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Investigation into the effects of stormwater attenuation within the lower third of a catchment on downstream waterways.

A DISSERTATION SUBMITTED BY

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Abstract

The planning and design guidelines of urban stormwater systems within Queensland is undertaken in accordance with The Queensland Urban Drainage Manual (QUDM). QUDM states that when designing detention systems to control downstream flooding, it is important to consider the issue of coincident flood peaks. This issue occurs when the peak runoff from a development is delayed or extended and causes this runoff to arrive at a critical location at the same time as flows arriving from the upper catchment. The simple 'one third rule' was developed in response to this issue. This rule stated that stormwater detention systems may not be appropriate within the lower third of a catchment because it could increase the peak runoff by aligning the peak discharge from different areas of the catchment.

This dissertation will examine the validity of the 'one third rule' by modelling a hypothetical undeveloped catchment planned for a residential subdivision that is located in Toowoomba, Queensland. The catchment was split into three equal sub-catchments and designed with an appropriate stormwater drainage system. Detention basins will then be designed for each sub-catchment to ensure that peak pre-developed stormwater discharge does not exceed the peak developed stormwater discharge. Detention basins will then be removed from each catchment in various configurations to assess the impact on the downstream waterway.

To examine the different detention basin scenarios throughout the catchment stormwater quantity and quality software packages were researched. This research into the software packages determined the most appropriate stormwater quantity package to be DRAINS and the most appropriate stormwater quality package to be MUSIC. DRAINS is arguably the industry leading hydrological and hydraulic software package and MUSIC is the industry leading stormwater quality software package.

Different scenarios were modelled in DRAINS and MUSIC. The scenarios including providing detention tanks with:

1. Pre-Development (no detention tanks);
2. Post-Development (no detention tanks);
3. All 3 thirds of the catchment;
4. Upper catchment only;
5. Upper and middle catchments;
6. Upper and lower catchments;
7. Middle catchment only;
8. Middle and lower catchments;
9. Lower catchment only;

The research demonstrated that the most appropriate detention scenario is to provide all sub catchments with detention basins. The research also confirmed that in some circumstance's detention within the lower third of a catchment does not have to be provided to ensure a non-worsening a peak discharge to downstream waterways. The one third rule does not aggravate peak flows or coincide with upstream peak flows to a degree that creates a worsening effect.

There is little to no benefit in some circumstances to provide detention within the lower third of a catchment. This has the potential of saving developers time and money by reducing design costs and construction costs.

The research showed the MUSIC has the potential to conceptually model detention scenarios. Although further research needs to be undertaken to confirm if it is possible as this research was not able to definitively determine this aspect. MUSIC does not have the capability of designing drainage systems and therefore it is very limited as to what functions it is able to perform.

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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.

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Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Background

Stormwater is rainwater that runs off impervious or saturated surfaces in the urban environment. In an undeveloped natural catchment, the pervious ground allows for rainwater to be stored on its surface allowing for infiltration into the soil while any nearby vegetation allows for transpiration and evaporation of water into the atmosphere. (Parliament of Australia, 2018). When these natural environments are replaced with urban development, otherwise known as urbanisation, the majority of the vegetation is removed and a large proportion of the pervious ground is often replaced with impervious surfaces such as buildings and ground pavements. This urbanisation reduces the rainwater storage capacity of the ground surface, decreases infiltration, transpiration and evaporation. Accordingly, the volume, frequency and velocity of stormwater runoff increases with urban development and can be attributed for an increase in flooding and a decrease in water quality in downstream receiving waterways. Dealing with stormwater is essential for flood mitigation, which has shaped how stormwater has typically been managed. (Parliament of Australia, 2018).

Having to manage stormwater is not something that is new to Australia. Drains were among the remains of the first Government House (built 1788, demolished' 1845) uncovered in Sydney in 1983 (O'Loughlin et al. 1987). The way in which stormwater is dealt with has changed greatly, in the Victorian age, "drainage' was more or less synonymous with "sewerage" and the great majority of systems were combined sewers, carrying faecal matter, sullage, industrial wastes and stormwater (O'Loughlin et al. 1987). Over the industrial age the explosion of population led to appalling sanitary conditions and terrible mortality rates especially in the larger urbanised cities of Europe. During the 1800’s and early 1900’s sewerage schemes were implemented to better manage these combined sewer and stormwater systems. In the 1920’s however full separation of stormwater and sewage became standard Australian practice (O'Loughlin et al. 1987).

Brisbane, Queensland had a slightly different experience, with the first stormwater drain built in 1860. Major storm events particularly in 1875 forced the authorities to provide a more comprehensive system and this led to a separate stormwater system from the very start (O'Loughlin et al. 1987). It therefore could be argued that Brisbane was the national leader in stormwater management, or perhaps simply the first to implement a standalone stormwater infrastructure system. Due to the continued high frequency of intense storm events across Brisbane and the continued flooding of the low-lying suburbs, the management of stormwater has been an important aspect in infrastructure planning of the city as it has grown. Figure 1 demonstrates the proportion of stormwater that Brisbane has to manage compared to the other capital cities in the overall management of water.

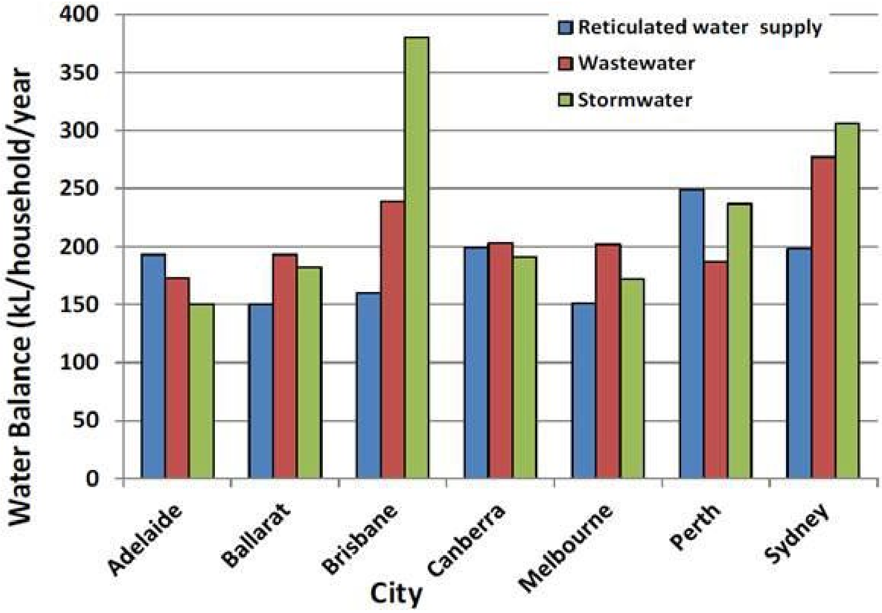


Figure 1. Average annual water balances from households, various cities (Parliament of Australia, 2018)

O'Loughlin (1987) further explains that over the last 200 years, hydrological methods for pipe systems have evolved as follows:

up to 1845 -	rules-of-thumb
1845-1935 -	empirical equations
1935-1985 -	the Rational Method
Post 1985 -	computer models

Computer models in the 21st Century have become important tools for the modelling of stormwater characteristics. Even though the methods and calculations that underpin these programs are often decades old, improvements can still be made. A more important focus should be utilising the power and calculation capabilities of this software to be able to accurately and quickly calculate changes to catchment hydrology.

1.2 Idea Development

I started working in the industry in 2004 as a civil designer and draftsman in Toowoomba. My experience in regard to stormwater was basically as long as you could prevent loss of property and maintain people’s safety and welfare then you could discharge stormwater in any way that you wished. Although this is a simplified view from a young inexperienced design draftsman it was one that was formed, nonetheless.

As is often the case with issues in society, important changes tend to occur following some kind of tragedy. In 2011, Toowoomba and several downstream small towns experienced flash flooding caused by intense rainfall, The Brisbane Times (2012) reports that Between 12.45pm and 2.15pm, heavy rainfall was recorded in the Toowoomba area resulting in flash flooding in the centre of the city. In the afternoon, the Lockyer Valley was also subjected to “unprecedented flash floods".

Flood water flowed through the Upper Lockyer Valley, causing severe damage in Murphy's Creek, Spring Bluff, Withcott, Postman's Ridge, Helidon and Grantham, finally reaching Gatton after 5pm. Twenty-two people died and three people remain missing after the Lockyer Valley and Toowoomba floods.

Following this event, it became clearer that the management of stormwater was very important. It was one of the most important issues following the event and on the lips of many concerned community members. Within the local industry the management of stormwater as noted above was nothing new, however more emphasis was placed on managing the quantity of stormwater.

Toowoomba Regional Council (TRC) began to enforce a non-worsening policy in regard to the design of stormwater systems for new developments. This non-worsening policy was generally a blanket requirement for all developments that ranged from small residential unit developments to large industrial factories and also subdivisions. Below are examples of the typical conditions imposed on developments at the time:

- No increase in peak flow rates downstream from the site for storm events with an ARI of 2 years, up to and including 100 years;
- No increase in flood levels external to the site;
- No increase in duration of inundation external to the site that cause loss or damage;
- The stormwater drainage system must be designed so that peak flows from the developed site do not exceed pre-developed flows, for storm events with an ARI of 2 years, up to and including 100 years. That is, there is to be a "no-worsening" effect as a result of this development.

So non-worsening generally requires that post development peak discharges are not to exceed predevelopment peak discharges at the developments lawful point of discharge (LDP). To satisfy these conditions new developments were required to construct on-site detention (OSD) tanks often privately owned and maintained. These conditions were often imposed on developments irrespective of the developments size, type or function or its position within a larger catchment or what other developments around it had already provided in terms of stormwater attenuation.

Council loosely started to accept that developments within the lower third of a catchment did not have to provide OSD systems. This is due to the potential for it to create coincidental flood peaks whereby the peak runoff from the OSD is delayed or extended so that it coincidentally matches the peak runoff from the upstream catchment. This is known as the 'one-third' rule which will be explained in more detail in the following sections. Given the high cost and often poor amenity of these OSD systems which are usually constructed from below ground concrete tanks, above ground poly tanks or dam structures this vague policy stance from council needed further investigation. It must be stated that Toowoomba Regional Council has begun assessing the management of stormwater for new development proposals more individually rather than just applying a blanket approach. This is primarily due to greater understanding on the effects of OSD systems that have led to amendments to planning scheme policies and other relevant legislation. The one-third rule requires further investigation into the effects of downstream runoff.

The methods for the calculation of stormwater runoff were widely available with the most common being the Rational Method. The Rational method however cannot be directly used to calculate stormwater attenuation or detention volumes. The 2007/08 version of The Queensland Urban Drainage Manual (QUDM) several basic methods to calculate detention sizes. However, as stormwater systems become more complicated sizing of these systems needs to be undertaken with the use of computer models. The 2 most widely used software packages for the simulation of hydrological and hydraulic models are DRAINS and XP-RAFTS.

Another important aspect in the management of stormwater is the quality of stormwater release. An important document locally, was the release of the State Planning Policy in 2010. It gave stormwater performance requirements for developments to achieve in regard to reducing nutrient and sediment discharge from developed sites. The timing of the release of this legislation coincided with the flooding event that occurred that same year. The management of stormwater quality is referred to as Water-sensitive urban design (WSUD) and TRC *PSP No.2 – Engineering Standards – Roads and Drainage Infrastructure (TRC, 2019)* states that its core principles of WSUD include:

- Protecting Natural Ecosystems;
- Integrating Stormwater treatment into the urban landscape
- Protecting water quality;
- Reducing run-off and peak flows;
- Add value while minimising development costs.

The WSUD performance requirements need to be evaluated and assessed with computer modelling. The most user-friendly software package and the most widely used is MUSIC, released by eWater. MUSIC stands for Model for Urban Stormwater Improvement Conceptualisation.

Currently all developments subject to local authority approval have to assess the developments impact on the stormwater quantity and quality coming to and leaving the site. The typical process for individual developments not including regional flooding is to undertake a one-dimensional (1D) stormwater quantity analysis using DRAINS software (or equivalent) and separately analysing stormwater quality using MUSIC software.

1.3 Aims and Objectives

The research will begin with a review of the stormwater runoff modelling and WSUD modelling software packages available. A catchment will then be selected or formulated for assessment. The research will then examine the validity of the simple ‘one-third’ rule by modelling the catchment with varying detention systems between the upper, middle and lower third of the catchment. In particular, the one-third rule will be analysed extensively with both the hydraulic and WSUD software to better understand the application of this rule and its potential implications to stormwater quantity discharge. If time permits the results can be compared in regard to stormwater quality for the different scenarios and what effects the one third rule has on quality.

The research will analyse how effective the WSUD software can model stormwater attenuation when compared to the more robust modelling results produced by the hydraulic software. The research will also assess if the 2 models can be correlated, namely the comparison of the real storm events the WSUD software utilises and the manufactured storm events and consequent hydrographs that the hydraulic model produces.

The final objective of the research is to determine if the WSUD model is effective for modelling stormwater attenuation and therefore if it can be considered within the industry as a reliable stormwater quality and quantity modelling tool. And if it is so, to what level of assessment will it be reliable i.e. can it be used for highly accurate detailed design or simply as a conceptual tool.

1.4 Expected Outcomes and Benefits

It is expected that the one-third rule has validity. However, the application of this rule in all scenarios may not be, and the overall effect that the one-third has on the peak runoff to downstream waterways may not be as significant as first thought. It is expected that the one-third rule will not have a significant effect on the stormwater quality.

This research will demonstrate if the WSUD model is going to be effective tool for the modelling of stormwater detention within an urban catchment. WSUD models typically do not have any hydraulic design capabilities; therefore, it will not be able to perform any design calculations on the stormwater infrastructure networks such as pipe sizing, hydraulic grade line or water levels just to name a few. It is expected that the results will be able to be manipulated to correlate with the hydraulic model. These results could then be used to better understand stormwater quantity measures within a catchment in a quicker more simplified manner without compromising accuracy.

I expect that the research will demonstrate the WSUD model as being an effective tool in the concept analysis of stormwater quantity measures. This could have the potential to simplify stormwater designs at the concept design stage. As concept design is typically utilised at the town planning stage of a development application the benefit would be a more simplified approach utilising a single software package rather than multiple packages to achieve relatively the same outcome.

Another possible outcome, although not expected, is that developers may see an opportunity to further develop the WSUD software to include more detailed hydraulic design components.

1.5 Knowledge Gap

Essentially there are two knowledge gaps that this research will be focusing on. Although there may be other gaps in the literature, it was deemed sufficient to focus on two research areas. Furthermore, the focus of the research will be utilising WSUD software to attempt to provide a better understanding of these gaps which in turn may be able to simplify modelling techniques in the industry, especially in concept design and assessment.

Firstly, it would appear that there is currently limited research into the effect of applying stormwater detention throughout an entire catchment and the effect of applying stormwater attenuation within the upper, middle and lower third of a catchment. The research that was found was more focused on the types of runoff-routing methods and optimising the methods rather than optimising the framework or legislation regarding individual catchments. The first part of the research will focus on the effectiveness of the simple ‘one-third rule’. This rule stated that stormwater detention systems may not be appropriate within the lower third of a waterway catchment. It is a rule that requires more research, especially using the more powerful computer software packages available today.

Secondly, the appears to be limited research into the effectiveness that WSUD software can have in analysing stormwater systems that include attenuation such as OSD. The use of this software will also allow the research to more easily change the conditions of the model such as:

- altering catchment sizes and lengths to suit different scenarios;
- adding/removing detention basin nodes at different parts of the catchment and in particular the lower third of the catchment;
- stormwater quality changes through the catchment;
- very easily changing the rainfall data for different locations and time periods;

1.6 Resource Requirements

Because the research is almost completely limited to software and data anyalysis the main resource required apart from the software packages will be the utilisation of time. The software packages required will be Microsoft Windows to enable the operation of the windows based software packages. Microsoft word and excel will also be required to document, process and then manipulate and present the findings and results. A personal computer will also be required although the caluclations will be complicated it is not expected that anything more than a typical desktop computer or laptop will be required. Access to current licensed versions of MUSIC and DRAINS is available.

Access to GIS and topography data will be required. Toowoomba Regional Councils online mapping data will be utilised and is accesible online. It will also be important to have access to backup system. A simple but effective way to achieve this will be to have a dedicated USB storage device or an online storage cloud.

The resource dedication of time will be of the up most importance. This time will need to be allocated outside of work hours. These work hours are typically 50 hours per week at 10 hours a day from approximately 7:00am to 7:pm accounting for travel time and lunch breaks. It is expected that 10 hours per week will need to allowed for to undertake the research project in the timeframe provided. Therefore, a good time split would be to allow for 2 hours for 3 out of the 5 weekdays with an allowance of 4 hours or half a day on the weekends. If time is unavailable during the week then this time would need to be made up of a weekend. 2 hours would be considered the minimum block of time required to undertake effective research. Where possible this time block should be extended to 3 hours to be more effective. The timeframe for the research begins at the beginning of semester 1, 2019 and finished in week 15 of semester 2, 2019. This equates to 35 weeks and with 10 hours a week of research a total of 350 hours of research time to be allocated.

The catchment in question should also be visited to scope the possible detention system locations. The site visit will also be useful in validating the GIS and online topography data.

1.8 Overview of dissertation

Chapter 2 – Literature Review: The dissertation will begin with a review of the relevant literature to provide the research with existing information that is available. This will include information on government legislation and technical guidelines in the area of stormwater quantity and quality control. Existing research that has been undertaken in the area of stormwater attenuation across different areas within a catchment will be provided as well. Current stormwater modelling software packages was reviewed and selected for use in the calculations.

Chapter 3 – Methodology: The information gathered and reviewed in Chapter 2 was applied to the research methodology. The software packages to be used in the calculations was formulated along with the following parameters:

- Catchment area parameters such as size, location, shape and slope etc
- Rainfall data;
- Detention basin sizing
- Detention and modelling scenarios;

This chapter will also describe how each of the objectives was met. The stormwater model parameters were implemented, and the models finalised and run.

Chapter 4 – Results: The results of the stormwater modelling were presented, and any preliminary findings highlighted. The results will focus on the effect that the detention scenarios have on the peak discharge to the downstream waterway.

Chapter 5 – Comparisons and Discussion: This chapter will compare and discuss the results of the modelling that has been undertaken through Chapters 3-4. The key outcomes were discussed, and the effectiveness of the modelling decided.

Chapter 6 – Conclusions and Recommendations: This chapter will make the final conclusions and assess if the aims and objectives of the research were satisfied. It will also make recommendations for future policy makers and provide information on how this research could be continued.

Chapter 2 Literature Review

2.1 Introduction

The literature review will review what existing research has been undertaken in the past and if there is a potential for further research. Government legislation and procedures were reviewed to determine what improvements can be made to the current stormwater design practices and their subsequent assessment by governing bodies. The stormwater modelling packages available to the marker will also be reviewed.

2.2 Principal references and legislation

At a National level the principal reference for almost all stormwater objectives within Australia is *"The Australian Rainfall and runoff – A Guide to Flood Estimation"* (ARR, 2018). ARR was provided by Engineers Australia (EA) with the aim of providing the best information available on flood estimation. ARR was first released in 1958 and has been updated three times since then with the latest edition being referred to as ARR 2016 (Geoscience Australia, 2018).

Engineers Australia and Geoscience Australia developed the latest version of ARR. Multiple projects were completed, primarily focusing on aspects of flood estimation. These projects considered topics such as the:

- hydraulics of urban drainage systems;
- spatial and temporal patterns of rainfall;
- channel loss models;
- blockage of hydraulic structures (Geoscience Australia, 2018).

The 1987 version ARR was developed when computer technology was emerging, and calculations were often done by hand and was based on data from the USA. Since 1987, there have been many developments in the understanding of rainfall-runoff processes and many new tools available for catchment simulation. ARR 2016 takes advantage of the large increase in Australian weather and rainfall metadata now available and also in advancements in computer technology, techniques and the understanding of rainfall-runoff processes and introduced changes to current practice (Geoscience Australia, 2018).

ARR 2016 explains that basins can have an important role in reducing downstream flood flows and associated flood risks to the community. A basin may be used in isolation or as part of a series of basins within a catchment to reduce peak design flood flows and risks for the design event(s) at key downstream locations. An effectively designed basin has to balance restriction of outlet capacity with having available storage capacity near the peak of a flood event. This enables the peak of flood flows to be stored and the stored volume discharged later in the event.

ARR 2016 also goes on to say that another key point in the design of detention basins is that where multiple basins are designed to provide more strategic benefits, i.e., away from the downstream boundary of their individual locations they should be designed on a catchment wide basis to ensure their interaction does not result in adverse impacts upon flood behaviour. Use of multiple basins in a catchment without consideration of interaction has the potential to result in adverse impacts on flood behaviour.

However, many individual developments have or can employ on site detention measurements. Therefore, there are likely constraints on how well a catchment can be modelled in relation to having multiple basins within it.

ARR 2016 goes into more detail regarding computer modelling software and states that a coupled analysis of storage basin volume and outlet capacity is necessary in order to determine the most appropriate configuration for a facility, including storage volume and the size of outlet structures. This analysis is usually iterative. Firstly, dimensions of the storage basin and outlet are estimated and tested by numerical calculation and then progressively adjusted to achieve hydrologic and hydraulic targets. This is normally undertaken using computer models that have been developed to assist with these calculations. The design and analysis of these facilities must include the interactions with other stormwater management facilities urban form in the catchment and catchment behaviours. The adopted modelling approach should also use rainfall time series and resolve full hydrographs of a total duration that is relevant to the objective being analysed. For peak discharge control this may only be minutes or hours. For water quality improvement and stormwater harvesting applications this may be years or decades. The model must have sufficient catchment resolution and detail to adequately represent the linked hydrologic processes in the catchment. Lumped models that simplify catchment representation and behaviours should be used with caution.

At a State level the principal reference documents that are of the most importance is *The Queensland Urban Drainage Manual* commonly referred to as QUDM and also the *State Planning Policy* referred to as SPP.

QUDM was initially released in 1992 in two hard copy volumes and was prepared for the purpose of assisting engineers and designers in the planning and design of urban stormwater systems. (Witheridge, 2013) In 2008 a modified version of QUDM was released on CD that included the design charts of Volume 2. (Witheridge, 2013)

Following the 2010/11 floods experienced in Queensland the Queensland Floods Commission was formed. QUDM (2016) states that in March 2012 the Queensland Floods Commission of Inquiry presented its final report to the Premier of Queensland. The recommendations contained within this report, specifically recommendation 10.8, suggested that QUDM be reviewed *'to determine whether it requires updating or improvement, in particular, to reflect the current law and to consider insights gained from the 2010/2011 floods'*. Following feedback on a 2013 provisional edition of QUDM, a fourth edition of QUDM was released. One notable change is the addition of a partner document named *'A Background to QUDM'* that contains the bulk of the discussion or explanatory notes. (DNRW, 2016)

This QUDM background document (DNRW, 2016) provides extensive recommendations on the use of computer models. In regard to runoff-routing it states that preference should be given to the use of computer-based, runoff-routing, numerical models when analysing the following drainage conditions:

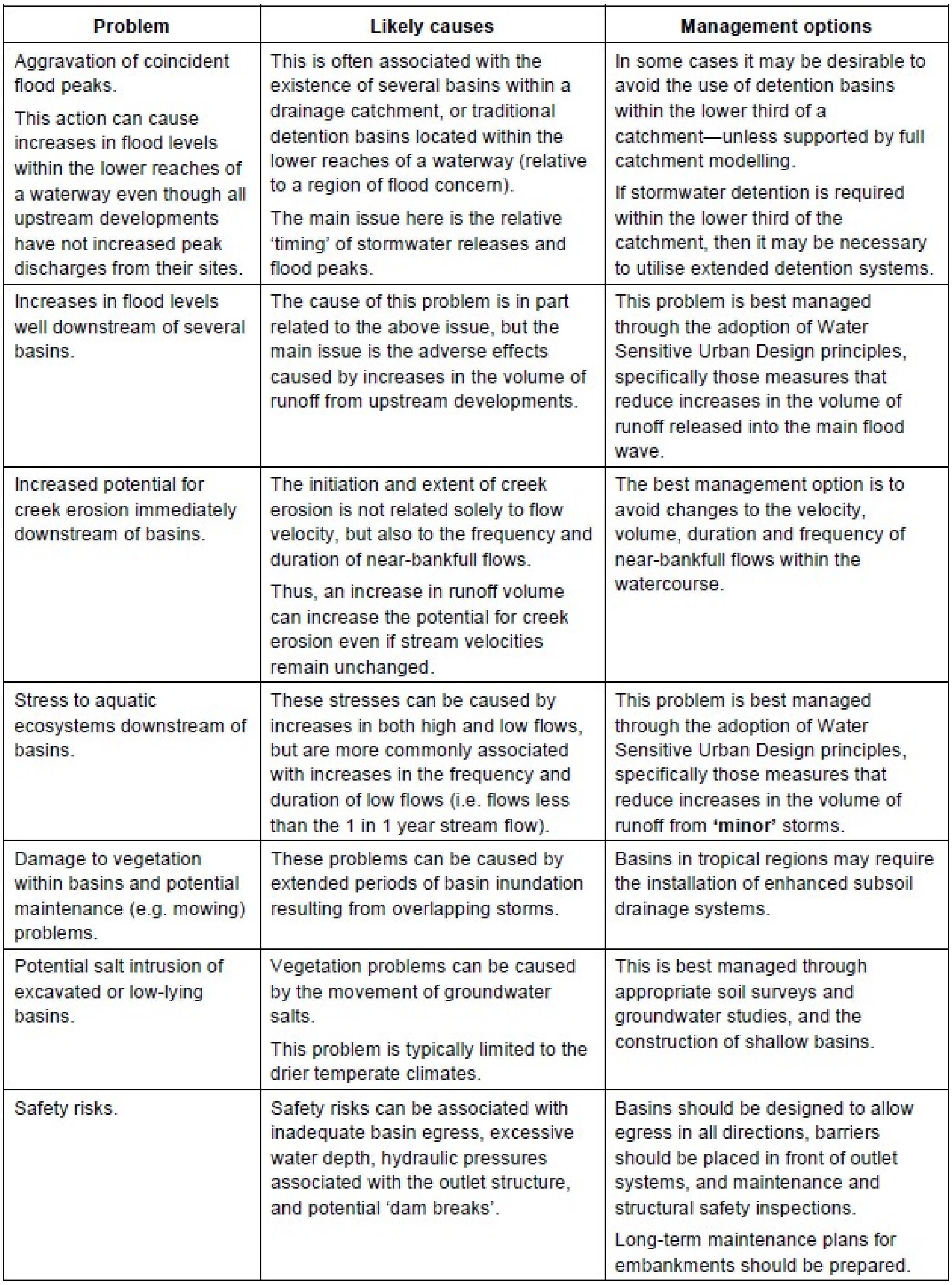
- urban catchments with an area greater than 500 hectares
- determination of minimum flood level for new buildings
- the analysis or design of drainage systems that are volume-dependent, such as detention and retention basins
- determination of peak discharges associated with historical (real) storms
- assessment of complex drainage catchments

QUDM (DNRW, 2016) also says that when utilising computer-based runoff-routing models to analyse urban drainage systems, the following practices should not be adopted:

- the extraction of peak discharges at model nodes that have fewer than 5 contributing sub-catchments, unless the model's user manual identifies that fewer sub-catchments are acceptable (e.g. XP-¬RAFTS);
- the adoption of a 'critical storm duration' based on the assessed Rational Method 'time of concentration'; these are two different hydrologic terms that should not be interchanged;
- the adoption, within 'design storm' runs, of those initial loss and continuing loss values determined from historical storm calibration runs without appropriate consideration of the likely effects of pre-storm rainfall;

A critical aspect of runoff-routing modelling is the choice of loss rates (e.g. initial and continuing losses). Designers should refer to the latest version of Australian Rainfall and Runoff for guidance on the choice of loss models and initial and continuing loss rates.

The QUDM background document (DNRW, 2016) outlines the potential problems resulting from the use of detention/retention systems in table 1below. The table lists the potential problems and then discusses the likely causes of the problem and finally what management options there may be to mitigate the problems. The problem that is specifically related to this research it the aggravation of coincident flood peaks which can cause increases in flood level at the lower end of the catchment. The likely cause is the timing of flood peaks and the management option suggested is to potentially avoid the use of detention basins in the lower third of the catchment.



