University of Southern Queensland

Faculty of Health, Engineering and Sciences

School of Sciences and Engineering

The investigation of stormwater runoff by utilising a combination of green infrastructure in different sized urban residential catchments.

A dissertation submitted by

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ABSTRACT

This dissertation investigates the performance of green infrastructures in urban residential catchments in Ipswich, Queensland. In total there were 4 catchments designed and tested. They were divided up by the total lots contained within the catchment. There was the single lot that contained 1 lot, the street or neighbourhood catchment that contained 10 lots, the subdivision catchment that contained 100 lots and finally, the suburb or cluster of subdivision catchment that contained 1000 lots. The aim is to identify the optimum combination in all of these different catchments.

The pre-development, post development and the inclusions of the green infrastructure were modelled using the MUSIC software package from eWater. The MUSIC software has become the benchmark software for analysing stormwater water quality in South East Queensland. However, the software still requires further investigation with regards to its frequent flow management capabilities. Because of the absence of research, this dissertation will carefully analyse all of the results outputted from this software. Although not the major aim of this dissertation, the paper also aims to assist in the understanding and development of the software's ability to model and assist in the management of frequent flow.

From the 20 models created with MUSIC (Appendix C), results will be outputted and presented in a number of hydrographs. They will represent the amount of urban runoff discharged, after treatment, on the different scaled catchments. Urban runoff velocity, retention and volume can be determined off the hydrographs. The best or ideal outcome will be to mimic or improve the pre-developed flow conditions.

It was found that all green infrastructure reduce the peak discharge. However, some infrastructure have little to no impact of the retention and velocity of urban runoff. Unexpectedly, the combination of green infrastructures either had no effect to the urban runoff or increased the runoff from the original infrastructure. This was assumed to be a calculation error from the software, when calculating bypass from one node to another.

Constructed wetlands were the best performing green infrastructure with having only minor runoff from these devices. This greatly improves the natural, pre-development conditions. These results were predictable when understanding the wetland's mechanics and processes. Although, these devices performed the best, the cost and land application must be considered in the decision process. Constructed wetlands consume a great deal of land. Their cost to design and construct was the most expensive of all the green infrastructures within this dissertation. Therefore their application can be acknowledged as over-engineering for the selected catchments in this investigation. It is suggested that these be placed downstream of larger catchments.

It was discovered that the bio-retention basin, in the larger catchments, did assist in approximately returning the post development back to pre-development conditions. These devices take up small amount of area of land. The use of retaining can dramatically reduce this further. The cost of design and construction of bio-retention are considered reasonable. Therefore, the bio-retention basin was the optimum solution. For the smaller catchments that did not have the basins installed, single lot and neighbourhood/street catchments, the optimum solution was the green roof. Although this did not return to natural pre-developed conditions, it was the best performing solution in the smaller catchments

There was no sufficient evidence that suggested that the catchment size has effects of the green infrastructure treatment in the model. The results varied between all of the catchment sizes. There was no definite proportion relationship between these two variables, catchment size and green infrastructure performance, that could be distinguished. Therefore with regards to catchment sizing, these findings were mixed and inconclusive.

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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.

Mark Lobwein

[redacted]

15/10/2020

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TABLE OF CONTENTS

Contents **Page**

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

NOMENCLATURE AND ACRONYMS (OR ABBREVIATIONS)

AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
ARQ	Australian Runoff Quality
ARR	Australian Rainfall and Runoff
BMP	Best Management Practices
BOD	Biochemical Oxygen Demand
BOM	Bureau of Meteorology
BPP	Best Planning Practices
CBR	California Bearing Ratio
COD	Chemical Oxygen Demand
DTMR	Department of Transport and Main Roads
EDAW	Eckbo, Dean, Austin and Williams (An international landscape architecture, urban and environment design firm.
ESA	Estimated Standard Axles
FAWB	Facility for Advancing Water Bio Filtration
GPT	Gross Pollutant Trap
ICC	Ipswich City Council
ISWR	Institute of Sustainable Water Resources
PCSWMM	Personal Computer Stormwater Management Model
PET	Potential Evapotranspiration
PSP	Planning Scheme Policy
PVC	Polyvinyl Chloride
LID	Low Impact Development
MRTS	Main Roads Technical Specification
MUSIC	Model for Urban Stormwater Improvement Conceptualisation
QLD	Queensland
QUDM	Queensland Urban Drainage Manual
SEQ	South East Queensland
SE QLD	South East Queensland
SPP	State Planning Policy
SUDs	Sustainable Urban Drainage Systems
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
WSUD	Water Sensitive Urban Design

CHAPTER 1

INTRODUCTION

1.1. Outline of the Study

Green infrastructures are becoming a popular selection for urban stormwater management in Australia and many other parts of the world. They have been demonstrated to improve stormwater quality and manage frequent flow from developed catchments. This dissertation investigates the combined performance of green infrastructure in different scale catchments. Results will focus on their performance in runoff attenuation and frequent flow management. At the conclusion of this research, a recommended combination for each catchment will be specified. This recommendation will also factor in the cost and land consumption of each device.

1.2. Introduction

Urban residential developments are increasing with the growth of the human population. These developments transform natural pervious surfaces into impervious hard surfaces. This changes the characteristics of hydrology of the catchment.

Stormwater runoff caused from this urbanisation has the largest negative human impact to the environment. The stormwater runoff cause from urbanisation is often referred to as urban runoff. Urban runoff increases the quantity of stormwater that discharges from a development and this can cause flooding. This excess water can result in damage to infrastructure. It also causes the degradation of natural waterways, destroying ecosystems.

Urban runoff also causes the entry of pollutions into natural waterways. Examples of the types of pollutants are heavy metals, oil, grease, pesticides, fertilizers, animal faeces, litter and debris. To improve water quality, developments must reduce the suspended solids, gross pollutants, phosphorus and nitrogen from its point of discharge. There are many more type of pollutants but the previous listed have the greatest impact to the environment.

Water Sensitive Urban Design (WSUD) have developed several practices to help solve this problem. One solution to this problem is the installation of green infrastructures. These devices improve stormwater quality and manage frequent flow. This dissertation aims to investigate the different combinations of green infrastructure at different scaled catchments. These catchments will be designed on the selected investigation site, this is to be located at Redbank Plains, which is a suburb in Ipswich, South East Queensland.

The MUSIC software has become the benchmark software for analysing stormwater water quality in South East Queensland. However, the software still requires further investigation to the frequent flow management capabilities. The software uses the water balance method to calculate stormwater inflow and outflow between nodes in the model. This dissertation has the potential to be used to test the software’s ability to calculate stormwater runoff. MUSIC output results will be scrutinised with hand calculations and with an overall engineering judgement. This investigation can determine if MUSIC is a suitable software to analyse frequent flow management.

1.3. The Problem

There was no research found on the urban runoff effects of a combination of green infrastructure in urban catchments. Past research has been completed of the runoff attenuation of single individual green infrastructure type, but none could be discovered of infrastructures in series or combinations. There has also been studies completed with green infrastructure and its scale-catchment effects. The literature review will document these relevant studies. Therefore it could be stated that there is a gap in the knowledge when analysing these infrastructures in combinations. This investigation will calculate the discharges of urban runoff after each treatment device. Models will be used to calculate the urban runoff discharge. All models will created in the MUSIC software package. This is commonly used in the industry, and is a benchmark package, for analysing stormwater quality. The model will ensure each device is in accordance with the water quality requirements. It is envisaged that this investigation will assist with that research by utilising MUSIC software in this investigation.

1.4. Research Aims and Objectives

Green infrastructure are designed and constructed to protect the quality of natural waterways by reducing pollutants that are cause from urban runoff. Therefore green infrastructure must meet the best practice targets of pollutant load reduction. The infrastructures are also implemented in developments to protect ecosystems from increased quantity of runoff. Frequent flow management is important to ensure that the changes are minimal with regards to the hydraulic disturbances to the ecosystem.

The aim of this investigation is to identify the optimum combination of green infrastructures. To investigate this, several infrastructure combinations will be modelled on different residential urban catchments, ranging from 1 lot to 1000 lots. Other than combinations, this investigation will also discover each green infrastructure’s individual performance. The modelling software will be able to calculate the hydrologic equations accurately. The model software is user friendly and parameters can be easily adjusted to check outputs and/or fix errors. As stated previously, the models will be created using the software MUSIC by eWater. The MUSIC guidelines state that there is research required for its use of frequent flow management in this software package. Incidentally, this dissertation will assist in the research for approximately determining its capability for analysing the frequent flow management.

All results will use engineering judgement to scrutinise all calculations. Hand calculations of peak flow will be used to verify MUSIC results. The runoff results are to be analysed against their associated cost. The optimum green infrastructure combination has considered cost as part of its criteria.

Results will be outputted in the form of a hydrograph. They will represent the amount of urban runoff discharge on the different scaled catchments. The slope of the graph represents the velocity of runoff, and the lag represents the retention influence of the green infrastructure. The best or ideal outcome will be to mimic or improve the natural flow runoff conditions.

1.5. Conclusion

At the conclusion of this dissertation the optimum combination of green infrastructures will be identified. Cost and land application will contribute to this decision. Over-engineered device and/or combinations will be identified and will not be classified as the optimum solution. The recommended combination will be the arrangement that achieves close to predevelopment conditions with the least amount of cost of infrastructure.

The expected results are that the urban runoff will be greater impacted by the number of green infrastructures implemented into the combination model. Principally, the runoff discharge properties are expected to be proportionate with the number of green infrastructure treatments used in the combination. The types of green infrastructure are also expected to differ, the devices with larger retention properties are expected to perform better. Other characteristics that are expected to change on each device are urban runoff quantity, velocity and lag. The stakeholder's interest also includes the quality of urban runoff of each device. There is expectation that all urban runoff quality outputs are in accordance with state planning policy.

The outcomes of this study will be used for the design and development of green infrastructure in residential catchments. Optimal combinations and top performing infrastructure will be highlighted in this dissertation. This will assist in the selection process of green infrastructure in future developments. This investigation is to be used as broad research of the performance of green infrastructure. These devices are site specific and should consider the site's specific historic rainfall, existing soil conditions and terrain.

The literature review for this research investigation will identify all guidelines and policies required in the design and construction of green infrastructure in Ipswich, Queensland. This includes all stormwater quality and quantity requirements in both state and local policies. The literature review will also identify the methodology of this investigation. This includes design of the residential catchments, software selection and modelling methods.

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

This chapter examines the current research in green infrastructure. These devices assist in the water quality and flood management in urban residential developments. This chapter also provides a background into the State and Local Council's Legislation and policies. These documents reinforce the State's relevant interest in this investigation can be summarised into water quality and natural flood hazard. Stormwater runoff management and water quality is the main purposed for the installation of these devices. Green infrastructure is a development to help satisfy the Water Sensitive Urban Design (WSUD). This investigation has utilised the current research and ongoing studies in WSUD. The mechanics and design parameters of each individual type of green infrastructure has been studied. To analyse the stormwater runoff this research utilised the software, MUSIC by eWater. To assist in modelling, consideration of this software and its capabilities and features has been studied.

2.2. PLANNING LEGISLATION & STATE PLANNING POLICY (SPP)

It is important for Engineers to follow policies and procedures to ensure they are in compliance with laws and regulations. This investigation will also follow these policies and adhere to the relevant Authority laws. The investigation site is located in Queensland and therefore all investigation should adhere to the Queensland state's interest defined under the Planning Act 2016 and the State Planning Policy 2017.

The purpose of the Planning Act is to establish an efficient, effective, transparent, integrated, coordinated, and accountable system of land use planning, development assessment and related matters that facilitates the achievement of ecological sustainability *(Queensland Government, 2017)*.

The Planning Act 2016 states that each local government must provide a planning scheme that is in accordance with state, regional and local planning and development assessment policies. The state planning policy supports local planning policies by specifying the state interests.

The state interests are represented in the state planning policy to secure a liveable, sustainable and prosperous state. With regards to land use planning and development, the state interests are

<u>Liveable Communities and Housing</u>

- Housing supply and diversity
- Liveable communities

<u>Economic Growth</u>

- Agriculture
- Development and construction
- Mining and extractive resources
- Tourism

<u>Environment and Heritage</u>

- Biodiversity
- Coastal environment
- Cultural heritage
- **Water quality**

<u>Safety and Resilience to Hazards</u>

- Emissions and hazardous activities
- **Natural hazards**, risk and resilience

<u>Infrastructure</u>

- Energy and water supply
- Infrastructure integration
- Transport infrastructure
- Strategic airports and aviation facilities
- Strategic Ports

The relevant state interest associated within this dissertation are water quality and natural hazards. Throughout the design process these interests must be considered.

2.2.1. SPP Water Quality Guidelines

2.2.1.1. Development Outcomes

The State interest policies must be appropriately integrated in the water quality planning and development outcomes, where relevant. Development water quality outcomes are items to be considered during the development's planning phase. The policies that are relevant to the water quality and will be address in this design of the proposed subdivision *(Queensland Government, 2017)*. These development outcomes include:

- The protection or enhancement of environmental values and the achievement of water quality objectives for Queensland waters.
- Development is located, designed, constructed and operated to avoid or minimise adverse impacts on environmental values of receiving waters arising from:
    - Altered stormwater quality and hydrology
    - The release and mobilisation of nutrients and sediments.
- After construction development must achieve design objectives in **Table 2.1** or provide an alternative solution that achieves equivalent or improved stormwater quality outcomes.

Climatic region	Design objectives			
	Reductions in mean annual load from unmitigated development (%)			
	Total suspended solids (TSS)	Total phosphorus (TP)	Total nitrogen (TN)	Gross pollutants >5mm
South East Queensland	**80**	**60**	**45**	**90**
Central Queensland (south)	85	60	45	90
Central Queensland (north)	75	60	40	90
Cape York, wet tropics and dry tropics	80	60	40	90
Western Queensland	85	60	45	90
Notes: • *Refer to **Figure 2.1** for SE QLD climate region.* • *In lieu of modelling, the default bio-retention treatment area to comply with load reduction targets for all Queensland regions in 1.5 per cent of the contributing catchment area.*				

Table 2.1 - Post Construction Phase: Stormwater Management Design Objectives
(Queensland Government, 2017)

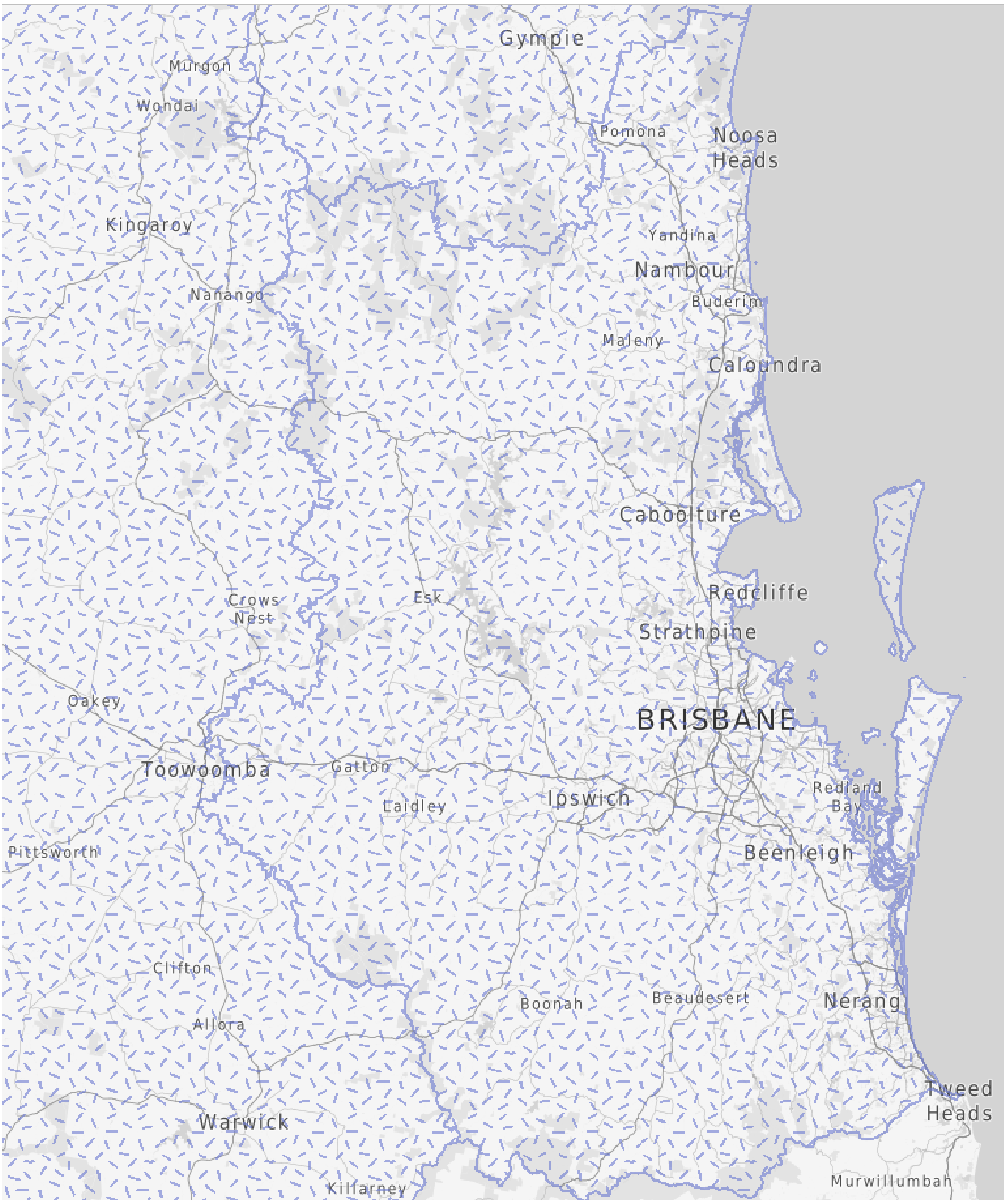


Figure 2.1 - SPP South East Queensland Water Quality Climate Region Boundary
(Queensland Government, 2020)

This investigation will disregard the following State interest policies and development outcomes. Further research is required to analysis if any of these development outcomes affect the aim of this investigation. These disregarded outcomes are:

- Land zoned for urban purposes is located in areas that avoid or minimise the disturbance to:
    - High risk soils
    - Groundwater dependent ecosystems
    - High ecological value aquatic ecosystems
    - Natural drainage lines and landform features
- Development is located, designed, constructed and operated to avoid or minimise adverse impacts on environmental values of receiving waters arising from:
    - Wastewater (other than contaminated stormwater and sewage)
    - The creation or expansion of non-tidal artificial waterways
- The construction phase, development stormwater management design objectives.
- Development in water resource catchments and water supply buffer areas avoids potential adverse impacts on surface waters and groundwaters to protect drinking water supply environmental values.

2.2.1.2. Assessment Benchmarks

The assessment benchmarks are the items within the development that must be assessed during development application. Each catchment size in this investigation must adhere to these assessment benchmarks *(Queensland Government, 2017).* The relevant benchmarks in the state planning policy for water quality are:

<u>For receiving waters, a development application for:</u>

- A material change of use for an urban purpose that involves premises 2500 metres^2 or greater in size and;
    - Will result in six or more dwellings; or
    - Will result in an impervious area greater than 25 per cent of the net developable area; or
- Reconfiguring a lot for an urban purpose that involves premises 2500 metres^2 or greater in size and will result in six or more lots; or
- Operational works for an urban purpose that involves disturbing a land area 2500 metres^2 or greater in size

<u>The following requirements are assessment benchmarks for the development</u>**:**

- Development is located, designed, constructed and operated to avoid or minimise adverse impacts on environmental values arising from:
    - Altered stormwater quality and hydrology
    - The release and mobilisation of nutrients and sediments.
- Development achieves the applicable stormwater management design objectives outlined in **table 2.1.**

2.2.2. Natural Hazards and Flooding Prevention Guidelines

A natural hazard is a naturally occurring event that may cause harm to people, damage to property and infrastructure, and impact our economy and the environment *(Queensland Government, 2017).* The natural hazard examined in this research is flash or minor event flooding. Planning and design of a development must reduce the probability and decrease the potential impact of flooding. There is a responsibility to manage floods and other natural disasters from the impact they have on the people, property, the economy, the environment and infrastructure.

The effects of climate change are projected to impact on the extent, frequency and intensity of flooding *(Queensland Government, 2017).* This investigation will use existing data and will not consider the future effects of climate change.

The state's interest in natural hazards, risk and resilience seeks to ensure flooding is appropriately considered at all levels of the planning system *(Queensland Government, 2017).*

Green infrastructures can reduce the impacts of flooding. The design and sizing of these devices must consider the natural flooding extent.

2.2.2.1. Development Outcomes

The State interest policies must be appropriately integrated in the flood planning and development outcomes, where relevant. Development flood outcomes are items to be considered during the development's planning phase. The policies that are relevant to flooding will be address in this design of the proposed subdivision. These development outcomes include:

- Flood hazard areas identified.
- A fit-for-purpose risk assessment. This is undertaken to identify and achieve an acceptable or tolerable level of risk for personal safety and property in flood hazard areas.
- Development to avoid the flood hazard area. (Where it is not possible to avoid the flood hazard area, development mitigates the risks to people and property to an acceptable or tolerable level.)
- Development in flood hazard areas supports and does not hinder disaster management capacity and capabilities.
- Development in flood hazard areas directly, indirectly and cumulatively avoids an increase in the exposure or severity of the flood hazard and the potential for damage on the site or to other properties.
- Development in flood hazard areas avoids risks to public safety and the environment from the location of the storage of hazardous materials and the release of these materials as a result of a flooding hazard.
- Development in natural hazard areas maintains or enhances the protective function of landforms and vegetation that can mitigate risks associated with the flooding hazard.

2.2.2.2. Assessment Benchmarks

The assessment benchmarks are the items within the development that must be assessed during development application for a material change of use, reconfiguration of a lot or operational works. For each catchment size in this investigation must adhere to these assessment benchmarks. The relevant benchmarks in the state planning policy for flood hazard areas are:

- Development does not occur in an erosion prone area within a coastal management district.
- Development avoids flood hazard areas, or where it is not possible to avoid the flood hazard area, development mitigates the risks to people and property to an acceptable or tolerable level.
- Development supports and does not hinder disaster management response or recovery capacity and capabilities.
- Development directly, indirectly and cumulatively avoids an increase in the severity of the flood hazard and the potential for damage on the site or to other properties.
- Risks to public safety and the environment from the location of hazardous materials and the release of these materials as a result of a natural hazard are avoided.
- The natural processes and the protective function of landforms and the vegetation that can mitigate risks associated with the flood hazard are maintained or enhanced.

2.2.3. Other State Legislation and Policies

Although the planning act and policy will take prominence in this investigation, there are other legislation acts and policies that may be considered:

- **The Environment Protection Act 1994**
  The purpose of this Act is to protect Queensland's environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends (ecologically sustainable development) *(Environmental Protection Act 1994).*
- **The environment protection (water and wetland biodiversity) policy 2009.**
  The purpose of this policy is defined within the Environmental Protection Act. It is achieved by:
  a. Identifying environmental values for waters and wetlands to be enhanced or protected; and
  b. Identifying management goals for waters; and
  c. Stating water quality guidelines and water quality objectives for enhancing or protecting the environmental values of waters; and
  d. Providing a framework for making consistent, equitable and informed decisions about waters; and
  e. Monitoring and reporting on the condition of waters.
  (The Environment Protection Policy 2009)

- **The Sustainable Planning Act 2009**

The purpose of this Act is to seek to achieve ecological sustainability by:

a. Managing the process by which development takes place, including ensuring the process is accountable, effective and efficient and delivers sustainable outcomes; and
b. Managing the effects of development on the environment, including managing the use of premises; and
c. Continuing the coordination and integration of planning at the local, regional and State levels.

(The Sustainable Planning Act 2009)

- **The Regional Planning Interests Act 2014 and Regulation 2014**

The purposes of this act are to:

a. identify areas of Queensland that are of regional interest because they contribute, or are likely to contribute, to Queensland's economic, social and environmental prosperity; and
b. give effect to the policies about matters of State interest stated in regional plans; and
c. manage, including in ways identified in regional plans—
   i. The impact of resource activities and other regulated activities on areas of regional interest; and
   ii. The coexistence, in areas of regional interest, of resource activities and other regulated activities with other activities, including, for example, highly productive agricultural activities.

(Queensland Regional Planning Interest Act 2014)

2.2.4. Conclusion

Local Councils and regions will have a set of guidelines in their planning policies. Research and study into the local authority's guidelines and planning policies will be discussed in detail in the next topic in the literature review.

To be in accordance with the state planning policy and the planning act, an urban development 2500m^2 or greater that contains 6 or more dwellings or lots must protect and enhance its water runoff quality. This also includes developments that are designed to have 25% or greater of impervious surface area. Water quality includes removing gross pollutant and litter from the source. Development must avoid the releasing of oil or visible sheen into waterways. South East Queensland's design objectives are 80% reduction in total suspended solids, 60% reduction in total phosphorus and 45% reduction in total nitrogen.

The development must also prevent the probability of flooding. The policy encourages designs to reduce the original flooding probability of the site. This must be accomplished with no flooding impact to neighbouring lots. Flooding impact to development is deemed acceptable when the site demonstrates flood levels to be non-worsening for a design storm of 1 in 100 ARI (1% AEP).

2.3. LOCAL PLANNING SCHEME POLICY (IPSWICH PSP)

Council interests requires that stormwater management address the objectives of the planning policy scheme. The state planning policy does not prevent Ipswich City Council from improving the SPP's outcomes of water quality. Where there is a difference between the SPP and Ipswich Planning Policy, the local government policy will take precedence.

The proposed development is to change the use of the current zoning to be a residential medium density zone. It is assumed that Council has already approved this change of use.

2.3.1. Ipswich Planning Policy Scheme

2.3.1.1. Future Urban Zone

The majority of the land in the Redbank Plains area is recognised as an urban growth area in the SEQ Regional Plan. The area is intended to comprise an urban growth corridor catering for a population of approximately 16 000 people *(Ipswich City Planning Policy Scheme, 2019, Part 4 Urban Areas, Div. 8)*. The investigation site is assumed to not be located in this future corridor. Therefore, the site will not be required to address the assessment criteria in the future urban zone.

2.3.1.2. Residential Medium Density

When designing, at high level, the proposed medium density development and its green infrastructure, the planning policy requires to following outcomes:

- Lots to contain full urban services such as reticulated water, sewerage, sealed roads, parks and other community facilities. In the high level design all these services can be assumed for future design, although allowance for road frontage to be considered.
- Infrastructure are located and designed to operate at the maximum efficiency and safety. Quality green infrastructure to be designed at maximum efficiency.
- Maintain the safety of people, buildings and works
- Avoid significant adverse effects on the natural environment.
- Buildings are set back 6 metres from the street frontage.
- Significant vegetation is conserved where possible.
- Area of lots to equal 450m^2 or more.
- The overall density does not exceed 50 dwellings per hectare and 2 storeys.

(Ipswich City Planning Policy Scheme, 2019, Part 4 Urban Areas, Div. 6)

2.3.1.3. Design Criteria for Site and Road Layout

The site layout for the area will be designed at a very high level. The items detailed in the Ipswich planning scheme policy should be considered in the future investigation of this site, if development was to proceed. Examples of items excluded from the site and road layout part of this investigation include:

- Intersections
- Consideration of road grades
- Boundary truncations
- Widening of any existing roads
- Roundabouts and cul-de-sacs
- Bikeways
- Kerb and Channel
- Sign and Road Markings
- Safety Barriers
- Bus stops

Some other engineering constraints in future investigation may include drainage overland flow paths, vertical alignment, horizontal alignment and reasonable access to allotments.

Lots will be situated in grid-like format with at least one road frontage. The road dimensions have been designed using the Access Place and Access Street typical road cross section (**Figure 2.2**). This is part of Ipswich City Council's standard drawing SR.02, Typical Cross Sections – Residential Streets. All minimum dimensions to be used.

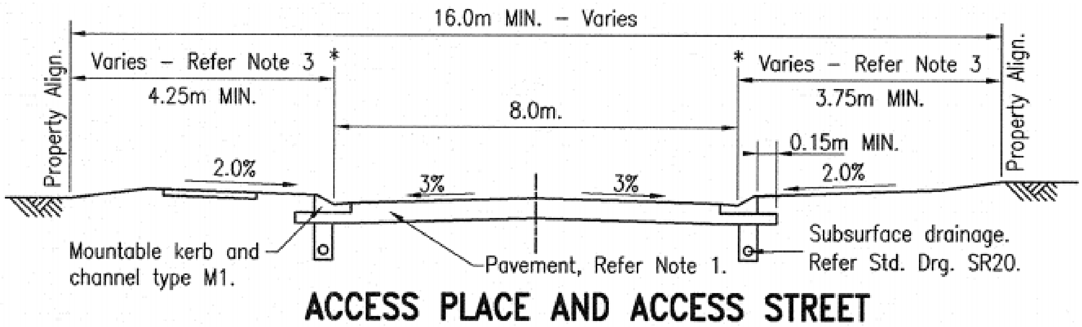


Figure 2.2 -Access Place and Access Street Typical Road Cross Section
(Ipswich City Council's standard drawing SR.02)

2.3.1.4. Design Criteria for Flexible Pavement

This investigation will assume that all road pavement will be permeable pavement. To calculate the permeable pavement thickness, the flexible pavement thickness will be adopted. Council planning policy does have criteria for designing this pavement and this will be utilised.

The California Bearing Ratio (CBR) is assumed to be 3%. A CBR is a strength test to determine the bearing capacity of the natural subgrade. Since this requires soil testing the planning policy allows for preliminary design to assume the CBR at 3%.

All roads are to be classed as an Access Street. This road is not to service more than 75 lots. The estimate standard axles (ESA) to use this road classification is 100,000 or 1.0 x 10^5. The minimum total design depth is 225mm (excluding asphalt layer).

Planning policy refers to the DTMR technical specification, MTRS30 for asphalt thickness. The asphalt layer thickness is dependent on the nominal size of the asphalt and the graded type.   has the nominated asphalt layer thickness limits. The investigation will use the open graded type since this resembles the parameters of permeable pavement. To minimise pavement depth the 10mm nominal size will be used. Therefore, the asphalt material will be OG10.

Asphalt Type	**Nominal Size of Asphalt (Asphalt Designation)**	**Layer Thickness (mm)**	
		Minimum	**Maximum**
Dense graded asphalt	7mm (AC7M and AC7H)	25	35
	10mm (AC10M and AC10H)	35	50
	14mm (AC14M and AC14H)	50	70
	20mm (AC20M and AC20H)	60	100
Open graded asphalt	**10mm (OG10)**	**25**	**35**
	14mm (OG14)	35	45
Stone graded asphalt	10mm (SMA10)	35	40
	14mm (SMA14)	50	60

Table 2.2 – Nominated Layer Thickness Limits
(Transport and Main Road (DTMR), 2019)

The minimum asphalt thickness of 25mm is selected. Therefore, the full total design depth is 250mm. This preliminary design of pavement will be used to design the permeable pavement and its associated parameters.

2.3.1.5. Design Criteria for Detention and Retention Basins

Detention and retention basins are to be designed in accordance with QUDM to criteria nominated by the Local Government for specific applications. All green infrastructure has retention properties therefore detention basins will not be designed in this investigation. Only the design criteria for retention basins will be considered. It is therefore not required to design outlet pipes from basins. The design of outlet pipes from constructed wetland will also be omitted. All basin initial and minor losses will also be disregarded within this investigation calculations.

As per **Table 2.1**, when modelling the basins, the default bio-retention treatment area is to be 1.5% of the contributing catchment area. Base of the basin in to be at 1 in 80

Basins to be sized to capture a Q_{100} storm event. The top of batters should be at a height to capture this volume. A factor of safety, the freeboard, is a level above the Q_{100} level. The minimum freeboard recommended in QUDM is 0.3m.

Extended detention depth is the maximum distance of water above the treatment base area. Overflow drainage system is to collect the water above this height. The extended detention depth is to be 0.3m. The orifice flow of this overflow drainage calculations will be ignored in the MUSIC model.

Bio-retention treatment layer to contain:

- A filter media (depth min. 0.3m / max. 1.0m) The average and most common filter media depth of 0.5m will be adopted.
- 0.1m transition layer
- 0.2m drainage layer

Underdrain system to be a system of slotted drainage uPVC pipes at diameter of 100 and 150mm, draining for maximum lengths of 25m. Stormwater management plans also states that these pipes are not to be wrapped in sock or geofabric. The drains are to be placed at 2.5m centres and grade at minimum 0.5% in accordance with WSUD Technical Design Guidelines for South East Queensland 2006 *(Healthy Waterways, 2006)*.

The saturated hydraulic conductivity of the filter media is to be designed at 200mm/hr.

To determine the infiltration type of the natural soil, the type must be assumed. The soil type of the site area will be assumed to be group B. This soil has a moderate to high infiltration capacity. Usually consists of moderately deep (greater than 0.5m), well-drained medium loamy texture sandy loams, loams or clay loam soils *(IPWEA, 2017)*.

Soil hydrologic group	**Typical infiltration rate (mm/hr)**		**K_{sat} (mm/hr)**
	Saturated	**Dry soil**	
A	25	>250	>120
B	13	200	10-120
C	6	125	1-10
D	3	75	<1

Table 2.3 – Typical infiltration rates for various soil hydrologic groups *(IPWEA, 2017)*

The site area will be assumed that the soil is neither saturated nor dry. The adopted infiltration rate for the site will be 100mm/hr, which is approximately in between both saturated and dry rates in **Table 2.3**.

2.3.1.6. Design Criteria for Water Quality

The investigation site area is assume to have no current or future erosion and sedimentation problems. This includes the degradation of surface and groundwater quality.
Ipswich Council recommends the implementation of Stormwater Quality Best Management Practices. Developments in the Ipswich region must provide water quality control measures. Water Quality Control measures can be divided into two categories, temporary and permanent. This investigation is solely interested in the permanent water quality control devices. These are implemented to control runoff water quality after construction.
The Ipswich Council water quality objectives are unchanged from the states objectives in **Table 2.1**. (Total Suspended Solids 80%, Total Nitrogen 45%, Total Phosphorous 60% and Gross Pollutants 90%.)

2.3.2. Stormwater Quality and Flood Management

With reference to the Ipswich Planning Scheme and the Queensland Urban Drainage Manual (QUDM), all development and works are to deliver a 'no-worsening' (zero net balance) outcome with respect to stormwater management. The definition of 'no-worsening' applies to:

a. flood levels
b. flood volumes and storage
c. velocities
d. timing
e. flow characteristics
f. duration
g. cumulative flooding impact

Ipswich City Council requires the development to satisfy or exceed the design objectives for stormwater quality and flow (quantity) management.

2.3.3. Stormwater Quality Treatment Design Requirements

Developments that are situated in the Ipswich Council region must adhere to their stormwater quality management. This states that all designs of all stormwater treatment measures must also be in accordance with:

- Healthy Waterways (2006 or current version)
- Water Sensitive Urban Design – Technical Guidelines for South East Queensland
- Water by Design (2012) Bio-retention Technical Design Guidelines.

Batter slopes in stormwater quality devices must be maximum slope of 1V:5H. Fencing must be provided to the perimeter of treatment device if the slope is greater than 1 in 5 or the extended detention depth is greater than 150mm. Extended detention depth is to be set at 300mm, so to avoid fencing the slope of the batters to be no greater than 1 in 5.

Vegetated swales are not designed with gradients less than 1% or greater than 5%. Swales beside roads will only be accepted, by Council, along public open space areas (such as parks or drainage corridors)

Infiltration systems such as permeable pavement are not accepted within the public space. This is due to limitable amount of research completed on permeable pavement. This material has a reputation of not providing a long design life, hence Council's reluctance to use it in public areas. This investigation will assume Council will accept permeable pavement within the road corridor.

Only water bodies that Council will accept is constructed wetlands. However, Council may consider an open water body where it provides a high amenity community value and satisfies hydrology, ecological and water balance requirements *(Ipswich City Planning Policy Scheme, 2019, Part 4 Urban Areas, Div. 6)*.

The most important input parameter for filter systems, such as bio-retention basins, is the surface area of filter treatment. The surface area can be calculated of the percentage of contributing catchment. This data is represented in **Table 2.4**.

Proposed Residential Density (dwellings/ha)	Percentage of Contributing Catchment
Large Lot Residential	0.25%
Less than 15 (excluding large lot)	0.8%
15 to < 20	1.0%
20	1.1%
>20 to < 40	Range between 1.1 to 1.5%[1]
> 40	1.5%
Note[1] Linear interpolation is to be used to establish the percentage.	

Table 2.4 - Filter area determination percentages for residential development
(Ipswich Stormwater Management Scheme (Implementation Guidelines), 2011)

This investigation will calculate all basin surface filter treatment areas with the 1.5% of the contributing catchment area. This is discussed previously and was first referenced in **Table 2.1**.

2.3.4. Model for Urban Stormwater Improvement Conceptualisation (MUSIC)

Ipswich Council have set guidelines for using MUSIC to keep consistency across the region. MUSIC is the approved software for preparing models for stormwater quality. Models must be in accordance with the MUSIC Modelling Guidelines from Water by Design.

The Ipswich Council will only accept models that use the infiltration node for non-vegetated infiltration systems. Any proposed vegetated 'infiltration system' must be modelled as bio-retention systems with a maximum filter depth of 2m (or less if groundwater is anticipated at shallower depths), with filter media properties representative of measured soil conditions (either in-situ or imported) at the site of the proposed infiltration system *(Ipswich Stormwater Management Scheme (Implementation Guidelines), 2011)*. This will exclude the modelling of the green roof infrastructure.

2.3.5. Conclusion

The medium density lot will be designed at the minimum size of 450m^2. The residential dwelling will be setback 6m from road frontage to be in accordance with Ipswich Council's standards. The density of lots to be designed at a maximum of 50 dwellings per hectare. Each lot must be connected, at the front, to a road. The road reserve dimensions are shown on the Access Place and Access Street typical road cross section. This section show the road reserve with a width of 18.0m and a road width of 8.0m. The pavement depth is to be a minimum of 250mm. Although Ipswich City Council do not permit the use of permeable pavement in public areas, for this investigation only, all roads will be designed with permeable attributes.

Vegetated swales to have a longitudinal grade between 1 and 5%. All embankments, in all green infrastructure, to have a maximum 1 in 5 grade.

The surface area of filter treatments in basins is to be 1.5% of the contributing catchment area. Bio-retention basin filter treatment layers must consist of 0.5m of filter media, 0.1m of transition layer and 0.2m of drainage layer. The saturated hydraulic conductivity of the filter media is to be a minimum of 200mm/hr. Natural infiltration of the existing soil will be assumed at 100mm/hr.

All development must be non-worsening to the flood extent. All green infrastructure to consider its contribution to the site's overall flooding. Results to analyse the green infrastructure's flooding contribution.

The development's water quality must remove a portion of pollutants and nutrients from the natural waterways downstream. Outlet of device must record a reduction of 80% of total suspended solids, 45% of total nitrogen, 60% of total phosphorus and 90% of all gross pollutants larger than 5mm.

2.4. STORMWATER QUANTITY

Stormwater quantity is recognised as the amount of stormwater produced from a particular catchment. Urban development increases the stormwater surface runoff, which can cause flooding. This is caused from the designed surfaces in developments contain a large percentage of impervious area. These areas are unable to match the amount of water absorption of the natural/pre-developed pervious land.

To prevent flooding in minor/frequent events, developments can design stormwater infrastructure systems to carry the runoff underground eventually discharging into waterways or an approved lawful point of discharge. This however, does not prevent the flooding downstream. It moves the problem downstream and into the natural waterways. This can have major impacts to the environment and ecological system. Natural and predeveloped catchments do not have this problem due to their pervious ground conditions. These areas can absorb a part of the stormwater runoff. These catchments usually contain large amounts of vegetation, which also assist in the absorption of runoff.

Major and infrequent events consist of large intensity rain occurrence. These events contain large amounts of water and is unaffected by the impervious and pervious type of surface. This study will focus on the minor and frequent flow events. Analysis of major storm events is not included in this investigation.

Stormwater harvesting and frequent flow management are similar techniques. Fundamentally they both use store and release behaviours to manage the urban runoff. Stormwater harvesting functions by holding a designed volume of water, where frequent flow management treats and slows down the water's flow rate. Flooding can be reduced by stormwater harvesting, although this topic will not be investigated within this research.

Water balancing is an equation used in hydrology to calculate volume of water entering and exiting a water store. This includes accounting for water lost in evaporation and soil infiltration. The first principles of this equation will be used for checking. Current available computer models are equipped to calculate the water balance efficiently.

2.4.1. Runoff Hydrology

Stormwater runoff is the surface water that flows downstream from rainfall (or snow melt) event. Also commonly known as rainfall excess and/or overland flow. This hydrological process that causes runoff is called runoff generation. There are a number of causes that affect the amount of runoff. Some of these include:

- Permeability
- Rainfall
- Slope
- Vegetation

2.4.1.1. Permeability

Permeability is the ground surface's ability to absorb water. This will affect the amount of surface runoff. High permeability soils have the ability to absorb high amounts of water. Where soils with low permeability will have a lower absorption ability. Areas that absorb significant amounts of water are classed as a pervious surface. These include grassed areas, such as parks, mulched groundcover, planted and vegetated areas. Less runoff is generated from the surfaces that are pervious.
Areas that absorbs insignificant amounts of water are classed as impervious. These area contain surfaces that are features of urbanisation, such as road, pathways, roofs, etc. With impervious surfaces, a large proportion of the rain is generated into runoff.

2.4.1.2. Rainfall

The amount of rainfall or snowfall directly affects the amount of runoff. The larger the rainfall event the larger the amount of runoff. Although large snowfalls will increase runoff, the important factor is the rate of which snow melts. When large amounts of snow melted in a short time period, the amount of runoff is increased.

2.4.1.3. Slope

The slope of a surface also contribute to the amount of runoff. A steep surface will produce a faster flow velocity. When water travels quickly over surfaces is does not have the opportunity to infiltrate the ground. A lower grade or flat surface will slow the water, giving it time to absorb. Therefore steeper sites will produce more stormwater runoff.

2.4.1.4. Vegetation

The vegetation of a landscape can also contribute to the amount of runoff. Plants extract water from the ground by their root systems. Runoff is lower from these vegetated areas since the water is being used by the plants. Vegetation and grass increases the roughness factor of the surface (Manning's or Horton's roughness coefficient). This property also contributes to the slowing the runoff for the catchment. This has a lower impact to the peak discharge for the catchment.

2.4.2. Frequent Flow Management

Frequent flow management is a technique to control urban runoff. This can be achieve by utilising store and release devices. These devices decrease the water discharge rate. In some cases these device also treat water for quality purposes. Types of devices used for frequent flow management include:

- Detention Basins
- Retention Basins
- Green infrastructure such as;
  - Bio-Retention Basins
  - Green roofs
  - Permeable pavement
  - Vegetated swales
  - Constructed wetlands

Frequent flow management assists in preventing flash/localised flooding. When stormwater runoff is not captured it is safely directed in overland flow paths to prevent inconvenience and risks to public safety.

2.4.3. Stormwater Harvesting

Stormwater harvesting can reduce the peak discharge and depending on the harvesting technique, can potentially reduce the volume of stormwater flow. Storage techniques can be in form of tanks and basin devices. Larger scaled basins can include water reservoir dams. Basins and tanks can reduce the volume of stormwater flow and retain water for possible reuse. Important to restate that when tanks are at capacity they bypass the flow, and the device has no effect on the peak discharge. Retention and Detention are two types of basin storage devices.

2.4.4. Retention Storage Devices

Retention storage devices are designed to treat the minor/frequent storm events. They store water and then treat urban stormwater by a specific rate. These devices could potentially hold water for extensive lengths of time. Treatment includes evaporation and infiltration techniques. Evaporation depends on surface area and weather temperature conditions. Unless evaporation is considered in the computer modelling, evaporation will be ignored in this investigation. Evaporation can be ignored because the amount during rain events is insignificant. Infiltration is dependent on the soil, sand and/or other mechanical properties within the device. Stormwater that does not reach the natural waterways is commonly referred to as ‘Lost’, as it is lost from the hydrology model. Retention end result has lost flow which is where it differs from detention basins.

2.4.5. Detention Storage Devices

Detention storage devices are designed to store water and release it a slower rate than the capture rate. In majority of cases, all stormwater captured will eventually reach the natural waterways. Hence there is no ‘Lost’ stormwater flow from the system. These devices can vary in sizes, some as small as ponds to as larger as water reservoir dams.

The principle difference between Detention and Retention basins is the control outlet. As shown in **Figure 2.3**, all basins only have emergency overflows. The major difference between basins is that the detention basin has an outlet pipe. Retention basins will hold water until evaporated or infiltrated into the ground.

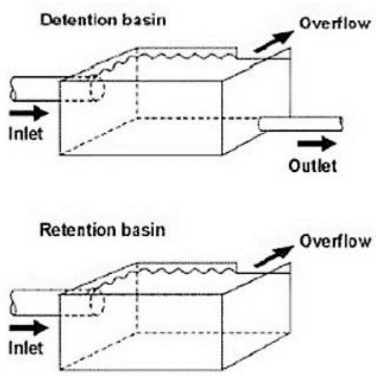


Figure 2.3 – The Difference between Detention and Retention Basins
(TUHH (n.y), 2006.)

2.4.6. Hydrographs

Hydrographs are graphs that show discharge or rainfall over time. In the SI system, discharge is represented by Q and is in the units m^3/s (cumecs). Rainfall is to be in millimetres collected at gauge. The time is represented by t and can be shown in multiple scales. Refer to **Figure 2.4** for an example of a Hydrograph.

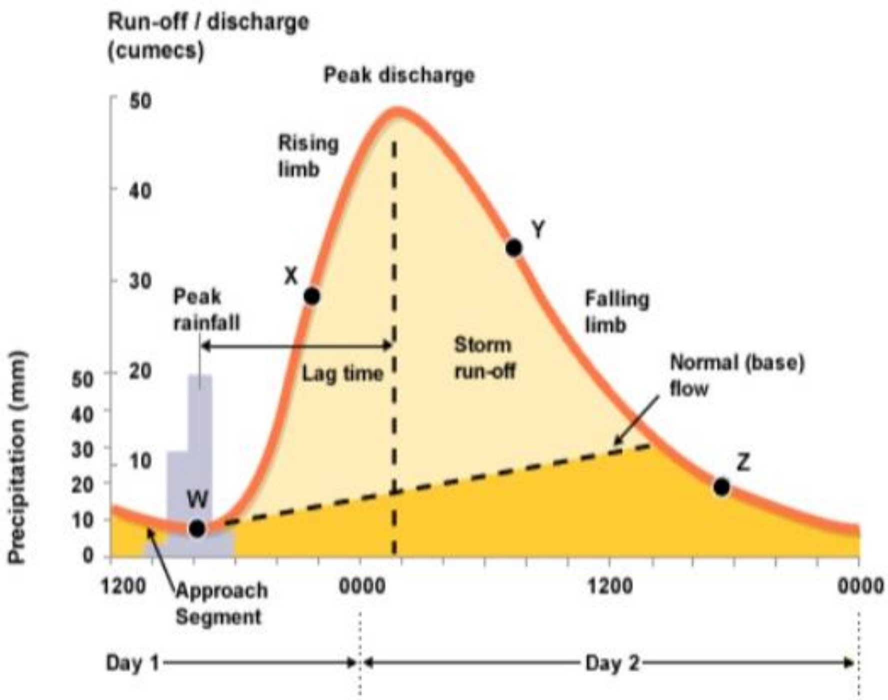


Figure 2.4 - Example of a Hydrograph
(Ngjingyi, 2013)

Australian Rainfall and Runoff provides different methods that can be applied in Design Flood prediction *(Commonwealth of Australian (Geoscience Australia), 2016)* (Commonly referred to as flood estimation):

- **Flood frequency analysis**
  When peak discharge is required, it is calculated from the probability analysis of recorded floods. This is commonly used for design of medium to high sized catchments. It is important to have a significant length of historical records and data available to complete calculations.
- **Runoff routing models**
  Modelling completed if a design flood hydrograph is required. These models predict the discharge produced from a catchment or structure from a storm event.
- **Rational Method**
  Simpler method used for the design of small to medium sized catchments where only the peak discharge is required for output.

2.4.7. Conclusion

Stormwater quantity, in this investigation, is defined by an amount of water caused from urban runoff. This runoff hydrology is dependent on the variables of permeability, rainfall, slope and vegetation. Rainfall can be predicted by use of historical data recorded at stations in proximity to the proposed development. Frequent flow management controls the urban runoff with engineering solutions. The most efficient solution is the utilisation of green infrastructure. These devices use retention properties to manage frequent flows, although the main objective of this devices is to improve the water quality.

2.5. STORMWATER QUALITY

Stormwater quality is measured by the amount of pollutants in runoff from a catchment. Urban residential developments produce large amounts of pollutants. The urban catchments do not have the pervious areas to naturally treat this water. This can negatively impact the water quality at downstream natural waterways.

Traditional stormwater management has been focused on the quantity and not quality of stormwater runoff into the receiving waterways. Lots of research have been completed to solve this quality problem. The most effective solution is to install quality infrastructure or devices. These devices treat the stormwater runoff and improve its quality, and this reduce adverse effects on receiving waterways.

These quality devices are designed to treat frequent minor flows. The waters from large rain events are assumed to have no to minimal effect of urban pollution. Therefore, it is unnecessary for the devices to treat such events.

In South East Queensland majority of local councils have supported and approved the use of the MUSIC software. It is to be used by Engineers when modelling developments for stormwater runoff quality design. Some of these local authorities also require Engineers to report on the MUSIC modelling methods and parameters.

For water quality in the Ipswich City Council area it is required to reduce;

- Gross Pollutants
- Total Suspended Solids
- Total Phosphorus
- Total Nitrogen

(Refer **Table 2.1** for Percentage of removal)

There are other pollutants that may contribute to the water quality and these are disregarded. These pollutants are only to be removed when the treated water is to be potable. These pollutants will be disregarded in this investigation. List of disregarded pollutants are:

- Chemical Oxygen Demand (COD)
- Biochemical Oxygen Demand (BOD)
- Oil & Grease
- Total Organic Carbon (TOC)
- pH
- Turbidity
- Total Lead
- Total Zinc
- Total Copper
- Total Cadmium
- Total Chromium
- Total Nickel
- Total Iron
- Total Manganese
- Total Mercury
- Total Coliforms
- Faecal Coliforms
- Faecal Streptococci

2.5.1. Total Suspended Solids (TSS)

Total Suspended Solids (TSS) are the particles larger than 2 microns that are suspended in water. These particles can include:

- Silt
- Algae
- Sediment
- Organic matter
- Inorganic solid matter

TSS absorb heat from sunlight. This causes the water temperature in natural waterways to increase. This results in a loss of dissolved oxygen in the water which can be hazardous to existing ecosystems. TSS units can be measures in either ppm, mg/L, g/L or %. Water quality in this investigation will be measured by percentage of reduction of TSS, and all pollutants, in water.

2.5.2. Total Phosphorus (TP)

Phosphorus is a nutrient important for plant growth. It is a limiting nutrient, which means that all substances important for plant growth (nitrogen, water, sunlight, warmth, etc.) is available in excess except for the actual phosphorous nutrient. A small increase in phosphorus can cause:

- Accelerated plant growth
- Algae blooms
- Low dissolved oxygen
- Death of certain fish, invertebrates, and other aquatic animals

An increase of phosphorus in water, results in the increase of plants and algae there are in the natural waterways. Phosphorus originates from many types of sources in residential urban developments. The main sources include:

- Human and animal wastes
- Soil erosion
- Detergents
- Septic systems
- Runoff from neighbouring farmland
- Runoff from fertilized lawns and gardens

2.5.3. Total Nitrogen (TN)

Total nitrogen is the sum of the following nutrient in a body of water:

- Nitrate (NO_3)
- Nitrite (NO_2)
- Organic nitrogen (N)
- Ammonia (NH_3)

Total nitrogen is an essential nutrient for the ecosystem in natural waterways. Similar to TSS, an excess amount of total nitrogen in a waterway may result in a decease level of dissolved oxygen and negatively change the existing ecosystems. The main sources of nitrogen include:

- Wastewater treatment plants
- Failing septic systems, runoff from animal manure and storage areas, and
- Industrial discharges that contain corrosion inhibitors
- Human and animal wastes
- Septic systems
- Runoff from farmland
- Runoff from fertilized lawns and gardens

2.5.4. Gross Pollutants

Gross pollutants generally consist of litter, debris and coarse sediments. With regards to water quality, gross pollutants are defined as material larger than 5mm. The main sources of gross pollutants include:

- Litter includes human derived rubbish. (E.g. Paper, plastic, Styrofoam, metal and glass.)
- Debris consists of organic material. (E.g. Leaves, branches, seeds, twigs and grass clippings.)

2.5.5. Conclusion

While the design of green infrastructure must consider its solution to manage the urban runoff, it must also consider the water quality. The water quality can be achieved by reducing the total suspended solids, total phosphorus, total nitrogen and gross pollutants. The removal of these and other pollutants is studied and implemented in a standard set of principles called Water Sensitive Urban Design (WSUD).

