WINGECARRIBEE SHIRE COUNCIL

Nattai River Flood Study

Final Report

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Catchment Simulation Solutions

Nattai River Flood Study

Final Report

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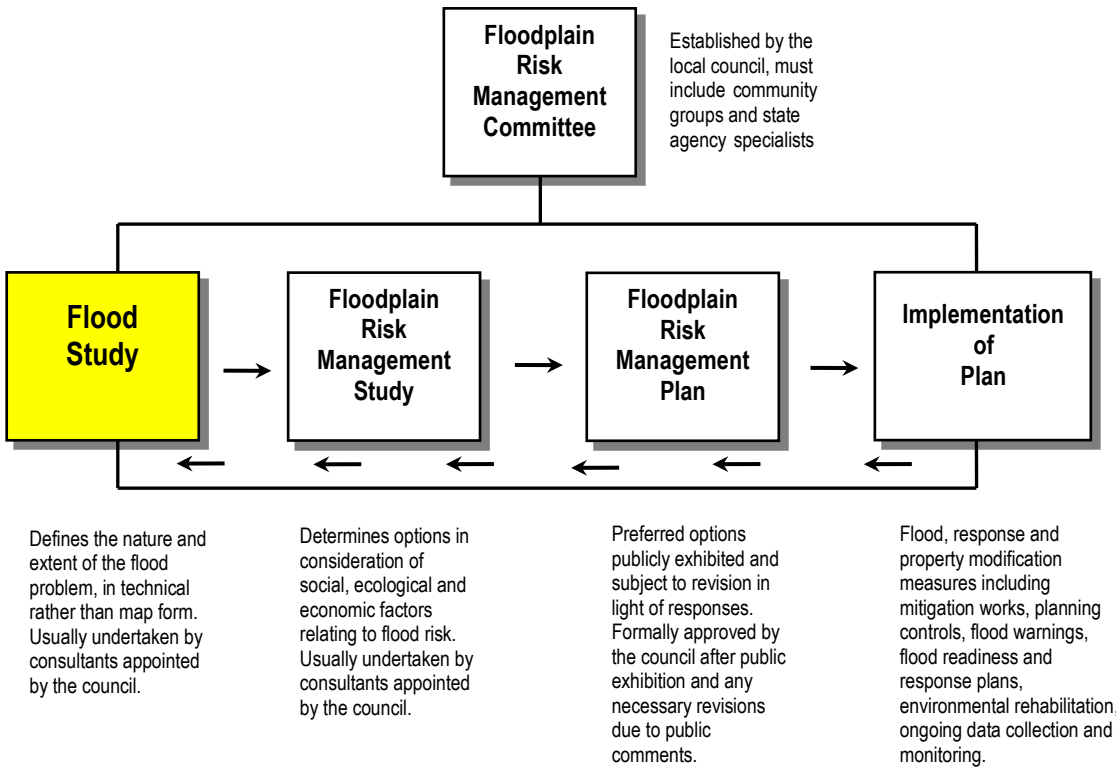
FOREWORD

The State Government's Flood Policy is directed towards providing solutions to existing flooding problems in developed areas and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas. The Policy is defined in the NSW Government's *Floodplain Development Manual* (NSW Government, 2005).

Under the Policy, the management of flood liable land remains the responsibility of Local Government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Local Government in its floodplain management responsibilities.

The Policy provides for technical and financial support by the State Government through the following stages:



The Nattai River Flood Study represents the first of the four stages in the process outlined above. The aim of the Nattai River Flood Study is to produce information on flood discharges, levels, depths and velocities, for a range of flood events under existing topographic and development conditions. This information can then be used as a basis for identifying those areas where the greatest flood damage is likely to occur, thereby allowing a targeted assessment of where flood mitigation measures would be best implemented as part of the subsequent Floodplain Risk Management Study and Plan.

ACKNOWLEDGEMENTS

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GLOSSARY

acid sulphate soils	are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
annual exceedance probability (AEP)	the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. Eg, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger events occurring in any one year (see ARI).
Australian Height Datum (AHD)	a common national surface level datum approximately corresponding to mean sea level.
average annual damage (AAD)	depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
average recurrence interval (ARI)	the long-term average number of years between the occurrence of a flood as big as or larger than the selected event. For example, floods with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the Local Governments Act.
catchment	the land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	the council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the council, however legislation or an EPI may specify

development

is defined in Part 4 of the Environmental Planning and Assessment Act (*EP&A Act*).

infill development: refers to development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development.

new development: refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.

redevelopment: refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.

disaster plan (DISPLAN)

a step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.

discharge

the rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).

ESD

Ecologically Sustainable Development (ESD) using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act, 1993. The use of sustainability and sustainable in this manual relate to ESD.

effective warning time

The time available after receiving advice of an impending flood and before floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.

emergency management

a range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.

flash flooding

flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.

flood	relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	the remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	is synonymous with flood prone land, i.e., land susceptible to flooding by the PMF event. Note that the term flood liable land covers the whole floodplain, not just that part below the FPL (see flood planning area).
flood mitigation standard	the average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	the measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	a management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at state, division and local levels. Local flood plans are prepared under the leadership of the SES.
flood planning area	the area of land below the FPL and thus subject to flood related development controls.
flood planning levels (FPLs)	are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in

	management studies and incorporated in management plans.
flood proofing	a combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	land susceptible to flooding by the PMF event. Flood prone land is synonymous with flood liable land.
flood readiness	Readiness is an ability to react within the effective warning time.
flood risk	potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. existing flood risk**:** the risk a community is exposed to as a result of its location on the floodplain. future flood risk: the risk a community may be exposed to as a result of new development on the floodplain. continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
freeboard	provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
hazard	a source of potential harm or a situation with a potential to cause loss. In relation to this study the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in Appendix L of the *Floodplain Development Manual* (*2005*).

historical flood	a flood which has actually occurred.
hydraulics	term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	a graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	councils have discretion in determining whether urban drainage problems are associated with major or local drainage. Major drainage involves: • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or • water depths generally in excess of 0.3m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or • major overland flowpaths through developed areas outside of defined drainage reserves; and/or • the potential to affect a number of buildings along the major flow path.
mathematical / computer models	the mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.

merit approach

the merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well-being of the State's rivers and floodplains.

The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into council plans, policy, and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local flood risk management policy and EPIs.

minor, moderate and major flooding

Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood.

minor flooding: Causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.

moderate flooding: Low lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.

major flooding: Appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

modification measures

measures that modify either the flood, the property or the response to flooding.

peak discharge

the maximum discharge occurring during a flood event.

probable maximum flood (PMF)

the PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.

probable maximum precipitation (PMP)

the PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.

probability	A statistical measure of the expected chance of flooding (*see annual exceedance probability*).
risk	chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	the amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	equivalent to water level (both measured with reference to a specified datum).
stage hydrograph	a graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	a plan prepared by a registered surveyor.
TUFLOW	is a 1-dimensional and 2-dimensional flood simulation software. It simulates the complex movement of floodwaters across a particular area of interest using mathematical approximations to derive information on floodwater depths, velocities and levels.
velocity	the speed or rate of motion (*distance per unit of time, e.g., metres per second*) in a specific direction at which the flood waters are moving.
water surface profile	a graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	the horizontal distance in the direction of wind over which wind waves are generated.
XP-RAFTS	is a non-linear runoff routing software. It incorporates subcatchment information such as area, slope, roughness and percentage impervious and is used to simulate the transformation of historic or design rainfall into runoff (i.e., discharge hydrographs).

Executive Summary

Wingecarribee Shire Council engaged Catchment Simulations Solutions to prepare a Flood Study for the Nattai River catchment. The extent of the catchment is shown in **Figure 1** (refer Flood Study: Volume 2).

The objectives of the Flood Study included:

- Define the nature of flood behaviour (i.e., flood extents, levels, depths & velocities) across the catchment for a range of design floods up to and including the Probable Maximum Flood;
- Identify areas that are particularly susceptible to flooding and determine how key facilities and infrastructure may be impacted by flooding;
- Define the variation in flood hazard across the catchment; and,
- Quantify the potential impact that climate change may have on flooding across the catchment.

In order to achieve these objectives, the Flood Study was completed in a staged manner. An overview of the outcomes of each stage is presented below.

Data Collection

Only a limited amount of flood-related information was available for the Nattai River catchment. Therefore, it was necessary to undertake additional data collection to ensure the study objectives could be met.

The additional data collection included the survey of 21 river cross-sections and 24 hydraulic structures (i.e., bridges and culverts). The extent of the survey information that was collected is shown in **Figure 4**.

A community information brochure and questionnaire was also distributed to 339 households and businesses within the Nattai River catchment (refer **Appendix A**). A total of 60 questionnaire responses were received. The questionnaire responses included photographs of past flooding within the catchment as well as descriptions of historic flood behaviour. This historic flood information was subsequently used to assist in the calibration of computer models.

Hydrologic Model

A hydrologic computer model of the Nattai River catchment was developed to define rainfall-runoff processes and generate discharge hydrographs at discrete locations across the catchment. The hydrologic model was developed using the XP-RAFTS software. The XP-RAFTS subcatchment layout is shown in **Figure 5**.

There are no stream gauges located within the Nattai River catchment. Therefore, the XP-RAFTS model could not be independently calibrated as part of the study. Nevertheless, a pseudo-calibration was attempted using the XP-RAFTS model with the TUFLOW hydraulic model.

Hydraulic Model

A fully two-dimensional hydraulic computer model of the Nattai River catchment was also developed as part of the Flood Study using the TUFLOW software. The TUFLOW model was used to route the flow hydrographs generated by the XP-RAFTS model across the catchment and produce information of flood levels, extents, depths and velocities. The layout of the TUFLOW model is shown in **Figure 8**.

A pseudo-calibration of the XP-RAFTS and TUFLOW models was performed using historic flood information gathered from the community questionnaire responses. The outcomes of the calibration determined that the XP-RAFTS and TUFLOW models were able to reproduced historic flood mark elevations to within 0.12 metres.

Design Flood Results

The calibrated XP-RAFTS and TUFLOW models were used to simulate design flood behaviour across the catchment for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events. The Probable Maximum Flood was also simulated. Peak floodwater depths and velocities were extracted from the results of the modelling and are presented in **Figures 11** to **17**.

The results of the design flood simulations were also used to determine the variation in provisional flood hazard (refer **Figures 18** to **23**) and hydraulic categories (refer **Figures 24** to **31**) across the catchment.

The results of the design flood modelling show that:

- Flood behaviour across the Nattai River catchment is typically characterised by relatively shallow depths of inundation (i.e., < 0.3 metres). However, more significant depths are predicted along and immediately adjacent to designated waterways.
- The relatively shallow depths of inundation result in the majority of the Nattai River floodplain being exposed to a low provisional flood hazard.
- However, several sections of the catchment are predicted to be exposed to more significant floodwater depths and velocities and, consequently, a high provisional flood hazard during large events. This includes:
  - Evans Street (between Payten Street and Colo Street)
  - Mittagong Swimming Centre
  - Oxley Road (between Nero Street and Murchison Street)
- A number of roadways are predicted to be overtopped during the 1% AEP flood. This would typically render the roadways impassable for at least 2 hours. This includes Range Road, Old South Road and the Old Hume Highway.
- The catchment incorporates a number of bridges and culverts. The results of a blockage sensitivity analysis shows that the severity of flooding upstream of these structures can be significantly increased due to blockage. This highlights the importance of routine maintenance on this infrastructure, particularly immediately after a flood.

1 INTRODUCTION

The Nattai River catchment is located in the Southern Highlands of New South Wales and occupies a total area of 6.75 km^2. The extent of the catchment is shown in **Figure 1** (refer Flood Study: Volume 2).

Nattai River originates near the intersection of Range Road and Old South Road at Mittagong and drains in a northerly direction through the eastern sections of Mittagong. The catchment comprises a variety of land uses including rural, residential, commercial, industrial and open space/recreational facilities.

The catchment is drained primarily by natural watercourses. The urbanised sections of the catchment are also drained by a stormwater system which carries local catchment runoff into the watercourses via a network of stormwater pipes, pits, open channels and culverts.

During periods of heavy rainfall, there is potential for the stormwater system to become overwhelmed and for water to overtop the banks of the natural watercourses and inundate the adjoining floodplain. Accordingly, there is potential for inundation of properties located in close proximity to the creeks and drainage lines. Flooding has been experienced on several occasions in the past, particularly across properties fronting Evans Street.

Although some flooding investigations have been completed at isolated locations across the catchment, a comprehensive flood study of the entire Nattai River catchment has not previously been prepared. Therefore, with the exception of isolated flooding complaints from residents, the extent of the existing flooding problem is not well understood.

In recognition of this, Wingecarribee Shire Council decided to prepare a Floodplain Risk Management Plan for the Nattai River catchment.

The first stage in the development of a Floodplain Risk Management Plan involves the preparation of a Flood Study. The Flood Study provides a technical assessment of flood behaviour.

This report forms the Flood Study for the Nattai River catchment. It documents flood behaviour across the catchment for a range of design floods for existing topographic and development conditions. This includes information on peak discharges, flood levels, flood extents, flood depths and flow velocities for a range of design floods. It also provides provisional estimates of the flood hazard and hydraulic categories across the catchment.

The Flood Study comprises two volumes:

- **Volume 1**: (i.e., this document) comprises the report text and appendices.
- **Volume 2**: contains all accompanying figures.

2 METHODOLOGY

2.1 Objectives

The objectives of the Nattai River Catchment Flood Study are:

- to review available flood-related information and data for the Nattai River catchment;
- to develop a hydrologic model to simulate the transformation of rainfall into runoff and generate flow hydrographs across the catchment;
- to develop a hydraulic computer model to simulate how the flows generated by the hydrologic model would be distributed/move across the catchment;
- to calibrate the hydrologic and hydraulic computer models to reproduce past floods;
- to use the calibrated computer models to define peak discharges, water levels, depths and velocities for the design 20%, 10%, 5%, 2%, 1% and 0.5% AEP floods, and the Probable Maximum Flood (PMF);
- to produce maps showing the extent, depth and velocity of floodwaters for the range of design floods; and,
- to produce maps showing flood hazard and hydraulic categories for the range of design floods.

2.2 Adopted Approach

The general approach and methodology employed to achieve the study objectives involved:

- compilation and review of available flood-related information (Chapter 3);
- the development and calibration of a computer based hydrologic model to simulate the transformation of rainfall into runoff (Chapter 4);
- the development and calibration of a computer based hydraulic model to simulate the movement of floodwaters across the catchment (Chapter 5);
- use of the computer models to estimate peak discharges, water levels, depths, flow velocities and flood extents for the full range of design events up to and including the PMF (Chapter 6);
- use of the computer model results to generate flood hazard and hydraulic category mapping (Chapter 7),
- assessment of potential climate change implications on existing flood behaviour (Chapter 8).
- testing the sensitivity of the results generated by the computer model to variations in model input parameters (Chapter 9);
- Identification of flooding “trouble spots” as well as key infrastructure and transportation links impacted by floodwaters (Chapter 10).

3 REVIEW OF AVAILABLE INFORMATION

3.1 Overview

A range of data were made available to assist with the preparation of the Nattai River Flood Study. This included previous reports, hydrologic data and GIS data.

A description of each dataset along with a synopsis of its relevance to the flood study is summarised below.

3.2 Previous Reports and Investigations

3.2.1 Mittagong Catchment MG1 Flood Study (2003)

The *'Mittagong Catchment MG1 Flood Study Report'* (2003), was prepared by Maunsell for Wingecarribee Shire Council. The primary purpose of the investigation was to define flood behaviour within the MG1 catchment, which is a major tributary of Nattai River. The extent of the MG1 study area is shown in **Figure 2**.

The study included the development of a hydrologic computer model of the MG1 catchment using the XP-RAFTS software (XP Software, 2009). The model was not calibrated due to a lack of stream flow and historic flooding information for the catchment. Therefore, the model was verified based on anecdotal information that the Colo Street culvert (located near the catchment outlet) is overtopped once every 1 to 2 years (on average). Accordingly, the peak 1 year ARI (i.e., 100% AEP) XP-RAFTS model discharge was compared against the Colo Street culvert capacity (estimated using a culvert nomograph) to ensure the XP-RAFTS model was generating realistic discharge estimates.

The XP-RAFTS model was subsequently used to estimate peak design discharges at various locations across the catchment for the 1%, 5%, and 100% AEP design storms. A summary of peak discharges extracted from the report is provided in **Table 1**.

Table 1 Peak design discharges extracted from Mittagong Catchment MG1 Flood Study (2003)

Location	Peak Discharge (m^3/s)		
	100% AEP	5% AEP	1% AEP
Range Road	0.59	3.33	4.70
Payten Street (between Evans St & Southey St)	3.42	16.13	22.82
Colo Street (between Evans St & Southey St)	3.76	19.96	24.18

A review of the MG1 catchment extent presented in the report indicates that the overall catchment extent may have been overestimated. As shown in **Plate 1**, the study assumed that a large subcatchment originating south of Range Road ultimately drains to Payten Street.

However, a review of detailed ALS data (refer Section 3.4.1), shows that this subcatchment would drain in a westerly direction into Nattai River. Accordingly, the contributing catchment area and associated discharge estimates downstream of Payten Street are considered to be over-estimated.

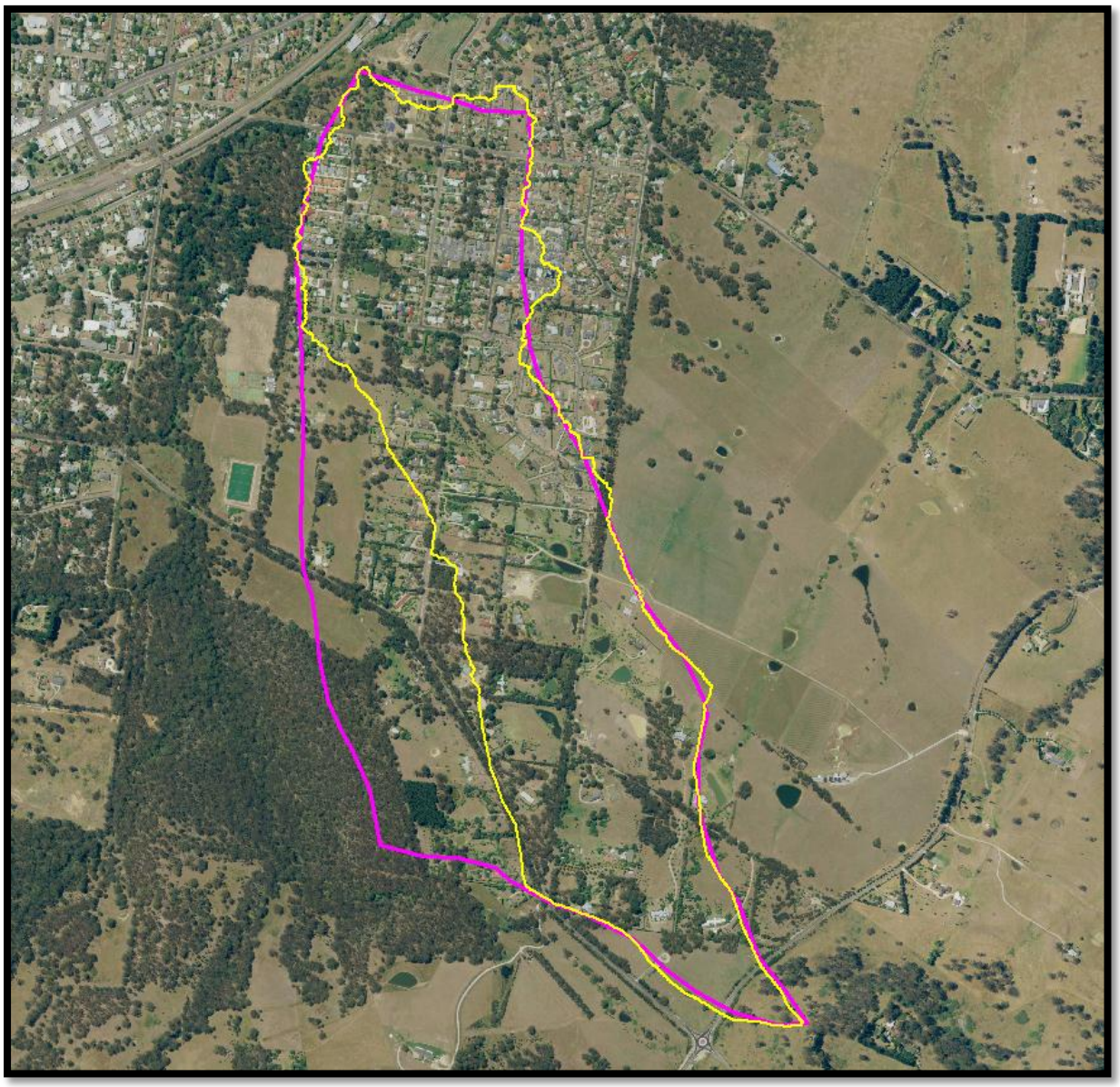


Plate 1 **Comparison between MG1 catchment extent as depicted in Mittagong Catchment MG1 Flood Study report (purple polygon) and catchment extent derived using detailed ALS data with CatchmentSIM(yellow polygon)**

Flood behaviour was defined along the main watercourse between Webb Street and the catchment outlet using a computer model developed using the HEC-RAS software. Flood extents were plotted for the 5% AEP and 1% AEP design floods for existing topographic and development conditions. Peak design flood levels were also included at select locations (typically bridge/culvert crossings) and are summarised in **Table 2**.

Table 2 Peak design flood levels extracted from Mittagong Catchment MG1 Flood Study (2003)

Location	Peak Discharge (m^3/s)	
	5% AEP	1% AEP
Payten Street (between Evans St & Southey St)	635.74	635.81
Colo Street (between Evans St & Southey St)	628.66	628.75

The report also documents culvert dimensions and roadway centreline elevations. This information can be used to assist with the development of the hydraulic model as part of this study. However, invert elevations were not included in the report and the HEC-RAS model/survey data that was acquired as part of the study could not be uncovered.

The report also includes additional 1% AEP inundation extents incorporating a proposed upgrade of the Colo Street culverts. The 1% inundation extents indicate that the proposed culvert upgrade would reduce the severity of flooding extending approximately 100 metres upstream of Colo Street.

It was noted in the report that flood behaviour downstream of Colo Street is likely to be influenced by backwater flooding from Nattai River, which was not modelled as part of this investigation. Accordingly, flood behaviour downstream of Colo Street may not be reliably defined as part of this study. It should also be noted that since this study was prepared, the replacement of the Colo Street culverts was completed. Therefore, "existing" flood behaviour immediately upstream of the Colo Street culvert will not be reliably defined by this study either.

As a result of the changes to hydraulic structures and over-estimation of the catchment area/discharges, it is considered that the results presented in this report are of limited value. Nevertheless, the hydraulic structure information could be used to assist in the hydraulic model developed for this study.

3.2.2 Bowral Floodplain Risk Management Study and Plan (2005)

The *'Bowral Floodplain Risk Management Study and Plan'* (2005) was prepared by Bewsher Consulting for Wingecarribee Shire Council. The study was commissioned to investigate a range of options that could be potentially implemented to reduce flood damages within the Mittagong Creek catchment. The Mittagong Creek catchment is located south-west of the Nattai River catchment.

Although this report does not contain any specific flooding information for the Nattai River catchment, it does incorporate newspaper clippings from 'The Bowral Free Press' documenting a large flood that occurred in March 1893. Photos are also provided showing flooding across different parts of Bowral on:

- January, 1915;
- March, 1975;
- March, 1978;
- November, 1985;
- August, 1986;

- April, 1988;
- October, 1999;
- February, 2005; and,
- June, 2007.

Given the proximity of the Nattai River catchment to the Mittagong Creek catchment, flooding may have also been experienced in the Nattai River catchment during each of these events.

3.3 Hydrologic Data

3.3.1 Historic Rainfall Data

A number of daily read and continuous (i.e., pluviometer) rainfall gauges are located within and in close proximity to the Nattai River catchment. The location of each gauge is shown in **Figure 3**. Key information for those gauges located within 10 kilometres of the catchment is summarised in **Table 3** and the temporal availability of rain gauge data is provided in **Table 4**.

The information provided in **Table 3** and **4** indicates that the majority of rain gauges have a limited record length. Nevertheless, the Mittagong (Alfred St) gauge has over 100 years of daily rainfall records. The Mittagong (Kia-Ora) gauge also provides over 100 years of daily rainfall records, however, the record is only 67% complete. **Table 3** also shows that no continuous rainfall data are available prior to November 1992.

A review of the available rainfall data was completed to identify when significant historic rainfall events have occurred and, consequently, when flooding may have been experienced in the catchment. The details of the top ten rainfall events are summarised in **Table 5**.

Table 3 Available rain gauges in the vicinity of the Nattai River catchment

Gauge Number	Gauge Name	Gauge Type	Owner *	Period of Record	Percentage of Record Complete	Distance From Catchment Centroid (km)
68044	Mittagong (Alfred St)	Daily	BOM	01/01/1886 -> present	86	1.7
68033	Mittagong (Kia-Ora)	Daily	SCA	01/01/1902 -> present	67	3.4
68102	Bowral (Parry Drive)	Cont.	BOM	30/11/1992 -> 28/02/2011	87	5.5
68102	Bowral (Parry Drive)	Daily	BOM	08/10/1961 -> present	98	5.5
68255	Bowral (Orchard St)	Daily	BOM	09/01/2000 -> present	99	5.6
68087	Spring Hill (Warana)	Daily	BOM	01/01/1959->31/12/1967	72	6.2
68163	Mittagong (Leicester Park)	Daily	SCA	01/01/1957 -> 31/12/1970	86	6.3
68005	Bowral Post Office	Daily	BOM	01/01/1885 -> 01/01/1965	99	6.5
68157	Yarrow (Boural)	Daily	BOM	01/01/1912 -> 31/12/1930	99	6.5
68184	Bowral Centennial Road	Daily	BOM	01/01/1967 ->31/12/1977	93	6.6
68239	Moss Vale AWS	Daily	BOM	01/09/2010 -> present	98	7.6
68092	Berrima (Hillview)	Daily	BOM	01/01/1959 -> 31/12/1967	98	8.4

NOTE: * BOM = Bureau of Meteorology, SCA = Sydney Catchment Authority

Table 4 **Temporal availability and percentage of annual record complete for rain gauges in the vicinity of the Nattai River catchment (source: http://www.bom.gov.au/climate/data/)**

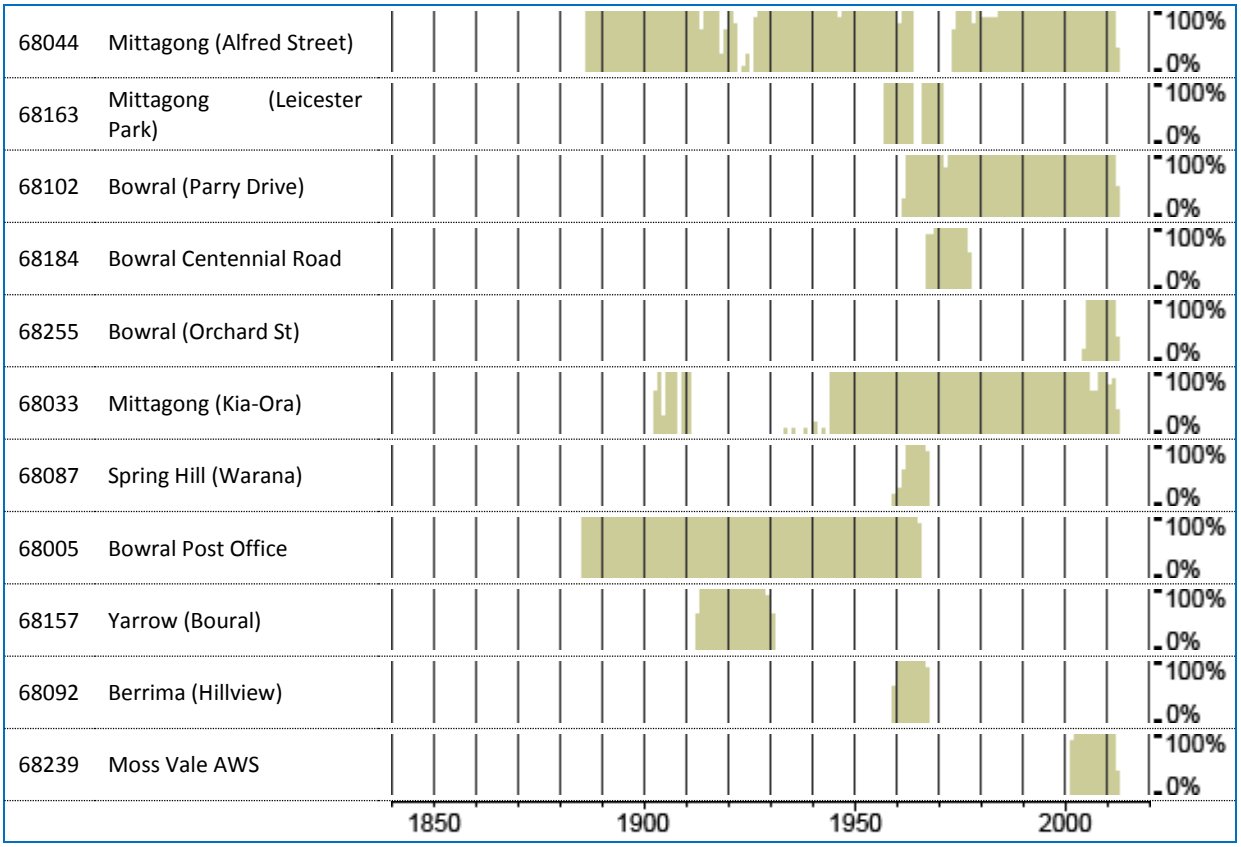


Table 5 **Significant Historic Rainfall Events**

Rank	Year	Day/Month	Rainfall in 24 hour Period (mm)	Rainfall in Preceding 24 Hour Period (mm)	Rainfall in Following 24 Hour Period (mm)
1	1893	5th March	297	15	4
2	1975	22nd June	218	0	19
3	1914	30th December	184	1	1
4	1955	1st May	179	55	38
5	1898	14th February	175	26	62
6	1900	5th July	166	11	112
7	1890	12th March	165	21	1
8	1978	19th March	162	144	109
9	1959	21st July	148	0	29
10	1956	25th July	147	27	2

(Alfred St), Mittagong (Leicester Park) & Bowral (Parry Drive) rain gauges.
#: this rainfall depth is the accumulated total from the preceding 48 hours

As shown in **Table 5**, the most significant rainfall event on record occurred in March 1893, where nearly 300 mm of rain fell within a 24 hour period. This concurs with a large reported flood documented in *'The Bowral Free Press'* (refer Section 3.2.2).

The most significant contemporary rainfall events occurred in June 1975 and March 1978.

3.3.2 Historic Streamflow Data

There are no stream gauges located within the Nattai River catchment. Accordingly, no stream flow information could be uncovered for the Nattai River catchment.

3.4 Topographic Data

3.4.1 Aerial Laser Survey (ALS)

AAM Pty Limited collected Aerial Laser Survey (ALS) data across a 124 km^2 section of the Wingecarribee Shire Council Local Government Area on 1st April 2010. This included a significant proportion of the Nattai River catchment (refer **Figure 2**).

