University of Southern Queensland
Faculty of Health, Engineering & Sciences

Water Sensitive Urban Design for the Spring Creek catchment and MUSIC Sensitivity Analysis

A dissertation submitted by

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Abstract

In recent times, water sensitive urban design (WSUD) has been used extensively in large cities such as Brisbane and Melbourne. As a city, Toowoomba has not been exposed to the benefits of stormwater management provided by WSUD.

In Australia, WSUD is thought of as the implementation of planning and design techniques which are sensitive to water sustainability and environmental protection. Obvious benefits of WSUD include the ability to reduce stormwater runoff flows and increase stormwater quality. WSUD uses specifically designed systems for the management of stormwater. As the Spring Creek catchment (Toowoomba, Queensland) has undergone extensive urban development in recent years, there has been an increasing need to manage stormwater that is released from the catchment. WSUD will aid in the management of these stormwater issues. An important aspect is selecting WSUD systems is soil characteristics such as saturated hydraulic conductivity. The model for urban stormwater improvement conceptualization (MUSIC) is an industry standard in the assessment of stormwater characteristics and WSUD systems. Generic (default) input parameters for the model have been developed by the creators of MUSIC in order for users to model the catchment without extensive knowledge of the local conditions (e.g. soil characteristics). These generic parameters have been proved to provide inaccurate results when used in MUSIC. By comparing a model using generic parameters against a model using local parameters, the relative inaccuracy of the results obtained from the models can be evaluated.

A soil investigation of the Spring Creek catchment was completed. This investigation involved single ring infiltrometer testing within the field and disturbed soil core testing in the laboratory. In addition, the results from the soil investigation have led to the development of localized soil input parameters for the MUSIC model. Generic input parameters and local input parameters were applied in separate models. The results of these models were compared in order to determine if MUSIC is highly sensitive to a change in soil input parameters.

The results from the soil investigation have revealed low saturated hydraulic conductivity soils within the catchment. Hence, ponds and wetlands were deemed most suitable for the catchment due to the soils water ponding ability. The results of the sensitivity analysis demonstrated that the local parameters were generally greater than the generic parameters. As a result the generic model achieved much greater stormwater runoff containing larger amounts of total suspended solids. The effectiveness of WSUD systems was evaluated in both models. Generic model WSUD systems generally had to increase in size by 8% in order to have the same treatment ability as the systems in the local model. It was concluded that the local parameters were preferred for modelling in MUSIC compared to generic parameters.

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ENG4111 Research Project Part 1 &
ENG4112 Research Project Part 2

Limitations of use

Certification

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own efforts, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Allister Henry Gaffney

Student Number: 0061004617

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Signature

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Date

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Nomenclature and Acronyms

K_{sat} – Saturated Hydraulic Conductivity

MUSIC – Model for Urban Stormwater Improvement Conceptualization

NCEA – National Centre for Engineering in Agriculture

SFD – Simplified Falling Head Method

WSUD – Water Sensitive Urban Design

1 Introduction

1.1 Outline of study

The main purpose of this research is to define the most suitable Water Sensitive Urban Design (WSUD) systems for the Spring Creek Catchment based on soil characteristics. A secondary objective is to perform a sensitivity analysis using the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) in order to assess the accuracy provided by generic (default) input parameters.

1.2 Project Topic

Water Sensitive Urban Design within the Spring Creek Catchment and MUSIC model sensitivity analysis

1.3 Project Background

1.3.1 Stormwater Runoff

Stormwater runoff can be characterized into the water quantities that are released from a catchment due to rainfall events. Urban developed catchments, in particular, have a greater amount of stormwater runoff than undeveloped catchments. The reason behind these issues is that urban development brings construction of roads, concrete surfaces, housing and other impervious surfaces. With an increase of impervious surfaces (e.g. roads and pavements) the stormwater has less of an opportunity to seep into pervious surfaces (e.g. open space and natural soil). If the stormwater does not infiltrate (seep) into the natural soil it flows overland on the impervious surfaces and contributes to an increased stormwater runoff.

The main consequences of an increase in stormwater runoff include:

- Flooding
- Erosion of the natural landscape, particularly water ways
- Risk to public health and safety
- Decreased water quality in local waterways due to pollution (e.g. road stormwater runoff)

Generally in an urban situation, stormwater runoff is managed by road systems followed by drains and piping. Finally the runoff is conveyed to local waterways (rivers and creeks) and is subsequently given the opportunity to flow downstream. WSUD systems reduce the stormwater runoff flow rate from a site and improve the stormwater quality before it is realised into local waterways.

The issues presented by stormwater runoff can be effectively managed by practices such as WSUD. WSUD is the integration of the natural water cycle with the urban environment. It encompasses water supply, sewerage and stormwater management (Wong, 2006). Typical WSUD systems are implemented in urban environments. WSUD systems have the capability to decrease stormwater runoff and improve water quality through processes such as bioretention, filtration, storage, chemical adsorption and natural soil infiltration.

The use of particular WSUD systems depends heavily on in-situ soil characteristics such as saturated hydraulic conductivity and infiltration. Many of these systems require in-situ soil infiltration such that the water can infiltrate into the natural soil and not contribute to stormwater runoff. It was a requirement of this project to investigate soil properties such as infiltration in order to effectively select appropriate WSUD systems.

An effective means of understanding stormwater runoff and predicting its effects on a development is the Model for Urban Stormwater Improvement Conceptualization (MUSIC). This modelling software also has the capability to evaluate the effects of WSUD systems when applied in a development. MUSIC is an industry standard software that aids in the assessment of developments.

Dotto et al. (2009) states that users of the MUSIC model tend to depend on the generic parameters which have been proven to provide inaccurate results. Dotto et al. (2008) demonstrated that using generic parameters within MUSIC has produced considerably inaccurate results for several catchments within the Melbourne area. This has particularly been evident in the selection of soil related parameters (e.g. infiltration capacity and available water holding capacity). By comparing models utilizing both generic and localized parameters it will be possible to assess the relative error presented by the results (if any) in selecting model parameters. This assessment will be useful in considering whether generic parameters are acceptable for use in modelling urban situations within the Spring Creek catchment.

1.3.2 Site Area

The Spring Creek Catchment is located within the South-western sector of Toowoomba, Queensland. The Spring Creek flows adjacent to Boundary Road in Glenvale as shown in Figure 1.1. The area of the Spring Creek Catchment included in the study is approximately 208 hectares. It is bound by Glenvale Road, McDougall Street, Euston Road, Greenwattle Street and Hampton Street. This area is entirely within the Toowoomba Regional Council region.

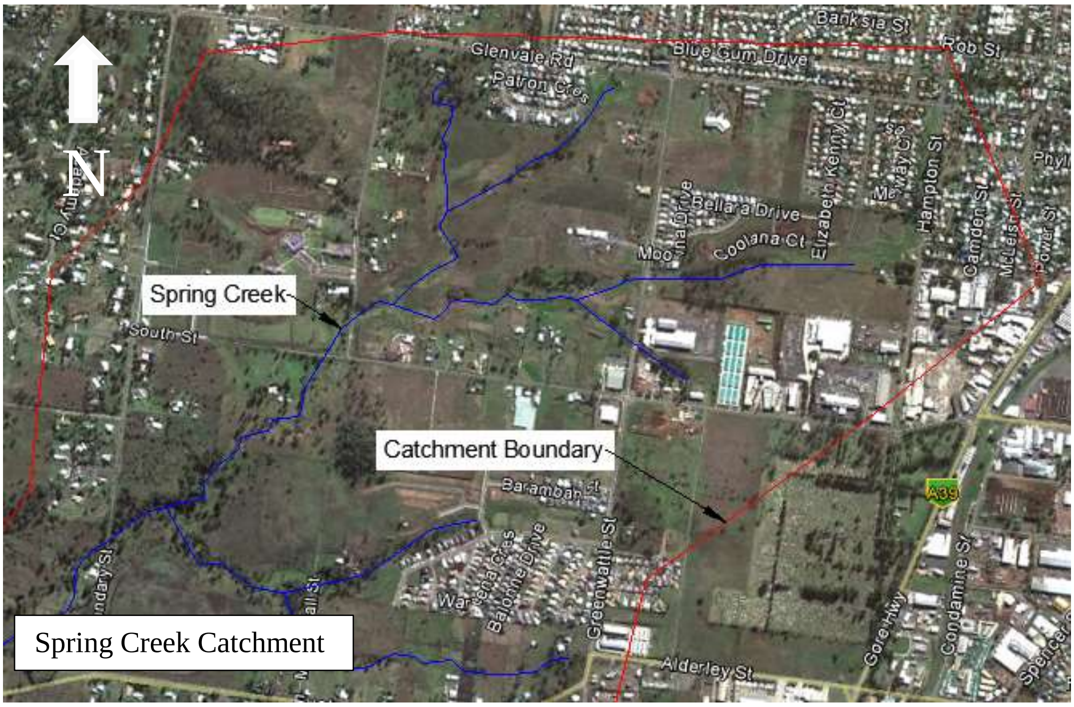


FIGURE 1.1- SPRING CREEK CATCHMENT (1:16,600) (GOOGLE MAPS 2013)

1.3.3 Topography

The elevation within the catchment ranges from approximately 670-547m (above sea level) (TRC 2013). The terrain involves gentle mountain slopes and considerably large grassland and grazing areas. The Spring Creek traverses the catchment area predominantly in an east-westerly fashion.

1.3.4 Current Land use

As defined by the Toowoomba Regional Planning Scheme (2013) the major land use areas within the Spring Creek Catchment are for rural purposes (e.g. farming and grazing), community purposes (e.g. schools and churches) and urban residential. Several of the urban residential areas have recently been developed or are currently under development.

1.3.5 Soils

On commencement of the project available soil information was collected for the subject area. Figure 1.2 demonstrates the soil map of the subject area. The information in this soil map is a graphical representation of the information available in the CSIRO soil archive (June, 2013). This information in this soil archive is based on soil type and approximated clay content. This information is of importance as the use of WSUD systems depends on the soil type in the subject area. WSUD will perform at optimum capacity if applied in the appropriate soil type. As shown in Figure 1.2, sand and loam soils are adjacent to the north-eastern and far south-eastern area boundaries. According to the soil map the majority of the area contains medium to light clay. The available soil information is very broad across the Spring Creek catchment and only provides characteristics such as soil type and clay content.

In order to select suitable WSUD systems for the catchment it is necessary to conduct a soil investigation that extends beyond the information that is already available. The soil investigation will need to determine soil characteristic such as infiltration rates, saturated hydraulic conductivity and field capacity for the purposes of this project.

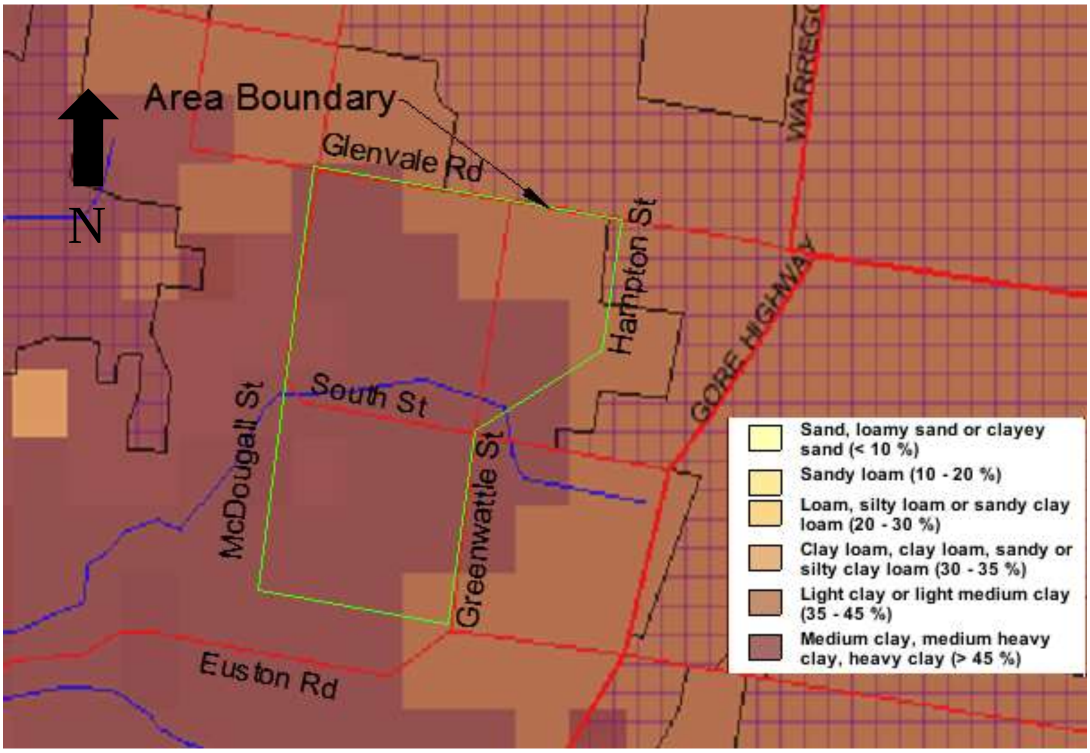


FIGURE 1.2 - SOIL MAP OF THE SUBJECT AREA 1:32,600 (CSIRO, 2013)

1.3.6 Meteorology

The average rainfall in the Toowoomba area is between 600-800mm (BOM, 2009). Maximum daily rainfalls of up to 100mm have been recorded in Toowoomba during particular rainfall events (ICA Hydrology Panel, 2011).

1.4 Research Aims and Objectives

Upon completion of this research project the information provided should be useful to stormwater practitioners. As such, in the initial stages of the project aims are set in order to justify the projects purpose.

This project seeks to perform an investigation into the local soil characteristics and utilize the relevant literature to define the most suitable water sensitive urban design (WSUD) system/s for the Spring Creek catchment. In addition, the local soil input parameters were developed from the results of the soil investigation. These local parameters will be implemented in the Model for Urban Stormwater Improvement Conceptualization (eWater, 2012), in order to assess the use of the generic input parameters commonly used for the software.

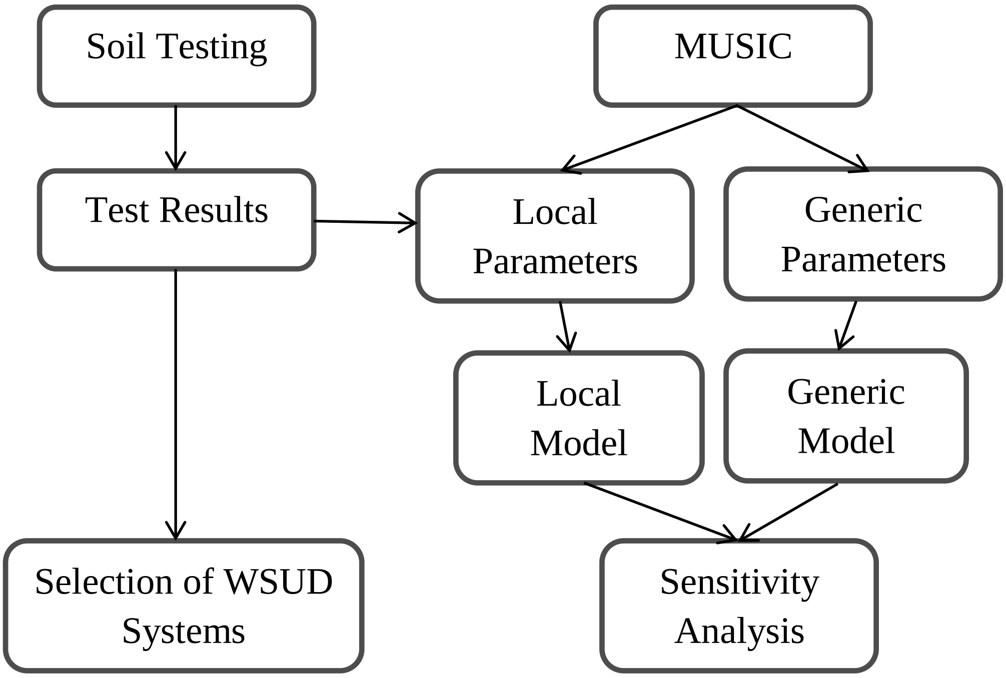
Objectives of this research are shown below:

- Research the specifications of WSUD systems in relation to soil characteristics;
- Perform a soil investigation within the subject area in order to relate the soils to the most suitable WSUD systems;
- From the results obtained from the soils investigation identify the most suitable WSUD system for the subject area;
- Calibrate the results of the soil investigation in order to create models within the Model for Urban Stormwater Improvement Conceptualization (MUSIC) based on local soil characteristics;
- Develop a Model within MUSIC based on generic input parameters as per the MUSIC user manual;
- Perform a sensitivity analysis to compare the results of the localized and generic models and evaluate their differences in terms of runoff characteristics;

If time permits:

- Model WSUD system scenarios within MUSIC and determine the comparative effects of the application of generic and local soil input parameters

A flow chart demonstrating the importance of the components in this project is shown below:



1.5 Scope

The testing conducted in this project was mainly concerned with soil infiltration and saturated hydraulic conductivity as they are the most important soil characteristics in considering stormwater runoff and WSUD systems. Other soil properties were also required for use in the MUSIC model. These properties include moisture content, total storage capacity and field capacity. Moisture content has the capability to change over time and thus the soil investigation considered an instantaneous measurement for this property.

The testing sites in this project were selected from a considerably large catchment size. Thus, results given in this project are representations of the particular sites that were tested.

Available resources permitted the use of the single ring infiltrometer testing method that was conducted in the field to determine the infiltration and saturated hydraulic conductivity of the soil. The laboratory tests, that were used to verify the field tests, mainly involved infiltration testing of oven-dried disturbed soil core samples.

1.6 Project Overview

Restoring predevelopment hydrological conditions is an important goal in an urban development. One of the most important hydrological components in urban areas is stormwater runoff. Stormwater runoff has the capacity to significantly affect communities and land through actions such as flooding, erosion and by contributing to poor water quality in waterways, effecting local ecology. With an increase in urban developments within the Spring Creek catchment the requirement to manage stormwater becomes more important because of the increase in stormwater runoff. WSUD involves practices that will help urban designers achieve their goals in urban situations. Its main focus is on the reduction in stormwater runoff and the improvement of water quality. The literature has demonstrated that soil properties, such as saturated hydraulic conductivity, have a significant impact on the selection of WSUD systems.

MUSIC is an industry standard model for the assessment of developments, particularly in urban situations. This model is particularly useful in determining the quality and quantity of stormwater runoff generated by a development. MUSIC is also capable of evaluating how WSUD systems effect a development in terms of runoff. MUSIC is important in aiding the decision making process in engineering design and development.

In the past, users of the MUSIC model have used generic input parameters. Understanding the effects of using generic parameters within the MUSIC model will be essential in achieving an efficient design solution. This project will assess the use of these generic parameters in the MUSIC model and compare them to a model applying more accurate local parameters obtained from soil investigations.

The research in this project will aid in the design process of WSUD systems within the Spring Creek catchment and create an awareness of the effects of generic modelling parameters in engineering practice.

The next chapter will demonstrate the literature that was identified as relating to the various aspects in this project. The review of this literature provided an improved understanding of research that was previously conducted. This understanding was used to benefit the research conducted in this project.

2 Literature review

2.1 Chapter Overview

This chapter has been developed to detail the work that has been conducted in the past in relation to WSUD and the application of the MUSIC model. A background into the practical applications and systems currently used in practice is given and will define this projects purpose in engineering. For the most part, this chapter will support the information provided throughout this report. Testing methods and the MUSIC models relevance to WSUD will be described in relation to the project.

2.2 Stormwater Runoff

Stormwater runoff has been an important concept in the design of urban developments. Stormwater naturally infiltrates into the ground at the capacity of the natural soil in areas considered as pervious surfaces (e.g. grass and open space). With urban development of catchments there is an increase in impervious surfaces (e.g. roads, sidewalks, roofs and driveways) and subsequent decrease in pervious surfaces. With less pervious surfaces the opportunity for the soil to allow the water to infiltrate decreases. In addition, when the total storage capacity of the soil is reached (i.e. the soil is saturated) the water will infiltrate at a slower rate with subsequent ponding on the soil surface. This leads to an increase in the overland flow of water after a rain event, classified as stormwater runoff. Stormwater runoff has led to issues such as flooding, erosion, a risk to public safety and poor water quality.

2.3 Water Sensitive Urban Design

Management of issues presented by stormwater runoff can be greatly improved with the use of Water sensitive urban design (WSUD). The term WSUD is a new paradigm in the planning and design of urban situations that is focussed on being sensitive to environmental and water sustainability issues (Wong, 2006). This can be seen as an improvement compared to the previous stormwater management paradigm that only considered the conveyance of stormwater safely and economically away from a catchment through engineering practices. WSUD involves progressing through the urban design process with a holistic view on management of the urban water cycle. When considering WSUD one must consider both appropriate Best Planning Practices (BPP) and Best Management Practices (BMP).

A BPP is the best planning approach for achieving water resource management objectives in urban scenarios (Wong, 2006). This mainly involves site analysis and land capability assessment. BMPs refer to the selection and feasibility assessment of the systems presented by WSUD. In general, the more systems (practices) used for a site the more likely that the objectives of design will be achieved. It is not uncommon to use several systems to achieve a set of objectives within a site. This process, as described by CVCA (2010), involves harvesting stormwater by intercepting, conveying and storing it for future uses. In general, harvesting the water involves using evapotranspiration through vegetation, infiltration into the native soil and conveying the water downstream assisting in maintaining the management of stormwater to a predevelopment standard. Components of BPP and BMPs are both required to design and construct the site layout.

The functions for which WSUD is used for depends on the stormwater management objectives and the site conditions. Functions of WSUD systems include, but aren't restricted to:

- Treatment of pollutants in stormwater
- Stormwater peak flow attenuation
- Diversion and direction of flow
- Aesthetic appeal for the region
- Reduction in flow due to impervious surfaces
- Making an urban area self-sufficient in regards to stormwater management
- Improving the water condition in waterways

At this point in time, application of WSUD systems has been evident to assist stormwater management in large Australian cities such as Melbourne and Sydney. It is expected that the local characteristics (e.g. soil) of inland cities such as Toowoomba will differ from those settled closer to the coast lines. Hence, selection of WSUD based on results from local investigations is important.

2.4 WSUD Systems

2.4.1 Introduction

WSUD includes the selection of the most suitable systems to service the stormwater management requirements of the site. During selection a number of conditions need to be considered. These include soil type, saturated hydraulic conductivity (permeability), groundwater level, physical feasibility, treatment suitability and location (Kannangara et al., 2012). As detailed in the later of this project a number of factors such as groundwater level and treatment suitability (water quality treatment) require a more extensive investigation and are not included in the scope of this project.

2.4.2 Types of Systems

The types of WSUD systems can be classified in several ways. It is typical for a system to belong to more than one classification or even be dependent on system in a different classification. The Auckland Regional Council (2003) defines each practice (system) as either storage, vegetative, infiltration and filtration practices. Examples of the systems within each classification are shown below:

- Storage: ponds, tanks, wetlands*
- Vegetative: swales, filter strips,
- Infiltration: basins, trenches and porous pavements
- Filtration: sand filters, bioretention basins*

*Systems such as bioretention basins and wetlands often belong in several classifications rather than a single.

The application of each system depends on the relative site constraints as will be discussed in section 2.4.3.

2.4.3 Site constraints

As mentioned in Section 2.4.1, the selection of the most appropriate systems also depends on the site of construction. Several of the constraints that need to be considered predevelopment include:

- the catchment area
- available surface area
- topography
- soil characteristics
- flow reception and nearby properties

(Auckland Regional Council, 2003)

Catchment Area

The catchment area that will drain to the systems will significantly contribute to their effectiveness. Auckland Regional Council (2003) suggests that in general, vegetative and filter media practices are most appropriate for smaller catchment areas as higher flows from large catchments could negate the effectiveness of filtration due to overflow. Storage practices such as ponds are more appropriate when used in larger catchments. In general, the recommended catchment area that each system types should serve can be viewed in Table 1. The suitability of systems based on the catchment area can be considered in Figure 2.1.

Systems Type	Recommended Catchment Area
Storage (e.g. ponds and wetlands)	6 – 40 ha
Vegetation (swales and buffer strips)	1 – 2 ha
Infiltration (basins and trenches)	1 - 20 ha
Filtration (bioretention basins)	6 – 20 ha

TABLE 1- RECOMMENDED CATCHMENT AREA FOR WSUD SYSTEMS (ARC (2003) & GCC (2007))

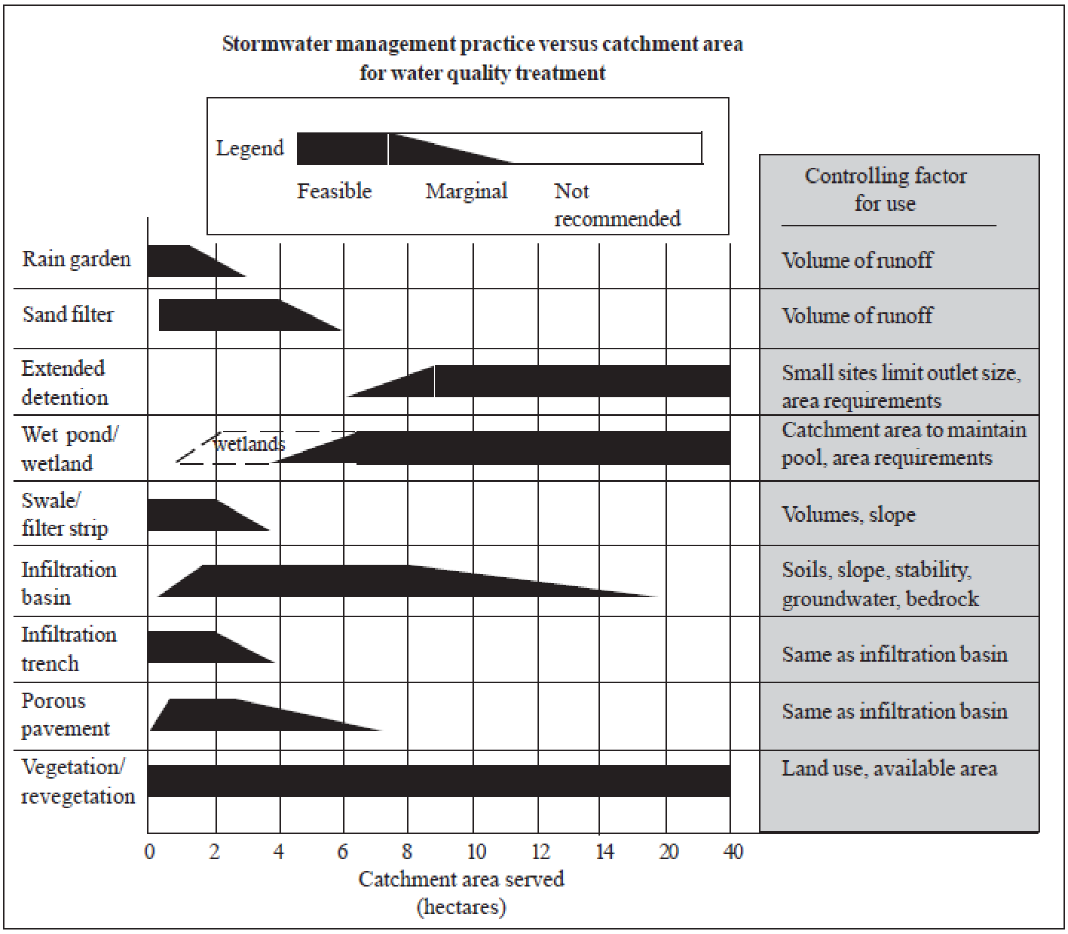


FIGURE 2.1- WSUD SYSTEM APPROPRIATENESS BASED ON CATCHMENT AREA (ARC, 2003)

Topography

As the slope of a catchment increases, the amount of systems applicable to that catchment decreases (ARC, 2003). This is due to the increased discharge of overland flow due to an increase in slope. The faster the overland flow the less likely that the water will be able to enter systems such as swales and infiltration basins.

