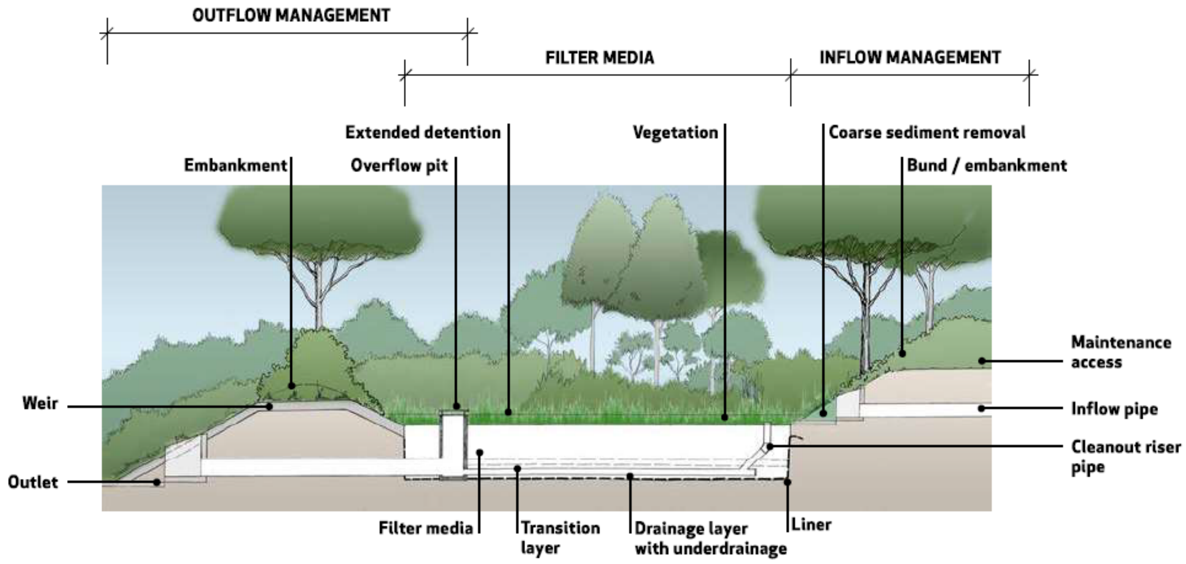


Figure 2.3.1 Bioretention cross section (Water by Design 2014)

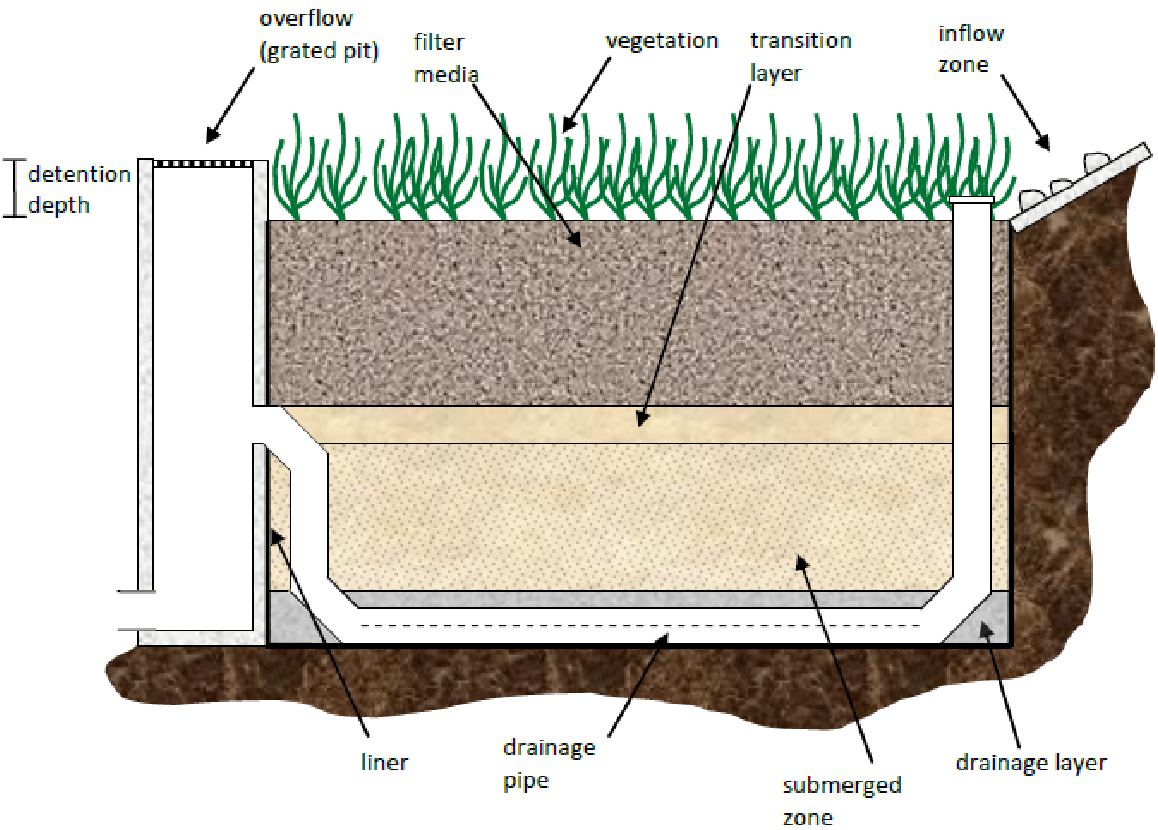


Figure 2.3.2 Bioretention cross section (FAWB 2009a)

Hydrologic changes due to urban environments are dealt with by slowing down runoff, reducing peak discharges and allowing at least partial reduction in outflow due to infiltration, plant uptake and evapotranspiration. Water quality treatment is provided as a result of microbial processing, vegetation uptake and filtering. Vegetation in the system slows runoff allowing sediments to settle, takes up nutrients and other pollutants from the water and provides oxygen in the filtration layer that encourages microbial growth for pollutant removal. Sediments and particulate nutrients are removed through physical contact with the filter media and soluble nutrients are removed through binding to particles within the filter media (sorption) (FAWB 2009a).

Other benefits of bioretention systems are to provide amenity (through attractive landscaping), habitat and biodiversity value and cooling of urban micro-climate through evapotranspiration and shading (FAWB 2009a). Types of bioretention systems include bioretention basins, bioretention swales, bipods and bioretention street trees. Table 2.3.1 below provides a summary of the typical features of each of these types of systems.

Table 2.3.1 Types of bioretention systems

Type	Typical Features	Example
Bioretention basins	• Treats stormwater from overland or pipe inflow • Allotments, streetscapes, civic spaces parklands, adjacent to bushland as per Table 2.3.1 • Vary greatly in size 5-800m^2 • Vegetation reflects location	 *Photo: Jack Mullaly, Healthy Waterways (Water by Design 2014)*
Bioretention swales	• Treats and conveys stormwater • Surface of filter media follows grade of swale's surface • Typically road reserves, parklands and drainage easements • Small catchments less than 2ha • Lateral flow directly across grassed or vegetated batters or pipe outlets • May include trees	 *Photo: Jack Mullaly, Healthy Waterways (Water by Design 2014)*
Biopods	• At-source bioretention receiving overland flow from hardstand • Streetscape, commercial, industrial and multi-unit developments • Typically less than 50m^2	 *Photo: Robin Allison, DesignFlow (Water by Design 2014)*
Bioretention street trees	• Combination of bioretention and traditional street trees • At-source bioretention receiving overland flow from hardstand • Typically only a few metres squared • Much of street tree's footprint covered by hardstand	 *Photo: Brad Dalrymple, DesignFlow (Water by Design 2014)*

Note: Table information summarised from Water by Design (2014)

Bioretention systems have a small footprint for the treatment they provide that is relative to the catchment area, usually ranging from about 2-4% (FAWB 2009a). Sizing and arrangement can be adjusted to correspond with vastly different catchment sizes and settings. Categorisation of bioretention system settings and their typical features have been outlined Table 2.3.2.

Table 2.3.2 Categories of bioretention systems within the landscape

Category	Typical Features	Example
Allotments	• Small raingardens or bioretention basins • Shallow surfaces usually less than 750mm below surroundings • Accept stormwater via surface flow or small shallow pipes • Typical surface area of filter media 5-200m^2	 *Photo: Jack Mullaly, Healthy Waterways (Water by Design 2014)*
Streetscapes	• Integrated into road reserves or traffic calming 'build-outs' • Filter media surface not substantially lower than road surface typically less than 500mm • Accept stormwater via surface flow • Typical surface area of filter media 5-50m^2	 *Photo: Shaun Leinster, DesignFlow (Water by Design 2014)*
Civic spaces and forecourts	• Integrated into civic spaces as an attractive feature • Can be combined with stormwater harvesting for non-potable uses • Plant species and density to complement surrounding urban space • Filter media surface close to level of adjacent urban space typically less than 500mm • Accept stormwater via small, shallow drains (e.g. grated trenches) • Typical surface area of filter media 5-100m^2	 *Photo: Robin Allison, DesignFlow (Water by Design 2014)*

Category	Typical Features	Example
Parklands	• Integrated with or adjacent to parkland increasing continuity of green space • Opportunities for stormwater reuse • Plant to complement surrounding landscape space, diverse species preferably trees and shrubs • Typically accept stormwater via end-of-pipe system, receiving inflows from a piped network • Can be sited within flood detention infrastructure • Typical surface area of filter media 50-800m^2	 *Photo: Shaun Leinster, DesignFlow(Water by Design 2014)*
Adjacent to bushland	• Enhance overall green space and provide for wildlife habitat and movement • Integrated with surrounding landscape through informal shapes and gentle batter slopes • Diverse planting of grasses, sedges, shrubs and trees • Typically accept stormwater via end-of-pipe system, receiving inflows from a piped network • Can be sited within flood detention infrastructure • Typical surface area of filter media 50-800m^2	 *Photo: Jack Mullaly, Logan City Council (Water by Design 2014)*

Note: Table information summarised from Water by Design (2014)

The drainage profile of a bioretention system explains how the system treats water based on the filter media, transition layer, and underdrainage and hydraulics structures. Figure 2.3.3 below shows the layout of the four main types of drainage profiles saturated zone, sealed, conventional and pipeless. Systems with a saturated zone incorporate water storage into the transition and drainage layers and supply water to vegetation during dry periods, maintaining the health of plants and soils and ensuring treatment performance of the system. Sealed systems have an impermeable liner that ensures treated water flows out through drainage pipes and does not infiltrate surrounding soils. This would typically be used where the surrounding soil is unsuitable for infiltration or if stormwater is being harvested. Conventional bioretention systems encourage water to infiltrate as much as possible into the surrounding soils while still having underdrainage pipes for flow that exceeds the soil’s infiltration capacity. In pipeless bioretention systems all treated water is infiltrated into the surrounding soil (Water by Design 2014).

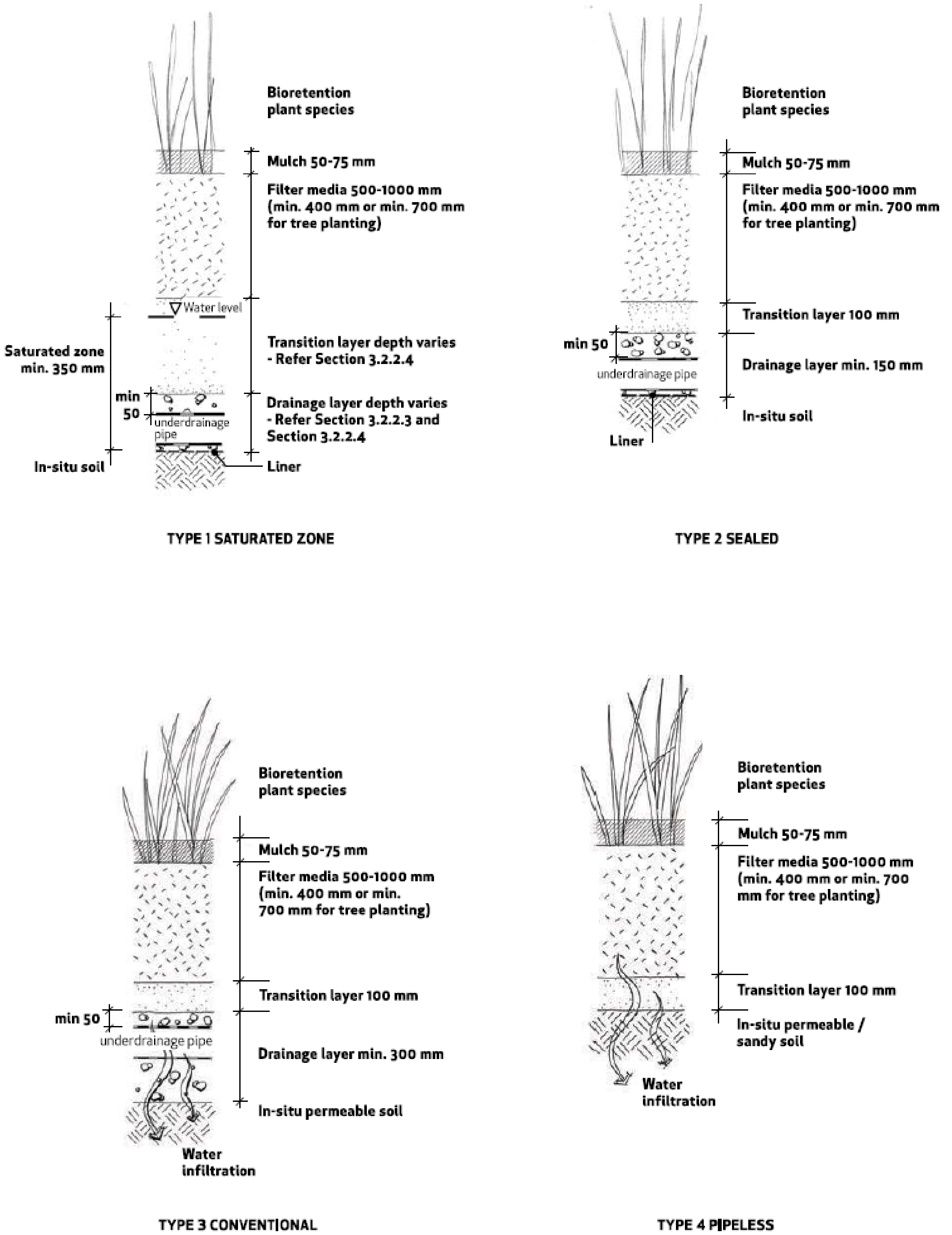


Figure 2.3.3 Drainage profiles (Water by Design 2014)

Bioretention systems are suitable for both small and large catchments, where space is constrained and in flat, moderate and steep topography. They manage litter, sediments, nutrients, metals and hydrocarbons in stormwater and moderate flows. Bioretention systems are not suitable for sites with insufficient elevation or tidal influence, continuous wetting without dry periods, sites with toxic or ASS runoff, swales with high velocities and sites without easy maintenance access (Water by Design 2014).

The three main functions of bioretention systems are managing hydrology (managing the quantity of stormwater runoff), pollutant removal (managing the quality of stormwater runoff) and amenity (improving appearance) (Water by Design 2014). In urban areas high volumes of stormwater runoff occurs with short, sharp peak flows (FAWB 2009a). Bioretention systems manage this sudden quantity of stormwater by detaining runoff, allowing infiltration into surrounding soils and providing slow release of remaining treated runoff into waterways, reducing degradation and erosion. With correct sizing, bioretention systems may reduce peak flows by around 80% for storms less than 1 year Average Recurrence Interval (ARI). In addition runoff volumes are reduced on average by around 30% and runoff from small events may often be completely absorbed, reducing the frequency of flow into waterways. Hydrologic benefits of bioretention systems will be provided indefinitely as long as the filter media retains its hydraulic conductivity (Water by Design 2014).

Several types of pollutants are removed by bioretention treatment, mainly sediments, nitrogen, phosphorous, hydrocarbons, heavy metals and gross pollutants. Sediments are removed through contact with the filter media and sediment removal will occur indefinitely as long as the filter media retains its hydraulic conductivity (Water by Design 2014).

Nitrogen removal occurs through microbial nitrogen processing and uptake by plants. Nitrogen removal will continue as long as there is sufficient cover of desirable plants within the system. Nitrogen removal in new systems may initially be below design rates until the vegetation is established (Water by Design 2014).

Phosphorous occurs in stormwater in two different forms, particulate and soluble. In particulate form the phosphorous is attached to sediment particles and removed, as with sediments, through physical contact with the filter media. Removal of particulate phosphorous will continue as long as hydraulic conductivity is retained. Soluble phosphorous is removed mainly by attaching to fine particles in the filter media. Over time a bioretention system's ability to absorb soluble phosphorous will be exhausted and the rate of phosphorous removal from the system will reduce. Some soluble phosphorous is removed through plant uptake that will continue with sufficient cover of desirable plants (Water by Design 2014).

Much like phosphorous, heavy metals occur in stormwater in particulate and soluble forms. Particulate heavy metals are removed through physical contact with the filter media and removal will continue while hydraulic conductivity is maintained. Soluble heavy metals are removed mainly by attaching to fine particles in the filter media and the removal capacity of the system will eventually be exhausted. Some soluble heavy metals are removed by plant uptake that will continue with sufficient cover of desirable plants (Water by Design 2014).

Hydrocarbons occur in stormwater from sources such as diesel and petrol contamination in road runoff and are treated through microbial processing in a bioretention systems. Hydrocarbon removal will continue to occur as long as the porosity of the filter media is maintained (Water by Design 2014).

Gross pollutants are larger items like litter that are washed into a bioretention system and are usually trapped by the plants. Regular maintenance should include removal of gross pollutants and ensure that these are not eventually washed into waterways.

Performance objectives and standards for operational WSUD systems ensure that systems are built as designed, are properly established, are adequately maintained and performance is confirmed (Water by Design 2014).

2.4 Policy and Planning

WSUD policy falls under several different Acts because of the number of issues involved including environmental protection, stormwater management, water conservation and wastewater management (Water by Design 2014).

Environmental protection falls under the *Environment Protection Act 1994* and *Environment Protection (Water) Policy 2009*. These establish environmental values and water quality objectives for waterways in Queensland. Planning policy for Queensland comes under the *Sustainable Planning Act 2009*. The purpose of the Act is to seek ecological sustainability by managing the development process, managing the effects of development on the environment and continuing to coordinate and integrate planning at local, regional and State levels (Sustainable Planning Act 2009). Figure 2.4.1 below illustrates how the Act supports the State planning regulatory provision and planning policy, the regional plan and local planning scheme provisions. WSUD principles are supported under the Act particularly in the following areas:

- Ensuring decision making is accountable, coordinated, effective and efficient and that it takes into account short and long-term environmental effects of development;
- Ensuring sustainable use of renewable natural resources;
- Avoiding or otherwise lessening adverse environmental effects of development;
- Supplying infrastructure in a coordinated, efficient and orderly way; and

- Applying standards of amenity, conservation, energy and health and safety (Sustainable Planning Act 2009).

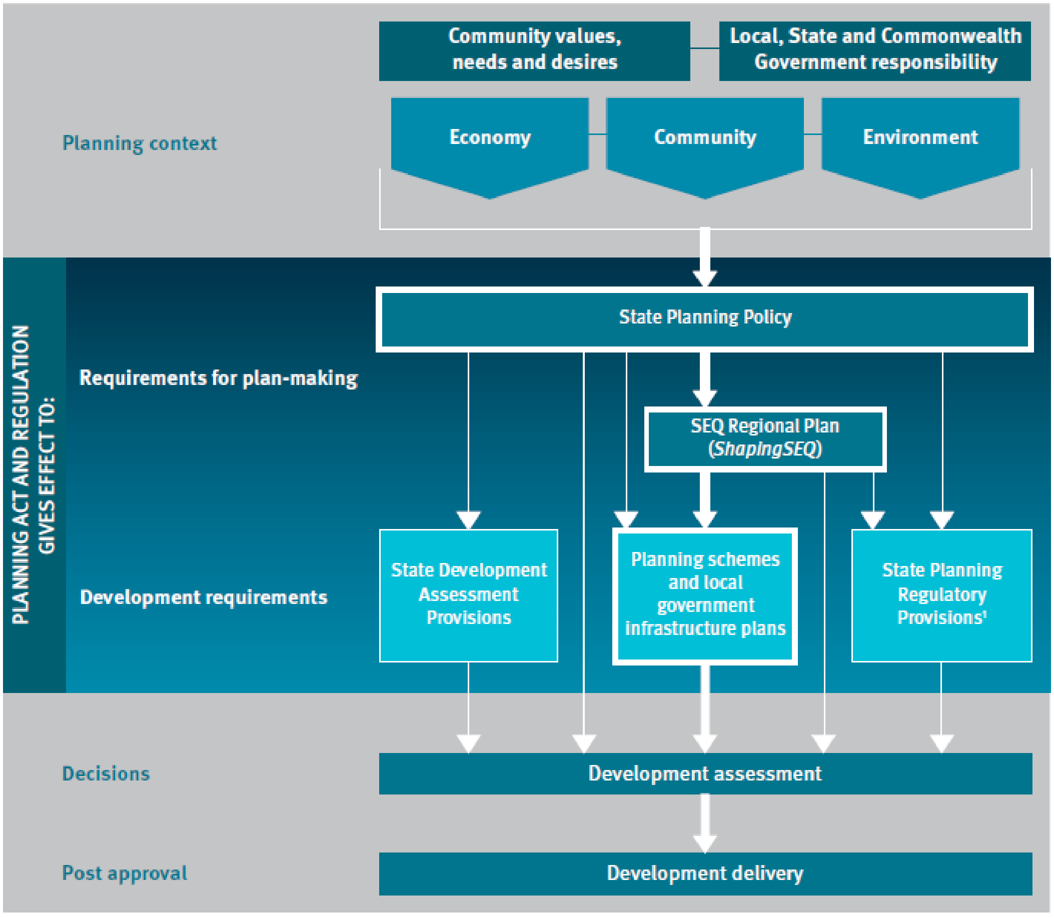


Figure 2.4.1 Queensland planning framework (South East Queensland Regional Plan 2009-2031 2009)

The relevant regional plan is the South East Queensland Regional Plan 2009-2031. The purpose of this document is to "manage regional growth and change in the most sustainable way to protect and enhance quality of life in the region" (*South East Queensland Regional Plan 2009-2031* 2009). This document underwent a review in 2016 and a draft of the new South East Queensland Regional Plan was released. A new regional plan is expected to be released in 2017. There are five themes are addressed in the draft, plan, grow, prosper, connect, sustain and live. WSUD principles are supported through the theme of sustain that proposes that we value and protect our natural systems, fundamental to the region's unique character, heritage and liveability (*ShapingSEQ Draft South East Queensland Regional Plan* 2016).

