University of Southern Queensland
Faculty of Health, Engineering and Sciences

Effects of Proposed Bioretention System on Existing Waterbird Habitat

A dissertation submitted by

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in fulfilment of the requirements of

ENG 4111/2 Research Project

towards the degree of

Bachelor of Engineering (Civil)

Submitted: October, 2013

Abstract

As stormwater quality becomes increasingly central to urban development, planning for solutions is necessary. With increased development and finite free space, Toowoomba Regional Council (TRC) has recognised a need for efficient stormwater quality treatment measures. For this reason, this study seeks to anticipate the effectiveness of a stormwater quality treatment system currently being considered by TRC.

Upstream of Toowoomba's existing Waterbird Habitat, TRC has proposed a bioretention system that is hoped will offset a rise in pollutants due to increased development further upstream. Little is known about the current water quality within the Waterbird Habitat, or the impact a bioretention system will have on it. Thus, this project seeks to determine the Waterbird Habitat's current water quality, and the effects that a bioretention system would have on this water quality. The findings of this report are based on existing literature and measured and modelled water quality results and is hoped to assist TRC in making informed decisions on the implementation and design of the bioretention system.

Water samples were taken to obtain an understanding of the current state of the Waterbird Habitat. From here, the process of modelling the effectiveness of the bioretention system included defining the catchment area, defining the areas of future development, defining the basic bioretention properties, and then modelling all of this in a program called MUSIC – *Model for Urban Stormwater Improvement Conceptualisation*.

The sample results gave approximate pollutant levels and were used to calibrate the values used in MUSIC, giving added confidence in the model. These pollutant levels were not found to be excessive or higher than expected.

The MUSIC program was used to model the differing states of the Waterbird Habitat – i.e. both as it currently is and what as it will be with the inclusion of future development and a bioretention system. Results from the model provided a comparison of Total Suspended Solids, Total Nitrogen & Total Phosphorus in both the amount being removed and the resulting concentrations within the Waterbird Habitat. It was found that the proposed bioretention system worked to decrease the pollutant levels in the Waterbird Habitat to less than or equal to pre-development levels. This gives some assurance that the bioretention system will help to improve stormwater quality for East Creek.

It was also found that the South East Queensland percentage reductions targets of TSS 80%, TP 60% and TN 45% were not met by either the proposed bioretention system or a much larger bioretention system scaled to more than 4 times the originally proposed size.

From the results that were produced within this report, it is recommended that the proposed bioretention system will be effective in the purpose of treating future increase in stormwater pollutants, and will increase the quality of the water within the Waterbird Habitat to a level higher than it is currently.

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Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, 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.

N. Kohn

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Signature

Date

Acknowledgements

I want to thank my supervisor Dr Ian Brodie for direction and encouragement, as well as Janaka Gunawardena who represented Toowoomba Regional Council. Toowoomba Regional Council made the project available and sponsored it by means of sample analyses. I want to acknowledge my workplace for making available the “MUSIC” and “AutoCad” software, and for the time taken off work to get the project finished. I would also like to thank my wife for helping out with the water sampling process, and her patience, support and coffee making skills throughout.

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University of Southern Queensland

October 2013

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Nomenclature & Acronyms

WSUD	Water Sensitive Urban Design
BPP	Best Planning Practise
BMP	Best Management Practise
TRC	Toowoomba Regional Council
TSS	Total Suspended Solids
TN	Total Nitrogen
TP	Total Phosphorous
DERM	Department of Environment and Resource Management
DNRM	Department of Natural Resources and Mines
DEHP	Department of Environment and Heritage Protection
NWQMS	National Water Quality Management Strategy
GPT	Gross Pollutant Trap
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
MUSIC	Model for Urban Stormwater Improvement Conceptualisation
FI	Fraction Impervious
WBH	Waterbird Habitat
QUDM	Queensland Urban Drainage Manual
PET	Potential Evapotranspiration
GP	Gross Pollutant
DMC	Daily Mean Concentration
MAL	Mean Annual Load

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1. Introduction

1.1.Background & Objectives

As the need for sustainability becomes more apparent and 'popular' within our society more sources of unsustainable practise are being addressed. Water Sensitive Urban Design (WSUD) comes out of this movement and cities such as Melbourne and Brisbane have taken up this mindset for the planning and managing of water in the city. Toowoomba Regional Council (TRC), along with other regional councils, has begun to address the need for WSUD in town planning.

Currently, TRC require an Engineers Stormwater Management Report detailing a plan for dealing with the change in quantity and quality of stormwater runoff within a development before approval is given. As well as the need to treat stormwater runoff in a localised setting, there is a need to look at stormwater treatment on a regional scale.

A report titled *Conceptual Plan for East Creek Basins within Ballin Drive Park & Garnett Lehman Park (Toowoomba Regional Council 2010),* expanded on its original scope in conceptualising flood mitigation measures for East Creek to looking at the integration of stormwater quality treatment measures being incorporated into the detention basin proposed for Ballin Drive Park, just upstream of Toowoomba's Waterbird Habitat (WBH) Wetland and is provided in Figure 1.1 below. Based on cost-benefit comparisons, the report recommended the use of a bioretention system for implementation in the Ballin Drive Park detention basin area.

A bioretention system is a stormwater quality treatment device that uses both extended detention and fine filtration to remove pollutants such as suspended solids and nutrients. Full explanation and details of typical bioretention systems is provided in Section 2.4 of this report.

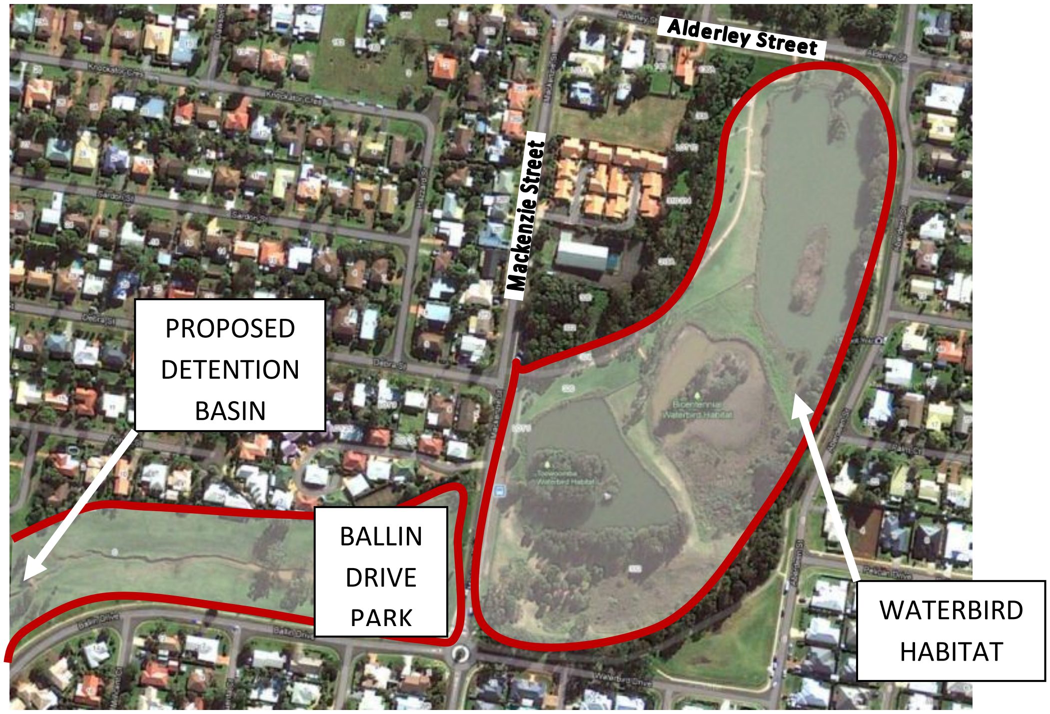


Figure 1.1 – Layout of Water Bird Habitat and proposed Detention Basin

The 2010 TRC report focused on choosing the best option but did not divulge into the details of what will be needed to treat the runoff from the catchment. Nor does the report touch on the existing water quality of the ponds within the WBH or extent of the impact urbanisation will have on the quality of stormwater runoff. Thus, this project aims to measure and model the current water quality within the WBH, to assess its expected future upstream development and calculate and model the effectiveness of an upstream bioretention system in treating the subsequent increase in water pollutants. This is broken down into the following set of tasks:

1. Research water sampling methods for stormwater runoff quality.
2. Plan and carry out a water sampling plan for assessing current water quality within the WBH and have samples analysed (outsource).
3. Using the sampling data and geometric measurements to produce a computer generated model of the existing WBH and catchment area.
4. Research the extent of future development expected within the WBH catchment.
5. Research typical bioretention system design including size, filter media, positioning, etc. and what parameters to specify for the computer model.
6. Add future development data to the model to predict the subsequent rise in pollutants; decide on suitable pollutant reduction targets. Use this model to calculate the required specifications for a bioretention system designed to manage the increase in pollutants.
7. Submit a dissertation on the research and findings.

As time permits:

8. Provide detailed design including drawings and explanation of a bioretention system option including layout and basin details.
9. Provide ideas for the integration of the systems engineering and social functioning – i.e. how can it be implemented with no adverse community effects.

The aim of this research project is that it will directly lead to the optimum design of a bioretention system to treat stormwater runoff from a developing catchment area. Indirectly it is anticipated that the research and results here will aid in developing the experimental approach and baseline data needed to evaluate proposed WSUD systems in the region. A copy of the full Project Specification is included in Appendix A of this report.

Computer Modelling Program

The computer program that will be used to model the stormwater quality treatment systems and catchment area will be *'MUSIC' – Model for Urban Stormwater Improvement Conceptualisation*. This program is commonly used within the civil engineering industry for the conceptualisation of stormwater treatment measures. The choice behind using this program and how it works is further outlined in Section 2.3.3.1 of this report.

1.2.Dissertation Overview

The structure of this report is outlined below:

- **Introduction** briefly covers the background & objectives of the dissertation.
- **Literature Review** covers the research portion of the study, looking into the initial report from TRC, the policies and guidelines relevant to stormwater quality treatment design and specific studies related to bioretention systems and the use of MUSIC.
- **Methodology** is the basic set-out and description of the activities and processes that were performed to achieve the aims of this project.
- **Results & Discussion** of this dissertation include results from both the water sampling and MUSIC modelling aspects of this study, with a discussion and interpretation of these results.
- **Conclusion & Recommendations** will summarise what took place within the study, what was revealed, and based on this give some recommendations on the implementation of the proposed bioretention system.

2. Literature Review

2.1. Concept Report for Detention Basin & Bioretention System

The 2010 report *Conceptual Plan for East Creek Basins within Ballin Drive Park & Garnett Lehman Park* was put together by TRC as a Stormwater Management Planning tool. In light of continuing development within the East Creek catchment, the report is an evaluation of multiple Stormwater quantity and quality management options within Ballin Drive Park & Garnett Lehman Park and includes preliminary designs and estimates. These two parks are situated just upstream and downstream of the Water Bird Habitat - an existing wetlands at the top end of East Creek.

The report was a follow on from a previous report titled *Gowrie Creek System Flood Risk and Mapping Study (2007),* which identified Ballin Drive Park and Garnett Lehman Park as potential sites for flood mitigating detention basins. The 2010 report expanded its scope to incorporate stormwater quality control measures, looking at both the Wetlands and the bioretention system within the detention basin. The report found that construction at Garnett Lehman Park would be more costly than Ballin Drive Park, and that the bioretention system would be more effective per unit area than the wetlands. Therefore, the report concluded that it was not as suitable to develop a stormwater quality treatment system within Garnett Lehman Park and that a large bioretention system in Ballin Drive Park basin area would be most cost effective. The Ballin Drive Park Basin was recommended for construction before the Garnett Lehman Park basin.

TRC's 2010 report is a study with the purpose of deciding which form of stormwater treatment will be the best option within the larger East Creek Stormwater Management Plan. The report does not go into great detail of the proposed bioretention System, using roughly estimated inputs for the MUSIC model and an example of a typical cross section of a bioretention. Consequently, before a plan can be finalized, TRC have required that follow up research be carried out on the bioretention system proposed for Ballin Drive Park. Thus, on that premise, this project requires calculation and modelling of the effectiveness of an upstream bioretention system in treating the subsequent increase in water pollutants.

2.2. Water Sensitive Urban Design (WSUD)

The bioretention system proposed for Ballin Drive Park must be a part of the WSUD approach that TRC are looking to further develop within the region. This has already begun during the detention and bioretention basin investigation stages but will need to continue during more detailed research and design.

2.2.1. Brief History of WSUD

The term WSUD was first used in the 1990's to describe a development style which was sensitive to the holistic approach to managing water. On the back of a global drive towards sustainability, WSUD has become widely accepted in practice and increasingly regulated by local and state governments. Traditionally the management of water was compartmentalized into potable water, wastewater and stormwater, which led to a general disassociation in thinking between the use and treatment of water and the consequences of this on the environment. The WSUD approach incorporates the following principles, as outlined in *Australian Runoff Quality* (Wong, T.H.F. 2006):

- Detention, rather than rapid conveyance, of stormwater
- Capture and use of stormwater as an alternative source of water to conserve potable water
- Use of vegetation for filtering purposes
- Water-efficient landscaping
- Protection of water-related environmental, recreational and cultural values
- Localised water harvesting for various uses
- Localised wastewater treatment system

Stormwater quality, in particular, has seen a rise in priority in recent years, with the idea that pollutants picked up in stormwater runoff are having a harmful effect, particularly on downstream creeks and rivers. One of the key WSUD objectives is outlined as '*treating urban stormwater to meet water quality objectives for reuse and/or discharge to surface waters'* (Wong, T.H.F. 2006).

2.2.2. Stormwater Pollutants

Stormwater pollution is caused by the build-up of pollutants on areas such as impervious surfaces, constructions sites and waste disposal areas, being washed off during rain events. Among the pollutants of concern are Total Suspended Solids (TSS), Total Nitrogen (TN), Total Phosphorous (TP), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Oil and Grease, Heavy Metals and Gross Pollutants. Of these pollutants, Gross Pollutants, TSS and nutrients (TN and TP) are most often referenced within runoff quality guidelines and handbooks, such as literature from the following sources:

- National water quality management strategy (NWQMS) - e.g. Australian Guidelines for Urban Stormwater Management, Australian and New Zealand Guidelines for Fresh and Marine Water Quality
- Healthy Waterways - e.g. Bioretention Technical Design Guidelines, Concept Design Guidelines for Water Sensitive Urban Design
- Department of Environment & Resource Management (DERM/DEHP) - e.g. State planning policy 4/10 Healthy Waters, Urban Stormwater Quality Planning, Queensland Urban Drainage Manual
- Faculty of Advancing Water Biofiltration – Adoption Guidelines

TSS is an easily recognised pollutant as it can be seen in the form of "dirty" water. It is the suspended material in water that can be removed easily by filtration and is harmful in large amounts as it can block drainage pipes and channels, prevents light penetration into water and is linked with the presence of many other pollutants (Wong T.H.F. 2006). Common causes for TSS pollution within built up areas are soil erosion, pavement and vehicle wear, organic material, atmospheric deposition, car washing and weathering of buildings/structures (CSIRO 1999).

TN and TP are nutrients which, if added to a body of water, can cause eutrophication, in which algae levels increase and lead to the depletion of dissolved oxygen (DO) levels, harming fish and other aquatic life. Nutrients can enter into urban runoff areas through organic matter, fertiliser, atmospheric deposition, animal faeces and car washing detergents (CSIRO 1999).

When BOD levels in stormwater are high, receiving waters have a consequent rise in BOD, leading to the depletion of DO and harm of aquatic life. Sources of BOD increase in stormwater include organic matter decay, atmospheric deposition and animal faeces.

Gross pollutants summarise the larger debris that makes its way into the stormwater flow and are made up of natural organic material and artificial litter. The organic material such as twigs and leaves tend to make up the majority of gross pollutants (above 50%), followed by plastic litter, paper litter and then other materials (Wong, T.H.F. 2006).

2.2.3. Stormwater Treatment Planning

To achieve the patterns and objectives typical of WSUD it is important to do more than simply prescribe a treatment method to achieve an objective, but instead include Best Planning Practises (BPP) and Best Management Practises (BMP) (Wong, T.H.F. 2006). This includes site inspection, planning and design BPP's and correct design of structural and non-structural elements of stormwater management. Much of the planning for this particular stormwater element has been undertaken and will continue to be undertaken by TRC. Including the previous studies and reports mentioned above, TRC planning includes improvement on Toowoomba's current stormwater environment as well as preparation for the impacts of current and future development.

The BMP for the Ballin Drive Park detention and bioretention basin has also begun, starting with the initial feasibility report *Conceptual Plan for East Creek Basins within Ballin Drive Park & Garnett Lehman Park (TRC 2010).* The BMP part of the design will continue to be relevant throughout this report as the correct guidelines are followed and correct practises used, particularly within the bioretention design and Sampling Planning.

2.3. Water treatment at Waterbird Habitat

The existing wetlands that make up the WBH play an important role as one of the first detention and retention points along East Creek. The purpose of an added bioretention system is to offset the increased runoff and pollutant loading caused by increased development. However, defining exactly how much quality treatment capacity increase is needed depends upon:

- Desired quality of treated stormwater
- Extent of future development in the catchment
- Current water quality of treated stormwater (WBH)

It is therefore critical to quantify each of these three components.

2.3.1. Guidelines and objectives for Stormwater Quality

Australian and New Zealand Environment Conservation Council (AMZECC) defines water quality guidelines as "...a numerical concentration limit or narrative statement recommended to support and maintain a designated water use" and an objective as "...specific water quality targets agreed between stakeholders, or set by local jurisdictions, that become the indicators of management performance" (National Water Quality Management Strategy 2000 (2)). For the purpose of recommending bioretention specifications, it will be necessary to decide upon appropriate guidelines and objectives for the system.

There are a number of different associations and authorities that provide guideline documents for work on stormwater quality. Local, state and national government put together the National Water Quality Management Strategy in 1994 and have released the '*Australian Guidelines for Urban Stormwater Management'* and *'Australian Guidelines for Water Quality Monitoring and Reporting'* (Wong, T.H.F. 2006). A number of other guidelines have been used to define objectives for this project such as the State Governments 2007 *'Queensland Urban Drainage Manual'* and its 2010 *'Urban Stormwater Quality Planning Guidelines'* linked to the State Planning Policy 4/10 Healthy Waters. The 2009 '*Concept Design Guidelines for* WSUD' and 2012 *'Bioretention Technical Design* Guidelines' by Healthy Waterways were also used for confirming and comparing recommendations. From these documents and others, water quality objectives for the WBH bioretention system design have been defined - see below.

2.3.1.1. Water quality guidelines

Commonly discussed pollutants

There are a large number of pollutants that are reported in relation to stormwater quality. Australian Runoff Quality (Wong, T.H.F. 2006) have a long list of pollutants and their typical urban concentrations including suspended solids, Total Nitrogen (TN), Total Phosphorus (TP), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), oil & grease (hydrocarbons), Total Organic Carbon, pH, turbidity, Total Coliforms and a number of heavy metals. To sample and assess all of these pollutants would require more time and technical skills than are immediately accessible so it will be important to know which pollutants should be monitored and factored into the design of the bioretention system.

Some of the most common pollutants discussed within guideline documents such as the Queensland Government's *Queensland Urban Design Manual* and *Urban Stormwater Quality Planning Guidelines 2010* as well as the NWQMS's *Australian Guidelines for Urban Stormwater Management* are TSS, TN, TP, pH, gross pollutants, hydrocarbons and some heavy metals. The *Urban Stormwater Quality Planning Guidelines 2010* and guideline documents by Healthy Waterways such as *Concept Design Guidelines for Water Sensitive Urban Design* and *Technical Design Guidelines for South East Queensland* focus on the reduction and monitoring of four of these pollutants – TSS, TN, TP and Gross Pollutants. These are the pollutants that will be looked at within this study, in particular TSS, TN and TP.

Percentage reduction targets for bioretention system

Water quality objectives have previously been specified in measurements of concentration. However, this method does not handle storm events which often cause concentrations much higher than the average concentration; nor can it restrict increased pollution due to increased runoff. For these reasons stormwater quality targets are now often defined as % reduction in total pollutant loading compared to the untreated runoff quality of the catchment. This method is a common WSUD practise and is the principle used in MUSIC to calculate effectiveness of water quality treatment devices.

Specific reduction targets are region specific, with Toowoomba City being in the South East Queensland region as defined in Figure 2.5 of *Urban Stormwater Quality Planning Guidelines 2010*. Table 2.2 of this guidelines document gives these values for South East Queensland as 80% TSS reduction, 60% TP reduction, 45% TN reduction and 90% reduction of Gross pollutants as a percentage of mean annual load (Department of Environment and Heritage Protection 2010). The reduction targets shown in the *Urban Stormwater Quality Planning Guidelines 2010* are echoed in Healthy Waterways conceptual and technical design guidelines.

Ambient water quality for an urban creek system

Although percentage reduction targets are typically used in relation to stormwater quality treatment, the need to understand the current state of the WBH requires an understanding of what concentrations are desirable such a system.

Melbourne Water, a government organisation in charge of Melbourne's waterways and water supply, are leading the way in Australia with a regional and holistic approach to looking after our water. In order to come up with some ambient water quality target for the WBH, Melbourne Water's extensive monitoring program of its creeks and rivers will be used. A yearly report is released by the organisation giving results of water monitoring on each of its waterways, including concentration levels of TSS, TN and TP, this is title Annual *Water Quality Factsheet: Long Term Water Quality Monitoring Sites 2006* (Melbourne Water 2006). Melbourne Water have also released a report which provides ratings for the water quality in each of these creeks, this is the, *Port Phillip and Westernport Regional River Health Strategy* (Melbourne Water Corporation) and was published in 2007.

From these annual water quality reports, an understanding of some typical concentrations of TSS, TN and TP can be obtained and used as a target for the WBH. The annual water quality fact sheets date back a number of years; the 2006 data was used to achieve some ball park figures, as the *Port Phillip and Westernport Regional River Health Strategy* report was released the following year. This data was collected across a broad range of sites (a total of 73 in 2006), with a total of 12 samples being taken throughout the year for the majority of the sites, with a 50 percentile figure being produced for each sample location for 2006 (Melbourne Water 2006). From this data, the sites with the ten highest and the site with the ten lowest 50 percentile values were selected, and an average of these was calculated.

From the process above, Table 2.1 was produced, which shows typical high quality (low pollutant concentrations) and low quality (high pollutant concentrations) are for Melbourne rivers. This data was used in the report to compare results from samples taken at the WBH and MUSIC results. These results are most accurately used for base flow comparison, as the majority of the sample would have been taken during base flow (although it is possible that some sample times coincided with a rain event).

Table 2.1 – Average pollutant concentrations in Melbourne's rivers (2006)

	TSS (mg/L)	TP (mg/L)	TN (mg/L)
Highest Quality	3.8	0.015	0.491
Lowest Quality	35.7	0.234	2.189

2.3.1.2. Objectives (Quality Targets)

Pollutants to monitor/design for

As mentioned above, the pollutants discussed within guidelines cover a range of pollutants. However the three pollutants that are consistently focused on are TSS, TN and TP. As is discussed in Section 2.3.3.1 below, the computer modelling program, MUSIC, models for TSS, TN and TP as well as Gross Pollutants.

After reviewing 9 case studies related to runoff quality in monitoring or design of treatment measures, 9 out of 9 studies included TSS in their pollutant selection. Of these case studies only 2 chose more than just TSS and nutrients to focus on, 1 study chose TSS and TP, 2 chose TSS and TN, and 5 out of 9 chose only TSS and nutrients to observe.

It is also worth noting the association between suspended solids and a number of other pollutants such as hydrocarbons, phosphorus and heavy metals and has frequently been used as a general indicator of urban stormwater pollution (Wong, T.H.F. 2006).

From the above information, and considering the scope of this research project and the common theme of these three pollutants in WSUD manuals, throughout other studies and within MUSIC, TSS, TN and TP will be the three design pollutants for the bioretention system.

2.3.2. Effects of Urbanisation

TRC require the proposed detention and bioretention basin to have the ability to subdue any impacts of current and future development within the WBH catchment area. Development within towns and cities, often referred to as urbanisation, has many effects on all types of stormwater management issues, including hydrology, water quality, water channels, vegetation and aquatic life. For stormwater quality, increased urbanisation causes higher loadings of suspended solids, nutrients, micro-organisms, heavy metals and organic material. This is due to a combination of increased impervious surface area affecting runoff volume, and an increased number of pollutant sources affecting pollutant build-up. (National Water Quality Management Strategy 2000 (1))

It is important then, that future urbanisation within the catchment can be appropriately classified and quantified. This can be measured via percentage impervious area which is one of the values used by MUSIC to define the catchment characteristics.

2.3.3. Determining current state of Waterbird Habitat

2.3.3.1. MUSIC

Background – why MUSIC?

As outlined in the MUSIC software help menu, the first developed by the Cooperative Research Centre for Catchment Hydrology, the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) is a computer software package with the ability to model stormwater quality and quantity and the effects of different treatment devices on catchment runoff. MUSIC can cater for small isolated suburban lots all the way up to very large urban catchment areas. The program's purpose is to aid decision making by assessing the effectiveness of stormwater management systems, assisting those involved in the planning and managing WSUD.

The program explains how its calculations are based on algorithms and look up tables derived from a foundation of past and new research into stormwater runoff characteristics and common stormwater improvement measures. While the research behind MUSIC is based on many known characteristics it is not perfect and knowledge gaps still exist.

How MUSIC functions

MUSIC works by setting up catchments and treatment devices as individual nodes connected by a user defined pipe or channel. These nodes are given certain properties according to what exists or what is being designed. This program will enable the modelling of the WBH and its catchment including the input variables outlined below. Using MUSIC, a comparison of the before and after of a bioretention system will be made easy.

Defining the WBH in MUSIC

The WBH will be modelled in MUSIC as three separate pond 'nodes' as oppose to a wetland node. This is because the WBH is made up of three ponds (see Figure 1.1), rather than a shallow body of water generally akin to a wetland. The pond node is a simple body of water that performs water treatment using the physical settling and also retains water in the same way as a detention or sedimentation basin.

The ponds will have a definable low flow and high flow bypass. However the WBH ponds will require a low flow bypass equal to zero as the upstream water discharges directly into the first of the WBH ponds. The overall volume of each of the three ponds will need to be defined in MUSIC also.

MUSIC has a number or storage properties that should be defined.

- Surface area
- Extended detention depth is the vertical distance between the permanent pool surface level and the overflow weir of the pond
- Permanent pool volume is the permanent volume of water within the ponds
- Vegetation cover (disabled in version 5 of MUSIC)
- Exfiltration rate is the rate that water seeps out of the ponds. MUSIC provides standard filtration rates for different soil types
- Evaporative loss is based on a percentage of the daily potential evapotranspiration which is based on the meteorological data in the model

The physical characteristics of the outlet pipe at each pond should be defined.

- Equivalent pipe diameter
- Overflow weir width is the width at which water can overflow out of the pond

As well as all the above parameters, MUSIC enables advanced properties to be defined as well.

Defining the Catchment properties in MUSIC

The WBH catchment will be modelled in MUSIC as a ‘source node’. This node includes a number of inputs and makes up part of the rainfall and runoff model affecting on the treatment systems.

The source node properties to be defined in MUSIC include:

- Total area of the catchment in hectares
- Pervious and impervious area proportions

A number of rainfall and runoff characteristics can also be defined, including:

- Impervious areas
- Rainfall threshold (mm)
- Soil storage capacity (mm)
- Initial storage
- Field capacity
- Infiltration capacity coefficient and exponent
- Groundwater
- Initial depth (groundwater)
- Daily recharge rate
- Daily baseflow rate
- Daily deep seepage rate

2.3.3.2. *Water Sampling*

What becomes clear from the above section is that the use of MUSIC to model a scenario and then give a resulting water quality can only be as accurate as the input data given, or the representative data set values it is based on. MUSIC allows a number of customisation options to make the model specific to the particular features of the WBH. However, each scenario has an indefinite number of variables that impact on the final quality of water within the ponds. For this reason the model needs to be calibrated, and one way this can be done to a certain degree of accuracy is by sampling.

Guidelines for water sampling stress the need for sample planning and design, focusing both on the planning of the sampling to be carried out and the techniques used to take the samples. Both NWQMS and DERM have guidelines for water quality monitoring/sampling and compliment Australian Standards AS/NZS 5667.1:1998 Water quality – Sampling – Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples. It is important to define the purpose for the sampling as well as the physical extents, period of time and the frequency of sampling. Sampling needs to take into account quality control, analyses of samples and any existing constraints.

The purpose of this sampling is to gauge the current quality of water within the WBH therefore the sampling plan for this project will include samples for both base flow and storm events, as it is common to have peaks in pollutant concentrations during storm events.

The first flush during a storm event is very likely to have high pollutant concentrations and the sampling plan for the storm event needs to take this into consideration (DERM, 2009). The sampling plan will take this into consideration by doing two rounds of sampling during the storm event, firstly during the first flush time frame and secondly at a point just after peak discharge.

DERM's Monitoring and Sampling Manual outline the specific technique of taking grab samples using an extendable pole, outlined below:

> *Sampling using extendable pole sampler*
>
> 1. *Remove the lid from the 1 L sample bottle and attach the bottle to the end of a sampling rod.*
> 2. *Extend the sampling rod into the main flow of the stream. Submerge the bottle to a depth of at least 0.3 m, keeping the mouth end pointing down.*
> 3. *Whilst submerged, rotate the sampling rod 180 degrees to bring the mouth of the bottle facing up, and allow the bottle to fill with water; and retrieve bottle.*
> 4. *Replace the lid and shake the bottle ensuring the inside of the bottle and the lid come into contact with the liquid. Discard the rinse liquid downstream of where you are sampling. Be sure to keep hands away from the mouth of the bottle and the underside of the lid.*
> 5. *Repeat steps 3 to 4 so that the sample bottle and its lid are rinsed twice with stream water then proceed to step 6.*
> 6. *Repeat step 1 to 3 to fill the bottle. Replace the lid and tighten. If sample requires freezing, ensure you leave 10–20 per cent space free.*
>   *(DERM 2009)*

One of the constraints on sampling will be the amount of sample analyses that TRC have made available to the project – the available analyses will be split among the base flow and storm event samples. Another constraint will be the availability of rainfall events suitable for sampling.

2.4.Bioretention system

2.4.1. Background

The bioretention system was first developed in the early 1990s starting as a simple excavated area filled with a layer of sand and planting soil over top. The bioretention system aim was to maximise the use of the chemical, physical and biological processes found in soil to remove pollutants from rain runoff, specifically the first flush containing highest pollutant concentrations. The idea for these systems came out of similar systems that were used for treatment of sewerage effluent. (Roy-Poirier, Audrey 2010)

2.4.2. Literature

The basic layout and design of treatment systems has been developed over a number of years, and the following authorities on stormwater treatment provide information on typical details of these systems, bioretention systems in particular; some examples are provided:

- National water quality management strategy (NWQMS) - e.g. Australian Guidelines for Urban Stormwater Management

- Healthy Waterways - e.g. Bioretention Technical Design Guidelines
- Department of Environment & Resource Management (DERM/DEHP) - e.g. State planning policy 4/10 Healthy Waters

The research outlined above was followed by a more specific look at the modelling of ponds, sedimentation basins, and bioretention systems in MUSIC. The following resources were important in gaining knowledge on the modelling guidelines and optimum practises for these systems:

- eWater – MUSIC software v5.1 'help' information 2012
- Faculty of Advancing Water Biofiltration – Adoption Guidelines

2.4.3. Definition/Description

The bioretention system "…can provide efficient treatment of stormwater through fine filtration, extended detention and some biological uptake." (Wong, T.H.F. 2006).

The system includes a shallow depression on the surface where water is detained and is allowed to filtrate through two or three layers of soil underneath. The top layer is typically a coarse sand material on top of finer loamy soils. As the water percolates down it is collected in a perforated pipe and discharged downstream into pipes or natural waterways. (Wong, T.H.F. 2006)

A cross-sectional view across the width of a typical bioretention system is provided in Figure 2.1.

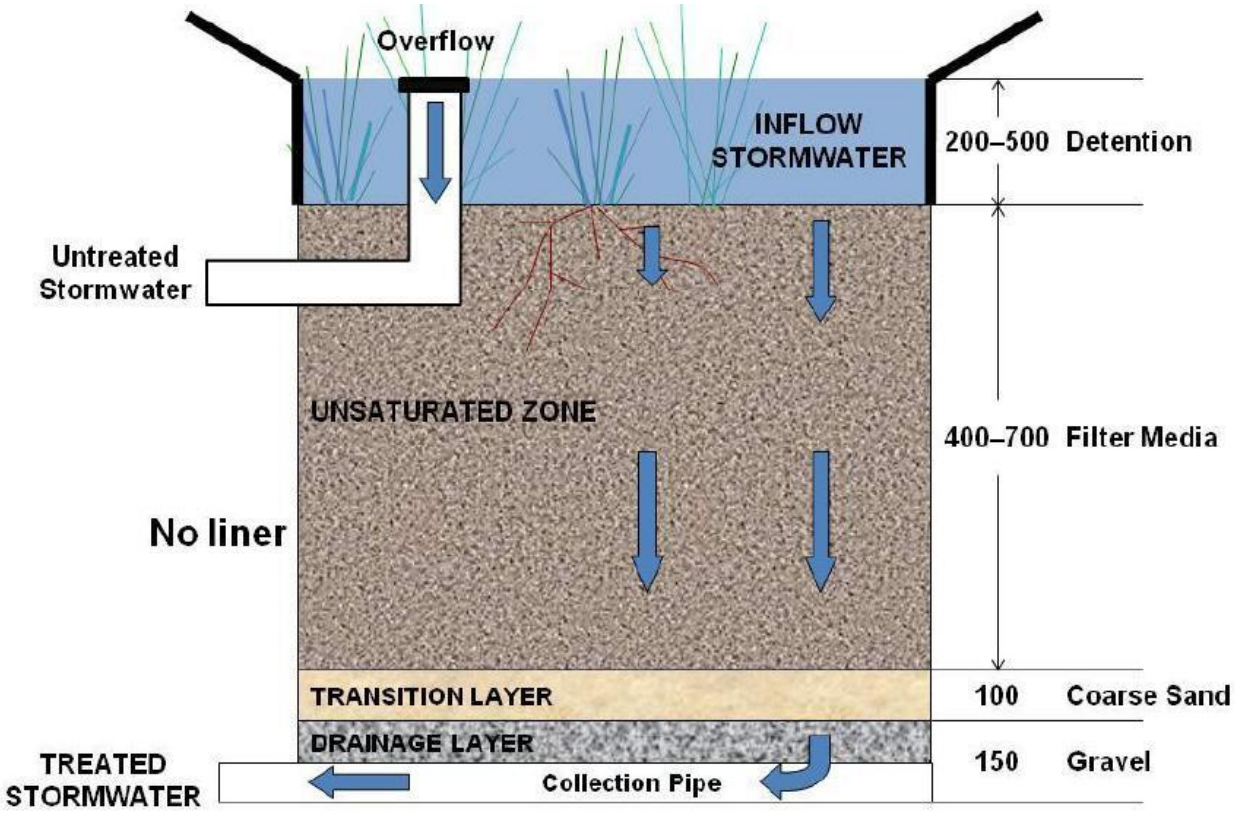


Figure 2.1 – Bioretention system cross section (width). FAWB (2009)

An important part of the bioretention system is the vegetation covering the basin area. The plant life is included for multiple reasons including:

- The protection of soil from scouring during heavy rainfall and high flows
- The physical collection of sediment during higher flows
- The increased activity around the root zone of the plant matter help in the uptake of non-soluble and soluble material as well as water. The root system is effective in its biological uptake of nutrients.
- During periods of no rainfall the plant life helps to keep the structural integrity of the soil as well as its hydraulic conductivity.

(Wong, T.H.F. 2006)

When the soil layers within a bioretention system become eroded or intermixed with other layers in the system or with surrounding soils the functionality of the bioretention system breaks down. Therefore, it can be seen how plant matter directly and indirectly assist in the role of the bioretention system to treat stormwater. (Wong, T.H.F. 2006)

Plant life can also be used along with other means to control traffic over the bioretention basin. It is important that the bioretention system is kept from being over compacted by any means as this can increase the chance of the soil layers being smothered or clogged. When this occurs, the ability for water to infiltrate through the filter layers is hampered and it is for this reason that bioretention systems need to be re-constructed approximately every 25 years. This is also an important factor during the construction of the bioretention system. (Wong, T.H.F. 2006)

2.4.3.1. Typical uses

From its early stages the bioretention system has been easy to implement in small landscaped areas and buffer strips as Roy-Poirier (2010) noted, a bioretention system with an area 5% of the size of the run off area can allow the first 1.27cm of rain to infiltrate the system, allowing easy integration into the landscaped area of an industrial site, typically sized at 6% of the site. This trend is continuing today; as requirements for the treatment of stormwater for improved quality is being imposed and regulated by local and state government, the bioretention system is becoming common practise for industrial developed sites as well as other urban use.

Table 3 of section 2.5 of the Bioretention Technical Design Guidelines outlines a number of different situations which, if designed appropriately, Bioretention Systems are effective, these are:

- For managing litter, sediments, nutrients, metals and hydrocarbons transported by stormwater
- For managing stormwater flows
- For urban or civic landscapes, residential parklands or riparian and bushland landscapes
- For small catchments or where space is constrained
- For large catchments
- On moderate to steep topography
- On flat topography
- For stormwater harvesting

(Water by Design 2012)

2.4.4. Conceptual and Planning

The conceptual planning stage for the bioretention system has largely been covered within TRC's 2010 *Concept Plan for East Creek Basins* report and reports preceding this. Matters such as location, treatment mechanisms and even a conceptual layout have largely been developed. There is room for some of these concepts to be reassessed against the more detailed guidelines for treatment trains and the surrounding factors that influence on the effectiveness of a bioretention system. Thus the detailing of the bioretention system may also include either a reiteration of, or a conflicting recommendation on matters already conceptualised by TRC; these matters are explained below.