The ALS data was used as the basis for the development of contours at 0.5 metre intervals as well as a 1 metre grid-based Digital Elevation Model (DEM). Both datasets were provided by Council for use as part of this study.

The ALS has a stated absolute horizontal accuracy of better than 0.55 metres and an absolute vertical accuracy of better than 0.15 metres (AAM, 2010). Validation of the ALS was completed using 290 reference points that were surveyed using traditional ground survey techniques. This included 92 reference points in the Mittagong area. The outcomes of the data validation determined that the mean difference between ALS and ground surveyed spot heights within the Mittagong area was less than 2 cm. Accordingly, the vertical and horizontal accuracy provided by the ALS data appears to be suitable for use in this study.

A review of aerial photography indicates that there has been negligible development across the catchment since the ALS was collected in 2010. As a result, the ALS provides a good representation of contemporary topography across the catchment and is considered to be suitable for use in defining topography across the majority of the catchment as part of this investigation.

However, as shown in **Figure 2**, the ALS does not extend across the entire catchment. The metadata supplied with the ALS also notes that the ALS data may be less reliable in areas of high vegetation density. In addition, the ALS will not pick up the details of topographic and drainage features that are obscured from aerial survey techniques, such as culvert obvert elevations. Accordingly, it will be necessary to supplement the ALS data with additional survey and topographic information to ensure a reliable representation of the terrain and drainage features is provided across all areas of the catchment.

3.4.2 10 Metre Contours

Land and Property Information (LPI) ground surface contours at 10 metres intervals were also provided by Council. The contours extend across all of the Nattai River catchment. The horizontal and vertical accuracy of the data is not available. However, it is considered that the contours are suitable for defining the ground surface topography across the rural areas of the catchment not covered by the ALS data. The extent of the area covered by the contours (not including that area already covered by ALS data) is shown in **Figure 2**.

The ALS data and the 10 metre contours were combined to form a complete Digital Elevation Model (DEM) of the study area. The DEM is shown in **Figure 2**.

3.5 GIS Data

A number of GIS data layers were also provided by Council to assist with the study. This included:

- Aerial Photography;
- Stormwater network;
- Bridges; and,
- Building footprint polygons.

Further detailed information on the GIS layers is provided below.

3.5.1 Aerial Photography

Aerial photography that was captured in 2009 was provided by Council to assist with the investigation. The imagery is provided at a 0.5 metre pixel size and allowed major features such as buildings to be identified.

The aerial photography was used to assist with the review of available information (e.g., identification of missing buildings). The photography also served as a background layer in the majority of report figures (refer Flood Study: Volume 2).

3.5.2 Stormwater Network GIS layer

The sub-surface stormwater pipe system can play a significant role in the conveyance of flows across the urban sections of the catchment during storm events. Accordingly, it is important to include the stormwater system in any computer model that is used to define flood behaviour across the Nattai River catchment.

Two stormwater-related GIS layers were provided by Council. This included:

- "Stormwater Nodes": contains stormwater pit locations and limited information about each pit including the degree of blockage. The database was last updated in October/November 2008 for the Mittagong area. It was noted that only major Council-owned pits were included (i.e., no pits on privately owned land are included).
- "Stormwater Conduits": contains stormwater pipe / culvert alignments and information including conduit type (e.g. pipe, box culvert), material (e.g., concrete), dimensions and length.

Accordingly, most of the information necessary to include the trunk stormwater drainage system in the hydraulic model is provided in these GIS layers. Nevertheless, some additional information including pit depths/invert elevations, pit types (e.g., kerb inlet, grated inlet) and culvert invert elevations are not available in these layers.

The extent of the area covered by the stormwater network GIS layers is shown in **Figure 2**. As shown in **Figure 2**, there is only limited sub-surface stormwater infrastructure across the Nattai River catchment. As a result, the majority of flow during significant storm events will travel overland across the catchment.

3.5.3 Bridges

A bridges GIS layer was provided by Council showing the location of Council owned bridges within the Local Government Area. A review of this GIS layer showed that bridges are located at the following Nattai River crossings:

- Range Road;
- Colo Street;
- Ferguson Crescent;
- Main Southern Railway; and
- Old Hume Highway.

All other stream crossings comprise pipe or box culverts.

3.5.4 Building Footprint Polygons

A GIS layer containing building footprint polygons for every significant building within the Nattai River catchment was also provided by Council. The building polygons can be used to define the impediment to flow afforded by buildings across the catchment.

A review of the building polygons relative to 2009 aerial photography showed the layer suitably described all major buildings across the catchment. However, some large sheds were not incorporated in the GIS layer. Therefore, additional polygons were digitised by hand based on the 2009 aerial photography to ensure all significant buildings and sheds were defined.

3.6 Community Consultation

A key component of the flood study involves development and calibration of hydrologic and hydraulic computer models. Calibration involves using the computer models to replicate floods that have occurred in the past. Council holds minimal information on historic flooding across the Nattai River catchment that can be used to assist with the calibration process.

However, it was considered that residents and business owners within the Nattai River catchment may have witnessed past flood events. Accordingly, several community consultation devices were developed to inform the community about the study and to obtain information from the community about their past flooding experiences. Further information on each of these consultation devices is provided below.

3.6.1 Flood Study Website

A flood study website was established for the duration of the study. The website address was: http://www.nattai.floodstudy.com.au/

The website was developed to provide the community with detailed information about the study and also provide a chance for the community to ask questions and complete an online questionnaire (this online questionnaire was identical to the questionnaire distributed to residents and business owners, as discussed in Section 3.6.2).

During the course of the study (until June 2013), the website was visited 68 times by 46 unique visitors.

3.6.2 Community Information Brochure and Questionnaire

A community information brochure and questionnaire was prepared and distributed to 339 households and businesses within the Nattai River catchment. A copy of the brochure and questionnaire is included in **Appendix A**.

The questionnaire sought information from the community regarding whether they had experienced flooding, the nature of flood behaviour, if roads and houses were inundated and whether residents could identify any historic flood marks. A total of 60 questionnaire responses were received, providing a questionnaire response rate of 18%. A summary of all questionnaire responses is provided in **Appendix A**. The spatial distribution of questionnaire respondents is shown in **Figure A1**, which is also enclosed in **Appendix A**.

The following information was gleaned from the responses to the questionnaire:

- The majority of respondents have lived in the Nattai River catchment for over 10 years. The average length of residence was about 13 years.
- The majority of flooding problems were reported in the vicinity of Evans and Southey Streets. However, there are isolated reports of flooding as far upstream as Webb Street and Chalker Crescent. The spatial distribution of respondents that have experienced past flooding problems is shown by the red dots in **Figure A1**.
- A number of respondents reported that the Colo Street Bridge has been overtopped a number of times in the past. No specific dates were provided, although the number of responses tends to indicate that inundation occurs relatively frequently. This tends to confirm the information provided in the *'Mittagong Catchment MG1 Flood Study Report'* (Maunsell, 2003) which stated that the Colo Street culvert is overtopped every 1 to 2 years (on average).
- The majority of respondents considered that obstruction of pipes and dense vegetation/weeds along the watercourses significantly increased the severity of flooding across the catchment.

No specific flood mark information was provided by any of the respondents. However, several residents provided information on typical floodwater depths during past floods that could be used to assist in the verification of the hydrologic and hydraulic models. This included:

- The driveway at 24 Evans Street was inundated to a depth of 250-300 mm during a flood approximately 10 years ago.
- Water reached the back porch at 14 Evans Street covering all the concrete leading up to their yard in the early 1990s. The bridge adjoining their property was also covered by water to a depth of 60 to 100 mm.
- Heavy rainfall in August 2006 as well as February 2012 resulted in flooding of a property at 18 Evans Street (refer to **Plates 2** to **5** on the following pages showing flooding during the February 2012 event).

Plate 2 View from Evans Street along southern side of house at 18 Evans Street showing floodwater extending up to side of house during February 2012 flood

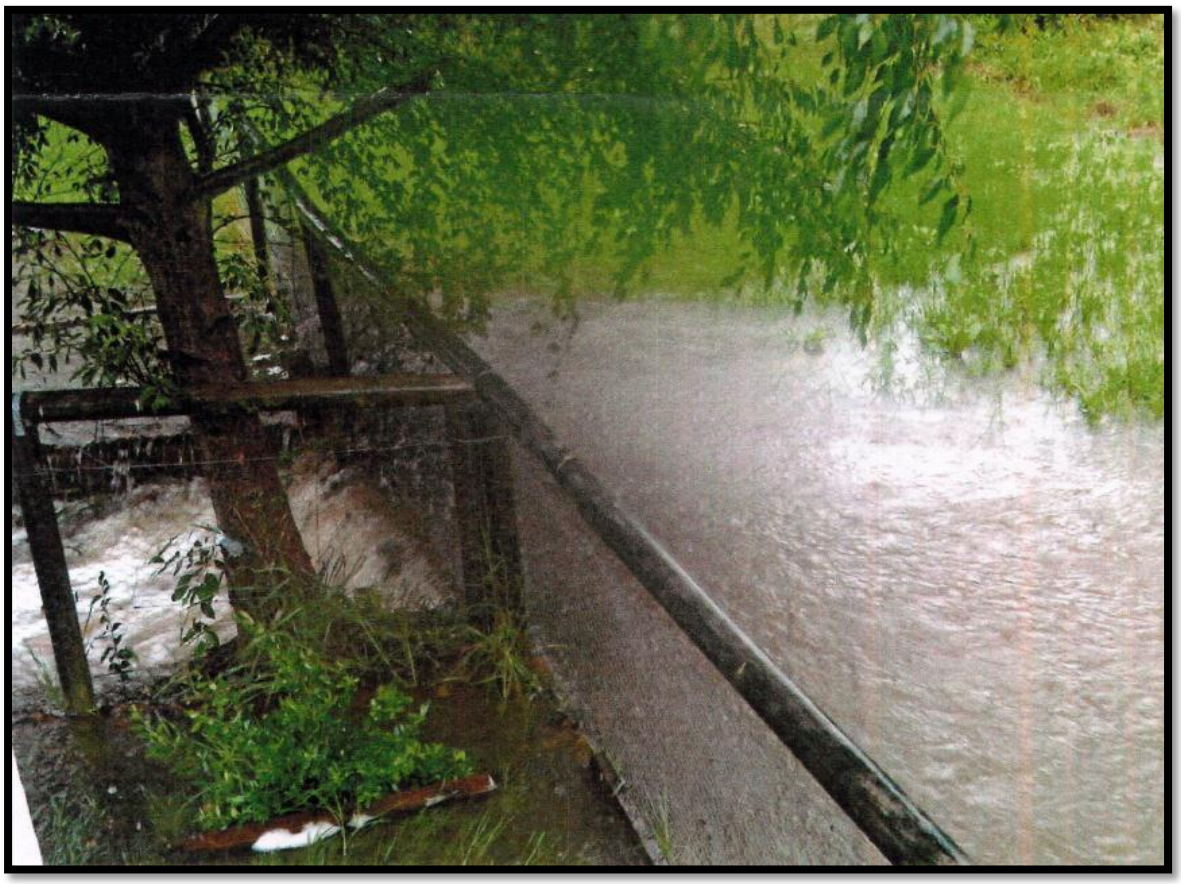


Plate 3 View showing floodwaters across rear of house at 18 Evans Street, Mittagong during February 2012 flood

Plate 4 View showing floodwaters across rear of house at 18 Evans Street, Mittagong during February 2012 flood

Plate 5 View looking south from rear of house at 18 Evans Street, Mittagong during February 2012 flood

3.6.3 Public Exhibition

Following preparation of the draft *'Nattai Creek Flood Study'* (draft, 2013), the report was placed on public exhibition for 2 months (3rd September 2013 to 4th November 2013). The public exhibition provided the community with an opportunity to review the content of the report and figures and provide feedback to Council if they considered the report could be improved.

As part of the public exhibition, two (2) submissions were received from the community. The first submission noted that the main watercourse draining through the study area is the Nattai River, not Nattai Creek. This was confirmed with the Geographical Names Board of NSW. Therefore, all references to Nattai Creek were changed to Nattai River in subsequent versions of the Flood Study.

The second submission questioned the accuracy of the 1% AEP flood results as they were considerably higher than peak 1% AEP flood levels that were previously defined as part of two separate site specific flood studies. The site in question is located between The Main Southern Railway line and Ferguson Crescent at Mittagong.

To support the submission, both of the previous flooding investigations were submitted, namely:

- *'1:100 and 1:20 Year Flood Levels for Proposed Development Upstream of Rail Bridge Nattai River, Mittagong'* (A&R Engineering Design Pty Ltd, 2007) – referred to as the "A&R Report" herein; and
- *'Flood Report for Proposed Dual Occupancy at Lot 10 DP 1069811, Ferguson Crescent Mittagong'* (SEEC, 2013) - referred to as the "SEEC Report" herein.

The "SEEC" report predicts the peak 1% AEP flood level across the site (i.e., between the Main Southern Railway and Ferguson Crescent) varies between 620.6 and 621.44. The '*Nattai River Flood Study'* predicts a peak 1% AEP flood level across the site of between 621.8 & 622.2 mAHD. Therefore, the '*Nattai River Flood Study'* is predicting 1% AEP flood levels that are approximately 1 metre higher relative to the "SEEC" report.

The "A&R" report documents a peak 1% AEP flood level of 621.3 mAHD. Accordingly, the '*Nattai River Flood Study'* is predicting peak 1% AEP flood levels that are between 0.5 and 0.9m higher than the "A&R" report.

Therefore, both reports were reviewed to determine potential reasons for the discrepancies and ultimately determine whether the '*Nattai River Flood Study'* results are reliable. It was noted that the "A&R" report was very brief (i.e., 4 pages, 3 of which show model results only). Therefore, it was difficult to provide a comprehensive commentary on the veracity of the results presented in this report. Therefore, the discussion below focusses primarily on the "SEEC" report. References to the "A&R" report are provided, where information is available.

- The "SEEC" report calculated peak flows using the Probabilistic Rational Method (PRM). This is a simplified hydrologic approach for estimating peak design discharges on rural catchments. As the Nattai Creek catchment is partially developed, peak discharges calculated using this approach will likely be underestimated as it does not consider the increased runoff from impervious surfaces. PRM calculations were completed as part of

the '*Nattai River Flood Study*' to help verify the results produced by the XP-RAFTS model. These calculations are provided in **Appendix F** and show the 1% AEP discharge in the vicinity of this site is 111 m^3/s. This compares reasonably well with the "SEEC" report (115 m^3/s). However, the XP-RAFTS model predicts a higher peak discharge at this location (i.e., 132 m^3/s). It is considered that the XP-RAFTS model provides a more reliable estimate of design flows as it can take into consideration the increases in runoff from impervious surfaces across the upstream catchment. Therefore, it is considered that the "SEEC" report is underestimating peak design flows at the site by around 15%. The lower design flows will, in turn, generate lower peak flood levels across the site.

The "A&R" report made use of the XP-RAFTS software. The peak 1% AEP discharge documented in this report is 124 m^3/s. This compares reasonably well with the peak discharge documented in the '*Nattai River Flood Study*' (132 m^3/s). The differences in peak discharge may be associated with the "A&R" report adopting more simplified approaches for calculating the impervious proportion (i.e., average values based upon each LEP zone). The '*Nattai River Flood Study*' employed a more detailed approach for defining impervious proportions by explicitly digitising impervious area polygons (e.g., roadways, car parks, houses, concrete) based on contemporary aerial images. Therefore, it is considered that XP-RAFTS model developed for the '*Nattai River Flood Study*' is providing a more detailed definition of design flows across the catchment.

- The "SEEC" and "A&R" reports only consider main stream flooding originating from the Nattai River catchment upstream of Ferguson Crescent. The '*Nattai River Flood Study*' determined that during large floods (e.g., 1% AEP event) there was potential for water from west of Beatrice Street to overtop the Southern Railway (immediately west of the Ferguson Crescent overpass of the railway line) and discharge across the Malting's site, before joining the Nattai River and discharging through the Ferguson Crescent Bridge and into the site (refer **Figure 15.8**). The additional contribution of flow from this subcatchment is likely to be a significant contributor to the higher flood levels predicted as part of the '*Nattai River Flood Study*'.
- The "SEEC" report uses the 1-dimensional HEC-RAS software to define flood behaviour across the site. It was noted that the HEC-RAS cross-section layout plan shows a number of cross-sections that overlap. As a result, the storage/conveyance provided across these overlapping cross-sections will be overestimated. The overestimation of cross-sectional conveyance/storage will result in flood levels being underestimated by the HEC-RAS model.
- The "SEEC" report does not appear to include the Main Southern Railway Bridge or Ferguson Crescent Bridge in the HEC-RAS model. The results from the '*Nattai River Flood Study*' indicate that the railway bridge causes a significant impediment to flow during large floods. Excluding these bridges from the model is likely to underestimate flood levels upstream of the railway line. In addition, the "SEEC" and "A&R" reports/modelling did not make any allowance for the impact of blockage. The ARR Project 11 Stage 2 report (Blockage of Hydraulic Structures), recommends a minimum of 10% blockage should be applied for structures when completing design flood simulations. Blockage factors varying between 20% and 50% were adopted for this study (refer Section 5.2.5). Not including blockage in the hydraulic model is likely to produce in lower peak design flood levels across the site.

- There is no discussion in the "SEEC" report on how the downstream boundary condition was defined for each design flood simulation. Given the downstream boundary of the HEC-RAS model is located immediately adjacent to the site, this boundary condition will have a significant impact on flood levels across the site. To avoid any uncertainties associated with the boundary condition impacting on results across the site, the downstream boundary of the HEC-RAS model should be extended well downstream of the site (e.g., downstream of Old Hume Highway).
- The "SEEC" HEC-RAS model adopted a Manning's 'n' roughness coefficient of 0.035 for the Nattai River channel. The '*Nattai River Flood Study*' adopted a Manning's 'n' value of 0.05 for this section of channel. The photos below show the Nattai River Channel looking upstream towards the Ferguson Crescent Bridge and downstream towards the Railway Bridge. The photos show significant reeds / vegetation within the river channel:

The following table is taken directly from the HEC-RAS hydraulic reference manual. For channels that are not maintained, it recommends a Manning's n value of at least 0.05. Accordingly, the Manning's 'n' value of 0.035 that was adopted in the HEC-RAS model is considered to be too low, leading to underestimation of peak stages across the site.

5.	**Channels not maintained, weeds and brush**			
a.	Clean bottom, brush on sides	0.040	0.050	0.080
b.	Same as above, highest stage of flow	0.045	0.070	0.110
c.	Dense weeds, high as flow depth	0.050	0.080	0.120
d.	Dense brush, high stage	0.080	0.100	0.140

- The XP-RAFTS and TUFLOW models developed for the '*Nattai River Flood Study*' were calibrated and verified against historic flood information and were shown to provide a reliable representation of flood behaviour.

Overall, it is considered that the differences in peak flood levels documented in the "SEEC" and "A&R" reports and the '*Nattai River Flood Study*' are associated with different modelling approaches and different assumptions. The '*Nattai River Flood Study*' made use of modern, two-dimensional hydraulic software that is widely used to assist in defining flood behaviour across Australia and the assumptions are based on current best practice and contemporary research/literature. The computer models developed for the '*Nattai River Flood Study*' were shown to provide a reliable description of historic flood behaviour relative to available historic flood information. The "SEEC" and "A&R" reports used simplified hydrologic calculations and 1-dimensional HEC-RAS models that were not calibrated / verified against any historic flood information. Therefore, the reliability of the results generated by the HEC-RAS models cannot

be confirmed. Therefore, it is considered that the results documented in the '*Nattai River Flood Study*' provide a reasonable description of design flood behaviour across the Nattai River catchment.

3.7 Cross-Section and Structure Survey

To enable development of a hydraulic model capable of providing reliable estimates of flood behaviour within the study area it was necessary to collect additional survey across the Nattai River catchment. Consulting surveyors, Lawrence Group, collected the additional survey information.

The additional data collection comprised the survey of 21 river cross-sections and 24 hydraulic structures (i.e., culverts and bridges). The location of cross-sections and structures that were surveyed is shown in **Figure 4**.

4 HYDROLOGIC MODEL

4.1 General

The most common method of quantifying flood flows (*i.e., discharges*) at a particular location in a catchment is via a hydrologic computer model. A hydrologic model is a mathematical representation of the various processes that transform rainfall into runoff. The model is developed so that it incorporates key hydrologic characteristics of the catchment such as area, slope and roughness. The model can then be used to simulate the transformation of rainfall into runoff for either historic or statistically derived (i.e., design) rainfall.

The XP-RAFTS software was used to develop a hydrologic computer model of the Nattai River catchment. XP-RAFTS is a lumped hydrologic computer model that is developed by XP Software (2009) and is used extensively across Australia for deriving discharge estimates. The following sections provide a summary of how the model was developed, the adopted input parameters and the outcomes of the model verification.

4.2 Hydrologic Model Development

4.2.1 Subcatchment Parameterisation

The Nattai River catchment was subdivided into 127 subcatchments based on the alignment of major flow paths, key topographic divides and the location of stormwater pipes and pits. The subcatchments were delineated with the assistance of the CatchmentSIM software (Catchment Simulation Solutions, 2012) using a 2 metre Digital Elevation Model (DEM) developed using ALS and contour data. The final subcatchment layout is presented in **Figure 5**.

The Nattai River catchment includes significant urban areas that are relatively impervious. Urbanisation effectively separates the catchment into two hydrologic systems, i.e.,:

- rapid rainfall response and low infiltration potential for impervious areas; and,
- slower rainfall response and high infiltration potential for pervious areas.

In recognition of the differing characteristics of the two hydrologic systems, each XP-RAFTS subcatchment was subdivided into two sub-areas. The first sub-area was used to represent the pervious sections of the subcatchment and the second sub-area was used to represent the impervious sections of the subcatchment. The division of each subcatchment into pervious and impervious sub-areas allows different loss rates and roughness coefficients to be specified, thereby providing a more realistic representation of rainfall-runoff processes from the two different hydrologic systems.

Key hydrologic properties including area and average vectored slope were calculated automatically for each subcatchment using CatchmentSIM. Calculated area and average vectored slopes for each subcatchment are provided in **Appendix B**.

The catchment was also subdivided into different land use types based on 2009 aerial imagery. Percentage impervious and Manning's 'n' roughness values were assigned to each land use and are summarised in **Table 6**. The percentage impervious and Manning's 'n' values were subsequently used to calculate weighted average percentage impervious and 'n' values for each subcatchment. The final subcatchment parameters are provided in **Appendix B**.

Table 6 Adopted Impervious Percentage and Manning's 'n' Values for Hydrologic Model

Land Use Description	Manning's 'n'	Impervious (%)
Short grass with isolated trees	0.035	5
Long grass with isolated trees	0.045	2
Light tree coverage	0.050	2
Medium density tree coverage	0.075	2
Dense stand of trees	0.100	2
Rock outcrops	0.040	80
Roadway pavement	0.016	100
Concrete surfaces	0.015	100
Car parks	0.022	100
Water bodies	0.030	100
Railway corridor	0.060	50
Buildings/roof area	0.025	100

4.2.2 Stream Routing

In addition to local subcatchment runoff, most subcatchments will also carry flow from upstream catchments along the main watercourses. The flow along the watercourses in XP-RAFTS is represented using a "link" between successive subcatchment "nodes".

"Routing" type links were used to represent the routing of runoff along the main watercourses into downstream subcatchments. The routing links employ Muskingum-Cunge routing procedures and require a representative cross-section, slope, length and Manning's 'n' values to be defined for each channel reach. Cross-sections were extracted from the DEM and main stream slopes and lengths were calculated automatically by CatchmentSIM. Manning's 'n' values for the main channel and overbank areas were defined by hand based on inspection of 2009 aerial photography in conjunction with the Manning's 'n' values listed in **Table 6**.

4.2.3 Rainfall Loss Model

During a typical rainfall event, not all of the rain falling on a catchment is converted to runoff. Some of the rainfall may be intercepted and stored by vegetation, some may be stored in small depression areas and some may infiltrate into the underlying soils.

To account for rainfall "losses" of this nature, the hydrologic model incorporates a rainfall loss model. For this study, the "Initial-Continuing" loss model was adopted, which is recommended in *'Australian Rainfall and Runoff – A Guide to Flood Estimation'* (Engineers Australia, 1987) for Eastern NSW.

This loss model assumes that a specified amount of rainfall is lost during the initial saturation/wetting of the catchment (referred to as the 'Initial Loss'). Further losses are applied at a constant rate to simulate infiltration/interception once the catchment is saturated (referred to as the 'Continuing Loss Rate'). The initial and continuing losses are effectively deducted from the total rainfall over the catchment, leaving the residual rainfall to be distributed across the catchment as runoff.

Initial and continuing losses were applied based on standard design values documented in *'Australian Rainfall and Runoff – A Guide to Flood Estimation'* (Engineers Australia, 1987) and are summarised in **Table 7**.

Table 7 Adopted XP-RAFTS Rainfall Losses for Calibration Simulations

Land Use Description	June 1991 Event		February 2012 Event	
	Initial Loss *(mm)*	Continuing Loss *(mm/hr)*	Initial Loss *(mm)*	Continuing Loss *(mm/hr)*
Pervious	10	2.5	20	2.5
Impervious	1.5	0	1.5	0

4.3 Hydrologic Model Calibration

4.3.1 General

Hydrologic computer models are typically developed using parameters that are not known with a high degree of certainty including imperious proportions, rainfall loss rates and catchment roughness. Accordingly, the model should be calibrated using rainfall and stream flow data from historic flood events to ensure the adopted parameters are producing reliable estimates of rainfall-runoff behaviour. Calibration is typically completed by routing recorded rainfall through the hydrologic model. Simulated discharge hydrographs are extracted from the model results at locations where recorded stream flow records are available. Calibration is completed by adjusting model parameters to achieve the best match possible between recorded and model-generated hydrographs.

Recorded stream flow records are required to perform a meaningful hydrologic model calibration. Unfortunately, no stream gauges are located within the catchment.

Therefore, the lack of stream flow data means that a comprehensive calibration of the hydrologic model cannot be completed. Nevertheless, it is possible to complete a 'pseudo-calibration' by routing historic rainfall through the hydrologic model and then routing the resultant discharge hydrographs through the hydraulic model. Peak flood extents and depths produced by the hydraulic model can then be compared against recorded flood extents / flood photographs to verify the combined performance of the hydrologic and hydraulic models. Calibration is achieved by jointly adjusting hydrologic and/or hydraulic inputs parameters until the recorded flood depths and extents are reproduced by the hydraulic model as closely as possible.

Some photographs and detailed descriptions of past floods were provided by residents as part of the responses to the community questionnaire. This included two significant floods that occurred on 10th June 1991 and 29th February 2012. Accordingly, these events were selected for the purposes of model calibration / verification. In addition, a number of residents provided general descriptions of flood behaviour that can be used to further validate the performance of the computer models.

Further details of the hydrologic model calibration / verification process are provided below. As a joint calibration was performed using both the hydrologic and hydraulic models, the hydrologic model calibration should be read in conjunction with the hydraulic model calibration, which is documented in Section 5.3.

4.3.2 Rainfall Data

Continuous rainfall data are required to define the temporal (i.e., time-varying) distribution of rainfall in the hydrologic computer model for the nominated calibration / verification event. The following continuous rainfall gauges are located in close proximity to the Nattai River catchment:

- 68102 Bowral (Parry Drive): November 1992 -> February 2011 (6 minute time step)
- 68239 Moss Vale AWS: September 2010 -> present (1 minute time step)
- 568054 Mittagong (Maquires Crossing): January 1990 -> present (60 minute time step)
- 568165 Moss Vale (Berrima Junction): June 1990 -> present (60 minute time step)

Therefore, continuous rainfall data are available for the June 1991 event (at a 60 minute temporal resolution) as well as the February 2012 flood (at a 1 minute temporal resolution).

There are also several daily read rainfall gauges located within or in close proximity to the catchment. The daily read rainfall records can be used to provide an indication of the spatial variation in rainfall during the historic event. Four daily read rainfall gauges were operational during the 1991 event and five daily read gauges were operational during the 2012 event. Accordingly, this provided sufficient information to describe the spatial variation in rainfall during both events.

4.3.3 Results of Calibration and Verification Simulations

June 1991 Simulation

A review of the rainfall records indicates that approximately 260 mm of rain fell over a 2 day period commencing on 9th June, 1991. Continuous rainfall data was extracted from the 'Mittagong (Maguires Crossing)' gauge for the 1991 event and is enclosed in **Appendix C** as **Figure C2**. A comparison between intensity-frequency-duration data for the Nattai River catchment with the continuous rainfall information from the Maquires Crossing gauge indicates that the 1991 event is slightly less severe than a 5% AEP flood (refer **Figure C1** in **Appendix C**).

Accumulated daily rainfall totals for each gauge that was operational during the 1991 event are provided in **Figure 6**. The accumulated daily rainfall totals were used to develop rainfall isohyet maps, which are also included on **Figure 6**. The isohyet maps shows that accumulated daily rainfall across the catchment varied between 119 mm and 131 mm on 10th June and 134 mm and 144 mm on 11th June. Accordingly, there was evidence of some spatial variation in rainfall across the catchment during the 1991 event. Therefore, the rainfall isohyets presented in

Figure 6 were used to estimate average rainfall depths for each subcatchment during the 1991 event. The unique rainfall depths were subsequently applied to each subcatchment in the XP-RAFTS model. That is, unique rainfall depths were applied to each subcatchment to ensure the historic spatial distribution of rainfall was represented in the XP-RAFTS model.

The 'Mittagong (Maguires Crossing)' rainfall gauge was used to describe the temporal distribution of rainfall across the 48 hour period for the 1991 event. This gauge provided a temporal resolution of 60 minutes.

A review of the daily read rainfall records indicates the June 1991 event was preceded by approximately 20 mm of rainfall. Therefore, the catchment would have been relatively 'wet' at the start of the main storm event. Accordingly, an initial loss at the lower end of the suggested *'Australian Rainfall and Runoff'* (Engineers Australia, 1987) range was applied to pervious areas for the 1991 event. A summary of the adopted initial losses and continuing loss rates is provided in **Table 2**.

A summary of peak discharges that were generated by the XP-RAFTS model for the 1991 simulation is provided in **Appendix C**.

The discharges generated by the XP-RAFTS model were subsequently input into the TUFLOW hydraulic model to simulate 1991 flood. Further information regarding the TUFLOW model setup and the outcomes of the 1991 flood simulation are provided in Section 5.3.

February 2012 Simulation

Available rainfall records indicate that approximately 100 mm of rain fell over a 2 day period between 29th February and 1st March, with 65mm falling on 29th February 2012. A review of intensity-frequency-duration data indicates that this rainfall intensity is slightly more severe than a 1 in 1 year ARI event (refer **Figure C1** in **Appendix C**). Continuous rainfall information was extracted from the Moss Vale AWS gauge for the 2012 event and is presented in **Figure C3** in **Appendix C**.