Local planning policy for the City of Gold Coast falls under the City Plan Version 3. The City Plan was prepared as a framework for managing development that advances the purposes of the SPA, advances

State and regional planning strategies and outlines City of Gold Coast's intention for the next 20 year period (City of Gold Coast 2016). Schedule SC6.9 of the City Plan contains the Land Development Guidelines with Schedule 6.9.3 providing the framework for WSUD. The City Plan WSUD policy aims to ensure that developments meet stormwater quality objectives as well as expectations for design standards, public safety, lifecycle management, environmental protection and amenity for WSUD systems (City of Gold Coast 2016). Design of bioretention systems in Schedule SC6.9.3.5.4 of the City Plan refers to the Water by Design (2014) Bioretention Technical Design Guidelines, with additional City of Gold Coast requirements. Schedules of the City Plan outline stormwater quality objectives, plant selection and planting densities for bioretention systems, requirements for dealing with acid sulfate soils and other important concepts. These will be discussed in the sections below.

2.5 Design Standards and Guidelines

The City Plan (City of Gold Coast 2016) provides information about the relevant standards and guidelines that apply for bioretention systems on the Gold Coast. In general the referenced guidelines are the Water By Design guidelines produced by Healthy Land & Water. Reference is also made to the Queensland Urban Drainage Manual (QUDM), particularly for planning and design of urban drainage systems. Standard drawings for WSUD systems are identified from the Institute of Public Works Engineering Australia – Queensland (IPWEAQ).

The relevant Water by Design guidelines for this project include the Bioretention Technical Design Guideline, the MUSIC modelling Guideline, Maintaining Vegetated Stormwater Assets and Rectifying Vegetated Stormwater Assets. The performance outcomes discussed below are summarised from the Bioretention Technical Design Guideline. Water by Design (2014) discusses the following important areas of site characteristics to identify before or during the design process:

- Topographical site survey;
- Boundaries;
- Catchments;
- Hydrology and drainage infrastructure;
- Services;
- Flora and fauna;
- Soil;
- Groundwater;
- Landscape features and integration issues; and

- Other such as site history, contamination, tidal information, cultural heritage information, flooding history;

In addition to the requirements addressed in the Bioretention Technical Design Guidelines, City of Gold Coast has particular requirements for bioretention design that must be adopted for Gold Coast systems and are addressed in the following sections. Table 2.5.1 below summarises design requirements from City of Gold Coast that are not covered in the following sections. Table 2.5.1 below summarises design recommendations from Water by Design that are not covered in the following sections.

Table 2.5.1 City of Gold Coast bioretention system requirements

System Element	City of Gold Coast Requirement
Filter media area (excluding batters)	Single or multiple cells < 800 m^2 each
Maximum width for maintenance access	15m (20m where accessible on both sides)
Maximum length for maintenance access	40m
Overflow pit location for maintenance access	Within 2m of edge of system
Coarse sediment removal method	None - Roof runoff only or catchment ≤2.5ha Coarse sediment forebay – catchment >2.5ha and ≤ 5ha Coarse sediment forebay + trashrack – catchment >5ha and ≤ 8ha Inlet pond - catchment >8ha
Coarse sediment maintenance access	Vehicle access to inlet zones at inflow level for bobcat or excavator silt removal
Maintenance access tracks	Gated to prevent public entry 2.5m wide for sediment forebay 3m wide for inlet pond Access path to > 40% of perimeter
Batters and embankments vegetated	Minimum 6 plants/m^2 ground cover with trees
Batter slope	1:4 preferred 1:2 – max vertical height <0.5m 1:2 – max vertical height <1.0m
Walls	Generally not approved where space is available for batters Preferred not using safety fencing Vegetated barriers required around walls >800mm drop must have compliant fencing and barriers
Outlet pipe levels	Ephemeral waterway - 300 mm above waterway invert or 100 mm above wet season water level 1 day after rain (whichever is highest). Perennial waterway - 300 mm above dry weather water level or 100 mm above wet season water level 1 day after rain (whichever is highest).

System Element	City of Gold Coast Requirement
	Natural wetland - 100 mm above wet season standing water level 1 day after rain. Natural ground - 100 mm above the maximum of the ground level or wet season standing water level 1 day after rain. Pipe drainage system - 50 mm above invert of downstream pit/pipe system and above wet season baseflow level.
Pit and pipe outlet	<800 m^2 - Pit and pipe outlet design to cater for minor event (2 year ARI) and weir to cater for maximum flow entering the bioretention system (typically 100 year ARI). Flow velocities must be maintained at less than 1 m/s up to maximum flow and that adequate scour protection is provided around hydraulic structures including inlet, outlet pit and overflow weir. Where this cannot be achieved then dedicated high flow bypass channel required. 800 m2 - Dedicated high flow bypass upstream comprising appropriately sized open channel designed for the full range of design storm event flows entering the system. Needs to be combined with an inlet pond.

Note: Table information summarised from City of Gold Coast (2016).

2.6 Performance Objectives

The City Plan (City of Gold Coast 2016) has performance objectives under the headings of stormwater quality, frequent flow, waterway stability and landscape integration. These are outlined in *Table 2.6.1* below.

Table 2.6.1 City of Gold Coast performance objectives

Stormwater Quality Objectives	
Gross Pollutants (>5mm)	90% reduction in mean annual load
Total Suspended Solids	80% reduction in mean annual load
Total Phosphorous	60% reduction in mean annual load
Total Nitrogen	45% reduction in mean annual load
Frequent Flow Objectives	
Baseflows	≥10% of mean annual rainfall volume converted to baseflow Less than baseflow threshold of 0.4L/s/ha
Surface Flow	≤ 20 surface runoff days per annum measured as days where the maximum daily flow rate exceeds the baseflow threshold of 0.4L/s/ha
Flow Reduction	≥ 25% reduction in mean annual runoff volume from unmitigated runoff
Waterway Stability Objective	
Limit post-development peak 1-year ARI event discharge within the receiving waterway to the pre-development peak 1-year ARI event discharge.	
Landscape Integration Objective	
Ensure stormwater management infrastructure is integrated into the urban design and landscape.	

Note: Table information summarised from the City of Gold Coast (2016) City Plan SC6.9.3.2.3-SC6.9.3.2.6

2.7 Performance Outcomes

In addition to the performance objectives from the City Plan listed above, the Water by Design (2014) Bioretention Technical Design Guidelines provides performance outcomes for different elements of bioretention design, listed in *Table 2.7.1* below.

Table 2.7.1 Performance outcomes of elements of bioretention systems

Element	Performance Outcomes
Drainage Profile	The selected drainage profile must: • Provide suitable growing conditions • Ensure bioretention drainage does not adversely affect adjacent assets • Be appropriate for the given design objectives.
Filter Media	Filter media must : • Support bioretention vegetation • Infiltrate water sufficiently to enable design objectives to be met • Not migrate downwards through the transition layer, drainage layer, underdrainage or in-situ soil.
Transition Layer	Transition layers must: • Ensure the filter media does not migrate downwards • Not migrate downwards themselves through the drainage layer, underdrainage or in -sit u soil • Not restrict flow rate through the filter media.
Drainage Layer	Drainage layers must: • Ensure overlying media does not migrate downwards • Not restrict flow through filter media.
Saturated Zone	Saturated zones must support plant health and stormwater treatment.
Design Levels	Outlet pipe levels must: • Be sufficient so that accumulated sediment does not block outlet pipe connection with receiving drainage system • Allow bioretention filter media to drain freely.
Outlet Levels into Waterways	Ephemeral waterway: • 300 mm above waterway invert or 100 mm above wet season water level, whichever is highest Perennial waterway • 300 mm above dry weather water level or100 mm above wet season water level, whichever is higher Natural wetland • 100 mm above the maximum of the ground level or wet season standing water level Natural ground • 100 mm above the maximum of the ground level or wet season standing water level Pipe drainage system • 50 mm above invert of downstream pit or pipe system and above wet season baseflow levels.
System Levels Relative to Ground Water and Tidal Levels	With respect to groundwater and tidal levels, bioretention systems must: • Ensure bioretention biota is not harmed by water infiltrating from the surrounding soil into bioretention system • Ensure groundwater is not drawn down by bioretention underdrainage.
Extended Detention	The extended detention must: • Have sufficient temporary storage to enable design objectives to be met • Not harm vegetation through excessive inundation.

Element	Performance Outcomes
Maximum Water Levels	The maximum water level must inform the minimum embankment height and flood conveyance.
Filter Surface Level Relative to Surrounding Surface	Relative to the surrounding landscape the filter media surface level must: • Ensure accumulated sediment does not block inlet pipe • Provide safe and stable bioretention system edges • Ensure the bioretention system forms an attractive landscape feature.
Minimum Embankment Height	Bioretention system embankments must: • Contain the maximum water level with appropriate freeboard • Prevent the bioretention system from being damaged by flows from external catchments.
Level Constrained Sites	Bioretention systems in level constrained sites must: • Adapt to the constraints of the site • Be robust and resilient • Demonstrate that they are the most appropriate solution for the site.
Liners	Impermeable liners must: • Ensure water cannot be exchanged between the bioretention system and the surrounding soil. Permeable liners must: • Prevent in-situ soils from contaminating filter media or the underdrainage network.
Filter Media Area	The filter media area must: • Be sufficient to achieve the bioretention system's design objectives • Not detrimentally affect the lifespan of the bioretention system.
Shape and Location	The shape and location of bioretention systems must: • Ensure the system is suitably integrated with the landscape and considers the site's constraints • Allow the system to be easily constructed with commonly available equipment, without compromising the system's ability to meet its design objectives.
Inlet and Outlet Locations	Inlet and outlet locations must: • Allow inflows and outflows to be efficiently managed without damaging the bioretention systems or surrounding areas • Ensure hydraulic structure locations are sympathetic to landscape considerations.
Surrounding Landscape	The layout of bioretention systems must not impact unacceptably on surrounding landscape features.
Public Access and Safety	The layout of bioretention systems must: • Integrate with adjacent public spaces • Enhance public access and safety.
Batters	Bioretention batters must: • Be safe and stable • Be low maintenance • Not create unacceptable visual impacts.
Embankments	Bioretention embankments must: • Be safe and stable • Be low maintenance • Not create unacceptable visual impacts • Provide for construction and maintenance of the system.

Element	Performance Outcomes
Walls	Walls around bioretention systems must: • Be safe and stable • Not create unacceptable visual impacts • Allow the system to be easily constructed and maintained.
Maintenance Access	Bioretention systems require regular, proactive but simple maintenance to ensure their effective long term operation and to minimise lifecycle costs. Typical maintenance activities involve weeding, litter collection, sediment removal, repair of localized scour and inspection of hydraulic structures. To ensure this can happen, it is vital that bioretention design: • Provides access for sediment removal • Provides access to the filter media and vegetation • Appropriately delineates the edge of the bioretention system.
Sediment Cleanout Access	Access for sediment cleanout must ensure accumulated sediment can be easily removed using commonly available equipment.
Filter and Vegetation Maintenance Access	Access for filter and vegetation must allow access for regular inspections and maintenance.
Outlet Pipe Access	Access must allow for maintenance to ensure the outlet pipe drains freely.
Maintenance Edges	Maintenance edges must : • Minimise the risk of turf and weeds encroaching into the bioretention system • Provide for easy maintenance of the bioretention system • Delineate the bioretention system from surrounding land uses if required.
Underground Services	Where underground services are located in proximity to a bioretention system, the design of the system must: • Ensure the operation of the bioretention system does not compromise the function of the service and vice versa • Ensure common maintenance and checking activities undertaken on the service do not compromise any component (e.g. filter media) or function of the bioretention system, or vice versa.
Road Reserves (Streetscape Bioretention Systems)	The layout of streetscape bioretention systems must: • Not compromise other streetscape functions • Integrate with the aesthetics of the streetscape.
Bioretention within Flood Storage	When bioretention systems are combined with flood storage, they must ensure that: • Flood storage outcomes are achieved • Flood storage design does not rely on extended detention volumes • Bioretention system design objectives are not compromised during or after flood events.
Design Inflows	Design inflow estimates must be accurate as they inform the design of both inlet and outlet components.
Selecting Pre-Treatment Type	Selecting the pre-treatment type for the site and catchment must: • Ensure that deposition of coarse sediment on the filter media does not affect the performance of the bioretention system • Ensure the bioretention system integrates with the surrounding landscape allow for the bioretention system to be easily maintained.
Sediment Forebay Design	Forebays must be designed to:

Element	Performance Outcomes
	• Remove 80% of particles that are 1 mm or larger in diameter from the peak three-month ARI flow • Provide appropriate storage for coarse sediment to ensure desilting is required no more than once per year • Provide energy dissipation of incoming flows.
Inlet Pond Design	Inlet ponds to bioretention systems must be designed to: • Remove coarse sediment by using a permanent water column to reduce flow velocities and promote settling • Regulate flows entering the bioretention filter media • Dissipate inflow energy • Allow for high flows to bypass the bioretention filter media • Provide appropriate storage for coarse sediment to ensure desilting is only required infrequently • Minimise safety risk • Provide visual amenity.
Inlet Energy Dissipation and Scour Protection	Energy dissipation and scour protection must: • Prevent filter media from scouring during a major storm event • Minimise re-suspension of coarse sediment collected near the inlet.
Filter Media Scour Velocity Check	Bioretention system design must ensure that flows across the filter media surface do not cause scouring of the filter media or damage to plants.
Flow Distribution	Flow must be evenly distributed across the bioretention filter media surface.
Underdrainage Pipes	Underdrainage pipes must: • Meet local authority requirements • Not restrict flow rates through filter media • Ensure access for inspection and cleaning • Prevent drainage layer material entering slots.
Overflow Pit	Overflow pits (or equivalent) must: • Pass the peak minor flow with acceptable upstream inundation • Have a low risk of being blocked with debris.
Outlet Pipe	The outlet pipe (or equivalent) must convey the peak minor flow to the receiving drainage system taking into account tailwater conditions.
Overflow Weir	Overflow weirs (or equivalent) must: • Be able to pass the peak major flow with acceptable upstream inundation • Have a low risk of being blocked with debris • Ensure the embankment does not scour during a peak major flow.
Connection to Waterways	The connection of the bioretention system to the receiving drainage system must prevent scour during peak major flows.
Flood Storage Outlets	Flood storage outlets must allow both bioretention and flood attenuation design objectives to be met.
Planting Style	The planting style of a bioretention system must: • Be suitable for the local landscape and ecology • Not interfere with sight lines • Be suitable for the available maintenance regime.
Species Diversity	The selected species must: • Meet local authority requirements • Have 90% plant cover within two growing seasons.

Element	Performance Outcomes
Species Selection	The plant species chosen for a bioretention system must: • Be suitable for the local landscape and ecology • Enable bioretention performance objectives to be met • Be suitable for the predicted wetting and drying regime.
Planting Density	Planting densities must: • Provide rapid coverage to out-compete weeds • Have a uniform root zone through the filter media • Enable bioretention performance objectives to be met • Have 90% coverage in two growing seasons.
Planting Set-out	The planting set-out must minimise the risk of bare patches developing if one species fails.
Mulch	Mulch must: • Ensure adequate soil moisture for plant health • Suppress weeds • Not hinder plant growth.
Resilience to Climatic Variations	Bioretention systems are installed in widely varying climatic regions. To ensure that bioretention systems function, and particularly that vegetation survives, bioretention design must be resilient and respond to local climatic conditions.

Note: Table information summarised from Water by Design (2014)

2.8 Planning and Design

The planning and design stage is critical for ensuring that design objectives and outcomes are achieved. It is important to consider the individual site opportunities and constraints during the planning and design of new systems. One of the main advantages of WSUD is adaptability to the individual site. Some of the main considerations are the setting, local treatment objectives, local water demands, catchment size and slope, obvious sources of high pollutant such as deciduous trees, existing drainage systems, existing infrastructure, existing soil properties and availability of space (FAWB 2009a). Figure 2.8.1 below summarised the design process. Detailed design documentation should include a design report, detailed design drawings and specifications.

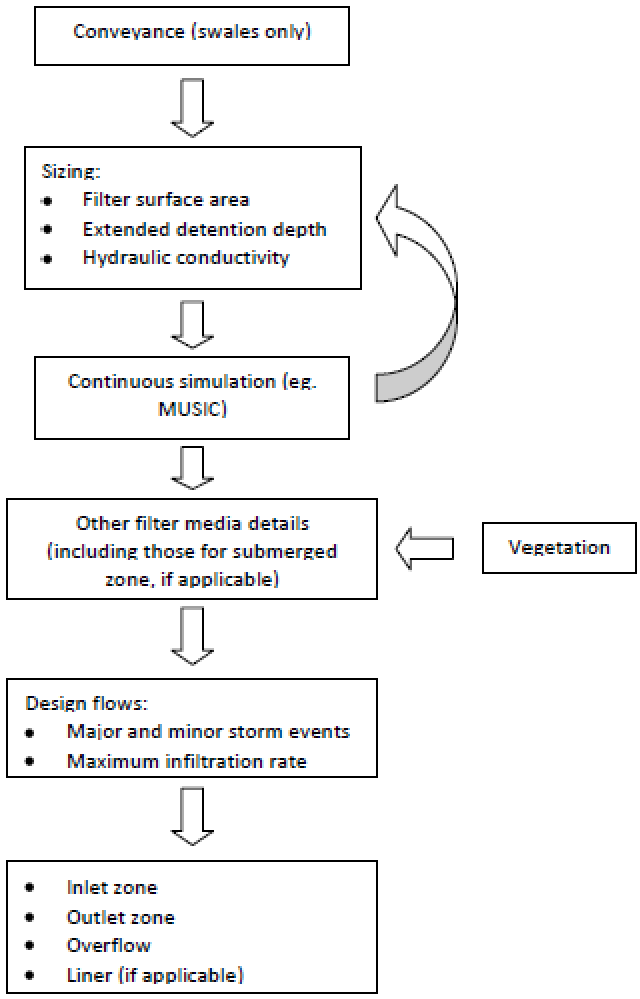


Figure 2.8.1 Design Process (FAWB 2009a)

2.9 Construction and Establishment

The construction and establishment phase is key to determining whether bioretention systems will succeed or fail (FAWB 2009a). Construction of a bioretention system should be in accordance with the detailed design, particularly for the filter, transition and drainage layers and vegetation layout. Handover of assets to local government is dependent on systems being in good working condition and meeting performance criteria. Protection of systems during construction works in the catchment is crucial to establishing plants and preventing clogging or scour of the filter media. Systems are kept off-line during works and sediment control measures must be in place. Systems should be protected by geotextile and turf or gravel coverings for best results. Temporary partitioning of a system to create a sacrificial forebay may also be used (City of Gold Coast 2016). A bond is paid to local government to ensure that activation of the asset will take place after construction works and to cover the costs of establishment maintenance.

This is returned when the system is deemed to be established. The period of establishment is usually based on meeting performance based criteria rather than being time based, however usually takes around 2 years (City of Gold Coast 2016). City of Gold Coast uses the Water By Design guidelines for construction and maintenance obligations.

2.10 Maintenance

Bioretention systems require a level of maintenance to continue to perform their design function (Water By Design 2012a). City of Gold Coast has a WSUD asset maintenance program that ranges from weekly to monthly maintenance visits. A section of the maintenance specification for bioretention systems is attached as Appendix B. Some of the routine maintenance tasks listed include:

- Weeding, watering and other vegetation maintenance, particularly during the establishment period;
- Removal of gross pollutants and sediments;
- Inspect inlet and outlet for blockages; and
- Inspection for erosion. (City of Gold Coast)

It is substantially more cost effective to regularly maintain bioretention assets than to rehabilitate systems that have failed. As well as this additional cost, bioretention assets that are not properly maintained may fail to meet the stormwater quality objects negatively impacting downstream waterways and their ecosystems. The value of the asset is reduced, as is their amenity level and they may cause health and safety problems such as mosquitos or offensive odours (Water By Design 2012a).

2.11 Monitoring

Monitoring of bioretention systems goes beyond a general maintenance program. The aim of a monitoring program will be to assess whether the system meets the management objectives it was designed for. FAWB (2009a) outlines the following reasons to monitor the performance of bioretention systems:

- To demonstrate compliance with legislative requirements (eg. load reduction targets);
- To assess overall and/or long-term performance (eg. large scale stormwater quality improvement);
- To collect data for model development; and
- To understand detailed processes.

Monitoring can be resource intensive and programs must be developed to best use available resources and work within budgets. A monitoring program will collect information on catchment characteristics, system characteristics and climate. Table 2.11.1 Monitoring tasks outlines the levels of monitoring and the tasks that are carried out.

Table 2.11.1 Monitoring tasks

Monitoring Level	Tasks
Preliminary	• Inspect for plant health, erosion and build-up of sediments • Hydraulic conductivity • Accumulation of heavy metals (unlikely to accumulate to levels of concern)
Intermediate	• Soil sampling • Water sampling • Water quantity measurements
Detailed	• Flow measurements • Continuous water quality sensors and discrete samples

Note: Table information summarised from FAWB (2009a).

2.12 Filter Media

A key factor in the performance of bioretention systems is whether runoff can pass through the filter media. The ability of runoff to enter the filter media depends on a number of factors. Erosion or scour can cause flow paths to bypass the filter media, particularly around the inlet. The system may not be sized appropriately with sufficient filter media area or detention depth to treat the volume of runoff, resulting in untreated runoff entering the overflow pit. The infiltration capacity of the filter media may be too low as a result of over compacting, sediment deposits clogging the media, algal growth, use of unsuitable filter media or lack of established vegetation that creates macropores through root growth and dieback (Le Coustumer et al. 2008).