Problem	Likely causes	Management options
Aggravation of coincident flood peaks. This action can cause increases in flood levels within the lower reaches of a waterway even though all upstream developments have not increased peak discharges from their sites.	This is often associated with the existence of several basins within a drainage catchment, or traditional detention basins located within the lower reaches of a waterway (relative to a region of flood concern). The main issue here is the relative 'timing' of stormwater releases and flood peaks.	In some cases it may be desirable to avoid the use of detention basins within the lower third of a catchment—unless supported by full catchment modelling. If stormwater detention is required within the lower third of the catchment, then it may be necessary to utilise extended detention systems.
Increases in flood levels well downstream of several basins.	The cause of this problem is in part related to the above issue, but the main issue is the adverse effects caused by increases in the volume of runoff from upstream developments.	This problem is best managed through the adoption of Water Sensitive Urban Design principles, specifically those measures that reduce increases in the volume of runoff released into the main flood wave.
Increased potential for creek erosion immediately downstream of basins.	The initiation and extent of creek erosion is not related solely to flow velocity, but also to the frequency and duration of near-bankfull flows. Thus, an increase in runoff volume can increase the potential for creek erosion even if stream velocities remain unchanged.	The best management option is to avoid changes to the velocity, volume, duration and frequency of near-bankfull flows within the watercourse.
Stress to aquatic ecosystems downstream of basins.	These stresses can be caused by increases in both high and low flows, but are more commonly associated with increases in the frequency and duration of low flows (i.e. flows less than the 1 in 1 year stream flow).	This problem is best managed through the adoption of Water Sensitive Urban Design principles, specifically those measures that reduce increases in the volume of runoff from **'minor'** storms.
Damage to vegetation within basins and potential maintenance (e.g. mowing) problems.	These problems can be caused by extended periods of basin inundation resulting from overlapping storms.	Basins in tropical regions may require the installation of enhanced subsoil drainage systems.
Potential salt intrusion of excavated or low-lying basins.	Vegetation problems can be caused by the movement of groundwater salts. This problem is typically limited to the drier temperate climates.	This is best managed through appropriate soil surveys and groundwater studies, and the construction of shallow basins.
Safety risks.	Safety risks can be associated with inadequate basin egress, excessive water depth, hydraulic pressures associated with the outlet structure, and potential 'dam breaks'.	Basins should be designed to allow egress in all directions, barriers should be placed in front of outlet systems, and maintenance and structural safety inspections. Long-term maintenance plans for embankments should be prepared.

Table 1. Potential problems resulting from the use of detention/retention systems (QUDM, 2016)

The QUDM background document (DNRW, 2016) states that when designing detention/retention systems to control downstream flooding. It is always important to consider the risk of 'coincident flood peaks' that could potentially make the downstream flooding worse. This problem occurs when delaying stormwater runoff from a development causes this runoff to arrive at a critical downstream location at the same time as flows arriving from the upper catchment. The simple 'one-third rule' was developed in response to this issue. This rule stated that stormwater detention systems may not be appropriate within the lower third of a waterway catchment. However, this simple rule may no longer apply if:

- the development site is located on a tributary within the lower third of the main creek catchment, and there are flood-prone properties located on this tributary immediately downstream of the development, or
- flood-prone properties are only located in the middle or upper reaches of the creek.

In such circumstances, consideration should be given to the use of 'extended detention' where stormwater runoff is delayed sufficiently to allow the upper catchment to drain past the flood-prone properties prior to the bulk of this detained water being released from the development. This normally results in a design objective where the detained water is released uniformly over a 24 to 72hour period (QUDM, 2016).

Given the great difficulty in designing extended detention systems due to the inherent volume of storage required, extended detention is rarely used in a catchment, especially smaller urban catchments where space is limited.

2.3 Stormwater Quality/WSUD Software Packages

The first stormwater quality modelling software package investigated is MUSIC. MUSIC Version 6 Documentation and Help Home - MUSIC Version 6 Documentation and Help - eWater Wiki describes MUSIC as being able to simulate both quantity and quality of runoff from catchments and calculate the effect of stormwater runoff treatment facilities, otherwise known as stormwater quality improvement devices (SQUID) on the quantity and quality of runoff downstream. MUSIC runs on a continuous basis, allowing analysis of the proposed strategies and SQUID over the short-term and long-term. (Wiki.ewater.org.au, 2019). The MUSIC Version 6 Documentation and Help Home - MUSIC Version 6 Documentation and Help – eWater Wiki (2018) also states in a 'cautionary note' that:

1. MUSIC is a conceptual design tool only and not a detailed design tool. It is not able to perform the calculations required for detailed sizing of stormwater quantity and/or quality facilities; (Wiki.ewater.org.au, 2019)
2. MUSIC should be only one of several tools used in designing stormwater management facilities for Water Sensitive Urban Design and Sustainable Drainage Systems because factors other than stormwater quantity and quality (e.g. land and soil characteristics, ecological requirements of receiving waters, amenity, passive recreation, and landscape design) also influence how these measures should be implemented. Detailed hydraulic analysis for stormwater drainage, indicators of ecosystem health, and the integration of urban stormwater management facilities into the urban landscape are currently omitted from the model; (Wiki.ewater.org.au, 2019)

As mentioned above, eWater Wiki (2018) states the MUSIC cannot size stormwater quantity facilities, however, MUSIC does contain hydrological routing capabilities. MUSIC uses the continuity equation and the relationship between detention volume and discharge. Although the calculations may be somewhat simplified the user can still specify a pipe or riser outlet (treated as an orifice of an equivalent diameter), a weir outlet for ponds and wetlands and a filter or weir outlet for bioretention systems. The storage-discharge relationship (or S-Q curve) for swales is derived using Manning's equation in the channel. The hydrologic routing used with MUSIC is based on Puls Method for reservoir routing, as described in Australian Rainfall and Runoff (Institution of Engineers Australia, 2001).

Almost all local council stormwater quality policies require that a MUSIC model be used to calculate the required SQUID's and their effectiveness to satisfy the stormwater quality objectives. In a lot of councils, they will request a copy of the MUSIC file for their assessment and it is the only modelling software that is actually accepted.

The second stormwater quality modelling software package investigated is XPSWMM. XPSWMM began as a SWMM based program. The Storm Water Management Model (SWMM) was developed for the US Environmental Protection Agency (EPA). XPSWMM is a proprietary product marketed in Australia by Innovyze with the Australian branch based in Tweeds Heads, NSW.

The xpswmm/xwpstorm Resource Center describes XPSWMM as a link-node model that performs hydrologic and hydraulic analysis of stormwater as one-dimensional flow (1D). It can also perform stormwater quality analysis, water quality control devices including sewage treatment. The software is also coupled with the 2D TUFLOW engine, and it has the ability to dynamically link to the 1D network of the XPSWMM engine. The model is also capable of simulating single storm events as well as continuous time series. In essence, the software is primarily a stormwater quantity model that can also perform stormwater quality analysis (Innovyze, 2019).

XPSWMM can use up to 7 different hydrological routing methods as described below:

- SWMM runoff non-linear reservoir method;
- Kinematic Wave runoff method;
- Laurenson Hydrology;
- SCS Hydrology;
- Unit Hydrographs;
- Rational method;
- UK Hydrology.

It is clear that the XPSWMM software can be utilised as a powerful stormwater quantity analysis tool.

As mentioned above this software began as a SWMM based program. SWMM simulates real storm events based on rainfall and other meteorological inputs to predict quantity and quality values. The xpswmm/xwpstorm Resource Center provides a description of SWMM in simple terms as being constructed in the form of block as follows:

1. The input sources: The Runoff Block generates surface and subsurface runoff based on arbitrary rainfall hyetographs, antecedent conditions, land use, and topography (Innovyze, 2019).
2. The central cores: The Runoff, Transport and Extended Transport (EXTRAN) Blocks route flows and pollutants through the drainage system. Very sophisticated hydraulic routing may be performed with EXTRAN (Innovyze, 2019).
3. The correctional devices: The Storage/Treatment Block characterizes the effects of control devices upon flow and quality. Elementary cost computations are also made (Innovyze, 2019).

The stormwater quality module is added to one of the rainfall-runoff models as described previously to generate a time series of pollution concentration in the stormwater runoff. Pollutographs are then calculated for each contaminant at each node. The equations within the software model describe the:

- Build-up of pollutants in catchments during dry periods;
- Rate of pollutant wash off during storms.

XPSWMM provides a global database that has pre-set values for several different pollutants across different land uses. It is not clear however if these values align with the requirements of local requirements noting that the SWMM engine is a US designed package. The pollutant data is mostly user input files which require extensive knowledge of pollutant concentration levels and wash off data.

XPSWMM is a powerful software package but its stormwater quality module does not appear user friendly for local conditions. The quality module does not appear to be in use within the local region yet. It is anticipated that due to its 1D/2D hydraulic and hydrological modelling versatility that if the pollutant parameters become easier to implement and analyse by the user this product could be used locally with more frequency. However, this is not expected to happen until council policy is amended to include the assessment of this type of model and its output data.

2.4 Stormwater Quantity/Runoff Routing Software Packages

The first stormwater runoff routing software package investigated was DRAINS. O'Loughlin and Stack (2012) describe DRAINS as a multi-purpose Windows program for designing and analysing urban stormwater drainage systems and catchments. It was first released in January 1998 and is marketed by Watercom Pty Ltd, based in Wooli, NSW. DRAINS ILSAX hydrological loss model is accepted by many local authorities and is arguably the leading hydrological and hydraulic software packages.

DRAINS can model drainage systems of all sizes, from small to very large (up to 10 km2 using sub-catchments with ILSAX hydrology, and greater using storage routing model hydrology). Working through a number of time steps that occur during the course of a storm event, it simulates the conversion of rainfall patterns to stormwater runoff hydrographs and routes these through networks of pipes, channels and streams. In this process, it integrates:

- design and analysis tasks
- hydrology (four alternative models) and hydraulics (two alternative procedures)
- closed conduit and open channel systems
- headwalls, culverts and other structures
- stormwater detention systems, and
- large-scale urban and rural catchments

Within a single package, DRAINS can carry out hydrological modelling using ILSAX, rational method and storage routing models, together with quasi-unsteady and unsteady hydraulic modelling of systems of pipes, open channels and surface overflow routes.

O'Loughlin and Stack (2012) explain that DRAINS original model used is the ILSAX hydrological model. This model uses time-area calculations and Horton infiltration procedures to calculate flow hydrographs from sub-catchments. The various sub-catchment flows are combined and routed through a pipe and channel system. Calculations are performed at specified times after the start of each storm, using time intervals of one minute or less. At each time step, a hydraulic grade line analysis is performed throughout the drainage network, determining flowrates and water levels.

The second stormwater runoff routing software package investigated was XPSWMM. As mentioned previously XPSWMM as a link-node model that performs hydrologic and hydraulic analysis of stormwater in 1D and 2D if required. (Innovyze, 2019). It is a versatile software package that can use up to 7 different hydrological routing methods as described previously.

The third stormwater runoff routing software package investigated was the 12D Model with the drainage module. The 12D model itself is a terrain modelling, surveying and civil engineering software package. Its primary use in the design of roads but it has grown in recent years with multiple additional modules now available of use with the software. The drainage module is most relevant, and its drainage analysis allows for rational method hydrology and can perform hydraulic analysis of a drainage network (12d, 2019).

The 12d dynamic drainage module uses the full St Venant equation to perform detailed hydrological and hydraulic modelling including the design of detention basins. 12d can transition between the rational method-based design to the dynamic module.

2.5 Software Packages Conclusion

The 2 software packages that were used for the project proposal were MUSIC and DRAINS. DRAINS was utilised to examine the validity of the one third rule and was used as a comparison to the results from MUSIC. MUSIC was the stormwater quality software package that will analysed on its hydrological and hydraulic capabilities.

DRAINS was selected as the stormwater quantity package due to the following factors:

- All stormwater quantity packages investigated required a paid license to access. As access to a current DRAINS license was available it was a major influencing factor;
- DRAINS is a user-friendly package compared to the others and access to customer support was available;
- During the research the capabilities of XPSWMM appeared to be very good however, it does require extensive knowledge which will take too long to become familiar with for this particular research project;

MUSIC was selected as the stormwater quality package due to the following factors:

- The stormwater quantity packages investigated required a paid license to access. As access to a current MUSIC license was available it was a major influencing factor;
- MUSIC is a user-friendly package compared to the others and access to customer support was available;
- MUSIC is referenced and accepted by all local councils when assessing the WSUD. If a software package is to be accepted for concept analysis of both stormwater quality and quantity, it should be a program that councils are familiar with;
- During the research the capabilities of XPSWMM appeared to be very good however, it does require extensive knowledge which will take too long to become familiar with for this particular research project.

Chapter 3 Methodology

3.1 Methodology Introduction

A catchment area and location will need to be selected. A real catchment and a hypothetical catchment was investigated and then a catchment type selected for analysis. The catchment parameters will also be investigated or researched and selected.

A concept design of the developed area is to be formulated and implemented in the modelling. It is not considered to be an important aspect of this particular research. What is important is that the catchment inputs between DRAINS and MUSIC is exactly the same so that the results can be compared.

Formulation of the MUSIC and DRAINS models is the largest, most time-consuming stage of the research project. The process will start by formulating the DRAINS model first with the catchment parameters outlined above. The infrastructure network framework will then be entered, and this will include:

1. Selection of appropriate hydrological parameters including rainfall data and soil conditions using values obtained from ARR 2016;
2. Catchment parameters with time of concentration calculated using techniques from QUDM;
3. Gully Pits, overland flow channels, bypass routes however selection of these will not be undertaken. The design tool of DRAINS was utilised to speed up the process of design. The actual pipe sizes etc are not of importance. An assessment will need to be undertaken early in the design if it is more appropriate to simply link the catchments with flow routes rather than with the traditional pits and pipes. This was a time management issue and may also help in linking the 2 software models.
4. Outlet conditions to be entered

The different DRAINS models to be run will contain the following differing detention tank scenarios. The catchment that will contain the detention tanks will include:

1. Pre-Development;
2. No detention tanks provided;
3. All 3 thirds of the catchment;
4. Upper catchment only;
5. Upper and middle catchments;
6. Upper and lower catchments;
7. Middle catchment only;

8. Middle and lower catchments;
9. Lower catchment only;

The results from the DRAINS analysis will then be examined, the peak discharge was of the most important use.

This process will then be repeated in the MUSIC software as close as possible to that undertaken in the DRAINS analysis.

3.2 Catchment Selection

To enable the investigation into the one-third rule and analyse the WSUD modelling software a catchment must first be selected. The catchment can be one of 2 options, a real catchment or a hypothetical one. A real catchment involves investigating a catchment that could be undeveloped, partially or fully developed with existing drainage structures, impervious areas, varying slopes and irregularly shaped sub-catchments among other parameters. A hypothetical catchment will have all its parameters set and planned to suit the modelling situation and is not restricted to any pre-determined conditions. Both options have advantages and disadvantages and were investigated further to decide which was the most appropriate to utilise for this research.

The selection of a real catchment has the following advantages:

- Surface falls and slopes are known if suitable GIS data is available and therefore are already set for modelling purposes;
- General soil properties can be obtained;
- Catchment shape, length and size are known;
- Existing drainage systems may already be in place and therefore drainage systems do not have to be designed from scratch;
- Rainfall data can be obtained directly from the known area;

The selection of a real catchment has the following disadvantages:

- Surface falls and slopes of a real catchment have the potential to affect the peak runoff and analysis of the one-third rule could be made more difficult;
- General soil properties can be obtained but there could be an extra expense involved;
- Catchment shape, length and size are known but have the potential to affect the analysis of the one-third rule;
- Existing drainage systems may already be in place, but they may be under designed or inadequate causing additional ponding or attenuation with the drainage system and thus affecting the analysis of the one-third rule. If the existing drainage system is complicated it could potentially be very time consuming in setting up the computer model;

A possible candidate for the analysis of a real catchment was further investigated and a small catchment in the town of Wyreema selected for consideration. The area is well known to the author and the bottom third of the catchment has good potential for future development and therefore relevant for this research. Part of the top of the catchment is currently being developed and a new detention basin constructed to service the development. GIS data via the Toowoomba Regional Council online mapping service was available that provided information on catchment levels, existing drainage systems and surface types via aerial imagery. See Figure 2.

Figure 2. Real Catchment - Wyreema (ArcGIS, 2019)

The Wyreema catchment as shown in Figure 2 has a single discharge point to a downstream waterway that could be used to analyse the discharge. The existing stormwater system is complex with multiple outlet points and gullies that converge at the downstream end. The odd shape and outlet configuration make it difficult to assess the one-third rule although this is to be expected with a real catchment. Opportunities also exist within the catchment for the retrofitting of SQUIDs into the existing drainage system if required. This would be beneficial for the WSUD software analysis.

At 188.4ha the catchment area is quite large and combined with the complex drainage system and multiple outlet locations it would be very time consuming to create the model in the DRAINS and

MUSIC. As time is the major limiting resource for the research the selection of a real catchment was a major disadvantage.

As mentioned above the other catchment selection option is to create a hypothetical one.

A hypothetical catchment involves creating all the catchment attributes. These attributes can be created or altered to suit the aims and objectives. Depending on the attributes selected they can closely represent a real catchment if required.

The selection of a hypothetical catchment has the following advantages:

- Surface falls and slopes can be set quickly and altered quickly for sensitivity analysis;
- General soil properties can be set quickly and altered to suit different soil types;
- Catchment shape, length and size can be selected with simple dimensions quickly;
- Drainage systems can be made as basic or as complex as required;
- Rainfall data can be set quickly and altered to suit different areas;

The selection of a hypothetical catchment has the following disadvantages:

- Surface falls and slopes are very simplified compared to real catchments and may not be comparable to a real scenario;
- Catchment shape, length and size are also very simplified which could be comparable to greenfield development but may not be comparable to existing developed catchments;
- All catchment attributes are created and therefore could be set to ensure the research hypothesis is proved to be true;

The hypothetical catchment option advantages are greater than its disadvantages. The hypothetical catchment option also shows a greater advantage than that of the real catchment option. The biggest factors affecting the choice of catchment selection is time and the future application to other catchments. Modelling a real catchment, especially one with existing drainage systems was very time consuming. A hypothetical catchment was much quicker to create and set the attributes rather than ensuring they match a real catchment. The drainage system of the hypothetical catchment can be designed to comply with the current standards and legislation which would be applicable to new developments which may be able to utilise the outcomes of this research. It is anticipated that the hypothetical catchment attributes can be altered quickly if trying to compare to a real catchment and its specific attributes. Therefore, by utilising a hypothetical catchment the outcomes of this research can be applied generally over future developments to attempt to save time in design and money by avoiding the construction of stormwater quality and quantity devices that may not be required.

3.3 Catchment Attributes

The hypothetical catchment is located in the Toowoomba region of QLD. This area was selected as it is in close proximity and the area conditions are well known therefore reducing time in creating the catchment. The hypothetical catchment attributes are limitless in what could be analysed, so attribute selection needed to be rationalised. The critical attribute is ensuring the catchment can be split into relatively equal thirds, each with its own detention basin and common downstream discharge point. An area of 22.5ha was selected which is similar to what would be considered a medium sized subdivision. This 22.5ha site was then split into 3 equal sized catchments of 7.5ha, an upper, middle and lower section. The size of these sections was large enough to identify any coincident flood peaks as a result of the attenuation within different sections.

3.4 Pre-Development Conditions

The attributes of the predeveloped catchment as shown in Figure 3, are as follows:

- 22.5ha total site area 250m x 900m, rectangular in shape;
- Surface is densely grassed consistent across the entire catchment;
- Soil is similar to the red volcanic soils of Toowoomba and classified as a clayey loam with slow to medium infiltration capacity.
- Average slope of 5% across the entire catchment;
- No upstream catchment contributing to stormwater runoff from the site or at the discharge point (just upstream of the downstream waterway);

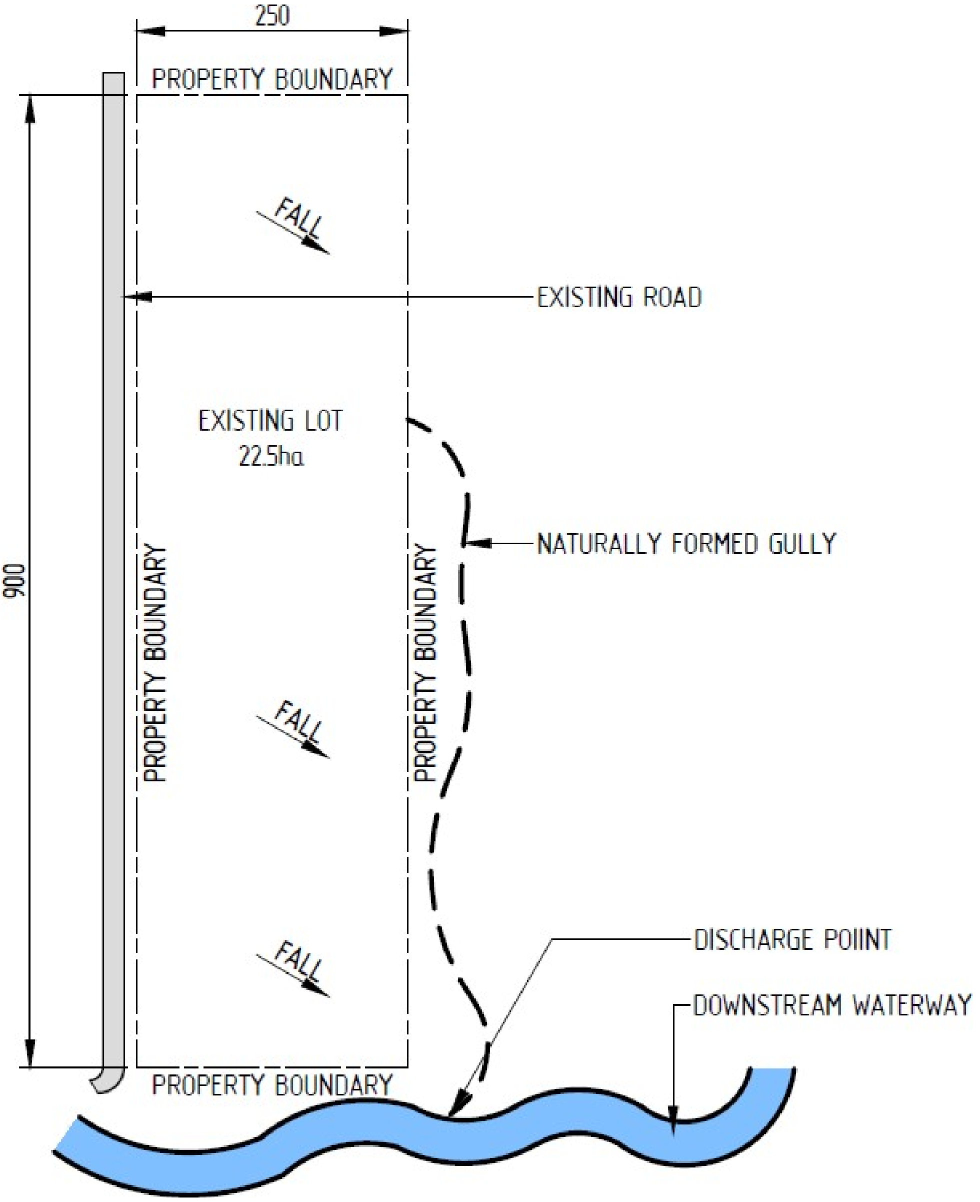


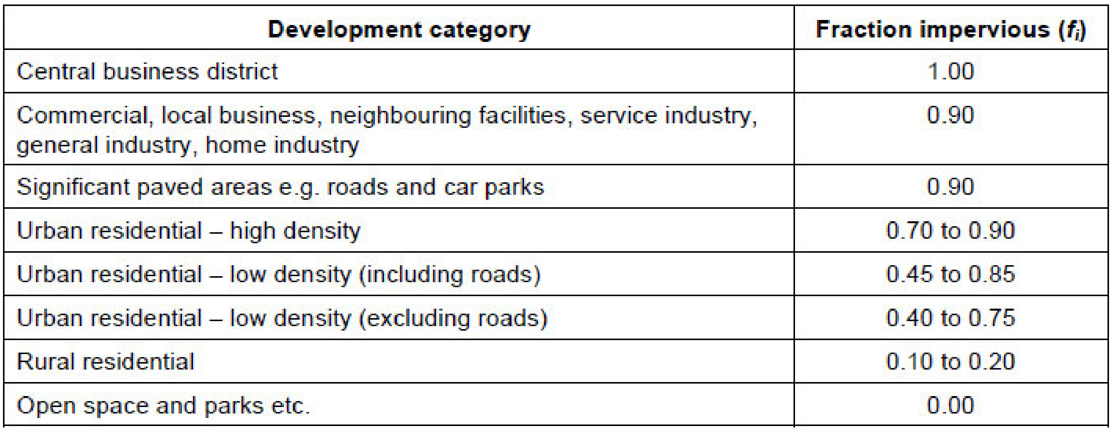
Figure 3. Predeveloped Catchment Site Plan

3.5 Post Development Conditions

The attributes of the post developed catchment as shown in Figure 3, are as follows:

- 3 equal area sub-catchments of 7.5ha in area, 250m x 300m, rectangular in shape;
- Individual lot sizes are 0.125ha, total number of lots per sub-catchment is 45;
- Total fraction impervious allowing for future houses, driveways and roads is 0.80 which is in the range for low density, urban residential development (including roads) as per Table 4.5.1 of QUDM, 2016 shown below;
- Pit and pipe stormwater drainage system provided that discharges to a detention basin for each catchment sized in accordance with the requirements of QUDM. Explained in detail in section 3.6;

- Trapezoidal grassed drainage channel provided to convey the runoff to the downstream waterway from each catchment. Detailed in section 3.6;
- Soil and average slope conditions remain as per predevelopment conditions;
- New roads were asphalt with concrete kerb and channels
- Pervious surfaces are considered to be mowed lawns;



Development category	Fraction impervious (f_i)
Central business district	1.00
Commercial, local business, neighbouring facilities, service industry, general industry, home industry	0.90
Significant paved areas e.g. roads and car parks	0.90
Urban residential – high density	0.70 to 0.90
Urban residential – low density (including roads)	0.45 to 0.85
Urban residential – low density (excluding roads)	0.40 to 0.75
Rural residential	0.10 to 0.20
Open space and parks etc.	0.00

Table 2. Fraction impervious vs. development category. Table 4.5.1, QUDM, 2016

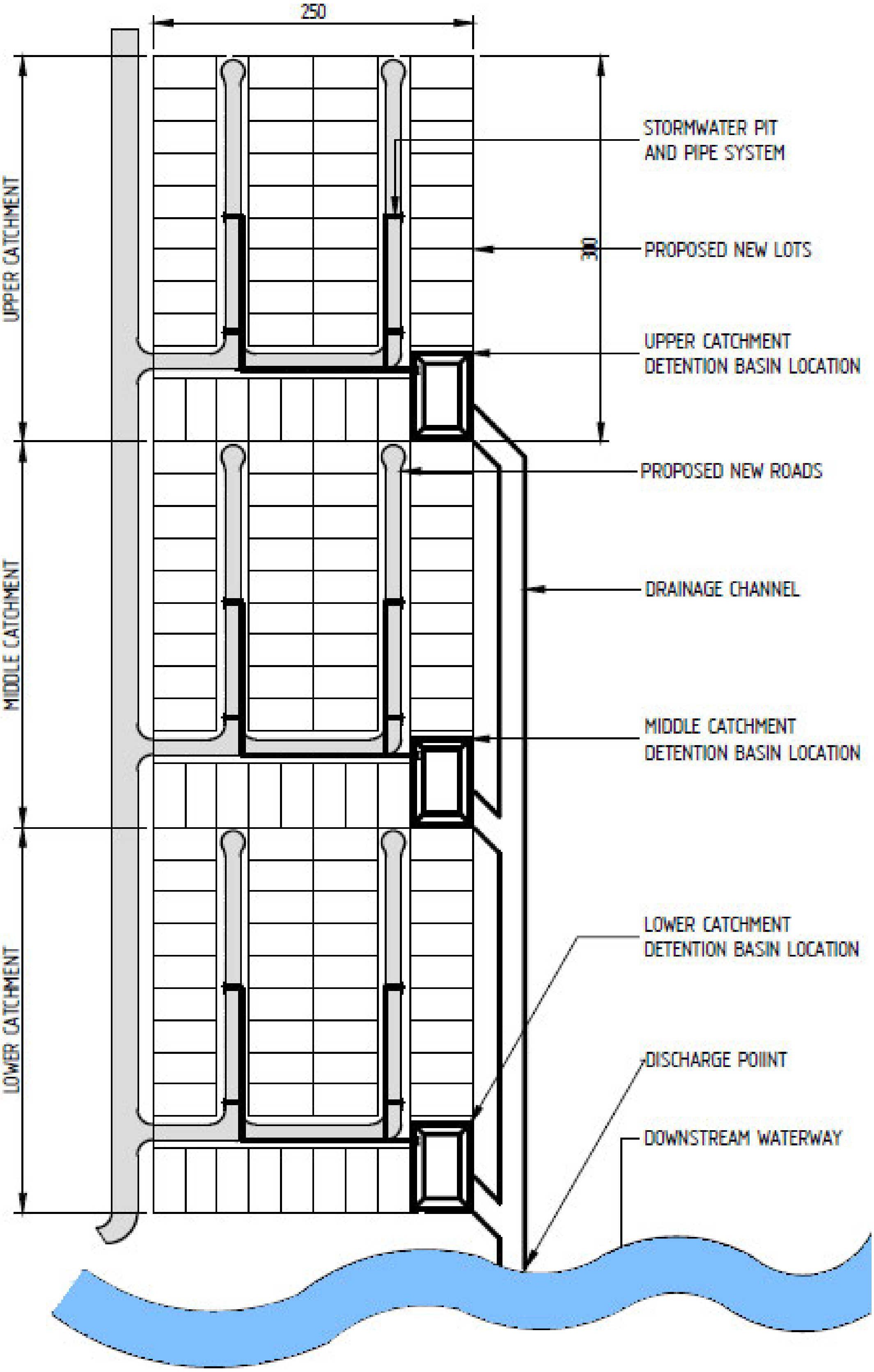
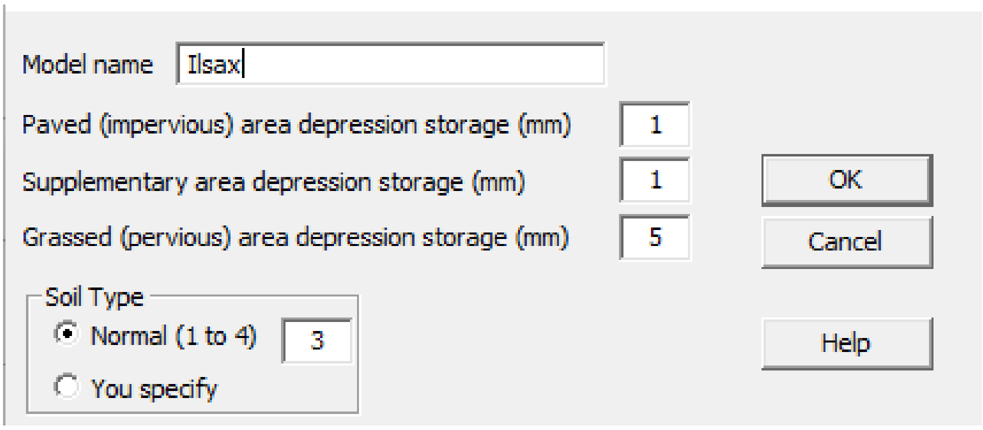


Figure 4. Post Developed Catchment Site Plan

3.6 DRAINS - Model

As discussed in Chapter 2, a DRAINS model was created to assess the validity of the one-third rule and for comparison to the MUSIC model results.