2.4.4.1. Concept guidelines on possible WSUD issues at Ballin Drive Park

The choice of using a bioretention system for the purpose of such a wide spread regional based quality treatment device will not be deeply researched as part of this project however a few comments are included. QUDM (Department of Natural Resources and Water 2007) would suggest that the use of a 'bioretention cell' as it has called it in its table, Table 11.05.2, is suited to servicing catchment areas up to 2ha. Initial measurements of the bioretention catchment area are close to 250ha, thus exceeding QUDM's recommendation. This recommendation however, may simply be referring to the catchment area per 'cell', implying that the total area treated by one bioretention 'system' may be higher. TRC's

2010 report conceptualises seven ‘cells’ or ‘pods’ making up the larger system, implying an approximate treatment of 35.7ha catchment per cell.

Water by Design’s *Bioretention Technical Design Guidelines* (2012) briefly describes typical total filter media area as 50-800m² for a bioretention system situated within park land or natural areas. This seems rather small when compared to TRC’s 2010 report conceptualising a total bioretention treatment area of 2820m². Which leads to the question, is a bioretention system as large as the one proposed at Ballin Drive Park feasible? Attention is drawn to the same guideline by Water by Design where Table 3 ‘When to use bioretention systems’ includes a row “*For large catchments*” stating that *“*bioretention *systems can manage runoff from large catchment if design solutions specifically developed for large systems are used (e.g. suitable distribution system)”.* This information is inconclusive and does not directly state what size a “large catchment” is. This may be an area of future study as it is not directly within the scope of this report.

Another characteristic of the Ballin Drive Park bioretention system will be its integration with the flood mitigation works, specifically the detention basin. Water by Design’s *Concept Guidelines for Water Sensitive Urban Design* (2009) specifically engages this issue under the heading ‘bioretention systems located within large, regional-scale flood retardation basins or along major overland flow paths and floodways. The key risks include the smothering of plants by sediment, high flow velocity causing plant and filter media damage and ‘blinding’ due to excess sediment loading of filter media or continuous wet conditions. These risks can be managed by proper design including the use of a sedimentation basin upstream of the bioretention system, placing the surface of the bioretention system’s filter media above the 1 year ARI peak flood level and a high flow bypass that causes water to backup over the bioretention system before the system encounters the high velocity flood water. (Water by Design 2009)

Table 4 of Bioretention Technical Design Guidelines also names the possible issue of continuous wet conditions mentioned above. It states that continuous inflow into the bioretention system causes algae growth in thick slime layers, hampering the ability of water infiltration through the filter media. This is a key concept for the proposed Ballin Drive Park bioretention system as it is located within East Creek, meaning constant flow will occur into the system. This puts much importance on the surface level of the bioretention basins such that the base flow is continually under the inflow level of the bioretention system, but that the heavily polluted first flush makes its way into the bioretention basins. These levels will be a detailed design issue but have been brought up here for a holistic conceptualisation of the bioretention system and detention basin. (Water by Design 2012)

2.4.5. System specifications

2.4.5.1. Defining the bioretention system in MUSIC

Ultimately, system specifications for the optimum bioretention system design should be the result of this project. These results will come from the MUSIC modelling program and will be an iterative process to find what areas, depths, media type, etc are needed to reach the chosen water quality objectives. The following outlines the information given in the MUSIC program on modelling for the bioretention system.

The bioretention system will be modelled in MUSIC as a bioretention system 'node'. This node can be used to model the bioretention system or a simple vegetated infiltration system. MUSIC defines the typical purpose of the bioretention system as the treatment of stormwater by removing pollutants within the filtration media.

A cross-sectional view across the length of a typical bioretention system is provided in Figure 2.2, below. The illustration shows some of the main design parameters of the bioretention system that have to be defined in MUSIC.

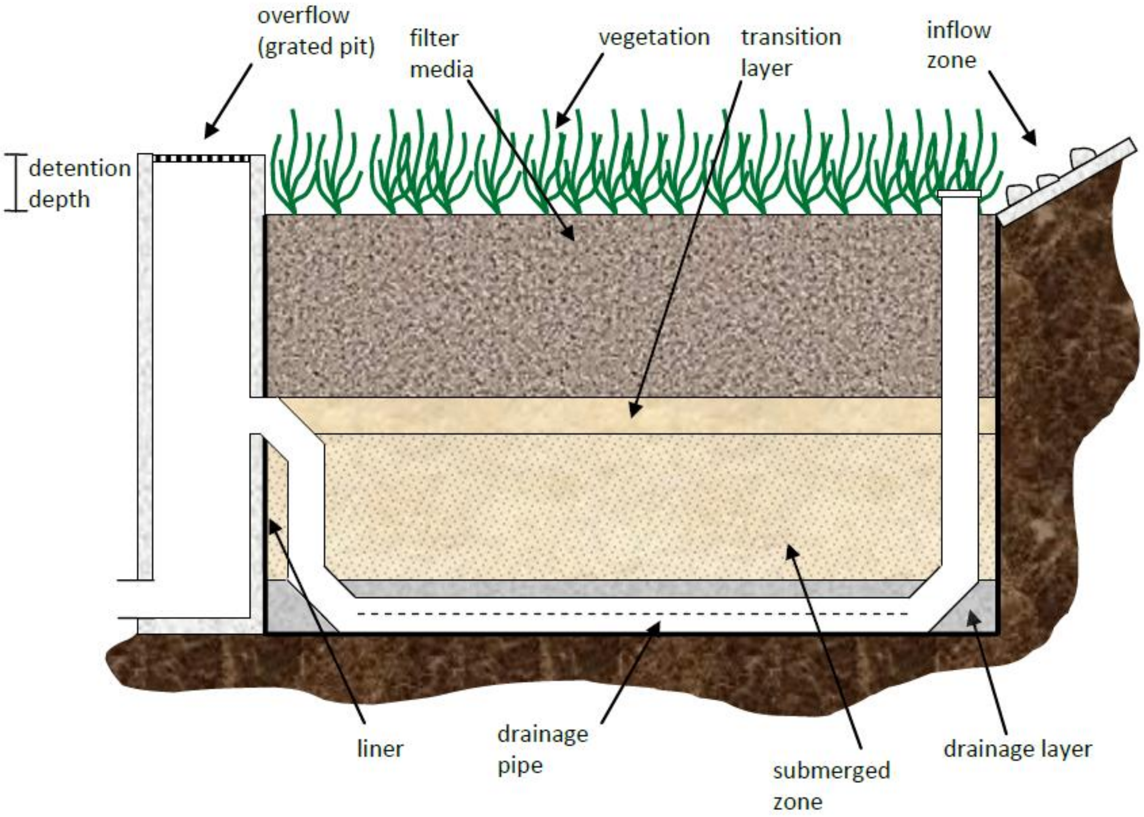


Figure 2.2 – Bioretention system cross section (length). FAWB (2009)

A full list of the bioretention system input properties to be defined within MUSIC are as follows:

Inlet Properties:

- **Low Flow bypass**, where discharges below a defined value pass by the bioretention system
- **High Flow bypass** defines the ultimate discharge that can be treated by the bioretention system, any additional flow will bypass untreated

Storage Properties:

- **Extended detention depth** is the vertical distance between the filter media level and the overflow weir of the basin

- **Surface area** of the bioretention system storage in m²

Filter and Media Properties:

- **Filter area** is the plan area of the filtration coverage
- **Unlined filter media perimeter** is used in MUSIC to calculate the amount of exfiltration that will occur
- **Saturated Hydraulic Conductivity** is the saturated hydraulic conductivity of the filter media in mm/hr
- **Filter depth** is the overall depth of the filter layers and excludes the extended detention and drainage layer
- **TN content of filter media (mg/kg)** is the nitrogen content in the filter media being used
- **Proportion of organic matter in filter media** is as a percentage
- **Orthophospate content of filter media** is in mg/kg

Lining Properties:

- **Is base lined** with some form of impermeable layer

Vegetation Properties

- **Vegetation cover** can be chosen (and MUSIC strongly encourages the use of vegetation within the bioretention system)

Outlet Properties:

- **Overflow weir width** is in meters and is the length of the surface storage overflow weir
- Is and **underdrain present? -** used for infiltration
- **Submerged zone with carbon present** – said to improve treatment success

Infiltration Properties:

- **Exfiltration rate** is water that seeps through the bioretention surrounds and is lost from the system, given in mm/hr.

As well as all the above parameters, MUSIC enables advanced properties to be defined as well.

3. Methodology

3.1. Overview

The methodology of the project is briefly outlined below:

- Water Sampling
- Define WBH catchment area
- Define extent of future development
- Research bioretention system design
- Produce MUSIC model of current scenario at Waterbird Habitat – Scenario 1
- Duplicate and adjust MUSIC model to include future development – Scenario 2
- Use MUSIC to model the impact of the proposed bioretention system – Scenario 3
- Use MUSIC to model a bioretention system to achieve SEQ reduction targets – Scenario 4
- Use MUSIC to find optimum bioretention system specifications – Scenario 5

The five scenarios outlined here represent the five scenarios that will be modelled in MUSIC. With the results from these five scenarios, comparisons can be made between the existing state of the WBH and the predicted state of the WBH under changed conditions. Scenario 2 results will give an indication on the impact of future development on the WBH water quality, while Scenario 3 results will demonstrate the effectiveness of the proposed bioretention system in treating the predicted pollutant increase. Scenarios 4 and 5 will provide further information on impact of changing aspects of the bioretention system; for Scenario 4 this will be the overall size of the system, while for Scenario 5 this will include a number of design options within the bioretention system. These five scenarios are explained in greater details in Sections 3.5 – 3.9 of this report.

3.2. Water Sampling

3.2.1. Collection of Samples

The purpose of the sampling that was undertaken was to gauge the current quality of water within the Waterbird Habitat and to calibrate the predicted results for the Waterbird Habitat in the MUSIC model. DERM's Monitoring and Sampling Manual (2009) was used as a guideline for the sampling exercise. This manual stresses the need for sampling design and planning.

After meeting with TRC, it was decided that they would sponsor the analyses of 30 samples, to be tested at Mt Kynoch water treatment plant laboratory. Thus, the sampling plan was based upon this number and divided among storm and base flow sampling.

With the relatively short time available for project completion, and the storm season coming to an end it was decided that the aim of the first sampling sets was to obtain grab samples during a storm event, so as to increase the early chance of getting a representative storm to sample. After visiting the site a rough map of the Waterbird Habitat was used to define the approximate locations of each of the grab samples to be obtained. In order to keep proper records of the samples an onsite sampling information form was put together including weather conditions and time and date of the sample. A TRC sample analyses request form was also obtained for submission to the Mt Kynoch water treatment plant.

With the planning and preparation in place, sampling was able to begin at the next available rain event. Samples were taken during three separate rain events, on the 14th May, 22nd May and the 6th June 2013.

The method used to gauge flow into the Waterbird Habitat was by measuring the depth of the water running through the outlet of the culvert running under McKenzie St and entering into the first pond. The culvert is made up of three 600mm diameter circular pipes shown in Figure 3.1 below. This recorded value was later converted to flow rate by estimating the velocity of the water through the culvert.

Figure 3.1 – Outlet of culvert under McKenzie St, discharging into WBH

Rain was recorded by a TRC pluviometer, situated at the WBH outlet, which takes rainfall data in 6 minute intervals. The pluviograph for the hours leading up to each storm event sample is shown in Figures C.1 – C.3 provided in Appendix C.1.

In order to preserve the samples, an esky with ice was used, in which the samples were placed once collected, as shown in Figure 3.2 below. The samples stayed on the ice and transferred to a fridge at below 4°C before being taken to Mt Kynoch water treatment plant. In all cases, the samples were taken to the water treatment plant within 24hrs of being collected. This is in accordance with DERM's Monitoring and Sampling Manual (2009).

Figure 3.2 – Samples collected and cooled on ice in esky

After the 'rain event samples' were taken, a number of base flow samples were also collected. 17 samples were collected over three separate days, the 16th of June, 8th of July and 15th of July 2013. Sample locations included the inlet and outlet of the WBH, and each pond of the WBH, as well as at the location of the proposed bioretention system further upstream. These samples were taken at least 80hrs after the previous rain event, where the base flow level through the culvert was steady for each sample day. See Table 4.1 for approximate flow rates for each different sample day.

A map showing each sample location has been included in Appendix C.1 as Figure C.4.

One particular sample location to note is the sample location shown as '0.2' in Figure C.4. This location is the outlet of a stormwater pipe that discharges into WBH pond 3. Approximately 50m away from the WBH pond 3 was an existing construction site, which had a visible impact on the quality of the water coming from this particular stormwater pipe. Figure 3.3 below show the sediments that were visible in the water discharging into the pond. For this reason a sample of 'interest's sake' was taken during one of the storm flow sample events.

Figure 3.3 – Sample taken downstream of building site (sample location 0.2)

The figure below, Figure 3.4 shows the construction site and inlet pit located approximately 50m from the outlet shown in the above figure.

Figure 3.4 –Building site located 50m from (sample location 0.2)

A full summary of sample results and their interpretations can be seen in Section 4.2 of this report. Each sample event was summarised and placed into Table C.1 of Appendix C.1.

3.2.2. Evaluation and implementation of sample data

3.2.2.1. Compilation and interpretation of data

Although the data collected from the samples at the WBH was based on a small sample size, it was still used for the purpose of adjusting and calibrating the MUSIC model. These sample results were put into an Excel spread sheet, which was used to compile the results into categories according the location at which they were taken, as well as the conditions during which they were taken, i.e. base flow or during storm conditions. In order to be able to graph the results from these categories into box and whisker plots, the mean, minimum, maximum, 1st quartile and 3rd quartile values were calculated. From these values, the mean of each category was used for the process of deriving MUSIC inputs. This process and results are shown in Section 4.2.

3.2.2.2. Deriving MUSIC inputs from results

There are a number of opportunities within MUSIC to define the properties of the pollutants in the model. The two parameters that were adjusted in this study were the k and C* values which help to define a treatment node, e.g. the WBH, and base flow and storm flow pollutant concentrations coming from the source nodes, i.e. the catchment areas.

k and C* values

> *"The selection of appropriate k and C* values for MUSIC is an important consideration for simulating any proposed treatment measure."* (MUSIC software v5.1 'help' information 2012)

The value of k for a treatment node is its decay parameter, which will not be largely investigated as part of this report. However, the C* value that must be set for each treatment node in MUSIC describes the background concentration of the water at that treatment node. The results from the samples collected within the WBH ponds during base flow conditions, were used to help choose an appropriate C* value for the WBH ponds.

Source node concentration parameters

The pollutant concentration levels must be defined for each source node (catchment area) which is placed into the MUSIC model. As for most input values in the model, these values are initially set to a default that has been chosen based on collaboration of a wide range of extensive studies. The collaboration process is undertaken by eWater Cooperative Research Centre. More information on eWater can be found here http://www.ewater.com.au/.

The results from the samples taken during both base flow and storm flow were used to help choose an appropriate pollutant concentration for these source nodes. These values were chosen for the whole catchment area. This process and its results are detailed in Section 4.2.4 of this report.

3.2.2.3. Comparing MUSIC results with sample results and other data

One aspect of the MUSIC modelling that will be undertaken, is to model the current situation at the WBH, i.e. the current water quality within the WBH ponds. The water samples that were taken at the

WBH can be used to compare with these MUSIC results to give some sort of idea whether or not the MUSIC results come close to the actual situation.

The 'wet weather' sample results were used to compare with the MUSIC average daily concentrations in the ponds. In Section 4.3.1 the process of comparing these results is outlined and the percentage difference between the two results is calculated.

3.3. Catchment Characteristics

3.3.1. Catchment zones and areas

In order to set the MUSIC model, a number of catchment properties had to be known including the area and fraction impervious (FI). Four different MUSIC models were created for four different scenarios and thus the areas and fractions impervious had to be known for each different model. The overall catchment for each MUSIC model remained the same in area, however the overall FI did change, as did the distribution of each sub-catchment.

Figure 3.5 shows the overall catchment outlined on a TRC online infrastructure map, showing the entire catchment area that outlets through the WBH's overflow weir (at the third pond). The figure shows the catchment extending towards the south-east of the WBH until it starts to find the edge of the Great Dividing Range, and finishing between Hume and Ramsay Streets to the west.

Figure 3.5 – Catchment Area in AutoCad (TRC mapping)

In order to create a MUSIC model that was both accurate and simple enough to produce, the catchment was broken up into sub-catchments. These sub-catchments were primarily based on areas of different fractions impervious. To calculate total impervious surfaces for such a large catchment would take a long time and could also prove inaccurate, therefore the catchment was divided up in accordance with TRC's town planning scheme zones. A map of the catchment outlined on TRC's online planning scheme map is provided in Figure 3.6. These zones are also shown in Table 3.1 along with their respective FI values.

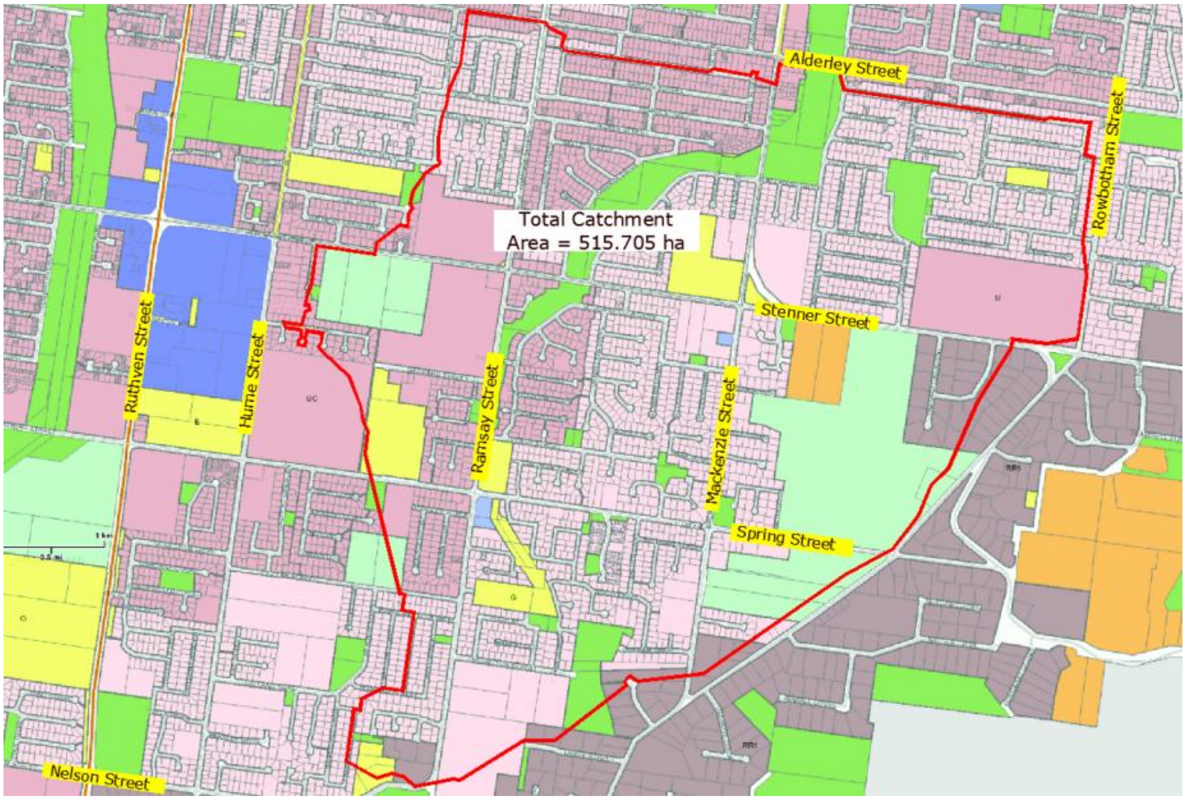


Figure 3.6 – Catchment Area in AutoCad (Planning Scheme)

As can be seen in Table 3.1, the zones are coloured according to their approximate colours in Figure 3.6, and there are a number of extra zones without a colour. Zones without an allocated colour have been included in the process of defining the catchment for the following purposes:

- **Undeveloped Areas**: 'Undeveloped areas' are areas found within the catchment that, according to available data and on site investigation, are yet to be developed. These areas were given a 0% FI for the "pre development" MUSIC model. However, for the "ultimate development" model these areas were designated a FI, according to the zone they were within. This was based on the presumption that any undeveloped areas would ultimately be developed to the extent allowable within its specific zone. For example, an undeveloped area in an "Open Space" zone will stay at 0% FI in its ultimate development state, while an undeveloped area in a "Residential Living" zone will have an ultimate FI of approximately 50% - Tables 3.1 & 3.2 show how the FI for each particular zone was chosen. The total area to undergo an increased FI from future development was calculated as 60.784Ha, which represents approximately 11.8% of the total catchment.

- **Road Areas**: These four zones indicate areas of road or road reserve within one of the coloured zones and have been included to allow more accurate assumptions on the FI values by separating them from the residential zones they are found within.
- **Remaining Area**: The remaining area is a zone with a small area that represents the margin of error that is the difference between the sum of all other zones and the known overall catchment area. It has been allocated a FI of 0 and represents a small fraction of the overall catchment.

The zones that have matching coloured FI cells in Table 3.1 have been combined together with zones of equal FI, in order to minimise the amount of catchments in MUSIC for the purpose of saving processing time and space. These combined zones can be seen in Tables 3.3 – 3.5. The process of selecting appropriate FI values for each zone is outline in Section 3.3.2 below.

Table 3.1 – Catchment Area list of zones & their FI value
(red=0%, green=100%)

Zone	Fraction Impervious (FI)
Residential Living exc. Rd	0.5
Residential Choice exc. Rd	0.4
Rural Residential	0.15
Community Purposes	0.22
Local Centre	0.9
Sports & Recreation	0
Limited Development (Constraint Land)	0
Open Space	0
Undeveloped Areas	0
Main Road (pavement only)	1
Main Road inc. reserve	0.7
Internal Road/Half Main Rd	1
Half Internal Road	1
Remaining Area	0

3.3.2. Selecting appropriate fractions impervious (FI)

The process of choosing an appropriate FI included reference to Table 4.05.1 of the Queensland Urban Drainage Manual (QUDM), as well as a number of basic calculations that come from measurements that were made in the AutoCad catchment area model. These calculations included measuring the FI for a small portion of that zone in the hope that this would be a close representation of the FI for the whole of that zone. The values from QUDM were used to calibrate the measured values, and adopted values were chosen for each zone according to those shown in Table 3.2 below.

Table 3.2 – Selecting FI for each catchment zone

Zone	QUDM (exc. roads)	Approx. Calculations in AutoCad	Adopt
Residential Living exc. road	0.40-0.75	0.47	0.5
Residential Choice exc. road	0.40-0.75	0.39	0.4
Rural Residential exc. road	0.1-0.2	0.14	0.15
Community Purposes	N/A	0.22	0.22
Local Centre	0.9	0.92	0.9
Sports & Recreation	0	0	0
Limited Development	N/A	0	0
Open Space	0	0	0
Undeveloped Areas	0	0	0
Main Road (pavement only)	N/A	1	1
Main Road inc. road reserve	N/A	0.7	0.7
Internal Road/Half Main Rd	N/A	1	1
Half Internal Road	N/A	1	1
Remaining Area	N/A	0	0

3.3.3. Calculating Total Area for each Sub-catchment

Outlined in Section 3.3.1 above, is the catchment area and the sub-catchments that make up this area. Figure 3.6 above shows the zonings that the sub-catchments were based upon, and Table 3.2 lists each of these zones and their adopted FI values. The following tables, Table 3.3 – 3.5, are a breakdown of each sub-catchment that was put into the MUSIC model for scenarios 1 – 3 respectively. These scenarios are explained in detail in the sections to follow.

Each column in the tables represents the treatment node in MUSIC (and in reality), to which that sub-catchment directly drains into.

Table 3.3 represents Scenario 1 and includes all areas as they currently stand, including some area calculated as currently undeveloped.

Table 3.3 – Sub-catchment areas for MUSIC Scenario 1 (ha)

Drains into→	Pond 1	Pond 2	Pond 3
Residential Living exc. Rd	126.909	35.822	20.063
Residential Choice exc. Rd	83.525	3.476	1.416
Rural Residential	4.192	10.161	0.000
Community Purposes	16.837	0.000	1.031
Local Centre	0.930	0.000	0.000
Limited Development (Constraint Land)	0.000	6.057	0.000
Sport/Open/Undeveloped/Remaining Areas	93.919	62.978	0.000
Road Only	21.946	4.979	2.261
Road Reserve	17.688	1.516	0.000
Total Catchment:	515.705		

Table 3.4 represents Scenario 2 and only changes by removing the undeveloped areas and adding it instead, to the sub-catchment they are found within, e.g. the undeveloped areas within the Residential Living zone is presumed as fully developed, in order to demonstrate what the catchment will look like once fully developed.

Table 3.4 – Sub-catchment areas for MUSIC Scenario 2 (ha)

Drains into→	Pond 1	Pond 2	Pond 3
Residential Living exc. Rd	154.054	35.822	20.063
Residential Choice exc. Rd	91.449	18.333	1.416
Rural Residential	6.372	10.161	0.000
Community Purposes	21.328	0.000	1.031
Local Centre	0.930	0.000	0.000
Limited Development (Constraint Land)	0.000	6.057	0.000
Sport/Open/Remaining Areas	48.119	48.120	0.000
Road Only	25.039	5.945	2.261
Road Reserve	17.688	1.516	0.000
Total Catchment:	515.705		

Table 3.5 represents Scenarios 3 & 4 and includes the sedimentation basin and bioretention system as a new treatment node. This addition of a treatment node upstream obviously changes the areas that discharge into each treatment system, as shown in Table 3.5 below.

Table 3.5 – Sub-catchment areas (ha) for MUSIC scenario 3, 4 & 5

Drains into→	Sedimentation Basin	Pond 1	Pond 2	Pond 3
Residential Living exc. Rd	112.835	41.218	35.822	20.063
Residential Choice exc. Rd	62.636	28.813	18.333	1.416
Rural Residential	4.660	1.711	10.161	0.000
Community Purposes	15.414	5.914	0.000	1.031
Local Centre	0.930	0.000	0.000	0.000
Limited Development (Constraint Land)	0.000	0.000	6.057	0.000
Sport/Open/Remaining Areas	33.056	15.064	48.120	0.000
Road Only	17.316	7.723	5.945	2.261
Road Reserve	11.498	6.190	1.516	0.000
Total Catchment:	515.705			

3.4.Treatment system characteristics

As well as the catchment characteristics just described above, the characteristics of existing and future treatment devices must be well understood, in order to create a MUSIC model that best represents both the current scenario and possible future scenarios.

Using guidelines such as those mentioned in Section 2.4.3 of this report provided the knowledge needed to achieve the following two outcomes:

1. Optimising our choice of bioretention system variables (e.g. filter type and depth, etc) which affect the system efficiency but have multiple options and;
2. The correct input of treatment system fixed variables into MUSIC that also affect the system efficiency, i.e. it was important that each aspect of the system was modelled realistically. This is important for both the existing WBH and the proposed sedimentation basin and bioretention system.

The full list of modelling inputs for each element of the treatment train is provided in Section 3.4.1 – 3.4.3 below.

3.4.1. WBH - Pond Characteristics

The parameters for ponds 1, 2 and 3 are shown in Tables 3.6, 3.7 & 3.8 below.

Table 3.6 –Pond 1 MUSIC parameters

Item	Inlet Properties			
1	Low-Flow By-pass (m^3/s)	0		
2	High-Flow By-pass (m^3/s)	100		
	Storage Properties			
3	Surface Area (m^2)	5132		
4	Extended Detention Depth (m)	0.3		
5	Permanent Pool Volume (m^3)	18460		
6	Vegetation Cover (% of Surface Area)	10		
7	Exfiltration Rate (mm/hr)	0.01		
8	Evaporative Loss (% of PET)	100		
	Outlet Properties			
9	Equivalent Pipe Diameter (mm)	600		
10	Overflow Weir Width (m)	32		
11	Notional Detention Time (hrs)	0.931		
	Advanced Properties			
12	Orifice Discharge Coefficient	0.6		
13	Weir Coefficient	1.7		
14	Number of CSTR Cells	3		
		k(m/yr)	C*(mg/L)	C**(mg/L)
15	Total Suspended Solids	400	13.0	12.0
16	Total Phosphorus	300	0.05	0.09
17	Total Nitrogen	40	1.2	1.0

Table 3.7 –Pond 2 MUSIC parameters

Item	Inlet Properties			
1	Low-Flow By-pass (m^3/s)	0		
2	High-Flow By-pass (m^3/s)	100		
	Storage Properties			
3	Surface Area (m^2)	3936		
4	Extended Detention Depth (m)	0.15		
5	Permanent Pool Volume (m^3)	4410		
6	Vegetation Cover (% of Surface Area)	10		
7	Exfiltration Rate (mm/hr)	0.01		
8	Evaporative Loss (% of PET)	100		
	Outlet Properties			
9	Equivalent Pipe Diameter (mm)	600		
10	Overflow Weir Width (m)	30		
11	Notional Detention Time (hrs)	0.505		
	Advanced Properties			
12	Orifice Discharge Coefficient	0.6		
13	Weir Coefficient	1.7		
14	Number of CSTR Cells	3		
		k(m/yr)	C*(mg/L)	C**(mg/L)
15	Total Suspended Solids	400	15.0	12.0
16	Total Phosphorus	300	0.05	0.09
17	Total Nitrogen	40	0.8	1.0

Table 3.8 –Pond 3 MUSIC parameters

Item	Inlet Properties			
1	Low-Flow By-pass (m^3/s)	0		
2	High-Flow By-pass (m^3/s)	100		
	Storage Properties			
3	Surface Area (m^2)	11941		
4	Extended Detention Depth (m)	0.05		
5	Permanent Pool Volume (m^3)	43403		
6	Vegetation Cover (% of Surface Area)	10		
7	Exfiltration Rate (mm/hr)	0.01		
8	Evaporative Loss (% of PET)	100		
	Outlet Properties			
9	Equivalent Pipe Diameter (mm)	50		
10	Overflow Weir Width (m)	23		
11	Notional Detention Time (hrs)	127		
	Advanced Properties			
12	Orifice Discharge Coefficient	0.6		
13	Weir Coefficient	1.7		
14	Number of CSTR Cells	3		
		k(m/yr)	C*(mg/L)	C**(mg/L)
15	Total Suspended Solids	400	15.0	12.0
16	Total Phosphorus	300	0.05	0.09
17	Total Nitrogen	40	1.1	1.0

An explanation and justification for the pond values used in the above tables is as follows:

1. The low-flow by pass is set to zero, as there is no low-flow by-pass at the WBH
2. The high-flow by-pass is set to 100(m^3/s) as a default and was not changed. Running the model revealed that no water by-passed the WBH ponds. The existing WBH does not appear to have any form of high-flow by-pass set-up; thus, 100(m^3/s) high-flow by-pass for this model is valid.
3. The surface area of each pond was measured from the AutoCad model.
4. The extended detention depth was based upon our rough measurements made on site at the WBH.
5. The permanent pool volumes were calculated by interpolating the known extended detention depths and surface areas, with the total storage volume which was provided by TRC. Thus, by subtracting the extended detention **volume** from the total storage volume, the permanent pool volume could be known.
6. The vegetation cover was set by MUSIC and could not be changed.
7. The exfiltration rate is dependent on the surrounding soil type. From the 2010 TRC report *Concept Plan for East Creek Basins,* in which a soil test was included, the surrounding soil type at Ballin Street Park and Garnett Lehmann Park proved to be heavy clay with very low hydraulic

conductivity at approximately 0.0015mm/hr. The MUSIC model provides representative rates of exfiltration for different soil types, with 0 to 0.36 mm/hr for heavy clays. Thus a value of 0.01mm/hr was chosen for the WBH ponds.

8. The evaporative loss for the ponds was left as a default of 100% of PET as no other data was known on this.
9. The equivalent pipe diameter for the outlet pipe for ponds 1 and 2 was set based on our onsite measurements. The value used for the third pond was set to MUSIC's minimum of 50mm. However, in reality, all of the water exiting from the third pond is over a sharp crested weir, and thus setting the outlet pipe diameter to a minimum will best represent this scenario. A check of the *node water balance* for Pond 3 in MUSIC has shown that 98.8% of water discharging from Pond 3 is over the weir, which is very close to the actual scenario.
10. The overflow weir width was based on our onsite measurements.
11. The notional detention time is calculated by MUSIC based on the permanent pool volume and outlet pipe diameter already specified.
12. The orifice discharge coefficient was left as MUSIC default.
13. The weir coefficient was left as the MUSIC default.
14. The number of CSTR cells was chosen by choosing the most suitable CSTR shape as provided by MUSIC. This was shape 'P' from the MUSIC menu.
15. The calculation of k and C* values for items 15-17 is explained in Section 4.2.4 of this report, and were based on literature and our own sample values from the WBH ponds. C** values set automatically by MUSIC.

3.4.2. Bioretention System Characteristics

The full list of modelling inputs for the bioretention system is provided in below. These values are the ones used for the original bioretention system MUSIC model. However, as described in Sections 3.5 – 3.9, subsequent MUSIC models tested for the impact of changing a number of these parameters.

Table 3.9 –Bioretention System MUSIC Parameters

Item	Inlet Properties		
1	Low-Flow By-pass (m^3/s)	0	
2	High-Flow By-pass (m^3/s)	18	
	Storage Properties		
3	Extended Detention Depth (m)	0.3	
4	Surface Area (m^2)	4125	
	Filter and Media Properties		
5	Filter Area (m^2)	3188	
6	Unlined Filter Media Perimeter (m)	720	
7	Saturated Hydraulic Conductivity (mm/hr)	90	
8	Filter Depth (m)	0.5	
9	TN Content of Filter Media (mg/kg)	800	
10	Orthophosphate Content of Filter Media (mg/kg)	80	
	Infiltration Properties		
11	Exfiltration Rate (mm/hr)	0.01	
	Lining Properties		
12	Is based lined?	No	
	Vegetation Properties		
13	Vegetated with Effective Nutrient Removal Plants?	Yes	
	Outlet Properties		
14	Overflow Weir Width (m)	360	
15	Underdrain Present?	Yes	
16	Submerged Zone with Carbon Present?	No	
17	Depth (m)	0.45	
	Advanced Properties		
18	Weir Coefficient	1.7	
19	Number of CSTR Cells	2	
20	Porosity of Filter Media	0.35	
21	Porosity of Submerged Zone	0.35	
22	Horizontal Coefficient	3	
23	Filter Media Soil Type	Loamy Sand	
		k(m/yr)	C*(mg/L)
24	Total Suspended Solids	8000	20.0
25	Total Phosphorus	6000	0.13
26	Total Nitrogen	500	1.4

An explanation and justification for the bioretention system values used in the above tables is as follows:

1. The low-flow by pass is set to zero which means that even small amounts of flow is directed into the bioretention system basins.
2. The high-flow by-pass is set to 18(m^3/s). This is the Q5 peak flow which was calculated using the rational method, shown in Appendix B, and is the recommended design storm for a bioretention system according to Section 3 of FAWB's *Guidelines for Stormwater Biofiltration Systems* (2009).
3. The extended detention depth was based upon typical depths for a bioretention system as shown in Section 3 of FAWB's *Guidelines for Stormwater Biofiltration Systems* (2009). This is also what appeared to have been modelled in the drawings from the *Concept Plan for East Creek Basins (*Toowoomba Regional Council 2010).
4. The surface area of the proposed bioretention system was measured from the AutoCad model based on the concept design in *Concept Plan for East Creek Basins*.
5. The filter area of the proposed bioretention system was measured from the AutoCad model based on the concept design in *Concept Plan for East Creek Basins*.
6. The unlined filter media perimeter was the whole perimeter of the bioretention basin, as no lining will be needed due to the heavy clay soil surrounds.
7. The saturated hydraulic conductivity of the filter media was set to 90 based on information from FAWB's *Guidelines for Stormwater Biofiltration Systems* (2009) and MUSIC software v5.1 'help' information (2012) to use 50% of the media's design hydraulic conductivity value. This value takes into account build of matter in the filter media which reduces the hydraulic conductivity. For the sandy loam soil proposed, the design saturated hydraulic conductivity is 180mm/hr.
8. The filter media depth is exclusive of the transition and drainage layers and was set to 0.5m in accordance with both FAWB's *Guidelines for Stormwater Biofiltration Systems* (p40, 2009) and Water by Design's *Bioretention Technical Design Guidelines(Version 1)* (p38, 2012), which recommend 400-600mm and 500-1000mm respectively.
9. The TN content of the filter media was left as default value. However, this is an area in which a bioretention system may improve efficiency dramatically, if soils with lower TN content are used.
10. The Orthophosphate content of the filter media was left as default value. However, this is an area in which a bioretention system may improve efficiency dramatically, if soils with lower Orthophosphate content are used.
11. The exfiltration rate is dependent on the surrounding soil type. From the 2010 TRC report *Concept Plan for East Creek Basins,* in which a soil test was included, the surrounding soil type at Ballin Street Park proved to be heavy clay with very low hydraulic conductivity at approximately 0.0015mm/hr. The MUSIC model provides representative rates of exfiltration for different soil types, with 0 to 0.36 mm/hr for heavy clays. Thus a value of 0.01mm/hr was chosen for the bioretention system.
12. See point 6 above.
13. As outlined in the MUSIC software v5.1 'help' information (2012), 'effective nutrient removal plants' are an important aspect of a bioretention system and should be used wherever possible to improve the efficiency of the device, and have been included in this model. Examples of these plants are found in Table 3 of Chapter 3 of *Adoption Guidelines for Stormwater Biofiltration Systems* (FAWB 2009).

14. The overflow weir width was measured in AutoCad as approximately half the overall bioretention basin perimeters, with the assumption that when water overflows the system it will do so across a large percentage of the basin.
15. An underdrain has been included due to the very low hydraulic conductivity of the surrounding soil, according to Section 3.2.1 of *Bioretention Technical Design Guidelines (Version 1)(*Water by Design 2012)
16. No saturated zone has been included in the model, however, this may be a viable option to look at and model, as according to Section 3.2.1 of *Bioretention Technical Design Guidelines (Version 1)* a saturated zone may help with the even distribution of flow across the filter media, to provide water for the vegetation needed within the bioretention system.
17. The depth of the outlet was set by MUSIC.
18. The weir coefficient has been left as MUSIC default value.
19. The number of CSTR cell reactors is 2, which corresponds to the typical bioretention layout.
20. The porosity of the filter media has been left as MUSIC's default value for the filter type we have specified.
21. The porosity of the submerged zone has been left as MUSIC's default value for the filter type we have specified.
22. Horizontal Coefficient has been left as MUSIC's default value which was chosen by MUSIC as a result of calibration studies. MUSIC recommends keeping this value as default. (MUSIC software v5.1 'help' information 2012)
23. The filter media soil type we are specifying is loamy sand. This filter media was chosen for its hydraulic conductivity and is recommended by MUSIC.
24. The default values have been used for all k and C* values within the bioretention system.