Maintaining the infiltration capacity is crucial for long-term success of bioretention treatment. Wong et al. (1999) found that the percentage of mean annual flow treated by a system, termed as the hydrologic effectiveness, was determined by three factors, the detention period, inflow characteristics and storage. In terms of bioretention these factors can be translated into the filter media surface area, the extended detention depth and the hydraulic conductivity (Le Coustumer et al. 2008). Figure 2.12.1 and Figure 2.12.2 below illustrate the relationship between these three elements in achieving the desired infiltration capacity.

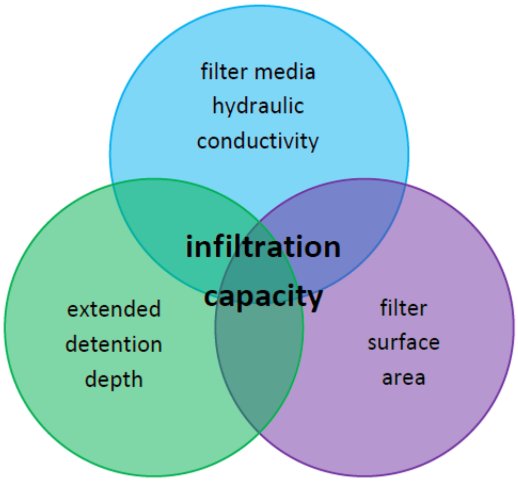


Figure 2.12.1 Optimisation of infiltration capacity (FAWB 2009b)

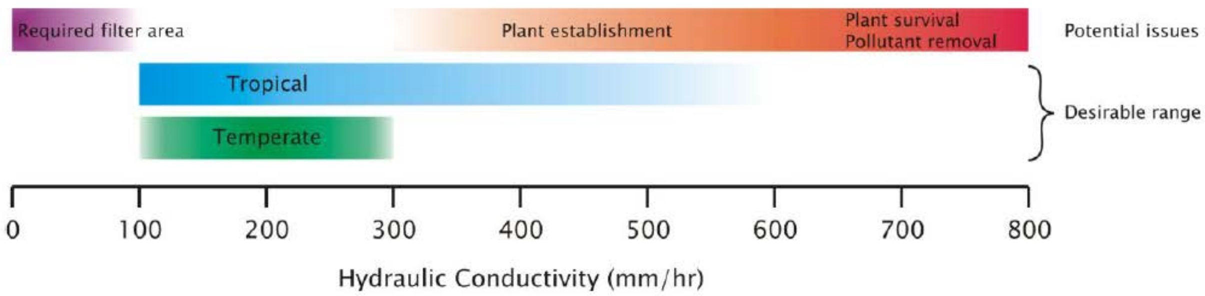


Figure 2.12.2 Hydraulic Conductivity Testing (FAWB 2009a)

A study by Le Coustumer et al. (2008) found that only 60% of systems tested had a saturated hydraulic conductivity in the recommended range, however the filter media area and detention depth generally compensated for the reduced hydraulic conductivity. They also found that where the hydraulic conductivity was below 5mm/hr, 71% of runoff was discharged untreated into waterways. Design of bioretention systems should optimize the filter media surface area, extended detention depth and hydraulic conductivity (FAWB 2009b). The Water By Design (2006) WSUD Technical Design Guidelines for South East Queensland recommends that the hydrological effectiveness should be greater than 80%, i.e. 80% of mean annual rainfall is treated by the system. Alternatively these factors can be balanced for peak discharge attenuation or capture and infiltration of a certain design storm, usually the 3 month ARI storm.

Bypass of the filter media can be established through visual inspection, looking at flow paths during a storm event or by inspecting for erosion or scour. Appropriate system sizing can be determined using modelling software such as MUSIC or can be calculated as a percentage of the catchment area. The current version of the City Plan (City of Gold Coast 2016) has a maximum filter media area requirement of 800m^2 before a system must be split into multiple cells. The hydraulic conductivity of a filter media may be too low and runoff unable to pass through. Alternatively the hydraulic conductivity may be too high resulting in lack of moisture retention for plant establishment and survival. The Water by Design (2014) Bioretention Technical Design Guidelines recommends that the detention depth be between 100-200mm with a maximum of 300mm, detention depths greater than this may impact plant health and could overload the filter media. Water by Design (2014) recommend a saturated hydraulic conductivity between 100-300 mm/hr but allow for up to 600mm/hr as long as vegetation can be maintained. It is unlikely that filter media with a hydraulic conductivity greater than 600mm/hr would support plant growth without creating a permanently submerged zone by raising the outlet pipe (FAWB 2009b).

The hydraulic conductivity of the original soil profile can also dictate the underdrainage profile for the system. If the surrounding soil hydraulic conductivity is less than 0.25mm/hr then a sealed bioretention system is recommended. For between 0.25mm/hr and twice that of the filter media, then a conventional underdrainage system is recommended with infiltration into soils as well as stormwater drainage pipes. Where the soil hydraulic conductivity is greater than twice that of the filter media a pipeless system will be sufficient for managing stormwater flow (Water by Design 2014).

The Bioretention Technical Design Guidelines (Water by Design 2014) recommend testing of the hydraulic conductivity of the filter media in line with the Guidelines for Filter Media in Bioretention Systems by the FAWB (2009b). This guideline recommends field testing of the hydraulic conductivity of the filter media at least twice, one month after activation and in the second year of operation. The FAWB (2009a) Stormwater Biofiltration Systems Adoption Guidelines recommend ongoing monitoring of bioretention systems that includes testing for hydraulic conductivity at least every two years and where visible signs show that the capacity may be declining, such as a clogging layer developing or signs of waterlogging. The recommended test is the single ring, constant head infiltration test method outlined in Le Coustumer et al. (2008), performed at a minimum of three points within the system (FAWB 2009b). Figure 2.12.3 below shows the single ring hydraulic conductivity test being performed on spatially distributed monitoring points within a bioretention system.

Hatt and Le Coustumer (2008) proposed a practice note for In Situ Measurement of Hydraulic Conductivity that is included in the FAWB (2009a) Stormwater Biofiltration Systems Adoption Guidelines. The practice note outlines a recommended method for field testing of hydraulic conductivity of the filter media of bioretention systems and has been adopted in the methodology of this project.

Figure 2.12.3 Single ring test carried out on spatially distributed monitoring points (FAWB 2009a)

2.13 WSUD Vegetation

Vegetation in a bioretention system provides a number of vital functional processes in bioretention systems. Aesthetic value is provided by reducing visual impacts of modified landscapes, promoting unbroken tree canopy and screening views of infrastructure and tracks. Physical value is provided by reducing stormwater velocity preventing scour and maintaining the porosity through root growth in the filter media. Plants provide chemical and biological processing of pollutants by stimulating microbial growth, taking up of nutrients and providing carbon for denitrification (Water by Design 2014).

Vegetation can be categorised into groundcovers, shrubs and trees. Groundcovers include tall grasses, sedges and rushes. These are most commonly used in bioretention systems as they are fast growing, have fibrous root systems and are effective at nutrient removal (Water by Design 2014).

Trees and shrubs are an important addition to bioretention system vegetation. Although they are slower growing and may initially have limited effect on nutrient uptake, once they are established they have a greater capacity for nutrient retention in the long run. They provide shade which can reduce weed growth and hence maintenance costs, lower the filter surface temperature, increase amenity and biodiversity, screen infrastructure, provide habitat for wildlife and help maintain porosity of the filter media (Water by Design 2014). Their inclusion in bioretention systems is likely to produce better performance outcomes long term.

When selecting plant species consideration must be given to regional climate and weather patterns, soil types and the extended detention depth. Other WSUD objectives should also be considered such as appropriate landscaping for the setting, amenity and conservation and ecological value (Water By Design 2006). Water By Design (2006) maintains that trees and shrubs incorporated into bioretention systems need to be tolerant of short periods of inundation followed by dry periods, have sparse canopies to allow light to support dense undergrowth, have shallow root systems and preferably be native to the area (Water By Design 2006).

Plant set-out is critical and planting areas should be measured out and staked prior to planting to ensure plants are placed as per the design. Planting should avoid large sections of monoculture (single species). Bioretention systems need more maintenance, particularly weeding and watering, during the establishment period to ensure that plants survive and functioning of the system is established as per the design. Watering of plants is recommended five times per week for the first six weeks, three times per week for the next four weeks and twice per week for a further four weeks (Water by Design 2014). Typically establishment requires a two year period for vegetation to fully mature and ensure system performance. During this period regular additional site monitoring and maintenance is necessary including watering and weeding particularly during the first dry period (Water By Design 2006). If less than 90% of plants survive during the establishment period, replanting will be required. When plants are robust, self-sustaining and healthy and free from disease, with the 90% cover and minimum 500m vegetation height, the system is considered established (Water by Design 2014).

2.13.1.1 Plant Species

Selection of plant species should consider the following criteria from City of Gold Coast (2016):

- Provide physical, chemical and biological conditions to achieve pollutant removal objectives;
- Provide a mix of species that will compete with weeds and provide cover and pollutant removal;
- Promote even distribution of stormwater inflows;
- Tolerance of wetting and drying cycles;
- Integration with landscape;
- Local climate conditions; and
- Enhancing biodiversity.

The desirable plant traits that help achieve these criteria are high values of growth rate, biomass, root density, shoot ratio, length of longest root and leaf area ratio *(FAWB 2009a)*. The City of Gold Coast (2016) provides a list of core functional bioretention plant species that have desirable traits that ensure treatment performance is achieved, these are listed in *Table 2.13.1* below. In addition to this list, Water by Design (2014) provides an extended list of supplementary plant species that can be used alongside the core list.

Table 2.13.1 Core functional bioretention plant species

Species Name	Common Name	Type	Example
Carex appressa	Tall Sedge	Groundcover	 *(Leiper et al. 2014)*
Ficinia nodosa	Knobby Club-sedge	Groundcover-sedge	 *(Leiper et al. 2014)*
Gahnia seiberiana	Red-fruit Saw-sedge	Groundcover-sedge	 *(Leiper et al. 2014)*

Species Name	Common Name	Type	Example
Imperata cylindrica	Blady Grass	Groundcover - grass	 *(Leiper et al. 2014)*
Lepidosperma laterale	Variable Sword-sedge	Groundcover-sedge	 *(Leiper et al. 2014)*
Lomandra hystrix	Green Mat-rush	Groundcover - herb	 *(Leiper et al. 2014)*

Species Name	Common Name	Type	Example
Lomandra longifolia	Spiny-headed Mat-rush	Groundcover - herb	 *(Leiper et al. 2014)*
Poa labillardieri	Common Tussock-grass	Groundcover - grass	 *(Leiper et al. 2014)*
Callistemon salignus	Bottlebrush Willow	Shrub	 *(Leiper et al. 2014)*

Species Name	Common Name	Type	Example
Leptospermum liversidgei	Olive Tea-tree	Shrub	 *(Leiper et al. 2014)*
Banksia robur	Swamp Banksia	Small tree	 *(Leiper et al. 2014)*
Melaleuca linariifolia	Flax-leaved Paperbark	Small tree	 *(Leiper et al. 2014)*

Species Name	Common Name	Type	Example
Lophostemon suaveolons	Swamp Mahogany	Tree	 *(Leiper et al. 2014)*
Melaleuca bracteata	Black Tea-tree	Tree	 *(Leiper et al. 2014)*
Melaleuca quinquenervia	Broad-leaved Paperbark	Tree	 *(Leiper et al. 2014)*

Note: Table information summarised from City of Gold Coast (2016).

2.13.1.2 Vegetation Cover

The City Plan (City of Gold Coast 2016) requirement for established bioretention systems is 90% vegetation cover or less than 10% of soil/mulch visible. Gaps in the vegetation cover result in areas that do not receive the treatment of pollutants that vegetation provides. *Lucas and Greenway (2008)* found that vegetated systems can provide up to 35% difference in TP treatment and up to 58% difference in TN treatment over barren retention systems. Many of the recommended species have root coverage that extends just past the edge of the leaf growth, therefore gaps where adjacent vegetation growth does not touch will result in poorer treatment of pollutants.

2.13.1.3 Planting Density

High density planting in bioretention systems facilitates rapid vegetation establishment, excludes weeds, ensures uniform root growth and porosity throughout the filter media, maximises pollutant removal, evenly distributes flow and prevents scour and flow bypassing (Water by Design 2014). City of Gold Coast (2016) recommends the planting density shown in *Table 2.13.2* in order to achieve vegetation coverage discussed above.

Table 2.13.2 Planting densities

Vegetation Type	Planting Density
Groundcover	6-8 plants per m^2
Shrubs	1 plant per 2-20 m^2
Trees	1 plant per 20-100 m^2

Note: Table information summarised from City of Gold Coast (2016)

2.13.1.4 Planting Diversity

Diversity of plant species is more likely to result in successful plant establishment and long-term resilience (Water by Design 2014) as well as providing better amenity. Water by Design (2014) recommends the minimum plant species diversity shown in *Table 2.13.3*.

Table 2.13.3 Planting diversity

Planting Style	Minimum plant species
Small scale urban	$2 < 100m^2$ $4 \geq 100m^2$
Medium-large scale urban	6
Bushland	10

Note: Table information summarised from Water by Design (2014)

2.13.1.5 Amenity

Landscape integration that increases visual amenity is one of the primary objectives for WSUD under the City Plan (City of Gold Coast 2016). Appropriate plant selection is one of the most important ways of ensuring integration with the local landscape and improving the amenity and aesthetic value of a bioretention system (Water by Design 2014).

2.13.1.6 Other Benefits

WSUD, including bioretention systems, have the potential to impact on urban micro-climates. Vegetation in an urban climate, particularly trees, provide cooling effects through evapotranspiration and shading. A study by Coutts et al. (2013) for the CRC for Water Sensitive Cities found that for a 10% increase in vegetation cover there was a 1^{o} reduction in land surface temperature.

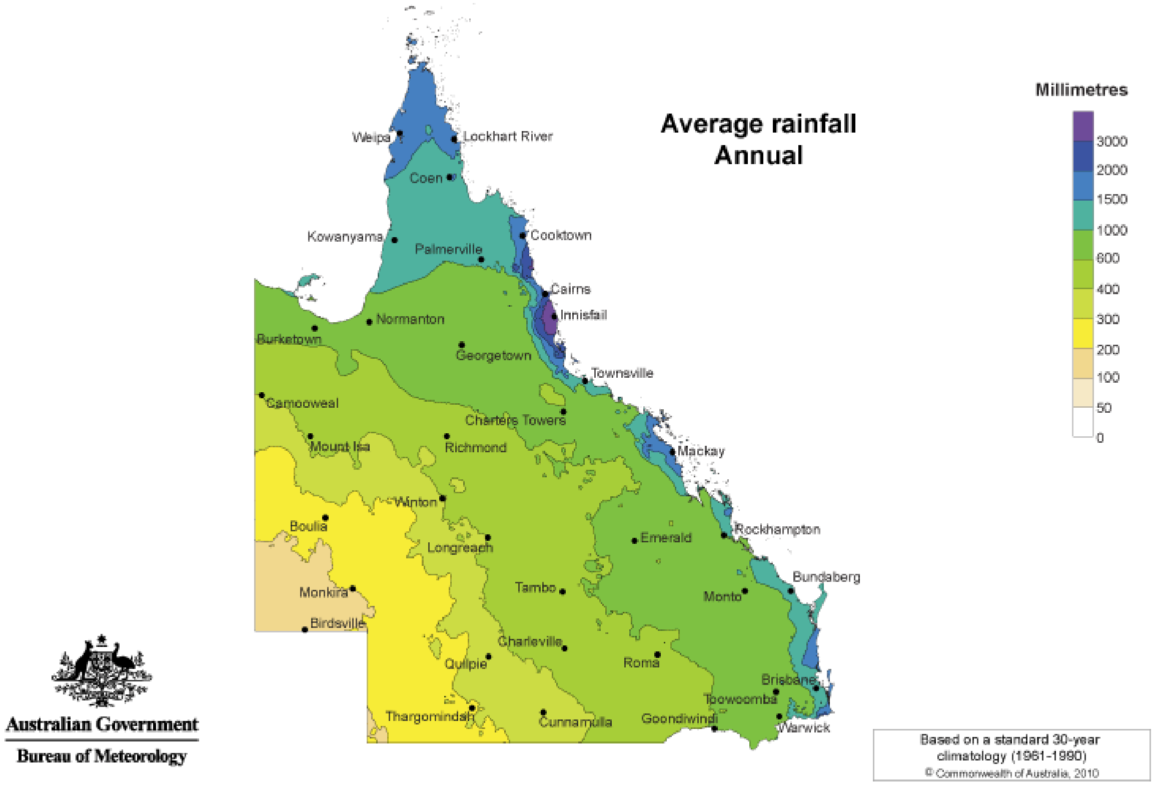
Natural environmental settings as provided by many bioretention gardens can also provide benefits for human health and well-being. Coutts et al. (2013) explains that natural settings, particularly those with higher levels of biodiversity, are capable of promoting psychological well-being, reducing stress levels, inducing positive emotions and renewing cognitive functioning.

2.14 Climate and Weather Conditions

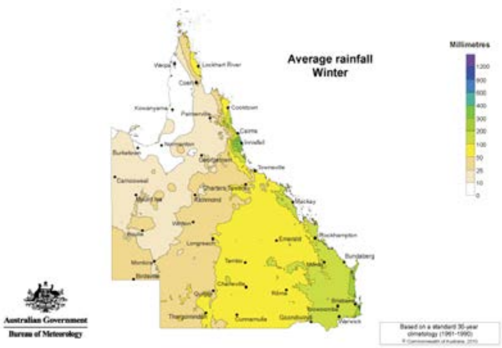
As with much of South East Queensland (SEQ) the seasonal weather pattern for the Gold Coast consists of wet summers and dry winters. This seasonal variation is illustrated by the Bureau of Meteorology (2017) in Figure 2.14.1 below.

Water By Design (2006) categorises SEQ into 4 climatic zones; Greater Brisbane, North Coast, Western Region and South Coast. The Gold Coast falls within the South Coast zone with 120-140 days of rain per year and a mean annual rainfall of 1300-1700mm (Water By Design 2006). Long dry periods during winter may require saturated zones or scheduled watering to ensure plant health particularly during the establishment period.

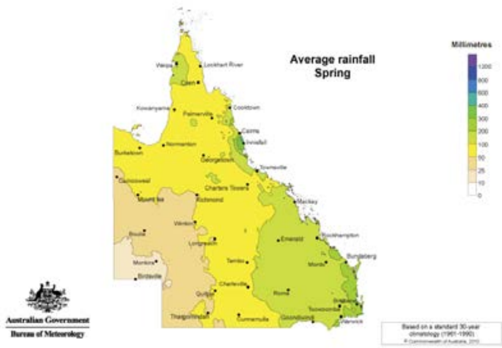
Annual Rainfall



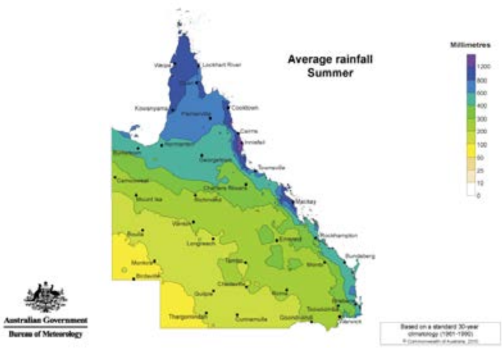
Winter Rainfall



Spring Rainfall



Summer Rainfall



Autumn Rainfall

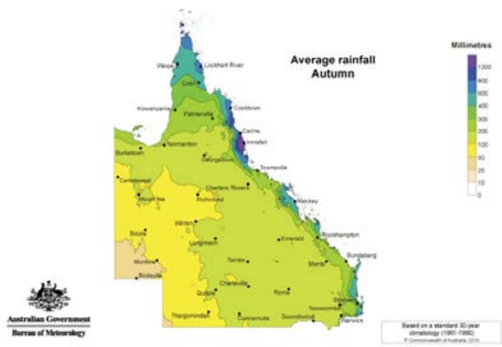


Figure 2.14.1 Queensland annual and seasonal rainfall (Bureau of Meteorology 2017)

2.15 Acid Sulfate Soils and Dispersive Soils

Acid sulfate soils (ASS) are soils that contain iron sulfide minerals due to deposits of marine or estuarine sediments. ASS are problematic as they produce sulfuric acid when exposed to air which can affect steel and concrete infrastructure and seep into waterways killing aquatic organisms, flora and fauna (Queensland Government 2015). ASS pose a particular problem for bioretention systems as the sulfuric acid runoff will kill off vegetation and compromise the performance of the system. Signs for identifying ASS have been summarised in Table 2.15.1 below.

ASS occur in coastal and near coastal areas, particularly at less than 5m AHD but up to 20m AHD (often buried under other soils). They are usually found in low lying wetlands or swamps or areas that have been water-borne and have accumulated marine sediments (Queensland Government 2015).

Table 2.15.1 Signs of ASS

Type of ASS	Signs	Example
Potential or Undisturbed (PASS)	• Water-saturated with sandy or muddy texture • 'Soup' of fine sulfidic sediments around larger rocks • Steely blue-grey 'gley' colour ranging from pale to dark	 *(Simmonds & Bristow 2017)*
Actual or Disturbed (AASS)	• Yellow jarosite mottling or orange mottling from iron oxides • 'Gley' colours replaced by dark to pale browns	 *(Department of Natural Resources and Mines 2003)*

	• Rust coloured staining • Vegetation dying off	 *(Water By Design 2012b)*
	• Monosulfidic black ooze at the bottom of slow moving waters	 *(Department of Natural Resources and Mines 2003)*
	• Clear blue-green acidic water	 *(Department of Natural Resources and Mines 2003)*

Note: Table information summarised from Department of Natural Resources and Mines (2003).