Ground Water

The level and quality of the groundwater within a site is significant when selecting appropriate systems for an area. High groundwater level with poor water quality can drastically hinder the effectiveness of certain systems. Where it is possible ground water table investigations should be conducted. For the purpose of this project, such investigations will not be possible.

Soil Characteristics

Certain systems are more appropriate to a site depending on the soil characteristics of the native soils. Figure 2.2 demonstrates the appropriateness of certain systems based on soil types. The solid black line indicates that the system is appropriate to that soil type.

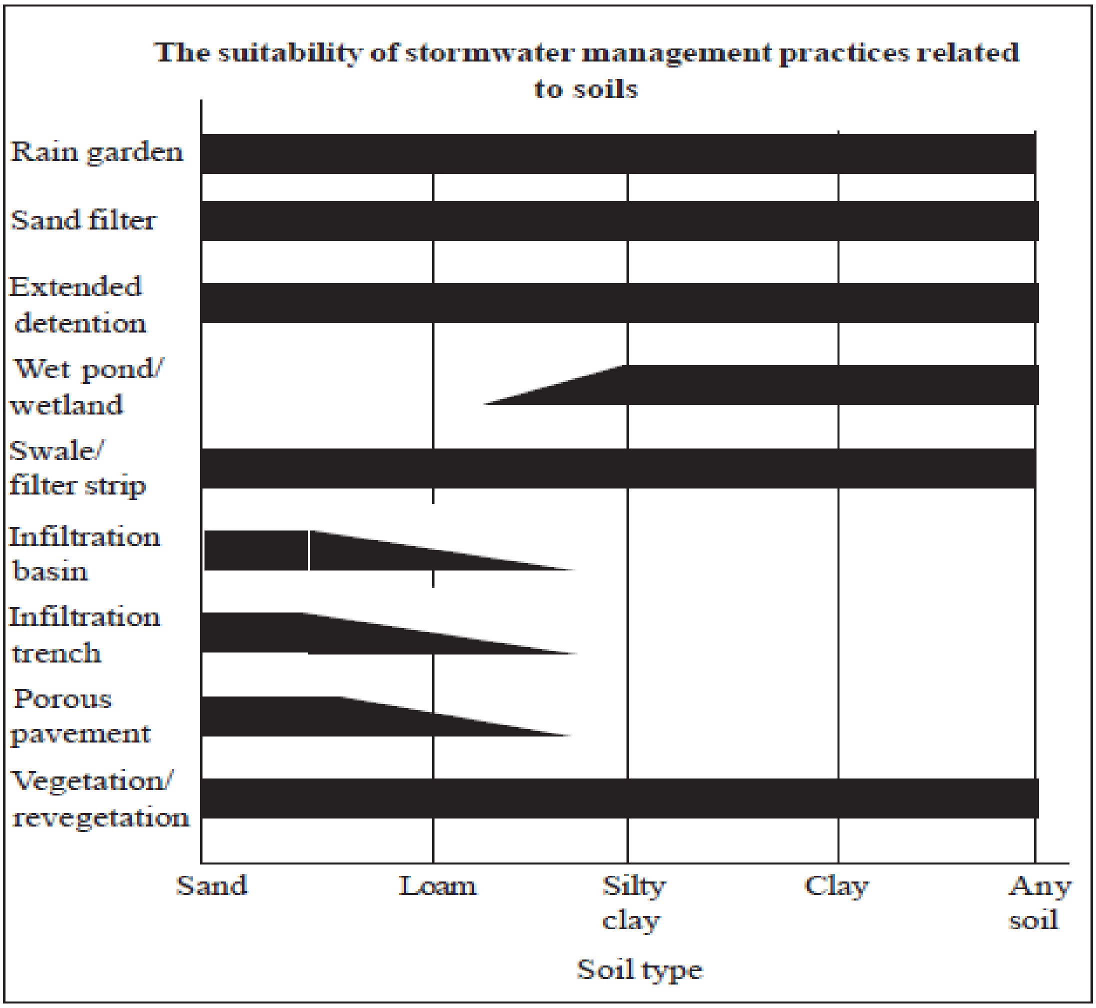


FIGURE 2.2- SYSTEMS BASED ON SOIL TYPES (ARC, 2003)

The literature generally classifies a systems appropriateness based on the saturated hydraulic conductivity (K_{sat}) of the native soils. Saturated hydraulic conductivity is the rate at which water passes through soil when it is saturated (i.e. all pores within the soil are filled with water). Similarly, infiltration is the measure of the rate of which water enters a soil at the soil surface. Infiltration differs from saturated hydraulic conductivity as it considers the effects of surface cracks, water repellence and change in moisture content. Whereas saturated hydraulic conductivity only considers the soils at saturated conditions.

Storage systems such as ponds and wetlands (Figure 2.3 – Constructed wetland (FMG Engineering, 2013)Figure 2.3) are most applicable to clay type soils as the saturated hydraulic conductivity of clay is much lower than for other soils. The main difference between ponds and wetlands are their volume to depth ratio. Ponds are generally deeper than wetlands and don't have large fluctuations of inflow and outflow. Wong (2006) recommends soils with a hydraulic conductivity of less than 36 mm/hr. Clay increases the effectiveness of these systems because the water infiltrates the local soil slowly. Water applied to clayey soils tends to pond on the surface of the soil after a short period of infiltration. Sites' where water is ponded is a favourable habitat for organisms such as mosquitos which could be harmful to human health. The Gold Coast Council (2007) recommends regular maintenance of storage systems under these conditions. The maintenance would include constant checks of water levels and presence of nutrients and harmful organisms.

FIGURE 2.3 – CONSTRUCTED WETLAND (FMG ENGINEERING, 2013)

Vegetation and filter systems such as buffer strips, swales and bioretention basins don't depend heavily on the local soil characteristics, although coarse grained soils at the surface assist in slowing down overland flow (ARC, 2003). These systems use a liner, when required, to ensure the soil flows within the system and to underground conveyance pipes. Typically, bioretention basins are constructed with several sub-layers of varying composition (soil type). The main components involve imported soil such as medium sand or loams (except where appropriate soils are found onsite). They are preferred for use in in-situ soils that have a much lower saturated hydraulic conductivity compared to the filter media used in the system. This ensures minimal lateral seepage of stormwater into the in-situ soil. These systems are primarily for water quality treatment purposes but they also aid in reducing stormwater flow rates due to detention of the water within the systems. Generally, once the water passes through the system it is then drained into an underground pipe (perforated) and conveyed away from the site as shown in Figure 2.4 below.

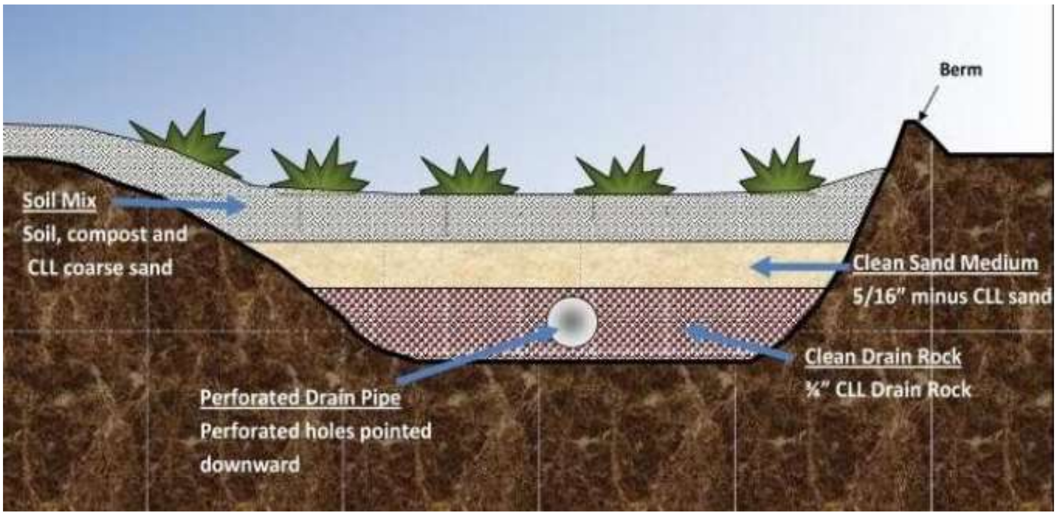


FIGURE 2.4 - TYPICAL BIORETENTION BASIN CROSS-SECTION (CLEARLAKE LAVA, N.D.)

The applicability of infiltration systems depends heavily on the local soil characteristics. The Department of Water (2007) suggests that infiltration systems operate best in soils with a saturated hydraulic conductivity greater than 36 mm/hr. It should be noted that infiltration systems are able to operate below this limit although it is not advisable as excessively large systems are required in these conditions. This characteristic is typical of sandy soils which allow water to pass through them at a reasonably fast rate. If the saturated hydraulic conductivity were lower than this value the system would be susceptible to water ponding which can give rise to issues such as mosquitos. In addition, dispersive clays and sodic soils tend to cause water logging and prevent infiltration of water. These types of soils should be avoided in planning for infiltration systems. At the other extreme, the use of infiltration systems are not recommended in windblown sands as the soil is easily displaced by the natural elements and the saturated hydraulic conductivity is too high (Wong, 2006).

Infiltration systems are usually installed with layers of different crushed gravel and geotextiles to separate each layers before allowing the water to pass through the in-situ soil. A typical infiltration system (trench) can be seen in Figure 2.5. It isn’t unusual to have another WSUD system at the surface that aids the delivery of the surface runoff into the infiltration system (e.g. filter strips). These types of systems can often decrease the velocity of the flow and ensure that the infiltration system is not bypassed.

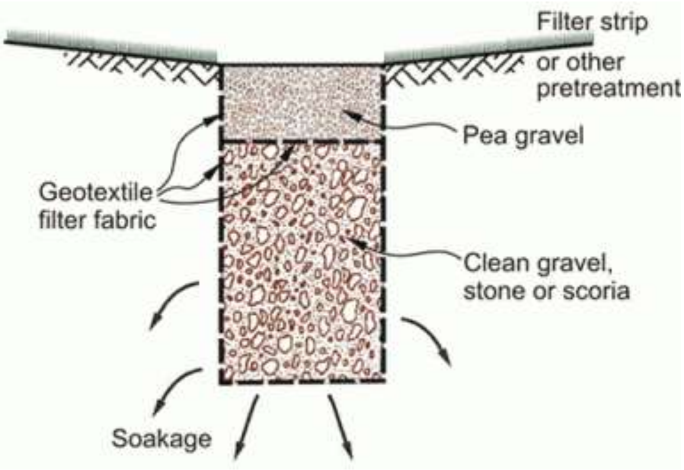


FIGURE 2.5- TYPICAL INFILTRATION TRENCH (RIVERSIDE, 2009)

The construction of infiltration systems (e.g. infiltration basins) and storage systems (e.g. wetlands) are often at a depth of 0.5 to 1.5m. For this reason it is appropriate to include an investigation into the soil at a depth 0.5m into the natural surface of the site.

2.4.4 Summary of WSUD Systems

The following is a summary of typical WSUD systems based on information obtained from Wong (2006) and ARC (2003):

Systems	System Type	Hydraulic Conductivity	Description
Wetlands	Storage/Vegetation	<36 mm/hr	These systems typically cover a large area, capture adsorbed pollutants through plant biological uptake and suspended solids (particles), contribute to the removal of pollutants (e.g. nitrogen, phosphorus) and achieve a decrease in stormwater attenuation by detaining runoff.
Ponds	Storage	<36 mm/hr	Ponds trap settling solids (coarse to medium), promote UV disinfection of water body, and are usually greater than 1.5m deep (large capacity), cover a large area, detain captured stormwater and release it at a lower rate.
Infiltration trenches	Infiltration	>36 mm/hr	These systems provide hydrological benefits by reducing the stormwater overland flow, typically involve non-native gravels and sands for operation, are effective in allowing the soil to seep into the surrounding natural soils, can recharge ground water tables, have an element of sediment (pollutant) capture and often require the stormwater to be pre-treated to aid in the water delivery to the system.
Buffer strips and swales	Filtration	Any	These types of systems are cost effective, appropriate for source control, provide the link between impervious areas and trunk drainage main components, use a narrow corridor (1-2m), require imported soils with higher K_{sat} than in-situ soils, partially remove pollutants, decrease stormwater attenuation before conveying downstream. Swales have the capacity to substitute for road drainage (e.g. kerb and channels) and convey minor flows.

Bioretention basins*	Filtration/Vegetation	All	These systems are generally applicable to flat ground, require a variety of filter media (loam and gravel), very effective in removal of pollutants before conveyance to underground drainage (pipes), can exist adjacent to roads, reduce the amount of stormwater flow and the amount of runoff received by water ways.

TABLE 2-SUMMARY OF TYPICAL WSUD SYSTEMS

Note: The possible systems that could be used in a catchment are not limited to those mentioned in the table above.

*Filtration and vegetation systems often incorporate aspects of infiltration and storage and thus are very broadly classified. These systems are mainly concerned with the improvement of stormwater quality. In general, they do not depend on soil characteristics. This is because they do not allow stormwater to infiltrate into underground soil, rather the water is often transmitted away from the site via perforated pipe as shown in Figure 2.4.

2.5 MUSIC

2.5.1 Introduction

The Model for Urban Stormwater Improvement (MUSIC) is used to analyse the stormwater within an urban situation. The aspects of stormwater that are considered are stormwater runoff flows and water quality. In the design phase of an urban development a stormwater practitioner would use MUSIC to model the various rainfall-runoff scenarios for the site, based on previous rainfall data, such that the post-development stormwater characteristics of the site can be accounted for in design.

The parameters involved in the development of MUSIC models include meteorological data, modelling time step and the catchment properties (Water by Design, 2010). The work in this project has included a sensitivity analysis using localized and generic (default) parameter inputs. Understanding the sensitivity analyses of the MUSIC model in the past will allow the research in this project to be well informed and justify its purpose in the engineering profession.

2.5.2 Modelling

Similar to other models, MUSIC requires input parameters when a model is created. The results that are produced for a model created in MUSIC include time series graphs which detail certain properties of the catchment over time. These properties include:

- flow rate at particular delivery points
- pollutant concentrations and mass loads (e.g. suspended solids, nitrogen, phosphorus)

The quantity of these properties over time can be viewed in a user defined time step. Typically the time step for the time series graphs is daily.

2.5.3 Rainfall-runoff

In the model, rainfall (as recorded historically) is converted to runoff as the water lands on impervious surfaces (e.g. roads) on the ground and partially when flowing over pervious surfaces (e.g. grass and open space). This process depends on the pervious area characteristics (e.g. soil types). In addition, the characteristics of the runoff are highly dependent on the catchment characteristics (e.g. size, topography, drainage). Thus, in modelling practices, it is important for the user to develop modelling parameters as they relate to the catchment characteristics. One of the most important concepts is the characteristics of the pervious areas, and in particular their dependency on soil to infiltrate water and convey it via ground water flow. If the soil allows water to pass through it at a high capacity, the amount of stormwater runoff will decrease significantly. The characteristics of soil and consequently the predicted rainfall runoff can be found through a soil investigation. McKenzie et al. (2002) explains that the prediction of runoff is very sensitive to the hydraulic conductivity of a soil surface. Hence, the results of an investigation of important soil characteristics (e.g. infiltration and hydraulic conductivity) within a catchment will be beneficial in developing an accurate rainfall-runoff model.

2.5.4 Sensitivity Analysis

A sensitivity analysis is used to understanding how the input parameters for a model influence the outputs (results) from the model. This type of analysis is particularly useful in situations where there are uncertainties in the modelling process. In summary, the analysis will define how sensitive a model is in relation to the deviation in input parameters.

Based on research conducted by Dotto et al. (2009), model uncertainties occur due to poorly defined model parameters which impacts on the results. A simple way to understand the impacts of the results is to perform a sensitivity analysis. Typically, pre-defined model parameters are provided by groups such as Melbourne Water (Melbourne Water 2010). Melbourne Water’s recommended input parameters were developed specifically for the broader Melbourne area to assist in the assessment of MUSIC models that are submitted to their organisation.

2.5.4.1 Value Calibration

Dotto et al (2009) calibrated the values used in a sensitivity analysis using the MICA software. This software considers parameter uncertainties and indicated the most probable values which could be used to obtain the best performance from the model. This model relates to a series of posterior distribution functions (PDF) and produces a curve based on the calibrated values. By using this method the model can analyse the sensitivity of the key parameters that can be used in MUSIC. Dotto et al. (2009) found that the sensitive parameters were the impervious area and pervious area proportions, soil storage capacity and infiltration characteristics.

2.5.4.2 Generic Values

For simplicity the literature provides MUSIC users with generic (default) values of which can be used in the model. The generic values are mainly applied when inadequate information is available to calibrate the model input parameters to the characteristics of the local site. The CRC (2005, p.30) provides the default values to be used in MUSIC throughout Australia as shown in Table 3. Note these parameters are the same as those provided by the Brisbane City Council (2003).

Input Parameters	Values
Impervious Threshold	1 mm/day
Initial Soil Storage	30%
Infiltration Capacity Coefficient	200 mm/day
Infiltration Exponent	1
Initial Groundwater Store	10 mm
Daily Recharge Rate	25%
Daily Drainage Rate	5%
Daily Deep Seepage Rate	0%
Soil Storage Capacity	120
Field Capacity	80 mm

TABLE 3 - CRC (2005) MUSIC DEFAULT PARAMTERTERS

Figure 2.6 shows how the MUSIC input parameters interrelate in the model in terms of rainfall-runoff generation.

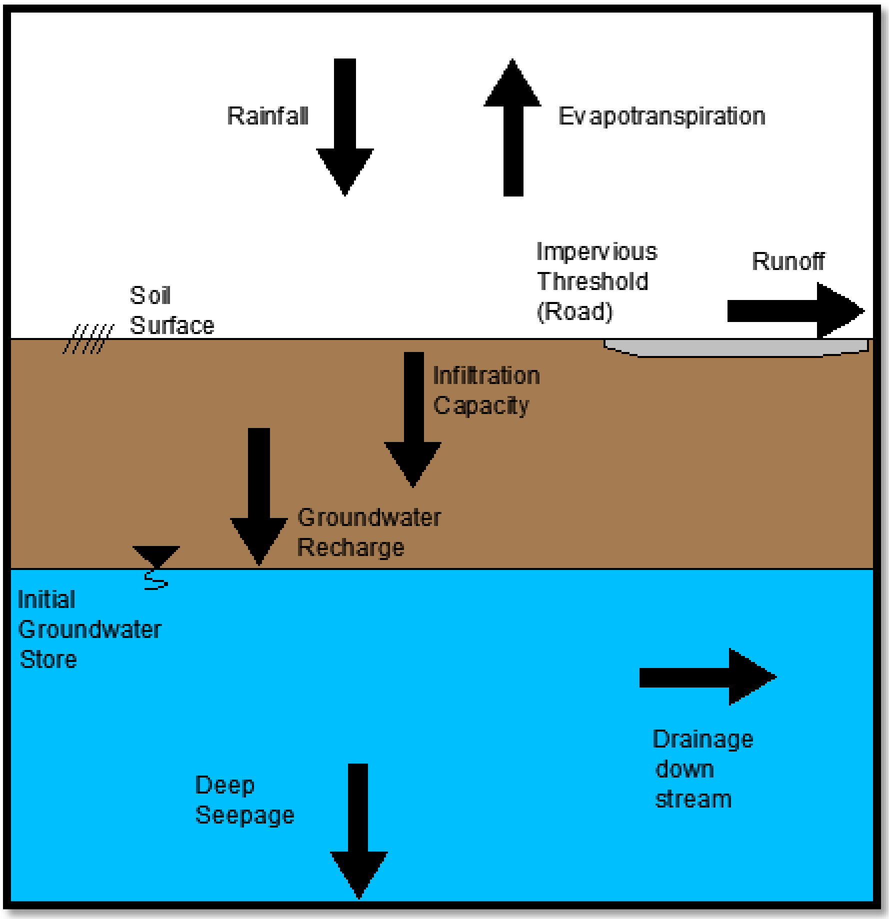


Figure 2.6 – Interrelation of MUSIC input parameters in the model

The soil input parameters such as soil storage capacity (water held in soil at saturation) and field capacity are demonstrated graphically in Figure 2.7. The field capacity is the amount of water held in a soil after it has had the opportunity to drain by gravity.

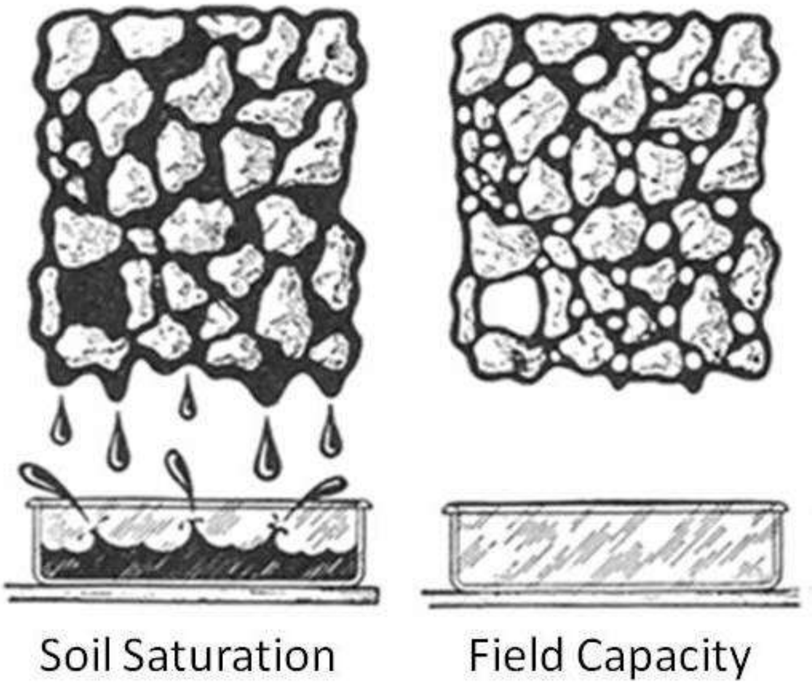


FIGURE 2.7 - SOIL SATURATION AND FIELD CAPACITY IN SOIL (LSU, 2013)

Melbourne Water (2010) provides suggested input parameters for modelling practices for areas located in the broader regions of Melbourne. Note, that for most of the input parameters Melbourne Water recommends the use of the generic values unless a reasonable investigation of the site can suggest otherwise. Thus, only the soil storage capacity and field capacity are provided by Melbourne Water as shown in Table 4.

Input Parameters	Values
Soil Storage Capacity	30mm
Soil Field Capacity	20mm

TABLE 4- MELBOURNE SUGGESTED INPUT PARAMETERS (MELBOURNE WATER, 2010)

In addition, Macleod provides recommendations on other soil input parameters which are explained in section 2.8.

2.5.4.3 Localized Values

Where possible, it is recommended that the input parameters should be localized i.e. represent the local site properties (CRC, 2005). Localized parameters can only be accurately estimated by an investigation of the site in question.

2.5.4.4 Significance of localized parameters

By using localized parameters in MUSIC the model will be the most accurate representation of the rain-runoff scenario demonstrated in reality. By having the most accurate representation decisions will be more justifiable and the risk of over designing or under designing of WSUD systems will be avoided. Catchments should be seen as unique as each catchment has different properties. Using predefined generic parameters standardizes the catchment characteristics that are used in the model and have the potential to provide inaccurate results.

2.5.4.5 Evaluation of Parameters

While analysing several catchments in the Melbourne region Dotto et al (2009) demonstrated that the default field capacity would be adequate for highly urbanised catchments and should remain in the range of 10-40mm otherwise the model results vary greatly. It has been proved that the groundwater initial depth, pervious area storage and infiltration capacity exponent for all catchments in the study remained insensitive, provided they remained within their recommended range. A summary of the results obtained by Dotto et al. (2009) are provided in Table 5. Note that calibration refers to localizing the input parameter.

Input Parameters	Sensitivity (high-low)	Result Description
Impervious Threshold	Low	Generic value for all catchments
Initial Soil Storage	Low	With high urbanisation
Infiltration Capacity Coefficient	High	This parameter showed a high correlation with pervious area flow
Infiltration Exponent	Low	Similar results with all catchments in the study
Daily Recharge Rate	Moderate	Should be calibrated
Daily Drainage Rate	Moderate	Should be calibrated
Daily Deep Seepage Rate	Moderate	Generally calibrated to zero*
Soil Storage Capacity	High	With significant pervious area flow
Field Capacity	Low	Highly urbanised catchments only

TABLE 5- SUMMARY OF SENSITIVITY ANALYSIS RESULTS (DOTO ET AL., 2009)

*Dotto et al. (2009) recommended that he daily deep seepage rate be calibrated to zero as its influence on the modelling results was negligible.

2.6 Soil Testing Considerations

Soil testing was required in this project in order to understand the characteristics of the soil within the Spring Creek catchment. Results from soil testing made it possible to provide recommendations on the most suitable WSUD systems for the catchment and allow localized modelling parameters to be developed for MUSIC. Due to the nature and possible extent of soil characteristics that could exist in such a large area it is important to consider a methodology of soil testing. This methodology will describe the way in which the soil testing will be conducted. Possible areas of interest include:

- Testing locations within the site
- Optimum time of testing
- The amount of tests required
- Suitable testing methods

2.6.1 Soil Characteristics

The soil characteristics required were derived based on two categories: WSUD systems requirements and MUSIC input parameters. These characteristics include:

- Infiltration
- Soil texture
- Hydraulic conductivity
- Soil moisture content
- Total water storage capacity

Due to the nature of the project the ground water properties will not be considered in the research. Groundwater investigations are a costly and timely process and are not within the scope of this project. As such, an estimate will be applicable within the MUSIC model.

2.6.2 Testing Location

Spatial Variability

When conducting soil testing of a catchment an important factor to consider is the possible variability of soil testing results. Without any previous knowledge of the catchment, it would be possible to obtain highly variant testing results or find consistent results throughout the catchment area. If these factors are not accounted for the behaviour and characteristics of stormwater could be poorly judged.

Sampling Patterns

The sampling pattern that will be used during testing must be considered. This is the pattern that defines the locations that will be tested within the site. The sampling pattern used is often based on knowledge of the site (e.g. from soil maps of the area). Secondary site conditions to consider include possible site soil uniformity and contaminants.

Hazelton & Murphy (2007) state that general sampling patterns that are used include regular grid, completely random, stratified sampling and stratified random sampling. Stratified sampling involves dividing the testing area into segments (zones). The testing and results are then analysed for each segment individually. It is appropriate within a highly developed catchment to be mindful of the disruption to the public in testing particular areas. This is important as some community reserved areas are of importance and have a large number of services and underground infrastructure nearby (e.g. schools, churches, shopping centres). In an attempt to avoid conflict with the community and the disruption of underground infrastructure, a manual selection of the areas to be tested should be considered.

Regular Grid

The regular grid sampling pattern involves the sectioning of the test area based on predefined grid properties. The grid properties are mainly defined by how many sections of grid the user wishes to use. This will be based on the both the length and width of the site.

2.6.3 Timing

The times at which the soil tests are conducted are important due to the water holding capacity and infiltration of water through the soil. Testing results are likely to vary based on site conditions and recent rainfall activity. Hazelton & Murphy (2007) suggest testing through time and standardizing testing conditions. CVCA (2010) recommend not conducting testing in the rain or within 24 hours of a significant rainfall event.

2.6.4 Soil Classification

Soil Classification is an important concept in engineering. It is required to define local land characteristics based on the particle size of the soils. Hazelton & Murphy (2007) suggests that particle size categories from the Unified Soil Classification System (USCS) could be used. A broad view of this classification system is shown Table 6.