Accumulated daily rainfall totals for each gauge that was operational during the 2012 event are provided in **Figure 7**. The accumulated daily rainfall totals were used to develop rainfall isohyet maps, which are also included on **Figure 7**. The isohyet maps show that accumulated daily rainfall across the catchment varied between 64.2 mm and 65.2 mm on 29th February and 35 mm and 38 mm on 1st March. Accordingly, there was negligible spatial variation in rainfall across the catchment during the 2012 event. Therefore, a uniform accumulated rainfall depth of 64.7 mm was adopted for the 29th February and a uniform accumulated rainfall depth of 36.5 mm was adopted for the 1st March.

The Moss Vale AWS gauge was used to describe the temporal distribution of rainfall across the 48 hour period for the 2012 event. This gauge provides a detailed description of the temporal variation in rainfall during the 2012 event (i.e., a 1 minute resolution).

A review of the daily read rainfall records indicates the February 2012 event was preceded by negligible rainfall (i.e., <5mm). Therefore, the catchment would have been relatively 'dry' at the start of the main storm event. Accordingly, a higher initial loss of 20 mm was applied to the 2012 event to reflect additional losses associated with the initial saturation of the catchment. A summary of the adopted initial losses and continuing loss rates is provided in **Table 2**.

A summary of peak discharges that were generated by the XP-RAFTS model for the 2012 simulation is provided in **Appendix C**.

The discharges generated by the XP-RAFTS model were subsequently input into the TUFLOW hydraulic model to simulate the distribution of flows during the 2012 event. Further information regarding the TUFLOW model setup and the outcomes of the 2012 flood simulation are provided in the following section.

5 HYDRAULIC MODEL

5.1 General

Hydraulic computer models are the most common method of simulating flood behaviour through a particular area of interest. They can be used to predict flood characteristics such as peak flood level and flow velocity and the results of the modelling can also be used to define the variation in flood hazard and hydraulic categories across the study area.

The TUFLOW software was used to develop a hydraulic computer model of the Nattai River catchment. TUFLOW is a fully dynamic, 1D/2D finite difference model developed by BMT WBM (2013). It is used extensively across Australia to assist in defining flood behaviour.

The following sections describe the model development process as well as the outcomes of the model calibration and verification.

5.2 Hydraulic Model Development

5.2.1 Model Extent

A linked 1-dimensional/2-dimensional hydraulic model of the river, floodplain, stormwater network and overland flow system was developed for the Nattai River catchment using the TUFLOW software. The model extends across all of the Nattai River catchment draining to a point approximately 500 metres downstream of the Mittagong swimming pool. The extent of the hydraulic model is shown in **Figure 8**.

The TUFLOW software uses a uniform grid to define the spatial variation in topography and hydraulic properties (e.g., Manning's 'n') across the 2D model domain. A 2 metre grid size was adopted for this study. The 2 metre grid size is considered to provide a reasonable representation of the variation in terrain across the catchment.

A dynamically linked 1-dimensional (1D) network was embedded within the 2D domain to represent areas that would not be well represented by the 2 metre grid (e.g., narrow river channels). The sub-surface piped stormwater system was also represented as a separate 1D domain. The stormwater pipes were inserted underneath the 2D domain allowing representation of the conveyance of flows by the stormwater system below ground as well as simulation of surficial flows in 2D once the capacity of the stormwater system is exceeded. The extent of the 1D (i.e., channel and stormwater pipe system) and 2D model domains is shown in **Figure 8**.

5.2.2 Model Topography

Elevations were assigned to grid cells within the 2D domain based on the Digital Elevation Model derived from ALS data and contours. As the ALS data was collected in 2010, the terrain representation in TUFLOW is indicative of topographic conditions at that time. That is, any topographic modifications completed since 2010 will not be reflected in the model. A review of recent aerial photography indicates there has been negligible large topographic modifications

across the catchment since the ALS data was collected. Therefore, the ALS is considered to provide a reliable representation of contemporary topographic conditions across the majority of the catchment.

However, it should be noted that the ALS data generally only extends across 'built up' areas of the catchment. Therefore, across the rural sections of the catchment, the topography is defined using less detailed 10 metre contours. Accordingly, the topography and, therefore, hydraulic model results across the rural sections of the catchment will be less reliable. However, in most instances, this area comprises incised channels with negligible floodplain (refer **Plate 6**). Accordingly, any discrepancies in elevation information across this area should not produce significant errors in the depicted lateral extent of inundation.

Plate 6 Example of rural sections of the catchment with a relatively steep, incised channel.

The elevations assigned to grid cells located within building footprints were elevated by 0.3 metres based on the assumption that the floor level of houses will typically be elevated above the natural ground surface.

The topography within the surficial 1D domain was defined using surveyed cross-sections (refer Section 3.7). This was also supplemented with cross-sections extracted from the ALS in areas that were not obstructed by vegetation. The properties of culverts were assigned based on survey information and properties of the sub-surface piped drainage network were defined based on information contained within Council's stormwater asset GIS layer.

5.2.3 Material Types / Manning's 'n' Roughness

The TUFLOW software employs material polygons to define the variation in hydraulic roughness (i.e., Manning's 'n' values) across a particular study area. 2010 aerial photography was used as a basis for subdividing the catchment into different material types. Different Manning's 'n' values were assigned to each material to define the resistance to flow afforded by the different material types. The spatial distribution of the different material types is shown in **Figure 8**.

1D cross-sections, pipes and culverts within the 1D domain of the TUFLOW model also require the specification of Manning's 'n' values. These values were defined based on field assessments, survey photography and inspection of 2010 aerial photography.

The adopted materials types and the corresponding Manning's 'n' values are provided in **Table 3**.

Table 8 TUFLOW Manning's 'n' Roughness Values

Material Description	Manning's 'n'
Open space (i.e., grass)	0.035
Rural grasslands / light brush	0.045
Grass with sparse trees	0.050
Grass with medium density trees	0.075
Dense tree coverage	0.100
Rock outcrops	0.040
Roadway pavement	0.016
Concrete surfaces	0.015
Water bodies	0.030
Railway corridor	0.06
Buildings	10.00

5.2.4 Culverts/Bridges

Culverts and bridges can have a significant influence on flood behaviour through a particular study area. Accordingly, all significant bridges and culverts located within the Nattai River catchment were surveyed and included within the TUFLOW model.

For circular or rectangular culverts, the physical dimensions and invert elevations of the structures were included directly in the TUFLOW model based on the survey information that was collected. Entry and exit loss coefficients were defined based on default values provided in the TUFLOW Manual (BMT WBM, 2010). Typically, an entry loss coefficient of 0.5 and an exit loss coefficient 1.0 was adopted for all culverts.

The catchment also includes several bridge crossings. The physical dimensions of each bridge were specified using a surveyed cross-section to define the variable waterway area beneath the bridge deck. Energy losses were defined using a height versus loss coefficient relationship that was developed based on procedures outlined in *'Hydraulics of Bridge Waterways'* (Bradley, 1978).

5.2.5 Bridge/Culvert Blockage

During a typical flood, sediment, vegetation and urban debris (e.g., shopping trolleys, fences) from the catchment can become mobilised leading to blockage of downstream culverts and bridges (refer **Plate 7**). Similarly, stormwater inlets may also become blocked by debris during the course of a flood. As a result, most stormwater inlets, bridge and culverts will not operate at full efficiency during most floods. This can increase the severity of flooding across areas located adjacent to this drainage infrastructure.

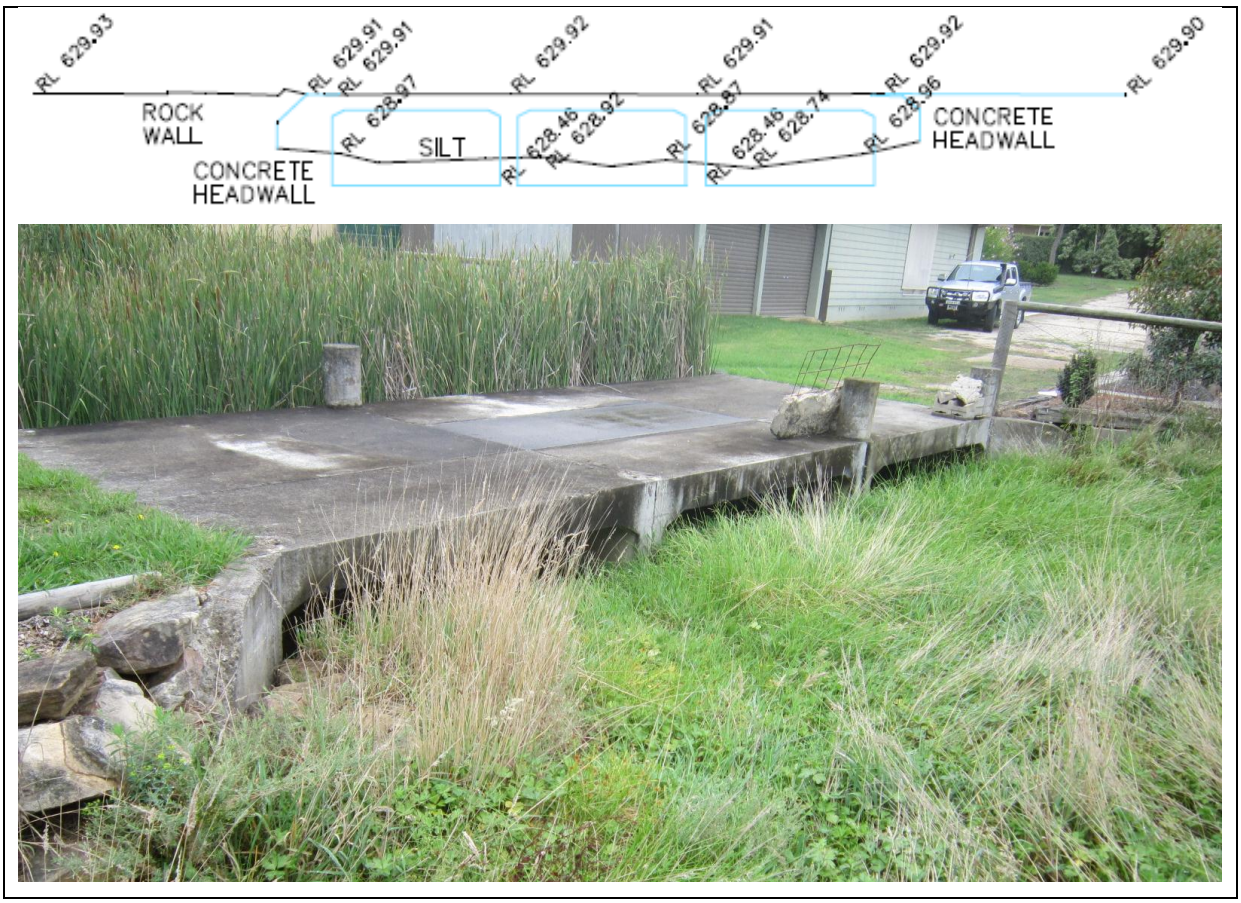


Plate 7 **Example of vegetation and silt partially blocking culvert at rear of property at 14 Evans Street, Mittagong.**

In recognition of this, blockage factors were applied to all stormwater inlets and culverts. A blockage factor of 50% was applied to all culvert and bridge crossings with a diagonal dimension of less than 6 metres in accordance with findings documented by Rigby et al (2002) following the 1998 Wollongong floods. A 50% blockage factor was also applied to all sag stormwater inlets and 20% blockage was applied to on-grade stormwater inlets.

It should be recognised that it is not known which structures will develop what percentage of blockage during any particular flood. Therefore, it is always important to consider the impact

that alternate blockage scenarios may have on flood behaviour. The impact of alternate blockage scenarios on flood behaviour is discussed in Section 9.3.

5.3 Hydraulic Model Calibration

5.3.1 General

A full calibration of the XP-RAFTS hydrologic and TUFLOW hydraulic computer models could not be completed due to the lack of stream gauges within the Nattai River catchment. Nevertheless, a joint calibration of the hydrologic and hydraulic models was attempted to verify that the computer models were providing realistic reproductions of past flood events.

5.3.2 Calibration/Verification Event Selection

As discussed in Section 4.3, photographs and descriptions of floods that occurred in June 1991 and February 2012 were provided by several residents (refer **Table 9**). Accordingly, these events were selected for the purposes of model calibration / verification. Further details of the hydraulic model calibration / verification process are provided below.

As a joint calibration was performed using the hydrologic and hydraulic models, the hydraulic model calibration should be read in conjunction with the hydrologic model calibration previously discussed in Section 4.3.

5.3.3 Model Boundary Conditions

Upstream Boundary Conditions

Upstream boundary conditions define the variation in flows with respect to time across the hydraulic model area. Inflows to the TUFLOW hydraulic model were defined using 'local' discharge hydrographs (representing flows from the local subcatchments only) extracted from the XP-RAFTS hydrologic modelling discussed in Section 4.3.

For those XP-RAFTS subcatchments containing stormwater pits, local inflows were distributed equally to the surface of all pits. For those subcatchments not containing stormwater pits, local inflows were applied to the lowest point within each sub-catchment.

Downstream Boundary Conditions

Hydraulic computer models also require the adoption of a suitable downstream boundary condition in order to reliably define flood behaviour throughout the area of interest. The downstream boundary is typically defined as a known water surface elevation (i.e., stage).

As shown in **Figure 8**, the downstream boundary of the TUFLOW model is located downstream of the Mittagong swimming pool. Accordingly, water travelling along Nattai River at this location can discharge freely downstream and there should be no 'backwater' effects from dams, creeks and rivers that may influence the water surface elevation in this area.

Accordingly, a 'normal depth' boundary was applied at the downstream end of the Nattai River TUFLOW model. This approach assumes that the downstream water level is influenced only by the geometry, roughness and slope of the Nattai River channel. Given the relatively steep slope of this section of the Nattai River channel, it is considered that any uncertainties associated with the downstream boundary condition should not impact on hydraulic model results across the "built up" sections of the catchment where historic flood information is available.

5.3.4 Modifications to Represent Historic Floodplain Conditions

A number of modifications were completed to the "existing" conditions TUFLOW model in order to represent catchment and floodplain conditions at the time of each historic flood.

June 1991

The current Colo Street box culverts replaced concrete pipes during the mid-2000s. Accordingly, the TUFLOW model was updated to include the concrete pipes that would have been present during the 1991 flood.

Information provided as part of the community questionnaire responses indicate that the 'MG1' channel between Colo and Payten Street has become significantly overgrown with vegetation / reeds over the past decade (refer **Plate 2**). Accordingly, it is likely that this channel segment would have been less vegetated in 1991 relative to current conditions. Therefore, the Manning's 'n' assigned to this channel section was reduced from 0.08-0.1 (reflecting the dense vegetation currently along this section of the channel) down to 0.05.

The questionnaire responses as well as the outcomes of the survey also indicate that a significant amount of sediment has been deposited in the 'MG1' channel between Colo and Payten Streets. Survey information for the MG1 channel (refer to **Plate 7**) shows approximately 25% of the culvert waterway area is blocked by silt/sediment. It is likely that the level of sedimentation along this section of the creek would have been significantly lower in 1991. Accordingly, it was assumed that sediment depths were half of current levels.

February 2012

No modifications were completed to the "existing" conditions model for the 2012 simulation.

5.3.5 Results of Calibration and Verification Simulations

June 1991 Simulation

Calibration of the TUFLOW hydraulic model was attempted based on descriptions of inundation extents and water depths during the 1991 flood (refer **Table 9**). The calibration was completed by routing the discharge hydrographs generated by the XP-RAFTS model for the 1991 event through the TUFLOW model and adjusting roughness parameter values until the model provided a reasonable reproduction of the historic descriptions of flood behaviour.

The roughness values listed in **Table 8** were adopted for the 1991 flood simulation. All roughness parameter values listed in **Table 8** are within reasonable limits.

The simulated extent and depth of inundation during the 1991 event is provided in **Figure 9**. **Figure 9** also incorporates velocity vector arrows, which show the direction and speed of movement of the floodwaters.

A comparison between recorded flood mark elevations and simulated flood levels for the 1991 flood is also provided in **Table 9**. The flood mark comparison locations are also shown on **Figure 9**. The comparison provided in **Table 9** and **Figure 9** shows that the TUFLOW model is producing flood level estimates that are within 120 mm of recorded flood mark elevations.

Table 9 Comparison between Recorded and Simulated Historic Flood Levels

Flood	Description	Flood Mark Elevation# (mAHD)	Simulated Flood Level (mAHD)
1991	Water was 6-10cm deep across bridge at rear of property at 14 Evans Street (8cm adopted for flood mark elevation definition).	630.0	629.88
1991	Water covered all concrete areas in back yard and extended up to rear porch at 14 Evans Street	630.3	630.28
2012	Rear of property at 18 Evans Street	630.8	630.76
2012	Looking south from rear of property at 18 Evans Street	630.9	630.90
N/A	Water depth over the driveway at 24 Evans Street never inundated to a depth of more than 250 mm	632.05 (min) 632.3 (max)	**1991:** 632.11 **2012**: 632.06
N/A	Colo Street at bruidge/culvert crossing inundated to depths of up to 0.5 metre (prior to Culvert upgrade)	628.3 (min) 628.8 (max)	**1991**: 628.41 **2012**: 628.38
N/A	Payten Street impassable (minimum 0.1m depth of water assumed across lowest point in roadway profile)	635.1 (min)	**1991**: 635.19 **2012**: 635.12

NOTE: # Flood mark elevations are based upon interpretation of photographs and flood descriptions provided by residents. Therefore, they should be considered approximate only.

Also included in **Table 9** are general descriptions of flood heights provided as part of the questionnaire responses. These heights weren't related to a specific date of flooding. However, the heights can be used to give a general indication of whether the hydraulic model is providing reasonable estimates of flood behaviour in areas away from the flood marks. The 1991 flood simulation produces simulated flood heights that are above the 'minimum' flood elevations and below the 'maximum' flood elevations listed in **Table 9**.

The close correlation between simulated and recorded flood mark elevations and the agreement with other reported instances of past flooding indicates that the TUFLOW model is providing a realistic representation of flood behaviour during the 1991 flood.

February 2012 Simulation

The TUFLOW hydraulic model was also verified using flood marks that were estimated based on two photographs of a flood that occurred in February 2012. The photographs show floodwater depths and extents at the rear of a property at 18 Evans Street, Mittagong (refer **Table 9**). The verification was completed by routing the discharge hydrographs generated by the XP-RAFTS model for the 2012 event through the TUFLOW model. The same model inputs and parameters were retained for the 2012 simulation as was adopted for the 1991 simulation with the exception of the model updates discussed in Section 5.3.4.

Peak floodwater depths, levels and velocities generated by the TUFLOW model for the 2012 simulation are provided in **Figure 10**. A comparison between recorded flood mark elevations and simulated flood levels for the 2012 flood is also provided in **Table 9**. The flood mark comparison locations are also shown on **Figure 10**.

The comparison provided in **Table 9** and **Figure 10** shows that the TUFLOW model is producing flood level estimates that are within 30 mm of recorded flood mark elevations. The extent and depth of inundation shown in the photographs in **Table 4** also appears to be reasonably well produced by the TUFLOW model (refer **Figure 10.7**).

The 2012 flood simulation also produces simulated flood heights that are typically above the non-date specific 'minimum' flood elevations and below the 'maximum' flood elevations listed in **Table 9**.

In general, the depths and extents of inundation produced by the TUFLOW model appear to provide a reasonable reproduction of peak flood levels and depths shown in historic flood photographs and also agree with anecdotal information provided for other floods. Accordingly, the TUFLOW model is considered to be providing realistic estimates of historic flood behaviour for the 2012 flood.

5.3.6 Additional Model Verification

Figures 9 and **10** also incorporate points corresponding to locations where community questionnaire responses were received. These locations were colour-coded based upon whether the resident had reported flooding or drainage problems as part of the questionnaire response or not. Accordingly, it was considered that this information could be compared against the extents of inundation for the 1991 and 2012 events to provide an additional means of verifying the model performance. That is, if the extents of inundation produced by the TUFLOW model where in close proximity to areas where flooding problems have been

reported, it would provide additional confidence that the model was providing a reasonable reproduction of past floods.

It should be noted that in a lot of instances the exact dates of the flooding problems were not specified. Accordingly, it is not known whether the reported flooding problems occurred in 1991 or 2012. In addition, the locations are based on the address provided by the respondent and may not reflect the actual location of the reported flooding "trouble spot". Nevertheless, it can provide a general indication of the "reasonableness" of the hydraulic model performance relative to past flood events.

As shown in **Figures 9** and **10**, the inundation extents are generally located in close proximity to locations where flooding/drainage problems were reported. There are some areas where inundation is shown and no flooding problems were reported. However, the depth of inundation across these areas is typically less than 50 mm and respondents may not have classified these shallow depths of inundation as flooding.

In general, **Figures 9** and **10** and show that the model is identifying areas were historic flooding problems have occurred.

5.3.7 Summary

A definitive calibration of the Nattai River XP-RAFTS hydrologic model and TUFLOW hydraulic model could not be completed due to the lack of historic stream gauging data. Nevertheless, a pseudo calibration and verification of the models was attempted using historic rainfall data in conjunction with descriptions of past floods and flood photographs provided by the community.

The outcomes of the calibration and verification simulations indicate that the XP-RAFTS hydrologic model and TUFLOW hydraulic model provides a reliable reproduction of the historic flood behaviour during small to medium sized floods. Accordingly, it is considered that the XP-RAFTS and TUFLOW models are suitable for use in simulating design flood behaviour across the Nattai River catchment.

It should be noted that no calibration is available for large floods (i.e., > 5% AEP flood). Therefore, the reliability of the model performance during large floods cannot be verified.

6 Design Flood Simulations

6.1 General

Design floods are hypothetical floods that are commonly used for planning and floodplain management investigations. Design floods are based on statistical analysis of rainfall and flood records and are typically defined by their probability of exceedance. This is typically expressed as an Annual Exceedance Probability (AEP).

The AEP of a particular flood level or discharge at a specific location is the probability that the flood level/discharge will be equalled or exceeded in any one year. For example, a 1% AEP flood has a 1% chance of being equalled or exceeded in any one year.

Design floods can also be expressed by their Average Recurrence Interval (ARI). For example, the 1% AEP flood can also be expressed as a 1 in 100 year ARI flood. That is, the 1% AEP flood will occur, on average, once every 100 years.

It should be noted that there is no guarantee that a 1% AEP flood will occur just once in a 100 year period. It may occur more than once, or at no time at all in the 100 year period. This is because design floods are based upon a long-term statistical average. For example, there is a 50% chance that a 1% AEP flood will occur once within a 70 year period and a 15% chance that it will occur twice within the same 70 year period. Therefore, it is prudent that the community understands that the occurrence of recent large floods does not preclude the potential for another large flood to occur in the immediate future.

Design floods are typically estimated by applying design rainfall to the hydrologic model to develop design flood hydrographs at various locations throughout the catchment. The design flood hydrographs are then routed through the hydraulic model to derive design flood level, depth and velocity estimates. The procedures employed in deriving design flood estimates for the Nattai River catchment are outlined in the following sections.

6.2 Hydrology

6.2.1 Design Rainfall

Design storms for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events were derived using standard procedures outlined in *'Australian Rainfall and Runoff – A Guide to Flood Estimation'* (Engineers Australia, 1987). Design rainfall intensities were extracted from *'Australian Rainfall and Runoff'* and were used in conjunction with design temporal patterns to describe the temporal variation in rainfall throughout each design storm.

Adopted rainfall intensities for each design storm and duration are summarised in **Table 10**
.

Table 10 Design Rainfall Intensities

DURATION	Rainfall Intensity (mm/hr)						
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMP
10 mins	100	114	132	156	175	196	N/A
15 mins	86.5	97.7	113	133	149	165	600
30 mins	59.5	67.8	78.7	93.1	104	118	440
45 mins	49.4	55.9	64.9	76.8	85.9	95.2	373
1 hour	40.5	46.1	53.6	63.4	71.0	81.2	320
90 mins	33.1	37.6	43.7	51.8	58.1	64.5	273
2 hours	26.6	30.4	35.4	41.9	47.0	54.6	240
2.5 hours	N/A	N/A	N/A	N/A	N/A	N/A	212
3 hours	20.7	23.6	27.5	32.6	36.6	43.1	193
4 hours	N/A	N/A	N/A	N/A	N/A	N/A	168
5 hours	N/A	N/A	N/A	N/A	N/A	N/A	146
6 hours	13.4	15.3	17.8	21.2	23.8	28.6	130
12 hours	9.31	10.7	12.6	15.1	17.1	19.1	N/A
24 hours	8.75	10.0	11.7	13.9	15.6	12.2	N/A
48 hours	5.80	6.64	7.73	9.18	10.3	7.66	N/A
72 hours	3.81	4.34	5.05	5.98	6.69	5.66	N/A

NOTE: N/A indicates a design rainfall is not applicable for this duration

6.2.2 Probable Maximum Precipitation (PMP)

As part of the flood study it was also necessary to define flood characteristics for the Probable Maximum Flood (PMF). The PMF is estimated by routing the Probable Maximum Precipitation (PMP) through the hydrologic model. The PMP is defined as the greatest depth of precipitation that is meteorologically possible for a given duration at a specific location at a particular time of year.

PMP depths were derived for a range of different durations for the Nattai River catchment based on procedures set out in the Bureau of Meteorology's *'Generalised Short Duration Method'* (GSDM) (Bureau of Meteorology, 2003). The GSDM PMP calculations are included in **Appendix E** and the PMP intensities are also summarised in **Table 10**.

6.2.3 Rainfall Loss Model

As discussed in Section 4.2.3, the "Initial-Continuing" loss model was adopted in the XP-RAFTS model to represent rainfall loses across the catchment. The rainfall losses that were adopted for the design flood simulations are summarised in **Table 11**. The adopted rainfall losses for all design events were consistent with those adopted in the calibration / verification simulations.

Table 11 Adopted XP-RAFTS Design Rainfall Losses

Land Use Description	Initial Loss *(mm)*	Continuing Loss *(mm/hr)*
Pervious	15.0	2.5
Impervious	1.5	0.0

6.2.4 Peak Discharges

The XP-RAFTS model was used to simulate the 20%, 10%, 5%, 2%, 1% and 0.5% AEP design floods as well as the PMF.

A range of storm durations were modelled for each design storm to establish the critical storm duration for each Nattai River subcatchment. Peak discharges were extracted from the XP-RAFTS model for each subcatchment and each storm duration and are provided in **Appendix E**. Peak discharges at key locations throughout the catchment are also summarised in **Table 12**.

The results of the design simulations indicate that the critical storm duration for the majority of subcatchments varies between 1.5 and 2 hours. However, during the PMF the critical duration reduces to between 15 and 45 minutes.

6.2.5 Verification of Design Discharges

Probabilistic Rational Method

As a comprehensive calibration of the XP-RAFTS model could not be completed due to a lack of recorded stream flow data, additional verification of the 1% AEP discharges was completed. The verification involved comparing peak 1% AEP discharges generated by the XP-RAFTS model against peak discharges calculated using the Probabilistic Rational Method (PRM). A complete listing of 1% AEP XP-RAFTS discharges and PRM discharges at the outlet of each subcatchment is provided in **Appendix F**.

In general, the XP-RAFTS and PRM discharges provided in **Appendix F** show a good correlation with discharges typically agreeing to within 15%. The PRM typically predicts slightly lower discharges relative to the XP-RAFTS model. This is not unexpected as the PRM fails to account for the increased runoff potential across impervious sections of the catchment.

Previous Studies

The peak 1% AEP discharges predicted by XP-RAFTS were also verified against previous flooding investigations. This comparison is summarised in **Table 13**.

The comparison shows that the peak 5% and 1% AEP discharges generated by the XP-RAFTS model compares favourably with peak discharges documented in the *'Mittagong Catchment MG1 Flood Study Report'* (Maunsell, 2003) at Webb Street. Design discharges agree to better than 10% at this location.

Table 12 Peak Design Discharges for Existing Conditions

Location (XP-RAFTS ID)		Peak Discharge (m^3/s)						
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Old South Road *(1.01)*	Nattai River	2.47	3.16	4.03	4.72	5.88	7.06	33.1
Range Road *(1.09)*	Nattai River	34.9	44.6	58.6	74.9	90.6	107	494
Games Field Access Road *(1.12)*	Nattai River	35.9	46.1	60.7	77.6	93.8	110	517
Colo Street *(1.16)*	Nattai River	39.1	50.1	65.1	82.6	99.8	119	575
Mittagong Maltings *(1.18)*	Nattai River	46.4	57.6	75.9	96.1	116	139	687
Ferguson Crescent *(1.19)*	Nattai River	46.6	57.9	76.2	96.5	117	139	691
Main Southern Railway *(1.20)*	Nattai River	46.6	57.9	76.3	96.7	117	140	692
Old Hume Highway *(1.21)*	Nattai River	46.9	58.2	76.6	97.2	118	140	695
US of Swimming Pool *(1.23)*	Nattai River	49.3	60.8	79.8	102	123	147	731
Downstream Boundary *(1.27)*	Nattai River	49.9	61.6	80.6	103	124	148	738
Webb Street *(23.05)*	MG1 Creek	6.05	7.76	10.1	13.0	15.9	18.6	88.4
Payten Street *(23.07)*	MG1 Creek	6.70	8.53	11.2	14.3	17.5	20.3	98.0
Colo Street *(23.10)*	MG1 Creek	8.21	9.93	13.0	16.8	20.3	23.6	118
Oxley Drive *(12.02)*	Unnamed Tributary	1.61	1.96	2.73	3.50	4.32	5.14	20.1
Robinson Street *(12.04)*	Unnamed Tributary	7.84	9.84	13.2	16.9	20.5	24.1	104
Nero Street *(14.02)*	Unnamed Tributary	1.91	2.39	3.21	4.07	5.05	5.89	24.7
Range Road *(20.02)*	Unnamed Tributary	1.65	2.14	2.85	3.47	4.07	4.74	26.4

Table 13 Comparison between XP-RAFTS Design Discharges and Discharges Documented in Previous Flooding Investigations

Location	5% AEP Peak Discharge (m^3/s)		1% AEP Peak Discharge (m^3/s)	
	Current Study	MG1 Flood Study Report (2003)	Current Study	MG1 Flood Study Report (2003)
MG1 crossing of Webb Street	10.1	9.76	15.9	14.8
MG1 crossing of Payton Street	11.2	16.3	17.5	22.8
MG1 Crossing of Colo Street	16.8	17.9	20.3	24.2

However, the comparison is less favourable at Payton Street and Colo Street. As discussed in Section 3.2.1, the *'Mittagong Catchment MG1 Flood Study Report'* (Maunsell, 2003) appears to have over-estimated the catchment draining to Payton Street. Consequently, the peak discharges documented in this report for the area downstream of Payton Street are considered to be overestimated. This appears to be confirmed in **Table 13** where the XP-RAFTS model produces lower peak discharges at both locations.

Overall, the comparison of XP-RAFTS model discharges with the PRM and previous studies shows the XP-RAFTS model is producing realistic design discharge estimates. Where significant differences do occur, it is considered to be associated with errors in the previous investigations.

6.3 Hydraulics

6.3.1 General

The TUFLOW hydraulic model was used to simulate design flood behaviour across the Nattai River catchment for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events as well as the Probable Maximum Flood (PMF).

The procedures employed in developing the design flood estimates are outlined in the following sections.