City of Gold Coast mapping of acid sulfate soils (ASS), Figure 2.15.1, indicates that the majority of Gold Coast locations have the potential for acid sulfate soils that could affect bioretention design and need to be considered during field testing. More detailed mapping from the Department of Natural Resources and Mines of identified ASS locations on the Gold Coast are provided as Appendix C. Development approval processes require undertaking ASS investigations that include testing borehole samples from the site. Where ASS are identified preparation of an ASS management plan is required in accordance with the Queensland Acid Sulfate Soil Technical Manual – Soil Management Guidelines (City of Gold Coast 2016).

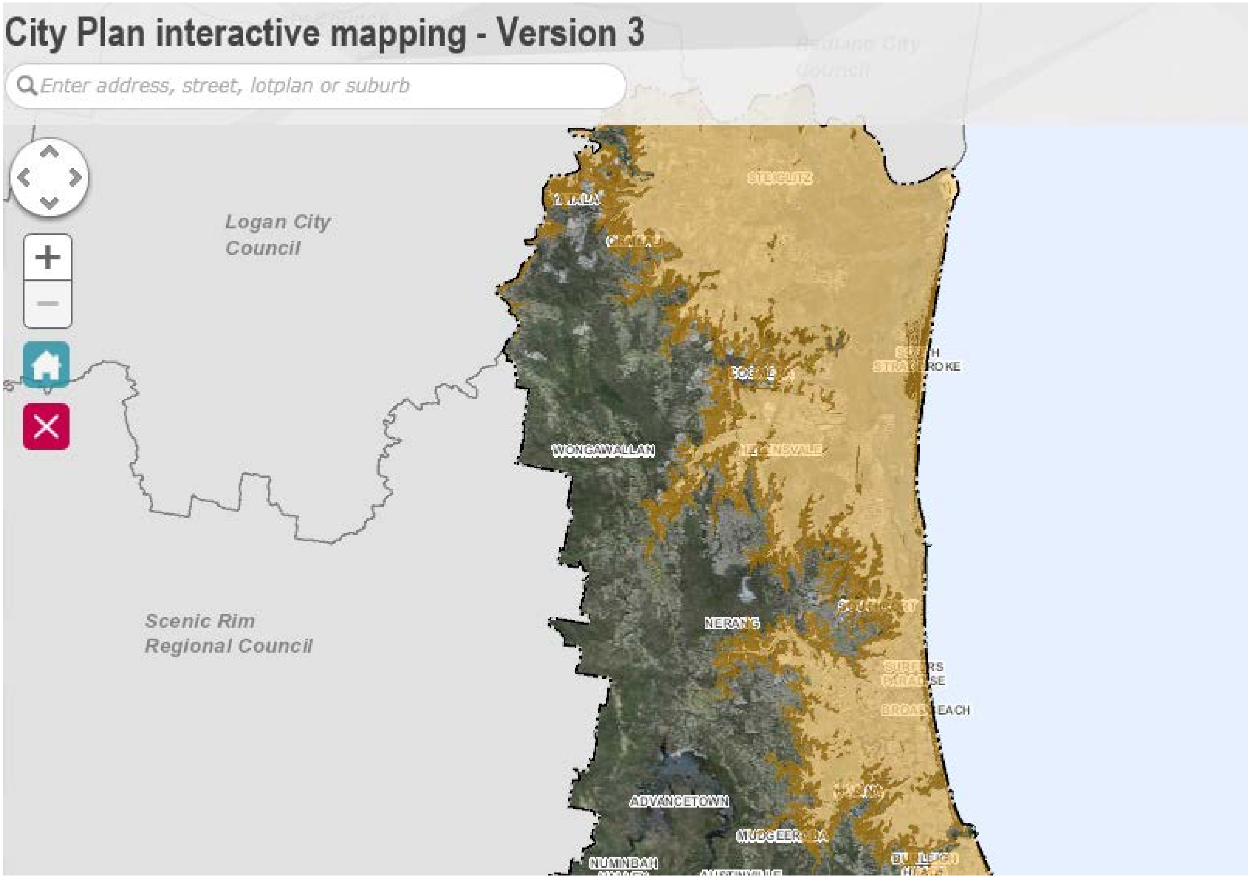


Figure 2.15.1 City Plan interactive mapping – acid sulfate soils overlay (City of Gold Coast 2016)

Dispersive or sodic soils are soils that have a high proportion of sodium ions compared with other cations. Sodicity is a naturally occurring feature in approximately 45% of Queensland soils that weakens the bond between soil particles and impacts on soil structure. Dispersive soils are problematic as they experience accelerated erosion which can cause the appearance of gullies. Crusting on the surface can limit leeching and cause salt accumulation in the soil which causes problems for vegetation. Table 2.15.2 below lists identifiers of dispersive soils.

Table 2.15.2 Signs of dispersive soils

Signs	**Example**
• Poor growth of vegetation; • Poor infiltration of water; • Crusting on soil surface; • Appearance of gullies and tunnels in soil surface; • Prismatic or columnar structure in subsoil; • Cloudy water in puddles; and • Soapy feeling when wet.	 (Queensland Government 2014)

Note: Table information summarised from Queensland Government (2014).

Queensland Government mapping of sodic soils, Figure 2.15.2, indicates that the Gold Coast is in a variable area and dispersive soils could be a concern.

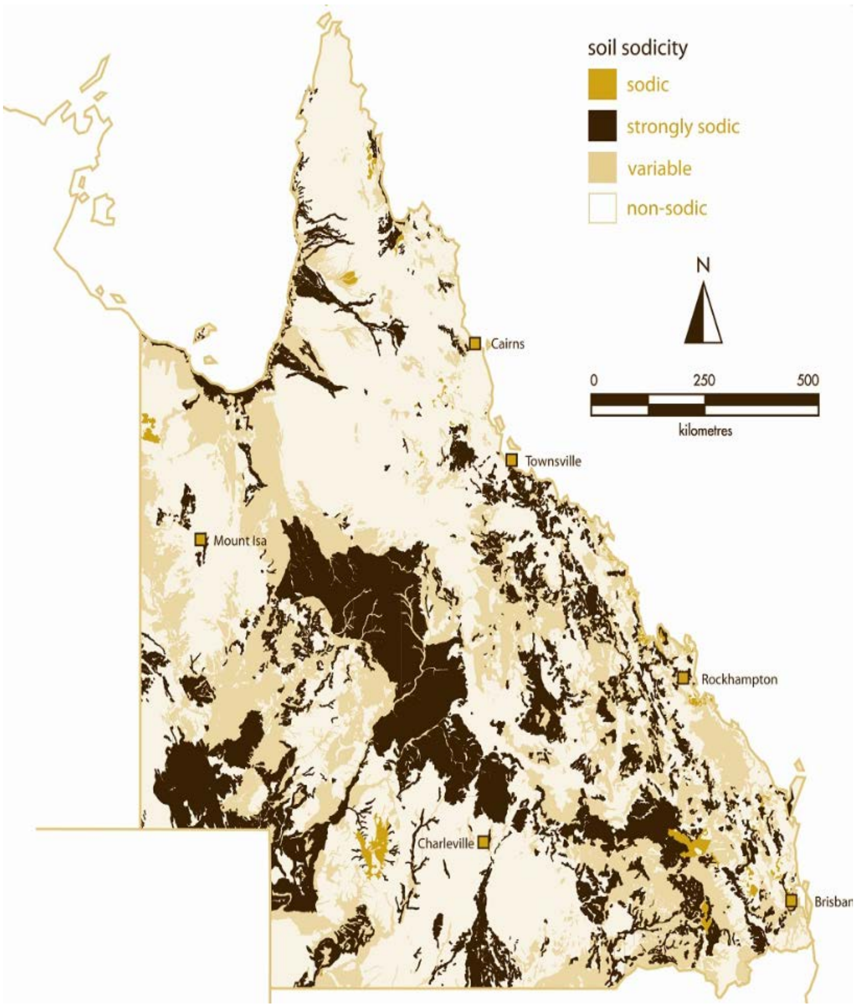


Figure 2.15.2 Soil sodicity in Queensland (Queensland Government 2014)

In addition to ensuring that surrounding soils in bioretention systems do not contain ASS or dispersive soils, the filter media must be free from actual and potential acid sulfate soils and must not be made from dispersive materials (Water by Design 2014). This is particularly important where natural or amended natural soils are used for the media.

2.16 MUSIC Modelling

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) is an eWater software for modelling urban stormwater catchments and is the recommended tool for designing stormwater quality treatment systems (Water By Design 2010). Water By Design (2010) produced the MUSIC Modelling Guidelines to ensure that modelling and assessment is being approached consistently and uniformly to achieve stormwater quality performance objectives. The City of Gold Coast stormwater quality performance objectives were discussed in Section 2.5. While MUSIC is useful for demonstrating compliance to stormwater quality management, the tool is not suitable for demonstrating compliance with waterway stability and frequent flow management performance objectives.

2.16.1 Rainfall Data

MUSIC uses recorded meteorological data from Bureau of Meteorology rainfall stations to generate rainfall-runoff and pollutant generation inputs for a catchment model. Rainfall data can be imported into MUSIC for three different rainfall stations on the Gold Coast, for central locations at Hinze Dam, for southern locations at Elanora Treatment Plant and for northern locations Beenleigh Bowls Club. Rainfall modelling is recommended in maximum time steps of 6 minutes (Water By Design 2010). City of Gold Coast (2016) requires simulation using 10 years of 6 minute rainfall data.

2.16.2 Catchment Area

Water By Design (2010) outlines the steps for modelling the catchment source nodes:

- Define the total area, sub-catchment areas and total catchment area;
- Split the catchment into similar land uses and surface types; and
- For each land use define the percentage impervious, rainfall-runoff parameter and pollutant export parameter.

Catchment land uses and surface types can be modelled using a split catchment or a lumped approach. The split catchment approach is a requirement for development applications. The split catchment or lumped catchment approach can be used for master planning, conceptual design and modelling existing catchments where development applications are not involved. Under the split catchment approach, areas of roof, road and ground surface types are identified and modelled. The lumped catchment approach is a broader scale approach where areas of land uses are identified under the categories of residential, rural residential, industrial and commercial and MUSIC applies a typical surface-type split for road, roof and ground areas (Water By Design 2010). Catchment source nodes for each type of land use are added to a MUSIC model. The input data for each node includes the catchment area entered and parameters detailed in the following sections.

2.16.3 Impervious Fraction

In urban catchments rainfall runoff is generated in great part by the impervious areas. A MUSIC model applies an impervious fraction to catchment source nodes depending on their land use. As with catchment area, this can be applied using the split catchment or the lumped catchment approach. Applying the split catchment approach the impervious fraction is based on whether the land use is road reserve, roof or ground level as well as residential density, industrial use or commercial use. Applying the lumped catchment approach the impervious fraction is based on a land use, residential density, industrial, commercial, public zones, infrastructure projects, rural or forest. The impervious fraction is based on a typical distribution of road, roof or ground for the type of land use.

2.16.4 Rainfall Runoff Parameters

Rainfall runoff parameters are based on the land use type of each node. MUSIC modelling simplifies rainfall runoff by separating impervious and pervious areas of a catchment (Water By Design 2010). The following is a list of rainfall runoff input parameters required for each source node:

- Rainfall threshold;
- Soil storage capacity;
- Initial storage;
- Field capacity;
- Infiltration capacity coefficient a;
- Infiltration capacity exponent b;
- Initial depth;
- Daily recharge rate;
- Daily baseflow rate and
- Daily deep seepage rate (Water By Design 2010).

These parameters are entered as typical values provided as tables unless justification can be made for variation.

2.16.5 Pollutant Export Parameters

MUSIC provides pollutant export parameters that are typical values of pollutants in runoff from each land use type. Typical pollutant levels are provided for:

- Total suspended solids (TSS);
- Total phosphorous (TP); and
- Total nitrogen (TN).

Treatment of TN levels in runoff is frequently the limiting factor for sizing stormwater treatment systems. As for catchment area and impervious fraction above, these values are provided for either the split or lumped catchment approaches. Pollutant levels are based on peer reviewed studies of stormwater quality in urban catchments and proposed deviation from these parameters must be supported by providing scientifically robust, independently peer reviewed stormwater quality monitoring results (Water By Design 2010).

2.16.6 MUSIC Inputs

The inputs required for modelling bioretention systems in MUSIC are outlined in Table 2.3.1.

Table 2.16.1 MUSIC model inputs for bioretention systems

Property	Input Element	Description
Inlet	Low-flow bypass (m^3/s)	The amount of flow during small storms that is lost before reaching the bioretention system, usually due to infiltration into surrounding soils.
	High-flow bypass (m^3/s)	The amount of flow that does not reach the bioretention system due to constraints on inflow such as inlet pipe sizes.
Storage	Surface area of the filter media (m^2)	This can be taken as equal to the filter media area, this is a conservative estimate for trapezoidal-shaped detention depth. This is the preferred method. Can be taken as the detention area at the median depth of the pond, often at less than half the detention depth and difficult to calculate. Maximum is the average of top and bottom detention area.
	Extended detention depth (m)	Depth between overflow inlet and filter media. Recommended 100-200mm and maximum 300mm.
Filter Media	Filter area (m^2)	Measured area of the filter media
	Unlined filter media perimeter (m)	Used to consider exfiltration from sides and batters and should generally not be used to demonstrate compliance with stormwater quality objectives. If exfiltration rate is set at 0mm/hr then unlined perimeter should be set at 0.01m. If unlined perimeter is to be used but is unknown a rule of thumb is 4x square root of surface area.
	Saturated hydraulic conductivity (mm/hr)	Standard settings for SEQ for loamy sand with particle diameter 0.45mm and hydraulic conductivity of 200mm/hr. For sensitivity testing this will also be simulated for 50mm/hr.
	Filter depth (m)	Recommended depth 400-1000mm, preferably 500-600mm. Depends on inlet and outlet levels and plant species.
	TN content of filter media (mg/kg)	Where this is unknown a default value of <800mg/kg is used.
	Proportion of organic material in filter (%)	Where this is unknown a default value of <5% is used.

Property	Input Element	Description
	Orthophosphate in filter (mg/kg)	Where this is unknown a default value of <55mg/kg is used.
Lining	Lined base	If unlined tick yes.
Vegetation Properties	Vegetated with effective nutrient removal plants	Three options: Vegetated with effective nutrient removal plants. Vegetated with ineffective nutrient removal plants (eg turf). Unvegetated.
Infiltration and Outlet	Overflow weir width (m)	Controls the discharge rate when water level reaches detention depth. Recommended as a starting point set to surface area divided by ten.
	Exfiltration rate (mm/hr)	Applies to base, sides and batters. Generally not modelled when demonstrating compliance with stormwater quality objectives and set at 0mm/hr. Secondary drainage link can be set up for infiltration.
	Underdrain present	Select yes as default as most bioretention systems are configured with collection pipes.
	Submerged zone with carbon present	Improves denitrification and provides moisture storage for plants. Should be included where practicable.
	Depth of submerged zone (m)	Modelled as zero unless submerged zone is confirmed through design documentation.
Additional property inputs for bioretention swales		
Inlet	Low-flow bypass (m^3/s)	Equal to infiltration rate of surface (length (m) x base width (m) x hydraulic conductivity of filter media (mm/hr) / 3600 / 1000).
Storage	Length (m)	Measured length of swale.
	Bed slope (%)	Measured bed slope.
	Base width (m)	Measured base width.
	Top width (m)	Measured top width.
	Depth (m)	Measured depth.
	Vegetation height (m)	Measured vegetation height.
	Exfiltration rate (mm/hr)	Set to zero

Note: Table information summarised from the MUSIC Modelling Guidelines (Water By Design 2010).

2.16.7 MUSIC Model Outputs

MUSIC modelling software has been developed to predict the performance of stormwater quality treatment systems. For individual bioretention systems the mean annual load reports will provide inputs, outputs and the percentage reduction of flows, TSS, TP and TN across the individual bioretention node. These percentage reductions can then be compared to stormwater quality performance objectives as detailed in Section 2.5.

City of Gold Coast (2016) City Plan schedule SC9.3.4.4.1 Modelling outlines the following procedures for calculating baseflow contribution, surface flow days and flow volume reduction from MUSIC outputs:

- Baseflow contribution is calculated by exporting outflows in 6 minute increments. All flows that exceed the baseflow threshold of 0.4L/s/ha are summed and converted to a mean annual volume (ML/yr). This is added to the infiltration volume then converted to a percentage of the mean annual rainfall volume for the catchment (City of Gold Coast 2016):

  Baseflow contribution (%) = (Outflows Below Threshold + Infiltrated Volume)/Mean Annual Rainfall ≥ 10% ; and

- Surface flow days are calculated by extracting a cumulative frequency plot from MUSIC of outflows based on the daily maxima. Determine frequency (%) where outflows exceeded the baseflow threshold. Calculate the flow days based on exceedance frequency multiplied by 365 (City of Gold Coast 2016):

  Surface Flow Days = Baseflow exceedance % x 365 ≤ 20 days.

2.17 ArcGIS

ArcGIS is a graphical information system (GIS) developed by ESRI software that builds desktop mapping and spatial data analysis. It allows a user to create maps as well as data tables that are associated with spatial features in the mapping. ArcGIS will be used to record data related to bioretention systems including recorded data from the field testing checklist and from MUSIC modelling.

Chapter 3 Methodology

3.1 Methodology Outline

The following steps outline the broad methodology for this project:

- Preparation;
- Field work;
- Laboratory testing; and
- Data analysis and write up.

Table 3.1.1 below further outlines this broad methodology.

Table 3.1.1 Project Tasks

Project Tasks	
1	**Preparation**
1.1	Project allocation request form
1.2	Preliminary project proposal including detailed introduction, literature review and methodology
1.3	Decide data collection fields and assessment criteria
1.4	Find an appropriate contact within City of Gold Coast
1.5	Email contact with outline of project, request for access to WSUD design documentation, outline of what City of Gold Coast would gain from project and request for meeting
1.6	Meeting with City of Gold Coast – modify project tasks as necessary to meet City requirements
1.7	Collect or purchase resources and set up field testing kit
1.8	Research soil hydraulic conductivity testing
1.9	Research plant species
1.10	Other research
1.11	Submit final preliminary project report
1.12	Set up site data collection plan and site mapping process using ArcGIS
1.13	Map collection sites
1.14	Collect site design and as constructed documentation
1.15	Prepare and maintain project schedule
2	**Field Work**
2.1	Maintain contact with City of Council
2.2	Site safety assessment
2.3	Collection of field data– field testing checklist
2.4	Take photos of site
2.5	Analysis of maintenance conditions – rubbish, filtration collection
2.6	Analysis of vegetation – diversity, coverage, condition, shade
2.7	Analysis of soil - soil hydraulic conductivity single ring test
2.8	Sampling of water – inlet and outlet sampling and storage
2.9	Analysis of water flow into and out of bioretention basin – view during rainfall
2.10	Comparison of existing vegetation and construction with design documentation

2.11	Recording of data
3	**Laboratory Testing**
3.1	Water sample quality testing
3.2	Recording of data
4	**Data Analysis and Write Up**
4.1	Review and editing of collected data
4.2	Modelling of selected sites using MUSIC software system
4.3	Statistical analysis using software package
4.4	Preparation of data plots and comparisons
4.5	Write dissertation
4.6	Submit draft dissertation
4.7	Revision of dissertation
4.8	Submit electronic copy of dissertation
4.9	Post two hard copies of dissertation

Specific methodologies for aspects of the field work and data analysis are outlined in the following sections. City of Gold Coast has provided a list of bioretention assets and their maintenance schedules, a map of these assets attached as Appendix D. Approval from City is pending for permission to be carry out testing on site at these systems. It is preferred that privately owned assets are also included in the testing as this might provide further insight into whether maintenance and condition differs between publicly and privately owned assets. Contact will be sought with Bunnings, 7-eleven and major housing developments for access to their assets for testing. It is anticipated that further assets may be discovered during field testing.

3.2 Catchment Information

The size of the catchment area of each bioretention system will be estimated prior to field testing using topography maps on Google Earth and by determining drainage infrastructure using Google Streetview. The estimate of the catchment and information on drainage infrastructure will be confirmed during the site visits. Information on catchment characteristics will also be determined during the site visit. Land uses will be identified so that their recommended impervious fraction, rainfall-runoff and pollutant parameters can be determined for MUSIC modelling. Modelling of the catchment for this project will use a simplified lumped approach that will require identification of the percentage of land use under the categories of residential, rural residential, industrial and commercial. For residential and rural residential this will be further broken down into categories based on whether the number of dwellings per hectare is 10, 15, 40 or 80+. Obvious pollutant loads such as deciduous trees or industrial sites will be pinpointed.

Prior to the site visit, the catchment will examined for levels of tidal waters and the likelihood of ASS using the City Plan Interactive Mapping (City of Gold Coast 2016). Soil types will be researched using the soil mapping layers of QGIS in Google Earth, particularly looking for the likelihood of dispersive soils. During site visits visible signs of potential or actual ASS soils and dispersive soils will be investigated.

Signs of ASS listed by Queensland Government (2015) are:

- Water-saturated with sandy or muddy texture;
- 'Soup' of fine sulfidic sediments around larger rocks;
- Steely blue-grey 'gley' colour ranging from pale to dark;
- Yellow jarosite mottling or orange mottling from iron oxides;
- 'Gley' colours replaced by dark to pale browns;
- Rust coloured staining;
- Vegetation dying off;
- Monosulfidic black ooze at the bottom of slow moving waters; and
- Clear blue-green acidic water;

Signs of dispersive soils:

- Poor growth of vegetation;
- Poor infiltration of water;
- Crusting on soil surface;
- Appearance of gullies and tunnels in soil surface;
- Prismatic or columnar structure in subsoil;
- Cloudy water in puddles; and
- Soapy feeling when wet.

3.3 Design and Construction Documentation

Design and construction documentation will be useful for comparing with current conditions of the bioretention systems and determining any contributing factors. A conversation with a representative from City of Gold Coast WSUD asset management indicated that design and construction documentation might be difficult to obtain. A search of the City of Gold Coast planning and development tool PD online will be undertaken to source documentation for the sites. Contact will be made with a further representative of City of Gold Coast responsible for handover of WSUD assets. Asset handover documentation may include design drawings as well as construction inspection records. Documentation may also be available directly through the developer or site owner, however it is considered unlikely that design and construction documentation will be easily given out.