Soil Classification	Particle Size (mm)
Fines (silts and clays)	<0.074
Fine sand	0.074-0.420
Medium sand	0.42-2.00
Coarse sand	2.00-4.76
Fine gravel	4.76-20.00
Coarse gravel	20-75

TABLE 6- UNIFIED SOIL CLASSIFICATION SYSTEM (USCS) (HAZELTON & MURPHY, 2007)

Soil Groups, as defined in AS1289 (Standard Association of Australia, 2000), are classified as demonstrated in Table 7.

Soil Group	Sieve of which >80% of particles pass
Fine-grained	2.36mm
Medium-grained	19mm
Coarse-grained	37.5mm

TABLE 7- SOIL GROUPS AS DEFINED IN AS1289

Note that the specifications of the sieves defined in Table 7 conform to AS1152 (Standard Association of Australia, 1993).

The literature also states methods on classifying soils based on texture. Determining the texture of a soil allows one to define the composition of the soil in terms of approximate clay content. The process in finding the soil texture by this method involves kneading a sufficiently large soil sample of dry soil in your hand and adding water to it. The importance of this step is to knead the soil until you can feel that it sticks to your fingers but not become saturated. The usual working time of the soil is 1-2 minutes. The soil will eventually form into a ball which is termed a soil bolus. The bolus should then be pressed between the forefinger and thumb in a shearing motion. The behaviour of the bolus as it is being formed and manipulated allows the field texture of the soil to be determined (CSIRO, 2009, p.164). Figure 2.8 demonstrates how the soil bolus is tested.

FIGURE 2.8 - STEPS FOR TESTING THE SOIL BOLUS (WWW.VRO.DPI.VIC.GOV.AU)

2.6.5 Sampling

Soil samples give a representation of what the soil conditions are like for the whole soil body on site. Typically, soil sampling can be divided into two categories: disturbed and undisturbed. Disturbed soil samples do not retain their natural characteristics such as structure, density and stress conditions. These samples often have to be adjusted for testing purposes. Undisturbed samples typically imitate the soil characteristics of the soil found on site. Undisturbed samples are often obtained by cutting blocks of soil or driving a tube into the ground (Clayton et al, 1982).

Care must be taken when sampling soil as to avoid as much disturbance as possible. The size of the sample taken from site depends on the purpose of the investigation (Clayton et al., 1982). The sample must be large enough that it can accurately represent the soil on site. Ease of transportation and use should be considered to enforce an upper limit on samples sizes.

2.6.6 Constant Head versus Falling Head

Similarly to laboratory testing, field testing can employ constant or variable (falling) head testing. The use of each method is discussed below.

2.6.6.1 Constant Head

Seybold (2010) suggests the use of the constant head method when determining the saturated hydraulic conductivity of the soil. When using this method, with the single ring apparatus, the water is ponded at a constant depth above the surface of the water within a ring. The water level is kept at a constant head either by use of a Mariotte bottle or via manually applying known volumes of water until the amount of water flow into the ground is constant over three consecutive time intervals. When manually adding water to the apparatus, underestimation of the hydraulic conductivity is obtained (Hatt et al, 2008). This occurs as the operator only knows when to apply additional water when the water level drops. This indicates that the water level is slightly lower than required throughout the test due to human error. In sand and loam soils the determination of the saturated hydraulic conductivity of the soil is relatively rapid (30-45mins) depending on the soil conditions (moisture). Soils, such as well-structured clays, often required additional time to reach steady-state flow (greater than 60 minutes). In unfavourable conditions, large amount of water are required before a soil reaches constant flow.

2.6.6.2 Falling Head

The falling head method is used less frequently as the constant head method. The falling head method involves applying a known volume of water in a ring that is inserted a known distance into the ground. The amount of time required for the water to infiltrate into the ground completely is measured. Unlike the constant head method, water is only applied to the soil once. In addition, soil properties such as the initial moisture content, saturated moisture content and soil texture/structure are used to determine the saturated hydraulic conductivity of the soil. This method in particular is labelled the simplified falling head (SFH) method (Bagarello et al., 2012a). The accuracy of the falling head method depends largely on the soil parameters used in the developed equations (see section 2.8). When compared to accurate methods such as the tension infiltrometer the results from the SFH method did not vary significantly, provided accurate parameters were defined (Bagarello et al., 2012a).

Bagarello et al. (2012b) suggests that the SFH method is more practical than conventional constant head methods as the amount of time required for the water to infiltrate the soil is greatly reduced. Secondly, the volume of water required to conduct each replicate of the SFH method is decreased. In summary, the operator is able to perform more replicates of the test with less water than the constant head method.

2.6.7 Replicates

In soil testing a lot of unfavourable conditions can occur on any given day. Such conditions include:

- Non-homogeneous soil within a small area
- Large amount of rainfall before and during field testing
- Cracks in the soil profile when measuring water infiltration
- Water repellence at the soil surface
- Swelling clays and sodic soils effecting results

Because of these unfavourable conditions it is appropriate to conduct a number of replicates of the each test (i.e. repeat the test to ensure the results collected are accurate).

McKenzie et al. (2002) gives recommendations for the amount of replicates that should be completed for particular testing methods as well as the preferred specimen type. These recommendations as they relate to the testing methods described in this chapter are shown in Table 8. The minimum amount of replicates is three for laboratory and field testing.

Measurement	Preferred specimen type	No. of replicates
Saturated hydraulic conductivity: field	In situ measurement with twin ring	3-7
Saturated hydraulic conductivity: laboratory	Undisturbed soil core (large preferred)	3-5

TABLE 8- REPLICATES AND SPECIMEN TYPES REQUIRED FOR SOIL TESTING METHODS

2.6.8 Comparing Laboratory and Field Testing Results

WSUD systems are often used to capture surface runoff from a catchment. As such they are required to be installed at a subsurface level. For this reason it is necessary to investigate the soil characteristics that can be found at specific depths within a site. To obtain a reasonable understanding of a soil profile NCST (2009, p.148) recommends analysing soil at a depth of approximately, but not greater than 1.5m. In addition GCC (2007) suggests that investigations should be taken into soil profile at subsurface depths. Some WSUD systems are installed to depths below the soil surface (e.g. 1-1.5m) to allow the water to infiltrate into the in-situ soil and for storage purposes.

Due to the impracticality of performing field testing at depth (i.e. the need to excavate the site before testing) particular authors in the literature have analysed the relative comparison between laboratory and field testing. This is due to the fact that obtaining soil samples at depth and testing them is much less labour intensive than performing field tests at depth. Reynolds et al. (2000) found that saturated hydraulic conductivity of undisturbed soils cores where equivalent to pressure infiltrometer results in sand and loam soils. However, in clay loam soils the soil core tests gave both higher and lower results compared to the pressure infiltrometer. This suggests that there is a known correlation between the results obtained from saturated hydraulic conductivity tests performed on undisturbed soil cores and pressure infiltrometer testing performed in the field. This correlation is most evident in sand and loam soils but there is much variability in clay soils. From the results obtained by Reynolds et al. (2002) the correlation between laboratory (soil cores) and field testing (pressure infiltrometer) could be appropriate in estimating field results at depth from laboratory results of samples obtained at depth. Using simple linear interpolation the results from Reynolds et al. (2002) suggests the following equation could be applied:

$$\frac{Surface\ Laboratory\ K_{sat}}{Deep\ Laboratory\ K_{sat}} = \frac{Surface\ Field\ K_{sat}}{Deep\ Field\ K_{sat}}$$

$$\therefore Deep\ Field\ K_{sat} = Surface\ Field\ K_{sat} \times \frac{Deep\ Laboratory\ K_{sat}}{Surface\ Laboratory\ K_{sat}}$$

Where laboratory K_{sat} is the saturated hydraulic conductivity obtained from testing undisturbed soil cores and field K_{sat} is the saturated hydraulic conductivity obtained from field testing.

2.6.9 Interpreting Soil Testing Results

It is reasonable to define a rating for hydraulic conductivity in order to define if the soil is suitable for each particular application. Table 9 provides a rating for each range of possible saturated hydraulic conductivity in a soil.

Saturated Hydraulic Conductivity (mm/h)	Rating	Interpretation
<0.5	Extremely low	Suitable for water storage
0.5-10	Very low	Likely to cause runoff during rainfall
10-20	Low	Runoff less regular
20-60	Moderate	Runoff only occasionally
60-120	High	Runoff rarely occurs and soil is becoming too permeable for some applications
>120	Very high	Contamination and excessive recharge of groundwater could occur if used for waste disposal

TABLE 9- RATING OF SATURATED HDYRALUIIC CONDUCTIVITY (HAZELTON & MURPHY, 2007)

Wong (2006) suggests that the upper limit of saturated hydraulic conductivity for storage WSUD systems is 36 mm/hour. Above this value the use of an infiltration system is recommended.

As mentioned in Section 2.4, the selection of WSUD systems depends largely on the Hydraulic Conductivity of soil. A soil type can often be identified by its hydraulic conductivity. Engineers Australia (2006) describes the typical hydraulic conductivity of soils as shown in Table 10.

Soil Type	Saturated Hydraulic Conductivity	
	mm/hr	m/s
Sand	>180	$>5 \times 10^{-5}$
Sandy Clay	36-180	$1 \times 10^{-5} – 5 \times 10^{-5}$
Medium Clay	3.6 to 36	$1 \times 10^{-6} - 1 \times 10^{-5}$
Heavy Clay	0.036 to 3.6	$1 \times 10^{-8} -1 \times 10^{-6}$

TABLE 10- HYDRAULIC CONDUCTIVITY OF VARIOUIS SOIL TYPES (WONG, 2006)

Combined, Table 9 and Table 10 provide an understanding of how different soil types effect runoff and storage applications.

2.6.10 Soil Storage Capacity

The storage of water in soil is critical to understanding soil characteristics in terms of rainfall runoff. Table 11 can be used to verify the soil storage of particular soil groups.

A Guide to Available Water Storage Capacities of Soils	
Soil Type	**Available Water Storage Capacity (mm water/m soil)**
Clay	200
Clay loam	200
Silty loam	208
Clay loam	200
Loam	175
Fine sandy loam	142
Sandy loam	125
Loamy sand	100
Sand	83

TABLE 11-WATER STORAGE CAPACITY OF SOIL (MAFF, 2002)

The soil storage capacity is the amount of water the soil can hold at saturation. This includes the amount of water in the soil at its wilting point; the amount of water between the field capacity and wilting point; and the excess capacity of water that is held above the field capacity that can be drained by gravity. These parameters are particularly useful when modelling rainfall-runoff in an urban situation.

2.7 Soil Testing Methods

The testing methods specific to this project are mostly concerned with obtaining the saturated hydraulic conductivity of soils. Saturated hydraulic conductivity is important in urban design as the amount of runoff generated by an impervious surface is highly dependent on how long it takes a soil to reach saturation and the ability of the soil to allow the water to pass through it (hydraulic conductivity). The McKenzie et al. (2002) suggests both field and laboratory methods of measuring the saturated hydraulic conductivity of a soil. For this project, the laboratory testing will be used to verify the field testing provided there is a correlation between each method. Fletcher et al. (2008) has identified a correlation between soil core laboratory testing and surface field testing for methods of determining the hydraulic conductivity of soil.

In a soil type spatial variance study Kannangara et al (2012) stated that the main factors influencing the performance of infiltration based WSUD systems are soil hydraulic conductivity and the ground water table characteristics.

2.7.1 Laboratory Testing

Laboratory testing to find the hydraulic conductivity (permeability) of soil is generally completed by measuring the flow of water through prepared cores of soil or specialized permeability cell.

Standards Australia (2003) and Bennett & Raine (2012) have each developed similar methods to determine the saturated hydraulic conductivity of soil using cores. The methods described by the above mentioned authors involves the collection of soil in the field (surface); and preparation of disturbed soil samples in PVC stormwater pipe (87.5mm inside diameter, 50mm length soil columns); subsequent compaction to desired bulk density; soaking the soil cores in a water bath; allowing the water to flow through the soil while maintaining a constant head at the surface of the soil; and measuring the amount of water that pass through the soil within given time intervals until a constant flow is achieved. Bennett & Raine (2012) chose to air dry the soil before commencing the test. Standards Australia (2003) describes testing the soil while it is at field capacity (or field moisture content) to maintain as much of the in-situ characteristics as possible.

Standards Australia (2003) and Bennett & Raine (2012) both required the pre-soaking of the soil before testing such that the soil would be closer to saturated conditions and the constant flow would be reached in a shorter time period. The method developed by Standards Australia (2003) is explained in AS4419. The method used by Bennett & Raine (2012) is summarized in Appendix C.

The use of permeability cells is an accurate method of determining the saturated hydraulic conductivity of soil. The permeability cell is often used for the Constant head method and the Falling head method. The constant head method involves testing for the saturate hydraulic conductivity of a soil whilst applying a constant head of water to the surface of the soil sample. In contrast, the falling head method allows the water level above the soil sample to vary during the testing procedure. Head (1982) states that the constant head permeability test is used for testing granular disturbed samples with little to no silt and the falling head permeability test is suited for soils with low permeability (e.g. silts and clays). Thus, the type of test to be implemented depends largely on the type of soil to be tested. Typical disturbed samples are used for this type of testing. The literature indicates that in most applications the constant head method is suitable. Standards Australia (1999) has developed AS1289.6.7.3 for constant head permeability test of both disturbed and undisturbed samples.

2.7.2 Field Testing

There are several apparatuses and methods to use for testing the saturated hydraulic conductivity in the field. These methods are explained in detail below. Each type of testing is subjective to the type of soil, site conditions, time and available equipment. CVCA (2010) and McKenzie et al. (2002) suggest the use of one of the following testing equipment should be used before selecting the most suitable WSUD systems:

- tension infiltrometer
- double-ring infiltrometer
- single-ring infiltrometer

Each apparatus relies on the flow rate of the water into the soil in order to determine the K_{sat} value. The benefits and shortfalls of the testing apparatuses are described below (McKenzie et al., 2002):

2.7.2.1 Tension Infiltrometer

This apparatus is also known as the disc permeameter. It is usually used in the field to take K_{sat} measurements at the surface of the soil. Ideally, a flat surface is required for testing (particularly on a natural slope). The soil must without swelling and water repellence. Otherwise, it is applicable to a large range of soils. Unlike other methods, a negative potential is applied to the soil surface (e.g. -10 to 150mm) where the soil extracts the water from the apparatus. The lower limit of measurement is at a K_{sat} of 0.1 mm/hour and the upper limit depends on the capability of individual devices. The tension infiltrometer is a rapid method. A single user is able to perform 10-15 tests in a day. The apparatus itself has a low to moderate cost. A typical tension infiltrometer is shown in Figure 2.9.

FIGURE 2.9 - TENSION INFILTROMETER (WWW.GENEQ.COM)

2.7.2.2 Twin-ring Infiltrometer (TR)

The TR apparatus is relatively simplistic. It involves two rings of differing diameters (smaller diameter ring placed within the larger ring). The rings are inserted a known distance into the ground. The idea is to pour water into the outer ring and wait a sufficient time (10 mins) before applying water to the inner ring (via Mariotte bottle). The water poured into the outer ring ensures that the water in the inner ring only flows vertically and not laterally as shown in Figure 2.10. This concept gives a moderately accurate measurement of saturated hydraulic conductivity. This is considered as a rapid test when the soil is at a favourable state (close to dry) and is suitable for a single operator. In well-structured soils the TR apparatus has be known to use a large amount of water which could impractical in many cases. When the test is conducted the soil moisture at of the soil should be uniform otherwise the results are affected considerably. A clear advantage of the TR apparatus is that it’s simple and low cost. A TR apparatus during operation is shown in Figure 2.11.

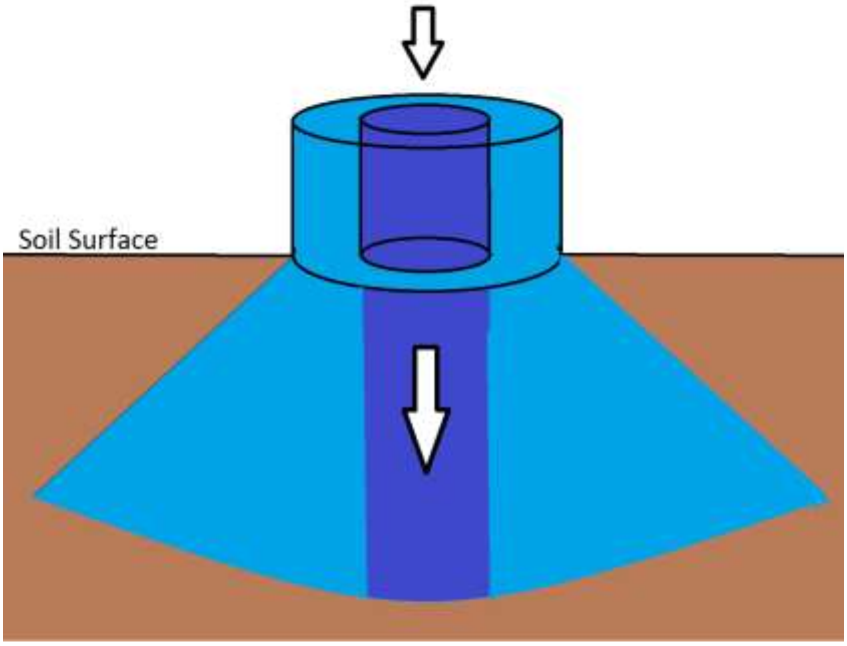


FIGURE 2.10 - VERTICAL FLOW OF INNER RING FOR A TWIN-RING INFILTROMETER

FIGURE 2.11 - TWIN RING INFILTROMETER (PKD.EIJKELKAMP.COM)

2.7.2.3 *Single Ring Infiltrometer*

The single ring apparatus is much like that of the twin-ring infiltrometer. The single ring is slightly disadvantaged as the water is allowed to flow laterally as well as vertically into the soil profile. Thus, at times the single ring method will overestimate high K_{sat} soil such as sand and loams. The relative inaccuracies of this apparatus decrease as the size of the ring increases (Hatt et al., 2008). As the ring size increases the relative error due of the results decreases. The error is often related to edge flow along the ring, soil disturbance due to ring installation and lateral water flow. Bagarello et al. (2012a) proved that 30cm rings are preferred when compared to 15cm rings. The results from each ring were compared against a more accurate method (tension infiltrometer). The 15cm rings are less accurate although, a plausible correlation was found between the two different rings sizes from the results obtained. The advantages of this technique lie in its simplicity and cost effectiveness despite its proven inaccuracy.

2.8 Theory of Soil Properties

2.8.1 Introduction

This chapter involves a review of the literature relative to the theory involved in soil testing and MUSIC model parameters determination (soil properties). This section will not only give guidance in selecting suitable WSUD systems but aid the development of key parameters within the MUSIC model.

2.8.2 Soil Properties

The determination of soil properties is required for both the selection of WSUD systems and the purposes of the local MUSIC model. Several of the soil properties are described by Das (2010) as explained below.

2.8.2.1 Saturated Hydraulic Conductivity

The saturated hydraulic conductivity (K_{sat}) of a soil is the capacity of the soil to allow water to pass through it. In comparison, infiltration is the measure of how soil allows water to enter it from the surface. For the constant head soil core method suggested by Bennett and Raine (2012) Darcy's Equations was used to determine K_{sat}. Darcy's equation is shown below:

$$K_{sat} = \frac{qL}{A(H+L)}$$

Where q is the steady date flow (L^3T^{-1}), L is the length of the core (L), A is the area of the core (L^2) and H is the water head above the soil core surface (H) (Das, 2010).

Bagarello et al. (2012a) used the following equation for determining the K_{sat} with the simplified falling head method (field test):

$$K_{sat} = \frac{\Delta\theta}{(1-\Delta\theta)t_a}\left[\frac{D}{\Delta\theta} - \frac{\left(D+\frac{1}{\propto}\right)}{1-\Delta\theta}\ln\left(1+\frac{(1-\Delta\theta)D}{\Delta\theta\left(D+\frac{1}{\propto}\right)}\right)\right]$$

Where K_{sat} is the saturated hydraulic conductivity (L^3T^{-1}), t_a (T) is the time taken for a known volume of water V (L^3) to infiltrate into the soil surface, ΔΘ (L^3L^{-3}) is the difference between the field saturated and initial volumetric soil water content, D=V/A (L) is the depth corresponding to the applied volume V, and α (L^{-1}) is the soil texture/structure parameter estimated according to Table 12.

Soil Structure and Texture Categories (Seybold, 2010)	α*
Compacted, structureless, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments.	0.01
Soils that are both fine textured (clayey or silty) and unstructured; may also include some fine sands.	0.04
Most structured soils from clays through loams; also includes unstructured medium and find sands. The category most frequently applicable for agricultural soils.	0.12
Coarse and gravelly sands; may also include highly structured or aggregated soils, as well as soils with large and/or numerous cracks, macropores.	0.36

TABLE 12 - SOIL MACROSCOPIC CAPILLARY LENGTH (REYNOLDS ET AL., 2002A) CITED IN SEYBOLD (2010))

2.8.2.2 Dry Infiltration

The dry infiltration is determined by measuring the time at which a known volume of water enters the surface of dry soil. Note in MUSIC the dry infiltration is referred to as the infiltration capacity coefficient (Macleod, 2008). This is often measured in mm per day and can usually only be determined through laboratory testing as it is difficult to find soil in the field that is at dry state (Macleod, 2008). The equation used to calculate the dry infiltration is shown below:

$$Infiltration = \frac{Q}{A}$$

Where infiltration is in LT^{-1}, Q is the flow rate of water through the dry sample (L^3T^{-1}) and A is the cross-sectional area of the medium that the water is flowing through (L^2). For the purposes of this project the dry infiltration values used in MUSIC were estimated according to the proportional relationship between laboratory and field soil testing results (refer to section 2.6.8). The estimated field infiltration for soils was used in the MUSIC model.

2.8.2.3 Moisture Content

The moisture content is a relative measure of how much water is present in a soil sample. The initial soil storage is measured instantaneously and is likely to change at any point in the day due to the influence of rainfall and evapotranspiration. In terms of the total weight of the saturated soil sample it is determined as follows.

$$Moisture\ Content = \frac{w_w}{w_s}$$

Where w_w is the weight of water in the soil (M) and w_s is the total weight of the dry soil sample (M).

However, MUSIC specifically requires the initial moisture content as percentage of the total storage capacity. This can be found as shown below.

$$Initial\ Moisture\ Content = \frac{Weight\ of\ water\ in\ initial\ sample}{Weight\ of\ water\ in\ saturated\ sample}$$

2.8.2.4 Total Storage Capacity

The total storage capacity is a relative measure of how much water is stored in a sample at saturation. After saturation occurs any water (rainfall) that is applied to the soil surface will be converted to runoff. In addition, the depth of the rooting zone (depth at which plant roots are present) is also required to determine the total storage capacity moisture content in MUSIC (Macleod, 2008). The total storage capacity is obtained from the following equation:

$$Total\ Storage\ Capacity = \frac{w_{sw}}{w_s} \times rooting\ zone\ depth$$

Where W_{sw} is the weight of the water in the sample at saturation.

2.8.2.5 Field Capacity

Field capacity is the point when the water in a soil is so tightly held in the soil matrix that it won’t drain by gravity three days after a rainfall event. This property is important when considering the water available for extraction by plants and vegetation. This proportion of water is referred to as the field capacity. It is calculated as shown below.

$$Field\ Capacity = \frac{w_f}{w_s} \times rooting\ zone\ depth$$

Where, w_f is the weight of the water retained in the sample at field capacity. Note, that the field capacity in MUSIC must also consider the rooting zone depth.

2.8.3 MUSIC Default soil properties

The following theory describes the methods used by Macleod (2008) in calculating generic (default) soil properties for use in MUSIC. Macleod (2008) demonstrated that the total storage capacity, field capacity and infiltration capacity of a soil body can be determined if the texture of that soil is known. During the soil investigation each the soil texture within each testing area was determine. Macleod (2008) suggests the use of the specific equations to determine the soil input parameters based on the soil texture within that area. The equations used to determine these soil characters are detailed in the following section. The values used in these equations have been provided by Macleod (2008).

2.8.3.1 Total Storage Capacity and Field Capacity

The total storage capacity was found as follows:

$$Total\ Storage\ Capacity = \frac{AWHC\ \left(\frac{mm}{m}\right) \times T(m)}{P\ (\%)} \times V$$

The field capacity was found as follows:

$$Field\ Capacity = (T(m) \times AWHC) + (W \times total\ storace\ capacity)$$

Where AWHC is the available water holding capacity (mm/m), T is the thickness of the rooting zone of the soil (m), P is the percentage of the water stored in the soil at field capacity relative to total storage capacity and V is the water volume percentage within the soil when it is effectively full. The variables for the above stated equations are determined based on soil texture as shown in Table 13.

Soil Texture	AWHC (mm/m)	P (%)	V (%)	W (%)
Sand	140	10	25	3
Loamy sand	130	14	30	5
Clayey sand	140	17	26	7
Sandy loam	130	20	30	11
Loamy sand	150	32	40	13
Silty loam	160	20	25	9
Sandy clay loam	130	27	45	17
Clay loam	180	34	45	19
Clay loam, sandy	160	27	45	19
Silty clay loam	125	25	35	17
Sandy clay	170	30	50	22
Silty clay loam	90	25	30	15
Light clay	125	35	55	27
Light-medium clay	115	35	55	27
Medium clay	120	35	55	27
Medium-heavy clay	120	35	55	27
Heavy clay	115	35	55	27

TABLE 13 - SOIL PROPERTY VARIABLES BASED ON SOIL TEXTURE (MACLEOD, 2008)

2.8.3.2 Infiltration capacity

Macleod (2008) suggests input values that could be used based on the soil type within the site. In particular, the infiltration capacity is difficult to measure as MUSIC requires these values to be determined through dry infiltration soil testing of undisturbed samples. Note that Macleod (2008) states that the infiltration capacity coefficient is essentially the dry infiltration in millimetres per day. Where such testing is not possible the following values can be applied based on soil texture as shown in Table 14.

Soil Texture	Infiltration capacity (mm/day)
Very sandy	350
Sandy loam to clay loam	150-350
Structured Clay	150-300
Poorly structured silt or fine sand	100
Weakly structured clay	100-250

TABLE 14- RECOMMENDED INFILTRATION CAPACITY BASED ON SOIL TYPE (MACLEOD, 2008)

Where the infiltration capacity cannot be reliably estimated the MUSIC default of 200mm/day is recommended.

2.8.4 Summary

This section has detailed the theory that was required to determine the soil properties of this project. The use of each soil property as they relate to this project is shown in Table 15.

Aspect of Project	Relevant Soil Properties
Selection of suitable WSUD systems	Saturated hydraulic conductivity
MUSIC Sensitivity Analysis	Infiltration capacity, moisture content, soil storage capacity, field capacity

TABLE 15 - SOIL PROPERTY RELEVANCE TO THE PROJECT

3 Project Methodology

3.1 Chapter Overview

This section details the methods and procedures that were undertaken to complete this research project. In particularly the methodology of this project included two sections: testing and modelling. The project methodology was developed from information gathered by the literature review. This project used both laboratory and field testing. The results from each type of testing were compared against each other in order to approximate saturated hydraulic conductivity of the soil at specific depths. This in turn led to the determination of suitable WSUD systems as they related to the Spring Creek catchment. The soil testing results were used to develop the models created in MUSIC for the catchment. Using the models a sensitivity analysis of the MUSIC software was completed.

3.2 Laboratory Testing

The laboratory testing used to find the saturated hydraulic conductivity (K_{sat}) of the soils in this project was a modified version of Bennett & Raine (2012). The type of water that was passed through the soil samples was collected rain water. The scope of this project involves stormwater runoff and its penetration into the natural soils. Hence, rain water was the most appropriate type of water to represent the reality of this scenario. The laboratory testing was conducted in Block P3 at the University of Southern Queensland.