6.3.2 Model Boundary Conditions

Flow Boundary Conditions

Flow boundary conditions provide a description of the spatial and time variation of flows across the hydraulic model domain during each design storm. Inflows to the TUFLOW hydraulic model were defined using 'local' discharge hydrographs (representing flows from the local subcatchments only) extracted from the XP-RAFTS hydrologic modelling.

Downstream Boundary Conditions

Downstream boundary conditions for the Nattai River TUFLOW model were defined using a "normal depth" calculation. That is, the downstream stage was defined based on the stream geometry and slope as well as the total discharge at the downstream model boundary.

Given the relatively steep slope of the downstream reaches of the Nattai River channel, it is considered that any uncertainties associated with the downstream boundary condition should not impact on hydraulic model results across the "built up" sections of the catchment.

6.3.3 Design Flood Envelope

The TUFLOW hydraulic model was used to simulate flood behaviour across the Nattai River catchment for a range of design floods and a range of storm durations. The model produced information on flood levels, depths and velocities across the Nattai River catchment for each design flood and each duration.

As discussed, a range of critical durations are evident across the study area. Therefore, a single storm duration will not necessarily produce the "worst case" flooding across all sections of the catchment.

An important outcome of this study was to ensure that the "worst case" flooding conditions were defined across the entire Nattai River catchment. Therefore, a design flood envelope was developed for each design flood based on analysis of each storm duration at each TUFLOW grid cell. This involved extracting and comparing peak flood levels, depths and velocities at each TUFLOW model grid cell for each simulated duration and the highest depth, level and velocity at each grid cell was subsequently adopted. It is this design flood envelope, comprising the worst case depths, velocities and levels at each grid cell that forms the basis for the results documented in the following sections.

6.3.4 Floodwater Depths, Levels and Velocities

Peak flood levels, depths and velocities for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events as well as the Probable Maximum Flood (PMF) were extracted from the results of the TUFLOW model. Peak floodwater depths, levels and velocity vectors are presented in **Figures 11** to **17**.

Peak flood levels were also extracted from the results of the modelling and are presented in **Table 14** at key locations throughout the Nattai River catchment. The location identification (ID) numbers can also be referenced by the yellow points in **Figures 11** to **17**.

6.3.5 Verification of Design Flood Levels

To help verify the reliability of the TUFLOW model, peak 1% AEP flood levels generated by the TUFLOW model were compared against peak 1% AEP flood levels documented in the *'Mittagong Catchment MG1 Flood Study Report'* (Maunsell, 2003). This comparison is presented in **Table 15**.

The flood level comparison provided in **Table 15** shows that the TUFLOW hydraulic model generally produces lower flood levels relative to the HEC-RAS hydraulic model developed as part of the *'Mittagong Catchment MG1 Flood Study Report'* (Maunsell, 2003). The differences in the vicinity of Payton Street are around 0.3 metres, while the differences in the vicinity of Colo Street are less than 0.1 metre.

Table 14Peak Design Floodwater Elevations

ID	Tributary	Location	Peak Stage *(mAHD)*						
			20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
1	Nattai River	Old South Road	753.40	753.66	753.76	753.83	753.88	753.92	754.35
2		Range Road	638.53	638.88	639.32	639.74	640.05	640.30	642.11
3		Games Field	633.87	634.06	634.31	634.53	634.73	634.92	636.91
4		Colo Street	628.21	628.45	628.59	628.70	628.80	628.90	630.22
5		Mittagong Maltings	623.71	623.90	624.11	624.29	624.42	624.54	626.47
6		Ferguson Crescent	620.89	621.23	621.71	621.99	622.23	622.67	625.15
7		Main Southern Railway	620.60	620.95	621.45	621.66	621.83	621.97	624.28
8		Old Hume Highway	620.52	620.86	621.33	621.48	621.60	621.67	623.32
9		US Swimming Pool	617.94	618.02	618.15	618.38	618.48	618.60	622.31
10		DS Swimming Pool	615.35	615.55	615.88	616.19	616.42	616.59	619.72
11	MG1	Unnamed Driveway	648.99	649.03	649.08	649.12	649.16	649.20	649.69
12		Webb Street	643.16	643.28	643.37	643.42	643.48	643.53	644.10
13		Payton Street	635.36	635.40	635.45	635.48	635.52	635.56	636.05
14		16 Evans Street	629.89	630.01	630.10	630.20	630.28	630.35	630.97
15		Colo Street	628.47	628.53	628.57	628.63	628.68	628.72	629.28
16	Unnamed Tributaries	Oxley Drive	690.53	690.59	690.67	690.74	690.78	690.82	691.32
17		Robinson Street	650.65	650.71	650.78	650.85	650.89	650.93	651.58
18		Range Road	659.53	659.56	659.60	659.64	659.65	659.67	660.08

refer to Figures 11 to 17 for Location ID

Table 15 Comparison between TUFLOW Design Flood Levels and Flood Levels Documented in Previous Flooding Investigations

Location	5% AEP Peak Stage *(mAHD)*		1% AEP Peak Stage *(mAHD)*	
	Current Study	MG1 Flood Study Report (2003)	Current Study	MG1 Flood Study Report (2003)
MG1 crossing of Payton Street	635.45	635.74	635.52	635.82
MG1 Crossing of Colo Street	628.57	628.66	628.68	628.73

As discussed in Section 6.2.5, the *'Mittagong Catchment MG1 Flood Study Report'* (Maunsell, 2003) is considered to have overestimated the catchment area and peak design discharges between Payton Street and Colo Street. Consequently, the peak design flood level estimates are also considered to be overestimated. The differences between peak design water levels at Colo Street are less pronounced due to the backwater effects from Nattai River (the previous study did not consider backwater flooding from Nattai River).

Overall, the comparison indicates the TUFLOW model produces flood levels that are within 0.3m of this previous study. If comparable peak discharges were used it is considered the flood level comparison would be even closer. Therefore, the TUFLOW model is generating realistic design flood level estimates.

7 Flood Hazard and Hydraulic Categorisation

7.1 Provisional Flood Hazard Categories

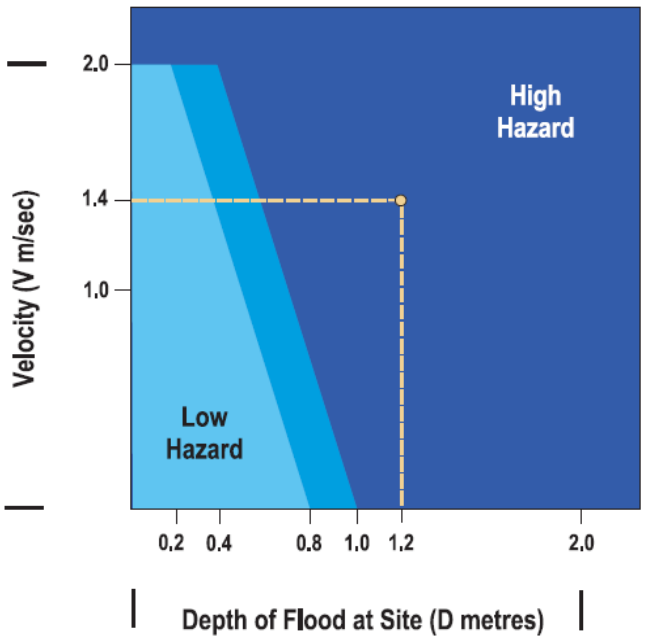
Flood hazard effectively defines the impact that flooding will have on development and people across different sections of the floodplain.

The determination of flood hazard at a particular location requires consideration of a number of factors, including (NSW Government, 2005):

- depth and velocity of floodwaters;
- size of the flood;
- effective warning time;
- flood awareness;
- rate of rise of floodwaters;
- duration of flooding; and
- potential for evacuation.

Consideration of all of the above items is generally completed as part of the Floodplain Risk Management Study. The scope of the Flood Study typically only requires a provisional estimate of the flood hazard to be determined. The provisional flood hazard is based solely on the depth and velocity of floodwaters.

The provisional flood hazard at a particular area of a floodplain can be established from **Figure L2** of the *'Floodplain Development Manual'* (NSW Government, 2005). This figure is reproduced on the right.



Notes

The degree of hazard may be either -

- reduced by establishment of an effective flood evacuation procedure.
- increased if evacuation difficulties exist.

In the transition zone highlight by the median colour, the degree of hazard is dependant on site conditions and the nature of the proposed development.

Example:

If the depth of flood water is **1.2 m**
and the velocity of floodwater is **1.4 m/sec**
then the provisional hazard is **high**

FIGURE L2 - Provisional Hydraulic Hazard Categories

As shown in **Figure L2**, the *'Floodplain Development Manual'* (NSW Government, 2005) divides hazard into two categories, namely high and low. It also includes a "transition zone" between the low and high hazard categories. Sections of the floodplain located in the "transition zone" may be classified as either high or low depending on site conditions or the nature of any proposed development.

7.1.1 Provisional Flood Hazard

The TUFLOW hydraulic software was used to automatically calculate the variation in provisional flood hazard across the Nattai River catchment based on the criteria shown in Figure L2. The hazard categories for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events as well as the PMF are shown in **Figures 18** to **24**.

It needs to be reinforced that the hazard represented in this mapping is provisional only. This is because it is based only on an interpretation of the flood hydraulics and does not reflect the effects of other factors that influence flood hazard.

Accordingly, modification of the hazard categories presented in **Figures 18** to **24** may occur as part of investigations to be carried out during the subsequent Floodplain Risk Management Study.

7.2 Hydraulic Categories

The NSW Government's *'Floodplain Development Manual'* (NSW Government, 2005) also characterises flood prone areas according to the hydraulic categories presented in **Table 16**. The hydraulic categories provide an indication of the potential for development across different sections of the floodplain to impact on existing flood behaviour and highlights areas that should be retained for the conveyance of floodwaters.

7.2.1 Adopted Hydraulic Categories

Unlike provisional hazard categories, the *'Floodplain Development Manual'* (NSW Government, 2005) does not provide explicit quantitative criteria for defining hydraulic categories. This is because the extent of floodway, flood storage and flood fringe areas are typically specific to a particular catchment.

However, the *'Floodplain Development Manual'* (NSW Government, 2005) does provide qualitative guidelines to assist in the delineation of hydraulic categories. The *'Floodway Definition'* guideline (Department of Environment and Climate Change, 2007) also provides additional guidance for the definition of floodway extents. These qualitative guidelines are also summarised in **Table 16**.

The results of the design flood simulations were interrogated to assess the potential extent of floodway, flood storage and flood fringe areas based on the qualitative guidelines listed in **Table 16**. Preliminary hydraulic category boundaries were delineated by hand across different areas of the Nattai River catchment. The extent of each preliminary hydraulic category boundary was superimposed on peak depth, flow velocity and velocity-depth product values to determine if the hydraulic categories could be defined numerically. The results of this assessment determined that the depth, velocity and velocity-depth product values listed in the third column of **Table 16** could be used to automate the delineation of hydraulic categories for the Nattai River catchment. Some additional post processing of the hydraulic categories was completed to ensure continuity of floodways and to remove small, isolated categories.

The resulting hydraulic category maps for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events as well as the PMF are shown in **Figures 25** to **31**.

Table 16 Qualitative and Quantitative Criteria for Hydraulic Categories

Hydraulic Category	Qualitative Description	Adopted Criteria*
Floodway	• those areas where a significant volume of water flows during floods • often aligned with obvious natural channels and drainage depressions • they are areas that, even if only partially blocked, would have a significant impact on upstream water levels and/or would divert water from existing flowpaths resulting in the development of new flowpaths. • they are often, but not necessarily, areas with deeper flow or areas where higher velocities occur.	• V x D > 0.3 m AND V > 0.5 m/s
Flood Storage	• those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood • if the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. • substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.	If not Floodway or Flood Fringe
Flood Fringe	• the remaining area of land affected by flooding, after floodway and flood storage areas have been defined. • development (e.g., filling) in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.	• V < 0.4 m/s AND D <= 0.05m

NOTES: V = Velocity, D = Depth
Hydraulic categories were only applied to areas subject to inundation (i.e., D > 0m)
**The adopted criteria were developed specifically for the Nattai River Catchment only and may not be appropriate for any other areas.*

7.2.2 Verification of Hydraulic Categories

Floodway

In order to verify the suitability of the delineated floodways, additional checks were performed in accordance with recommendations outlined in the former Department of Environment and Climate Change (now Office of Environment and Heritage) *'Floodway Definition'* (Department of Environment & Climate Change, 2007) guideline. This involved blocking sections of the delineated floodways and quantifying the impact that this blockage had on peak flood levels as well as the distribution of floodwaters in the vicinity of the blockage during the 1% AEP flood. The outcomes of this assessment are presented in **Appendix G** as **Plates G1** to **G4** (blockage locations are highlighted in Black/Red).

The flood level difference mapping shows that partial blockage of the delineated floodway extents would increase peak flood levels by more than 0.2 metres in most instances. This is considered to be a "significant impact" on upstream water levels. The depth and velocity mapping also shows that the blockages would cause a significant redistribution of floodwaters in most instances.

The results depicted in **Plates G1** to **G4** are considered to be consistent with the qualitative floodway descriptions outlined in the *'Floodway Definition'* guideline and *'Floodplain Development Manual'* (NSW Government, 2005) and indicate that the delineated floodway extents are reasonable.

Flood Storage

The *"Floodplain Development Manual"* (NSW Government, 2005) states that flood storages are areas that are important for the temporary storage of water during the passage of a flood. They are areas that are typically exposed to relatively deep, but slow moving water.

The suitability of the delineated flood storage areas was verified by increasing the Manning's 'n' value assigned to the storage areas to 0.2 and re-simulating the 1% AEP flood. The results of the simulations were then reviewed to determine if the increases in Manning's 'n' produced an unacceptable increase in flood level. Flood level difference mapping was prepared and is presented in **Appendix G** as **Plates G5** to **G6**.

The difference mapping indicates that increasing the roughness of all flood storage areas will increase peak 1% AEP flood levels by less than 0.20 metres. In most cases, the increases in peak 1% AEP flood level are between 0.05 and 0.15 metres. Given the significant increase in Manning's 'n' across the flood storage areas it is considered that increases in peak flood level of this magnitude are within acceptable limits. Accordingly, it is suggested the extent of the flood storages is appropriate.

Flood Fringe

Flood fringes are areas that, by definition, can be completely filled without having a significant impact on flood behaviour. Therefore, in order to verify the suitability of the delineated flood fringe areas, an additional 1% AEP simulation was completed incorporating filling of all flood fringe areas. Flood level difference mapping was prepared based on the outcomes of the additional simulation and is presented in **Appendix G** as **Plate G7**.

The difference mapping indicates complete filling of all flood fringe areas will typically increase peak 1% AEP flood levels by less than 0.1 metres. This is considered to be a relatively minor impact and indicates that adopted flood fringe extents are reasonable.

8 CLIMATE CHANGE ASSESSMENT

8.1 General

The Office of Environment and Heritage's (formerly Department of Environment, Climate Change and Water) *'Practical Consideration of Climate Change'* states that climate change is expected to have adverse impacts on sea levels and rainfall intensities into the future. Although any future rises in see level are unlikely to have an impact on flood behaviour across the Nattai River catchment, increases in rainfall intensities have the potential to increase runoff volumes and peak discharges, thereby increasing the severity of flooding.

This flood study will form the basis for defining flood behaviour for a number of years into the future. It will also form the basis for the future Floodplain Risk Management Study, where a range of flood risk mitigation measures will be evaluated. Therefore, it is important that potential climate change impacts are quantified so that development decisions and the robustness of flood risk mitigation measures can be assessed in an informed manner.

The following sections describe the process that was employed to quantify climate change impacts on flooding across the Nattai River catchment.

8.2 Hydrology

8.2.1 General

The *'Practical Consideration of Climate Change'* (Department of Environment and Climate Change, 2007) guideline states that rainfall intensities are predicted to increase in the future. The NSW Government's *'Climate Change in the Sydney Metropolitan Catchments'* (CSIRO, 2007) elaborates on this further and suggests that annual rainfall is likely to decrease, however, extreme rainfall events are likely to more intense. It is anticipated that extreme rainfall intensities could increase by between 2% and 24% by 2070 (Department of Environment and Climate Change, 2007).

Due to the wide potential variability of future rainfall intensities, the *'Practical Consideration of Climate Change'* (Department of Environment and Climate Change, 2007) provides guidelines for quantifying the potential impacts of these changes. The guideline states that additional simulations should be completed with 10%, 20% and 30% increases in rainfall intensities to quantify the potential impacts associated with climate change.

8.2.2 Results

The XP-RAFTS model was used to perform additional simulations incorporating increases in 1% AEP rainfall intensity of 10%, 20% and 30% in accordance with the OEH guideline. Peak discharges were extracted from the results of each climate change simulation and are summarised in **Appendix H**. XP-RAFTS discharges for "existing" conditions are also included in **Appendix H** for comparison.

The results provided in **Appendix H** show that a 10% increase in peak 1% AEP design rainfall intensities will increase peak 1% AEP discharges about 14%, on average. The results also show that a 20% and 30% increase in design rainfall intensities will increase average peak 1% AEP discharges by about 28% and 42% respectively. Accordingly, increases in rainfall intensity of this magnitude have the potential to cause significant increases in flood flows across the entire catchment.

8.3 Hydraulics

8.3.1 Results

In order to quantify the impact that increases in rainfall intensity of 10%, 20% and 30% may have on design floodwater levels, depths and velocities, the flows from the XP-RAFTS climate change simulations were extracted and routed through the TUFLOW hydraulic model.

Peak floodwater levels were extracted from the results of the modelling at select locations across the catchment and are presented in **Appendix I**. Peak levels for "existing" conditions are also provided in **Appendix I** for comparison.

The results provided in **Appendix I** show that a 10% increase in peak 100 year ARI design rainfall intensities will increase peak 100 year flood levels by less than 100mm, on average. The results also show that a 20% and 30% increase in design rainfall intensities will increase peak 1% AEP flood levels by about 150 mm and 200 mm respectively. Accordingly, as floodwater depths across the majority of the floodplain areas are quite shallow, increases in flood level of this magnitude have the potential to increase the severity of flooding considerably.

9 SENSITIVITY ANALYSIS

9.1 General

Hydrologic and hydraulic computer models require the estimation of several parameters that are not necessarily known with a high degree of certainty. Each of these parameters can impact on the results generated by the model.

Typically hydrologic and hydraulic computer models are calibrated using recorded rainfall, stream flow and/or flood mark information. Calibration is achieved by adjusting the parameters that are not known with a high degree of certainty until the computer models reproduce the recorded flood information.

As discussed, the XP-RAFTS hydrologic and TUFLOW hydraulic models developed for this study could not be comprehensively calibrated as there was insufficient recorded stream flow information. However, the models were verified against floods that occurred in 1991 and 2012 and were found to provide a reasonable description of historic flood behaviour.

Nevertheless, it is important to understand how any uncertainties in model input parameters may impact on the results produced by the model. Therefore, a sensitivity analysis was undertaken to establish the sensitivity of the results generated by the computer model to changes in model input parameter values. The outcomes of the sensitivity analysis are provided below.

9.2 Hydrologic Model

9.2.1 Initial Loss

An analysis was undertaken for the 1% AEP storm to assess the sensitivity of the results generated by the XP-RAFTS model to variations in antecedent wetness conditions (i.e., the dryness or wetness of the land within the catchment prior to the design storm event). A catchment that has been saturated prior to a major storm will have less capacity to absorb rainfall. Therefore, under wet antecedent conditions, there will be less "loss" of rainfall and consequently more runoff.

The variation in antecedent wetness conditions was represented by modifying the adopted initial rainfall losses in the XP-RAFTS model. The results of the sensitivity simulations for each XP-RAFTS subcatchment are provided in **Appendix J**.

The results of the initial loss sensitivity analysis show that decreasing the initial losses would increase the peak 1% AEP discharges generated by the model by over 20% at some locations. However, the average increase in peak 1% AEP discharge is predicted to be 13%.

Increasing the initial loss would decrease peak discharge by 24% (on average). However, isolated decreases of over 30% are predicted to occur at some isolated locations.

Therefore, it can be concluded that the XP-RAFTS model is moderately sensitive to changes in the adopted initial loss. *'Australian Rainfall & Runoff'* (Engineers Australia, 1987) suggests adopting an initial loss of between 10 mm and 30 mm for design flood estimation. The adopted initial loss of 15 mm is towards the lower end of the suggested range and would, therefore, provide reasonably conservative design flood discharge estimates.

9.2.2 Continuing Loss Rate

An analysis was also undertaken to assess the sensitivity of the results generated by the XP-RAFTS model for the 1% AEP event to variations in the adopted continuing loss rates. This involved decreasing and increasing the continuing loss rates by 1 mm/hour relative to 'base' conditions. The results from the continuing loss sensitivity analysis simulations are provided in **Appendix J**.

The results of the sensitivity analysis show that the XP-RAFTS model is relatively insensitive to changes in continuing loss rates. Increasing the adopted continuing loss values is predicted to decrease peak 1% AEP discharges by an average of 1%. Similarly, decreasing the adopted loss rates is predicted to increase peak discharges by an average of about 1%.

Therefore, it can be concluded that any uncertainties associated with the adopted continuing loss rates are unlikely to have a significant impact on the results generated by the XP-RAFTS model.

9.3 Hydraulic Model

9.3.1 Pipe/Culvert Blockage

As discussed in Section 5.2.5, a default blockage factor of 50% was applied to all minor culverts in the TUFLOW hydraulic model. A minor pipe/culvert was defined as having a diameter (for circular pipes/culverts) or diagonal dimension (for rectangular culverts) less than 6 metres.

Additional TUFLOW simulations were completed to determine the impact that alternate blockage scenarios would have on simulated flood behaviour. Specifically, additional simulations with no blockage as well as complete blockage of all minor pipes and culverts were completed.

The TUFLOW model was updated to represent no blockage of minor pipes and culverts and was used to re-simulate the 1% AEP flood. Peak floodwater depths and velocity vectors were extracted from the results of the modelling and are presented in **Figure 33**. The predicted extent of inundation for "baseline" conditions is superimposed on **Figure 33** for comparison.

The TUFLOW model was also updated to include 100% blockage of all minor pipes and culverts and was used to re-simulate the 1% AEP flood. Peak floodwater depths and velocity vectors were extracted from the results of the modelling and are presented in **Figure 34**. The predicted extent of inundation for "baseline" conditions is superimposed on **Figure 34** for comparison.

Peak flood levels were also extracted from the results of the modelling at selected locations across the catchment and are provided in **Appendix K**. Peak flood levels for "baseline" conditions are also included in **Appendix K** for comparison.

The results documented in **Figures 33** and **34** and **Appendix K** show that complete blockage typically increases the severity of flooding upstream of blocked pipes and culverts and decreases the severity of flooding downstream of blocked pipes and culverts. The average increase in peak flood level with 100% blockage is predicted to be 200 mm. However, isolated increases of over 1 metre are predicated at some locations (e.g., upstream of the Main Southern Railway).

The no blockage scenario typically increases the severity of flooding downstream of the pipes/culverts and decreases the severity of flooding upstream of pipes/culverts. The average reduction in peak 1% AEP flood level is about 150mm, although decreases of over 0.5 metres are predicted at isolated locations.

The results of the blockage simulations show some significant changes in flood levels relative to the adopted "baseline" blockage scenario. Accordingly, it is considered that the hydraulic model is relatively sensitive to variation in culvert and pipe blockage. This outcome emphasises the need to ensure key drainage infrastructure and bridges/culverts are well maintained (i.e., debris is removed on a regular basis) to ensure the structures are operating at maximum efficiency.

9.3.2 Manning's 'n'

Manning's' 'n' roughness coefficients are one of the primary hydraulic model inputs and calibration parameters. They are used to describe the resistance to flow afforded by different land uses / surfaces across the catchment. However, they can be subject to considerable variability (e.g., vegetation density in the summer would typically be higher than the winter leading to higher Manning's 'n' values). Therefore, additional analyses were completed to quantify the impact that any uncertainties associated with Manning's 'n' roughness values may have on predicted design flood behaviour.

The TUFLOW model was updated to reflect an increase and a decrease in "baseline" Manning's 'n' values of 20%. Tabulated flood level comparisons are provided at selected location across the catchment in **Appendix K**.

The results listed in **Appendix K** show that increasing or decreasing the Manning's 'n' values by 20% will typically alter peak 1% AEP flood levels by less than 0.1 metres. On average, increasing Manning's 'n' values by 20% will increase peak 1% AEP flood levels by 0.02 metres and decreasing Manning's 'n' values by 20% will decrease peak 1% AEP flood levels by 0.01 metres. Some more significant increases occur at isolated locations, such as the Mittagong swimming pool.

In general, the model is relatively insensitive to changes in Manning's 'n' values. However, changes in the vicinity of bridges and culverts can be more substantial. Therefore, care should be taken in interpreting results in the vicinity of hydraulic structures as the combined effect of increases in Manning's 'n' and blockage of structures (both of which can be caused by debris accumulation) has the potential to impact on predicted flood behaviour.

9.4 Computer Model Confidence Limits

As discussed, the development of computer models requires the estimation of parameters that are not always known with a high degree of certainty. The computer models that were created as part of this study were developed based upon best estimates of model parameters. The models were subsequently shown to produce realistic results relative to the limited amount of historic flood information that is available. Accordingly, the computer models are considered to provide a reasonable estimate of design flood behaviour across the catchment for existing conditions.

However, the outcomes of the climate change assessment and sensitivity analysis indicate that the design flood level estimates may be subject to variations if one or more of the input variables change (e.g., culvert blockage, rainfall intensities, hydraulic roughness). Accordingly, the model input parameters and design flood level estimates presented in this report are subject to some uncertainty.

In recognition of this uncertainty, additional statistical analyses were completed based upon the outcomes of the various sensitivity and climate change analyses in an attempt to assign "confidence limits" to the peak 1% AEP flood level estimates. Peak 1% AEP flood levels from each sensitivity/climate change run were extracted at each TUFLOW model grid cell and compared with "base" 1% AEP flood levels. This enabled flood level differences to be calculated at over 1.5 million different locations across the catchment which, in turn, enabled basic flood level difference statistics to be calculated (e.g., mean flood level difference and standard deviation of difference). Assuming a normal distribution of flood level differences, the 95% confidence limits can be estimated as the mean flood level difference ± two standard deviations.

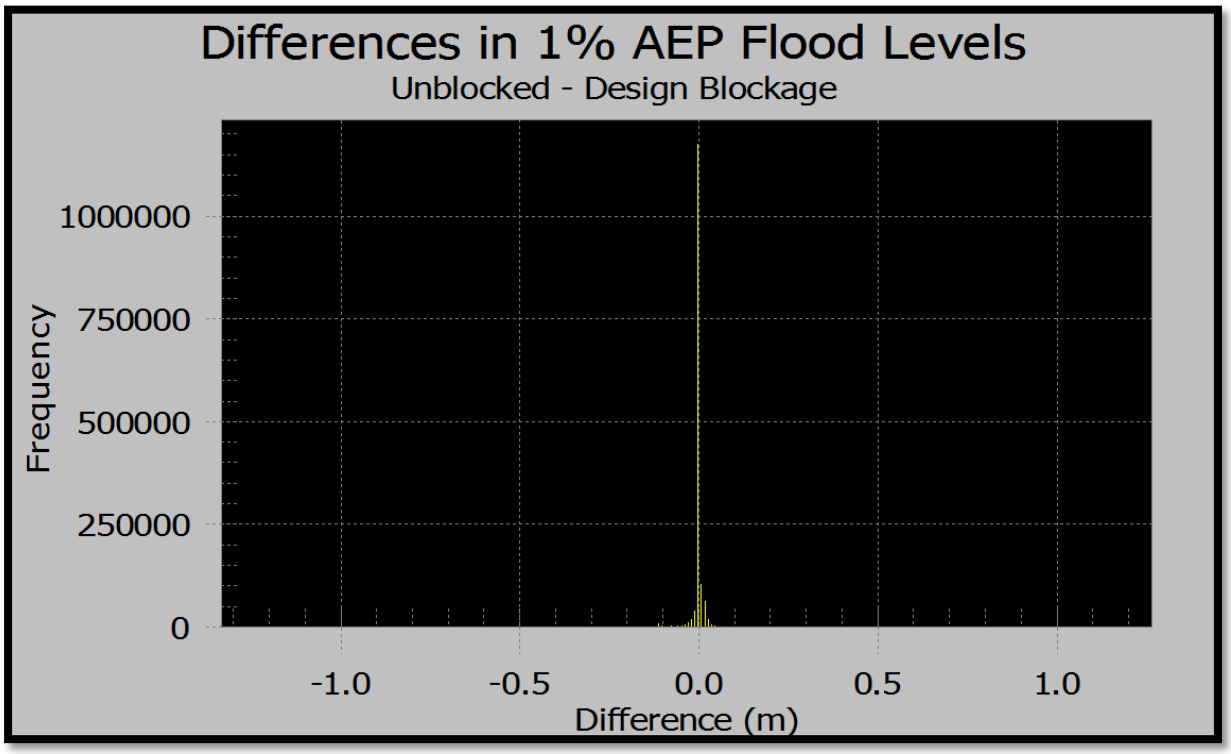


Plate 8 **Distribution of differences in peak 1% AEP flood levels between unblocked and 'design' blockage simulations**

Plate 8 shows an example of the distribution of flood level differences from one of the sensitivity analyses. It indicates the normal flood level distribution assumption is a reasonable approximation. It also shows that small differences in water levels are much more common than large differences.

The outcomes of the confident limits assessment are summarised in **Table 17**. It shows that the mean difference in flood levels across most of the sensitivity / climate change simulations is typically less than 0.1 metres.

Table 17 Summary of Peak Flood Level Confidence Limits

Sensitivity Analysis		Flood Level Difference Statistics* (m)		95 % Confidence Limits
		Mean	Std Deviation	
Initial Loss	0mm	0.03	0.06	+0.15 -0.09
	30mm	-0.04	0.08	+0.12 -0.20
Continuing Loss	1.5mm/hr	0.01	0.01	+0.03 -0.01
	3.5mm/hr	-0.01	0.01	+0.01 -0.03
Manning's 'n'	-20%	-0.01	0.06	+0.11 -0.13
	+20%	0.02	0.05	+0.12 -0.08
Bridge / Culvert Blockage	No Blockage	-0.01	0.02	+0.03 -0.05
	Complete Blockage	0.04	0.19	+0.42 -0.34
Climate Change	10% Increase in 1% AEP Rainfall Intensity	0.02	0.05	+0.12 -0.08
	20% Increase in 1% AEP Rainfall Intensity	0.05	0.10	+0.25 -0.15
	30% Increase in 1% AEP Rainfall Intensity	0.07	0.13	+0.33 -0.19
Adopted 95% Confidence Limits				± 0.5

NOTE: * Flood level difference statistics were calculated based upon the difference in peak flood level estimates from the various sensitivity analyses relative to the 'base' 1% AEP flood results documented in Section 6.3. The flood level comparisons were completed at every TUFLOW model grid cell (i.e., every 2m).

The outcomes of the blockage sensitivity analysis show that blockage of structures has a potential to cause some large differences in peak 1% AEP flood levels (refer Section 9.3.1). Consequently, the 95% confidence limits are quite large. However, it should be noted that in most circumstances, bridges and culverts will not be completely blocked during a flood. Accordingly, the 100% blockage scenario is considered to be conservative. Nevertheless, it does highlight the large impact that blockage of structures can have on flood behaviour and the key role that these blockage assumptions have on modelled flood behaviour.