The following information will be sought from the design and construction documentation:

- Age of the system;
- When the asset was handed over;
- Original design and whether the system was constructed as per the design;
- Original vegetation planting and whether the vegetation has survived;
- The drainage profile of the system;
- Details of the filter media for MUSIC modelling;
- Did the system have protection during construction works such as geofab and turf coverings; and
- Was the system handed over in good condition after the establishment period.

3.4 Field Testing of Bioretention Systems

Field testing of the bioretention systems is central to the aims and objectives of this research project. The testing will aim to assess whether each system is meeting performance objectives and outcomes and will collect data for developing the MUSIC model. A field testing checklist will be completed for each bioretention system that will record testing data and enable easy entry into ArcGIS.

3.4.1 Site Information

Each site visit will start with a site safety assessment including looking for site specific hazards such as traffic, weather conditions and possible impacts on the public.

The following site information will be recorded on the field testing checklist:

- Site Location;
- GPS coordinates;
- Date and time of visit/s;
- Weather conditions; and
- The asset owner.

Photos of the system will be taken including the inlet, outlet, overflow pit or weir, vegetation cover and condition, filter media condition and testing and outlet pit.

3.4.2 Bioretention System Information

The following system information will be recorded on the field testing checklist:

- Type of system: basin, swale, biopod, street tree;
- Setting of the system: allotment, streetscape, civic space, parkland, bushland, large scale;
- Drainage profile: Type 1 saturated zone, Type 2 sealed, Type 3 conventional, Type 4 pipeless;
- Age of the system (this may be ascertained through the design documentation or may need to be estimated;
- Whether the system has a coarse sediment forebay or inlet pond;
- Existence of walls;
- Existence of fencing;
- The original design (from design documentation);
- Safety aspects of the batter slope and fencing; and
- Amenity of the system.

3.4.3 Filter Surface

3.4.3.1 Flow Regime

Visual inspection of each bioretention site will be carried out to determine whether any bypassing or potential future bypassing of the filter media is occurring. Ideally each system will be observed during a rainfall event to ensure that runoff is entering the system and being treated. In the event that a site is not observed during rainfall a contingency plan would be to simulate water flow into the system.

3.4.3.2 System Sizing

Measurements of the bioretention systems will be taken and the filter media surface area and batter slope area calculated. City of Gold Coast (2016) has a current maximum filter media area of 800m^2 before the system should be spilt into multiple cells. For maintenance access the system should be a maximum of 15m wide (20m where access is available from both sides) and 40m long. Systems will be checked against these current maximums. The filter media area will be calculated as a percentage of the catchment area to check whether this percentage meets the deemed to comply solutions for small-sized developments from City of Gold Coast (2016) listed in Table 3.4.2 below. Alternatively this percentage will be compared to the conceptual treatment size for bioretention systems listed in SC6.9.3-13 (City of Gold Coast 2016) which is 1-1.5% of the catchment area for the filter media area or 4% of the catchment area for the filter media area and batters. The measurements will then be applied in the music model along with the detention depth and hydraulic conductivity to determine whether the balance of these three factors is achieving water quality objectives.

Table 3.4.1 Deemed to comply solutions

Development Type	Deemed to comply solution
Residential	A bioretention device(s) that is not less than 2% of the total contributing catchment (including roof areas).
High Rise	A bioretention device(s) that is not less than 2% of the total contributing catchment (including roof areas). a gross pollutant trap (hydrocarbon and litter separator) for high-rise development that includes a basement car park for > 10 cars.
Commercial/Industrial	A bioretention device(s) that is not less than 2.5% of the total contributing catchment (including roof areas). A gross pollutant trap (hydrocarbon and litter separator) for high-rise development that includes a basement car park for > 10 cars.

Note: Table information summarised from City of Gold Coast (2016).

3.4.3.3 Detention Depth

The system's extended detention depth will be measured on site and compared to the recommended range 100-200mm and maximum 300mm depth (Water by Design 2014). The measured detention depth will be applied in the music model along with the filter media area and hydraulic conductivity to determine whether the balance of these three factors is achieving water quality objectives.

3.4.3.4 Clogging

Visual inspection will show any obvious signs of clogging, particularly sediment runoff from construction works. If the hydraulic conductivity test below indicates underperforming filtration media, the top layer or crust of the filter media will be removed and testing repeated to check whether clogging in this layer is responsible.

3.4.3.5 Biofilms Layers and Fine Sediment Layers

Biofilms are a layer of algae that develops on the surface of a bioretention system and affects infiltration, usually caused by continuous wetting of the system. Deposition of fine sediments can also form a surface layer that affects infiltration, this is often caused by runoff from construction works. Signs of biofilms or fine sediment layers will be recorded.

3.4.3.6 Ponding

Evidence of ponding on the surface of the system will be inspected. Ponding can be caused by blockage of the underdrainage, surface level of the system being below that of receiving waterways or problems with the filter media (Water By Design 2012a)

3.4.3.7 Hydraulic Conductivity Testing

The methodology to be used for testing the hydraulic conductivity of the filter media will be the single ring infiltrometer test outlined in Practice Note 1: In Situ Measurement of Hydraulic Conductivity, Appendix E of the Stormwater Biofiltration Systems Adoption Guidelines by FAWB (2009a).

The test will be conducted on at least three spatially distributed areas within the bioretention system. For systems larger than $50m^2$ an additional testing point will be added for every $100m^2$ of filter media area. Monitoring sites should be flat and level and vegetation should not be included. The equipment listed in Table 3.4.1 below will be required, set up as per Figure 3.4.1.

Table 3.4.2 Equipment for single ring test

Qty	Equipment	Notes
3	PVC rings	100mm diameter 220mm height Outside of ring marked at 50mm from the bottom (ring to be driven into filter media to this level). Inside of ring marked at 100mm from the bottom 200mm from the bottom (50mm and 150mm from filter media level)
40L	Water	
3	Measuring cylinders	100mL, 250mL, 1000mL
1	Stopwatch	Mobile phone to be used
1	Thermometer	
1	Measuring tape	
1	Spirit level	
1	Hammer	
1	Block of wood	Approximately 200x200mm
1	Sponge	

Note: Table information summarised from FAWB (2009b).

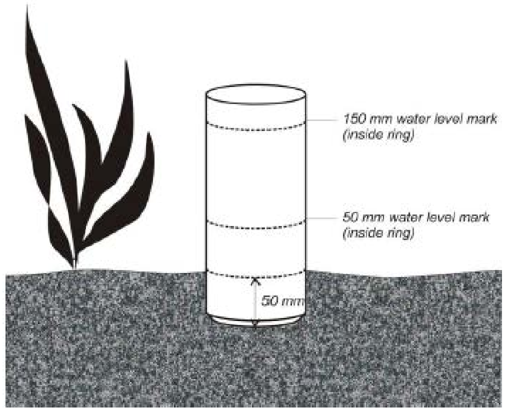


Figure 3.4.1 Single ring infiltrometer setup (FAWB 2009a)

The testing procedure is explained below:

- Clear the surface covering of any mulch, leaves or gravel without disturbing the filter media;
- Place the ring on the surface of the filter media, place the block of wood on the top of the ring and gently tap with the hammer to drive the ring in to the 50mm outside mark. Do not disturb the filter media profile. Check the ring is level using the spirit level;
- Record the initial water temperature;
- Fill the 1000mL measuring cylinder;
- Place the sponge at the bottom of the ring;
- Slowly fill the ring to above the 50mm mark, minimising disturbance by pouring onto the sponge;
- Remove the sponge;
- When the water level reaches the 50mm mark start the stopwatch;
- Maintain the water level at the 50mm mark using the appropriate measuring cylinder for the volume of water required
- At 1 minute time intervals recording the volume of water required to do so (for slow draining media the time interval may be increased up to 5 minutes);
- Continue to maintain the water level until the infiltration rate is steady, the volume poured per time interval will remain steady for at least 30 minutes;
- Repeat the process above for the 150mm water level;
- Record the final water temperature;
- Enter the data into a calculation spreadsheet to find the saturated hydraulic conductivity. An example calculation spreadsheet from FAWB (2009a) is attached as Appendix D;

- The procedure will be repeated in a minimum of three spatially diverse locations within the bioretention systems. If the system has a filter media area of greater than $50m^2$ an additional location will be added for every $100mm^2$ of area; and
- If the hydraulic conductivity is found to be below the recommended minimum 100mm/hr a top layer of filter media will be scraped away and the test repeated. This will establish whether clogging in the top layer of the filter media is responsible for low conductivity.

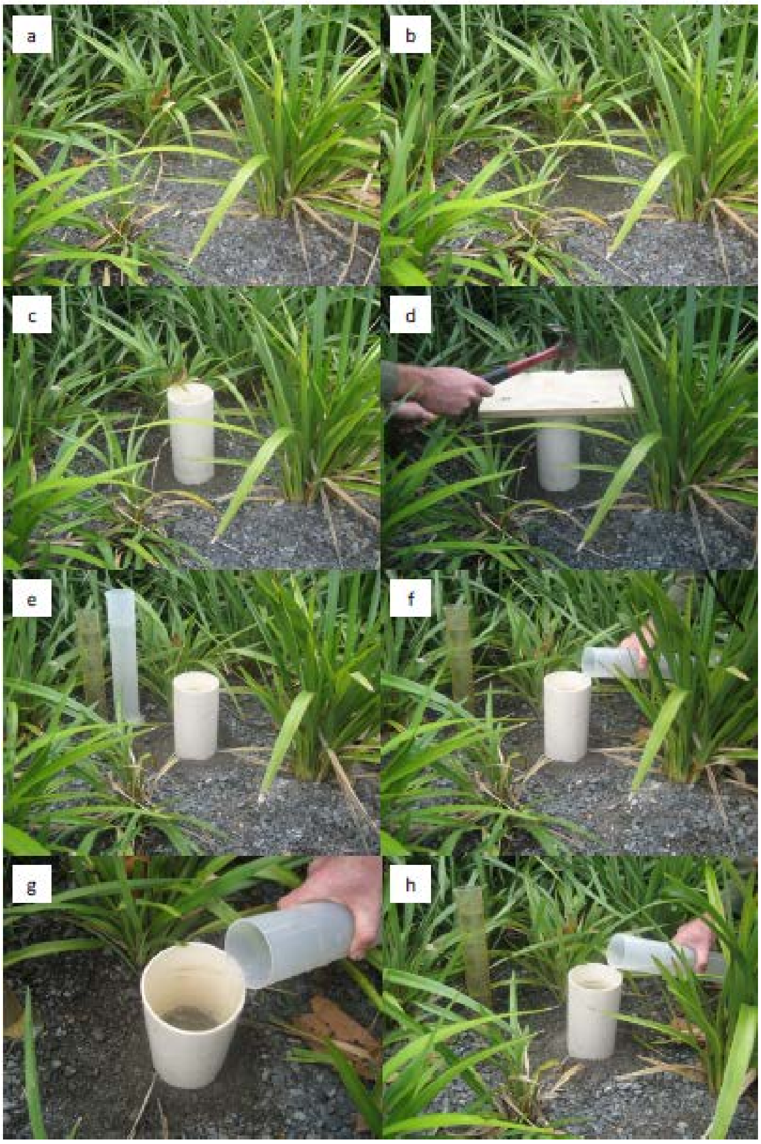


Figure 3.4.2 Single ring infiltrometer test procedure (FAWB 2009a)

Figure 3.4.2 illustrates the test procedure explained above. Field tests from the different monitoring points will be considered to be comparable if they differ by less than 50%. Where a difference greater than this occurs, localised inconsistency in the filter media may be the cause and additional measurements at alternative locations will be performed until comparable results are achieved (FAWB 2009a). An average of comparable results will be calculated and compared with design documentation to examine whether any deterioration has occurred. The result will also be used in the MUSIC model. Australian Runoff Quality (Wong 2006) advises that a correction factor be applied to field tested hydraulic conductivity. The correction factors in Table 3.4.2 below will be applied to the tested hydraulic conductivity before being applied in the MUSIC model.

Table 3.4.3 Correction factors for field tests

Soil Type	Correction Factor
Clay	2.0
Sandy Clay	1.0
Sandy	0.5

Note: Table information summarised from Wong (2006).

Tested hydraulic conductivity will be compared with the recommendation of 100-300mm/hr (Water by Design 2014).

3.4.4 Vegetation

3.4.4.1 Plant Species

Bioretention systems will be visually inspected and plant species will be identified with the aid of a field guide to native vegetation. Each species and the number of plants found will be recorded. The presence of weed species and non-planted species growing will also be noted. The identified vegetation will be compared to the desirable plant species identified in the City Plan (City of Gold Coast 2016) and the Bioretention Technical Design Guidelines (Water by Design 2014). Identified species and numbers will be compared to design documentation if available.

3.4.4.2 Presence of Trees and Shrubs

The presence of trees and shrubs and their type and number will be recorded. The identified trees and shrubs will be compared to the desirable plant species identified in the City Plan (City of Gold Coast 2016) and the Bioretention Technical Design Guidelines (Water by Design 2014). Identified species and numbers will be compared to design documentation if available.

3.4.4.3 Vegetation Cover

Vegetation cover will be assessed as a percentage of the filter area. The City Plan (City of Gold Coast 2016) requirement is for 90% cover for established systems or less than 10% of soil/mulch visible. Gaps in the vegetation cover will be noted. Many of the recommended species have root coverage that extends just past the edge of the leaf growth therefore gaps will be identified by areas where adjacent vegetation growth does not touch.

3.4.4.4 Planting Density

Planting density of groundcovers, shrubs and trees will be established by dividing the number of each type within the system by the filter media area. Planting density on batters and embankments will be calculated in the same way. This will be compared with Table 3.4.3 below from the City Plan (City of Gold Coast 2016).

Table 3.4.4 Planting densities

Vegetation Type	Planting Density
Groundcover	6-8 plants per m^2
Shrubs	1 plant per 2-20 m^2
Trees	1 plant per 20-100 m^2
Planting on batters and embankments	6 plants per m^2

Note: Table information summarised from City of Gold Coast (2016)

3.4.4.5 Planting Diversity

Planting diversity will be established by counting the number of species within the system. This will be compared with the recommendation in Table 3.4.4 below from Water by Design (2014)

Table 3.4.5 Planting diversity

Planting Style	Minimum plant species
Small scale urban	$2 < 100m^2$ $4 \geq 100m^2$
Medium-large scale urban	6
Bushland	10

Note: Table information summarised from Water by Design (2014)

3.4.4.6 Other Vegetation Information

The following other vegetation information as recommended in Water by Design (2014) will also be recorded:

- Presence or absence of vegetation on batter slopes;
- Presence or absence of mulch;
- Whether vegetation height is greater than 500mm;
- Whether plants are healthy and free from disease;
- Does the planting style match with the local environment;
- Does the planting interfere with any line of sight;

3.4.4.7 Comparison with Design

Where available the current conditions of the system will be compared with design and construction documentation and discrepancies noted and discussed.

3.4.4.8 Amenity

A qualitative assessment be made on the visual amenity of the system and a rating of 1-10 decided. This decision will involve the vegetation type, cover, density and diversity discussed above as well as the presence of concrete structures, walls and fencing. A description of the reason for the score will also be recorded.

3.4.4.9 MUSIC Model

MUSIC modelling requires a judgement of whether the system is vegetated with effective nutrient removal plants, vegetated with ineffective nutrient removal plants or unvegetated. This will be decided based on the vegetation type, cover, density and diversity discussed above. Use of vegetation such as traditional garden lawn or insufficient cover, density or diversity to meet City Plan (City of Gold Coast 2016) criteria will result in a category of vegetated with ineffective nutrient removal being used.

3.4.5 Underdrainage and Outflow

Blockages in the underdrainage and outflow can result in stormwater bypassing treatment through the filter media. Water is more likely to pond on the surface and overflow without treatment if the drainage is not working. Any blockages in the underdrainage will be identified by observing outlet flow during a rainfall event and looking for ponding during dry conditions. In addition the outflow chamber will be inspected for signs of cracks or sediment laden outflow that may indicate that the filter media is seeping out.

Table 3.4.6 Outlet levels

Outlet	Minimum Level
Ephemeral Waterway	300 mm above waterway invert or 100 mm above wet season water level 1 day after rain (whichever is highest).
Perennial Waterway	300 mm above dry weather water level or 100 mm above wet season water level 1 day after rain (whichever is highest).
Natural Wetland	100 mm above wet season standing water level 1 day after rain.
Natural Ground	100 mm above the maximum of the ground level or wet season standing water level 1 day after rain.
Pipe drainage system	50 mm above invert of downstream pit/pipe system and above wet season baseflow level.

Note: Table information summarised from (City of Gold Coast 2016).

3.4.6 Maintenance

Evidence of the following tasks having been performed as part of routine maintenance will be recorded:

- Sediment deposition removed from forebays or pre-treatment measures or from the surface where pre-treatment is not provided;
- Gross pollutants removed;
- Plants free from pests and diseases;
- Weeds removed;
- Gaps in planting infilled; and
- Pits and grates clear of litter and debris.

Overflow pits must be located within 2m of the edge of the system for maintenance access. Requirements for system sizing for maintenance access were discussed in Section 3.4.3.2 on System Sizing.

3.4.7 Observation of Local Waterways

Observation health of local waterways will be conducted, specifically looking for evidence of aquatic ecosystem health, growth of weed species, evidence of sediment runoff and pollutants.

3.4.8 Compliance with Design Standards and Guidelines

Compliance with Design Standards and Guidelines has been addressed in the preceding chapters and will be incorporated into the Field Testing Checklist.

3.4.9 Field Testing Checklist

A field testing checklist was prepared to assist in site data collection. Reference was made in preparing the field testing checklist to the Bioretention Compliance Checklists from the Water By Design (2012b) document Transferring Ownership of Vegetated Stormwater Assets and the Transfer Checklist and Maintenance Checklist from the FAWB (2009b) Stormwater Biofiltration Systems Adoption Guidelines. A copy of the checklist is attached as Appendix F. The intention of the checklist was to capture the necessary data for analysis of system performance and to enable easy data entry into ArcGIS.

3.5 MUSIC Modelling

3.5.1 Rainfall Data

City of Gold Coast (2016) requires simulation using 10 years of 6 minute rainfall data. Appropriate rainfall data for the location of each system will be imported as per Figure 3.6.1 below.

COUNCIL	STATION ID	STATION NAME	CLIMATE PERIOD FOR MUSIC	MEAN ANNUAL RAINFALL OVER PERIOD (mm)	MEAN PET (mm) (CLIMATE ATLAS OF AUSTRALIA)											
					JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Brisbane City Council (east)	40223	Brisbane Aero	1/1/1980 – 31/12/1989	1149	193	151	150	109	75	63	65	84	112	148	175	199
Brisbane City Council (west)	40659	Greenbank Thompson Rd	1/1/1980 - 31/12/1989	784	181	139	137	102	72	62	63	81	108	138	159	184
Brisbane City Council (central)	40214	Brisbane Regional Office	1/1/1980 -31/12/1989	1178	188	146	146	107	74	63	65	84	111	144	171	192
Moreton Bay Regional Council	40063	Dayboro Post Office	1/1/1980 – 31/12/1989	1256	189	145	147	109	77	67	68	86	112	146	166	188
Gold Coast City Council (north)	40406	Beenleigh Bowls Club	1/1/1990 – 31/12/1999	1152	192	151	147	106	73	61	62	79	108	147	170	195
Gold Coast City Council (south)	40609	Elanora Treatment Plant	1/1/1989 – 31/12/1998	1436	160	134	133	101	72	57	58	72	95	132	145	163
Gold Coast City Council (central)	40584	Hinze Dam	1/1/1976 – 31/12/1985	1371	176	143	137	140	72	59	60	75	102	141	158	180

Figure 3.6.1 MUSIC rainfall data (Water By Design 2010)

3.5.2 Catchment Area

Catchment areas will be identified using topographical and GIS mapping. As modelling is for existing catchments and not for development applications the simplified lumped approach will be implemented which will require identification of the percentage of land use under the categories of residential, rural residential, industrial and commercial. For residential and rural residential this will be further broken down into categories based on the number of dwellings per hectare, 10, 15, 40 or 80+.

3.5.3 Impervious Fraction

Impervious fractions for the land use categories under the lumped approach will be applied as identified in Tables A1.1, A2.1, A3.1, A4.1, A5.1 and A6.1 from the MUSIC Modelling Guidelines (Water By Design 2010), attached as Appendix G.

3.5.4 Rainfall Runoff Parameters

Impervious fractions for the land use categories under the lumped approach will be applied as identified in Tables A1.2, A2.2, A3.2, A4.2, A5.2 and A6.2 from the MUSIC Modelling Guidelines (Water By Design 2010), attached as Appendix G.

3.5.5 Pollutant Export Parameters

Impervious fractions for the land use categories under the lumped approach will be applied as identified in Tables A1.3, A2.3, A3.3, A4.3, A5.3 and A6.3 from the MUSIC Modelling Guidelines (Water By Design 2010), attached as Appendix G.

3.5.6 MUSIC Inputs

The input values adopted for modelling bioretention systems in MUSIC are outlined in *Table 3.6.1*.