3.2.1 Soil Sampling at Testing Sites

A map detailing the sites selected for testing is shown in Figure 3.1. The sites were selected based on ease of access, least disturbance to the public and areas of interest determined by existing soil data (Soil Maps demonstrated in section 1.3.2). Notice the project boundary that has been placed to limit sample collection to a defined area in the catchment. The main purpose of the project boundary is to defined approximate areas which were used in the MUSIC model. The project area is a 'hypothetical catchment' and is not an accurate representation of the drainage characteristics of the Spring Creek catchment. The hypothetical catchment was created for the purpose of modelling in the MUSIC model.

FIGURE 3.1 - MAP OF THE TESTED AREAS WITHIN THE SPRING CREEK CATCHMENT (SCALE 1:17,500)

The samples collected for testing included surface soil and soil at depth (ranging from 0.3 to 1.0m). NCST (2009, p.148) recommended taking samples using an auger at a depth approximately 1 m but not greater than 1.5m. Sampling soils at depth is required due to the fact that WSUD systems are often constructed at subsurface levels. This is because these systems capture surface runoff and in most cases allow water to infiltrate the natural surrounding soils. A typical soil auger is shown in Figure 3.2.

FIGURE 3.2-TYPICAL SOIL AUGER (ENVCO GLOBAL, 2009)

Initially, samples were to be extracted from 1000mm beneath the surface. At certain sites it was not possible to obtain samples at this depth. This was due to the characteristics of the site (e.g. decayed parent rock at shallow depths and highly consolidated soil). The labour intensiveness of the auger extraction process at times made it difficult to retrieve the soil auger equipment from the ground during sampling. The depth of sampling for each site is shown in Table 16.

Site	Depth of Sampling (mm)
A	300
B	100
C	100
D	100
E	100
F	500
G	500
H	500

TABLE 16- SAMPLING DEPTH OF DISTURBED SAMPLES

The testing results of samples taken from the surface and at depth were compared. This comparison gave an indication as to the possible results that would be achieved if field testing was completed at depth. This was based on an assumed proportional linear relationship between surface and depth tests in the field as discussed in Section 2.6.8. It was expected that the saturated hydraulic conductivity of the soil at the surface would be greater than soil at depth. The soil at depth has had the opportunity to consolidate (thus it would have a higher bulk density) and would not have been disturbed as frequently as the soil sample at the surface by external influences (e.g. earthworks, grazing, etc.). The soil from each test site was classified based on texture. The soil textures were determined based on the process described in section 2.6.4.

3.2.2 Testing Procedure

3.2.2.1 Moisture Content, Bulk Density and Field Capacity

For the purpose of modelling the soil characteristics, additional testing procedures were required. These procedures include calculating the bulk density, moisture content and field capacity of the soil. These values were obtained through simple soil analysis procedures details by Das (2010). The moisture content of the soil was found by first weighing the soil in its natural state and then removing the moisture in the soil via oven drying (100 degrees Celsius for 48 hours) before weighing the soil again (Department of Sustainable Natural Resources, 2013). A set of oven drying samples is shown in Figure 3.3.

FIGURE 3.3 - DISTURBED SOIL SAMPLES DRYING IN AN OVEN

The dry bulk density of the soil was found by calculating the volume and weight of the sample after the moisture had been removed (via oven drying, but before the soil had the opportunity to absorb moisture form the air). The field capacity is the point at which the maximum amount of water is held in the sample that doesn’t drain by gravity. This was found by weighing the soil after drying, saturating the soil and leaving it until the water draining from the soil seized. This time period was a maximum of 72 hours.

3.2.2.2 Cores

After being oven dried, the dry soils were first crushed and processed through a 2.36mm sieve in preparation. The soils were placed into columns (altered stormwater pipes) to the dimensions of 87.5mm diameter and 50mm length and labelled ‘cores’. Filter paper was placed at the bottom of each core (Whatman No.4). These were the final dimensions of the cores after they were consolidated by dropping from a height of 50mm for three repetitions. Finally two layers of filter paper were placed on top of the cores. Mesh cloth was installed at the bottom of each stormwater pipe section in order to contain the soil and allow the water too pass through. Figure 3.4 shows a typical stormwater pipe section that was used during testing.

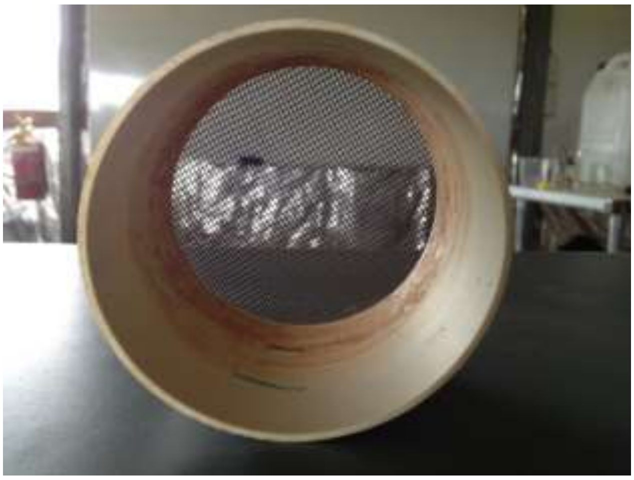


FIGURE 3.4 – STORMWATER PIPE SECTION USED TO CONTAIN THE SOIL CORES

3.2.2.3 Saturated Hydraulic Conductivity

The cores were placed in funnels which allowed them to be open to the atmosphere at the bottom interface. The funnel was placed into a stormwater pipe offcut which allows the cores to stand upright on the apparatus. This ensured the ponded water surface was parallel with the soil core surface. An application of a continuous water supply (via an inverted 1200 mL clear water bottle) was applied to the surface of each core with a head of 2cm (relative to the surface of the cores).

The water from the bottles passed through the samples and was caught in a plastic container at a specific time interval. The flow rate of the water through the samples was calculated based on the weight of the water caught in the plastic container. The test continued until the flow rate through the sample was constant for three consecutive measurements.

Finally, the saturated hydraulic conductivity was calculated using Darcy's equation (refer to section 2.8). In addition, the time for the first drop of water to pass through the dry soil samples made it possible to approximate the dry infiltration capacity of the soil (as discussed in section 2.8). The appartus used in the laboratory testing is shown in Figure 3.5.

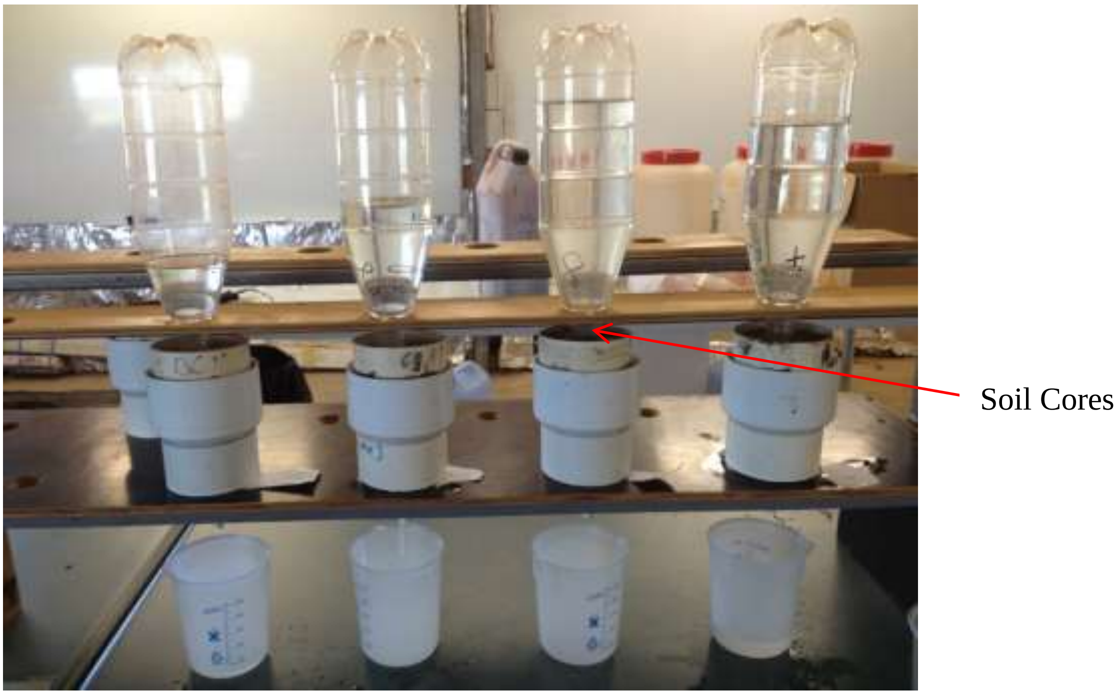


FIGURE 3.5- LABORATORY TESTING APPARATUS

3.2.2.4 *Effects of Temperature*

During the testing in the laboratory it was appropriate to moderate the temperature of the water. For the purposes of this project the room temperature was kept at 25 degrees Celsius the night before and during testing. Drastic changes in temperature were likely to affect the results of the tests (Campanella & Mitchell, 1968).

3.2.2.5 *Water Supply*

As the apparatus used in testing could only support 1200 mL bottles, when the bottles emptied it was necessary to replace them with a new bottle full of water to continue the test. Due care was taken to minimize the bottle change time such that the results from testing would not be effected.

3.3 Field Testing

In order to verify results obtained from laboratory testing, field testing was conducted. A single ring infiltrometer was be used for the testing. The simplified falling head method was adopted as discussed in Section 2.6.

3.3.1 Equipment

As shown in Figure 3.6, a ring infiltrometer is very simplistic. As such they are created in multiple sizes depending on their application. The single rings used in this project were 30cm in height with diameter of 23.75 cm. The edges of the ring (i.e. the ring perimeter at each end) were bevelled to allow for easier installation and to minimize soil surface disturbance.

FIGURE 3.6- SINGLE RING INFILTROMETER

3.3.2 Time of testing

The majority of the field testing was conducted during the months of June and July. Most sites were tested in the early morning (initiated between 8am and 10am). From inspection, the soil from sites C, D and E appeared to have high moisture contents at the time of ring installation. Table 17 shows the monthly rainfall totals and monthly percentage of the total yearly rainfall during the year of testing. In comparison the period of testing had a relatively low rainfall when compared to the rainfall in previous months.

Month	**Monthly Totals (mm)**	**Percentage of Total**
January	416	47
February	184.2	21
March	113	13
April	41	5
May	51.4	6
June*	61.2	7
July*	27.8	3
Yearly Total to Date	894.6	

TABLE 17 - MONTHLY TOTALS OF RAINFALL TO DATE FOR 2013

*Period when testing occurred

3.3.3 Testing Procedure

The simplified falling head method with the single ring infiltrometer was used for field testing.

3.3.3.1 Set up

Any leaves, grass or loose debris were cleared from the surface to be tested. The 23.75cm diameter ring was then driven into the ground by placing a thick wooden log horizontally over its surface and applying force via sledge hammer (Figure 3.7). A minimum insertion depth of 3cm was required. The tested surface was flat to ensure the water would infiltrate the ground uniformly. Similarly, the ring had to be parallel to the tested surface during the test. This was ensured by measuring the distance the ring was inserted into the ground on four opposing sides. The soil at the edge of the ring was made firm to create extra protection against surface seepage. This also minimized the disturbance of the soil inside the ring. A cloth was laid on the surface of the soil to prevent any surface disturbance when water was applied.

FIGURE 3.7 - RING INSERTION METHOD

3.3.3.2 Running the test

A known volume of water was poured inside the ring (1L or 650mL) and the timer was started. The amount of time required for the ponded water to completely infiltrate the soil surface was recorded. Throughout the testing period the water head above the soil was measured in order to check the progress of the test, although it was inherently used for determining the results of the test. Where necessary the effects of solar heat were minimized during the process of the testing by providing shade with a cloth. This test was replicated a minimum of three times in spatially distributed locations of the test areas (shown in Figure 3.1.)

3.3.3.3 Samples

Similar to the laboratory testing, disturbed soil samples were collected near the ring which was used to determine the initial moisture content of the soil. Previously, the saturated moisture content had been determined during the soil core testing described in Section 3.2.

3.3.3.4 Calculation

The results from the soil testing allowed the saturated hydraulic conductivity values for the soils to be determined as described in section 2.8.

3.3.3.5 Complications in Testing

For several sites the time of testing was several days after considerable rainfall. As shown in Table 18, 20.6mm of rainfall was recorded on the first day of testing (28/6/13). For this reason the testing time of these sites was increased significantly; although as the initial moisture content was considered in the simplified fall head test it should not have affected the results.

Testing Day	1	2	3	4	5	6	7	8
Date	28/06	29/06	30/06	1/07	2/07	3/07	4/07	5/07
Daily Rainfall (mm)	20.6	0.2	0	5	4.8	0	0	0

TABLE 18 - DAILY RAINFALL DATA AT THE TOOWOOMBA AIRPORT GAUGE DURING THE TESTING PERIOD (BOM, 2013)

Site A contained imported mixed soil material with high amounts of shallow decayed rock. Consequently, the deep soil extraction process (auger process) was limited to shallow depths.

After reviewing the literature it was evident that constant head tests were the preferred method of testing in the field. Typically a Mariotte bottle is utilized with the constant head method as it maintains a constant head of on the soil surface. However, early attempts at Mariotte bottle construction provided a constant supply with an unsatisfactory flow rate. Thus, it was not suitable for testing particularly in fast sand soils. The manual constant head test was employed for site E. The simplified fall head test was applied on the same site. With appropriate selection of parameters the simplified falling head test achieved very similar results to the constant head method. From the results of the initial testing phase and the information provided in the literature it was decided that the simplified fall head test was appropriate for the goals of this project. The constant head method was not used in this project.

3.3.3.6 Limitations

As advised by a Soil Scientists at the NCEA (Bennett, pers. comm., 2013), the use of a single ring infiltrometer is not as sophisticated as other methods of testing found in the industry; however, a single ring infiltrometer supplied the relevant information required for the completion of this project. The scope of this project was limited to the available resources that could be obtained by the author. It is recommended that future work in similar projects employs a more sophisticated field testing apparatus.

3.4 MUSIC Modelling based on soil characteristics

The MUSIC model will be used to perform the analyses required in this research project. The two models were created in MUSIC one created using generic (default) parameters the other using local parameters. The difference in results produced by each of these models indicated the sensitivity of MUSIC when modelling the Spring Creek catchment.

Certain literature offer guidance into developing models and parameter calibration specifically for MUSIC. The Brisbane City Council (2003) developed the *Guidelines for Pollutant Export Modelling in Brisbane Version 7* to allow designers to apply MUSIC specifically to the Brisbane Area. In particular, this document gives guidance to selecting input parameters for the model. These inputs include:

- Meteorological Data
- Source Nodes: area, soil properties and pollutant concentrations
- Drainage Links
- Treatment Devices

Macleod (2008) suggests procedures that are used to calibrate MUSIC parameters based on the characteristics of specific sites, described in section 3.4.3.1.

3.4.1 Data

The time step that was used in the model was 6 minutes. This is largely due to the fact that the rainfall information for a 6min rainfall time step was readily available and with a smaller time step it is likely that the results of the model will be more accurate. The period of recorded rainfall used was from 12th of September 2009 to 17th of December 2013. This information was recorded at the Toowoomba Airport station.

3.4.2 Source Nodes and Areas

A hypothetical catchment was used in the MUSIC model. The hypothetical catchment applied the soil characteristics of the Spring Creek catchment but doesn’t represent it geographically. As shown in Figure 3.8, all of the test areas (labelled letters A to H) were defined as urban source nodes. The agricultural land within the centre of the subject area contained the same properties as site F, excluding pervious area and drainage area. Each source node was aligned according to the location of the creek (i.e. Spring Creek). Each node was assigned to drain to specific junctions based on the topography of the sites (junctions were labelled J1, J2, etc.). The areas assigned to each node were calculated based on polygons that were drawn on the map. Each node/site area was calculated based on the polygon area that it is contained in. This is illustrated in Figure 3.9. Note that these areas are not actual catchment areas they were only created for the purposes of modelling in this project.

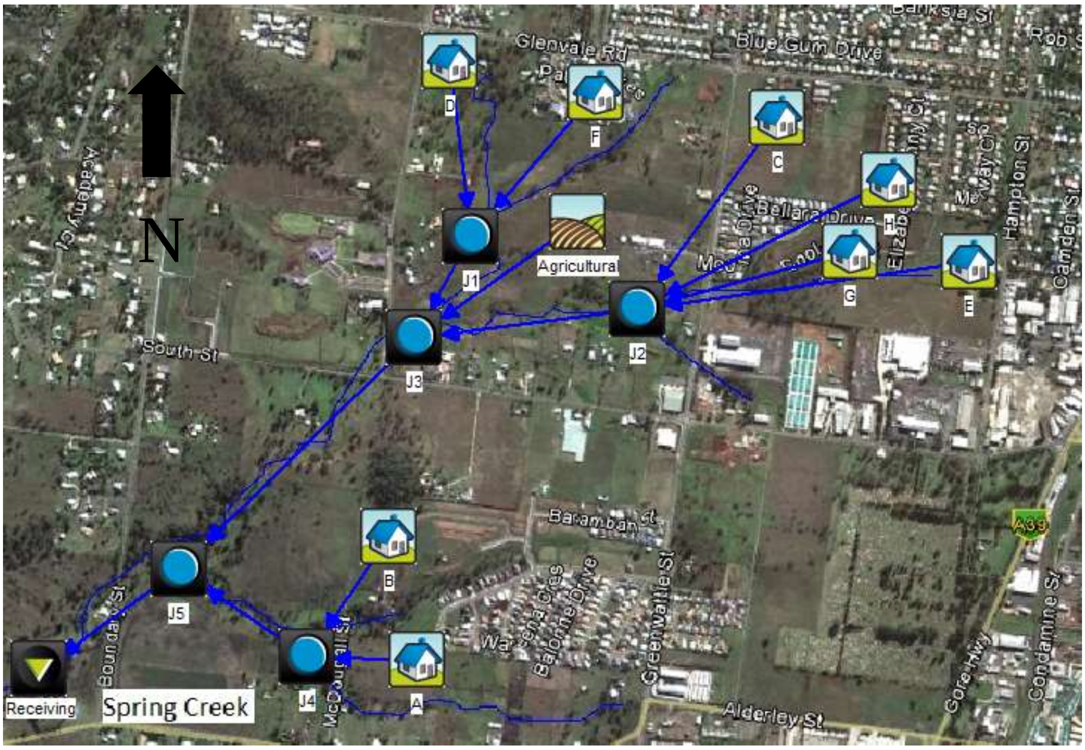


FIGURE 3.8 - MUSIC MODEL SOURCE NODES AND JUNCTIONS (SCALE 1:28,000)

FIGURE 3.9 - EFFECTIVE AREA OF NODES USED IN THE MUSIC MODEL (SCALE 1:28,100)

The effective areas in Figure 3.9 were used because not all of the Spring Creek Catchment was investigated. The soils that were investigated exist within the boundaries shown in Figure 3.9. Hence, these were the sites that were modelled.

3.4.3 Input parameters

Two models were created within MUSIC. One model using the generic input parameters and the other applying localised input parameters. The input values that did not differ between the two models included:

- Land use
- Site Area
- Water quality and pollutants
- Meteorological Data

In reality the user of the MUSIC model would also need to consider the water quality of the site. As the scope of this project is only related to the soil characteristics of the site, water quality was not a part of this project. For this reason the water quality input parameters in MUSIC will remain the same for both the generic and localised models (MUSIC water quality default parameters).

The models used in this project were developed with guidance from the literature, in particular Brisbane City Council (2003), Macleod (2008) and eWater (2012). The values that will apply to the characteristics of each site will involve the pervious area properties which include:

- soil storage capacity
- initial soil storage
- field capacity
- infiltration capacity coefficient

The remaining parameters will be set to the generic values as the investigation into these parameters is not in the scope of this project. There parameters include impervious area, groundwater properties and known pollutants concentrations (e.g. total dissolved solids, phosphorus, nitrogen). Note that extensive testing is required to obtain groundwater properties and pollutant concentrations. The parameters that will be set to the generic (default) values in the localized model include:

- impervious area rainfall threshold
- initial groundwater store
- daily recharge rate of groundwater
- daily drainage rate of ground water
- daily deep seepage rate of ground water

These default (generic) input parameters that were used in the models are shown in Table 19.

Impervious Area Properties	
Rainfall Threshold (mm/day)	1
Ground Water Properties	
Initial Groundwater Store (mm)	10
Daily Recharge Rate (%)	25
Daily Drainage Rate (%)	5
Daily Deep Seepage Rate (%)	0

TABLE 19- GENERIC INPUT PARAMETERS

Soil properties

In order to define the input parameters for the soil properties in the model the rooting zone of each location had to be known. For the purpose of this project, the rooting zone for all areas was assumed to be 400mm. The rooting zone is the region within the soil where roots from plants and vegetation exist. The soil properties used in the MUSIC model were calculated as discussed in section 2.8.

3.4.3.1 Generic Soil Parameters

The values that were used to produce the generic model for the catchment with in MUSIC were the default values provided by CRC (2005) as specified in section 2.5.4.2. The guidelines provided by the Macleod (2008) in conjunction with the MUSIC User Manual (CRC 2005) have been used to create the models in this project. The guidance provided by Macleod is explained in section 2.8.

3.4.3.2 Localised Values

The localised MUSIC model were created using values that have been adapted to the local conditions of the site within the Spring Creek Catchment. The area in which the localised values will differ from the generic will be largely based on the soil characteristics. With differing soil characteristics in the model the runoff results are likely to differ. The soil properties that were used were determined based on the results of the soil collected at the surface of the soil profile. MUSIC promotes the use of surface soil properties and as such it was the most applicable to the modelling practices in this project. The localised MUSIC model parameters were calculated using the equations derived in section 2.8.2.

3.4.3.3 Sensitivity Analysis

To perform the sensitivity analysis the properties of the outputs from MUSIC must be evaluated. There are a number of properties that can be viewed from the advanced charting tool produced by MUSIC. These properties either relate to flow characteristics or water quality. This section of the project will only evaluate the flow characteristics results generated by MUSIC and not water quality. The flow characteristics resulting from each model will give an indication of the sensitivity of the MUSIC input parameters.

3.4.4 Modelling WSUD Scenarios

In the process of this report WSUD systems were selected for each site (node) that was investigated. Three sites, apply three different WSUD systems, were selected. Within the MUSIC model these sites applied their respective WSUD system. Specifically the sites and WSUD systems that were selected included site C (bioretention basin), site D (infiltration system) and site G (wetland). These systems were applied in both the generic and local models. The MUSIC default WSUD system properties were applied. A summary of the sites can be viewed in Table 20.

Site	Area (ha)	Soil Type	WSUD applied
C	17	Loam	Bioretention Basin
D	18	Sand	Infiltration System
G	28	Heavy Clay	Wetland

TABLE 20 - SITES APPLYING WSUD SYSTEMS IN MUSIC

By modelling these systems their effectiveness on the catchment and the sensitivity of the catchment properties can be assessed. Specifically, the models were assessed based on the in and out flow of total suspended solids (TSS). By assessing the sites in this manner it was possible to determine if the systems were sensitive to the soil input parameters (similar to the sensitivity analysis). Hence, the author was evaluating whether the TSS outflow from the generic model was significantly different to the local model. If it was significantly different, the model would be sensitive.

To understand what effect the generic and local parameters had on the WSUD systems the properties of the systems in the generic model were modified such that both models would achieve the same results. This determined how the design of the WSUD systems would change if the generic parameters had been used in MUSIC instead of the local input parameters.

3.5 Resource Analysis

The National Centre for Engineering in Agriculture (NCEA) located at the University of Southern Queensland, Toowoomba, had all the resources need for the laboratory and field testing required by this research project. Laboratory Testing was conducted at the NCEA facility. Field testing was be completed by the use of the ring infiltrometer currently owned by the NCEA.

The MUSIC model was provided to author by the University of Southern Queensland in order to apply the model as it relates to this research project.

4 Results and Discussion

4.1 Chapter Overview

This chapter critically analyses and discusses the results obtained from the laboratory and field testing within the Spring Creek catchment and modelling based on local site characteristics including a sensitivity analysis. The presentation of the results in this chapter will begin with the soil laboratory testing for saturated hydraulic conductivity and dry infiltration where graphical representation will aid in the explanation of the results. Field testing results will be evaluated as they relate to the laboratory testing. Local and generic parameters used in the MUSIC model will be discussed as well as their application to WSUD. Finally, the effects of the chosen water sensitive urban design systems will be evaluated.

4.2 Soil Investigation

4.2.1 Laboratory Testing

4.2.1.1 Saturated Hydraulic Conductivity (K_{sat})

For simplicity, the results from the soil core testing were analysed and discussed based on the soil type. The soil textures encountered within the subject area included sand, sandy loam, loam, medium and heavy clays. Table 21 shows the statistical comparison of the laboratory results that were obtained from both surface and deep soil samples.

	Surface Ksat (mm/hr)				Deep Ksat (mm/hr)*			
Site	Min	Max	Standard Deviation	Mean	Min	Max	Standard Deviation	Mean
A	7	10	2	9	0.5	0.9	0.3	0.7
B	90	98	4	94	38	52	10	45
C	111	152	21	132	100	108	6	104
D	160	172	6	165	101	121	14	111
E	563	581	9	572	472	498	18	485
F	682	741	34	702	456	468	9	462
G	680	759	42	712	11	19	6	15
H	1041	1081	20	1060	321	423	72	372

TABLE 21- STATISTICAL COMPARISON OF LABORATORY TESTING RESULTS

*Due to the labour intensiveness of extracting deep soil samples only two replicates were conducted for each site.

Generally, the K_{sat} values of the replicates obtained in laboratory testing had little variance as demonstrated by the low values of standard deviation for the data sets.

The results discussed below include averages based on replicated tests from each site. Throughout the discussion of results samples collected at the surface of sites were denoted by a subscript s (e.g. A_s is a sample collected from the surface of site A) and samples collected at depths denoted by a subscript d (e.g. A_d is a sample collected from depth of site A). The results obtained during laboratory test were compared to the results obtained in field testing

Sandy Soil

Sand textured soil was located in site D and E. Based on laboratory testing dry infiltration of the water into the surface soil cores from site D and E were very fast at 635 and 1796 mm/hour, respectively. Surface sample D_s achieved a saturated hydraulic conductivity values (K_{sat}) of 1060 mm/hour which is high compared to sample D_d which only stabilized at 372 mm/hour. Sample E_s and E_d gave similar K_{sat} values of 572 and 485 mm/hour respectively. Results obtained from site E suggest that K_{sat} of the soil does not change rapidly with depth. A representation of the data obtained from the sand textured soils is shown in Figure 4.1.