2.6. WATER SENSITIVE URBAN DESIGN (WSUD)

Water Sensitive Urban Design (WSUD) is a set of principles that can be applied to sustainably manage water *(Water by Design, 2010)*. This is a term used in Australian and Middle East and it known by other names around the world. The United States call this practice Low Impact Development (LID), where the United Kingdom call it Sustainable Urban Drainage Systems (SuDS).

QUDM states that WSUD involves the planning and design of urban developments in a method that uses water in an ecologically sustainable manner. This is achieved by:

- Preserve and enhance the natural drainage system
- Integrating public open space and landscape with stormwater drainage corridors
- Preserving the natural hydrological system of catchments
- Using surface water and groundwater as a resource
- Protecting surface water and ground water quality
- Minimising the lifecycle costs of stormwater infrastructure
- Reduce Drinkable ‘potable’ water demand through water efficient appliances, rainwater and greywater reuse. (minimise demand on water supply)
- Minimise wastewater generation
- Treatment of wastewater to a high standard for reuse opportunities or release into natural waterways.
- Treating urban stormwater to a high standard for reuse opportunities or release into natural waterways.
- Reduce runoff and peak flows by utilising relevant infrastructure and minimising impervious areas.

Stormwater management is a subset of WSUD directed at providing flood control, flow management, water quality improvements and opportunities to harvest stormwater to supplement mains water for non-potable uses *(Lloyd, S., Wong, T. and Chesterfield, C.J., 2010)*. To aid the success of the urban development’s stormwater management scheme two types of practices have been developed by the Victorian Stormwater Committee in 1999 (Urban Stormwater: Best Practice Environmental Management Guidelines). They are Best Planning Practices (BPPs) and Best Management Practices (BMPs). These practice are presently acknowledged country wide.

2.6.1. Best Planning Practices (BPPs)

Best Planning Practice achieves water resource management in urban developments *(Taylor, W and Wong, T., 2002)*. BPPs are implemented in stormwater management schemes. The stormwater management scheme includes a site analysis, land capability assessment and the creation of a land-use plan.

2.6.1.1. Site Analysis

Site analysis involves researching the proposed development’s current land-use zoning, climate and landscape features. Other site analysis may include analysing the stormwater runoff and pollutant load. This information can determine the selection of BMP to achieve the project objectives.

Within the current land-use zoning the following site characteristics are considered:

- Geology and soils
- Landforms
- Flooding levels and Drainage patterns
- Climate (e.g. historical rainfall patterns and evaporation rates)
- Significant natural features (e.g. remnant vegetation, habitat of threatened, endangered species, wetlands, etc.)
- Existing urban infrastructure (e.g. Stormwater drainage, water reticulation, gas lines, sewerage mains, etc.)
- Historical/cultural features (e.g. heritage buildings, archaeological sites, etc.).

2.6.1.2. Land Capability Assessment

Land capability assessment involves evaluating the development's capability of sustaining future land-use practices. The assistance of a land capability assessment matrix can identify areas most capable of sustaining land-use practices. The landscape features under assessment are to be assumed that the site is fully developed.

2.6.1.3. Land-use Plans

A land-use plan regulates the acceptance of development in local council areas. Plans include the layout, scale and arrangement of amenities at a site are drawn to scale. The outcomes of a site analysis and land capability assessment may suggest that different site layout options are possible *(Lloyd, S., et al 2010)*. The successful option should provide the greatest benefit for the downstream environment and is also sustainable for maintenance suggested in stormwater management scheme. Minimising these costs can be achieved in the site analysis.

(Lloyd, S., et al 2010) Examples of planning provisions that can improve overall effectiveness of the stormwater management scheme include:

- Whenever possible, orientate roads to run diagonally across the contour to achieve a grade of 4% or less to help incorporate BMPs into the streetscape

- Promote cluster lot arrangements around public open space to allow greater community access to, and regard for associated natural and landscaped water features forming the local stormwater management scheme

- Maintain and/or re-establish vegetation along waterways, and establish public open spaces down drainage lines to promote them as multi-use corridors linking public and private areas and community activity nodes.

2.6.2. Non-structural Best Management Practices (BMPs)

Non-structural BMPs include environmental and urban development policy, environmental considerations on construction sites and education and enforcement programs *(Lloyd, S., et al 2010)*. There are five key non-structural BMPs, refer to **Table 2.5**.

Best Management Practices	Comments
Environmental and urban development policy	Environmental and urban development policy at the local, state and federal level is required to encourage widespread adoption of Ecologically Sustainable Development practices, including the incorporation of WSUD into the urban planning process.
Environmental considerations on construction sites	Poor planning and management of construction/building sites can severely deteriorate the quality of stormwater runoff. Site management plans are a useful strategy to minimise the generation of pollutants from land development and building activities.
Education and staff training • Local government • Industry • Business	Education programs including staff training should be directed at all staff levels to instigate effective changes in practice. Training should provide the necessary tools/techniques to enable staff to plan for future activities (i.e. approval, construction, operation or maintenance activities).
Community education programs	Community education programs addressing stormwater management issues encourage change in social 'norms' and behaviours. Individual changes in behaviour may collectively contribute to reduce the impact of urban development on stormwater. However community awareness and understanding of issues related to stormwater pollution is not necessarily a precursor to changes in behaviour. Equally important is the concept that an informed community can place pressure on local government, industry and business to be responsible for their impact on stormwater.
Enforcement programs	Financial penalties are potentially an effective deterrent to reduce activities that result in the pollution of stormwater. Enforcement programs are largely the responsibility of the Environmental Protection Authority and local government. A number of studies are being conducted to measure the effectiveness of enforcement programs.

Table 2.5 - Examples of non-structural best management practices
(Lloyd, S., et al 2010)

The effectiveness of non-structural BMPs is unknown. The assumption is that these practices change the community's behaviour and minimises the quantity and quality of stormwater runoff. However, this investigation must consider the non-structural practices, the intent of this study is to closely analyse only the structural practices.

2.6.3. Structural Best Management Practices (BMPs)

Structural BMPs are stormwater treatment devices that filter, treat, retain and/or detain stormwater runoff. A treatment train approach is recommended, whereby BMPs are distributed across a catchment and their design may be modified for effective use at source or regional scales *(Lloyd, S., et al 2010)*.

Table 2.6 below lists some of the types of structural BMPs and their effective use and scale. Land availability is an important factor when considering which type of structural BMP is to be implemented. Some BMPs have been successfully in rain and stormwater harvesting. These BMPs include:

- Basins
- Wetlands
- Green roofs
- Water recycling devices

Structural BMP	Allotment	Streetscape or Precinct	Open Space Networks or Regional Scale
Diversion of runoff to garden beds	☑		
Rainwater tanks/ reuse scheme (i.e. garden watering, toilet flushing)	☑		
Sediment trap	☑		
Infiltration and collection system (bio-filtration system)	☑	☑	☑
Infiltration system	☑	☑	☑
Native vegetation, mulching, drip irrigation systems	☑	☑	☑
Permeable pavement	☑	☑	☑
Buffer Strip		☑	☑
Constructed Wetland		☑	☑
Dry detention basin		☑	☑
Litter trap (side entry pit trap)		☑	
Pond and sediment trap		☑	☑
Swale		☑	☑
Lake			☑
Litter trap (gross pollutant trap)			☑
Rehabilitated waterway			☑
Reuse scheme (i.e. open space irrigation and toilet flushing)			☑
Urban forest			☑

Table 2.6 -Opportunities for the Placement of Structural BMP in Urban Catchments
(Lloyd, S., et al 2010)

2.6.3.1. The Treatment Train Approach

No single non-structural or structural BMP can effectively prevent or remove the full range of urban stormwater pollutants *(Lloyd, S., et al 2010)*. Sometimes to achieve the required water quality, a number of BMPs will have to be used. Water quality will required the removal of pollutants such as Litter, Suspended solids, Nitrogen and Phosphorus. BMPs improve the water quality by physical, biological and chemical processes. Treatment methods based on physical processes are often the first to be used in a treatment train *(Lloyd, S., et al 2010)*. A BMP's physical treatment process involves removing gross pollutants, coarse sediments and fine sediments, such as silts and clay.

2.6.3.2. Selecting Appropriate Structural Best Management Practices

Selection of structural BMPs should be based on maximising flow control and/or water quality benefits relative to the costs of construction and maintenance. Other objectives may include treatment effectiveness and design issues. In summary selection process must consider the following:

- Flow control
- Water quality improvement
- Treatment effectiveness
- Design issues
- Cost considerations.

The cost consideration process will require a feasibility assessment of each BMP. It must consider the BMP's cost of construction and cost of the maintenance of the practice during its design life.

2.6.3.3. Flow Control

Flow control provides the basis for all stormwater management schemes. The three flow control issues to consider:

- Flood management
- Flow attenuation
- Runoff volume reduction.

There are a number of BMPs effective at providing flow control, refer to **Table 2.7**.

Stormwater reuse schemes are an effective way to reduce urban runoff volume. However, it is important to harvest only the flows larger than those occurring before the catchment was developed to ensure environmental flows are maintained in natural waterways *(Lloyd, S., et al 2010)*.

Best Management Practices	Primary Flow Control Function		
	Flood Management	Flow Attenuation	Reduction in Volume
Retarding Basin	☑	☑	
Lake/Pond	☑	☑	
Wetland		☑	
Rehabilitated waterway (pool and riffle system)		☑	
Vegetated Swale		☑	
Buffer Strip		☑	
Infiltration and collection system (bio-filtration system)		☑	☑
Infiltration system		☑	☑
Water reuse scheme		☑	☑

Table 2.7 - Flow Control Functions Associated with Structural BMPs
(Lloyd, S., et al 2010)

2.6.3.4. Treatment Effectiveness

Estimating treatment effectiveness involves identifying the proportion of mean annual runoff volume that enters and flows through a BMP. Modelling tools such as the MUSIC software provide a simple means to rapidly assess the treatment effectiveness of BMPs *(Lloyd, S., et al 2010)*.

2.6.3.5. Design Issues

The design of a BMP strategy should considered the following:

- Site topography
- Site climate characteristics
- Area of available land
- Water quality requirements

2.6.4. Conclusion

Water sensitive urban design (WSUD) is an approach and set of principles to the planning and design of urban developments. The objective is to improve the health of natural waterways. Stormwater management is an important component of WSUD, it consist of two types of practices. They are Best Planning Practices (BPPs) and Best Management Practices (BMPs). BPPs include site analysis, land capability assessment and the land-use plan. This practice must be consider when designing the lot layout of the development in this investigation. There are two types of BMPs; Non-structural and structural. The non-structure practice must be considered. However the investigation's approach will utilise the structural best management practice. These practices will include the planning and design of the green infrastructure.

2.7. GREEN INFRASTRUCTURE

To solve the urban runoff pollution problem and improve water quality there are several types of solutions. The implementation of green infrastructures is one such solution. Green infrastructures manage the runoff of frequent flow by imitating the natural environment. It does this by the process of retention and filtration. All green infrastructure has some form of retention. The retention feature of these devices is a key parameter during this investigation.

There are many types of green infrastructure available. It was decided to study five of the most common infrastructures in research papers. Several different types of devices will give the research a diverse range of results. These chosen green infrastructures are:

1. Green Roof and Walls
2. Permeable Pavement
3. Vegetated Swales
4. Bio-Retention Basins
5. Constructed Wetlands

These green infrastructures are then organised into the catchment size they would likely to be constructed in. **Table 2.8** shows these relationships. These relationships were configured using the **Table 2.6** -Opportunities for the placement of structural best management practices in urban catchments *(Lloyd, S., et al 2010).*

Green Infrastructure	**Single Lot (1 lot)**	**Neighbourhood / Street (10 lots)**	**Subdivision (100 lots)**	**Cluster / Suburb (1000 lots)**
Green Roof and Walls	☑	☑	☑	☑
Permeable Pavement	☑	☑	☑	☑
Vegetated Swales	☑	☑	☑	☑
Bio-Retentions Basins			☑	☑
Constructed Wetlands				☑

Table 2.8 - Relationship between Green Infrastructure and Catchment Size

- The introduced green infrastructure in the single lot catchment size (1 lot) will be the green roof and the permeable pavement.
- The introduced green infrastructure in the neighbourhood / street catchment size (10 lots) will be the green roof and the permeable pavement.
- The introduced green infrastructure in the subdivision catchment size (100 lots) will be the bio-retention basins.
- The introduced green infrastructure in the cluster of subdivisions / suburb catchment size (1000 lots) will be the constructed wetland and vegetated swales.

2.7.1. Green Roof and Walls

2.7.1.1. History

Green roofs and walls are infrastructures that utilise the technology of infiltration. It changes the original impervious building material into pervious vegetation. This investigation focus will be on the green roofs. Wall treatment is common in denser living conditions where taller buildings exist.
A green roof is a modern type of green infrastructure. Although the procedure is not a new concept, their application to treat stormwater is new. In the 1960s green roof technologies have been researched and developed in many countries, mainly in Germany and Switzerland. During the 1990s Germany increased its use of green roofs.

2.7.1.2. Green Roof Mechanisms

There are several layers involved in the mechanics of a green roof. The top layer of the green roof is the vegetation and planting medium. As the plants grow, they extract water from the soil and lower storage layers. The rainfall lands on the top vegetation layer and then filters through its lower layers. Once filtered, it is temporarily stored on the roof until storage reaches its capacity. Once at capacity the drainage pipes can discharge the water at a controlled rate. This controlled rate will be designed for a particular storm event. The green roof is a retention system and therefore reduce the amount of stormwater runoff. As the water runs through the filtered layer it traps suspended solids and pollutants, improving the water quality.

The layers and their function within the green roof systems:

- **Vegetation / planting medium Layer**
  This layer's function is for the aesthetics and medium required to keep the vegetation alive. The vegetation extracts nutrients out of the water, improving its quality. This is determine by the species of plant. The vegetation type / species is usually specified by the landscape architect. Although design consideration must determine the type of plants used and their absorption properties. Vegetation

- **Geotextile Filter Fabric**
  Geotextile fabric is a permeable material made from either polypropylene or polyester. There are three type of basic geotextile forms, they are:
    - Non-woven geotextiles
    - Woven geotextiles
    - Heat bonded geotextiles

  The geotextile's function is to separate the planting medium from the storage/drainage layer. Without this layer the storage/drainage layer would become clogged with soils and sands. This layer acts as a filter, preventing large suspended solids and sediment from passing.

- **Storage/Drainage Layer**
  Most popular storage/drainage layer material is the drainage plates and mats shown in **Figure 2.8.** The storage layer's function is to retain water. This reduces the stormwater runoff from the roof of the building. The storage layer can only hold a specified volume of water. After the storage cells are at capacity the water is released into the drainage layer. The most popular location of this drainage layer sits underneath the storage layer. The drainage layer's function is to discharge the excess water. Drainage avoids water travelling back through the filters, which could damage the system. The storage layer is then used by the vegetation layer above or otherwise evaporated.

- **Insulation**
  This is an option layer on the green roof. It can be position below the roof substrate layer. Insulation installed above the waterproof membrane layers is known as an inverted green roof. Inverted green roofs are preferred since the insulation layer can protect the waterproof membrane from damage. The material used in inverted systems is extruded polystyrene (XPS) foam.
  The main function of the insulation layer is to regulate temperatures within the building. This thermal insulation is used to prevent heat loss from the building. This makes the building much more efficient when heating.

- **Waterproof Membrane**
  Waterproof membrane sheeting is an impermeable material made from various types of materials. These types include:
    - Polyurethane
    - Acrylic
    - Bentonite
    - Torch-on bitumen primer
    - PVC (Polyvinyl Chloride)

  The functions of the waterproof membrane is to hold water in the drainage layer and prevent it from developing in between layers. If water does escape the drainage layer this could potentially pool and occur damage to the roof substrate.

- **Roof Substrate**
  Roof substrate can also be refer to as roof decking or roof structure. This is the layer upon which the waterproof membrane is applied. Roof substrate can be manipulated to have intentional channels and depressions. This alteration can be done to assist in the drainage of the roof. This layer must ensure the roof is free flowing and can drain to the outlet/s. The main function of this layer is to be the structural base of the green roof. This structural element must be able to support all of the structural forces, including those loads from the green roof.

There is much variation in the usage and composition of these layers. **Figure 2.5** shows the average cross section of green roof used in the research papers by Stovin, Simmons, Carter and Mentens. **Figure 2.6** shows a photographic image of an example of the types of materials used in the green roof layers. The image shows the planting medium being spread across the top of the filter fabric, where the fabric has been peeled back to expose the drainage and storage layers.

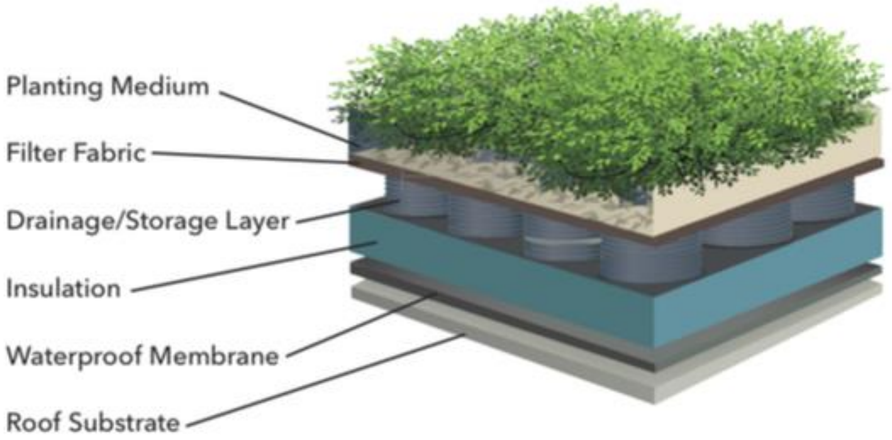


Figure 2.5 -Typical Green Roof Cross Section
(Tip of the Mitt Watershed Council, 2019)

Figure 2.6 - Photo of Layers in a Green Roof System
(Magill, J., Midden, K., Groninger, J. and Therrell, M., 2011)

2.7.1.3. Infrastructure Performance and Design Considerations

Green roofs have numerous benefits including retaining stormwater runoff, sequestering carbon dioxide and pollutants in biomass, improving aesthetic appearance, creating wildlife habitat and providing a noise reduction in buildings *(Dunnett, N. and Kingsbury, N., 2004)*.

Green roofs can either be provided on flat or sloped roofs. The pitch of the roof does affect the stormwater retention of the green roof infrastructure. When the storage layer is place on an angle, the volume of storage is decreased. The average Australian roof pitch is 22.5°. Although this pitch is too steep for studying the retention properties of the green roof. Therefore, for this research, all roofs will be considered flat in the computer modelling parameters.

When green roofs are combined with other sustainable methods of stormwater mitigation, these systems can work together to more effective than any one system by itself *(Stovin, V., Poë, S. and Berretta, C., 2013)*. This statement from Stovin harmonises with the aim of this investigation.

Research has discovered two investigation into the retention values of green roofs. In Sheffield, UK, a test plot during spring 2006 had average volume retention of stormwater of 57% *(Stovin, V., et al, C., 2013).* Maximum run-off retention has been demonstrated as high as 88% and 44% for medium and large rain events *(Simmons, M., Gardiner, B., Windhager, S. and Tinsley, J., 2008)*. There is no change in hydrology across watershed for storm events greater than that 2-year, 24 hr event *(Carter, T. and Fowler, L., 2008)*. The only source of water inflow is from the rainfall that lands directly onto the roof. There is no sequential runoff from other areas.

The annual rainfall-runoff relationship for green roofs is strongly determined by the depth of the substrate layer *(Mentens, J., Raes, D. and Hermy, M., 2006)*. Seasons also affect the retention of water; 80% winter runoff versus 52% summer run-off *(Mentens, J., et al, 2006)*

2.7.2. Permeable Pavement

2.7.2.1. History

Permeable pavement can be also referred as porous or pervious pavements. It is a pavement that is constructed with open graded aggregates which have air voids that can allow water to pass through. Consequently this water is filtered through the pavement and it reduces the amount of surface flow. This process also traps suspended solids and pollutants within the pavement.
Permeable concrete was first seen in the 1800s in Europe and was used for various structural purposes, including load-bearing walls, infill panels, and pavement surfacing *(Green Building Alliance, 2020)*. The concept was proposed in 1960s to utilise permeable pavement to reduce flooding and increase water into underground water tables and aquifers. Although permeable pavement has been in use for decades, quantifying the stormwater quality benefits of various forms of permeable pavement is ongoing with recent advancements in design, construction, and maintenance *(Green Building Alliance,*

2020). This pavement has a low design life because of the strength of the open graded aggregate material. This is because of the reduced surface area of binding material.

2.7.2.2. Permeable Pavement Mechanism

Permeable pavements is a load bearing pavement surface treatment that will allow water to flow through it. Refer to Figure **2.7** for a section of one example of permeable pavement.

- Permeable surface layer (porous asphalt, porous concrete, clay blocks, concrete blocks)
- Storage layer (crushed stone or gravel)
- Optional underdrains
- Optional geotextile fabric / impermeable layer
- Subgrade

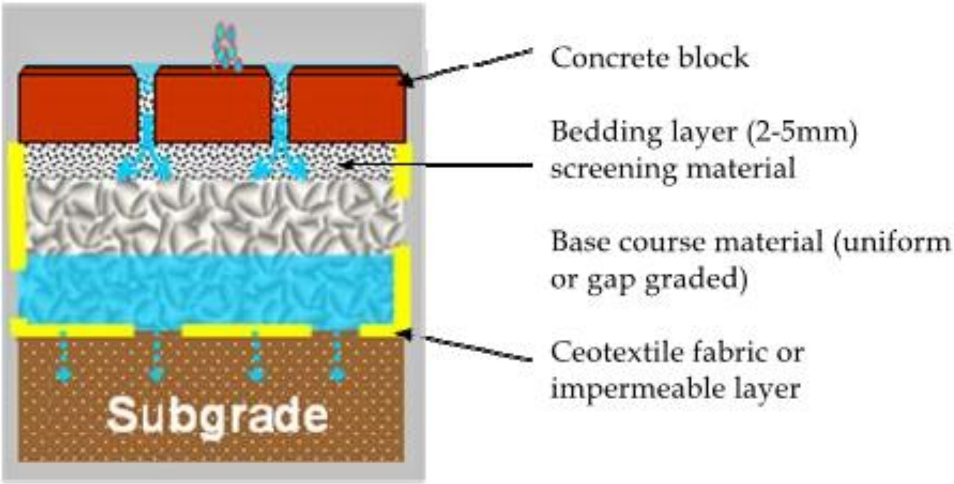


Figure 2.7 - Example section of permeable pavement (concrete block with no underdrains)
(Healthy Waterways, 2006)

The layers and their function within the permeable pavement systems:

- **Permeable Surface Layer**
  The permeable surface layer properties will be selected through the design process.

  This layer's function is to be the wearing surface for the traffic or pedestrian loads. This surface layer can be constructed with materials such as:
  - Porous asphalt
  - Porous concrete
  - Clay blocks
  - Concrete blocks

  The surface type should be specified with any material requirements and specifications.

- **Bedding Layer**
  The bedding is a foundation layer for block surface treatment. While adding support to the blocks, the bedding helps level the blocks during construction. In road, asphalt and flexible pavement design, this layer is not necessary. This layer is constructed using a 2 to 5 millimetres open graded screening gravel material.

- **Base and Subbase Course Layer**
  The base course layer is located underneath the surface and bedding layers (if required). It provides further load supports. In normal pavements it contributes to drainage, however in permeable pavements this layer is also porous. Base courses in permeable pavements are constructed with open graded crushed aggregate. This material is used to filter the water.

- **Storage/Drainage Layer**
  Storage/drainage layer material is also known as the subbase reservoir. This layer is also constructed with open grade aggregate, which is clean (free of fine material). Size of open graded aggregate to be a uniform size between 20 to 100 millimetres in diameter. Its function is to store/detain filtrated water. The volume of air voids within the subbase will be the maximum volume of water of storage. This reduces the stormwater runoff by infiltrating surface water from the road and therefore reducing road surface runoff. In infiltration types of permeable pavement, the water penetrates into the natural subgrade. This type is dependent on the type of material of the subgrade. Detention is the other type of permeable pavement used. This type requires slotted underdrain pipes to discharge the water.

- **Waterproof Membrane**
  Waterproof membrane sheeting is an impermeable material made from various type of materials. These types include:
    - Polyurethane
    - Acrylic
    - Bentonite
    - Torch-on bitumen primer
    - PVC (Polyvinyl Chloride)

  This material layer is only present in detention types of permeable pavements. The functions of the waterproof membrane is to detain the water in the drainage/storage layer. It prevents water from developing into natural subgrade material. Depending on the drainage properties of the natural material, too much water can potentially damage the subgrade. It also functions as a separation barrier to prevent the natural subgrade from mixing with the storage/drainage layer. Without this layer the storage/drainage layer could become clogged with soils and sands.

- **Geotextile Filter Fabric**
  Geotextile fabric is a permeable material made from either polypropylene or polyester. There are three type of basic geotextile forms, they are:
    - Non-woven geotextiles
    - Woven geotextiles
    - Heat bonded geotextiles

  This material layer is present in infiltration types of permeable pavements. The geotextile filter fabric layer functions as a separation barrier to prevent the natural subgrade from mixing with the storage/drainage layer. Without this layer the storage/drainage layer could become clogged with soils and sands.

- **Natural Subgrade**
  This layer is the lowest layer of the road. Its function is to provide a base support for the vehicle loads applied above. Properties of the subgrade include strength and stability. Strength can be determined by the penetration test, otherwise known as the Californian Bearing Ratio (CBR) test.

2.7.2.3. Infrastructure Performance and Design Considerations

Borgwardt reported that permeable paving constructed with gravel chips with 2mm to 5mm drainage openings had a permeability of 36,000 mm/hr once constructed, which decreased over time *(Borgwardt, S, 1994)*. After five years a permeability of 3600 mm/hr was measured *(Healthy Waterways, 2006)*. This is the disadvantage of permeable pavements; the effect of clogging can dramatically change its permeable properties. The use of geofabrics in permeable pavements can also reduce the infiltration rate to as low as 2mm/hr *(Healthy Waterways, 2006)*. Other disadvantages of using permeable pavements include:

- Infiltration types may affect the subgrade stability
- Geotextile filter fabrics are susceptible to blockage
- Pavement clogging
- Vegetation within the voids
- Unable to treat large flows
- Slopes of pavement restricted to be 4% or less

The pavements are most practical and cost effective when serving catchments between 0.1 and 0.4ha. Permeable pavements can be utilised in:

- Streets with low traffic volumes and light traffic weight
- Car parks and for paving within residential and commercial development (e.g. pedestrian paths or footpaths)
- Public squares
- Areas with sediment loads
- Moderate soil infiltration rates

Table 2.9 shows the different types of permeable surfaces and where they are recommended for application.

Condition/Use	Porous Asphalt/Concrete	Porous Pavers/ Grid Systems	Interlocking Concrete Paving Systems
Low traffic roads	Yes	Yes	-
Commercial parking lots	Yes	Yes	Yes
Overflow parking	Yes	Yes	Yes
Light Commercial Driveways	Yes	Yes	-
Patio/other paved areas	Yes	Yes	-
Sporting Courts	Yes	-	-
Industrial storage yards/loading zones	Yes	Yes	-
Parking pads (e.g. caravan parks)	-	Yes	Yes

Table 2.9 - Potential Applications for Permeable Pavements
(Healthy Waterways, 2006)

There are the three different types of permeable pavements. They differ by the method of water discharge. The types are:

1. **Infiltration**
   In this type water is discharged into the natural subgrade.
2. **Detention**
   In this type water is discharge by an underdrain system. A waterproof membrane is installed to protect the natural subgrade.
3. **Combined Infiltration and Detention**
   In this type water is discharged by both the natural subgrade and underdrain system.

Refer to **Figure 2.8** for illustration of these three different types of pavements.

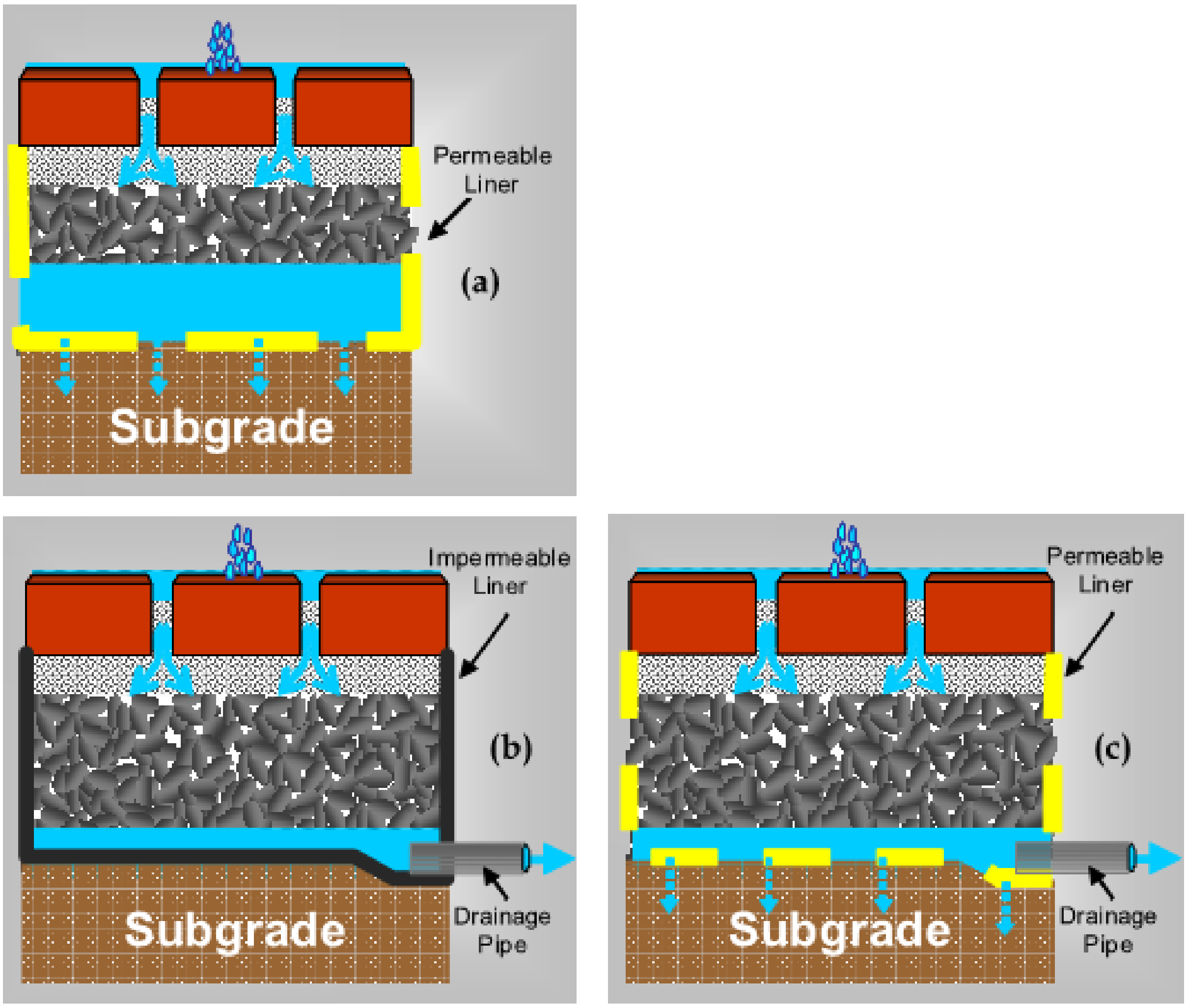


Figure 2.8 - (a) Infiltration (b) Detention (c) Combined Infiltration and Detention Permeable Pavement Systems

(Healthy Waterways, 2006)

The size of a permeable paving system requires consideration of:

- The volume and frequency of runoff discharged to the permeable pavement
- The available detention or retention volume
- The infiltration rate of subgrade or underdrain discharge rate

Hydraulic conductivity of the surface treatment

2.7.3. Vegetated Swales

2.7.3.1. History

Swales are channels in the terrain which can be either cut man-made or naturally carved. They consist of gentle slopes usually between 1% and 5%. The gentle slopes are important since they decrease the velocity of flow. The swales provide areas in an urban development that stormwater runoff can be captured and infiltrated into the natural soils.

Swales can be vegetated with a variety of vegetation types. For best performance the vegetation height should be above the design storm event's water level. However, for this research a variety of grass/turf will be implemented.

2.7.3.2. Vegetated Swale Mechanisms

A vegetated swale is a shallow stormwater channel that is densely planted along the bottom and sides of the channel with a variety of grasses, shrubs, and/or trees. It changes the pervious character of the surface. The swale is designed to channel, slow, filter, and infiltrate stormwater runoff.
The main difference between swales and drains is base of the channel (**Figure 2.9**). Swales have flat bases and are designed in areas which can drain freely. Drains have a 'v' shaped base configuration which results in them less surface to infiltrate the ground. This usually results into the drains holding water.

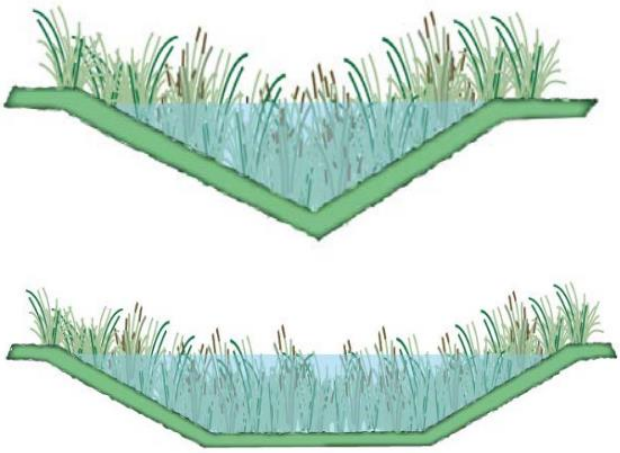


Figure 2.9 - Vegetated Drain (top) and Vegetated Swale (bottom) Cross Sections

Another type of green infrastructure and closely related to the vegetated swale and drain is the bio-swale. This is a vegetated swale with infiltration properties and an under drain. Bio-swales are essentially bio-basins in slimmer areas and potentially steeper grades.

This research will investigate the properties of the vegetated swale and not of the vegetated drain and bio-swale.

2.7.3.3. Infrastructure Performance and Design Considerations

The design of swales seeks to reduce stormwater volume through infiltration, improve water quality through infiltration and vegetative filtering, and reduce runoff velocity by increasing flow path lengths and channel roughness.

The capacity of the channel is to hold the maximum design storm event volume with free board for a factor of safety. The reduction of flow velocities will determine the capacity to manage water quality and quantity. Native plant types will also determine the performance of the swale. Maintenance of the swale should also be considered in the design.

The maximum longitudinal grade of a vegetated swale is 4.0%. (Ipswich City Council will allow swales to be designed at a maximum 5% grade). The minimum grade is 1.0%, swales with less than 1.0% will require underdrains and fit into the bio-swale category.

Vegetated swales can remove coarse and medium sized sediments.

2.7.4. Bio-Retention Basins

2.7.4.1. History

Bio-Retention basins are also referred to as Rain Gardens in North America. The idea conceived in the United States in the early 1990s. It was invented to adhere to Better Management Practices, which is stated in the Water Sensitive Urban Design (WSUD). Essentially these terms are used to describe the practice of stormwater pollution control. The result is an aesthetically cost-effective solution to stormwater quality management.

2.7.4.2. Bio-Retention Basin Mechanisms

These basins or rain gardens are a man-made pond device that attempt to simulate natural processes. Underneath the base of the basin is filter media. The low flow polluted water runs through this filter to slotted drains at the base. The treated water is then drained to the natural waterways or discharge point. Specific type of plant species are planted at calculated densities within the basin area. These plants aid in the absorption of water.

There are several types if bio-retention devices. Some of these types include:

- Bio-retention basins
- Bio-retention swales
- Bio-pods
- Bio-retention street trees

This research will focus on the bio-retention basins. The basin type is most suited for water quality treatment in urban residential areas.

All types of bio-retention basins have a similar process. The one major difference is the bio-basins method of drainage. There are four different types of drainage zones for basins. These types of drainage zones are:

- Saturated drainage zone
- Sealed drainage zone
- Conventional drainage zone
- Pipe-less drainage zone

2.7.4.2.1. Saturated Drainage Zone

This type of basin is designed for storage of water in the transition and drainage layers. This allows for the vegetation to thrive during dry periods. To retain water in this saturated zone there is an impermeable liner installed at the base. The invert of the drainage outlet pipes is installed above the design water storage level. The water in storage can only be removed by plant or evapotranspiration. **Figure 2.10** shows a cross section of a saturated basin type.

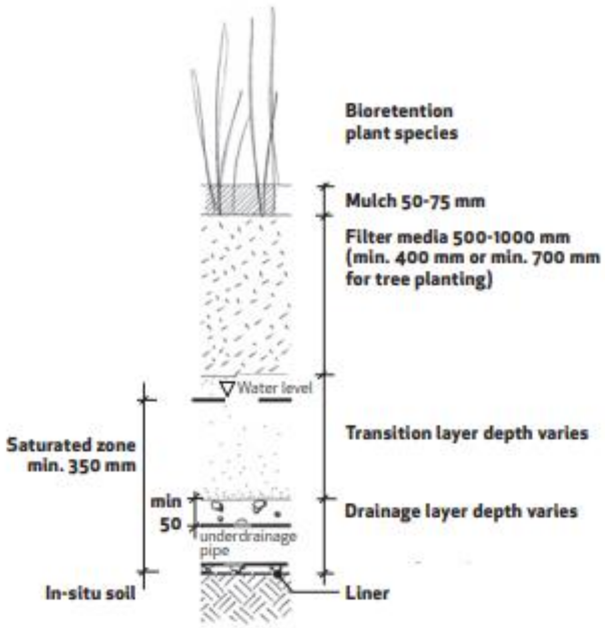


Figure 2.10 - Cross Section of Bio-Retention Basin with a Saturated Drainage Zone
(Healthy Waterways, 2014)

2.7.4.2.2. Sealed Drainage Zone

This type of basin is designed to redirect stormwater and prevent water from infiltrating the natural material. The drainage layer is then used to discharge water away from the bio-retention basin system. This is completed by installing an impermeable liner at the base of the basin. The invert of the drainage outlet pipes are installed below the invert of the underdrainage pipes. This ensures that the drainage zone is always allowed to free drain. The water can also be removed by plant or evapotranspiration. **Figure 2.11** shows a cross section of a sealed basin type.

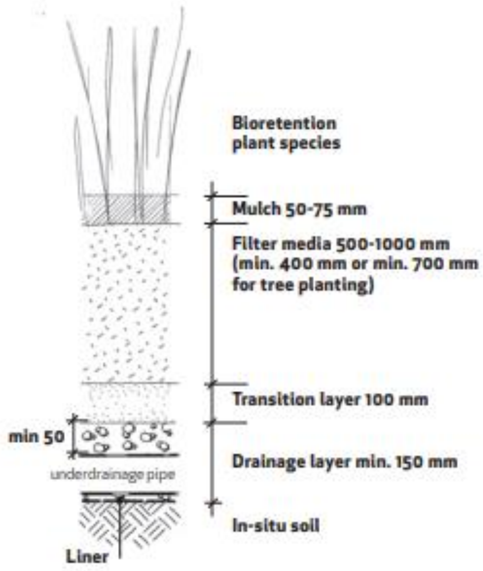


Figure 2.11 - Cross Section of Bio-Retention Basin with a Sealed Drainage Zone
(Healthy Waterways, 2014)

2.7.4.2.3. Conventional Drainage Zone

This type of basin is designed to redirect stormwater and allow water to infiltrate into the natural material. The drainage layer is still used to discharge water away from the bio-retention basin system. It has not installed with a liner, therefore water is unable to be held in this layer. The invert of the drainage outlet pipes are installed below the invert of the underdrainage pipes. This ensures that the drainage zone is always allowed to free drain. The water can also be removed by plant or evapotranspiration. **Figure 2.12** shows a cross section of a conventional basin type.

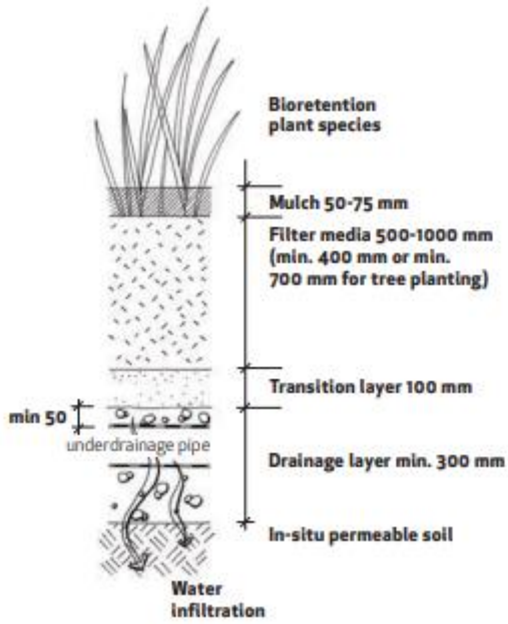


Figure 2.12 - Cross Section of Bio-Retention Basin with a Conventional Drainage Zone
(Healthy Waterways, 2014)

2.7.4.2.4. Pipe-less Drainage Zone

This type of basin is designed without a drainage layer and allows water to infiltrate into the natural material. The only methods water can be removed from the system are removal by plant, evapotranspiration and/or infiltration into the natural material. There is no installation of underdrainage pipes and impermeable liners. **Figure 2.13** shows a cross section of a pipe less basin type.

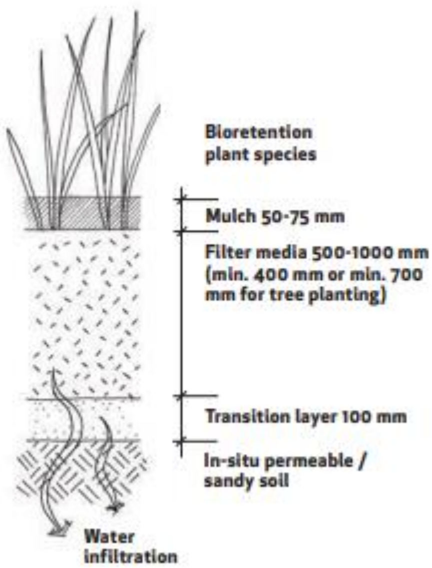


Figure 2.13 - Cross Section of Bio-Retention Basin with a Pipe less Drainage Zone
(Healthy Waterways, 2014)

To avoid testing the natural soil properties this investigation will model the sealed bio-retention drainage zone type. This is the most popular type used in South East Queensland.

The typical cross section of a bio-retention basin consist of several layers. The layers and their function within the bio-retention systems:

- **Extended Detention Reserve Layer**

  This is the level at which the water will get treated prior to bypassing to the major stormwater overflow pit. The treated volume is the surface area of the basin multiplied with this extended detention depth. This dimension is commonly in the range of 200 - 400mm. The basin should also contain an emergency overflow weir to control the flow in very major storm events. The weir is usually located with a free board under the top of basin. Designed correctly, this method can prevent nuisance flooding of buildings and property.

- **Vegetation and Mulch Surface Layer**

  Council have a list of their approved plant species they desire to be introduced to basins in their areas. However, the plant species should be suited to a sandy residence and be drought tolerant. These plants should also be chosen for their ability to remove nutrients. FAWB guidelines gives further information into each the properties of suitable plant species.

  The vegetation contributes to the occurrence of sediments settling to the base of the basin. The plants digest the nutrients in the water and the ones present in the filter media. This plant life does provides oxygen to the filtration layer. This encourages microbial growth for further pollutant removal.

- **Filter Media Layer**

  As water passes through this layer, its function is to remove pollutants. This filter media contains a sandy loam type of material with an average particle size of 0.45mm. The average depth of this filter media is 500mm, which will be utilised in this research.

- **Transition Layer**

  The transition layer is positioned between the filter media and drainage layer. Its function is to keep these two layers separated. It contains a coarse sand type of material with an average particle size of 1mm. The average depth of this filter media is 100mm, which will be utilised in this research.

- **Drainage Layer**

  The function of this layer is to drain the treated water out of the bio-basin system. This layer also prevents the loss of filter media through the slotted pipes. This drainage zone is capable of holding a certain volume of the treated water. The drainage layer contains a coarse sand/gravel material with an average particle size of 2 - 20mm. The average depth of this drainage layer is 200mm, which will be utilised in this research.

- **Waterproof Membrane**
  Waterproof membrane sheeting is an impermeable material made from various type of materials. These types include:
    - Polyurethane
    - Acrylic
    - Bentonite
    - Torch-on bitumen primer
    - PVC (Polyvinyl Chloride)

  The functions of the waterproof membrane is to detain the water in the drainage layer. It prevents water from infiltrating into natural material. It also functions as a separation barrier to prevent the natural subgrade from mixing with the drainage layer.

2.7.4.3. Infrastructure Performance and Design Requirements

Benefits that a bio-retention basin provides include:

- Cost-effective compared to Gross Pollutant Traps and other similar treatment devices
- Reduces impervious areas
- Advances the ecosystem health of the area
- Aesthetically gives a natural look to the development
- Provides detention of stormwater, therefore less impact downstream during floods
- Reduces Pollutants
- Small footprint
- Suitable to treat varied sized catchments
- Designs can suit moderate and steep terrain/topography

The target pollutants of bio-retention basins are sediment, suspended solids, heavy metals, nutrients (Phosphorus, Nitrogen) and bacteria. Sediment and particulate nutrients are removed through physical contact with the filter media and soluble nutrients are removed through binding to particles within the filter material *(FAWB, 2009)*.

The hydraulic conductivity of the all layers of material, specifically the filter media, should be in the range of 100-300mm/hr and this is to be higher in tropical areas of the country. In this investigation 200mm/hr to be adopted.

Treatment area is approximately 2-4% of the catchment size *(FAWB, 2009).*

Bio-retention basins are designed in accordance with FAWB (Facility for Advancing Water Bio filtration) Guidelines. FAWB was formed in 2005 as an unincorporated joint venture between ISWR, Monash University and EDAW. FAWB are leading researchers in this field and are funded by the Victorian State Government. Stormwater quality has software programs to calculate the required area of the basin and the layer depths. Example of these software packages are MUSIC and SWMM.

2.7.5. Constructed Wetlands

2.7.5.1. History

Constructed wetlands are man-made wetlands that are used for water quality treatment. The use of natural wetlands for water treatment can be traced to the ancient Chinese and Egyptian civilisations *(Brix, H., 1994)*. So therefore humans when discharging their waste into the local environment have intentionally or unintentionally using wetlands to clean stormwater and wastewater. In modern times, man-made or constructed wetlands have been designed and built for the purpose of treating water and wastewater. These constructed wetlands have been developed into fully engineered systems. They defined as green, sustainable, low-cost, robust, and efficient engineered systems for water treatment, with added ecosystem services *(Carvalho, P., Arias, C. and Brix, H., 2017)*.

2.7.5.2. Constructed Wetland Mechanisms

Constructed wetlands are overflow areas for natural waterways. These areas can be import for amphibians and dragonfly species and are a breeding ground for many species of birds. The area can also serve as parkland feature and can bring great aesthetics to a development. Wetlands are designed and construction to function without any pumping devices. They utilise gravity, inflow, sedimentation and natural vegetation to treat the stormwater and in some case waste water.

There are three main types of constructed wetlands. These three types are:

- Surface Flow Wetlands Systems
- Subsurface Flow Wetlands Systems
- Hybrid/Multistage Wetland Systems

The most typical wetland constructed in urban areas in the surface flow wetlands system. All wetland systems will be constructed with several components. These components and their function are:

- **Inflow pipe**
  The function of this pipe is to carry the underground stormwater or wastewater into the construction wetland.

- **Gross Pollutant Trap (GPT)**
  This is a man-made structure with screenings and/or separating physical process devices that remove the suspended solids, such as litter and sediments. These devices can trap solids above 5 millimetres in size. Most commonly these GPT device must be manually emptied. If maintenance does not occur regularly it may restrict the performance of the device.

- **Energy Dissipation**
  Energy dissipation devices are engineered and designed to reduce the storm water's velocity, energy and turbulence. Examples of these devices are rip-rap/gravel aprons and rock/concrete baffles placed at the outlet.

- **Sediment Removal Basin**
  These basins remove small matter by allowing the settlement of suspended particles within the water. In constructed wetlands, it achieves this by controlling the velocity and the uniform flow conditions. The outlet is located at the top of the water level. This ensures no sediment is transferred into the next treatment component phase. Maintenance is required for the removal of excess sediment at the base of the pond after time.

- **High flow Bypass / Emergency weir**
  This is a safety mechanism to divert larger storm events away from preceding treatment areas. This protects them from flood damage or contamination.

- **Leaf and Organic matter capture area**
  This is an optional component in the constructed wetland. It is used to remove any floating matter, such as leaves. This component is utilised when floating leaf and organic matter is a problem.

- **Flow spreader (porous rock wall)**
  This porous rock wall flow regulation structure ensures flow velocities remain low and well distributed across the wetland. This rock walls also filter any further or missed large sediments and/or suspended solids. This component requires regular maintenance and so must be easy to gain access.

- **Vegetation bands planted in shallow water**
  The macrophyte vegetation in the component slows flow and promotes further sedimentation. Biofilms on plants assist in the removal of pollutants and nutrients. Plants absorb nutrients such as Nitrogen (N) and phosphorus (P) that improve the water quality. Other nutrients plants absorb include potassium, calcium magnesium and sulphur. Plant's root system also oxygenates the planting area, improving the aerobic conditions of the wetland.

- **Submerged vegetation in open water pond**
  The main function of this component is to store water. The submerged vegetation and deep open water pond promotes further sedimentation and water treatment. Submerged plants assist in increasing oxygen levels.

- **Outlet pit and overflow pipe**
  The function of this pit and pipe is to capture and carry the treated water out of the construction wetland. The inlet to the pit is set at a level above the designed water level to ensure that wetland holds water for its environment.

- **Emergency overflow**
  This is a safety mechanism to control flow from larger storm events away from the constructed wetland. This protects them from flood damage or contamination. It also allows a safe flow path to prevent backflow and flooding.

Figure 2.14 shows a schematic sections of the constructed wetland and all of its components.

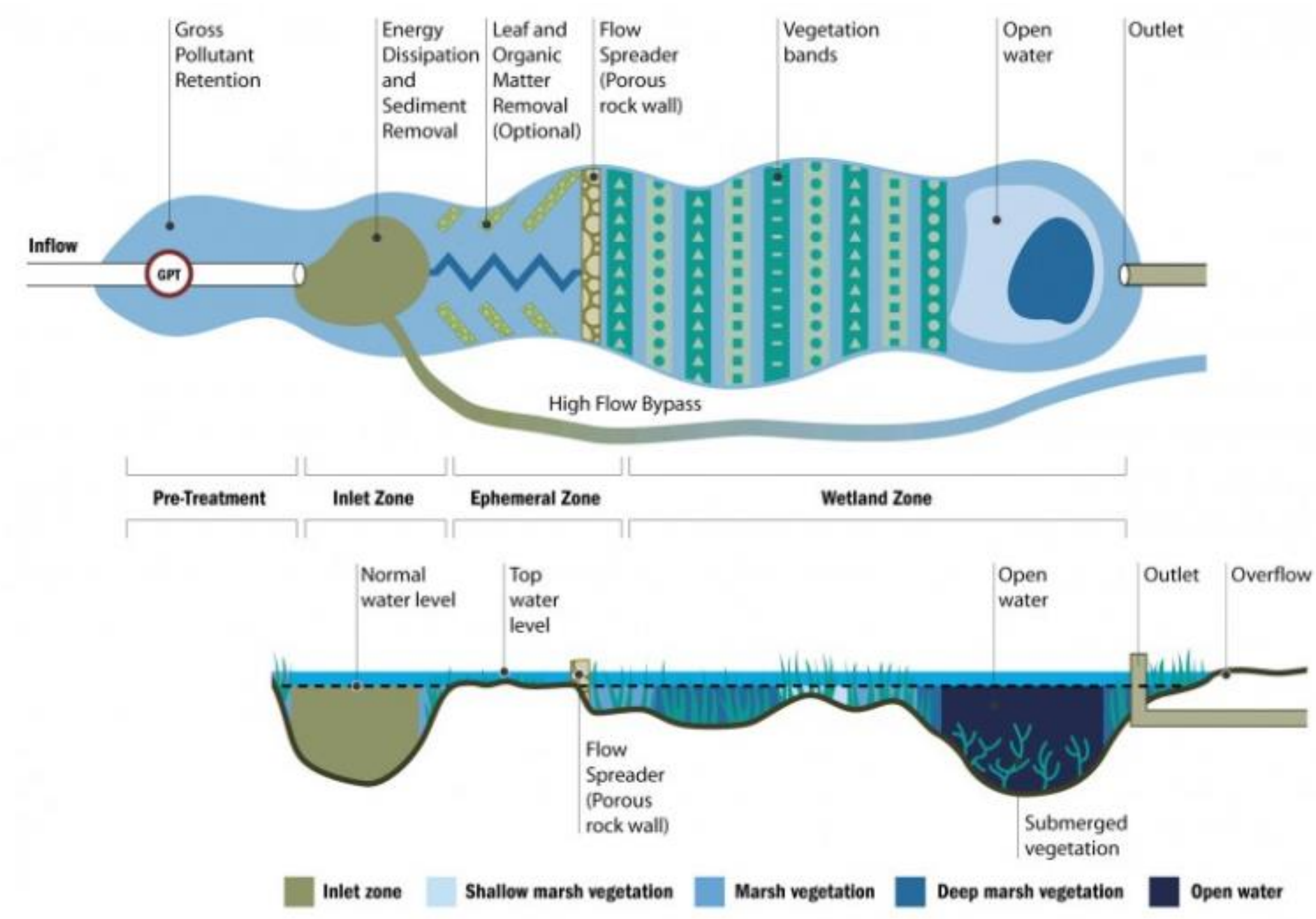


Figure 2.14 - Schematic Representation of a Typical Constructed Wetland *(Melbourne Water, 2005)*

2.7.5.3. Infrastructure Performance and Design Considerations

The size of the wetland is determined by a percentage of the upstream catchment. The general percentage is about 2 to 10% of the total upstream catchment areas *(QLD Government, 2018).* If the urban wetland serves to purify rainwater run-off, the indicated design of a wetland surface is approximately 5% of the surface from which the rainwater runs off *(Melbourne Water, 2005)*. The macrophyte vegetation bands and open water area should cover approximately 80% of the wetland.