3.4.3. Sedimentation Basin Characteristics

Table 3.10 –Sedimentation Basin MUSIC Parameters

Item	Inlet Properties			
1	Low-Flow By-pass (m^3/s)	0		
2	High-Flow By-pass (m^3/s)	100		
	Storage Properties			
3	Surface Area (m^2)	932		
4	Extended Detention Depth (m)	0.4		
5	Permanent Pool Volume (m^3)	1464		
6	Exfiltration Rate (mm/hr)	0.01		
7	Evaporative Loss (% of PET)	75		
	Outlet Properties			
8	Equivalent Pipe Diameter (mm)	1400		
9	Overflow Weir Width (m)	46		
10	Notional Detention Time (hrs)	0.0359		
	Advanced Properties			
11	Orifice Discharge Coefficient	0.6		
12	Weir Coefficient	1.7		
13	Number of CSTR Cells	2		
		k(m/yr)	C*(mg/L)	C**(mg/L)
14	Total Suspended Solids	8000	20	20
15	Total Phosphorus	6000	0.13	0.13
16	Total Nitrogen	500	1.4	1.4

1. The low-flow by pass is set to zero, as there is no low-flow by-pass for the basin.
2. The high-flow by-pass is set to 100(m^3/s) as the Sedimentation Basin does not appear to have any high-flow by-pass set-up in it conceptual stage, and flows coming into the basin will not be above 100(m^3/s) as stated in Section 3.4.2.
3. The surface area of the basin was measured from the conceptual drawings in the AutoCad model.
4. The extended detention depth was based upon rough measurements made according to the conceptual drawings and an estimate of likely overflow levels.
5. The permanent pool volumes were calculated by measuring an approximate area from the contours of the conceptual drawings, and also measuring approximate depths from these drawings as well.
6. The exfiltration rate is dependent on the surrounding soil type. From the 2010 TRC report *Concept Plan for East Creek Basins,* in which a soil test was included, the surrounding soil type at Ballin Street Park proved to be heavy clay with very low hydraulic conductivity at approximately 0.0015mm/hr. The MUSIC model provides representative rates of exfiltration for different soil

types, with 0 to 0.36 mm/hr for heavy clays. Thus a value of 0.01mm/hr was chosen for the WBH ponds.

7. The evaporative loss for the basin was left as a default of 75% of PET as no other data was known on this.
8. The equivalent pipe diameter for the outlet pipe for the basin was roughly estimated according to approximations of what dimensions an outlet could look like at the Sedimentation Basin site.
9. The overflow weir width was based on a measurement of likely overflow perimeter, according to the contours on the conceptual drawings from the *Concept Plan for East Creek Basins* report.
10. The notional detention time is calculated by MUSIC based on the permanent pool volume and outlet pipe diameter already specified and was pre-set.
11. The orifice discharge coefficient was left as MUSIC default.
12. The weir coefficient was left as the MUSIC default.
13. The number of CSTR cells was decided by choosing the most suitable CSTR shape as provided by MUSIC.
14. The default values have been used for all k and C* values within the bioretention system

3.4.4. Treatment system effectiveness

For a thorough comparison of pollutant removal efficiency of the treatment systems in each scenario, we will be looking at three different measures of the pollutants:

- Mean Annual Load (MAL) – A measure of the total mass of the pollutant coming into or leaving from a system or device each year (kg/yr).
- Percentage Reduction – A measure of the decrease in mean annual load of a pollutant as it passes through a treatment node or treatment train (%).
- Daily Mean Concentration (DMC) – This value is taken from MUSIC's 'Daily Sample Statistics' output, and is a measure of the mean concentration of the pollutant in the water coming into or out from a treatment node or treatment train, on a daily basis (mg/L).

A "treatment node" is equivalent to a treatment system – e.g. a bioretention basin or a Pond. The term "treatment train" is used to describe a treatment process made up of multiple treatment measures.

3.5.MUSIC model, Scenario 1 – current scenario

The MUSIC model was used to calculate theoretical values of current water quality both within the Waterbird Habitat ponds and the runoff coming from the Waterbird Habitat catchment area. This model was called Scenario 1 and is the current scenario within the WBH (consisting of three ponds) and the WBH catchment. The final layout of the model within the MUSIC program is shown in Figure 3.7 below.

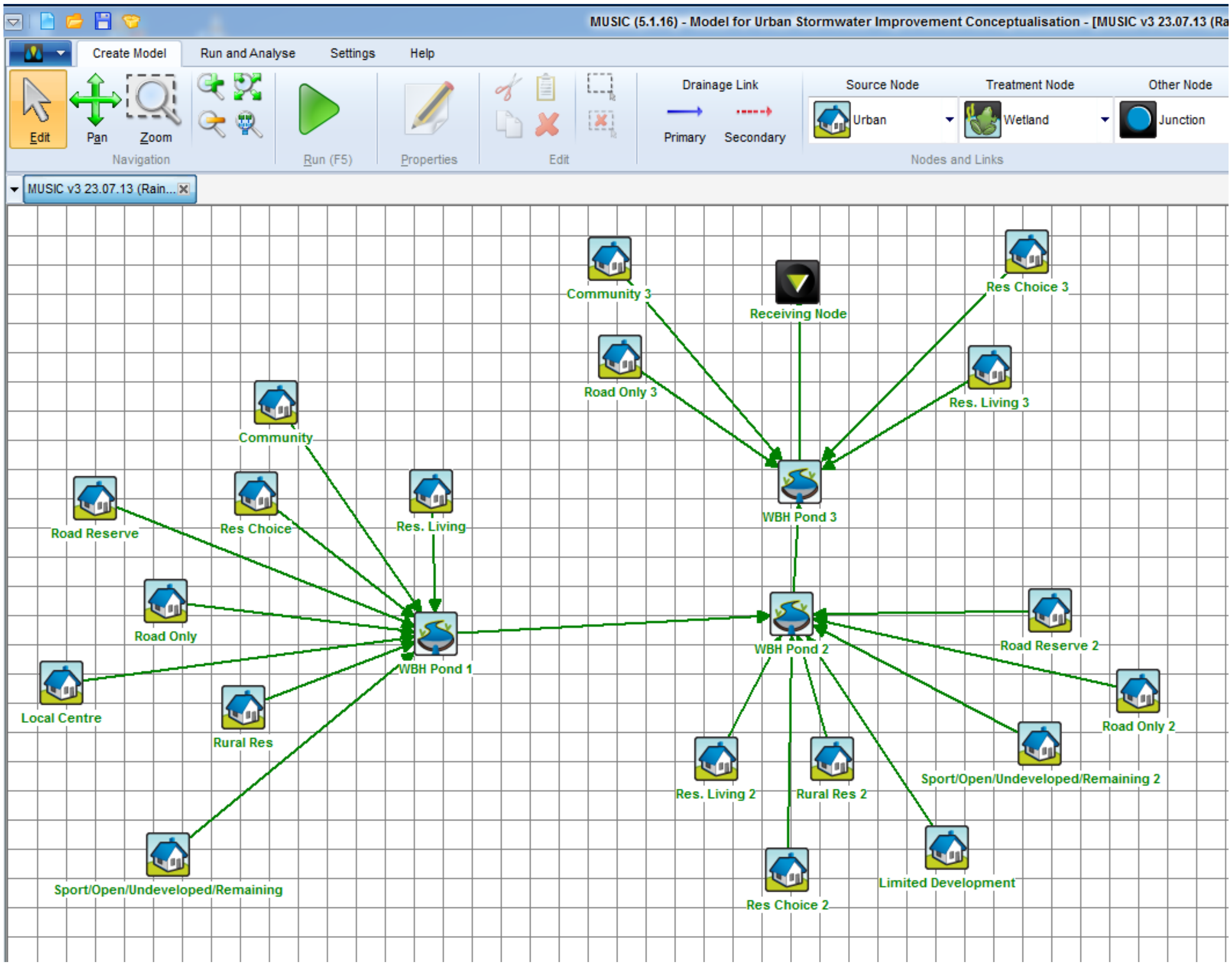


Figure 3.7 – Scenario 1 MUSIC model layout

The MUSIC model was created in a number of steps, those being:

1. Rainfall and Runoff

This step is basically the setting of the model for a particular site or location. The MUSIC model for the Scenario 1, current scenario, and all subsequent Scenario models was set up with the following data:

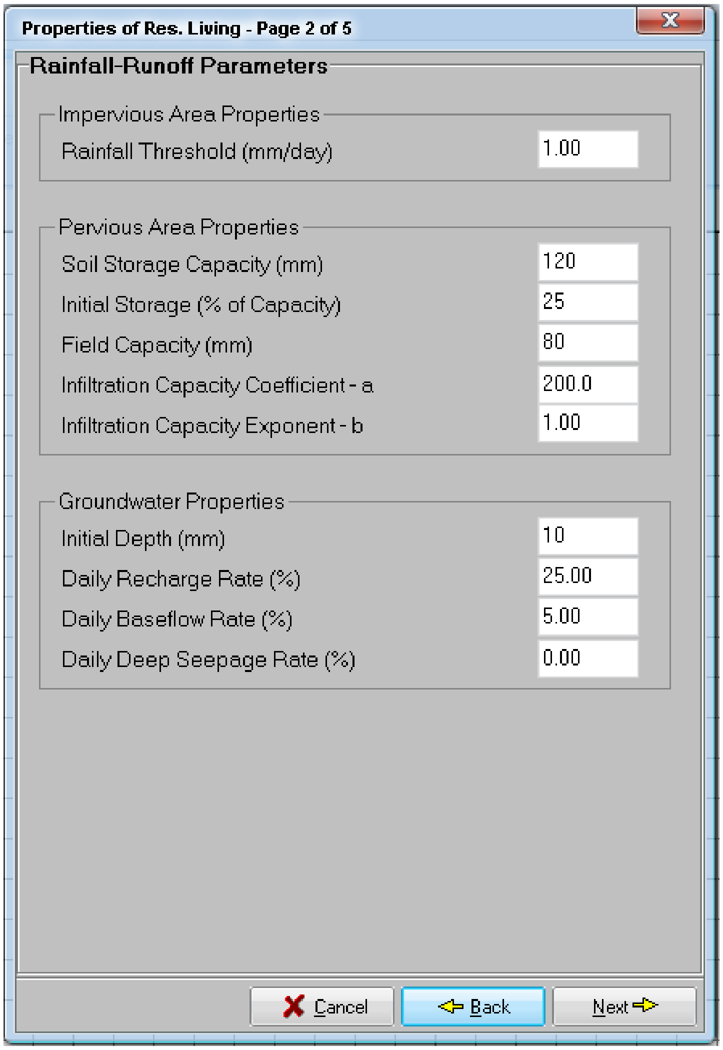
- Rainfall data from rainfall station ‘41467 TOOWOOMBA’, 1st January 1957 to 31st December 1983. It is worth noting here the difference between rainfall data for MUSIC and rainfall **quantity** models. Typically programs used for stormwater quantity modelling use a ‘design’ storm such as a ‘Q20’ or ‘Q100’ that is base on statistical information such as average rainfall intensities and temporal patterns and provides peak discharge values. The MUSIC program uses measured rainfall from a particular weather station, taking the 6 minute rainfall data measured over a number of years, and looks at total yearly volume of discharge as oppose to peak discharges.

- Evapotranspiration data from MUSIC's default 'Toowoomba Daily' data set. This data represents the amount of evaporation that is taken into account.
- Modelling time step of 12 minutes. A 6 minute modelling time step is recommended by MUSIC for accuracy of results; however, a 12 minute time step was chosen for this project, as it was expected that the models for Scenarios 3 – 5 would contain a large number of source nodes and decrease processing time. This proved to be useful when using the laptop, which took up to 50 minutes to run the model.

2. Source Nodes

The source nodes define the sub-catchments that drain into a particular treatment system. The area and FI for each source node has to be defined, as well as a number of rainfall-runoff properties. As well as this, the source node pollutant concentration parameters can be modified. In the figure above, the source nodes are represented by the picture of a house, with the green arrow representing the point at which the sub-catchment drains into.

For this model, the area and FI for each source node was determined using the processes outlined in Section 3.3 above. The pollutant concentration parameters were also calibrated, the method and outcomes for this are shown in Section 4.2. The rainfall-runoff parameters for each source node were not changed from the default values set by MUSIC. Figure 3.8 below shows these rainfall-runoff parameters, as set by MUSIC. The Soil Storage Capacity and Field Storage values set by MUSIC are the values calibrated for the Brisbane area.



Rainfall Threshold (mm/day) 1.00

Soil Storage Capacity (mm) 120

Initial Storage (% of Capacity) 25

Field Capacity (mm) 80

Infiltration Capacity Coefficient - a 200.0

Infiltration Capacity Exponent - b 1.00

Initial Depth (mm) 10

Daily Recharge Rate (%) 25.00

Daily Baseflow Rate (%) 5.00

Daily Deep Seepage Rate (%) 0.00

Figure 3.8 – Source Node rainfall-runoff parameters

3. Treatment Nodes

The treatment nodes within MUSIC represent the point to which a catchment drains to, and where this stormwater is treated. For this model there are three treatment nodes, these being the three ponds that make up the WBH. These can be seen in Figure 3.7 above, named 'WBH Pond 1', 'WBH Pond 2' and 'WBH Pond 3'. The treatment nodes have a number of parameters to be specified. The Scenario 1, Scenario 2 and Scenario 3 treatment node input parameters are shown in Section 3.4 above, with the some of these changing slightly for Scenarios 4 and 5, as outlined in Section 3.8 and 3.9.

4. Receiving Node

The receiving node has no input parameters but is simply the point in the model representing the outlet of the entire catchment area being model. For this model, the outlet point is the outlet of the third pond within the WBH.

3.6.Scenario 2 – ultimate development

A second MUSIC model was copied from the original one in order to replicate the WBH and its catchment in its ultimate state of development i.e. when there is no more area in the catchment available for development under the current planning scheme. The second MUSIC model was altered according to the calculations of future development as outlined above. Apart from an overall change in FI for the WBH Catchment, the MUSIC model for scenario 1 and 2 are identical.

The comparison of pollutant levels between the first and second scenarios will give a good indication of the increase of pollutants due to the increased development within the catchment, and does not include any additional treatment measures other than what currently exists.

3.7.Scenario 3– ultimate development + proposed bioretention system

Another MUSIC file was set-up for a third scenario, in which the proposed bioretention system and Detention Basin was modelled upstream of the WBH. The calculations, as outlined in Section 3.3, were again adjusted to suit the new treatment nodes in MUSIC; that is, the catchment was split up according to which treatment node it would initially discharge to as shown in Figure 4.20 (Sedimentation Basin, Pond 1, Pond 2 or Pond 3). The overall catchment for the model does not change from the previous two scenarios – it is only the distribution of this catchment that changes.

Scenario 3 models the effect of the bioretention system in its proposed location and overall size, and the results are provided in Section 4.3.3. Therefore, comparison of pollutant levels between this third scenario and the second scenario will give a good indication of the decrease of pollutants due to the implementation of this proposed bioretention system.

Another comparison can be made, this time between Scenario 3 results and the results from Scenario 1. These two results can provide an understanding of the quality of water at the receiving node (the outlet of the WBH), that would be achieved with the proposed bioretention system and ultimate development conditions, compared with the quality of water at the receiving node for current conditions.

3.8.Scenario 4– bioretention system to satisfy water quality objectives

A number of water quality objectives based on different calculations have been discussed – see Section 2.3 of this report. Scenario 4 has been set up in order to gain an understanding of what size bioretention system/Detention Basin would be required to achieve the typical percentage reduction targets outlined earlier. In this way, Scenario 4 is set up in the same way as Scenario 3. The changes that have been made to achieve the percentage reduction targets are the bioretention surface area, filter media area and unlined perimeter.

The MUSIC model was run for five different bioretention sizes as shown in Table 3.11 below.

Note: Increase in size of bioretention is not linear, and all other MUSIC inputs were kept constant for comparison purposes.

Table 3.11 – Five different bioretention system sizes run in MUSIC

Trial Number	Surface Area (m^2)	Filter Media Area (m^2)	Filter Media Perimeter (m)
4.1	2000	1500	400
4.2 (Scenario 3)	4125	3188	720
4.3	7000	6000	1300
4.4	12000	10500	1900
4.5	20000	18000	3400

3.9.Scenario 5– bioretention system calibration

Once Scenario 3 was modelled and initial results viewed, aspects of the bioretention system node in MUSIC were changed, one at a time, in order determine the impacts that different components of the bioretention system has on its efficiency. Nine 'trials' were run; with only one input being varied from the Scenario 3 model per trial. A summary of each trial run is shown in Table 3.12 below.

Table 3.12 – Modification made during each 'trial run' of Scenario 5

	Trial Description	Scenario 3	Scenario 5, Trial #
Trial 5.1	Orthophosphate Content (mg/kg)	80	50
Trial 5.2	Orthophosphate Content (mg/kg)	80	20
Trial 5.3	Low-flow by-pass (m^3/s)	0	0.05
Trial 5.4	Submerged Zone with carbon present?	No	Yes
Trial 5.5	TN content (mg/kg)	800	500
Trial 5.6	Filter Media Depth (m)	0.5	0.8
Trial 5.7	Extended Detention Depth (m)	0.3	0.5
Trial 5.8	Filter media type	Loamy Sand	Sandy Loam
Trial 5.9	Vegetated with Effective Nutrient Removal Plants?	Yes	No vegetation

Trial 5.1 - The trial 5.1 modification is the lowering of the orthophosphate content of the filter media from 80mg/kg to 50mg/kg. This relates to the lowering of the phosphate content in the filter media. It is hoped that this modification increases the removal of TP, as there will be lower level of phosphate in the soil.

Trial 5.2 - The trial 5.2 modification is the lowering of the orthophosphate content of the filter media from 80mg/kg to 20mg/kg. This is the same as for trial 5.1 however the feasibility of obtaining filter media with particular levels of orthophosphate has not been researched.

Trial 5.3 – The low-flow by-pass was changed in order to model the base-flows from East Creek by-passing the bioretention system. The value of 0.05(m^3/s) was chosen as it was calculated to be the approximate base flow rate coming into the WBH using the method described in Section 3.2.1. This test was carried out in order to understand the impact of including the low-flow by-pass on the pollutant removal rate, if it is the case that a low-flow by-pass is required.

Trial 5.4 – A submerged zone is a method of bioretention design that includes a bottom layer of material in the bioretention basin that is constantly submerged. As stated in the FAWB *Adoption Guidelines for Stormwater Biofiltration Systems* (p31, 2009), a submerged zone can sometimes be beneficial to the health of the bioretention system to support the microbial community and plant growth for periods of no rain. Trial 5.4 was included to test the impact of having a submerged zone on the pollutant removal.

Trial 5.5 – This trial tests the impact of decreasing the TN content within the filter media of the system on the pollutant removal rate. This is similar to trial 5.1 and 5.2, in that it is hoped that lowering the TN content in the filter media will allow greater removal of TN pollutant from the stormwater. However, it is important to note that MUSIC suggests TN content of less than 600 mg/kg may cause difficulty for plant establishment.

Trial 5.6 – This modification involves increasing the depth of filter media within the bioretention and is hoped to increase the pollutant removal rate of the bioretention. The value of 0.8m was set based on the maximum recommended by FAWB in their *Adoption Guidelines for Stormwater Biofiltration Systems* as 0.6m and maximum recommended by water by design in their *Bioretention Technical Design Guidelines(Version 1)* as 1.0m.

Trial 5.7 – This modification involves increasing the depth of the extended detention area within the bioretention and is hoped to increase the pollutant removal rate of the bioretention, in particular the TSS removal. The value of 0.5m was set based on the maximum recommended by FAWB in their *Adoption Guidelines for Stormwater Biofiltration Systems*.

Trial 5.8 – This modification filter media type from Loamy Sand to Sandy Loam was included to test for the impact of changing the filter media type. A Sandy Loam was chosen as it is the default and recommended value provided by MUSIC.

Trial 5.9 – This modification is included to demonstrate the impact of omitting effective nutrient removal plants from the bioretention system design. It is expected that this would have an adverse impact on the bioretention systems pollutant removal. If the impact is relatively small then the exclusion of these plants can be considered if so desired; however if the impact is great this will provided evidence for the need for vegetation.

The results from these nine trials were compared with each other and the Scenario 3 results to determine whether or not any of the modifications were effective in increasing the efficiency of the bioretention system.

3.10. Implementation of Methodology

In order to carry out all that has been detailed within Section 3 of this report, a number of resources were required. These resources and there acquisition are outlined within Table 3.13 below, including resources used for the background research of this project.

Table 3.13 – List of resources and sources

Resource	Purpose	Provided By
Report - *Concept Plan for East Creek Basins within Ballin Drive Park & Garnett Lehman Park*	This report forms the start point of this report and was used for background and project specification purposes.	TRC
Pluviometer readings for May & June from the pluviometer stationed at WBH.	The pluviometer readings were required to get an idea of how much rain fell before each storm event sample.	TRC
Analysis of samples that were taken from the WBH.	These samples were used to gauge the levels of TSS, TP and TN within the WBH.	TRC provided the analyses of 30 samples for TSS, TP and TN.
Water Sampling Containers	Initial sample containers to use before taking to TRC water treatment plant.	USQ
MUSIC software	MUSIC was used to model the water quality at the WBH and bioretention system for different scenarios.	The use of the MUSIC software was provided by a Toowoomba Civil Engineering Consultancy.
AutoCad software	AutoCad was used to draw up and measure the WBH catchment area, and other areas associated with the calculations of fraction impervious, overland flow distances, pipe flow distances, channel flow distances, etc	The use of the AutoCad software was provided by a Toowoomba Civil Engineering Consultancy.

4. Results & Discussion

4.1. Introduction

Over the course of this project a number of results were produced from both physical testing and numerical modelling. In particular these include analysis results of the water samples that were taken at and around the WBH and MUSIC outputs for each treatment scenario that was modelled. These results are documented and discussed below.

4.2. Water sample test results

4.2.1. Scope and limitations

The water sampling plan put together for this project was limited in its scope, this mainly due to resources. The limited number of water tests available in conjunction with the amount of time available meant the sample results were also more susceptible to inadequate rain conditions. However, a number of tests were performed and the results analysed.

4.2.2. Viable use of results

The original purpose of these test samples was to gain an understanding of the current quality of water within the WBH. It was never an exercise that would provide highly accurate results of water quality over time and throughout different conditions, including throughout the duration of a storm event. For this reason, even though samples were sporadic and low in number (see Table C.1), they can still be of some use when it comes to regulating the data used in the MUSIC model, and calibrating the results from the model. This allows for comparison with previously tested data and does not leave the samples taken in this project as standalone data used to make decisions upon.

4.2.3. Summary of Results

4.2.3.1. Sample summary

The first rain event sampled was on 14th May 2013 and occurred during a relatively low intensity event, with a total rainfall of approximately 16mm over 4hrs. The increased flow generated by the runoff was measurable during sampling but the rain was not as intense as was hoped.

The second rain event sampled was on 22nd May 2013 and occurred during a smaller rain event with approximately 4mm of rain over 2.5hrs. The effects of the runoff caused by this event were barely measurable, but still existent, at the culvert outlet.

The third rain event sample was taken on 6th June 2013 during a rain event that had a higher intensity than the previous two. In the two hours leading up to the time of sampling, the WBH received 8mm of rain, of that, 6.5mm fell in the last hour before sampling, as recorded by TRC pluviometer, situated at the WBH outlet. The flow through the culvert was higher than previously measured and the results reflected what was to be expected from the increased runoff – higher concentrations of TSS and TP. Interestingly though, TN concentrations decreased.

The rainfall measured using TRC's pluviometer for the hours leading up to each storm event sample is shown in Tables C.2 – C.4 provided in Appendix C.1.

After the 'rain event samples' were taken, a number of base flow samples were also collected.

Table 4.1 is a summary of the six separate occasions on which samples were taken. As mentioned, the full details of sample conditions for each lot of samples are shown in Table C.1 within Appendix C.1. Table 4.1 shows that samples included three wet days and three dry days of sampling.

Note: 'Wet' samples refer to those taken during storm flow conditions, while 'Dry' samples are those that were taken during base flow conditions.

Table 4.1 – Summary of Sample Events

Sample Dates	14.05.13	22.05.13	13.06.13	16.06.13	08.07.13	15.07.13
Conditions	Wet	Wet	Wet	Dry	Dry	Dry
Approx. Flow into WBH (m^3/s)	0.2225	0.085	0.7075	0.0475	0.0475	0.0475

The rainfall that occurred before and during these sample events was graphed using information from a pluviograph located at the outlet of the WBH, which is owned by TRC, and takes data at five minute intervals. This pluviometer measures rainfall at the north end of the WBH within 20m of sample location '3.3' as shown in Figure C.4, Appendix C.1. A graph showing rainfall intensity throughout each sample event is provided in Appendix C.1, Figures C.1 – C.3.

There were a number of different locations within and around the WBH that samples were taken. These are shown in Table 4.2 below. A rough map showing these locations has been included as Figure C.4 of Appendix C.1.

Table 4.2 – Summary of Sample Locations

Location No.	Description of Location (see Figure B.1.1 in Appendix B.1 for Map of locations)
0.1	Upstream of WBH, at the proposed location of Sedimentation Basin
0.2	Pipe discharging into Pond 3, 25m from overflow weir. Visible soil sediment in the water that was discharging into WBH due to a construction site directly upstream of the outlet.
1.1	Location of inlet into Pond 1 via McKenzie St culvert.
1.2	Located on the bank of Pond 1, 15m from outlet.
2.1	Pond 2 inlet - outlet of pipe from pond 1.
2.2	Located on bank of Pond 2, at the edge of its overflow weir.
2.3	Located on bank of Pond 2, 10m from outlet.
3.1	Pond 3 inlet - outlet of pipe from pond 2.
3.2	Located on bank of Pond 3, half way along pond 3.
3.3	Pond 3 outlet/overflow weir.

4.2.3.2. TSS results

The results for each pollutant, TSS, TP and TN were collated in excel and a number of calculations were performed in order to understand what the data could provide. A full set of the TSS sample data is provided in Table C.5 in Appendix C.2, showing the concentrations in mg/L for each sample taken. It should be noted that the minimum detectable concentration of TSS is 2mg/L and thus, any samples below this have been assumed at 1mg/L for calculation purposes.

To get an initial assessment of the concentrations measured within the WBH and surrounds, the samples were divided into 'dry' and 'wet' samples. These dry samples are simply those taken during base flow conditions and the wet during a rain event as outlined in Table 4.1. These samples were then divided up into their separate ponds, and the results for TSS are shown in Figure 4.1 and Figure 4.2 below.

From Table 4.2 above, the sample locations that make up the Pond 1 results for the 'dry' sample results are those from location 1.1 and 1.2. Those that make up Pond 2 results are from location 2.1, 2.2 and 2.3. Pond 3 is made of samples from 3.1, 3.2 and 3.3. The upstream results are from samples taken at location 0.1. Tables C.5 – C.7 in Appendix C.2 help to explain which particular samples make up these graphs.

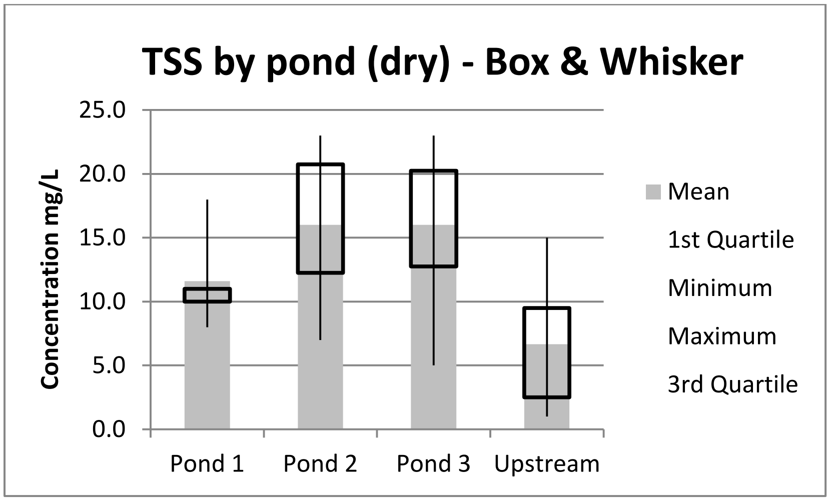


Figure 4.1 – TSS by pond (dry)

Figure 4.1 gives the base flow mean, minimum, maximum, first quartile and third quartile concentrations of TSS (mg/L) for each pond and a location further upstream, in a box and whisker plot. The simplest value to consider here is the mean value, which is 11.6 mg/L for the first pond, 16.0 mg/L for the second and third ponds, and 6.7 mg/L at the proposed bioretention location upstream. Comparing these values with those found in Table 2.1 of this report, where the ten highest values came to an average of 35.7 mg/L and the ten lowest values came to an average of 3.8 mg/L, the samples taken at the WBH ponds and upstream sit towards the lower end. Thus, from this data it appears as though the quality of water within the WBH, with regards to TSS, is relatively high (i.e. relatively low concentrations of TSS).

From Table 4.2 above, the sample locations that make up the Pond 1 results for the TSS 'wet' sample results are those from location 1.1. Those that make up Pond 2 results are from location 2.1. Pond 3 is made of samples from 3.1. The WBH outlet results are from samples taken at location 3.3. Tables C.5 – C.7 in Appendix C.2 help to explain which particular samples make up these graphs.

These are somewhat different to the 'dry' samples as they took into account samples taken at an upstream location as well as those taken at each pond.

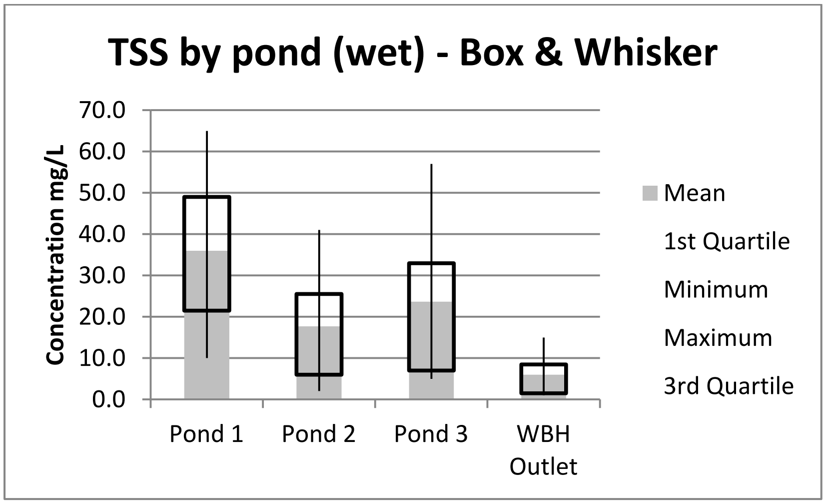


Figure 4.2 – TSS by pond (wet)

Figure 4.2 gives the storm flow mean, minimum, maximum, first quartile and third quartile concentrations of TSS (mg/L) for the inlet of each pond and the outlet of pond three, in a box and whisker plot. Here the mean values are 36.0 mg/L at the inlet of pond one, 17.7 mg/L at the second inlet, 23.7 mg/L at the third inlet, and 6.0 mg/L at the outlet of the third pond.

Without taking any other factors into account, it would be ideal for the concentration of pollutants leaving the WBH to be much lower than those coming in, which is the case for these particular results.

4.2.3.3. TP results

A full set of the TP sample data is provided in Tables C.8 in Appendix C.3, showing the concentrations in mg/L for each sample taken. It should be noted that the minimum detectable concentration of TP is 0.02mg/L and thus, any samples below this have been assumed at 0.01mg/L for calculation purposes.

The results for TP have been compiled in the same manner as for TSS above, and are shown in Figure 4.3 and Figure 4.4 below. Tables C.8 – C.10 in Appendix C.3 help to explain which particular samples make up these graphs.

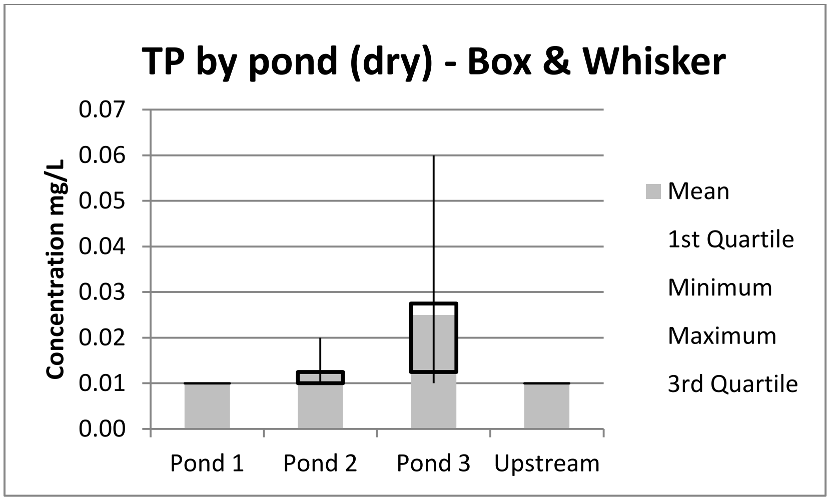


Figure 4.3 – TP by pond (dry)

As with TSS, the simplest value from Figure 4.3 is the mean value, which is 0.01 mg/L for the first pond, 0.01 mg/L for the second, 0.03 mg/L for the third and 0.01 mg/L at the proposed bioretention location upstream. Although we cannot pick up on exact TP values below 0.02 mg/L, these results make it clear that the average values of TP for base flow concentrations are all very low, at approximately 0.02mg/L. Comparing these values with those found in Table 2.1 of this report, where the ten highest values came to an average of 0.234 mg/L and the ten lowest values came to an average of 0.015 mg/L, the samples taken at the WBH ponds and upstream sit at the very lowest end. Thus, from this data it appears as though the quality of water within the WBH, with regards to TP, is very high (i.e. very low levels of TP).

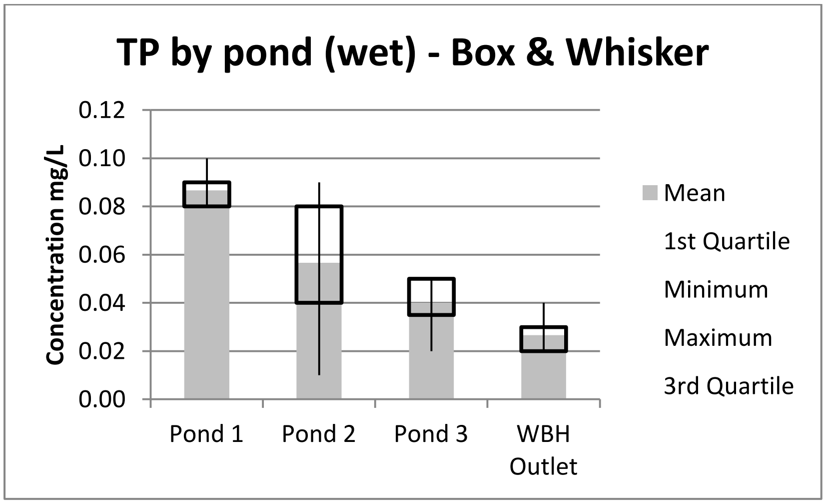


Figure 4.4 – TP by pond (wet)

Figure 4.4 gives results for storm flow conditions. Here the mean values are 0.09 mg/L at the inlet of pond one, 0.06 mg/L at the second inlet, 0.04 mg/L at the third inlet, and 0.03 mg/L at the outlet of the third pond. As with the TSS storm flow results, these averages are highest at the inlet of the WBH and lowest at the outlet. Given the function of the WBH is to treat the stormwater, these results are ideal in that it shows the concentration of the pollutant decreasing as it passes through the ponds – meaning the ponds are having the desired impact. However, this gradual decrease in pollutant concentration as it passes through each pond is not as clearly defined for the TSS and TN wet samples results.

4.2.3.4. TN results

A full set of the TN sample data is provided in Table C.11 in Appendix C.4, showing the concentration in mg/L for each sample taken. Again, it should be noted that the minimum detectable concentration of TN is 0.3mg/L and thus, any samples below this have been assumed at 0.2mg/L for calculation purposes.

The results for TN have been compiled in the same manner as for TSS and TP above, and are shown in Figure 4.5 and Figure 4.6 below. Tables C.11 – C.13 in Appendix C.4 help to explain which particular samples make up these graphs.

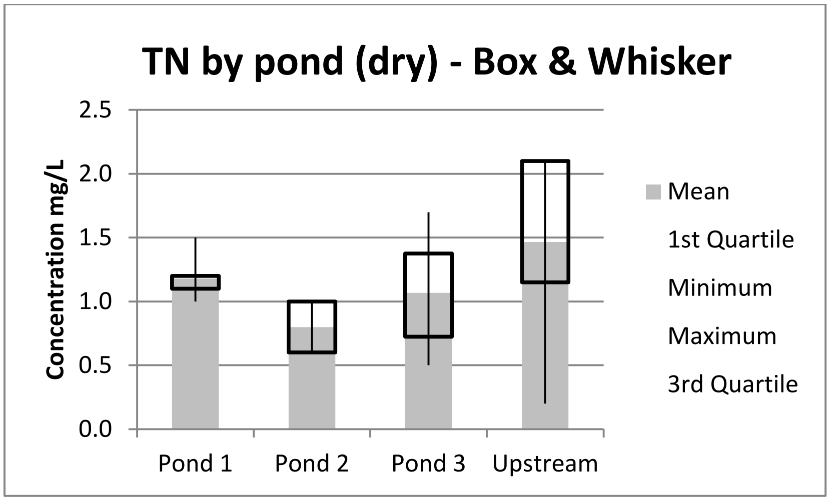


Figure 4.5 – TN by pond (dry)

The mean base flow values, which are shown in Figure 4.5, are 1.2 mg/L for the first pond, 0.8 mg/L for the second, 1.1 mg/L for the third and 1.5 mg/L at the proposed bioretention location upstream. Comparing these values with those found in Table 2.1 of this report, where the ten highest values came to an average of 2.189 mg/L and the ten lowest values came to an average of 0.491 mg/L, the samples taken at the WBH ponds and upstream sit within the lower half, between highest and lowest. Thus, from this data it appears as though the quality of water within the WBH, with regards to TP, is relatively high (i.e. relatively low levels of TN).