The 95% confidence limits from the 30% increase in rainfall intensity climate change scenario are also quite large (i.e., > 0.3 metres). This confirms the outcomes of the climate change sensitivity analysis discussed in Section 8.3, which indicates that increases in rainfall intensity of 30% has the potential to significantly increase the severity of flooding across the Nattai River catchment.

The results provided in **Table 17** indicate that the 95% confidence limits for most sensitivity simulations is less than ± 0.2 metres and in all but one of the sensitivity simulations less than ± 0.4 metres. Accordingly, it is considered reasonable to adopt 1% AEP confidence limits of ± 0.4 metres. That is, the 1% AEP flood levels presented in Section 6.3 are reliable to within ± 0.4 metres. As previously discussed, the calculated confidence limits are based upon a comparison of flood levels at each TUFLOW model grid cell (i.e., 2m intervals). Localised increases beyond the 95% limits may occur at some locations. Therefore, consideration of larger confidence limits/freeboard may be considered in particularly sensitive areas of the catchment (e.g., in the immediate vicinity of bridges/culverts where blockage may be prevalent).

10 Discussion

10.1 General

The results of the design flood modelling show that:

- Flood behaviour across the Nattai River catchment is typically characterised by relatively shallow depths of inundation (i.e., < 0.3 metres). However, more significant depths are predicted along and immediately adjacent to designated waterways.
- The relatively shallow depths of inundation result in the majority of the Nattai River floodplain being exposed to a low provisional flood hazard.
- However, several sections of the catchment are predicted to be exposed to more significant floodwater depths and velocities and, consequently, a high provisional flood hazard during large events. This includes:
  - Evans Street (between Payten Street and Colo Street)
  - Mittagong Swimming Centre
  - Oxley Road (between Nero Street and Murchison Street)

Further detailed discussion on the impact of flooding on key infrastructure and transportation routes is provided below.

10.2 Impact of Flooding on Key Facilities

10.2.1 Key Infrastructure

There is some significant infrastructure located within the Nattai River catchment that can play a key role in emergency response management during floods. As such, it was considered important to assess the impact of flooding on these facilities to determine their suitability for use / evacuation during floods.

Such infrastructure includes:

- **Schools:**
  - ***Frensham*** (Range Road, Mittagong): the school building infrastructure is not predicted to be inundated during any design flood up to and including the PMF. However, access to and from the school may be cut for a period during large floods due to overtopping of the Old Hume Highway. The school games fields and 'Holt Farm' experience inundation in all design events.
- **Fire Stations**: There are no fire stations located within the catchment;
- **Police Stations**: There are no police stations located within the catchment;
- **State Emergency Service**: There are no SES buildings located within the catchment;
- **Ambulance Stations**: There are no ambulance stations located within the catchment;
- **Hospitals**: There are no hospitals located within the catchment;
- **Aged Care Facilities**

- ***The Abbey Nursing Home*** (Range Road, Mittagong): Habitable areas of the retirement village are predicted to remain "flood free" during all floods up to an including the PMF. Access may be restricted due to flooding of the Old Hume Highway.

Other Facilities

- ***Mittagong Swimming Centre*** (Hawkins Road, Mittagong): is predicted to experience significant depths of inundation (>1 metre) during all design events. Accordingly, there is a significant risk to any people located in the vicinity of the swimming centre during large floods.
- ***Mittagong Caravan Park*** (Beatrice St, Mittagong): is predicted to experience shallow depths of inundation during all design events. 1% AEP depths are typically around 0.1 m, with some localised areas exposed to 0.4 metres, increasing up to 0.6 metres during the PMF. Accordingly, some inundation of cabins/vans may occur during large floods.

The outcomes of this assessment are also summarised in **Table 18**.

Table 18 Impact of Flooding on Key Infrastructure

Key Infrastructure		1% AEP Flood		PMF	
		Inundated?	Access Cut?	Inundated?	Access Cut?
Fire Stations		There are no fire stations located within the catchment			
Police Stations		There are no police stations located within the catchment			
State Emergency Service		There are no SES buildings located within the catchment			
Ambulance Stations		There are no ambulance stations located within the catchment			
Hospitals		There are no hospitals located within the catchment			
Schools	*Fresham* (Range Road, Mittagong)		☑		☑
Aged Care Facilities	*The Abbey Nursing Home* (Range Road, Mittagong)		☑		☑
Other Facilities	*Mittagong Swimming Centre* (Hawkins Road, Mittagong)	☑	☑	☑	☑
	Mittagong Caravan Park (Beatrice Street, Mittagong)		☑		☑

10.2.2 Transportation Links

There are several major roadways within the Nattai River Catchment which may be required for evacuation or emergency services access during floods. It is important to have an understanding of the impacts of flooding on these roads so that appropriate emergency planning can occur.

- ***Old Hume Highway***: The Old Hume Highway is predicted to experience inundation during all of the design floods. This ranges from 0.2m during the 20% AEP flood and 0.3m during the 1% AEP to more than 2 metres during the PMF. Accordingly, the highway would likely remain trafficable during smaller events but access would be cut during events greater than the 1% AEP flood.

- ***Colo Street:*** Colo Street is predicted to be inundated during all of the simulated design floods. Depths of inundation are predicted to range from 0.4m during the 20% AEP event to ~2.5 m during the PMF. Accordingly, it is unlikely that vehicular access along Colo Street would be possible during any of the simulated design floods.
- ***Payten Street:*** some shallow depths of inundation are predicted along Payten Street during all simulated design floods. Depths are predicted to vary from 0.1m during the 20% event up to 0.7cm during the PMF. As a result, vehicular access along Payten Street would be possible during small floods, but would not be possible during floods equal to or greater than the 1% AEP flood.
- ***Range Road:*** Range Road is predicted to be inundated near the intersection of Range Road with Tyndall and Devon Streets. Depths at the intersection are predicted to range from 0.15m during the 20% AEP event, 0.25m during the 1% AEP event up to 0.35m during the PMF. According, access may be cut during events in excess of the 1% AEP event.
- ***Oxley Road:*** Oxley Road provides access from the Mittagong central business district to a number of properties within the upper Nattai River Catchment. It is predicted to be overtopped during floods as frequent as the 20% AEP flood, where water depths are predicted to exceed 0.4m at some locations. Depths of up to 0.5m are predicted during the 1% AEP event and depths of over 2m are predicted during the PMF. Accordingly, Oxley Road is unlikely to be trafficable at the peak of any of the design floods considered as part of this study.
- ***Old South Road***. This roadway is predicted to be overtopped by up to 1 metre during the 1% event, and 1.3 metres during the PMF near the intersection with Range Road. The roadway is not predicted to overtop during the 20% AEP event.
- ***Main Southern Railway:*** The railway line is predicted to be overtopped at the following locations during the 1% AEP flood:
  - near the western Ferguson Road overpass (adjacent to the Old Hume Highway) where depths range from 0.1m during the 20% AEP flood, 0.15m during the 1% AEP event, and 1.3 metres during the PMF
  - near the eastern Ferguson Road overpass (adjacent to Bong Bong Road), where the maximum depth of inundation is predicted to be 0.1m during the 20% AEP, 0.2m during the 1% AEP event, and 1.5 metres during the PMF.

The outcomes of this assessment are also summarised in **Table 19**.

Table 19 Impact of Flooding on Key Transportation Links

Roadway	Access Cut During 20% AEP Flood?	Access Cut During 1% AEP Flood?	Access Cut During PMF?
Old Hume Highway	☑	☑	☑
Colo Street		☑	☑
Payten Street		☑	☑
Range Road	☑	☑	☑
Oxley Road	☑	☑	☑
Old South Road		☑	☑
Main Southern Railway	☑	☑	☑

11 CONCLUSION

This report documents the outcomes of investigations completed to quantify contemporary flood behaviour across the Nattai River catchment for a full range of design. It provides information on design flood discharges, levels, depths and velocities as well as hydraulic and flood hazard categories.

Flood behaviour across the study area was defined using a hydrologic computer model of the Nattai River catchment as well as a two-dimensional hydraulic model of the lower 60 km^2 of the catchment. The hydrologic computer model was developed using the XP-RAFTS software and the hydraulic model was developed using the TUFLOW software.

The computer models were calibrated/verified using rainfall data and reports of flooding received from the community for floods that occurred in 1991 and 2012. The models were subsequently used to simulate a range of design floods including the 20%, 10%, 5%, 2%, 1% and 0.5% AEP floods as well as the PMF. The following conclusions can be drawn from the results of the study:

- Flooding across the Nattai River catchment can occur as a result of major watercourses overtopping their banks as well from overland flooding when the capacity of the stormwater system is exceeded.
- Flooding can occur as a result of a variety of different storm durations. However, a storm duration of 2 hours typically produces the worst case flooding conditions across most of the catchment.
- A number of properties are predicted to be inundated during the 1% AEP flood. This includes:
  - Evans Street between Payten and Colo Streets;
  - Mittagong Swimming Centre;
  - Oxley Drive between Bracken and Reservoir Street
- A number of roadways are predicted to be overtopped during the 1% AEP flood. This would typically render the roadways impassable for at least 2 hours. This includes Range Road, Old South Road and the Old Hume Highway.
- The catchment incorporates a number of bridges and culverts. The results of a blockage sensitivity analysis shows that the severity of flooding upstream of these structures can be significantly increased due to blockage. This highlights the importance of routine maintenance on this infrastructure, particularly immediately after a flood.

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APPENDIX A

COMMUNITY CONSULTATION

Council calls for local data as part of flood studies

Wingecarribee Shire Council is calling on residents living near Nattai Creek to provide information on flooding "trouble spots" as part of a major flood study designed to help better prepare for future flood events.

Flooding causes over $100 million worth of damage each year across the nation and historically causes more damage annually than any other natural disasters in Australia.

Council is currently preparing major flood studies across some of the Shire's key catchment areas in an effort to better plan, predict and manage the risk of flooding across our Shire.

The studies will form part of Council's Floodplain Risk Management Program which aims to reduce the impact of flooding on the community.

The Nattai Creek Flood Study will focus attention on the Nattai Creek catchment, which covers an area approximately 6.75 km² across eastern Mittagong.

As part of the study, computer models will be used to simulate flood behaviour across the catchment.

For the study to be as reliable as possible, Council is asking residents to submit any historical information they may have collected from past floods. This could include written data or historical photographs/videos.

Alternatively, a questionnaire can be completed online at the dedicated website, www.nattai.floodstudy.com.au. Responses close on the 21st of December 2012 but earlier responses will be appreciated.

For further information about the Nattai Creek Flood Study or to fill out an online questionnaire visit: www.nattai.floodstudy.com.au, contact Council's Floodplain and Stormwater Engineer on phone 4868 0798 or via email at: sha.prodhan@wsc.nsw.gov.au, or Council's consultant - *Catchment Simulation Solutions* - David Tetley on (02) 9223 0882 or via email at: dtetley@csse.com.au.

END

Why do we need to prepare a flood study?

Flooding in Australia is estimated to cause over $100 million worth of damage each year. Over 2,300 people have also lost their lives due to floods in Australia over the past 200 years. Accordingly, flooding can impose significant financial burdens and place lives at risk.

The preparation of a flood study will help Council to understand the existing flooding problem within the Nattai Creek catchment. It will also help Council to identify where flood damage reduction measures may be best implemented to reduce the cost of flooding to the community, assist with emergency management / evacuation processes and guide future development in a way that is compatible with the flood hazard.

How you can help!

The flood study will include the development of computer models to simulate flood behaviour across the catchment. To ensure the computer models are providing reliable descriptions of flood behaviour they will be calibrated so they reproduce floods that have occurred in the past.

Enclosed with this brochure is a questionnaire that aims to collect as much historic flood information as possible to assist with the model calibration. Anybody with information and/or historic flood photographs is encouraged to complete the questionnaire and return it by **21 December 2012**. Alternatively, the questionnaire can be completed online via the Nattai Creek Flood Study website:

www.nattai.floodstudy.com.au

Further Information:

To obtain further information on the Nattai Creek Flood Study or to submit any information that you think may be valuable to the study, please contact:

Catchment Simulation Solutions

David Tetley
Catchment Simulation Solutions
Suite 302, 5 Hunter Street
Sydney NSW 2000
(02) 9223 0882
(02) 8415 7118
dtetley@csse.com.au

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WINGECARRIBEE SHIRE COUNCIL

Sha Prodhan
Wingecaribee Shire Council
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Moss Vale NSW 2577
(02) 4868 0798
(02) 4869 1203
sha.prodhan@wsc.nsw.gov.au

Alternatively, you can visit the flood study website:
www.nattai.floodstudy.com.au

Your contribution to this study is greatly appreciated!

Brochure prepared by:

Catchment Simulation Solutions

Nattai Creek Flood Study

Community Information Brochure

WINGECARRIBEE SHIRE COUNCIL

Introduction

The Nattai Creek catchment covers an area of approximately 6.75 km^2 within the Wingecarribee Shire Council Local Government Area. It incorporates Nattai Creek as well as a number of unnamed tributaries, which flow past many rural and residential properties in Mittagong. Accordingly, there is potential for damage, inconvenience and risk to life during large floods within the catchment. The extent of the Nattai Creek catchment is shown below.

In recognition of these issues, Wingecarribee Shire Council has decided to prepare a flood study for the Nattai Creek catchment. The flood study is the first step in assisting Council to better understand, plan and manage the risk of flooding across the catchment.

The flood study is being completed as part of Council's Floodplain Risk Management Program, which aims to reduce the impact of flooding on the community.

Background

The NSW State Government's Flood Prone Land Policy is directed towards providing solutions to existing flood problems in developed areas and ensuring new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land is the responsibility of Local Government with financial and technical support provided by the State Government. The Policy specifies a staged approach to the floodplain management process:

Council has initiated this process by commissioning the Nattai Creek Flood Study. The main purpose of the flood study is to determine the nature and extent of the existing flood problem.

Once the Flood Study is completed, a Floodplain Risk Management Study and Plan can be prepared. This will quantify the benefits of implementing a range of measures aimed at reducing the damage and inconvenience caused by flooding.

So what's a flood study?

A considerable amount of work is involved in the preparation of a flood study. This work typically includes:

- Collection and review of all available flood-related information for the catchment
- Consultation with the community to obtain additional information on flooding
- Development of computer models to simulate the transformation of rainfall into runoff and to simulate how the runoff moves across the catchment
- Calibration of the computer models to reproduce historic floods
- Use of computer models to simulate a range of hypothetical floods ranging from relatively frequent storms right up to the largest flood that could conceivably occur
- Interpretation of the computer model outputs to identify the variation in flood hazard across the catchment and to identify areas that should be preserved in the future for the conveyance of flood flows
- Preparation of a flood study report and maps summarising the outcomes of all stages of the investigation

The flood study will ultimately provide Council with information on flood flows, extents, levels, depths and velocities throughout the catchment. Council has commissioned specialist flood consultants, Catchment Simulation Solutions, to prepare the flood study.

Thank you for taking the time to complete this questionnaire!

The questionnaire can be returned without a postage stamp or scanned and emailled to dtetley@csse.com.au by 21 December 2012. Flood photos and videos can also be sent to this email address. “Hard copies” of photos or VHS tapes can be posted to:

Catchment Simulation Solutions
Suite 302, 5 Hunter Street
Sydney, NSW 2000

Catchment Simulation Solutions will analyse the community responses and report back to Council. If you would like to have items returned please note this and the items will be returned at the conclusion of the study.

Fold Here

How to send back this questionnaire...

Please fold this questionnaire using the ‘Fold Here’ lines as a guide to form a business sized evelope with the address on the front and this text box on the back. Seal the folded pages with a piece of tape to help maintain privacy and then post it back.

Fold Here

Delivery Address:
PO Box 141
MOSS VALE NSW 2577

No stamp required
if posted in Australia

WSC
Reply Paid 141
MOSS VALE NSW 2577

Nattai Creek Flood Study

Nattai Creek Flood Study

Community Questionnaire

Wingecarribee Shire Council is completing a flood study for the Nattai Creek catchment. The flood study is the first step in assisting Council to better understand, plan and manage the risk of flooding across the catchment. The extent of the Nattai Creek catchment is shown in the image below.

The information that you provide in the following questionnaire will prove invaluable in the calibration of computer models that are being developed as part of the Flood Study. It will also provide Council with an understanding of existing flooding problems and areas where flood damage reduction measures should be investigated in the future.

The following questionnaire should only take around 10 minutes to complete. Try to answer as many questions as you can and give as much detail as possible (attach additional pages if necessary). Once complete, please return the questionnaire via email or mail (no postage stamp required) by **21 December 2012**. Alternatively, if you have internet access, an online version of the questionnaire can be completed at: www.nattai.floodstudy.com.au

If you have any questions or require any further information please contact:

Catchment Simulation Solutions
David Tetley
Catchment Simulation Solutions
(02) 9223 0882
dtetley@csse.com.au

WINGECARRIBEE SHIRE COUNCIL
Sha Prodam
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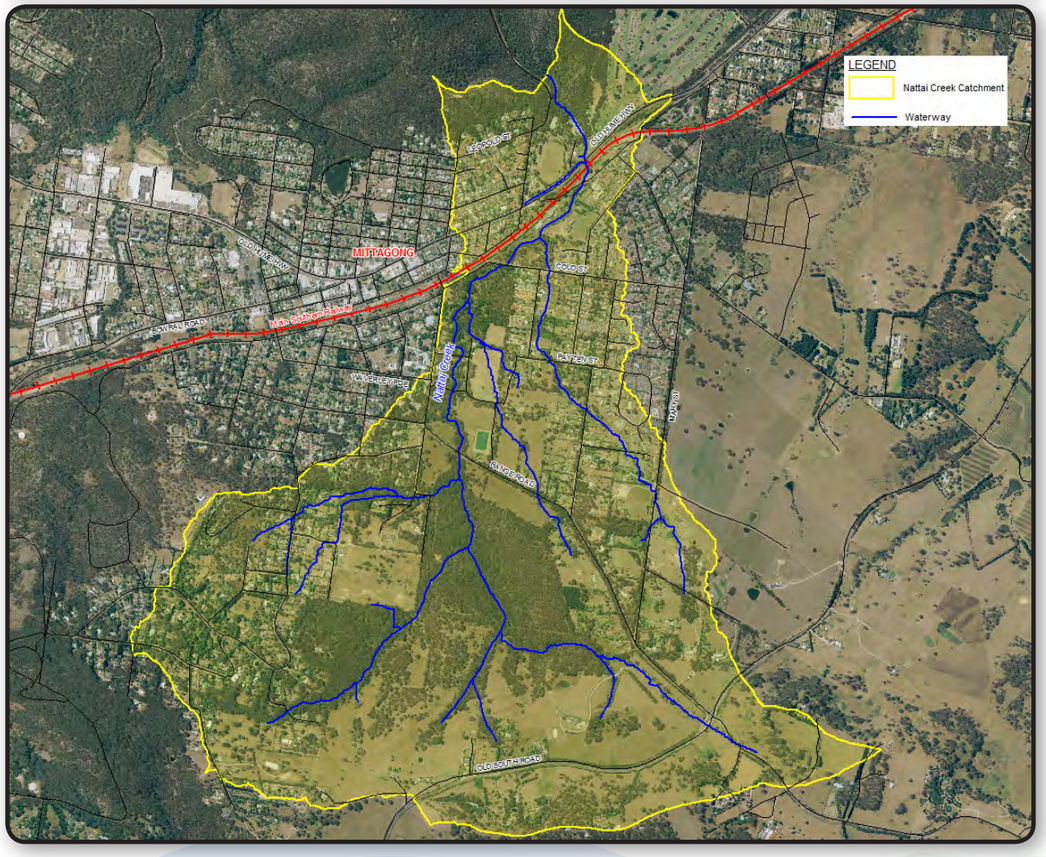


QUESTION 1

Please provide the following contact details so that we can identify the location of the flooding trouble spot (if you have moved from the 'flood zone', please provide your previous address). If you consent, we may also contact you to obtain further information.

Note that the information that you provide will become the property of Wingecarribee Shire Council. However, your personal information will remain confidential at all times and will only be used to identify specific locations of flooding problems.

Name:_____ **Phone Number:**_____

Address:_____ **Email:** _____

_____

_____

Are you happy to be contacted in the future to obtain additional information? ☐ **Yes** ☐ **No**

QUESTION 2

How long have you lived and/or worked in the area?

At current address: _____ **Years** _____ **Months**

In the general area: _____ **Years** _____ **Months**

QUESTION 3

Have you been affected by flooding in the past?

☐ **Yes** ☐ **No**

If 'Yes', how have you been affected? (You can select more than one. Please also list the location/address at which the flooding problem occured and the approximate date of the flood)

☐ **Traffic was disrupted** (please provide a description below if possible)

☐ **My back/front yard was flooded** (please provide a description below if possible)

☐ **My house/business and its contents were flooded** (please provide a description below if possible)

☐ **Other** (please provide a description below if possible)

Description: _____

_____

_____

_____

_____

_____

QUESTION 4

Can you provide specific details or evidence of how high floodwaters reached (e.g. photos, high water mark on building, depth of water across roadway)?

☐ **Yes** ☐ **No**

a) If 'Yes', please give as much detail as possible (e.g. dates, times, description of water movement, depth of water, flood mark location, high water mark on building, level on flood depth indicator)?

_____

_____

_____

_____

b) In your opinion, what was the main source/cause of the flooding (e.g. water overtopping creek banks, blockage of culverts/pipes, insufficient stormwater system capacity)?

_____

_____

_____

_____

QUESTION 5

Are you concerned that your property could be flooded in the future?

☐ **Yes** ☐ **No**

If 'Yes', what makes you concerned?

_____

_____

_____

_____

QUESTION 6

Do you have any other comments or information that you think would be useful for this investigation? (feel free to attach additional pages)

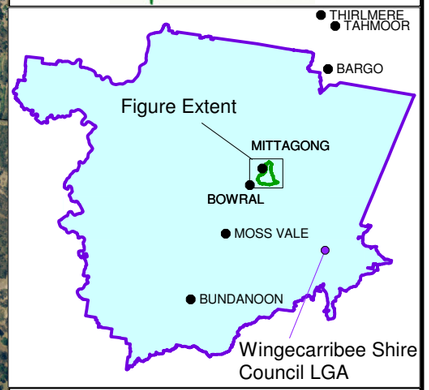
_____

_____

_____

_____

WINGECARRIBEE SHIRE COUNCIL



LEGEND

- Catchment Boundary
- Railway
- Watercourse
- Roads

Questionnaire Response Locations
Has flooding been experienced?

- Yes
- No

Notes:

Aerial Photograph Date: 2009

N
W E
S

Scale 1:16,000 (at A3)

0 0.5 1
Km

Figure A1: Spatial Distribution of Questionnaire Responses

Prepared By:
Catchment Simulation Solutions
Suite 302, 5 Hunter St
Sydney, NSW 2000

File Name: FigureA1 Spatial Distribution of Questionnaire Responses.wor

Community Questionnaire Responses - Nattai River Flood Study

#	How long have your lived in area?		Have you been affected by flooding in the past?					Can you provide historic flood information?		Are you worried your property could be flooded in the future?	Any additional nformation?
	Current Address	In General Area	Traffic Disrupted	Yard Flooded	House/Business Flooded	Other	Description	Flood Descriptions	Source of Flooding		
1	4.25 Years	Years	Yes	Yes	No	No	In 2008/9 when we were about to purchase 54 Southey Street, the creek crossing in Colo Street flooded the road after days of rain. In Summer 2010/2011 after days of rain a great amount of run-off flowed through our property from the properties in Oakland Road above us. This flowed through our garage and required us to put everything in the garage up on bricks. 54 Southey St is in an area where there are a large number of very tall eucalypts. Every rain or wind storm litters the ground and driveways with shredded bark and leaves. If they are not cleaned up and also removed from the gutters they clog the drains when it rains. Every time it rains for a few days or a heavy downpour the drain at the front of 56 Southey St is blocked by leaves. If these leaves manage to flow through the drain to the creek then they accumulate and block the flows of the creek. There could be insufficient drainage in the properties on the slope above us in Oaklands Road. If their gutters are blocked the water runs off through our property. We have to remove the debris from our roof regularly but not everyone does this. I feel that if the council provided a Green waste service in this area some of the debris could be avoided. We don't want the trees removed and we can't stop the pattern of rainfall but can manage the flow of water into the creek and through the creek and on its way to the reservoirs.	No	No	No	
2	10.92 Years	48 Years	Yes	No	No	No	Old Hume Highway adjacent to the Golf club. Water was from road near the Nattai River	No	Inadequate drainage adjacent to the Highway. Water ran downslope on both sides of the bridge across the highway and exceeds the capacity of engineering works. This happened 3 or 4 times in the last 11 years.	No	
3	30 Years	60 Years	No	Yes	No	No	Front of my property is subjected to minor flooding at times of heavy rain but I believe it is not serious. I am always able to drive through. There was never over 250-300 mm on the driveway. The rear of my property was flooded about 10 years ago- due to reasons explained on attachment.	Minor flooding at times of heavy rain, cannot supply dates of floods during heavy rain.	Through the length of the watercourse from Payton St to Colo St a relatively flat section water course that is obstructed by debris. The channel below the bridge near 14-18 Evans St is heavily obstructed by weeds.	Council is digging near my property which may affect future flooding	I have written to the council from 1996 to 2005, Reference numbers SM.SC D8897_51, GJH:SC LUAO5/0527. Further downstream from the area near Evan's St, there is plenty of room for water to flow away. This makes me think that no serious flooding can occur compared to say the Mittagong Rivulet in Bowral where there appears to be less room to flow to the local river.
4	9.08 Years	9.08 Years	No	No	No	No		No	No	No	
5	6.42 Years	16.83 Years	No	Yes	No	No	Flooding during August 2006 and Winter of 2012 with heavy rain	Photos emailed to council in 2006	Insufficient stormwater drainage and overgrown rivulet	Yes, frequent flooding occurs during heavy rain	Please refer to WSC Customer request number 2012-001254 dated 20/02/12. Photos were provided to council.
6	3.83 Years	3.83 Years	No	No	No	No		No	No	No	
7	6.83 Years	8 Years	No	Yes	No	No	Lower part of garden has flooded several times during heavy rain.	No	Lack of drainage maintenance near the creek	Yes similar floods will occur unless council clears up the obstructed	Yes similar floods will occur unless council clears up the obstructed drains near the creek
8	33 Years	Years	No	No	No	No		No	No	No	
9	3.17 Years	Years	No	No	No	No		No	No	No	Quite steep in this area, water flows away very quickly
10	0.5 Years	15.42 Years	No	No	No	No		No	No	No	
11	8 Years	14.92 Years	No	No	No	No		No	No	No	
12	8.33 Years	8.33 Years	No	No	No	No		No	No	No	
13	11 Years	Years	No	No	No	No		No	No	No	
14	2.5 Years	2.5 Years	Yes	No	No	No	Colo Street near the park, floods during heavy rain	No	No	No	
15	14 Years	63 Years	No	No	No	No		No	No	No	
16	6.5 Years	6.5 Years	No	No	No	No		No	No	Yes, property is at the end of the creek and there is a high collection of water accumulating in the area. Yes, property is at the end of the creek and there is a high collection of water accumulating in the area.	The Creek is obstructed by thick weeds and needs to be cleared
17	10.92 Years	10.92 Years	No	No	No	No		No	No	No	Area in Evans Street just downhill for my property flooded 11 years ago
18	20 Years	25 Years	No	No	No	No		No	No	No	
19	15.75 Years	Years	No	No	No	No		No	No	No	
20	40 Years	65 Years	No	No	No	No		No	No	No	
21	8.92 Years	8.92 Years	No	No	No	No		No	No	No	
22	3.5 Years	3.5 Years	No	No	No	No		No	No	No	Bridge on Colo St could flood during heavy rain

#	How long have your lived in area?		Have you been affected by flooding in the past?					Can you provide historic flood information?		Are you worried your property could be flooded in the future?	Any additional nformation?
	Current Address	In General Area	Traffic Disrupted	Yard Flooded	House/Business Flooded	Other	Description	Flood Descriptions	Source of Flooding		
23	12 Years	Years	No	No	No	No		No	No	No	
24	12 Years	12 Years	No	No	No	No		No	No	No	
25	9.25 Years	Years	No	No	No	No		No	No	No	
26	66 Years	Years	No	Yes	No	No	Before any houses were built, flooding will occur just under our back fence, this accumulated as more homes were built near the boundary.	No	Water over flowing the creek banks	No	
27	2 Years	54 Years	No	No	No	No		No	No	No	
28	3 Years	12 Years	No	No	No	No		No	No	No	
29	4.33 Years	4.33 Years	No	No	No	No		No	No	No	The creeks in the area are blocked
30	1.5 Years	9 Years	No	No	No	No		No	No	No	
31	2.66 Years	17 Years	No	No	No	No		No	No	No	
32	21 Years	25 Years	No	No	No	Yes	Flow in streets affected by lower pipe which as been obstructed about 6-7 years ago	No	Culvert Blocked by leaves	No	Roof drainage is inadequate, requires larger outlet
33	26.92 Years	26.92 Years	No	No	No	No		No	No	No	
34	15 Years	31.25 Years	No	No	No	Yes	Dangerous conditions due to debris across road from street flooding	No	The Creek near Webb St does not cope well with heavy rain, the flood water can stretch to Colo St.	No	
35	13 Years	13 Years	No	No	No	No		No	No	No	
36	13 Years	Years	No	No	No	No		No	No	No	
37	25 Years	25 Years	Yes	No	No	No		No	Overflowing creek	No	
38	14 Years	Years	No	Yes	No	No	Flooding in section of property from the overflow of uphill neighbouring property. No flooding from natural watercourses only that which has been altered/Diverted by human interaction. No flooding from Nattai Creek.	The water flowing from excess dam water was approximately 10-20 cm high but It caused significant damage and erosion of the soil. My solicitor has photo defects- Marya Hugley 0425351359	A new dwelling was constructed uphill of property all rain was captured by the roof and diverted to underground tank which overflows onto property.	Minimal effects by neighbours to remove excess debris, causes overflowing rain water onto my property.	Contact my solicitor Marya Hyley 0425351359 for more info
39	13 Years	17 Years	No	No	No	No		No	No	No	The creek (Nattai Rivulet) which runs under Webb St is completely overgrown with vegetation and does not flow easily after heavy or constant rain. This causes saturation of the ground surrounding the creek and constant bogginess of the lower parts of neighbours' yards. The worst I've seen was Oct 1999 when there was so much water that it was flooding over the road. This will more than likely happen again if the creek is not kept free of vegetation.
40	8 Years	8 Years	No	No	No	No		No	No	No	
41	46 Years	66 Years	No	No	No	No		No	No	No	
42	18 Years	18 Years	No	No	No	No		No	No	No	
43	7.25 Years	35.92 Years	Yes	No	No	No	Bridge on Colo St Mittagong floods from heavy rain. Even with the new bridge, a few years ago floods had occurred over the bridge due to bad drainage.	No	Blockage of culverts/Pipes and insufficient stormwater system.	No	
44	20 Years	25 Years	No	Yes	No	No	Had to block the front door to prevent water from entering the house in the early 1990s	It reached over to the back porch and covered all the concrete. The depth was 6 to 10 cm over the bridge and we had to block our doors to stop water from entering.	No	No	Clean out weeds in the creek as the raised the bed of the creek. Clearing it may allow stormwater to run through it.
45	10 Years	35 Years	No	No	No	No		No	No	No	
46	6 Years	12 Years	No	No	No	No		No	No	No	New culvert in Colo Road has helped a lot
47	19 Years	36 Years	No	No	No	No		No	No	No	
48	2.42 Years	2.42 Years	No	No	No	No		No	No	No	
49	4 Years	22 Years	No	No	No	No		No	No	No	
50	9 Years	28 Years	Yes	No	No	No	Roads were cut off in Bowral at corner of old south Road and Merrigang St as well as the old bridge across from Bowral Pool	No	Need to improve infrastructure	No	
51	27 Years	Years	Yes	No	No	No	Colo Street near the park had flooded and traffic was forced to take Southey St as a detour	No	No	No	
52	3.83 Years	Years	No	No	No	No		No	No	No	
53	9 Years	Years	No	No	No	No		No	No	No	
54	3 Years	4 Years	No	No	No	No		No	No	No	
55	1 Years	Years	No	No	No	No		No	No	No	
56	4.5 Years	Years	No	No	No	No		No	No	No	
57	8 Years	8 Years	No	No	No	No		No	No	No	
58	54 Years	54 Years	Yes	No	No	Yes	TRAFFIC:Colo Street inundated to1m depth between Southey and Evans Streets,also Payten Street culvert impassable, Old Hume Highway impassable between Maltings and Drabble Bridges, railway line threatened. OTHER IMPACTS: All properties between Southey and Evans streets inundated to lesser or greater extent, ie water in every yard, garages flooded but no homes badly affected. I don't have dates but believe there were several similar occurrences of this nature in 1960s and early 70s.	No	Insufficient capacity downstream in the pre-1980s, since improved by WSC. New bridge essential in Colo Street to replace timber structure. This work is long overdue.	No	Pedestrian safety in this area is being ignored by WSC. Colo Street is a very dangerous stretch of road for the many pedestrians who trek it daily. Flooding dangers to foot traffic and poor lighting should be considerations in this study.
59	10 Years	10 Years	No	No	No	No		No	No	No	

#	How long have your lived in area?		Have you been affected by flooding in the past?					Can you provide historic flood information?		Are you worried your property could be flooded in the future?	Any additional nformation?
	Current Address	In General Area	Traffic Disrupted	Yard Flooded	House/Business Flooded	Other	Description	Flood Descriptions	Source of Flooding		
60	13.75 Years	15 Years	No	No	No	No		On two or three occasions since we have lived in Webb Street, the reserve at the rear of our property has partially flooded during heavy constant rain. The reserve drained fairly quickly after the rain say, 3 to 4 hours. Not sure of the dates this occurred but we can provide a photo or two.	Heavy rain	Whilst we would expect the house would be a fair distance from flood waters, we would think that a lot of rain over a number of days would possibly flood the lower part of the property.	We have been informed some years ago that flood waters covered the eastern side of Evans Street in the past. We are also concerned that land presently being put up for sale in Como Street would possibly be under water in heavy constant rains.