Constructed wetland designs can be only handle maximum fluctuations in water levels of up to 30 cm *(Melbourne Water, 2005)*. This is why it is important that a high flow bypass is designed to be diverted away from treatment areas. This bypass must consider the excess water produced from large storm events.

In unsuitable soil conditions, water proof liners to be provided on the base of the wetland to separate it from it groundwater. This is to avoid contamination with groundwater, especially important when treating waste water.

Mosquitoes and chironomid midges can be a problem in wetland areas. To avoid problems, wetlands should be designed to maintain a continual flow between each component. This will prevent stagnant water and therefore reducing the growth of mosquito and chironomid midges' population.

2.8. COMPUTER MODELS

The selection of computer model software is an important phase of the investigation. It is impossible to identify all potential issues a user may have during modelling. However preliminary consideration of software limitations should be factored into decision making *(Commonwealth of Australian (Geoscience Australia), 2016)*.

The decision of the software and type of modelling process can following steps:

1. Defining the problem and required output
2. Identifying the available data
3. Selecting a level of modelling complexity (higher the complexity of the model the higher the accuracy of results)
4. Identifying the software's advantages and disadvantages
5. Selecting a software package and modelling approach that matches the investigation constraints (e.g. time, model choices and modeller experience)

Computer modelling is now a standard practice in the industry when designing drainage systems. Although it is good practice to always check and calibrate the model with manual calculations. For stormwater drainage systems there are generally three current computer models categories;

- Hydrologic
- Hydraulic
- Quality

This investigation will use the computer model software for Quality and analyse the hydrology component of the model to determine stormwater runoff.

2.8.1. Factors for Consideration

Prior to developing a catchment modelling system the problem and required outputs must be defined. It is important to consider all of the possible scenarios that will need to be run. Modelling is a beneficial tool that can assist in predicting the behaviour of drainage systems under different scenarios and conditions. Typical drainage system problems include:

- Floodplain studies
- Flood Emergency Response
- Urban drainage studies
- Dam Break assessments
- Sizing of a spillway
- Land filling for development
- In any environment in order to assess the flood impact due to development
- In-bank river flow modelling
- **Wetland modelling**
- **Water quality and sediment transport studies**

Typical model inputs include:

- Spatial extent
- Rainfall probability
- Parameter range

Typical model outputs include:

- Flow
- Volume
- Flood levels
- Rate of rise
- Warning time

Outputs can be generally presented as;

- Peak
- Hydrograph
- Spatial Map
- Animations

Other items to consider during model drainage system:

- Existing conditions
- Historic conditions
- Change in land use (pre-development / post development)
- Infrastructure
- Structural flood mitigation measures (e.g. dams, levees, etc.)
- Future development scenarios
- Change in dam operations
- Changed catchment conditions assessment
- Climate change
- Parameter sensitivity tests
- Ocean interaction

2.8.2. Identify Modelling Method, Inputs and Mechanisms

Some methods, inputs and mechanisms used to estimate the design flood include:

- Rainfall Models
- Runoff generation
- Overland flow
- Hydrologic routing
- Hydraulic routing

It is essential to choose a modelling system with methods, inputs and mechanisms that is relevant and will provide the correct type of data to solve the original defined problem. Some problems may require multiple processes, experimenting with different input parameters. Therefore, if required, the chosen modelling platform and catchment modelling system must be flexibility when altering the model's input processes.

2.8.3. Data Availability and Model Complexity

The input data is not required to be collected prior to model set-up. However knowledge and insight of what data is or might be available will assist in the determination of which catchment modelling system should be used. The level of complexity of the model is compromise between data availability and predictive performance **(Figure 2.15)**. When usually there is not enough observed data. The reduction of model complexity is a technique that could be used to save time. It achieves this by lowering the number and accuracy of the calculations of the data. That is why it is essential to find what minimum level of complexity is suitable to solve the problem.

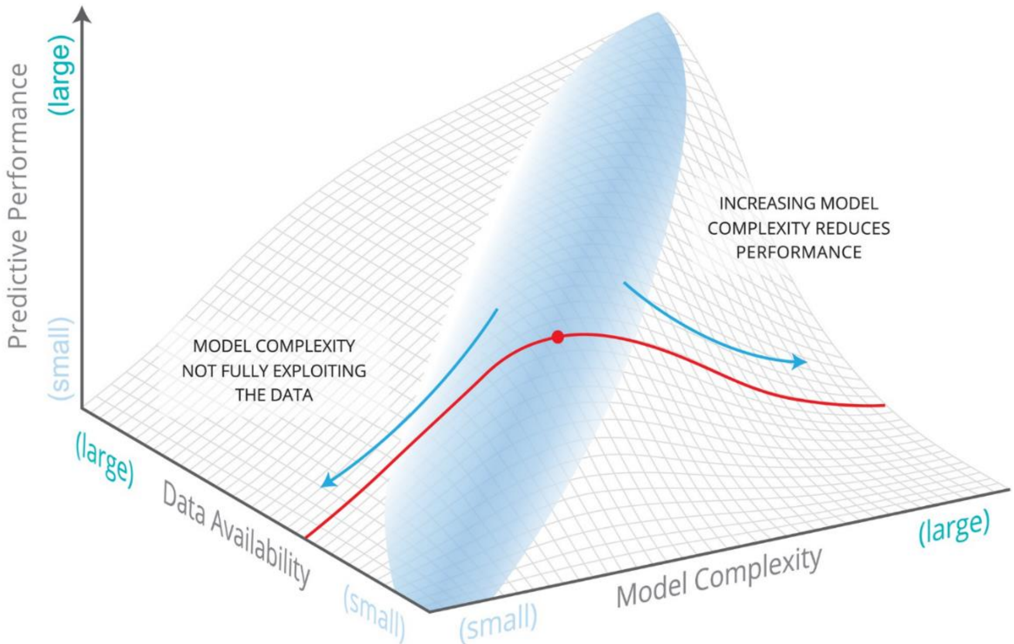


Figure 2.15 - Conceptual Relationship between Data Availability, Model Complexity and Predictive Performance
(Grayson, R.B. and Blöschl, G., 2000)

2.8.4. Selecting Modelling Software Package(s)

By understanding the problem, the model methods and data availability, it is now possible to select a preferred modelling software. A single modelling software may contain all the methods, inputs and mechanisms required to solve the problem. However, in many cases is it more desirable to combine a number of modelling software packages.

Other reasons that might influence the choice of modelling software:

- Reliable regional/default parameters
- Software can model specific features
- Client preference
- Authority standardisation
- Model's computation run time
- Expected resolution of the model and model outputs
- Existing modelling information available

The User's experience with the modelling software will be another important factor. The user's experience of the modelling software can affect the;

- Accuracy of assessment (knowledge of appropriate input parameter ranges)
- Model set up time
- Efficiency and Utilisation (knowledge of shortcuts and key features)

2.8.5. Hydrologic Models

2.8.5.1. Individual Rainfall Event Simulation

Predominantly used for running models to analyse intense flood events using an individual rainfall event. Duration of rain events are usually less than one day. *(IPWEA, 2017)*

2.8.5.2. Continuous, Long-term Simulation of Runoff Characteristics

This simulation better represents the total hydrologic cycle. Models can calculate volumetric runoff, base flow in streams and season variability, and the effects of development and infrastructure on the hydrologic cycle. This method is associated with stormwater management and can also be used for calculations of catchment pollutant yields.

2.8.6. Quality Models

There are two types of quality modelling. The continuous hydrologic and event-based modelling.

2.8.6.1. Continuous Hydrologic Simulation

Continuous simulation is best used for infrastructure design. Using existing rainfall data to achieve the proposed development's hydrograph. This is usually calculated with small time steps. Continuous hydrologic simulation models are for analysing future trends. Some software examples of the continuous method are:

- **MUSIC**
- XP-AQUALM
- **PCSWMM**

Both MUSIC and PCSWMM are link-node model formats. The model is created by linking these source nodes to simulate the design of the development. Each source node has its own parameters and pollutant solutions.

2.8.6.2. Event-based or Channel Water Body Process Models

Event-based models are best used for analysing floods. This data could be used for flood forecast, flood risk assessments, flood mapping and/or designing development's flood impact. Some software examples of event-based model are:

- MIKE-11 WQ
- MIKE-21 WQ
- SOBEK
- Delft 3D

2.9. MUSIC MODELLING

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) is a software tool for continuous hydrologic simulation of urban catchments. The software package is developed by eWater, an Australian Government owned, non-profit organisation.

The purpose of this software is to assist in the decision-making and the performance of stormwater quality management systems. The software gives assistance to organisations to conceptually plan and design quality stormwater systems. MUSIC has an easy-to-use and simply interface to aid the modelling of both simple and complex urban stormwater systems. It can model urban catchments ranging from a residential lot up to a suburb or small town (0.01 km^2 to 100km^2). The time scales can be set to or anywhere between 6 minutes and 24 hours *(Water by Design, 2010)*.

During this investigation the most current version of MUSIC will be used. At the time of this investigation MUSIC version 6.3 was available. This version of MUSIC was the software used throughout this investigation. However, the current guidelines to this software package reference version 4. These guidelines were still relevant since only minor differences between packages.

2.9.1. Design Objectives

Objectives are first addressed in State Planning Policies and Local Government Planning Schemes. The design objectives that MUSIC can assist with are stormwater quality and frequent flow management. It cannot address any objectives of problems in the topic of waterway stability. **Table 2.10** indicates the objectives suitable or not suitable for the use of the MUSIC software.

Objective	Objective Description	Suitability of MUSIC (V4) to Demonstrate Compliance
Stormwater Quality	This objective aims to protect the quality of receiving waters by limiting the quantity of stormwater pollutants that are discharged. This objective adopts best practice targets for reducing pollutant loads.	Suitable
Waterway Stability	This objective aims to prevent additional in-stream erosion downstream of urban areas by controlling the size and duration of sediment-transporting flows.	Not Suitable
Frequent Flow Management	This objective aims to protect in-stream ecosystems from the effects of increased frequency of runoff by capturing the initial portion of runoff from impervious areas. This approach ensures that the frequency of hydraulic disturbance to in-stream, ecosystems in developed catchments is similar to pre development conditions.	Further investigation required

Table 2.10 - Suitability of MUSIC V4 to Address Stormwater Management Objectives
(Water by Design, 2010)

This investigation aim is to reduce the gap in knowledge of utilising MUSIC software to model frequent flow management. However this software package is primarily used for stormwater quality. It is not suitable to analysing waterway stability.

2.9.2. Model Setup

2.9.2.1. Meteorological Data

MUSIC requires the input of the appropriate meteorological data for the different climatic regions. This builds a climate template profile for the catchment. The rain station that is closest proximity to the catchment is to be selected using **Figure 2.16**. The closest rain stations differ from the gauges discussed in stormwater quantity. Where more than one rainfall station is provided within a single assessment authority boundary or a rainfall station in a neighbouring local government area is noted to be in close proximity to the site, use the rainfall station closest to the development site (providing the mean annual rainfall volume is consistent (within 10%) with that expected at the site) *(Water by Design, 2010)*. The pluviography rainfall data can be downloaded in the toolkit at the eWater website. (https://ewater.org.au/products/music/related-tools/pluviograph-rainfall-data-tool/) Using the relevant rain station, the data in **Appendix B** can be used to determine the approximate rainfall period and PET data. Rainfall and evaporation data are provided directly within the software package. Selection of appropriate meteorological data is important to ensure that the correct rainfall runoff and pollutant generation is running in the model to assist with fundamental predictions.

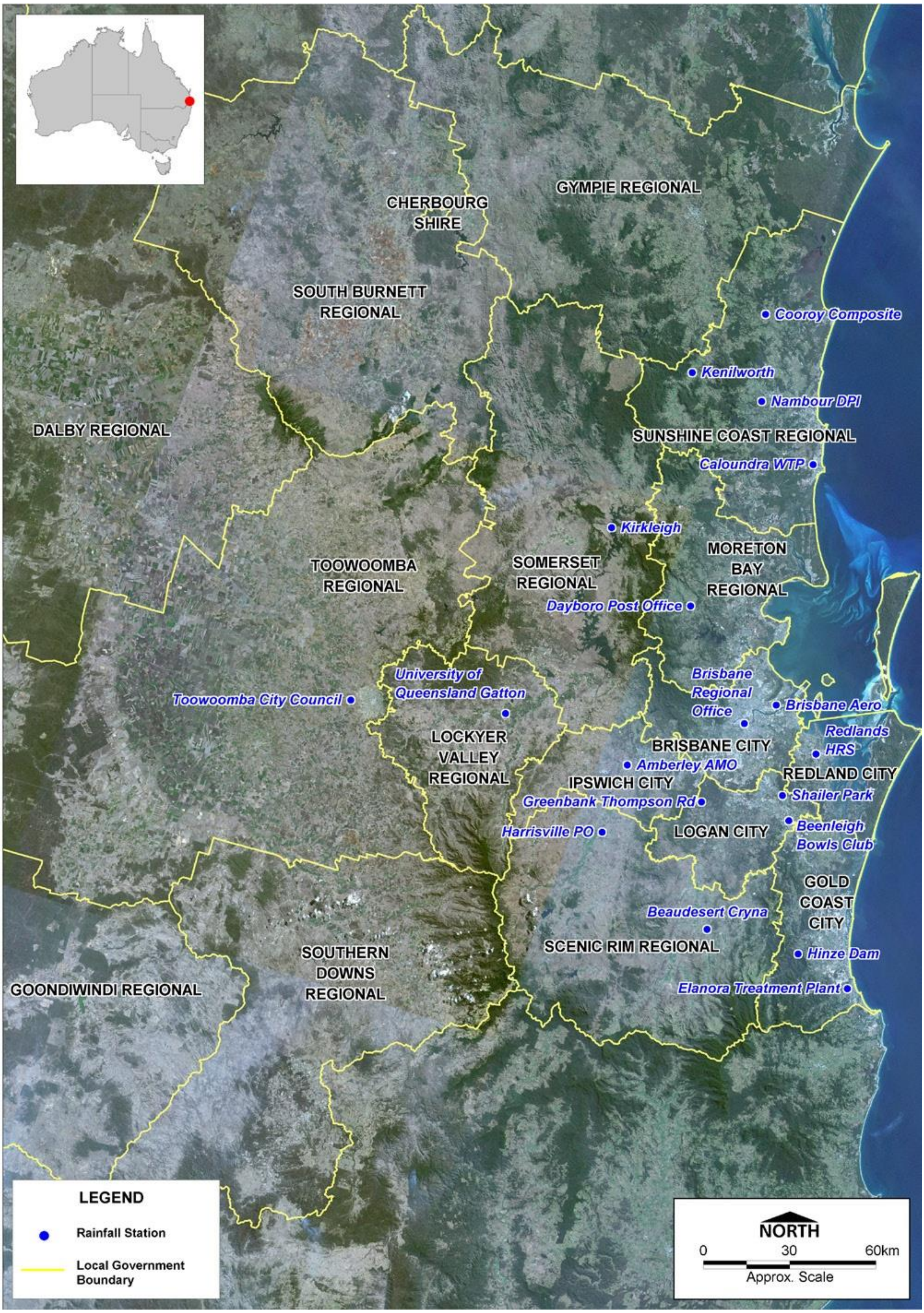


Figure 2.16 - Rainfall Station Locations across SEQ

(Water by Design, 2010)

2.9.2.2. Modelling Period and Time-step

A 10 year climate period is sufficient amount of data to represent the range of storm events. It allows a reasonable balance between model accuracy, computer capability and memory requirements *(Water by Design, 2010)*.

A time-step of 6 minutes in recommended for MUSIC version 4. However this research will use the 5 minute time-step available in the newer versions of the software. The smaller the time-step the more accurate results. The 5 minute time step is the lowest this parameter can be set.

2.9.2.3. Catchment Properties

The source catchment nodes require manual user input, this will set the catchment characteristics in the model. The input parameters involve:

- Defining total area, sub-catchment areas and total catchment areas
- Splitting the catchments into similar land use or surface types
- Defining the percentage of impervious areas for each land use or surface type.
- Selecting rainfall runoff parameters
- Selecting pollutant export parameters.

2.9.2.4. Nodes

MUSIC software is a link-node type of modelling. Nodes are created with relevant data and linked to each other in the software's interface. The model nodes can be set up in either a lumped, split or combination of both methods. **Table 2.11** is a list of the split catchment nodes. **Table 2.12** is a list of the lumped catchment nodes. This investigation will use the split catchment approach to separate the catchment into a better structured model system for this investigation. **Figure 2.17** illustrates an example of the setup of the split catchment approach.

MUSIC Node Symbol	Node Name	Node Description
	**Roof**	Applies to the area of the roof within the catchment.
	**Road**	Applies to the area of the road within the catchment. Investigation will used a second node for driveways.
	**Ground Level**	Applies to the rest of the area in the catchment that is not already denoted by a node. This is represent the turf and garden areas.

Table 2.11 - Split MUSIC Node Type
(Water by Design, 2010)

MUSIC Node Symbol	Node Name	Node Description
	**Residential**	Applies to residential areas including activities servicing local neighbourhood needs. While these areas will typically comprise a mix of land uses, including small nodes of commercial use, the majority of these areas will consist of residential dwellings together often with all associated facilities such as roads, parks and school grounds.
	**Rural Residential**	Applies residential uses on large allotments, with a high proportion of pervious areas. Rural residential source nodes also include activities serving local needs, such as schools and parklands. Areas of broad hectare, low-intensity farming activities (where soil is not exposed) and semi natural broad hectare land may also be included. These nodes typically have less than 10% total impervious area.
	**Industrial**	Applies to areas of light and general industry, including activities associated with the manufacture or distribution of goods (e.g. heavy machinery). The industrial node includes building envelopes, parking areas, adjacent roads and road reserves. Extractive industry cannot be modelled using this source node.
	**Commercial**	Applies to activities such as shops, offices and restaurants. The area of the commercial node includes building, parking area/driveways, adjacent roads and road reserves. Use a commercial source node to model special purpose or multipurpose centres such as hospitals, major educational facilities, shopping centres and community centres.
	**Forest**	Applies to undisturbed, natural bushland areas, and therefore this node will not regularly apply in urban areas (including most parks).
	**Agricultural**	Applies to areas of large-scale cropping or grazing land. This node can usually be set to 0% of total impervious area after local authority approval.

Table 2.12 - Lumped MUSIC Node Type

(Water by Design, 2010)

Figure 2.17 - Split MUSIC model example diagram
(Water by Design, 2010)

2.9.3. Conclusion

MUSIC software by eWater will model the proposed development to manage the frequent flow. The software guidelines states that frequent flow management requires further investigation. This investigation has the potential to contribute to this study. Water quality will also be assessed through the same models. MUSIC is suitable for analysing the water quality and it currently its main purpose within the industry.
The split catchment approach will be used when modelling all of the catchment sizes. All historical meteorological data to be obtained from the eWater's toolkit *(eWater, 2020).*

2.10. CATCHMENT SCALE FACTOR/EFFECT

There is currently inadequate understanding about the catchment scale factor for improving hydraulic conditions for green infrastructures. The efficiency of green infrastructures in their associated catchment varies from site to site. Scaling green infrastructure practices to catchments is an emerging science *(Golden, H. and Hoghooghi, N., 2017).*

Catchment scaling factor considered the quantifying variation in the cumulative effect of green infrastructure on downstream waters, focusing largely on moving from plots to multiple nested catchment scales *(Golden, H. and Hoghooghi, N., 2017).* The visualisation of the scaling effects of green infrastructure is shown in **Figure 2.18**.

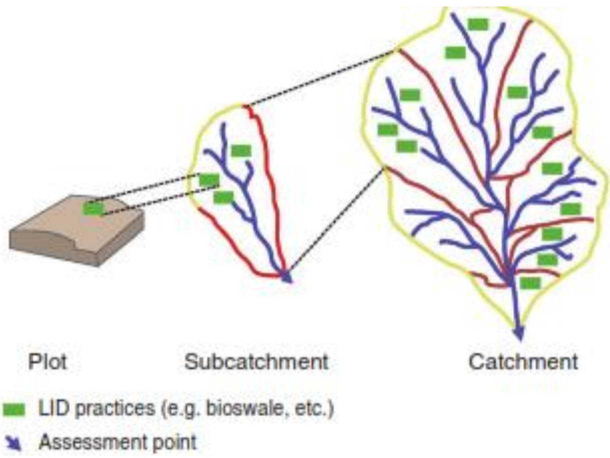


Figure 2.18 - Scaling effects of green infrastructure on downstream waters

*** LID is the United States version of WSUD*

(Golden, H. and Hoghooghi, N., 2017)

A key consideration for scaling green infrastructure to catchments is the plot scale and that of which the model is scaling to. It is important to determine the effect of the scale of measurement or modelling unit on the accuracy of the upscaling. For example, as the scale of the measurement or modelling unit coarsens (plot to suburban neighbourhood), the magnitude of the process, such as a flow path to the stream, may appear more attenuated *(Golden, H. and Hoghooghi, N., 2017).* This model effect of the scale on the flow path is shown in **Figure 2.19**. The single flow path's magnitude may decrease if the scale increases (from left to right in **Figure 2.19**). This is because the smaller scaled analyse along the flow path is minimised when upscaling, which reduces the flow path magnitude.

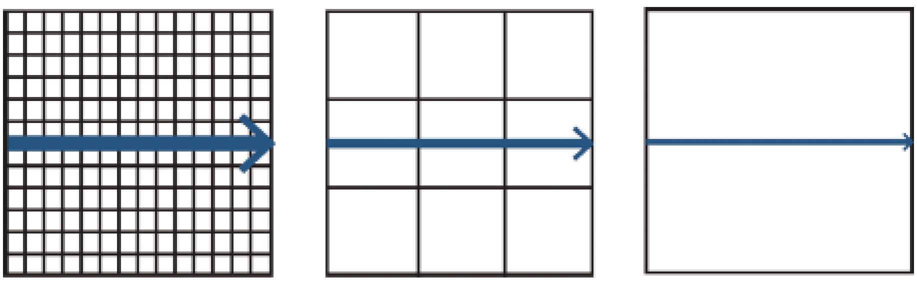


Figure 2.19 - The effect of the scale of a modelling unit on the magnitude of a flow path

(Golden, H. and Hoghooghi, N., 2017)

The green infrastructure are promising approaches for reductions in peak flow and runoff volume but exhibit varied potential for the attenuation of pollutant delivery to a stream or other surface water *(Golden, H. and Hoghooghi, N., 2017).*

The catchment-scale implementation of green roofs had a positive effect in terms of peak discharges *(Schmitter, P., Goedbloed, A., Galelli, S. and Babovic, V., 2016)*. Green roofs and permeable pavements exhibit considerable potential for minimizing rapid runoff and peak flows, although they may be less effective for solute and particulate matter retention *(Golden, H. and Hoghooghi, N., 2017).* The combination of green roofs with other infiltration-based technologies would further reduce the runoff volume and peak discharge and potentially increase the time of concentration *(Schmitter, P., et al, 2016)*. Green infrastructures can be used to meet hydrological targets of smaller catchment areas (i.e., lots, <0.1 km^2). The hydrologic target includes reducing peak flow volumes and returning baseflow to predevelopment conditions. However, research results across multiple studies are mixed with regard to how different green infrastructure contribute to these responses and the local-scale effects of green infrastructures on water quality *(Schmitter, P., et al, 2016)*. Scientific advances on how to upscale and evaluate local green infrastructures to catchments are emerging *(Schmitter, P., et al, 2016)*. There is a common topic across all of these studies and that is that the location and spatial distribution of green infrastructures throughout the landscape contributes to the catchment-scale effectiveness *(Schmitter, P., et al, 2016)*.

2.11. CONCLUSIONS

Planning and design of the development must adhere to the legislation and policies of the Authorities. Ipswich City Council and the Queensland Government are the authorities in the location of this investigation. The relevant subject of interest is the water quality and natural flood hazard.

Urban development decrease the quality of runoff water. Water quality treatment involves reducing pollutants and nutrients from natural waterways. The main pollutants, that have an inverse impact to the environment, are suspended solids, nitrogen, phosphorus and gross pollutants.

The development of urban areas is also a contributor to flash flooding. The pervious and impervious natural of the ground can alter the amount of stormwater runoff. Large amounts of runoff can cause erosion and damage to the local waterway environment. Retention devices help mimic nature and provide relief for urban stormwater runoff. All green infrastructure in this investigation contain retention properties.

The literature review has determined the process of investigating the green infrastructures. The lot layout of the development will be analysed at four different catchment sizes. These catchment sizes are lot, street, subdivision and suburb. Each lot will be designed with a minimum area, an Australian average house size, a minimum driveway width and frontage to a Council standard access road. The introduction to one and several green infrastructures will also be design as per the guidelines and standards found in the literature review. The computer model can then be run with different scenarios.

The investigation will use the computer software, MUSIC by eWater. It can be a tool to model and analyse the stormwater runoff and quality. Re-design of green infrastructure devices might be necessary if desired water quality objectives are not originally achieved. Stormwater runoff results from these computer models will be represented by hydrographs. These graphs will clearly highlight the impact of the green infrastructure. Graphs should include the data from predevelopment and post development without any green infrastructures. This data will assist in presenting the results of the green infrastructures.

CHAPTER 3

METHODOLOGY

3.1. INTRODUCTION

This chapter outlines the methodology used in this investigation. In the literature review it was recognised that computer modelling will be used to determine stormwater runoff. The preparation and details of each of these models will be described within the methodology. This will also include the design and detail of all green infrastructures. Catchments will be designed at a high-level and will detail the lot layout for each catchment size. Several items in the literature review will assist in the design of all of these elements.
A design storm will be selected and modelled to be applied to this investigation. This will maintain that the results are easily interpreted and conclusions can be made. The design storm will be selected as the largest storm to occur in the range of data collected.
The summary and analysation of the results will be presented on several hydrographs. This will assist in the comparison of each simulation.

3.2. METHODOLOGY OUTLINE

The methodology of this investigation will use the MUSIC software by eWater. The MUSIC models will assembled in accordance with the MUSIC Modelling Guidelines *(Water by Design, 2010)*. This software has a user friendly interface and is simple to learn and use. There was a small portion of training required to use this software. The methodology has not included the learning of the MUSIC software. All other steps of the methodology are discussed in this chapter. A basic outline of the steps of the methodology used in this investigation, are as followed:

1. **Site selection**
   The location was completed at early stages of this dissertation. This is because the state planning policy and local council planning policy had to be researched. Although the site location does determine most of the input parameters it is in fact insignificant to this investigation. The research could be completed at any location. Ipswich was chosen for reasons discussed within this chapter.
2. **Design the lot layout at high level for each catchment size**
   The research from the literature review will be utilised to design the lot layouts to be in accordance with Ipswich City Council. Design of the lot layout will be completed for the catchment sizes of single lot (1 lot), neighbourhood (10 lots), subdivision (100 lots) and suburb (1000 lots). Details of the catchments are discussed within this chapter
3. **Collect data from the site**
   All existing data to be collected from selected site. All previous research to be considered. Historical rainfall data collected from the Bureau of Meteorology (BOM). Range of data to be in accordance with the MUSIC Guidelines.
4. **Using collected data create a MUSIC template file**
   This involves importing rainfall and PET into template file. This template file is to be used on all models to be consistent.
5. **Create and run pre-development models for lot catchment**
   Using MUSIC software to model the pre-development conditions. Assume total area of the catchment is pervious. Source node for pre-development to comply

with the Forest source node parameters. This is completed to achieve the correct rainfall-runoff parameters, urban residential will produce incorrect numbers for the parkland area.

6. **Design green infrastructure**
   Using the design considerations in the literature review, a first-past design of green infrastructure will be completed. Design parameters will be included in this chapter.
7. **Create and run post development models**
   Using MUSIC software and the design catchments to model the post development conditions. Source node parameters to be detailed in this chapter.
8. **Create and run green infrastructure models**
   Use the MUSIC software, post development nodes and the treatment nodes to model the different combination conditions. Source and treatment node parameters to be detailed in this chapter.
9. **Check the water quality from green infrastructure is in accordance with relevant standards**
   Output water quality is assessed in model. If the pollutant reductions are not satisfactory, redesign of the green infrastructure is necessary. Return to step 6 and repeat until quality outcomes are in accordance with SPP.
10. **Checking accuracy of the model**
    MUSIC output results will be scrutinised with hand calculations and overall engineering judgement. This investigation can determine if MUSIC is a suitable software to analyse frequent flow management.
11. **Provide hydrographs to display results.**
    As described in previous chapters, hydrographs are the best method to display runoff from a storm event. This will assist in analysing the model's outputs.
12. **Summarise and analyse results**
    Items and patterns in the hydrographs are examined to analyse flow attributes, such as lag time, peak flow, raising limb and falling limb, time of concentration, volume of runoff, etc.

The methodology consist of these outlined twelve steps. This chapter will describe each step in further detail. For ease of duplicating and remodelling this investigation, each model parameter will be documented. If any models are lost during this investigation this record of parameters will assist in rebuilding the model.

The use of MUSIC software is common in South East Queensland. Majority of Councils in the area have standards and guidelines for each step of modelling. This methodology has been aligned with Ipswich City Council MUSIC recommendations.

3.3. SITE LOCATION

The site is located at Redbank Plains Recreational Reserve, Moreton Avenue Redbank Plains, Queensland, Australia. This is within the Ipswich City Council jurisdiction and within the Bremer Catchment which is approximately 2030km² (203,000 ha) in area. The Bremer River Catchment has six major waterways, these being the Bremer River, Bundamba Creek, Purga Creek, Reynolds Creek, Warrill Creek and Western Creek. Rainfall runoff from the site runs into the minor waterway, Goodna Creek and eventually finds its way to the Bremer River. Refer to **Figure 3.1** for a general map of the site area sourced from QLD Base Map within Ipswich Planning Scheme.

Figure 3.1 - QLD Base Map
(Ipswich City Planning Policy Scheme, 2019)

Ipswich City Council have adopted the same water quality interests defined in the state's planning policy. The city and surrounding areas experience diverse weather conditions resulting in severe weather events spanning both ends of the spectrum (e.g. droughts and flooding). These weather conditions in this area make the site interesting for building a case study as most of the major studies and observed data on green infrastructure have been completed in Melbourne and other parts of the world.

Water by Design is a team that has been working to improve sustainable water management practices. In January 2020 they completed a case study of the constructed wetland system at Redbank Plains with the assistance of Ipswich City Council, Synergy Solutions and BMTWBM *(Water by Design, 2020)*.

The area was experiencing issues with flooding downstream of the Redbank Plains Recreational Reserve. To solve the issue, a detention basin, vegetated swales and a stormwater harvesting wetland (5300m^2) were constructed in March 2016. This infrastructure converted the flooding threat into an alternative irrigation supply (up to 44ML/year) for the local sports fields, which potentially saves ratepayer funds *(Water by Design, 2010)*. Ipswich Council did partly fund the project with further funding from state authorities. The wetland also provides wetland habitat for local native birds and plants. The case study helped discover the importance for understanding soil properties and groundwater actions across large sites

Figure 3.2 has been extracted from Ipswich planning scheme, it indicates that the site is mostly located on recreation/parkland. This open space parkland has potential for development. The parkland topography is flat. The constructed wetland is positioned downstream from the parkland. This investigation will assume that this parkland will be developed. Developing parkland into medium density residential lots would require a change of land-use. The change of land-use will be assumed to be accepted by both Council and the Community. It should also be noted that the vacant land acts as a detention basin (90,000m^3). This is to be ignored in this research and assumed flooding impact will be developed further downstream to allow for this development.

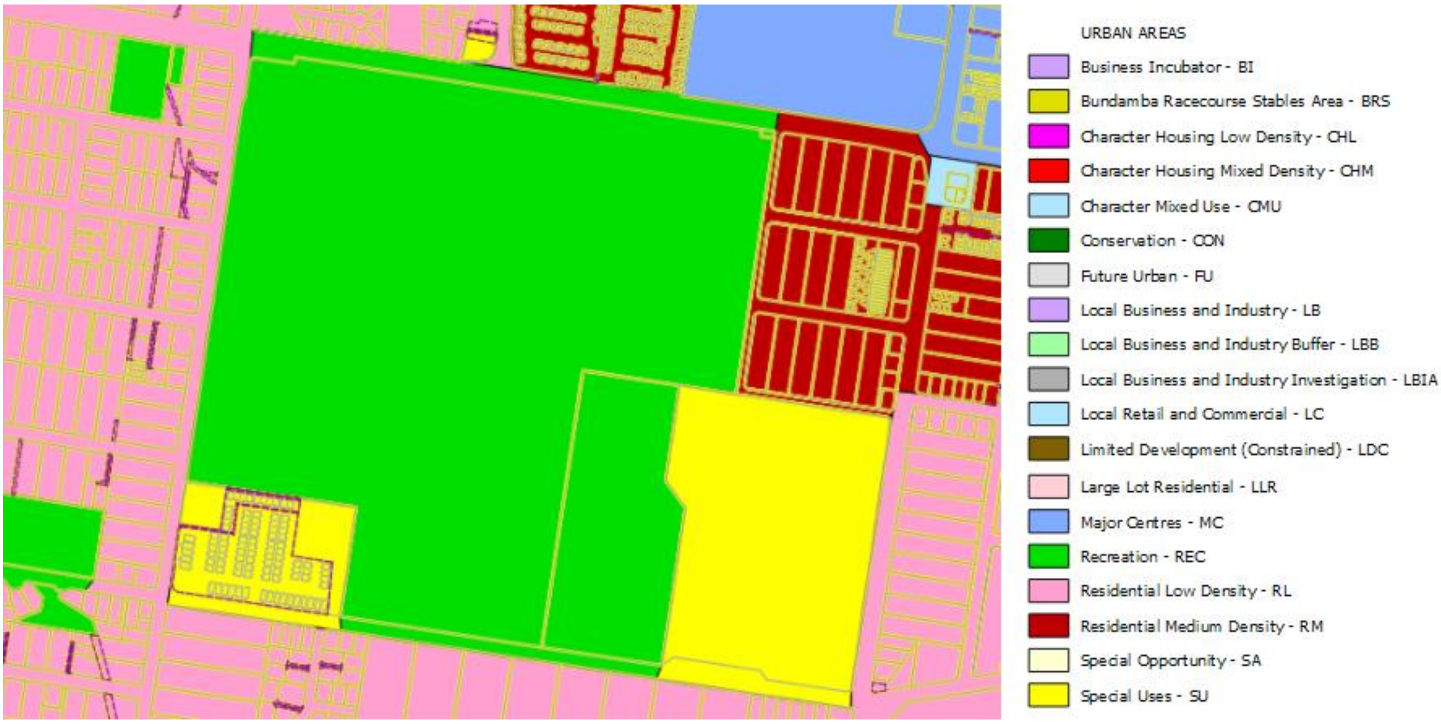


Figure 3.2 - Planning Scheme Land Use Zone Map & Legend
(Ipswich City Planning Policy Scheme, 2019)

The level of design of the urban residential subdivision will be completed at high level. With regards to this investigation the actual layout of lots in irrelevant.

The approximate area of the developable land is 715,000m^2 (71.5ha). The minimum lot size for medium density urban developments is 450m^2. The minimum road frontage length for that lot size is 15m. For the lot size catchment only half the road and verge is to be calculated. The road reserve will consume 120m^2 of total area. Lot width, 15 metres, multiplied by half the road reserve, 8 metres.

The total catchment size of the 1 lot is 570m^2. This area is calculated by adding together the lot size and the road reserve area (450m^2 + 120m^2). Therefore, to approximately calculate the maximum amount of lots that this development can hold, the development area of 715,000m^2 is divided by the residential lot catchment area of 570m^2. This is calculated to be 1,255 lots. This will be rounded down to a maximum of a 1,000 lots to allow for lot layout configurations and parklands. The parklands will host the green infrastructure, such as swales, basins and the constructed wetland.

The layout will be designed at a high level for 4 different catchment sizes to cater for the aim of this investigation. The four catchment sizes are:

- Single lot (1 lot)
- Neighbourhood / Street (10 lots)
- Subdivision (100 lots)
- Cluster of Subdivisions / Suburb (1,000 lots)

3.4. CATCHMENT LAYOUT DESIGN

The simulated residential development is to be design at a high-level. This level of design will be the approximate arrangement of detail design features. The single lot will be designed in accordance with Ipswich Planning Scheme. The minimum area for this parcel is to be adopted. This is formulated to avoid urban spread and increase the profitably of the development. The layout of the single lot will then be duplicated to match the next catchment size. The single lot catchment is to consist of a road, house, driveway and ground level. The ground level is to be assumed to be covered with turf and vegetation.

3.4.1.Single Lot Catchment

The single lot catchment is to contain a medium density residential land parcel. 450m^2 is the minimum area for the residential land parcel in the Ipswich Region. Minimum frontage of a lot with this area is 15 metres. This concludes that the dimensions of the lot are to be 15 x 30 metres. Refer the **Figure 3.3** for single lot catchment.

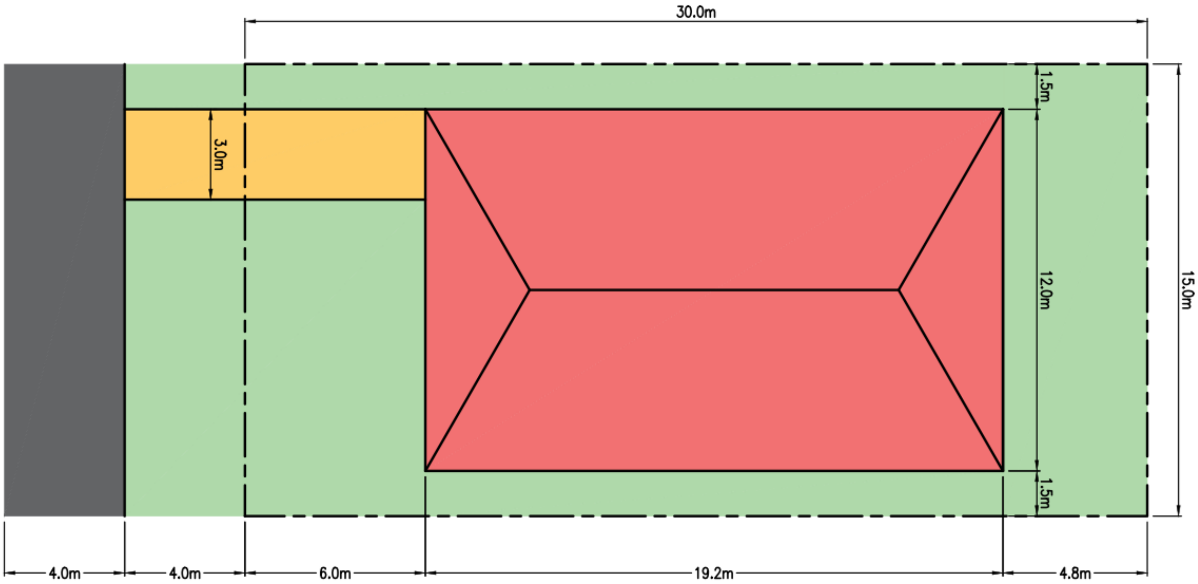


Figure 3.3 – Single Lot Catchment (1 Lot)

For this high-level design, each lot must have access to a road. The road reserve area for each lot will be included in the single lot catchment. The literature review identified that the road type is to be an Access Place/Street. This type contains a 16.0m road reserve with an 8.0m road width. The area of road and road reserve must be calculated to only service the single lot catchment. This will assist in duplicating for the larger catchments. Therefore, half the road and road reserve is to be provided for the full length of the lot. Area of half the road is $60m^2$ (15 x 4 metres). Area of half the verge is $60m^2$ (15 x 4 metres). Therefore, the total area of the road and road reserve is $120m^2$. The area of the total catchment is $570m^2$.

The average house is Queensland is $230.4m^2$ *(James, C. and Felsman, R., 2018)*. The house is to be setback 6 metres from the road frontage and have a minimum of 1.5 metres from side and rear boundaries. It was assumed that the average house builder will prefer the large proportion of vacant land to be in the backyard rather than the sides and front. The minimum side offsets were used, and the backyard was calculated as large as possible to suit the other catchment dimensions.

The minimum driveway width for a residential dwelling in the Ipswich region is 3 metres. This 3 metres width is to be used in this catchment. The minimum driveway width was selected and used because of the size of the lot frontage. The small lot frontage and verge will have to consider services and landscaping from Council. The driveway must travel 10 metres to run from the house to the road. Therefore, this area is already constricted and minimum dimensions must be used. The area of the driveway is $30m^2$ (3 x 10 metres).

This assigns the area of the ground level to be 249.6 m^2. All areas are represented in **Table 3.1**.

Catchment Split Type	Area (m^2)
House (Roof)	230.4
Road	60
Driveway	30
Ground Level (Turf)	249.6
Total Catchment Area	570

Table 3.1 – Area of Split Types in a Single Lot Catchment

3.4.2. Neighbourhood / Street Catchment

Since the single lot catchment was carefully planned, calculations for the Neighbourhood / Street Catchment will be straightforward. Refer to **Figure 3.4** for the neighbourhood / street catchment.

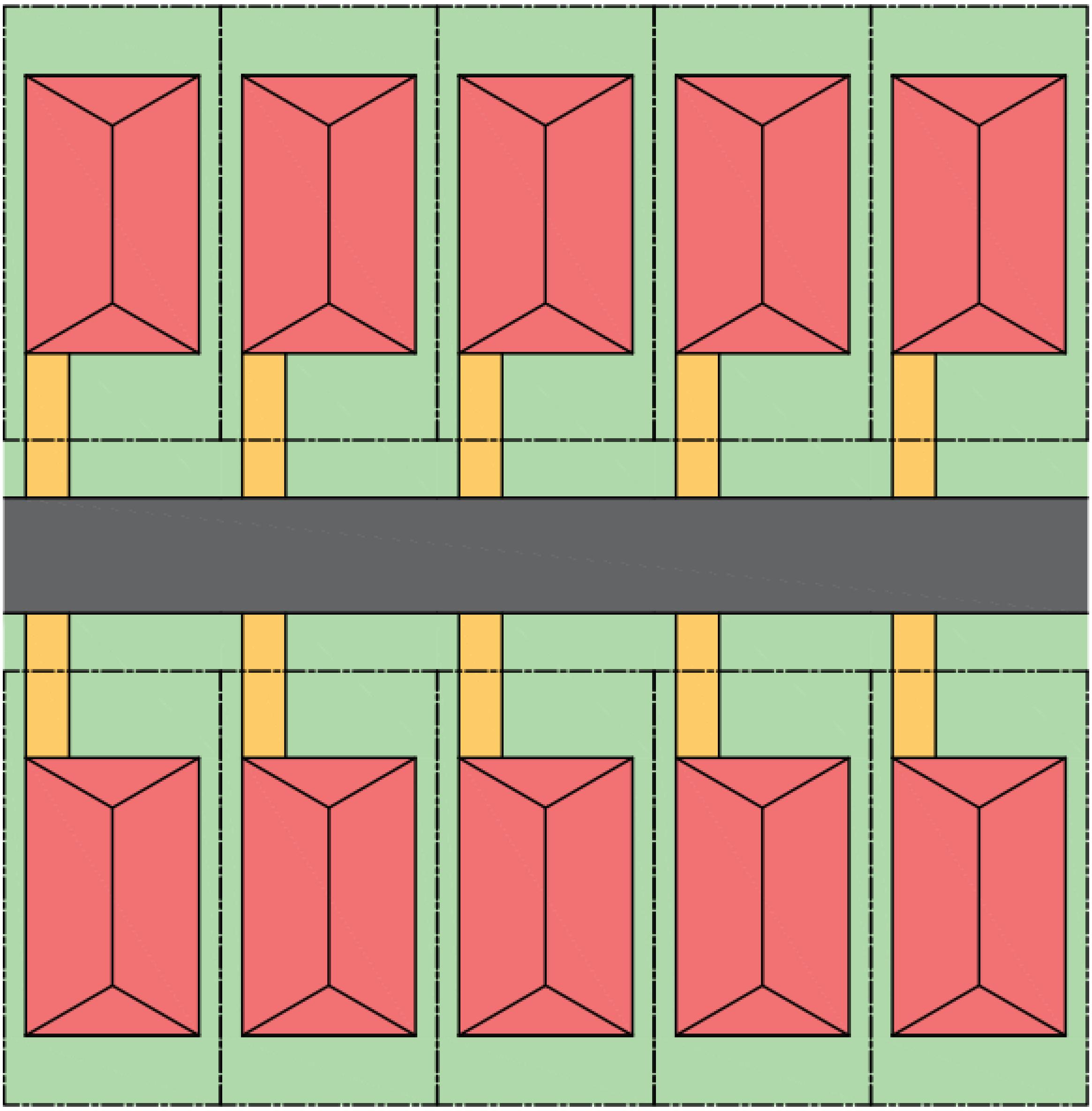


Figure 3.4 – Neighbourhood / Street Catchment (10 Lots)

The areas in this catchment can be calculated by multiplying the single lot catchment areas by 10. The road, driveway, roof and ground level are uniformly increased. All areas are represented in **Table 3.2**.

Catchment Split Type	Area (m^2)
House (Roof)	2,304
Road	600
Driveway	300
Ground Level (Turf)	2,496
Total Catchment Area	5,700

Table 3.2 – Area of Split Types in a Neighbourhood / Street Catchment

3.4.3. Subdivision Catchment

The subdivision catchment is unable to be calculated by a multiple of the single lot catchment because of the addition of the basin and parkland. The literature review discovered that the basin's area can be approximated by 1.5% times the contributing catchment. The total contributed area can be calculated by multiplying the total catchment area in the neighbourhood / street catchment by 10. The contributing area to the basin is equal to 57,000m^2. This can also be calculated by multiplying the single lot total area, 570m^2, by the number of lots. Therefore, the basin treatment area is 855m^2. This basin is position in the centre of the proposed parkland. Refer to **Figure 3.5** for the subdivision catchment.

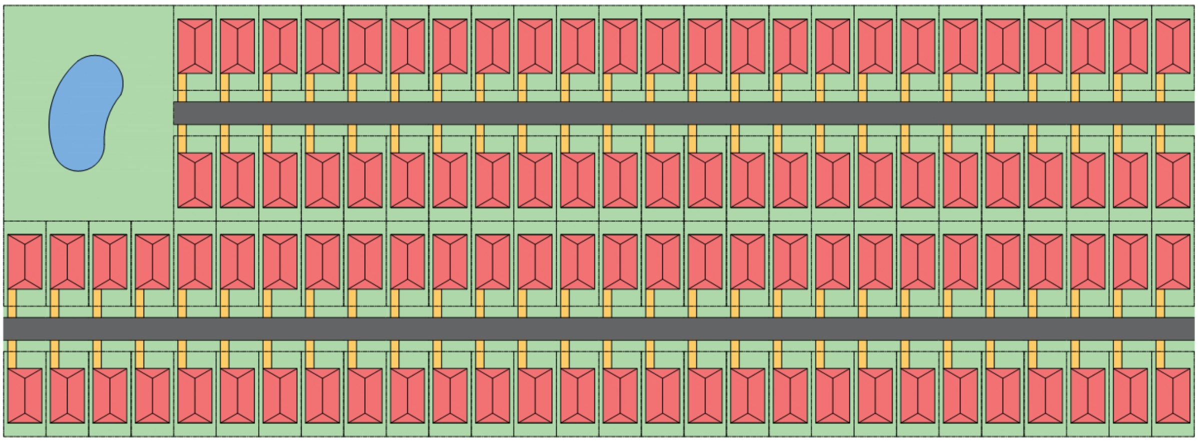


Figure 3.5 – Subdivision Catchment (100 Lots)

The roof, road, driveway and ground level areas in this catchment can be calculated by multiplying the neighbourhood / street associated areas by 10. These catchment areas are uniformly increased. The basin and parkland areas to be a separate catchment split type. The parkland catchment area is the dimensions of 8 single lot catchments. That gives the total parkland, including the basin treatment, an area of 4,560m^2. Without the basin treatment area, the parkland area for the basin is equal to 3,705m^2. The total subdivision catchment area can be calculated by adding the basin area to the residential split catchments. All areas are represented in **Table 3.3**.

Catchment Split Type	Area (m^2)
House (Roof)	23,040
Road	6,000
Driveway	3,000
Ground Level (Turf)	24,960
Basin Treatment Area	855
Basin Parkland	3,705
Total Catchment Area	67,260

Table 3.3 – Area of Split Types in a Subdivision Catchment

3.4.4. Cluster of Subdivisions / Suburb Catchment

The cluster / suburb catchment is unable to be calculated by a multiple of subdivision catchment because of the addition of the wetland and its associated parkland. The literature review discovered that the wetland's area can be approximated by between 2 - 10% times the contributing catchment. This investigation will size the constructed wetland by calculating 2% of the total contributed area. This is a larger size to the existing wetland. The existing wetland contributing catchment did contain of mostly pervious parkland. The new wetland is to receive urban runoff from impervious surface, therefore it must increase in size. To exclude all basins and wetlands, this can be calculated by multiplying the amount of lots by 570. The contributing area to the wetland is calculated to be equal to 570,000m^2. Therefore, the wetlands area is 11,400m^2. This wetland is position in the centre of the proposed parkland. Refer to **Figure 3.6** for the cluster of subdivisions / suburb catchment.