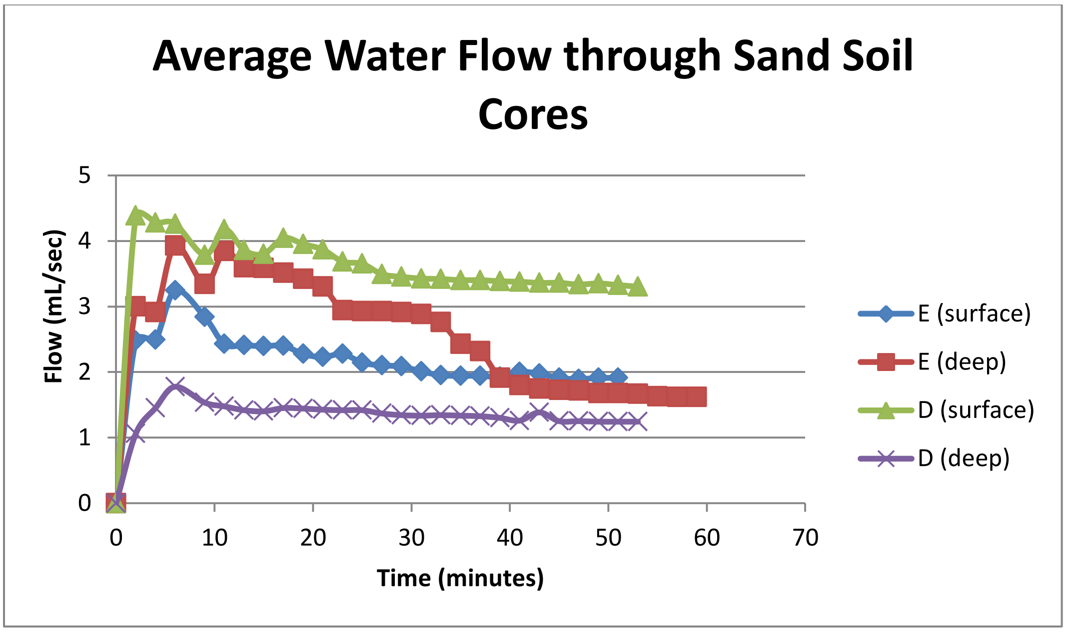


FIGURE 4.1- WATER FLOW THROUGH SAND SAMPLES

Figure 4.1 demonstrates how the dry hydraulic conductivity of E_d is higher than E_s. Although, the surface sample at site E still maintained a higher steady state flow at approximately 1.9 mL/sec (after 52 minutes).

Loamy Soil

Sites B, C were identified as loam soils. In contrast, Site F was identified as containing sandy loam soil. Samples B_s and C_s gave K_{sat} values of 132 and 702 mm/hour, respectively. Sample B_d correlated closely with it surface equivalent yielding 104 mm/hr. C_d produced a notable decrease when compared to the surface sample with a K_{sat} of 462 mm/hour. Site H gave low K_{sat} values similar to Site B.

The K_{sat} values produced by samples H_s and H_d were 165 and 111 mm/hour, respectively. Site F gave extreme results with samples F_s and F_d giving saturated hydraulic conductivity values of 712 and 15 mm/hour, respectively. This suggests that there is a large decrease in K_{sat} as the water passes through deeper layers of the soil profile. As site F presented a sandy loam soil rather than a loam the author expected that the sample soil properties would differ when compared to site B and C (i.e. K_{sat} values would be greater). This was evident from the results. For analysis purposes the results were displayed on separate graphs. The results of site B and H are presented in Figure 4.2. Figure 4.3 demonstrates the results yielded by site C and F.

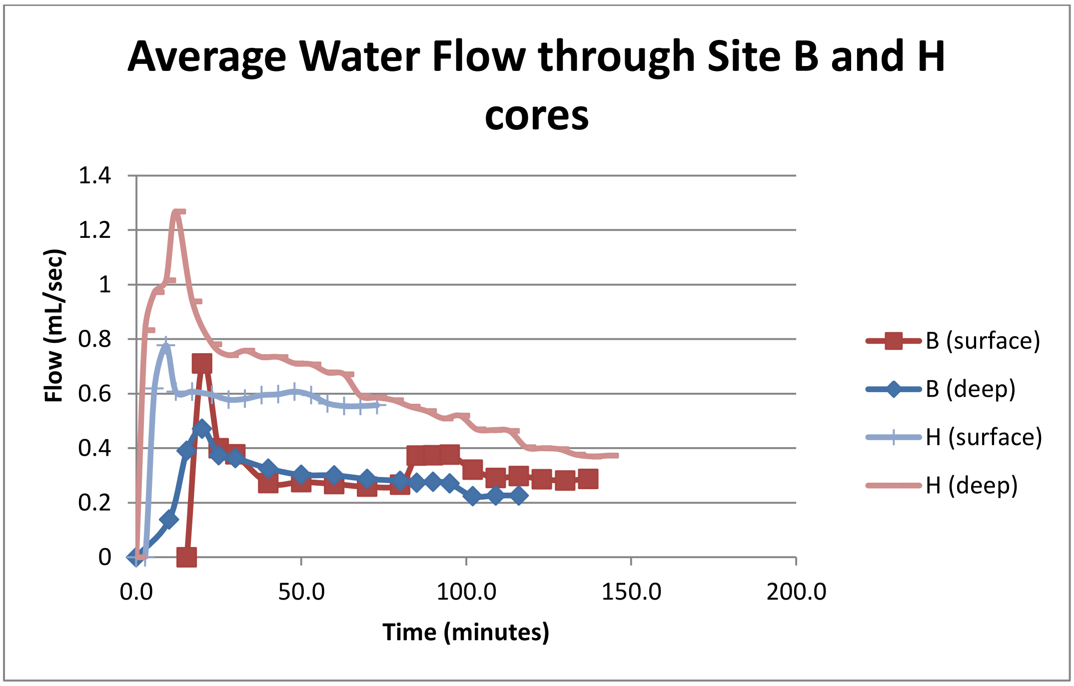


FIGURE 4.2-AVERAGE WATER FLOW THROUGH SITE B AND H SAMPLES

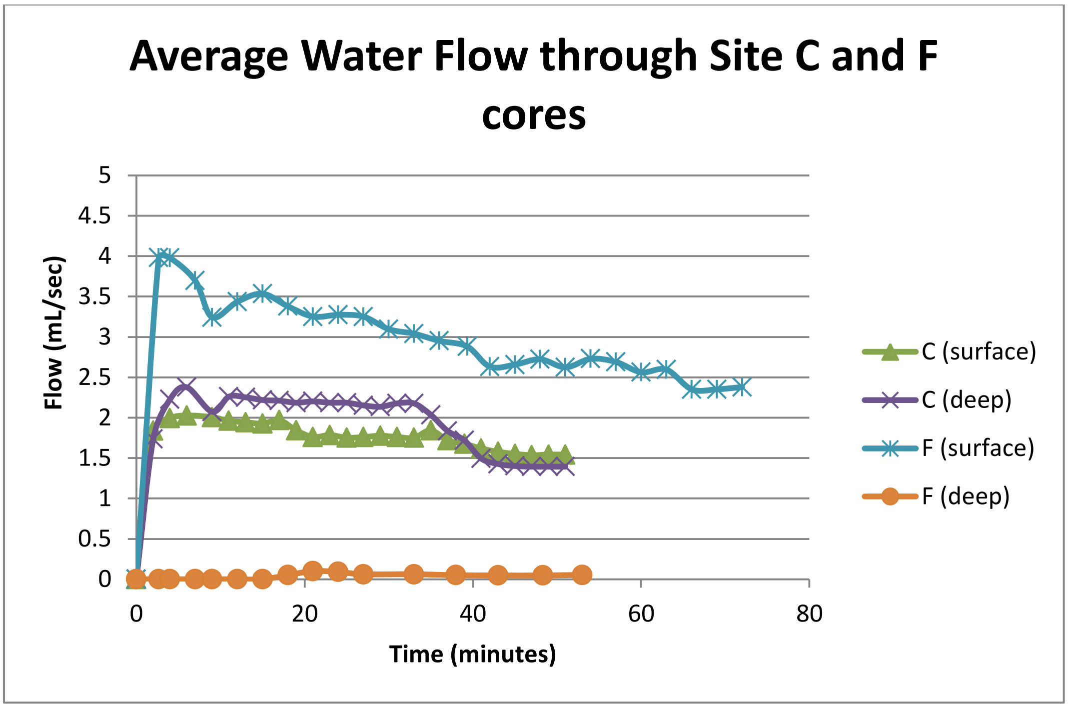


FIGURE 4.3- AVERAGE WATER FLOW THROUGH SITE C AND F SAMPLES

The most notable aspect of the loam soil cores (based on the graphic) is that the steady state flow varies considerably between each site. Samples from sites B, C and H relate closer to each other as opposed to the samples from site F which vary considerably. Interestingly, sample H_d presented a high initial flow rate and took a longer duration to reach steady state flow when compared to H_s. However, H_s obtain a higher K_{sat} than the sample at depth as shown in Figure 4.2. Site F produced results which were both greater than (at surface) and less than (at depth) that sample from site C demonstrated by Figure 4.3.

Clayey Soil

Sites A and G were identified as consisting of medium clay and heavy clay, respectively. Site A consisted of soils that were largely in the presence of decayed-shallow parent rock. For this reason the samples were only collected at a depth of 300mm. Samples A_s and A_d gave Ksat results of 8.98 and 0.74 mm/hour respectively. The saturated hydraulic conductivity for site A samples was very low although the relative difference between the surface and depth samples was a decrease of approximately 92%. During the test the author noticed that the soil had dispersed (expanded) considerably. The initial length of each core was 50mm which developed to 62mm after 60 mins of testing. This suggests that site A contains swelling clays or sodic soils causing the dispersion of the particles after they have absorbed water, causing the volume of the soil to increase over a short duration. The results for samples A_s and A_d are shown in Figure 4.4.

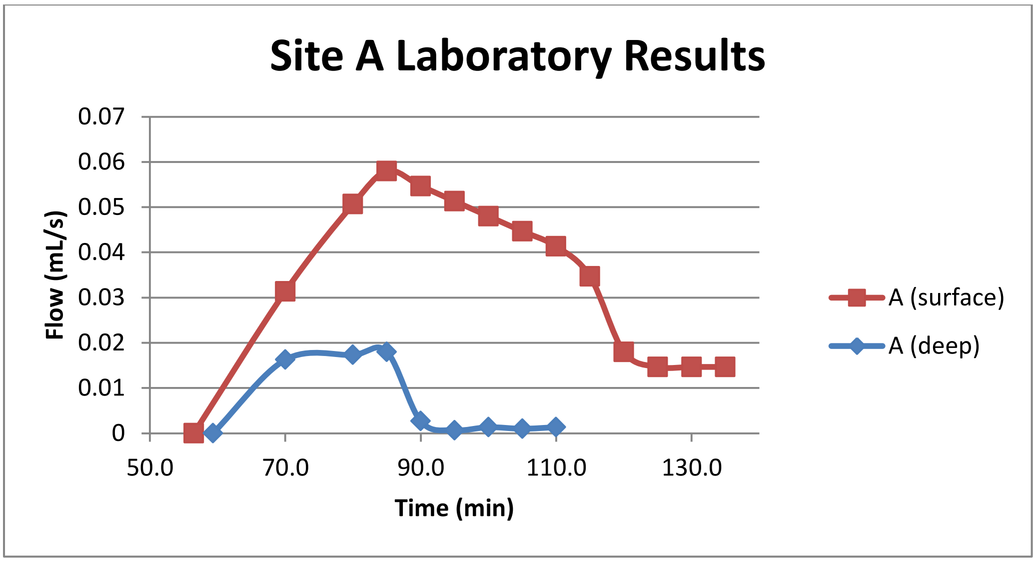


FIGURE 4.4- AVERAGE WATER FLOW THROUGH SITE A SAMPLE

As expected the A_s achieved a large stead state flow than A_d. Site G presented heavy clays that produced very low saturated hydraulic conductivity values. G_s and G_d gave K_{sat} values of 94 and 45 mm/hour, respectively. The results from site G are shown in Figure 4.5. Unexpectedly, sample G_s reached steady state flow after a longer duration than G_d. As expected, G_s achieved a higher maximum and steady state flow when compared to the sample at depth (G_s).

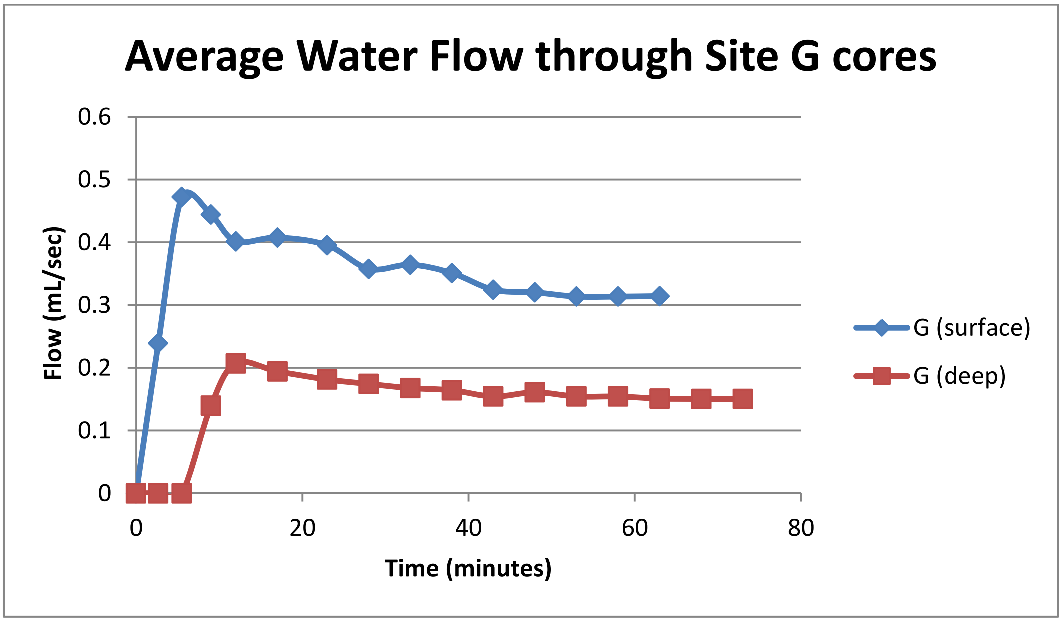


FIGURE 4.5- AVERAGE WATER FLOW THROUGH SITE G SAMPLES

From the results of the laboratory testing the author was able to compare and calculate the relative difference between the surface and depth samples. This difference is demonstrated in Table 22.

Site	Lab Surface K_{sat} (mm/hr)	Lab Deep K_{sat} (mm/hr)	K_{sat} Decrease (%)
A	8.9	0.7	92
B	132	104	21
C	702	462	34
D	1060	372	65
E	572	485	15
F	712	15	98
G	94	45	52
H	165	111	33

TABLE 22- COMPARING SURFACE AND DEPTH SAMPLES

The most noticeable difference was demonstrated by sites A and F. As mentioned earlier, site A produced very low K_{sat} values and as such the relative difference between samples A_s and A_d is large. Site F demonstrated a difference of 98% between samples. This appears irregular for a sandy loam soil and the author believes that other influences may have affected the result of the sample at depth (e.g. subsurface or seeped pollution into the soil profile).

4.2.1.2 Dry Infiltration Rate

In general, the estimated field dry infiltration of the samples was higher than the steady state flow, as expected. The results for the dry infiltration for the soil at each site are shown in Table 23. These results were applicable for use in the MUSIC and did not relate directly to the selection of WSUD systems. The estimated field infiltration for soils was used in the MUSIC model.

Site	Dry Infiltration (mm/day)
A	20
B	651
C	367
D	674
E	1513
F	413
G	40
H	362

TABLE 23 - DRY INFILTRATION CAPACITY OF EACH SITE

4.2.1.3 Other Soil Properties

In addition to the main focus of the laboratory testing (saturated hydraulic conductivity) other soil characteristics were important for the completion of this project which included moisture content, field capacity, total storage capacity (amount of water filling voids at saturation) and soil texture. The results of the laboratory determination of these characteristics are shown in Table 24.

Site	Soil Characteristics			
	Moisture Content* (%)	Field Capacity (%)	Total Storage Capacity (%)	Texture
A_s	34.2	39.5	51.2	Medium Clay
A_d	39.4	32.9	40.5	
B_s	15.2	21.4	38.3	Loam
B_d	19.7	40.4	51.7	
C_s	27.0	50.5	45.2	Loam
C_d	28.9	23.9	38.8	
D_s	29.0	26.1	41.2	Sand
D_d	29.6	31.6	63.5	
E_s	35.1	50.1	61.9	Sand
E_d	29.0	39.0	52.1	
F_s	34.7	39.5	56.3	Sandy Loam
F_d	37.1	44.7	49.7	
G_s	34.8	32.2	49.8	Heavy Clay
G_d	30.2	40.8	63.8	
H_s	30.1	34.1	55.1	Sand
H_d	28.8	46.8	61.4	

Table 24- Additional Soil Characteristics based on collected disturbed soil samples

*The moisture content measurement is instantaneous and varies depending on the time of soil sampling.

4.2.2 Field Testing

4.2.2.1 Saturated Hydraulic Conductivity (K_{sat})

The simplified falling head method was replicated a minimum of 3 times in the field for each site. The saturated hydraulic conductivity for each site is shown in Table 25. This table illustrates the standard deviation of the testing data. Large standard deviations values imply that the results were not concentrated around the average. As shown, in most cases the variance in results was relatively low, with the exception of site D and F with a standard deviation of 30 and 27, respectively. These sites contained sand and loam soils which generally gave higher K_{sat} values. McKenzie et al. (2002) states that the single ring apparatus generally overestimates K_{sat} for sand and loam soils. This was possibly why the variance in results was experienced for these sites.

Field Saturated Hydraulic Conductivity (mm/hour)				
Site	**Minimum**	**Maximum**	**Standard Deviation**	**Average**
A	0.7	0.9	1	0.8
B	82	103	12	95
C	9	24	6	15
D	101	160	30	134
E	526	562	18	547
F	165	215	27	184
G	0.3*	0.3	1	0.3
H	18	22	2	19

TABLE 25- FIELD SATURATED HYDRAULIC CONDUCTIVITY BASED ON EACH SITE

*Site G values were very low and were not equal for each replication

The field K_{sat} results for each site can be easily compared as shown in Figure 4.6.

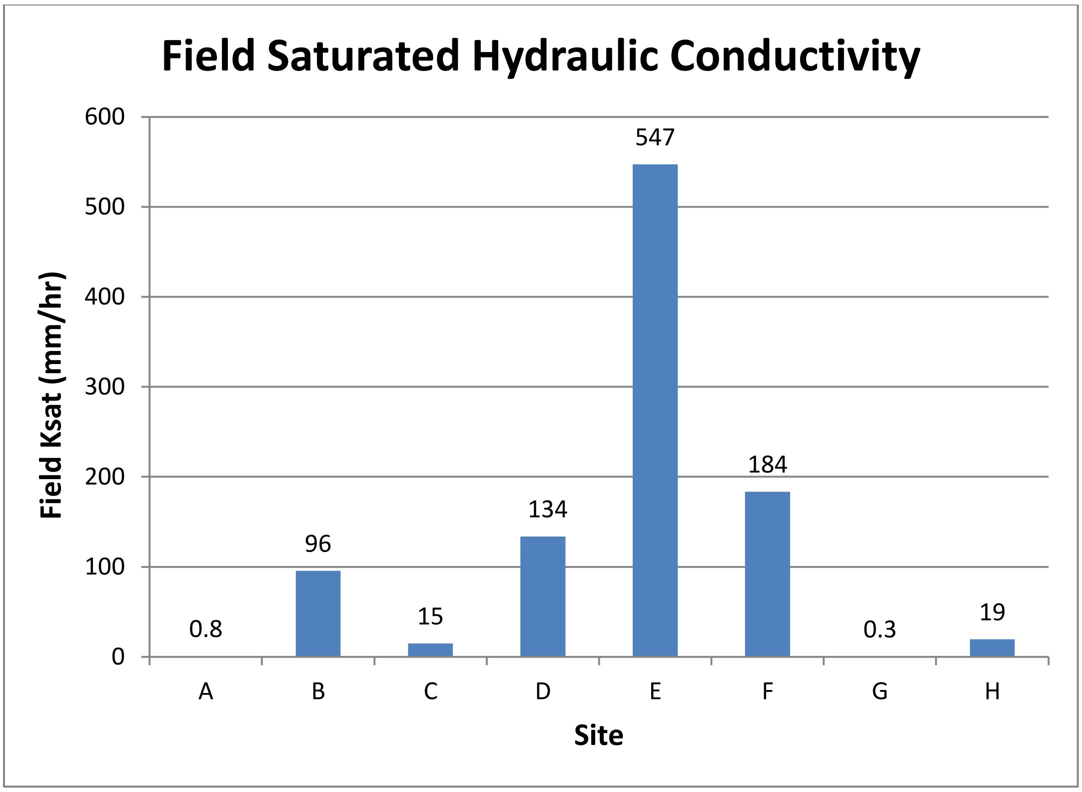


FIGURE 4.6- FIELD SATURATED HYDRAULIC CONDUCTIVITY

As shown the K_{sat} from site E was the greatest of all the sites (547 mm/hour), followed by the sandy loam results of site F (183 mm/hour). As sites E and D contain sand type soils they achieved field K_{sat} results greater than all of the other sites, excluding site F. Sites A and G achieved low K_{sat} values which was expected due to the clayey nature of the soil.

4.2.3 Comparing Laboratory and Field Results

The comparison of K_{sat} results from the field and the laboratory (surface samples) is demonstrated in Figure 4.7.

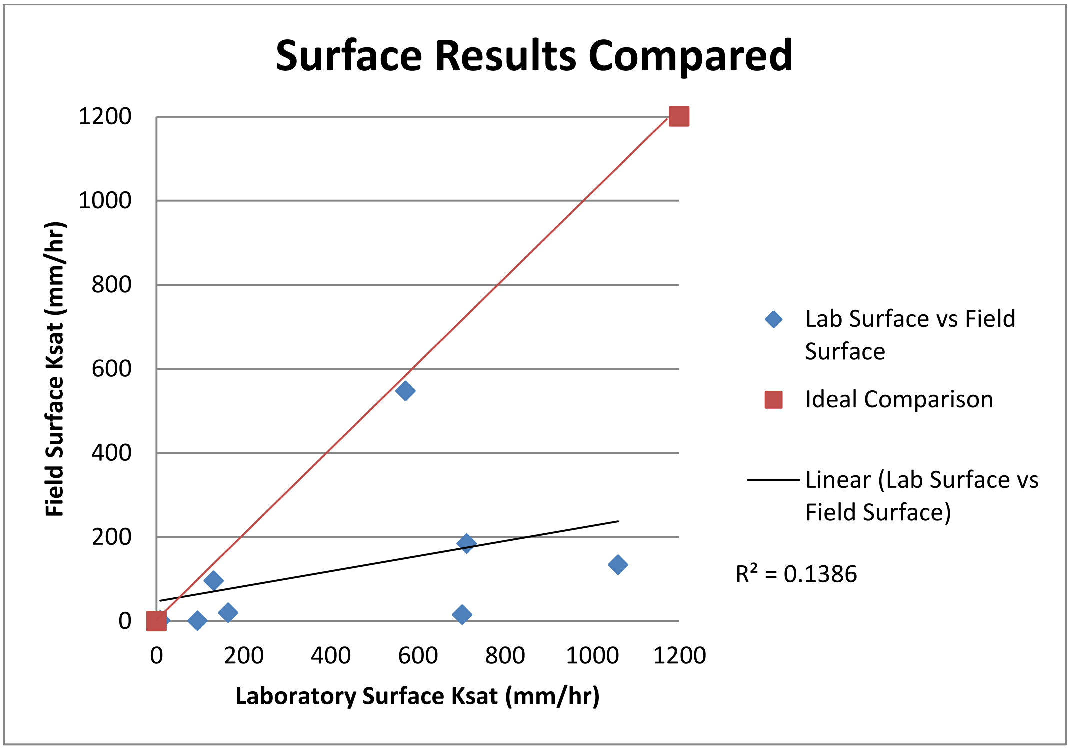


FIGURE 4.7- COMPARING LABORATORY AND FIELD SURFACE RESULTS

Figure 4.7 demonstrates that in all cases the laboratory surface K_{sat} testing method provided greater results. As shown on the graph the trend of data is located closer to the laboratory surface K_{sat} axis. The linear trend line shows that there is little correlation between the two testing methods ($R^2=0.1386$). The clay soils ($K_{sat} < 200$ mm/hr) provided correlated close to the ideal comparison line. However, sand and loam soils ($K_{sat} > 500$ mm/hr) produced considerably larger laboratory results compared to field results. As the field testing method was considered more accurate (Reynolds, 2002), it is proven that the laboratory method overestimated the K_{sat} for the soils.

The relative percentage difference between laboratory and field K_{sat} results are shown in Table 26.

Site	Lab Surface K_{sat} (mm/hr)	Field K_{sat} (mm/hr)	Field Results as a Percentage of Lab Results (%)
A	9	1	11
B	132	96	73
C	702	15	2
D	1060	134	13
E	572	547	96
F	712	184	26
G	94	0.3	0.3
H	165	19	12

TABLE 26- RELATIVE DIFFERENCE BETWEEN LABORATORY AND FIELD RESULTS

As expected, the field and laboratory results were not similar, with the exception of site B (loam) and site E (sand) which produced field results that were 73% and 96% (respectively) of the laboratory results that were found. In particular, the clay soil (site A and G) produced very low relative percentages of 11% and 0.3% respectively. This is possibly due to the slow movement of water through clay soils. On average, the field results were only 29% of the laboratory results.

4.2.4 Field Saturated Hydraulic Conductivity at Depth

From the results in the previous section, the author has made recommendations on the likely K_{sat} that would be present in soils at specific depths in the soil profile. These estimated were made based on the proportional relationship between lab surface results and lab deep results (refer to section 2.6.8). The field surface K_{sat} and estimated deep K_{sat} for each site is shown in Table 27. Note the ratio used to calculate the field deep K_{sat} values is shown in the last column of the table.

Sites	Field Surface K_{sat} (mm/hr)	Field Deep K_{sat} (mm/hr)	Surface to Deep Ratio
A	0.8	0.1	12.2
B	95.5	75.6	1.3
C	14.8	9.7	1.5
D	133.8	47.0	2.8
E	547.1	463.6	1.2
F	183.5	3.9	47.6
G	0.3	0.1	2.1
H	19.4	13.1	1.5

TABLE 27- COMPARISON OF FIELD SATURATED HYDRAULIC CONDUCTIVITY RESULTS

The difference between surface field results and deep field results is compared in Figure 4.8.

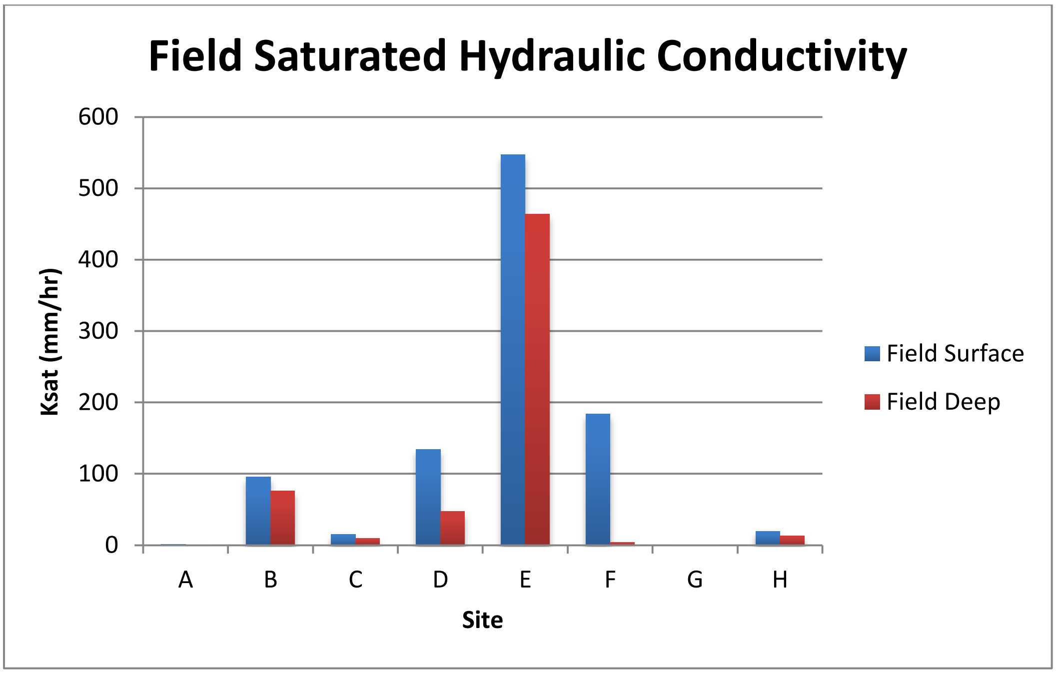


FIGURE 4.8- COMPARING SURFACE AND DEPTH FIELD SATURATED HYDRAULIC CONDUCTIVITY RESULTS

From inspection of Figure 4.8, it can be noted that the surface to depth ratio considerably affected the field deep K_{sat} of the soils. Using field surface K_{sat} values to select WSUD systems is likely to produce results different to when field deep K_{sat} values are used. The selection of WSUD systems based on these results is explained in the section 4.3.