APPENDIX B

XP-RAFTS MODEL INPUT PARAMETERS

XP-RAFTS INPUT PARAMETERS - Nattai River

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
1.01	1	24.68	7.69	0	0.046
	2	1.66	7.69	100	0.015
1.02	1	11.38	8.42	0	0.042
	2	0.92	8.42	100	0.015
1.03	1	7.62	5.39	0	0.037
	2	0.82	5.39	100	0.015
1.04	1	12.17	12.82	0	0.068
	2	0.73	12.82	100	0.015
1.05	1	13.14	11.06	0	0.054
	2	0.65	11.06	100	0.015
1.06	1	8.27	9.76	0	0.091
	2	0.20	9.76	100	0.015
1.07	1	10.70	6.45	0	0.098
	2	0.22	6.45	100	0.015
1.08	1	8.96	4.58	0	0.097
	2	0.19	4.58	100	0.015
1.09	1	8.60	5.66	0	0.059
	2	0.37	5.66	100	0.015
1.1	1	2.97	2.71	0	0.062
	2	0.47	2.71	100	0.015
1.11	1	2.70	4.83	0	0.069
	2	0.31	4.83	100	0.015
1.12	1	4.70	3.34	0	0.062
	2	0.60	3.34	100	0.015
1.13	1	2.43	4.63	0	0.063
	2	0.35	4.63	100	0.015
1.14	1	3.05	2.00	0	0.088
	2	0.08	2.00	100	0.015
1.15	1	1.56	2.02	0	0.086
	2	0.15	2.02	100	0.015
1.16	1	2.96	3.50	0	0.075
	2	0.61	3.50	100	0.015
1.17	1	2.13	2.02	0	0.056
	2	0.16	2.02	100	0.015
1.18	1	3.64	2.50	0	0.047
	2	0.83	2.50	100	0.015
1.19	1	2.01	3.35	0	0.041
	2	0.41	3.35	100	0.015
1.2	1	1.32	4.82	0	0.033
	2	0.47	4.82	100	0.015
1.21	1	0.02	12.67	0	0.052
	2	0.01	12.67	100	0.015
1.22	1	0.05	3.58	0	0.038
	2	0.04	3.58	100	0.015
1.23	1	5.14	5.71	0	0.055
	2	0.52	5.71	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
1.24	1	1.38	6.14	0	0.045
	2	0.64	6.14	100	0.015
1.25	1	1.32	10.10	0	0.071
	2	0.10	10.10	100	0.015
1.26	1	4.06	19.87	0	0.080
	2	0.08	19.87	100	0.015
1.27	1	4.97	23.84	0	0.084
	2	0.13	23.84	100	0.015
2.01	1	24.85	10.96	0	0.047
	2	1.70	10.96	100	0.015
2.02	1	6.54	5.15	0	0.041
	2	0.34	5.15	100	0.015
3.01	1	17.71	11.67	0	0.053
	2	1.38	11.67	100	0.015
3.02	1	5.94	11.66	0	0.057
	2	0.27	11.66	100	0.015
3.03	1	6.87	6.93	0	0.072
	2	0.20	6.93	100	0.015
4.01	1	15.51	12.25	0	0.039
	2	1.17	12.25	100	0.015
4.02	1	5.43	10.61	0	0.047
	2	0.34	10.61	100	0.015
5.01	1	2.96	16.28	0	0.043
	2	0.35	16.28	100	0.015
5.02	1	7.79	12.47	0	0.063
	2	1.17	12.47	100	0.015
5.03	1	10.59	9.23	0	0.058
	2	0.49	9.23	100	0.015
5.04	1	16.80	5.93	0	0.087
	2	0.46	5.93	100	0.015
5.05	1	11.58	5.63	0	0.079
	2	0.30	5.63	100	0.015
6.01	1	5.90	17.57	0	0.039
	2	0.46	17.57	100	0.015
7.01	1	1.70	18.33	0	0.043
	2	0.26	18.33	100	0.015
7.02	1	6.51	15.60	0	0.059
	2	0.97	15.60	100	0.015
8.01	1	5.71	16.23	0	0.040
	2	0.62	16.23	100	0.015
9.01	1	11.83	12.91	0	0.043
	2	0.53	12.91	100	0.015
10.01	1	14.99	7.55	0	0.062
	2	1.58	7.55	100	0.015
11.01	1	7.03	10.29	0	0.062
	2	0.21	10.29	100	0.015
12.01	1	3.38	13.54	0	0.058
	2	0.74	13.54	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
12.02	1	7.66	9.51	0	0.046
	2	2.22	9.51	100	0.015
12.03	1	4.20	5.85	0	0.054
	2	0.68	5.85	100	0.015
12.04	1	6.47	4.48	0	0.070
	2	0.40	4.48	100	0.015
12.05	1	2.16	5.86	0	0.078
	2	0.19	5.86	100	0.015
13.01	1	1.20	7.01	0	0.040
	2	0.29	7.01	100	0.015
13.02	1	9.47	17.10	0	0.061
	2	0.96	17.10	100	0.015
13.03	1	9.09	10.43	0	0.060
	2	0.52	10.43	100	0.015
14.01	1	6.65	10.34	0	0.055
	2	1.88	10.34	100	0.015
14.02	1	7.53	6.49	0	0.040
	2	1.97	6.49	100	0.015
14.03	1	2.45	7.61	0	0.048
	2	0.39	7.61	100	0.015
14.04	1	6.25	9.03	0	0.055
	2	0.55	9.03	100	0.015
15.01	1	2.80	7.34	0	0.081
	2	0.23	7.34	100	0.015
16.01	1	3.91	7.17	0	0.050
	2	0.32	7.17	100	0.015
17.01	1	3.26	5.10	0	0.048
	2	0.94	5.10	100	0.015
18.01	1	3.66	7.92	0	0.054
	2	1.18	7.92	100	0.015
18.02	1	2.37	7.95	0	0.067
	2	0.54	7.95	100	0.015
19.01	1	4.43	3.66	0	0.046
	2	0.30	3.66	100	0.015
20.01	1	11.85	8.20	0	0.062
	2	0.85	8.20	100	0.015
20.02	1	7.68	4.56	0	0.071
	2	0.69	4.56	100	0.015
20.03	1	2.27	2.49	0	0.040
	2	0.28	2.49	100	0.015
20.04	1	2.64	2.40	0	0.044
	2	0.18	2.40	100	0.015
20.05	1	1.51	1.52	0	0.037
	2	0.21	1.52	100	0.015
20.06	1	1.09	2.71	0	0.085
	2	0.03	2.71	100	0.015
21.01	1	1.59	3.95	0	0.069
	2	0.08	3.95	100	0.015

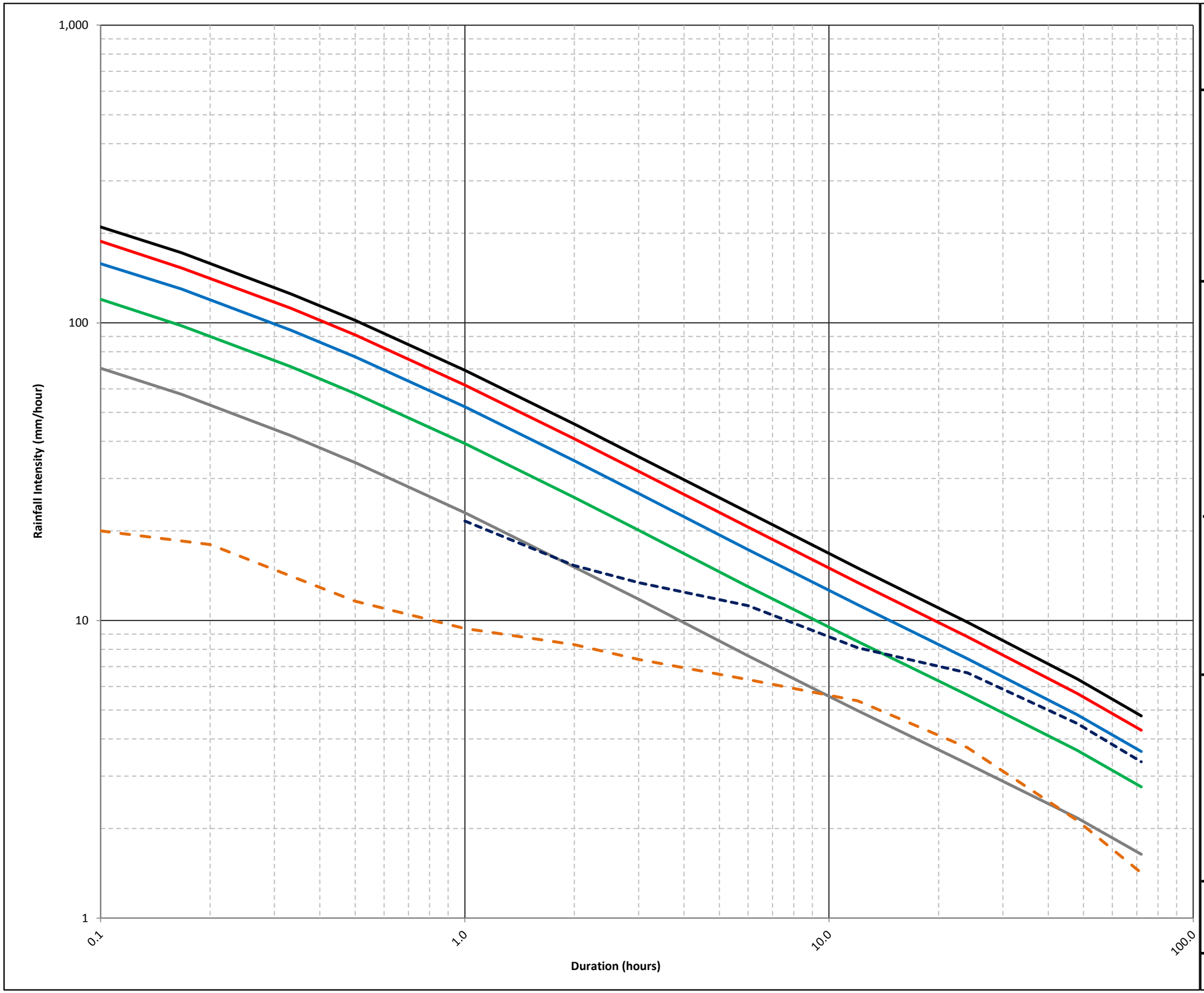
Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
21.02	1	2.24	4.66	0	0.035
	2	0.76	4.66	100	0.015
21.03	1	3.44	4.12	0	0.041
	2	0.34	4.12	100	0.015
21.04	1	6.30	1.31	0	0.052
	2	0.40	1.31	100	0.015
22.01	1	3.57	1.58	0	0.082
	2	0.18	1.58	100	0.015
23.01	1	13.49	11.69	0	0.042
	2	1.33	11.69	100	0.015
23.02	1	11.26	4.34	0	0.040
	2	1.52	4.34	100	0.015
23.03	1	9.34	4.79	0	0.041
	2	1.48	4.79	100	0.015
23.04	1	2.44	3.58	0	0.035
	2	0.71	3.58	100	0.015
23.05	1	2.80	4.14	0	0.037
	2	0.95	4.14	100	0.015
23.06	1	3.88	4.70	0	0.044
	2	1.08	4.70	100	0.015
23.07	1	3.10	3.40	0	0.040
	2	0.57	3.40	100	0.015
23.08	1	2.26	2.77	0	0.037
	2	1.15	2.77	100	0.015
23.09	1	1.72	2.44	0	0.037
	2	1.04	2.44	100	0.015
23.1	1	3.24	2.12	0	0.035
	2	1.64	2.12	100	0.015
23.11	1	3.36	2.50	0	0.049
	2	1.19	2.50	100	0.015
24.01	1	8.83	7.53	0	0.046
	2	1.78	7.53	100	0.015
24.02	1	5.04	5.60	0	0.051
	2	0.70	5.60	100	0.015
25.01	1	0.94	9.74	0	0.044
	2	0.21	9.74	100	0.015
26.01	1	0.56	6.19	0	0.039
	2	0.28	6.19	100	0.015
27.01	1	1.53	6.79	0	0.030
	2	0.74	6.79	100	0.015
28.01	1	1.00	6.83	0	0.032
	2	0.31	6.83	100	0.015
29.01	1	1.14	4.63	0	0.028
	2	1.14	4.63	100	0.015
29.02	1	3.42	3.77	0	0.038
	2	1.92	3.77	100	0.015
30.01	1	1.02	5.19	0	0.029
	2	0.88	5.19	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
31.01	1	2.41	4.89	0	0.033
	2	1.52	4.89	100	0.015
31.02	1	2.04	4.40	0	0.034
	2	0.84	4.40	100	0.015
32.01	1	0.00	501.20	0	0.016
	2	0.00	501.20	100	0.015
33.01	1	1.05	1.07	0	0.040
	2	0.39	1.07	100	0.015
34.01	1	2.18	6.46	0	0.032
	2	0.77	6.46	100	0.015
35.01	1	1.61	1.12	0	0.036
	2	0.35	1.12	100	0.015
35.02	1	2.51	1.94	0	0.033
	2	1.29	1.94	100	0.015
36.01	1	4.19	12.62	0	0.074
	2	0.59	12.62	100	0.015
36.02	1	1.31	2.88	0	0.027
	2	1.34	2.88	100	0.015
36.03	1	0.30	3.09	0	0.030
	2	0.20	3.09	100	0.015
36.04	1	1.15	2.41	0	0.030
	2	0.47	2.41	100	0.015
36.05	1	0.32	2.08	0	0.029
	2	0.14	2.08	100	0.015
36.06	1	0.25	2.52	0	0.028
	2	0.16	2.52	100	0.015
36.07	1	0.04	2.27	0	0.031
	2	0.01	2.27	100	0.015
37.01	1	1.97	1.56	0	0.029
	2	1.55	1.56	100	0.015
38.01	1	1.39	1.66	0	0.029
	2	0.88	1.66	100	0.015
38.02	1	0.45	3.85	0	0.030
	2	0.22	3.85	100	0.015
39.01	1	0.88	2.57	0	0.028
	2	0.84	2.57	100	0.015
40.01	1	3.63	16.06	0	0.068
	2	0.45	16.06	100	0.015
40.02	1	1.34	4.88	0	0.030
	2	0.71	4.88	100	0.015
40.03	1	1.16	1.08	0	0.032
	2	0.24	1.08	100	0.015
40.04	1	0.11	3.76	0	0.026
	2	0.20	3.76	100	0.015
41.01	1	1.90	16.16	0	0.047
	2	0.64	16.16	100	0.015
41.02	1	0.83	6.68	0	0.034
	2	0.32	6.68	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
41.03	1	0.69	1.83	0	0.030
	2	0.25	1.83	100	0.015
42.01	1	2.42	1.08	0	0.032
	2	1.69	1.08	100	0.015
42.02	1	2.03	1.51	0	0.036
	2	0.97	1.51	100	0.015
43.01	1	3.96	6.29	0	0.057
	2	0.11	6.29	100	0.015
43.02	1	0.67	2.40	0	0.034
	2	0.27	2.40	100	0.015
44.01	1	4.31	6.87	0	0.058
	2	0.24	6.87	100	0.015
45.01	1	3.14	14.37	0	0.067
	2	0.09	14.37	100	0.015
46.01	1	2.14	18.61	0	0.081
	2	0.12	18.61	100	0.015
46.02	1	0.72	22.42	0	0.090
	2	0.02	22.42	100	0.015

APPENDIX C

XP-RAFTS MODEL RESULTS FOR CALIBRATION SIMULATIONS



WINGECARRIBEE SHIRE COUNCIL

LEGEND

- 1% AEP
- 2% AEP
- 5% AEP
- 20% AEP
- 100% AEP
- June 1991 Event
- Feb-March 2012 Event

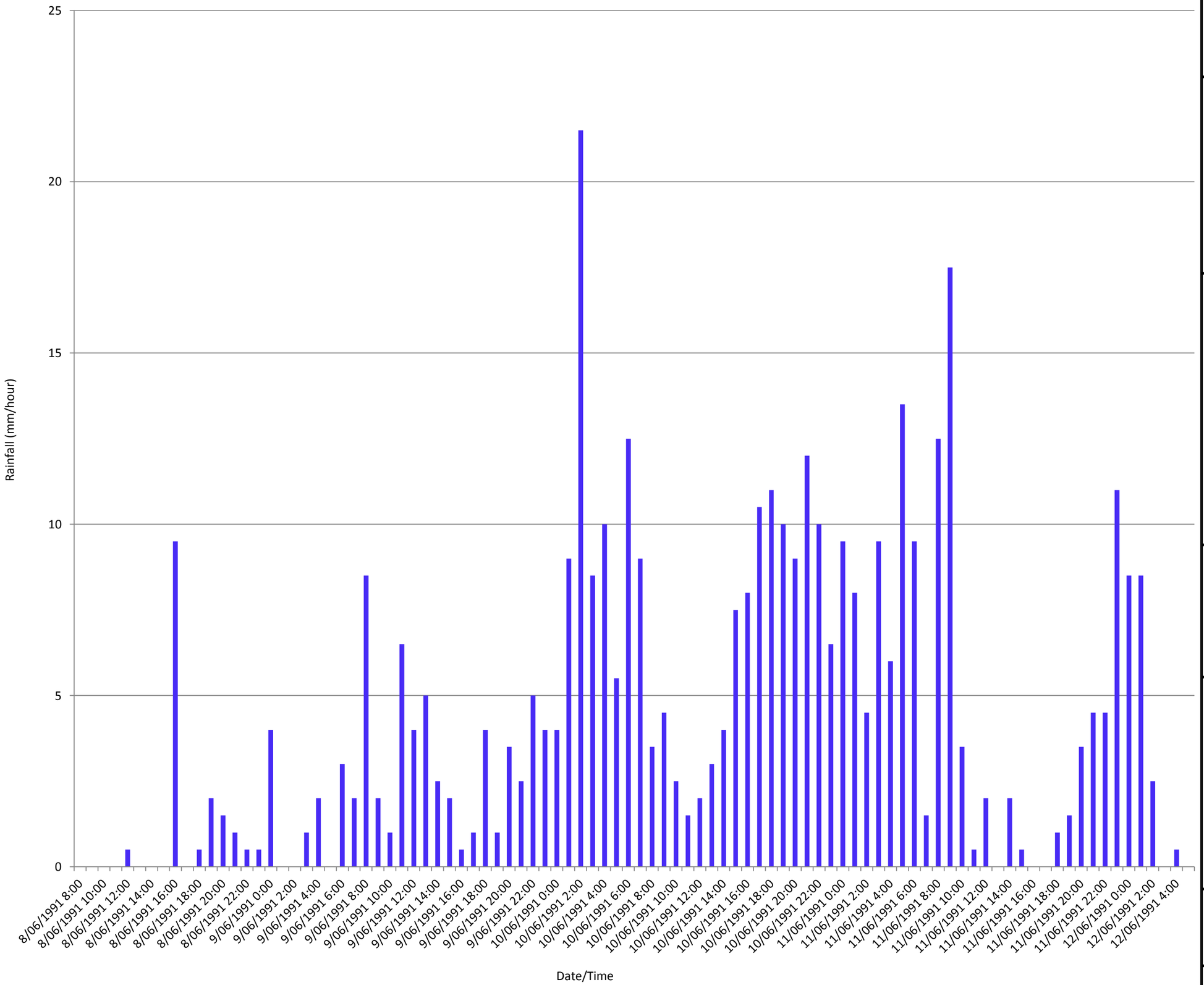
Notes:

Historic intensity-duration information is based upon the following information:
- 1991 event: SCA guage #568054 - Mittagong Maguires Crossing. This gauge only provides hourly data. Therefore, sub-hourly intensities cannot be calculated
- 2012 event: BoM gauge #68239 - Moss Vale AWS

Figure C1: Intensity-Frequency-Duration Curves for Nattai River Catchment

Prepared By:
Catchment Simulation Solutions
Suite 302, 5 Hunter Street
Sydney, NSW, 2000

File Name: IFD_Curves.xls



WINGECARRIBEE SHIRE COUNCIL

LEGEND:

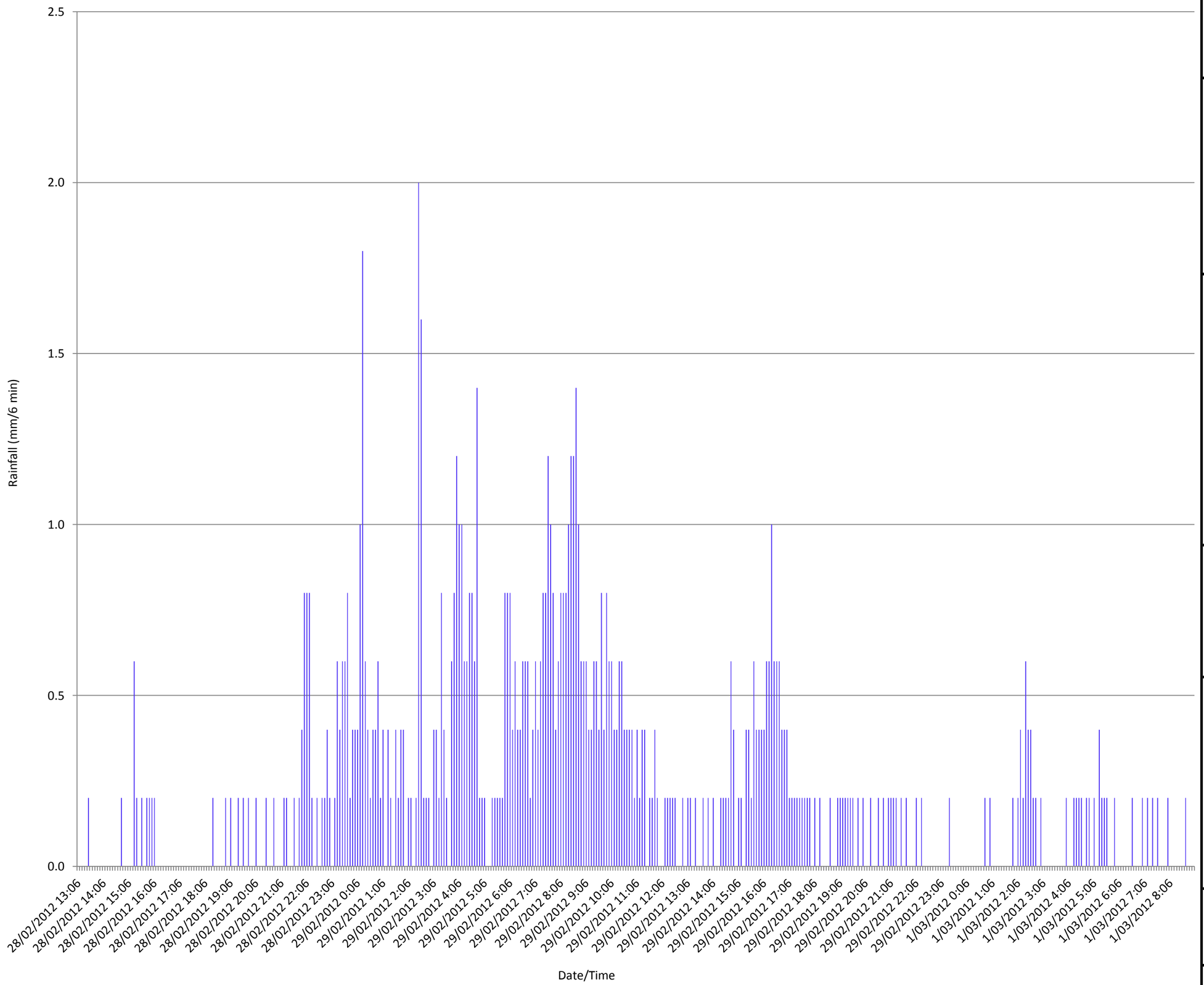
- Mittagong (Maquires Crossing)

Notes:

Figure C2:
Continuous Rainfall Data for the June 1991 Event

Prepared By:
Catchment Simulation Solutions
Suite 302, 5 Hunter Street
Sydney, NSW, 2000

File Name: Nattai_Pluviographs.xlsx



WINGECARRIBEE SHIRE COUNCIL

LEGEND:

- Moss Vale AWS

Notes:

Figure C3: Continuous Rainfall Data for the February-March 2012 Event

Prepared By:
Catchment Simulation Solutions
Suite 302, 5 Hunter Street
Sydney, NSW, 2000

File Name: Nattai_Pluviographs.xlsx

PEAK DESIGN FLOOD DISCHARGES - Calibration Events

Subcatchment ID	Peak Discharge (m^3/s)	
	10th & 11th June 1991	29th February & 1st March 2012
1.01	1.24	0.60
1.02	1.81	0.89
1.03	2.18	1.07
1.04	4.27	2.12
1.05	4.84	2.38
1.06	7.63	3.83
1.07	7.99	4.01
1.08	12.85	6.47
1.09	16.68	8.28
1.1	16.95	8.38
1.11	17.30	8.54
1.12	17.50	8.64
1.13	17.52	8.67
1.14	18.95	9.41
1.15	18.94	9.40
1.16	19.11	9.50
1.17	19.09	9.52
1.18	22.51	11.35
1.19	22.67	11.43
1.2	22.70	11.45
1.21	22.83	11.53
1.22	23.66	12.02
1.23	23.82	12.13
1.24	23.84	12.14
1.25	23.90	12.17
1.26	23.99	12.25
1.27	24.10	12.27
2.01	1.23	0.63
2.02	1.54	0.78
3.01	0.87	0.45
3.02	1.15	0.59
3.03	2.44	1.29
4.01	0.75	0.43
4.02	1.01	0.56
5.01	0.15	0.09
5.02	1.24	0.73
5.03	2.00	1.14
5.04	3.15	1.71
5.05	4.58	2.37
6.01	0.28	0.18
7.01	0.09	0.06
7.02	0.42	0.25
8.01	0.28	0.18
9.01	0.55	0.31
10.01	0.71	0.35

Subcatchment ID	Peak Discharge (m^3/s)	
	10th & 11th June 1991	29th February & 1st March 2012
11.01	0.32	0.17
12.01	0.18	0.11
12.02	0.63	0.35
12.03	1.79	0.97
12.04	3.38	1.82
12.05	3.68	1.92
13.01	0.07	0.04
13.02	0.53	0.30
13.03	0.95	0.52
14.01	0.38	0.23
14.02	0.81	0.43
14.03	0.93	0.50
14.04	1.22	0.65
15.01	0.13	0.07
16.01	0.19	0.11
17.01	0.19	0.11
18.01	0.22	0.13
18.02	0.35	0.20
19.01	0.21	0.11
20.01	0.57	0.27
20.02	0.89	0.44
20.03	0.98	0.49
20.04	1.08	0.54
20.05	1.13	0.57
20.06	1.74	0.88
21.01	0.07	0.03
21.02	0.21	0.11
21.03	0.37	0.20
21.04	0.58	0.31
22.01	0.11	0.06
23.01	0.69	0.37
23.02	1.28	0.63
23.03	2.48	1.20
23.04	2.64	1.27
23.05	2.93	1.38
23.06	3.19	1.48
23.07	3.34	1.54
23.08	3.43	1.59
23.09	3.85	1.80
23.1	4.10	1.91
23.11	4.51	2.15
24.01	0.50	0.26
24.02	0.75	0.39
25.01	0.05	0.03
26.01	0.04	0.03
27.01	0.11	0.08
28.01	0.06	0.04

Subcatchment ID	Peak Discharge (m^3/s)	
	10th & 11th June 1991	29th February & 1st March 2012
29.01	0.11	0.10
29.02	0.36	0.21
30.01	0.09	0.08
31.01	0.18	0.14
31.02	0.32	0.19
32.01	0.00	0.00
33.01	0.06	0.04
34.01	0.13	0.09
35.01	0.08	0.04
35.02	0.25	0.14
36.01	0.21	0.12
36.02	0.33	0.19
36.03	0.36	0.20
36.04	0.80	0.47
36.05	0.82	0.47
36.06	0.84	0.48
36.07	1.39	0.80
37.01	0.16	0.13
38.01	0.10	0.07
38.02	0.14	0.08
39.01	0.08	0.07
40.01	0.18	0.11
40.02	0.27	0.16
40.03	0.33	0.19
40.04	0.56	0.32
41.01	0.12	0.08
41.02	0.17	0.11
41.03	0.21	0.13
42.01	0.19	0.14
42.02	0.31	0.17
43.01	0.18	0.10
43.02	0.22	0.12
44.01	0.20	0.11
45.01	0.14	0.08
46.01	0.10	0.06
46.02	0.13	0.08