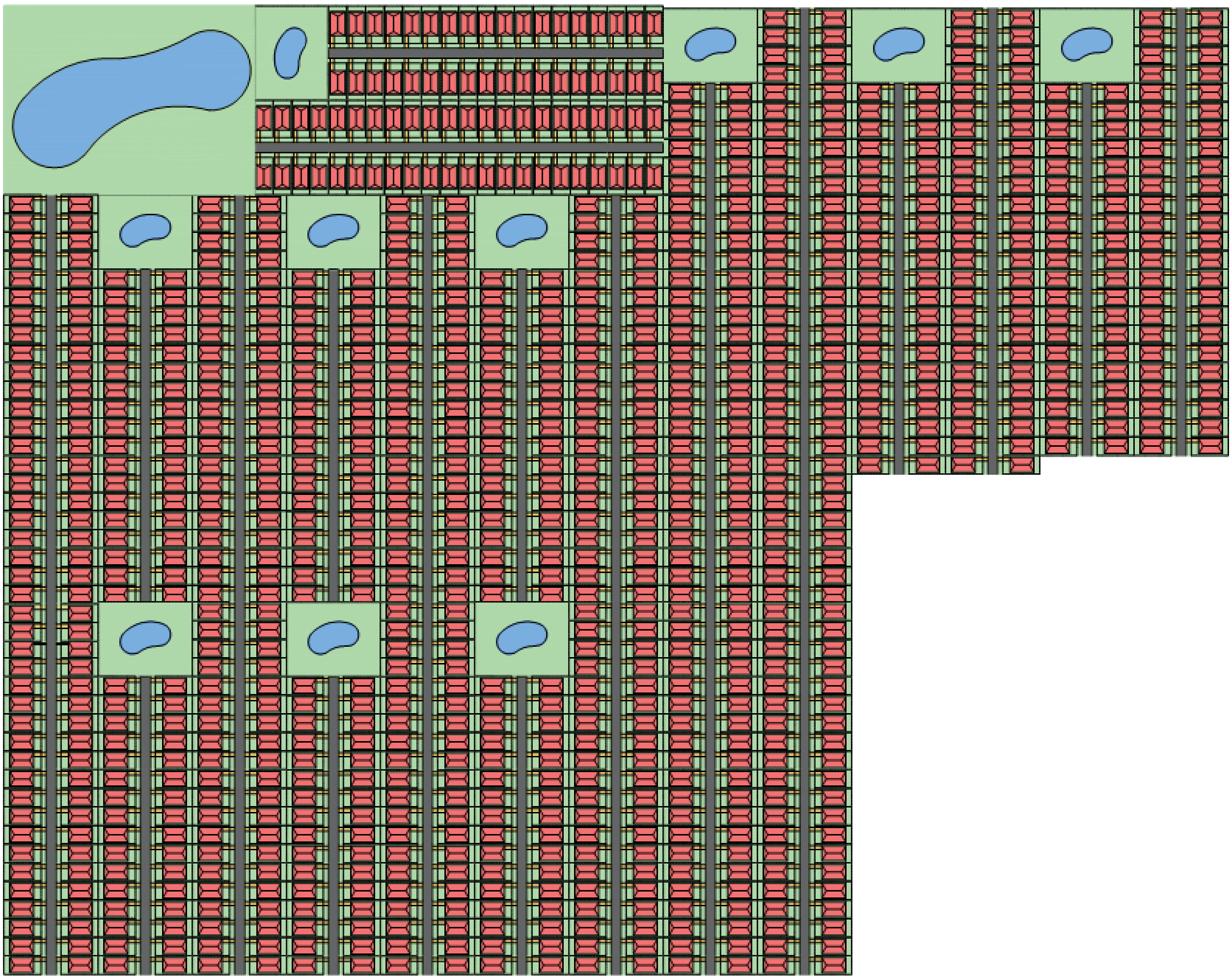


Figure 3.6 – Cluster / Suburb Catchment (1,000 Lots)

The areas in this catchment can be calculated by multiplying the subdivision catchment areas by 10. The road, driveway, roof, ground level, basin treatment area and basin parkland are uniformly increased. The wetland and associated parkland areas to be a separate catchment split type. The parkland catchment area is the dimensions of 56 single lot catchments. That gives the total parkland (including wetland) an area of 31,920m^2. Without the constructed wetlands, the parkland area for the wetland has an area of 20,520m^2. The addition of these split catchments to calculate the total cluster / suburb catchment area. All areas are represented in **Table 3.4**.

Catchment Split Type	Area (m^2)
House (Roof)	230,400
Road	60,000
Driveway	30,000
Ground Level (Turf)	249,600
Basin Treatment Area	8,550
Basin Parkland	37,050
Wetland Treatment Area	11,400
Wetland Parkland	20,250
Total Catchment Area	714,510

Table 3.4 – Area of Split Types in a Cluster / Suburb Catchment

The overall proposed development continuously considered the existing lot area and shape during design. The overlay of the development was developed on top of DCDB (Digital Cadastral Database) boundaries is shown in **Figure 3.7**. From this figure, the preliminary design layout is recognised to be located fully within the existing boundary. It must be noted that this layout is at a basic high-level. Further investigation into the lot layout would be required prior to developing this parcel of land. The number of basins and parklands would be expected to reduce to one or two larger basins. However, for the purposed of this investigation this lot layout will be acceptable.

Figure 3.7 – Overall Development in Location with DCDB Boundaries

3.5. MUSIC MODEL SETUP

Several models are required for this investigation. First model will be the pre-development models created without any urbanisation. Next model will be the post development models created without any infrastructure in the designed catchments. The next models will include the green infrastructures. There are 20 models, in total, within this investigation. List of models are as followed:

Single Lot Catchment Models

1. Pre-development Model
2. Post development Model
3. Green Roof Model
4. Green Roof and Permeable Pavement Model

Neighbourhood / Street Catchment Models

5. Pre-development Model
6. Post development Model
7. Green Roof Model
8. Green Roof and Permeable Pavement Model

Subdivision Catchment Models

9. Pre-development Model
10. Post development Model
11. Green Roof Model
12. Green Roof and Permeable Pavement Model
13. Green Roof, Permeable Pavement and Bio-retention Basin Model

Cluster of Subdivisions / Suburb Catchment Models

14. Pre-development Model
15. Post development Model
16. Green Roof Model
17. Green Roof and Permeable Pavement Model
18. Green Roof, Permeable Pavement and Bioretention Basin Model
19. Green Roof, Permeable Pavement, Bioretention Basin and Vegetated Swale Model
20. Green Roof, Permeable Pavement, Bioretention Basin, Vegetated Swale and Constructed Wetland Model

Refer to **Appendix C** for all of these MUSIC model arrangements. To set up each of these MUSIC models the following steps are to be undertaken:

1. Historical rainfall data collection inputted (Rainfall and evapo-transpiration)
2. Define source node
    a. Defining catchment area
    b. Define input rainfall runoff parameters
    c. Define input pollutant parameters
3. Define treatment and other nodes
4. Link nodes
5. Run MUSIC model simulation
6. Check Water Quality Output
7. If Water Quality is not satisfactory, increase green infrastructure attributes and re-run MUSIC model simulations again. Repeat until water quality is satisfactory.

Figure 3.8 shows a schematic diagram of the modelling process that Engineers and Designers use to model development projects. The model in this investigation to follow a similar process method.

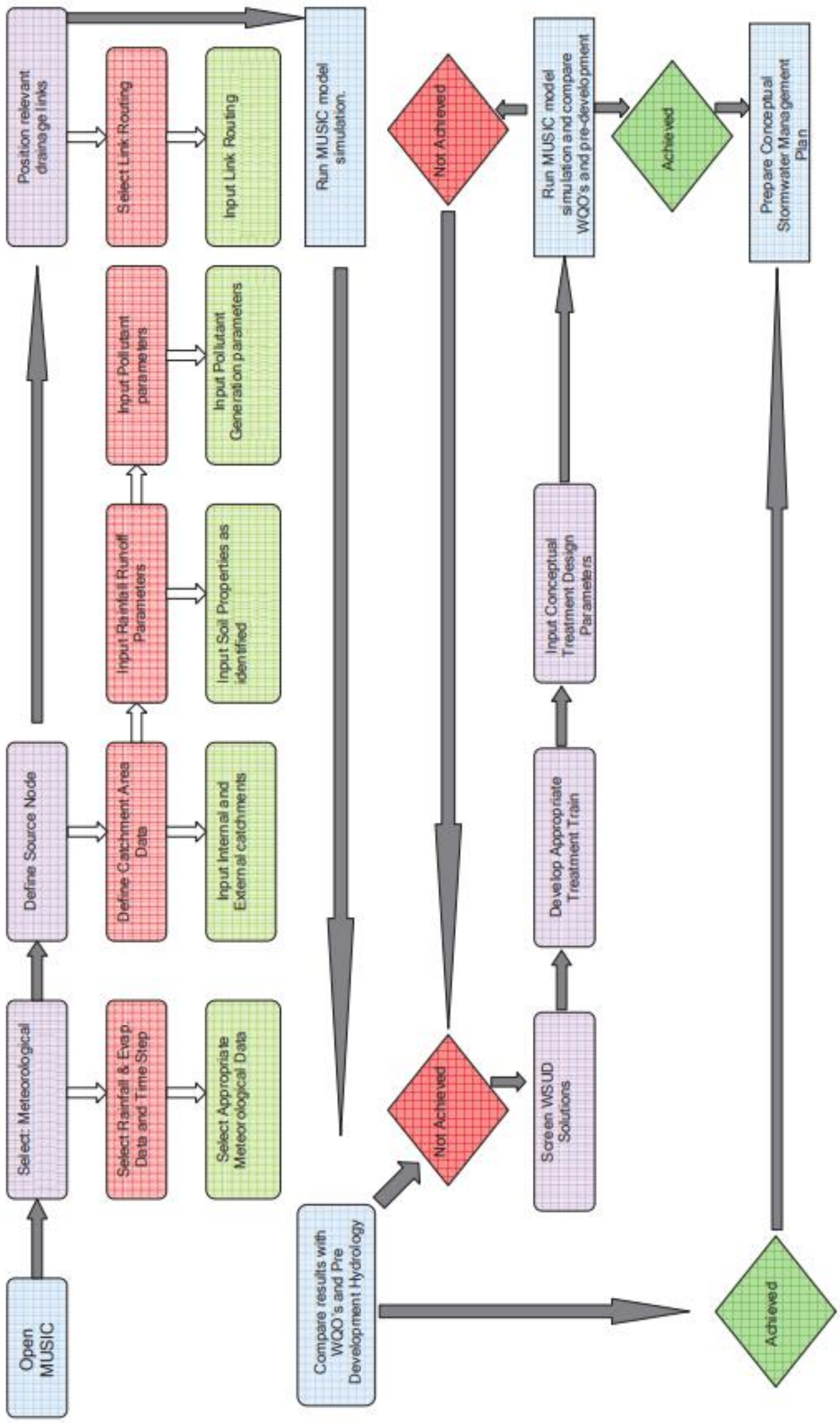


Figure 3.8 – Schematic of MUSIC modelling process
(Kuringgai Council, 2006)

3.5.1.Historical Rainfall Data Collection

Historical rainfall data to be collected from a selected rainfall station. Refer **Figure 2.16** for a map of these station location across South East Queensland. The closest rainfall station to the site is to be used to collect data. **Appendix B** has details of all the stations in South East Queensland. The locality of the site is on the Eastern region of the Ipswich area. Therefore, the selected station for the investigation will be;

- station ID number: 40659, Greenbank, Thompson road.

The rainfall station was then explored in the eWater pluviograph rainfall data tool kit software. This software package is available online and is provided by Bureau of Meteorology (BOM). The toolkit can also be used to find further information about the station. This includes the station's name, number, location, elevation and the station's first and last rainfall data entry. **Figure 3.9** shows the Greenbank station selected in the toolkit with all the station's further details.

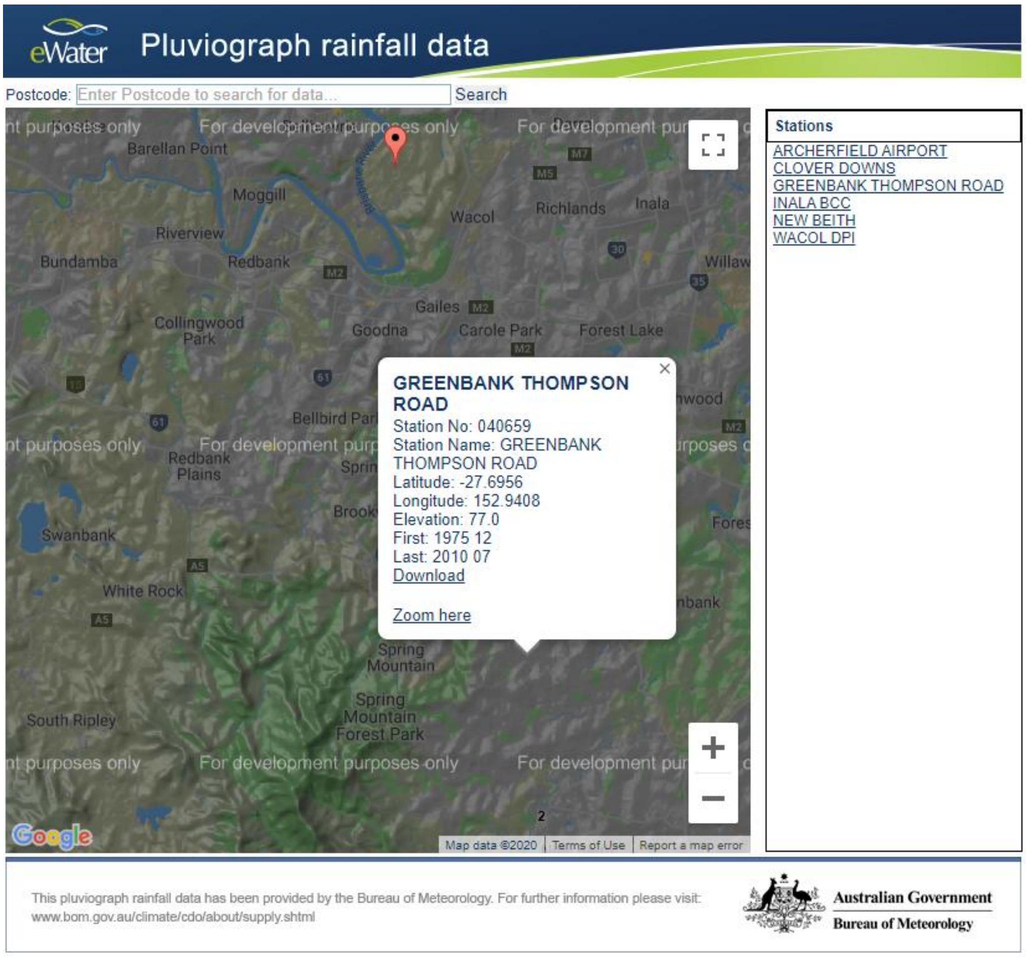


Figure 3.9 – Greenbank Selected on eWater Pluviograph Rainfall Data Toolkit
(eWater, 2020)

The station's rainfall data can be downloaded from this site. Download hyperlink can be seen in **Figure 3.9**. This data is downloaded as a '.dat' file (this is just a generic data file that the MUSIC software use to read meteorological data).

A new template file can be created at the MUSIC default home screen. The home screen is shown in **Figure 3.10**. Here you make a new project and import the rainfall data. To avoid continually loading the meteorological data a MUSIC template file was specifically made for the site.

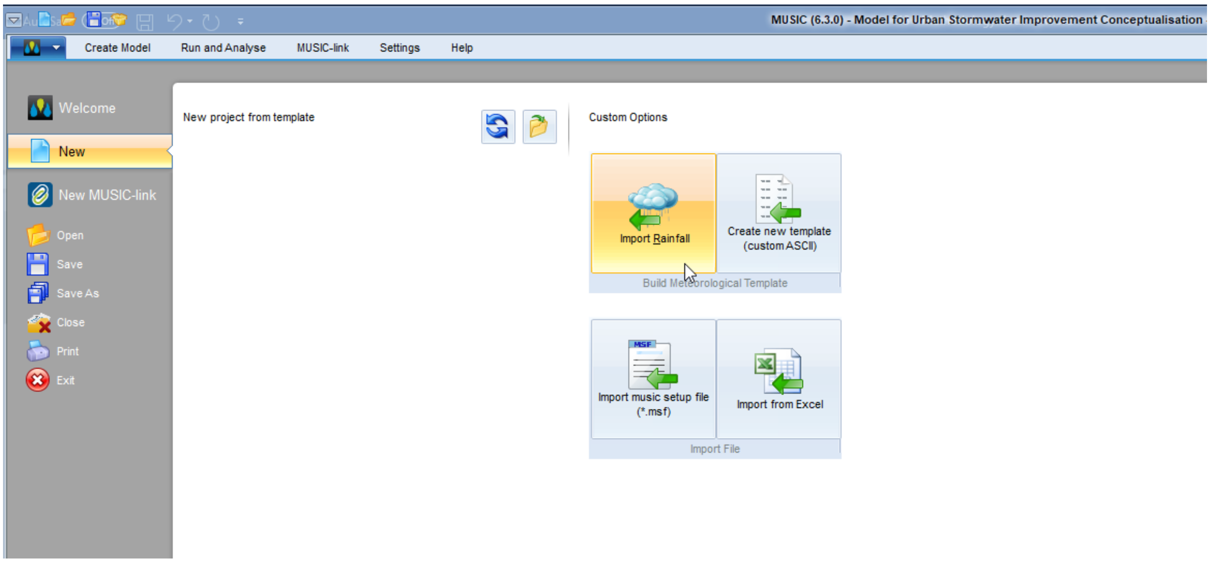


Figure 3.10 – MUSIC default home screen

Figure 3.11 is a screen capture of the meteorological template builder in MUSIC. The rainfall data downloaded from toolkit was browsed and imported into MUSIC software. The climate period was adjusted to the start date, 01/01/1980 and to the end date of 31/12/1989. This climate period was extracted from the table in **Appendix B**. The climate period will be important to nominate a design storm and check the water quality output. The rainfall data time step will be set to 6 minutes. The low time step will increase the model's accuracy as discover in the literature review. The potential evapo-transpiration (PET) was imported from the monthly average volumes, also located in **Appendix B**. The monthly averages to be manually imported into the PET template builder. **Figure 3.12** shows the PET data imported for the Greenbank Thompson Road station.

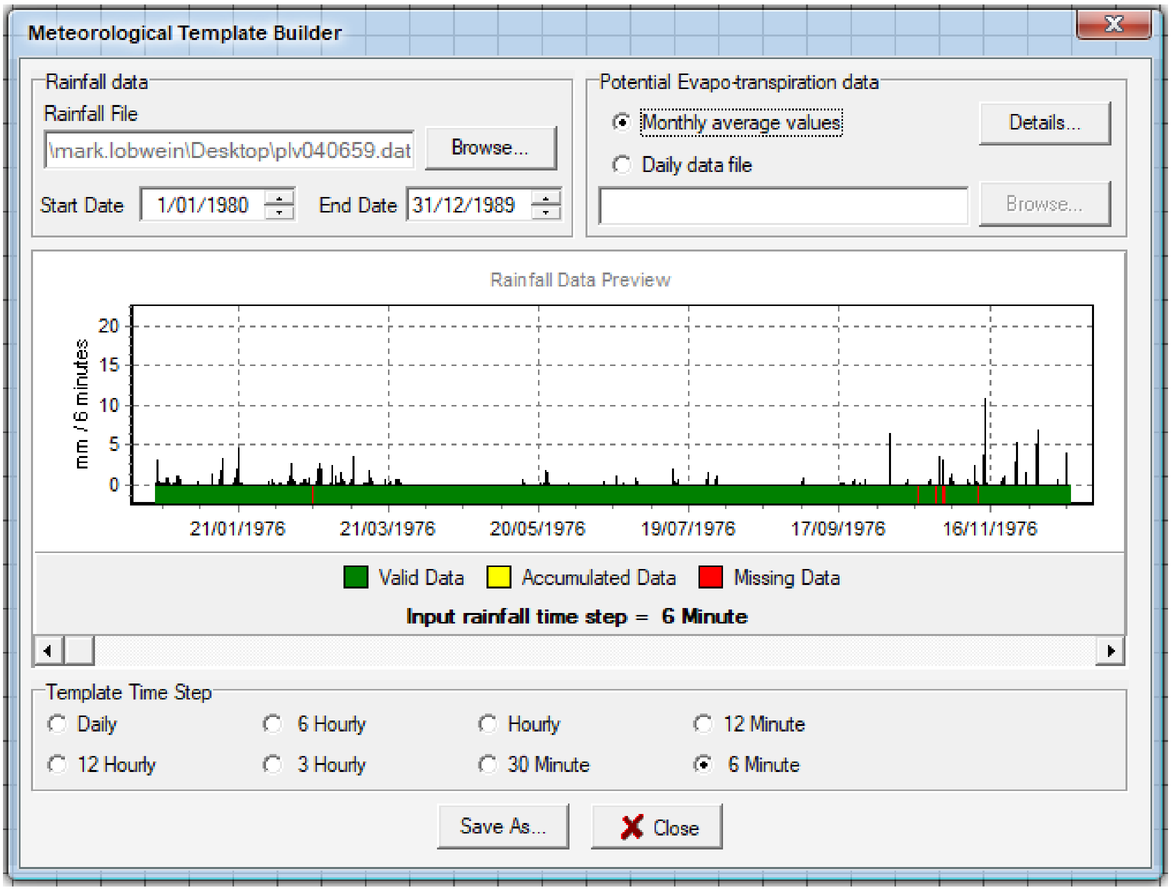


Figure 3.11 – MUSIC Meteorological Template Builder

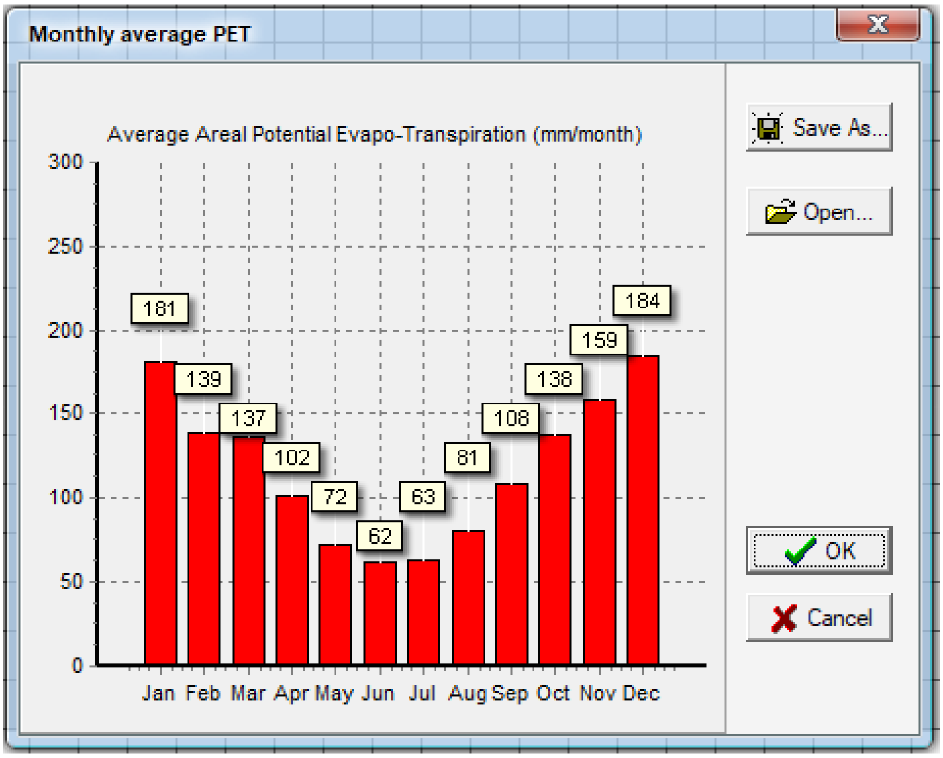


Figure 3.12 – MUSIC Potential Evapo-transpiration Template Builder

3.5.2. Define Source Nodes

3.5.2.1. Defining Catchment Area

The areas of the catchment are defined in the source nodes in the unit of hectares. The split catchment method involves dividing each element of the catchment into separate node. These nodes also require the zoning/surface type and the percentage fraction of impervious/pervious area. Source nodes are unable to be linked to each other and modelling will have to consider this constraint. Imported flow can be used to add more runoff to the node than the catchment rainfall input. MUSIC uses the fluxes options in the menu to output data to a '.csv' file. These flux options, within each node, will be used to output the data from the model. **Table 3.5** is the catchment parameters used in the post development catchments.

Location	Zoning/Surface type	Percentage Impervious (%)	Percentage Pervious (%)
Urban Residential (Ground Level)	Mixed	15	85
Urban Residential (Road)	Sealed road	100	0
Urban Residential (Driveway)	Sealed road	100	0
Urban Residential (Roof)	Roof	100	0

Table 3.5 – Post Development Catchment Parameters

The road, driveway and road are modelled as 100% impervious. It is a common to analyse this type of surface as impervious, although in practice this is not entirely true. The ground level has been assumed at 15% impervious area. This is to allow for garden sheds, patios, footpath and other impervious surfaces that might be constructed. The other 85% can be modelled as pervious land because it usually contains grass, gardens, vegetation, etc. The pre-development source node can assume the full catchment contains 100% pervious area. The current land use has no impervious surface and this is a reasonable assumption due to the existing land-use.

3.5.2.2. Define Input Rainfall-Runoff Parameters

These parameters include the properties for impervious area, pervious area and groundwater. All these parameters are to match the MUSIC guidelines for South East Queensland. Refer to **Table 3.6** for the recommended MUSIC rainfall-runoff parameters. The pervious area and soil parameters can significantly affect model results when modelling areas with <10% impervious areas *(Water by Design, 2010)*. Important to note that MUSIC produces an error message when the soil storage capacity is outside the range of 10 and 400mm. However this message should be ignored, 500mm is generally appropriate in South East Queensland *(Water by Design, 2010).*

Parameter	Land Use			
	Urban Residential	Commercial and Industrial	Rural Residential	Forested
Rainfall threshold (mm)	**1**	1	1	1
Soil storage capacity (mm)	**500**	18	98	120
Initial Storage (% capacity)	**10**	10	10	10
Field capacity (mm)	**200**	80	80	80
Infiltration capacity coefficient a	**211**	243	84	200
Infiltration capacity coefficient a	**5.0**	0.6	3.3	1.0
Initial Depth (mm)	**50**	50	50	50
Daily recharge rate (%)	**28**	0	100	25
Daily baseflow rate (%)	**27**	31	22	3
Daily deep seepage rate (%)	**0**	0	0	0

Table 3.6 – Recommended MUSIC Rainfall-Runoff Parameters
(Water by Design, 2010)

For pre-developed the forested rainfall-runoff parameters to be implemented. This scenario to also use the pollutant parameters of forested node.

3.5.2.3. Define Input Pollutant Parameters

Runoff pollutant concentrations can be generated stochastically (from a defined mean and standard deviation) or by a constant mean concentration. For development applications the stochastic option must be used for modelling stormwater runoff and treatment *(Water by Design, 2010)*.

Flow Type	Surface Type	TSS $\log^{10}$ values		TP $\log^{10}$ values		TN $\log^{10}$ values	
		Mean	**St. dev.**	**Mean**	**St. dev.**	**Mean**	**St. dev.**
Baseflow parameters	Roof	N/A	N/A	N/A	N/A	N/A	N/A
	Roads	1.00	0.34	-0.97	0.31	0.20	0.20
	Ground level	1.00	0.34	-0.97	0.31	0.20	0.20
	Forested	0.51	0.28	-1.79	0.28	-0.59	0.22
Stormflow parameters	Roof	1.30	0.39	-0.89	0.31	0.26	0.23
	Roads	2.43	0.39	-0.30	0.31	0.26	0.23
	Ground level	2.18	0.39	-0.47	0.31	0.26	0.23
	Forested	1.90	0.20	-1.10	0.22	-0.075	0.24

Table 3.7 – Pollutant Export Parameters for Split Urban Residential Catchment ($\log^{10}$ values)
(Water by Design, 2010)

First source node to be defined is the pre-development source node. There are also four source nodes to be defined as part of the post development. They are the roof, ground level, driveway and road sources.

3.5.2.4. Pre-development Source Node

The predevelopment source node is to be created for the modelling of the natural run-off flow. The ideal results from the implementation of the green infrastructure in this investigation, will be that the run-off flow will return to the pre-developed/natural flow behaviour. Therefore, it is important to model the existing catchment prior to development. This will assist in the analysation of the results. This source node is set up with the pollutants and rain-fall parameters of that in a forested source node. Refer to **Figure 3.13** for the setup of the source node within the MUSIC software.

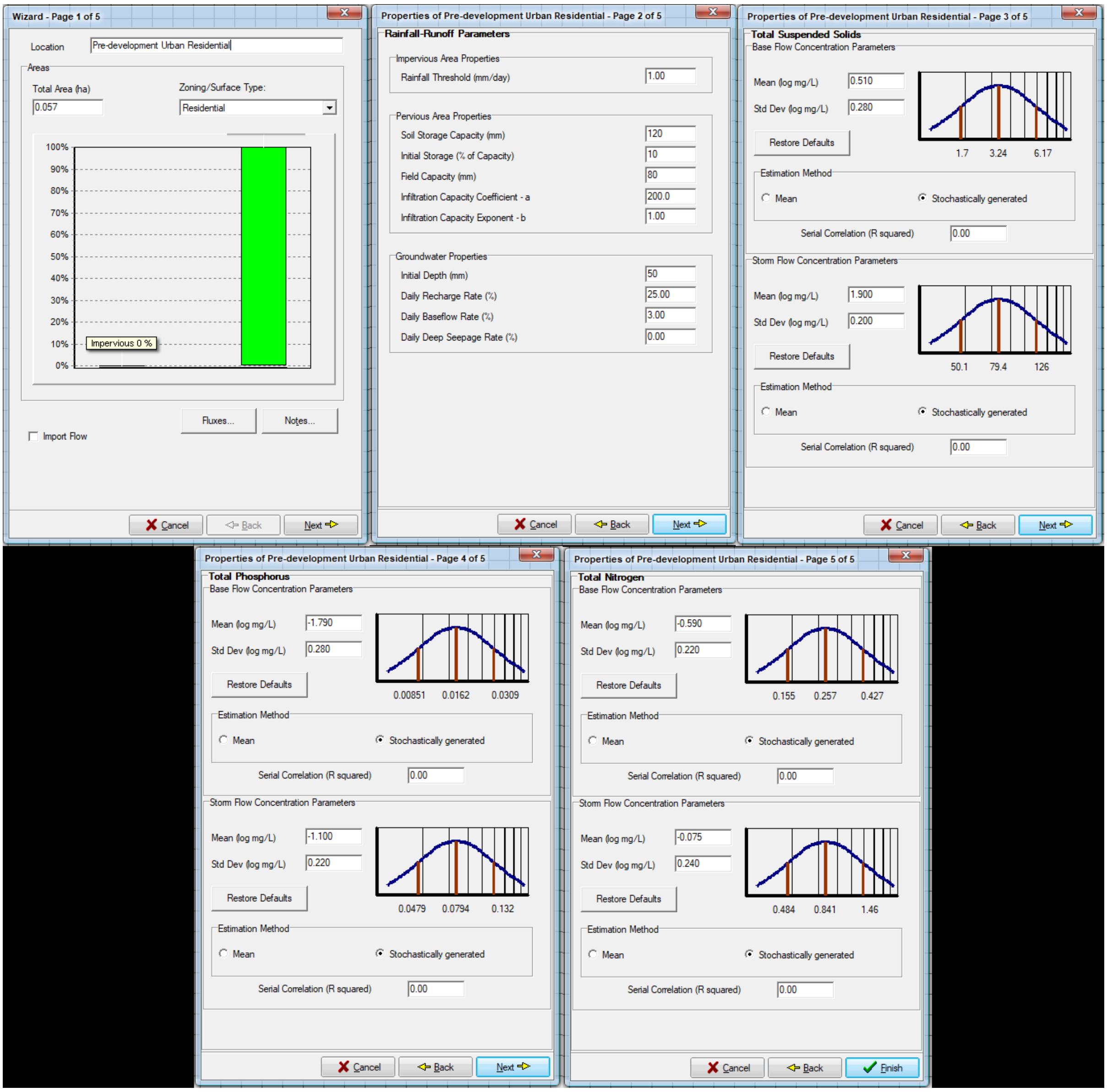


Figure 3.13 – Pre-development Define Source Node

3.5.2.5. Urban Residential (Roof) Source Node

The roof source node's purpose is to model how the rainfall run-off flows from the house's roof in the catchment. It is important to understand the flow changes caused from the introduction of the impervious roof. This flow must be analysed prior to the installation of any green infrastructure, particularly the green roof system. Refer to **Figure 3.14** for the setup of the source node within the MUSIC software. All source nodes setup in accordance with MUSIC guidelines.

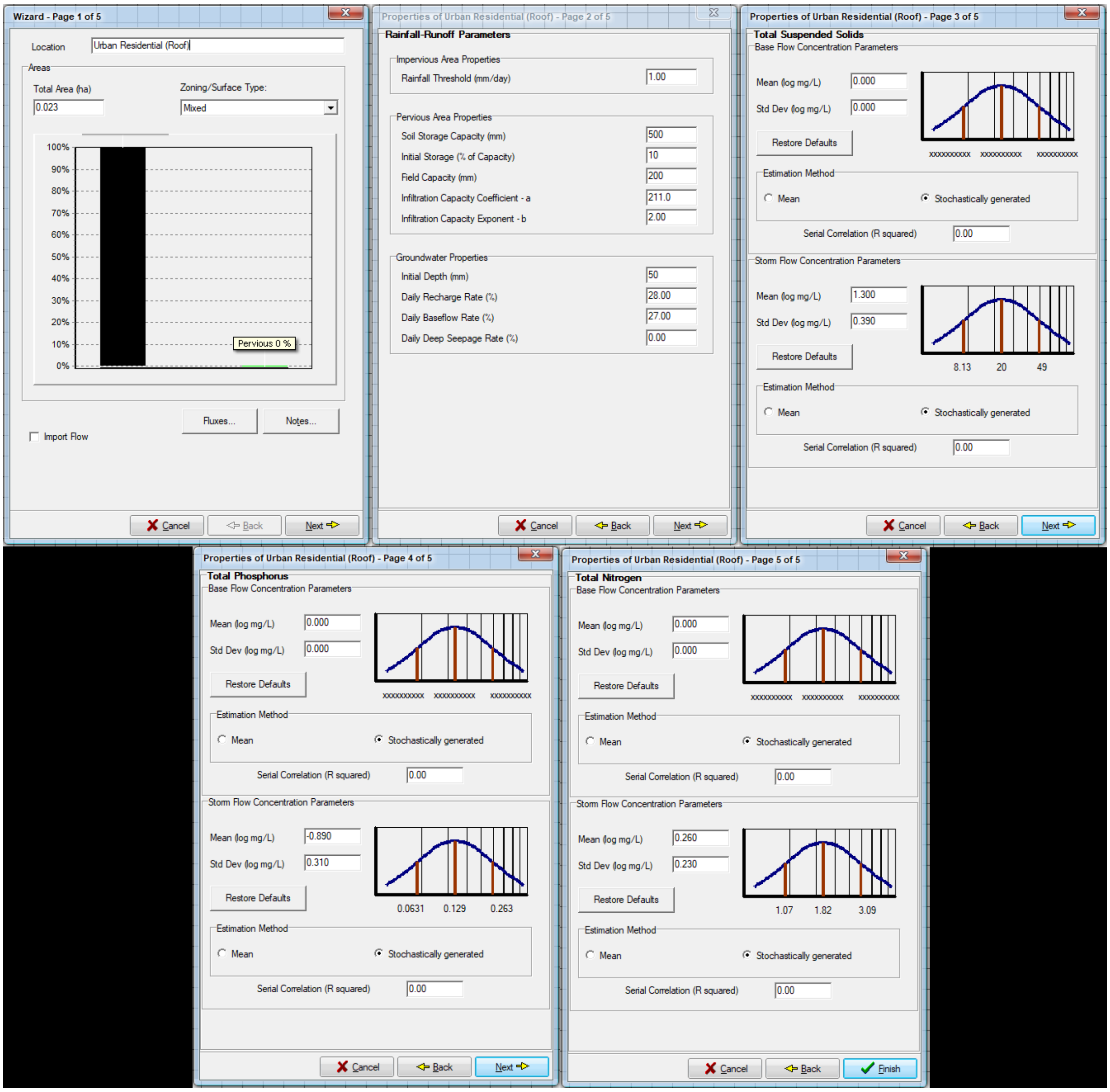


Figure 3.14 – Urban Residential (Roof) Define Source Node

3.5.2.6. Urban Residential (Ground Level) Source Node

The ground level source node's purpose is to model how the rainfall run-off flows from the open areas in the catchment. It is important to understand the flow changes caused from the introduction of the 15% impervious area. This flow must be analysed prior to the installation of any green infrastructure. Refer to **Figure 3.15** for the setup of the source node within the MUSIC software. All source nodes setup in accordance with MUSIC guidelines.

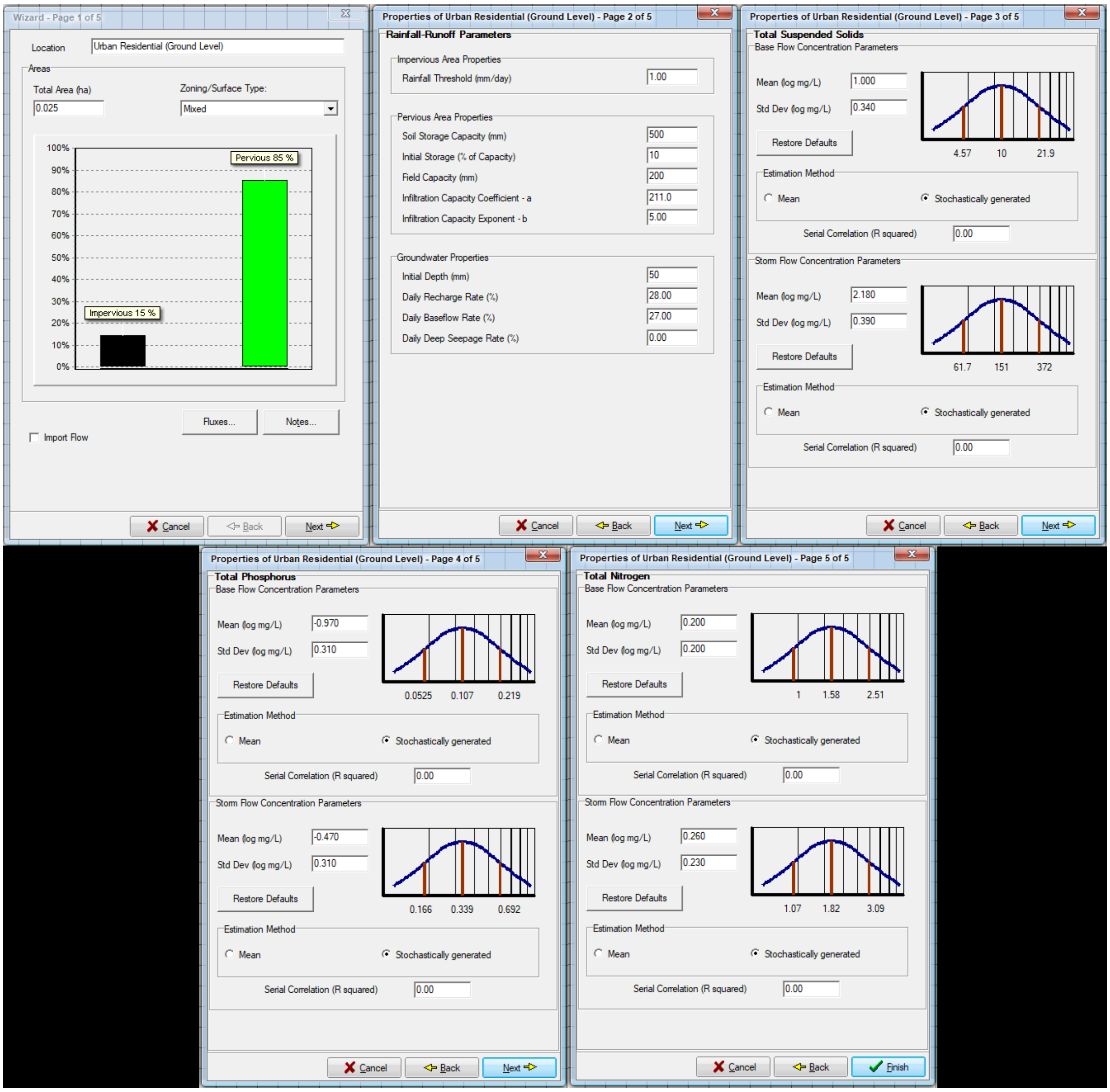


Figure 3.15 – Urban Residential (Ground Level) Define Source Node

3.5.2.7. Urban Residential (Driveway) Source Node

The driveway source node's purpose is to model how the rainfall run-off flows from the driveway in the catchment. It is important to understand the flow changes caused from the introduction of the impervious driveway. This flow must be analysed prior to the installation of any green infrastructure, particularly the permeable pavement. This source node is set up similar to the road source node. Refer to **Figure 3.16** for the setup of the source node within the MUSIC software. All source nodes setup in accordance with MUSIC guidelines.

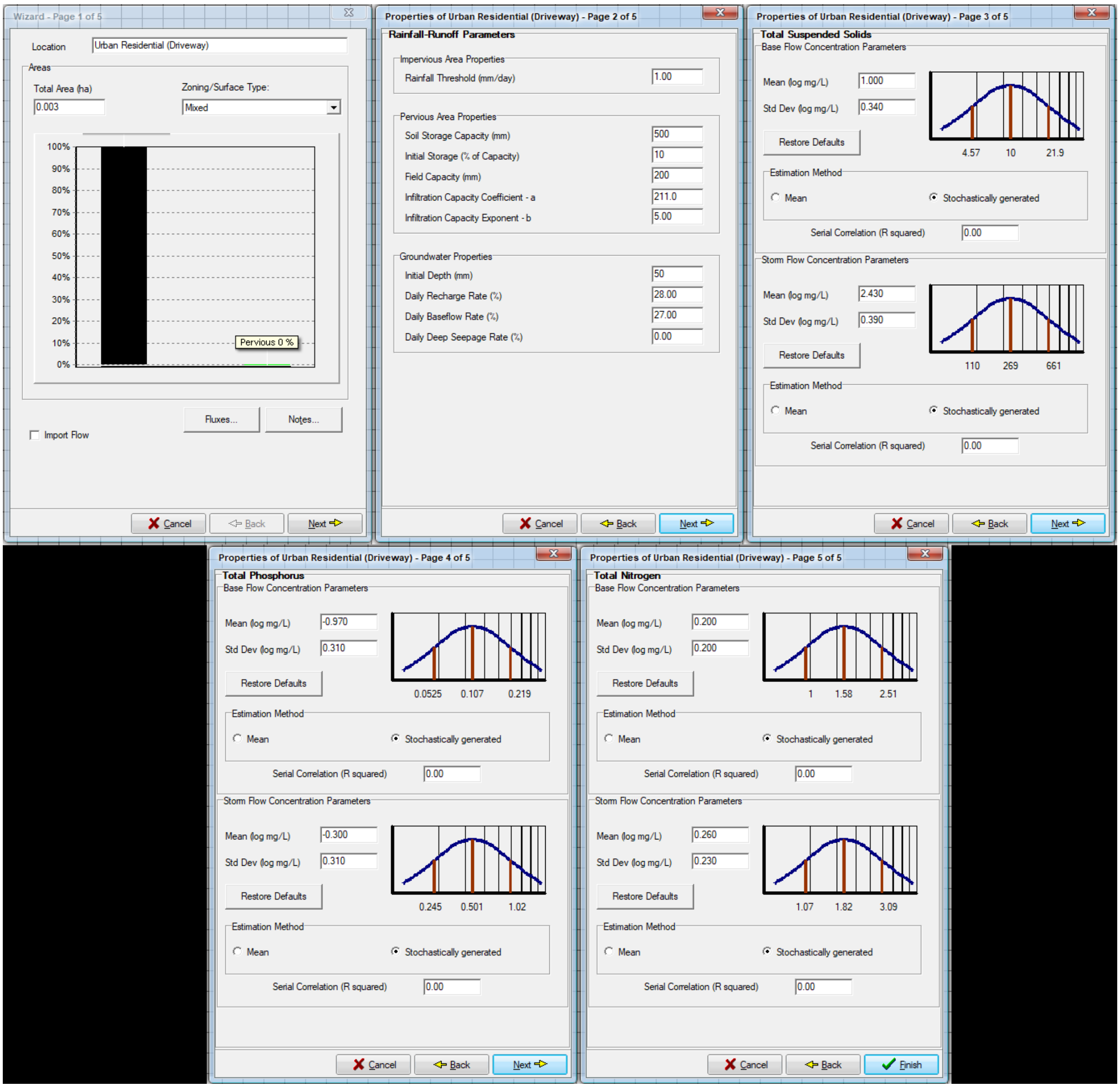


Figure 3.16 – Urban Residential (Driveway) Define Source Node

3.5.2.8. Urban Residential (Road) Source Node

The road source node's purpose is to model how the rainfall run-off flows from the local road in the catchment. It is important to understand the flow changes caused from the introduction of the sealed road. This flow must be analysed prior to the installation of any green infrastructure, particularly the permeable pavement. Refer to **Figure 3.17** for the setup of the source node within the MUSIC software. All source nodes setup in accordance with MUSIC guidelines.

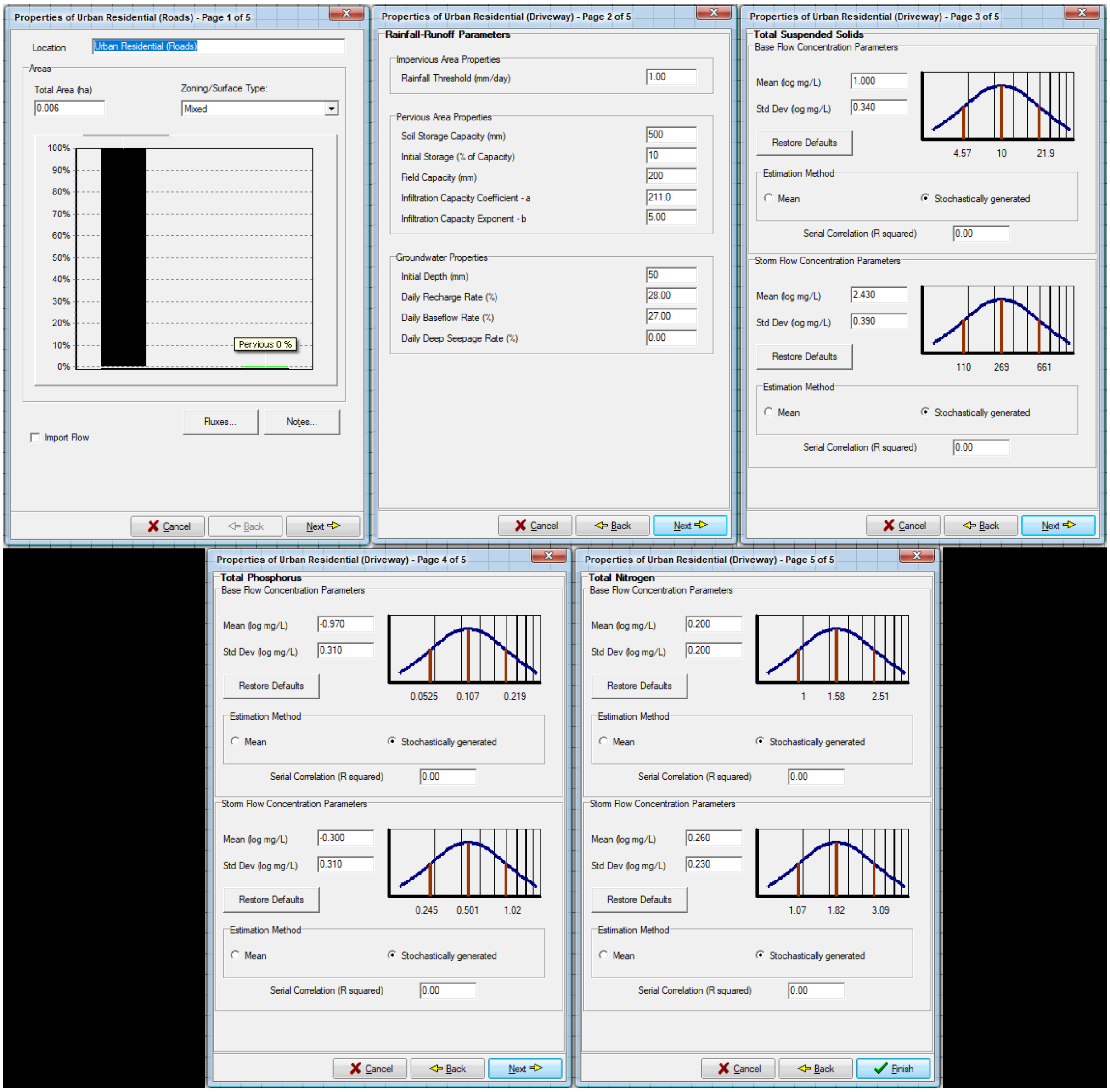


Figure 3.17 – Urban Residential (Road) Define Source Node

3.5.3.Link Nodes

The Drainage Link, as its name implies, links flows from one node to the next downstream node. There are two types of links, primary and secondary. Refer to **Figure 3.18** for how these links are displayed in MUSIC.

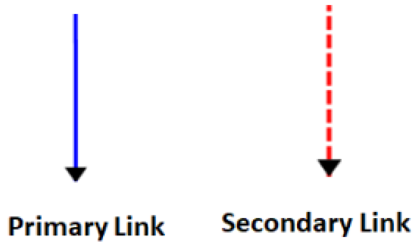


Figure 3.18 – Two Different Link Types

The main drainage path will use the Primary drainage link. If there are minor flow paths from one node to another the Secondary drainage link is used. Therefore, the only reason to use the secondary link is for a split flow situation. The investigation will avoid split flow and only use the primary links within the model.

The properties of a drainage link can be edited. These links can be utilised to analyse the flow-routing properties between each drainage link. Refer to **Figure 3.19** for the properties of the drainage link that can be altered.

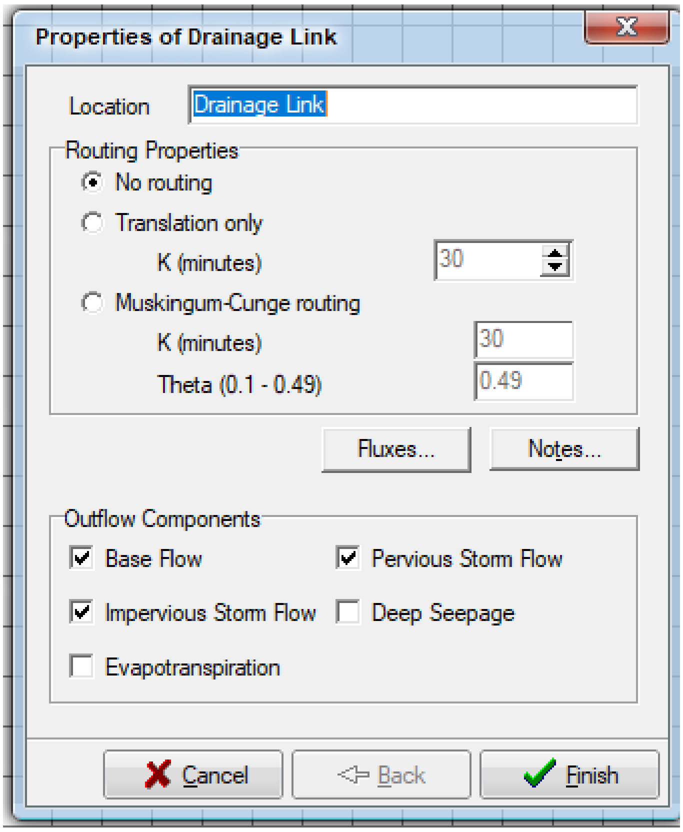


Figure 3.19 – Properties of Drainage Link

3.5.4. Run MUSIC Model Simulation

Model is to be saved before running. Before changes are made to the model copies of model will be placed in a superseded folder. This method will ensure the risk of overwriting models is low.

3.6. GREEN INFRASTRUCTURE DESIGN

The process for designing green infrastructure using MUSIC is illustrated in **Figure 3.20**. This process is similar to the process described in **Figure 3.8**.

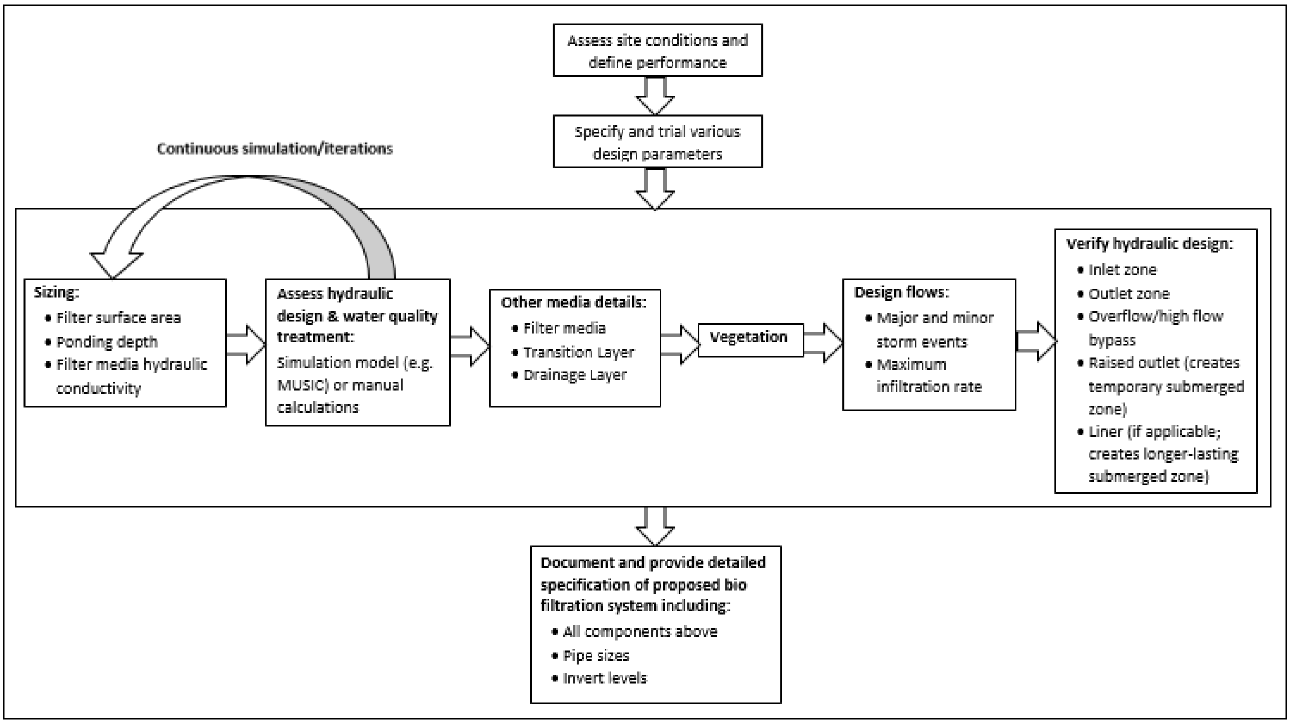


Figure 3.20 – Green Infrastructure MUSIC Design Method
(Payne, E., Hatt, B., Deletic, A., Dobbie, M., McCarthy, D. and Chandrasena, G., 2015)

Some of the general input parameters of green infrastructure that control the volume of water include:

- filter surface area
- extended detention depth
- filter media hydraulic conductivity

Some of the general input parameters of green infrastructure that control the level of water quality treatment include:

- filter media characteristics
- vegetation
- submerged zone attributes

Some parameters of green infrastructure will be excused from this investigation. Future studies may be performed to analyse if these attributes will have influence to the results. The parameters not considered in this report are:

- vegetation
- major storm events
- liner
- under drain details
- submerged systems

3.6.1. Green Roofs

Inlet properties for low and high bypass flow to be calculated off the product guides. The green roof storage properties will have to be manually defined into the parameters of the permeable pavement node. These input parameters include:

- Surface area (square metres)
- Exfiltration rate (mm/hr)
- Filter area (equal to surface area when extended detention depth equal zero)
- Filter depth (metres)
- Filter median particle diameter (mm)
- Saturated hydraulic conductivity (mm/hr)
- Depth below underdrain pipe (% of Filter Depth)
- Overflow weir width (metres)

The extended detention depth will be set to zero since there will be no ponding in the design and no water will pond on the roof.