The hydrological model selected within DRAINS was the Ilsax method as described in previous chapters, the DRAINS input parameters are shown in Figure 5.



Model name: Ilsax

Paved (impervious) area depression storage (mm): 1

Supplementary area depression storage (mm): 1

Grassed (pervious) area depression storage (mm): 5

Soil Type

● Normal (1 to 4): 3

○ You specify

Figure 5. Horton/ILSAX type hydrological model inputs

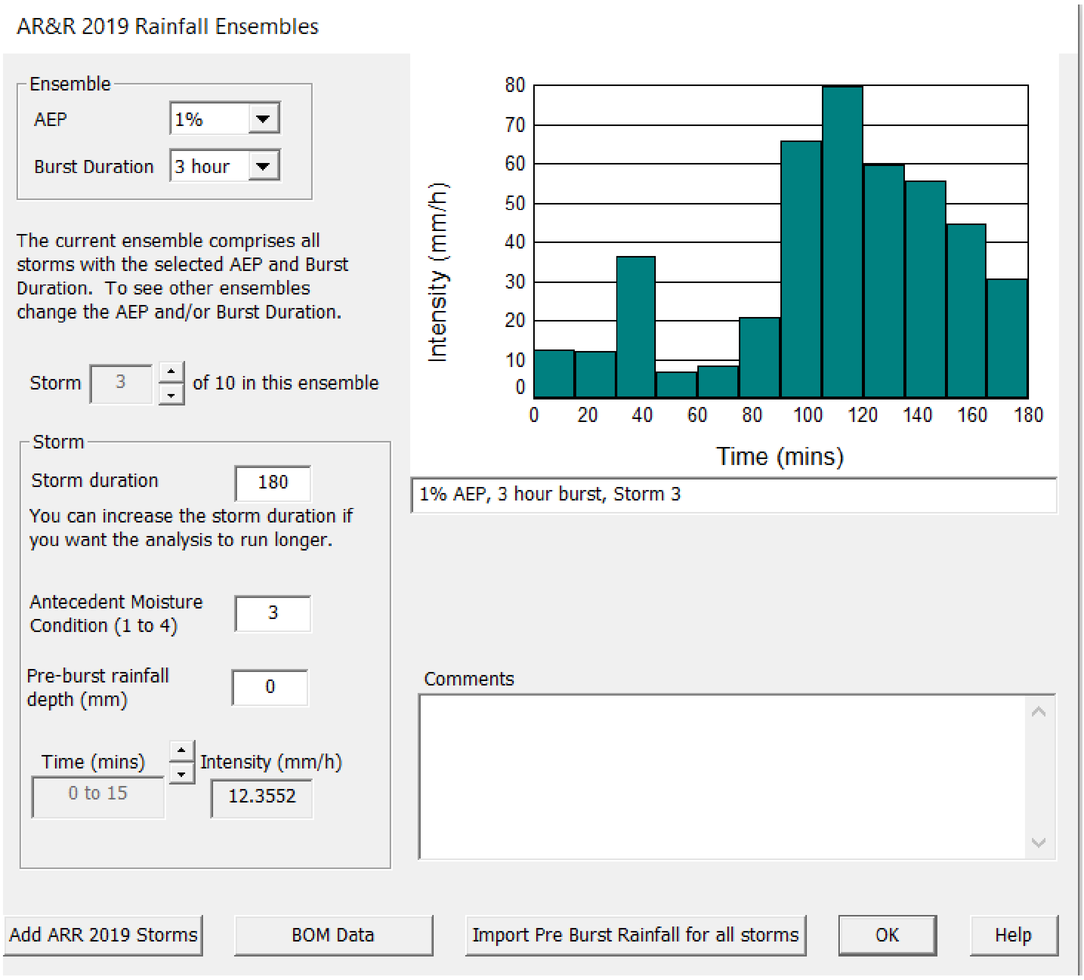
The depression storage is a depth of rainfall that is retained in depressions and the values used are those suggested by the DRAINS manual.

As described earlier the soil is a clayey loam with low to medium infiltration capacity. The DRAINS manual describes type 3 soils as having layers that impeded downward movement of water or soils with slow infiltrations rates. Type 3 soils were considered the most appropriate for the catchment area.

The Ilsax hydrological model converts rainfall hyetographs to runoff hydrographs and therefore requires rainfall intensity data and temporal pattern inputs. 2019 temporal patters were downloaded from the ARR Data Hub for the Toowoomba area as .csv files. 2016 intensity-frequency-duration (IFD) data were downloaded from the BOM website for the Toowoomba area also as .csv files. DRAINS requires this information when adding ARR 2019 storms in the rainfall data entry tab as shown in Figure 6.

Once the temporal pattern was selected DRAINS then requests the selection of the storms to create, as shown in Figure 7, for analysis. The Annual Exceedance Probability (AEP) is the probability of exceedance of a given rainfall intensity within a period of one year (QUDM, 2016). The AEP were selected to include the major/minor storms of 0.5EY and 1% AEP and through experience the other critical AEP is 5% which was included as well. The storm durations selected provide a range of durations up to 3 hours which is the maximum recommended storm duration (QUDM, 2016). The rainfall ensembles are then created following input of the IFD data.

The antecedent moisture condition is used for initial infiltration relationships of the Ilsax model and specifies how wet the soil is at the beginning of the storm. An AMC of 3 is considered conservative with 12.5-25mm of total rainfall allowed for in the 5 preceding days to the storm.



AR&R 2019 Rainfall Ensembles

Ensemble
AEP: 1%
Burst Duration: 3 hour

The current ensemble comprises all storms with the selected AEP and Burst Duration. To see other ensembles change the AEP and/or Burst Duration.

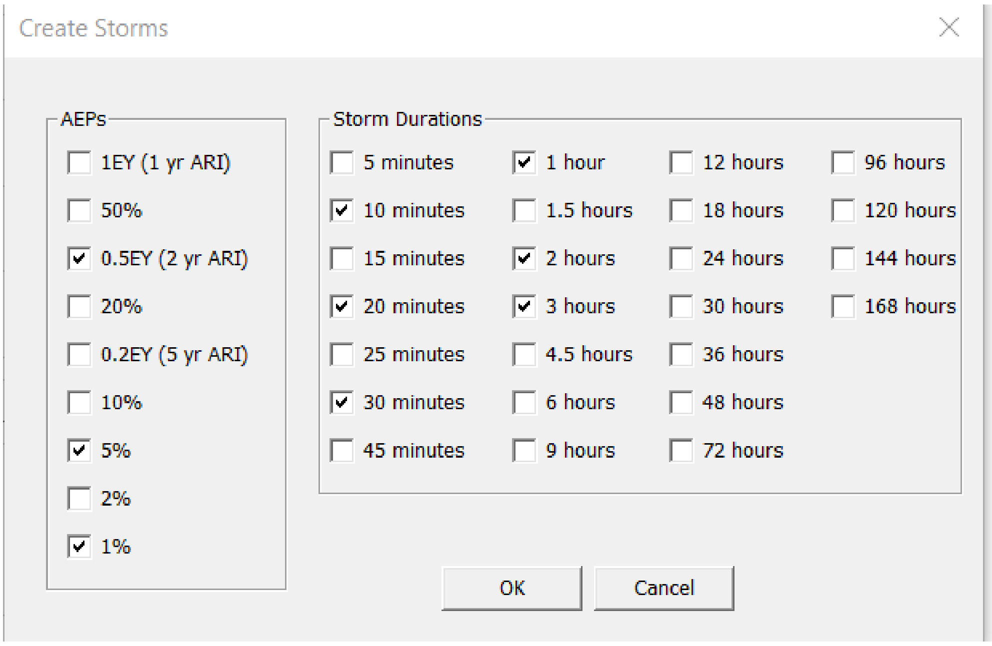
Storm 3 of 10 in this ensemble

Storm
Storm duration: 180
You can increase the storm duration if you want the analysis to run longer.
Antecedent Moisture Condition (1 to 4): 3
Pre-burst rainfall depth (mm): 0
Time (mins): 0 to 15
Intensity (mm/h): 12.3552

1% AEP, 3 hour burst, Storm 3

Comments

Figure 6. DRAINS rainfall data input tab



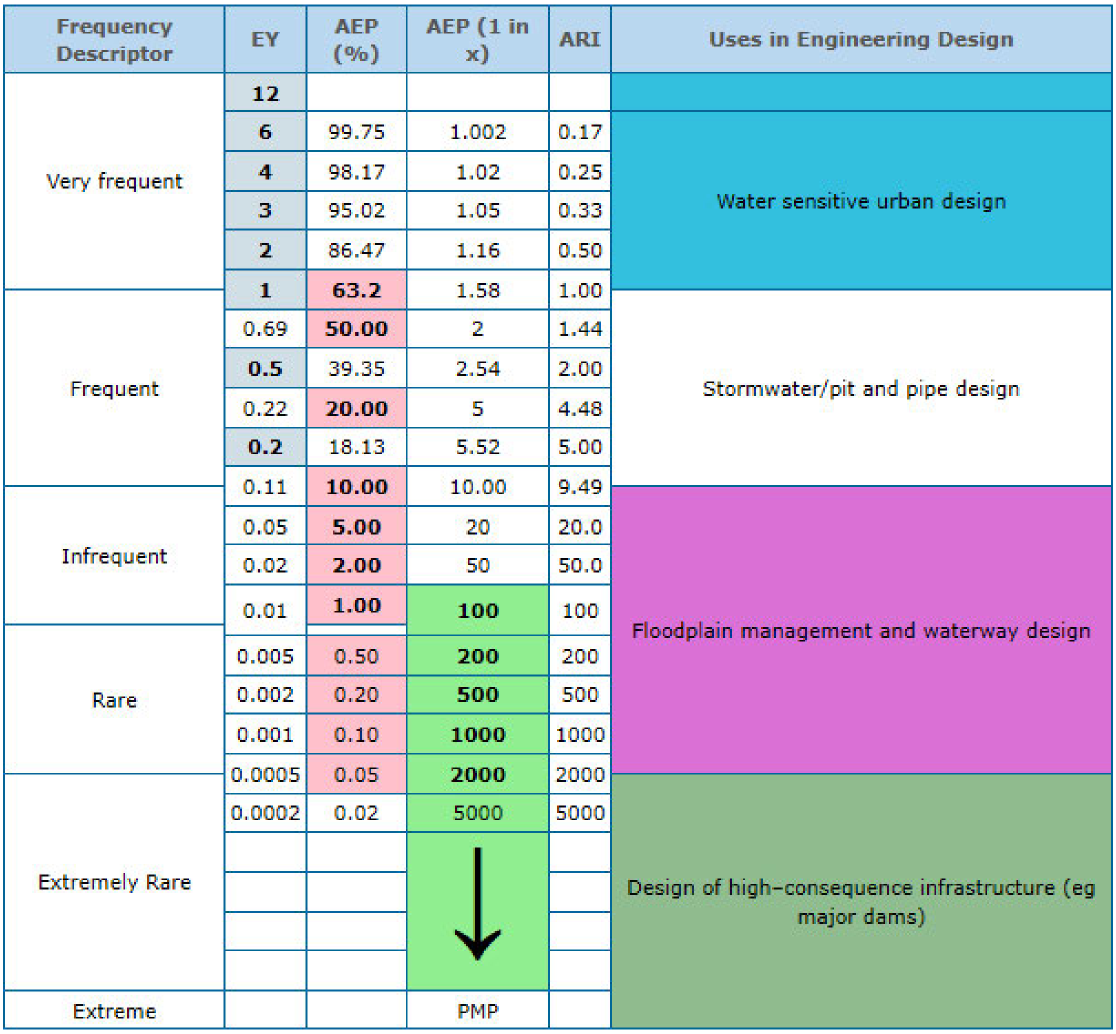
Create Storms

AEPs
☐ 1EY (1 yr ARI)
☐ 50%
☑ 0.5EY (2 yr ARI)
☐ 20%
☐ 0.2EY (5 yr ARI)
☐ 10%
☑ 5%
☐ 2%
☑ 1%

Storm Durations
☐ 5 minutes
☑ 10 minutes
☐ 15 minutes
☑ 20 minutes
☐ 25 minutes
☑ 30 minutes
☐ 45 minutes
☑ 1 hour
☐ 1.5 hours
☑ 2 hours
☑ 3 hours
☐ 4.5 hours
☐ 6 hours
☐ 9 hours
☐ 12 hours
☐ 18 hours
☐ 24 hours
☐ 30 hours
☐ 36 hours
☐ 48 hours
☐ 72 hours
☐ 96 hours
☐ 120 hours
☐ 144 hours
☐ 168 hours

Figure 7. DRAINS storm selection

For some frequent design rainfalls, the term EY is used, EY is the number of times a storm event is likely to be exceeded within any given year (Bureau of Meteorology, 2019). The terminology within DRAINS is in accordance with ARR, 2016 and the Bureau of Meteorology (BOM). The 39% AEP is referred to as the 0.5 EY storm event in accordance with Table 3. Australian Rainfall and Runoff Terminology (BOM, 2019).



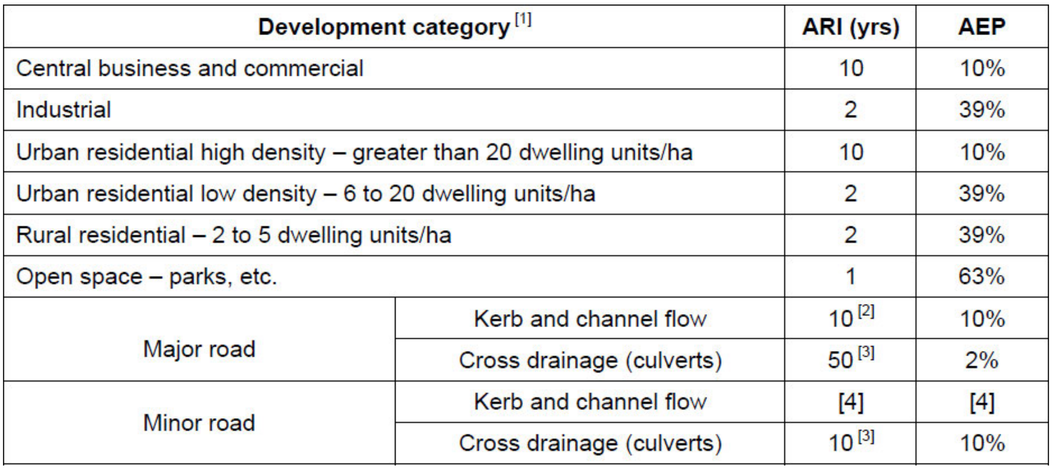
Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI	Uses in Engineering Design
Very frequent	**12**				
	6	99.75	1.002	0.17	Water sensitive urban design
	4	98.17	1.02	0.25	
	3	95.02	1.05	0.33	
	2	86.47	1.16	0.50	
	1	**63.2**	1.58	1.00	
Frequent	0.69	**50.00**	2	1.44	Stormwater/pit and pipe design
	0.5	39.35	2.54	2.00	
	0.22	**20.00**	5	4.48	
	0.2	18.13	5.52	5.00	
Infrequent	0.11	**10.00**	10.00	9.49	Floodplain management and waterway design
	0.05	**5.00**	20	20.0	
	0.02	**2.00**	50	50.0	
	0.01	**1.00**	**100**	100	
Rare	0.005	0.50	**200**	200	
	0.002	0.20	**500**	500	
	0.001	0.10	**1000**	1000	
	0.0005	0.05	**2000**	2000	
Extremely Rare	0.0002	0.02	5000	5000	Design of high-consequence infrastructure (eg major dams)
			↓		
Extreme			PMP		

Table 3. Australian Rainfall and Runoff Terminology (BOM, 2019)

The drainage system was design in accordance with the Major/Minor drainage concept as outlined in QUDM, 2016. The drainage system during a Minor storm allows the normal use of the land and flood-free movement of vehicles and pedestrians (QUDM, 2016). Basically, the drainage system must capture surface flow and convey the stormwater to a lawful point of discharge while maintaining freeboard to the surface at the inlet locations and ensuring surface flow depths/width are limited. The drainage system during a Major storm must not cause unacceptable safety risks or cause unacceptable flood damage (QUDM, 2016). An important factor in the design of the drainage system during a Major storm event is to ensure overland flow paths are provided that protect property and people's safety. This is achieved by maintaining a minimum freeboard from the Major storm water level within overland flood routes to the floor levels of adjacent buildings and ensuring the depth and velocity of the stormwater flow is limited.

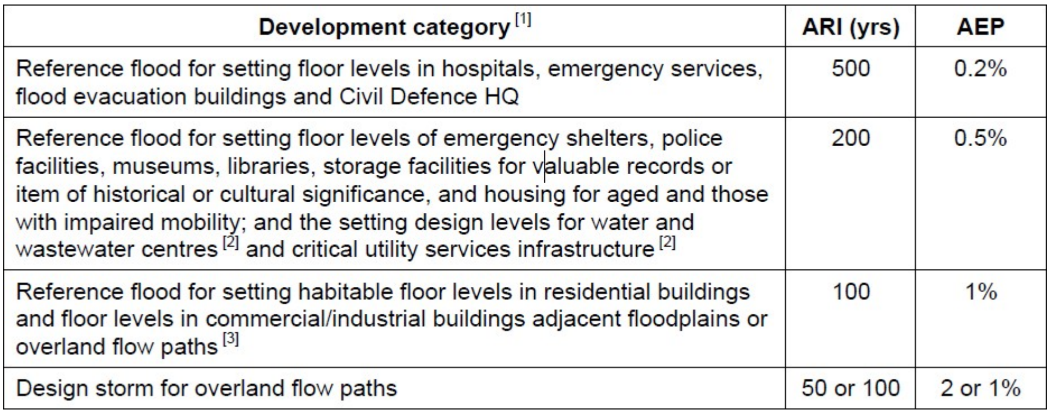
The AEP for the design of the drainage system have been selected in accordance with Tables 7.3.1 and 7.3.2 of QUDM, 2016 and are as follows:

- Minor Storm – 39% AEP (0.5 EY) for Urban Residential low density – 6 dwelling units/ha;
- Major Storm – 1% AEP for setting habitable floor levels in residential buildings;



Development category [1]		ARI (yrs)	AEP
Central business and commercial		10	10%
Industrial		2	39%
Urban residential high density – greater than 20 dwelling units/ha		10	10%
Urban residential low density – 6 to 20 dwelling units/ha		2	39%
Rural residential – 2 to 5 dwelling units/ha		2	39%
Open space – parks, etc.		1	63%
Major road	Kerb and channel flow	10 [2]	10%
	Cross drainage (culverts)	50 [3]	2%
Minor road	Kerb and channel flow	[4]	[4]
	Cross drainage (culverts)	10 [3]	10%

Table 4. Recommended design average recurrence intervals (ARI) and annual exceedance probabilities (AEP) for the minor system. Table 7.3.1, QUDM, 2016.



Development category [1]	ARI (yrs)	AEP
Reference flood for setting floor levels in hospitals, emergency services, flood evacuation buildings and Civil Defence HQ	500	0.2%
Reference flood for setting floor levels of emergency shelters, police facilities, museums, libraries, storage facilities for valuable records or item of historical or cultural significance, and housing for aged and those with impaired mobility; and the setting design levels for water and wastewater centres [2] and critical utility services infrastructure [2]	200	0.5%
Reference flood for setting habitable floor levels in residential buildings and floor levels in commercial/industrial buildings adjacent floodplains or overland flow paths [3]	100	1%
Design storm for overland flow paths	50 or 100	2 or 1%

Table 5. Recommended design average recurrence intervals (ARI) and annual exceedance probabilities (AEP) for the combined minor/major system. Table 7.3.2, QUDM, 2016

The completed post developed DRAINS is shown below in Figure 8. The lower sub-catchment drainage system was designed first as a standalone system and then exactly replicated at the higher elevations of the middle and upper catchments.

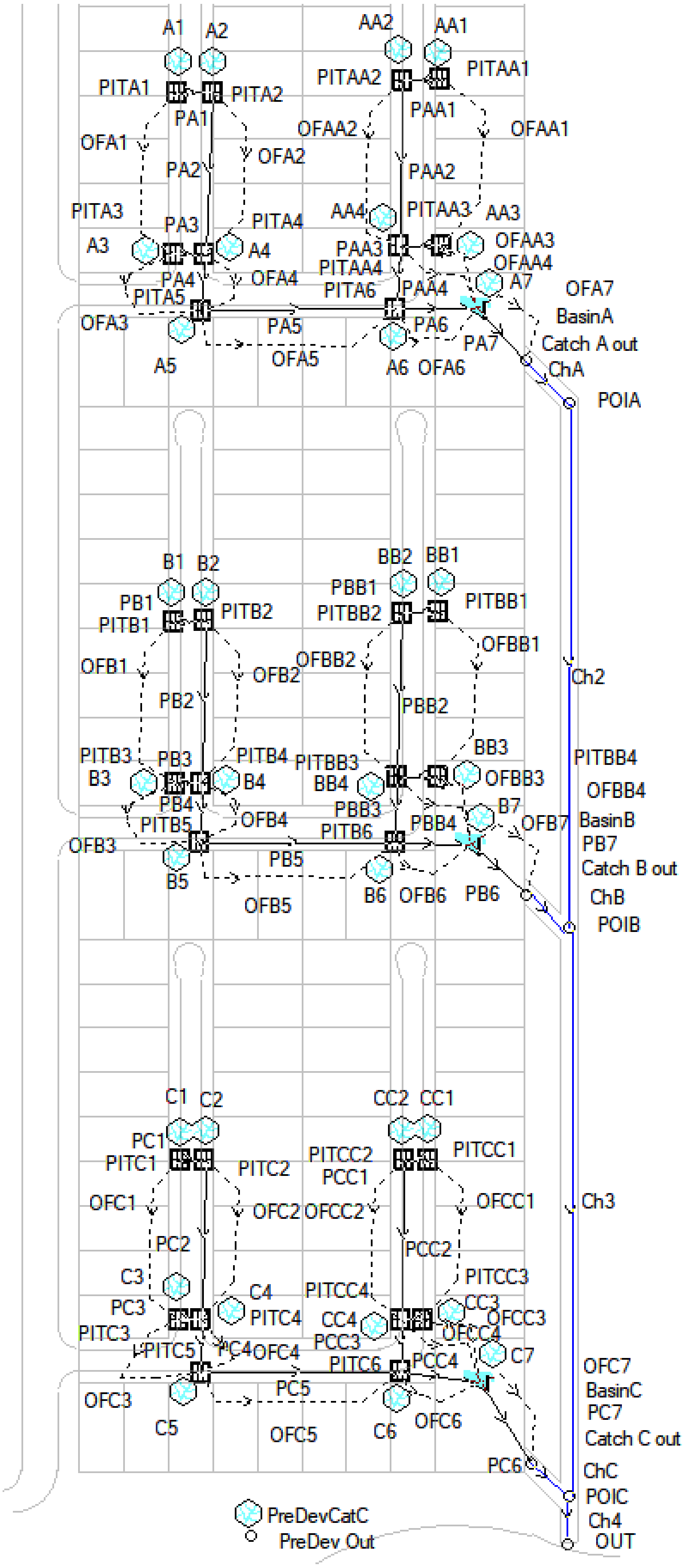


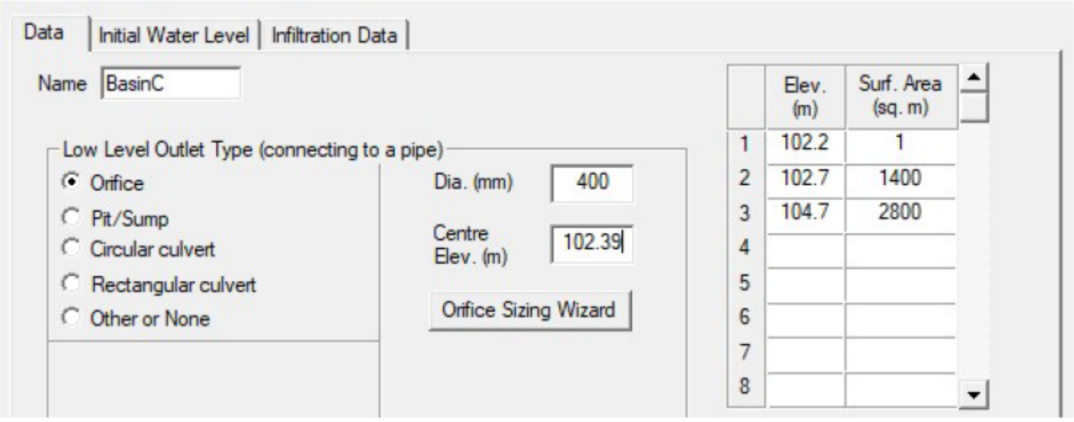
Figure 8. DRAINS model - All Catchments Attenuated

The design of the standalone stormwater drainage system for the lower sub-catchment was an iterative approach to ensure compliance with QUDM, refer Appendix E for details. The predeveloped peak runoff was compared with the post developed peak runoff without detention, refer Table 6.

AEP		0.5 (EY)	5	1
Peak Discharge (m^3/s)	Pre-development	0.454	1.330	1.890
	Post-development	1.690	3.170	4.550
Differences (cumecs)		1.236	1.840	2.660
Percentage Increase		272.25	138.35	140.74

Table 6. DRAINS - Pre v Post Peak Runoff - Lower Catchment unmitigated

The results show that due to the development there was a large increase in the peak discharge to the downstream waterway as expected. To ensure a non-worsening of peak discharge the detention basin was then designed to ensure post developed peak runoff was less than or equal to the predeveloped peak runoff. This was an iterative process with the final detention size shown in Figure 9.



Name BasinC

Low Level Outlet Type (connecting to a pipe)

● Orifice
○ Pit/Sump
○ Circular culvert
○ Rectangular culvert
○ Other or None

Dia. (mm) 400

Centre Elev. (m) 102.39

	Elev. (m)	Surf. Area (sq. m)
1	102.2	1
2	102.7	1400
3	104.7	2800
4		
5		
6		
7		
8		

Figure 9. DRAINS - Detention Basin Details - Typical

The predeveloped peak runoff was compared with the post developed peak runoff with detention, refer Table 7.

AEP		0.5 (EY)	5	1
Peak Discharge (m^3/s)	Pre-development	0.454	0.509	1.890
	Post-development	0.298	0.444	1.710
Differences (cumecs)		-0.156	-0.065	-0.180
Percentage Increase		-34.36	-12.77	-9.52

Table 7. DRAINS - Pre v Post Peak Runoff - Lower Catchment mitigated

Table 7 shows that as a result of the detention basin being constructed within the drainage system the peak post-development discharge from the lower catchment is reduced to values slightly less than the peak pre-developed discharge. Therefore, the development now how a non-worsening effect on peak discharge to the downstream waterway.