APPENDIX D

PMP CALCULATIONS

GSDM CALCULATION SHEET

LOCATION INFORMATION

Catchment Nattai Creek Flood Study Area 6.80 km^2

State New South Wales Duration Limit 6.0 hrs

Latitude 34.4629^0S Longitude 150.4549^0E

Portion of Area Considered:

Smooth, **S** = 0.00 (0.0 - 1.0) Rough, **R** = 1.00 (0.0 - 1.0)

ELEVATION ADJUSTMENT FACTOR (EAF)

Mean Elevation 699 m

Adjustment for Elevation (-0.05 per 300m above 1500m) 0.00

EAF = **1.00** (0.85 – 1.00)

MOISTURE ADJUSTMENT FACTOR (MAF)

MAF = **0.68** (0.40-1.00)

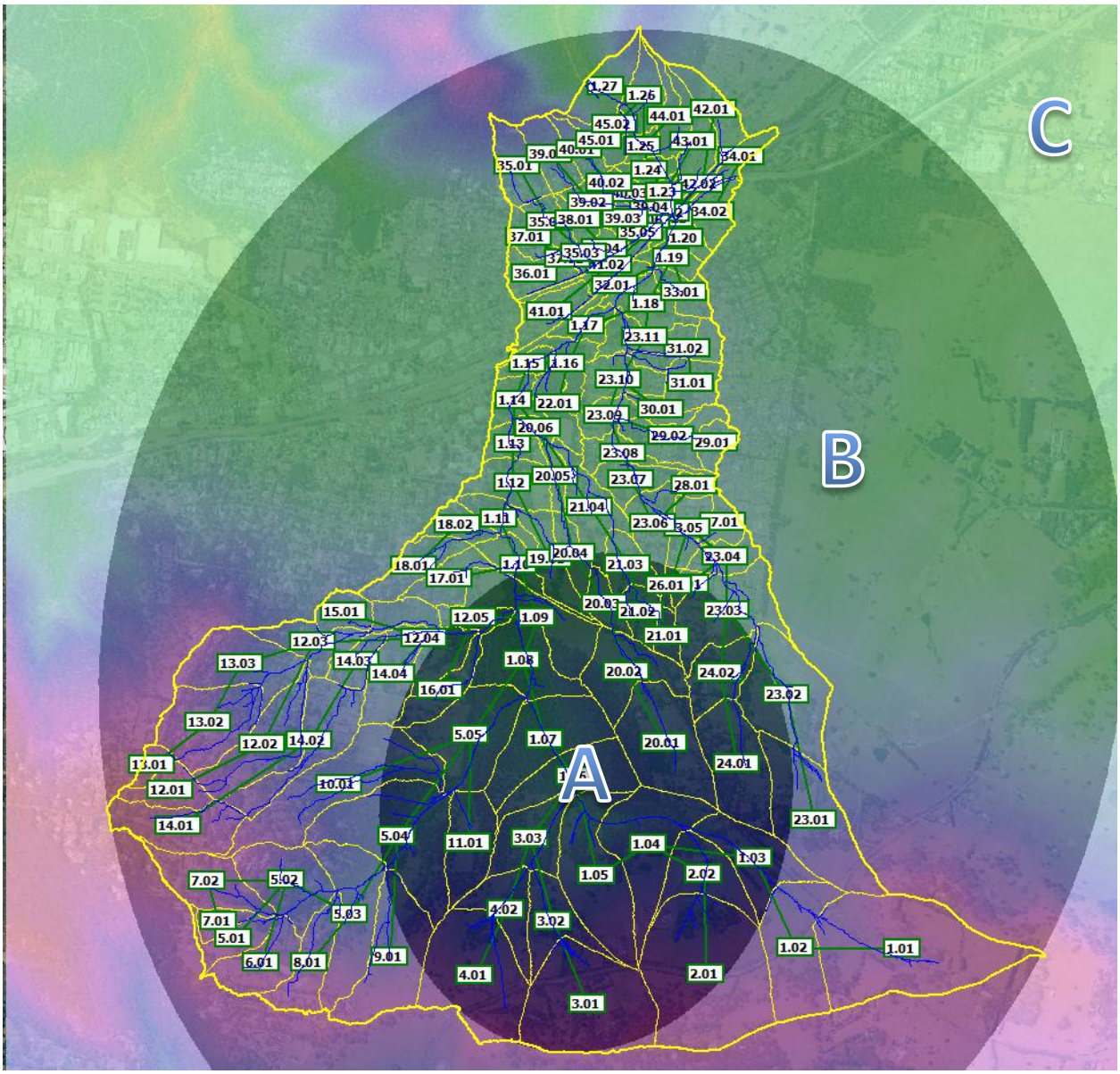
PMP VALUES (mm)

Duration (hours)	Initial Depth -Smooth (D_S)	Initial Depth -Rough (D_R)	PMP Estimate = (D_SxS + D_RxR) x MAF x EAF	Rounded PMP Estimate (nearest 10 mm)
0.25	218	218	148	150
0.50	320	320	217	220
0.75	406	406	276	280
1.00	473	473	322	320
1.50	539	606	412	410
2.00	604	710	483	480
2.50	643	782	532	530
3.00	676	857	583	580
4.00	743	982	668	670
5.00	799	1079	734	730
6.00	846	1146	779	780

Prepared By D.Tetley Date 03/05/2013

Checked By D.Fedczyna Date 17/05/2013

GSDM SPATIAL DISTRIBUTION



GSDM SPATIAL DISTRIBUTION

DURATION = 0.25 Hours							
Ellipse	**Catchment Area Between Ellipse (km^2)**	**Catchment Area Enclosed by Ellipse (km^2)**	**Initial Mean Rainfall Depth (mm)**	**Adjusted Mean Rainfall Depth (mm)**	**Rainfall Volume enclosed by Ellipse ($mm.km^2$)**	**Rainfall Volume between Ellipses ($mm.km^2$)**	**Mean Rainfall Depth between ellipses (mm)**
A	2.59	2.59	232	158	409	409	158
B	4.20	6.80	218	148	1006	596	142
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 0.50 Hours							
Ellipse	**Catchment Area Between Ellipse (km^2)**	**Catchment Area Enclosed by Ellipse (km^2)**	**Initial Mean Rainfall Depth (mm)**	**Adjusted Mean Rainfall Depth (mm)**	**Rainfall Volume enclosed by Ellipse ($mm.km^2$)**	**Rainfall Volume between Ellipses ($mm.km^2$)**	**Mean Rainfall Depth between ellipses (mm)**
A	2.59	2.59	336	229	593	593	229
B	4.20	6.80	320	217	1477	884	210
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 0.75 Hours

Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.59	2.59	425	289	750	750	289
B	4.20	6.80	406	276	1874	1124	268
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 1.0 Hours

Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.59	2.59	493	335	870	870	335
B	4.20	6.80	473	322	2185	1315	313
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 1.5 Hours							
Ellipse	**Catchment Area Between Ellipse (km^2)**	**Catchment Area Enclosed by Ellipse (km^2)**	**Initial Mean Rainfall Depth (mm)**	**Adjusted Mean Rainfall Depth (mm)**	**Rainfall Volume enclosed by Ellipse ($mm.km^2$)**	**Rainfall Volume between Ellipses ($mm.km^2$)**	**Mean Rainfall Depth between ellipses (mm)**
A	2.59	2.59	636	433	1122	1122	433
B	4.20	6.80	606	412	2801	1679	400
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 2.0 Hours							
Ellipse	**Catchment Area Between Ellipse (km^2)**	**Catchment Area Enclosed by Ellipse (km^2)**	**Initial Mean Rainfall Depth (mm)**	**Adjusted Mean Rainfall Depth (mm)**	**Rainfall Volume enclosed by Ellipse ($mm.km^2$)**	**Rainfall Volume between Ellipses ($mm.km^2$)**	**Mean Rainfall Depth between ellipses (mm)**
A	2.59	2.59	744	506	1313	1313	506
B	4.20	6.80	710	483	3283	1970	469
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 2.5 Hours							
Ellipse	**Catchment Area Between Ellipse (km^2)**	**Catchment Area Enclosed by Ellipse (km^2)**	**Initial Mean Rainfall Depth (mm)**	**Adjusted Mean Rainfall Depth (mm)**	**Rainfall Volume enclosed by Ellipse ($mm.km^2$)**	**Rainfall Volume between Ellipses ($mm.km^2$)**	**Mean Rainfall Depth between ellipses (mm)**
A	2.59	2.59	821	558	1449	1449	558
B	4.20	6.80	782	532	3616	2167	516
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 3.0 Hours							
Ellipse	**Catchment Area Between Ellipse (km^2)**	**Catchment Area Enclosed by Ellipse (km^2)**	**Initial Mean Rainfall Depth (mm)**	**Adjusted Mean Rainfall Depth (mm)**	**Rainfall Volume enclosed by Ellipse ($mm.km^2$)**	**Rainfall Volume between Ellipses ($mm.km^2$)**	**Mean Rainfall Depth between ellipses (mm)**
A	2.59	2.59	901	613	1590	1590	613
B	4.20	6.80	857	583	3959	2369	564
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 4.0 Hours							
Ellipse	**Catchment Area Between Ellipse (km^2)**	**Catchment Area Enclosed by Ellipse (km^2)**	**Initial Mean Rainfall Depth (mm)**	**Adjusted Mean Rainfall Depth (mm)**	**Rainfall Volume enclosed by Ellipse ($mm.km^2$)**	**Rainfall Volume between Ellipses ($mm.km^2$)**	**Mean Rainfall Depth between ellipses (mm)**
A	2.59	2.59	1030	700	1818	1818	700
B	4.20	6.80	982	668	4536	2719	647
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 5.0 Hours							
Ellipse	**Catchment Area Between Ellipse (km^2)**	**Catchment Area Enclosed by Ellipse (km^2)**	**Initial Mean Rainfall Depth (mm)**	**Adjusted Mean Rainfall Depth (mm)**	**Rainfall Volume enclosed by Ellipse ($mm.km^2$)**	**Rainfall Volume between Ellipses ($mm.km^2$)**	**Mean Rainfall Depth between ellipses (mm)**
A	2.59	2.59	1135	772	2003	2003	772
B	4.20	6.80	1079	734	4986	2983	710
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 6.0 Hours							
Ellipse	**Catchment Area Between Ellipse (km^2)**	**Catchment Area Enclosed by Ellipse (km^2)**	**Initial Mean Rainfall Depth (mm)**	**Adjusted Mean Rainfall Depth (mm)**	**Rainfall Volume enclosed by Ellipse ($mm.km^2$)**	**Rainfall Volume between Ellipses ($mm.km^2$)**	**Mean Rainfall Depth between ellipses (mm)**
A	2.59	2.59	1200	816	2118	2118	816
B	4.20	6.80	1146	779	5296	3178	757
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

APPENDIX E

XP-RAFTS MODEL RESULTS FOR DESIGN FLOOD SIMULATIONS

PEAK DESIGN FLOOD DISCHARGES - 20% AEP

Subcatchment ID	15 min	20 min	25 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min
1.01	0.65	0.92	1.19	1.45	2.07	2.36	2.45	2.54	2.16	**2.83**	2.48
1.02	0.96	1.37	1.90	2.32	3.17	3.62	3.75	3.95	3.14	**4.21**	3.74
1.03	1.23	1.67	2.30	2.80	3.84	4.45	4.60	4.88	3.81	**5.02**	4.55
1.04	2.26	3.34	4.62	5.65	7.74	9.02	9.35	9.91	7.73	**10.14**	9.12
1.05	2.41	3.77	5.18	6.36	8.75	10.25	10.62	11.31	8.87	**11.45**	10.38
1.06	3.80	6.36	8.76	10.55	14.33	16.79	17.51	**18.80**	14.45	18.52	16.73
1.07	3.76	6.46	8.87	10.74	14.67	17.28	18.04	**19.32**	15.00	19.17	17.38
1.08	6.14	10.73	14.66	17.56	23.77	28.19	29.71	**31.95**	24.69	31.01	27.98
1.09	7.75	13.33	18.07	21.79	30.03	36.11	38.40	**41.23**	32.34	39.99	36.28
1.10	7.79	13.35	18.12	21.85	30.25	36.13	38.70	**41.41**	32.78	40.32	36.71
1.11	7.89	13.49	18.30	22.07	30.69	36.71	39.47	**42.24**	33.60	41.06	37.55
1.12	7.92	13.54	18.37	22.06	30.92	36.90	39.76	**42.56**	34.21	41.53	38.17
1.13	7.94	13.55	18.38	22.05	30.91	36.93	39.84	**42.62**	34.36	41.59	38.34
1.14	8.39	14.17	19.35	23.15	33.16	39.60	42.78	**45.67**	37.35	45.05	41.90
1.15	8.35	14.04	19.22	23.01	32.95	39.40	42.61	**45.48**	37.34	44.90	41.89
1.16	8.39	14.10	19.29	23.10	33.10	39.61	42.93	**45.84**	37.72	45.26	42.31
1.17	8.37	14.07	19.23	23.04	32.91	39.39	42.60	**45.56**	37.74	44.99	42.25
1.18	9.63	15.70	21.29	25.48	37.27	43.69	48.95	**52.75**	45.10	51.56	49.83
1.19	9.63	15.68	21.21	25.45	37.26	43.69	49.07	**52.89**	45.36	51.79	50.08
1.20	9.63	15.67	21.21	25.44	37.26	43.69	49.11	**52.92**	45.42	51.85	50.14
1.21	9.66	15.71	21.26	25.50	37.34	43.79	49.29	**53.12**	45.69	52.12	50.40
1.22	9.81	15.89	21.49	25.75	37.75	44.27	50.68	**54.73**	47.71	53.92	52.43
1.23	9.86	15.93	21.54	25.79	37.83	44.36	50.97	**55.09**	48.18	54.30	52.89
1.24	9.86	15.93	21.54	25.79	37.82	44.35	51.01	**55.15**	48.26	54.38	52.96
1.25	9.87	15.94	21.55	25.80	37.85	44.38	51.12	**55.28**	48.44	54.54	53.14
1.26	9.87	15.93	21.55	25.80	37.85	44.40	51.23	**55.46**	48.71	54.80	53.40
1.27	9.87	15.92	21.55	25.80	37.86	44.42	51.30	**55.57**	48.90	54.98	53.58
2.01	0.69	1.05	1.45	1.79	2.37	2.70	2.81	2.94	2.30	**3.06**	2.72
2.02	0.84	1.29	1.77	2.19	2.94	3.39	3.52	3.71	2.89	**3.81**	3.40
3.01	0.54	0.79	1.08	1.26	1.71	1.95	2.05	2.17	1.65	**2.22**	1.98
3.02	0.70	1.04	1.46	1.68	2.27	2.62	2.79	**2.98**	2.21	2.94	2.62
3.03	1.45	2.45	3.35	3.91	5.11	6.00	6.29	**6.88**	5.10	6.36	5.67
4.01	0.61	0.98	1.32	1.47	1.81	2.20	2.27	**2.54**	1.89	2.11	1.85
4.02	0.77	1.27	1.69	1.98	2.40	2.92	3.04	**3.35**	2.54	2.84	2.45
5.01	0.21	0.30	0.37	0.39	0.45	0.56	0.70	**0.73**	0.55	0.50	0.37
5.02	1.13	1.82	2.37	2.67	3.15	3.77	4.25	**4.66**	3.50	3.63	3.07
5.03	1.57	2.62	3.50	3.94	4.80	5.77	6.38	**6.93**	5.19	5.63	4.86
5.04	2.02	3.51	4.65	5.36	6.70	8.08	8.74	**9.52**	7.00	8.19	7.20
5.05	2.45	4.30	5.80	6.80	8.98	10.70	11.47	**12.37**	9.35	11.41	10.19
6.01	0.36	0.58	0.71	0.73	0.84	1.06	1.27	**1.35**	1.02	0.95	0.71
7.01	0.16	0.23	0.25	0.25	0.27	0.36	**0.48**	0.47	0.34	0.30	0.22
7.02	0.47	0.66	0.79	0.90	1.06	1.27	1.45	**1.57**	1.20	1.21	1.05
8.01	0.34	0.56	0.65	0.72	0.82	1.02	1.22	**1.31**	0.99	0.93	0.71
9.01	0.41	0.73	0.99	1.10	1.35	1.62	1.71	**1.91**	1.39	1.57	1.36
10.01	0.60	0.63	0.83	0.78	1.13	1.30	1.37	1.47	1.33	**1.63**	1.43
11.01	0.17	0.27	0.39	0.50	0.66	0.76	0.80	0.83	0.64	**0.84**	0.75
12.01	0.29	0.34	0.42	0.39	0.47	0.56	0.65	**0.70**	0.53	0.54	0.46
12.02	0.84	1.02	1.26	1.19	1.42	1.62	1.82	**1.88**	1.46	1.74	1.54
12.03	1.51	1.93	2.61	3.00	3.92	4.55	4.80	**5.21**	3.97	4.85	4.28
12.04	2.54	3.60	4.62	5.05	6.92	7.99	8.54	**9.10**	7.09	8.83	7.80
12.05	2.71	3.82	4.92	5.49	7.43	8.60	9.18	**9.74**	7.63	9.56	8.42
13.01	0.11	0.13	0.17	0.16	0.19	0.23	0.28	**0.29**	0.23	0.22	0.17
13.02	0.47	0.68	0.88	1.02	1.26	1.51	1.56	**1.76**	1.31	1.49	1.31
13.03	0.65	1.01	1.39	1.65	2.11	2.47	2.59	**2.83**	2.13	2.58	2.29
14.01	0.71	0.74	0.89	0.81	0.82	0.96	**1.23**	1.13	0.93	1.02	0.93
14.02	0.89	1.13	1.52	1.55	1.70	1.96	**2.29**	2.21	1.79	2.12	1.87
14.03	0.96	1.30	1.69	1.77	1.93	2.30	**2.62**	2.53	2.04	2.43	2.15
14.04	1.11	1.55	2.01	2.22	2.48	3.02	**3.35**	3.26	2.61	3.23	2.81
15.01	0.09	0.10	0.14	0.17	0.23	0.26	0.27	0.29	0.25	**0.32**	0.28
16.01	0.13	0.20	0.27	0.32	0.41	0.47	0.50	**0.56**	0.40	0.51	0.46
17.01	0.35	0.37	0.43	0.39	0.37	0.46	**0.57**	0.51	0.40	0.49	0.45
18.01	0.44	0.47	0.56	0.50	0.47	0.56	**0.71**	0.65	0.53	0.58	0.53
18.02	0.62	0.64	0.70	0.64	0.72	0.83	**0.97**	0.95	0.76	0.91	0.83
19.01	0.12	0.16	0.21	0.26	0.36	0.42	0.44	0.45	0.39	**0.52**	0.44
20.01	0.33	0.42	0.54	0.67	0.95	1.10	1.14	1.19	1.03	**1.34**	1.16
20.02	0.46	0.59	0.73	0.91	1.37	1.62	1.70	1.82	1.65	**1.95**	1.79
20.03	0.52	0.64	0.82	1.03	1.53	1.81	1.90	2.04	1.83	**2.18**	2.01
20.04	0.53	0.69	0.90	1.14	1.68	2.00	2.13	2.26	2.03	**2.40**	2.24

Subcatchment ID	15 min	20 min	25 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min
20.05	0.53	0.71	0.93	1.18	1.73	2.08	2.23	2.36	2.13	**2.50**	2.37
20.06	0.81	1.12	1.50	1.77	2.67	3.18	3.40	3.56	3.22	**3.77**	3.63
21.01	0.03	0.05	0.06	0.08	0.13	0.14	0.15	0.16	0.13	**0.17**	0.15
21.02	0.30	0.30	0.39	0.35	0.40	0.48	0.54	**0.56**	0.43	0.51	0.47
21.03	0.39	0.45	0.56	0.59	0.74	0.87	0.90	**0.98**	0.74	0.95	0.84
21.04	0.39	0.48	0.61	0.70	0.93	1.12	1.19	1.26	1.02	**1.27**	1.19
22.01	0.07	0.07	0.09	0.08	0.11	0.13	0.16	0.18	0.19	0.19	**0.21**
23.01	0.53	0.83	1.12	1.25	1.56	1.86	1.92	**2.15**	1.59	1.84	1.63
23.02	0.68	1.10	1.58	1.87	2.52	2.97	3.10	**3.34**	2.52	3.22	2.79
23.03	1.45	1.95	2.89	3.36	4.68	5.50	5.69	**6.14**	4.78	6.01	5.41
23.04	1.52	2.05	3.08	3.51	4.95	5.83	6.03	**6.51**	5.12	6.38	5.77
23.05	1.62	2.23	3.31	3.75	5.33	6.30	6.59	**7.05**	5.65	7.02	6.36
23.06	1.70	2.39	3.50	4.00	5.64	6.71	7.09	**7.58**	6.16	7.52	6.88
23.07	1.72	2.43	3.58	4.11	5.80	6.92	7.35	**7.86**	6.45	7.77	7.18
23.08	1.72	2.46	3.60	4.09	5.85	7.06	7.55	**8.04**	6.70	7.95	7.44
23.09	1.97	2.65	3.84	4.36	6.23	7.62	8.31	**8.81**	7.51	8.69	8.26
23.10	2.15	2.81	3.96	4.50	6.41	7.94	8.69	**9.19**	7.96	9.05	8.78
23.11	2.82	3.35	4.23	4.74	6.83	8.51	9.41	**9.96**	8.79	9.74	9.66
24.01	0.67	0.70	0.90	0.81	0.97	1.12	**1.31**	1.27	1.01	1.25	1.14
24.02	0.82	0.96	1.12	1.07	1.42	1.65	1.78	1.81	1.44	**1.85**	1.66
25.01	0.08	0.11	0.14	0.13	0.15	0.19	0.25	**0.25**	0.19	0.17	0.13
26.01	0.11	0.11	0.14	0.12	0.11	0.14	**0.21**	0.19	0.14	0.13	0.10
27.01	0.28	0.30	0.39	0.34	0.31	0.41	**0.53**	0.49	0.37	0.34	0.26
28.01	0.12	0.14	0.18	0.16	0.18	0.23	**0.30**	0.29	0.22	0.20	0.15
29.01	0.43	0.45	0.48	0.44	0.37	0.50	**0.59**	0.51	0.38	0.35	0.26
29.02	0.83	0.97	1.10	1.03	0.87	1.01	1.10	**1.17**	0.88	0.95	0.84
30.01	0.33	0.35	0.39	0.35	0.29	0.41	**0.49**	0.42	0.32	0.29	0.22
31.01	0.57	0.60	0.68	0.61	0.49	0.67	**0.80**	0.69	0.55	0.54	0.45
31.02	0.85	0.84	0.96	0.87	0.77	0.96	**1.19**	1.08	0.86	0.89	0.77
33.01	0.14	0.15	0.16	0.15	0.12	0.15	**0.18**	0.16	0.12	0.15	0.13
34.01	0.30	0.32	0.42	0.38	0.38	0.45	**0.59**	0.58	0.44	0.43	0.33
35.01	0.13	0.13	0.15	0.14	0.13	0.15	0.19	0.17	0.16	**0.19**	0.17
35.02	0.50	0.49	0.60	0.56	0.44	0.58	**0.66**	0.60	0.48	0.59	0.53
36.01	0.23	0.27	0.35	0.34	0.44	0.51	0.54	**0.59**	0.44	0.56	0.51
36.02	0.62	0.60	0.70	0.65	0.67	0.76	0.83	**0.89**	0.70	0.87	0.78
36.03	0.66	0.64	0.75	0.70	0.71	0.80	0.89	**0.96**	0.74	0.93	0.83
36.04	1.86	1.90	2.09	1.93	1.68	2.02	**2.43**	2.41	1.83	2.03	1.85
36.05	1.86	1.90	2.11	1.96	1.71	2.07	**2.47**	2.45	1.87	2.06	1.89
36.06	1.89	1.95	2.15	1.99	1.75	2.13	**2.53**	2.51	1.91	2.10	1.93
36.07	2.72	2.92	3.23	2.99	3.03	3.55	4.32	**4.48**	3.34	3.59	3.26
37.01	0.57	0.57	0.61	0.56	0.48	0.57	**0.68**	0.59	0.41	0.41	0.38
38.01	0.32	0.33	0.36	0.33	0.27	0.34	**0.42**	0.35	0.28	0.27	0.25
38.02	0.41	0.39	0.44	0.40	0.34	0.43	**0.53**	0.47	0.35	0.36	0.32
39.01	0.31	0.33	0.34	0.31	0.27	0.33	**0.41**	0.34	0.27	0.25	0.20
40.01	0.18	0.26	0.31	0.36	0.44	0.54	0.55	**0.63**	0.47	0.51	0.45
40.02	0.43	0.42	0.51	0.54	0.65	0.79	0.82	**0.94**	0.69	0.77	0.68
40.03	0.46	0.49	0.54	0.60	0.75	0.91	0.95	**1.07**	0.78	0.91	0.81
40.04	0.89	0.97	1.09	1.09	1.31	1.56	1.79	**1.97**	1.44	1.54	1.36
41.01	0.25	0.31	0.38	0.35	0.34	0.43	**0.59**	0.57	0.42	0.38	0.29
41.02	0.36	0.40	0.48	0.44	0.50	0.61	0.80	**0.80**	0.60	0.55	0.42
41.03	0.41	0.44	0.52	0.51	0.58	0.71	0.89	**0.91**	0.68	0.66	0.52
42.01	0.62	0.63	0.65	0.60	0.52	0.60	**0.70**	0.61	0.42	0.41	0.38
42.02	0.63	0.70	0.73	0.70	0.65	0.76	**0.81**	0.81	0.61	0.67	0.62
43.01	0.07	0.15	0.20	0.26	0.35	0.41	0.42	0.44	0.34	**0.47**	0.41
43.02	0.10	0.18	0.23	0.29	0.40	0.47	0.50	0.53	0.42	**0.54**	0.49
44.01	0.10	0.18	0.24	0.29	0.40	0.46	0.47	0.50	0.38	**0.53**	0.46
45.01	0.11	0.18	0.25	0.28	0.35	0.41	0.44	**0.49**	0.36	0.41	0.35
46.01	0.07	0.15	0.19	0.21	0.25	0.31	0.32	**0.35**	0.26	0.29	0.25
46.02	0.10	0.20	0.25	0.28	0.33	0.40	0.43	**0.48**	0.36	0.38	0.33

PEAK DESIGN FLOOD DISCHARGES - 10% AEP

Subcatchment ID	15 min	20 min	25 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min
1.01	0.89	1.27	1.65	2.00	2.62	2.95	3.08	3.17	2.62	**3.43**	3.00
1.02	1.38	2.03	2.68	3.15	3.97	4.51	4.69	4.99	3.95	**5.07**	4.46
1.03	1.65	2.49	3.26	3.79	4.84	5.56	5.77	**6.20**	4.88	6.11	5.41
1.04	3.18	4.95	6.57	7.67	9.82	11.31	11.78	**12.62**	9.88	12.21	10.83
1.05	3.57	5.63	7.36	8.64	11.14	12.87	13.37	**14.31**	11.30	13.87	12.31
1.06	6.01	9.47	12.33	14.35	18.27	21.24	22.11	**23.82**	18.70	22.38	19.82
1.07	6.04	9.61	12.53	14.60	18.77	21.81	22.78	**24.48**	19.29	23.20	20.67
1.08	9.92	15.95	20.61	23.89	30.34	35.68	37.63	**40.42**	31.74	37.55	33.41
1.09	12.39	19.66	25.56	29.79	38.77	45.89	48.66	**52.00**	41.27	48.69	43.38
1.10	12.41	19.69	25.67	29.94	38.91	46.04	49.05	**52.45**	41.63	49.20	43.96
1.11	12.54	19.89	25.95	30.31	39.47	46.82	50.00	**53.48**	42.62	50.13	44.96
1.12	12.59	19.86	25.97	30.45	39.62	47.14	50.35	**53.80**	43.17	50.72	45.78
1.13	12.60	19.85	25.95	30.43	39.63	47.18	50.44	**53.85**	43.33	50.84	45.97
1.14	13.24	20.82	27.48	32.43	42.52	50.66	53.69	**57.22**	46.84	54.92	50.33
1.15	13.12	20.67	27.29	32.18	42.29	50.37	53.44	**56.81**	46.75	54.75	50.32
1.16	13.18	20.75	27.39	32.29	42.50	50.69	53.82	**57.22**	47.24	55.16	50.85
1.17	13.15	20.67	27.22	32.12	42.12	50.40	53.62	**57.03**	47.12	55.05	50.88
1.18	14.83	22.79	30.31	36.12	46.62	57.51	61.20	**65.43**	56.14	62.64	60.73
1.19	14.81	22.78	30.29	36.09	46.62	57.52	61.36	**65.58**	56.45	62.90	61.07
1.20	14.80	22.77	30.28	36.07	46.60	57.52	61.38	**65.64**	56.51	62.97	61.15
1.21	14.84	22.82	30.35	36.15	46.69	57.64	61.59	**65.89**	56.85	63.27	61.51
1.22	15.03	23.08	30.67	36.54	47.14	58.45	63.23	**67.88**	59.43	65.29	64.21
1.23	15.07	23.11	30.72	36.59	47.21	58.59	63.56	**68.28**	59.98	65.71	64.81
1.24	15.07	23.11	30.71	36.60	47.22	58.59	63.62	**68.33**	60.06	65.82	64.89
1.25	15.08	23.12	30.73	36.62	47.23	58.66	63.74	**68.50**	60.31	66.01	65.15
1.26	15.08	23.12	30.73	36.62	47.25	58.69	63.90	**68.70**	60.63	66.30	65.50
1.27	15.07	23.12	30.72	36.61	47.25	58.69	64.00	**68.84**	60.85	66.50	65.75
2.01	1.05	1.52	2.08	2.42	2.94	3.38	3.55	**3.77**	2.95	3.62	3.22
2.02	1.26	1.86	2.56	2.99	3.71	4.24	4.46	**4.76**	3.71	4.55	4.02
3.01	0.80	1.14	1.49	1.72	2.16	2.49	2.59	**2.77**	2.14	2.61	2.35
3.02	1.04	1.57	2.02	2.29	2.91	3.38	3.48	**3.77**	2.93	3.47	3.08
3.03	2.34	3.61	4.63	5.32	6.48	7.67	7.97	**8.69**	6.82	7.61	6.67
4.01	0.95	1.43	1.80	2.02	2.29	2.73	2.87	**3.16**	2.54	2.51	2.14
4.02	1.21	1.86	2.33	2.65	3.06	3.61	3.83	**4.25**	3.34	3.37	2.86
5.01	0.32	0.43	0.51	0.49	0.53	0.71	**0.90**	0.89	0.65	0.58	0.43
5.02	1.78	2.70	3.28	3.38	3.87	4.78	5.55	**5.84**	4.41	4.35	3.58
5.03	2.52	3.98	4.85	5.17	5.91	7.27	8.12	**8.72**	6.59	6.75	5.68
5.04	3.29	5.25	6.42	7.14	8.40	10.24	11.15	**12.00**	9.14	9.83	8.52
5.05	3.99	6.45	8.08	9.25	11.32	13.59	14.58	**15.68**	12.11	13.80	12.15
6.01	0.61	0.83	0.97	0.95	1.01	1.33	1.62	**1.67**	1.23	1.10	0.82
7.01	0.23	0.31	0.36	0.32	0.33	0.47	**0.61**	0.56	0.39	0.35	0.25
7.02	0.66	0.92	1.09	1.16	1.32	1.56	1.91	**1.98**	1.54	1.48	1.22
8.01	0.58	0.79	0.91	0.92	1.00	1.29	1.57	**1.62**	1.21	1.09	0.82
9.01	0.70	1.09	1.35	1.46	1.70	2.07	2.19	**2.41**	1.87	1.87	1.58
10.01	0.73	0.83	1.05	1.07	1.43	1.66	1.71	1.81	1.59	**2.03**	1.76
11.01	0.26	0.42	0.58	0.67	0.83	0.95	1.01	**1.10**	0.84	1.00	0.89
12.01	0.35	0.43	0.53	0.52	0.60	0.69	0.86	**0.88**	0.70	0.66	0.53
12.02	1.00	1.34	1.57	1.50	1.75	2.11	2.34	**2.42**	1.87	2.07	1.79
12.03	1.91	2.74	3.58	3.99	4.91	5.79	6.19	**6.61**	5.07	5.78	5.04
12.04	3.54	4.91	6.22	6.82	8.74	10.20	10.82	**11.62**	9.06	10.62	9.26
12.05	3.71	5.26	6.67	7.40	9.37	10.94	11.70	**12.45**	9.70	11.49	9.98
13.01	0.14	0.20	0.25	0.22	0.23	0.28	**0.36**	0.36	0.28	0.25	0.19
13.02	0.69	1.00	1.23	1.34	1.57	1.90	1.99	**2.20**	1.70	1.77	1.52
13.03	0.97	1.53	1.93	2.19	2.64	3.13	3.26	**3.59**	2.74	3.06	2.69
14.01	0.83	0.85	1.10	1.00	1.06	1.24	**1.55**	1.50	1.20	1.20	1.09
14.02	1.18	1.48	1.90	1.95	2.12	2.51	**2.91**	2.85	2.26	2.53	2.22
14.03	1.32	1.70	2.17	2.25	2.42	2.95	**3.28**	3.25	2.57	2.93	2.55
14.04	1.54	2.08	2.66	2.87	3.14	3.84	**4.24**	4.19	3.27	3.87	3.32
15.01	0.11	0.15	0.19	0.22	0.29	0.33	0.35	0.36	0.30	**0.39**	0.34
16.01	0.20	0.28	0.38	0.43	0.53	0.63	0.64	**0.72**	0.55	0.60	0.54
17.01	0.41	0.42	0.53	0.50	0.48	0.57	**0.70**	0.66	0.53	0.58	0.53
18.01	0.51	0.53	0.68	0.62	0.62	0.71	**0.91**	0.88	0.70	0.71	0.62
18.02	0.72	0.73	0.87	0.80	0.93	1.08	1.23	**1.26**	1.00	1.08	0.98
19.01	0.17	0.23	0.28	0.35	0.48	0.55	0.56	0.59	0.46	**0.62**	0.55
20.01	0.42	0.58	0.75	0.91	1.21	1.39	1.45	1.50	1.24	**1.63**	1.42
20.02	0.64	0.82	1.02	1.25	1.79	2.05	2.13	2.26	1.97	**2.41**	2.16
20.03	0.67	0.92	1.15	1.40	1.99	2.30	2.40	2.53	2.20	**2.69**	2.43
20.04	0.70	1.01	1.28	1.55	2.19	2.56	2.67	2.82	2.44	**2.97**	2.72