This extraction value can also denote the soil properties on the in-situ soils (Sandy soils can produce a larger extraction rate). To meet water quality objectives the conservative approach is to set the exfiltration to zero.

Green roof node to be modelled with a filtration node. For MUSIC model recommended set up refer to **Figure 3.21**

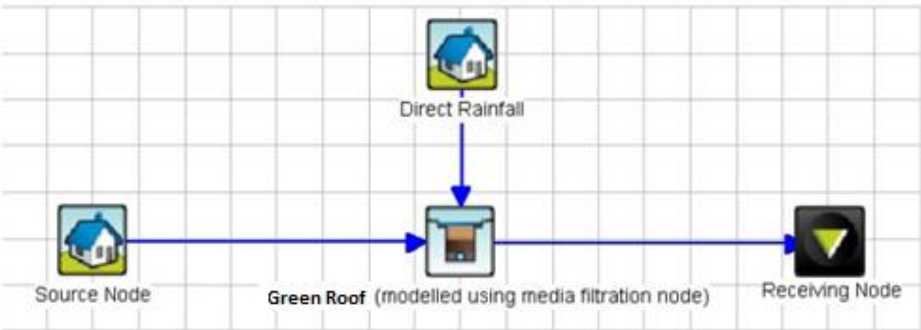


Figure 3.21 - Green Roof MUSIC Recommended Arrangement

Treatment nodes to be set with the parameters in **Table 3.8**. Majority of these parameters were determined in the literature review. All areas to match with the lot configuration. These nodes to be duplicated for every green infrastructure installed. Refer to **Figure 3.22** for MUSIC menu input.

MUSIC parameter name	MUSIC parameter input
low bypass flow	0 m^3/s
high bypass flow	100 m^3/s
Extended detention depth	0 m
Surface area	230.4 m^2
Exfiltration Rate	0 mm/hr
Filter area	230.4 m^2
Filter depth	0.2 m
Filter median particle diameter	0.1 m
Saturated hydraulic conductivity	200 mm/hr
Overflow weir width	0.4 m

Table 3.8 – Green Roof MUSIC Parameter Inputs

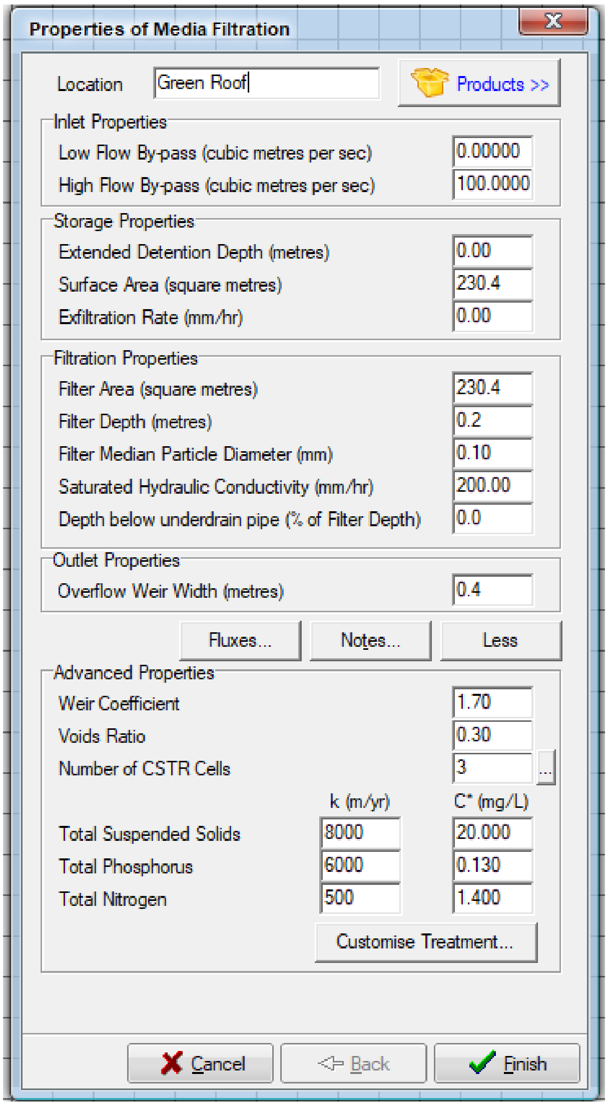


Figure 3.22 – Properties of Green Roof Parameter Inputs MUSIC Menu

3.6.2. Permeable Pavement

Inlet properties for low and high bypass flow to be calculated. The permeable pavement storage properties will have to be manually defined into the parameters of the permeable pavement node. These input parameters include:

- Extended detention depth (metres)
- Surface area (square metres)
- Exfiltration rate (mm/hr)
- Filter area (equal to surface area when extended detention depth equal zero)
- Filter depth (metres)
- Filter median particle diameter (mm)
- Saturated hydraulic conductivity (mm/hr)
- Depth below underdrain pipe (% of Filter Depth)
- Overflow weir width (metres)

The extended detention depth will be set to zero since it can be assumed that there will be no ponding on the road’s surface.

Since there is no under drains:

- Extraction rate is to be set to 0 mm/hr.
- Filter area is to equal surface area since extended detention depth is equal to zero.
- Depth below underdrain pipe is to be set to 0%

This extraction value can also denote the soil properties on the in-situ soils (Sandy soils can produce a larger extraction rate). To meet water quality objectives the conservative approach is to set the exfiltration to zero.

Filter depth, filter particle size and saturated hydraulic conductivity will be calculated in the design of the pavement.

Catchments to the permeable pavement are to be split into two sub-catchments:

1. One node to represent the surface flow to the pavement
2. Second node to represent the direct rainfall on the impervious pavement. (Adopt a 100% impervious fraction to this source node)

Porous pavement node to be modelled with a filtration node. For MUSIC model set up refer to **Figure 3.23**.

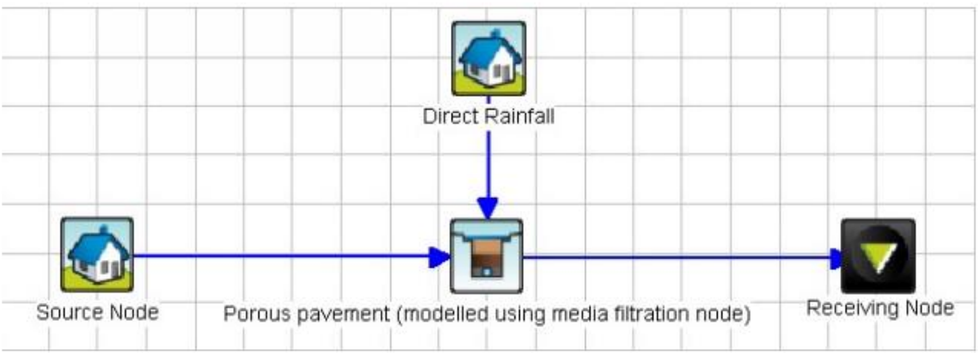


Figure 3.23 - Typical Permeable Pavement MUSIC Arrangement

Treatment nodes to be set with the parameters in **Table 3.9.** Majority of these parameters were determined in the literature review. All areas to match with the lot configuration. These nodes to be duplicated for every green infrastructure installed. Refer to **Figure 3.24** for MUSIC menu input.

MUSIC parameter name	MUSIC parameter input
low bypass flow	0 m^3/s
high bypass flow	100 m^3/s
Extended detention depth	0 m
Surface area	90 m^2
Exfiltration Rate	0 mm/hr
Filter area	90 m^2
Filter depth	0.3 m
Filter median particle diameter	0.1 m
Saturated hydraulic conductivity	200 mm/hr
Overflow weir width	8 m

Table 3.9 – Permeable MUSIC Parameter Inputs

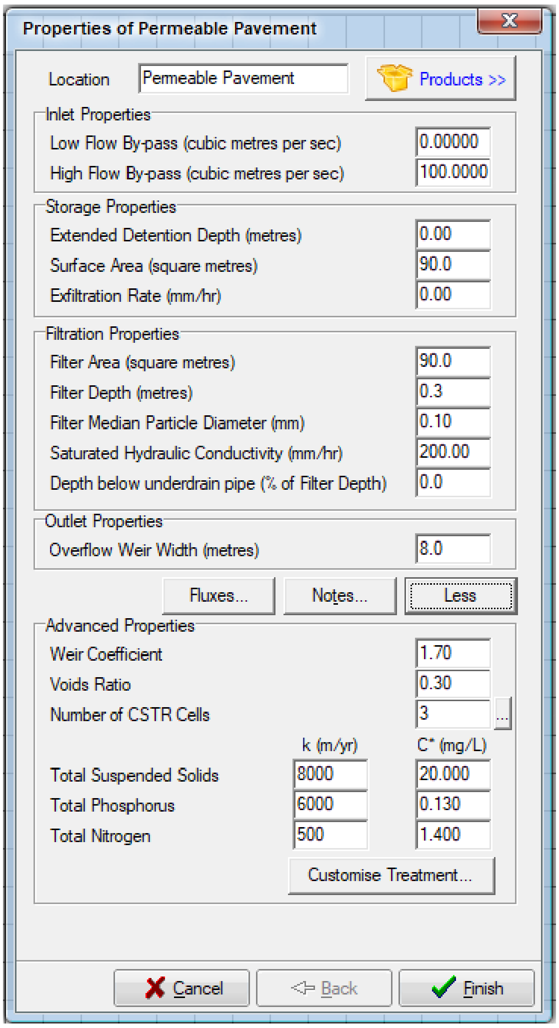


Figure 3.24 – Properties of Permeable Parameter Inputs MUSIC menu

3.6.3. Bio-Retention Basins

Inlet properties for low and high bypass flow is to be calculated and designed for the basin. The bio-retention basin storage properties will have to be manually defined into the parameters of the bio-retention node. These input parameters include:

- Extended detention depth (metres) [Maximum 0.3m]
- Surface area (square metres)
- Filter area (square metres)
- Unlined filter media perimeter (metres)
- Saturated hydraulic conductivity (mm/hr) [200mm/hr]
- Filter depth (metres)
- TN content of filter media (mg/kg)
- Proportion of organic material in filter (%)
- Orthophosphate content material in filter (mg/kg)
- Define if the base is lined (yes or no)
- Vegetated with effective nutrient removal plants
- Overflow weir width (metres)
- Exfiltration rate (mm/hr)
- Underdrain present (yes or no)
- Submerged zone with carbon present
- Depth (of submerged zone)

The extended detention depth will be set to a maximum of 0.3m. This depth is recommended by WSUD, greater depths will affect the mechanics of the basin. Depths greater than 0.3m will increase pressure head that force water too abruptly through filter media.

The design of basin should use material that aim for the saturated hydraulic conductivity of 200mm/hr. This is the conductivity recommended in the MUSIC guidelines. It also states that this can run as low as 50mm/hr and still present results.

Filter depth can be set somewhere between 0.4 and 1.0 metres. MUSIC guidelines recommends a typical depth of between 0.5 and 0.6 metres.

TN content, organic material and orthophosphate material in filter media is required to be tested and examined. For the purpose of this investigation maximum input parameters to be used. TN content of filter media will be set to 800mg/kg. Proportion of organic material in filter will be set to 5%. Orthophosphate content in filter media will be set 55mg/kg.

Since the basin will be a sealed bio-retention drainage zone type, the basin will be lined with under drains. To meet water quality objectives the conservative approach is to set the exfiltration to zero. The submerged basin drainage zone type will not be used in this investigation, therefore all of the submerged input factors can be set to zero.

Native plants to be utilised in basins. These types of plants and vegetation can be assumed to be effective in the removal of nutrients. The detail of these plants will not be discussed in this investigation. Usually the Landscape Architects determine the plant density and species.

Basins to be modelled with a bio retention node.

For MUSIC model set up, the bio-retention basin is to be modelled by directly connecting the bio-systems with the upstream catchment nodes. Refer to **Figure 3.25** for an example of this model layout.

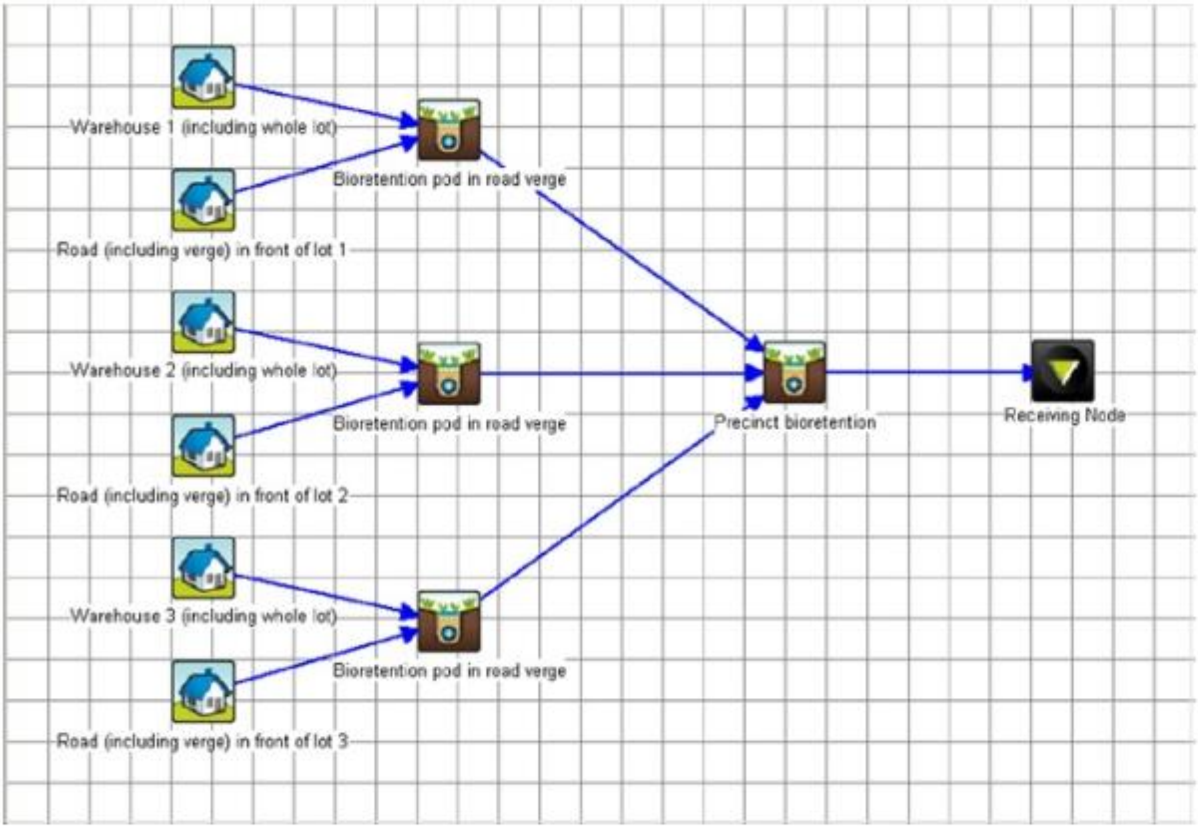


Figure 3.25 - Typical Directly Connected Bio-Retention Systems

Treatment nodes to be set with the parameters in **Table 3.10.** Majority of these parameters were determined in the literature review. All areas to match with the lot configuration. These nodes to be duplicated for every green infrastructure installed. Refer to **Figure 3.26** for MUSIC menu input.

MUSIC parameter name	MUSIC parameter input
low bypass flow	0 m^3/s
high bypass flow	100 m^3/s
Extended detention depth	0.3 m
Surface area	855 m^2
Filter area	855 m^2
Unlined filter media perimeter	14 m
Saturated hydraulic conductivity	200 mm/hr
Filter depth	0.5 m
TN content of filter media	400 mg/kg
Orthophosphate content material in filter	55 mg/kg
Define if the base is lined	No
Vegetated with effective or ineffective nutrient removal plants	effective
Overflow weir width	10 m
Underdrain present	yes
Submerged zone with carbon present	no
Submerged zone depth	0 m

Table 3.10 – Bio-Retention MUSIC Parameter Inputs

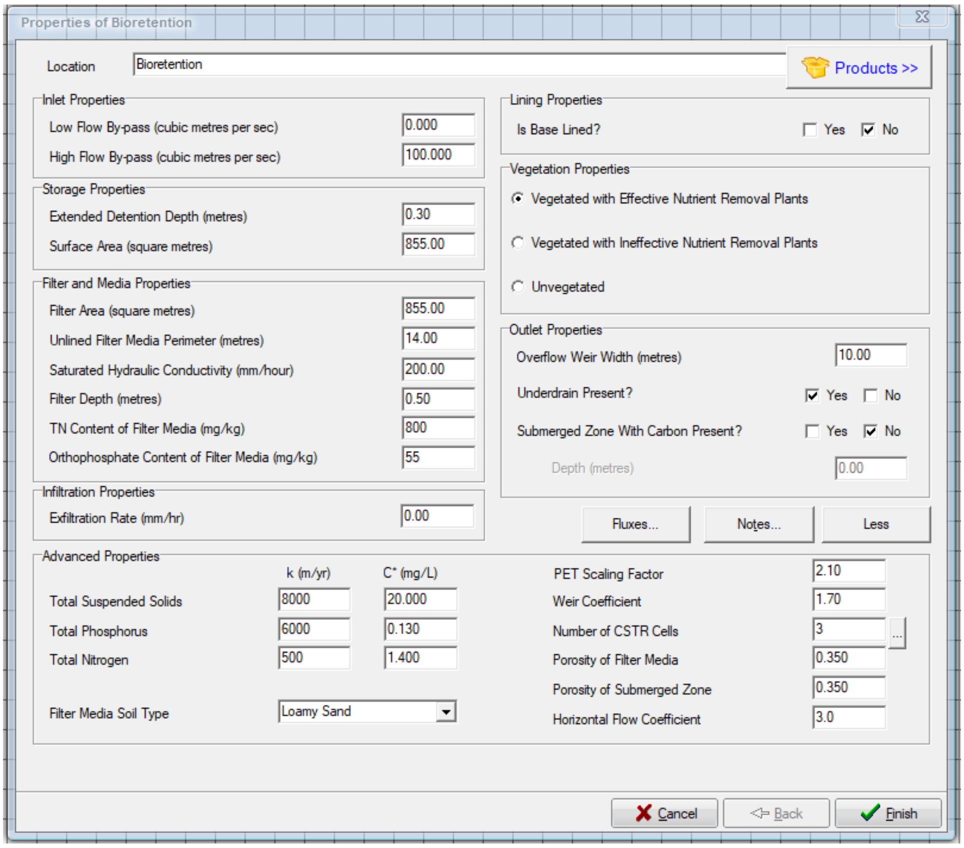


Figure 3.26 – Properties of Bio-Retention Parameter Inputs MUSIC Menu

3.6.4. Vegetated Swales

Vegetation swales do not require calculations for inlet properties for low bypass flow, this should be set to zero. The swale's storage properties will have to be manually defined into the parameters of the swale node. These input parameters include:

- Length of Swale (metres)
- Longitudinal Bed Slope (%) [max. 5% min. 1%]
- Base Width (metres)
- Top Width (metres)
- Vegetation height (metres) [turf = 0.05m]

Since there is no under drains the Extraction rate is to be set to 0 mm/hr. This extraction value can also denote the soil properties on the in-situ soils (Sandy soils can produce a larger extraction rate). To meet water quality objectives the conservative approach is to set the exfiltration to zero.

The plant types can have an impact on reducing nutrients. All vegetation parameters will be ignored in this research.

Generally, turf has an estimate height of 50mm. Native grasses and sedges can grow to larger height of 300mm or more. All swale vegetation in this investigation will be set to be a simple turf layer at 50mm in height.

All swales will be designed to capture the runoff from roads. The MUSIC model will be assumed to receive inflow from the full length of the swale. Therefore, a single source node and swale node will used to model this green infrastructure (**Figure 3.27**).

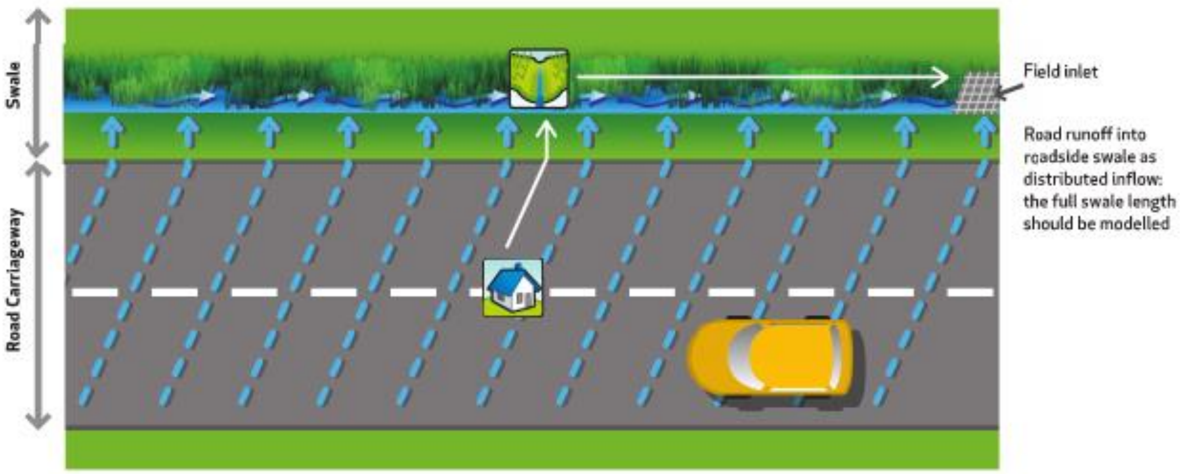


Figure 3.27 - Typical Distributed Inflow MUSIC Arrangement to a Vegetated Swale

Treatment nodes to be set with the parameters in **Table 3.11.** Majority of these parameters were determined in the literature review. All areas to match with the lot configuration. These nodes to be duplicated for every green infrastructure installed. Refer to **Figure 3.28** for MUSIC menu input.

MUSIC parameter name	MUSIC parameter input
low bypass flow	0 m^3/s
length	100 m
Bed slope	0.1 %
Base width	1.0 m
Top width	5.0 m
depth	1.50 m
Vegetation height	0.075 m
Exfiltration rate	0 mm/hr

Table 3.11 – Vegetated Swale MUSIC Parameter Inputs

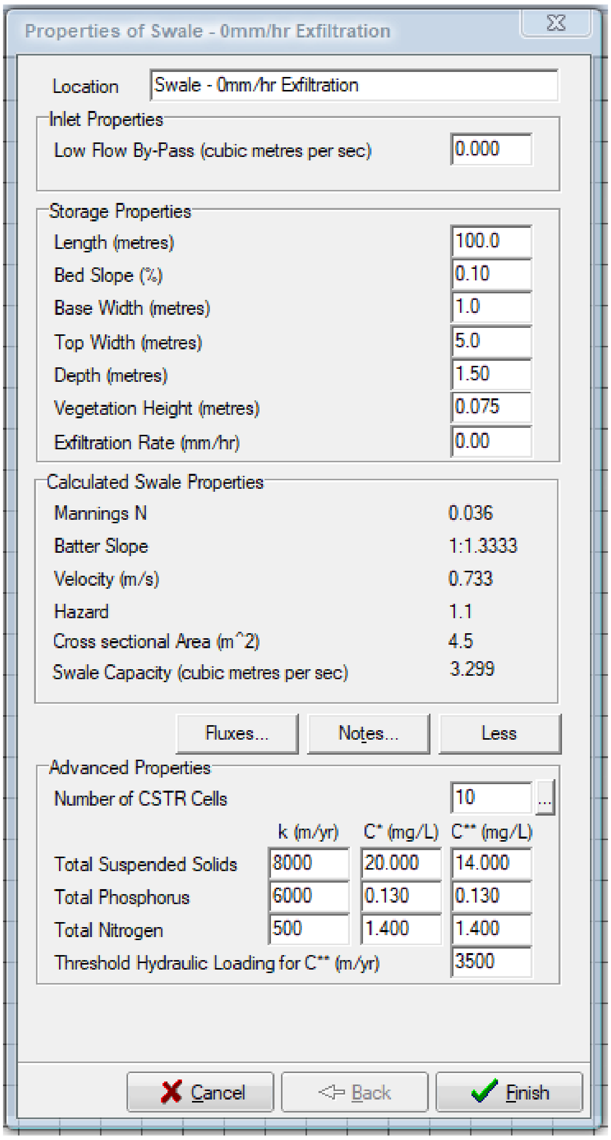


Figure 3.28 – Properties of Vegetated Swale Parameter Inputs MUSIC Menu

3.6.5. Constructed wetlands

In this investigation the wetland will be designed with no low flow bypass, therefore this inlet property should be set to 0 m^3/s. The high flow bypass is to be design to divert 100 m^3/s.

The wetland sedimentation / inlet pond volume will have to be manually defined into the parameters of the wetland node. This must be sized to remove coarse sediment (>125µm) during 1-year ARI storm event. Other input parameters for storage and outlet properties include:

- Surface area (square metres)
- Extended detention (metres) [0.5m maximum]
- Permanent pool volume (cubic metres)
- Evaporative loss as of PET [125mm]
- Outlet pipe diameter (mm)
- Overflow weir width (metres)
- Notional detention time (hrs)

Since there is no under drains the extraction rate is to be set to 0 mm/hr. This extraction value can also denote the soil properties on the in-situ soils (Sandy soils can produce a larger extraction rate). To meet water quality objectives the conservative approach is to set the exfiltration to zero.

Permanent pool volume is the water the constructed wetland will store, with evaporation only source of outlet. Its volume is generally calculated by multiplying the surface area with the permanent depth (approximately 0.2m to 0.3m).

Evaporative loss is site specific and should be obtained for each individual location. However, MUSIC modelling guidelines do allow for a 125mm (PET) default quantity for South East Queensland.

The outlet pipe diameter must be designed to ensure that there is a notional detention time as close as possible to 48 hours. The emergency overland weir must be design to convey a major storm event with 0.3m head or have a surface area (m^2) divided by 10 (whichever is greater).

Treatment nodes to be set with the parameters in **Table 3.12.** Majority of these parameters were determined in the literature review. All areas to match with the lot configuration. These nodes to be duplicated for every green infrastructure installed. Refer to **Figure 3.29** for MUSIC menu input.

MUSIC parameter name	MUSIC parameter input
low bypass flow	0 m^3/s
high bypass flow	100 m^3/s
Extended detention depth	0.5 m
Surface area	11,400 m^2
Permanent Pool Volume	3,420 m^3
Initial Volume	3,420 m^3
Exfiltration Rate	200 mm/hr
Evaporative Loss	125 mm (% of PET)
Outlet pipe diameter	200 mm
Overflow weir width	10 m

Table 3.12 – Constructed Wetland MUSIC Parameter Inputs

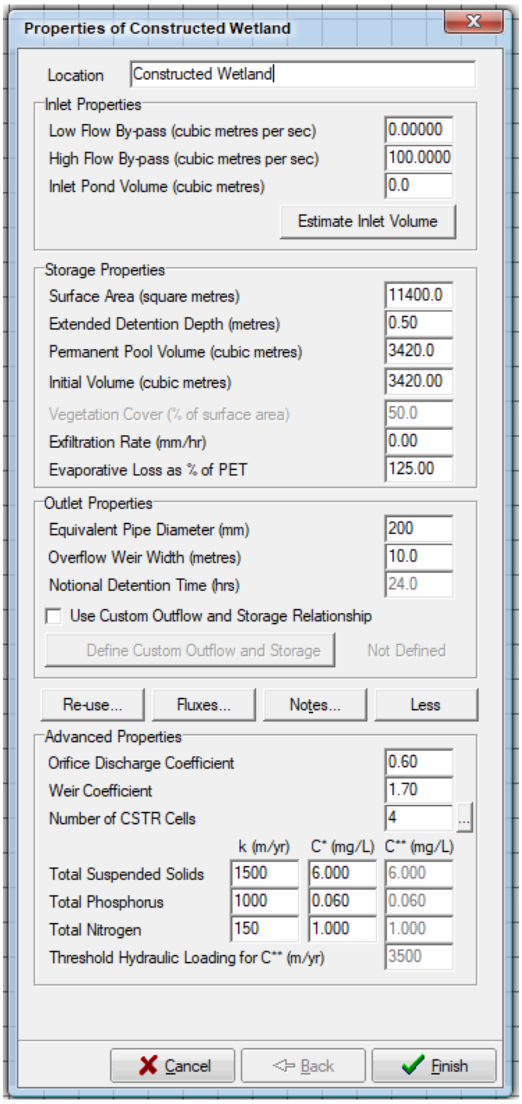


Figure 3.29 – Properties of Constructed Wetland Parameter Inputs MUSIC Menu

3.7. PRESENTATION OF RESULTS

The literature review discovered that frequent and nuisance flows are classified as a 1 in 10 year (AEP 10%) design storm event. The climate period used in the MUSIC model was from 01/01/1980 to the 31/12/1989. This data had a total range of 10 years. Therefore, the largest storm event to happen within this climate period, will be the 1 in 10 year design storm event. Once event has been identified a hyetograph is to be outputted for details of this storm.
The full climate period will be used in the model to be in accordance with MUSIC guidelines. The output data will focus on the design storm to form the discharge runoff results.

Results and output data from the MUSIC models are to be developed in the form of hydrographs. Several hydrographs will be required to display the results from the model. These graphs will assist in the interpretation of the data. All graphs will have the data from the pre-development and post development models. This will give each graph some contrast in the information. The list of hydrographs required to be outputted include:

- Single Lot Green Roof Hydrograph
- Single Lot Green Roof and Permeable Pavement Hydrograph
- Neighbourhood / Street Lot Green Roof Hydrograph
- Neighbourhood / Street Lot Green Roof and Permeable Pavement Hydrograph
- Subdivision Lot Green Roof Hydrograph
- Subdivision Lot Green Roof and Permeable Pavement Hydrograph
- Subdivision Lot Green Roof, Permeable Pavement and Bio-retention Basin Hydrograph
- Cluster Subdivision / Suburb Lot Green Roof Hydrograph
- Cluster Subdivision / Suburb Lot Green Roof and Permeable Pavement Hydrograph
- Cluster Subdivision / Suburb Lot Green Roof, Permeable Pavement and Bio-retention Basin Hydrograph
- Cluster Subdivision / Suburb Lot Green Roof, Permeable pavement, Bio-retention Basin and Vegetated Swale Hydrograph
- Cluster Subdivision / Suburb Lot Green Roof, Permeable Pavement, Bio-retention Basin, Vegetated Swale and Constructed Wetland Hydrograph

All these hydrographs will be used to determine the characteristic of the stormwater runoff. The changing parameters being the size of the catchment and the arrangement of green infrastructure. This will give detail on the best performing green infrastructure. The features that can be extracted from the hydrograph are:

- Peak Flow (m^3/s)
  This is maximum discharge runoff rate during storm event.
- Peak Rainfall (mm)
  The largest amount of rainfall
- Lag time (minutes)
  This is the time between the peak rainfall and the peak flow.
- Raising Limb
  This is for analysing the rate of incline. This rate indicates the velocity of runoff water. Steeper the incline the faster the velocity.
- Falling Limb
  This is for analysing the rate of decline. This rate also indicates the velocity of runoff water. Steeper the decline the faster the velocity.
- Time of Concentration (minutes)
  This is the time the runoff is above the baseflow. It is the amount of time the runoff sheds on the catchment. The longer this time, the more chance the runoff has to be infiltrated into the ground.
- Volume of Runoff (m^3)
  This is represented by the area under the graph. There will be no significance to calculate this in this dissertation, although this understanding can support the interpretation of these graphs.

The accuracy of the model is to be checked using these features of the hydrograph and general engineering judgement. Basic hydrology hand calculations on each catchment will be used to check discharge rate against Peak flow.

$$Q_p = \frac{\text{CIA}}{360}$$

Where Q_p is the peak flow (m3/s), C is runoff coefficient, I the rainfall intensity at time of concentration (mm/h), A is the catchment area (ha). Runoff coefficient derive for tables in QUDM to be equal to 0.84.

(IPWEA, 2017)

This will determine the accuracy of the MUSIC models. Since there is little research on this data, this will assist in checking the software's capability to analyse frequent flow management. All data will be summarised, and the results will be analysed.

3.8. CONCLUSIONS

The methodology used in this investigation will consist of modelling several simulations of different green infrastructures developed over different catchment sizes. The parameters designed in this chapter are to be inputted into the software. The MUSIC software is to be used and results will be checked with hand calculations as part of quality assurance. This will determine if there is confidence for using this software with frequent flow management. All modelling output data will be converted and presented in this dissertation as hydrographs. These graphs can be used to determine the peak flow, peak rainfall, lag time, raising limb, falling limb, time in concentration and volume of runoff. It is the ideal method of displaying discharge runoff and interpreting what is happening in the catchment.

CHAPTER 4

RESULTS

4.1. INTRODUCTION

The result data obtained for this dissertation has been extracted from the MUSIC models and presented onto hydrographs. The hydrograph is a plot of runoff discharge against time. These graphs can be used to analyse the runoff during the selected rainfall event. Peak discharge, discharge lag/delay, attenuation, storage capacity and runoff velocity are all calculations that can be determined on the hydrographs. The distance from peak rainfall to peak runoff is the lag, this occurs due to the attenuation or retention of stormwater. The slope of graphs also determine the velocity at which the runoff is travelling. The area under the graph determines the volume of water from the storm event on the catchment.

The green infrastructure’s ultimate objective is to return runoff conditions back to natural. If the treated runoff is determined to be less than natural/predeveloped conditions, investigation must occur downstream. This investigation must be done to avoid drying and depriving natural waterways from their source of water. Removing too much runoff can have adverse effects.

4.2. DESIGN STORM EVENT

4.2.1. Design Storm Event

The 1 in 10 year storm event (10% AEP) was selected as the largest rain fall event between 01/01/1980 and 31/12/1989. Both intensity and peak rainfall were factors in this selection. The largest event during this time period occurred on Sunday, the 9th of March 1986. To centre the data on the graph the start time of the rainfall was set at the 42-minute mark. The peak rainfall occurred at this 42-minute mark with a rainfall of 15.69mm. There is a 2nd surge in the event where it peaks at the 108-minute mark with a rainfall of 3.69mm. There was a total of 47.9mm of rainfall in the storm period of 108 minutes. Therefore, the intensity of this total storm event is approximately 26.61mm/hr. The first peak is where this investigation will focus its study on, since it is the largest and will contribute better data. The intensity of the first surge will be used in hand calculations to check the MUSIC software accuracy. In that surge there was a total of 37.25mm of rainfall in the storm period of 36 minutes. This calculates a storm intensity of 62.08mm/hr. This intensity is more accurate since it removes the variation of intensity in the total storm.

4.2.2. MUSIC Input Rainfall Data

Table 4.1 represents the design storm's data inputted into the MUSIC model. The table shows the rainfall event on the 9th of March 1986 at the investigation site, broken into 6 minute intervals. To be in accordance with MUSIC guidelines the full climate period of 01/01/1980 to 31/12/1989 was used in the model. The unnecessary output data was then filtered out. This ensured that only the necessary information was inputted into the hydrographs from the selected design rainfall event.

Time (6-minute intervals)	Rainfall (mm)
0	0.00
6	0.00
12	0.00
18	0.00
24	0.00
30	0.00
36	0.00
42	15.69
48	9.64
54	10.08
60	1.72
66	0.04
72	0.08
84	0.16
90	0.46
96	1.97
102	1.97
108	3.69
114	1.88
120	0.27
126	0.06
132	0.06
138	0.06
144	0.06
150	0.01
156	0.00
162	0.00
168	0.00
174	0.00
180	0.00

Time (6-minute intervals)	Rainfall (mm)
186	0.00
192	0.00
198	0.00
204	0.00
210	0.00
216	0.00
222	0.00
228	0.00
234	0.00
240	0.00
246	0.00
252	0.00
258	0.00
264	0.00
270	0.00
276	0.00
282	0.00
288	0.00
294	0.00
300	0.00
306	0.00
312	0.00
318	0.00
324	0.00
330	0.00
336	0.00
342	0.00
348	0.00
354	0.00
360	0.00

Tables 4.1 – MUSIC Rainfall Data Output

4.2.3. Hyetograph of Design Storm

Figure 4.1 represents the design storm's hyetograph using the data in **Table 4.1**. This graph clearly represents both peak rainfalls and represents the two surges. The double surge storm event provides this investigation with significant and suitable data for interpretation. However, as stated previously, the first peak on the storm will be the focus of this investigation. This hyetograph data is usually shown on hydrographs assist in interpretation of rainfall data. For clarity of hydrographs, this rainfall data will only be shown in **Figure 4.1**. Furthermore, the hydrograph evaluations will not require this data for the graph examination.

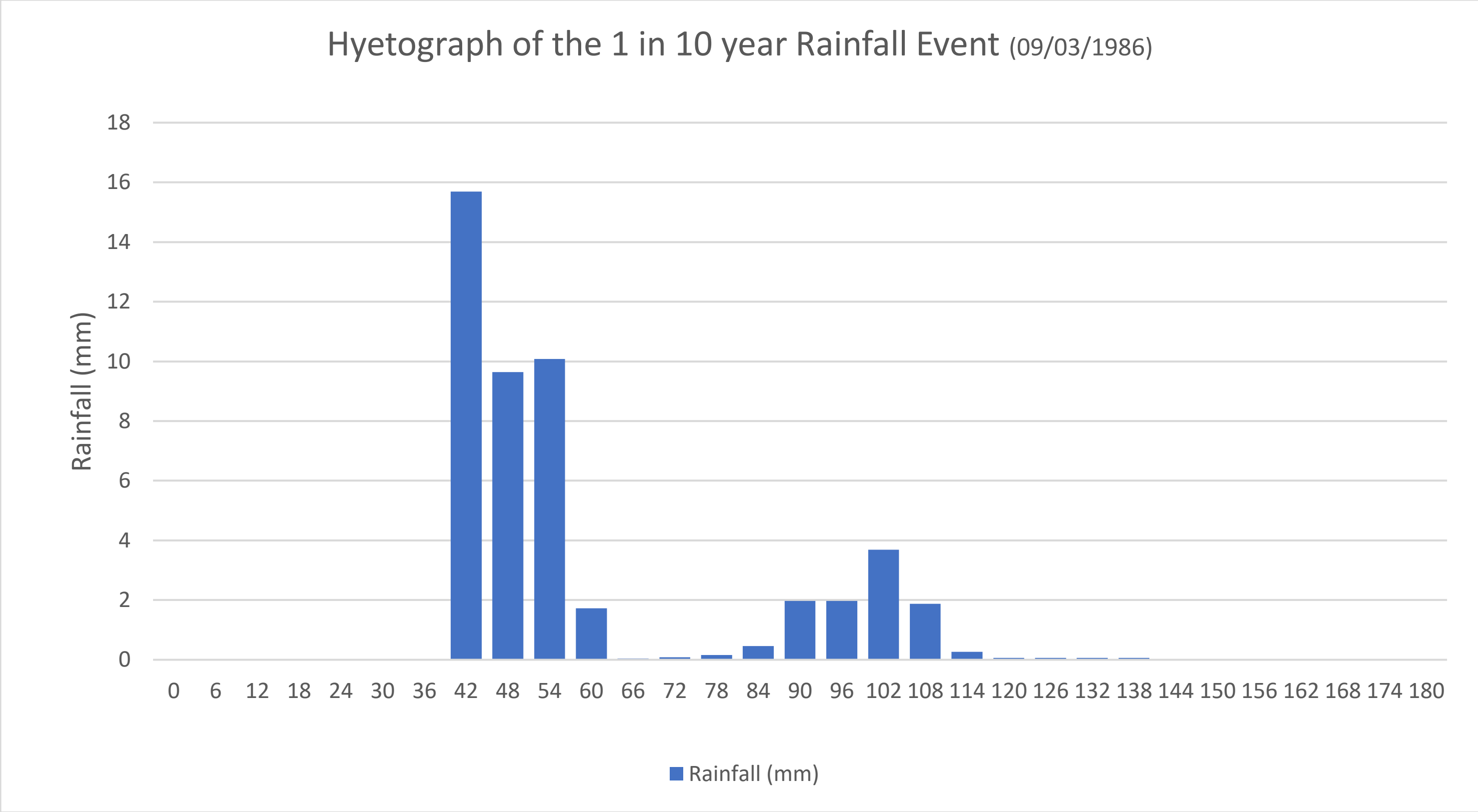


Figure 4.1 – Hyetograph of the 1 in 10 Year Rainfall Event

4.3. MUSIC OUTPUT DATA

Appendix D contains the tables of the output data from MUSIC model. These tables were used to create the hydrographs. This output data used the MUSIC model flux options to convert data into excel '.csv' files. The relevant storm data was extracted and placed into a spreadsheet to create the graphs. Output data for each catchment was placed into separate spreadsheets. These table names consist of:

- Table D1 - Single Lot Catchment MUSIC Output Data
- Table D2 - Neighbourhood / Street Catchment MUSIC Output Data
- Table D3 - Subdivision Catchment MUSIC Output Data
- Table D4 - Cluster of Subdivision / Suburb Catchment MUSIC Output Data

4.4. HYDROGRAPHS

4.4.1. Single Lot Green Roof Hydrograph

The green roof treatment was modelled in the single lot catchment, and the hydrograph results are available in **figure 4.2**. The graph shows that the peak flow of 0.0070m^3/s is originally reduced to 0.0025m^3/s. This is a reduction of 64.3%. The water is retained on the roof until capacity is reached. Then the new peak flow occurs, with a lag time of approximately 48 minutes. This peak can be seen to reach 0.0043m^3/s. Which is a reduction of 0.0027m^3/s. That calculates at a reduction of 38.6%. The second surge is slightly reduced by 17.0%. This is most likely cause from the green roof having enough time to restore its retention properties.

Both the rising and falling limb slopes have reduced in rate of incline and decline, respectively. This demonstrates that the runoff velocity is reducing, which is an improvement from post development velocities. The green roof alone does not treat the urban runoff to natural/pre-developed flow conditions.

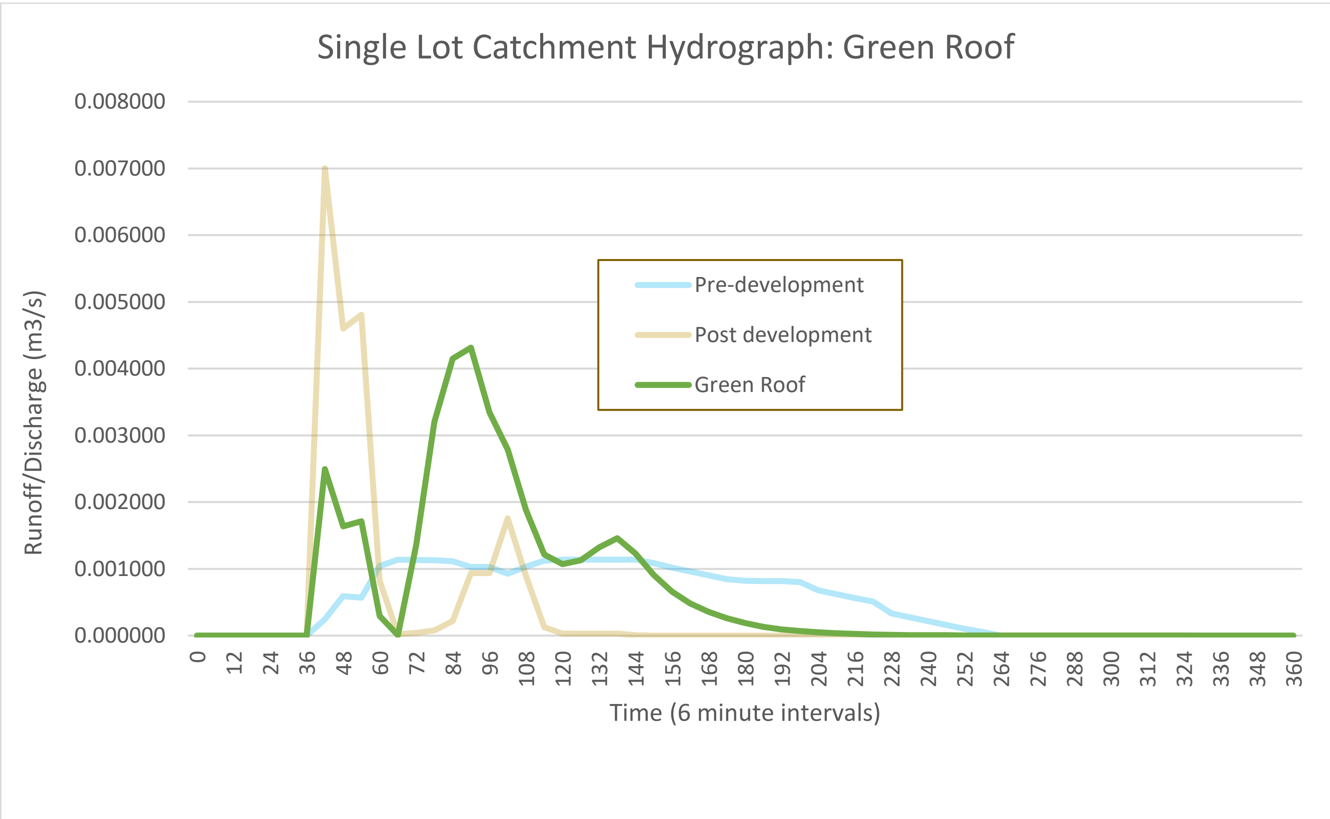


Figure 4.2 – Hydrograph of Single Lot Catchment: Green Roof

4.4.2. Single Lot Permeable Pavement Hydrograph

The permeable pavement treatment was modelled in the single lot catchment, and the hydrograph results are available in **figure 4.3**. The graph shows that the peak flow of 0.0070m^3/s is reduced to 0.0056m^3/s. This is a reduction of 20.0%. The water is diverted into the pavement until capacity is reached. Little to no lag time occurs. The second surge is not reduced at all.

The rising limb slope on both events does not seem to be changed. The falling limb slope on both events does seem to have a slight reduction in the rate of decline. This demonstrates that the runoff velocity is reducing slightly at the end of a rainfall event. The permeable pavement only has a small impact to the runoff and it alone does not treat the urban runoff to natural/pre-developed flow conditions.

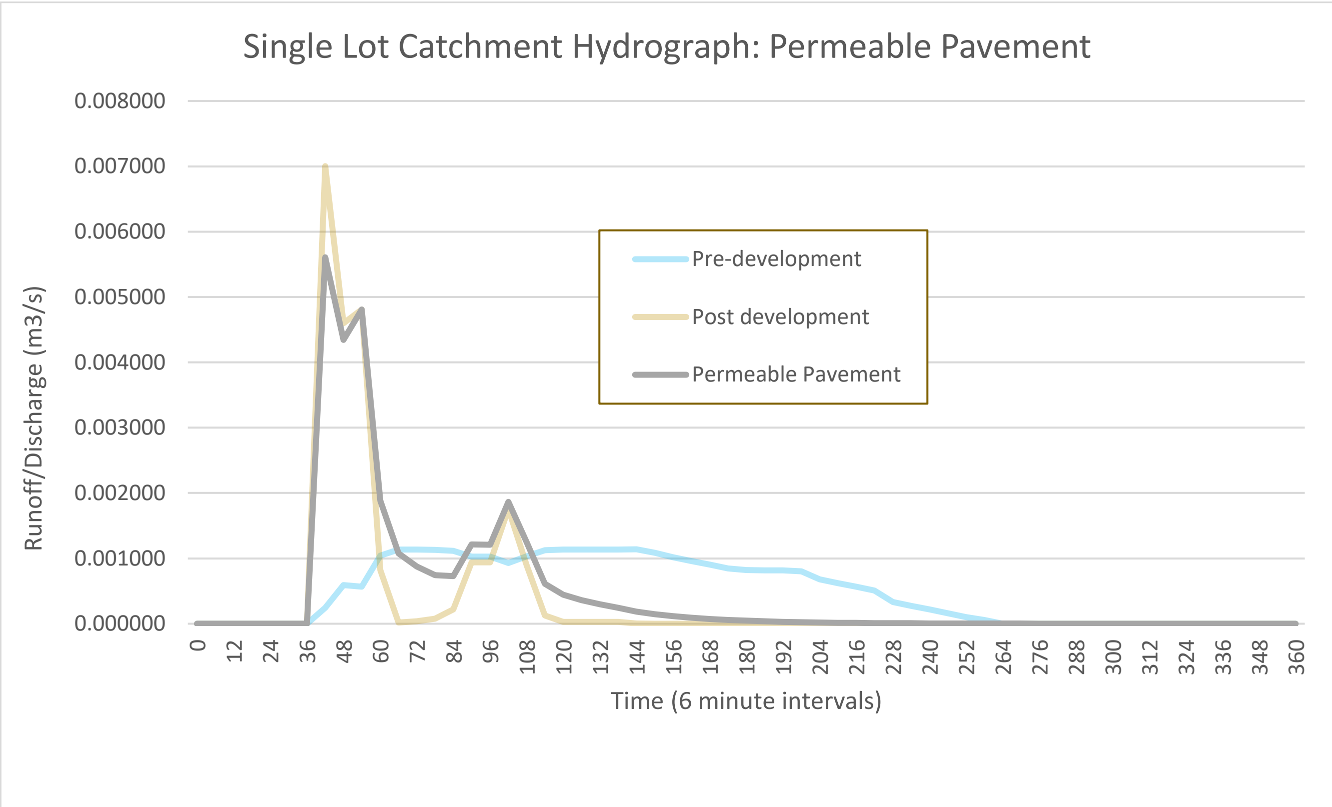
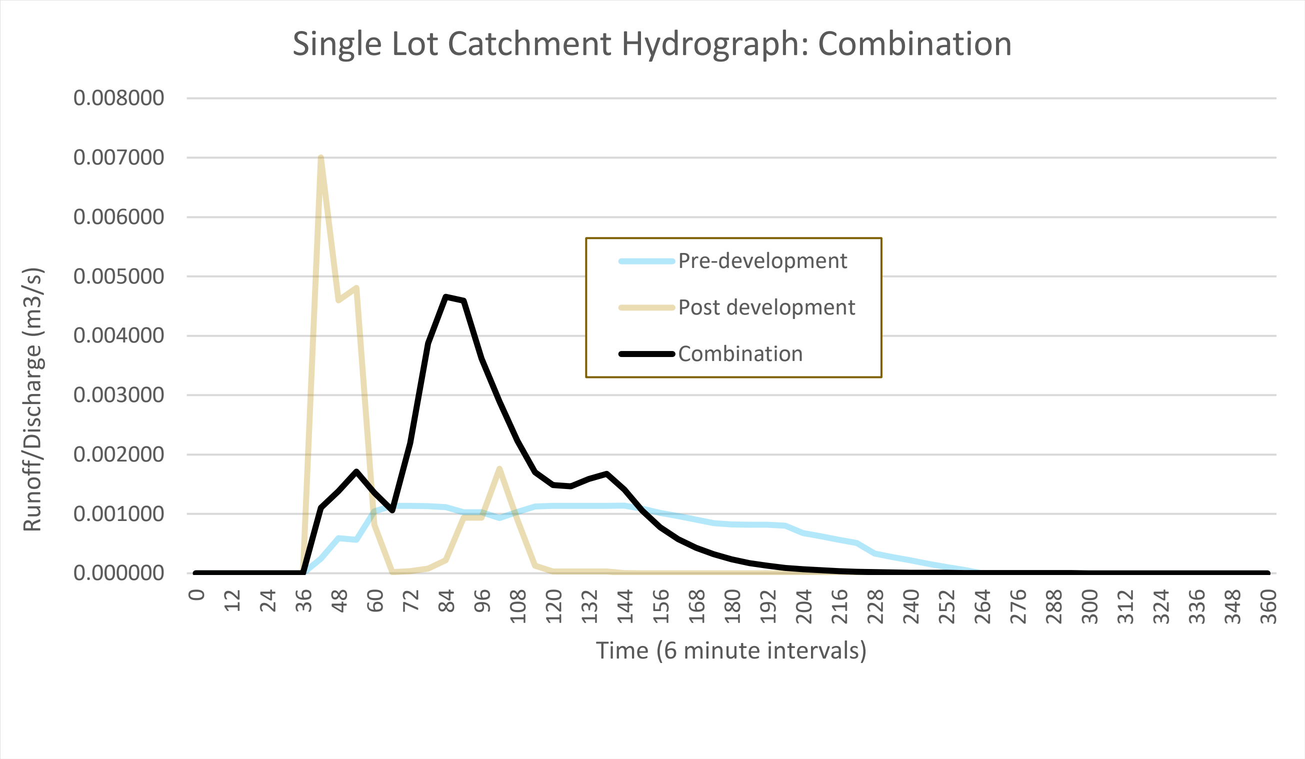


Figure 4.3 – Hydrograph of Single Lot Catchment: Permeable Pavement

4.4.3. Single Lot Combination Hydrograph

The combination of both the green roof and permeable treatments were modelled in the single lot catchment, and the hydrograph results are available in **figure 4.4**. The graph shows that the peak flow of 0.0070m^3/s is originally reduced to 0.0011m^3/s. This is a reduction of 84.3%. The new peak flow occurs, with a lag time of approximately 42 minutes. This peak can be seen to reach 0.0047m^3/s. Which is a reduction of 0.0023m^3/s. That calculations at a reduction of 32.9%. The second surge has a similar peak discharge with little change between post development and green infrastructure. There is an approximate 4.7% reduction.