Table 3.6.1 Adopted MUSIC model inputs for bioretention systems

Property	Input Element	Adopted Value
Inlet	Low-flow bypass (m^3/s)	
	High-flow bypass (m^3/s)	
Storage	Surface area of the filter media (m^2)	Equal to filter media area.
	Extended detention depth (m)	Measured detention depth.
Filter Media	Filter area (m^2)	Measured area of the filter media.
	Unlined filter media perimeter (m)	0.01
	Saturated hydraulic conductivity (mm/hr)	Measured hydraulic conductivity (Field test correction factor to be applied as per Wong (2006)). For sensitivity testing this will also be simulated for 50mm/hr.
	Filter depth (m)	Depth confirmed by design drawings OR Measured filter depth OR Adopt 400mm where unknown.
	TN content of filter media (mg/kg)	800mg/kg

Property	Input Element	Adopted Value
	Proportion of organic material in filter (%)	5%
	Orthophosphate in filter (mg/kg)	55mg/kg
Lining	Lined base	If unlined tick yes.
Vegetation Properties	Vegetated with effective nutrient removal plants	Observed vegetated state.
Infiltration and Outlet	Overflow weir width (m)	Measured width of overflow weir OR Measured perimeter of overflow pit.
	Exfiltration rate (mm/hr)	Secondary drainage link can be set up for infiltration if confirmed by design drawings OR Zero
	Underdrain present	As confirmed by design drawings OR Yes
	Submerged zone with carbon present	Only if confirmed by design drawings.
	Depth of submerged zone (m)	As confirmed by design drawings OR Zero
Additional property inputs for bioretention swales		
Inlet	Low-flow bypass (m^3/s)	Equal to infiltration rate of surface (length (m) x base width (m) x hydraulic conductivity of filter media (mm/hr) / 3600 / 1000).
Storage	Length (m)	Measured length of swale.
	Bed slope (%)	Measured bed slope.
	Base width (m)	Measured base width.
	Top width (m)	Measured top width.
	Depth (m)	Measured depth.
	Vegetation height (m)	Measured vegetation height.
	Exfiltration rate (mm/hr)	Set to zero

Note: Table information summarised from the MUSIC Modelling Guidelines (Water By Design 2010).

3.5.7 MUSIC Outputs

The following output reports will be obtained from the MUSIC:

- Mean annual load report including reduction of flows, TSS, TP and TN;
- Outflows in 6 minute increments;
- Cumulative frequency plot of outflows based on daily maxima; and
- Mean annual volume;

The following calculations from this data will be made:

- Baseflow contribution (%) = (Outflows Below Threshold + Infiltrated Volume)/Mean Annual Rainfall ≥ 10%; and
- Surface Flow Days = Baseflow exceedance % x 365 ≤ 20 days.

The MUSIC reports and the calculations above will provide a comparison with the City of Gold Coast (2016) performance objectives as per *Table 3.6.2* below.

Table 3.6.2 City of Gold Coast performance objectives

City of Gold Coast Performance Objectives	
Stormwater Quality Objectives	
Gross Pollutants (>5mm)	90% reduction in mean annual load
Total Suspended Solids	80% reduction in mean annual load
Total Phosphorous	60% reduction in mean annual load
Total Nitrogen	45% reduction in mean annual load
Frequent Flow Objectives	
Baseflows	≥10% of mean annual rainfall volume converted to baseflow Less than baseflow threshold of 0.4L/s/ha
Surface Flow	≤ 20 surface runoff days per annum measured as days where the maximum daily flow rate exceeds the baseflow threshold of 0.4L/s/ha
Flow Reduction	≥ 25% reduction in mean annual runoff volume from unmitigated runoff
Waterway Stability Objective	
Limit post-development peak 1-year ARI event discharge within the receiving waterway to the pre-development peak 1-year ARI event discharge.	

Note: Table information summarised from the City of Gold Coast (2016) City Plan SC6.9.3.2.3-SC6.9.3.2.6

3.6 ArcGIS

The field testing checklist, design and construction documentation and MUSIC model will provide data on each bioretention system that will be collated using the ArcGIS system.

3.7 Statistical Analysis

Statistical Analysis will be conducted using Microsoft Excel or SPSS software packages.

3.8 Recommendations for System Mitigation

Specific recommendations will be recorded for each site for any improvements that could be made or problems mitigated that would result in increased performance of the bioretention system.

3.9 Resource Requirements

Appendix H provides is a list of resources required for this research project. Where high cost items have been listed, appropriate alternative resources have been listed as a contingency if the preferred resource cannot be acquired.

3.10 Project Schedule

The project schedule is attached as Appendix I.

3.11 Consequential Effects and Ethics

As discussed in Section 1.4 the aim of my research is to identify trends in the design, construction and maintenance of bioretention systems that can improve future design outcomes. In order to achieve this aim it will be important that my research project can be relied upon to be accurate and credible. Inaccurate information and conclusions could prove misleading for any future research and decision making based on this project. The first step of ensuring this is to be well researched, identifying past research, industry bodies and standards that will guide the field testing, modelling and reporting elements of the project. It is vital that sufficient bioretention systems in a variety of types and locations are tested in order to obtain results and draw conclusions that can be relied upon. At the same time the accuracy of data such as catchment area information, measurements, field testing and modelling will decide the accuracy of these results. It may be better to produce more accurate results for a smaller number of sits than to rush testing and modelling of a greater number of sites and obtain inaccurate results. A balance will need to be drawn between analysing sufficient systems to draw conclusions and ensuring that enough time is taken in field testing and modelling to obtain accurate results. Furthermore results and conclusions drawn need to be objectively obtained and represented.

Engineers Australia (2017) points out that as engineers we should use our skills and knowledge to find solutions that benefit the community and provide a sustainable future. Waterways are an important part of our ecosystems and lifestyles and are viewed by the community as valuable assets. Bioretention systems when performing well can minimise negative impacts on natural waterways and their ecosystems (Water By Design 2006). If successful, this research project could contribute to promoting functional performance of bioretention systems in the short and long term, improving outcomes for natural waterways and ecosystems, protecting them for future generations and providing benefits to the community in terms of amenity and urban climate reduction.

Streetscape bioretention systems are located in close proximity to roadways and traffic. The risk assessment in Section 3.11 provides strategies for mitigation of the risks involved with working around traffic. Personal safety and the safety of motorists will be a crucial consideration for this research project. Traffic lines of sight must not be impacted. Consideration for testing locations and parking locations will be based on personal safety as well as not providing distraction to drivers. Time will be taken to stop, think and check for risks before any action is taken for this project.

The field testing component of this project will be publically visible within community spaces. Experience with the public suggests that this brings the possibility of objections or disapproval from members of the community. It will be important to clearly represent myself as a private university student and not a representative of the City of Gold Coast or Calibre Consulting. This will be achieved in part through wearing unbranded, personally purchased PPE. Permission to be on site for field testing will need to be obtained from the site owner. Voicing any personal opinions or holding discussions with members of the public will be avoided where possible and handled with discretion if unavoidable.

There is a potential for conflict of interest to arise between personal project objectives and client confidentiality with my employer Calibre Consulting. Calibre client information and records of design and construction documentation will not be accessed for the purposes of this project.

Services infrastructure such as telecommunications, water and wastewater, electricity and gas can be located within bioretention systems. Although the project is unlikely to interfere with such services it is worth keeping in mind if any digging is required on site. Dial before you dig will be consulted for service conflicts if digging is required.

The Engineers Australia (2017) Code of Ethics outlines the following main areas of ethical professional conduct. Table 3.11.1 below outlines how compliance with the Code of Ethics will be achieved during the research project.

Table 3.11.1 Achieving ethical project conduct

Ethical Conduct		**Research Project Conduct**
Demonstrate integrity	Act on the basis of a well-informed conscience.	• Ensure a sufficient literature review is completed so that project is well informed
	Be honest and trustworthy.	• Ensure project is own work • Correctly cite works referenced in dissertation
	Respect the dignity of all persons.	• Behave appropriately when conducting project in community spaces • Be polite and respectful during project based interactions
Practice competently	Maintain and develop knowledge and skills.	• Research fully WSUD and bioretention system design, construction and maintenance • Develop skills in MUSIC modelling and ArcGIS • Seek input and feedback on project from suitably experienced engineers
	Represent area of competence objectively.	• Ensure project results and conclusions are objectively obtained and represented
	Act on the basis of adequate knowledge.	• Locate and test sufficient bioretention systems in order to accurately be able to obtain results and draw conclusions
Exercise Leadership	Uphold the reputation and trustworthiness of the practice of engineering.	• Ensure project results and conclusions are objectively and accurately obtained and represented • Locate and test sufficient bioretention systems in order to accurately be able to obtain results and draw conclusions
	Communicate honestly and effectively, taking into account the reliance of others on engineering expertise.	• Ensure project results and conclusions are objectively and accurately obtained and represented • Locate and test sufficient bioretention systems in order to accurately be able to obtain results and draw conclusions
Promote Sustainability	Engage responsibly with the community and other stakeholders.	• Behave appropriately when conducting project in community spaces • Be polite and respectful during project based interactions • Be careful of saying too much about my project or about City processes if engaged by community members
	Practise engineering to foster the health, safety and wellbeing of the community and the environment.	• Project aims to promote functioning bioretention systems which will help reach water quality objectives, protect aquatic ecosystems and provide benefits

		to the community in terms of amenity and urban climate
	Balance the needs of the present with the needs of future generations.	• Project aims to report on immediate issues with bioretention systems that can be corrected • Project aims to achieve better future design outcomes

Note: Table information on Ethical Conduct summarised from Engineers Australia (2017)

3.12 Risk Assessment

The risks associated with this research project have been summarised and analysed in Table 3.12.1 below. This risk register was based on a Calibre Consulting Pty Ltd (2016) template and personalised for this project. The risk register is attached as Appendix J.

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Appendices

Appendix A Project Specification

ENG4111/4112 Research Project

Project Specification

For: Julia McLeod

Title: Performance of Water Sensitive Urban Design Bioretention Gardens on the Gold Coast

Major: Civil Engineering

Supervisors: Dr Ian Brodie, USQ

Enrolment: ENG4111 – EXT S1, 2017
ENG4112 – EXT S2, 2017

Project Aim: To investigate existing bioretention gardens on the Gold Coast to discover trends in design, construction and maintenance that are affecting their performance.

Programme: Version 3, 23rd May 2017

1. Research background information on water sensitive urban design (WSUD) including soil hydraulic conductivity testing, water quality testing, plant species, modelling and guidelines and standards for design, maintenance and field testing. Research GIS systems such as ArcGIS and MapInfo.

2. Make contact with the local government body, City of Gold Coast, to discover the research areas they see as having beneficial outcomes and to gain access to location, design and maintenance records for WSUD assets. Make contact with other WSUD bodies to discover the research areas they see as having beneficial outcomes.

3. Develop a GIS file for recording the location of bioretention installations and the field testing results. Identify the location of bioretention installations on the Gold Coast and produce an updatable location map.

4. Develop a field testing methodology and collect resources for a field testing kit. Test the methodology on an identified bioretention installation and update the methodology with any learnings.

5. Perform field testing of the identified bioretention installations including analysing maintenance conditions and vegetation cover, performing hydraulic conductivity testing and observing water flow.

6. Compare the existing vegetation cover and construction of the bioretention installations with design and as constructed documentation. Analyse the collected field data.

If time and resources permit:

7. Perform modelling of the bioretention installations with MUSIC modelling software to investigate their effectiveness in water treatment.

Appendix B Maintenance Specification – Section on Bioretention Systems

(City of Gold Coast 2016)

3.2 Bioretention System

3.2.1 Maintenance

Each bioretention system and its active maintenance area must undergo maintenance unless advised otherwise by the Principal's nominated representative. During each maintenance rotation the following tasks are to be completed:

3.2.2 Weed Control

All weeds within a bioretention system and its active maintenance area must be removed during each rotation to maintain and control weed infestations. Weed removal will be conducted in accordance with methods approved by the Principal's nominated representative managed in accordance with the detail provided in **Clause 3.1.2.**

3.2.3 Rubbish Removal

All weeds that are physically removed, all litter and debris from within a bioretention system or its batters must be removed and taken off-site and disposed and managed in accordance with the detail provided in **Clause 3.1.3**.

3.2.4 Inlet/Outlet Maintenance

All inlets and outlets within a bio retention system must be inspected for blockages during each maintenance rotation. Services to be provided and managed in accordance with the detail provided in **Clause 3.1.4**.

3.3 Algae Control

Constant wetting of the filter media surface of a bioretention system can result in the growth of algae and/or moss which can clog the filter media and prevent infiltration. Where this occurs it is an indication that either base flows are entering the basin or there is a problem with infiltration.

The algae coverage within a bioretention system is to be monitored and documented during each maintenance rotation. Where the cover of algal and moss growth is greater than 10% of the filter surface the matter is to be referred to the Principal's nominated representative who will assess the situation and provide direction.

3.3.1 Erosion Maintenance

During each maintenance rotation the bioretention basin and its active maintenance area must be inspected for evidence of erosion. The findings will be documented on the Daily Record Sheet. Erosion within a bioretention basin generally results from fast flows, poor soil placement or compaction, inadequate vegetative cover, or dispersive soils and managed in accordance with the detail provided in **Clause 3.1.7.**

3.3.2 Vegetation Maintenance

Regular, long-term maintenance of plants is essential to ensure that a bioretention system functions as designed. The Principal's long term goal for all bioretention systems is to achieve and maintain 90% desired vegetation coverage within all bioretention systems (exclusive of weeds).

During each maintenance rotation, the percent coverage of vegetation within a bioretention system is to be monitored and documented, with the details provided to the Principal's nominated representative.

In a bioretention system where the existing vegetation coverage is below 90%, the Principal may undertake additional planting during the term of the contract. Monitoring and documentation of vegetation coverage will enable the Principal to proactively respond to changes in vegetation coverage and prioritise planting where coverage is below 90%.

At the discretion of the Principal's nominated representative, the Principal may provide to the Contractor with plants for planting. Planting may be as part of the service or may be additional, and charged at the hourly rate or the most appropriate provisional item or by quote.

The undertaking of additional planting will be at the direction and control of the Principal. The Principal may invite quotes for the supply, planting and maintenance of plants.

Where there is evidence of drier patches within a basin or plants that are drying out, if unevenness in the basin floor is detected, a rake or spreader is to be used to level out the surface and ensure that the full filter media area is engaged.

Vegetation monitoring within the active maintenance area is to be undertaken during each maintenance rotation and managed in accordance with the detail provided in **Clause 3.1.8.**

3.3.3 Sediment Removal

Sediment forebays are designed to capture coarse sediment in excess of 1mm and provide protection to the filter media within the basin.

During each monitoring rotation, sediment levels within a sediment forebay must be monitored and documented. Where a sediment forebay becomes 50% full or greater, the sediment material is to be removed by hand (shovel etc.) or mechanically if access is available.

Where sediment has escaped the forebay area and is evident on the basin floor, the sediment must be removed by hand (shovel etc.), by scraping it from the surface to prevent this material from impacting upon the permeability of the filter media.

Sediment removed from within the forebay area or basin can be spread around the batter area if deemed appropriate to do so by the Principal's nominated representative. Alternatively, it is to be removed from site and disposed of.

3.3.4 Weir Inspection and Maintenance

During each maintenance rotation any weirs within a bioretention system must be inspected for evidence of erosion, damage or vegetation growth.

Where damage or erosion to a weir is identified, it is to be locally re-profiled or reinforced using hand tools and material on site. Where works require the use of machinery or the importation of material to undertake the erosion maintenance, the Principal's nominated representative must be contacted to assess the situation and provide direction.

Weir structures must be maintained free of vegetation. Where vegetation is present on a weir at the time of a maintenance rotation the contractor will inform the Principal's nominated representative who will assess the situation and provide direction. If weeds are to be removed, this must be undertaken and managed in accordance with the detail provided in **Clause 3.1.2**.

3.3.5 Inspection Caps

Where surface inspection points are provided within a bioretention basin they must be inspected during each maintenance rotation to ensure that the inspection caps have not been damaged or removed. Where they have been damaged (e.g. vandalism or wear and tear etc.) or removed, new caps are to be provided by the Contractor at the price provided for that item in the Price Submission.

3.3.6 General Maintenance

In addition to the works specified for the active maintenance area above a bioretention system where the batter extends beyond the active maintenance area may undergo general maintenance when advised by the Principal's nominated representative. The general maintenance of this batter area will be scheduled by the Principal at the same time as a maintenance rotation.

During the general maintenance rotation the following tasks are to be completed:

- Weed Control – managed in accordance with the detail provided in **Clause 3.1.2.**
  All weeds within the wetland batter area are to be removed during the general maintenance rotation to maintain and control weed infestations.

- Weed and Rubbish Removal – managed in accordance with the detail provided in **Clause 3.1.3.**
  All litter and debris within the wetland batter area must be removed during the general maintenance rotation.

- Erosion Inspection and Maintenance – managed in accordance with the detail provided in **Clause 3.1.7.**

- Vegetation Monitoring – managed in accordance with the detail provided in **Clause 3.1.8.**

  Vegetation monitoring within the wetland batter area must be undertaken during the general maintenance rotation to ensure that densely vegetated batters are maintained. During the general maintenance rotation, batters with bare areas >5m2 must be documented and the details provided to the Principal's nominated representative.

3.4 Sediment Basin

3.4.1 Maintenance

Each sediment basin and its active maintenance area are to undergo maintenance unless advised otherwise by the Principal's nominated representative.

3.4.2 Weed Control

All aquatic and terrestrial weeds within the wetland area and its active maintenance area are to be removed during each rotation to maintain and control weed infestations.

All weeds within the sediment basin batter area are to be removed during the general maintenance rotation to maintain and control weed infestations. Weed removal will be conducted in accordance with methods approved by the Principal's nominated representative.

Weed removal must be conducted and managed in accordance with the detail provided in **Clause 3.1.2.**

3.4.3 Rubbish Removal

All litter and debris within a swale system and its active maintenance area (where one exists) is to be removed during each rotation and managed in accordance with the detail provided in **Clause 3.1.3.**

3.4.4 Inlet/Outlet Maintenance

All inlets and outlets within a swale system are to be inspected for blockages during each maintenance rotation and managed in accordance with the detail provided in **Clause 3.1.4.**

3.4.5 Algae Monitoring and Maintenance

Algae can occur naturally within a sediment basin due to the high nutrient concentrations of the stormwater inflows. The algae coverage within a basin is to be monitored and documented during each maintenance rotation with the details provided to the Principal's nominated representative.

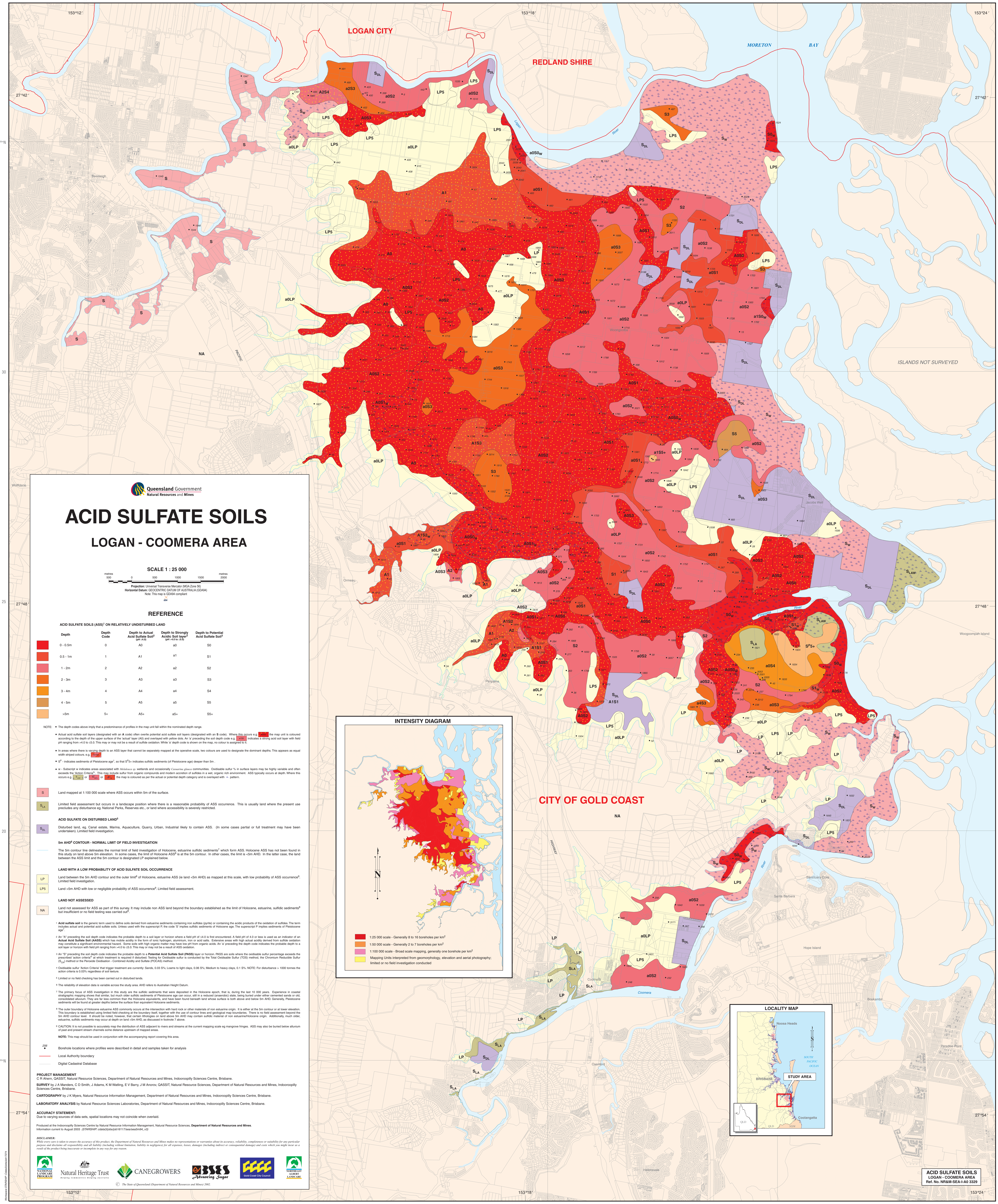
Where algae coverage exceeds 50% of the wetland area, the algae is to be removed from the wetland during the maintenance rotation and managed in accordance with the detail provided in **Clause 3.2.2 Weed Control.**