It is interesting to note that there are large discrepancies between the three samples taken at the proposed bioretention location, location '0.1', during base flow; these values are provided in Table C.12 in Appendix C.4. Two of these samples measured TN concentrations of 2.1mg/L while the last sample measured a concentration of 0.2mg/L. With such a small sample space it is impossible to know the influencing factors. It could be that the 0.2 mg/L reading was not a true reading, or that the higher readings were from some point source or a totally unrelated factor.

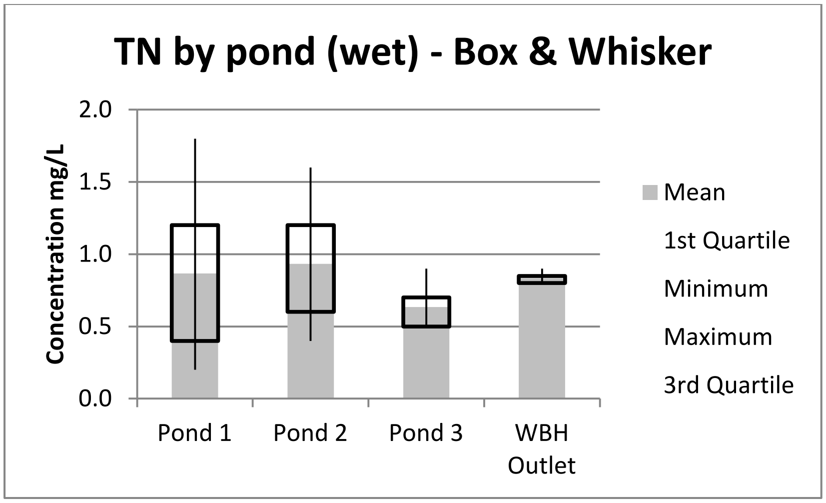


Figure 4.6 – TN by pond (wet)

Figure 4.6 gives results for storm flow conditions. Here the mean values are 0.9 mg/L at the inlet of pond one, 0.9 mg/L at the second inlet, 0.6 mg/L at the third inlet, and 0.8 mg/L at the outlet of the third pond.

These storm flow results are a little less clear as far as the impact of the WBH on the TN concentrations. It is more interesting however, to note that the average TN concentrations during the storm events were similar or even lower than their respective base flow values. It would appear that the stormwater runoff may not have a huge effect on increasing the TN concentration in the water. In fact the results would say that the increased runoff due to rainfall may actually be diluting the TN concentration in the water. Looking at Table 4.1 and Table C.13 in Appendix C.4, seems to confirm this assertion, as the TN concentrations were lowest for the samples taken during the highest flow rate through the culvert. With such a small amount of data this trend is simply an interesting observation, but in more detailed studies the effect of stormwater events on the increase (or decrease) in pollutant concentrations is important, as it has an effect on the modelling of treatment systems.

4.2.4. Deriving MUSIC input values from sample results

4.2.4.1. Process for choosing k and C* values

As outlined in Section 3.2.2, C* values were derived with the help of the sample values. The process included a total of five values and these are outlined, with an explanation, in Table 4.3 below.

Table 4.3 – Choosing C values*

		Choosing C* values for Ponds		
		Pond 1	Pond 2	Pond 3
MUSIC	Theoretical	Theoretical values chosen by eWater CRC		
	Calibrate at Blackburn Lake	Values obtained from monitoring program at Blackburn Lake		
	Recommended	A recommended range in light of the above two values		
	Default	The default value that has been used by MUSIC		
Dry Samples	Mean	Values taken from base flow results for each pond shown in Section 4.2.3. above.		
	Minimum			
	Maximum			
	Adopt:	Derived from the above five values.		

Table 4.3 shows that the values adopted for C* in the MUSIC model, are based heavily upon the research undertaken by eWater and others, combined with some sort of WBH specific results from the samples taken.

Blackburn Lake is the pond that was used for calibration of the pond k and C* values in MUSIC. This lake is located along a tributary, within an urban area of Melbourne. Its catchment is approximately 296Ha made up of about 48% residential and 40% industrial and commercial use. (MUSIC software v5.1 'help' information, Appendix G, 2012).

The WBH is also located along a small creek in an urban area and its catchment area, 516Ha, is not too dissimilar in size.

The dimensions of Blackburn Lake are approximately 500x15m (RossRakesh et al., 1999), giving it an approximate area of 7500m^2. The approximate surface areas of the three ponds at the WBH are 5132m^2, 3936m^2 and 11941m^2, and so are all on a similar scale to Blackburn Lake.

As there are similarities between Blackburn Lake and the WBH, the results can be used with confidence.

The records of flow and water quality were carried out during 1996-1997 and include in depth measurements during storm and base flow. (RossRakesh et al., 1999)

The k values have been derived in the same manner outlined in Table 4.3 above except for the influence of any local data from the WBH – as no information was collected in regards to this decay parameter.

4.2.4.2. Process for choosing source node concentration parameters

Table 4.4 – Choosing Storm flow concentrations

MUSIC Default	The default value that has been used by MUSIC
3 Sample Avgerage	Average of three 'wet' samples taken at WBH inlet
Sample 13.06.13	Single 'wet' sample taken at WBH inlet on 13-June-13
Sample 22.05.13	Single 'wet' sample taken at WBH inlet on 22-May-13
From Building Site	Single 'wet' sample at location 0.2 (see Figure C.4)
Adopt	Derived from the above five values

The process of adopting a Storm flow figure for use in MUSIC took into account the research that had gone behind the values used for the MUSIC default and thus, the sample results were not used as the basis for the adopted value but instead were used to adjust the default values already provided by MUSIC.

The samples at the WBH inlet were used because the value we were trying to determine here was the concentration coming off the catchment into the treatment node.

The reason for including the single samples on the two dates shown is because these two samples were performed under the highest two flow conditions.

The single sample taken directly downstream from the building site (location 0.2), was included to get another comparison with a known high TSS content, as it was quite visible at the time of sampling.

Table 4.5 – Choosing C* values

MUSIC Default	The default value that has been used by MUSIC
3 Sample Avg.	Average of three 'dry' samples taken at WBH inlet
Melbourne Rivers 2012	Average of the median of multiple samples from 136 locations along Melbourne's rivers in 2012.
Adopt	Derived from the above three values

As for storm flow, the process of adopting a base flow figure took into account the research that had gone behind the values used for the MUSIC default and thus, the sample results were not used as the basis for the adopted value but instead were used to adjust the default values already provided by MUSIC.

Again, the samples at the WBH inlet were used because the value we were trying to determine here was the concentration coming off the catchment into the treatment node.

The data from Melbourne Water's fact sheet: "Summary Waterway Water Quality Data 2012" is based on monthly samples of 136 sites within Greater Melbourne. It was included as another comparison and is beneficial because it is based on such a large number of samples. The disadvantage of this particular value is that it is an average of samples from a whole range of different water quality sites. The final value may also contain a small number of storm flow concentrations effecting final results as the samples are on a monthly time scale and some may be taken during a rain event.

4.2.4.3. Deriving MUSIC inputs from TSS results

TSS k and C* values for each pond

Table 4.6 shows the adopted value of C*, background TSS concentration, for each pond. Ponds two and three have been given adopted C* values of 15mg/L, which is the conservative end of recommended range given in MUSIC. It is also close to the average sampled value of 16mg/L in each of these ponds, and was chosen with confidence as the values for both these ponds and Blackburn Lake were very close.

The adopted value for Pond 1 was 13mg/L, which is within the range recommended in MUSIC. The 11.6mg/L average sampled value from Pond 1 was the reason for choosing a less conservative value for this pond. The value was chosen with confidence as the measured concentration was very close to the theoretical value calculated.

Table 4.6 – Choosing TSS C values for WBH ponds*

	Choosing C* values for Ponds			
		Pond 1	Pond 2	Pond 3
MUSIC	Theoretical	12		
	Testing at Blackburn Lake	15		
	Recommended	12-15		
	Default	12		
Dry Samples	Mean	11.6	16.0	16.0
	Minimum	8.00	7.00	5.00
	Maximum	18.00	23.00	23.00
	Adopt:	13	15	15

The adopted TSS k value of 400 m/yr is shown in Table 4.7, where the theoretical and least conservative value is 1000 m/yr and the value for Blackburn Lake is 200-300 m/yr. As no other comparisons were available, a value of 400 m/yr was chosen as it is the default in MUSIC and it is towards the conservative end of the recommended range.

Table 4.7 – Choosing TSS k values for WBH ponds

	Choosing k values for Ponds			
		Pond 1	Pond 2	Pond 3
MUSIC	Theoretical	1000		
	Calibration at Blackburn Lake	200-300		
	Recommended	200-1000		
	Default	400		
	Adopt default	400	400	400

TSS ‘source node’ concentration parameters (Base Flow and Storm Flow)
Figure 4.7 is a comparison of concentrations of the five values used to derive the storm flow TSS concentration for the catchment source node in MUSIC. The comparison involves the MUSIC default value for TSS storm flow concentrations, the average of the three storm event samples taken at the WBH inlet (sample location 1.1), the storm event sample taken at the WBH inlet on 13/06/13, the storm event sample taken at the WBH inlet on 22/05/13 and the sample taken downstream of the building site (sample location 0.2). The yellow shows the TSS storm flow concentration adopted for the MUSIC source node.

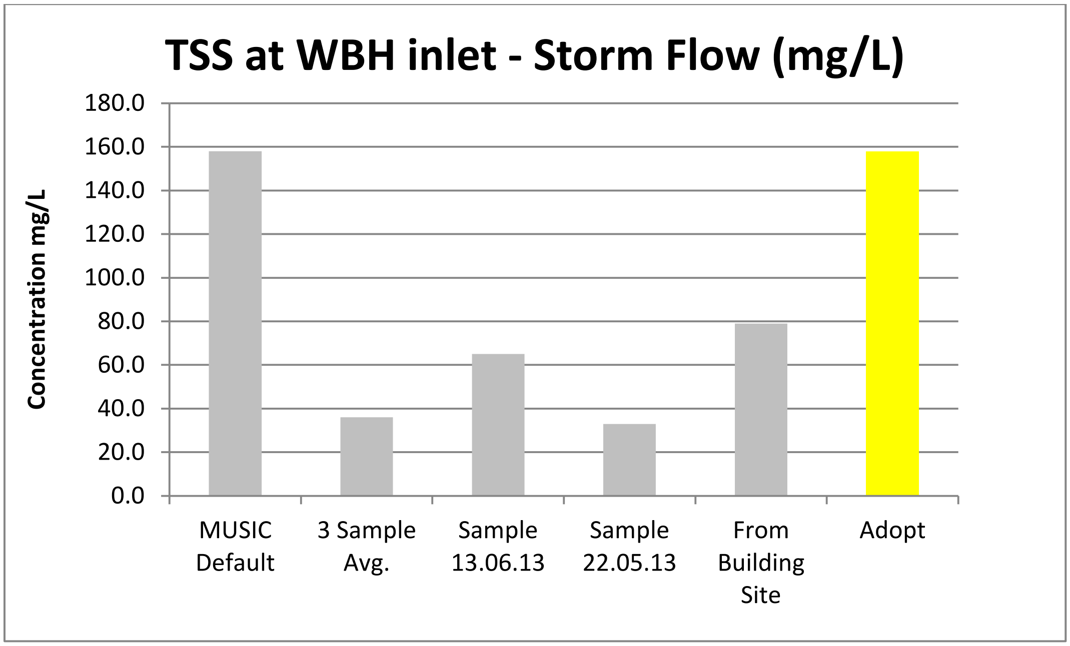


Figure 4.7 – Choosing Storm flow TSS concentration

The MUSIC default value is shown to be much higher than all the sample results. As is shown, this default value of 158mg/L was adopted regardless. This was due to the fact that the reliability of the storm samples is unknown, as they were based on a small number of samples, which were taken during rain events that were less than desirable. 158mg/L although conservative in comparison, is not in disagreeance with the sample results, i.e. knowing what we know about the conditions of the Storm flow samples, it is easy to see the MUSIC value of 158mg/L being accurate. For this reason these values were still chosen with confidence.

Figure 4.8 is a comparison of concentrations of the three values used to derive the base flow TSS concentration for the catchment source node in MUSIC. The comparison involves the MUSIC default value for TSS base flow concentrations, the average of the three base flow event samples taken at the WBH inlet (sample location 1.1) and the average of the TSS values found in Melbourne’s rivers in 2012 as conducted by Melbourne Water (2012). The yellow shows the TSS base flow concentration adopted for the MUSIC source node.

The adopted TSS base flow concentration of 12.6 mg/L, equal to the MUSIC default value, was chosen with confidence of being appropriate for the model, as the average of the sample values, 9.7 mg/L, was just slightly lower. Therefore, the default value is within close range of both our own sample data and the data collected by Melbourne Water in 2012.

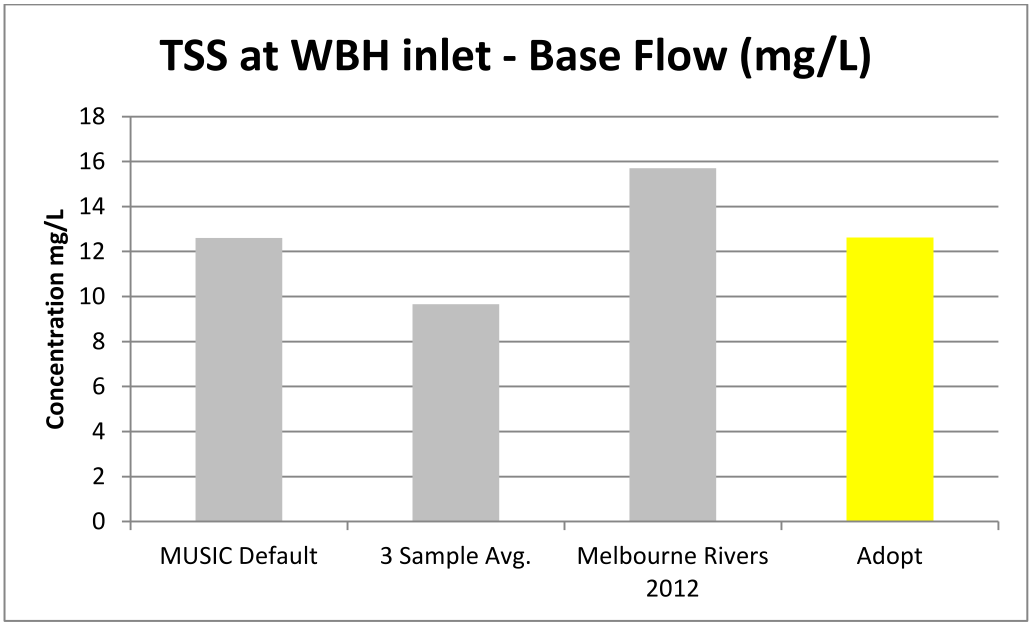


Figure 4.8 – Choosing Base flow TSS concentration

4.2.4.4. Deriving MUSIC inputs from TP results

TP k and C* values for each pond

As is shown in Table 4.8, the values adopted for C*, background TP concentration, for each pond is 0.05 mg/L. This is the value given for the Blackburn Lake and is the lowest value in MUSIC's recommended range, with the most conservative value being the theoretical 0.13 mg/L. The sampled average for ponds one and two were 0.01 mg/L and pond three was 0.03 mg/L. 0.05 mg/L was adopted as it was closer to the very low sample results but still within MUSIC's recommended range. Despite it being a lower than the default value, the adopted value for each pond was chosen with confidence that it was appropriate and still conservative for the model.

Table 4.8 – Choosing TP C values for WBH ponds*

	Choosing C* values for Ponds			
		Pond 1	Pond 2	Pond 3
MUSIC	Theoretical	0.13		
	Testing at Blackburn Lake	0.05		
	Recommended	0.05-0.13		
	Default	0.09		
Dry Samples	Mean	0.01	0.01	0.03
	Minimum	0.01	0.01	0.01
	Maximum	0.01	0.02	0.06
	Adopt:	0.05	0.05	0.05

The adopted value of 300 m/yr is shown in Table 4.9, where the theoretical and least conservative value is 500 m/yr and the value for Blackburn Lake is 150-300 m/yr. As no other comparisons were available, a value of 300 m/yr was chosen as it is the default in MUSIC and was within the range found at Blackburn Lake.

Table 4.9 – Choosing TP k values for WBH ponds

	Choosing k values for Ponds			
		Pond 1	Pond 2	Pond 3
MUSIC	Theoretical	500		
	Calibration at Blackburn Lake	150-300		
	Recommended	150-500		
	Default	300		
	Adopt default	300	300	300

TP ‘source node’ concentration parameters (Base Flow and Storm Flow)

As for TSS Storm flow concentration, the default value of 0.355 mg/L was chosen for the Storm flow concentration of TP coming from the catchment source nodes. The values in Figure 4.9 tell a similar story to the TSS values in which the sample results are much lower than the MUSIC default value. For the same reasons as for TSS, the adopted value was chosen as the conservative looking 0.355 mg/L because of the uncertainty with the sampled results. Again, while the value chosen is conservative, it does not disagree with the sample data and can be used with confidence that it will be appropriate for the model.

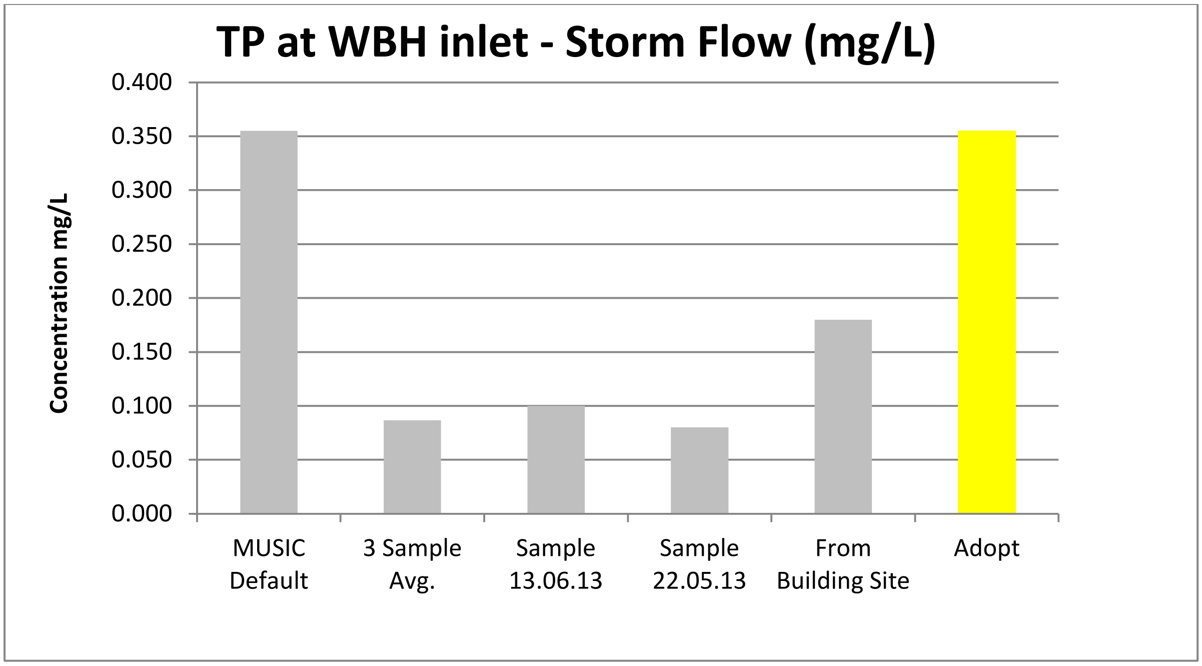


Figure 4.9 – Choosing Storm flow TP concentration

The adopted Base flow TP concentration for the catchment was 0.080 mg/L as shown in Figure 4.10. The MUSIC default is 0.151 mg/L and the average median value from Melbourne waterways in 2012 is 0.120 mg/L. However, even though the WBH sample size was small, the results were consistently low for TP, including the Storm flow results. With low variability in the Base flow samples, it was decided that the adopted value could be lowered with confidence that it would be indicative of the TP concentrations coming from the WBH catchment. The chosen concentration value is almost half that of the MUSIC default value.

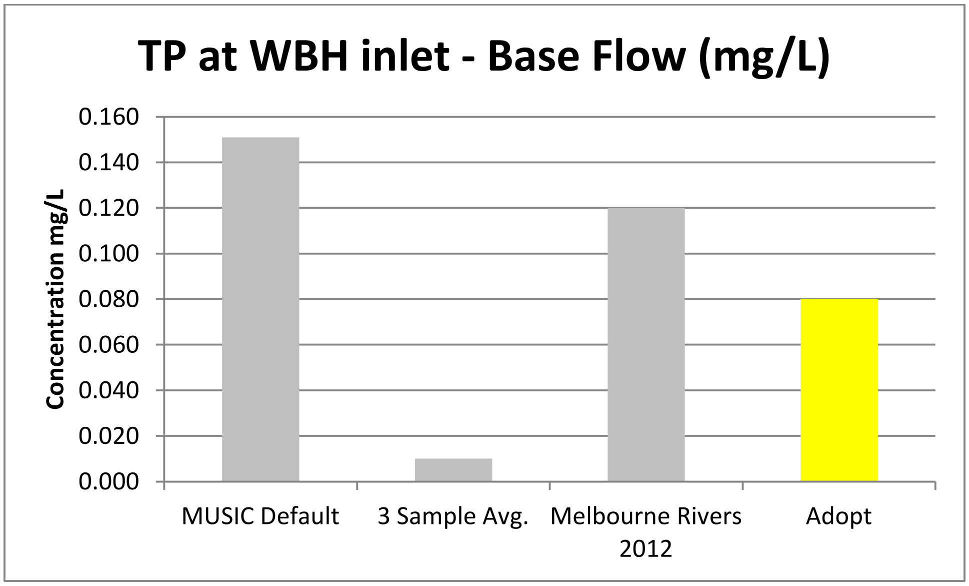


Figure 4.10 – Choosing Base flow TP concentration

4.2.4.5. Deriving MUSIC inputs from TN results

TN k and C* values for each pond

The adopted values for TN C*, background concentration of TN, in each pond was chosen as shown in Table 4.10. The adopted value for each pond was taken as the average sampled concentration for that pond, as each of these values were both close to the default MUSIC value of 1.0 mg/L, and within the MUSIC recommended range. With consistent sample results that are within MUSIC's recommended range, the choice of TN concentration for each pond was made with confidence that it is an accurate reflection of the physical properties of the ponds.

Table 4.10 – Choosing TN C values for WBH ponds*

	Choosing C* values for Ponds			
		Pond 1	Pond 2	Pond 3
MUSIC	Theoretical	1.3		
	Testing at Blackburn Lake	0.7		
	Recommended	0.7-1.3		
	Default	1		
Dry Samples	Mean	1.2	0.8	1.1
	Minimum	1.00	0.60	0.50
	Maximum	1.50	1.00	1.70
	Adopt:	1.2	0.8	1.1

The k value adopted for TN within the ponds is shown in Table 4.11 as 40 m/yr. This is simply the default MUSIC value and sits within both the Blackburn Lake range and MUSIC recommended range.

Table 4.11 – Choosing TN k values for WBH ponds

	Choosing k values for Ponds			
		Pond 1	Pond 2	Pond 3
MUSIC	Theoretical	50		
	Calibration at Blackburn Lake	30-50		
	Recommended	30-50		
	Default	40		
	Adopt default	40	40	40

TN 'source node' concentration parameters (Base Flow and Storm Flow)

The adopted TN concentration parameter for the catchment during Storm flow was simply the 2.63 mg/L MUSIC default. This was chosen for the same reasons as the two previous Storm flow concentrations, this being the lack of confidence in the results from the WBH samples. The MUSIC value was adopted as it is conservative yet does not disagree with the sampled data.

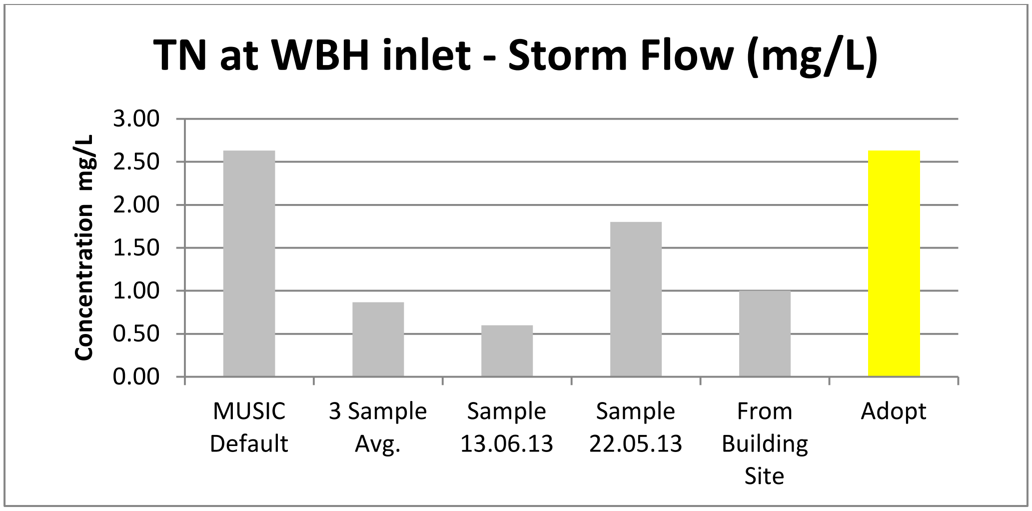


Figure 4.11 – Choosing Storm flow TN concentration

The adopted value for TN Base flow concentration is the default MUSIC value of 2.09 mg/L. This value was taken with confidence that it is accurate yet conservative. It is comfortably higher than the WBH sample average, yet still within two times this amount. Figure 4.12 shows a comparison of all these values, including an additional value not used for the comparison of TP and TSS concentrations. This is the maximum TN concentration measured at the proposed bioretention system location upstream. It is not an average of this amount as the third sample taken was much lower, at 0.2 mg/L. The maximum value of 2.1 mg/L was measured the first two times and was included in the comparisons to confirm how plausible/reasonable the MUSIC default value of 2.1 mg/L is. With the average median value measured in Melbourne waterways in 2012 also being close, 1.50 mg/L, the adopted value was taken with confidence that it is appropriate for the modelling of the WBH catchment runoff TN concentration.

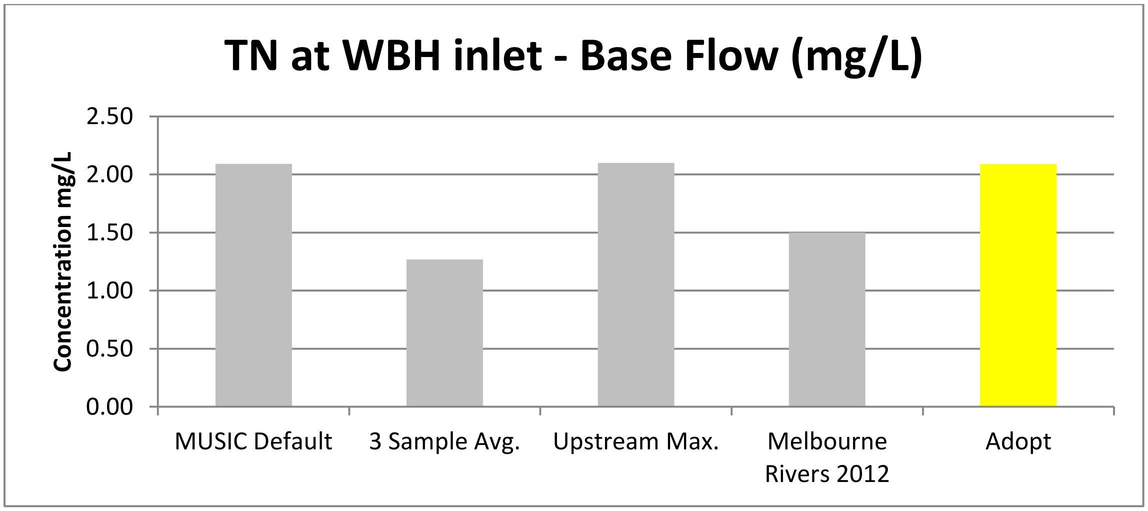


Figure 4.12 – Choosing Base flow TN concentration

4.2.5. Comments on results

On a whole, the sample data shows the levels of TSS, TP and TN to be relatively low compared to those being compare with. The storm samples are all well below the default value set by MUSIC, this was somewhat expected, as the storm events that were sampled were relatively small rainfall events, with the only significant increase in flows provided by the storm event on the 13/06/13, as shown in Figure C.1 – C.3, Appendix C.1.

The base flow samples presented results generally closer to both those provided as defaults by MUSIC, and the average of the 2012 samples of Melbourne Rivers. The exception with the base flow results was for the TP sample. Which, showed average concentrations of TP in the ponds during base flow conditions considerably lower than both the MUSIC default values and the Melbourne rivers sample values – less than one tenth of both.

In any case, the values adopted for the MUSIC model are all shown in the above section. It is shown that the pollutant concentrations adopted for the source node within the model have all been conservative with respect to the measured concentrations within the WBH ponds.

4.3.MUSIC results and comparisons

4.3.1. Scenario 1 – Current scenario

4.3.1.1. MUSIC model and predicted total pollutant removal

The results of the Scenario 1 MUSIC model that was used to determine the likely current water quality at the WBH ponds is outlined within this section. A layout of the model is provided in Figure 4.13 below. This model includes the three WBH ponds and the sub-catchments draining into each of these ponds. The receiving node represents the outlet of the third pond and is the point at which the overall effectiveness of the treatment train will be assessed.

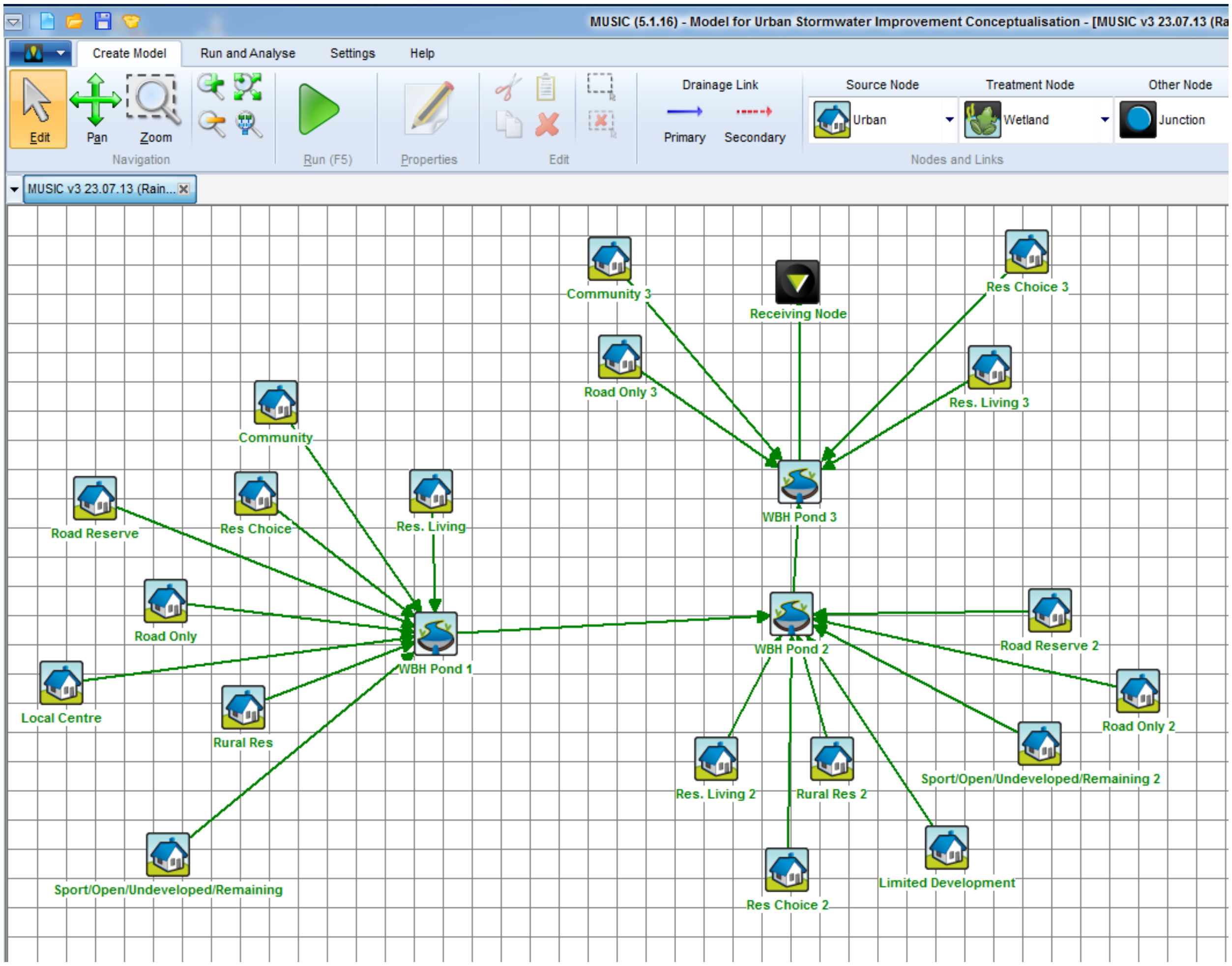
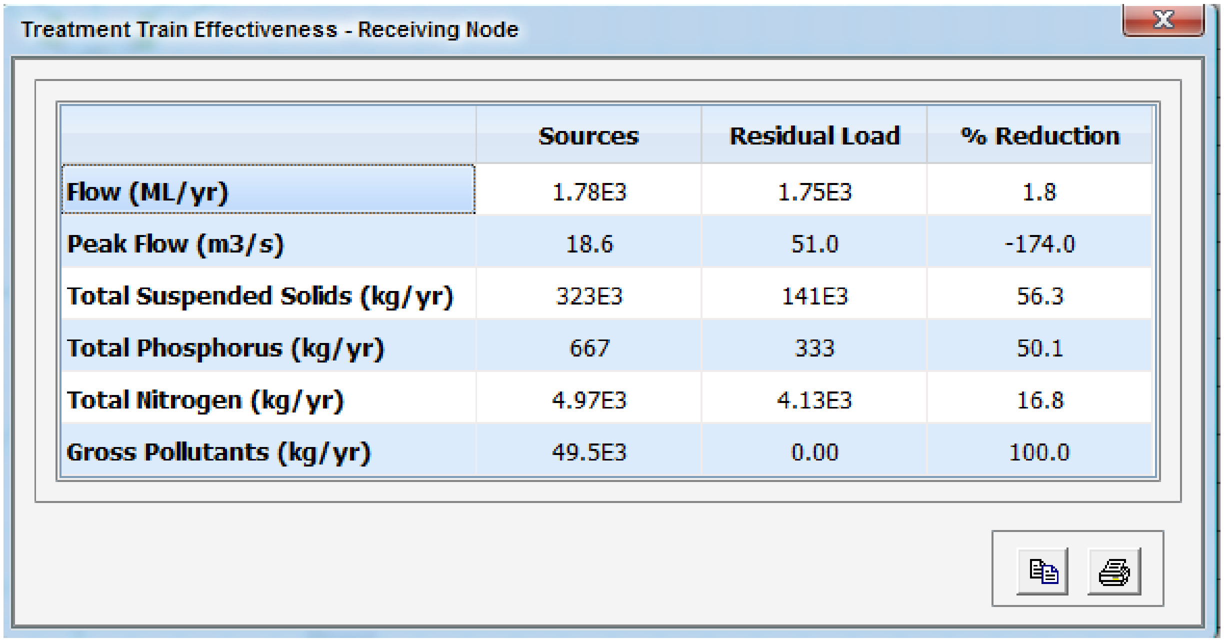


Figure 4.13 – Scenario 1 model layout

This model gave the results shown in Figure 4.14 for Mean Annual Load (MAL – see Section 3.4.5) and percentage reduction of pollutants found at the outlet of the WBH pond 3, shown as the 'Receiving Node' in the Music model. The percentage reduction values show a 56.3%, 50.1%, 16.8% reduction in TSS, TP and TN respectively. For an initial comparison, the minimum targets for the Toowoomba region are TSS – 80%, TP – 65% and TN – 45%, as outline in Tables 2.2 – 2.3 of *Urban Stormwater Quality Planning Guidelines* (Department of Environment and Heritage Protection 2010). Thus, according to the MUSIC results, the required percentage reduction targets are not currently being met by the WBH ponds.

Note: The region covered by TRC overlap's two zones, South East Queensland (SEQ) and Western Districts, as can be seen in Figure 2.5 of *Urban Stormwater Quality Planning Guidelines* (Department of Environment and Heritage Protection 2010). South East Queensland design objectives are TSS – 80%, TP – 60% and TN – 45%, while Western Districts are TSS – 85%, TP – 70% and TN – 45%. This report assumes the design objectives of South East Queensland for comparison purposes but does not have a recommendation on which of these would be more appropriate for the WBH.



	Sources	Residual Load	% Reduction
Flow (ML/yr)	1.78E3	1.75E3	1.8
Peak Flow (m3/s)	18.6	51.0	-174.0
Total Suspended Solids (kg/yr)	323E3	141E3	56.3
Total Phosphorus (kg/yr)	667	333	50.1
Total Nitrogen (kg/yr)	4.97E3	4.13E3	16.8
Gross Pollutants (kg/yr)	49.5E3	0.00	100.0

Figure 4.14 – Full treatment train effectiveness

What is also noted from the percentage reduction values in Figure 4.14, is the increase in Peak Flow. The MUSIC output shows the total of peak flows coming from the catchments (Sources) is 18.6 m^3/s, while the peak flow coming from pond 3 of the WBH is 51.0 m^3/s. This would indicate a rise in peak flow of 174.0% as a result of the WBH ponds. With the ponds ability to store water it has the ability to decrease peak flow. However, the ponds do not have any ability to store and then release water, e.g. opening a flood gate, and thus are not able to *increase* peak flow. Which creates some doubt in the validity of this 174% increase in peak flow.