4.2.5 MUSIC input parameters

For the purpose of creating the models in MUSIC the results from the soil investigation were used to give an accurate representation of the site that is being modelled. The soil investigation results influenced the selection of both local and generic parameters.

4.2.5.1 Local parameters

Based on the results of the soil testing and field investigations the following local parameters have been used to construct the localized MUSIC model. The soil property parameters that were applied to the MUSIC model are shown in Table 28. Note that a rooting zone of 400mm was used for the local and generic model.

Site	Total soil storage (mm)	Initial Storage (%)	Field Capacity (mm)	Infiltration Capacity Coefficient (mm/day)	Texture
A	205	67	158	20	Medium Clay
B	153	40	86	465	Loam
C	181	60	202	262	Loam
D	165	70	104	482	Sand
E	248	57	201	1081	Sand
F	225	62	158	295	Sandy Loam
G	199	70	129	30	Heavy Clay
H	220	55	136	259	Loam
Ag	225	62	158	295	Sandy Loam

TABLE 28 - SOIL PROPERTIES FOR THE NODES IN THE MUSIC MODEL

*Ag- the agricultural land in the centre of the subject area. It was defined as having similar soil characteristics as site F.

4.2.5.2 Generic Parameters

From the soil investigation the soil type in each testing site was found. The soil parameters used in the generic model are shown in Table 29. These values were determined based on the methods described by Macleod (2008) (refer to Chapter 3).

Site	Texture	AWHC	P (%)	V (%)	W (%)	TSC (mm)	FC (mm)	IS (%)	IC
A	Medium Clay	120	35	55	27	75	68	67	175
B	Loam	150	31	40	13	77	70	40	200
C	Loam	150	31	40	13	77	70	60	200
D	Sand	140	10	25	3	140	60	70	400
E	Sand	140	10	25	3	140	60	57	400
F	Sandy Loam	130	14	30	5	111	58	62	200
G	Heavy Clay	115	35	55	27	72	66	70	175
H	Loam	150	31	40	13	77	70	55	200
Ag	Sandy Loam	130	14	30	5	111	58	62	200

TABLE 29 - GENERIC PARAMETERS USED IN THE MUSIC MODEL

Where:

TSC = total storage capacity

FC = field capacity

IS = initial moisture storage of soil

IC = infiltration capacity coefficient

4.3 Selection of Water Sensitive Urban Design Systems

WSUD systems depend heavily on the soil types. For the selection of WSUD systems each area has been grouped below according to their soil type.

In general, the upper limits of soils applicable to storage type systems have a saturated hydraulic conductivity of 36 mm/hour. As such, infiltration systems are applicable to soils with a K_{sat} greater than 36 mm/hour (Wong, 2006).

Sand soil

As mentioned previously in this chapter both site D and E were identified as sites containing sand textured soils. These soils are most suitable for instances where stormwater attenuation is a requirement. They allow fast infiltration of large amounts of stormwater runoff.
Site E achieved a very high estimated K_{sat} (464 mm/hour) and as such infiltration systems such as an infiltration trench or basin would be most applicable for the site. These systems will allow the exploitation of the high K_{sat} of the sub surface soil.

In comparison, testing for Site D resulted in a lower estimated K_{sat} (47 mm/hour) which is only 31% greater than the K_{sat} recommended for infiltration systems (36mm/hour). Although an infiltration basin would be applicable in this situation, the use of a hybrid bioretention basin with a leaky base is recommended (Wong, 2006, p.10-2). Such a system will allow stormwater attenuation and effective stormwater treatment. This system will allow the use of the subsurface infiltration with any excess water being transmitted away from the site via a perforated pipe. As the K_{sat} is relatively close to the lower limit for infiltration systems a hybrid bioretention basin will ensure the stormwater is diverted away from the site and prevent any ponding that could occur due to poor subsoil infiltration. Note that as the K_{sat} for this site is so fast, a clay liner or impervious membrane will be required to ensure a defined flow path through the filter media in the bioretention basin. Otherwise, water will have the opportunity to seep laterally and bypass the treatment process that is available in bioretention basins.

Loam Soils

Sites B, C and H were classified as loam soil areas and site F was classified as a sandy loam. Site B demonstrated a K_{sat} (76 mm/hour) when compared to the other loam soils. This site will be very suitable for infiltration basins and trenches which promote the use of the subsoil infiltration.

Sites C, F and H achieved much lower K_{sat} values (10, 4 and 13 mm/hour, respectively) when compared to site B (an average decrease of 65%). As site F maintained such low water conductivity ability, extended detention of stormwater wouldn't be an issue as the seepage loss of the water into the subsurface soil would be negligible for design. This type of extended detention is most applicable to constructed ponds and wetlands. Newly constructed ponds have the capacity to outlet the water when the water height exceeds a specified level. Ponds normally have a small range of water level fluctuation which is suitable to a soil type with a very low K_{sat}.

Sites C and H provided low K_{sat} values but could still demonstrate noticeable water loss if water were applied on the soil surface. Therefore, wetlands are most suitable for these sites. As the water level fluctuates regularly in a wetland the water loss due to seepage would not be considerable. In a pond the water loss would be considerable (for sites C and H) due to the extended detention of the water on the soil surface. The soil characteristics of sites C and H would benefit the regular infill and outflow of water for a wetland system. The opportunity to lose the water through seepage would be decreased due to lower stormwater detention periods. Ponds are less applicable to these sites as ponds don't demonstrate regular water level fluctuation.

If road side stormwater attenuation and treatment was a requirement in these areas, a bioretention basin could be applicable, depending available space. The natural low K_{sat} of the in-situ soils would ensure that there would be a definitive flow path through the filter media of the bioretention basin. This water would be conveyed to an underground perforated pipe which would convey the water downstream and consequently decrease stormwater runoff peaks. It is recommended that a buffer strip (with a subsurface perforated pipe) be employed as pre-treatment for the bioretention basin to assist in the attenuation of stormwater runoff.

Clay Soil

Clay soils were predominantly located in sites A and G. These sites obtained the lowest K_{sat} values of all of the sites (A: 0.07 mm/hr and G:0.15 mm/hr). These values suggest that the soils would be most applicable in storage scenarios; namely with the use of ponds and wetlands. Sites A and G would be most beneficial for a constructed pond due to the desirable extended detention time. As the subsurface soils obtained such a low K_{sat} seepage loss would be insignificant to a pond in these sites. Most importantly, the subsurface soils would remove the need for pond liners to avoid seepage loss. Depending on the stormwater objectives, considerations into the use of wetlands should be considered for these sites.

It is important to remember that the applicability of WSUD is not solely based on soil type. Their applicability also depends on stormwater management objectives and site constraints (e.g. catchment area) as described in Chapter 2. For this reason, a range of WSUD systems were selected for most sites, rather than individual systems. A summary of the suitable systems for each site is shown in Table 30.

Site	Field Deep K_{sat} (mm/hr)	Suitable Systems
A	0.1	Ponds
B	76	Infiltration trench and basin
C	10	Wetland, Bioretention basin
D	47	Bioretention basin (leaky base), infiltration basin
E	464	Infiltration trench and basin
F	4	Pond (preferred) and wetland
G	0.2	Ponds
H	13	Wetland, Bioretention basin, Buffer strips

TABLE 30- SUITABLE WSUD SYSTEMS FOR EACH SITE

4.4 MUSIC Sensitivity Analysis

The results of the Sensitivity analysis were highly influenced by the input parameters chosen for each model. This influence translates to the results generated by each model.

4.4.1 Input parameters

The comparison between the localized parameters and the generic parameters is shown in Figure 4.9, Figure 4.10 and Figure 4.11. To compare the data sets for each parameter the generic parameters were plotted against the local parameters for each source node (site). The correlation of the data sets on each graph is demonstrated by a trend line. Note that there isn't a graph for the initial moisture content as this parameter was the same for both models.

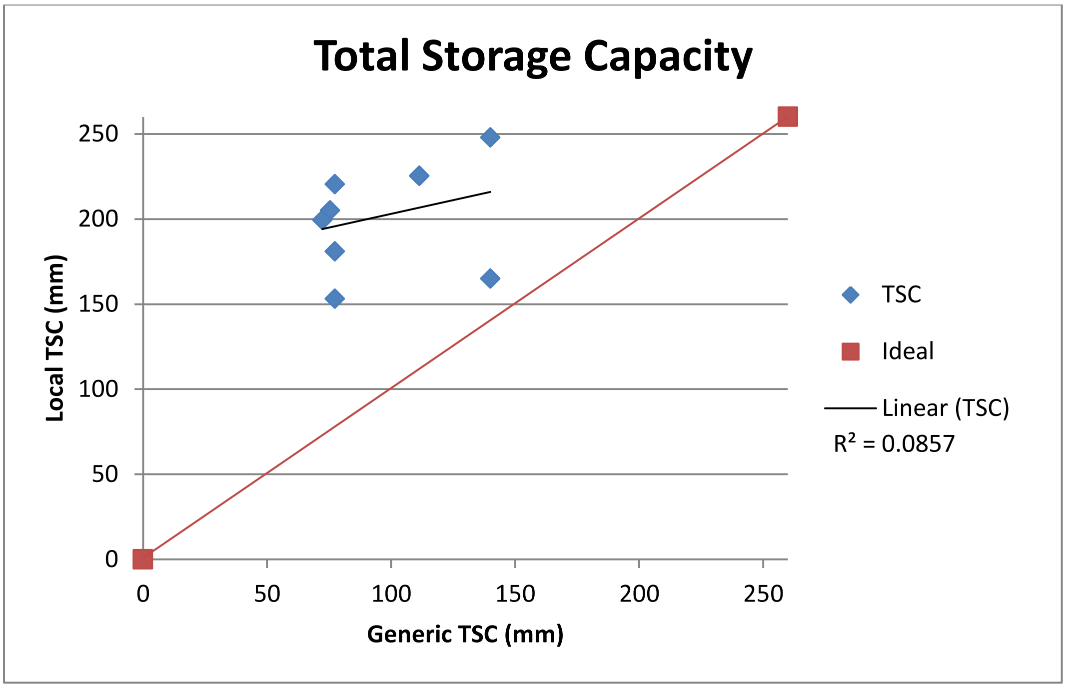


FIGURE 4.9 – COMPARING TOTAL STORAGE CAPACITY (TSC) OF THE GENERIC AND LOCAL MODELS

The local TSC parameters are greater than the generic TSC parameters. A very poor correlation is demonstrated by the trend line on the graph ($R^2 = 0.09$). Due to these characteristics the soil in the local model was able to allow more water to infiltrate impervious areas before the water is converted into stormwater runoff. This implies that the generic model will produce rainfall runoff before the local model during the model simulation (time) period.

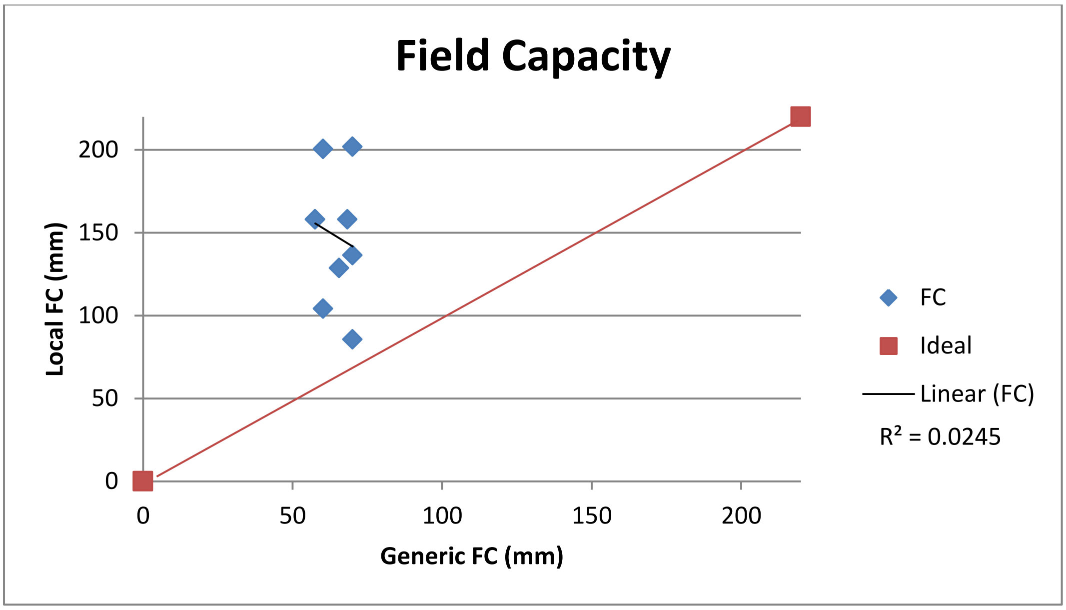


FIGURE 4.10 – COMPARING FIELD CAPACITY (FC) OF THE GENERIC AND LOCAL MODELS

Similar to the TSC, the FC parameters are generally greater in the local model compared to the generic model. As the soil has a greater capacity to store water in the soil without allowing it to drain by gravity, successive rainfall events will allow the local model to generate stormwater runoff faster than the generic model, in the long term.

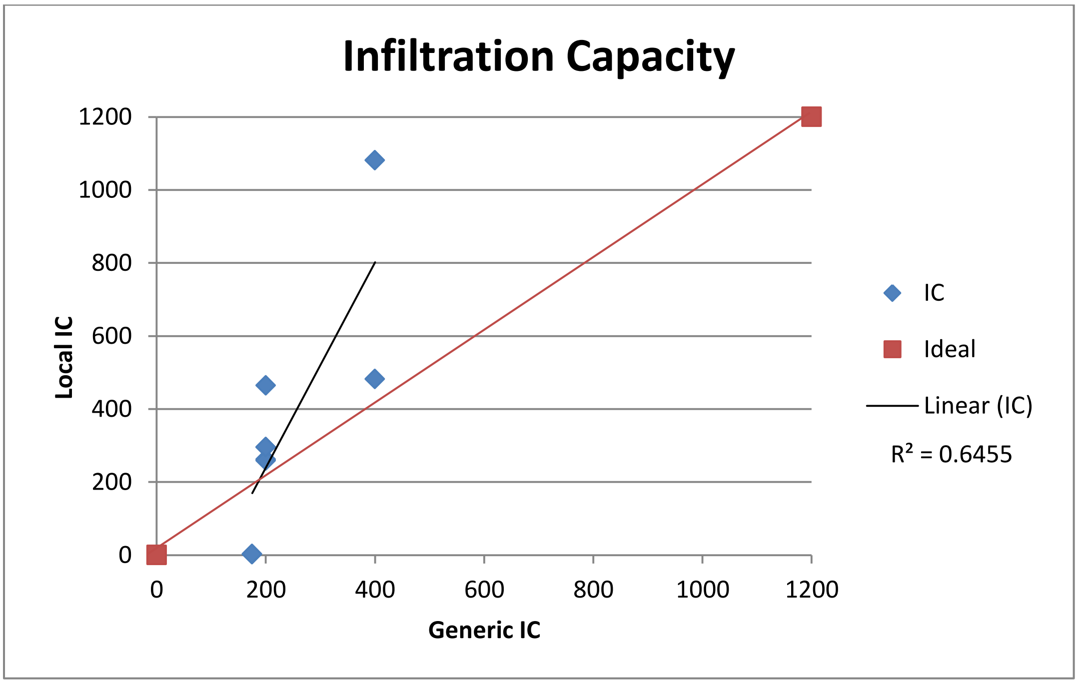


FIGURE 4.11 – COMPARING INFILTRATION CAPACITY (IC) OF THE GENERIC AND LOCAL MODELS

Unlike the other soil input parameters the infiltration capacity parameters showed a strong correlation between the local and generic model ($R^2 = 0.65$). Again the generic parameters are less the local parameters. As the local model generally has a greater infiltration capacity the soil in the model will allow the water to enter it faster. This means that the storage capacity of the soil will be reached in a short time period which equates to a faster generation of stormwater runoff.

4.4.2 Sensitivity Analysis of MUSIC Models

The evaluation of the model outputs involved both the stormwater runoff flow rate from individual areas (source nodes) and the overall flow rate of the catchment. A hypothetical catchment was created based on the soil information from the soil investigation (refer to section 4.2).

The hypothetical catchment involved eight areas (labelled A to H). To determine the sensitivity of the models the flow characteristics of each node/site was first analysed. Figure 4.12 demonstrates the flow rate (ML/year) from each site based on the site area (ha).

Yearly Flow Rate ML/year per hectare			
Site	**Generic**	**Local**	**Local/Generic Ratio**
A	3.9	3.8	0.98
B	1.9	1.9	0.96
C	2.2	1.9	0.89
D	2.5	2.3	0.91
E	2.1	1.6	0.80
F	3.9	3.8	0.96
G	3.4	3.3	0.97
H	3.4	3.3	0.96
Ag	1.1	0.6	0.61
		Average	0.90

FIGURE 4.12 - FLOW RATE FROM EACH SITE BASED ON SITE AREA

In general the sites flow characteristics were very similar. Overall the local model produced flows that were 90% of the generic model flows. However, Site Ag (agricultural land) showed a lower local to generic ratio of 0.61. This is likely due to the large pervious land area of this site (38.2 ha). These results suggest that there is not a significant difference between the results produced by each model.

The evaluation of the overall flow rate outputs from each model was based around the flow to a node within that model that received all of the stormwater runoff from the hypothetical catchment. This node was labelled the '*receiving catchment node* '. The nodes used in the MUSIC model can be viewed in Figure 3.8. As mentioned in Chapter 3, two models were created for the hypothetical catchment. The model were labelled the 'Generic model' (generic parameters) and 'Local model' (local parameters). The difference in total flow rates characteristics of each model is shown in Table 31.

Results	Generic	Local	Local to Default ratio
Flow (ML/yr)	550	513	93%
Peak Flow (m3/s)	0.93	0.86	93%

Table 31 – Flow rate results for each model

The local model has a maximum flow rate of 0.86 m^3/s which is less than the maximum flow rate of the generic model, 0.93 m^3/s. Table 31 demonstrates that the local model produced flow results that were 93% of the generic model results.

In summary, the generic model sustained a greater maximum and yearly flow rate. As described in Section 4.4.1, the total storage capacity for the local model was greater than the generic model. This suggests a longer period of time was required until the local model was able to generate runoff in the impervious areas. This difference would have been significant in reducing the average and total flows generated by the model. Also, the local parameters for the field capacity were greater than the generic parameters. Once saturation had occurred in the local model, a shorter time period would be required to achieve soil saturation (hence runoff) in the previous areas when compared to the generic model. Thus, the maximum flow was greater for the local due to its capacity to generate runoff in shorter time period during successive rainfall events.

The flow generated from the generic and local models are compared in Figure 4.13. The trend line of the data on the graph suggests that the generic model flows were general higher than the local model flows. Although, the R^2 value (0.98) of the trend line demonstrates that the two data set correlate very well (above the 95th percentile). An interesting characteristic is that the data points are above and below the 'ideal line'. This implies that the local model had the greater flow rate in some instances.

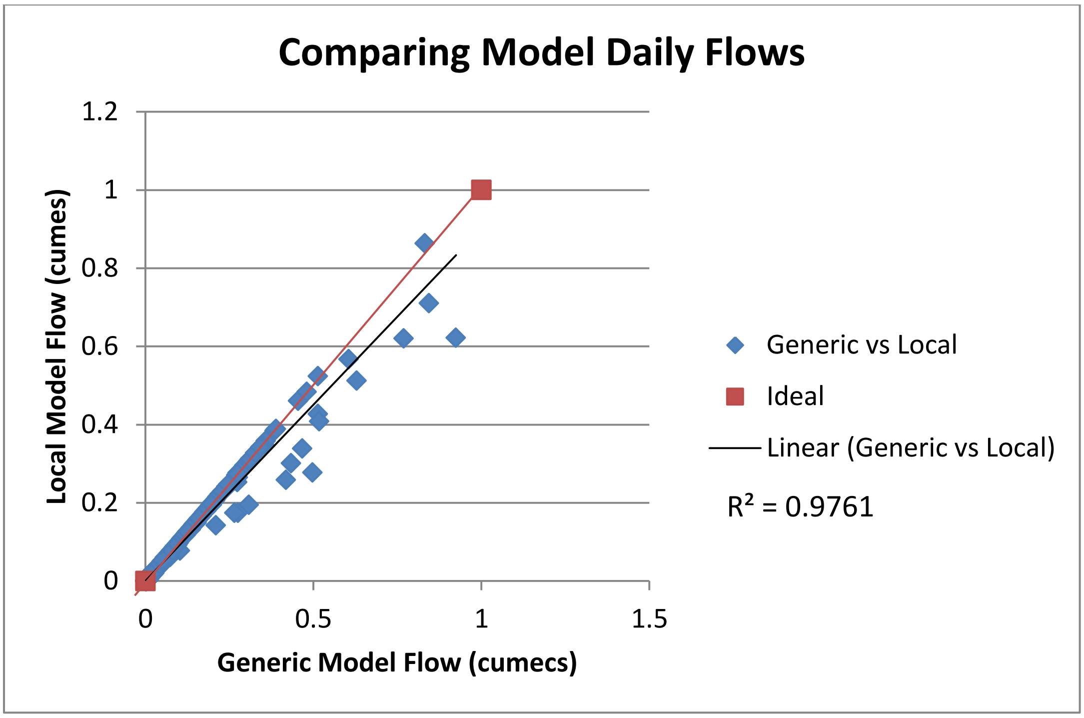


FIGURE 4.13 – COMPARING THE FLOW GENERATED BY THE GENERIC AND LOCAL MODELS

As an improved visual aid, the total monthly flow rates produced from each catchment are compared in Figure 4.14. Note the model was simulated over the period of the rainfall data that was used (81 months). Figure 4.14 demonstrates that at peak flow intervals the difference between each model is evident (e.g. months 10 and 20). During months of moderate to minimal runoff (0-1.0 m^3/s) the flow rates are relatively similar. This is most accurately demonstrated from month 20 to 30 and month 40 to 70.

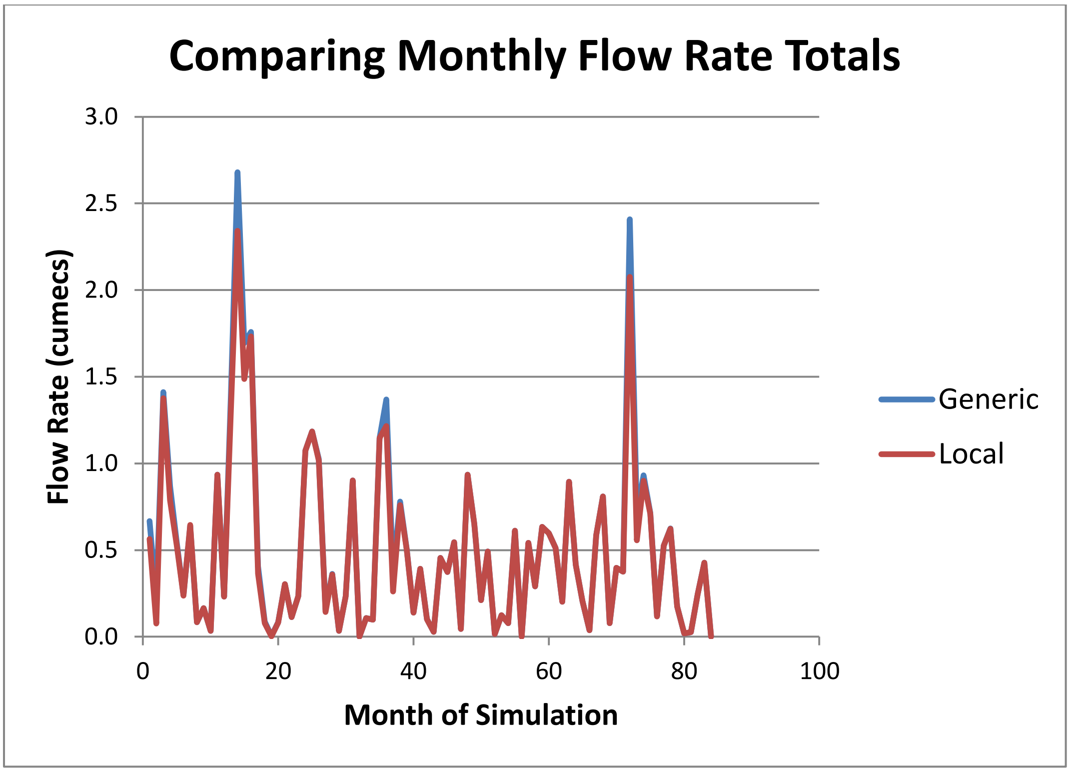


FIGURE 4.14 - TOTAL MONTHLY FLOW RATES FOR EACH MODEL

4.4.3 Sensitivity Analysis of WSUD systems in MUSIC

4.4.3.1 Comparing Model Results

A secondary objective of this project was to define if the generic parameters had significant effects on the performance of the WSUD systems that could be modelled in MUSIC. This was completed by comparing the generic and local models. WSUD systems were modelled in three specific sites within both the generic and local model (refer to section 3.4.4). The systems that were implemented in the model included a wetland, infiltration system and a bioretention basin.

Flow attenuation and pollutant removal outline the purpose of WSUD systems. To demonstrate the difference between default model outputs and local model outputs pollutant removal will be analysed and discussed. To understand the pollutant removal by the systems the analysis was focussed on the removal of total suspended solids (TSS). The pollutant removal of each system is demonstrated in Table 32.

System	TSS Results	Generic	Local
Wetland	Inflow (kg/year)	19,800	20,000
	Outflow (kg/year)	17,100	17,000
	Reduction (%)	14	15
Infiltration System	Inflow (kg/year)	8,070	8,380
	Outflow (kg/year)	6,370	6,520
	Reduction (%)	21	22
Bioretention Basin	Inflow (kg/year)	7,690	7120
	Outflow (kg/year)	5,510	4890
	Reduction (%)	28	31

TABLE 32 – WSUD SYSTEM TSS REMOVAL FOR GENERIC AND LOCAL MODELS

Note that Table 32 demonstrates the inflow and outflow of TSS for each system but also the relative percentage reduction for each system. The comparative differences are easily viewed in a graphical representation of this data as shown in Figure 4.15.