Both the rising and falling limb slopes have reduced in rate of incline and decline, respectively. This demonstrates that the runoff velocity is reducing, which is an improvement. The green roof and the permeable pavement do not treat the urban runoff to natural/pre-developed flow conditions. The green roof seems to have a larger impact to runoff than the permeable pavement and the combined.



**Combination: Green Roof + Permeable Pavement*

Figure 4.4 – Hydrograph of Single Lot Catchment: Combination

4.4.4. Neighbourhood Green Roof Hydrograph

The green roof treatment was modelled in the neighbourhood catchment, and the hydrograph results are available in **figure 4.5**. The graph shows that the peak flow of 0.0700m^3/s is originally reduced to 0.0187m^3/s. This is a reduction of 73.3%. The water is retained on the roof until capacity is reached. Then the new peak flow occurs, with a lag time of approximately 48 minutes. This peak can be seen to reach 0.0423m^3/s. Which is a reduction of 0.0277m^3/s. That calculates at a reduction of 39.6%. The second surge is slightly reduced by 17.1%. This is most likely cause from the green roof having enough time to restore its retention properties.

Both the rising and falling limb slopes have reduced in rate of incline and decline, respectively. This demonstrates that the runoff velocity is reducing, which is an improvement. The green roof alone does not treat the urban runoff to natural/pre-developed flow conditions.

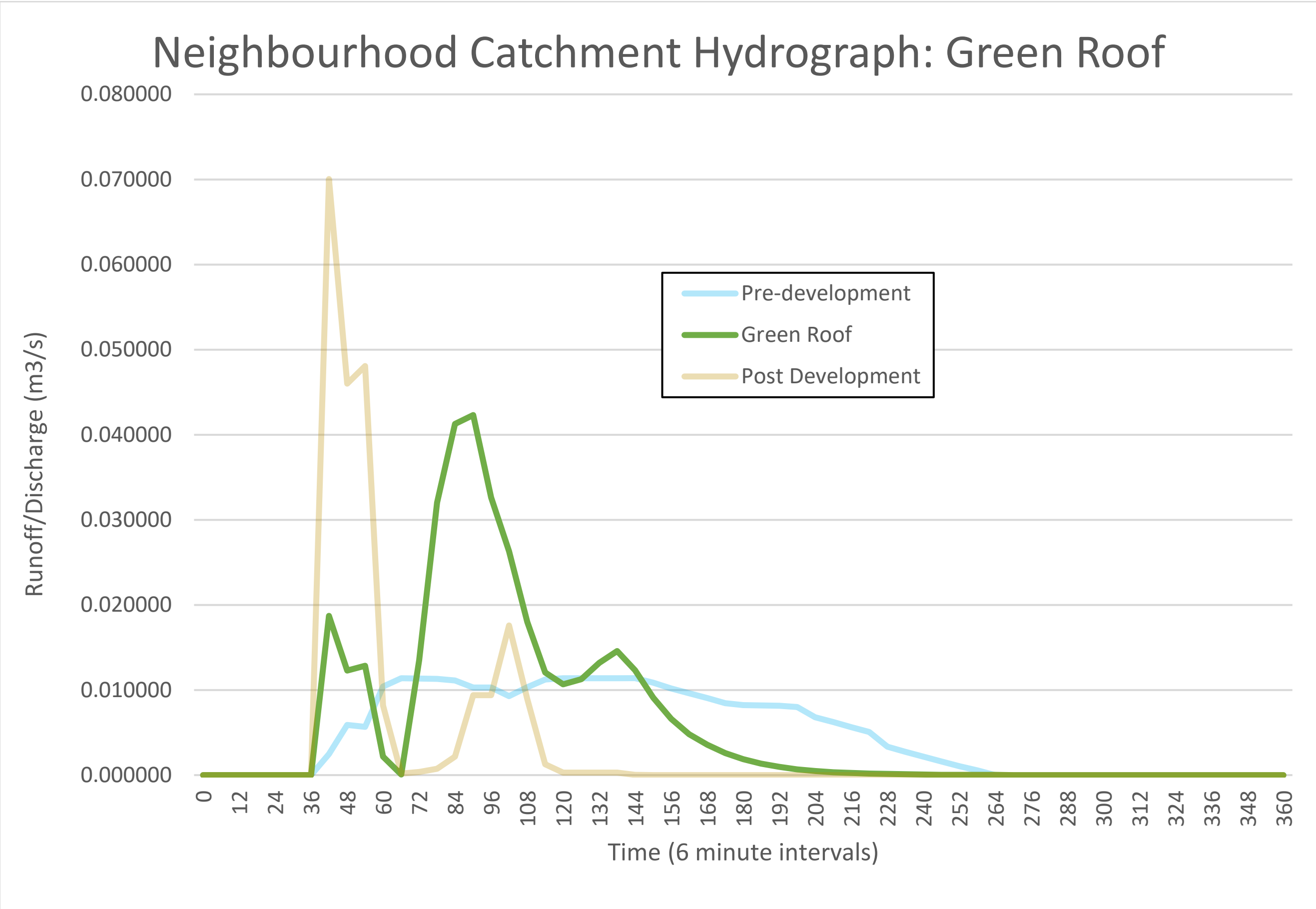


Figure 4.5 – Hydrograph of Neighbourhood Catchment: Green Roof

4.4.5. Neighbourhood Permeable Pavement Hydrograph

The permeable pavement treatment was modelled in the neighbourhood catchment, and the hydrograph results are available in **figure 4.6**. The graph shows that the peak flow of $0.0700m^3/s$ is reduced to $0.0561m^3/s$. This is a reduction of 19.9%. The water is retained within the pavement until capacity is reached. Little to no lag time occurs. The second surge is not reduced at all. This scale of catchment can determine that the treatment is in actual fact, slightly increasing the runoff at this second surge.

The rising limb slope on both events does not seem to be changed. The falling limb slope on both events does seem to have a slight reduction in the rate of decline. This demonstrates that the runoff velocity is reducing slightly at the end of a rainfall event. The permeable pavement only has a small impact to the runoff and it alone does not treat the urban runoff to natural/predeveloped flow conditions.

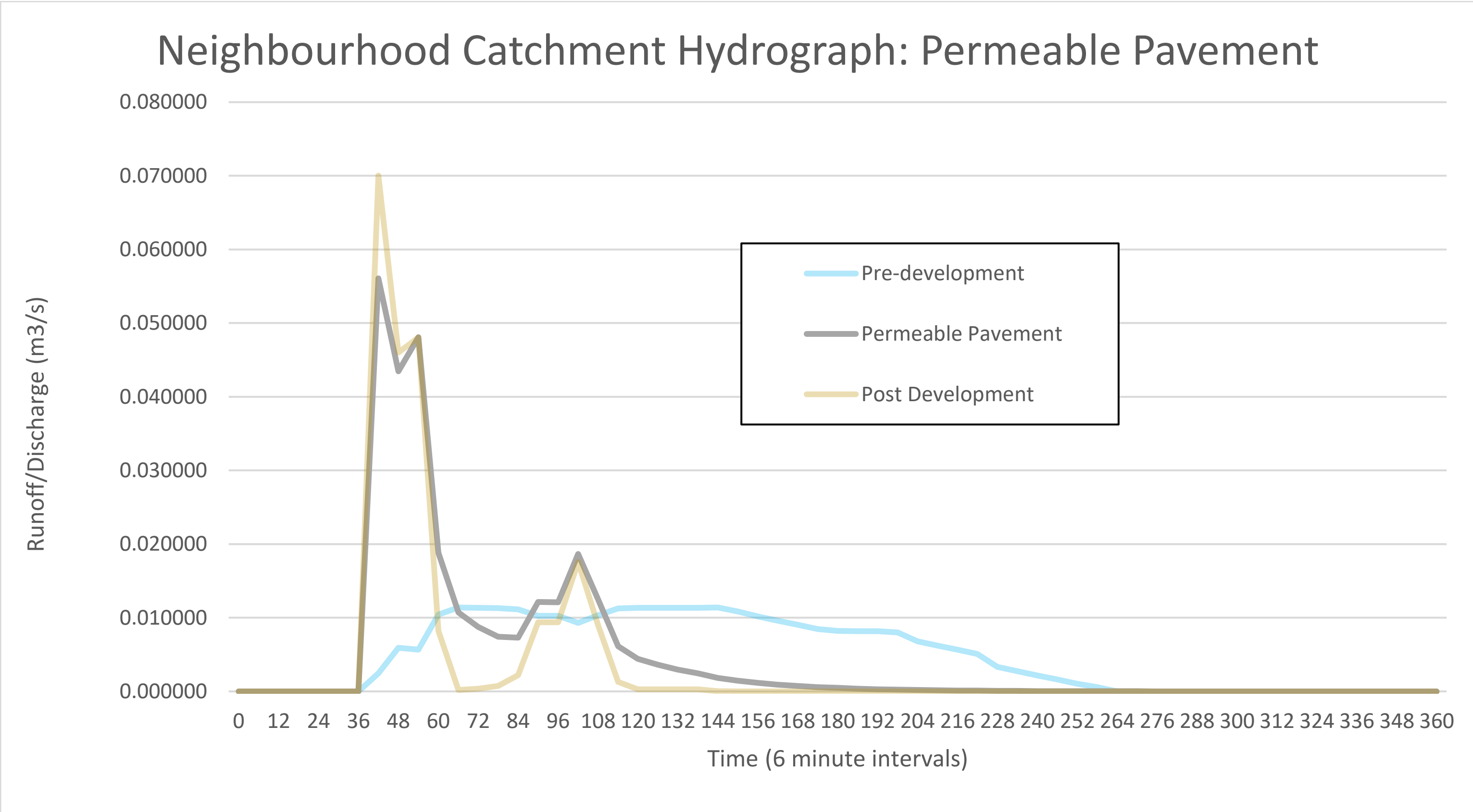
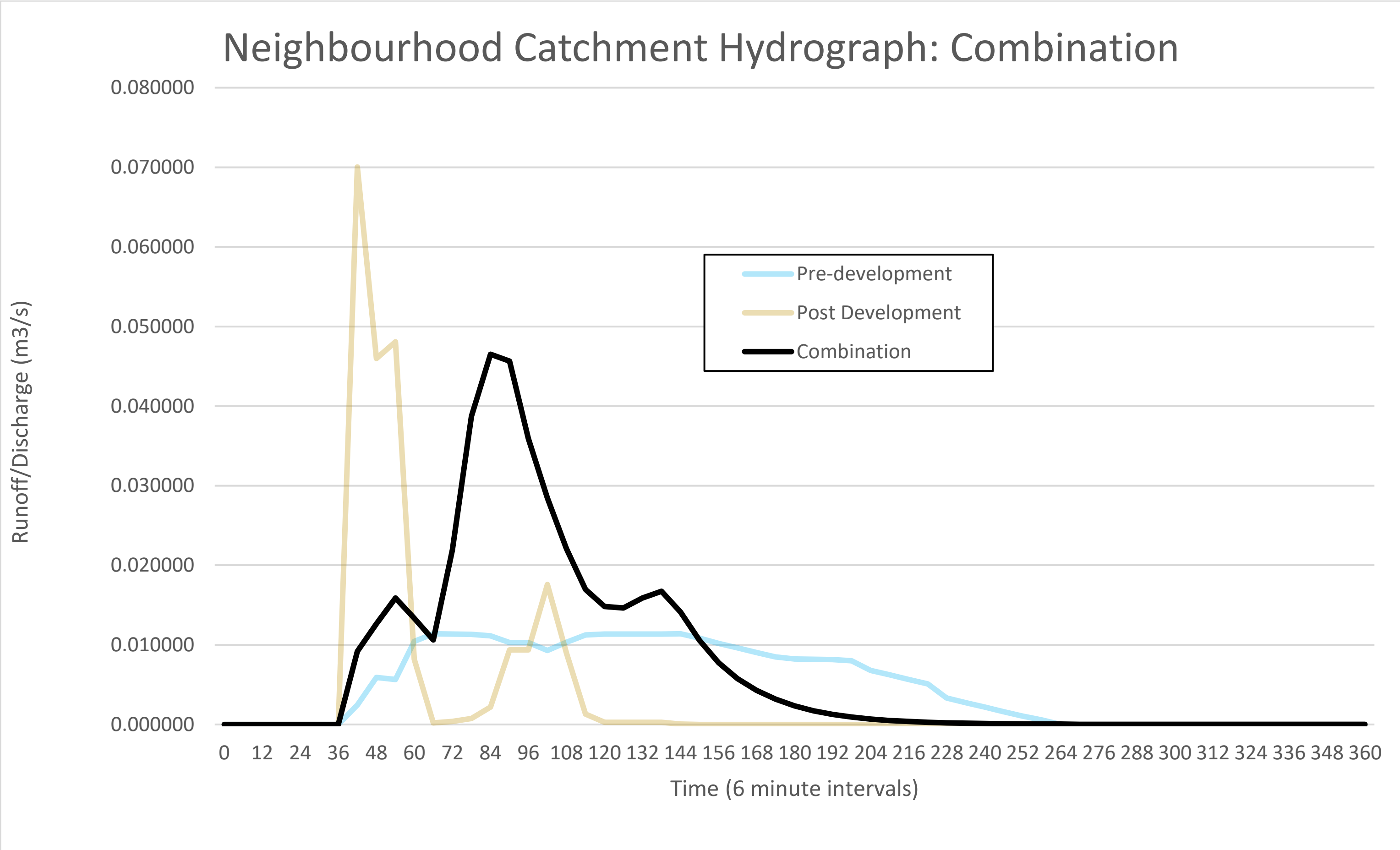


Figure 4.6 – Hydrograph of Neighbourhood Catchment: Permeable Pavement

4.4.6. Neighbourhood Combination Hydrograph

The combination of both the green roof and permeable treatments were modelled in the neighbourhood catchment, and the hydrograph results are available in **figure 4.7**. The graph shows that the peak flow of 0.0700m^3/s is originally reduced to 0.0092m^3/s. This is a reduction of 86.9%. The new peak flow occurs, with a lag time of approximately 42 minutes. This peak can be seen to reach 0.0465m^3/s. Which is a reduction of 0.0235m^3/s. That calculations at a reduction of 33.6%. The second surge has a similar peak discharge with little change between post development and green infrastructure. There is an approximate 4.7% reduction.

Both the rising and falling limb slopes have reduced in rate of incline and decline, respectively. This demonstrates that the runoff velocity is reducing, which is an improvement. The green roof and the permeable pavement do not treat the urban runoff to natural/pre-developed flow conditions. The green roof seems to have a larger impact to runoff than the permeable pavement. The neighbourhood combination is shown to reduce the original peak further than the single lot. Although the general graph shape is consistent. The graph expands uniformly with the larger runoff discharge data.



**Combination: Green Roof + Permeable Pavement*

Figure 4.7 – Hydrograph of Neighbourhood Catchment: Combination

4.4.7. Subdivision Green Roof Hydrograph

The green roof treatment was modelled in the subdivision catchment, and the hydrograph results are available in **figure 4.8**. The graph shows that the peak flow of 0.8305m^3/s is originally reduced to 0.2987m^3/s. This is a reduction of 64.0%. The water is retained on the roof until capacity is reached. Then the new peak flow occurs, with a lag time of approximately 48 minutes. This peak can be seen to reach 0.4390m^3/s. Which is a reduction of 0.3915m^3/s. That calculates at a reduction of 47.1%. The second surge is reduced by 0.0623m^3/s which is a greater reduction than previous catchments. There is an approximate 29.9 % reduction.

Both the rising and falling limb slopes have reduced in rate of incline and decline, respectively. This demonstrates that the runoff velocity is reducing, which is an improvement. The green roof alone does not treat the urban runoff to natural/pre-developed flow conditions.

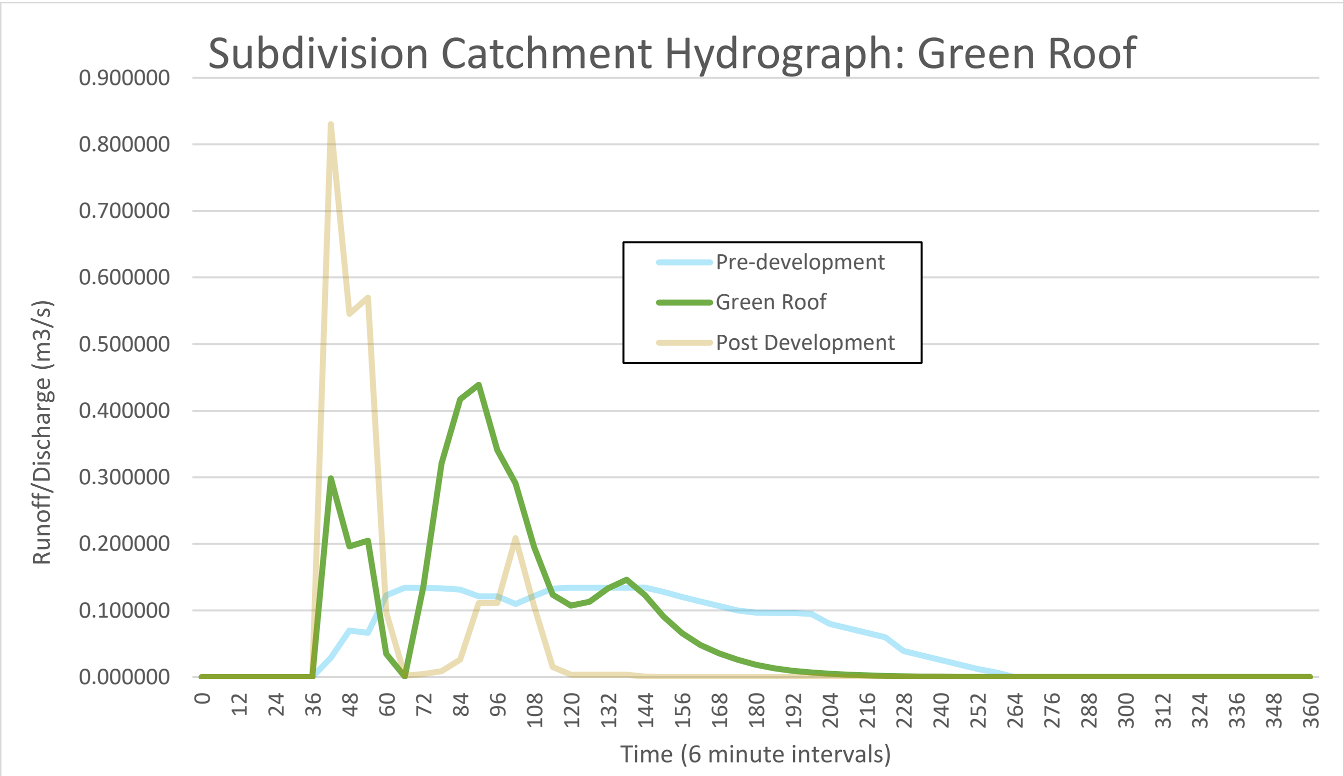


Figure 4.8 – Hydrograph of Subdivision Catchment: Green Roof

4.4.8. Subdivision Permeable Pavement Hydrograph

The permeable pavement treatment was modelled in the subdivision catchment, and the hydrograph results are available in **figure 4.9**. The graph shows that the peak flow of $0.8305m^3/s$ is reduced to $0.6552m^3/s$. This is a reduction of 21.1%. The water is retained within the pavement until capacity is reached. Little to no lag time occurs. The second surge is not reduced at all. This scale of catchment can determine that the treatment is in actual fact, slightly increasing the runoff at this second surge.

The rising limb slope on both events does not seem to be changed. The falling limb slope on both events does seem to have a slight reduction in the rate of decline. This demonstrates that the runoff velocity is reducing slightly at the end of a rainfall event. The permeable pavement only has a small impact to the runoff and it alone does not treat the urban runoff to natural/pre-developed flow conditions.

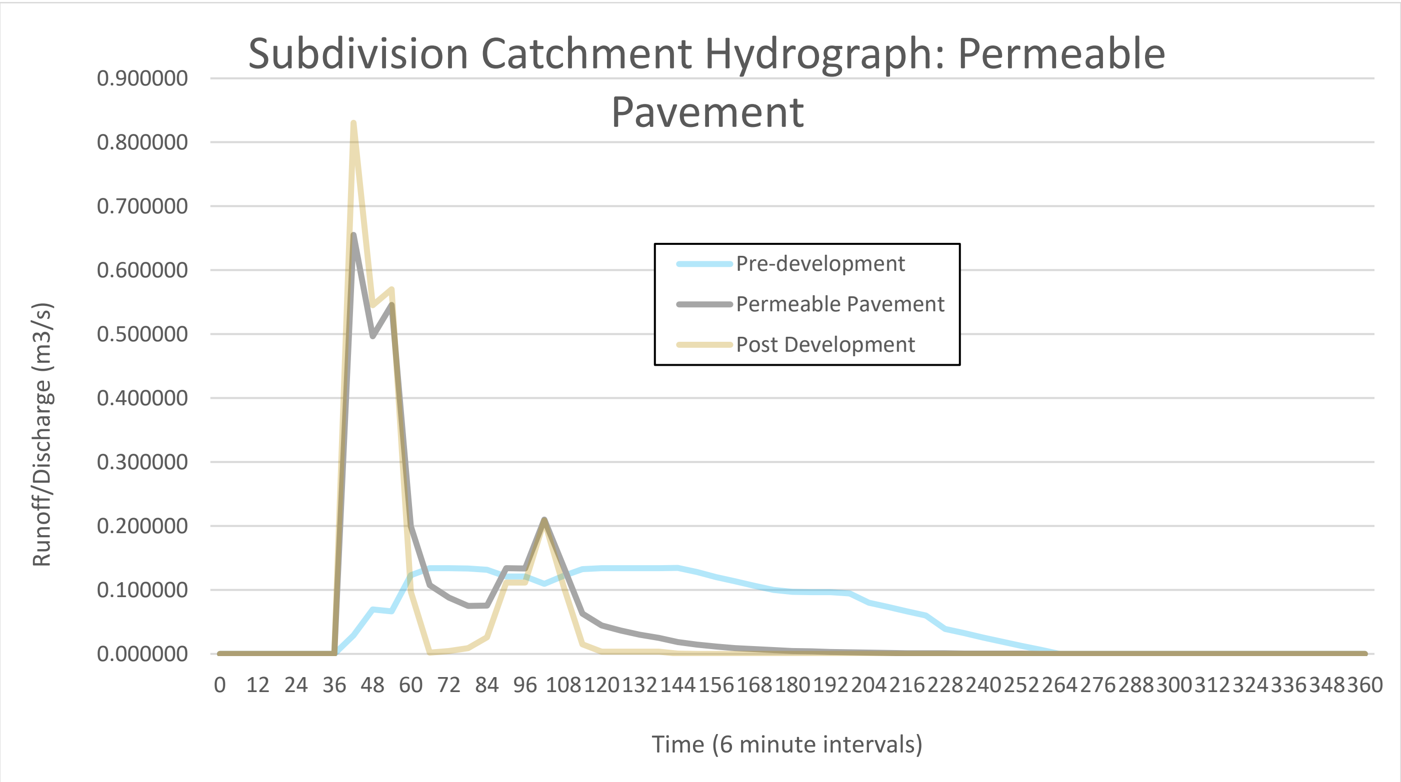


Figure 4.9 – Hydrograph of Subdivision Catchment: Permeable Pavement

4.4.9. Subdivision Bio-Retention Basin Hydrograph

The bio-retention basin treatment was modelled in the subdivision catchment, and the hydrograph results are available in **figure 4.10**. The graph shows that the peak flow of 0.8305m^3/s is originally reduced to 0.0172m^3/s. This is a reduction of 97.9%. The water is retained in the basin and the water is gently discharged. The new peak flow occurs, with a lag time of approximately 24 minutes. This peak can be seen to reach 0.1144m^3/s. Which is a reduction of 0.7161m^3/s. That calculates at a reduction of 86.2%. The second peak is removed since the basin never reaches capacity. This could be reported as a reduction of 0.1029m^3/s, which calculates to a reduction of 49.4%.

Both the rising and falling limb slopes have reduced in rate of incline and decline, respectively. This demonstrates that the runoff velocity is reduced immensely. The bio-retention basin alone does return the urban runoff to natural/pre-developed flow conditions.

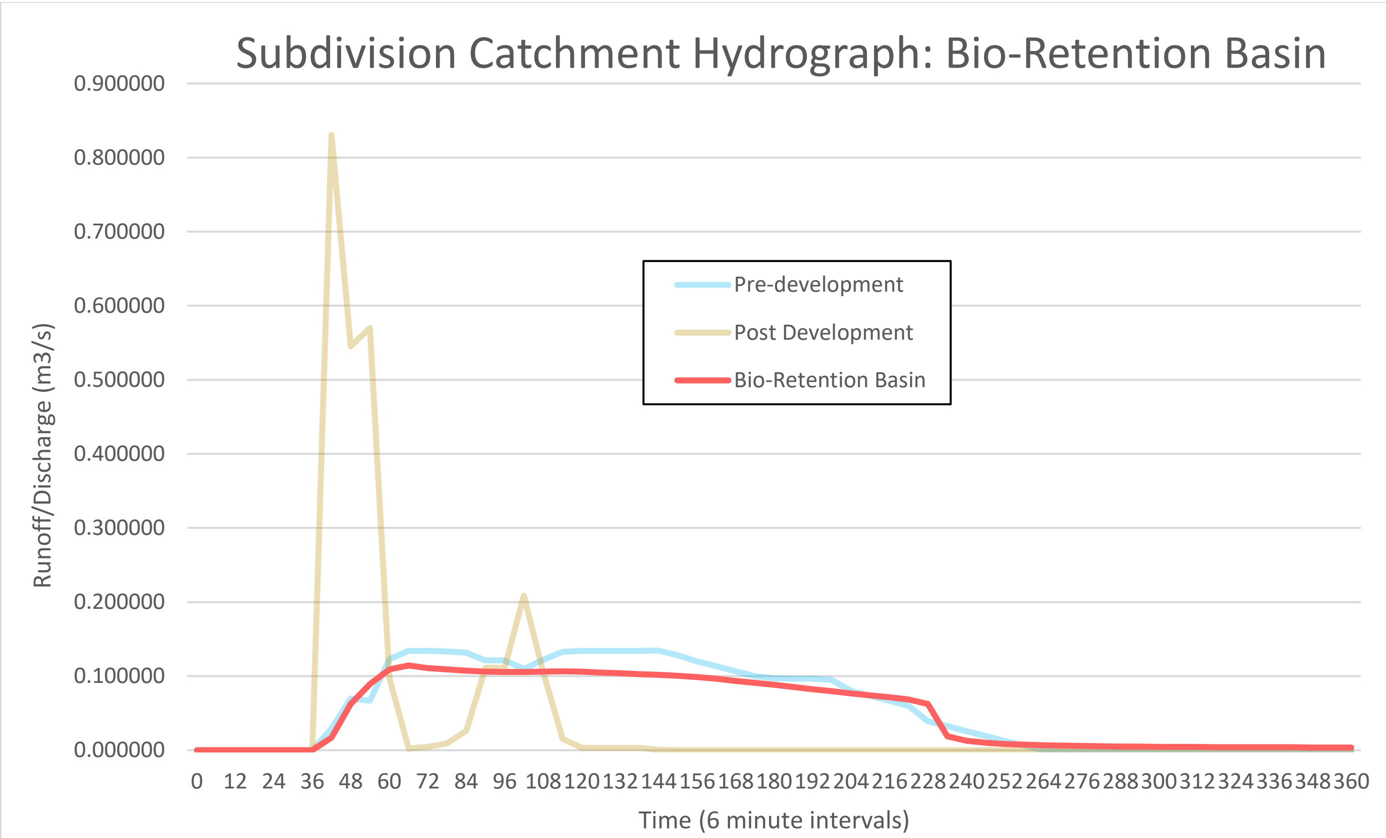
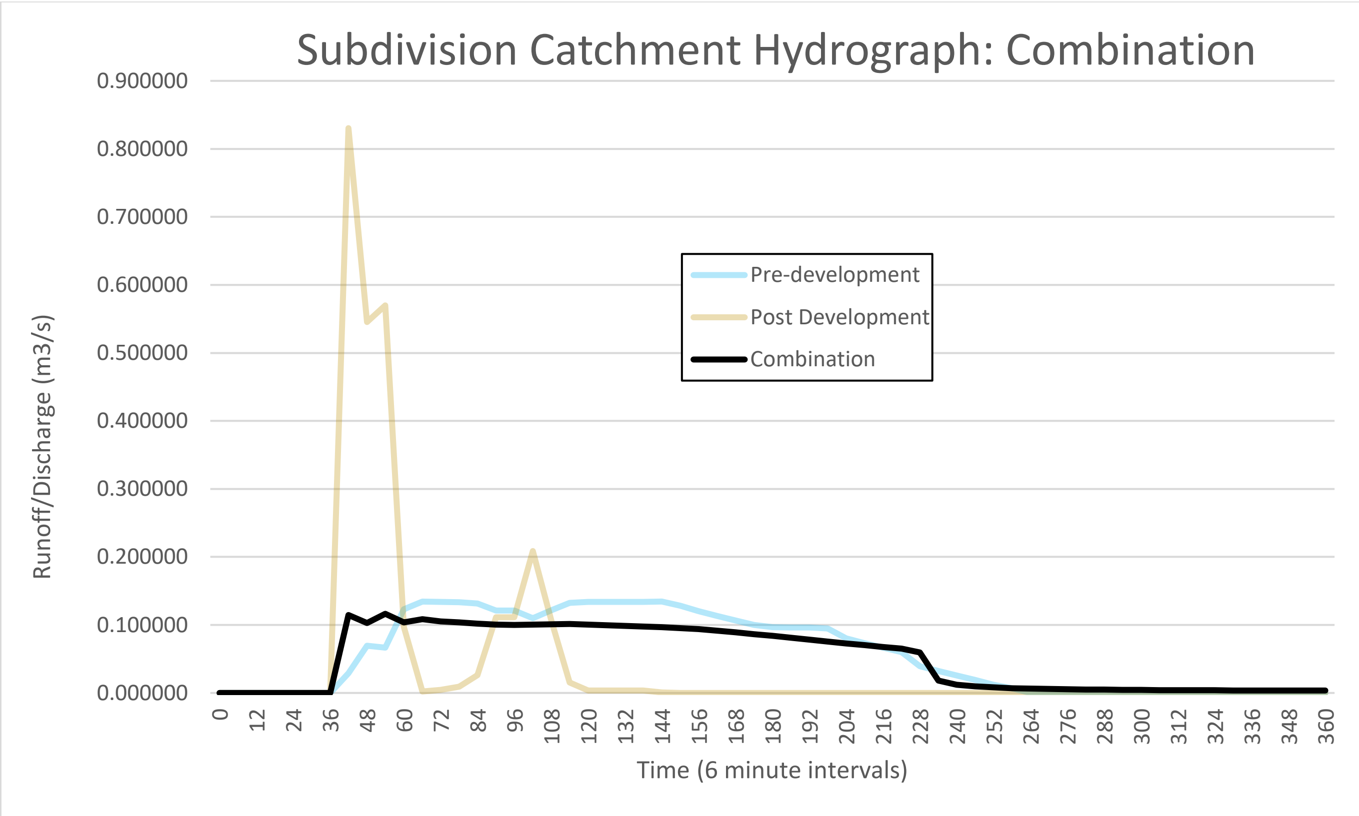


Figure 4.10 – Hydrograph of Subdivision Catchment: Bio-Retention Basin

4.4.10. Subdivision Combination Hydrograph

The combination of the green roof, permeable treatments and the bio-retention basin were modelled in the subdivision catchment, and the hydrograph results are available in **figure 4.11**. The graph shows that the peak flow of 0.8305m^3/s is originally reduced to 0.1145m^3/s. This is a reduction of 86.2%. The water is retained in the basin and the water is gently discharged. The new peak flow occurs, with a lag time of approximately 12 minutes. This peak can be seen to reach 0.1164m^3/s. Which is a reduction of 0.7141m^3/s. That calculates at a reduction of 86.0%. The second peak is removed since the basin never reaches capacity. This could be reported as a reduction of 0.1082m^3/s, which calculates to a reduction of 51.9%.

Both the rising and falling limb slopes have reduced in rate of incline and decline, respectively. This demonstrates that the runoff velocity is reduced immensely. This combination does return the urban runoff to natural/pre-developed conditions. Although it seems to be the bio-retention basin attributes contributing to these results.



**Combination: Green Roof + Permeable Pavement + Bio-Retention Basin*

Figure 4.11 – Hydrograph of Subdivision Catchment: Combination

4.4.11. Suburb Green Roof Hydrograph

The green roof treatment was modelled in the suburb catchment, and the hydrograph results are available in **figure 4.12**. The graph shows that the peak flow of 8.8257m^3/s is originally reduced to 3.1765m^3/s. This is a reduction of 64.0%. The water is retained on the roof until capacity is reached. Then the new peak flow occurs, with a lag time of approximately 48 minutes. This peak can be seen to reach 4.4157m^3/s. Which is a reduction of 4.4100m^3/s. That calculates at a reduction of 50.0%. The second surge is reduced by 0.7531m^3/s which is a greater reduction than previous catchments. There is an approximate 34.0% reduction.

Both the rising and falling limb slopes have reduced in rate of incline and decline, respectively. This demonstrates that the runoff velocity is reducing, which is an improvement. The green roof alone does not treat the urban runoff to natural/pre-developed flow conditions.

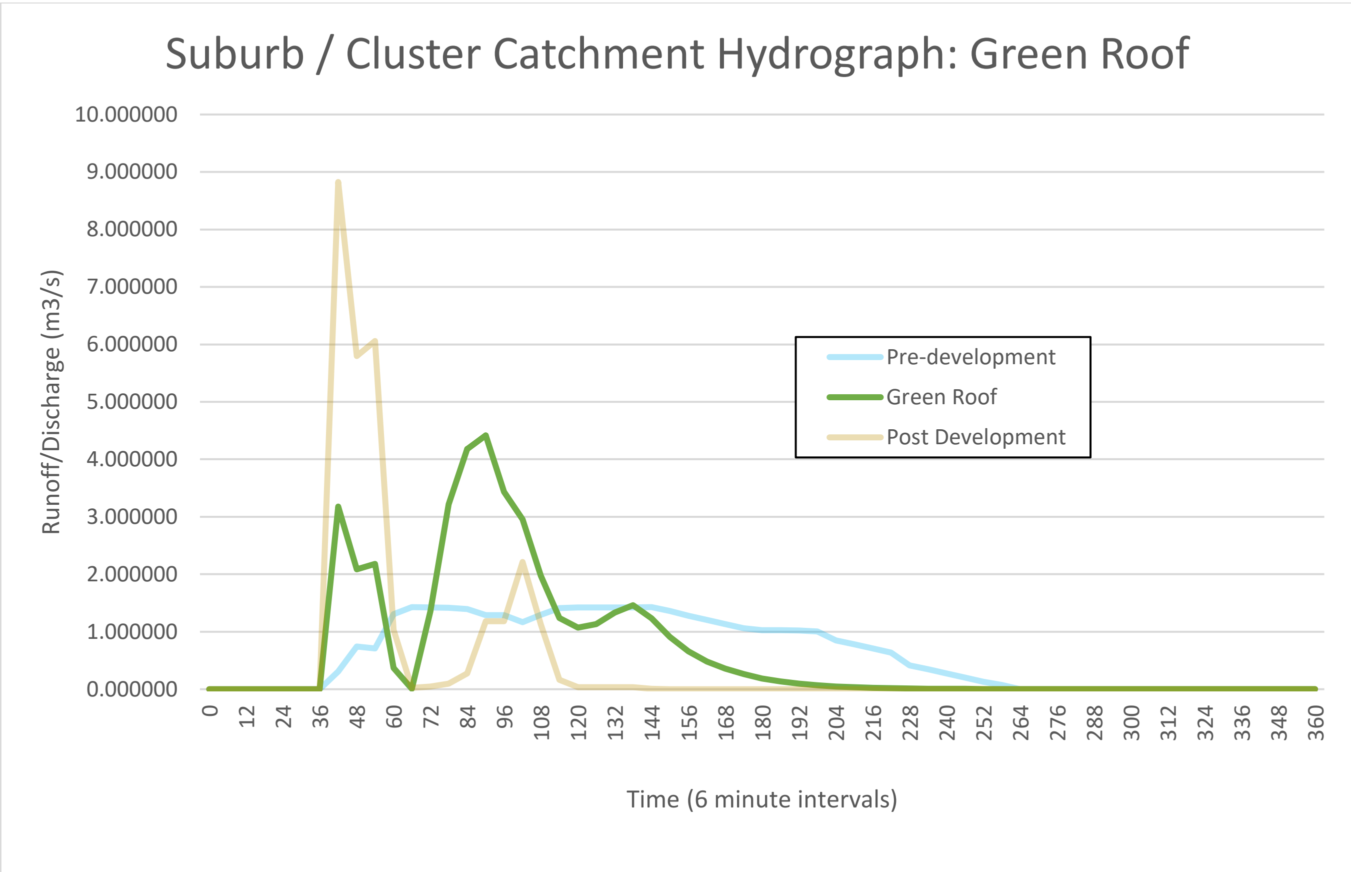


Figure 4.12 – Hydrograph of Suburb Catchment: Green Roof

4.4.12. Suburb Permeable Pavement Hydrograph

The permeable pavement treatment was modelled in the suburb catchment, and the hydrograph results are available in **figure 4.13**. The graph shows that the peak flow of 8.8257m^3/s is reduced to 6.9371m^3/s. This is a reduction of 21.4%. The water is retained within the pavement until capacity is reached. Little to no lag time occurs. The second surge is not reduced at all and remains the same as post development conditions.

The rising limb slope on both events does not seem to be changed. The falling limb slope on both events does seem to have a slight reduction in the rate of decline. This demonstrates that the runoff velocity is reducing slightly at the end of a rainfall event. The permeable pavement only has a small impact to the runoff and it alone does not treat the urban runoff to natural/pre-development flow conditions.

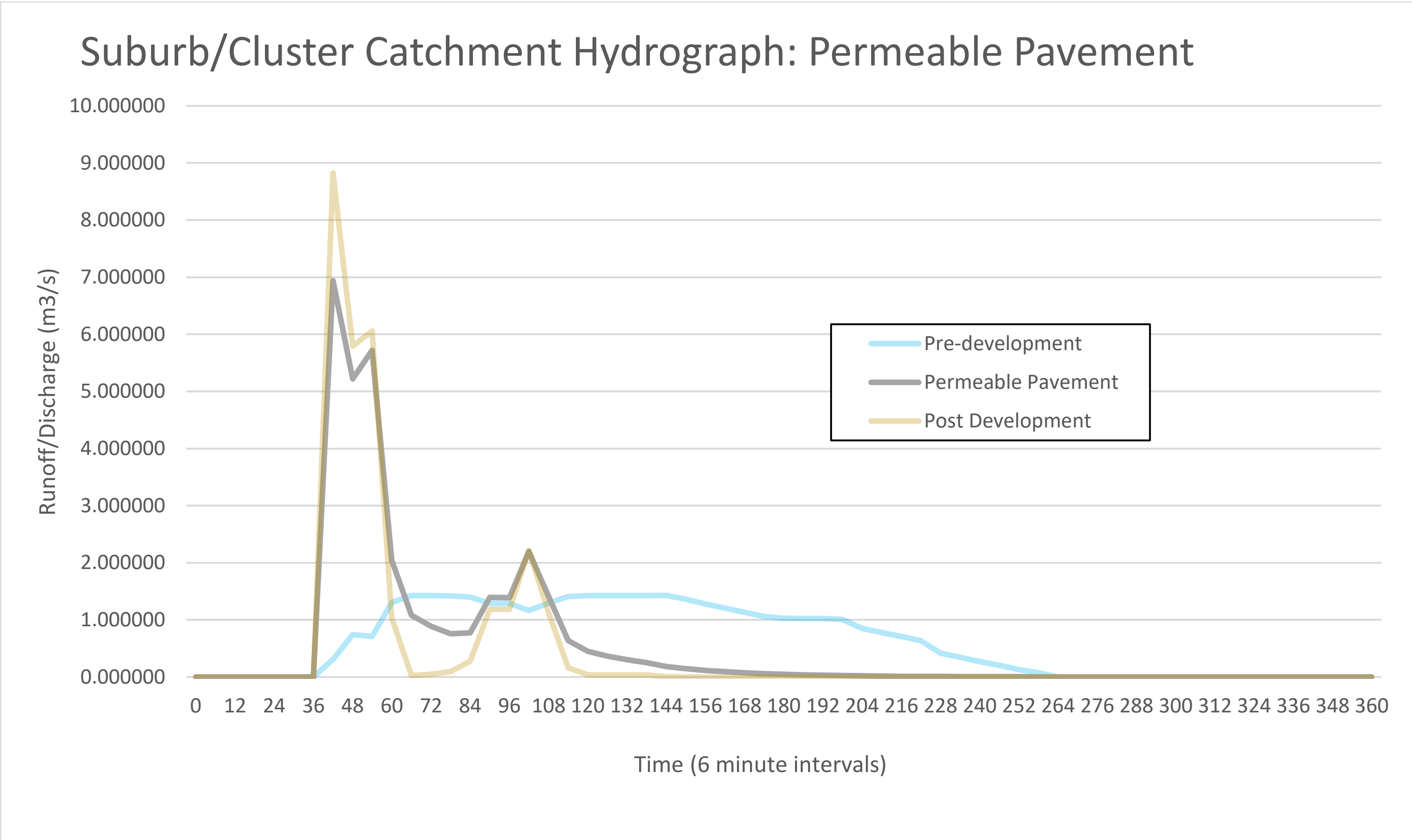


Figure 4.13 – Hydrograph of Suburb Catchment: Permeable Pavement

4.4.13. Suburb Bio-Retention Basin Hydrograph

The bio-retention basin treatment was modelled in the subdivision catchment, and the hydrograph results are available in **figure 4.14**. The graph shows that the peak flow of 8.8257m^3/s is originally reduced to 0.1697m^3/s. This is a reduction of 98.1%. The water is retained in the basin and the water is gently discharged. The new peak flow occurs, with a lag time of approximately 30 minutes. This peak can be seen to reach 1.4000m^3/s. Which is a reduction of 7.4257m^3/s. That calculates at a reduction of 84.1%. The second peak is removed since the basin never reaches capacity. This could be reported as a reduction of 0.9813m^3/s, which calculates to a reduction of 55.7%.

Both the rising and falling limb slopes have reduced in rate of incline and decline, respectively. This demonstrates that the runoff velocity is reduced immensely. The bio-retention basin alone does return the urban runoff to natural/pre-developed flow conditions.

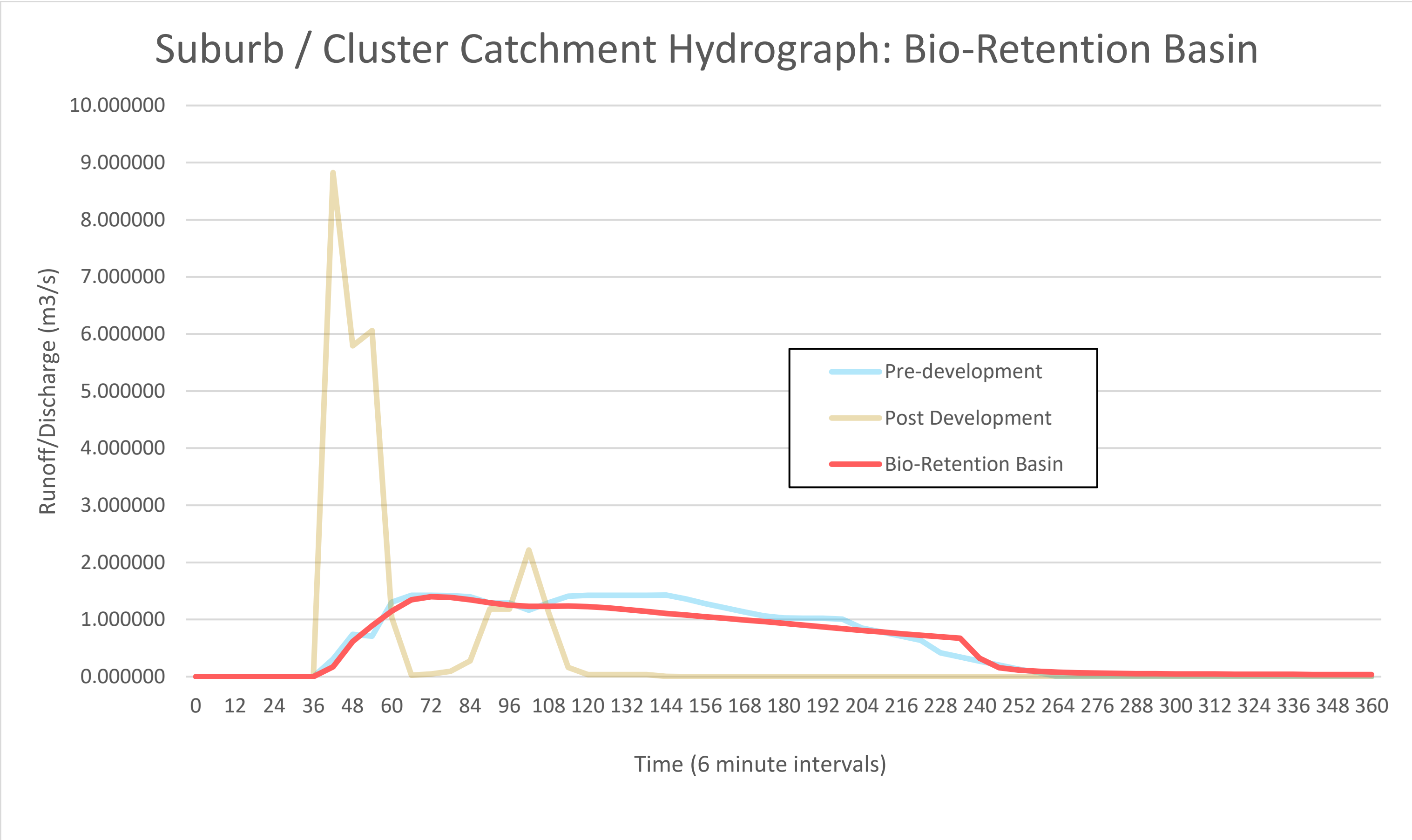


Figure 4.14 – Hydrograph of Suburb Catchment: Bio-Retention Basin

4.4.14. Suburb Vegetated Swale Hydrograph

The vegetated swale treatment was modelled in the suburb catchment, and the hydrograph results are available in **figure 4.15**. The graph shows that the peak flow of 8.8257m^3/s is originally reduced to 0.0359m^3/s. This is a reduction of 99.6%. Then the new peak flow occurs, with a lag time of approximately 24 minutes. This peak can be seen to reach 2.0850m^3/s. Which is a reduction of 6.7407m^3/s. That calculates at a reduction of 76.4%. The second peak is reduced by approximately 0.6111m^3/s. That calculates at a reduction of 27.6%.

Both the rising and falling limb slopes have reduced in rate of incline and decline, respectively. This demonstrates that the runoff velocity is reduced immensely. The vegetated swale does get close, but it alone does not treat the urban runoff to natural/pre-developed flow conditions. It must be noted that the vegetated swale is position downstream of the bio-retention basin. The peaks in this treatment is assumed to be cause by direct rainfall onto the swale. After rain event the swale then carries the discharge from the bio-retention basin.

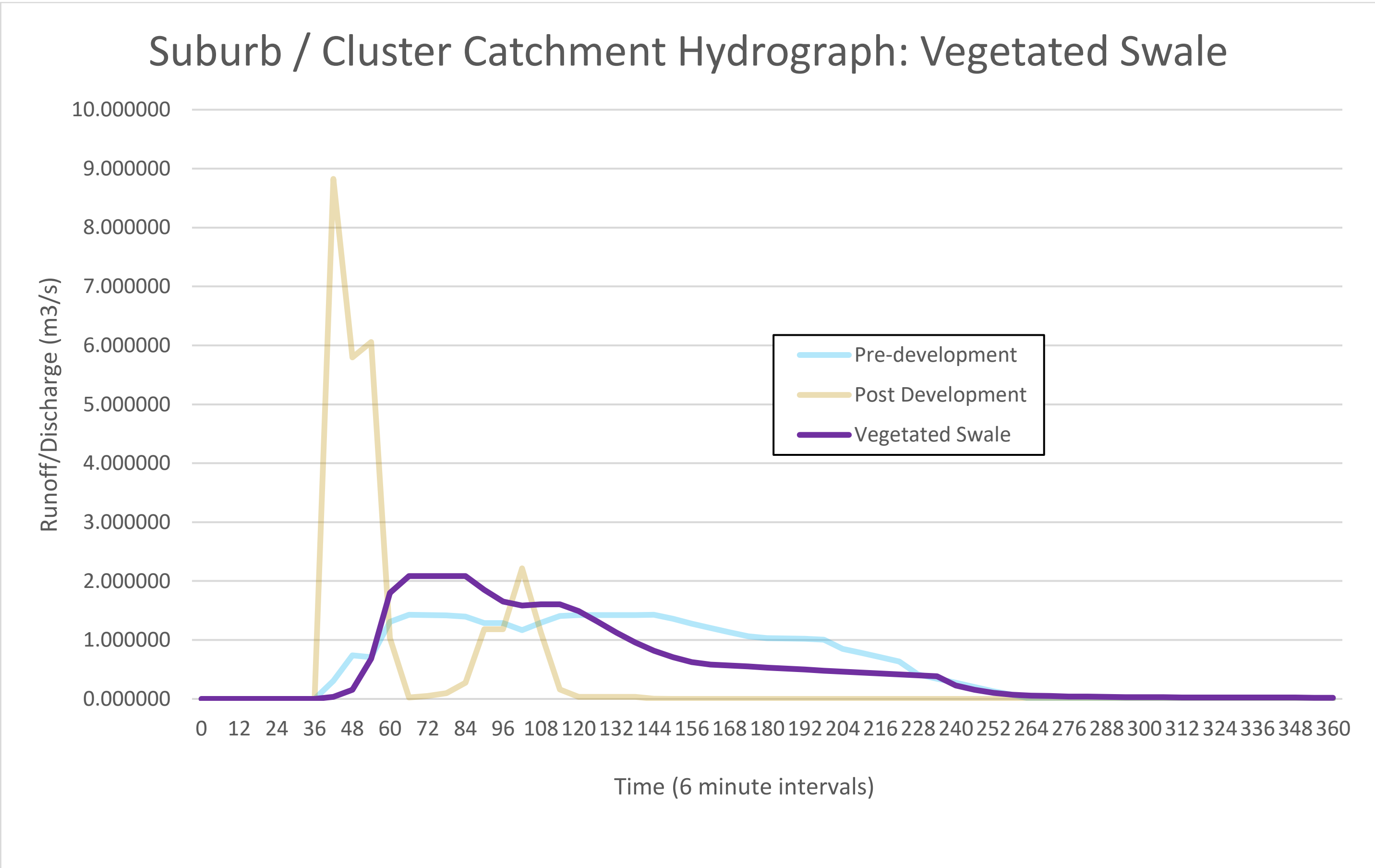


Figure 4.15 – Hydrograph of Suburb Catchment: Vegetated Swale

4.4.15. Suburb Constructed Wetland Hydrograph

The constructed wetland treatment was modelled in the suburb catchment, and the hydrograph results are available in **figure 4.16**. The graph shows that the peak flow of 8.8257m^3/s is originally reduced to practically no runoff. This is a reduction of 100%.