It must be noted that the detention basin was designed to ensure non-worsening for the median storm in the critical storm ensembles. DRAINS analyses 10 different rainfall hyetographs for each storm duration per AEP/EY, refer Figure 10 for peak flows of each storm duration for 0.5 EY. The results displayed on the screen is the worst-case scenario or the storm that results in the maximum discharge. In the case of the 0.5EY storm for the mitigated lower catchment the maximum discharge occurs in the 1 hour burst for storm 7, shown in red in Figure 10 below. The maximum discharge for each of the other storm durations is show in pink.

During the run DRAINS therefore analyses 60 different storm events per AEP/EY. To reduce run time the option for DRAINS to assess the entire storm ensemble is then changed to analyse only the maximum discharge for each storm duration. The storms are referred to as the critical storm durations, shown as the pin and red storms below. The peak discharges for the critical storms are then assessed to ensure non-worsening is achieved with the previously designed detention basin.

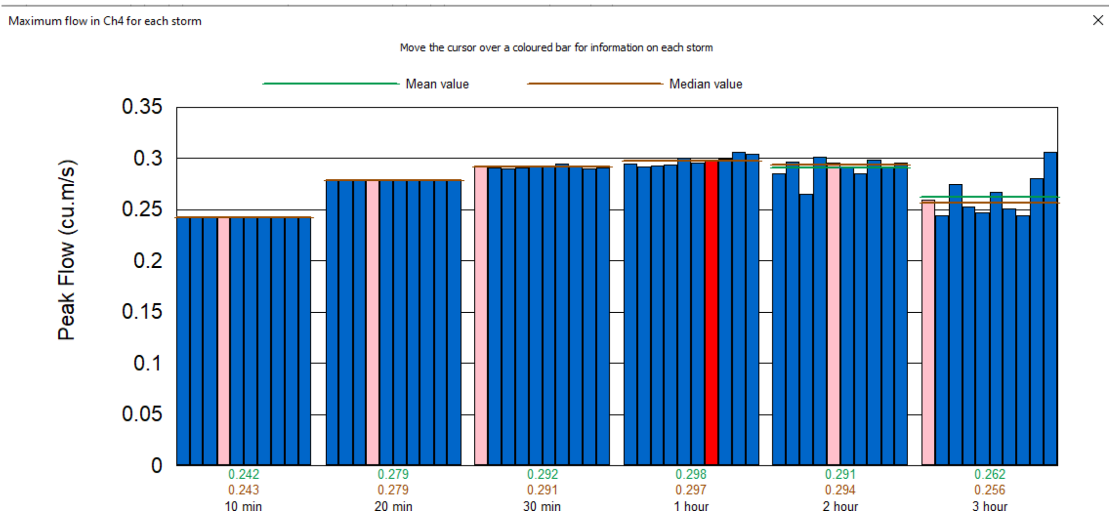


Figure 10. Lower Catchment - Peak Flow 0.5EY storm ensemble

The same process as mentioned above is carried out to determine the critical storm durations for the 5% and 1% AEP's. Results of the assessment of critical storm durations are shown below.

All but 2 out of the 18 critical storm durations achieve non-worsening as highlighted in the tables below. As these values are not the maximum discharge for each AEP/EY the minor increases in peak flow are considered acceptable.

AEP (%)		0.5 (EY)					
Critical storm duration (mins)		10	20	30	60	120	180
Peak Discharge (m^3/s)	Pre-development	0.244	0.392	0.454	0.456	0.491	0.226
	Post-development	0.242	0.279	0.292	0.298	0.295	0.259
Differences (cumecs)		-0.002	-0.113	-0.162	-0.158	-0.196	0.033
Percentage Increase		-0.82	-28.83	-35.68	-34.65	-39.92	14.60

Table 8. Pre v Post Peak Runoff - Lower Catchment mitigated 0.5EY Critical Storms

AEP (%)		5					
Critical storm duration (mins)		10	20	30	60	120	180
Peak Discharge (m^3/s)	Pre-development	0.695	1.070	1.270	1.140	0.965	0.643
	Post-development	0.307	0.366	0.387	0.444	0.406	0.380
Differences (cumecs)		-0.388	-0.704	-0.883	-0.696	-0.559	-0.263
Percentage Increase		-55.83	-65.80	-69.53	-61.05	-57.93	-40.90

Table 9. Pre v Post Peak Runoff - Lower Catchment mitigated 5% Critical Storms

AEP (%)		1					
Critical storm duration (mins)		10	20	30	60	120	180
Peak Discharge (m^3/s)	Pre-development	1.040	1.570	1.890	1.470	1.490	1.260
	Post-development	0.360	0.779	1.690	1.610	1.350	1.200
Differences (cumecs)		-0.680	-0.794	0.200	0.140	-0.140	-0.060
Percentage Increase		-65.38	-50.57	-10.58	9.52	-9.40	-4.76

Table 10. Pre v Post Peak Runoff - Lower Catchment mitigated 1% Critical Storms

The drainage system designed for the lower catchment was then replicated within the middle and upper catchments with the same design. As the catchments were identical the only change required was to lift the whole system in elevation to match the average slope across the site. This then replicates each third of the catchment being designed to attenuate its own flow without having regards to the entire catchment on its own. The various modelling scenarios will then determine the effects of the one third rule at the discharge location.

3.7 DRAINS - Modelling Scenarios

Several DRAINS models were created to assess the effect the different scenarios will have on peak flows to the discharge point. Detention basin/s were removed from the system and the resulting effect on the discharge point to the downstream waterway was analysed.

The different DRAINS models to be run will contain the following differing detention tank scenarios. The catchment that will contain the detention tanks will include:

10. Pre-Development;
11. No detention tanks provided;
12. All 3 thirds of the catchment;
13. Upper catchment only;
14. Upper and middle catchments;
15. Upper and lower catchments;
16. Middle catchment only;
17. Middle and lower catchments;
18. Lower catchment only;

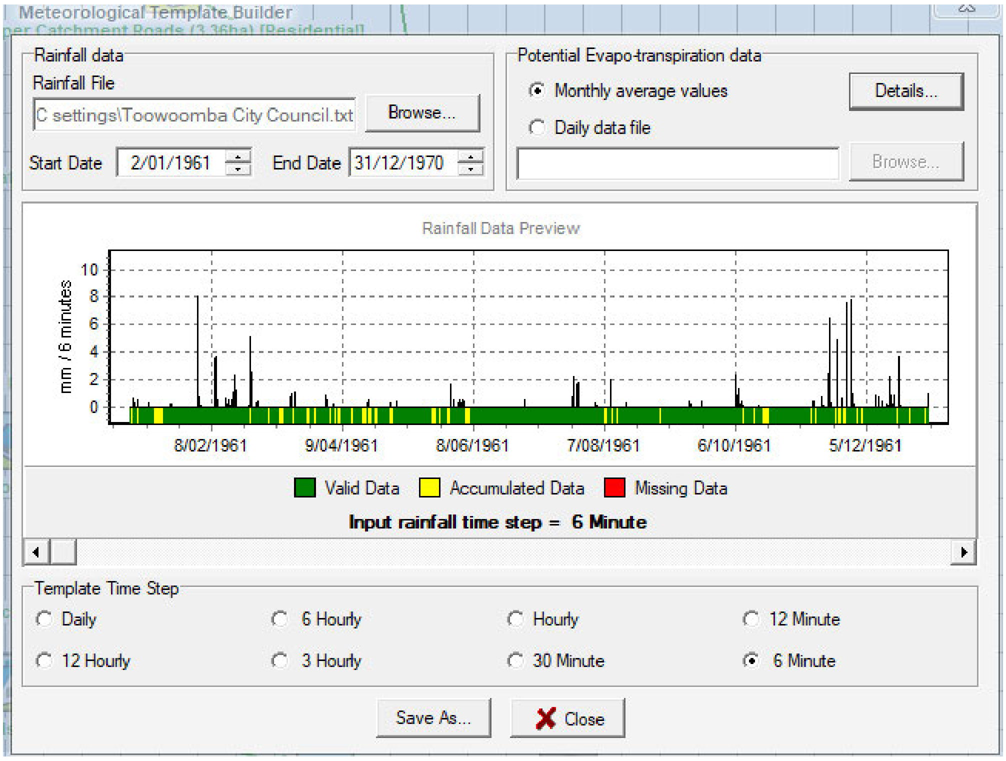
3.8 MUSIC - Model

As discussed in Chapter 2, a MUSIC model was created to assess if the software can model stormwater attenuation in comparison to DRAINS and it the software can be used as a stormwater quantity modelling tool. The MUSIC model was created to replicate the DRAINS model.

As discussed earlier the rainfall data to enter is very different, this was expected. The first step was to create a new template and select the rainfall data. BOM 6minute rainfall file for Cooby Creek was utilised and entered for years between 1961 and 1970 as recommended by the MUSIC modelling Guidelines (Water by Design, 2010).

Potential evapo-transpiration (PET) data was also entered utilising the Toowoomba Monthly Areal PET data provided by the MUSIC software.

No elevation data can be entered into the source/catchment nodes, that includes slopes or shapes.



Meteorological Template Builder

Rainfall data

Rainfall File: C settings\Toowoomba City Council.txt

Start Date: 2/01/1961 End Date: 31/12/1970

Potential Evapo-transpiration data

● Monthly average values

○ Daily data file

Rainfall Data Preview

Input rainfall time step = 6 Minute

Template Time Step

○ Daily ○ 6 Hourly ○ Hourly ○ 12 Minute

○ 12 Hourly ○ 3 Hourly ○ 30 Minute ● 6 Minute

Figure 11. MUSIC rainfall input data

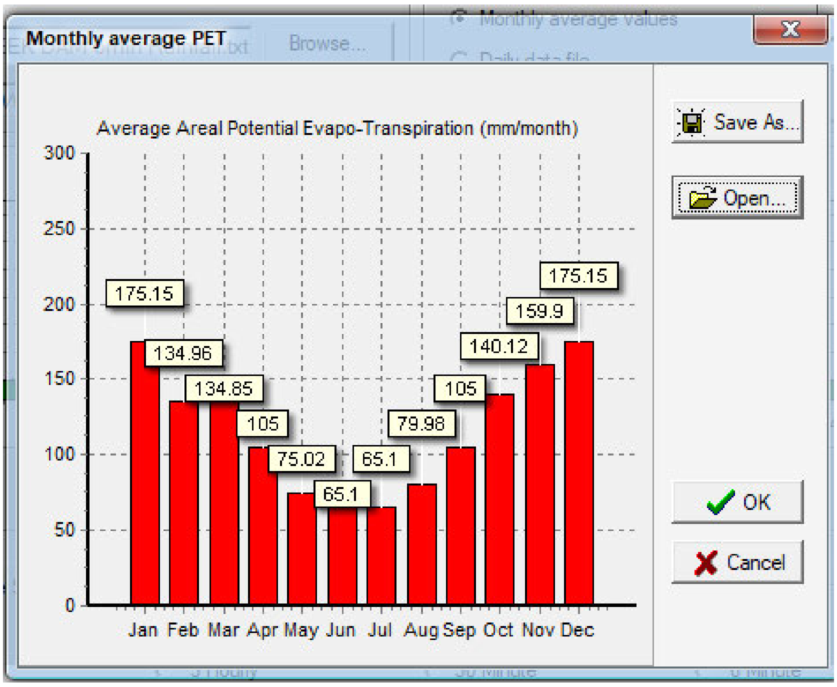


Figure 12. MUSIC PET input data

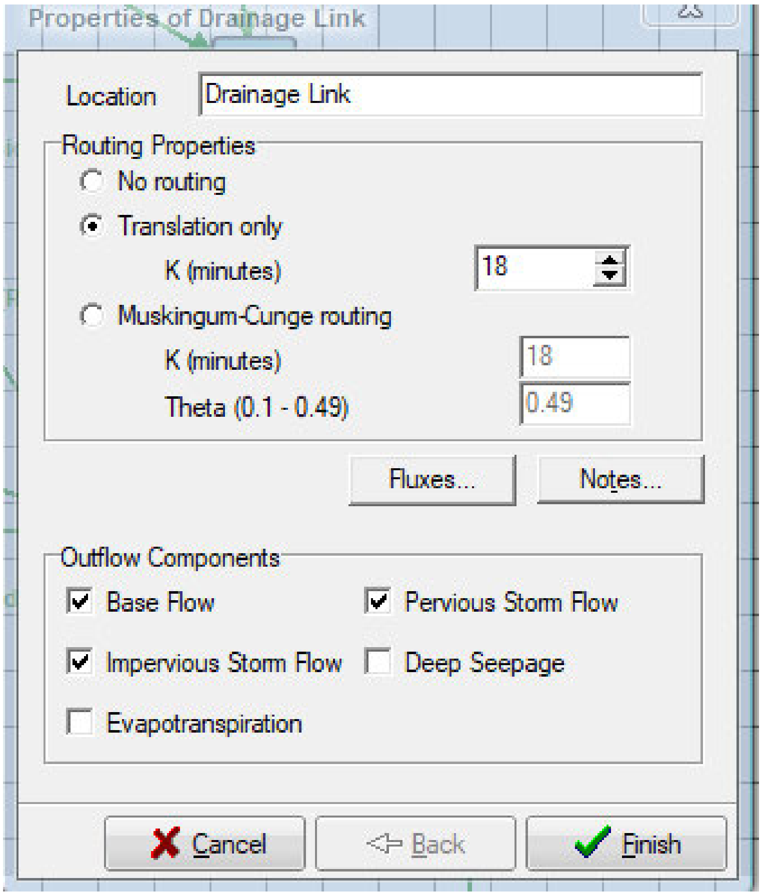
The source nodes represent the catchments and sub-catchments and are split into 3 different areas as recommended by the MUSIC modelling Guidelines (Water by Design, 2010). The land use was also selected as Urban Residential as recommended by the MUSIC modelling Guidelines (Water by Design, 2010). Each 7.5ha sub catchment was split into the following areas:

- 2.64ha of roof area (impervious);
- 3.36ha of roads area including driveways (impervious);
- 1.50ha of ground area that includes landscaping and grass (pervious);

The pollutant export parameters for each surface type was also selected as recommended by the MUSIC modelling Guidelines (Water by Design, 2010).

Detention basin treatment nodes were then added to the MUSIC model at the outlet of each sub catchment and then all catchments were linked together with junction nodes and a receiving node provided as the discharge location for entire catchment. Refer to Figure 15 for the MUSIC model layout.

The link nodes have a basic routing option as shown in Figure 13. The parameter inputs are very simplified and are simply an estimation or best guess. An 18minute translation routing was selected to attempt to replicate a time of stormwater flow through the system across the roads. The roof and ground level source nodes were provided with 30minute times as the discharge from these areas will take longer to reach the outlet. These values were also pre-set to 6minute intervals only.



Properties of Drainage Link

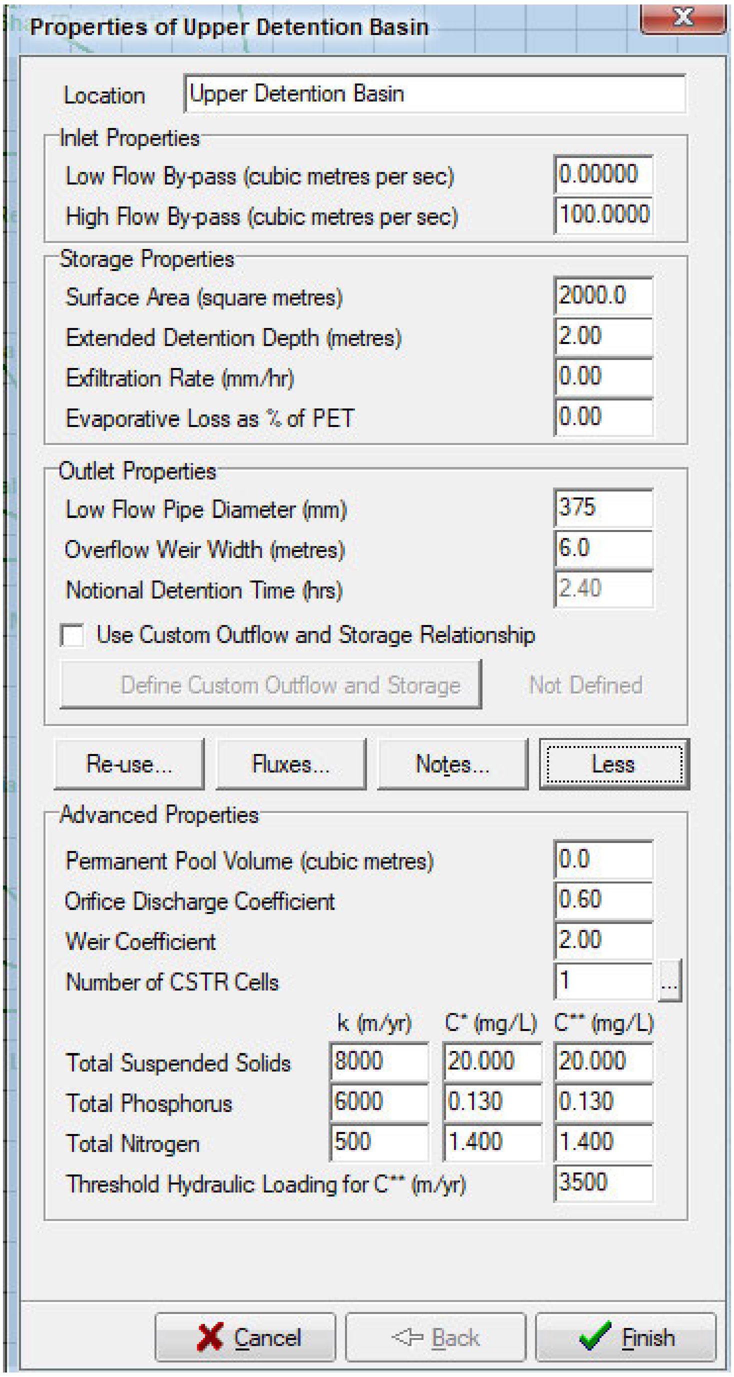
Location: Drainage Link

Routing Properties
○ No routing
● Translation only
K (minutes): 18
○ Muskingum-Cunge routing
K (minutes): 18
Theta (0.1 - 0.49): 0.49

Outflow Components
☑ Base Flow
☑ Pervious Storm Flow
☑ Impervious Storm Flow
☐ Deep Seepage
☐ Evapotranspiration

Figure 13. MUSIC drainage link parameters

The input for the detention basins is very simplified as shown below in Figure 14. The advanced properties were assumed to be correct for the detention node and were left as per the software default setting. Similarly, with DRAINS an estimate of the detention parameters was initially estimated.



Properties of Upper Detention Basin

Location: Upper Detention Basin

Inlet Properties
Low Flow By-pass (cubic metres per sec): 0.00000
High Flow By-pass (cubic metres per sec): 100.0000

Storage Properties
Surface Area (square metres): 2000.0
Extended Detention Depth (metres): 2.00
Exfiltration Rate (mm/hr): 0.00
Evaporative Loss as % of PET: 0.00

Outlet Properties
Low Flow Pipe Diameter (mm): 375
Overflow Weir Width (metres): 6.0
Notional Detention Time (hrs): 2.40
☐ Use Custom Outflow and Storage Relationship
Define Custom Outflow and Storage: Not Defined

Advanced Properties
Permanent Pool Volume (cubic metres): 0.0
Orifice Discharge Coefficient: 0.60
Weir Coefficient: 2.00
Number of CSTR Cells: 1

	k (m/yr)	C* (mg/L)	C** (mg/L)
Total Suspended Solids	8000	20.000	20.000
Total Phosphorus	6000	0.130	0.130
Total Nitrogen	500	1.400	1.400

Threshold Hydraulic Loading for C** (m/yr): 3500

Figure 14. MUSIC detention basin parameters

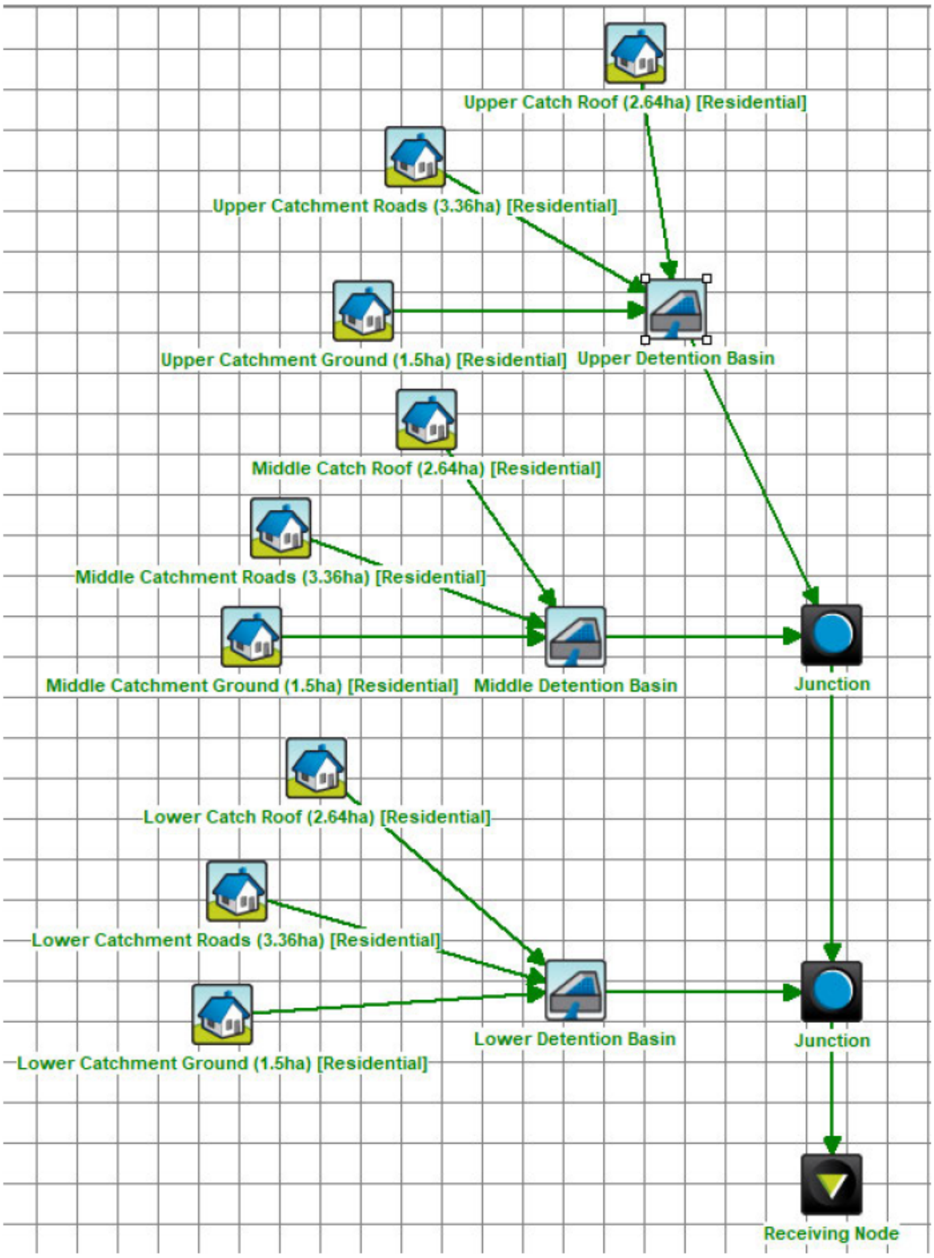


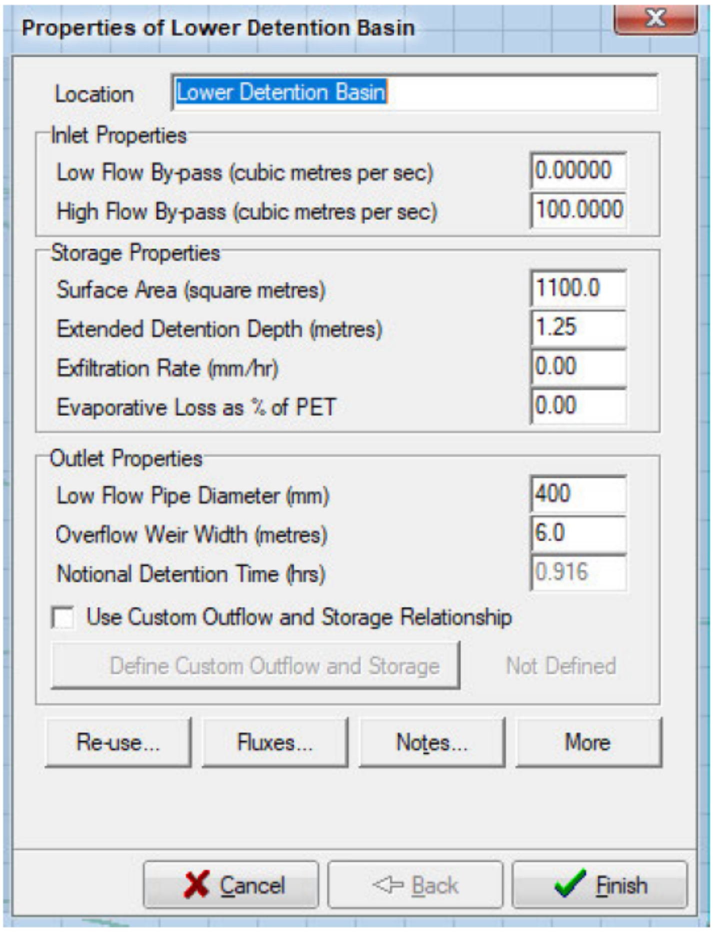
Figure 15. MUSIC model layout – All attenuated

The design of the standalone stormwater drainage system for the lower sub-catchment was an iterative approach. The predeveloped peak runoff was compared with the post developed peak runoff without detention, refer Table 11Table 6. The peak runoff was determined by obtaining the maximum 6minute time step flow at each outlet.

Peak Discharge (m^3/s)	Pre-development	0.864
	Post-development	1.430
Differences (cumecs)		0.566
Percentage Increase		65.51

Table 11. MUSIC Pre v Post Peak Runoff - Lower Catchment unmitigated

The results show that due to the development there was a large increase in the peak discharge to the downstream waterway as expected. To ensure a non-worsening of peak discharge the detention basin was then designed to ensure post developed peak runoff was less than or equal to the predeveloped peak runoff. This was an iterative process with the final detention size shown in Figure 16.



Properties of Lower Detention Basin

Location: Lower Detention Basin

Inlet Properties
Low Flow By-pass (cubic metres per sec): 0.00000
High Flow By-pass (cubic metres per sec): 100.0000

Storage Properties
Surface Area (square metres): 1100.0
Extended Detention Depth (metres): 1.25
Exfiltration Rate (mm/hr): 0.00
Evaporative Loss as % of PET: 0.00

Outlet Properties
Low Flow Pipe Diameter (mm): 400
Overflow Weir Width (metres): 6.0
Notional Detention Time (hrs): 0.916
☐ Use Custom Outflow and Storage Relationship
Not Defined

Figure 16. MUSIC - Detention Basin Details – Typical

The predeveloped peak runoff was compared with the post developed peak runoff with detention, refer Table 12.

Peak Discharge (m^3/s)	Pre-development	0.864
	Post-development	0.807
Differences (cumecs)		-0.057
Percentage Increase		-6.60

Table 12. MUSIC Pre v Post Peak Runoff - Lower Catchment mitigated

Table 12 shows that as a result of the detention basin being constructed within the drainage system the peak post-development discharge from the lower catchment is reduced to values slightly less than the peak pre-developed discharge. Therefore, the development now how a non-worsening effect on peak discharge to the downstream waterway.

3.9 MUSIC - Modelling Scenarios

Several MUSIC models were created to compare with the DRAINS software. Detention basin/s were removed from the system and the resulting effect on the discharge point to the downstream waterway was analysed.

The different DRAINS models to be run will contain the following differing detention tank scenarios. The catchment that will contain the detention tanks will include:

1. Pre-Development;
2. No detention tanks provided;
3. All 3 thirds of the catchment;
4. Upper catchment only;
5. Upper and middle catchments;
6. Upper and lower catchments;
7. Middle catchment only;
8. Middle and lower catchments;
9. Lower catchment only;

Chapter 4 Results

4.1 Introduction

All the MUSIC and DRAINS models that were explained in the previous Chapter were run and analysed in the software. The DRAINS results were first examined and the selection of what data to be exported for the best representation of peak discharge was selected.

A similar process for DRAINS above was undertaken for MUSIC.

4.2 DRAINS - Outputs

The objective of the DRAINS modelling was to assess the validity of the one third rule on the downstream waterway. Therefore, the point of interest is the outlet node of the drainage system. The outlet node however is not able to output hydrograph data therefore, the last section of trunk drainage channel was considered to be the appropriate link for assessment.

All the model scenarios were run and the peak flow for the Major and Minor AEP/EY, 1% and 0.5 EY respectively, and critical storm duration entered into an excel spreadsheet. The results presented in the next section.

4.3 DRAINS - Results

The peak flow results for the Minor storm event are shown in Table 13.