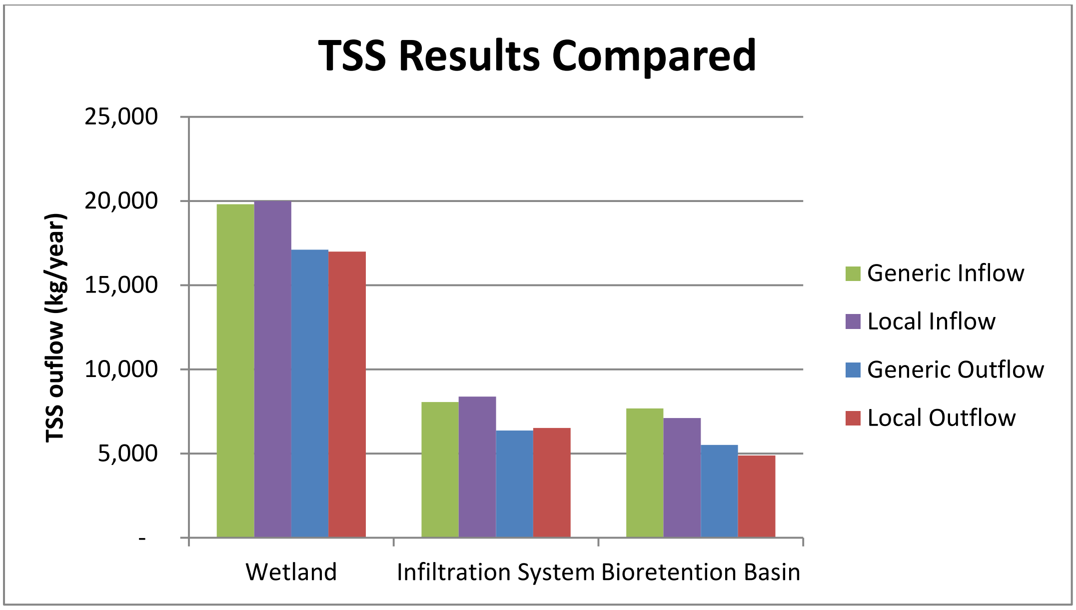


FIGURE 4.15 - COMPARING TSS INTFLOW AND OUTFLOW FOR WSUD SYSTEMS

Figure 4.15 demonstrate that generally the pollutant removal efficiency was consistent for each system. For all systems, where the TSS inflow was larger the TSS removal percentage was greater. Notably for the wetland and infiltration system the local TSS inflow was greater than the generic TSS inflow despite the generic model producing the greater average flow rate over the simulation period (refer to section 4.4.2). It is expected that as the flow rate increases the TSS content would increase; due to the fact that a greater flow has the capacity to carry more TSS in a given time period.

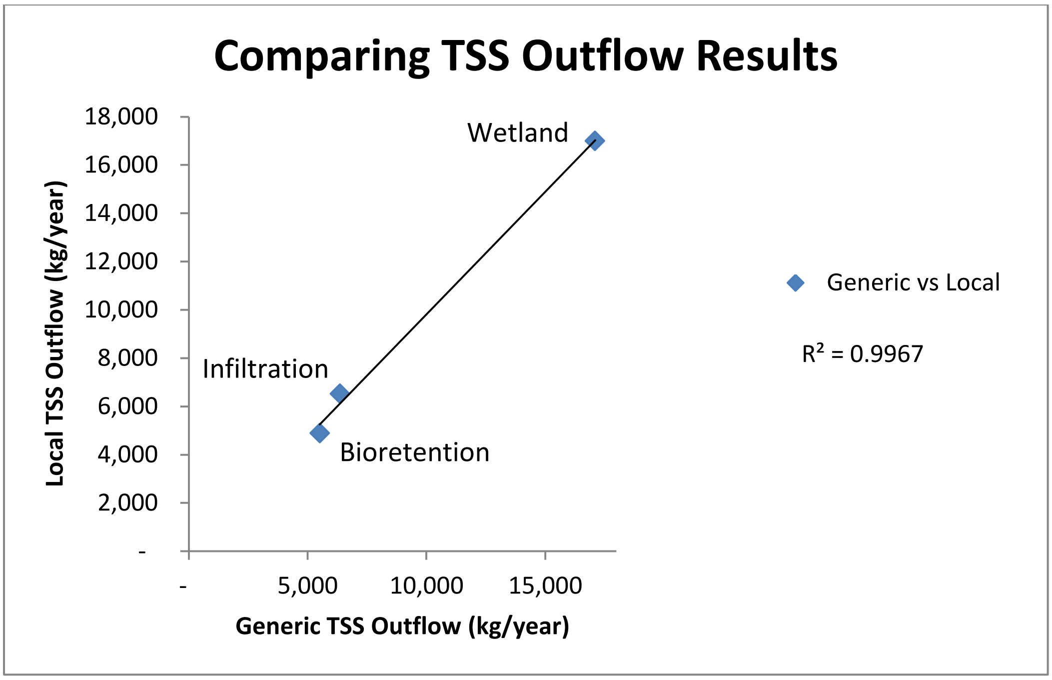


FIGURE 4.16 - COMPARING TSS OUTFLOWS FROM GENERIC AND LOCAL MODELS

The trend line shown on Figure 4.16 demonstrates a very strong correlation between the generic model and local model TSS outflows from each system ($R^2 = 0.99$). The wetland TSS outflows were virtually identical between each model. The bioretention basin showed greater TSS outflow in the generic model. The infiltration systems were noticeably above the trend implying that the local model had the greater TSS outflows.

In reality, if a stormwater practitioner was to design WSUD systems for a catchment using the generic TSS outflow results the systems would be either over-designed or under-designed. The next section demonstrates how the generic model WSUD systems should be redesigned according to the local model TSS outflow results. Note that the local model results are considered as more accurate due to the accurate input parameters that were used to create the model.

4.4.3.2 Redesigning the WSUD Systems

The WSUD systems in the generic model generally achieved a different TSS output then the local model. As such, the systems in the generic model were then redesigned to achieve the same TSS output as the systems in the local model. Due to simplicity the only design specification that varied for each system was the surface area. The surface area of the systems has a considerable impact on the pollutant removal (Wong, 2006).

An iterative process was used. The author changed the surface area of the systems in the generic model in progressive increments until the TSS outflow of the generic model was equivalent to the TSS outflow of the local model. A summary of the redesign specifications of each system in the generic model is shown in Table 33.

Systems	Original Surface Area (m^2)	Redesigned Surface Area (m^2)
Wetland	50	52
Infiltration System	10	6
Bioretention Basin	10	16

TABLE 33 - REDESIGN SPECIFICATION OF WSUD SYSTEMS TO ACHIEVE DESIRED TSS OUTPUTS

The generic model TSS outflow was greater than the local model outflow for the wetland and bioretention basin. As such these systems had to increase in size. The surface area of the wetland only needed a small increase of 2 m^2 which is negligible in design. The bioretention basin had to increase in size to 16 m^2. As the infiltration system in the generic model demonstrated a lower TSS outflow that the local model, the infiltration system was able to decrease in size to 6 m^2. In general the surface area of the WSUD systems did not have to change greatly to account for the difference in TSS outflow. The greatest change in surface area was required of the bioretention basin which was an increase of 6 m^2. This surface area increase is not very large in terms of design specifications.

5 Conclusions

5.1 Introduction

This project has involved a soil investigation in order select suitable WSUD systems for the Spring Creek catchment. In addition, the results from the soil investigation were used to develop valuable parameters which were applied in the MUSIC model. This model, deemed as localized, was compared against a model applying generic (default) parameters in order to determine the sensitivity of the MUSIC model. As a secondary objective, the effects of local and generic soil properties on WSUD systems were evaluated in the MUSIC model.

The soil investigation was mainly concerned with the saturated hydraulic conductivity of the soils in the catchment. The tests include the use of laboratory soil cores and the simplified falling head method in the field.

The local and generic MUSIC models were compared based on the flow characteristics produced. The WSUD systems that were considered were assessed based on their stormwater treatment of TSS.

5.2 Soil Investigation

This project developed a procedure of soil testing required for the selection of WSUD systems based on soil characteristics. The eight sites that were investigated presented a range of soil types. These included two sand, one sandy loam, three loam and two clay soils. In general the clay soils were discovered nearby local water ways (water reserves).

When comparing surface a deep laboratory results an average K_{sat} difference of 51% was measured for all sites. As the soil characteristics from surface to shallow depths changed rapidly, the investigation into soil characteristics at depth is deemed significant. The dry infiltration of the soil cores from each site were much higher than expected. It was concluded that the preparation of the disturbed samples for testing (i.e. crushing and consolidating) had a noticeable effect on the results of the test. As such, the dry infiltration results from the laboratory had to be calibrated according to the comparative difference between laboratory and field results (refer to section 2.6.8).

In general, there was a weak correlation between laboratory and field K_{sat} results (R^2=0.14). The average difference between laboratory surface and field surface K_{sat} values was 71.2%. As expected, sandy soils obtained the highest K_{sat} results followed by loams. Clay soils achieved the lowest K_{sat} values which were relatively similar across all discovered clays in the catchment. The results from laboratory testing had a significant effect on the estimated field deep K_{sat} results.

Based on difference between laboratory and field testing the estimated field deep K_{sat} was found for each site. Analysing these results was critical to the selection of suitable WSUD systems. Most of the estimated field deep K_{sat} values were below 36 mm/hour.

5.3 Water Sensitive Urban Design Systems

The field and laboratory results were applied to select suitable WSUD systems. Due to the low saturated hydraulic conductivity found in the catchment generally ponds and wetlands were the most applicable systems in the catchment. With a continued investigation into stormwater management objectives and water quality it is likely that the broad range of suitable systems will be more defined.

5.4 MUSIC Model Sensitivity

The sensitivity of the MUSIC model was assessed considering the flow rate produced by each model. The effectiveness of the WSUD systems was assessed based on the ability to remove TSS from the stormwater.

When compared to the local parameters the generic parameters underestimated soil properties such as total soil storage and field capacity. Consequently, the local model showed a delay in reaching saturation, allowing the generic model to produce higher initial daily flow rates. As the field capacity in the local model was higher than that of the generic model it was able to produce larger peak flows after several months of simulation (6 year model simulation period in total). The infiltration capacity coefficient was generally greater in the local model. This contributed to a 7% average decrease in flow rate from the catchment over the simulation period. This concluded that the MUSIC model is not sensitive when considering soil parameters. It is recommended that the default parameters be utilized when modelling the Spring Creek catchment.

In general, the WSUD systems in the generic model achieved greater TSS outflow. This occurred because the generic model underestimated the soil parameters of the site. For the generic model, to achieve the same outflow as the local model the surface area of each system required an average increase in surface of 8%. It was concluded that 8% is small change in surface area. This suggests that if the generic parameters are used for modelling WSUD systems the systems won’t be significantly overdesigned.

5.5 Conclusion

This research project critically analysed two general concepts: selection of WSUD systems of the Spring Creek catchment based on soil and a sensitive analysis of the MUSIC model in terms of soil parameters. Due to the low saturated hydraulic conductivity of soil generally found at depth wetlands and ponds were the most suitable systems for the majority of the catchment. Secondly, generic parameters were recommended for MUSIC when modelling areas in the Spring Creek Catchment.

6 Recommendations

6.1 Introduction

This project has been a learning experience which involved achievements with the presence of limitations and challenges particularly during soil testing. The lessons learnt throughout this project shall be beneficial to future work involved in this field.

6.2 Limitations and Challenges

Throughout the duration of this project the author recognised certain limitations and challenges which were considered. These limitations include:

- Minimal time period available for extensive testing
- Only several areas within the subject area were tested due to the large catchment area
- The testing equipment used is accepted by industry although more formal methods exist
- Long periods of rain limited the available time for field testing

6.3 Recommendations for future work

This project has provided a broad clarification of local soil characteristics within the Spring Creek catchment with the motivation that future work will involve research into and the use of WSUD systems. The suitability of WSUD systems for a site depends not only on soil characteristics but also on available area, groundwater characteristics and water quality. The effects of implementing WSUD in the Spring Creek catchment needs to be analysed in depth. The selection of WSUD systems will also depend on the hydrology of the site as different systems have different stormwater capacities. A summary of the recommended action for future work in this field includes:

- Investigation into possibly high ground water table presence and water quality
- Measuring the water quality of local water ways within the area
- Economic analysis of feasible WSUD systems and there consequential effects within urban areas of the Spring Creek catchment
- Hydrological study of the catchment

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Appendix A: Project Specifications

University of Southern Queensland
Faculty of Engineering and Surveying

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: Allister Gaffney
TOPIC: Investigation of WSUD systems using MUSIC within the Spring Creek Catchment
SUPERVISOR: Dr. Ian Brodie
ENROLMENT: ENG4111-Semester 1, 2013;
ENG4112- Semester 2, 2013
PROJECT AIM: This project seeks to define the most suitable infiltration based WSUD systems for the Spring Creek catchment and evaluate generic MUSIC modelling of the catchment in terms of runoff characteristics

PROGRAMME: **Issue A: 1st March 2013**

1. Research the background specifications of WSUD systems in relation to soil properties
2. Define which soil properties are used to select WSUD systems
3. Research the testing methods used to measure the required soil properties of which can be used to develop a site model within the model for urban stormwater improvement conceptualisation (MUSIC)
4. Perform required tests to obtain data based on the soil characteristics
5. Obtain Rainfall data over a sufficient time period for the catchment
6. Import the relevant data into MUSIC and develop a localised model of the catchment
7. Develop a model within MUSIC based on generic specifications for the catchment
8. Perform a sensitivity analysis comparing the results generated from the localised and generic models and evaluate the differences in terms of runoff characteristics
9. From the data obtained from the soil tests identify the most suitable WSUD systems for the catchment

If time permits:

10. Model the WSUD system scenarios within MUSIC and evaluate their effects on the catchment

AGREED:

______________________ (Student) ______________________ (Supervisor)
___/___/___ ___/___/___

Appendix B: Soil Testing

Laboratory Testing

Site A (1)		Site A (2)		Site A (3)	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0	0	0
55	0	51	0	5	0
56.5	0	61.8	102	10	112
70	90	71	96	15	96
80	95	81	89	20	92
85	82	91	92	25	94
90	81	101	81	30	96
95	80	111	73	35	92
100	79	121	71	40	90
105	78	131	70	45	89
110	77	141	65	50	80
115	75	151	65	55	71
120	70	161	65	60	63
125	69			65	63
130	69			70	63
135	69				
Container Weight (g)	64.6	Container Weight (g)	63.9	Container Weight (g)	64.6

Site A1 (deep)		Site A2 (deep)	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0
55	0	62	89
59	0	65	86
70	75	70	84
80	75	75	79
85	70	80	72
90	65.4	85	68
95	64.8	90	56
100	65	95	56
105	64.9	100	55
110	65	105	52
115	65	110	54
		115	54
		120	54
Container Weight (g)	64.6	Container Weight (g)	64.6

Site B (1)		Site B (2)		Site B (3)	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0	0	0
10	82.9	10	91	5	118
15.3	125	15.3	131	10	120
20	132	20	111	15	112
25	112	25	110	20	109
30	109	30	105	25	109
40	195	40	186	30	107
50	181	50	172	35	105
60	180	60	181	40	102
70	172	70	172	45	103
80	168	80	168	50	98
85	82	85	84	55	95
90	83	90	79	60	94
95	81	95	75	65	94
102	94	102	94	70	91
109	95	109	91	75	87
116	95	116	92	80	86
		121	92	85	83
		126	92	90	82
				95	82
				100	82
Container Weight (g)	64.6	Container Weight (g)	64.6	Container Weight (g)	64.6

Site B1 (deep)		Site B2 (deep)	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0
3	0	7	125
10	111.9	14	112
15	122.4	19	124
20	199.05	24	132
25	120	29	125
30	113.1	34	124
40	162.7	39	121
50	165.4	44	121
60	161	49	121
70	154.9	54	120
80	159.8	59	118
85	111.6	64	118
90	112	69	117
95	112.7	74	117
102	135	79	116
109	122	84	112
114	125	89	109
119	120	94	108
124	118	99	108
129	120.5	104	108
Container Weight (g)	64.6	Container Weight (g)	64.6

Site C (1)		Site C (2)		Site C (3)	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0	0	0
2	239.5	2	254	2	220
4	258	4	270	4	251
6	262	6	255	6	249
9	380	9	342	9	242
11	254	11	240	11	238
13	252	13	235	13	235
15	250	15	235	15	246
17	255	17	232	17	230
19	240	19	225	19	231
21	230	21	224	21	225
23	233	23	223	23	218
25	229	25	223	25	215
27	230	27	223	27	209
29	232	29	222	29	207
31	230	31	220	31	205
33	229	33	219	33	202
35	240	35	219	35	201
37	225	37	225	37	196
39	220	39	220	39	196
41	213	41	213	41	191
43	208	43	212	43	189
45	205	45	210	45	189
47	203	47	202	47	189
49	204	49	210		
51	204	51	211		
		53	211		
		55	211		
Container Weight (g)	64.6	Container Weight (g)	64.6	Container Weight (g)	64.6

Site C1 (deep)		Site C2 (deep)	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0
2	227	5	218
4	286	10	225
6	304	15	250
9	392	20	251
11	290	25	245
13	289	30	239
15	285	35	235
17	284	40	228
19	281	45	224
21	283	50	221
23	281	55	220
25	281	60	220
27	277		
29	275		
31	280		
33	280		
35	263		
37	239		
39	225		
41	190		
43	187		
45	186		
47	186		
49	186		
Container Weight (g)	64.6	Container Weight (g)	64.6

Site D1		Site D2		Site D3	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0	0	0
2	545	2	480	2	532
4	532	4	553	4	531
6	530	6	550	6	520
9	700	9	752	9	524
11	520	11	522	11	518
13	482	13	519	13	519
15	475	15	516	15	510
17	504	17	510	17	509
19	493	19	482	19	482
21	483	21	476	21	462
23	461	23	475	23	451
25	457	25	475	25	450
27	438	27	474	27	448
29	433	29	433	29	446
31	430	31	430	31	440
33	429	33	429	33	435
35	427	35	410	35	432
37	427	37	408	37	429
39	425	39	399	39	425
41	424	41	395	41	421
43	422	43	387	43	419
45	422	45	385	45	412
47	419	47	385	47	410
49	418	49	385	49	409
51	418			51	409
53	418			53	409
Container Weight (g)	64.6	Container Weight (g)	64.6	Container Weight (g)	64.6

Site D1 (deep)		Site D2 (deep)	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0
2	146	2	135
4	193	4	186
6	232	6	185
9	295	9	185
11	196	11	184
13	189	13	183
15	187	15	182
17	193	17	183
19	192	19	180
21	190	21	179
23	189	23	179
25	189	25	178
27	183	27	177
29	180	29	177
31	179	31	176
33	180	33	176
35	179	35	177
37	178	37	178
39	175	39	175
41	170	41	175
43	168	43	174
45	168	45	172
47	168	47	171
		49	171
		51	171
Container Weight (g)	64.6	Container Weight (g)	64.6

Site E1		Site E2		Site E3	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0	0	0
2	320	2	316	2	350
4	325	4	318	4	349
6	316	6	408	6	320
9	318	9	530	9	335
11	408	11	310	11	329
13	530	13	308	13	328
15	310	15	306	15	327
17	308	17	307	17	322
19	306	19	292	19	298
21	307	21	286	21	296
23	292	23	292	23	292
25	286	25	276	25	284
27	292	27	271	27	281
29	276	29	269	29	275
31	271	31	260	31	271
33	269	33	253	33	276
35	260	35	252	35	273
37	253	37	252	37	269
39	252	39	250	39	265
41	252	41	250	41	259
43	250	43	250	43	241
45	259			45	236
47	256			47	236
49	248			49	235
51	250			51	233
53	248			53	233
55	248			55	233
57	248				
Container Weight (g)	64.6	Container Weight (g)	64.6	Container Weight (g)	64.6

Site E1 (deep)		Site E2 (deep)	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0
2	379	2	382
4	368	4	378
6	490	6	369
9	620	9	364
11	480	11	363
13	450	13	354
15	449	15	352
17	440	17	341
19	429	19	335
21	415	21	321
23	372	23	308
25	370	25	280
27	370	27	272
29	368	29	269
31	365	31	245
33	350	33	242
35	310	35	241
37	297	37	241
39	248	39	240
41	235	41	238
43	228	43	236
45	226	45	235
47	225	47	226
49	220	49	225
51	220	51	221
53	219	53	199
55	214	55	199
57	213	57	199
59	213		
61	213		
Container Weight (g)	64.6	Container Weight (g)	64.6

Site F1		Site F2		Site F3	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0	0	
2	656	1	643	1	620
4	337	4	500	4	559
7	684	7	687	7	632
9	408	9	405	9	592
12	637	12	637	12	589
15	655	15	655	15	583
18	627	18	635	18	575
21	604	21	620	21	570
24	608	24	610	24	568
27	604	27	600	27	556
30	576	30	582	30	548
33	566	33	565	33	536
36	550	36	552	36	523
39	595	39	595	39	513
42	440	42	462	42	502
45	497	45	486	45	495
48	509	48	480	48	489
51	491	51	473	51	475
54	510	54	470	54	469
57	503	57	465	57	465
60	480	60	462	60	464
63	486	63	460	63	462
66	442	66	447	66	458
69	442	69	445	69	455
72	447	72	442		
		75	436		
		78	435		
		81	435		
Container Weight (g)	64.6	Container Weight (g)	64.6	Container Weight (g)	64.6

Site F1 (deep)		Site F2 (deep)	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0
2	0	2	0
4	0	4	0
7	0	7	0
9	0	9	0
12	0	12	0
15	0	15	36
18	28	18	40
21	37	21	35
24	35	24	33
27	30	27	32
33	41	33	31
38	34	38	29
43	33	43	29
48	34	48	29
53	34		
Container Weight (g)	64.6	Container Weight (g)	64.6

Site G1		Site G2		Site G3	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0	0	0
2	57	2	67	2	71
5	99	5	95	5	145
9	112	9	109	9	152
12	91	12	92	12	143
17	141	17	135	17	141
23	161	23	170	23	135
28	126	28	121	28	134
33	128	33	118	33	131
38	124	38	115	38	129
43	116	43	109	43	129
48	119	48	109	48	128
53	115	53	109	53	128
58	114	58	108	58	128
63	113	63	108		
		68	108		
Container Weight (g)	64.6	Container Weight (g)	64.6	Container Weight (g)	64.6

Site G1 (deep)		Site G2 (deep)	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0
2	0	2	0
5	0	5	20
9	48	9	61
12	56	12	87
17	77	17	82
23	84	23	79
28	71	28	72
33	69	33	71
38	68	38	69
43	65	43	68
48	67	48	65
53	65	53	63
58	65	58	62
63	64	63	60
68	64	68	59
73	64	73	59
		78	59
Container Weight (g)	64.6	Container Weight (g)	64.6

Site H1		Site H2		Site H3	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	0	0	0
2	0	3	0	3	0
5	124	5	130	5	152
9	182	9	186	9	199
12	128	12	135	12	203
17	201	17	195	17	202
23	233	23	198	23	201
28	192	28	196	28	205
33	193	33	186	33	200
38	197	38	185	38	201
43	198	43	180	43	198
48	201	48	176	48	197
53	197	53	176	53	197
58	188	58	175	58	196
63	185	63	170	63	195
68	185	68	172	68	195
73	186	73	169	73	195
		78	169		
		83	169		
Container Weight (g)	64.6	Container Weight (g)	64.6	Container Weight (g)	65.2

Site H1 (deep)		Site H2 (deep)	
Time (min)	Total Weight (g)	Time (min)	Total Weight (g)
0	0	0	
2	101	2	120
5	152	5	192
9	184	9	186
12	232	12	185
17	247	17	172
23	300	23	165
28	300	28	164
33	241	33	164
38	246	38	163
43	239	43	162
48	239	48	161
53	232	53	152
58	231	58	140
63	222	63	121
68	220	68	158
73	196	73	157
78	195	78	156
83	192	83	154
88	185	88	151
93	180	93	149
98	172	98	147
103	175	103	145
108	160	108	143
113	159	113	141
118	146	118	141
123	135	123	141
128	131		
133	130		
138	130		
143	130		
Container Weight (g)	64.6	Container Weight (g)	63.8

Field Testing Data

The letter denotes the site and the number represents the replicate, in the first column.

Sites	Volume (L)	Time (s)	Initial moisture content (m/m)	Saturated moisture content (m/m)	alpha(per m)
A1	0.65	4410	0.52	0.63	1
A2	0.65	875	0.15	0.63	1
A3	0.44	1880	0.53	0.63	1
B1	0.62	93	0.18	0.6	12
B2	0.65	85	0.21	0.6	12
B3	0.55	60	0.17	0.6	12
C1	0.8	1031	0.49	0.631	12
C2	0.5	805	0.49	0.631	12
C3	0.5	1512	0.51	0.631	12
C4	1	2165	0.41	0.631	12
D1	0.65	112	0.15	0.61	36
D2	0.65	98	0.15	0.61	36
D3	0.65	156	0.15	0.61	36
E1	1.1	86	0.48093	0.697	36
E2	1	80	0.48093	0.697	36
E3	1	75	0.48093	0.697	36
F1	0.65	50	0.4	0.7	12
F2	0.65	65	0.4	0.7	12
F3	0.65	63	0.4	0.7	12
G1	0.63	3746	0.3	0.6	1
G2	0.65	4007	0.3	0.6	1
G3	0.65	4102	0.31	0.6	1
H1	0.65	952	0.21	0.6	36
H2	0.65	1019	0.35	0.6	36
H3	0.65	1235	0.36	0.6	36

Appendix C: Original Laboratory Testing Method

Method of determining the saturated hydraulic conductivity of a soil derived from Bennett & Raine (2012).

1. Air dry soil samples
2. Crush samples to pass through a 2.36mm sieve
3. Soil samples (internal diameter 87.5mm, length 50mm) are inserted into stormwater pipe columns (90mm external diameter, 75mm length) with filter placed at the bottom of each
4. The soil columns are then dropped from a 50mm height three times. The average bulk density for all of the samples is found and each sample is re-packed to this bulk density
5. Two filter papers are placed on top of the soil columns
6. The columns are pre-soaked in a bath of rain water for a minimum of 12 hours
7. The columns are removed from the bath and 1000cm^3 of water is applied to the top of each column. The columns have a Bucher funnel attached at the bottom allowing it to be open to the atmosphere. The water is given the opportunity to drain (approximately 2 hours).
8. A second supply of water is applied to the top of the columns with a constant head of 20mm (relative to the surface of the column)
9. The discharge from the base of each column is measured in particular time intervals until a constant discharge is recorded.
10. The Hydraulic Conductivity is calculated using Darcy’s Equation.

Appendix D: MUSIC Model Parameters and Results

Note: water quality and groundwater parameters were default for both the generic and local models.