There are no rising and falling limbs to analyse, the hydrograph shows no runoff from wetland. The constructed wetland improves the original natural/pre-developed flow conditions. All, or very close to all, runoff from this site will be collected by the constructed wetland in a 1 in 10 year storm.

Constructed wetlands have the characteristic of having little to no output discharge. The implementation of wetlands must consider the downstream impact they occur. Downstream natural waterways may be reliant on the runoff from this catchment. If runoff is completely stopped this may cause drying natural waterways and therefore destroying ecosystems.

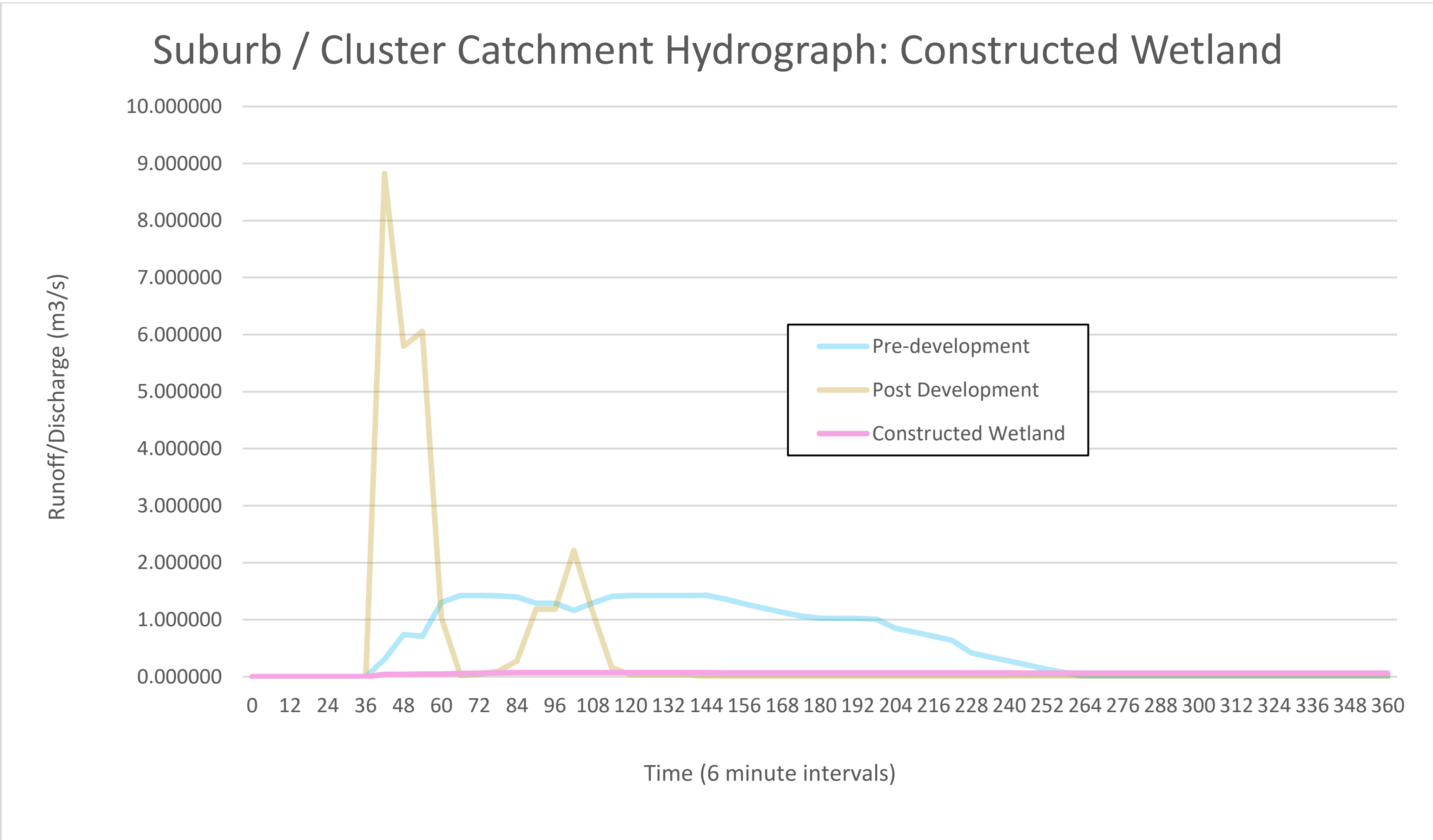


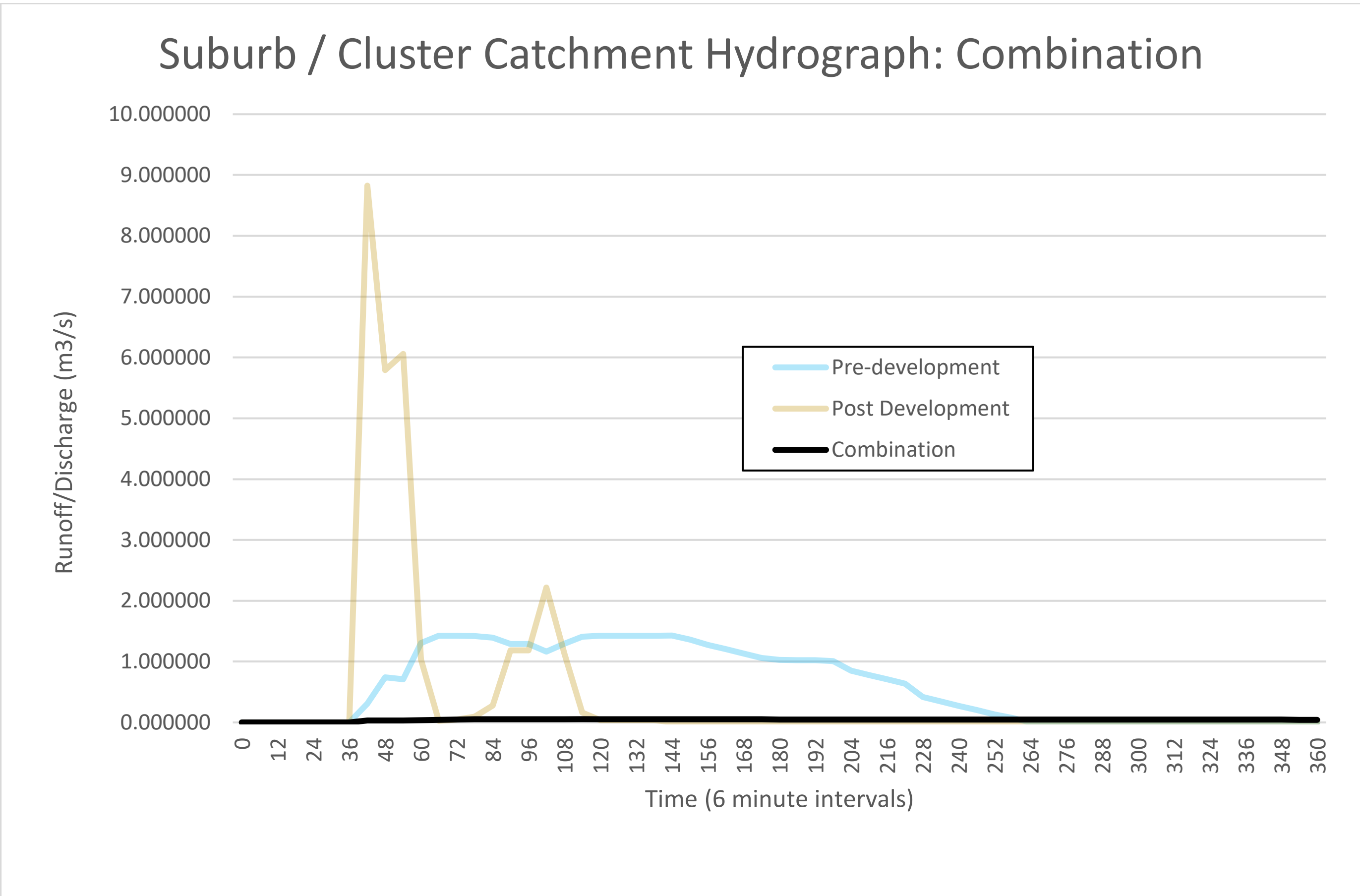
Figure 4.16 – Hydrograph of Suburb Catchment: Constructed Wetland

4.4.16. Suburb Combination Hydrograph

The combination of the green roof, permeable treatments, bio-retention basin, vegetated swale and the constructed wetland were modelled in the suburb catchment, and the hydrograph results are available in **figure 4.17**. The graph shows that the peak flow of 8.8257m^3/s is originally reduced to practically no runoff. This is a reduction of 100%.

There are no rising and falling limbs to analyse, the hydrograph shows no runoff from the combination. The combination of infrastructure improves the original natural/pre-developed flow conditions. Although it seems to be the constructed wetland attributes contributing to these results.

All previous infrastructure become negligible and the combination would achieve similar results as shown in **Figure 4.16**.



**Combination: Green Roof + Permeable Pavement + Bio-Retention Basin+ Vegetated Swale + Constructed Wetland*

Figure 4.17 – Hydrograph of Suburb Catchment: Combination

4.4.17. Conclusions

A summary of all the results from the output are listed below in **Table 4.2**. Numbers in blue denote the best performance for its particular catchment. Hydrographs show that the bio-retention basin runoff did approximately return the post development flows back to natural/pre-developed conditions. It also demonstrates that the combinations did not perform as expected. The only example of an effective combination is the reduction of the 2nd peak in the subdivision catchment. The suburb showed an effective combination but this might have been the wetland controlling this data. This outcome is unexpected and is not entirely clear why this is occurring in the model. It is assumed to be a calculation error from the software, when calculating bypass from one node to another. This concludes that the MUSIC software is not suitable to analyse the combinations of green infrastructure. A solution may involve a different technique to solve this problem.

With that being stated there is suitable data collected to determine the best performing infrastructure. This was discovered to be the constructed wetland. The second best performing infrastructure was the bio-retention basins, then followed by the vegetated swales, green roofs and then the permeable pavement. The cost and land application must be considered in the decision process for optimum green infrastructure solution.

Catchment	Green Infrastructure	Peak Flow Reduction (%)	2nd Peak Reduction (%)	Lag Time (minutes)	Rising Limb (reduced velocity)	Falling Limb (reduced velocity)
Single Lot	Green Roof	**38.6**	**17.0**	**48**	Slightly	Slightly
	Permeable Pavement	20.0	0.0	0	No	Slightly
	Combination	32.9	4.7	42	Yes	Yes
Neighbourhood	Green Roof	**39.6**	**17.1**	**48**	Slightly	Slightly
	Permeable Pavement	19.9	0.0	0	No	Slightly
	Combination	33.6	4.7	42	Yes	Yes
Subdivision	Green Roof	47.1	29.9	**48**	Slightly	Slightly
	Permeable Pavement	21.1	0.0	0	No	Slightly
	Bio-Retention Basin	**86.2**	49.4	24	Yes	Yes
	Combination	86.0	**51.9**	12	Yes	Yes
Suburb	Green Roof	50.0	34.0	**48**	Slightly	Slightly
	Permeable Pavement	21.4	0.0	0	No	Slightly
	Bio-Retention Basin	84.1	55.7	30	Yes	Yes
	Vegetated Swale	76.4	27.6	24	Yes	Yes
	Constructed Wetland	**100.0**	**100.0**	n/a	n/a	n/a
	Combination	**100.0**	**100.0**	n/a	n/a	n/a

Table 4.2 – Results Table

4.5. GREEN INFRASTRUCTURE WATER QUALITY PERFORMANCE

The modelled green infrastructures were checked for water quality outputs in the treatment train effectiveness option in the software. This process of modelling and design is clearly shown in **Figure 3.8**. Output water quality is assessed in model. If the pollutant reductions are not satisfactory, redesign of the green infrastructure is necessary. This would be repeat until quality outcomes are in accordance with SPP.

All infrastructure were required to have reduction in pollution in accordance with **Table 2**.1. All devices did comply with quality requirements except for the total phosphorus reduction for bio-retention basin in the subdivision catchment. This 58.4% reduction was considered suitable for this investigation. Requirement is 60% reduction; the model is 1.6% short of this target. This small difference would require a slight increase to the treatment area. This was deemed to be an unnecessary change for the objectives of this investigation. Other parameters that could be adjusted to fix the quality outcome are filter media characteristics, vegetation and submerged zone attributes.

4.5.1. Green Roof

The water quality treatment train effectiveness for the green roof infrastructure are shown in **Table 4.3**. This data is a direct output from the relevant MUSIC models. The green roofs reduced the required pollutants in accordance with the state planning policy and Ipswich planning policy.

Catchment	Reduction (%) in Total Suspended Solids (TSS)	Reduction (%) in Total Phosphorus (TP)	Reduction (%) in Total Nitrogen (TN)	Reduction (%) in Gross Pollutants >5mm
Single Lot	93.1	73.4	46.5	100.0
Neighbourhood	93.0	73.3	46.1	100.0
Subdivision	93.1	73.2	46.3	100.0
Suburb	93.1	73.3	46.3	100.0

Table 4.3 – Green Roof Water Quality Results Table

4.5.2. Permeable Pavement

The water quality treatment train effectiveness for the permeable pavement infrastructure are shown in **Table 4.4**. This data is a direct output from the relevant MUSIC models. The permeable pavements reduced the required pollutants in accordance with the state planning policy and Ipswich planning policy.

Catchment	Reduction (%) in Total Suspended Solids (TSS)	Reduction (%) in Total Phosphorus (TP)	Reduction (%) in Total Nitrogen (TN)	Reduction (%) in Gross Pollutants >5mm
Single Lot	94.3	76.4	50.2	100.0
Neighbourhood	94.3	76.2	49.8	100.0
Subdivision	94.3	76.4	50.1	100.0
Suburb	94.3	76.5	50.1	100.0

Table 4.4 – Permeable Pavement Water Quality Results Table

4.5.3. Bio-Retention Basin

The water quality treatment train effectiveness for the bio-retention basin infrastructure are shown in **Table 4.5**. This data is a direct output from the relevant MUSIC models. The bio-retention basins reduced the required pollutants in accordance with the state planning policy and Ipswich planning policy. All except for the total phosphorus reduction, discussed previously. This imprecision is represented in orange in the table.

Catchment	Reduction (%) in Total Suspended Solids (TSS)	Reduction (%) in Total Phosphorus (TP)	Reduction (%) in Total Nitrogen (TN)	Reduction (%) in Gross Pollutants >5mm
Subdivision	93.7	58.4	67.3	100.0
Suburb	99.2	68.8	89.2	100.0

Table 4.5 – Bio-Retention Basin Water Quality Results Table

4.5.4. Vegetated Swale

The water quality treatment train effectiveness for the vegetated swale infrastructure are shown in **Table 4.6**. This data is a direct output from the relevant MUSIC models. The vegetated swale reduced the required pollutants in accordance with the state planning policy and Ipswich planning policy.

Catchment	Reduction (%) in Total Suspended Solids (TSS)	Reduction (%) in Total Phosphorus (TP)	Reduction (%) in Total Nitrogen (TN)	Reduction (%) in Gross Pollutants >5mm
Suburb	96.4	73.1	87.2	100.0

Table 4.6 – Vegetated Swale Water Quality Results Table

4.5.5. Constructed Wetland

The water quality treatment train effectiveness for the constructed wetland infrastructure are shown in **Table 4.7**. This data is a direct output from the relevant MUSIC models. The constructed wetland reduced the required pollutants in accordance with the state planning policy and Ipswich planning policy.

Catchment	Reduction (%) in Total Suspended Solids (TSS)	Reduction (%) in Total Phosphorus (TP)	Reduction (%) in Total Nitrogen (TN)	Reduction (%) in Gross Pollutants >5mm
Suburb	97.6	91.7	87.6	100.0

Table 4.7 – Constructed Wetland Water Quality Results Table

4.6. OTHER CONSIDERATIONS

There are further considerations when deciding on the green infrastructure to be installed. The other main considerations are the cost of construction & maintenance, and the amount of land the device acquires. The amount of land can also be set at a cost value. Therefore, both considerations can be rated by a unit of cost. The green infrastructures in this investigation were rated against each other for cost and land application. This can assist in the developer's choice with regards to green infrastructure. A cost versus performance analyse.

4.6.1. Cost Rating

The costing rating shown in **Table 4.8** have considered the approximate costing of construction, materials and land. This data has used estimates from existing development with similar infrastructures in the area. The data collected is from a confidential source. Although, not all products for costing were sourced from this confidential database. Some products had to be sourced from product brochures online. Cost can all be assumed to be estimates only. The actual cost is irrelevant and it is the order that is the relevant information required for this investigation. The cost prices are only used for the rating system between green infrastructures used in this investigation.

Green Infrastructure	Cost Rating (1=most expensive, 5=least expensive)
Green Roof	3
Permeable Pavement	2
Bio-Retention Basin	4
Vegetated Swale	1
Constructed Wetland	5

Table 4.8 – Cost of Infrastructure Rating Table

4.6.2. Land Application Rating

The land application rating shown in **Table 4.9** have considered the approximate area of land the infrastructure consumes. Green roof and permeable pavement rate the highest in this category because technically they do not consume any additional land. The existing land use is converted into these types of green infrastructures, therefore no extra land will be required.

Green Infrastructure	Land Application Rating (1=smallest area req'd, 5=largest area req'd)
Green Roof	1
Permeable Pavement	1
Bio-Retention Basin	4
Vegetated Swale	3
Constructed Wetland	5

Table 4.9– Land Application of Infrastructure Rating Table

4.6.3. Overall Consideration Rating

The overall rating shown in **Table 4.10** is the addition of both cost and land application rating shown in **Table 4.8** and **Table 4.9**. This table will assist in selecting the optimum solution. The most inexpensive and less land invasive infrastructure was the permeable pavement. The second most inexpensive and less land invasive infrastructure was the green roof and vegetated swale, then followed by the bio-retention basin and then the constructed wetland. The cost and land application must be considered in the decision process for optimum green infrastructure solution.

Green Infrastructure	Total Rating
Green Roof	4
Permeable Pavement	3
Bio-Retention Basin	8
Vegetated Swale	4
Constructed Wetland	10

Table 4.10 – Overall Consideration Rating Table

When considering performance, cost and land application, the bio-retention basin was the optimum solution. This was considered after careful engineering judgement. Two experts in the industry confirmed this analysis. For the smaller catchments that did not have the basins installed, (single lot and neighbourhood/street catchments), the optimum solution was the green roof. Although this did not return to natural conditions, it was the best performing, cost effective solution.

4.7. HAND CALCULATIONS

As stated in the literature review the accuracy of the MUSIC model is to be checked using hand calculations. The post development's peak discharge runoff will be checked in every catchment. Hand calculations will use the basic hydrology equation below.

$$Q_p = \frac{\mathrm{CIA}}{360}$$

Where Q_p is the peak flow (m3/s), C is runoff coefficient, I the rainfall intensity at time of concentration (mm/h), A is the catchment area (ha). Runoff coefficient derive for tables in QUDM to be equal to 0.84.

(IPWEA, 2017)

This will determine the accuracy of the MUSIC models. Since there is little research on this data, this will assist in checking the software's capability to analyse frequent flow management. All data will be summarised, and the results will be analysed.

4.7.1. Single Lot Catchment Check

$C = 0.85$

$I = 62.083mm/hr$

$A = 0.057ha$

$$Q_p = \frac{C \cdot I \cdot A}{360}$$

$$Q_p = \frac{0.85 \times 62.083 \times 0.057}{360} = 0.0084m^3/s$$

Hydrograph peak flow of $Q_i = 0.0070m^3/s$

Therefore;

$$Percentage\ Error = \frac{Q_p - Q_i}{Q_p} = \frac{0.0084 - 0.0070}{0.0084} = 16.7\%$$

It will be assume that 10% error will be the maximum acceptance for there to be suitable accuracy in the MUSIC model. Therefore 16.7% is too high of an error, and the MUSIC software is not calculating accurate data.

4.7.2. Neighbourhood Catchment Check

$C = 0.85$

$I = 62.083mm/hr$

$A = 0.570ha$

$$Q_p = \frac{C \cdot I \cdot A}{360}$$

$$Q_p = \frac{0.85 \times 62.083 \times 0.570}{360} = 0.0836m^3/s$$

Hydrograph peak flow of $Q_i = 0.0700m^3/s$

Therefore;

$$Percentage\ Error = \frac{Q_p - Q_i}{Q_p} = \frac{0.0836 - 0.0700}{0.0836} = 16.3\%$$

It will be assume that 10% error will be the maximum acceptance for there to be suitable accuracy in the MUSIC model. Therefore 16.3% is too high of an error, and the MUSIC software is not calculating accurate data.

4.7.3. Subdivision Catchment Check

$C = 0.85$

$I = 62.083mm/hr$

$A = 6.726ha$

$$Q_p = \frac{C \cdot I \cdot A}{360}$$

$$Q_p = \frac{0.85 \times 62.083 \times 6.726}{360} = 0.9859m^3/s$$

Hydrograph peak flow of $Q_i = 0.8305m^3/s$

Therefore;

$$Percentage\ Error = \frac{Q_p - Q_i}{Q_p} = \frac{0.9859 - 0.8305}{0.9859} = 15.8\%$$

It will be assume that 10% error will be the maximum acceptance for there to be suitable accuracy in the MUSIC model. Therefore 15.8% is too high of an error, and the MUSIC software is not calculating accurate data.

4.7.4. Suburb Catchment Check

$C = 0.85$

$I = 62.083mm/hr$

$A = 71.451ha$

$$Q_p = \frac{C \cdot I \cdot A}{360}$$

$$Q_p = \frac{0.85 \times 62.083 \times 71.451}{360} = 10.4736m^3/s$$

Hydrograph peak flow of $Q_i = 8.8257m^3/s$

Therefore;

$$Percentage\ Error = \frac{Q_p - Q_i}{Q_p} = \frac{10.4736 - 8.8257}{10.4736} = 15.7\%$$

It will be assume that 10% error will be the maximum acceptance for there to be suitable accuracy in the MUSIC model. Therefore 15.7% is too high of an error, and the MUSIC software is not calculating accurate data.

4.8. CONCLUSIONS

The storm event that occurred on the 9th of March 1986 was used as the design 1 in 10-year input storm. This event is represented in **Figure 4.1** as a hyetograph. This graph clearly shows the rainfall in 6-minute intervals. It was discovered that this was a dual peak event. However, the dissertation objectives focused on the first larger peak. The storm intensity of this first peak was calculated to be 62.083mm/hr. This intensity estimate was used in the calculations to determine the accuracy of the MUSIC software.

The hand calculation assessment of the MUSIC was completed on the peak discharge in the post development outputs in each catchment. The single lot catchment's model had a percentage error of 16.7%. The neighbourhood/street catchment's model had a percentage error of 16.3%. The subdivision catchment's model had a percentage error of 15.8%. The suburb catchment's model had a percentage error of 15.7%. Which leaves the MUSIC modelling program to have an average percentage error of 16.1%. It was assumed that to have any confidence with the modelling capability, this percentage error would have to be 10% or less. Therefore, this research suggests that there is no confidence in the MUSIC software's capability to handle frequent flow management. There were also bypass errors when comparing the combinations with the single infrastructures. This bypass error would have to be fixed in the water balance internal calculations within MUSIC. Further research would be required to demonstrate if this software is capable or not capable to analyse frequent flows. This percentage error might affect the exact calculation however, the results from this dissertation could be used for comparison of single treatments.

All devices did comply with quality requirements in the planning policies, except for the total phosphorus reduction for bio-retention basin in the subdivision catchment. This 58.4% reduction was considered suitable for this investigation. Requirement is 60% reduction; the model is 1.6% short of this target. This small difference would require a slight increase to the treatment area. This small oversight would not impact the investigation's results.

The summary of all the performance results from the output are listed in **Table 4.2**. This table shows all green infrastructure reduced the peak flow. The bio-retention basin's hydrograph showed that its discharge runoff approximately returned the post development conditions back to pre-development conditions. The cost and land application were also included in the selection of the optimum infrastructure combination. Although the constructed wetlands were the best performing, the bio-retention basin was selected as the optimum green infrastructure in the subdivision and suburb catchments. This is due to the bio-retention basins is less expensive to construct and maintain. It also consumes smaller land area application. The green roof was selected for the smaller catchments, single lot and neighbourhood. It also rated well in its cost parameters.

CHAPTER 5

CONCLUSION

5.1. Introduction

From the results the optimum green infrastructure for each catchment was selected. This was green roof for the smaller catchments; single lot and neighbourhood. The bio-retention basin was selected as the optimum system in the subdivision and suburb catchments. However, the best performing system in runoff attenuation and frequent flow management was the constructed wetland. This wetland infrastructure was an over-engineered solution for the catchment sizes in this investigation. To assist in selecting an optimum combination, to match a real-life simulation, the analysation also included the controls of cost and land application. This assisted in identifying the best engineering solution for each catchment. This dissertation also analysed the MUSIC software's capability of analysing frequent flow management and runoff attenuation.

5.2. Conclusions

All green infrastructures reduce the peak runoff discharge. However, some infrastructure have little to no impact of the retention and velocity of urban runoff. Unexpectedly, the combination of green infrastructures either had increased the runoff from the original best performing infrastructure.

It was discovered that the bio-retention basin, in all relevant catchments, did assist in approximately returning the post development flows back to pre-developed flows. These devices consume small areas of land and the cost of design and construction of bio-retention are reasonable when compared to the other infrastructures. Therefore, the bio-retention basin, not in any combination, was the optimum solution. For the smaller catchments that did not have the basins installed, single lot and neighbourhood/street catchments, the optimum solution was the green roof. Although this did not return to pre-developed flow conditions, it was the best performing solution.

These results are unexpected. It was assumed that the urban runoff will be impacted by the number of green infrastructures in the model. Because this expectation seems practical, it is assumed that there might be an error in the model calculations. It does give the indication that the original peak reduction is bypass onto the retention/lag peak that occurs later. It could not be proved that the runoff discharge is proportionate with the number of green infrastructure treatments used in the combination.

Constructed wetlands were the best performing green infrastructure with having only minor runoff from these devices. This greatly improves the natural, pre-development conditions. These results were predictable after understanding the infrastructure's mechanics and processes. Although, these devices performed the best, the cost and land application must be considered in the decision process. Constructed wetlands consume a large proportion of land. Their cost to design, construct and maintain was the most expensive of all the green infrastructures. Therefore, their application can be acknowledged as over-engineering for the selected catchments in this investigation. It is suggested that these be placed downstream of larger catchments.

There was not enough evidence that suggested that the catchment size has effects of the green infrastructure treatment in the model. The results varied between all of the catchment sizes. There was no definite proportion relationship between the two variables, catchment size and green infrastructure performance, that could be distinguished. Therefore with regards to catchment scale factor, these findings were mixed and inconclusive.

5.3. Further Discussions

This dissertation has highlighted the requirement for further research. The MUSIC software used in this investigation was examined for its accuracy to determine discharge runoff. It was discovered that in this investigation, percentage of error was too large. Therefore, for this investigation, MUSIC did not have the capability to analyse the frequent flow. Further research would be required to confirm these statements. It was not the primary objective of this dissertation.

Further research is also required into the combinations of infrastructures. The results from this investigation determined that there might be a bypass or other runoff miscalculation when combining treatment devices.

If this error could be fixed this investigation could be completed again to determine the results from the combination model. The other studies could include experimenting with different combinations and arrangements. They could even include the green infrastructures not included in this investigation. (Green walls, bio-swales, rain gardens, planter boxes, blue roofs, subsurface detention systems, rainwater harvesting, rain barrels and cisterns, etc.)

It was originally planned to use the data in this investigation and run with another similar software identified in the literature review. The PCSWMM software was a suitable software package discovered. Comparison of results from this software, or similar, would give a good representation of the accuracy of results. It would be interesting to discover how the software would compare.

The MUSIC guidelines only recommended the historical rainfall of 10 years (01/01/80-31/12/89). To gain more confidence in the results it is recommended that a larger range of data be used. The 1 in 10-year storm event rainfall records seemed to be minor compared to rainfall data of recent events. This is recommended from the flood modelling software packages. They use a much larger range of historical data.

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APPENDICES

ENG4111/4112 Research Project

Project Specification

For: Mr. Mark Lobwein

Title: The investigation of stormwater runoff by utilising a combination of green infrastructure in different sized urban residential catchments.

Major: Civil Engineering

Supervisor: Dr. Rezaul Chowdhury

Enrolment: ENG4111 – EXT S1, 2020

ENG4112 – EXT S2, 2020

Project Aim: The project aim is to investigate the combined performance of green infrastructure in different sized catchments with the aid of stormwater modelling software package/s. The engineering benefit of the combination will be scrutinised.

The performance will be represented in the model by the amount of stormwater quantity runoff attenuation and frequent flow from catchments. Ideal situation will be mimic or improve natural flow runoff.

Programme: Version 1, 17th March 2020

1. Research background information on water sensitive urban design (WSUD) and green infrastructure.
2. Research into stormwater quality and quantity design. Including stormwater runoff attenuation and frequent flow management.
3. Research and locate any WSUD monitoring sites suitable for dissertation. Preferably site location to be situated in Queensland. Site location will be selected with an area with the most data available and most relevance to the dissertation. If monitored site location cannot be acquired.
4. Investigate the limitations of both software packages MUSIC and PCSWMM. Complete a comparison report between each software to determine the most suitable for the project aim.
5. Design a system of green infrastructure arrangement/combination for each catchment size in accordance with state planning guidelines and policies.
6. Collect observed data at the site location (e.g. rainfall, device inflow, overflow pollutants, LIDAR, etc.)
7. Software recommended parameter values to be calibrated and validated with the observed data. Ensure all parameters are in accordance with the local and state requirements.
8. Learn software packages and Model the 3 catchment sizes (lot, subdivision and cluster/suburb). Utilise models to critically analyse runoff attenuation and frequent flow. Stormwater quality of the WSUD design examined by the model to ensure it meets requirements.
9. Checking accuracy of the model by using engineering judgement and Stormwater hydrology calculations (such as the rational method)
10. Summarise and analyse results and data
11. Complete and submit a draft dissertation for review
12. Complete and submit an academic dissertation with detailed research methodology, findings, model and conclusions.

If time and resources permit:

13. Trial a varied combination of green infrastructure in model
14. Model in unsuccessful software package to compare results.
15. Model the infrastructure over larger catchments (larger suburb, districts or city scales).

Table B1: Rainfall data and modelling periods for regions within South East Queensland

Council	Station ID	Station Name	Climate Period for Music	Mean Annual Rainfall over period (mm)	Mean PET (mm) (CLIMATE ATLAS OF AUSTRALIA)											
					JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Brisbane City Council (East)	40223	Brisbane Area	1/1/1980 – 31/12/1989	1149	193	51	150	109	75	63	65	84	112	148	175	199
Brisbane City Council (West)	40659	Greenbank Thompson Rd	1/1/1980 – 31/12/1989	784	181	139	137	102	72	62	63	81	108	138	159	184
Brisbane City Council (Central)	40214	Brisbane Regional Office	1/1/1980 – 31/12/1989	1178	188	146	146	107	74	63	65	84	11	144	171	192
Moreton Bay Regional Council	40063	Dayboro Post Office	1/1/1980 – 31/12/1989	1256	189	145	147	109	77	67	68	86	112	146	166	188
Gold Coast City Council (North)	40406	Beenleigh Bowls Club	1/1/1990 - 31/12/1999	1152	192	151	147	106	73	61	62	79	108	147	170	195
Gold Coast City Council (South)	40609	Elanora Treatment Plant	1/1/1989 – 31/12/1998	1436	160	134	133	101	72	57	58	72	95	132	145	163
Gold Coast City Council (Central)	40584	Hinze Dam	1/1/1976 – 31/12/1985	1371	176	143	137	140	72	59	60	75	102	141	158	180
Ipswich City Council (East)	**40659**	**Greenbank Thompson Rd**	**1/1/1980 – 31/12/1989**	**784**	**181**	**139**	**137**	**102**	**72**	**62**	**63**	**81**	**108**	**138**	**159**	**184**
Ipswich City Council (West)	40004	Amberley AMO	1/1/1990 – 31/12/1999	854	172	133	131	101	73	63	64	82	106	136	153	178
Sunshine Coast Regional Council (North)	40059	Cooroy Composite	1/1/1973 – 31/12/1983	1600	198	159	161	121	89	76	77	93	118	162	182	193
Sunshine Coast Regional Council (East)	40496	Caloundra WTP	1/1/1997 – 31/12/2006	1348	198	155	160	121	86	73	74	91	118	160	180	201

Sunshine Coast Regional Council (West)	40106	Kenilworth	1/1/1988 – 31/12/1997	1075	195	158	160	119	87	76	77	92	117	161	179	190
Sunshine Coast Regional Council (Central)	40282	Nambour DPI	1/1/1989 – 31/12/1998	1527	204	166	169	125	89	76	78	93	121	168	187	199
Lockyer Valley Regional Council	40082	University of Queensland Gatton	1/1/1980 – 31/12/1989	756	179	138	140	104	74	63	66	82	108	142	160	181
Logan City Council (East)	400715	Shailer Park	1/1/1990 – 31/12/1999	1119	195	153	149	107	74	61	63	80	110	148	173	199
Logan City Council (West)	40659	Greenbank Thompson Rd	1/1/1980 – 31/12/1989	784	181	139	137	102	72	62	63	81	108	138	159	184
Redland City Council	40265	Redlands HRS	1/1/1997 – 31/12/2006	1088	202	160	156	111	75	62	64	81	112	155	181	209
Scenic Rim Regional Council (East)	40014	Beaudesert Cryna	1/1/1968 – 31/12/2006	829	175	138	136	101	70	60	61	77	104	138	156	176
Scenic Rim Regional Council (West)	40094	Harrisville PO	1/1/1997 – 31/12/2006	579	176	136	134	101	71	62	63	80	106	138	155	180
Somerset Regional Council	40318	Kirkleigh	1/1/1980 – 31/12/1989	910	189	149	151	112	80	70	71	87	114	153	170	186
Toowoomba Regional Council	41467	Toowoomba City Council	1/1/1961 – 31/12/1970	898	173	133	137	100	74	63	66	81	104	139	158	173