0.5 EY AEP - Storm Event Peak Discharge to Downstream Waterway (m^3/s)						
Model Scenario	10 min burst	20 min burst	30 min burst	1-hour burst	2-hour burst	3-hour burst
Pre-Development	0.341	0.944	1.209	1.268	1.047	1.706
No Detention	4.66	4.86	3.258	2.51	2.933	2.551
All Catchments attenuated	0.714	0.827	0.868	0.89	0.88	0.774
Upper Attenuated	3.195	3.495	2.452	2.023	2.235	1.948
Middle Attenuated	2.957	3.383	2.413	1.907	2.106	1.958
Lower Attenuated	3.398	3.588	2.488	2.027	2.266	1.974
Upper and Middle Attenuated	1.605	2.098	1.646	1.444	1.458	1.345
Upper and Lower Attenuated	1.814	2.172	1.665	1.454	1.489	1.378
Middle and Lower Attenuated	2.052	2.205	1.684	1.465	1.53	1.397

Table 13. 0.5 EY AEP - Storm Event Peak Discharge to Downstream Waterway (m^3/s)

This table has been generated using the peak flows within the last section of trunk drainage channel just upstream of the downstream waterway for the Minor storm event.

The difference in peak flow was then calculated by subtracting the developed modelling scenarios from the pre-developed scenario and shown in Table 14.

0.5 EY AEP - Storm Event Peak Discharge to Waterway difference to **Pre-Dev** (m^3/s)						
Model Scenario	10 min burst	20 min burst	30 min burst	1-hour burst	2-hour burst	3-hour burst
All Catchments attenuated	0.373	-0.117	-0.341	-0.378	-0.167	-0.932
Upper Attenuated	2.854	2.551	1.243	0.755	1.188	0.242
Middle Attenuated	2.616	2.439	1.204	0.639	1.059	0.252
Lower Attenuated	3.057	2.644	1.279	0.759	1.219	0.268
Upper and Middle Attenuated	1.264	1.154	0.437	0.176	0.411	-0.361
Upper and Lower Attenuated	1.473	1.228	0.456	0.186	0.442	-0.328
Middle and Lower Attenuated	1.711	1.261	0.475	0.197	0.483	-0.309

Table 14. 0.5 EY AEP - Storm Event Peak Discharge to Waterway difference to Pre-Dev (m^3/s)

The highlighted cells represent the scenarios that achieved a reduction or non-worsening in the peak discharge. When all catchments are provided with detention the peak discharge is reduced in almost all 0.5 EY storm events. The smallest storm duration of 10minutes however, does not have a reduction in peak flow.

The difference in peak flows when all catchments are provided with detention in comparison to the other attenuated modelling scenarios was calculated and shown in Table 15.

0.5 EY AEP - Storm Event Peak Discharge to Waterway difference to **All attenuated** (m^3/s)						
Model Scenario	10 min burst	20 min burst	30 min burst	1-hour burst	2-hour burst	3-hour burst
Upper Catchment Only	2.481	2.668	1.584	1.133	1.355	1.174
Middle Catchment Only	2.243	2.556	1.545	1.017	1.226	1.184
Lower Catchment Only	2.684	2.761	1.62	1.137	1.386	1.2
Upper and Middle Catchment	0.891	1.271	0.778	0.554	0.578	0.571
Upper and Lower Attenuated	1.1	1.345	0.797	0.564	0.609	0.604
Middle and Lower Attenuated	1.338	1.378	0.816	0.575	0.65	0.623

Table 15. 0.5 EY AEP - Storm Event Peak Discharge to Waterway difference to All attenuated (m^3/s)

The table demonstrates that for all 0.5 EY storm events, providing detention within all 3 thirds of the total catchment is the most effective method of reducing peak discharge.

The peak flow results for the Major storm event are shown in Table 16.

1% AEP - Storm Event Peak Discharge to Downstream Waterway (m^3/s)						
Model Scenario	10 min burst	20 min burst	30 min burst	1-hour burst	2-hour burst	3-hour burst
Pre-Development	2.956	4.602	5.561	5.537	4.381	3.716
No Detention	12.541	12.743	10.704	10.227	6.118	5.217
All Catchments attenuated	1.074	2.259	4.698	4.643	3.939	3.381
Upper Catchment Only	8.504	8.937	7.293	7.037	4.533	3.826
Middle Catchment Only	8.627	8.544	7.398	6.825	4.699	3.829
Lower Catchment Only	8.84	9.033	7.515	7.236	5.095	3.826
Upper and Middle Catchment	4.547	5.017	4.163	4.437	3.746	3.571
Upper and Lower Attenuated	4.778	5.026	4.997	4.922	3.997	3.578
Middle and Lower Attenuated	4.886	5.258	5.803	5.229	4.422	3.594

Table 16. 1% AEP - Storm Event Peak Discharge to Downstream Waterway (m^3/s)

This table has been generated using the peak flows within the last section of trunk drainage channel just upstream of the downstream waterway for the Major storm event.

The difference in peak flow was then calculated by subtracting the developed modelling scenarios from the pre-developed scenario and shown in Table 17.

1% AEP - Storm Event Peak Discharge to Waterway difference to **Pre-Dev** (m^3/s)						
Model Scenario	10 min burst	20 min burst	30 min burst	1-hour burst	2-hour burst	3-hour burst
All Catchments attenuated	-1.882	-2.343	-0.863	-0.894	-0.442	-0.335
Upper Attenuated	5.548	4.335	1.732	1.5	0.152	0.11
Middle Attenuated	5.671	3.942	1.837	1.288	0.318	0.113
Lower Attenuated	5.884	4.431	1.954	1.699	0.714	0.11
Upper and Middle Attenuated	1.591	0.415	-1.398	-1.1	-0.635	-0.145
Upper and Lower Attenuated	1.822	0.424	-0.564	-0.615	-0.384	-0.138
Middle and Lower Attenuated	1.93	0.656	0.242	-0.308	0.041	-0.122

Table 17. 1% AEP - Storm Event Peak Discharge to Waterway difference to Pre-Dev (m^3/s)

The highlighted cells represent the scenarios that achieved a reduction or non-worsening in the peak discharge. When all catchments are provided with detention the peak discharge is reduced in all 1% AEP storm events. Several of the other modelling scenarios produced a non-worsening result as well including the model with no detention in the lower third of the catchment.

The difference in peak flows when all catchments are provided with detention in comparison to the other attenuated modelling scenarios was calculated and shown in Table 18.

1% AEP - Storm Event Peak Discharge to Waterway difference to **All attenuated** (m³/s)						
Model Scenario	10 min burst	20 min burst	30 min burst	1-hour burst	2-hour burst	3-hour burst
Upper Catchment Only	7.43	6.678	2.595	2.394	0.594	0.445
Middle Catchment Only	7.553	6.285	2.7	2.182	0.76	0.448
Lower Catchment Only	7.766	6.774	2.817	2.593	1.156	0.445
Upper and Middle Catchment	3.473	2.758	-0.535	-0.206	-0.193	0.19
Upper and Lower Attenuated	3.704	2.767	0.299	0.279	0.058	0.197
Middle and Lower Attenuated	3.812	2.999	1.105	0.586	0.483	0.213

Table 18. 1% AEP - Storm Event Peak Discharge to Waterway difference to All attenuated (m³/s)

The table demonstrates that for almost all 1% AEP storm events, providing detention within all 3 thirds of the total catchment is the most effective method of reducing peak discharge. The highlighted cells represent the scenarios that achieved a reduction greater than that achieved when providing detention to all 3 catchments. The only scenario that achieved a larger reduction was when the stormwater discharge from the lower third of the catchment was not attenuated.

4.5 MUSIC - Outputs

The objective of the MUSIC modelling was to analyse how effective the software can model stormwater attenuation when compared to the more robust modelling results of DRAINS.

The final objective of the research was to determine if MUSIC is effective for modelling stormwater attenuation and be utilised as a conceptual hydraulic modelling tool.

All the model scenarios were run and the maximum flow for the scenario presented in the next section.

Music can also produce hydrographs as outputs that cover the period of the rainfall data entered. These are also presented in the next section.

4.6 MUSIC - Results

The peak flow results for the continuous storm event are shown in Table 19.

Model Scenario	Discharge to Downstream Waterway (m^3/s)
Pre-Development	2.590
No Detention	3.700
All Catchments attenuated	2.220
Upper Attenuated	2.830
Middle Attenuated	2.910
Lower Attenuated	3.660
Upper and Middle Attenuated	2.130
Upper and Lower Attenuated	2.550
Middle and Lower Attenuated	2.600

Table 19. MUSIC - Peak Discharge to Downstream Waterway (m^3/s)

This table has been generated using the peak flows within the last section of trunk drainage channel just upstream of the downstream waterway for the continuous storm event.

The difference in peak flow was then calculated by subtracting the developed modelling scenarios from the pre-developed scenario and shown in Table 20.

Model Scenario	MUISC - Peak Discharge to Waterway difference to **Pre-Dev** (m³/s)
All Catchments attenuated	-0.370
Upper Attenuated	0.240
Middle Attenuated	0.320
Lower Attenuated	1.070
Upper and Middle Attenuated	-0.460
Upper and Lower Attenuated	-0.040
Middle and Lower Attenuated	0.010

Table 20. MUSIC - Peak Discharge to Waterway difference to **Pre-Dev** (m³/s)

The highlighted cells represent the scenarios that achieved a reduction or non-worsening in the peak discharge. 3 scenarios achieve non-worsening and they include:

- All catchments attenuated;
- Upper and Lower catchments attenuated;
- Upper and Middle catchments attenuated (one third rule).

The difference in peak flow when all catchments are provided with detention in comparison to the other attenuated modelling scenarios was calculated and shown in Table 21.

Model Scenario	MUISC - Peak Discharge to Waterway difference to All attenuated (m³/s)
Upper Attenuated	0.610
Middle Attenuated	0.690
Lower Attenuated	1.440
Upper and Middle Attenuated	-0.090
Upper and Lower Attenuated	0.330
Middle and Lower Attenuated	0.380

Table 21. MUISC - Peak Discharge to Waterway difference to All attenuated (m³/s)

The highlighted cells represent the scenarios that achieved a reduction greater than that achieved when providing detention to all 3 catchments. The only scenario that achieved a larger reduction was when the stormwater discharge from the lower third of the catchment was not attenuated.

As mentioned earlier MUSIC can produce hydrographs. The hydrographs are a continuous event hydrograph so therefore, it was produced for the same length of time that the rainfall data was selected. In this research there was 10 years of rainfall data provided.

The outlet hydrograph for the Upper and Lower catchments attenuated scenario is provided below as an example.

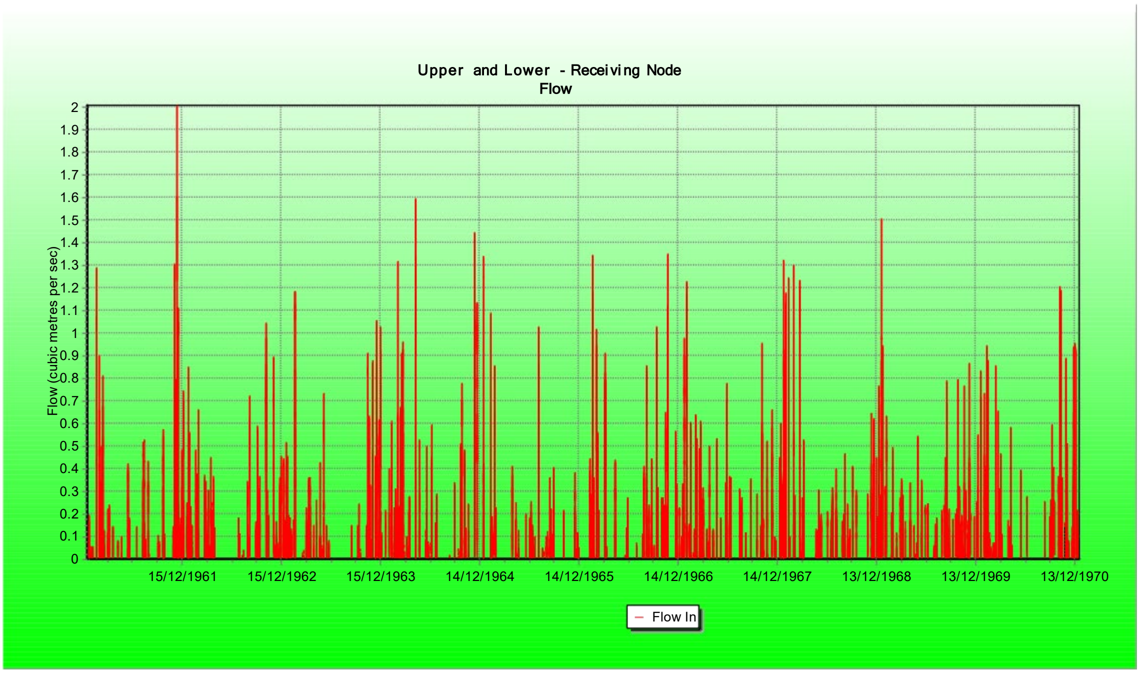


Table 22. MUSIC - 6 Minute Flow Hydrograph

Chapter 5 Comparisons and Discussion

5.1 Introduction

In this chapter the results of the modelling scenarios from both DRAINS and MUSIC will discussed. An assessment into the validity of the one third rule was discussed using both the DRAINS and MUSIC results. An assessment into the capability of MUSIC in being able to conceptually model detention at a conceptual level will also be discussed.

Then a discussion about what further research could be done to build on the findings of this research project was provided. This discussion will also include what further research is needed to validate and confirm the results obtained.

5.2 One-third Rule Effectiveness

The DRAINS results was analysed first. 2 rainfall frequencies were analysed, the major and minor storm events. These were selected because these are the storm events that drainage infrastructure design is based on and are the most appropriate for this analysis.

Table 13 demonstrates that for all the minor storm (0.5 EY) durations and frequencies the most effective scenario in reducing peak discharge to the downstream waterway is when all 3 catchments are provided with individual detention basins. Table 23 shows the percentage difference in peak flow compared to when all catchments are attenuated in the 0.5 EY storm event. The one third rule was the next best performer to the all catchments attenuated.

Table 13 also shows that the attenuation scenario that achieved the lowest reduction in peak flows was when only the lower catchment was provided with detention. Although when compared to providing no detention throughout the catchment it still reduces the peak discharge by approximately 27%.

0.5 EY AEP - Storm Event Peak Discharge to Waterway % difference to All attenuated (m^3/s)						
Model Scenario	10 min burst	20 min burst	30 min burst	1-hour burst	2-hour burst	3-hour burst
Upper and Middle Catchment	125	154	90	62	66	74

Table 23. DRAINS - 0.5 EY one third rule effectiveness

Table 16 demonstrates that for all the major storm (1% AEP) durations and frequencies the most effective scenario in reducing peak discharge to the downstream waterway is when all 3 catchments are provided with individual detention basins. This scenario achieved non-worsening for all 6 storm durations. The one third rule scenario achieved non-worsening for 4 out of the 6 storm durations. Table 24 shows the percentage difference in peak flow compared to when all catchments are attenuated in the 1% AEP storm event. The one third rule scenario outperformed the all attenuated scenario in 3 out of the 6 storm durations but only by a small percentage.

Table 16 also shows that the attenuation scenario that achieved the lowest reduction in peak flows was when only the lower catchment was provided with detention. Although when compared to providing no detention throughout the catchment it still reduces the peak discharge by approximately 29%.

1% AEP - Storm Event Peak Discharge to Waterway % difference to All attenuated (m^3/s)						
Model Scenario	10 min burst	20 min burst	30 min burst	1-hour burst	2-hour burst	3-hour burst
Upper and Middle Catchment	323	122	-11	-4	-5	6

Table 24. DRAINS - 1% AEP one third rule effectiveness

It has been demonstrated that with the given catchment, soil and rainfall parameters set in the drainage system and the hypothetical catchment within DRAINS that when all catchments are provided with detention basins it is the most effective scenario. That is, it reduces the peak flow by a greater quantity and frequency than any other scenario. This is especially true for higher frequency and lower duration storm events. The one third rule is effective in low frequency and longer duration storm events. When only the lower third of the catchment is provided with detention the effectiveness of the basin is the lowest out of all the detention scenarios. Although the peak flows are the highest when the lower third catchment is attenuated it provides a reduction of approximately 30% when compared to providing no detention at all.

The DRAINS model although being able to be easily replicated to the other 2 catchments was very time consuming. The drainage system was at a level of design that could be submitted to council for assessment at the construction stage of documentation. The DRAINS results provided therefore, are considered to be very accurate and reliable.

The continuous rainfall event that MUSIC analyses for modelling was the basis of the analysis. Table 19 demonstrates that the most effective scenario in reducing peak discharge to the downstream waterway is when the Upper and Middle catchments (one third rule) are provided with individual detention basins. The next best performer was when all catchments are attenuated.

Table 19 also shows that the attenuation scenario that achieved the lowest reduction in peak flows was when only the lower catchment was provided with detention. When compared to providing no detention throughout the catchment it reduces the peak discharge by only approximately 1%.

It has been demonstrated that with the given catchment and rainfall parameters set in the hypothetical catchment within MUSIC that when the Upper and Middle catchments are provided with detention basins it is the most effective scenario. That is, it reduces the peak flow by a greater quantity and frequency than any other scenario. When only the lower third of the catchment is provided with detention the effectiveness of the basin is the lowest out of all the detention scenarios. Although the peak flows are the highest when the lower third catchment is attenuated it provides a reduction of approximately 1% when compared to providing no detention at all.

The MUSIC model was relatively quick and easy to setup. However, there were a lot of parameters that were left at their default settings. The only parameters that were changed were as recommended by the MUSIC modelling Guidelines (Water by Design, 2010). The drainage system was non-existent with the source nodes or catchments only linked by a very basic routing time that was only roughly estimated. The design was very conceptual, and the MUSIC results provided therefore, are considered to be conceptual only and not appropriate for detailed design.

The results between the DRAINS and MUSIC models as presented are not comparable. The MUSIC peak flow results are simply the maximum flow experienced at the discharge point between the years 1961 and 1970. The maximum flow is recorded over a time step interval of 6 minutes. The DRAINS peak flow results are an event result based on a particular storm even frequency and duration and much different to that of the MUSIC software. Therefore, in their simplest form they are not comparable.

5.3 MUSIC Capabilities

As mentioned previously the MUSIC results in their simple form are not comparable to the hydrology and hydraulic capabilities of DRAINS. However, the results of the peak discharge across the different modelling scenarios indicated a similar trend, refer Table 25.

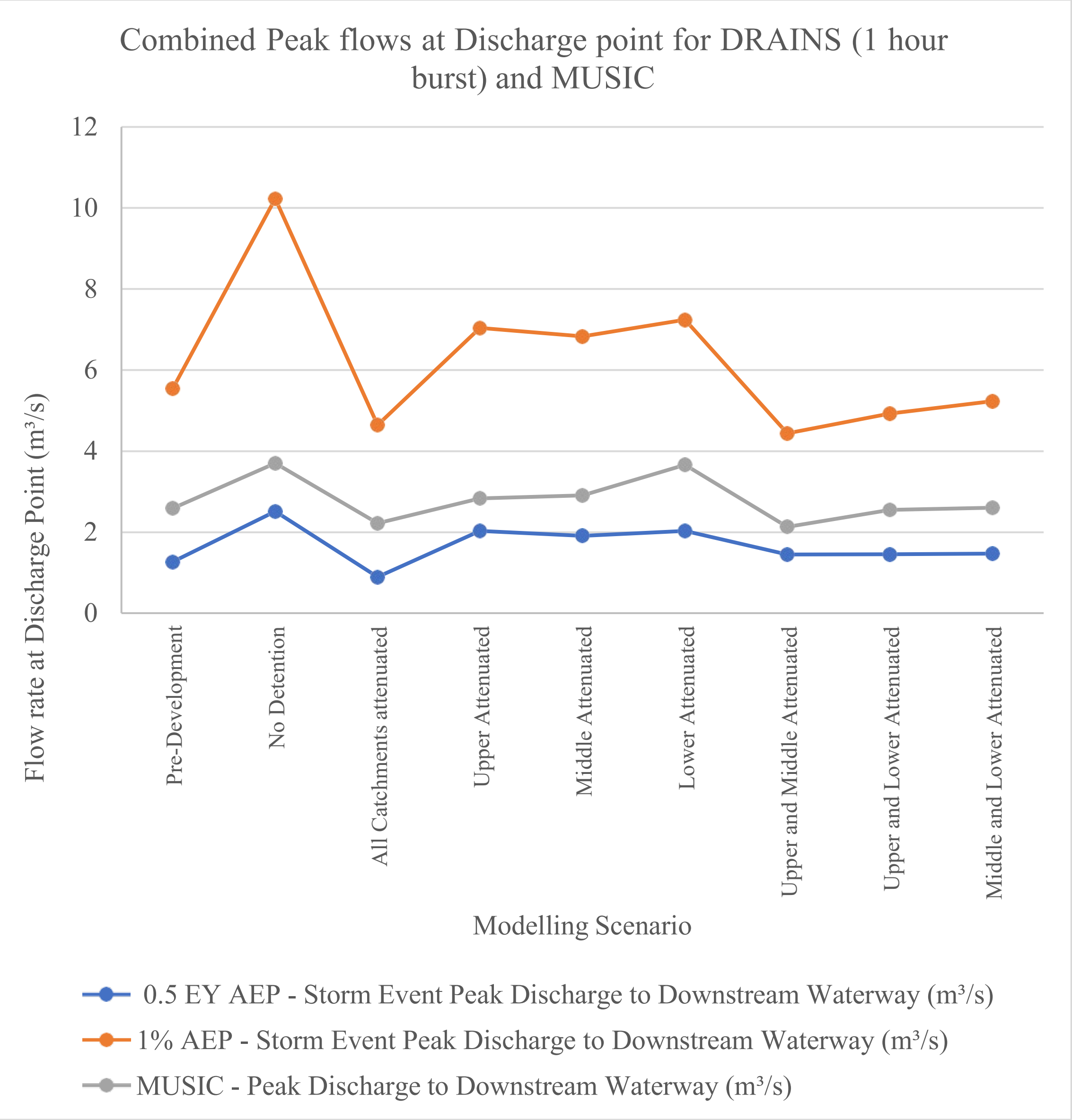


Table 25. Combined peak flows at Discharge point for DRAINS (1-hour burst) and MUSIC

This indicates the MUSIC clearly follows the trends of DRAINS. The real difference is just the peak flow values. If the rainfall data of MUSIC could be compared to the rainfall data of DRAINS, then it is possible that MUSIC could be reasonably accurate. The larger storm events within the continuous rainfall data would need to be calibrated against the rainfall data that is input into DRAINS. The single storm events may be able to be found within the continuous rainfall data.

The timeframe of the continuous rainfall data may not have included a 1% AEP single event. It is likely the peak flow result in MUSIC occurred at a storm frequency in somewhere in between the 0.5 EY and 1% AEP. The peak flow found in MUSIC could be validated against a single storm event in DRAINS by modelling different storm frequencies and durations within DRAINS until a close match was obtained. Alternatively, the range of continuous rainfall could need to be broadened to include the maximum amount of time and therefore include the maximum number of single storm events possible. The peak storm events in MUSIC could then be compared to the single storm events in DRAINS and validated. Once validated the dates of the single events could be used to specifically analyse a particular storm frequency and duration within MUSIC, which it is not currently able to do.

5.4 Further Research

The results obtained are for a single hypothetical catchment. The one third rule does have some validity which could be found to have a greater impact in other catchments. The research could be expanded to include a range of differing catchment sizes and shapes with differing catchment surfaces and impervious surface ratios. The parameters that could be changed within a hypothetical catchment are very numerous a could be further explored at length.

A more relevant and preferred option for further research would be to investigate a real catchment. Due to time constraints that wasn’t able to be done in this research. The parameters are then limited the real-world situation and the results therefore can be manipulated as they can with a hypothetical catchment.

Further research into the capabilities of MUSIC could be undertaken. This research only scratched the surface of what MUSIC is capable of. The peak flow trends demonstrate that with further manipulation of the results something comparable to DRAINS could be obtained.

The rainfall data between the continuous storm events that MUSIC utilises and the single storm events that DRAINS utilises can be researched further to narrow down the timeframes and storm events that closely compare to each other. If this is achievable then MUSIC could perhaps be utilised further.

Further research into what the effect the different modelling scenarios have on stormwater quality needs to be undertaken. There was not enough time available to include this part of the research in this dissertation.

Chapter 6 Conclusions and Recommendations

6.1 Conclusions

The purpose of this research was to review the stormwater runoff routing modelling and WSUD modelling software packages available and investigate what effects varying the detention between 3 equal sub catchments within a single larger catchment. In particular, the one-third rule was to be analysed within the software packages and compare the peak flows in comparison to the different modelling scenarios and then compare the peak flows in comparison to each of the software packages.

The investigation was completed within a hypothetical catchment in the Toowoomba, QLD area where instances of the one third rule being applied had been observed.

The research demonstrated that the most appropriate detention scenario is to provide all sub catchments with detention basins. This ensures that peak pre-development discharge rates to downstream waterways are not exceeded once the catchment is developed. The research also confirmed that in some circumstance's detention within the lower third of a catchment does not have to be provided to ensure a non-worsening a peak discharge to downstream waterways. For this particular catchment the one third rule does not aggravate peak flows or coincide with upstream peak flows to a degree that creates a worsening effect. The research shows that detention within the lower third of a catchment may not be required. There is little to no benefit in some circumstances to provide detention within the lower third of a catchment. This has the potential of saving developers time and money by reducing design costs and construction costs.

The research showed the MUSIC has the potential to conceptually model detention scenarios. Although further research needs to be undertaken to confirm if it is possible as this research was not able to definitively determine this aspect. MUSIC does not have the capability of designing drainage systems and therefore it is very limited as to what functions it is able to perform.

6.2 Recommendations

The implementation of the one third rule should not be adopted without catchment wide analysis. This is a common recommendation of similar reports and technical stormwater documents and guidelines. It is a common statement because it is a very valid one that applies to a wide range of areas. Although this is time consuming and what one person or department deem to be a sensitive or critical location may not be shared by other stakeholders. The recommendation would be to tighten up legislation to ensure that all new developments that increase the impervious area are required to provide detention to attenuate the increase in peak flows. This scenario generally provided the largest reductions in peak flows. Developers will then be able to plan and budget for the extra increases in cost. Implementing a clear policy then provides a clear direction for engineers and designers to adhere by and thus creating an even playing field within the industry.

If possible, it would have been beneficial to repeat the same analysis on a real catchment that had similar properties to the hypothetical catchment. This would have provided support to the conclusions obtained in this research.

The use of MUSIC of a conceptual design tool is not recommended. If further research is completed that can link the continuous rainfall data to the single storm event values, then the use of MUSIC as a conceptual may be possible.

Chapter 7 References

12d 2019. *Drainage & Utilities*. [online] Available at: https://www.12d.com/downloads/pdf/12d_Drainage_and_Utilities.pdf [Accessed 15 Oct. 2019].

Australian rainfall and runoff. (2016). Canberra, A.C.T.: Geoscience Australia.

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2019, *Australian Rainfall and Runoff: A Guide to Flood Estimation*, Commonwealth of Australia

Brisbane Times. (2018). *Timeline: how disaster unfolded*. [online] Available at: https://www.brisbanetimes.com.au/national/queensland/timeline-how-disaster-unfolded-20120106-1poia.html [Accessed 21 Oct. 2018].

Bureau of Meteorology 2019. *Frequently asked questions: Intensity–Frequency–Duration: Design Rainfalls: Water Information: Bureau of Meteorology*. [online] Available at: http://www.bom.gov.au/water/designRainfalls/ifd/ifd-faq.shtml [Accessed 13 Oct. 2019].

Cook, G. (2015). *On-Site Detention Methods & The Cumulative Effect*. Bachelor of Engineering (Civil). University of Southern Queensland.

Davis, G. (2018). *MUSIC Version 6 Documentation and Help Home - MUSIC Version 6 Documentation and Help - eWater Wiki*. [online] Wiki.ewater.org.au. Available at: https://wiki.ewater.org.au/display/MD6/MUSIC+Version+6+Documentation+and+Help+Home [Accessed 21 Oct. 2018].

Department of Natural Resources and Water, 2016, Queensland Urban Drainage Manual - Fourth Edition 2016, Institute of Public Works Engineering Australasia, Queensland Division

Geoscience Australia 2018. *History - Australian Rainfall and Runoff*. [online] Available at: http://arr.ga.gov.au/about/history [Accessed 21 Oct. 2018].

Innovyze 2019. *Analytical Engine - xpswmm/xpstorm Resource Center - Innovyze Resource Center*. [online] Available at: https://help.innovyze.com/display/xps/Analytical+Engine [Accessed 15 Oct. 2019].

Innovyze 2019. *Stormwater & Wastewater Management Model*. [online] Available at: https://www.innovyze.com/media/2340/product-brochure-xpswmm.pdf [Accessed 15 Oct. 2019].

Maps.tr.qld.gov.au. (2019). *ArcGIS Web Application*. [online] Available at: https://maps.tr.qld.gov.au/WAB/Infra/ [Accessed 12 Oct. 2019].