It is unclear why this particular output from MUSIC gives an increase in peak flow, the trend continues for the ‘Full Treatment Train’ outputs for each scenario. However, Scenario 3 (Section 4.3.3) also looks at the results for each separate treatment device along the ‘treatment train’; Figures 4.25 – 4.29 show results for MAL and percentage reduction for each device. This is a measure of what is coming into (Inflow) and out of (Outflow) the device, compared to the Figure 4.14 (above) measurement of what is being generated by the catchment (Sources) and what is leaving the WBH pond 3 (Residual Load). For these Scenario 3 results, peak flow is shown to decrease for each treatment device.

If the outflow peak discharge is lower than the inflow discharge for each treatment device, it would follow that the peak flow coming from pond 3 of the WBH would be lower than the total peak flow generated by the catchment. It is thought that the increase in peak flow shown in Figure 4.14 (above) could be due to a discrepancy in calculation of the peak flow actually being generated.

4.3.1.2. Daily Mean Concentration at WBH Ponds

The Daily Mean Concentration (DMC) values from MUSIC were taken from the Daily Sample Statistics as outlined in Section 3.4.5. The DMC values for each Pond are shown in Tables 4.12 – 4.14 below.

Table 4.12 – Daily Mean Concentration, Pond 1

TSS (mg/L)		TP (mg/L)		TN (mg/L)	
Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
46.5	25.6	0.132	0.069	10.20	1.13

Table 4.13 – Daily Mean Concentration, Pond 2

TSS (mg/L)		TP (mg/L)		TN (mg/L)	
Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
35.0	18.6	0.108	0.051	12.10	0.95

Table 4.14 – Daily Mean Concentration, Pond 3

TSS (mg/L)		TP (mg/L)		TN (mg/L)	
Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
28.4	22.0	0.087	0.064	12.50	1.40

Part of the use of the sample data taken from the ponds, was to check how closely they aligned with the Scenario 1 MUSIC results. If the Scenario 1 results can be somewhat justified, we can increase our faith in the models that follow.

The average wet weather samples for each pond shown in Figures 4.2, 4.4 & 4.6, will be compared against the MUSIC model's outflow values for each pond, as provided in Tables 4.12 – 4.14 above.

Note: The sample used to compare with MUSIC's 'Outflow from Pond 1' was the sample location called 'P2 Inlet' (see Table 4.2), as this is the point in Pond 2 to which Pond 1 outlets to, and thus is most indicative of the 'Outflow from Pond 1'; this is so for Outflow Pond 2 & 3 also.

As noted previously, the amount of sample data that we have, allows for a rough checking of the results against some measured values within the pond. That is, the results do not provide the basis for this report but merely a back-up. To properly compare sample data with MUSIC's DMC value, a very large number of samples would need to be taken during all kinds of rainfall and weather conditions over a period of time. Instead we are comparing it to a small number of 'wet weather' samples, and this should be kept in mind when comparing the values.

The comparison is shown in Table 4.15 below.

Table 4.15 – Comparison of MUSIC DMC vs sample concentrations at WBH

	TSS		TP		TN	
	Sample	MUSIC	Sample	MUSIC	Sample	MUSIC
Outflow Pond 1 ('Pond 2' sample)	17.7	25.6	0.060	0.069	0.90	1.13
Outflow Pond 2 ('Pond 3' sample)	23.7	18.6	0.040	0.051	0.60	0.95
Outflow Pond 3 ('WBH outlet' sample)	6.0	22.0	0.030	0.064	0.80	1.40
Avg. of ponds 1-3	15.8	22.1	0.043	0.061	0.77	1.16
% 'error'	28.4		29.4		33.9	

For the average TSS concentrations from Ponds 1 – 3, the sample results are 28.4% less than the MUSIC values. For TP and TN this is 29.4% and 33.9% respectively. Considering the fact that these samples are limited in number and from random times and weather conditions, it is surprising that these results are even this close. What the results do provide, is some sort of confidence that MUSIC has modelled the catchment and WBH relatively closely to the actual scenario.

4.3.2. Scenario 2 – Ultimate development

4.3.2.1. MUSIC Model and predicted total pollutant removal

As can be seen in Figure 4.15, the MUSIC model layout for Scenario 2 does not change from Scenario 1. The only change occurs in sub-catchment area totals as outlined in Section 3.3.

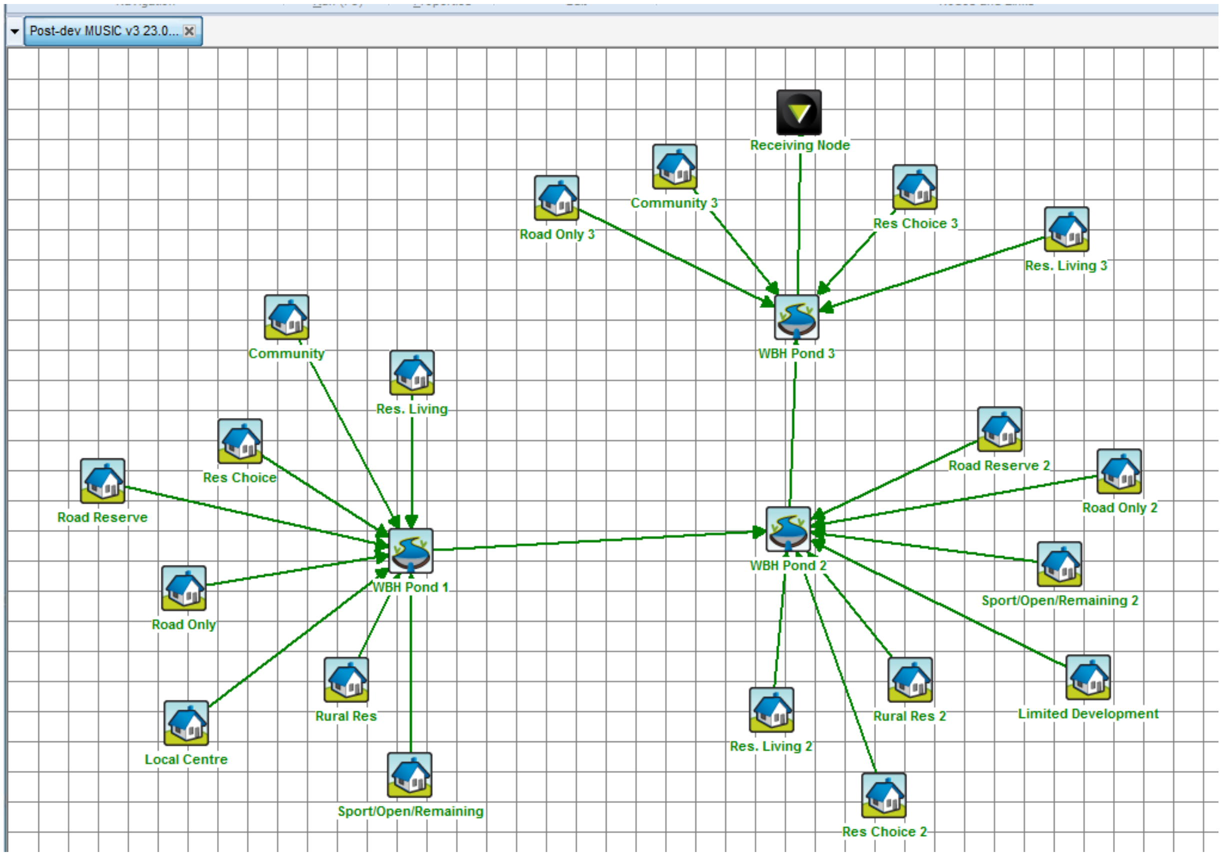
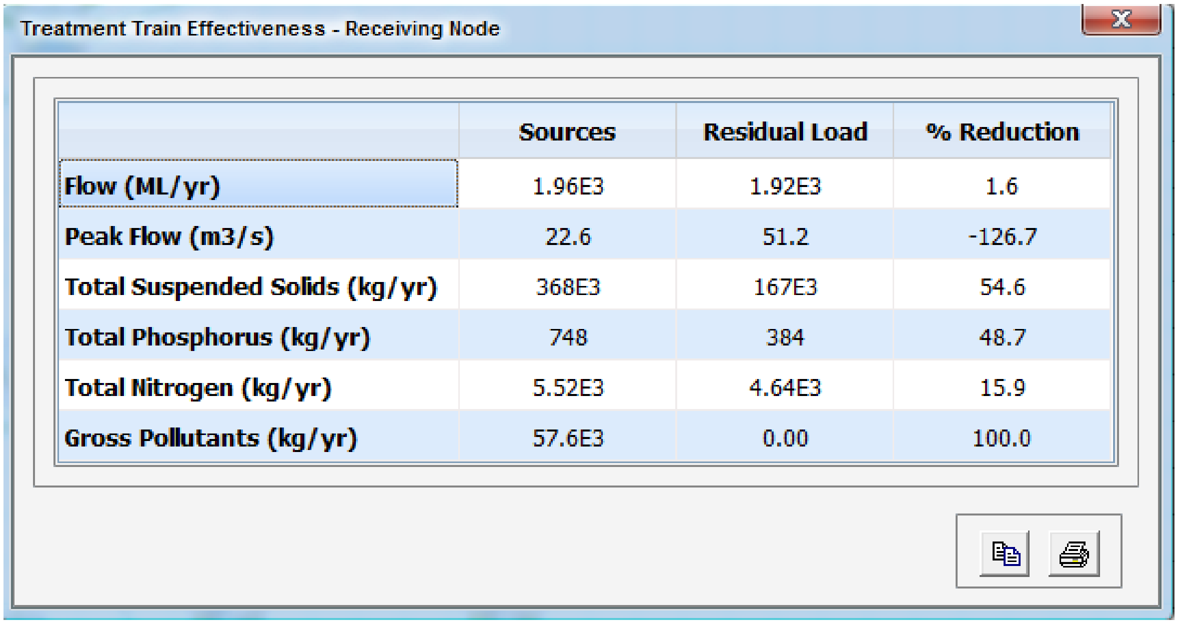


Figure 4.15 – Scenario 2 model layout

This model gave the results shown in Figure 4.16 for MAL and percentage reduction of our pollutants. The percentage reduction values show a 54.6%, 48.7% and 15.9% reduction in TSS, TP and TN respectively.



Treatment Train Effectiveness - Receiving Node

	Sources	Residual Load	% Reduction
Flow (ML/yr)	1.96E3	1.92E3	1.6
Peak Flow (m3/s)	22.6	51.2	-126.7
Total Suspended Solids (kg/yr)	368E3	167E3	54.6
Total Phosphorus (kg/yr)	748	384	48.7
Total Nitrogen (kg/yr)	5.52E3	4.64E3	15.9
Gross Pollutants (kg/yr)	57.6E3	0.00	100.0

Figure 4.16 – Full treatment train effectiveness

4.3.2.2. Daily Mean Concentration at WBH outlet

Table 4.16 shows the DMC at the outlet of the third pond, which is the same as the DMC for the receiving node in the model. This gives an indication of the mean concentration of the water once it has been treated in full by the treatment train.

Table 4.16 – Daily Mean Concentration for full treatment train

	TSS	TP	TN
Outflow from Pond 3 (mg/L)	24.0	0.068	1.43

4.3.2.3. Comparison of Scenario 1 to Scenario 2 results

Comparisons of DMC, MAL and percentage reduction between Scenarios 1 and 2 are shown in Figures 4.17 – 4.19 below.

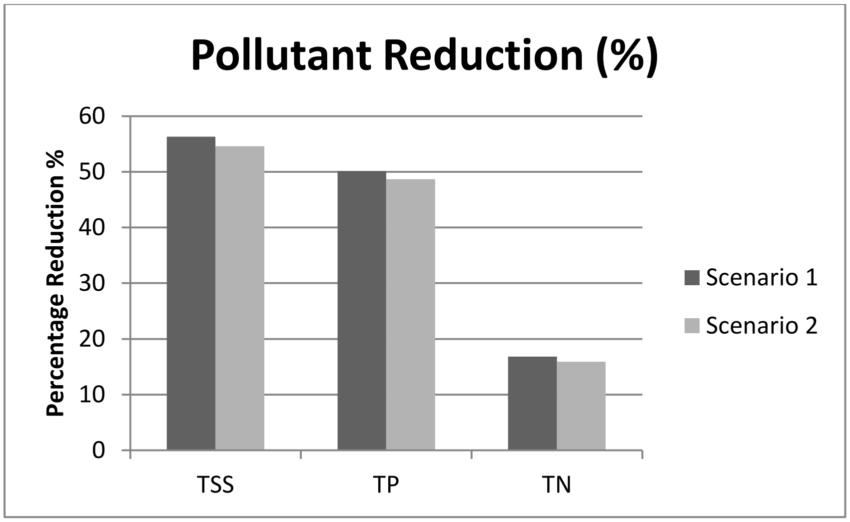


Figure 4.17 – Percentage Reduction, Scenario 1 and 2

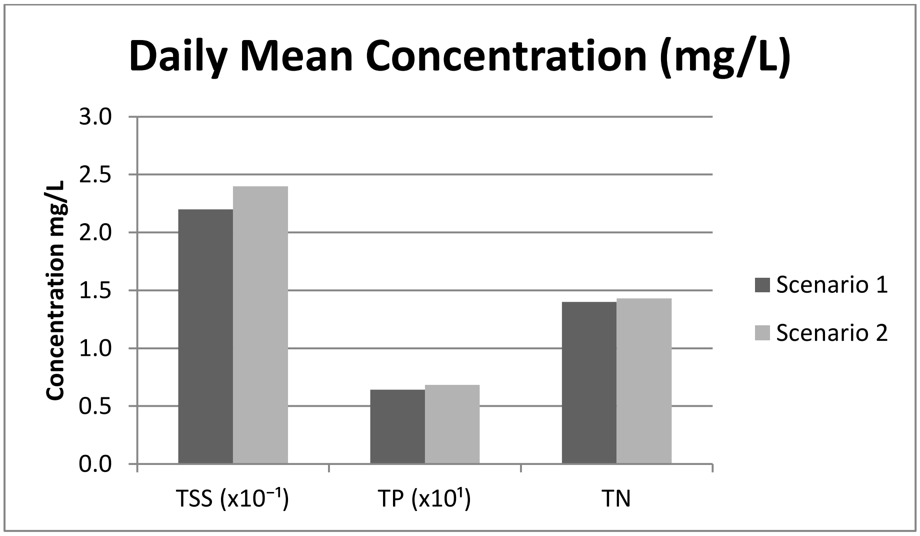


Figure 4.18 - Daily Mean Concentration, Scenario 1 and 2

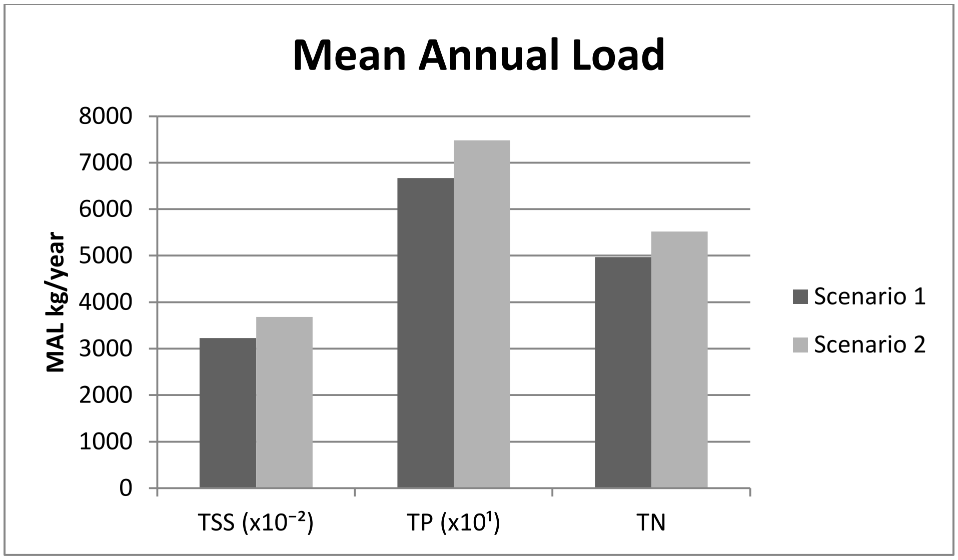


Figure 4.19 - Mean Annual Load, Scenario 1 and 2

The resulting increase in pollutant runoff due to the predicted development affected the overall pollutant values in MUSIC; however it did not cause large increases. This is shown in the above three figures, where percentage reduction decreases for all pollutants, and DMC and MAL increases for each.

The predicted impact of the WBH catchment being further developed in the future, in terms of Mean Annual Load (MAL), as shown in Figure 4.19, is an increase in TSS of 45,000 kg/yr (14%), an increase in TP of 81kg/yr (12%), and an increase in TN of 550 kg/yr (11%).

Section 3.3.1 of this report outlines the process undertaken to calculate the total area expected to undergo future development, this was calculated as 60.784Ha, which represents approximately 11.8% of the total catchment. This increase correlates very closely with the increase in MAL for each pollutant, which ranges from 11-14% increase of each pollutant. This is the sort of result that would be desired for the Scenario 2 model, as this report is based on the expectation that future development would indeed increase the pollutant loads generated from the catchment.

4.3.3. Scenario 3 – Ultimate development with proposed bioretention system

4.3.3.1. MUSIC model and predicted total pollutant removal

The MUSIC model for Scenario 3 includes the WBH ponds from the previous scenarios, as well as the proposed bioretention system and accompanying sedimentation basin. The catchments that were discharging into Pond 1 in the previous two scenarios have now been divided between Pond 1 and the sedimentation basin, as per the catchment calculations outlined in Section 3.3. Provided as Figure 4.20 below, is the layout of the Scenario 3 model in MUSIC.

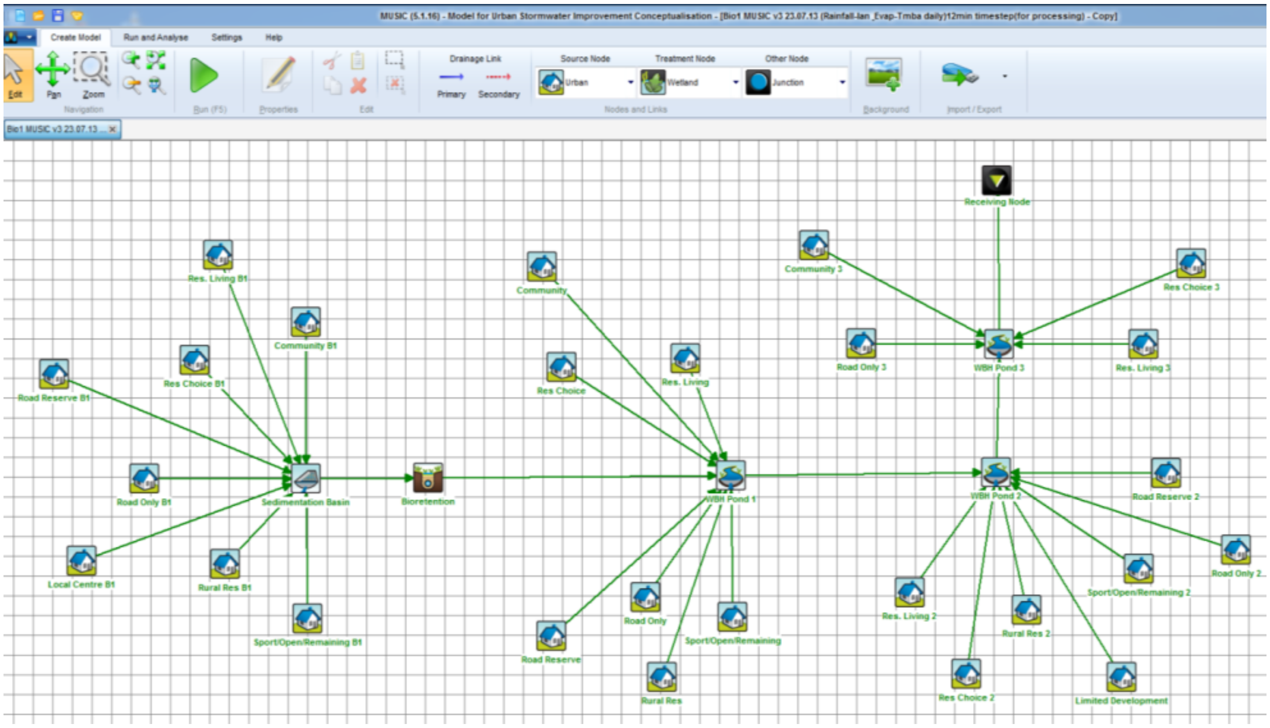


Figure 4.20 – Scenario 3 model layout

Figure 4.21 below shows the area, as a section of the whole catchment, which discharges into the sedimentation/bioretention system. This area corresponds to the source nodes shown in Figure 4.20 (above) that are connected into the sedimentation basin treatment node. The areas that discharge directly into the three WBH ponds effectively by-pass the bioretention system and do not undergo any treatment before entering into the WBH.

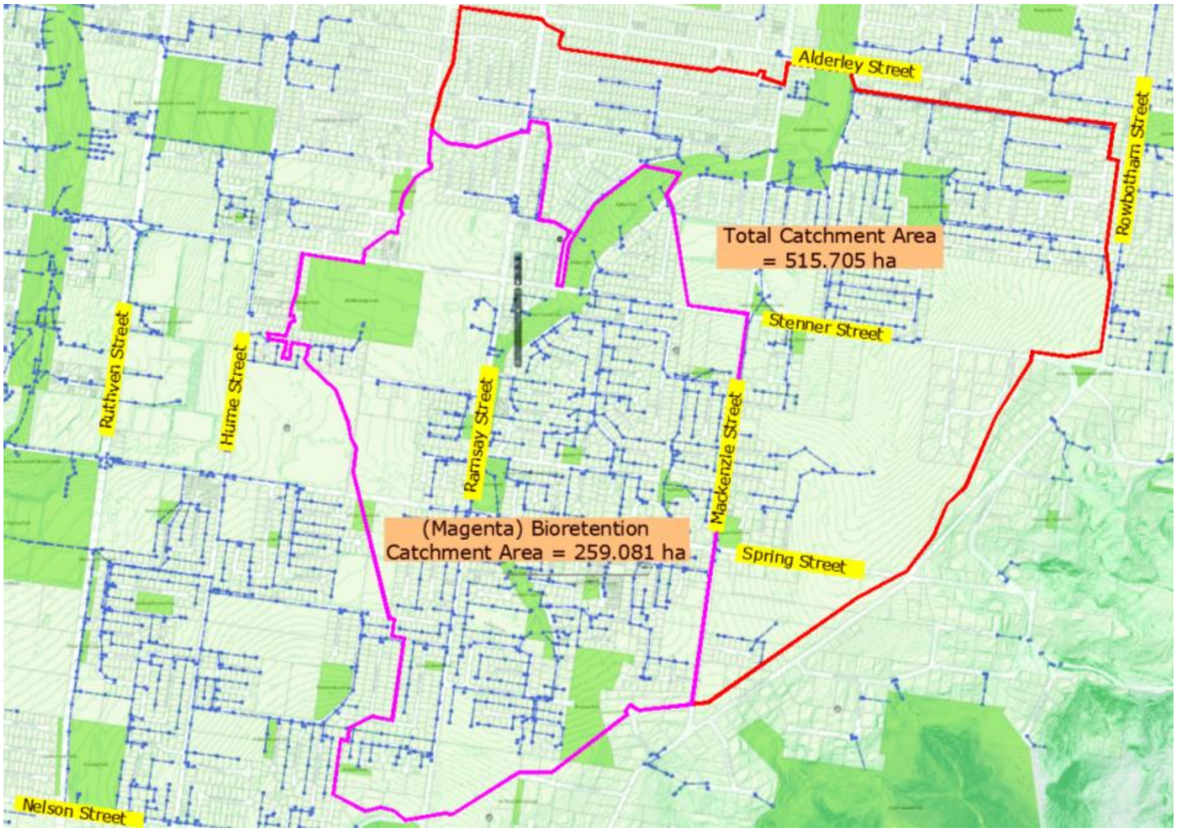
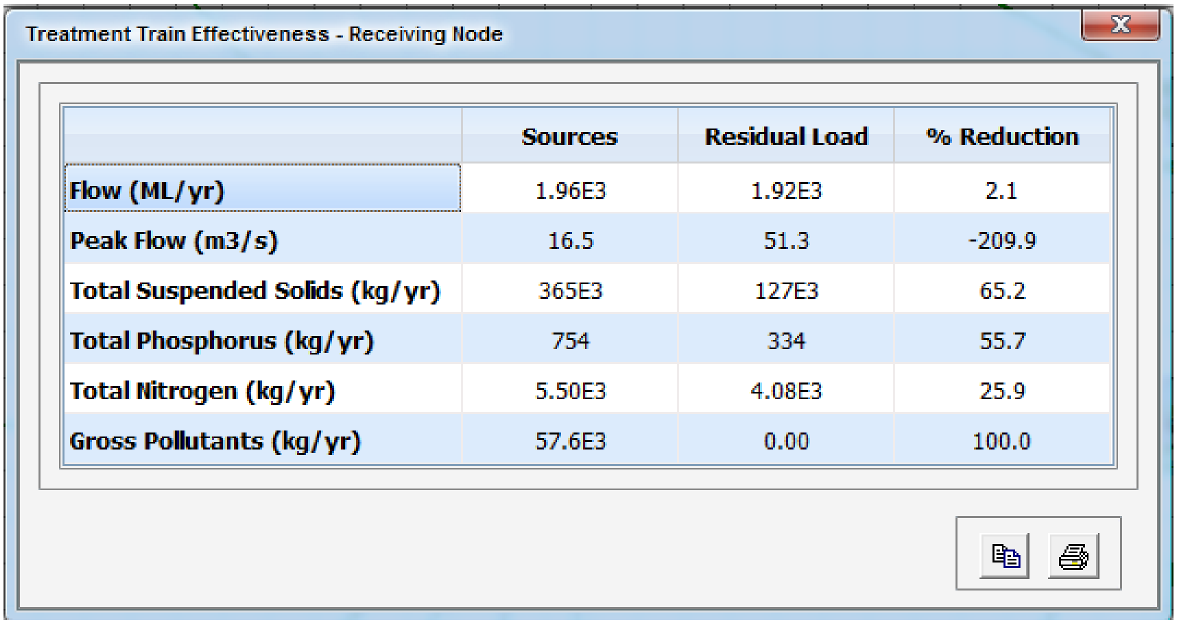


Figure 4.21 – Bioretention catchment area shown within WBH catchment

The Scenario 3 model gave the results shown in Figure 4.22 for MAL and percentage reduction of our pollutants. The percentage reduction values show a 65.2%, 55.7% and 25.9% reduction in TSS, TP and TN respectively.



	Sources	Residual Load	% Reduction
Flow (ML/yr)	1.96E3	1.92E3	2.1
Peak Flow (m3/s)	16.5	51.3	-209.9
Total Suspended Solids (kg/yr)	365E3	127E3	65.2
Total Phosphorus (kg/yr)	754	334	55.7
Total Nitrogen (kg/yr)	5.50E3	4.08E3	25.9
Gross Pollutants (kg/yr)	57.6E3	0.00	100.0

Figure 4.22 – Full treatment train effectiveness

Figure 4.23 is a graph that compares percentage reduction of the total treatment train for the first three scenarios. It illustrates a clear increase in percentage reduction of pollutants compared to Scenario 2; this was the expected outcome. However, the more telling piece of information from this figure is that for all pollutants, the percentage reduction is higher for Scenario 3 than for Scenario 1. This increase shows the impact of the bioretention system on the overall ability of the treatment train to remove pollutants. Despite the fact that approximately half of the total WBH catchment area does not actually pass through the bioretention system, it still has a noticeable impact on the pollutant removal. As a percentage increase in percentage reduction, it can be seen that the added bioretention and sedimentation systems impact greatest on the TN removal, with a rise of 63% of the percentage reduction without these systems. TSS and TP have a 19% and 14% rise respectively.

The other comparison that is made in Figure 4.23 is of the percentage reduction targets outlined in *Urban Stormwater Quality Planning Guidelines*. It can be seen in the figure that this target is not met in the Scenario 3 MUSIC model for any of the pollutants. Each pollutant falls short of the guidelines targets by varying degrees, with TP being the closest at 4.3 percentage points below the target of 60%, and TN being the furthest, at 19.1 percentage points below the target of 45%.

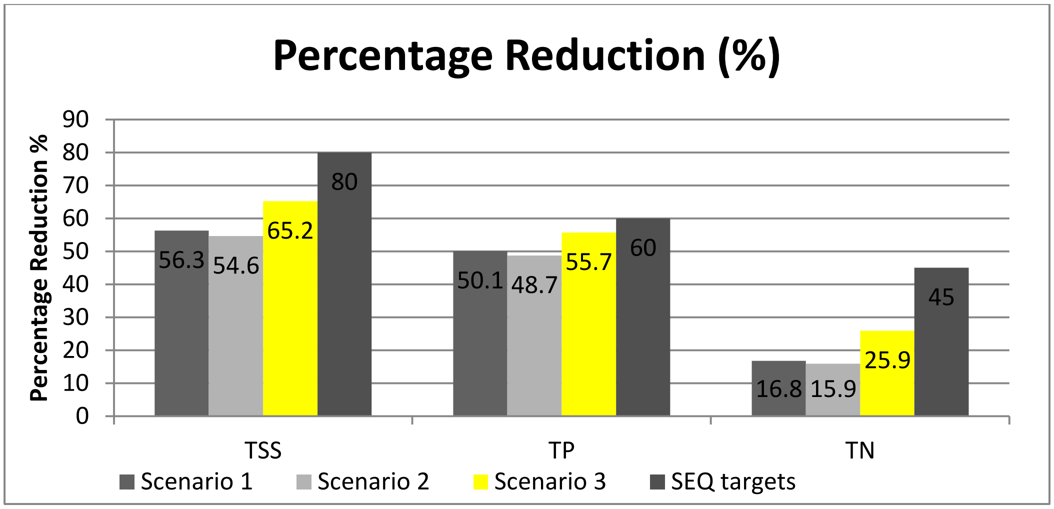


Figure 4.23 – Percentage Reduction for total treatment train, Scenarios 1 – 3

4.3.3.2. Daily Mean Concentration at WBH outlet

The following table, Table 4.17 shows the model's average concentrations of TSS, TP and TN in the water discharging from the WBH (and into the receiving node).

Table 4.17 – Daily Mean Concentration for full treatment train

	TSS	TP	TN
Outflow from Pond 3 (mg/L)	19.7	0.062	1.24

Figures 4.24 below, provides a comparison of DMC for Scenarios 1 – 3, as well as the high and low concentrations measured within Melbourne's rivers that was calculated and provided in Table 2.1 of this

report. The figure shows that DMC for Scenario 3 is lower than Scenario 2, as expected, and also lower than Scenario 1 for all pollutants, as hoped. That is to say, according to the MUSIC model, the water in the WBH during Scenario 3 will be of a higher quality than it is currently (Scenario 1). The figure also shows how the quality of water discharging from pond 3 compares to the highest and lowest concentrations measure in Melbourne's rivers. The figure reveals that the TSS and TN concentrations discharging from the WBH are approximately squarely in between the 'high' and 'low' values from Table 2.1. However, the TP concentration at the outlet of the WBH is shown to be much closer to the 'low' TP concentration from Table 2.1. This would say that the TP values coming from the WBH are relatively low.

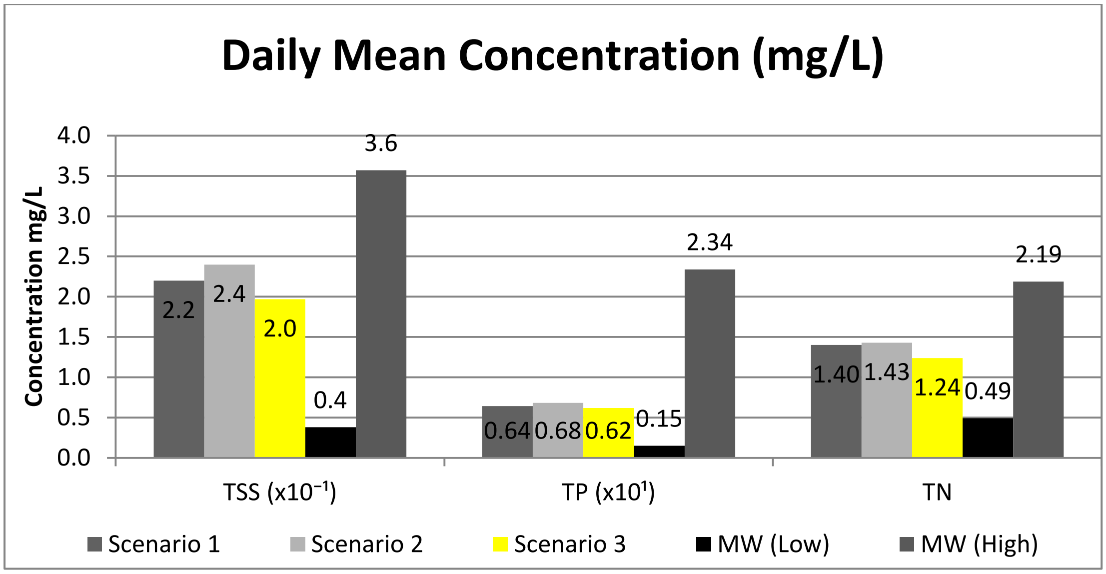


Figure 4.24 - Daily Mean Concentration at WBH outlet, Scenarios 1 – 3 and; concentrations (low and high) of Melbourne's rivers - Table 2.1 of this report

4.3.3.3. Effectiveness of specific treatment devices

From the above section it is clear that the added sedimentation basin and bioretention system in Scenario 3 has resulted in an overall improvement in predicted water quality compared to what it is currently. However, in order to get a better understanding of the actual working efficiency of the proposed treatment systems, we need to look at the input and output at each system. For this reason, Figures 4.25 - 4.27 are provided showing Mean Annual Load (MAL) for each treatment device. It is important to note that the "Mean Annual Load" output gives the percentage reduction for the water entering and exiting at that particular system only, while the "Treatment Train Effectiveness" output gives the percentage reduction for the collective reduction in pollutants up until and including that system.

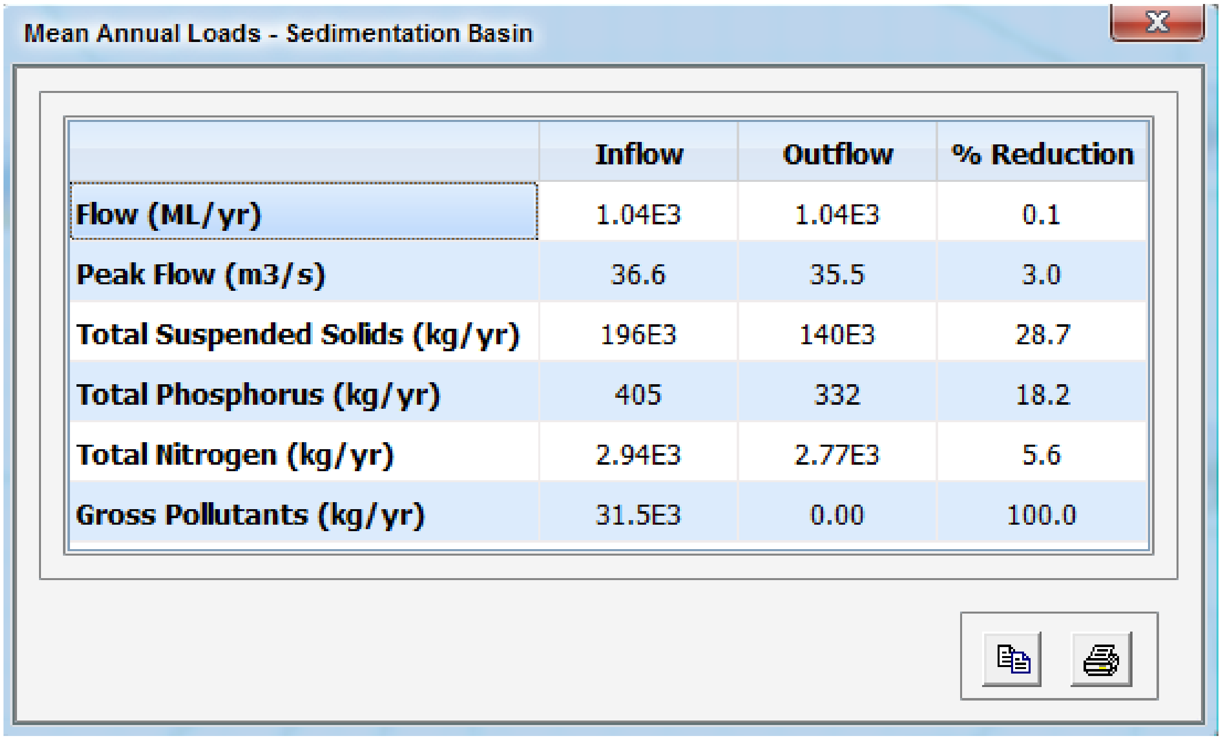
Figure 4.25 below, is a MUSIC output summarising the MAL's coming into and discharging from the sedimentation basin. There are a number of characteristics of the sedimentation basin that may be better understood from the figure. One aspect of the Sedimentation Basin is its Gross Pollutant (GP) removal efficiency. As stated in Section 2.2.2 of this report, gross pollutants summarise the larger debris that makes its way into the stormwater flow and are made up of natural organic material and artificial litter. The organic material such as twigs and leaves tend to make up the majority of gross pollutants (above 50%), followed by plastic litter, paper litter and then other materials (Wong, T.H.F. 2006).