3.4.6 Erosion Inspection and Maintenance

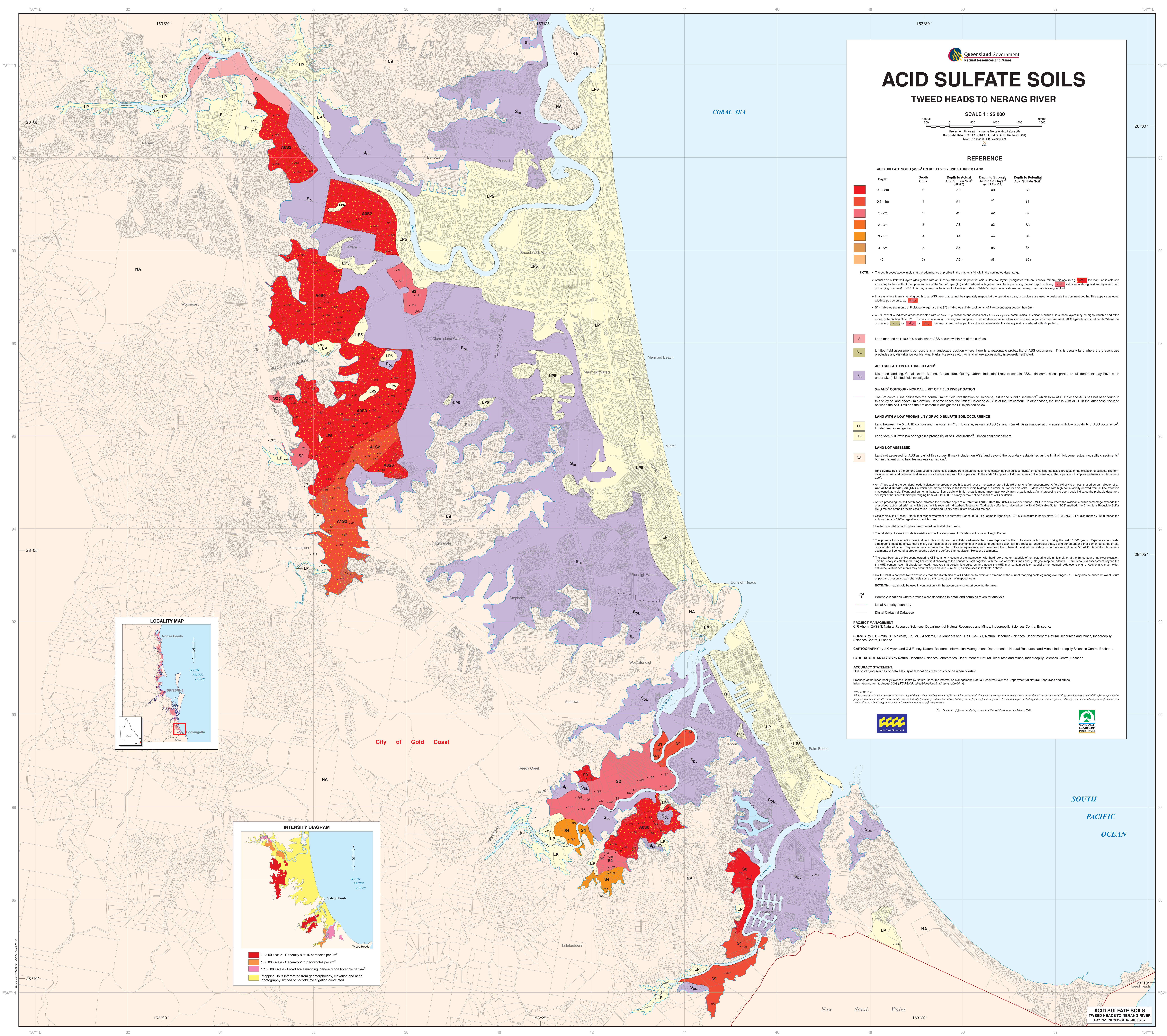
Erosion Inspection and Maintenance – During each maintenance rotation the sediment basin and its active maintenance area are to be inspected for evidence of erosion and managed in accordance with the detail provided in **Clause 3.1.7.**

Appendix C Acid Sulfate Soils Queensland Government Mapping

(Department of Natural Resources and Mines 2003)



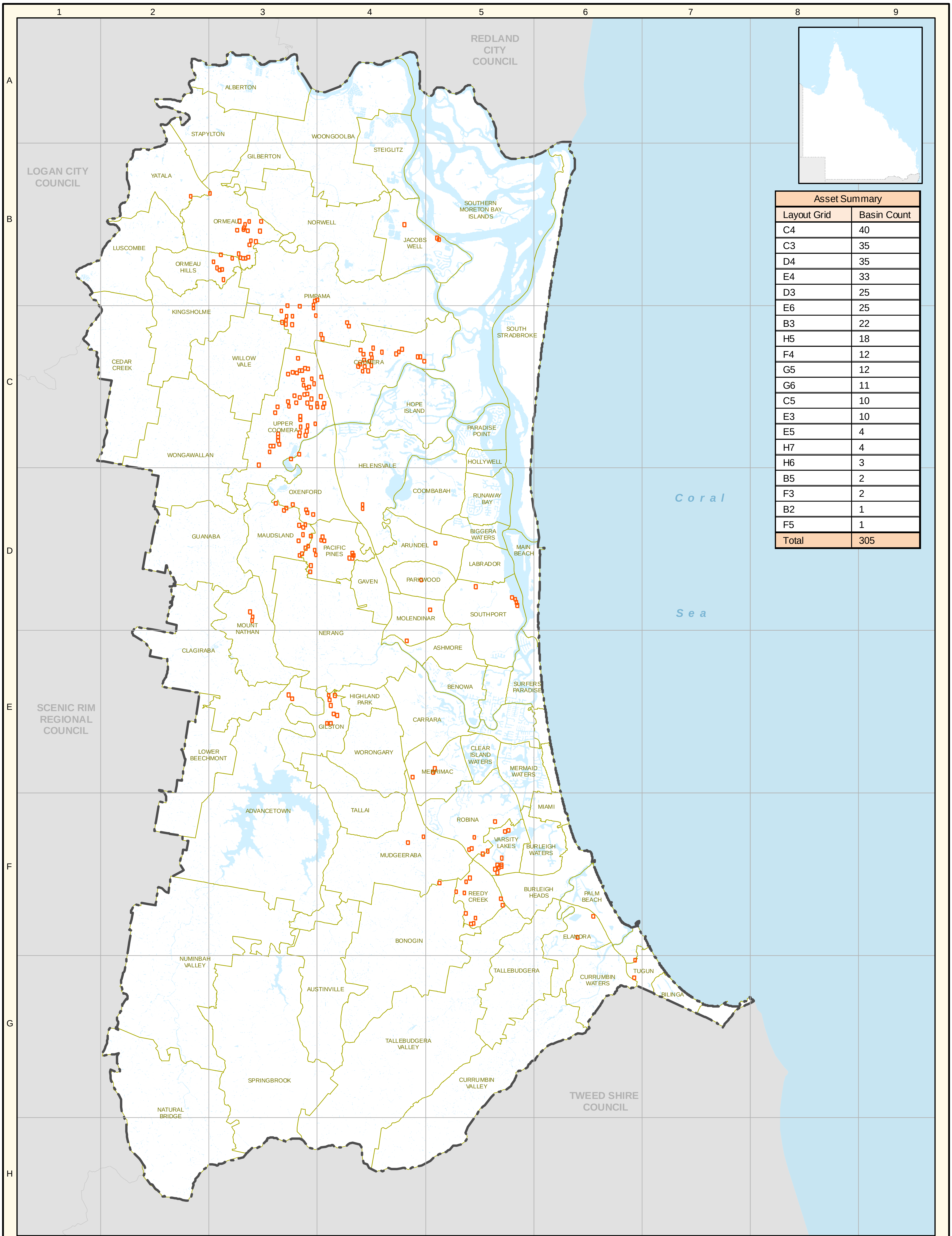
Information current to August 2003 (Version 3)



Information current to August 2003 (Version 3)

Appendix D City of Gold Coast WSUD Assets Map

(City of Gold Coast 2016)



Asset Summary	
Layout Grid	Basin Count
C4	40
C3	35
D4	35
E4	33
D3	25
E6	25
B3	22
H5	18
F4	12
G5	12
G6	11
C5	10
E3	10
E5	4
H7	4
H6	3
B5	2
F3	2
B2	1
F5	1
Total	305

Legend

- Detail Grid
- 1km Grid Area of Interest
- Roads Casement

WSUD Maintenance Keymap

N

2 0 4 Km

Produced By:	City Assets
Production Date:	09 Dec 2016
Project No:	1003132
Projection:	MGA94 Zone 56

CITY OF GOLDCOAST.

Appendix E Single Ring Infiltration Test Calculation Spreadsheet

(FAWB 2009)

Single ring infiltration test

Site:
Date:

radius (m)	0.05
depth (m)	0.05
Head 1 (m)	0.05
Head 2 (m)	0.15

K_{fs} (m/s)	8.3E-05
K_{fs} (mm/h)	298
ϕ	3.3E-05
α (m^{-1})	2.5

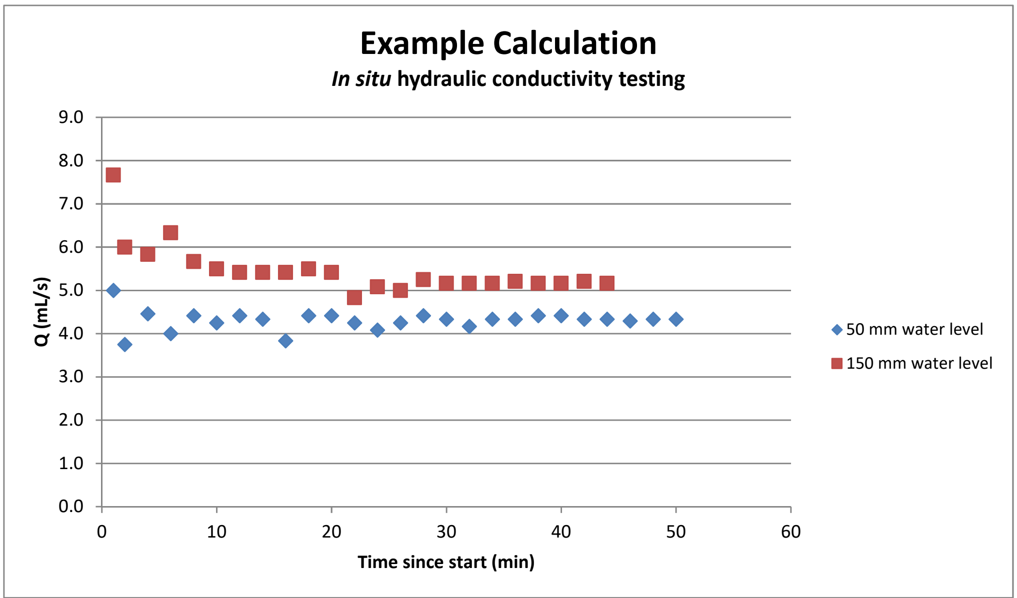
G	0.5

Constant water level = 50 mm		
time (min)	Volume (mL)	Q (mL/s)
1	300	5.00
2	225	3.75
4	535	4.46
6	480	4.00
8	530	4.42
10	510	4.25
12	530	4.42
14	520	4.33
16	460	3.83
18	530	4.42
20	530	4.42
22	510	4.25
24	490	4.08
26	510	4.25
28	530	4.42
30	520	4.33
32	500	4.17
34	520	4.33
36	520	4.33
38	530	4.42
40	530	4.42
42	520	4.33
44	520	4.33
46	515	4.29
48	520	4.33
50	520	4.33
AVERAGE LAST 8		4.35

Q_1 (ml/s)	4.35
Q_1 (m/s)	4.35E-06

Constant water level = 150 mm		
time (min)	Volume (mL)	Q (mL/s)
1	460	7.67
2	360	6.00
4	700	5.83
6	760	6.33
8	680	5.67
10	660	5.50
12	650	5.42
14	650	5.42
16	650	5.42
18	660	5.50
20	650	5.42
22	580	4.83
24	610	5.08
26	600	5.00
28	630	5.25
30	620	5.17
32	620	5.17
34	620	5.17
36	625	5.21
38	620	5.17
40	620	5.17
42	625	5.21
44	620	5.17
AVERAGE LAST 8		5.18

Q_2 (ml/s)	5.18
Q_2 (m3/s)	5.18E-06



Appendix F Field Testing Checklist

Field Testing Checklist	Julia McLeod ERP2017	Site Identifier	

Site Information			
Site name			
Description			
GPS coordinates		Asset owner	
Date and time		Weather conditions	
Photos Taken	☐ Inlet ☐ Outlet ☐ Overflow ☐ Vegetation ☐ Filter media ☐ Outlet ☐ Testing		

Catchment Information								
Catchment Area			Catchment Characteristics					
Residential %	10/ha		15/ha		40/ha		80+/ha	
Rural residential %			Industrial %			Commercial %		
Public Zones %			Rural %			Forest %		
Tidal area	☐ Yes ☐ No		Signs of ASS		☐ Yes ☐ No	Signs of dispersive soils		☐ Yes ☐ No
Details								

Bioretention System Information											
Type of bioretention system			☐ Basin ☐ Swale ☐ Biopod ☐Street Tree								
System setting	☐ Allotment ☐ Streetscape ☐ Civic Space ☐ Parkland ☐Bushland ☐ Large Scale										
Drainage profile	☐ Type 1 Saturated ☐ Type 2 Sealed ☐ Type 3 Conventional ☐ Type 4 Pipeless										
Batters	H (m)		V (m)		Vegetated	☐ Yes ☐ No	Density		Trees	☐ Yes ☐ No	
Walls	☐ Yes ☐ No		H (m)		Vegetated barrier	☐ Yes ☐ No	Fence	☐ Yes ☐ No			
Coarse sediment removal		☐ Yes ☐ No	Type								
Low-flow bypass			High-flow bypass								
Overflow weir length (m)			Overflow weir width (m)								
Underdrain present	☐ Yes ☐ No	Submerged zone present	☐ Yes ☐ No	Depth (m)							
Safety features		Amenity rating									
Swale	☐ Yes ☐ No	Length (m)		Slope (%)		Depth (m)					

Field Testing Checklist	**Julia McLeod**	**ERP2017**	Site Identifier	

Base width (m)		Top width (m)		Vegetation height (m)	

Filter Surface

Length (m)		Width (m)		Filtration area (m^2)		Batter area (m^2)	
Filter depth (m)		Extended detention depth (m)				Multiple cells	

Scour or erosion	
Flow bypassing	
Clogging	
Biofilm	
Fine sediment layer	
Ponding	

Vegetation

Plants - filter media

Name	Type	Number

Plants - batters

Name	Type	Number

Area of gaps (m^2)		Vegetation cover (%)		Presence of mulch	☐ Yes ☐ No
Planting matches environment	☐ Yes ☐ No	Vegetation height (m)		MUSIC	☐ Veg w/ effective ☐ Veg w/o effective ☐ Unvegetated

Field Testing Checklist	**Julia McLeod ERP2017**	Site Identifier	

Line of sight conflicts	☐ Yes ☐ No	

Inlet			
Inlet type		Flow controls	

Underdrainage and Outlet			
Underdrainage flow observation	☐ Yes ☐ No		
Outlet type		Level	

Maintenance							
Sediment removal	☐ Yes ☐ No	Gross pollutant removal			☐ Yes ☐ No	Pits and grates cleared	☐ Yes ☐ No
Planting gaps filled	☐ Yes ☐ No	Weeds removed			☐ Yes ☐ No	Plants pest & disease free	☐ Yes ☐ No
Access tracks	☐ Yes ☐ No	W (m)		Gated	☐ Yes ☐ No	At inflow level	☐ Yes ☐ No
Overflow pit within 2m of edge				☐ Yes ☐ No			

Observation of local waterways

Other Notes

3

Field Testing Checklist			Julia McLeod	ERP2017		Site Identifier		
Hydraulic Conductivity Test – 50mm head								
Time	**Site 1**	**Site 2**		**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**
1								
2								
4								
6								
8								
10								
12								
14								
16								
18								
20								
22								
24								
26								
28								
30								
32								
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36								
38								
40								
42								
44								
46								
48								
50								
52								
54								
56								
58								
60								

Field Testing Checklist			Julia McLeod	ERP2017		Site Identifier		
Hydraulic Conductivity Test – 150mm head								
Time	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**
1								
2								
4								
6								
8								
10								
12								
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6

Appendix G MUSIC Modelling Parameters Summary

(Water By Design 2010)

APPENDIX A – Source node parameter summaries

A1 Residential urban source node Summary

Table A1.1 Typical breakdown of surface types and impervious fraction for split and lumped residential urban source nodes[34] (extracted from Table 3.3, Table 3.5 and Table 3.6).

SURFACE TYPE	SPLIT						LUMPED	
DEVELOPMENT TYPE	ROAD RESERVE		ROOF		GROUND LEVEL		IMPERVIOUS FRACTION (%)	
	Breakdown of surface types (%)	Impervious fraction (%)	Breakdown of surface types (%)	Impervious fraction (%)	Breakdown of surface types (%)	Impervious fraction (%)	Range	Preferred
Residential 10 dwellings/ha	25	60	25 (based on 250 m² roof area)	100	50	15	40–55	45
Residential 15 dwellings/ha	25	60	32.5 (based on 215 m² roof area)	100	42.5	20	50–60	55
Residential 40 dwellings/ha	30	70	35	100	35	30	60–70	65
Residential 80+ dwellings/ha	32.5	80	Residential 80+ dwellings/ha	32.5	80	Residential 80+ dwellings/ ha	32.5	80

Table A1.2 Rainfall-runoff parameters for residential urban source nodes (extracted from Table 3.7).

PARAMETER	URBAN RESIDENTIAL
Rainfall threshold (mm)	1
Soil storage capacity (mm)	500[35]
Initial storage (% capacity)	10
Field capacity (mm)	200
Infiltration capacity coefficient a	211
Infiltration capacity exponent b	5.0
Initial depth (m)	50
Daily recharge rate (%)	28
Daily baseflow rate (%)	27
Daily deep seepage rate (%)	0

[34] To be used for conceptual design and broad planning only. Development applications require measurement of areas from development plans.

[35] MUSIC will warn that the normal range is between 10 and 400 mm. 500 mm is generally appropriate in SEQ.

Table A1.3 Pollutant export parameters for residential urban source nodes ($\log_{10}$ values) (extracted from Table 3.8).

	FLOW TYPE	POLLUTANT SOURCE	TSS $\log_{10}$ values		TP $\log_{10}$ values		TN $\log_{10}$ values	
			Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
Lumped	Baseflow	Urban lumped	1.00	0.34	-0.97	0.31	0.31	0.20
	Storm flow		2.18	0.39	-0.47	0.32	0.32	0.23
Split	Baseflow	Roof	N/A	N/A	N/A	N/A	N/A	N/A
		Roads	1.00	0.34	-0.97	0.31	0.20	0.20
		Ground level	1.00	0.34	-0.97	0.31	0.20	0.20
	Stormflow	Roof	1.30	0.39	-0.89	0.31	0.26	0.23
		Roads	2.43	0.39	-0.30	0.31	0.26	0.23
		Ground level	2.18	0.39	-0.47	0.31	0.26	0.23

A2 Rural residential urban source node Summary

Table A2.1 Typical impervious fraction for lumped rural residential urban source nodes[36] (extracted from Table 3.6).

DEVELOPMENT LAND USE OR SURFACE TYPE	IMPERVIOUS FRACTION (%)	
	Range (%)	Preferred (%)
Rural Uses		
Rural residential (greater than 0.4 ha lots)	5–20	10
Rural residential (smaller than 0.4 ha lots)	10–25	20
Rural	0–5	2
Public zones		
Public open space	5–50	20
Car parks	70–95	90
Library, sporting, depots	50–90	70
Schools and university	50–80	70

Table A2.2 Rainfall-runoff parameters for lumped rural residential urban source nodes (extracted from Table 3.7).

PARAMETER	RURAL RESIDENTIAL
Rainfall threshold (mm)	1
Soil storage capacity (mm)	98
Initial storage (% capacity)	10
Field capacity (mm)	80
Infiltration capacity coefficient a	84
Infiltration capacity exponent b	3.3
Initial depth (mm)	50
Daily recharge rate (%)	100
Daily baseflow rate (%)	22
Daily deep seepage rate (%)	0

Table A2.3 Pollutant export parameters for lumped rural residential urban source nodes (log^{10} values) (extracted from Table 3.8).

FLOW TYPE	TSS log^{10} values		TP log^{10} values		TN log^{10} values	
	Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
Baseflow	0.53	0.24	-1.54	0.38	-0.52	0.39
Storm flow	2.26	0.51	-0.56	0.28	0.32	0.30

[36] To be used for conceptual design and broad planning only. Development applications require measurement of areas from development plans.

A3 Industrial urban source node Summary

Table A3.1 Typical breakdown of surface types and impervious fraction for split and lumped industrial urban source nodes (extracted from Table 3.3, Table 3.5 and Table 3.6)[37].

SURFACE TYPE	SPLIT				LUMPED			
Development type	Road Reserve		Roof		Ground level		Impervious fraction	
	Breakdown of surface types(%)	Impervious fraction (%)	Breakdown of surface types	Impervious fraction (%)	Breakdown of surface types(%)	Impervious fraction (%)	Range(%)	Preferred(%)
Typical industrial (warehouse, manufacturing, workshop etc.)	30	75	50	100	20	60	70–95	90

Table A3.2 Rainfall-runoff parameters for split and lumped industrial urban source nodes (extracted from Table 3.7).

PARAMETER	INDUSTRIAL
Rainfall threshold (mm)	1
Soil storage capacity (mm)	18
Initial storage (% capacity)	10
Field capacity (mm)	80
Infiltration capacity coefficient a	243
Infiltration capacity exponent b	0.6
Initial depth (mm)	50
Daily recharge rate (%)	0
Daily baseflow rate (%)	31
Daily deep seepage rate (%)	0

Table A3.3 Pollutant export parameters for industrial urban source nodes (log^{10} values) (extracted from Table 3.8).