O'Loughlin, GG and Joliffe, IB. Historical Overview of Urban Stormwater Drainage Hydraulics [online]. In: Conference on Hydraulics in Civil Engineering (3rd:1987: Melbourne, Vic.). Conference on Hydraulics in Civil Engineering 1987: Preprints of Papers. Barton, ACT: Institution of Engineers, Australia, 1987: 82-87. National conference publication (Institution of Engineers, Australia); no. 87/14. Availability: <https://search-informit-com-au.ezproxy.usq.edu.au/documentSummary;dn=526492643084864;res=IELENG> ISBN: 0858253550. [cited 21 Oct 18].

O'Loughlin, G. and Stack, B. (2012). *A manual on the DRAINS program for urban stormwater drainage system design and analysis*. Sydney: Watercom Pty Ltd.

Parliament of Australia 2018. *Chapter 2 – Parliament of Australia*. [online] Available at: https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/Stormwater/Report/c02 [Accessed 21 Oct. 2018].

van der Sterren, M; Rahman, A; Shrestha, S and Thomson, A. *Urban Stormwater Modelling in Australia: Comparison of Three Commercial Software Packages* [online]. In: Lambert, Martin (Editor); Daniell, TM (Editor); Leonard, Michael (Editor). Proceedings of Water Down Under 2008. Modbury, SA: Engineers Australia; Causal Productions, 2008: 375-386. Availability: <https://search-informit-com-au.ezproxy.usq.edu.au/documentSummary;dn=563436138899741;res=IELENG> ISBN: 0858257351. [cited 21 Oct 18].

Water.gov.my. (2018). [online] Available at: https://www.water.gov.my/jps/resources/auto%20download%20images/584646818e9dc.pdf [Accessed 21 Oct. 2018].

Water by Design (2010), *MUSIC modelling Guidelines*. SEQ Healthy Waterways Partnership, Brisbane, Queensland

Witheridge (2013), *A Pictorial Overview of the Queensland Urban Drainage Manual*. Catchments & Creeks Pty Ltd., Brisbane, Queensland

Chapter 8 Appendices

Appendix A – Project Specification

For: Jayden Karaka

Title: Effectiveness of MUSIC software in modelling stormwater attenuation in comparison with DRAINS for the future developed catchment of Drayton, Toowoomba, QLD.

Major: Civil Engineering

Supervisors: Dr. Malcolm Gillies

Enrolment: ENG4111 – EXT S1, 2019
ENG4112 – EXT S2, 2019

Project Aim: Analyse how well MUSIC software can model stormwater attenuation in comparison to DRAINS software. The one-third rule will be analysed and its implications to both stormwater quantity and quality discharge.

Programme: Version 1, 27th April 2019

1. Review the stormwater runoff modelling packages available which might be relevant to developing catchments in the local region
2. Investigate whether DRAINS or MUSIC are used and how they are applied and calibrated in local catchments.
3. Identify and select the undeveloped catchment and visit site for suitability of modelling.
4. Design a basic stormwater system that could service the catchment in the future once developed and identify node locations for the assessment of attenuation at different levels of the catchment.
5. Apply both the DRAINS and MUSIC models to evaluate the effectiveness of the stormwater attenuation system, while attempting to keep input parameters as close as possible in order to enable comparison of the models.
6. Compare the results in regard to stormwater attenuation for the different scenarios and evaluate the effectiveness of the one third rule.
7. Compare the results in regard to the effectiveness of MUSIC modelling stormwater attenuation in comparison to DRAINS.
8. Make recommendations on the use of MUSIC for stormwater attenuation analysis.

   If time and resources permit:
9. Compare the results in regard to stormwater quality for the different scenarios and what effects the one third rule has on quality.
10. Make recommendations on stormwater design for the catchment area investigated.

Appendix B – Resource requirements

Resource Item	Quantity	Source	Cost
PC with Microsoft Windows	2	Personal and LPCE	$0
Word & Excel	1	Personal and LPCE	$0 (personal and LPCE)
DRAINS	1	Personal and LPCE	$0 (LPCE)
MUSIC	1	Personal and LPCE	$0 (LPCE)
Internet Access	2	Personal and LPCE	$50 monthly for home use
USB backup	2	Personal	$50
Vehicle	1	Current	Utilise existing $20 petrol
PPE	Hat, Steel Caps, High Vis, Sunscreen	Personal and LPCE	$0 (personal and LPCE)
Time	350 hours	Personal	Priceless

Figure 17. Resource Requirements

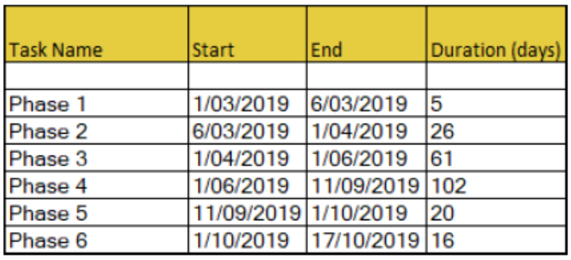
Appendix C –Timeline and Schedule

The current timeline to undertake the research project as part of ENG4111 (Research Project 1) and ENG4112 (Research Project 2) and ENG4903 (Professional Practice 2) in 2019. Semester 1 of 2019 doesn't officially start until the 25th of February with the project topic allocation being required by the end of week 1. It is therefore paramount that the project topic and allocation be undertaken well before and even decided upon by the end of 2018. The research project has been split into different phases and summarised below.

Phase 1	Preparation Phase
1A	Be allocated to a supervisor
1B	Obtain approval from supervisor on topic and commence research project
1C	Procure resources and ensure access to the latest software packages is available and up to date. Ensure compatibility between personal and LPCE computers and storage devices.
Phase 2	Formulation of Catchment Parameters Phase
2A	Access online topography and mapping data to investigate extent of real world catchment
2B	Confirm suitability of catchment with a site visit identifying any issues and future locations of potential detention basin sites
2C	Access TRC planning scheme and identify any future plans for the area and establish future catchment characteristics
2D	Estimate future development extent of roads and flow networks and draw concept design in Autocad
Phase 3	Modelling using DRAINS Phase
3A	Enter catchments parameters from phase 2 into a new DRAINS/ILSAX model
3B	Forumlate concept stormwater infrastructure including roads and drainage structures and utilise DRAINS design function to select pipe sizes etc and then optomize the layout
3C	Implement the detention tanks into the catchment roughly a locations to split it into thirds i.e top third, middle third and lower third of the catchment
3D	Run the model with different detention arrangements as explained in the methodology and collate and compate the outlet hydrographs briefly
Phase 4	Modelling using MUSIC Phase
4A	Enter catchments parameters from phase 2 into a new MUSIC model

4B	Utilise the layout adopted in the DRAINS model
4C	Implement the detention tanks into the catchment roughly a locations to split it into thirds i.e top third, middle third and lower third of the catchment
Phase 5	Data Analysis Phase
5A	Fully realise the differences in software outputs and compare
5B	Create excel worksheets or similar to correlate results
5C	Compare the level of attentuation and the outlet results
5D	Investigation into application of results
Phase 6	Presentation Phase
6A	Prepare and submit draft dissertation to supervisor
6B	Further develop results and present research for ENG4903
6C	Finalise and submit completed research project

Figure 18. Planning Phase



Task Name	Start	End	Duration (days)
Phase 1	1/03/2019	6/03/2019	5
Phase 2	6/03/2019	1/04/2019	26
Phase 3	1/04/2019	1/06/2019	61
Phase 4	1/06/2019	11/09/2019	102
Phase 5	11/09/2019	1/10/2019	20
Phase 6	1/10/2019	17/10/2019	16

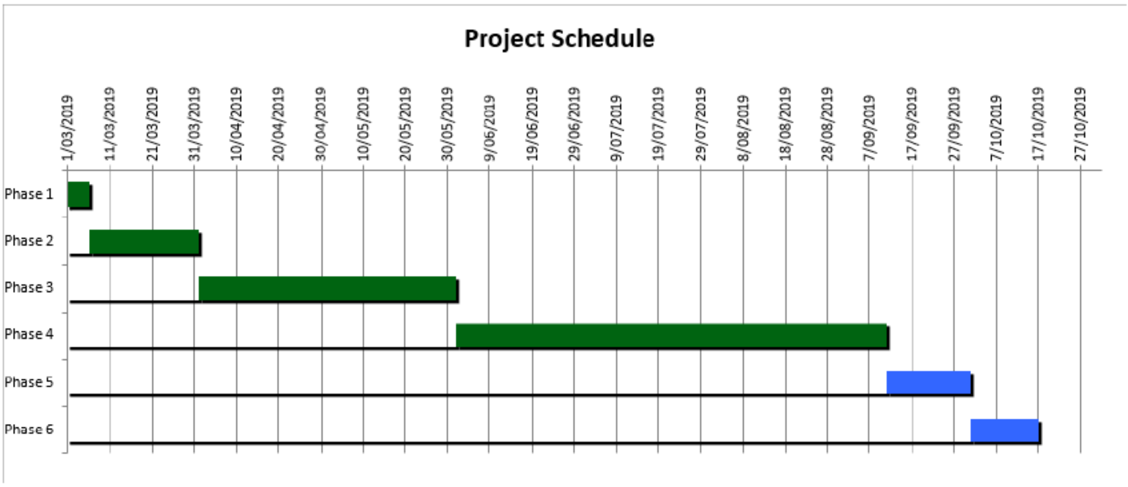


Figure 19. Project Schedule

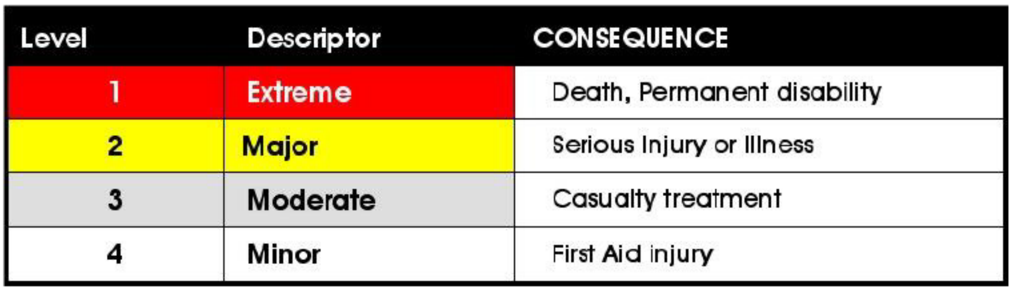
Appendix D – Risk Assessment

A Risk assessment table has been provided below.

What is the "LIKELIHOOD" of the incident occurring?

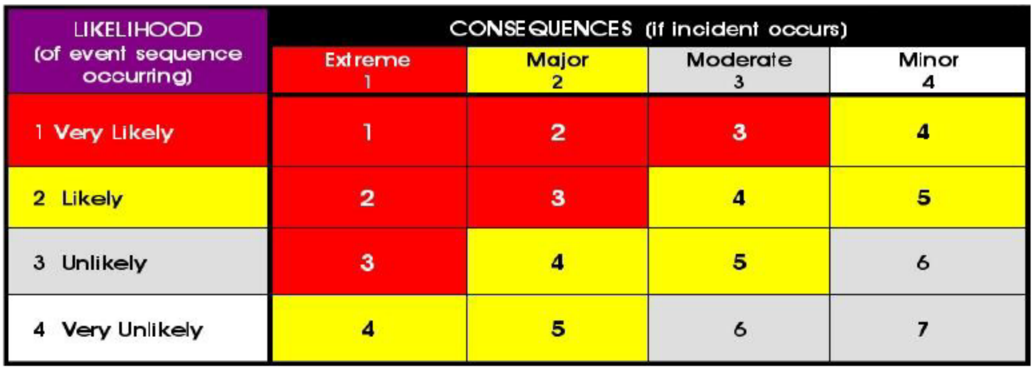
Level	Descriptor	LIKELIHOOD
1	Very Likely	Could happen Frequently
2	Likely	Could happen Occasionally
3	Unlikely	The event could happen, but Rarely.
4	Very Unlikely	The event could happen, but probably never will.

what would be the "CONSEQUENCES" if the incident occurred?

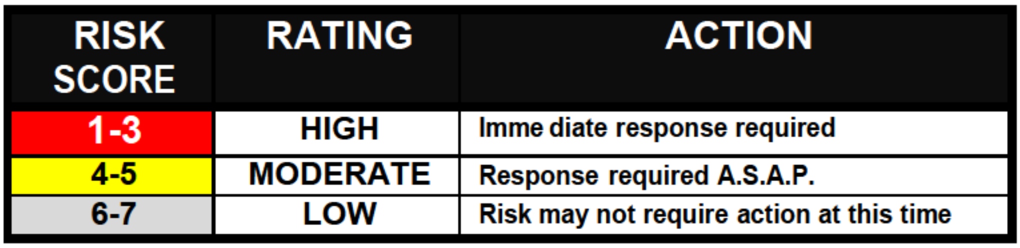


Level	Descriptor	CONSEQUENCE
1	Extreme	Death, Permanent disability
2	Major	Serious Injury or Illness
3	Moderate	Casualty treatment
4	Minor	First Aid injury

Risk Score calculator



LIKELIHOOD (of event sequence occurring)	CONSEQUENCES (if incident occurs)			
	Extreme 1	Major 2	Moderate 3	Minor 4
1 Very Likely	1	2	3	4
2 Likely	2	3	4	5
3 Unlikely	3	4	5	6
4 Very Unlikely	4	5	6	7



RISK SCORE	RATING	ACTION
1-3	HIGH	Imme diate response required
4-5	MODERATE	Response required A.S.A.P.
6-7	LOW	Risk may not require action at this time

Task Break the whole job down into steps.	**Risk Before Control Measure**	**Control Measures** What you are going to do to make the job as safe as possible.	**Risk After Control Measure**
Approval from supervisor not granted	2	Select and approach supervisor in 2018 and discuss project proposal and make any necessary adjustments early 2019 or late 2018	5
Latest software packages not up to date or issues with licensing	4	From this point forward ensure the software license are kept up to date	7
Online mapping data and topography is no longer unavailable	5	Research alternative online resources or even approach TRC directly for any hard copy mapping etc	6
No suitable catchment located within the Drayton area or the catchment parameters are far too difficult to model in time	2	Preliminary site visits required prior to submission of topic allocation. Site visiting should be undertaken as soon as possible during typical daily routines i.e. travel to and from work is not too far out of the way	5
Incorrect data entered into software	2	Undertake model review and possibly request a peer or mentor at LPCE to check modelling	6
Injury at site visits	1	Ensure all PPE equipment is worn. Do not access private property. Do not attend site in bad or unsafe weather or inappropriate times such as at night	6
Loss of data through file corruption or computer malfunction	1	Utilise multiple backup facilities such as workstation at LPCE and dedicated separate hard drive spaces available. Also utilise USB storage devices	6
One of the phases takes longer than anticipated	3	Being modelling as soon as possible. Scope of research may need to narrow to suit time available	5