Section 7.1 of *Urban Stormwater Quality Planning* (Department of Environment and Heritage Protection 2010) states that the typical work of a primary treatment device, of which a sedimentation basin is one, is to remove gross pollutants and course sediments. It is noted that the GP removal of the sedimentation basin is predicted to be 100%, while the TSS removal is predicted to be 28.7%, or 56,000kg/yr. This would lead us to believe that the sedimentation basin works effectively in its role as the primary level of treatment, to remove GP's and coarse sediments.

Despite this reports focus on TSS, TP and TN, it is interesting to note that Table 7.1 of *Urban Stormwater Quality Planning* (Department of Environment and Heritage Protection 2010) states that while sediment settling basin removal efficiency of course sediment is medium to high; its GP removal efficiency is negligible. This then puts some doubt on the accuracy of MUSIC's calculation of GP removal. This may require a further look into GP removal, including:

- The effectiveness of the sedimentation basin in GP removal and;
- Additional/alternative measures that may need to be taken to ensure adequate protection of the bioretention system by properly removing GP's at the primary treatment level.

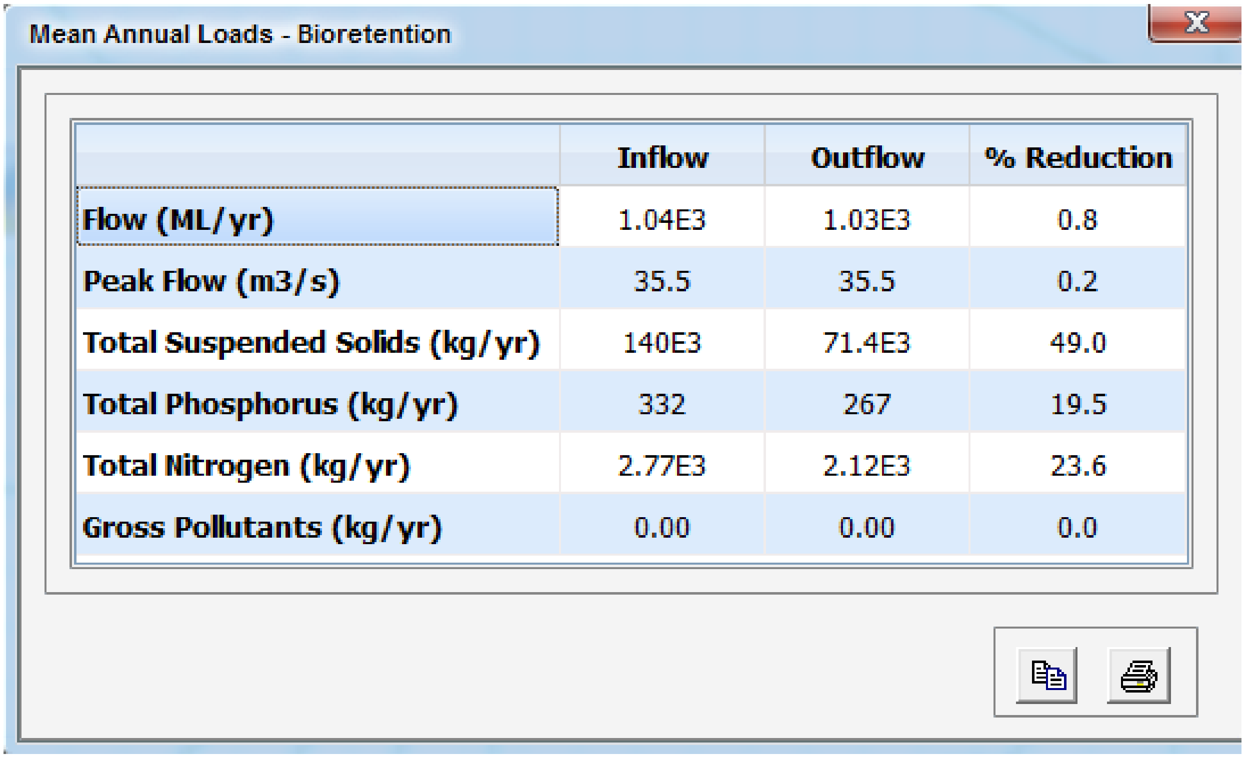
Figure 4.25 also shows the sedimentation basin removes 18.2%, or 73kg/yr, of TP and 5.6%, or 170kg/yr, of TN.


Mean Annual Loads - Sedimentation Basin

	Inflow	Outflow	% Reduction
Flow (ML/yr)	1.04E3	1.04E3	0.1
Peak Flow (m3/s)	36.6	35.5	3.0
Total Suspended Solids (kg/yr)	196E3	140E3	28.7
Total Phosphorus (kg/yr)	405	332	18.2
Total Nitrogen (kg/yr)	2.94E3	2.77E3	5.6
Gross Pollutants (kg/yr)	31.5E3	0.00	100.0

Figure 4.25 – Effectiveness of Sedimentation Basin

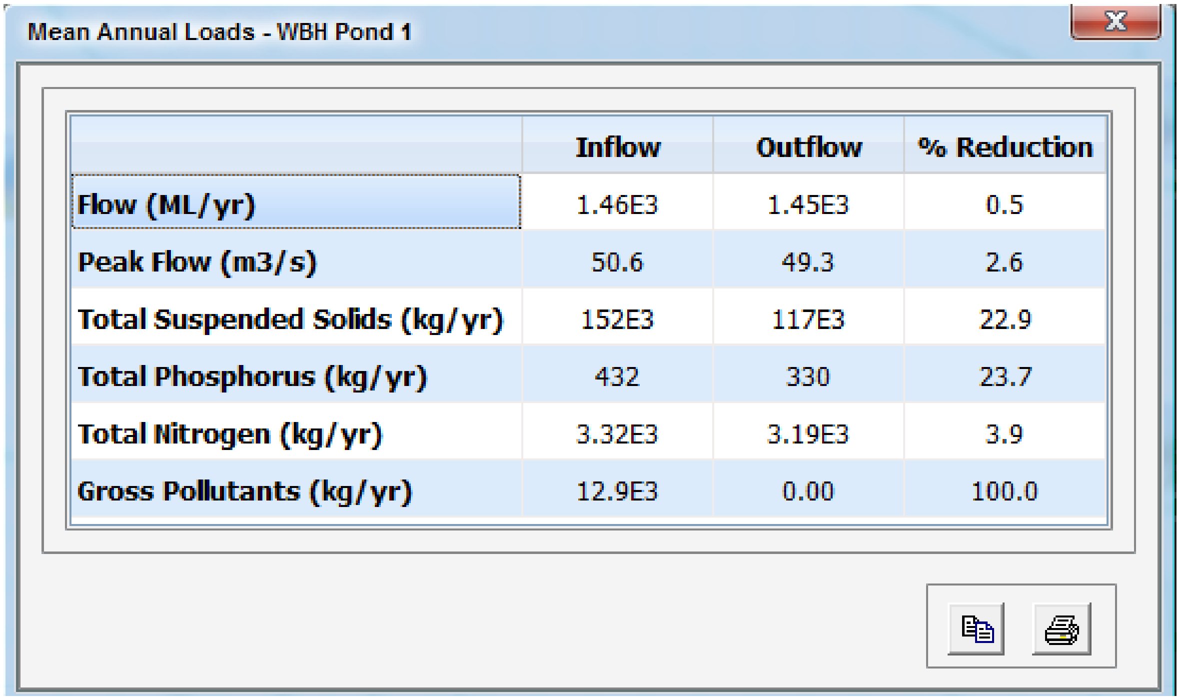
Figure 4.26 below, gives an indication of the effectiveness of the bioretention system within the treatment train. TSS removal is shown to be 49.0% of the TSS that is coming into the system, or 68,600kg/yr. TP removal is modelled at 19.5%, or 65kg/yr and TN removal at 23.6%, or 650kg/yr.



	Inflow	Outflow	% Reduction
Flow (ML/yr)	1.04E3	1.03E3	0.8
Peak Flow (m3/s)	35.5	35.5	0.2
Total Suspended Solids (kg/yr)	140E3	71.4E3	49.0
Total Phosphorus (kg/yr)	332	267	19.5
Total Nitrogen (kg/yr)	2.77E3	2.12E3	23.6
Gross Pollutants (kg/yr)	0.00	0.00	0.0

Figure 4.26 – Effectiveness of bioretention system

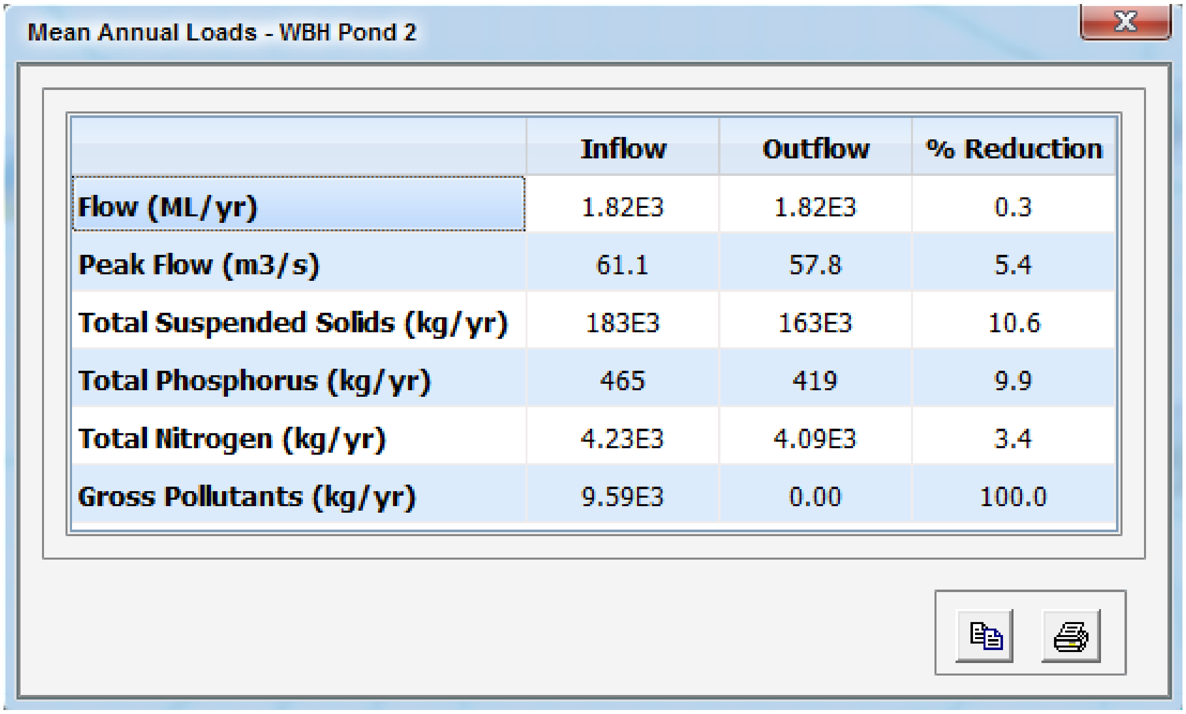
In order to get an understanding of the bioretention system's efficiency compared to the sedimentation basin and all three WBH ponds, Figures 4.27 – 4.29 have been included. These figures show the WBH ponds' MAL outputs from the Scenario 3 MUSIC model.



Mean Annual Loads - WBH Pond 1

	Inflow	Outflow	% Reduction
Flow (ML/yr)	1.46E3	1.45E3	0.5
Peak Flow (m3/s)	50.6	49.3	2.6
Total Suspended Solids (kg/yr)	152E3	117E3	22.9
Total Phosphorus (kg/yr)	432	330	23.7
Total Nitrogen (kg/yr)	3.32E3	3.19E3	3.9
Gross Pollutants (kg/yr)	12.9E3	0.00	100.0

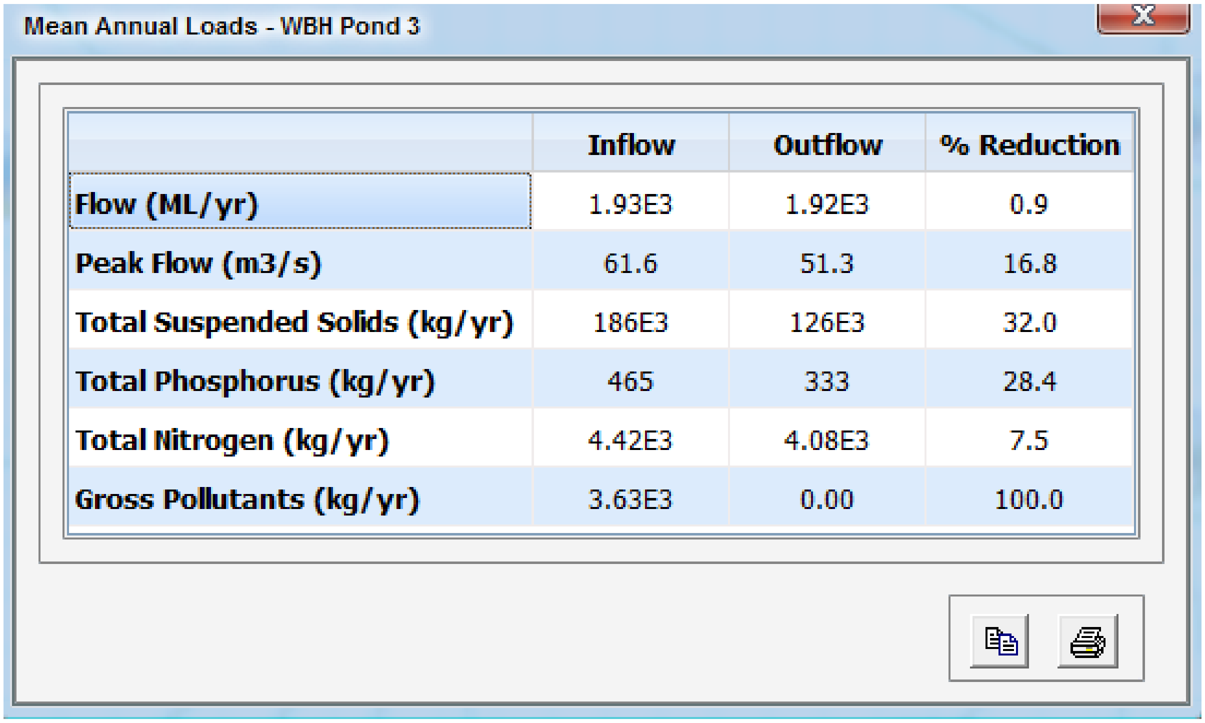
Figure 4.27 – Effectiveness of Pond 1



Mean Annual Loads - WBH Pond 2

	Inflow	Outflow	% Reduction
Flow (ML/yr)	1.82E3	1.82E3	0.3
Peak Flow (m3/s)	61.1	57.8	5.4
Total Suspended Solids (kg/yr)	183E3	163E3	10.6
Total Phosphorus (kg/yr)	465	419	9.9
Total Nitrogen (kg/yr)	4.23E3	4.09E3	3.4
Gross Pollutants (kg/yr)	9.59E3	0.00	100.0

Figure 4.28 – Effectiveness of Pond 2



Mean Annual Loads - WBH Pond 3

	Inflow	Outflow	% Reduction
Flow (ML/yr)	1.93E3	1.92E3	0.9
Peak Flow (m3/s)	61.6	51.3	16.8
Total Suspended Solids (kg/yr)	186E3	126E3	32.0
Total Phosphorus (kg/yr)	465	333	28.4
Total Nitrogen (kg/yr)	4.42E3	4.08E3	7.5
Gross Pollutants (kg/yr)	3.63E3	0.00	100.0

Figure 4.29 – Effectiveness of Pond 3

For comparison, the results of Figures 4.25 -4.29 have been graphed and put into three figures below. Figure 4.30 is a comparison of percentage reduction of each pollutant by all five treatment systems along the treatment train. On a percentage reduction basis, the bioretention system appears to be providing TN reduction much more than any other device. TSS is also much higher, while for TP, the bioretention system is providing about an average amount of percentage reduction.

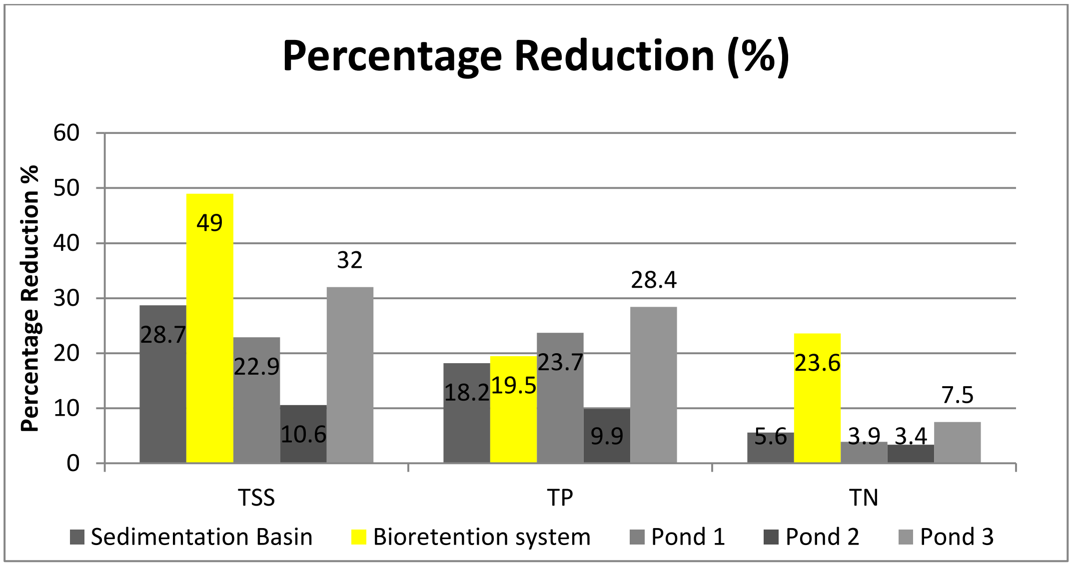


Figure 4.30 – Percentage Reduction by each Treatment Device

Figure 4.31 is a comparison of MAL reduction of each pollutant by all five treatment systems along the treatment train. These results tell a similar story to the percentage reduction totals shown above, where the bioretention system has extremely high removal of TN, reasonably high removal of TSS and average or even below average removal of TP.

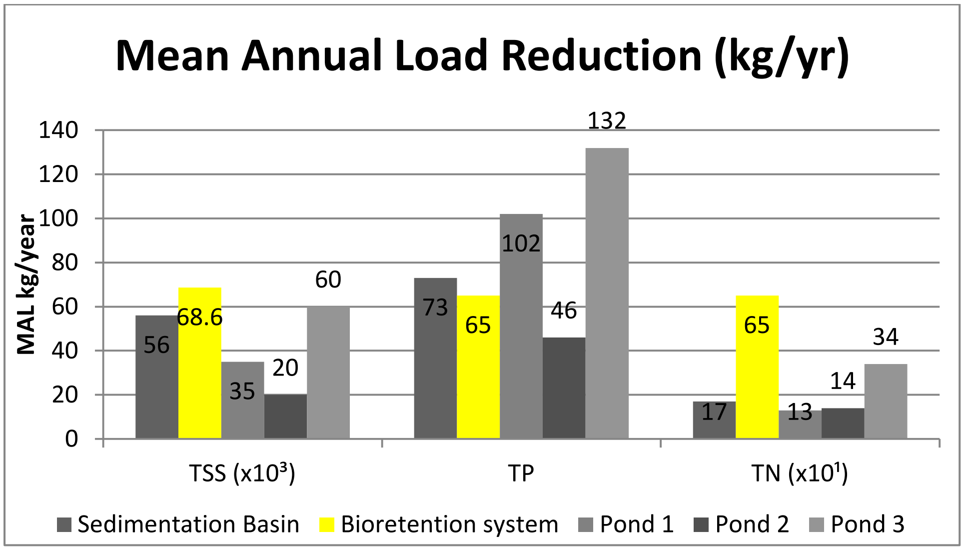


Figure 4.31 – Mean Annual Load Reduction by each Treatment Device

The purpose of comparing the treatment system removal efficiency is not to find what treatment system is most efficient; it was already made clear, in the 2010 report provided by TRC, that a bioretention system would be the most effective form of treatment system per surface area take-up. Rather, it simply portrays how much pollutants are being removed by each treatment system. This helps to determine what pollutant removal is carried out by the bioretention system on top of what is carried out by the existing WBH ponds.

Some useful points that can be taken here are:

- The TN removal that the bioretention system performs is extremely effective in comparison to that carried out by the other systems within the treatment train.
- The bioretention system reduces the MAL of TP in the treatment train, however it is no more effective than Pond 1 and 2 of the WBH, as well as the sedimentation basin. This is not to be expected as the typical bioretention system is specifically effective in the removal of nutrients, both TP & TN, as it uses sedimentation, filtration and even some biological uptake. This was looked into further, and is discussed in the following section.

4.3.3.4. Daily Mean Concentration at bioretention system outlet

The following table, Table 4.18, provides DMC values for the bioretention system in the Scenario 3 MUSIC model. Most intriguing from this table, is the TP values, which show an increase in mean concentrations as the water flows in and out of the bioretention system. This is obviously of some concern as the idea is to decrease the concentration of pollutant in the water. The increase in mean concentration does not mean that no decrease in mass load of TP is occurring. Figure 4.26 confirms this, where the percentage reduction in MAL through the bioretention system is shown to be 19.5%. What the rise in DMC means is that when the inflow TP concentration drops below a certain level, typically during base-flow conditions, the bioretention system can no longer decrease the TP in the water.

Table 4.18 – Daily Mean Concentrations for bioretention system

	Inflow	Outflow
TSS	26.50	2.28
TP	0.100	0.142
TN	7.590	0.415

The above situation could be compared to a cooling system used to cool a room. The cooling system pumps out air at 20˚C. The system will lower the rooms temperature as long as the starting/background temperature of the room is higher than 20˚C. However, as soon as the room temperature drops below 20˚C, for whatever reason (e.g. outside temperature is 15˚C), the 'cooling system' will actually start to raise the temperature of the room.

Some of the ways in which this TP increase can be avoided may include:

- Decreasing the minimum concentration of TP that the bioretention system can treat. Section 3.4.3. of this report outlines the bioretention system characteristics, and what values were used to 'describe' the bioretention system in MUSIC. In this section, characteristic no. 10 is Orthophosphate, which defines the orthophosphate content in the soil used as the filter media. This value was kept to a default of 80mg/kg, however in reality a soil could be used for the filter media that has much lower orthophosphate content. This could improve TP removal efficiency and lower the minimum TP concentration that can be treated.
- Providing a low-flow by-pass that allows base flow to by-pass the bioretention system. This would prevent these flows, which typically have negligible pollutant loads, to undergo an increase in TP (or TN, TSS), while still allowing higher flows during storm conditions to enter the bioretention system and be treated.

These two scenarios can be modelled within the MUSIC program and are variables that may influence the final design specifications of the bioretention system. For this reason these two scenarios, along with a number of other variations, have been modelled in MUSIC; the results are shown in Section 4.3.5.

Another finding from this set of data is the outflow DMC values for TSS and TN are low. When compared with the concentrations of TSS and TN measured in Melbourne's rivers in 2006, as shown in Table 2.1, they are both lower than the lowest concentrations. This would infer that the bioretention system is treating the water to a high standard, in regards to the removal of both these pollutants.

As noted previously, in Section 4.3.3, there is a large percentage (approximately 50%) of the WBH catchment that does would discharge into the proposed bioretention system; this is specifically shown in Figure 4.21. With this in mind, and looking at the results above, that show the bioretention system to be treating the water to a high standard, it could be that the overall percentage reduction that is measured at the outlet of the WBH, is being impacted by the water that by-passes the bioretention system. In this way, to increase the size of the bioretention system may not greatly increase the overall percentage reduction of pollutants, as the majority of pollutants are being carried in by runoff that discharges straight into one of the WBH ponds.

The following section, Section 4.3.4, provides the results for this hypothesis.

4.3.4. Scenario 4 – Ultimate development with proposed bioretention system, adjusted to satisfy water quality objectives

4.3.4.1. MUSIC model and predicted total pollutant removal

The layout of the Scenario 4 MUSIC model is the same as for Scenario 3 and is shown in Figure 4.32. The idea of Scenario 4 was to size a bioretention system that would satisfy the percentage reduction targets, as outline in Tables 2.2 – 2.3 of *Urban Stormwater Quality Planning Guidelines* (Department of Environment and Heritage Protection 2010).

What was found during these MUSIC 'runs' was that as the overall area of the bioretention system was increased, the rate at which pollutant reduction increased became less and less. This may be best described by Figure 4.32, which shows percentage reduction through the bioretention system as its total area increases. The case of 'diminishing return' is most obvious for TP, where percentage reduction begins to flatten out drastically by the last 'trial run'. For this reason, the testing of the bioretention system stopped at a total surface area of 20,000m². This may be attributed to the amount of water by-passing the bioretention system, as proposed in the above section.

The MUSIC model was run for five different bioretention sizes as shown in Table 3.11 in Section 3.8.

Note: Increase in size of bioretention is not linear, and all other MUSIC inputs were kept constant for comparison purposes.

As well as the graph shown in Figure 4.32 below, the MAL reductions for each trial run are shown in Figures D.1 – D.5 in Appendix D.

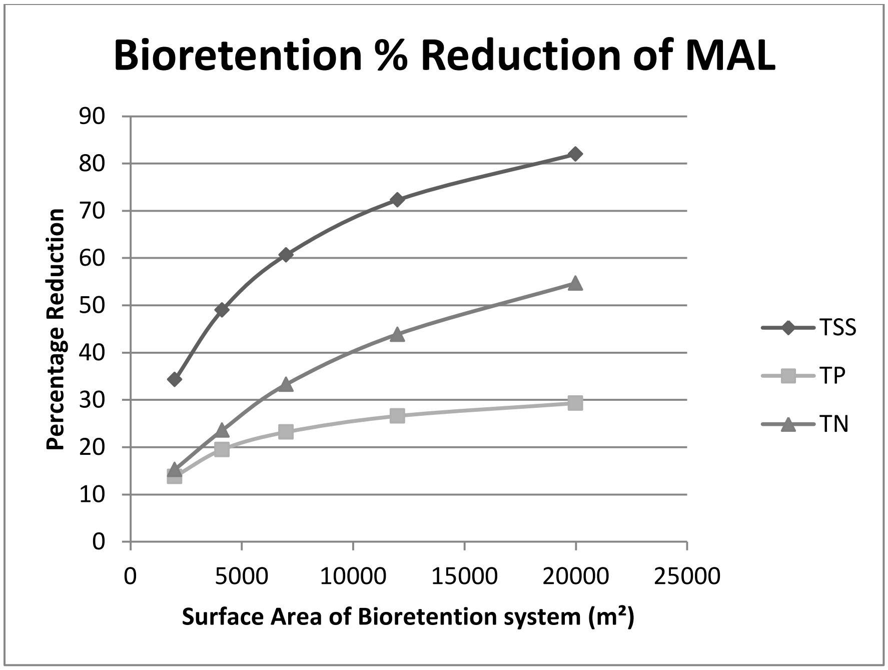
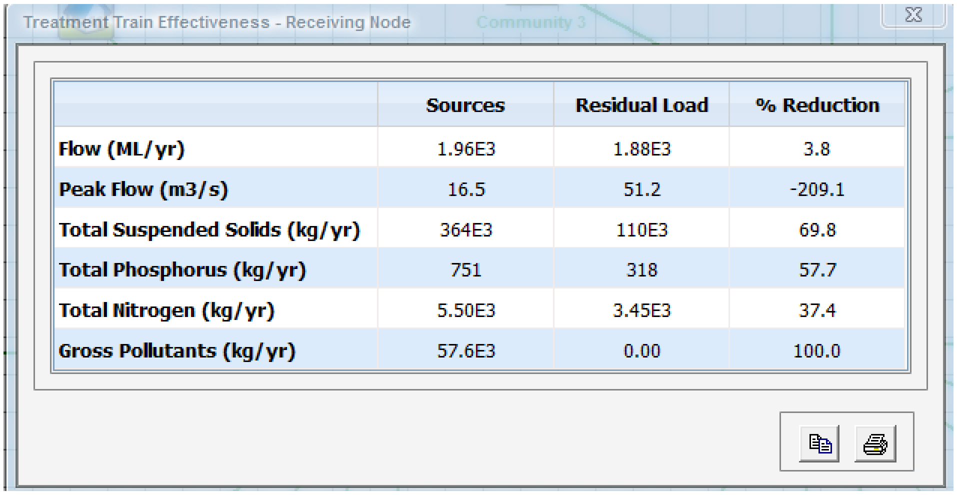


Figure 4.32 – MAL Percentage Reduction at bioretention system

The full treatment train result for the final trial run, 'trial number 4.5', is shown in Figure 4.33 below. This figure shows the percentage reduction of the whole system, when a bioretention system with a surface area of 20,000m² is used. Despite being 4 to 5 times the size currently proposed, the overall system would reach reductions of TSS – 69.8%, TP – 57.7%, TN – 37.4%, still shy of the target outlined in the *Urban Stormwater Quality Planning* guideline.



	Sources	Residual Load	% Reduction
Flow (ML/yr)	1.96E3	1.88E3	3.8
Peak Flow (m3/s)	16.5	51.2	-209.1
Total Suspended Solids (kg/yr)	364E3	110E3	69.8
Total Phosphorus (kg/yr)	751	318	57.7
Total Nitrogen (kg/yr)	5.50E3	3.45E3	37.4
Gross Pollutants (kg/yr)	57.6E3	0.00	100.0

Figure 4.33 – Total Treatment Train effectiveness for 'Trial Number 4.5'

To compare the total treatment train effectiveness shown in Figure 4.33 with Scenarios 1-3, Figure 4.34 has been provided below.

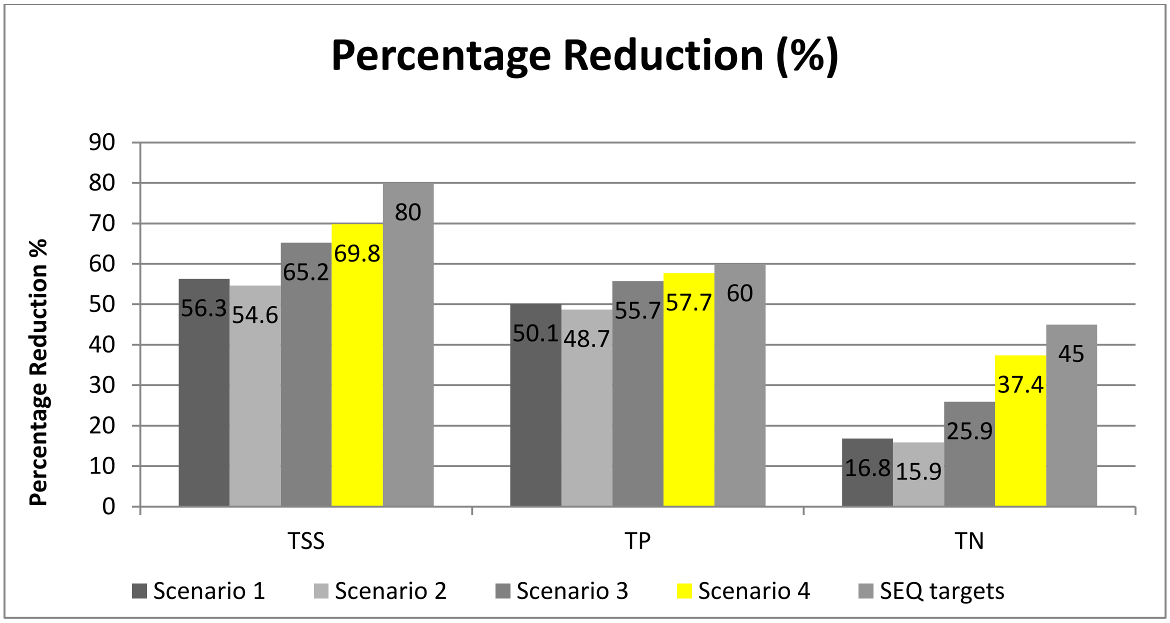


Figure 4.34 – Total Treatment Train effectiveness scenarios 1 - 4

4.3.4.2. Comparison of Area – proposed bioretention vs trial 4.5 bioretention

A map of 20,000m² of bioretention basin is shown in Figure 4.35. This map gives just a rough idea of how much extra land would be needed to reach the bioretention size modelled in ‘trial 4.5’ mentioned within this section. In this figure, the yellow is an outline of the currently proposed detention basin, the cyan is the currently proposed bioretention system, and the red is the extra bioretention basins showing how much of an increase in size this ‘trial 4.5’ is modelling. As this is a rough diagram, it may be noted that factors such as the spacing of the bioretention basins is not coherent throughout, and thus it is not a direct concept for a larger bioretention system.

Figure 4.35 – Map of $20,000m^2$ bioretention system at proposed location

Table 4.19 gives the Daily Mean Concentrations at the bioretention system for largest bioretention size modelled. When compared with the Scenario 3 results in Table 4.18, the outflow for each pollutant is reduced, which was expected. As with the Scenario 3 model, the mean TP concentration increases through the bioretention system but to a lesser degree. This would be a result of a higher removal rate during storm flow conditions, when pollutant loads are very high.

Table 4.19 – DMC values at bioretention system for 'Trial Number 4.5'

	Inflow	Outflow
TSS	26.50	1.39
TP	0.100	0.125
TN	7.570	0.343

Another finding from this set of data is the outflow DMC values for TSS and TN are low. When compared with the concentrations of TSS and TN measured in Melbourne's rivers in 2006, as shown in Table 2.1, they are both lower than the lowest concentrations. This would infer that the bioretention system is treating the water to a high standard, in regards to the removal of both these pollutants.

As noted previously, in Section 4.3.3, there is a large percentage (approximately 50%) of the WBH catchment that would not discharge into the proposed bioretention system; this is specifically shown in Figure 4.21. With this in mind, and looking at the results above, that show the bioretention system to be treating the water to a high standard, it could be that the overall percentage reduction that is measured at the outlet of the WBH, is being largely impacted by the water that by-passes the bioretention system. This would explain why increasing the size of the bioretention system did not greatly increase the overall percentage reduction of pollutants, i.e. because the majority of pollutants are being carried in by runoff that discharges straight into one of the WBH ponds.

It is also worth comparing the outflow concentrations at the three WBH ponds; this is shown in Tables 4.20 – 4.22 below. The pollutant concentrations in the water discharging from these ponds are generally a lot higher than in the water discharging from the bioretention system. There are a few exceptions, being the TN value for Pond 1, and all the TP values. As discussed previously, the TP concentrations coming into the treatment system are already relatively low and the bioretention system is struggling to treat the water for TP at these low levels. However, the high TN and TSS concentrations coming from the ponds would suggest that the water by-passing the bioretention system is carrying the bulk of the pollutants and preventing the overall percentage reduction of pollutants from increasing by a large degree.

Table 4.20 – DMC values at Pond 1 for 'Trial Number 4.5'

	Inflow	Outflow
TSS	21.50	14.80
TP	0.155	0.067
TN	6.740	0.195

Table 4.21 – DMC values at Pond 2 for 'Trial Number 4.5'

	Inflow	Outflow
TSS	26.80	15.20
TP	0.107	0.054
TN	9.440	0.766

Table 4.22 – DMC values at Pond 3 for 'Trial Number 4.5'

	Inflow	Outflow
TSS	24.30	18.40
TP	0.088	0.061
TN	10.100	1.090

4.3.5. Scenario 5 – Testing of modifications to Scenario 3 bioretention system

4.3.5.1. MUSIC model and predicted pollutant removal

As stated in Section 3.9, this Scenario 5 MUSIC model is used to test for variations in the bioretention system and the impact of these variations on the systems efficiency. In order to isolate the modified component, no other part of the model was changed from the Scenario 3 model. The results are shown in Figures 4.36 – 4.38, which compare the bioretention system's percentage reduction of each pollutant. As the model does not change, the MAL coming into the bioretention system will be the same for each trial, and therefore comparison of MAL reduction between trials is a direct comparison of efficiency. A description of what modification was made during each trial is provided in Table 3.12 in Section 3.9.

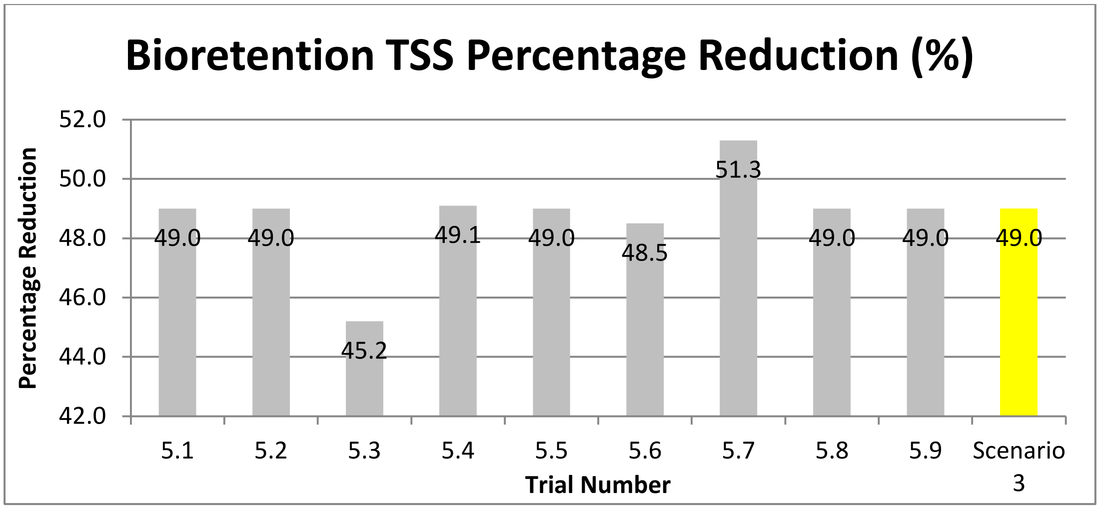


Figure 4.36 – Percentage Reduction of TSS for each trial run.