Generic Model Input Parameters

Rooting Zone Thickness: 400 mm

Site	Faction Impervious	Area (ha)	Total soil storage (mm)	Initial Moisture (%)	Field Capacity (mm)	Infiltration Capacity Coefficient (mm/day)
A	70	30.1	75	67	68	175
B	30	35.9	77	40	70	200
C	35	16.9	77	60	70	200
D	40	18	140	70	60	400
E	30	4.7	140	57	60	400
F	70	21.0	111	62	58	200
G	60	28.1	72	70	66	175
H	60	15.8	77	55	70	200
Ag	10	38.2	111	62	58	200

Local Model Input Parameters

Rooting Zone Thickness: 400 mm

Site	Impervious (%)	Area (ha)	Total soil storage (mm)	Initial Moisture (%)	Field Capacity (mm)	Infiltration Capacity Coefficient (mm/day)
A	70	30.1	205	67	158	20
B	30	35.9	153	40	86	465
C	35	16.9	181	60	202	262
D	40	18	165	70	104	482
E	30	4.7	248	57	201	1081
F	70	21.0	225	62	158	295
G	60	28.1	199	70	129	30
H	60	15.8	220	55	136	259
Ag	10	38.2	225	62	158	295

Raw Results

Date	Generic (cumecs)	Local (cumecs)
17/12/2002	0.00715386	0.00117244
18/12/2002	0.00679616	0.00111382
19/12/2002	0.00645635	0.00105813
20/12/2002	0.00613354	0.00100522
21/12/2002	0.00582686	0.00095496
22/12/2002	0.00553552	0.00090721
23/12/2002	0.00525874	0.00086185
24/12/2002	0.13569884	0.1315218
25/12/2002	0.27041791	0.26107858
26/12/2002	0.27513299	0.1739664
27/12/2002	0.0084734	0.00256574
28/12/2002	0.00860683	0.00270825
29/12/2002	0.00833877	0.00261607
30/12/2002	0.00792183	0.00248527
31/12/2002	0.00752574	0.002361
1/01/2003	0.00714946	0.00224295
2/01/2003	0.00679198	0.00213081
3/01/2003	0.00645238	0.00202427
4/01/2003	0.00612976	0.00192305
5/01/2003	0.00582328	0.0018269
6/01/2003	0.00553211	0.00173556
7/01/2003	0.00525551	0.00164878
8/01/2003	0.00499273	0.00156634
9/01/2003	0.00474309	0.00148802
10/01/2003	0.00450594	0.00141362
11/01/2003	0.00428064	0.00134294
12/01/2003	0.00406661	0.00127579
13/01/2003	0.00386328	0.001212
14/01/2003	0.00367012	0.0011514
15/01/2003	0.00348661	0.00109383
16/01/2003	0.00331228	0.00103914
17/01/2003	0.00314667	0.00098718
18/01/2003	0.00298933	0.00093782
19/01/2003	0.00283987	0.00089093
20/01/2003	0.00269787	0.00084639
21/01/2003	0.07382195	0.07206304
22/01/2003	0.00243483	0.00076386
23/01/2003	0.00231309	0.00072567
24/01/2003	0.00219743	0.00068939
25/01/2003	0.00208756	0.00065492
26/01/2003	0.00198318	0.00062217
27/01/2003	0.00188403	0.00059106

28/01/2003	0.00178982	0.00056151
29/01/2003	0.00170033	0.00053343
30/01/2003	0.00161532	0.00050676
31/01/2003	0.00153455	0.00048143
1/02/2003	0.009799	0.00879853
2/02/2003	0.00138493	0.00043449
3/02/2003	0.00131569	0.00041276
4/02/2003	0.1949869	0.19412912
5/02/2003	0.07181287	0.07099799
6/02/2003	0.00544644	0.0046723
7/02/2003	0.00507329	0.00433785
8/02/2003	0.00101805	0.00031939
9/02/2003	0.00096715	0.00030342
10/02/2003	0.00091879	0.00028825
11/02/2003	0.00677503	0.00617601
12/02/2003	0.00082921	0.00026014
13/02/2003	0.00078775	0.00024714
14/02/2003	0.00074836	0.00023478
15/02/2003	0.00071094	0.00022304
16/02/2003	0.0006754	0.00021189
17/02/2003	0.00064163	0.00020129
18/02/2003	0.12308756	0.12266924
19/02/2003	0.04249611	0.04209871
20/02/2003	0.00055011	0.00017258
21/02/2003	0.00052261	0.00016395
22/02/2003	0.45498662	0.46068952
23/02/2003	0.19832499	0.1946346
24/02/2003	0.03596467	0.03266059
25/02/2003	0.2102101	0.14261549
26/02/2003	0.02454312	0.01887733
27/02/2003	0.10300293	0.07746553
28/02/2003	0.00794197	0.00111575
1/03/2003	0.02713373	0.02025654
2/03/2003	0.00772479	0.00108846
3/03/2003	0.00733855	0.00103404
4/03/2003	0.00697162	0.00098233
5/03/2003	0.00662304	0.00093322
6/03/2003	0.00629189	0.00088656
7/03/2003	0.00597729	0.00084223
8/03/2003	0.00567843	0.00080012
9/03/2003	0.00539451	0.00076011
10/03/2003	0.00512478	0.00072211
11/03/2003	0.00486854	0.000686
12/03/2003	0.07135452	0.0673811
13/03/2003	0.15262392	0.14884917

14/03/2003	0.00417417	0.00058816
15/03/2003	0.00396546	0.00055875
16/03/2003	0.01463183	0.01139546
17/03/2003	0.00357883	0.00050427
18/03/2003	0.02240509	0.01948427
19/03/2003	0.00322989	0.00045511
20/03/2003	0.0030684	0.00043235
21/03/2003	0.26095291	0.25844867
22/03/2003	0.12095545	0.11831751
23/03/2003	0.00289978	0.00037069
24/03/2003	0.00275479	0.00035215
25/03/2003	0.00261705	0.00033455
26/03/2003	0.01726803	0.01509965

WSUD system Specifications

The WSUD systems specifications were the same for the local and generic model except where specified.

Node Type	**Wetland**	{Node Type}
Node Name	Wetland	{Node Name}
Node ID	16	{Node ID}
Coordinates	419.80373153938:-235.372858999364	{Coordinates}{[X:Y]}
General - Location	Wetland	
General - Notes		
General - Fluxes		
Stormwater Re-use - Use stored water for irrigation or other purpose	1	
Stormwater Re-use - Annual Demand Type	0	{Index from 0 to 1 for "PET" | "PET - Rain"}
Stormwater Re-use - Annual Demand (kL/yr) Scaled by Daily: PET	-9999	{kL/yr}
Stormwater Re-use - Annual Demand (kk/yr) Scaled by Daily: PET - Rain	-9999	{kk/yr}
Stormwater Re-use - Daily Demand (kL/day)	-9999000	{kL/day}
Stormwater Re-use - User-defined distribution of Annual Demand (ML/yr)	-9999	{ML/yr}
Stormwater Re-use - User-defined time series		
Inlet Properties - Low Flow By-pass (cubic metres per sec)	0	{cubic metres per sec}
Inlet Properties - High Flow By-pass (cubic metres per sec)	100	{cubic metres per sec}
Inlet Properties - Inlet Pond Volume (cubic metres)	0	{cubic metres}
Storage Properties - Surface Area (square metres)	50	{square metres}
Storage Properties - Extended Detention Depth (metres)	1	{metres}
Storage Properties - Permanent Pool Volume (cubic metres)	50	{cubic metres}
Storage Properties - Exfiltration Rate (mm/hr)	0	{mm/hr}
Storage Properties - Evaporative Loss as % of PET	125	
Outlet Properties - Equivalent Pipe Diameter (mm)	200	{mm}
Outlet Properties - Overflow Weir Width (metres)	3	{metres}
Outlet Properties - Notional Detention Time (hrs)	0.149022413	{hrs}
Advanced Properties - Orifice Discharge Coefficient	0.6	

Advanced Properties - Weir Coefficient	1.7	
Advanced Properties - Number of CSTR Cells	4	
Advanced Properties - Total Suspended Solids - k (m/yr)	1500	{m/yr}
Advanced Properties - Total Suspended Solids - C* (mg/L)	6	{mg/L}
Advanced Properties - Total Suspended Solids - C** (mg/L)	6	{mg/L}
Advanced Properties - Total Phosphorus - k (m/yr)	1000	{m/yr}
Advanced Properties - Total Phosphorus - C* (mg/L)	0.06	{mg/L}
Advanced Properties - Total Phosphorus - C** (mg/L)	0.06	{mg/L}
Advanced Properties - Total Nitrogen - k (m/yr)	150	{m/yr}
Advanced Properties - Total Nitrogen - C* (mg/L)	1	{mg/L}
Advanced Properties - Total Nitrogen - C** (mg/L)	1	{mg/L}
Advanced Properties - Threshold Hydraulic Loading for C** (m/yr)	3500	{m/yr}
Advanced Properties - User Defined Storage-Discharge-Height		
Node Type	**Infiltration System**	{Node Type}
Node Name	Infiltration System	{Node Name}
Node ID	17	{Node ID}
Coordinates	213.357698585129:-86.5979850485275	{Coordinates}{[X:Y]}
General - Location	Infiltration System	
General - Notes		
General - Fluxes		
Inlet Properties - Low Flow By-pass (cubic metres per sec)	0	{cubic metres per sec}
Inlet Properties - High Flow By-pass (cubic metres per sec)	100	{cubic metres per sec}
Storage and Infiltration Properties - Pond Surface Area (square metres)	10	{square metres}
Storage and Infiltration Properties - Extended Detention Depth (metres)	0.2	{metres}
Storage and Infiltration Properties - Filter Area (square metres)	10	{square metres}
Storage and Infiltration Properties - Unlined Filter Media Perimeter (metres)	14	{metres}
Storage and Infiltration Properties - Depth of Infiltration Media (metres)	1	{metres}
Storage and Infiltration Properties - Exfiltration Rate (mm/hr)	100	{mm/hr}
Storage and Infiltration Properties - Evaporative Loss as % of PET	100	

Outlet Properties - Overflow Weir Width (metres)	2	{metres}
Advanced Properties - Weir Coefficient	1.7	
Advanced Properties - Number of CSTR Cells	1	
Advanced Properties - Total Suspended Solids - k (m/yr)	400	{m/yr}
Advanced Properties - Total Suspended Solids - C* (mg/L)	12	{mg/L}
Advanced Properties - Total Suspended Solids - C** (mg/L)	12	{mg/L}
Advanced Properties - Total Phosphorus - k (m/yr)	300	{m/yr}
Advanced Properties - Total Phosphorus - C* (mg/L)	0.09	{mg/L}
Advanced Properties - Total Phosphorus - C** (mg/L)	0.09	{mg/L}
Advanced Properties - Total Nitrogen - k (m/yr)	40	{m/yr}
Advanced Properties - Total Nitrogen - C* (mg/L)	1	{mg/L}
Advanced Properties - Total Nitrogen - C** (mg/L)	1	{mg/L}
Advanced Properties - Threshold Hydraulic Loading for C** (m/yr)	3500	{m/yr}
Advanced Properties - Porosity of Infiltration Media	0.35	
Advanced Properties - Horizontal Flow Coefficient	3	
Advanced Properties - User Defined Storage-Discharge-Height		
Node Type	**BioRetentionNodeV4**	{Node Type}
Node Name	Bioretention	{Node Name}
Node ID	18	{Node ID}
Coordinates	412.281406451978:-106.657518614932	{Coordinates}{[X:Y]}
General - Location	Bioretention	
General - Notes		
General - Fluxes		
Inlet Properties - Low Flow By-pass (cubic metres per sec)	0	{cubic metres per sec}
Inlet Properties - High Flow By-pass (cubic metres per sec)	100	{cubic metres per sec}
Storage Properties - Extended Detention Depth (metres)	0.2	{metres}
Storage Properties - Surface Area (square metres)	10	{square metres}
Filter and Media Properties - Filter Area (square metres)	10	{square metres}
Filter and Media Properties - Unlined	14	{metres}

Filter Media Perimeter (metres)		
Filter and Media Properties - Saturated Hydraulic Conductivity (mm/hr)	100	{mm/hr}
Filter and Media Properties - Filter Depth (metres)	0.5	{metres}
Filter and Media Properties - TN Content of Filter Media (mg/kg)	800	{mg/kg}
Filter and Media Properties - Orthophosphate Content of Filter Media (mg/kg)	80	{mg/kg}
Infiltration Properties - Exfiltration Rate (mm/hr)	0	{mm/hr}
Lining Properties - Base Lined	1	
Vegetation Properties - Vegetation Properties	0	{Index from 0 to 2 for "Vegetated with Effective Nutrient Removal Plants" | "Vegetated with Ineffective Nutrient Removal Plants" | "Unvegetated"}
Outlet Properties - Overflow Weir Width (metres)	2	{metres}
Outlet Properties - Underdrain Present	0	
Outlet Properties - Submerged Zone With Carbon Present	1	
Outlet Properties - Submerged Zone Depth (metres)	0.45	{metres}
Advanced Properties - Total Suspended Solids - k (m/yr)	8000	{m/yr}
Advanced Properties - Total Suspended Solids - C* (mg/L)	20	{mg/L}
Advanced Properties - Total Phosphorus - k (m/yr)	6000	{m/yr}
Advanced Properties - Total Phosphorus - C* (mg/L)	0.13	{mg/L}
Advanced Properties - Total Nitrogen - k (m/yr)	500	{m/yr}
Advanced Properties - Total Nitrogen - C* (mg/L)	1.4	{mg/L}
Advanced Properties - Filter Media Soil Type	1	{Index from 0 to 4 for "Sand" | "Loamy Sand" | "Sandy Loam" | "Silt Loam" | "Loam"}
Advanced Properties - Weir Coefficient	1.7	
Advanced Properties - Number of CSTR Cells	3	
Advanced Properties - Porosity of Filter Media	0.35	
Advanced Properties - Porosity of Submerged Zone	0.35	
Advanced Properties - Horizontal Flow	3	

Coefficient		

WSUD System Modelling Results

Three months of TSS inflow and outflow data have been provided as an example of the results.

Generic Model

	Bioretention		**Infiltration**		**Wetland**	
	[TSS]	(mg/L)	[TSS]	(mg/L)	[TSS]	(mg/L)
Date	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
17/12/2002	11.0	3.5	14.3	14.1	14.8	6.0
18/12/2002	11.2	2.9	16.6	0.0	13.2	6.0
19/12/2002	18.6	2.5	22.0	18.5	7.3	6.0
20/12/2002	12.5	2.2	11.4	0.0	14.3	6.0
21/12/2002	19.9	2.0	7.0	9.6	11.9	6.0
22/12/2002	7.8	1.9	17.1	0.0	13.8	6.0
23/12/2002	18.1	1.8	6.3	0.0	8.7	6.0
24/12/2002	196.6	123.8	162.7	149.8	387.8	304.9
25/12/2002	220.4	181.2	149.2	154.9	84.8	176.1
26/12/2002	428.0	378.9	38.7	104.9	91.3	85.7
27/12/2002	11.4	14.2	11.5	36.5	13.8	83.4
28/12/2002	19.2	1.5	15.6	0.0	17.6	0.0
29/12/2002	23.0	1.5	12.4	13.8	10.3	6.0
30/12/2002	16.4	1.5	11.5	0.0	6.9	6.0
31/12/2002	25.7	1.5	15.9	0.0	10.1	6.0
1/01/2003	16.2	1.5	13.8	0.0	19.9	6.0
2/01/2003	26.7	1.5	11.0	0.0	17.0	6.0
3/01/2003	11.8	1.5	14.1	0.0	8.1	6.0
4/01/2003	6.9	1.5	11.2	0.0	9.7	6.0
5/01/2003	7.6	1.5	7.6	0.0	10.6	6.0
6/01/2003	10.6	1.5	18.9	0.0	11.3	6.0
7/01/2003	11.7	1.5	6.7	0.0	10.8	6.0
8/01/2003	34.5	1.5	9.2	0.0	16.0	6.0
9/01/2003	17.9	1.5	8.2	0.0	14.7	6.0
10/01/2003	10.2	1.5	26.8	0.0	12.7	6.0
11/01/2003	11.8	1.5	14.2	0.0	10.0	6.0
12/01/2003	11.3	1.5	20.1	0.0	12.6	6.0
13/01/2003	13.9	1.5	18.0	0.0	19.2	6.0
14/01/2003	10.6	1.5	11.6	0.0	19.0	6.0
15/01/2003	13.6	1.5	7.2	0.0	40.3	6.0
16/01/2003	21.5	1.5	9.2	0.0	11.0	6.0
17/01/2003	23.7	1.5	9.4	0.0	8.2	6.0
18/01/2003	20.5	1.5	12.8	0.0	12.4	6.0

19/01/2003	7.3	1.5	13.7	0.0	12.1	0.0
20/01/2003	18.5	1.5	14.3	0.0	21.1	6.0
21/01/2003	158.0	72.6	92.1	83.2	329.6	213.0
22/01/2003	9.1	2.5	19.2	0.0	13.1	225.8
23/01/2003	6.9	1.5	9.6	0.0	11.5	0.0
24/01/2003	16.8	1.5	5.8	0.0	13.6	0.0
25/01/2003	12.4	1.6	24.0	0.0	16.3	6.0
26/01/2003	10.4	1.6	11.2	0.0	10.5	6.0
27/01/2003	9.1	1.6	8.4	0.0	12.0	6.0
28/01/2003	13.8	1.6	5.4	0.0	5.4	6.0
29/01/2003	16.3	1.6	17.9	0.0	11.6	6.0
30/01/2003	20.3	1.6	15.7	0.0	29.5	6.0
31/01/2003	7.1	1.6	14.3	0.0	17.1	6.0
1/02/2003	114.6	8.7	113.7	0.0	392.2	15.6
2/02/2003	23.6	1.6	16.6	0.0	10.2	15.9
3/02/2003	5.8	1.6	17.3	0.0	10.4	0.0
4/02/2003	93.8	72.8	375.8	364.0	284.9	242.4
5/02/2003	128.5	60.9	139.7	313.3	63.3	206.5
6/02/2003	333.1	1.8	131.3	0.0	269.0	62.9
7/02/2003	141.4	1.5	369.8	0.0	78.6	11.5
8/02/2003	22.3	1.5	20.5	0.0	10.0	0.0
9/02/2003	21.0	1.6	7.5	0.0	13.0	0.0
10/02/2003	12.8	1.6	13.6	0.0	20.3	0.0
11/02/2003	98.4	1.8	55.7	0.0	273.3	7.6
12/02/2003	18.8	1.6	18.3	0.0	16.3	7.8
13/02/2003	10.6	1.6	15.3	0.0	5.3	0.0
14/02/2003	10.1	1.6	12.7	0.0	11.4	0.0
15/02/2003	11.1	1.7	19.7	0.0	23.3	0.0
16/02/2003	8.7	1.7	15.4	0.0	13.4	0.0
17/02/2003	10.0	1.7	18.7	0.0	25.4	0.0
18/02/2003	145.0	89.6	250.0	240.7	61.4	48.7
19/02/2003	142.9	52.1	85.1	207.2	74.9	56.0
20/02/2003	10.4	1.8	18.5	0.0	14.3	0.0
21/02/2003	16.0	1.7	13.8	0.0	6.8	0.0
22/02/2003	89.9	81.8	137.9	136.5	285.3	265.1
23/02/2003	100.3	77.7	71.0	118.7	131.8	230.0
24/02/2003	221.1	62.5	145.1	84.2	258.1	137.2
25/02/2003	492.0	409.5	76.5	91.1	132.9	135.5
26/02/2003	109.2	28.6	70.5	75.6	150.6	121.4
27/02/2003	62.7	44.0	779.9	586.7	240.2	178.5
28/02/2003	24.9	2.0	5.9	0.0	10.0	0.0
1/03/2003	57.9	19.9	228.8	149.8	207.4	49.1
2/03/2003	11.2	1.4	6.0	0.0	15.4	51.0
3/03/2003	16.9	1.4	10.7	0.0	37.7	0.0
4/03/2003	7.5	1.4	12.9	0.0	19.4	0.0

5/03/2003	9.3	1.4	12.3	0.0	17.8	0.0
6/03/2003	13.8	1.5	11.6	0.0	18.0	0.0
7/03/2003	6.6	1.5	12.8	0.0	10.9	0.0
8/03/2003	8.2	1.5	9.3	0.0	18.5	6.0
9/03/2003	16.7	1.5	12.5	0.0	26.6	6.0
10/03/2003	23.6	1.5	12.7	0.0	14.1	6.0
11/03/2003	16.5	1.5	21.0	0.0	29.2	6.0
12/03/2003	51.1	30.2	119.0	102.6	297.5	187.0
13/03/2003	69.1	50.6	358.5	279.7	72.3	128.8
14/03/2003	6.7	2.6	18.4	0.0	18.2	63.9
15/03/2003	12.7	1.5	8.5	0.0	17.5	0.0
16/03/2003	184.0	17.9	134.8	0.0	631.7	41.4
17/03/2003	12.6	1.5	4.0	0.0	17.1	47.5
18/03/2003	134.0	28.5	192.7	135.2	175.3	42.7
19/03/2003	13.0	1.5	10.3	0.0	13.4	42.1
20/03/2003	9.8	1.5	13.3	0.0	16.2	0.0
21/03/2003	68.2	57.8	134.3	129.5	228.3	202.0
22/03/2003	140.9	85.6	251.2	173.0	287.9	231.0
23/03/2003	14.2	3.5	18.7	0.0	11.9	0.0
24/03/2003	11.8	1.5	19.8	0.0	8.7	0.0
25/03/2003	13.1	1.5	12.6	0.0	8.2	0.0
26/03/2003	168.4	24.6	61.6	0.0	111.8	17.3
27/03/2003	14.7	1.5	10.8	0.0	6.8	19.8
28/03/2003	144.7	93.2	646.0	604.4	265.5	210.2
29/03/2003	6.5	4.3	11.4	0.0	14.1	218.0
30/03/2003	10.3	1.5	21.8	0.0	17.2	0.0

Local Model

	Bioretention		**Infiltration**		**Wetland**	
	[TSS]	(mg/L)	[TSS]	(mg/L)	[TSS]	(mg/L)
Date	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
17/12/2002	0.0	0.0	7.3	0.0	0.0	0.0
18/12/2002	0.0	0.0	15.5	0.0	0.0	0.0
19/12/2002	0.0	0.0	11.7	0.0	0.0	0.0
20/12/2002	0.0	0.0	13.0	0.0	0.0	0.0
21/12/2002	0.0	0.0	12.8	0.0	0.0	0.0
22/12/2002	0.0	0.0	5.2	0.0	0.0	0.0
23/12/2002	0.0	0.0	17.1	0.0	0.0	0.0
24/12/2002	344.9	211.2	84.0	81.9	344.9	269.5
25/12/2002	224.3	182.6	64.1	71.3	224.3	248.4
26/12/2002	180.0	129.6	90.7	75.4	180.0	195.8
27/12/2002	0.0	11.3	13.8	0.0	0.0	0.0
28/12/2002	0.0	2.3	9.1	0.0	0.0	0.0

29/12/2002	0.0	2.4	6.6	0.0	0.0	0.0
30/12/2002	0.0	2.4	6.7	0.0	0.0	0.0
31/12/2002	0.0	0.0	11.4	0.0	0.0	0.0
1/01/2003	0.0	0.0	9.5	0.0	0.0	0.0
2/01/2003	0.0	0.0	11.4	0.0	0.0	0.0
3/01/2003	0.0	0.0	9.8	0.0	0.0	0.0
4/01/2003	0.0	0.0	8.5	0.0	0.0	0.0
5/01/2003	0.0	0.0	18.3	0.0	0.0	0.0
6/01/2003	0.0	0.0	12.1	0.0	0.0	0.0
7/01/2003	0.0	0.0	11.6	0.0	0.0	0.0
8/01/2003	0.0	0.0	20.4	0.0	0.0	0.0
9/01/2003	0.0	0.0	13.0	0.0	0.0	0.0
10/01/2003	0.0	0.0	7.9	0.0	0.0	0.0
11/01/2003	0.0	0.0	4.2	0.0	0.0	0.0
12/01/2003	0.0	0.0	11.2	0.0	0.0	0.0
13/01/2003	0.0	0.0	16.6	0.0	0.0	0.0
14/01/2003	0.0	0.0	16.0	0.0	0.0	0.0
15/01/2003	0.0	0.0	9.2	0.0	0.0	0.0
16/01/2003	0.0	0.0	7.9	0.0	0.0	0.0
17/01/2003	0.0	0.0	9.2	0.0	0.0	0.0
18/01/2003	0.0	0.0	15.4	0.0	0.0	0.0
19/01/2003	0.0	0.0	12.4	0.0	0.0	0.0
20/01/2003	0.0	0.0	14.4	0.0	0.0	0.0
21/01/2003	212.2	94.1	209.3	195.4	212.2	136.1
22/01/2003	0.0	5.6	24.3	0.0	0.0	144.0
23/01/2003	0.0	3.0	15.4	0.0	0.0	0.0
24/01/2003	0.0	2.9	13.3	0.0	0.0	0.0
25/01/2003	0.0	2.8	9.3	0.0	0.0	0.0
26/01/2003	0.0	0.0	12.6	0.0	0.0	0.0
27/01/2003	0.0	0.0	10.9	0.0	0.0	0.0
28/01/2003	0.0	0.0	7.6	0.0	0.0	0.0
29/01/2003	0.0	0.0	11.8	0.0	0.0	0.0
30/01/2003	0.0	0.0	13.9	0.0	0.0	0.0
31/01/2003	0.0	0.0	12.8	0.0	0.0	0.0
1/02/2003	226.1	10.4	62.0	0.0	226.1	9.0
2/02/2003	0.0	2.6	11.0	0.0	0.0	10.6
3/02/2003	0.0	2.5	12.3	0.0	0.0	0.0
4/02/2003	108.1	83.1	154.9	151.6	108.1	92.0
5/02/2003	306.2	129.8	141.3	152.0	306.2	145.0
6/02/2003	316.5	2.6	349.6	0.0	316.5	208.2
7/02/2003	118.9	1.8	91.9	0.0	118.9	14.4
8/02/2003	0.0	1.8	12.6	0.0	0.0	0.0
9/02/2003	0.0	1.9	14.4	0.0	0.0	0.0
10/02/2003	0.0	2.0	9.9	0.0	0.0	0.0
11/02/2003	232.3	1.9	78.8	0.0	232.3	6.9

12/02/2003	0.0	1.9	10.2	0.0	0.0	7.3
13/02/2003	0.0	2.0	23.3	0.0	0.0	0.0
14/02/2003	0.0	2.1	14.7	0.0	0.0	0.0
15/02/2003	0.0	2.2	9.9	0.0	0.0	0.0
16/02/2003	0.0	0.0	21.2	0.0	0.0	0.0
17/02/2003	0.0	0.0	8.7	0.0	0.0	0.0
18/02/2003	357.3	209.5	192.9	187.2	357.3	273.8
19/02/2003	113.9	44.7	215.7	198.4	113.9	252.2
20/02/2003	0.0	2.1	8.1	0.0	0.0	0.0
21/02/2003	0.0	2.0	11.6	0.0	0.0	0.0
22/02/2003	227.3	203.7	71.6	71.1	227.3	211.7
23/02/2003	165.4	125.1	28.8	59.4	165.4	201.8
24/02/2003	81.4	31.0	302.0	68.5	81.4	138.8
25/02/2003	73.0	52.1	270.0	275.1	73.0	67.1
26/02/2003	275.3	41.5	205.4	0.0	275.3	81.4
27/02/2003	106.5	53.6	58.2	84.8	106.5	103.7
28/02/2003	0.0	3.2	9.0	0.0	0.0	0.0
1/03/2003	133.7	27.5	171.2	0.0	133.7	19.1
2/03/2003	0.0	1.6	14.4	0.0	0.0	30.0
3/03/2003	0.0	1.8	11.8	0.0	0.0	0.0
4/03/2003	0.0	1.9	24.6	0.0	0.0	0.0
5/03/2003	0.0	2.0	22.3	0.0	0.0	0.0
6/03/2003	0.0	0.0	14.1	0.0	0.0	0.0
7/03/2003	0.0	0.0	11.7	0.0	0.0	0.0
8/03/2003	0.0	0.0	20.2	0.0	0.0	0.0
9/03/2003	0.0	0.0	8.8	0.0	0.0	0.0
10/03/2003	0.0	0.0	12.5	0.0	0.0	0.0
11/03/2003	0.0	0.0	18.8	0.0	0.0	0.0
12/03/2003	171.3	75.9	563.0	533.3	171.3	102.2
13/03/2003	58.1	43.7	116.5	256.2	58.1	83.6
14/03/2003	0.0	5.0	15.5	0.0	0.0	0.0
15/03/2003	0.0	2.2	10.0	0.0	0.0	0.0
16/03/2003	160.6	15.1	23.5	0.0	160.6	0.0
17/03/2003	0.0	2.0	7.8	0.0	0.0	13.0
18/03/2003	441.3	63.1	345.3	0.0	441.3	84.3
19/03/2003	0.0	1.9	22.1	0.0	0.0	89.6
20/03/2003	0.0	2.0	13.7	0.0	0.0	0.0
21/03/2003	84.1	70.5	479.1	472.5	84.1	74.5
22/03/2003	139.9	84.8	299.7	425.5	139.9	94.8
23/03/2003	0.0	6.0	11.2	0.0	0.0	0.0
24/03/2003	0.0	1.9	19.5	0.0	0.0	0.0
25/03/2003	0.0	2.0	9.3	0.0	0.0	0.0
26/03/2003	117.3	19.9	180.3	0.0	117.3	8.3