Table 26. Risk Assessment

Appendix E – DRAINS model – Lower Catchment Only

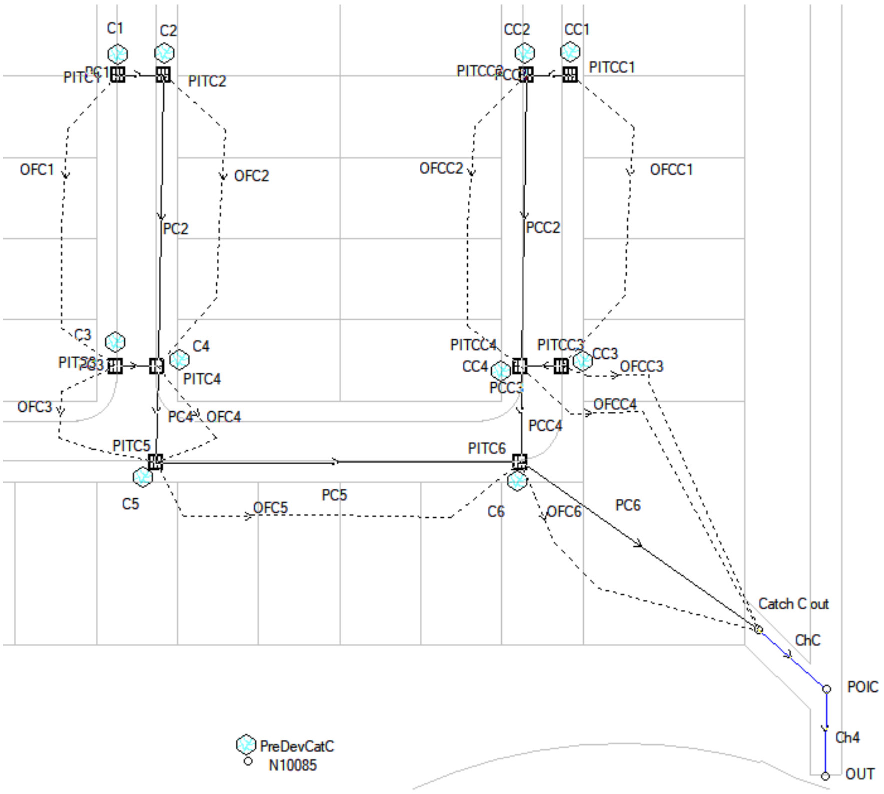


Figure 20. Lower Catchment DRAINS layout – unmitigated

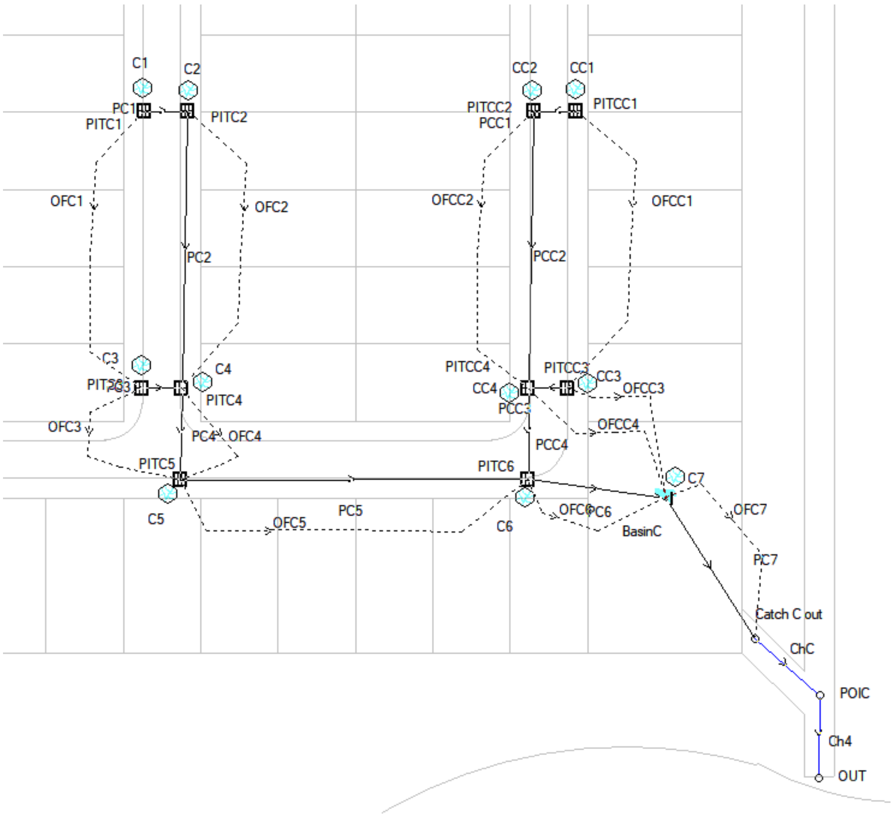


Figure 21. Lower Catchment DRAINS layout – mitigated

Appendix F – DRAINS modelling scenarios

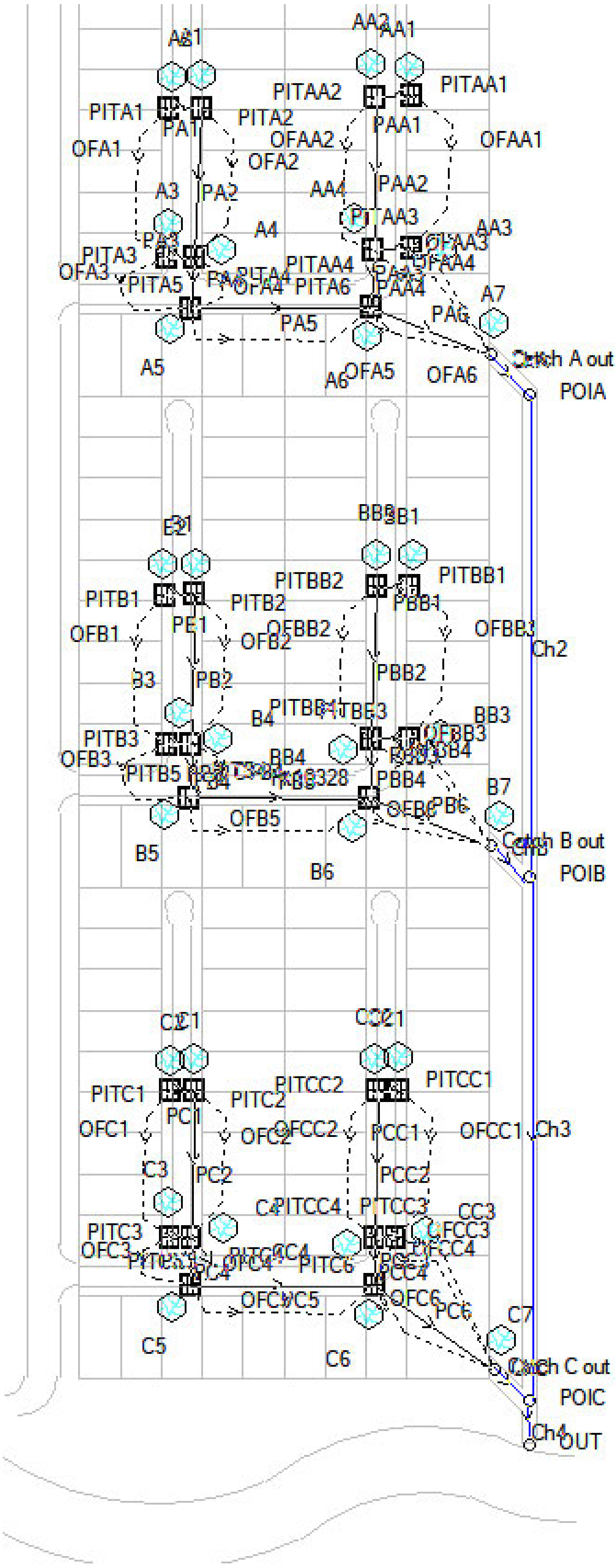


Figure 22. DRAINS model - No detention

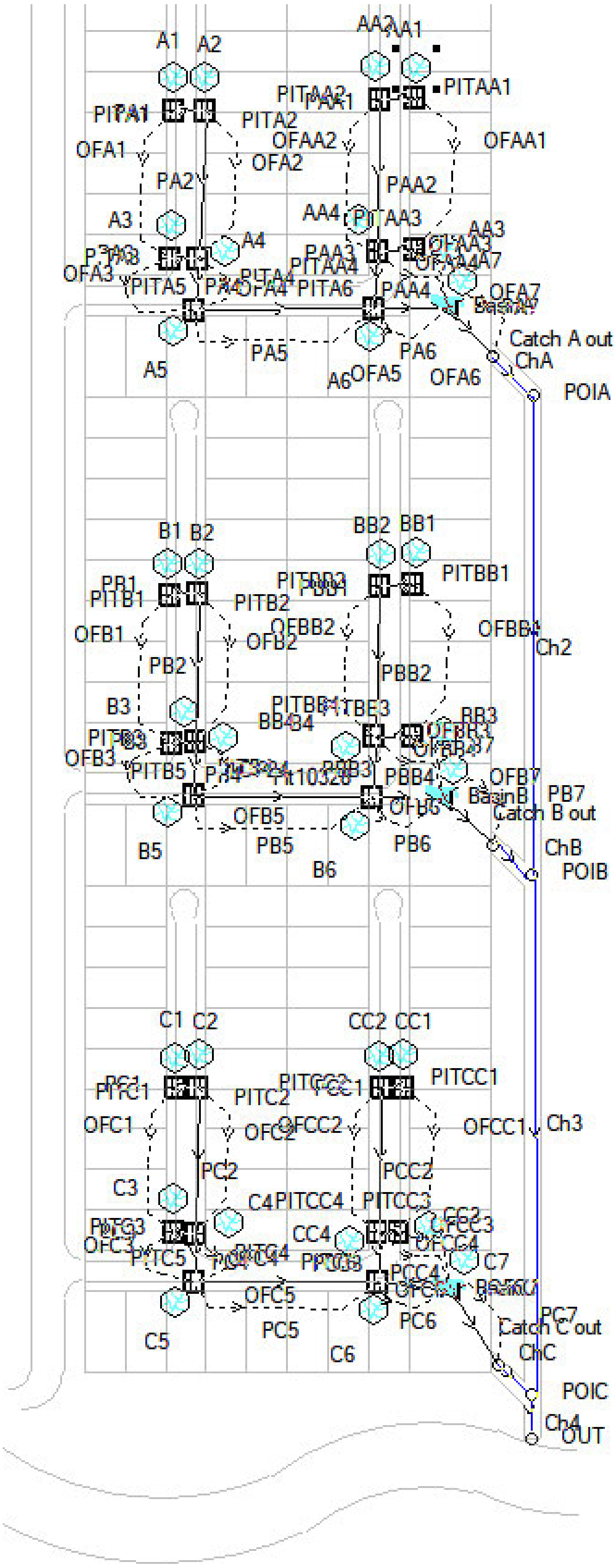


Figure 23. DRAINS model - All attenuated

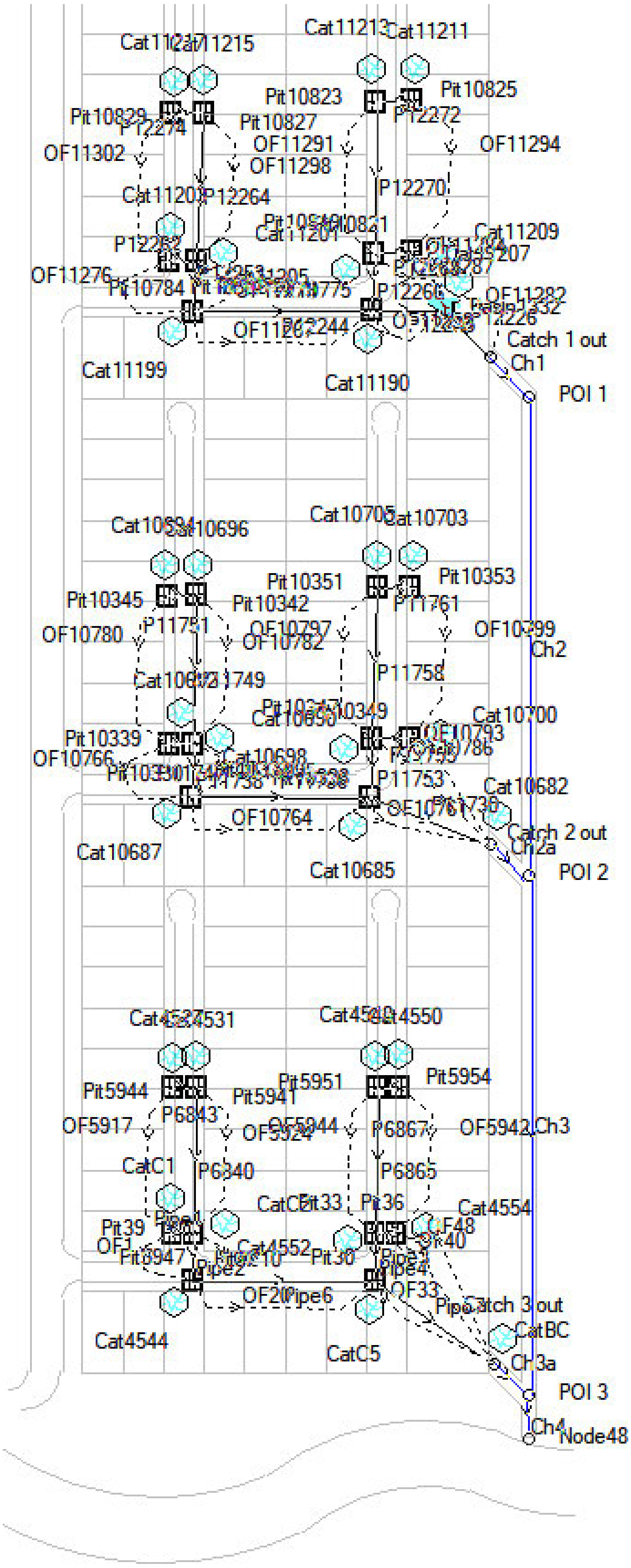


Figure 24. DRAINS model - Upper attenuated

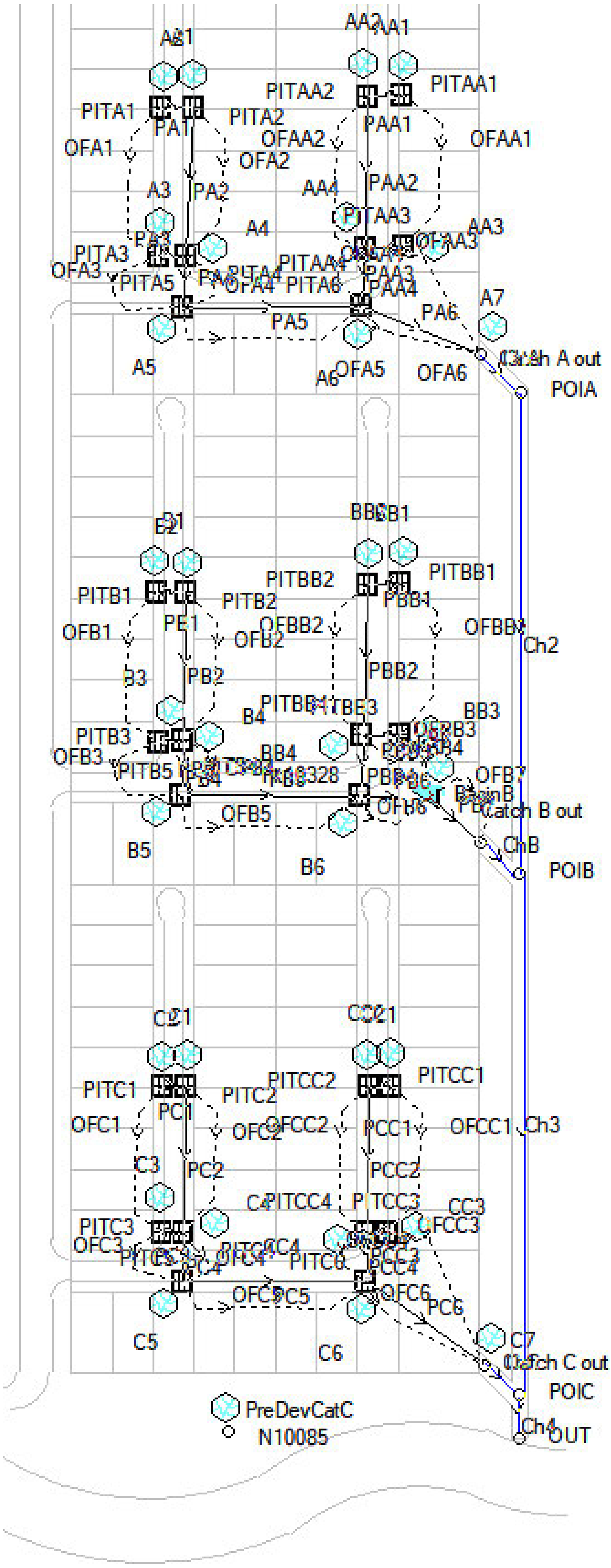


Figure 25. DRAINS model - Middle attenuated

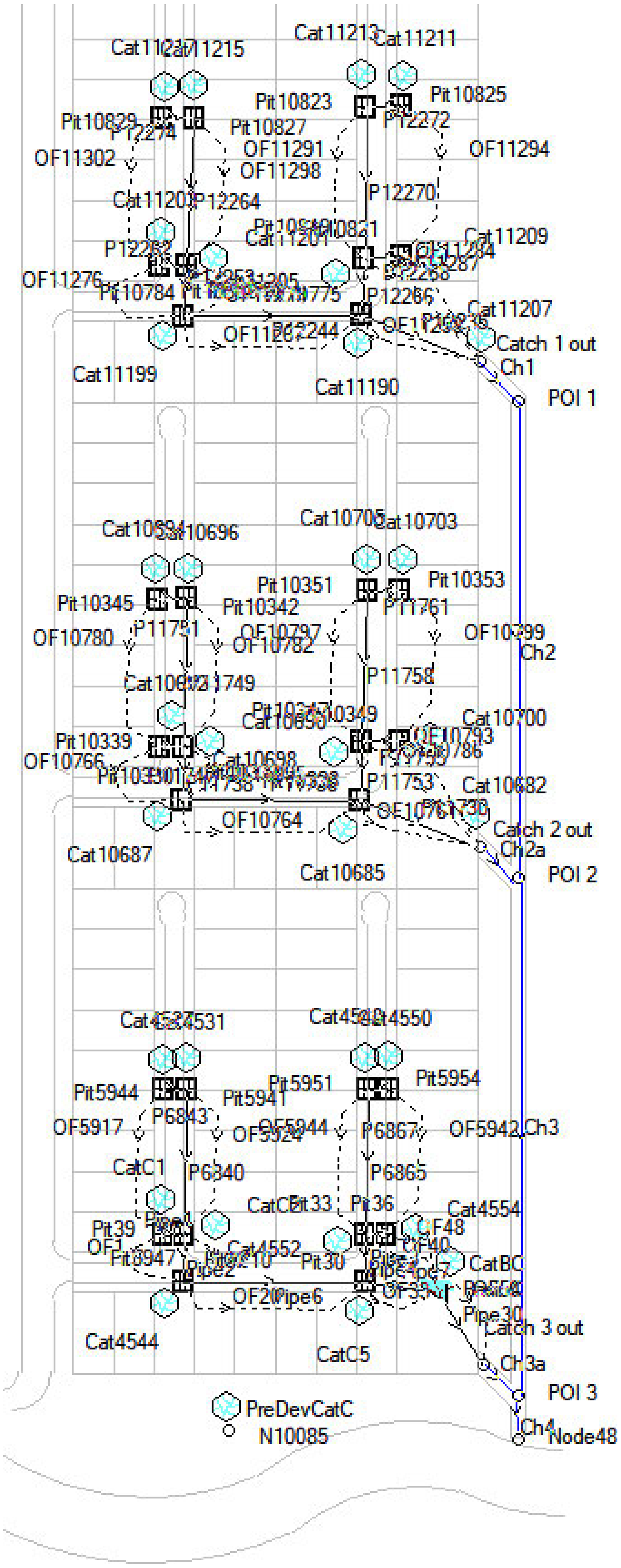


Figure 26. DRAINS model - Lower attenuated

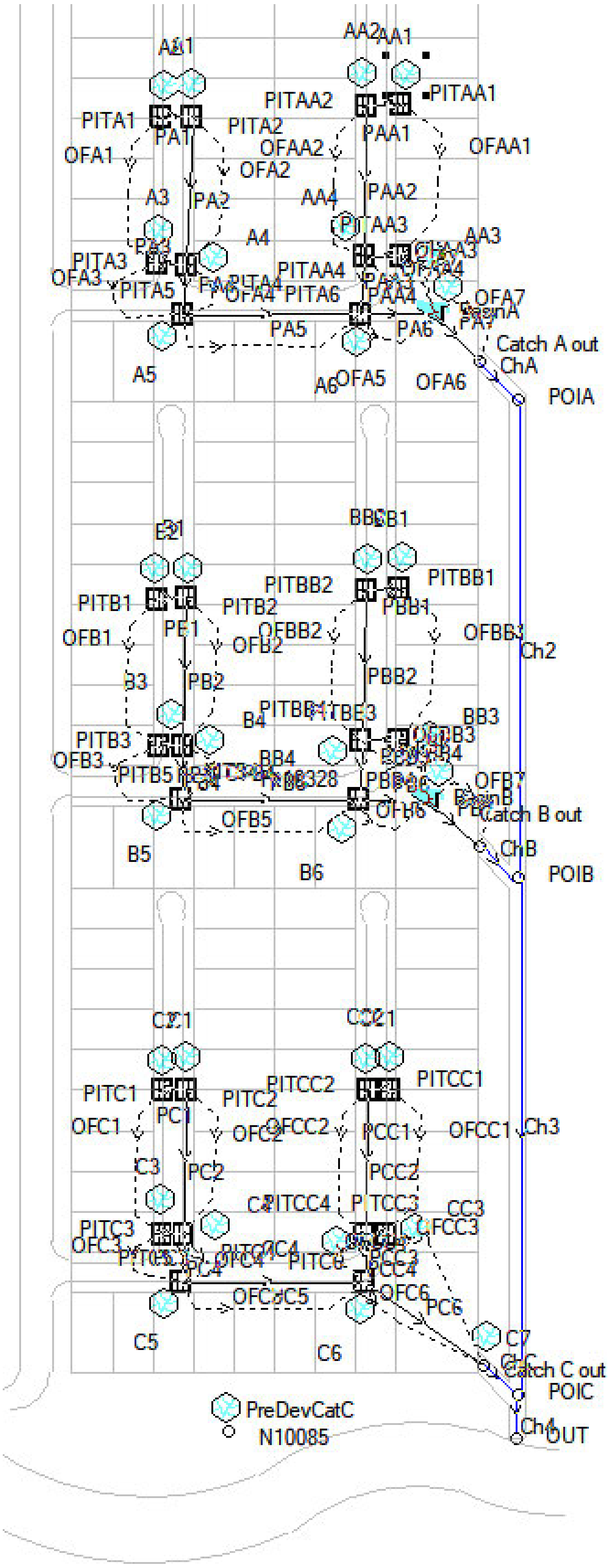


Figure 27. DRAINS model - Upper and Middle attenuated

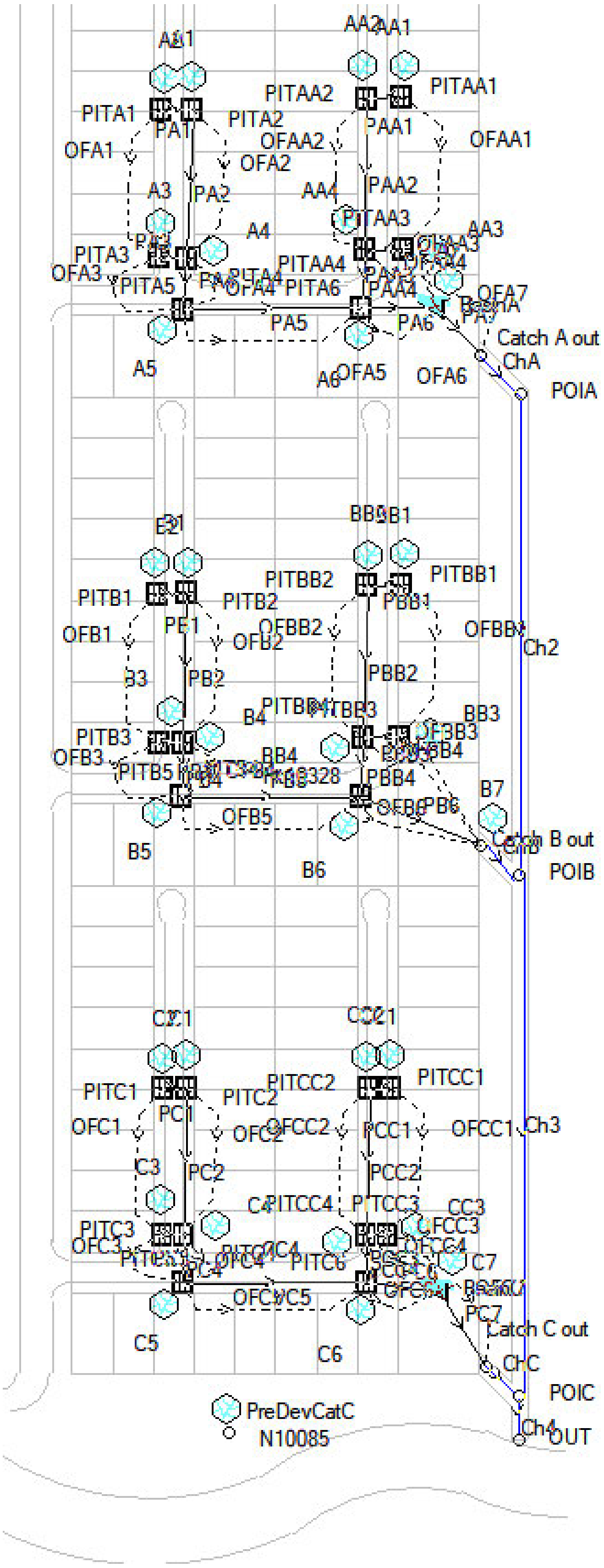


Figure 28. DRAINS model - Upper and Lower attenuated

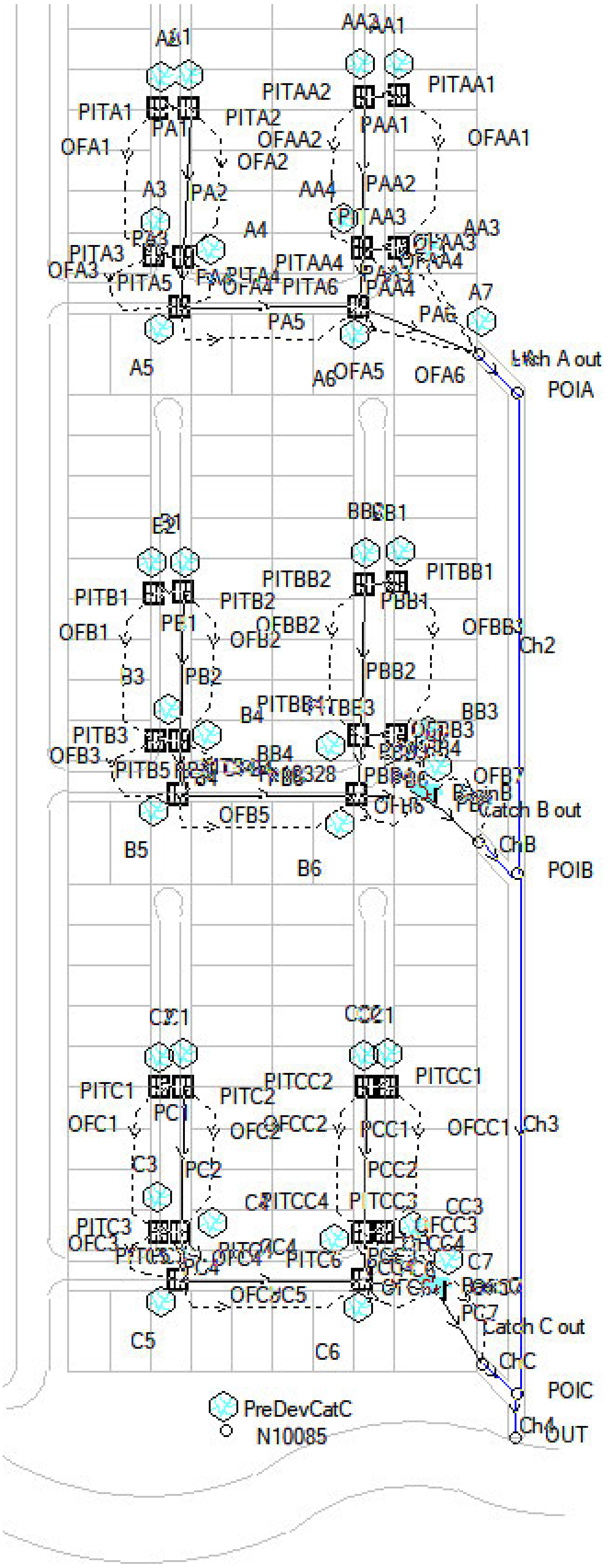


Figure 29. DRAINS model - Middle and Lower attenuated

Appendix G – MUSIC model – Detention basin sizing

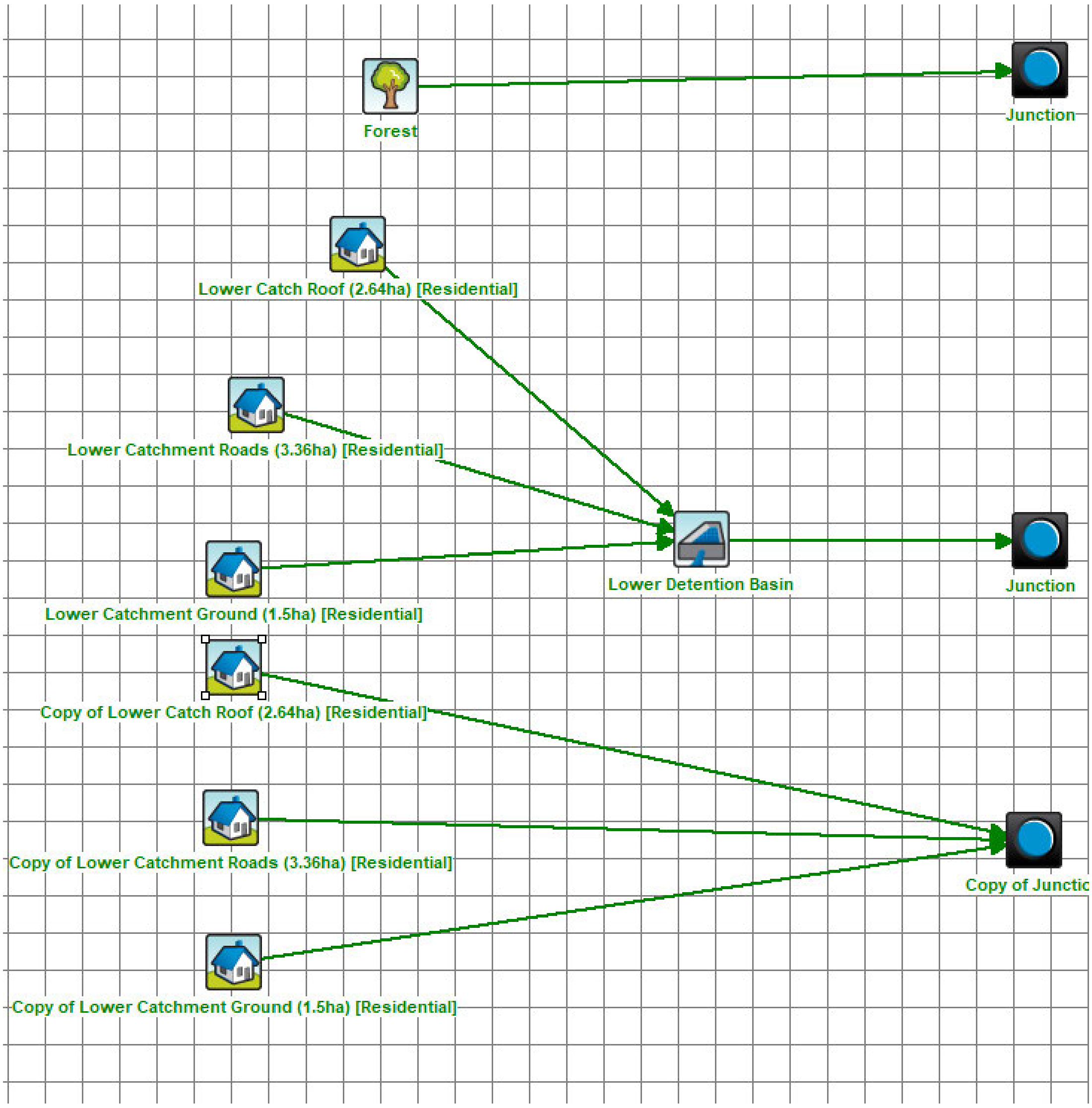


Figure 30. MUSIC model layout for detention basin sizing

Appendix H – MUSIC modelling scenarios

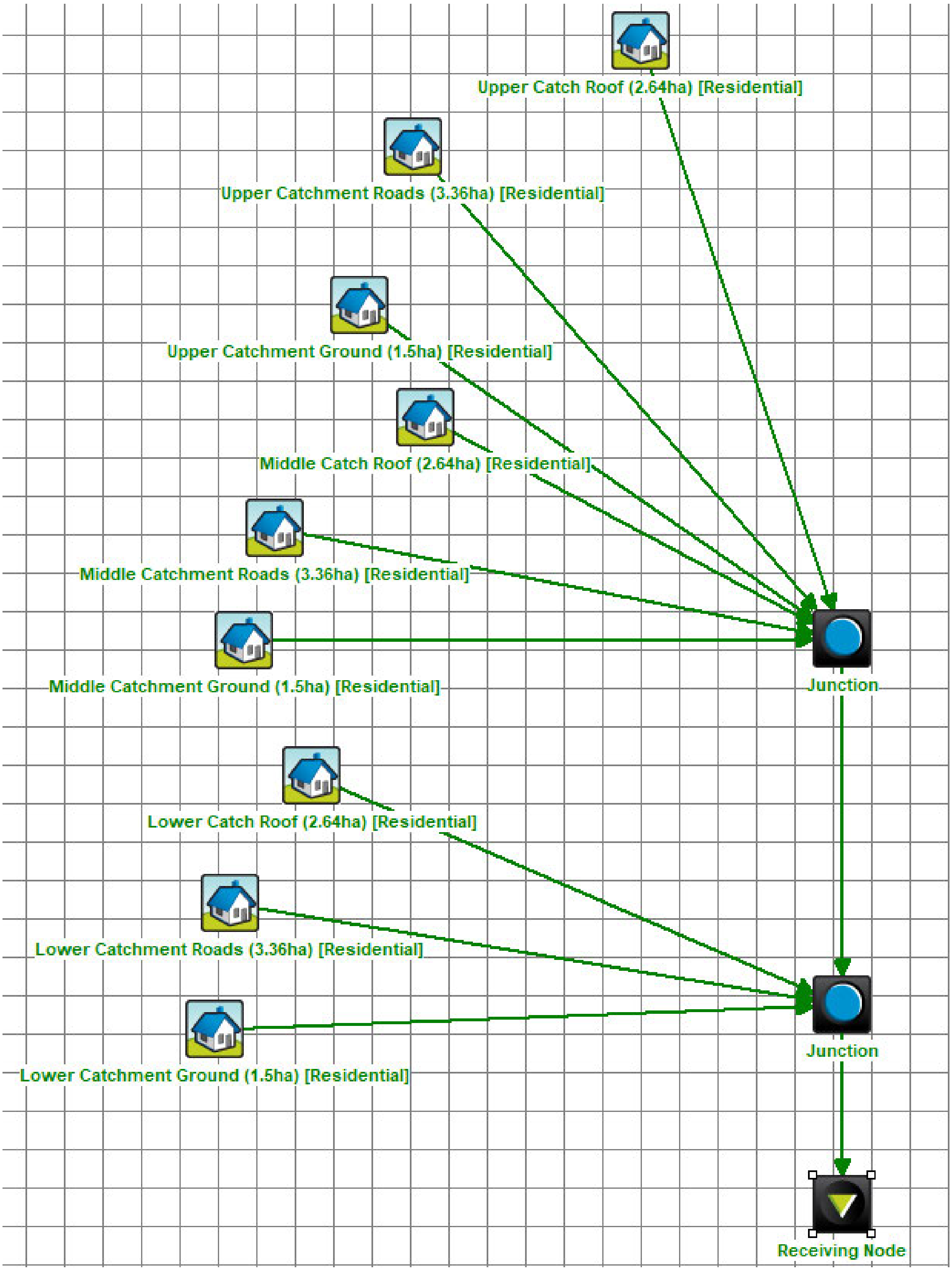


Figure 31. MUSIC model - No detention

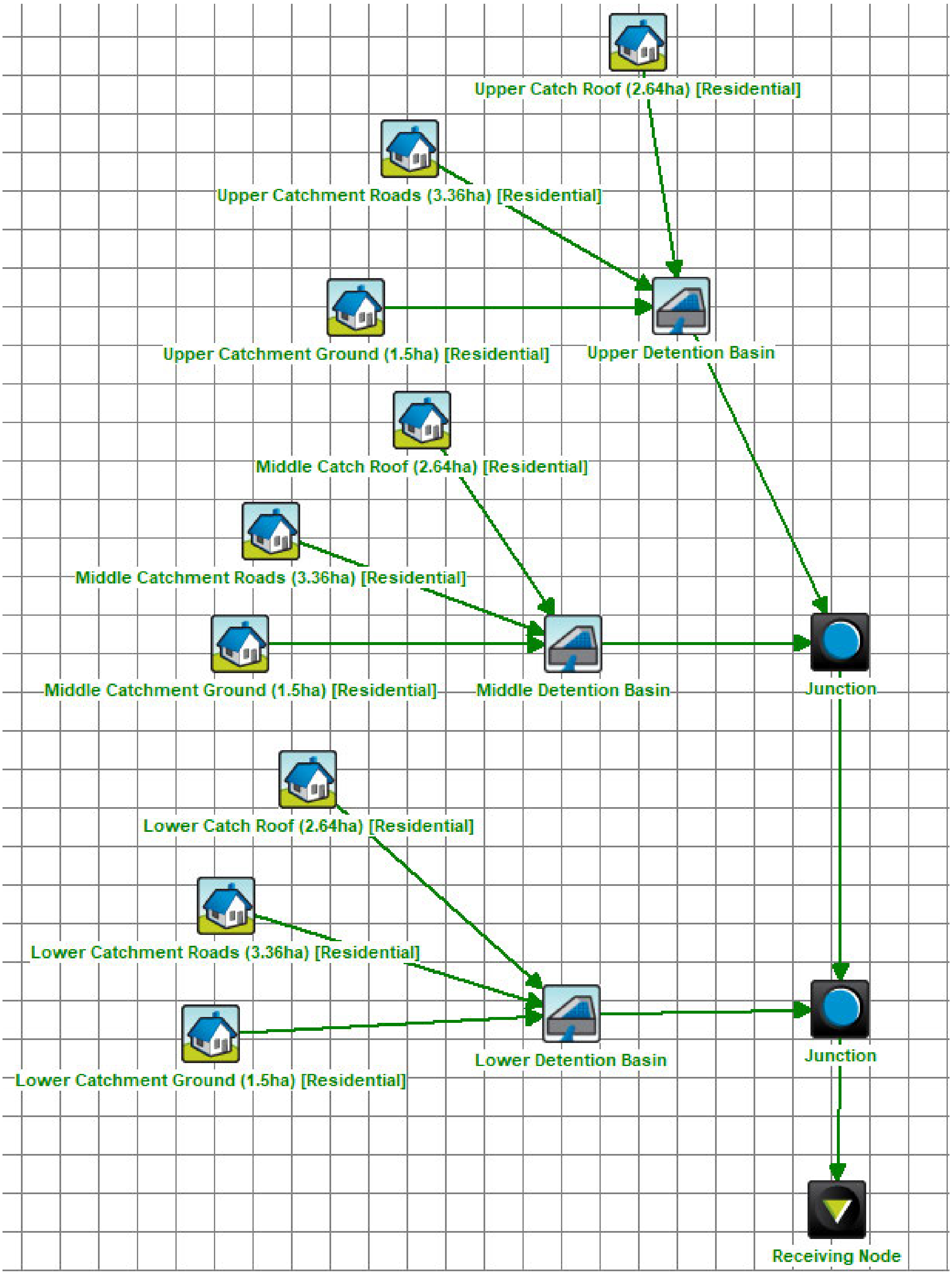


Figure 32. MUSIC model - All attenuated

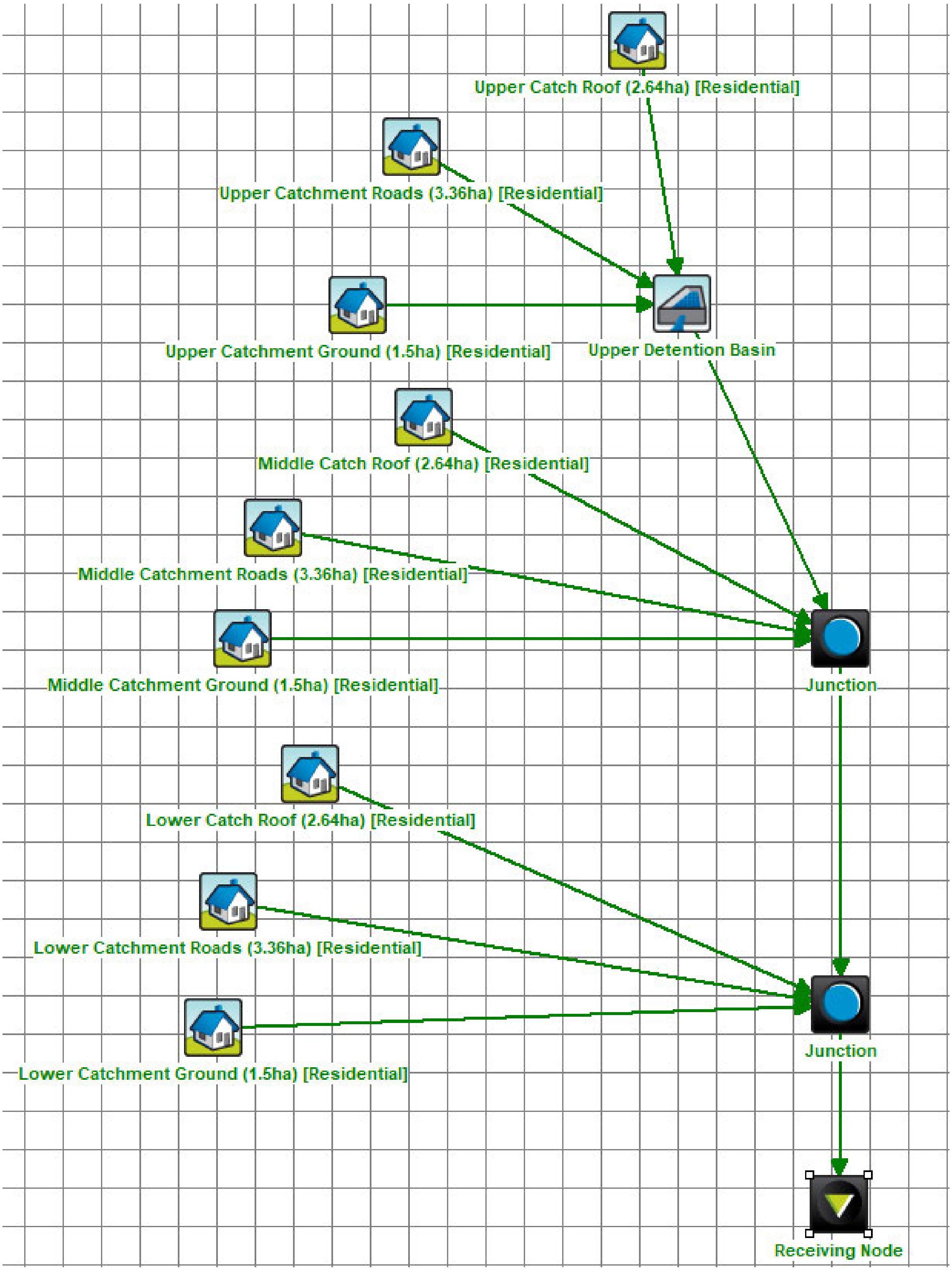


Figure 33. MUSIC model - Upper attenuated

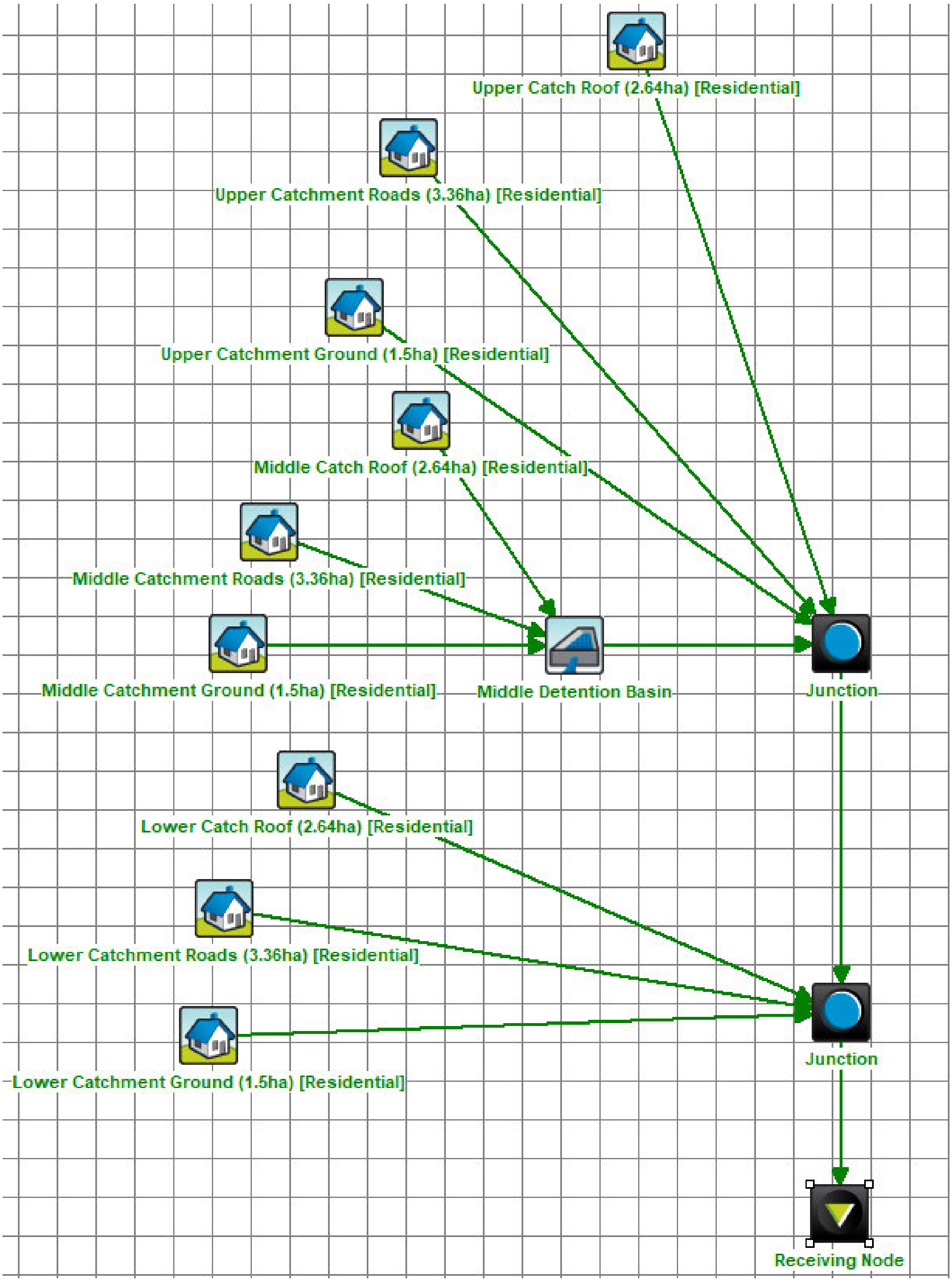


Figure 34. MUSIC model - Middle attenuated

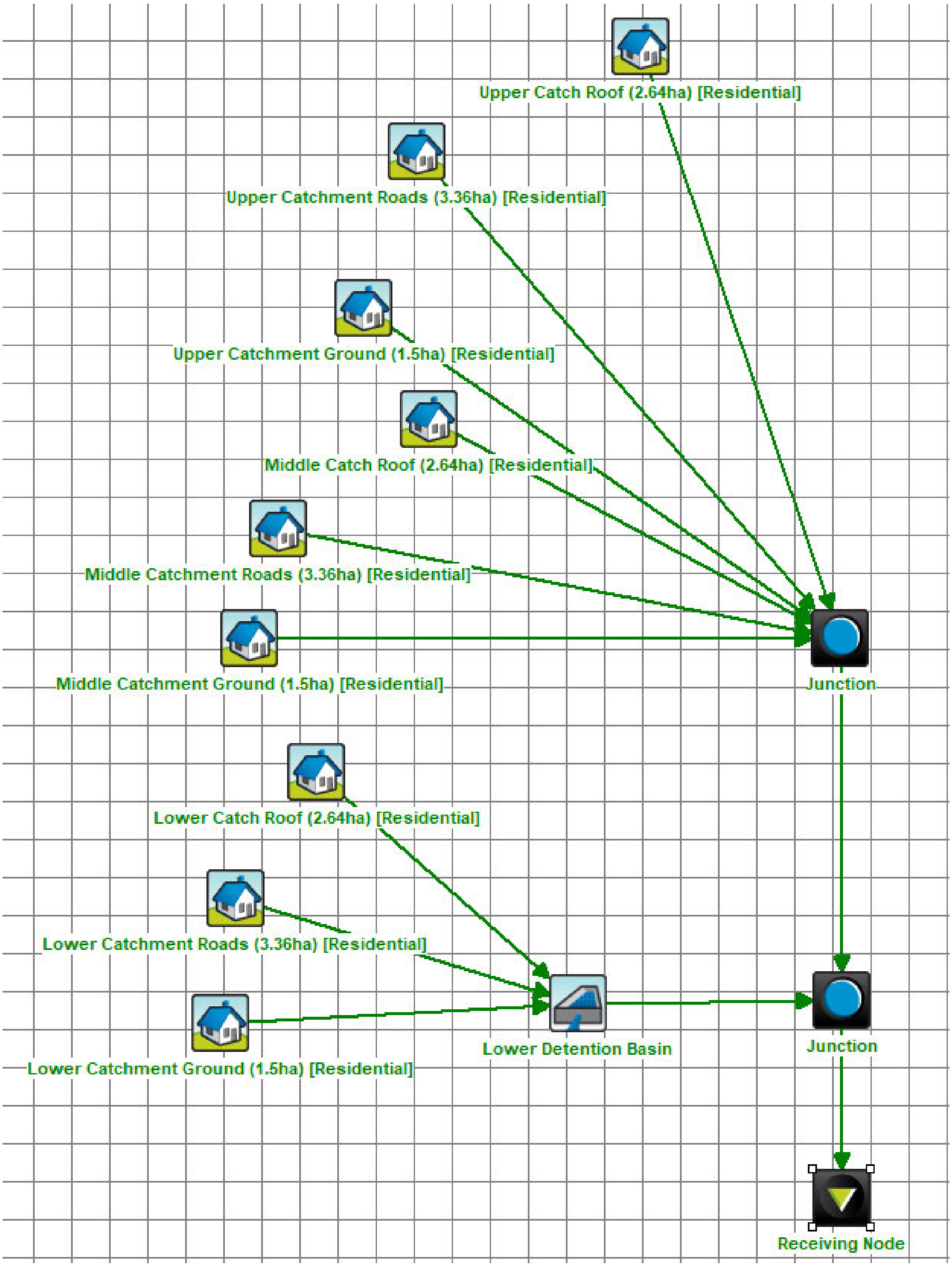


Figure 35. MUSIC model - Lower attenuated

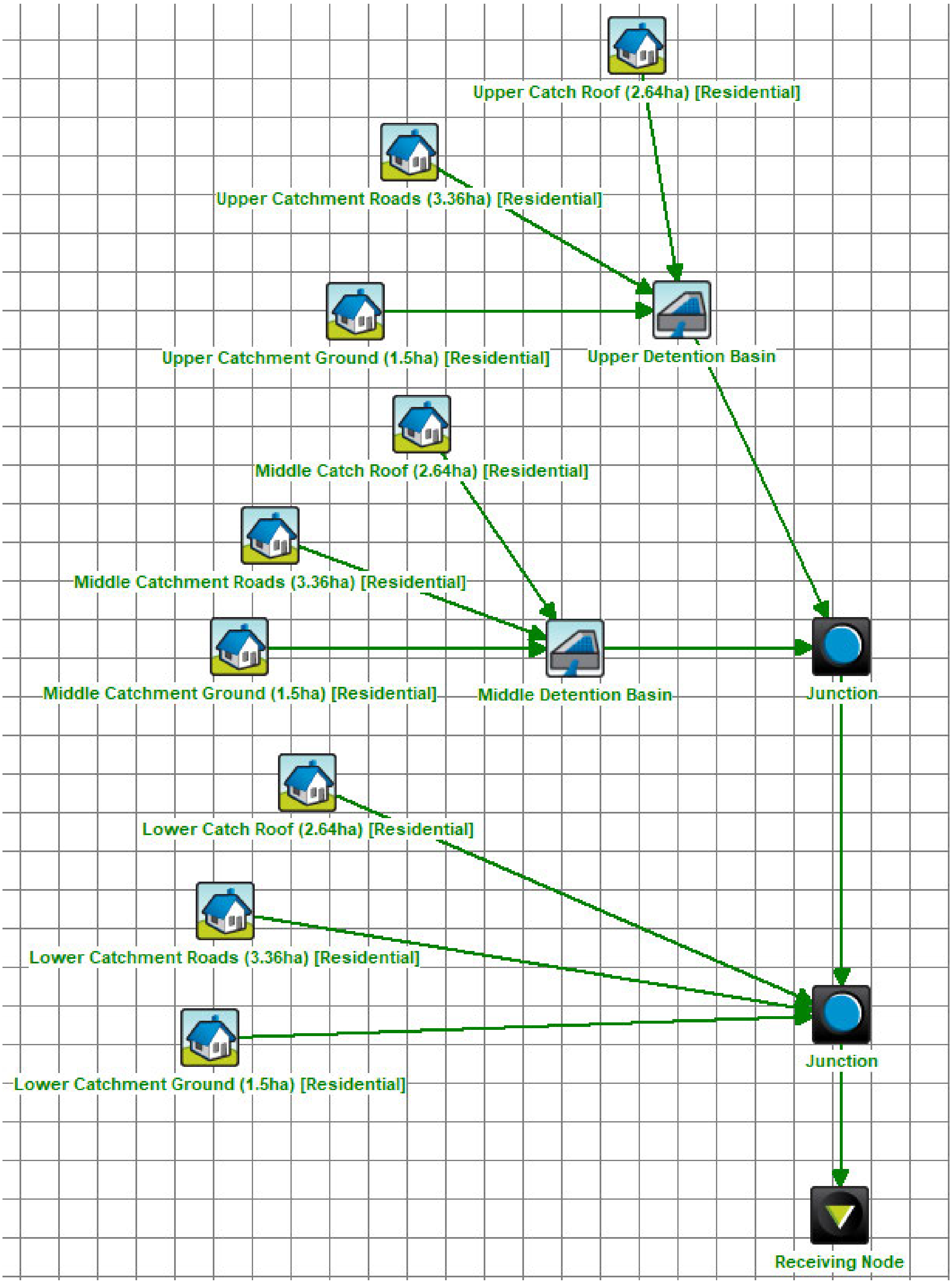


Figure 36. MUSIC model - Upper and Middle attenuated

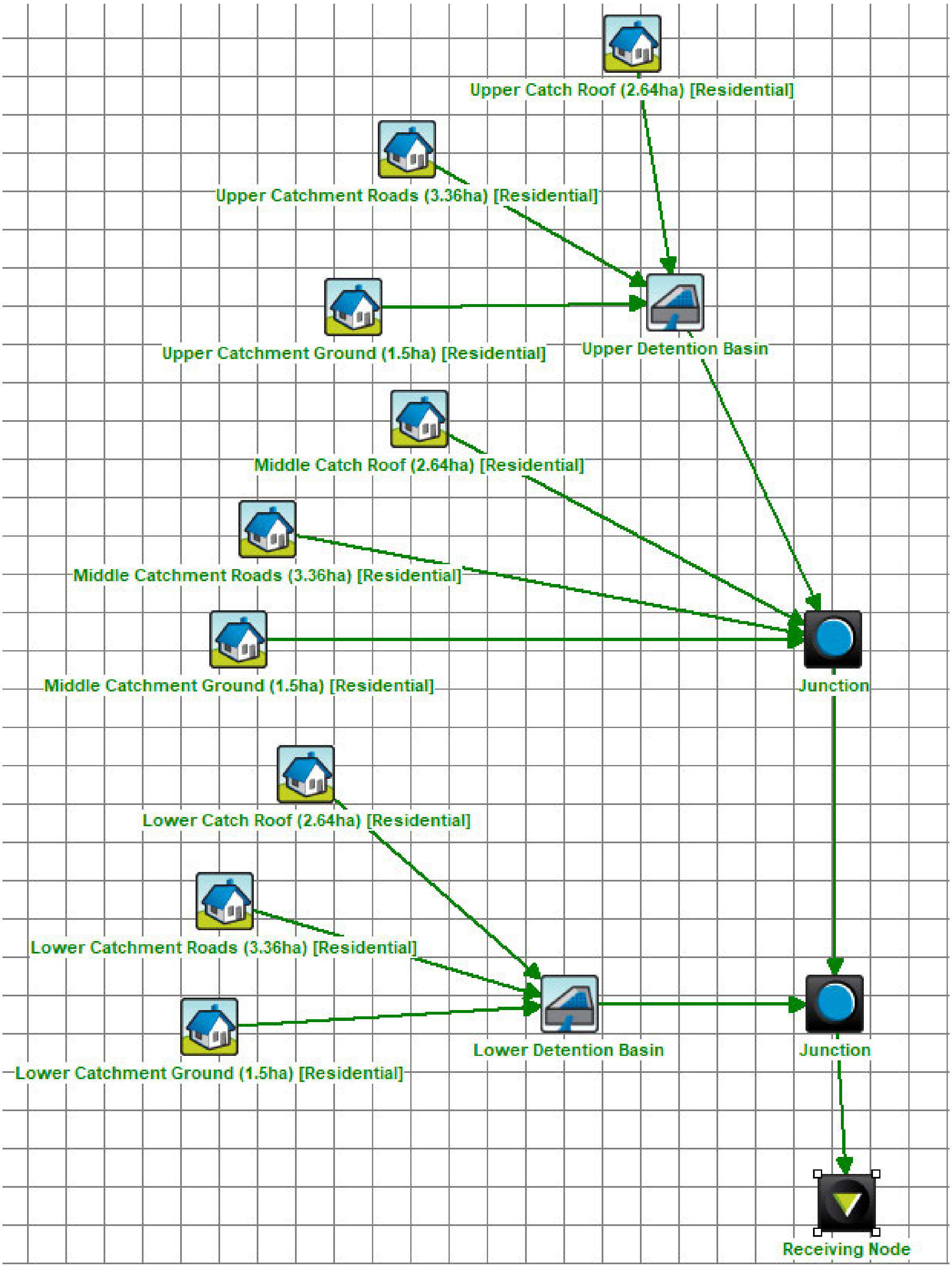


Figure 37. Upper and Lower attenuated

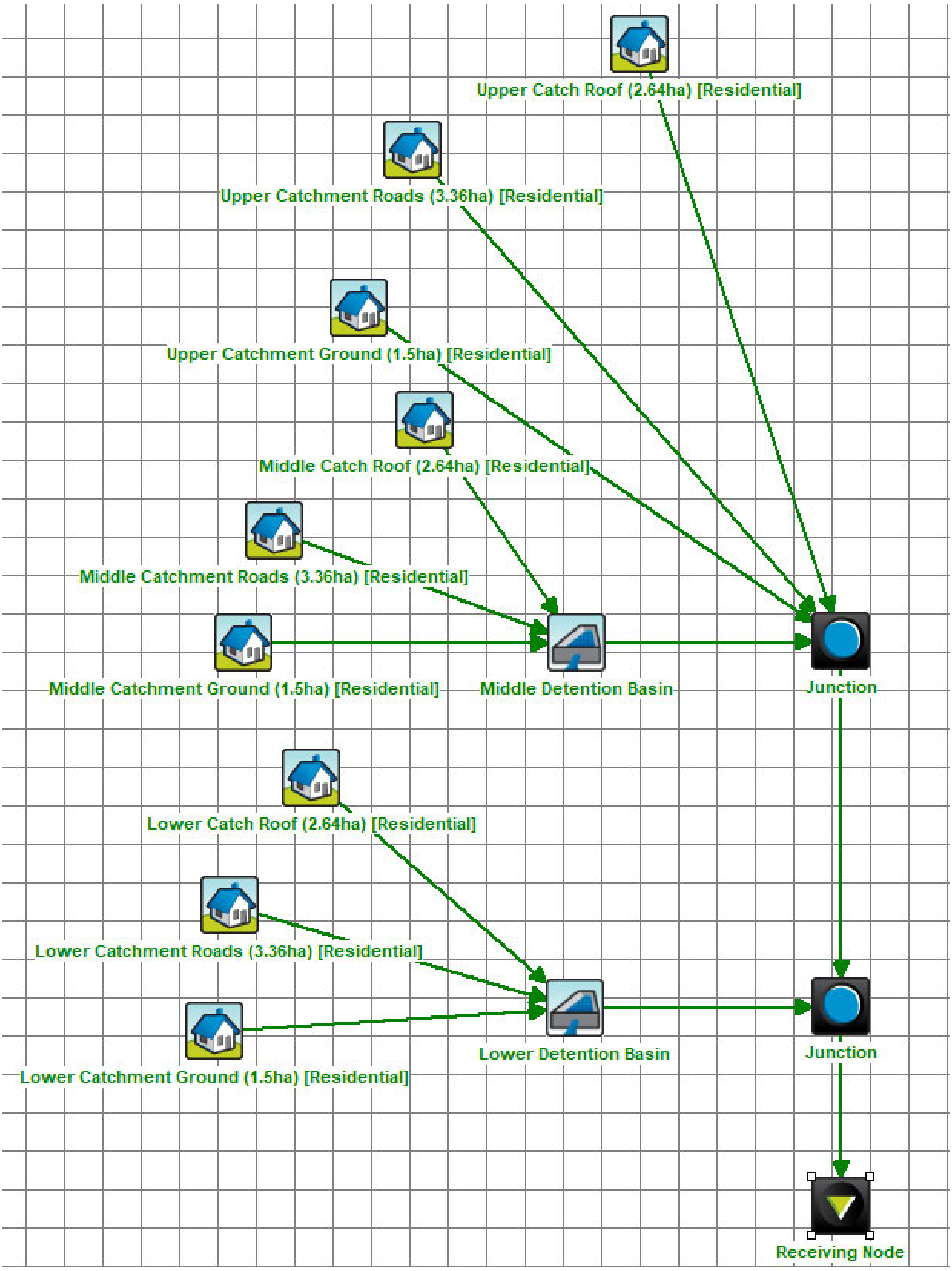


Figure 38. MUSIC model - Middle and Lower attenuated

Appendix I – DRAINS drainage system details

PIT / NODE DETAILS					
Name	Type	Family	Size	Pressure Change Coeff. Ku	Surface Elev (m)
PITCC3	On Grade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.3	107
PITCC4	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	1.5	107
PITC6	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	1.5	105.5
Catch C out	Node				102
POIC	Node				101
OUT	Node				100
PITC3	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 2.5%, 1% grade	Maxflow B300 2.5 3TP/X	2.2	112.5
PITC4	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	1.6	112.5
PITC5	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	1.8	111
PITC1	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.3	117
PITC2	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.5	117
PITCC1	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.3	112
PITCC2	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.5	112
PITB3	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 2.5%, 1% grade	Maxflow B300 2.5 3TP/X	2.2	127.5
PITB4	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	1.6	127.5
PITB5	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	1.8	126
Pit10328	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	1.5	120.5

Catch B out	Node				117
POIB	Node				116
PITB1	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.3	132
PITB2	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.5	132
PITBB3	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.3	122
PITBB4	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	1.5	122
PITBB1	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.4	127
PITBB2	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.5	127
PITA3	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.2	142.5
PITA4	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	1.6	142.5
PITA5	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	1.8	141
PITA6	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	1.5	135.5
Catch A out	Node				132
POIA	Node				131
PITAA3	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.3	137