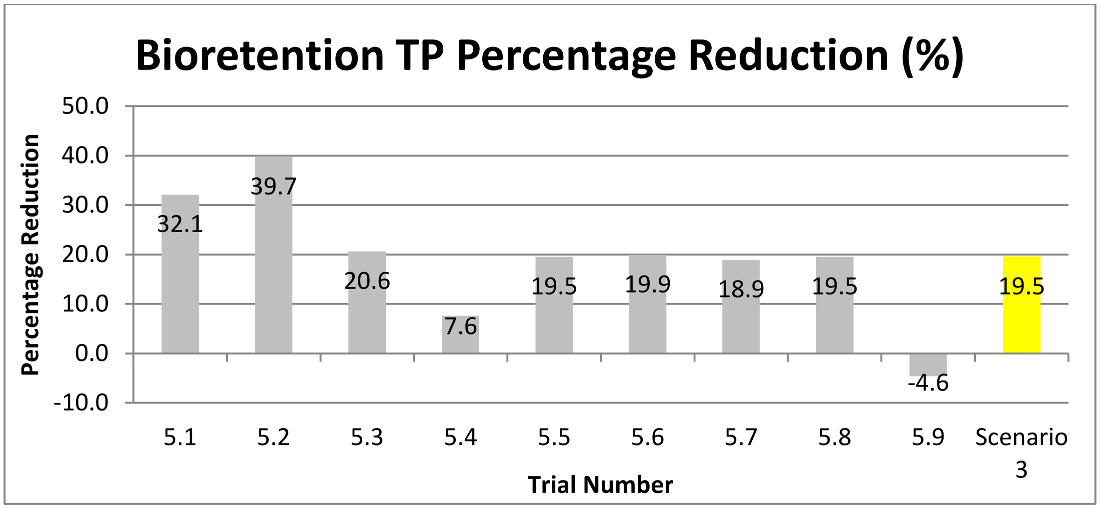


Figure 4.37 – Percentage Reduction of TP for each trial run.

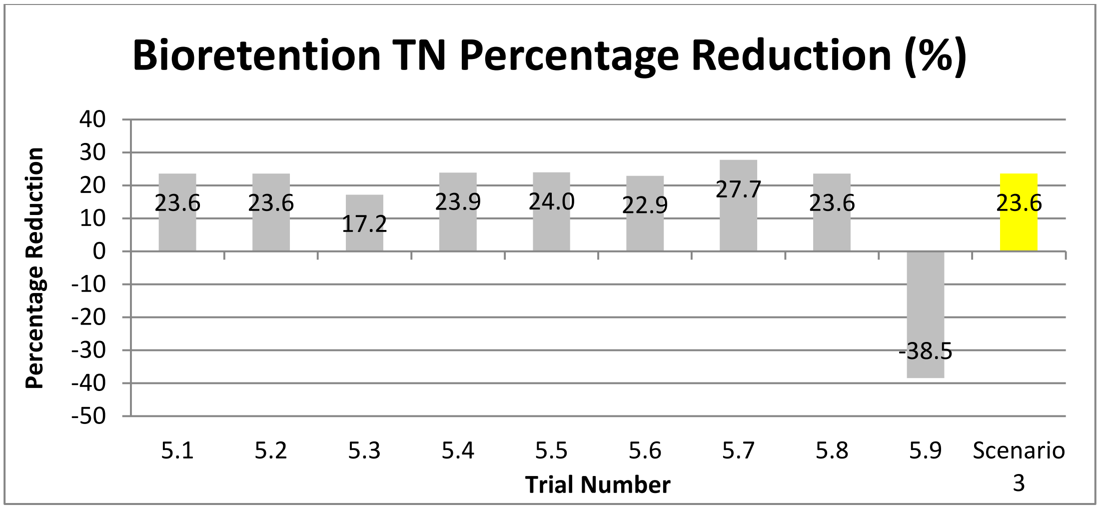


Figure 4.38 – Percentage Reduction of TN for each trial run.

The following is a results summary and discussion relating to Figures 4.36 – 4.38 above in order of trial type.

4.3.5.2. Trial 5.1 –Orthophosphate Content 50mg/kg

The trial 5.1 modification was the lowering of the orthophosphate content of the filter media from 80mg/kg to 50mg/kg. The TSS and TN removal did not change from Scenario 3, while the TP removal jumped 12.6 percentage points above the Scenario 3 result, i.e. 1.65 times more removal. This proves that lowering the orthophosphate content by this amount will effectively increase TP removal efficiency, without hindering the TSS and TN removal.

This was to be expected to some degree; however the magnitude of the increase in removal efficiency is notable. As has been stated, Table 4.20 shows an increase in DMC of TP in the bioretention system, meaning the TP content in the water is increasing as it passes through the bioretention system during periods of low inflow concentrations. It is thought that a decrease in orthophosphate content within the filter media would allow for removal of TP in water with lower TP concentrations and lessen the amount of leaching that occurs. The results in the figures above appear to confirm this is taking place, resulting in a higher reduction in TP overall.

4.3.5.3. Trial 5.2 –Orthophosphate Content 20mg/kg

The trial 5.2 modification was the lowering of the orthophosphate content of the filter media from 80mg/kg to 20mg/kg. The TSS and TN removal did not change from Scenario 3, while the TP removal jumped 20.2 percentage points above the Scenario 3 result, i.e. 2.04 times more removal. This proves that lowering the orthophosphate content by this amount will effectively increase TP removal efficiency, without hindering the TSS and TN removal, as is the case for trial 5.1.

4.3.5.4. Trial 5.3 – Low-flow by-pass 0.05m³/s

The trial 5.3 modification allowed for a low-flow by-pass of 0.05m³/s, which was left as 0m³/s for Scenario 3. This factor allows for flow of less than 0.05m³/s to pass by the bioretention system without being treated. Although the water that by-passes generally has low pollutant levels, it still means that less treatment occurs and a corresponding decrease in TSS (3.8 percentage points) and TN (6.4 percentage points) reduction is shown in the results, which was to be expected to some degree. However, it can be seen that TP reduction is actually increased, by 1.1 percentage point, with the inclusion of a low-flow by-pass. It would appear as though the low-flow by-pass decreases the amount of TP leaching that occurs during inflows of low TP concentration, as discuss in Section 4.3.5.1 above.

Overall the result of the low-flow by-pass is a lower reduction of TSS and TN pollutants, and a comparatively small increase in TP reduction. This option does not appear to be beneficial but may need to be implemented for the health of the bioretention system – see Section 2.4.3.1 of this report.

4.3.5.5. Trial 5.4 – Submerged Zone with Carbon present

The trial 5.4 model implemented a submerged zone in the bioretention system. This option provided some benefit to the reduction of TSS and TN, with an increase of 0.1 and 0.3 percentage points respectively compared to the Scenario 3 model. However, the TP reduction decreased dramatically by 11.9 percentage points. That is, the amount of TP removed by the bioretention with the submerged zone is half that of the bioretention without a submerged zone.

It would appear as though the decrease in TP removal out-ways the comparatively small increase in TSS and TN reduction.

4.3.5.6. Trial 5.5 – TN content of 500mg/kg

The TN content was lowered from 800mg/kg to 500mg/kg for trial 5.5. Not surprisingly, the results only varied from Scenario 3 for TN reduction. This variation was an increase in TN reduction by 0.4 percentage points. An increase in TN reduction was to be expected as a result of lowering the content of TN in the filter media. When comparing with trial 1, the decrease in orthophosphate content (by the same portion), it seems the impact of the TN content on the removal efficiency is much less. This may be due to higher relative concentrations of TN in the water than for TP. If the TN concentrations were lower, the TN content in the filter media may have a much larger impact on the bioretention system's efficiency.

From these results it can be seen that while lowering the TN content of the filter media may increase the TN removal marginally, it would not help attain an extra 5-10 percentage points on the percentage reduction count of this bioretention system. As stated, this may change for a scenario where TN concentrations in the water are lower.

4.3.5.7. Trial 5.6 – Filter Media Depth 0.8m

Trial 5.6 tested the impact of increasing the filter media depth from 0.5m to 0.8m. The results varied between pollutants, with small changes for each. TSS removal decreased by 0.5 percentage points, TP removal increased by 0.4 percentage points, and TN removal decreased by 0.7 percentage points. It is notable that the increased filter media depth does not translate into higher pollutant reductions overall.

These results do not provide conclusive evidence that increasing the depth of the filter media in the bioretention basins will improve the efficiency of the system.

4.3.5.8. Trial 5.7 – Extended Detention Depth 0.5m

The increase in extended detention depth for trial 5.7 was from 0.3m to 0.5m and proved to be the factor that had the biggest positive impact on the TSS and TN removal efficiencies. Results show TSS removal increased by 2.3 percentage points and TN by 4.1 percentage points. However, at the same time, TP removal dropped 0.6 percentage points. It is interesting to note again, that the effect on the TP removal is opposite to that on the TSS and TN removal. The reason for the drop in TP removal is not known.

From the results it appears as though the TSS removal efficiency is enhanced by the longer detention time that the water will experience in the deeper extended detention area of the bioretention basin. The TN removal increases even more than the TSS removal, and it is thought that this may be due to the work of the biological uptake occurring within the bioretention system. Although it is unknown why the TP removal decreases with a deeper detention area, it is noted that by comparison of percentage points alone, the increase in TSS and TN reduction far out ways the decrease in TP. This may be reason enough to incorporate this option within the bioretention system design, assuming no other hazards or requirements (e.g. required outlet level).

4.3.5.9. Trial 5.8 – Filter Media Type sandy loam

The filter media type was changed from 'loamy sand' to 'sandy loam' for trial 5.8. This change is a minor one as these two soil types are similar in properties. Not surprisingly, there was no deviation from the results of Scenario 3 for any pollutant.

4.3.5.10. Trial 5.9 – No vegetation

Trial 5.9 was included to investigate and demonstrate the impact of vegetating the bioretention system with effective nutrient removal plants. Without these nutrient removing plants it was expected that it would have little impact on the TSS removal, while reducing the TP and TN removal efficiency. The results show that this was the case, however the impact on the TP and TN removal was greater than expected. The TSS removal remained the same, the TP removal dropped 24.1 percentage points to -4.6% reduction, and TN removal dropped 62.1 percentage points to -38.5% reduction. Thus, without the effective nutrient removing plants, the bioretention system will actually increase the TP and TN concentrations in the water.

This result shows the impact of the vegetation in the bioretention system – it loses its ability to treat water for TP and TN pollutants. The use of appropriate plant species will be important for the ultimate function of the bioretention system.

4.3.6. Scope and limitations with the MUSIC models

Limitations on the accuracy of results from the MUSIC model are dependent on what was put into the model. The three components that we looked at for the model were the source node properties, the treatment node properties and briefly the hydrological data. Hydrological data, including the rainfall and evapotranspiration data sets, were local Toowoomba measured or derived values, as outlined in Section 3.5, no calibration of this information has occurred. It was not expected that a calibration of this data be necessary for a study such as this, but is still flagged here as an area of possible error.

The source node properties were all left as default apart from the area, fraction impervious and the pollutant concentrations. There is room for error for all the source node parameters, from the measuring of the catchment area and fractions impervious, which was measured in AutoCad, to the calibration of the pollutant concentrations, which were dependent on the water sampling results; see Section 4.2.1 of this report for the scope and limitations within the water sampling process. However, the areas are of particular threat to the accuracy of the model are the following:

- **Rainfall-Runoff parameters**, e.g. rainfall threshold, soil storage capacity, initial storage, etc.
- **Water Quality Parameters**, i.e. mean base flow and storm flow concentrations coming from the catchment. The process of calibrating these values is outlined in Section 4.2.4 of this report and hinges on the measured values at the WBH pond.

The treatment node properties for the ponds, sedimentation basin and bioretention system are all shown in Section 3.4 of this report, including an explanation on how each value, default or otherwise, was chosen. The process of calibrating the **k and C* values** is outlined in Section 4.2.4 of this report, and as with the Water Quality Parameters of the source node, are very dependent on the accuracy of the measured values at the WBH. There are also a number of properties that were of some concern, in that either little was known about them, or it was unclear on their actual characteristics, these have been shown below:

- **Extended detention depth** of each pond, as this was somewhat hard to define when performing the measuring of the ponds, this value may have some error.
- **Equivalent pipe diameter** for pond 3 may have caused some error as this pond does not actually have an outlet pipe; rather its outlet IS the sharp crested overflow weir. This may have some impact on the **notional detention time** of the pond. However, the equivalent diameter was set to the minimum possible, to best represent the set-up.
- The **orifice discharge coefficient** for the sedimentation basin and ponds, as well as the **weir coefficient** for all treatment devices, were simply left as default and no more was known about these values.
- For the bioretention system alone, the **porosity of the filter media and submerged zone**, as well as the **horizontal coefficient** were all left as default and no more was known about these values.
- **Evaporative Loss (% of PET)** was left as default and was not looked into at all. This is a component of the ponds and sedimentation basin.

It is not expected these factors will cause the results outlined in previous sections to be invalid or prevent the aims of this project from being achieved. However, the possible areas for error outlined within this section point to discrepancies that could be addressed in future studies if it was thought that this would benefit in any way.

4.3.7. Summary of MUSIC findings

In this section of the report, Section 4, all MUSIC results were provided and discussed, including results from all five scenario's, with a number of outputs from each. The main result from Scenario 1 was the comparison made in Table 4.15 of the MUSIC DMC values and the measured values at the outlet of the WBH, where approximately a 30% difference was found between the two.

Scenario 2, modelling the catchment areas in ultimate development conditions, showed the predicted results of an increase in MAL and a correlating decrease in percentage reduction for all pollutants. In particular, see Figures 4.17 – 4.19 to see these trends.

The Scenario 3 model was able to answer the question, *'Is the bioretention system capable of removing the increase in pollutants caused by the development that is expected to occur within the WBH catchment in the future?"*. Figure 4.23, comparing the percentage reduction of the entire treatment train for Scenarios 1, 2 and 3, shows that the answer is clearly yes, in which the Scenario 3 percentage reduction is greater than that of the original scenario, Scenario 1, for all pollutants.

Scenario 4 model seeks to find the size of the bioretention system required to bring the overall treatment train effectiveness to SEQ percentage reduction targets. Instead of finding the size required, it was found that there was a diminishing return on pollutant removal as the bioretention size increased, in particular for TP removal. This is recognisable in Figure 4.32 of Section 4. Meanwhile, the overall percentage reduction reached was increased from Scenario 3, as expected, but did not reach SEQ targets.

A number of bioretention system design parameters were tested in Scenario 5, and some were found to have positive impacts on the bioretention system's pollutant removal, while others had some severe impacts. The most obvious was the removal of effective nutrient removal plants from the system, which caused the bioretention to have no ability to decrease TP and TN in the water. Other parameters that negatively affected the efficiency of the system included including a submerged zone and including a low-flow by-pass. The positive impacts were caused by increasing the extended detention depth and lowering the orthophosphate content of the filter media.

5. Conclusion & Recommendations

5.1.Conclusion

This report looks at quantifying the effectiveness of a Toowoomba Regional Council (TRC) proposed bioretention system on the quality of water within the existing Waterbird Habitat (WBH). The catchment area that flows into the WBH is expected to undergo continued development in the future. Consequently, TRC want to know what effect this future development will have on the WBH, and if the proposed bioretention system will be able to treat the expected increase in pollutants coming into the WBH.

A stormwater quality modelling program, MUSIC, was used to model the situation and answer these questions. However, in order to calibrate the inputs and outputs of the MUSIC model, some water sampling was undertaken at the WBH. Thirty samples were taken, which included storm flow and base flow samples. Although the sample data was limited, the results were used in the process of calibrating both the treatment and source node characteristics in MUSIC, see Section 4.2.

The MUSIC modelling consisted of five scenarios which allowed for the comparison of pollutant removal between the existing state of the WBH, the state of the WBH with future development, the WBH with the proposed bioretention system, increasing the size of this bioretention system, and different design parameters within the system. These comparisons showed the bioretention system to be effective in bringing the pollutant removal rate to levels better than current removal rates. It was also found that the SEQ percentage reductions targets of TSS 80%, TP 60% and TN 45% were not met by either the proposed bioretention system or a much larger bioretention system scaled to 4.8 times the originally proposed size. The final model gave an indication as to the positive and negative impacts of nine different design parameters within the bioretention system. These results are discussed in full detail in Section 4.3 of this report.

This project aims to define the effectiveness of a proposed bioretention system based on existing literature and measured and modelled results. This has been achieved and the recommendations, based on the work carried out within this project, are provided below.

5.2.Impact of expected future development

As stated in the above section, this report aims to quantify the impact that the expected future development within the WBH catchment will have on the quality of water within the WBH. Section 3.3.1 of this report outlines the process undertaken to calculate the total area expected to undergo future development, this was calculated as 60.784Ha, which represents approximately 11.8% of the total catchment.

The predicted impact of this area being developed, in terms of Daily Mean Concentration (DMC) of water within the WBH ponds, is shown in Figure 5.1 below. The figure shows an increase in TSS of 2 mg/L (9%), an increase in TP of 0.0041 mg/L (6%), and an increase in TN of 0.03 mg/L (2%). Thus, the future development within the WBH catchment area is predicted to increase the daily mean concentration of pollutants within the water for each of the pollutants being modelled. This is further investigated in Section 4.3.2 of this report.

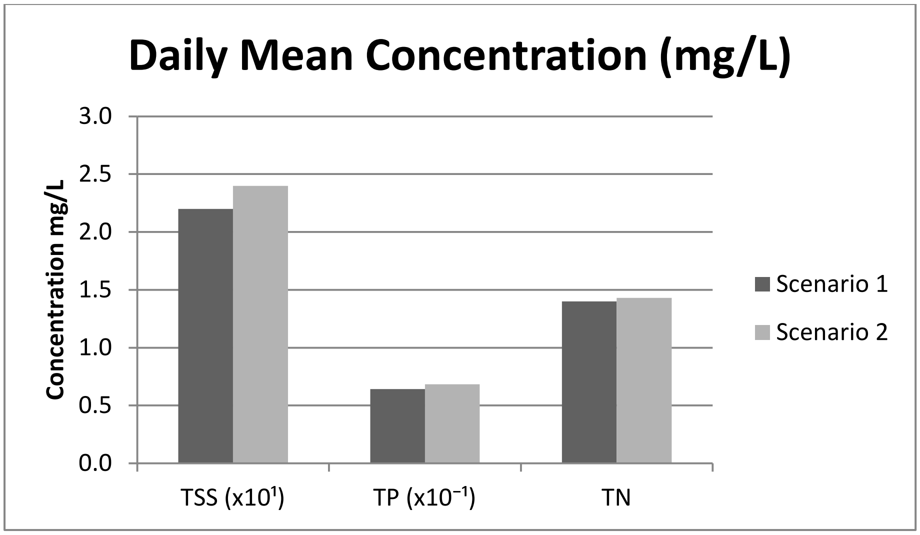


Figure 5.1 – Daily Mean Concentration, Scenario 1 and 2

5.3.Implementation of bioretention system

Section 4.3.3 provides results for the bioretention system's performance in treating stormwater runoff. The ability of the bioretention system in treating the predicted increase in pollutant load due to future development, may be best documented in terms of total treatment train percentage reduction, as shown in Figure 5.2. The figure compares percentage reduction of pollutants for the current state of the WBH, the future developed state and the future developed state with the inclusion of a bioretention system (Scenarios 1 – 3). As well as this, the figure includes the SEQ percentage reduction targets, as outlined in *Urban Stormwater Quality Planning Guideline.*

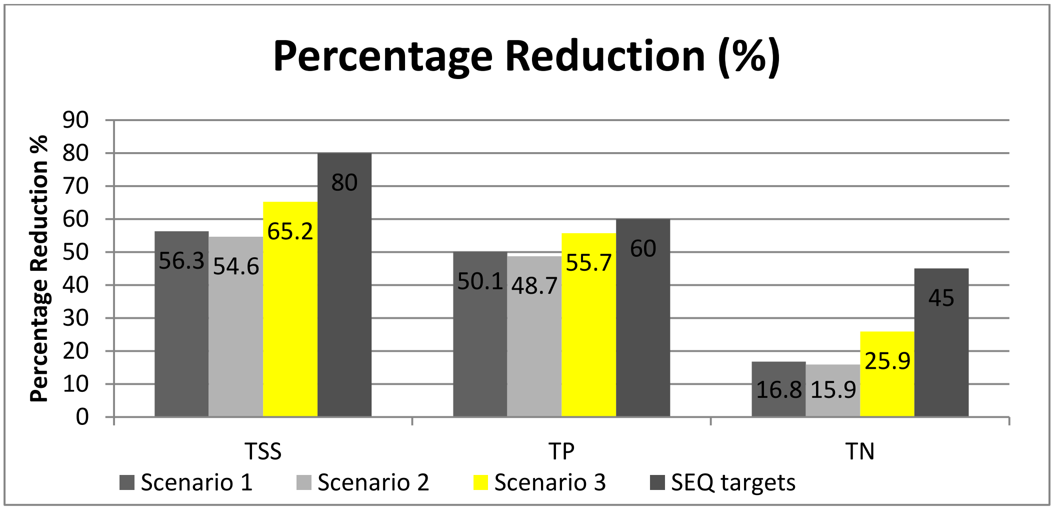


Figure 5.2 – Percentage reduction for total treatment train, Scenarios 1 – 3

Figure 5.3 provides details of the DMC at the WBH outlet for the same three Scenarios as above.

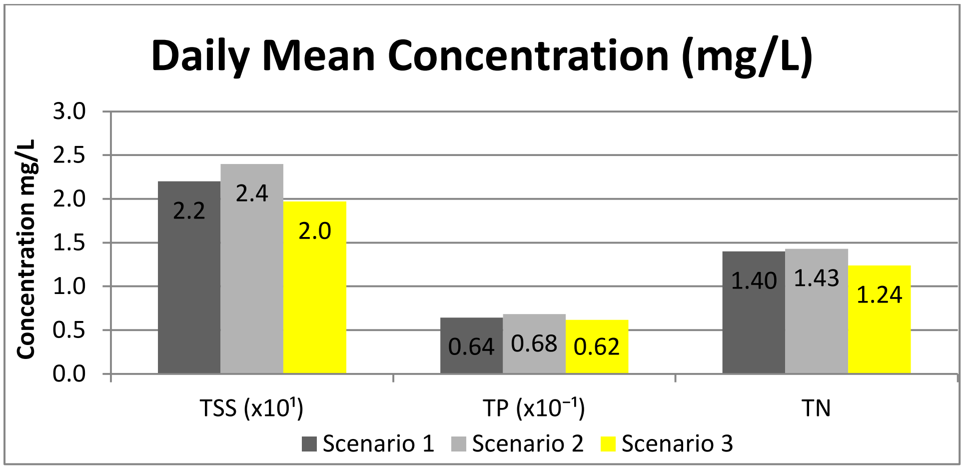


Figure 5.3 – Daily Mean Concentration at WBH outlet, Scenarios 1 – 3

The following recommendations are made in accordance with the results provided in Section 4.3.3 of this report, and in particular, the two figures provided above.

1. The proposed bioretention system will be effective in treating the increase in stormwater pollutants that is predicted to be generated as a result of future development.

As a result of the modelling performed, it is expected that the implementation of the proposed bioretention system will bring the level of pollutant percentage reduction well above the existing percentage reduction that occurs within the WBH. With this knowledge it is thought that the bioretention system should be implemented as proposed.

2. The South East Queensland percentage reduction targets as outline in Tables 2.2 – 2.3 of *Urban Stormwater Quality Planning Guidelines* will not be met solely by the inclusion of a bioretention system of the size proposed.

5.4.Alternative options for treatment device/location

As a result of the second recommendation in the above section, an additional scenario was modelled in MUSIC of an enlarged bioretention system, scaled up from a surface area of 4125m² to 20,000m², in order to achieve a size that attained the SEQ targets mentioned above. Section 4.3.4 contains the full set of results; however, Figure 5.4 below provides the general findings of the model in terms of percentage reduction.

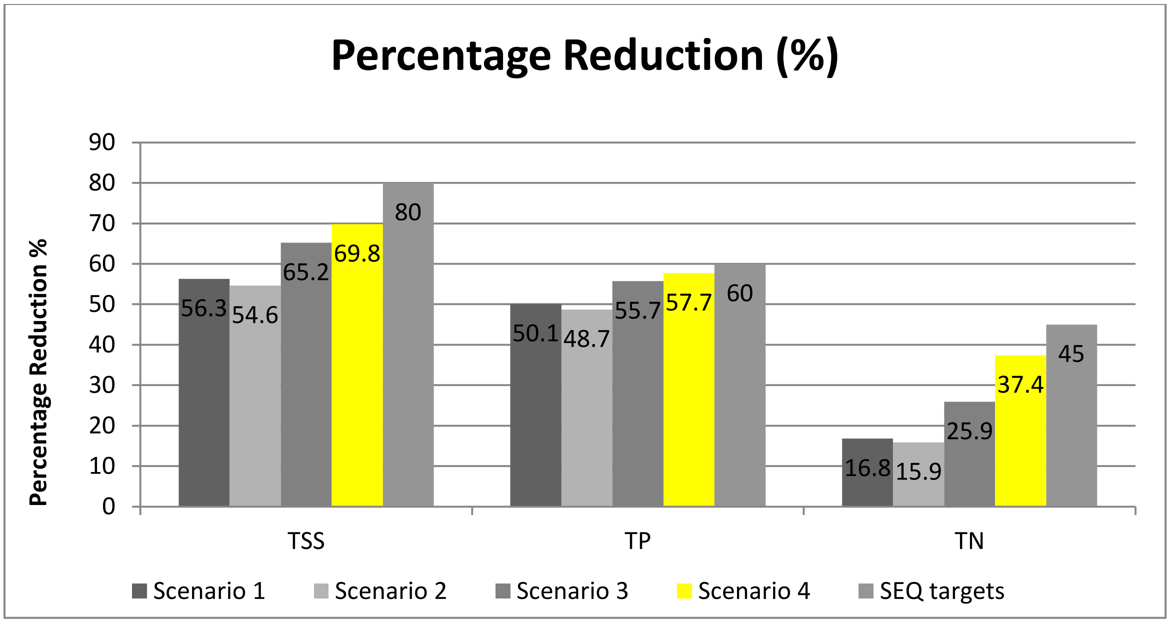


Figure 5.4 – Percentage reduction for total treatment train, Scenarios 1 – 4

The graph shows that for each pollutant, percentage reduction was increased somewhat, but did not reach SEQ reduction targets. Consequently, it is recommended that if TRC desire to have these reduction targets met for the catchment, alternative options will have to be looked into.

Section 4.3.3 proposes that the area of the WBH catchment that does not get treated by the bioretention system causes the increase in bioretention size to have less effect on the overall treatment train effectiveness. Thus, it is recommended that the method that should be used to reach SEQ reduction targets for the WBH catchment, is to include another secondary treatment system at another point within the catchment, that will collect and treat stormwater runoff that does not make its way into the currently proposed bioretention system. In this way, the effect of ‘untreated’ stormwater discharging straight into the WBH will be decreased.

5.5.Design of bioretention system for optimum performance

Section 4.3.5 of the report (Scenario 5), provides results for modelling of a number of modifications of the bioretention system that was first modelled in Section 4.3.3 (Scenario 3). Figures 4.36 – 4.38 show the impact of each of the components tested on the removal of all three pollutants. Consequently, recommendations on the components that should or should not be changed from those specified in Section 3.4.2 of this report are provided below.

Priority: High

- Include effective nutrient removal vegetation. Results show that without this vegetation, the bioretention system lacks the ability to remove TP & TN.

Priority: Medium

- Use a filter media with a lower orthophosphate content – e.g. 50 mg/kg or lower. This allows the removal of TP when it is at lower concentrations in the stormwater. More research may need to be carried out in order to find an optimum orthophosphate content that allows both efficient removal of TP as well as encourages plant growth.
- Do not include a submerged zone with carbon present – this had a negative impact on the TP removal within the bioretention system.
- Unless it is found that a continuous flow of water into this bioretention system will not adversely affect the function of the system, it is recommended that a low-flow by-pass be included in the bioretention system design, as discussed in *Bioretention Technical Design Guidelines* (Water by Design 2012).

Priority: Low

- The Extended Detention Depth could be increased in order to increase the TSS and TN removal rate of the system. However, the results show this to have a relatively small negative impact on the TP removal.
- The TN content within the filter media could be lowered to improve TN removal; however it did not show large increases in removal, and the TN content of the filter media must be high enough so as not to discourage plant growth. MUSIC recommends no less than 600mg/kg (MUSIC software v5.1 'help' information 2012).

5.6.Further Study

As outlined above, the work carried out on this project has led to a number of recommendations and outcomes relating directly to the aims of the project. It is expected that further work will be required to move forward from here, in order to reach the point of design and construction of the proposed bioretention system. It is also possible that further work be carried out to put further confidence in the findings of this study. Future work may include the following:

1. **In depth water sampling,** including a larger sample size that is carefully planned and designed in a way that covers a large range of base flow and storm flow conditions. From which, highly reliable conclusions can be drawn, and used to add more foundation to any modelling that may be carried out.
2. **Further design on proposed bioretention and detention basin** would allow a number of 'treatment node parameters' within MUSIC to be specified to a greater degree of certainty. For example, the amount of fall that is available in the bioretention system will determine the allowable depth of the filter media and extended detention depth. There is also area to confirm other design parameters within the bioretention system, as outlined within Section 4.3.6 of this report.
3. **Study into bioretention size** is needed in order to address issues raised in Section 2.4.3.1 of this report, which references QUDM guidelines that state that optimum catchment area for a bioretention system is up to 2ha. The catchment area of the proposed bioretention system is

approximately 250ha. Section 2.4.3.1 also references the 2012 *Bioretention Technical Design Guidelines* which points out in Table 3, that bioretention systems can handle runoff from large catchments if specific design solutions are made. One of the main factors here is the ability to distribute the runoff evenly through the bioretention system, which, for this bioretention system, includes seven basins. It highly recommended that this particular issue be resolved before final design of the bioretention system begins.

4. **Study into design of bioretention within detention basin** is needed in order to address issues raised in Section 2.4.3.1 of this report. This section refers to the *Concept Guidelines for Water Sensitive Urban Design* (2009) which have a section outlining some of the problems and solutions involved in placing a bioretention system within a regional-scale flood retardation basin.
5. **Study into bioretention systems in continuous wet conditions** and whether or not a low-flow by-pass is needed. Table 4 of *Bioretention Technical Design Guidelines* touches on this topic. As outlined in the results section of this report, the inclusion of a low-flow by-pass does lower the TSS and TN removal efficiency, if it can be proven that the by-pass is not needed, it may help the efficiency of the bioretention system.
6. **Study into Gross Pollutant (GP) removal** is necessary in order to confirm the method that will be used here. Table 7.1 of *Urban Stormwater Quality Planning Guidelines* (Department of Environment and Heritage Protection 2010) categorises the sediment settling basin as having negligible ability to remove gross pollutants. The proposed primary treatment device at the bioretention system location is the sedimentation basin and it is important that the bioretention system be protected by the removal of GP's, thus, a method of GP removal needs to be confirmed. This may simply require a Gross Pollutant Trap (GPT) at some point in the sedimentation basins outlet pipe, or it may require further investigation.
7. **The implementation of the detention basin and bioretention system into Ballin Drive Park** is another area of further work. It is important that the entire proposed stormwater system will be able to perform its stormwater mitigation and treatment purposes while also adding to other aspects of the park, including interaction of the public with nature and general aesthetics, as is typical of current WSUD.
8. **Detailed design** will obviously be required at some point. TRC's 2010 report includes a basic conceptual layout of the Ballin Drive Park detention basin and bioretention system within. The layout includes the initial sedimentation basin and seven basins making up the bioretention system. Based on this study and possible future work, there will be an opportunity for this conceptual layout to be modified and designed with greater justification and detail.

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Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR:	**NICHOLAS KOHN**
TOPIC:	EFFECTS OF PROPOSED WSUD SYSTEM (BIORETENTION BASIN) ON EXISTING WATERBIRD HABITAT
SUPERVISORS:	Dr. Ian Brodie, Janaka Gunawardena
ENROLMENT:	ENG 4111 – S1, ONC, 2013 ENG 4112 – S2, ONC, 2013
PROJECT AIM:	This project aims to gauge and model the current water quality within the Waterbird Habitat, to assess its expected future upstream development and calculate and model the effectiveness of an upstream Bioretention Basin in treating the subsequent increase in water pollutants.
SPONSORSHIP:	TRC
PROGRAMME:	**Issue A, 13th March 2013**

1. Research water sampling methods for stormwater runoff quality.
2. Plan and carry out a water sampling plan for assessing current water quality within the Waterbird Habitat and have samples analyzed (outsource).
3. Using the sampling data and geometric measurements to produce a MUSIC model of the existing situation – Waterbird Habitat and catchment area.
4. Research the extent of future development expected within the Waterbird Habitat catchment.
5. Research typical Bioretention System design including size, filter media, positioning, etc. and what parameters to specify for the MUSIC model.
6. Add future development data to the MUSIC model to predict the subsequent rise in pollutants; decide on suitable pollutant reduction targets. Use this model to calculate the required specifications for a Bioretention System designed to manage the increase in pollutants.
7. Submit a dissertation on the research and findings.

As time permits:

8. Provide detailed design including drawings and explanation of a Bioretention System option including layout and basin details.
9. Provide ideas for the integration of the systems engineering and social functioning – i.e. how can it be implemented with no adverse community effects.

AGREED:

____________________(Student)____________________ , **APPROVED**(Supervisors)

______/______/______ ______/______/______ _____/______/______

Appendix B – Catchment runoff calculations – rational method

The following calculations have been carried out in accordance with the *Queensland Urban Drainage Manual Volume 1* (QUDM) (Department of Natural Resources and Water 2007) and are for the purpose of finding the approximate peak flow discharging into the proposed bioretention system for a particular storm event. The Q5 peak flow has been calculated in this particular example.

QUDM Section 4.03 Rational Method

The equation used to calculate peak flow for the rational method is as follows, from QUDM Section 4.03.1 – General.

Q=C.I.A (QUDM Eq. 4.01) or;

$$Q_y = (2.78E - 3) * C_y.\ {}^{t}I_y.A \quad \text{(QUDM Eq. 4.02)}$$

Where:

Q_y = is the peak flow in m³/s, 'y' is the ARI storm event

C_y = is the coefficient of discharge for ARI of 'y' years

${}^{t}I_y$ = is the Rainfall Intensity mm/hr for a Time of Concentration of 't' hours/mins and ARI 'y' years

A = is the area of the catchment (hectares)

$(2.78E - 3)$ is a conversion factor

This equation was solved in the following steps:

A. Find ${}^{t}I_y$, by finding the Time of Concentration of the catchment Tc.

The Tc of the catchment was calculated in accordance with QUDM Section 4.06.3(a), using the calculation of time for the following consecutive runoff flows:

1. Inlet time - overland flow to road, at top of catchment.
2. Pipe flow from first inlet point to start of open channel flow.
3. Open channel flow from end of pipe flow to proposed bioretention inlet.

1. Inlet time - overland flow to road, at top of catchment.

Full length of sheet flow = 150m

From QUDM Table 4.06.1, if slope less than 3% use 15min inlet time, with a maximum inlet time of 20 minutes recommended. Friend's Equation is used below to confirm/modify this time.

Friend's Equation:

$$t = \frac{107nL^{0.333}}{S^{0.2}} \quad \text{(QUDM Eq. 4.06)}$$

Where:

t = is the time in seconds;

n = Horton’s roughness coefficient;
L = length of overland flow meters;
S = slope of surface %

Thus,

$$t = \frac{107 * 0.045 * 150^{0.333}}{2.2^{0.2}}$$

$$t = 21.81 mins$$

As QUDM recommends an inlet time not higher than 20mins, the inlet time was taken as 20mins.

2. Pipe flow from first inlet point to start of open channel flow – 1718m total.

The pipe flow time was calculated in accordance with QUDM Section 4.06.9, with reference to QUDM Figure 4.09. This process is shown in Table A.1.1 for each length of pipe along the section calculated.

Table B.1 – Pipe flow time calculations

Pipe Dia.	Upstream Invert Level (RL)	Downstream Invert Level (RL)	Fall (m)	Length (m)	Slope %	Flow time (mins) (from figure 4.09 QUDM)
225	715.675	711.435	4.240	102.2	4.15	1.1
300	710.660	707.987	2.673	206.7	1.29	3.2
375	707.912	706.097	1.815	76.9	2.36	1.0
525	706.000	700.000	6.000	136.9	4.38	1.3
600	700.000	697.450	2.550	63.7	4.00	0.8
750	697.450	687.330	10.120	308.6	3.28	2.5
675	687.350	679.120	8.230	213.9	3.85	1.9
825	678.970	676.390	2.580	89.8	2.87	1.3
1050	676.090	675.950	0.140	23.0	0.61	0.2
1800	675.630	675.340	0.290	29.4	0.99	0.2
1650	675.330	669.700	5.630	187.4	3.00	2.0
2100	669.250	665.450	3.800	122.4	3.10	1.5
2400	665.250	663.792	1.458	156.8	0.93	3.0
		Total Travel Time in Pipe System:				20.0 minutes

3. Open channel flow from end of pipe flow to proposed bioretention inlet – 873m total.

The open channel flow time was calculated in accordance with QUDM Section 4.06.10, using QUDM equation 4.8, Manning’s Equation, to calculate the velocity of the channel. Firstly, QUDM equation 9.03 was used to find the ‘composite roughness of the channel’ to find the manning’s roughness coefficient as shown below:

$$n = \frac{(A^{\frac{5}{3}}/P^{\frac{2}{3}})}{\Sigma(Ai^{\frac{5}{3}}/ni.Pi^{\frac{2}{3}})} \quad \text{(QUDM Eq. 9.03)}$$

Where:

n = equivalent composite manning's roughness coefficient for the whole channel
A = Cross-sectional area of the channel
P = Wetted perimeter of channel cross-section
ni = manning's roughness coefficient for each channel section
A = Cross-sectional area of each channel section
P = Wetted perimeter of each section of channel

Thus,

$$n = \frac{(2^{\frac{5}{3}}/2.06^{\frac{2}{3}})}{\Sigma(0.5^{\frac{5}{3}}/(0.037 * 2.06^{\frac{2}{3}})) + (1^{\frac{5}{3}}/(0.08 * 2^{\frac{2}{3}}))}$$

$$n = \frac{1.961}{10.516 + 7.875}$$

$$n = 0.107 \approx 0.10$$

Now, using Manning's equation to find flow velocity in the channel:

$$V = \frac{R^{\frac{2}{3}}.S^{\frac{1}{2}}}{n} \quad \text{(QUDM Eq. 4.08)}$$

$$V = \frac{(2/6.12)^{\frac{2}{3}} * 0.024^{\frac{1}{2}}}{0.1}$$

$$V = 0.735m/s$$

This channel flow extends 873m, therefore the travel time will be velocity multiplies by length:

$$t = 0.735 * 873$$

$$t = 1188\,\text{sec} \approx 19.8\,mins, say\;20\,mins$$

Therefore, the total time of concentration = Tc(1) + Tc(2) + Tc(3) = 20+20+20 = 60mins.