	FLOW TYPE	POLLUTANT SOURCE	TSS log^{10} values		TP log^{10} values		TN log^{10} values	
			Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
Lumped	Baseflow	Industrial lumped	0.78	0.45	-1.11	0.48	0.14	0.20
	Storm flow		1.92	0.44	-0.59	0.36	0.25	0.32
Split	Baseflow	Roof	N/A	N/A	N/A	N/A	N/A	N/A
		Roads	0.78	0.45	-1.11	0.48	0.14	0.20
		Ground level	0.78	0.45	-1.11	0.48	0.14	0.20
	Stormflow	Roof	1.30	0.44	-0.89	0.36	0.25	0.32
		Roads	2.43	0.44	-0.30	0.36	0.25	0.32
		Ground level	1.92	0.44	-0.59	0.36	0.25	0.32

[37] To be used for conceptual design and broad planning only. Development applications require measurement of areas from development plans.

A4 Commercial urban source node Summary

Table A4.1 Typical breakdown of surface types and impervious fraction for split and lumped commercial urban source nodes [38] (extracted from Table 3.3, Table 3.5 and Table 3.6).

SURFACE TYPE	SPLIT						LUMPED	
Development type	Road Reserve		Roof		Ground level		Impervious fraction	
	Breakdown of surface types(%)	Impervious fraction (%)	Breakdown of surface types(%	Impervious fraction (%)	Breakdown of surface types(%)	Impervious fraction (%)	Range(%)	Preferred(%)
Business or town centre, offices and bulky goods	30	75	50	100	20	80	70–95	90
Garden and landscape suppliers							30–60	50

Table A4.2 Rainfall-runoff parameters for lumped commercial urban source nodes (extracted from Table 3.7).

PARAMETER	COMMERCIAL
Rainfall threshold (mm)	1
Soil storage capacity (mm)	18
Initial storage (% capacity)	10
Field capacity (mm)	80
Infiltration capacity coefficient a	243
Infiltration capacity exponent b	0.6
Initial depth (mm)	50
Daily recharge rate (%)	0
Daily baseflow rate (%)	31
Daily deep seepage rate (%)	0

Table A4.3 Pollutant export parameters for commercial urban source nodes (log^{10} values) (extracted from Table 3.8).

	FLOW TYPE	POLLUTANT SOURCE	TSS log^{10} values		TP log^{10} values		TN log^{10} values	
			Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
Lumped	Baseflow	Commercial lumped	0.78	0.39	-0.60	0.50	0.32	0.30
	Storm flow		2.16	0.38	-0.39	0.34	0.37	0.34
Split	Baseflow	Roof	N/A	N/A	N/A	N/A	N/A	N/A
		Roads	0.78	0.39	-0.60	0.50	0.32	0.30
		Ground level	0.78	0.39	-0.60	0.50	0.32	0.30
	Stormflow	Roof	1.30	0.38	-0.89	0.34	0.37	0.34
		Roads	2.43	0.38	-0.30	0.34	0.37	0.34
		Ground level	2.16	0.38	-0.39	0.34	0.37	0.34

[38] To be used for conceptual design and broad planning only. Development applications require measurement of areas from development plans.

A5 Forest source node Summary

Table A5.1 Typical impervious fraction for lumped forest source nodes (extracted from Table 3.6)

DEVELOPMENT LAND USE OR SURFACE TYPE	IMPERVIOUS FRACTION (%)	
	Range	Preferred
Forest or conservation	0–5	0

Table A5.2 Rainfall-runoff parameters for lumped forest source nodes (extracted from Table 3.7).

PARAMETER	FORESTED
Rainfall threshold (mm)	1
Soil storage capacity (mm)	120
Initial storage (% capacity)	10
Field capacity (mm)	80
Infiltration capacity coefficient a	200
Infiltration capacity exponent b	1.0
Initial depth (mm)	50
Daily recharge rate (%)	25
Daily baseflow rate (%)	3
Daily deep seepage rate (%)	0

Table A5.3 Pollutant export parameters for lumped forest source nodes (log^{10} values) (extracted from Table 3.8).

FLOW TYPE	TSS log^{10} values		TP log^{10} values		TN log^{10} values	
	Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
Baseflow	0.51	0.28	-1.79	0.28	-0.59	0.22
Storm flow	1.90	0.20	-1.10	0.22	-0.075	0.24

A6 Agricultural source node Summary

Table A6.1 Typical impervious fraction for lumped agricultural source nodes (extracted from Table 3.6).

DEVELOPMENT LAND USE OR SURFACE TYPE	IMPERVIOUS FRACTION (%)	
	Range	Preferred
Rural	0–5	2

Table A6.2 Rainfall-runoff parameters for lumped agricultural source nodes (extracted from Table 3.7).

PARAMETER	RURAL
Rainfall threshold (mm)	1
Soil storage capacity (mm)	98
Initial storage (% capacity)	10
Field capacity (mm)	80
Infiltration capacity coefficient a	84
Infiltration capacity exponent b	3.3
Initial depth (mm)	50
Daily recharge rate (%)	100
Daily baseflow rate (%)	22
Daily deep seepage rate (%)	0

Table A6.3 Pollutant export parameters for lumped agricultural source nodes (log^{10} values) (extracted from Table 3.8).

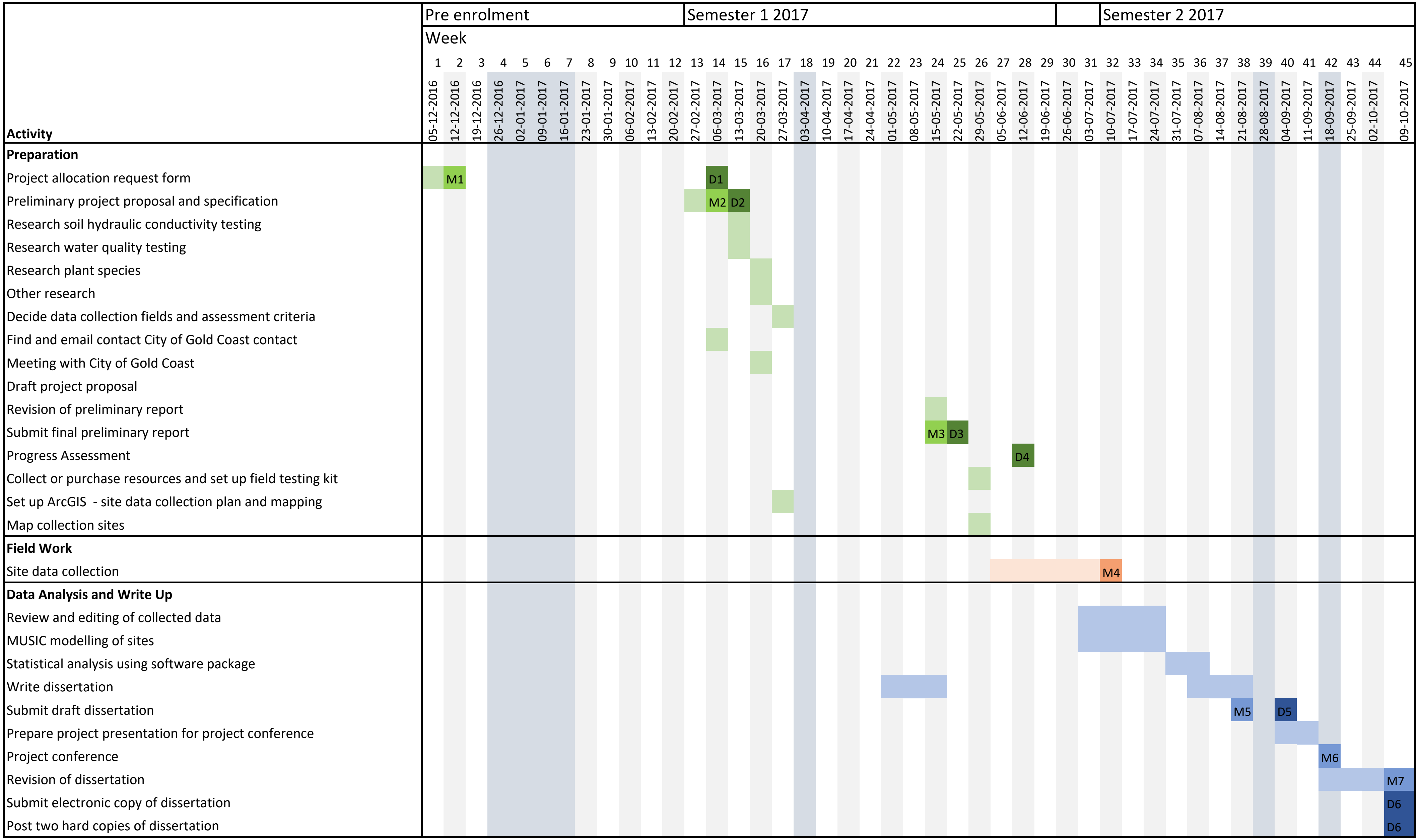
FLOW TYPE	TSS log^{10} values		TP log^{10} values		TN log^{10} values	
	Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
Baseflow	1.0	0.13	-1.155	0.13	-0.155	0.13
Storm flow	2.477	0.31	-0.495	0.30	0.29	0.26

Appendix H Resource Requirements

Item No.	Resource	Qty	Source	Project Cost	Alternative Resource	Qty	Source	Project Cost
1	**Preparation**							
1.1	Laptop computer and charger	1	Student	Nil				
1.2	Microsoft Word software	1	Student	Nil				
1.3	ArcGIS Software	1	Calibre	Nil	Microsoft Access or Excel software	1	Student	Nil
1.4	Backup hard drive	1	Student	Nil				
1.5	USB drives	1	Student	Nil				
1.6	UDrive	1	Student	Nil				
1.7	Locations and design documentation	30+	City	Nil	As Constructed Documentation	30+	PD Online	Nil
2	**Field Work**							
2.1	Vehicle and Petrol	1	Student	Nil				
2.2	Storage tub	1	Student	$20				
2.3	Trolley	1	Student	Nil				
2.4	PPE:							
2.4.1	Steel cap boots	1	Student	Nil				
2.4.2	Hi vis long sleeve shirt	1	Student	$25.00	Hi Vis Vest	1	Student	$12.00
2.4.3	Garden Gloves	1	Student	$6.60				
2.5	Sun protection:							
2.5.1	Sunscreen	1	Student	$10				
2.5.2	Sun hat	1	Student	Nil				
2.5.3	Sunglasses	1	Student	Nil				
2.6	Weather protection:							
2.6.1	Waterproof jacket and pants	1	Student	Nil				
2.6.2	Umbrella	1	Student	Nil				
2.6.3	Jumper	1	Student	Nil				
2.7	First aid kit	1	Student	$15.45				
2.8	Water and food	1	Student	Nil				
2.9	Electronic Equipment:							
2.9.1	Waterproof camera	1	Student	$320.00	Mobile phone camera	1	Student	Nil
2.9.2	Mini camera tripod	1	Student	Nil				
2.9.3	Mobile phone	1	Student	Nil				
2.9.4	Mobile phone car charger	1	Student	Nil				
2.9.5	Mobile phone powerbank	1	Student	Nil				
2.9.6	Laptop computer	1	Student	Nil				
2.9.7	Laptop car charger	1	Student	Nil				
2.9.8	Microsoft OneNote	1	Student	Nil				
2.10	Soil testing:							

2.10.1	PVC pipe ring	3	Student	$27.40				
2.10.2	Large 10L water container	5	Student	$20.00				
2.10.3	Measuring cylinders	3	Student	Nil				
2.10.4	Hammer	1	Student	Nil				
2.10.5	Block of wood	1	Student	Nil				
2.10.6	Spirit level	1	Student	Nil				
2.10.7	Sponge	1	Student	Nil				
2.10.8	Stopwatch	1	Student	Nil				
2.10.9	Thermometer	1	Student	Nil				
2.10.10	Tape measure	1	Student	Nil				
2.10.11	Measuring wheel	1	Student	$25	Tape measure	NA	Student	Nil
2.11	Other equipment:							
2.11.1	Field Testing Sheet	1 per site	Student	$20	Electronic record	NA	Student	Nil
2.11.2	Field guide to native vegetation	1	Student	$45	Internet identification	NA	Student	Nil
2.11.3	Notebook	1	Student	Nil				
2.11.4	Pens	3	Student	Nil				
2.11.5	Clipboard	1	Student	Nil				
2.11.6	Small garden trowel	1	Student	$6.00				
3	**Data Analysis and Write Up**							
3.1	As per preparation section							
3.2	MUSIC modelling software	1	Calibre	Nil	No flood modelling component			
3.3	Statistics software: SPSS	1	Student	$49	Microsoft Excel	1	Student	Nil
4	**Total Cost**			**$704.45**				**$257.45**

Appendix I   Project Schedule


Activity
Pre enrolment
Semester 1 2017
Semester 2 2017
Week
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45
05-12-2016 12-12-2016 19-12-2016 26-12-2016 02-01-2017 09-01-2017 16-01-2017 23-01-2017 30-01-2017 06-02-2017 13-02-2017 20-02-2017 27-02-2017 06-03-2017 13-03-2017 20-03-2017 27-03-2017 03-04-2017 10-04-2017 17-04-2017 24-04-2017 01-05-2017 08-05-2017 15-05-2017 22-05-2017 29-05-2017 05-06-2017 12-06-2017 19-06-2017 26-06-2017 03-07-2017 10-07-2017 17-07-2017 24-07-2017 31-07-2017 07-08-2017 14-08-2017 21-08-2017 28-08-2017 04-09-2017 11-09-2017 18-09-2017 25-09-2017 02-10-2017 09-10-2017
Preparation
Project allocation request form
M1
D1
Preliminary project proposal and specification
M2
D2
Research soil hydraulic conductivity testing
Research water quality testing
Research plant species
Other research
Decide data collection fields and assessment criteria
Find and email contact City of Gold Coast contact
Meeting with City of Gold Coast
Draft project proposal
Revision of preliminary report
Submit final preliminary report
M3
D3
Progress Assessment
D4
Collect or purchase resources and set up field testing kit
Set up ArcGIS - site data collection plan and mapping
Map collection sites
Field Work
Site data collection
M4
Data Analysis and Write Up
Review and editing of collected data
MUSIC modelling of sites
Statistical analysis using software package
Write dissertation
Submit draft dissertation
M5
D5
Prepare project presentation for project conference
Project conference
M6
Revision of dissertation
M7
Submit electronic copy of dissertation
D6
Post two hard copies of dissertation
D6

Milestone Table	Milestone Date		Deadline Date	
Project allocation request form	M1	10/12/2017	D1	8/03/2017
Preliminary project proposal and specification	M2	12/03/2017	D2	15/03/2017
Submit final preliminary report	M3	24/05/2017	D3	24/05/2017
Progress Assessment			D4	14/06/2017
Site data collection	M5	1/07/2017		
Submit draft dissertation	M6	27/08/2017	D5	6/09/2017
Project conference	M7	18/09/2017		
Revision of dissertation	M8	9/10/2016		
Submit electronic copy of dissertation	M8	9/10/2016	D6	12/10/2017
Post two hard copies of dissertation	M8	9/10/2016	D6	12/10/2017

Appendix J Risk Register

Item	Hazards / Risk	Risk Class			HOC	Control Method / Action	Residual Risk		
		L	C	RL			L	C	RRL
1	**Preparation**								
1.1	Project allocation rejected	3	2	Med	4	• Prepare project proposal early • Allow time in schedule for rewriting project proposal • Ensure proposal is well written and has an appropriate research element	2	1	Low
1.2	Supervisor unavailable	4	2	Med	4	• Prepare project proposal early	2	2	Low
1.3	Failure to identify enough bioretention sites	3	3	Med	4	• Start identifying sites early • Make contact with City of Gold Coast to identify sites	2	3	Low
1.4	Failure to gain a contact within City of Gold Coast	4	2	Med	2	• Use contacts at Calibre and Gold Coast Waterways to identify a suitable person at City • Use online development application records to gain access to design documentation	3	1	Low
1.5	Failure to gain access to design documentation	4	2	Med	2	• Ensure project is designed so that design documentation are not essential for assessment process • Use online development application records to gain access to design documentation	3	1	Low
1.6	Lack of budget for project resources	2	2	Low	1/2	• Ensure high budget items are not required for the project • Use alternative items eg mobile phone camera instead of new waterproof camera	1	1	Low
1.7	Project becomes unviable	3	5	High	1/2	• Ensure that project is well researched and set up appropriately • Have alternative ideas ready eg flood modelling of a catchment area and identifying flood mitigation methods • Start project early to allow time to adjust project • Gain input on relevance of the project from industry people	2	4	Med
2	**Field Work**								
2.1	Unaware of and unprepared for site conditions	2	3	Low	5	• Identify existing site conditions prior to site visit	1	3	Low
2.2	Unknown whereabouts	3	2	Low	1	• Message family member with daily itinerary prior to site visits • Update family member if changes to itinerary occur • Check in with family member upon arriving or leaving remote sites	1	2	Low
2.3	Remote sites	3	2	Low	5	• Check in with family member upon arriving or leaving remote sites • Check means of communication • First aid kit to be stored in vehicle • Have RACQ roadside assistance • Keep phone charger and power bank in car	1	1	Low
2.4	Work under traffic conditions	5	5	High	1/6	• PPE including high vis clothing and protective footwear • Assess site for safety prior to commencing work • Where possible park car to provide a barrier or put trees or other barriers between myself and traffic • Be careful crossing roads	3	4	Med
2.5	Work on a 'greenfield' site	3	3	Med	1/6	• PPE including high vis coveralls, wide brimmed hat, sunscreen, insect repellent, protective footwear • Assess site for safety prior to commencing work • Keep first aid kit, mobile phone and power bank	2	2	Low
2.6	Driving to, from and around site	5	5	High	1/6	• Obey road rules and speed limits • Pre plan parking location • Concentrate on traffic not thinking about project • First Aid Kit to be stored in vehicle • Vehicle to be regularly serviced • Have RACQ roadside assistance	4	3	Med
2.7	Exposure to UVR and/or extreme weather conditions	4	2	Med	6	• PPE including high vis coveralls, wide brimmed hat, sunscreen, protective footwear • Keep rain gear and jumper in car	3	1	Low
2.8	Slips, trips and falls	3	3	Med	5/6	• PPE including protective footwear • Assess site for safety prior to commencing work • Be aware of surroundings and walkways • Stay within designated walkways where possible and always attempt to take the safest route to your destination	2	2	Low

						• Obey on-site signage and instructions and never enter an exclusion or restricted zone unless authorised to do so			
2.9	Bites and stings due to contact with snakes, spiders and general vermin	3	3	Med	6	• PPE including high vis coveralls, insect repellent, protective footwear, gardening gloves when working with soil • First aid kit to be stored in vehicle • Carry mobile phone	2	2	Low
2.10	Environmental damage due to testing	2	1	Low	1	• Be aware of minimising damage to sites	2	1	Low
2.11	Too many identified sites	3	1	Low	1	• Choose most appropriate sites or sites with the most complete data collection	3	1	Low
2.12	Lack of rainfall during data collection period	4	3	Med	1	• Design project so that data can still be collected and analysed without viewing site during rain	2	3	Low
3	**Data Analysis and Writeup**								
3.1	Lack of quality field data collected	4	4	High	1	• Ensure that project methodology is sound • Test the methodology on several sites before to check whether it is appropriate • Start data collection early	3	3	Med
3.2	Unable to access modelling software	4	3	Med	2	• View modelling as an extra that can be eliminated if unviable	4	1	Low
3.3	Modelling software too time consuming to model all sites	4	3	Med	2	• View modelling as an extra that can be eliminated if unviable	4	1	Low
3.4	Problems with statistical analysis	4	3	Med	1	• Take statistics data analysis course • Get help from university	2	2	Low
3.5	Loss of data due to computer problems or other e.g. fire	4	5	High	1	• Purchase a backup portable hard drive and USB flash drives • Ensure that work is backed up continuously to a USB flash drive while working, alternating drives dailiy • Ensure that work is backed up regularly to the portable hard drive • Ensure that work is backed up regularly to USQ	2	1	Low
3.6	Time delays due to weather, external commitments, etc	3	4	Med	4	• Start research project early • Build contingency time into each milestone and into final delivery	4	1	Low
3.7	Illness (Including other family members)	5	4	High	1/4	• Start research project early • Eat well, exercise and take vitamins • Build contingency time into each milestone and into final delivery • Arrange parents as backup if illness of kids occurs at critical times	4	3	Med
3.8	Work commitments	3	4	Med	1	• Maintain work schedule of 3 days per week • Prioritise final year of uni • Take annual leave at key milestone delivery times • Ensure that study days continue	2	4	Med
3.9	Other subject commitments	5	5	High	1	• Start research project early to get ahead and work over uni breaks • Have one study day a week that is dedicated to the research project • Arrange research project delivery milestones around assignment due dates for other subjects • Build contingency time into each milestone	3	4	Med
3.10	Distractions	4	2	Med	1	• Study at Bond university library on dedicated dissertation writing days	3	2	Low
3.11	Lack of ergonomically sound study area	2	1	Low	2	• Study at Bond university library • Ensure home study area is set up with appropriate furniture and is clean and tidy	1	1	Low

		Consequences				
		Minor (1)	**Moderate (2)**	**Serious (3)**	**Major (4)**	**Extreme (5)**
Likelihood	**Almost certain (5)**	Low	Medium	High	High	High
	Likely (4)	Low	Medium	Medium	High	High
	Possible (3)	Low	Low	Medium	Medium	High
	Unlikely (2)	Low	Low	Low	Medium	Medium
	Rare (1)	Low	Low	Low	Low	Medium
	Injury	First air treatment, no lost time, insignificant environmental or financial damage	Medical treatment or hospital required, notable environmental or financial damage	Serious injury/illness requiring hospitalisation overnight or longer, substantial environmental or financial damage	Single fatality or permanent disability, significant environmental or financial damage	Multiple fatalities, extensive financial loss, disruption to services and/or disastrous environmental loss
	Impact	Minor Impact	Events with no adverse effects	Events with temporary adverse effects	Events with long term effects, attracts authorities, detrimental environmental effects	Event with major impact, revoking of licence, mass media attention

Hierarchy of Controls (HOC)
1. Elimination
2. Substitution / Isolation
3. Engineering
4. Administration
5. Training
6. Personal Protective Equipment (PPE)