MUSIC model arrangements

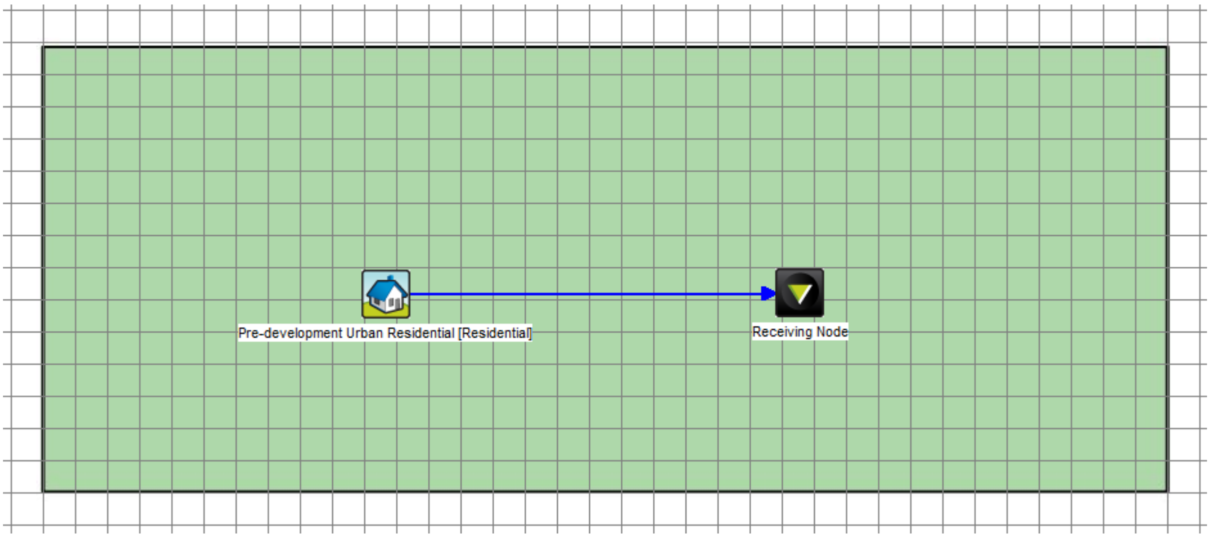

Figure C1 - Single Lot Catchment: Pre-development

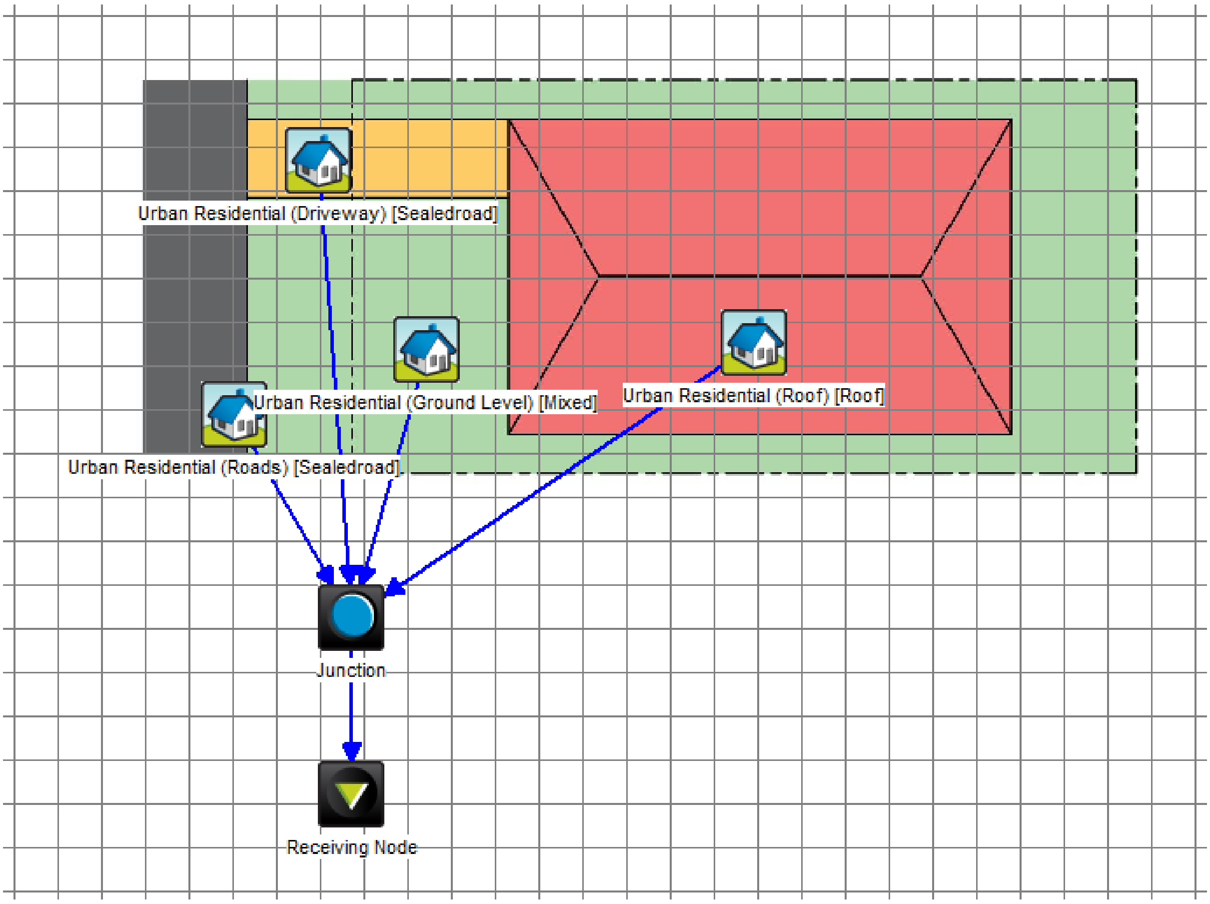

Figure C2 - Single Lot Catchment: Post Development

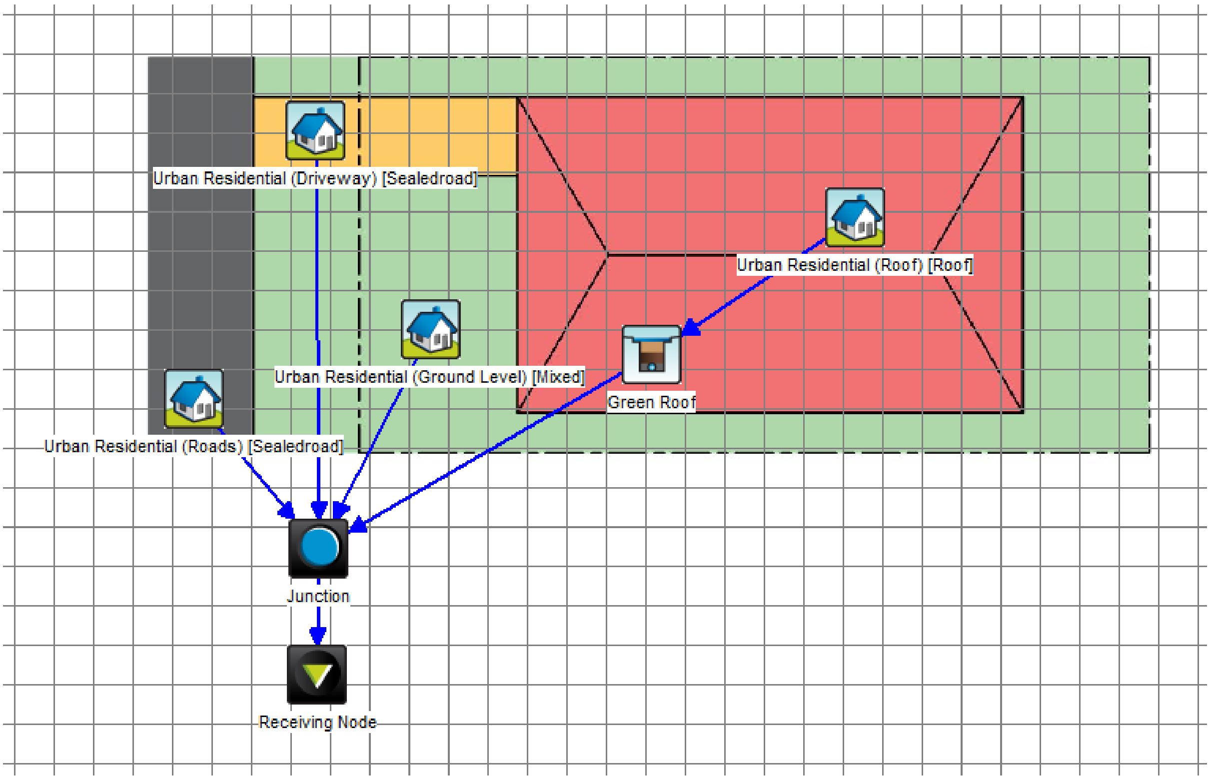

Figure C3 - Single Lot Catchment: Green Roof Treatment

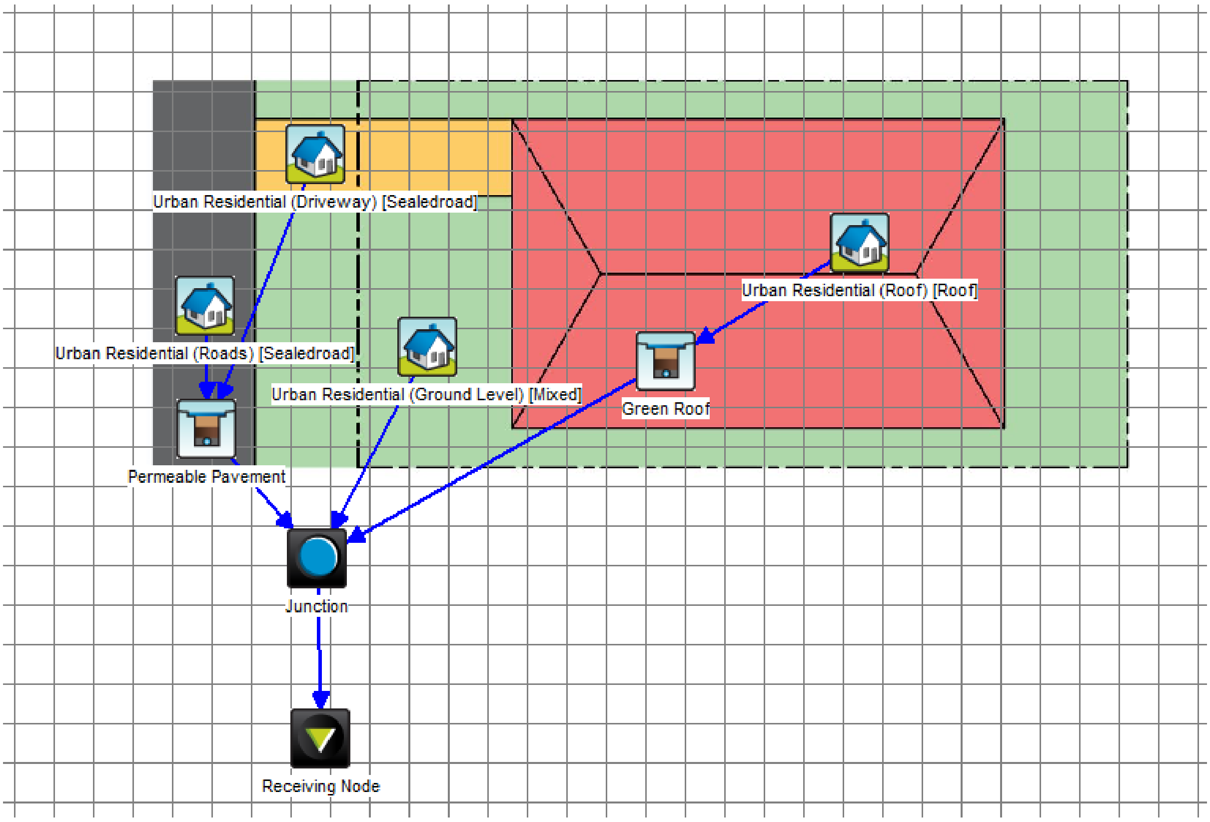

Figure C4 - Single Lot Catchment: Green Roof and Permeable Pavement Treatment

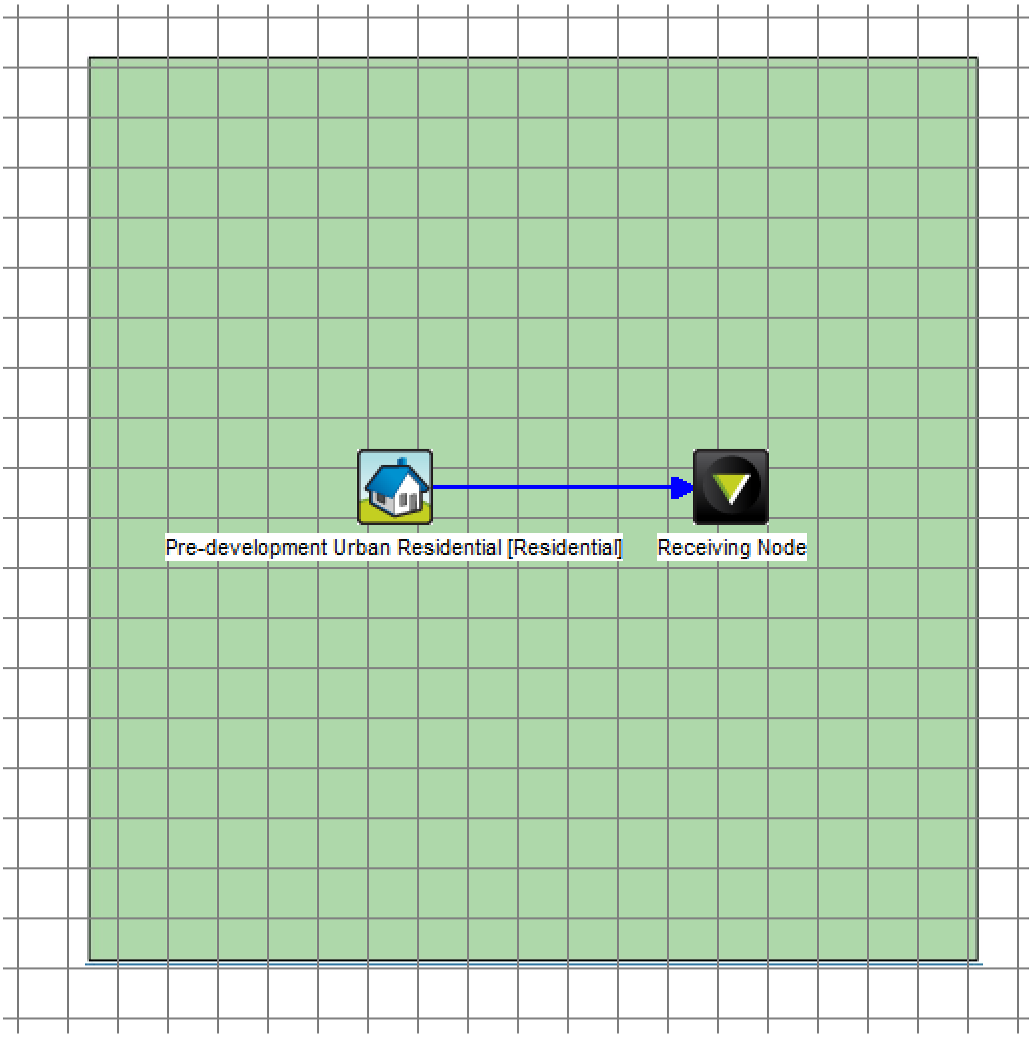

Figure C5 - Neighbourhood / Street Catchment: Pre-development

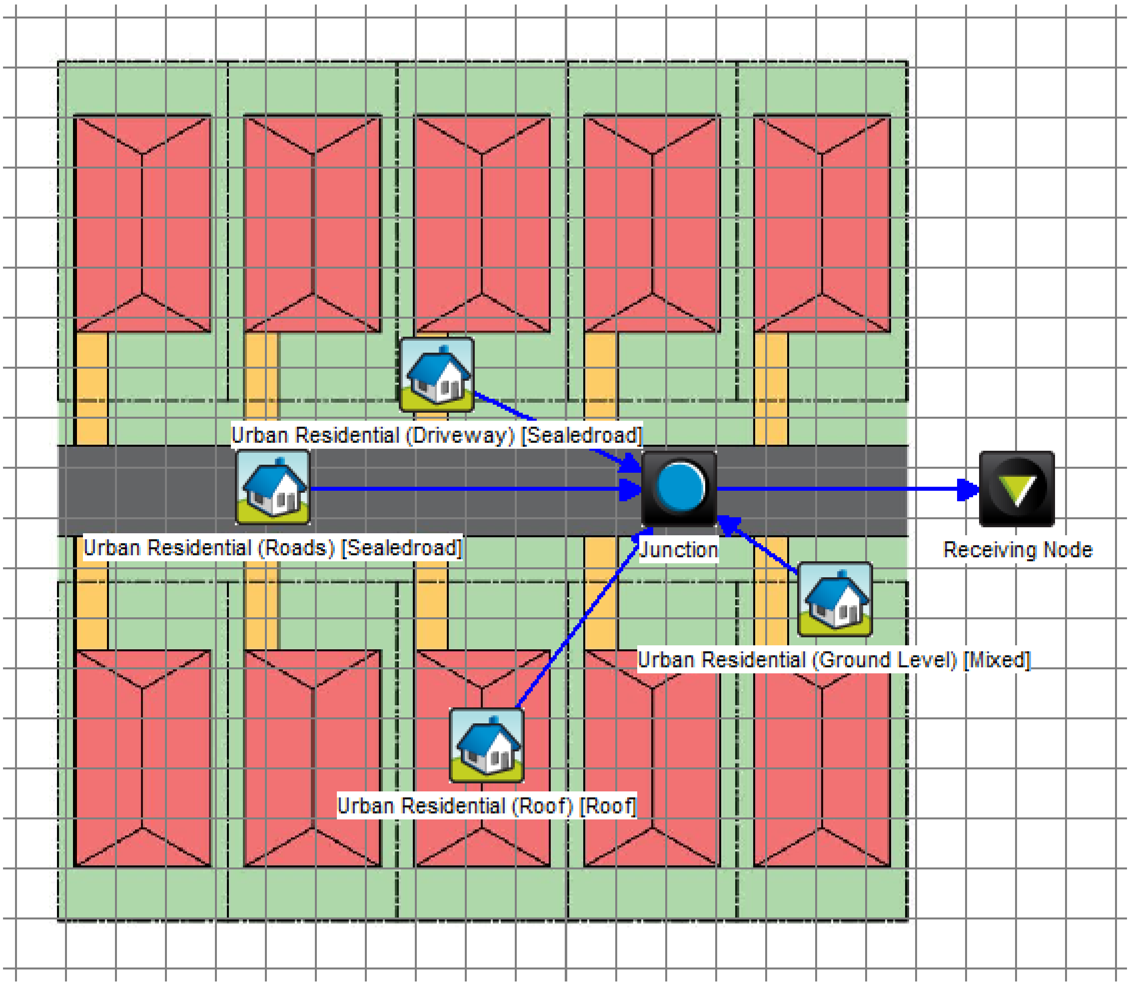

Figure C6 - Neighbourhood / Street Catchment: Post development

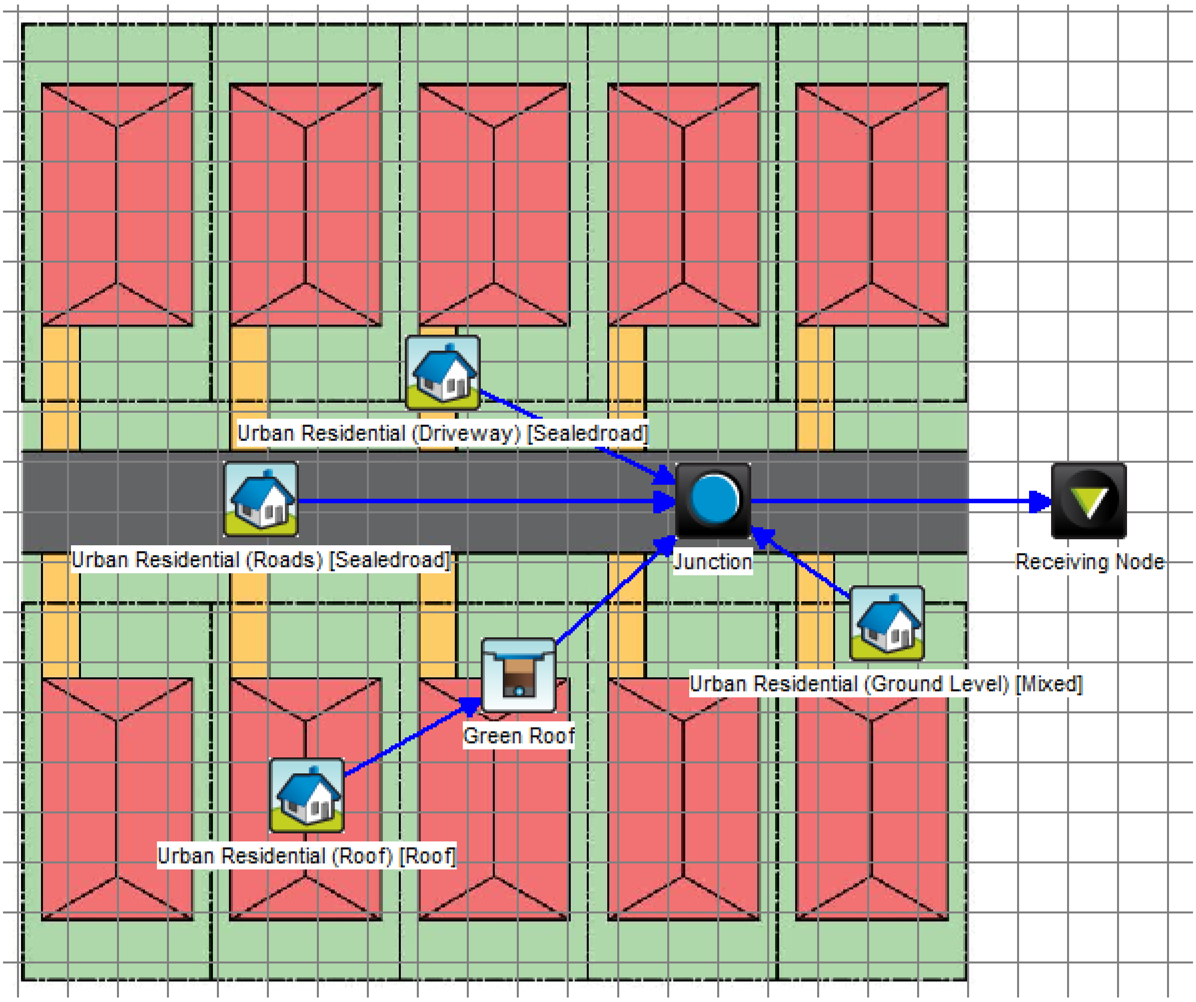

Figure C7 - Neighbourhood / Street Catchment: Green Roof Treatment

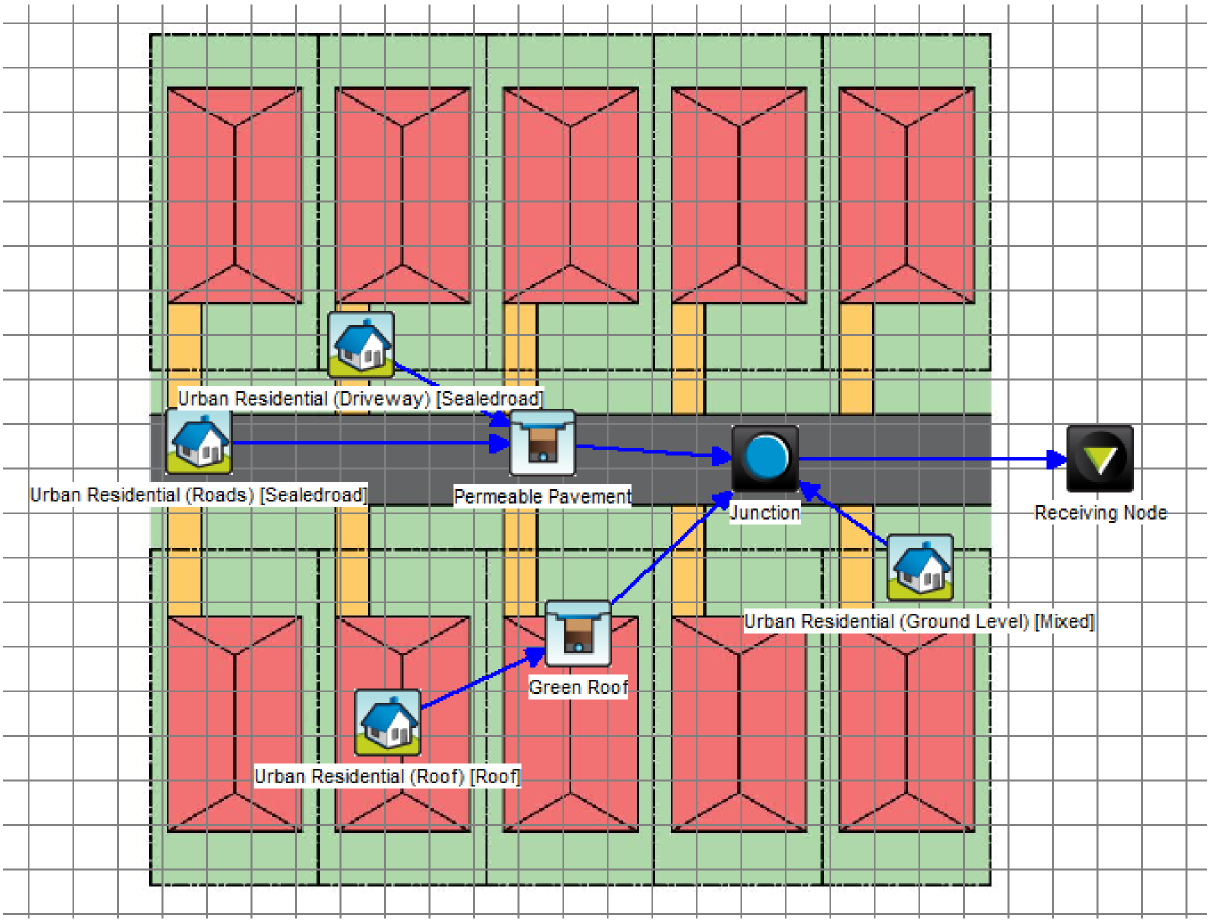

Figure C8 - Neighbourhood / Street Catchment: Green Roof and Permeable Pavement Treatment

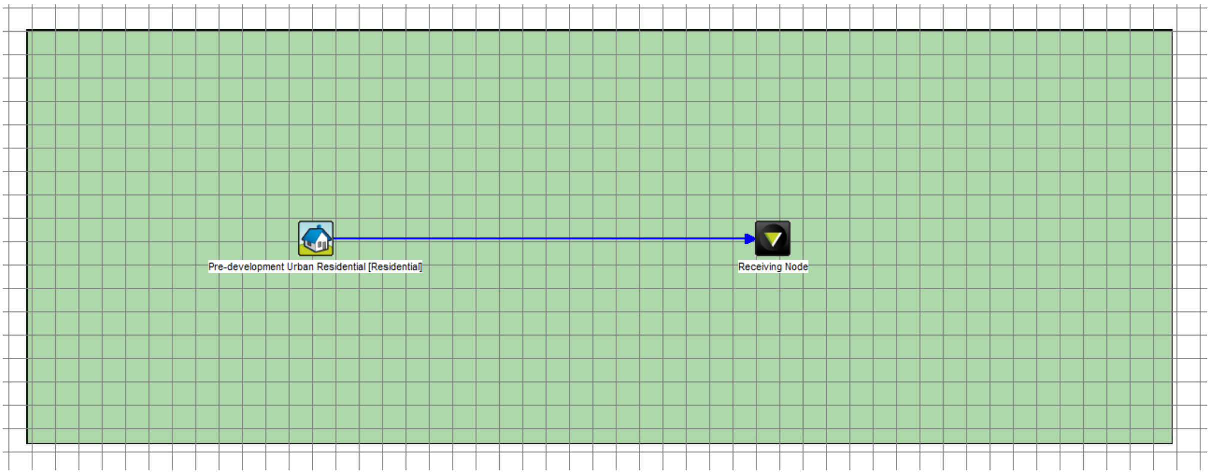

Figure C9 - Subdivision Catchment: Pre-development

Figure C10 - Subdivision Catchment: Post development

Figure C11 - Subdivision Catchment: Green Roof Treatment

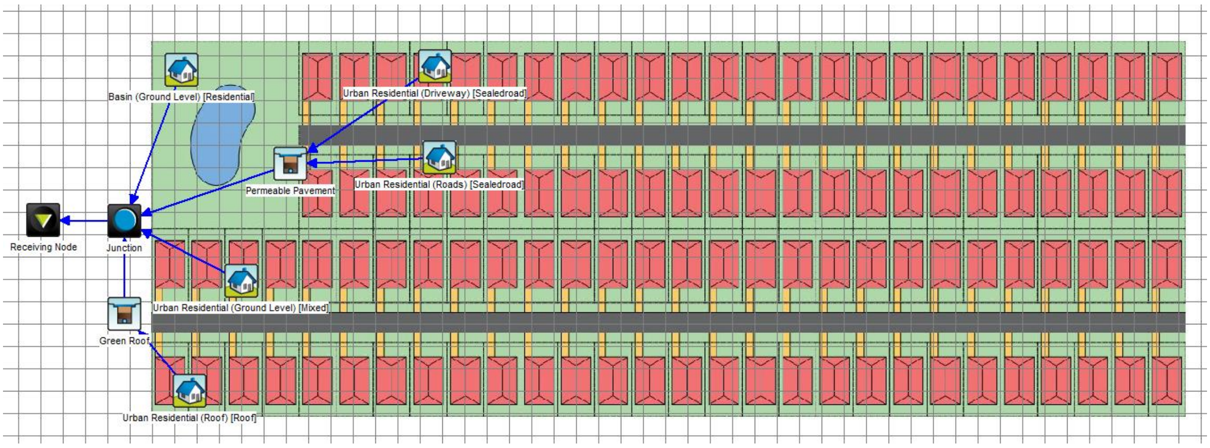

Figure C12 - Subdivision Catchment: Green Roof and Permeable Pavement Treatment

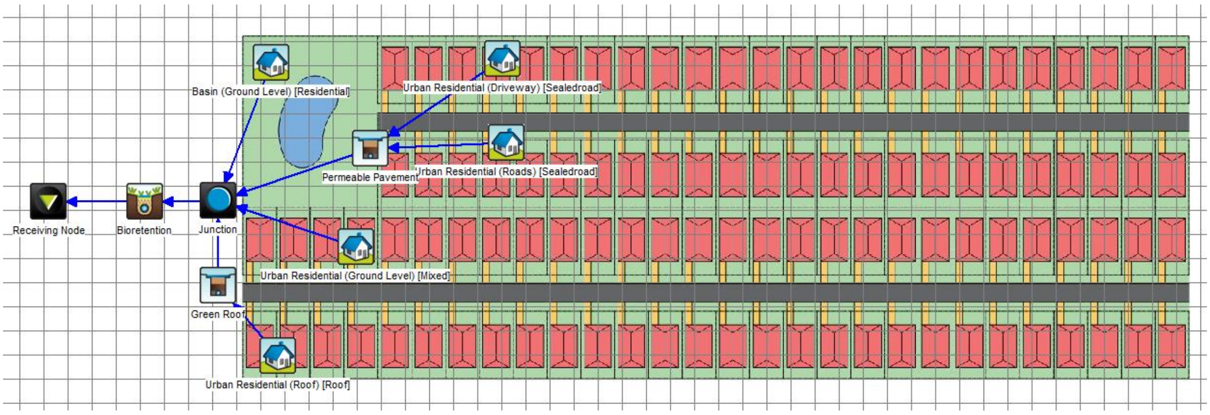

Figure C13 - Subdivision Catchment: Green Roof, Permeable Pavement and Bio-retention Basin Treatment

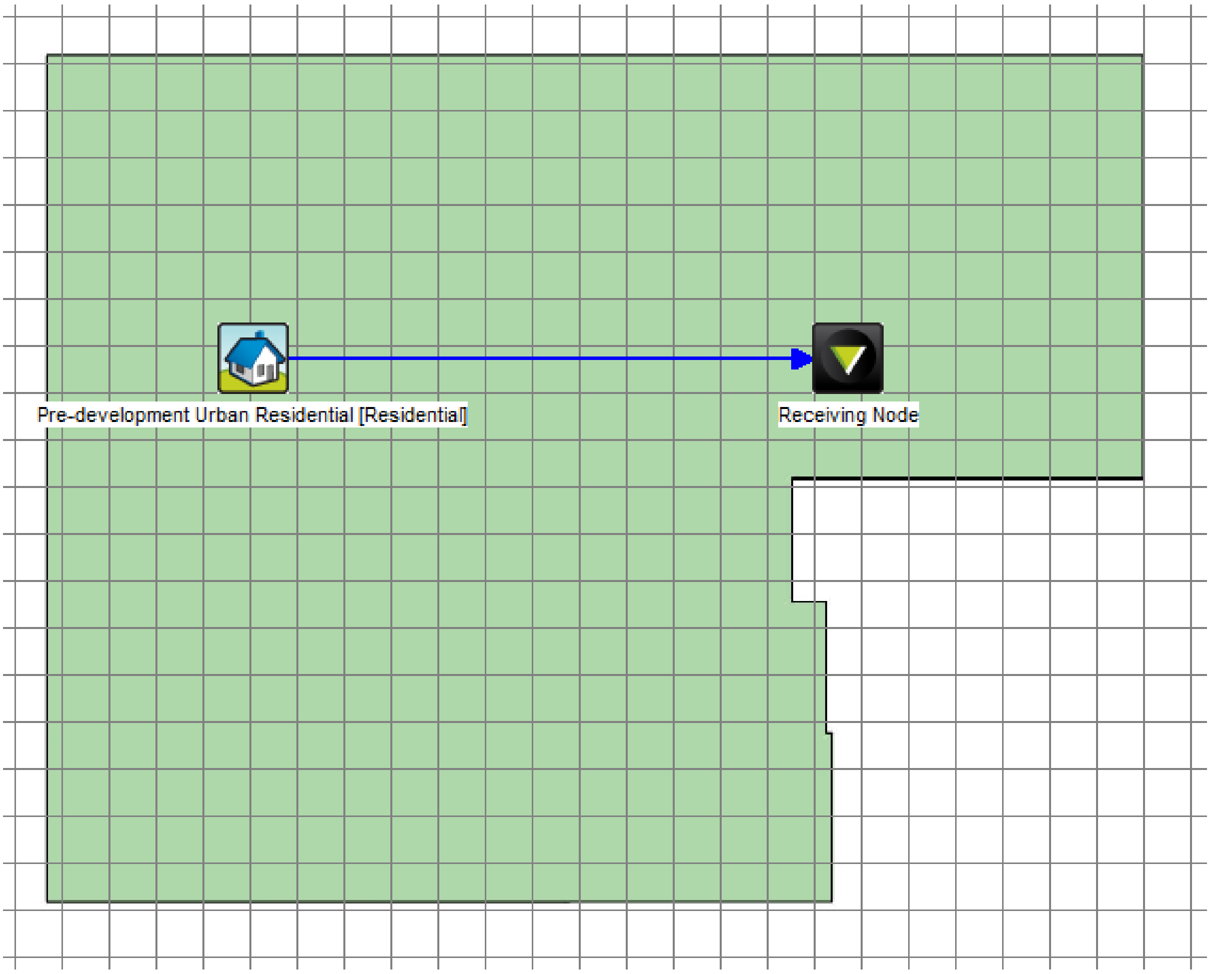

Figure C14 - Cluster / Suburb Catchment: Pre-development

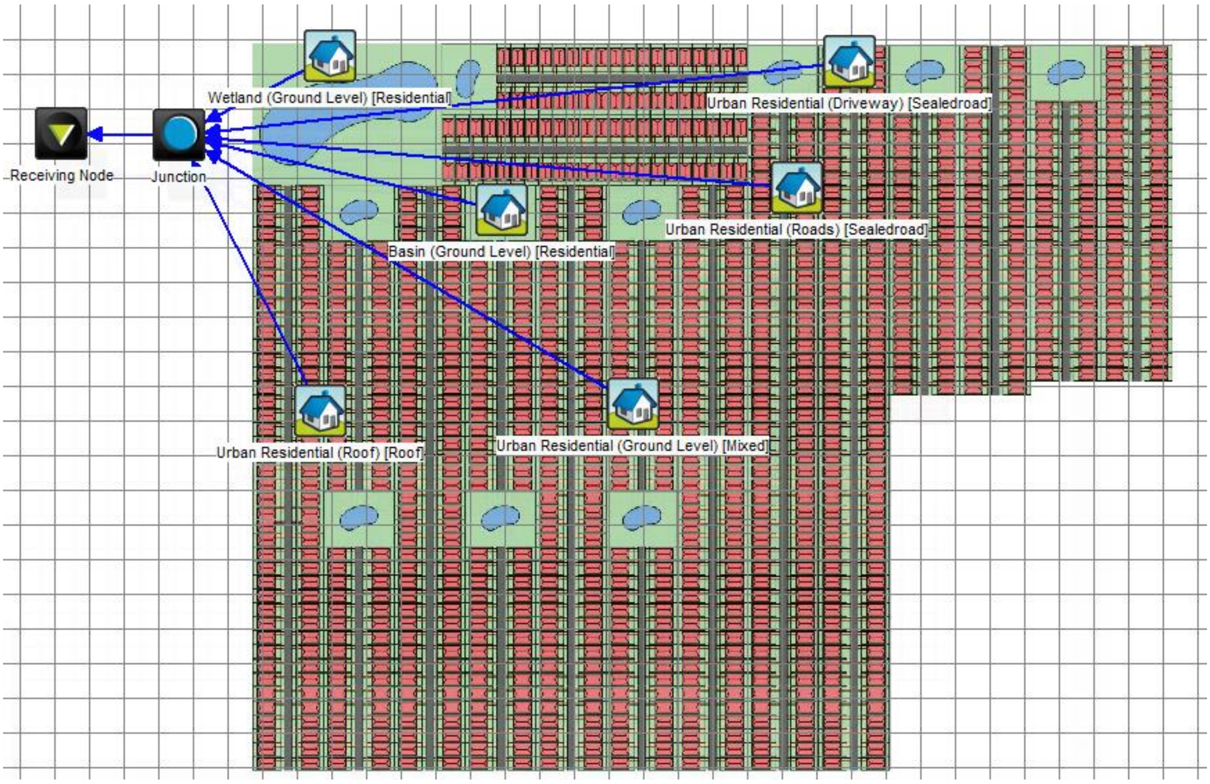

Figure C15 - Cluster / Suburb Catchment: Post development

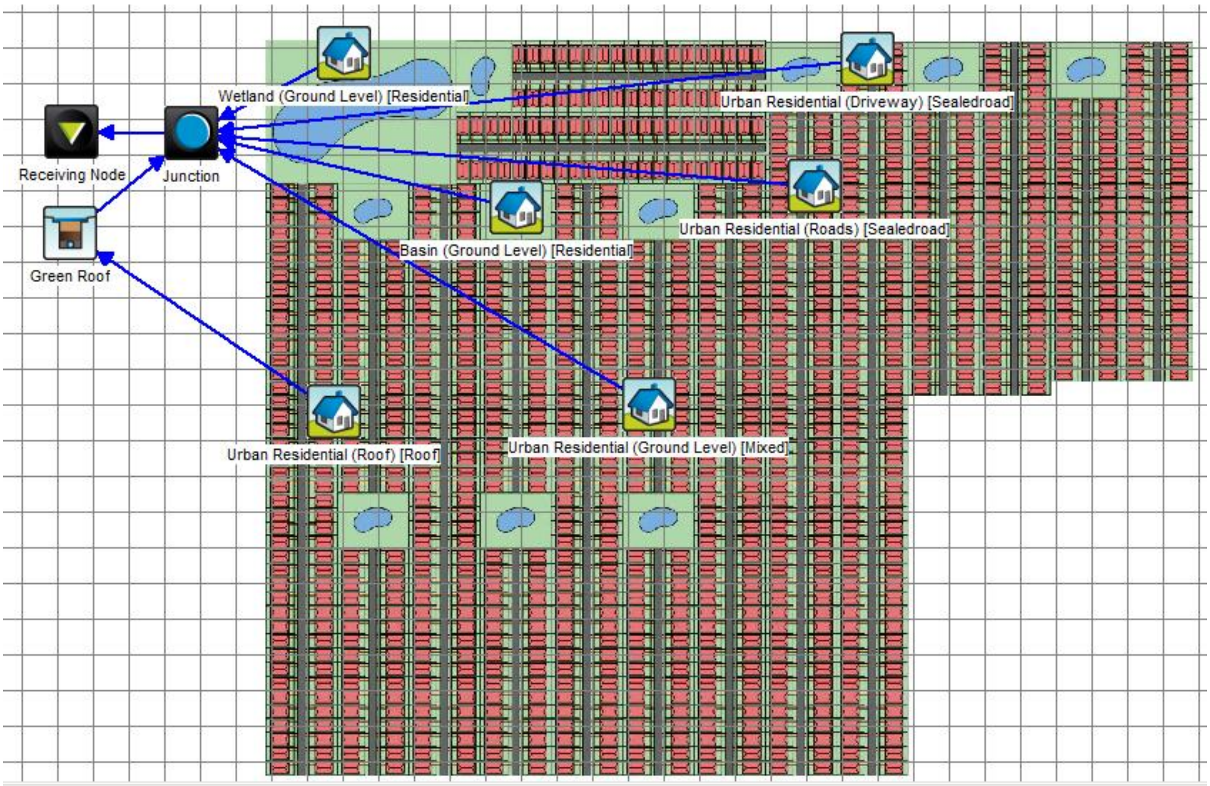

Figure C16 - Cluster / Suburb Catchment: Green Roof Treatment

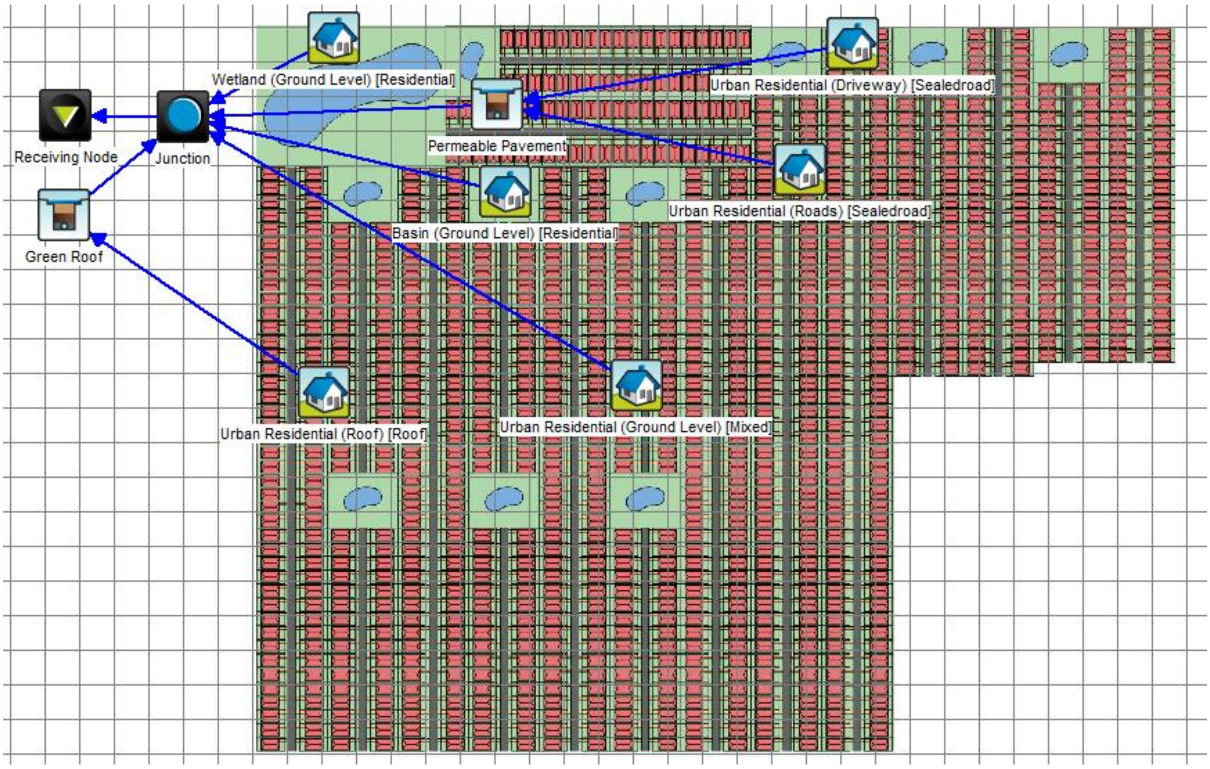

Figure C17 - Cluster / Suburb Catchment: Green Roof and Permeable Pavement Treatment

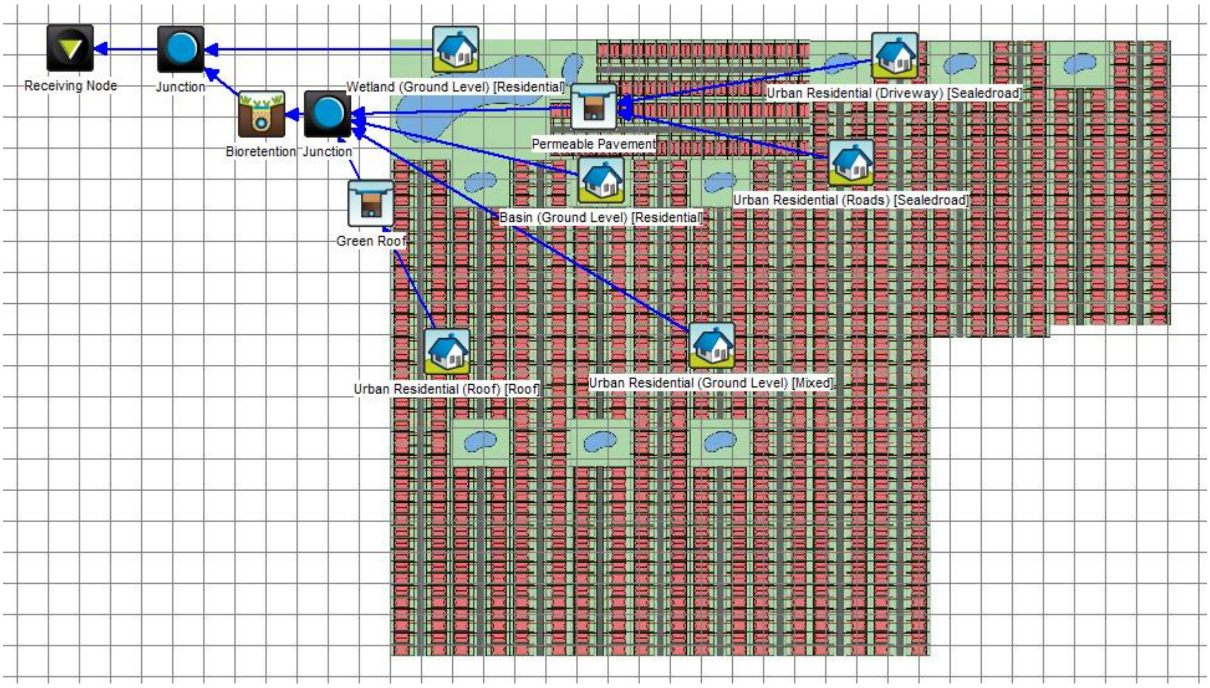

Figure C18 - Cluster / Suburb Catchment: Green Roof, Permeable Pavement and Bio-retention Basin Treatment

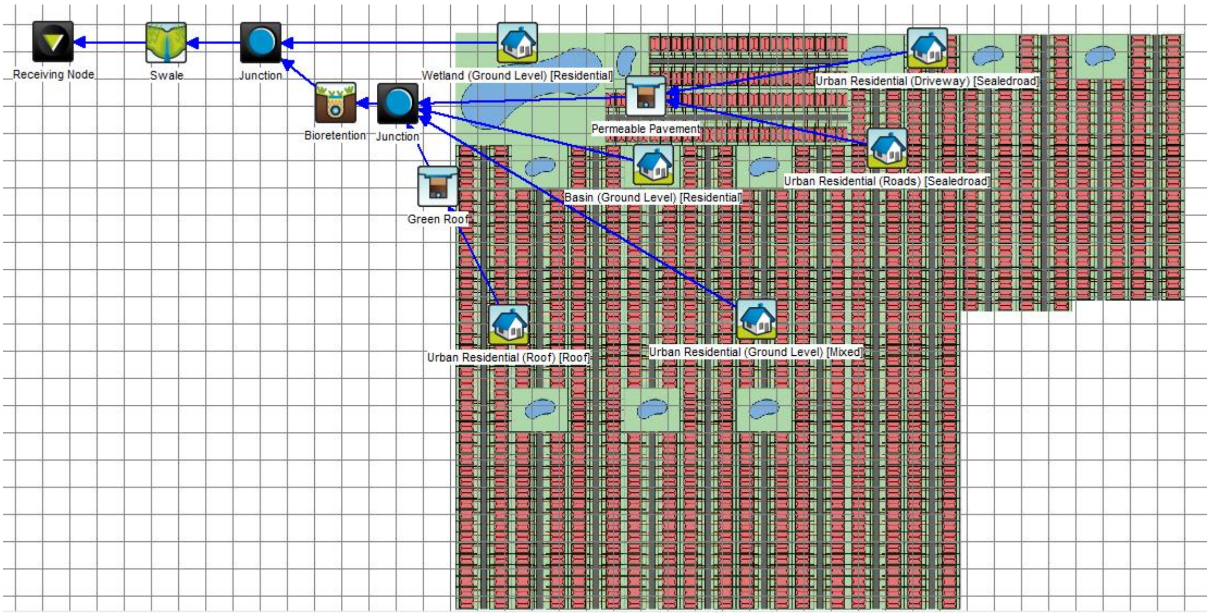

Figure C19 - Cluster / Suburb Catchment: Green Roof, Permeable Pavement, Bio-retention Basin and Vegetation Swale Treatment

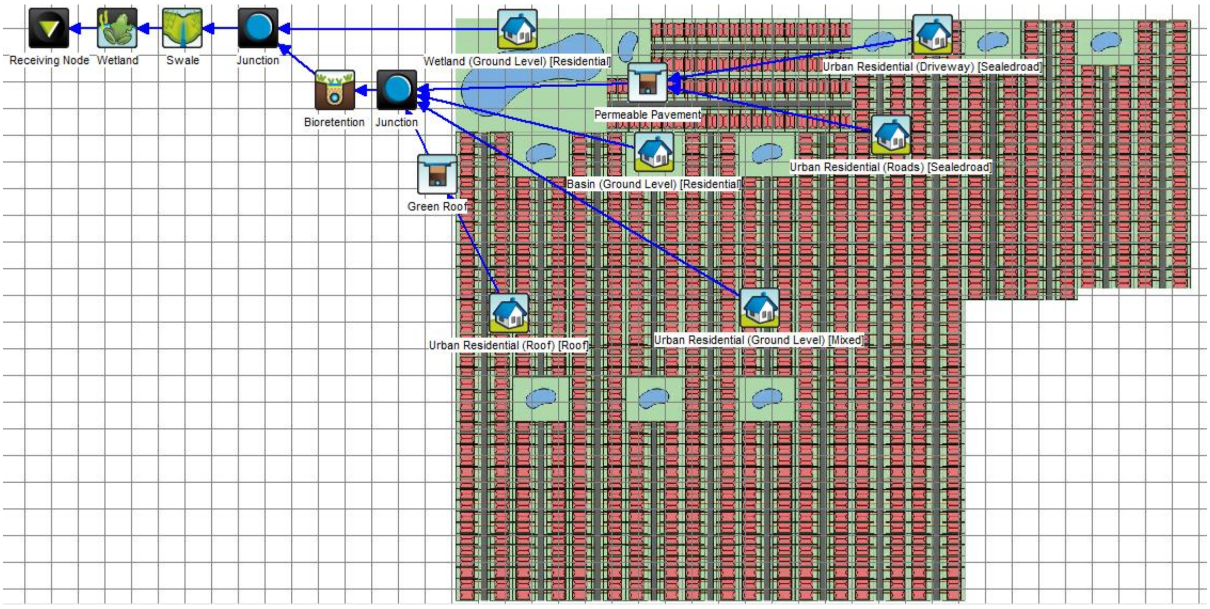

Figure C20 - Cluster / Suburb Catchment: Green Roof, Permeable Pavement, Bio-retention Basin, Vegetation Swale and Constructed Wetland Treatment

MUSIC Output Data Tables

Table D1 - Single Lot Catchment MUSIC Output Data					
Time	Pre-development	Post development	Green Roof	Permeable Pavement	GI Combination
0	0.000000	0.000000	0.000000	0.000000	0.000000
6	0.000000	0.000000	0.000000	0.000000	0.000000
12	0.000000	0.000000	0.000000	0.000000	0.000000
18	0.000000	0.000000	0.000000	0.000000	0.000000
24	0.000000	0.000000	0.000000	0.000000	0.000000
30	0.000000	0.000000	0.000000	0.000000	0.000000
36	0.000000	0.000000	0.000000	0.000000	0.000000
42	0.000246	0.007004	0.002497	0.005608	0.001102
48	0.000591	0.004599	0.001639	0.004345	0.001385
54	0.000565	0.004807	0.001713	0.004807	0.001714
60	0.001042	0.000820	0.000292	0.001884	0.001356
66	0.001138	0.000019	0.000007	0.001074	0.001062
72	0.001135	0.000038	0.001354	0.000878	0.002193
78	0.001131	0.000076	0.003207	0.000742	0.003873
84	0.001114	0.000219	0.004148	0.000728	0.004657
90	0.001028	0.000939	0.004315	0.001215	0.004591
96	0.001028	0.000939	0.003345	0.001211	0.003617
102	0.000930	0.001759	0.002787	0.001864	0.002892
108	0.001033	0.000896	0.001880	0.001247	0.002231
114	0.001125	0.000129	0.001216	0.000612	0.001699
120	0.001137	0.000029	0.001070	0.000442	0.001484
126	0.001137	0.000029	0.001130	0.000361	0.001463
132	0.001137	0.000029	0.001320	0.000296	0.001588
138	0.001137	0.000029	0.001460	0.000244	0.001676
144	0.001139	0.000005	0.001232	0.000184	0.001411
150	0.001085	0.000000	0.000909	0.000144	0.001053
156	0.001018	0.000000	0.000660	0.000115	0.000775
162	0.000961	0.000000	0.000482	0.000092	0.000574
168	0.000904	0.000000	0.000355	0.000074	0.000429
174	0.000847	0.000000	0.000260	0.000059	0.000319
180	0.000821	0.000000	0.000187	0.000047	0.000234
186	0.000817	0.000000	0.000133	0.000038	0.000171
192	0.000817	0.000000	0.000095	0.000030	0.000126
198	0.000802	0.000000	0.000068	0.000024	0.000092
204	0.000679	0.000000	0.000049	0.000019	0.000068
210	0.000622	0.000000	0.000035	0.000016	0.000050
216	0.000565	0.000000	0.000025	0.000012	0.000037
222	0.000508	0.000000	0.000018	0.000010	0.000028
228	0.000332	0.000000	0.000013	0.000008	0.000021
234	0.000275	0.000000	0.000009	0.000006	0.000015
240	0.000218	0.000000	0.000006	0.000005	0.000012
246	0.000161	0.000000	0.000005	0.000004	0.000009
252	0.000104	0.000000	0.000003	0.000003	0.000007
258	0.000057	0.000000	0.000002	0.000003	0.000005
264	0.000000	0.000000	0.000002	0.000002	0.000004
270	0.000000	0.000000	0.000001	0.000002	0.000003
276	0.000000	0.000000	0.000001	0.000001	0.000002
282	0.000000	0.000000	0.000001	0.000001	0.000002
288	0.000000	0.000000	0.000000	0.000001	0.000001
294	0.000000	0.000000	0.000000	0.000001	0.000001
300	0.000000	0.000000	0.000000	0.000001	0.000001
306	0.000000	0.000000	0.000000	0.000000	0.000001
312	0.000000	0.000000	0.000000	0.000000	0.000000
318	0.000000	0.000000	0.000000	0.000000	0.000000
324	0.000000	0.000000	0.000000	0.000000	0.000000
330	0.000000	0.000000	0.000000	0.000000	0.000000
336	0.000000	0.000000	0.000000	0.000000	0.000000
342	0.000000	0.000000	0.000000	0.000000	0.000000
348	0.000000	0.000000	0.000000	0.000000	0.000000
354	0.000000	0.000000	0.000000	0.000000	0.000000
360	0.000000	0.000000	0.000000	0.000000	0.000000

Table D2 - Neighbourhood / Street Catchment MUSIC Output Data					
Time	Pre-development	Post development	Green Roof	Permeable Pavement	GI Combination
0	0.000000	0.000000	0.000000	0.000000	0.000000
6	0.000000	0.000000	0.000000	0.000000	0.000000
12	0.000000	0.000000	0.000000	0.000000	0.000000
18	0.000000	0.000000	0.000000	0.000000	0.000000
24	0.000000	0.000000	0.000000	0.000000	0.000000
30	0.000000	0.000000	0.000000	0.000000	0.000000
36	0.000000	0.000000	0.000000	0.000000	0.000000
42	0.002457	0.070040	0.018730	0.056083	0.009180
48	0.005905	0.045987	0.012290	0.043447	0.012640
54	0.005654	0.048067	0.012850	0.048073	0.015880
60	0.010420	0.008201	0.002191	0.018840	0.013345
66	0.011377	0.000191	0.000051	0.010743	0.010615
72	0.011354	0.000381	0.013502	0.008775	0.021920
78	0.011309	0.000763	0.032004	0.007421	0.038710
84	0.011138	0.002193	0.041285	0.007283	0.046512
90	0.010277	0.009387	0.042310	0.012145	0.045659
96	0.010277	0.009387	0.032610	0.012105	0.035919
102	0.009297	0.017587	0.026300	0.018640	0.028460
108	0.010328	0.008959	0.017999	0.012470	0.022075
114	0.011246	0.001287	0.012044	0.006123	0.016961
120	0.011366	0.000286	0.010677	0.004424	0.014833
126	0.011366	0.000286	0.011277	0.003614	0.014623
132	0.011366	0.000286	0.013177	0.002964	0.015873
138	0.011366	0.000286	0.014577	0.002444	0.016753
144	0.011394	0.000048	0.012313	0.001836	0.014104
150	0.010850	0.000000	0.009090	0.001440	0.010530
156	0.010180	0.000000	0.006600	0.001150	0.007750
162	0.009610	0.000000	0.004820	0.000923	0.005743
168	0.009040	0.000000	0.003550	0.000738	0.004288
174	0.008470	0.000000	0.002600	0.000591	0.003191
180	0.008213	0.000000	0.001870	0.000473	0.002343
186	0.008173	0.000000	0.001330	0.000378	0.001708
192	0.008166	0.000000	0.000953	0.000302	0.001255
198	0.008019	0.000000	0.000681	0.000242	0.000923
204	0.006790	0.000000	0.000486	0.000194	0.000680
210	0.006221	0.000000	0.000347	0.000155	0.000502
216	0.005651	0.000000	0.000248	0.000124	0.000372
222	0.005082	0.000000	0.000177	0.000099	0.000276
228	0.003321	0.000000	0.000127	0.000079	0.000206
234	0.002750	0.000000	0.000090	0.000063	0.000154
240	0.002180	0.000000	0.000065	0.000051	0.000115
246	0.001610	0.000000	0.000046	0.000041	0.000087
252	0.001040	0.000000	0.000033	0.000033	0.000066
258	0.000570	0.000000	0.000024	0.000026	0.000050
264	0.000000	0.000000	0.000017	0.000021	0.000038
270	0.000000	0.000000	0.000012	0.000017	0.000029
276	0.000000	0.000000	0.000009	0.000013	0.000022
282	0.000000	0.000000	0.000006	0.000011	0.000017
288	0.000000	0.000000	0.000004	0.000009	0.000013
294	0.000000	0.000000	0.000003	0.000007	0.000010
300	0.000000	0.000000	0.000002	0.000005	0.000008
306	0.000000	0.000000	0.000002	0.000004	0.000006
312	0.000000	0.000000	0.000001	0.000003	0.000005
318	0.000000	0.000000	0.000001	0.000003	0.000004
324	0.000000	0.000000	0.000001	0.000002	0.000003
330	0.000000	0.000000	0.000000	0.000002	0.000002
336	0.000000	0.000000	0.000000	0.000001	0.000002
342	0.000000	0.000000	0.000000	0.000001	0.000001
348	0.000000	0.000000	0.000000	0.000001	0.000001
354	0.000000	0.000000	0.000000	0.000001	0.000001
360	0.000000	0.000000	0.000000	0.000001	0.000001

Table D3 - Subdivision Catchment MUSIC Output Data						
Time	Pre-development	Post development	Green Roof	Permeable Pavement	Bio Retention Basin	GI Combination
0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
12	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
18	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
24	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
30	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
36	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
42	0.028989	0.830493	0.298707	0.655177	0.017200	0.114512
48	0.069681	0.545285	0.196005	0.496435	0.062400	0.102997
54	0.066722	0.569945	0.204932	0.545485	0.089067	0.116431
60	0.122951	0.097246	0.034942	0.199452	0.109200	0.103740
66	0.134251	0.002261	0.000813	0.107683	0.114400	0.108680
72	0.133982	0.004522	0.135627	0.088267	0.110933	0.105387
78	0.133444	0.009043	0.321253	0.075234	0.109200	0.103740
84	0.131426	0.026007	0.417330	0.075783	0.107333	0.101967
90	0.121270	0.111302	0.439030	0.134099	0.106000	0.100700
96	0.121270	0.111302	0.341030	0.133699	0.105467	0.100193
102	0.109701	0.208530	0.290954	0.210088	0.105600	0.100320
108	0.121875	0.106227	0.195259	0.136760	0.106133	0.100827
114	0.132704	0.015256	0.123486	0.062959	0.106667	0.101333
120	0.134116	0.003391	0.107220	0.044625	0.106000	0.100700
126	0.134116	0.003391	0.113220	0.036525	0.104800	0.099560
132	0.134116	0.003391	0.133220	0.030025	0.103733	0.098547
138	0.134116	0.003391	0.146220	0.024825	0.102667	0.097533
144	0.134453	0.000565	0.123203	0.018421	0.101733	0.096647
150	0.128030	0.000000	0.091000	0.014400	0.100400	0.095380
156	0.120124	0.000000	0.066100	0.011500	0.098667	0.093733
162	0.113398	0.000000	0.048300	0.009230	0.096400	0.091580
168	0.106672	0.000000	0.035600	0.007380	0.093733	0.089047
174	0.099946	0.000000	0.026100	0.005910	0.091067	0.086513
180	0.096913	0.000000	0.018700	0.004730	0.088267	0.083853
186	0.096441	0.000000	0.013400	0.003780	0.085333	0.081067
192	0.096359	0.000000	0.009550	0.003020	0.082400	0.078280
198	0.094624	0.000000	0.006820	0.002420	0.079600	0.075620
204	0.080122	0.000000	0.004870	0.001940	0.076800	0.072960
210	0.073402	0.000000	0.003480	0.001550	0.074000	0.070300
216	0.066682	0.000000	0.002490	0.001240	0.071333	0.067767
222	0.059962	0.000000	0.001780	0.000991	0.068667	0.065233
228	0.039191	0.000000	0.001270	0.000793	0.062533	0.059407
234	0.032450	0.000000	0.000906	0.000634	0.018933	0.017987
240	0.025724	0.000000	0.000647	0.000507	0.012920	0.012274
246	0.018998	0.000000	0.000462	0.000406	0.010200	0.009690
252	0.012272	0.000000	0.000330	0.000325	0.008587	0.008157
258	0.006726	0.000000	0.000236	0.000260	0.007520	0.007144
264	0.000000	0.000000	0.000168	0.000208	0.006760	0.006422
270	0.000000	0.000000	0.000120	0.000166	0.006187	0.005877
276	0.000000	0.000000	0.000086	0.000133	0.005733	0.005447
282	0.000000	0.000000	0.000061	0.000106	0.005387	0.005117
288	0.000000	0.000000	0.000044	0.000085	0.005093	0.004839
294	0.000000	0.000000	0.000031	0.000068	0.004853	0.004611
300	0.000000	0.000000	0.000022	0.000055	0.004653	0.004421
306	0.000000	0.000000	0.000016	0.000044	0.004480	0.004256
312	0.000000	0.000000	0.000011	0.000035	0.004333	0.004117
318	0.000000	0.000000	0.000008	0.000028	0.004213	0.004003
324	0.000000	0.000000	0.000006	0.000022	0.004107	0.003901
330	0.000000	0.000000	0.000004	0.000018	0.004013	0.003813
336	0.000000	0.000000	0.000003	0.000014	0.003933	0.003737
342	0.000000	0.000000	0.000002	0.000011	0.003867	0.003673
348	0.000000	0.000000	0.000002	0.000009	0.003800	0.003610
354	0.000000	0.000000	0.000001	0.000007	0.003747	0.003559
360	0.000000	0.000000	0.000001	0.000006	0.003693	0.003509

Table D4 - Cluster of Subdivision / Suburb Catchment MUSIC Output Data								
Time	**Pre-development**	**Post development**	**Green Roof**	**Permeable Pavement**	**Bio Retention Basin**	**Vegetated Swales**	**Constructed Wetland**	**GI Combination**
0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
12	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
18	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
24	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
30	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
36	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
42	0.307954	8.825705	3.176480	6.937149	0.169679	0.035850	0.042300	0.031725
48	0.740232	5.794776	2.084338	5.217473	0.614855	0.153750	0.042500	0.031875
54	0.708794	6.056845	2.179270	5.719352	0.893648	0.681750	0.043800	0.032850
60	1.306124	1.033444	0.371582	2.039665	1.147175	1.800000	0.047700	0.035775
66	1.426162	0.024026	0.008649	1.077884	1.346678	2.085000	0.054300	0.040725
72	1.423304	0.048052	1.357298	0.884767	1.400024	2.085000	0.061400	0.046050
78	1.417588	0.096103	3.214597	0.756535	1.386714	2.085000	0.066700	0.050025
84	1.396153	0.276376	4.179211	0.769913	1.346802	2.085000	0.069800	0.052350
90	1.288262	1.182814	4.415684	1.392644	1.291249	1.852500	0.071200	0.053400
96	1.288262	1.182814	3.435684	1.388644	1.252583	1.650000	0.071800	0.053850
102	1.165366	2.216058	2.957066	2.197641	1.231755	1.582500	0.071900	0.053925
108	1.294692	1.128879	1.976848	1.416863	1.228556	1.605000	0.071900	0.053925
114	1.409728	0.162130	1.238338	0.636673	1.234746	1.605000	0.072000	0.054000
120	1.424733	0.036039	1.072974	0.447825	1.228018	1.492500	0.071900	0.053925
126	1.424733	0.036039	1.132974	0.366825	1.205351	1.312500	0.071600	0.053700
132	1.424733	0.036039	1.332974	0.301825	1.173351	1.125000	0.071100	0.053325
138	1.424733	0.036039	1.462974	0.249825	1.140018	0.960000	0.070500	0.052875
144	1.428305	0.006006	1.232162	0.184471	1.108003	0.817500	0.069700	0.052275
150	1.360076	0.000000	0.910000	0.144000	1.078667	0.708000	0.069000	0.051750
156	1.276090	0.000000	0.661000	0.115000	1.049333	0.625500	0.068300	0.051225
162	1.204639	0.000000	0.483000	0.092300	1.021333	0.582750	0.067700	0.050775
168	1.133188	0.000000	0.356000	0.073800	0.993333	0.565500	0.067200	0.050400
174	1.061737	0.000000	0.261000	0.059100	0.964000	0.549750	0.066800	0.050100
180	1.029521	0.000000	0.187000	0.047300	0.933333	0.532500	0.066400	0.049800
186	1.024507	0.000000	0.134000	0.037800	0.902667	0.515250	0.066200	0.049650
192	1.023630	0.000000	0.095500	0.030200	0.872000	0.498000	0.065900	0.049425
198	1.005203	0.000000	0.068200	0.024200	0.841333	0.480750	0.065700	0.049275
204	0.851144	0.000000	0.048700	0.019400	0.810667	0.464250	0.065500	0.049125
210	0.779756	0.000000	0.034800	0.015500	0.781333	0.447000	0.065300	0.048975
216	0.708368	0.000000	0.024900	0.012400	0.753333	0.431250	0.065100	0.048825
222	0.636979	0.000000	0.017800	0.009910	0.725333	0.415500	0.065000	0.048750
228	0.416334	0.000000	0.012700	0.007930	0.698667	0.399750	0.064800	0.048600
234	0.344720	0.000000	0.009060	0.006340	0.672000	0.385500	0.064700	0.048525
240	0.273269	0.000000	0.006470	0.005070	0.321333	0.229500	0.064400	0.048300
246	0.201818	0.000000	0.004620	0.004060	0.157333	0.156750	0.063900	0.047925
252	0.130367	0.000000	0.003300	0.003250	0.114400	0.100500	0.063400	0.047550
258	0.071451	0.000000	0.002360	0.002600	0.092667	0.073200	0.062900	0.047175
264	0.000000	0.000000	0.001680	0.002080	0.079200	0.058200	0.062500	0.046875
270	0.000000	0.000000	0.001200	0.001660	0.069867	0.048825	0.062100	0.046575
276	0.000000	0.000000	0.000859	0.001330	0.063200	0.042525	0.061800	0.046350
282	0.000000	0.000000	0.000614	0.001060	0.058133	0.038025	0.061500	0.046125
288	0.000000	0.000000	0.000438	0.000851	0.054133	0.034650	0.061200	0.045900
294	0.000000	0.000000	0.000313	0.000681	0.050933	0.032025	0.061000	0.045750
300	0.000000	0.000000	0.000224	0.000545	0.048267	0.029925	0.060700	0.045525
306	0.000000	0.000000	0.000160	0.000436	0.046000	0.028275	0.060600	0.045450
312	0.000000	0.000000	0.000114	0.000349	0.044267	0.026850	0.060400	0.045300
318	0.000000	0.000000	0.000082	0.000279	0.042667	0.025725	0.060300	0.045225
324	0.000000	0.000000	0.000058	0.000223	0.041333	0.024675	0.060100	0.045075
330	0.000000	0.000000	0.000042	0.000179	0.040267	0.023850	0.060000	0.045000
336	0.000000	0.000000	0.000030	0.000143	0.039200	0.023175	0.059900	0.044925
342	0.000000	0.000000	0.000021	0.000114	0.038400	0.022500	0.059800	0.044850
348	0.000000	0.000000	0.000015	0.000091	0.037600	0.021975	0.059700	0.044775
354	0.000000	0.000000	0.000011	0.000073	0.036933	0.021525	0.059600	0.044700
360	0.000000	0.000000	0.000008	0.000059	0.036400	0.021075	0.059500	0.044625