Therefore the critical rainfall intensity, ${}^{t}I_{y}$, will be for 60 minutes or 1 hour, thus for a Q5 that will be ${}^{1}I_{5}$. From the Intensity Frequency Duration (IFD) design rainfall chart for Toowoomba:

$^{1}I_{5}$ = 43.8 mm/hr

B. Find coefficient of discharge, Cy

The Cy of the catchment was calculated in accordance with QUDM Section 4.05, using QUDM equation 4.05:

$$C_y = F_y \, . \, C_{10} \qquad \text{(QUDM Eq. 4.05)}$$

The fraction impervious for the entire bioretention system catchment is known to be approximately 43% from previous calculations, and the ${}^{1}I_{10}$ value for Toowoomba is 48.2 mm/hr from the IFD chart. Following this, C_{10} is selected from QUDM Table 4.05.3(a) as 0.6.

The Fy value for a Q5 event is 0.95, provided in QUDM Table 4.05.2.

$$C_5 = 0.95 * 0.6 = 0.57$$

C. Find the area of the catchment, A

The area of the entire bioretention system catchment is known to be 258.346 ha.

D. Calculate the 5 year ARI peak flow, Q

$$Q_5 = (2.78E - 3) * 0.57 * 43.8 * 258.346 = \boldsymbol{17.93\ m^3/s}$$

Appendix C – Sample results

C.1 – Summary of sample conditions and locations

Table C.1 – Full Details of Sample Event Conditions

Sample Dates	14.05.13	22.05.13	12.06.13	16.06.13	08.07.13	15.07.13
Time	7:30am	3:00pm	10:15pm	10:00am	5:00pm	11:00am
Sample Type	Wet	Wet	Wet	Dry	Dry	Dry
Flow Height in culvert - 3 pipes(mm)	80, 110, 100	40, 60, 50	220, 240, 200	20 , 40, 40	20 , 40, 40	20 , 40, 40
Approximate Flow in WBH (m^3/s)	0.223	0.085	0.708	0.048	0.048	0.048
Days since previous rain event	1 (0.5mm)	9 (16mm)	1 (1mm)	3.5 (12mm)	3+ (6mm)	10+ (6mm)
Weather conditions	Raining	Raining	Raining	Sunny	Sunny	Overcast
Temperature	Mild Morning	Cold Morning	Mild Night	Mild Morning	Warm Afternoon	Warm Morning
Wind	Still	Light Breeze	Still	Slight	Slight	Slight
Rain	Light	Light	Drizzle	No	No	No
Stage of Rain event	End	Start/Peak	End	N/A	N/A	N/A
Rising/Receding Waters	Receding	Rising slowly	Peaking	N/A	N/A	N/A

Table C.2 – Pluviometer results preceding sample at 07:30, 14/05/13

Date/Time	Rainfall Since 00:01a.m. (mm)
5/14/13 2:49 AM	0.0
5/14/13 2:54 AM	0.5
5/14/13 2:59 AM	0.5
5/14/13 3:04 AM	0.5
5/14/13 3:09 AM	0.5
5/14/13 3:14 AM	0.5
5/14/13 3:19 AM	1.0
5/14/13 3:24 AM	1.0
5/14/13 3:29 AM	1.0
5/14/13 3:34 AM	1.5
5/14/13 3:39 AM	1.5
5/14/13 3:44 AM	1.5
5/14/13 3:49 AM	2.5
5/14/13 3:54 AM	3.0
5/14/13 3:59 AM	3.5
5/14/13 4:04 AM	3.5
5/14/13 4:09 AM	3.5
5/14/13 4:14 AM	4.0
5/14/13 4:19 AM	4.0
5/14/13 4:24 AM	4.0
5/14/13 4:29 AM	4.5
5/14/13 4:34 AM	5.0
5/14/13 4:39 AM	6.5
5/14/13 4:44 AM	7.5
5/14/13 4:49 AM	8.5
5/14/13 4:54 AM	8.5
5/14/13 4:59 AM	8.5
5/14/13 5:04 AM	9.5
5/14/13 5:09 AM	9.5
5/14/13 5:14 AM	10.0
5/14/13 5:19 AM	10.0
5/14/13 5:24 AM	10.0
5/14/13 5:29 AM	10.0
5/14/13 5:34 AM	10.5
5/14/13 5:39 AM	11.0
5/14/13 5:44 AM	11.0
5/14/13 5:49 AM	11.5
5/14/13 5:54 AM	11.5
5/14/13 5:59 AM	11.5
5/14/13 6:04 AM	11.5
5/14/13 6:09 AM	12.0
5/14/13 6:14 AM	12.0
5/14/13 6:19 AM	12.0
5/14/13 6:24 AM	12.0
5/14/13 6:29 AM	12.0
5/14/13 6:34 AM	12.0
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5/14/13 6:44 AM	12.5
5/14/13 6:49 AM	12.5
5/14/13 6:54 AM	12.5
5/14/13 6:59 AM	12.5
5/14/13 7:04 AM	12.5
5/14/13 7:09 AM	12.5
5/14/13 7:14 AM	12.5
5/14/13 7:19 AM	12.5
5/14/13 7:24 AM	13.0
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5/14/13 7:39 AM	13.0
5/14/13 7:44 AM	13.0

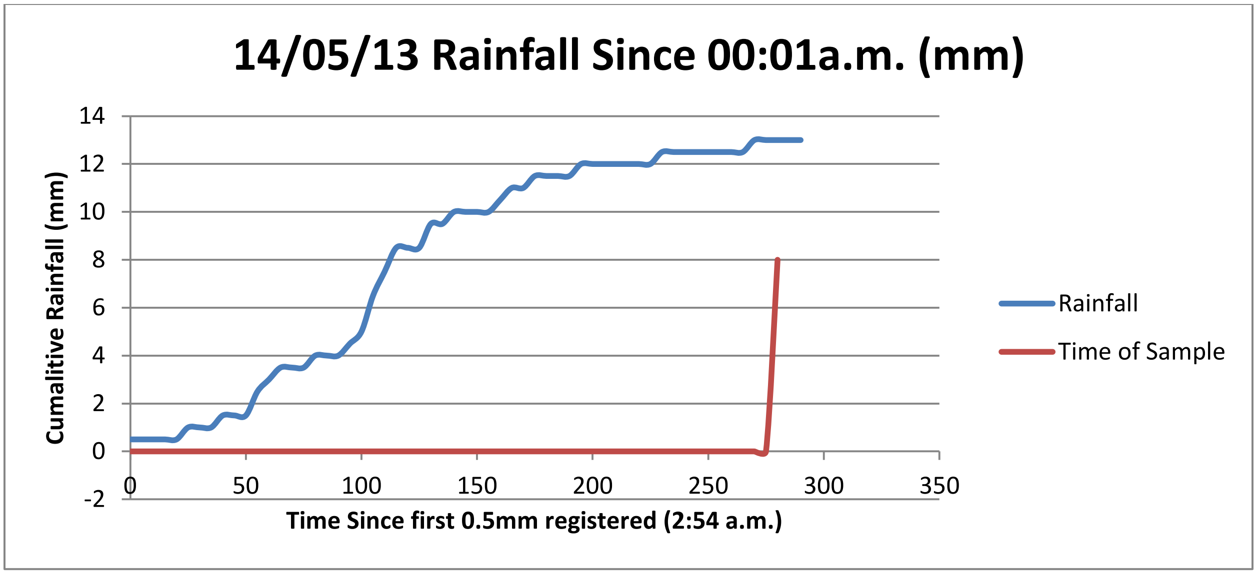


Figure C.1 – Graph of above rainfall results for 14/05/13

Table C.3 – Pluviometer results preceding sample at 15:00, 22/05/13

Date/Time	Rainfall Since 00:01a.m. (mm)
5/22/13 10:39 AM	0.5
5/22/13 10:44 AM	0.5
5/22/13 10:49 AM	0.5
5/22/13 10:54 AM	0.5
5/22/13 10:59 AM	0.5
5/22/13 11:04 AM	0.5
5/22/13 11:09 AM	0.5
5/22/13 11:14 AM	0.5
5/22/13 11:19 AM	0.5
5/22/13 11:24 AM	0.5
5/22/13 11:29 AM	0.5
5/22/13 11:34 AM	0.5
5/22/13 11:39 AM	0.5
5/22/13 11:44 AM	0.5
5/22/13 11:49 AM	0.5
5/22/13 11:54 AM	0.5
5/22/13 11:59 AM	0.5
5/22/13 12:04 PM	0.5
5/22/13 12:09 PM	0.5
5/22/13 12:14 PM	0.5
5/22/13 12:19 PM	0.5
5/22/13 1:09 PM	0.5
5/22/13 1:14 PM	0.5
5/22/13 1:19 PM	0.5
5/22/13 1:24 PM	0.5
5/22/13 1:29 PM	0.5
5/22/13 1:34 PM	0.5
5/22/13 1:39 PM	1.0
5/22/13 1:44 PM	1.0
5/22/13 1:49 PM	0.0
5/22/13 1:54 PM	0.0
5/22/13 1:59 PM	0.0
5/22/13 2:04 PM	0.0
5/22/13 2:09 PM	0.0
5/22/13 2:14 PM	0.0
5/22/13 2:19 PM	0.0
5/22/13 2:24 PM	0.0
5/22/13 2:29 PM	0.0
5/22/13 2:34 PM	0.0
5/22/13 2:39 PM	0.0
5/22/13 2:44 PM	0.0
5/22/13 2:49 PM	0.0

5/22/13 12:24 PM	0.5
5/22/13 12:29 PM	0.5
5/22/13 12:34 PM	0.5
5/22/13 12:39 PM	0.5
5/22/13 12:44 PM	0.5
5/22/13 12:49 PM	0.5
5/22/13 12:54 PM	0.5
5/22/13 12:59 PM	0.5
5/22/13 1:04 PM	0.5

5/22/13 2:54 PM	0.0
5/22/13 2:59 PM	0.0
5/22/13 3:04 PM	1.0
5/22/13 3:09 PM	1.0
5/22/13 3:14 PM	4.0
5/22/13 3:19 PM	4.0
5/22/13 3:24 PM	4.0
5/22/13 3:29 PM	4.0
5/22/13 3:34 PM	4.0

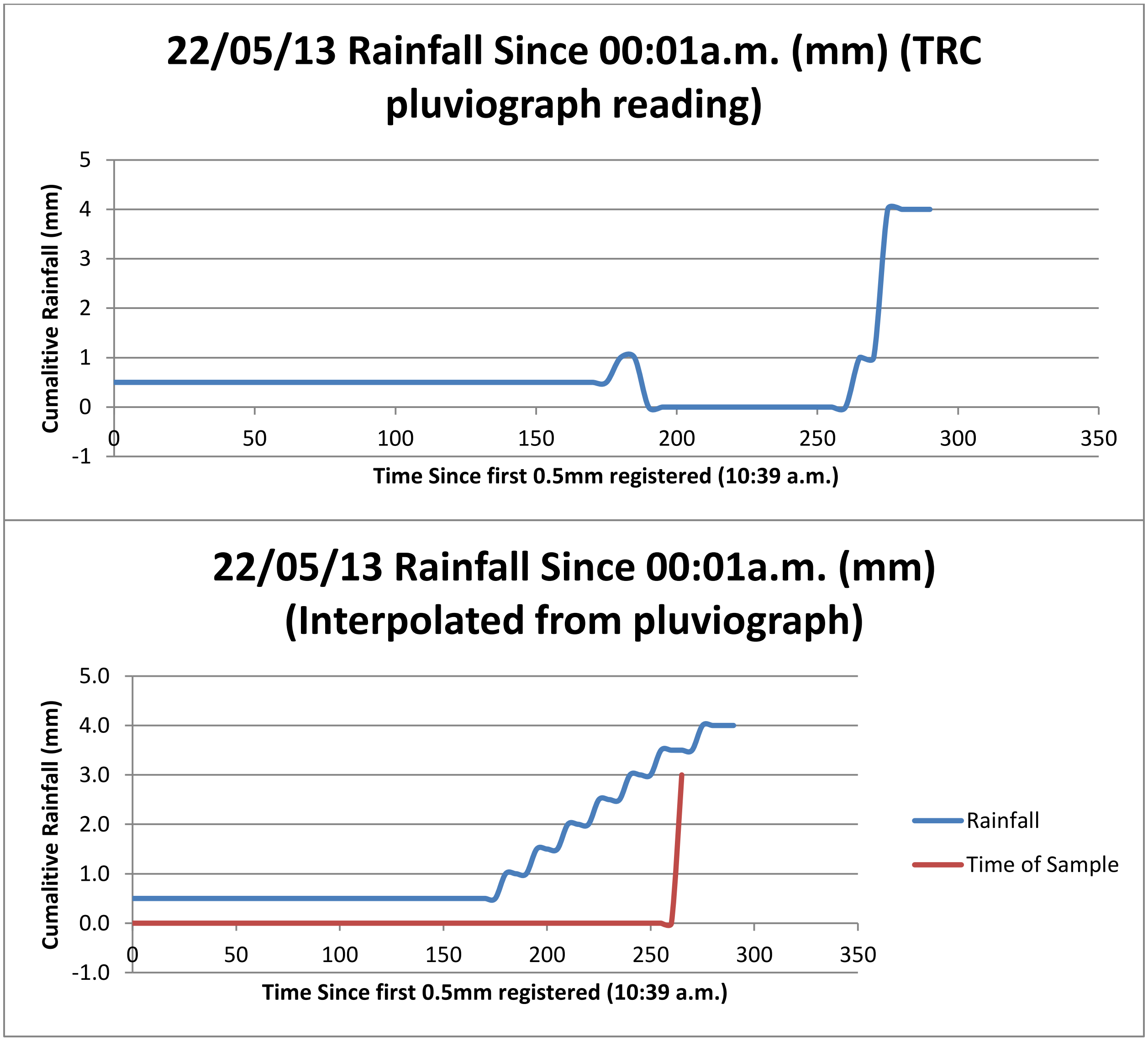


Figure C.2 – Graph of above rainfall results for 22/05/13 (Note: the data from the TRC pluviometer contained a period of data that appeared to contain error, therefore the second graph was created by interpolating this information.)

Table C.4 – Pluviometer results preceding sample at 22:15, 12/06/13

Date/Time	Rainfall Since 00:01a.m. (mm)
6/12/13 3:30 PM	0.5
6/12/13 3:35 PM	0.5
6/12/13 3:40 PM	0.5
6/12/13 3:45 PM	0.5
6/12/13 3:50 PM	0.5
6/12/13 3:55 PM	0.5
6/12/13 4:00 PM	1.0
6/12/13 4:05 PM	1.0
6/12/13 4:10 PM	1.5
6/12/13 4:15 PM	1.5
6/12/13 4:20 PM	1.5
6/12/13 4:25 PM	1.5
6/12/13 4:30 PM	1.5
6/12/13 4:35 PM	1.5
6/12/13 4:40 PM	1.5
6/12/13 4:45 PM	1.5
6/12/13 4:50 PM	1.5
6/12/13 4:55 PM	1.5
6/12/13 5:00 PM	1.5
6/12/13 5:05 PM	1.5
6/12/13 5:10 PM	1.5
6/12/13 5:15 PM	1.5
6/12/13 5:20 PM	1.5
6/12/13 5:25 PM	1.5
6/12/13 5:30 PM	1.5
6/12/13 5:35 PM	1.5
6/12/13 5:40 PM	1.5
6/12/13 5:45 PM	1.5
6/12/13 5:50 PM	1.5
6/12/13 5:55 PM	1.5
6/12/13 6:00 PM	2.0
6/12/13 6:05 PM	2.0
6/12/13 6:10 PM	2.5
6/12/13 6:15 PM	2.5
6/12/13 6:20 PM	2.5
6/12/13 6:25 PM	2.5
6/12/13 6:55 PM	2.5
6/12/13 7:00 PM	2.5
6/12/13 7:05 PM	2.5
6/12/13 7:10 PM	2.5
6/12/13 7:15 PM	2.5
6/12/13 7:20 PM	2.5
6/12/13 7:25 PM	2.5
6/12/13 7:30 PM	2.5
6/12/13 7:35 PM	2.5
6/12/13 7:40 PM	2.5
6/12/13 7:45 PM	2.5
6/12/13 7:50 PM	2.5
6/12/13 7:55 PM	2.5
6/12/13 8:00 PM	3.0
6/12/13 8:05 PM	3.0
6/12/13 8:10 PM	3.0
6/12/13 8:15 PM	3.5
6/12/13 8:20 PM	3.5
6/12/13 8:25 PM	3.5
6/12/13 8:30 PM	3.5
6/12/13 8:35 PM	3.5
6/12/13 8:40 PM	3.5
6/12/13 8:45 PM	3.5
6/12/13 8:50 PM	4.0
6/12/13 8:55 PM	4.0
6/12/13 9:00 PM	4.0
6/12/13 9:05 PM	5.0
6/12/13 9:10 PM	7.5
6/12/13 9:15 PM	9.5
6/12/13 9:20 PM	9.5
6/12/13 9:25 PM	9.5
6/12/13 9:30 PM	9.5
6/12/13 9:35 PM	9.5
6/12/13 9:40 PM	9.5
6/12/13 9:45 PM	9.5
6/12/13 9:50 PM	10.5

6/12/13 6:30 PM	2.5
6/12/13 6:35 PM	2.5
6/12/13 6:40 PM	2.5
6/12/13 6:45 PM	2.5
6/12/13 6:50 PM	2.5

6/12/13 9:55 PM	10.5
6/12/13 10:00 PM	10.5
6/12/13 10:05 PM	11.0
6/12/13 10:10 PM	11.0

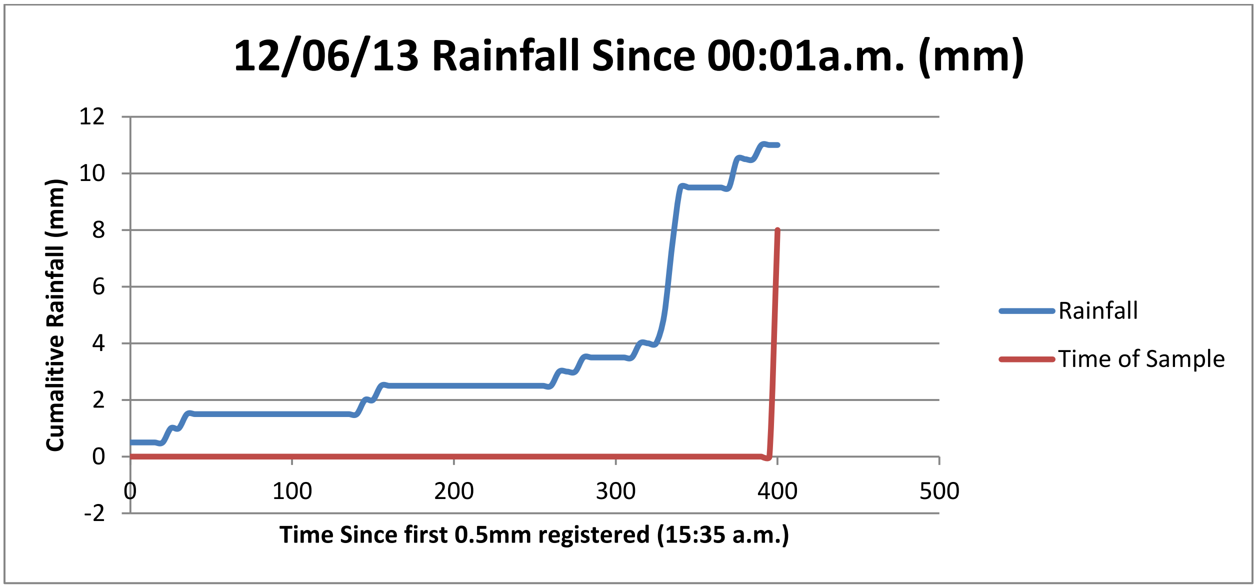


Figure C.3 – Graph of above rainfall results for 12/06/13

Figure C.4 – Map of Sample Locations

C.2 – Summary of sample results TSS

Table C.5 – Full set of TSS analysis data (mg/L)

	Date↓ Location→	1.1	1.2	2.1	2.2	2.3	3.1	3.2	3.3	0.1	0.2
Wet	14.05.13	10		10			9		2		
	22.05.13	33		2			5		1		79
	12.06.13	65		41			57		15		
Dry	17.06.13	8		7			11		5	1	
	08.07.13	11	11		14			18	18	4	
	15.07.13	10	18		20	23		23	21	15	
	Location→	1.1	1.2	2.1	2.2	2.3	3.1	3.2	3.3	0.1	0.2
	Mean	22.8	14.5	15.0	17.0	23.0	20.5	20.5	10.3	6.7	79.0
	1st Quartile	10.00	12.75	5.75	15.50	23.00	8.00	19.25	2.75	2.50	79.00
	Minimum	8.00	11.00	2.00	14.00	23.00	5.00	18.00	1.00	1.00	79.00
	Maximum	65.00	18.00	41.00	20.00	23.00	57.00	23.00	21.00	15.00	79.00
	3rd Quartile	27.50	16.25	17.75	18.50	23.00	22.50	21.75	17.25	9.50	79.00

Table C.6 – 'Dry' TSS analysis data (mg/L)

TSS by Pond (DRY)	8	7	11	1
	11	14	18	4
	10	20	23	15
	11	23	5	
	18		18	
			21	
Location→	1.1 - 1.2	2.1 - 2.3	3.1 - 3.3	0.1
Mean	11.6	16.0	16.0	6.7
1st Quartile	10.00	12.25	12.75	2.50
Minimum	8.00	7.00	5.00	1.00
Maximum	18.00	23.00	23.00	15.00
3rd Quartile	11.00	20.75	20.25	9.50

Table C.7 – 'Wet' TSS analysis data (mg/L)

TSS by Pond (WET)	10	10	9	2	
	33	2	5	1	79
	65	41	57	15	
Location→	1.1	2.1	3.1	3.3	0.2
Mean	36.0	17.7	23.7	6.0	79.0
1st Quartile	21.50	6.00	7.00	1.50	79.00
Minimum	10.00	2.00	5.00	1.00	79.00
Maximum	65.00	41.00	57.00	15.00	79.00
3rd Quartile	49.00	25.50	33.00	8.50	79.00

C.3 – Summary of sample results TP

Table C.8 – Full set of TP analysis data (mg/L)

	Date↓ Location→	1.1	1.2	2.1	2.2	2.3	3.1	3.2	3.3	0.1	0.2
Wet	14.05.13	0.08		0.09			0.05		0.04		
	22.05.13	0.08		0.01			0.02		0.02		0.18
	12.06.13	0.1		0.07			0.05		0.02		
Dry	17.06.13	0.01		0.02			0.03		0.02	0.01	
	08.07.13	0.01	0.01		0.01			0.02	0.06	0.01	
	15.07.13	0.01	0.01		0.01	0.01		0.01	0.01	0.01	
	Location→	1.1	1.2	2.1	2.2	2.3	3.1	3.2	3.3	0.1	0.2
	Mean	0.05	0.01	0.05	0.01	0.01	0.04	0.02	0.03	0.01	0.18
	1st Quartile	0.01	0.01	0.02	0.01	0.01	0.03	0.01	0.02	0.01	0.18
	Minimum	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.18
	Maximum	0.10	0.01	0.09	0.01	0.01	0.05	0.02	0.06	0.01	0.18
	3rd Quartile	0.08	0.01	0.08	0.01	0.01	0.05	0.02	0.04	0.01	0.18

Table C.9 – 'Dry' TP analysis data (mg/L)

TP by Pond (DRY)	0.01	0.02	0.03	0.01
	0.01	0.01	0.02	0.01
	0.01	0.01	0.01	0.01
	0.01	0.01	0.02	
	0.01		0.06	
			0.01	
Location→	1.1 - 1.2	2.1 - 2.3	3.1 - 3.3	0.1
Mean	0.01	0.01	0.03	0.01
1st Quartile	0.01	0.01	0.01	0.01
Minimum	0.01	0.01	0.01	0.01
Maximum	0.01	0.02	0.06	0.01
3rd Quartile	0.01	0.01	0.03	0.01

Table C.10 – 'Wet' TP analysis data (mg/L)

TP by Pond (WET)	0.08	0.09	0.05	0.04	
	0.08	0.01	0.02	0.02	0.18
	0.10	0.07	0.05	0.02	
Location→	1.1	2.1	3.1	3.3	0.2
Mean	0.09	0.06	0.04	0.03	0.18
1st Quartile	0.08	0.04	0.04	0.02	0.18
Minimum	0.08	0.01	0.02	0.02	0.18
Maximum	0.10	0.09	0.05	0.04	0.18
3rd Quartile	0.09	0.08	0.05	0.03	0.18

C.4 – Summary of sample results TN

Table C.11 – Full set of TN analysis data (mg/L)

	Date↓ Location→	1.1	1.2	2.1	2.2	2.3	3.1	3.2	3.3	0.1	0.2
Wet	14.05.13	0.2		0.4			0.5		0.8		
	22.05.13	1.8		1.6			0.9		0.9		1
	12.06.13	0.6		0.8			0.5		0.8		
Dry	17.06.13	1.2		1			0.5		0.7	2.1	
	08.07.13	1.5	1.1		1			0.8	1.3	2.1	
	15.07.13	1.1	1		0.6	0.6		1.7	1.4	0.2	
	Location→	1.1	1.2	2.1	2.2	2.3	3.1	3.2	3.3	0.1	0.2
	Mean	1.1	1.1	1.0	0.8	0.6	0.6	1.3	1.0	1.5	1.0
	1st Quartile	0.73	1.03	0.70	0.70	0.60	0.50	1.03	0.80	1.15	1.00
	Minimum	0.20	1.00	0.40	0.60	0.60	0.50	0.80	0.70	0.20	1.00
	Maximum	1.80	1.10	1.60	1.00	0.60	0.90	1.70	1.40	2.10	1.00
	3rd Quartile	1.43	1.08	1.15	0.90	0.60	0.60	1.48	1.20	2.10	1.00

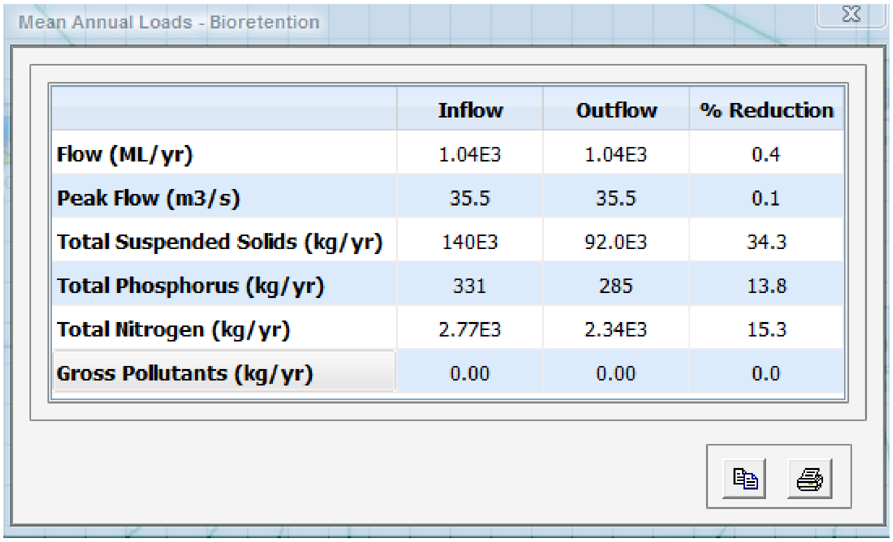
Table C.12 – 'Dry' TN analysis data (mg/L)

TN by Pond (DRY)	1.2	1.0	0.5	2.1
	1.5	1.0	0.8	2.1
	1.1	0.6	1.7	0.2
	1.1	0.6	0.7	
	1.0		1.3	
			1.4	
Location→	1.1 - 1.2	2.1 - 2.3	3.1 - 3.3	0.1
Mean	1.2	0.8	1.1	1.5
1st Quartile	1.10	0.60	0.73	1.15
Minimum	1.00	0.60	0.50	0.20
Maximum	1.50	1.00	1.70	2.10
3rd Quartile	1.20	1.00	1.38	2.10

Table C.13 – 'Wet' TN analysis data (mg/L)

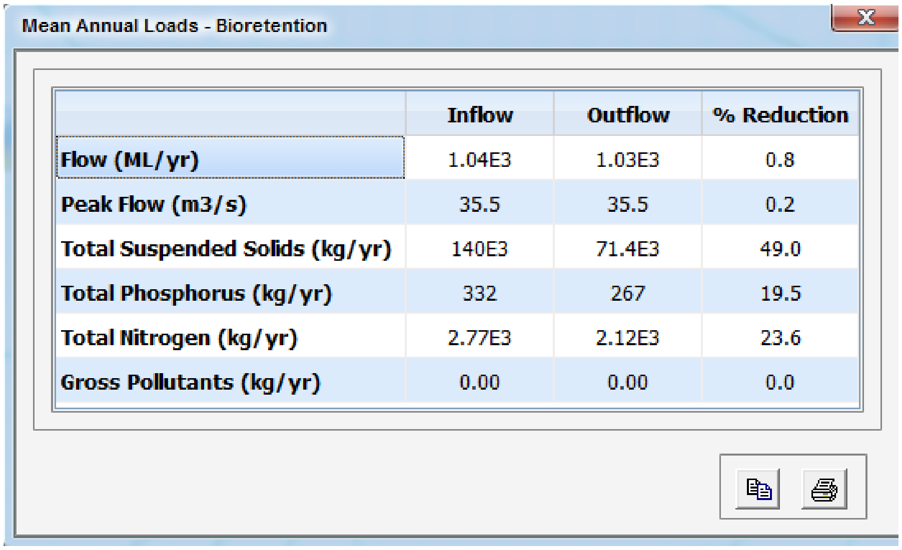
TN by Pond (WET)	0.2	0.4	0.5	0.8	
	1.8	1.6	0.9	0.9	1.0
	0.6	0.8	0.5	0.8	
Location→	1.1	2.1	3.1	3.3	0.2
Mean	0.9	0.9	0.6	0.8	1.0
1st Quartile	0.40	0.60	0.50	0.80	1.00
Minimum	0.20	0.40	0.50	0.80	1.00
Maximum	1.80	1.60	0.90	0.90	1.00
3rd Quartile	1.20	1.20	0.70	0.85	1.00

Appendix D Mean Annual Loads for all Scenario 4 bioretention sizes



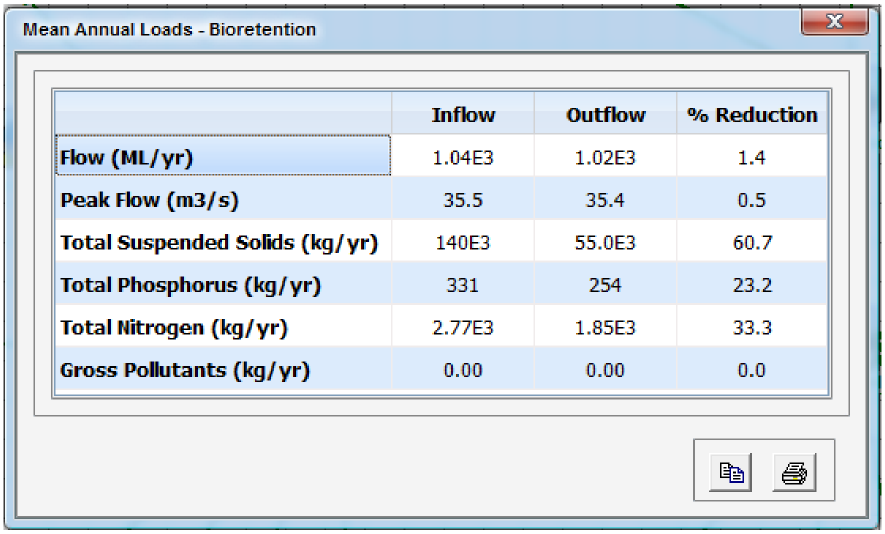
	Inflow	Outflow	% Reduction
Flow (ML/yr)	1.04E3	1.04E3	0.4
Peak Flow (m3/s)	35.5	35.5	0.1
Total Suspended Solids (kg/yr)	140E3	92.0E3	34.3
Total Phosphorus (kg/yr)	331	285	13.8
Total Nitrogen (kg/yr)	2.77E3	2.34E3	15.3
Gross Pollutants (kg/yr)	0.00	0.00	0.0

Figure D.1 – Mean Annual Loads through bioretention system 'Trial Number 1'



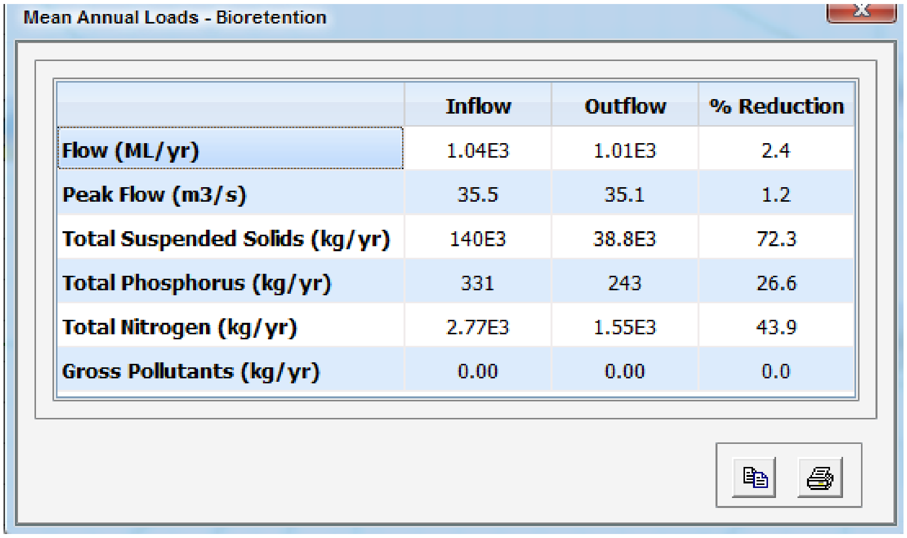
	Inflow	Outflow	% Reduction
Flow (ML/yr)	1.04E3	1.03E3	0.8
Peak Flow (m3/s)	35.5	35.5	0.2
Total Suspended Solids (kg/yr)	140E3	71.4E3	49.0
Total Phosphorus (kg/yr)	332	267	19.5
Total Nitrogen (kg/yr)	2.77E3	2.12E3	23.6
Gross Pollutants (kg/yr)	0.00	0.00	0.0

Figure D.2 – Mean Annual Loads through bioretention system 'Trial Number 2'



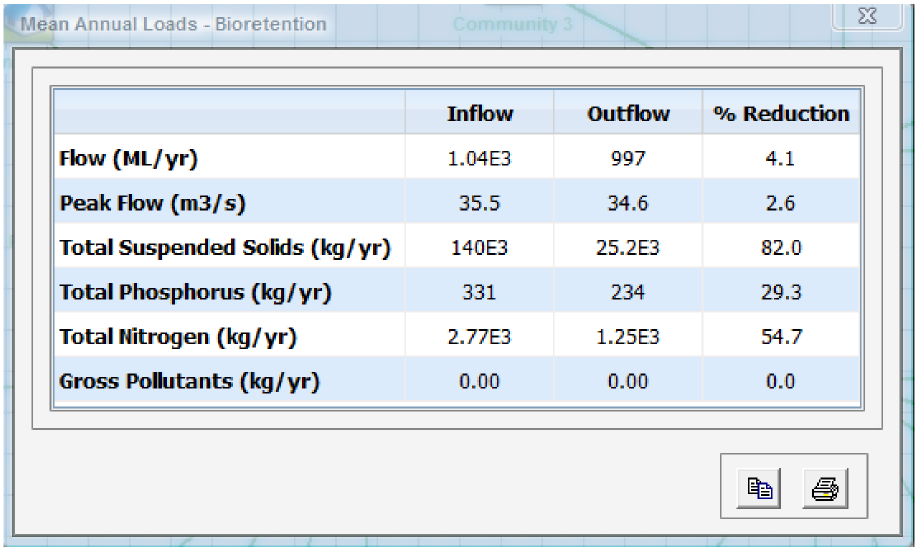
	Inflow	Outflow	% Reduction
Flow (ML/yr)	1.04E3	1.02E3	1.4
Peak Flow (m3/s)	35.5	35.4	0.5
Total Suspended Solids (kg/yr)	140E3	55.0E3	60.7
Total Phosphorus (kg/yr)	331	254	23.2
Total Nitrogen (kg/yr)	2.77E3	1.85E3	33.3
Gross Pollutants (kg/yr)	0.00	0.00	0.0

Figure D.3 – Mean Annual Loads through bioretention system 'Trial Number 3'



	Inflow	Outflow	% Reduction
Flow (ML/yr)	1.04E3	1.01E3	2.4
Peak Flow (m3/s)	35.5	35.1	1.2
Total Suspended Solids (kg/yr)	140E3	38.8E3	72.3
Total Phosphorus (kg/yr)	331	243	26.6
Total Nitrogen (kg/yr)	2.77E3	1.55E3	43.9
Gross Pollutants (kg/yr)	0.00	0.00	0.0

Figure D.4 – Mean Annual Loads through bioretention system 'Trial Number 4'



	Inflow	Outflow	% Reduction
Flow (ML/yr)	1.04E3	997	4.1
Peak Flow (m3/s)	35.5	34.6	2.6
Total Suspended Solids (kg/yr)	140E3	25.2E3	82.0
Total Phosphorus (kg/yr)	331	234	29.3
Total Nitrogen (kg/yr)	2.77E3	1.25E3	54.7
Gross Pollutants (kg/yr)	0.00	0.00	0.0

Figure D.5 – Mean Annual Loads through bioretention system 'Trial Number 5'