PITAA4	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	1.5	137
PITAA1	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.3	142
PITAA2	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.5	142
PITA1	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.3	147
PITA2	OnGrade	MaxQ Drainway Plus-Maxflow-B Kerb-300mm Chnl, 3%, 1% grade	Maxflow B300 3 3TP/X	2.5	147

DETENTION BASIN DETAILS					
Name	Elev	Surf. Area	Outlet Type	Dia(mm)	Centre RL
BasinC	102.2	1	Orifice	400	102.39
	102.7	1400			
	104.7	2800			
BasinB	117.2	1	Orifice	400	117.39
	117.7	1400			
	119.7	2800			
BasinA	132.2	1	Orifice	400	132.39
	132.7	1400			
	134.7	2800			

SUB-CATCHMENT DETAILS						
Name	Pit or	Total	Paved	Grass	Paved	Grass
	Node	Area	Area	Area	Time	Time
		(ha)	%	%	(min)	(min)
CC3	PITCC3	0.56	80	20	5	15
CC4	PITCC4	0.56	80	20	5	15
C6	PITC6	0.96	80	20	5	17
C7	BasinC	0.4	0	100	5	5
C3	PITC3	0.56	80	20	5	15
C4	PITC4	0.56	80	20	5	15
C5	PITC5	0.58	80	20	5	15
C1	PITC1	0.83	80	20	5	17
C2	PITC2	0.83	80	20	5	17
CC1	PITCC1	0.83	80	20	5	17
CC2	PITCC2	0.83	80	20	5	17
B3	PITB3	0.56	80	20	5	15
B4	PITB4	0.56	80	20	5	15
B5	PITB5	0.58	80	20	5	15
B6	Pit10328	0.96	80	20	5	17
B7	BasinB	0.4	0	100	5	5
B1	PITB1	0.83	80	20	5	17
B2	PITB2	0.83	80	20	5	17
BB3	PITBB3	0.56	80	20	5	15
BB4	PITBB4	0.56	80	20	5	15
BB1	PITBB1	0.83	80	20	5	17
BB2	PITBB2	0.83	80	20	5	17
A3	PITA3	0.56	80	20	5	15
A4	PITA4	0.56	80	20	5	15
A5	PITA5	0.58	80	20	5	15
A6	PITA6	0.96	80	20	5	17
A7	BasinA	0.4	0	100	5	5
AA3	PITAA3	0.56	80	20	5	15

AA4	PITAA4	0.56	80	20	5	15
AA1	PITAA1	0.83	80	20	5	17
AA2	PITAA2	0.83	80	20	5	17
A1	PITA1	0.83	80	20	5	17
A2	PITA2	0.83	80	20	5	17

PIPE DETAILS										
Name	From	To	Length	U/S IL	D/S IL	Slope	Dia	I.D.	Rough	Chg From
			(m)	(m)	(m)	(%)	(mm)	(mm)		
PCC3	PITCC3	PITCC4	13	105.6	105.2	3.08	375	375	0.013	PITCC3
PCC4	PITCC4	PITC6	25	105.1	103.9	4.8	525	525	0.013	PITCC4
PC6	PITC6	BasinC	24	103.8	102.7	4.58	750	750	0.013	PITC6
PC7	BasinC	Catch C out	20	102.2	102	1	450	450	0.013	BasinC
PC3	PITC3	PITC4	13	111	110.6	3.08	375	375	0.013	PITC3
PC4	PITC4	PITC5	25	110.5	109.3	4.8	525	525	0.013	PITC4
PC5	PITC5	PITC6	110	109.2	103.9	4.82	600	600	0.013	PITC5
PC1	PITC1	PITC2	13	115.6	115	4.62	375	375	0.013	PITC1
PC2	PITC2	PITC4	90	114.9	110.6	4.78	450	450	0.013	PITC2
PCC1	PITCC1	PITCC2	13	110.6	110	4.62	375	375	0.013	PITCC1
PCC2	PITCC2	PITCC4	90	109.5	105.2	4.78	450	450	0.013	PITCC2
PB3	PITB3	PITB4	13	126	125.6	3.08	375	375	0.013	PITB3
PB4	PITB4	PITB5	25	125.5	124.3	4.8	525	525	0.013	PITB4
PB5	PITB5	Pit10328	110	124.2	118.9	4.82	600	600	0.013	PITB5
PB6	Pit10328	BasinB	24	118.8	117.7	4.58	750	750	0.013	Pit10328
PB7	BasinB	Catch B out	20	117.2	117	1	450	450	0.013	BasinB
PB1	PITB1	PITB2	13	130.6	130	4.62	375	375	0.013	PITB1
PB2	PITB2	PITB4	90	129.9	125.6	4.78	450	450	0.013	PITB2
PBB3	PITBB3	PITBB4	13	120.6	120.2	3.08	375	375	0.013	PITBB3
PBB4	PITBB4	Pit10328	25	120.1	118.9	4.8	525	525	0.013	PITBB4
PBB1	PITBB1	PITBB2	13	125.6	125	4.62	375	375	0.013	PITBB1
PBB2	PITBB2	PITBB4	90	124.5	120.2	4.78	450	450	0.013	PITBB2
PA3	PITA3	PITA4	13	141	140.6	3.08	375	375	0.013	PITA3

PA4	PITA4	PITA5	25	140.5	139.3	4.8	525	525	0.013	PITA4
PA5	PITA5	PITA6	110	139.2	133.9	4.82	600	600	0.013	PITA5
PA6	PITA6	BasinA	24	133.8	132.7	4.58	750	750	0.013	PITA6
PA7	BasinA	Catch A out	20	132.2	132	1	450	450	0.013	BasinA
PAA3	PITAA3	PITAA4	13	135.6	135.2	3.08	375	375	0.013	PITAA3
PAA4	PITAA4	PITA6	25	135.1	133.9	4.8	525	525	0.013	PITAA4
PAA1	PITAA1	PITAA2	13	140.6	140	4.62	375	375	0.013	PITAA1
PAA2	PITAA2	PITAA4	90	139.5	135.2	4.78	450	450	0.013	PITAA2
PA1	PITA1	PITA2	13	145.6	145	4.62	375	375	0.013	PITA1
PA2	PITA2	PITA4	90	144.9	140.6	4.78	450	450	0.013	PITA2

CHANNEL DETAILS											
Name	From	To	Length	U/S IL	D/S IL	Slope	Base Width	L.B. Slope	R.B. Slope	Man	Depth
			(m)	(m)	(m)	(%)	(m)	(1:?)	(1:?)	n	(m)
ChC	Catch C out	POIC	20	102	101	5	4	4	4	0.035	2
Ch4	POIC	OUT	20	101	100	5	4	4	4	0.035	2
ChB	Catch B out	POIB	20	117	116	5	4	4	4	0.035	2
Ch3	POIB	POIC	300	116	101	5	4	4	4	0.035	2
ChA	Catch A out	POIA	20	132	131	5	4	4	4	0.035	2
Ch2	POIA	POIB	300	131	116	5	4	4	4	0.035	2