Subcatchment ID	15 min	20 min	25 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min
20.05	0.73	1.04	1.33	1.61	2.26	2.66	2.80	2.96	2.57	**3.11**	2.88
20.06	1.07	1.65	2.10	2.54	3.43	4.07	4.26	4.58	3.90	**4.71**	4.40
21.01	0.04	0.06	0.10	0.12	0.16	0.18	0.19	0.20	0.16	**0.21**	0.18
21.02	0.37	0.40	0.49	0.45	0.51	0.62	0.68	**0.71**	0.56	0.60	0.55
21.03	0.52	0.61	0.74	0.77	0.93	1.12	1.15	**1.28**	0.97	1.12	1.00
21.04	0.52	0.67	0.81	0.92	1.20	1.43	1.49	**1.63**	1.26	1.56	1.45
22.01	0.08	0.08	0.11	0.10	0.14	0.17	0.21	0.23	0.23	0.23	**0.27**
23.01	0.83	1.21	1.52	1.67	1.95	2.37	2.44	**2.68**	2.18	2.19	1.90
23.02	1.07	1.72	2.19	2.52	3.19	3.79	3.90	**4.20**	3.35	3.82	3.30
23.03	1.89	3.12	3.98	4.59	5.93	6.95	7.24	**7.79**	6.22	7.34	6.37
23.04	2.01	3.29	4.24	4.80	6.26	7.34	7.67	**8.24**	6.60	7.84	6.82
23.05	2.15	3.48	4.54	5.05	6.74	7.91	8.31	**8.90**	7.19	8.60	7.52
23.06	2.29	3.69	4.83	5.42	7.14	8.39	8.88	**9.53**	7.78	9.23	8.13
23.07	2.34	3.77	4.91	5.56	7.32	8.64	9.22	**9.85**	8.07	9.52	8.47
23.08	2.36	3.80	4.93	5.64	7.42	8.83	9.47	**10.14**	8.34	9.73	8.77
23.09	2.61	4.09	5.26	6.08	7.91	9.57	10.37	**11.11**	9.31	10.65	9.75
23.10	2.75	4.23	5.44	6.27	8.17	9.95	10.87	**11.62**	9.89	11.09	10.35
23.11	3.41	4.46	5.72	6.62	8.79	10.66	11.73	**12.58**	10.88	11.95	11.40
24.01	0.81	0.88	1.12	1.02	1.21	1.44	**1.67**	1.63	1.34	1.47	1.33
24.02	0.98	1.10	1.42	1.43	1.79	2.10	2.30	**2.39**	1.89	2.22	1.94
25.01	0.11	0.18	0.21	0.18	0.18	0.24	**0.31**	0.30	0.22	0.20	0.15
26.01	0.13	0.13	0.17	0.15	0.13	0.20	**0.25**	0.22	0.17	0.15	0.11
27.01	0.34	0.37	0.49	0.44	0.37	0.52	**0.66**	0.60	0.44	0.40	0.30
28.01	0.15	0.21	0.26	0.24	0.21	0.30	**0.38**	0.35	0.26	0.23	0.17
29.01	0.49	0.51	0.60	0.55	0.42	0.60	**0.71**	0.62	0.45	0.40	0.30
29.02	1.06	1.15	1.19	1.20	1.04	1.29	**1.38**	1.36	1.11	1.13	0.98
30.01	0.38	0.39	0.49	0.45	0.34	0.49	**0.59**	0.51	0.38	0.34	0.25
31.01	0.66	0.67	0.81	0.74	0.58	0.80	**1.00**	0.89	0.69	0.65	0.51
31.02	0.98	0.96	1.15	1.06	0.96	1.18	**1.46**	1.38	1.10	1.06	0.89
33.01	0.16	0.16	0.18	0.17	0.14	0.18	**0.21**	0.19	0.14	0.18	0.16
34.01	0.35	0.41	0.52	0.48	0.46	0.57	**0.77**	0.74	0.55	0.50	0.38
35.01	0.15	0.15	0.18	0.17	0.17	0.19	**0.25**	0.22	0.18	0.23	0.21
35.02	0.59	0.57	0.72	0.66	0.53	0.69	**0.81**	0.75	0.60	0.71	0.64
36.01	0.28	0.35	0.44	0.46	0.57	0.67	0.71	**0.76**	0.61	0.67	0.60
36.02	0.72	0.72	0.84	0.77	0.86	0.99	1.09	**1.16**	0.89	1.03	0.93
36.03	0.77	0.76	0.88	0.81	0.92	1.06	1.16	**1.24**	0.95	1.09	0.99
36.04	2.17	2.21	2.48	2.29	2.05	2.53	**3.04**	2.98	2.31	2.40	2.19
36.05	2.17	2.23	2.52	2.32	2.10	2.58	**3.07**	3.04	2.35	2.46	2.24
36.06	2.21	2.29	2.57	2.37	2.14	2.66	**3.14**	3.11	2.39	2.51	2.28
36.07	3.23	3.41	4.03	3.71	3.77	4.55	5.53	**5.63**	4.28	4.37	3.84
37.01	0.65	0.65	0.71	0.65	0.54	0.69	**0.79**	0.71	0.50	0.49	0.44
38.01	0.37	0.38	0.42	0.38	0.31	0.42	**0.50**	0.44	0.34	0.33	0.29
38.02	0.46	0.45	0.51	0.47	0.39	0.54	**0.65**	0.59	0.44	0.43	0.37
39.01	0.36	0.37	0.40	0.37	0.30	0.41	**0.49**	0.43	0.32	0.29	0.23
40.01	0.24	0.35	0.42	0.49	0.57	0.67	0.74	**0.80**	0.65	0.63	0.52
40.02	0.51	0.56	0.66	0.71	0.84	1.01	1.08	**1.18**	0.93	0.94	0.79
40.03	0.56	0.60	0.71	0.81	0.96	1.16	1.23	**1.35**	1.05	1.10	0.95
40.04	1.02	1.20	1.45	1.41	1.62	2.03	2.38	**2.51**	1.90	1.89	1.58
41.01	0.31	0.40	0.48	0.45	0.41	0.56	**0.76**	0.69	0.50	0.45	0.33
41.02	0.41	0.56	0.66	0.61	0.59	0.79	**1.02**	0.99	0.72	0.65	0.48
41.03	0.48	0.60	0.72	0.67	0.72	0.90	**1.14**	1.14	0.82	0.78	0.60
42.01	0.70	0.71	0.75	0.69	0.59	0.71	**0.81**	0.74	0.50	0.50	0.46
42.02	0.75	0.84	0.86	0.84	0.76	0.91	0.96	**0.97**	0.74	0.82	0.75
43.01	0.14	0.22	0.30	0.35	0.45	0.52	0.54	**0.58**	0.44	0.55	0.50
43.02	0.17	0.25	0.34	0.39	0.52	0.61	0.63	**0.67**	0.52	0.66	0.59
44.01	0.17	0.24	0.33	0.40	0.50	0.58	0.60	**0.66**	0.50	0.62	0.56
45.01	0.17	0.27	0.34	0.38	0.44	0.54	0.57	**0.64**	0.49	0.49	0.41
46.01	0.14	0.21	0.25	0.28	0.31	0.38	0.40	**0.45**	0.35	0.34	0.29
46.02	0.19	0.28	0.32	0.36	0.42	0.50	0.56	**0.62**	0.47	0.46	0.38

PEAK DESIGN FLOOD DISCHARGES - 5% AEP

Subcatchment ID	15 min	20 min	25 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min
1.01	1.36	1.84	2.39	2.76	3.37	3.84	3.99	**4.21**	3.37	4.17	3.66
1.02	2.15	3.04	3.82	4.28	5.10	5.91	6.12	**6.65**	5.27	6.11	5.42
1.03	2.61	3.73	4.65	5.26	6.26	7.28	7.51	**8.14**	6.55	7.43	6.57
1.04	5.10	7.48	9.30	10.55	12.71	14.76	15.26	**16.61**	13.18	14.91	13.07
1.05	5.78	8.46	10.45	11.86	14.46	16.76	17.40	**18.91**	15.02	17.01	14.82
1.06	9.70	14.22	17.59	19.74	23.65	27.53	28.73	**31.23**	24.84	27.36	23.81
1.07	9.77	14.43	17.94	20.13	24.33	28.34	29.61	**32.07**	25.44	28.44	24.91
1.08	16.10	23.88	29.80	32.89	39.44	46.25	48.88	**52.63**	41.58	46.16	40.46
1.09	19.88	29.54	37.37	41.54	50.75	59.49	62.89	**67.31**	53.65	60.09	52.53
1.10	19.91	29.62	37.07	41.52	51.07	59.98	63.37	**67.73**	54.21	60.75	53.32
1.11	20.09	29.97	37.46	42.03	51.90	61.03	64.52	**68.98**	55.37	61.92	54.53
1.12	20.05	29.97	37.27	42.10	52.22	61.54	65.04	**69.50**	55.98	62.81	55.51
1.13	20.04	29.91	37.22	42.04	52.25	61.49	65.02	**69.48**	56.12	62.91	55.76
1.14	21.01	31.61	39.32	44.79	55.76	65.92	69.63	**74.06**	60.21	68.41	61.02
1.15	20.85	31.29	38.98	44.46	55.41	65.50	69.21	**73.66**	59.98	68.24	61.01
1.16	20.93	31.40	39.11	44.67	55.67	65.86	69.70	**74.23**	60.55	68.75	61.64
1.17	20.85	31.19	38.76	44.11	55.41	65.43	69.29	**73.81**	60.50	68.55	61.73
1.18	23.04	34.94	42.07	48.48	60.87	75.03	80.52	**85.77**	71.42	79.67	73.38
1.19	23.03	34.88	42.05	48.47	60.87	75.06	80.76	**86.09**	71.82	79.88	73.81
1.20	23.03	34.88	42.03	48.44	60.85	75.06	80.78	**86.15**	71.90	79.98	73.91
1.21	23.09	34.95	42.10	48.52	60.94	75.20	81.12	**86.55**	72.32	80.33	74.35
1.22	23.34	35.30	42.44	48.92	61.47	76.33	83.65	**89.62**	75.62	82.51	77.64
1.23	23.36	35.35	42.49	48.98	61.55	76.55	84.14	**90.17**	76.25	83.00	78.35
1.24	23.37	35.35	42.49	49.00	61.55	76.56	84.19	**90.22**	76.37	83.08	78.46
1.25	23.38	35.36	42.51	49.01	61.59	76.63	84.40	**90.49**	76.64	83.27	78.77
1.26	23.37	35.36	42.49	49.01	61.60	76.67	84.66	**90.80**	77.04	83.54	79.21
1.27	23.37	35.34	42.46	49.00	61.59	76.67	84.81	**90.98**	77.31	83.72	79.51
2.01	1.63	2.30	2.86	3.21	3.82	4.42	4.55	**5.06**	3.89	4.36	3.87
2.02	1.98	2.88	3.57	4.00	4.79	5.58	5.73	**6.34**	4.92	5.49	4.82
3.01	1.23	1.67	2.16	2.35	2.77	3.22	3.34	**3.64**	2.90	3.15	2.80
3.02	1.66	2.32	2.89	3.23	3.69	4.36	4.49	**4.91**	3.99	4.18	3.67
3.03	3.76	5.40	6.64	7.29	8.35	9.79	10.29	**11.26**	9.03	9.20	7.95
4.01	1.50	2.13	2.47	2.67	2.95	3.47	3.72	**4.11**	3.29	3.03	2.53
4.02	1.96	2.78	3.29	3.50	3.90	4.61	5.02	**5.51**	4.33	4.07	3.38
5.01	0.50	0.67	0.75	0.70	0.68	0.90	**1.13**	1.07	0.77	0.68	0.51
5.02	2.91	3.99	4.57	4.56	4.87	6.08	7.13	**7.41**	5.59	5.24	4.24
5.03	4.13	5.84	6.87	6.94	7.54	9.33	10.55	**11.13**	8.41	8.20	6.76
5.04	5.37	7.77	9.30	9.66	10.83	13.12	14.37	**15.37**	11.83	12.01	10.28
5.05	6.54	9.56	11.84	12.68	14.76	17.54	18.92	**20.25**	15.79	16.98	14.76
6.01	0.94	1.20	1.36	1.26	1.27	1.72	**2.08**	2.04	1.47	1.30	0.97
7.01	0.35	0.47	0.54	0.48	0.45	0.64	**0.73**	0.66	0.46	0.41	0.30
7.02	1.03	1.35	1.54	1.52	1.69	1.99	2.48	**2.53**	1.97	1.79	1.44
8.01	0.89	1.15	1.27	1.21	1.24	1.65	**2.01**	2.00	1.46	1.29	0.97
9.01	1.13	1.60	1.87	2.01	2.20	2.61	2.85	**3.10**	2.48	2.28	1.87
10.01	0.95	1.13	1.41	1.48	1.94	2.16	2.26	2.32	1.97	**2.51**	2.23
11.01	0.42	0.65	0.83	0.92	1.07	1.25	1.31	**1.44**	1.13	1.21	1.07
12.01	0.48	0.60	0.71	0.67	0.76	0.89	1.13	**1.13**	0.88	0.79	0.63
12.02	1.41	1.72	2.00	2.01	2.31	2.75	3.00	**3.12**	2.51	2.47	2.12
12.03	2.90	4.02	5.03	5.51	6.32	7.55	8.05	**8.66**	6.65	6.97	5.97
12.04	5.24	7.03	8.82	9.40	11.33	13.20	14.32	**15.12**	11.80	12.91	11.10
12.05	5.54	7.51	9.40	10.06	12.18	14.20	15.43	**16.22**	12.67	13.97	11.98
13.01	0.20	0.27	0.32	0.30	0.29	0.37	**0.46**	0.45	0.34	0.30	0.23
13.02	1.06	1.47	1.68	1.84	2.05	2.44	2.63	**2.86**	2.28	2.13	1.80
13.03	1.58	2.25	2.73	3.00	3.41	4.07	4.28	**4.72**	3.68	3.70	3.20
14.01	1.07	1.16	1.46	1.33	1.40	1.57	**2.01**	1.93	1.58	1.51	1.29
14.02	1.72	2.16	2.56	2.56	2.73	3.21	**3.70**	3.65	2.94	3.10	2.66
14.03	1.91	2.46	2.94	2.96	3.12	3.77	**4.23**	4.15	3.32	3.56	3.04
14.04	2.26	3.07	3.64	3.80	4.03	4.93	5.38	**5.53**	4.27	4.68	3.99
15.01	0.16	0.22	0.27	0.30	0.38	0.43	0.45	**0.48**	0.37	0.48	0.42
16.01	0.30	0.41	0.54	0.60	0.69	0.81	0.83	**0.92**	0.75	0.73	0.63
17.01	0.51	0.53	0.68	0.62	0.65	0.74	**0.94**	0.90	0.75	0.72	0.63
18.01	0.65	0.66	0.86	0.79	0.81	0.91	**1.18**	1.12	0.92	0.87	0.74
18.02	0.86	0.91	1.13	1.06	1.23	1.40	1.63	**1.67**	1.33	1.33	1.16
19.01	0.24	0.32	0.43	0.51	0.62	0.71	0.73	**0.79**	0.63	0.75	0.67
20.01	0.62	0.85	1.10	1.28	1.60	1.81	1.87	1.99	1.57	**2.00**	1.75
20.02	0.87	1.16	1.52	1.80	2.36	2.69	2.78	2.91	2.45	**3.08**	2.69
20.03	0.95	1.33	1.70	2.03	2.63	3.01	3.12	3.27	2.74	**3.42**	3.02
20.04	1.06	1.49	1.89	2.25	2.90	3.34	3.48	3.66	3.06	**3.76**	3.37

Subcatchment ID	15 min	20 min	25 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min
20.05	1.09	1.53	1.94	2.31	3.02	3.51	3.67	3.89	3.23	**3.93**	3.56
20.06	1.71	2.44	3.05	3.53	4.59	5.41	5.62	**6.05**	4.95	5.99	5.50
21.01	0.07	0.11	0.14	0.16	0.21	0.23	0.24	0.25	0.21	**0.26**	0.23
21.02	0.45	0.52	0.63	0.59	0.68	0.77	0.93	**0.96**	0.77	0.73	0.67
21.03	0.68	0.84	0.98	1.07	1.25	1.44	1.58	**1.70**	1.35	1.35	1.21
21.04	0.73	0.93	1.14	1.30	1.59	1.90	1.98	**2.18**	1.73	1.96	1.83
22.01	0.10	0.11	0.13	0.14	0.19	0.23	0.27	0.30	0.29	0.29	**0.34**
23.01	1.29	1.77	2.10	2.31	2.56	2.99	3.28	**3.51**	2.86	2.67	2.24
23.02	1.76	2.51	3.11	3.58	4.17	4.84	5.06	**5.56**	4.44	4.63	4.00
23.03	3.15	4.52	5.72	6.31	7.85	9.00	9.39	**10.28**	8.26	9.00	7.71
23.04	3.33	4.74	6.03	6.56	8.30	9.48	9.92	**10.85**	8.72	9.62	8.25
23.05	3.62	5.01	6.44	7.03	8.99	10.17	10.67	**11.61**	9.40	10.54	9.08
23.06	3.83	5.28	6.79	7.46	9.53	10.78	11.37	**12.36**	10.08	11.36	9.84
23.07	3.92	5.42	6.94	7.65	9.75	11.07	11.72	**12.70**	10.38	11.71	10.25
23.08	3.93	5.45	7.00	7.74	9.88	11.28	12.00	**12.96**	10.69	11.97	10.62
23.09	4.19	5.77	7.42	8.42	10.63	12.18	13.07	**14.15**	11.80	13.08	11.80
23.10	4.30	5.95	7.60	8.64	10.95	12.64	13.67	**14.84**	12.53	13.62	12.53
23.11	4.49	6.29	7.92	9.09	11.78	13.50	14.74	**15.98**	13.76	14.71	13.79
24.01	1.04	1.19	1.49	1.39	1.61	1.87	**2.18**	2.17	1.80	1.76	1.58
24.02	1.23	1.50	1.95	1.93	2.40	2.76	3.04	**3.20**	2.58	2.70	2.34
25.01	0.18	0.24	0.28	0.26	0.23	0.32	**0.38**	0.37	0.27	0.24	0.18
26.01	0.16	0.20	0.25	0.21	0.19	0.26	**0.31**	0.27	0.20	0.18	0.13
27.01	0.44	0.50	0.63	0.58	0.48	0.69	**0.84**	0.72	0.53	0.47	0.35
28.01	0.21	0.29	0.34	0.31	0.28	0.39	**0.46**	0.42	0.31	0.27	0.20
29.01	0.59	0.58	0.73	0.68	0.51	0.74	**0.86**	0.76	0.53	0.48	0.35
29.02	1.00	1.14	1.42	1.31	1.29	1.64	**1.76**	1.64	1.48	1.38	1.17
30.01	0.47	0.47	0.60	0.56	0.43	0.62	**0.71**	0.64	0.45	0.40	0.29
31.01	0.81	0.77	1.00	0.92	0.73	1.04	**1.28**	1.11	0.88	0.78	0.61
31.02	1.17	1.14	1.46	1.33	1.23	1.52	**1.90**	1.81	1.43	1.30	1.05
33.01	0.20	0.19	0.23	0.21	0.17	0.22	**0.27**	0.24	0.20	0.22	0.20
34.01	0.48	0.54	0.68	0.62	0.56	0.76	**0.98**	0.90	0.68	0.60	0.45
35.01	0.19	0.18	0.23	0.21	0.22	0.24	**0.31**	0.27	0.23	0.29	0.26
35.02	0.72	0.72	0.89	0.82	0.68	0.85	**1.01**	0.96	0.77	0.87	0.79
36.01	0.38	0.48	0.58	0.65	0.74	0.87	0.94	**0.99**	0.82	0.81	0.72
36.02	0.86	0.90	1.05	0.98	1.12	1.28	1.41	**1.50**	1.22	1.24	1.11
36.03	0.92	0.95	1.10	1.03	1.19	1.36	1.50	**1.60**	1.28	1.32	1.17
36.04	2.63	2.68	3.08	2.86	2.63	3.21	**3.84**	3.79	2.97	2.97	2.60
36.05	2.67	2.73	3.13	2.90	2.69	3.30	**3.90**	3.87	3.02	3.05	2.66
36.06	2.73	2.80	3.20	2.96	2.74	3.39	**3.98**	3.95	3.07	3.12	2.71
36.07	4.06	4.32	5.15	4.77	4.84	5.98	7.03	**7.12**	5.49	5.41	4.59
37.01	0.77	0.76	0.87	0.81	0.65	0.84	**0.97**	0.87	0.63	0.61	0.53
38.01	0.44	0.44	0.53	0.48	0.38	0.52	**0.61**	0.54	0.42	0.40	0.34
38.02	0.54	0.54	0.65	0.59	0.48	0.69	**0.80**	0.73	0.54	0.52	0.44
39.01	0.43	0.43	0.52	0.46	0.36	0.51	**0.59**	0.52	0.39	0.35	0.27
40.01	0.37	0.51	0.59	0.65	0.73	0.86	1.00	**1.05**	0.83	0.76	0.62
40.02	0.62	0.76	0.88	0.96	1.08	1.27	1.45	**1.54**	1.22	1.12	0.93
40.03	0.68	0.84	1.01	1.10	1.24	1.47	1.61	**1.73**	1.38	1.33	1.13
40.04	1.32	1.71	1.98	1.92	2.13	2.58	3.05	**3.16**	2.41	2.29	1.88
41.01	0.43	0.56	0.66	0.59	0.54	0.78	**0.92**	0.82	0.60	0.53	0.39
41.02	0.56	0.75	0.89	0.81	0.75	1.07	**1.26**	1.19	0.86	0.76	0.57
41.03	0.62	0.83	0.99	0.91	0.88	1.23	**1.42**	1.36	1.01	0.92	0.71
42.01	0.82	0.83	0.90	0.83	0.70	0.87	**0.98**	0.90	0.62	0.61	0.57
42.02	0.92	1.05	1.06	1.02	0.95	1.13	1.21	**1.21**	0.93	1.02	0.92
43.01	0.22	0.33	0.44	0.50	0.59	0.68	0.71	**0.78**	0.61	0.67	0.59
43.02	0.26	0.37	0.48	0.56	0.69	0.79	0.82	**0.89**	0.71	0.81	0.70
44.01	0.25	0.37	0.50	0.56	0.66	0.77	0.80	**0.87**	0.67	0.75	0.67
45.01	0.26	0.39	0.48	0.52	0.58	0.68	0.75	**0.82**	0.65	0.60	0.49
46.01	0.21	0.30	0.35	0.37	0.41	0.49	0.55	**0.60**	0.47	0.42	0.34
46.02	0.29	0.41	0.47	0.48	0.54	0.66	0.77	**0.81**	0.62	0.56	0.45

PEAK DESIGN FLOOD DISCHARGES - 2% AEP

Subcatchment ID	15 min	20 min	25 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min
1.01	2.08	2.73	3.41	3.85	4.44	4.96	5.04	**5.41**	4.19	4.79	4.18
1.02	3.34	4.45	5.42	5.90	6.69	7.61	7.70	**8.43**	6.58	7.04	6.16
1.03	4.09	5.47	6.58	7.18	8.15	9.29	9.41	**10.27**	8.10	8.59	7.46
1.04	7.98	10.93	13.20	14.46	16.61	18.85	19.14	**20.91**	16.39	17.23	14.82
1.05	9.07	12.31	14.70	16.23	18.95	21.39	21.88	**23.76**	18.66	19.73	16.85
1.06	15.29	20.82	24.58	26.73	30.78	34.97	35.95	**39.04**	30.62	31.64	27.01
1.07	15.36	21.12	25.07	27.31	31.74	36.02	37.05	**40.00**	31.39	33.03	28.34
1.08	25.41	35.04	41.32	44.48	51.30	58.59	60.87	**65.11**	50.90	53.76	46.29
1.09	31.48	43.78	52.07	56.39	66.16	75.50	78.23	**82.87**	65.37	70.00	60.14
1.10	31.31	43.38	52.09	56.60	66.70	76.15	78.81	**83.48**	66.03	70.86	61.04
1.11	31.64	43.82	52.73	57.36	67.84	77.52	80.24	**84.95**	67.38	72.30	62.44
1.12	31.61	43.58	52.66	57.52	68.50	78.37	81.03	**85.78**	68.20	73.43	63.63
1.13	31.53	43.48	52.56	57.54	68.46	77.95	80.53	**85.55**	68.32	73.58	63.89
1.14	33.25	45.92	55.06	60.79	73.66	83.71	86.36	**91.72**	73.62	80.17	70.23
1.15	32.93	45.44	54.56	60.27	73.29	83.10	85.69	**91.16**	73.40	79.97	70.25
1.16	33.02	45.66	54.74	60.50	73.66	83.59	86.37	**91.81**	74.10	80.62	71.04
1.17	32.74	45.07	54.29	60.15	73.26	83.15	86.02	**91.37**	73.91	80.51	71.09
1.18	36.34	48.85	58.47	66.08	83.62	94.76	99.86	**106.97**	88.20	94.11	85.30
1.19	36.27	48.77	58.38	66.01	83.66	94.82	100.01	**107.43**	88.77	94.41	85.89
1.20	36.26	48.76	58.37	66.03	83.66	94.82	100.07	**107.51**	88.94	94.50	86.00
1.21	36.34	48.84	58.45	66.13	83.81	95.05	100.53	**108.06**	89.54	94.90	86.56
1.22	36.68	49.21	58.86	66.64	84.84	96.65	103.84	**111.97**	93.92	97.65	91.05
1.23	36.72	49.25	58.88	66.67	85.04	97.03	104.50	**112.82**	94.85	98.24	91.96
1.24	36.72	49.24	58.88	66.65	85.03	97.02	104.59	**112.93**	95.04	98.35	92.10
1.25	36.73	49.23	58.87	66.68	85.10	97.13	104.88	**113.31**	95.43	98.57	92.52
1.26	36.72	49.21	58.86	66.67	85.13	97.21	105.24	**113.82**	96.05	98.89	93.10
1.27	36.70	49.20	58.83	66.64	85.12	97.23	105.46	**114.11**	96.42	99.13	93.47
2.01	2.56	3.34	4.14	4.42	4.98	5.70	5.69	**6.27**	4.99	5.00	4.37
2.02	3.10	4.18	5.12	5.51	6.26	7.16	7.20	**7.88**	6.25	6.29	5.45
3.01	1.87	2.50	3.03	3.19	3.55	4.12	4.11	**4.48**	3.61	3.60	3.15
3.02	2.56	3.44	4.01	4.29	4.75	5.50	5.57	**6.12**	4.87	4.79	4.15
3.03	5.89	7.93	9.14	9.64	10.71	12.27	12.85	**14.05**	10.96	10.55	8.97
4.01	2.38	3.05	3.37	3.46	3.73	4.27	4.72	**5.12**	3.93	3.46	2.83
4.02	3.07	3.95	4.48	4.55	4.91	5.74	6.32	**6.78**	5.14	4.64	3.79
5.01	0.76	0.93	0.94	0.89	0.89	1.15	**1.29**	1.22	0.86	0.76	0.57
5.02	4.41	5.72	6.01	5.81	6.14	7.51	8.61	**8.87**	6.51	5.95	4.75
5.03	6.34	8.39	9.14	8.96	9.57	11.55	12.75	**13.20**	9.96	9.35	7.61
5.04	8.33	11.27	12.55	12.64	13.80	16.33	17.59	**18.53**	14.14	13.92	11.77
5.05	10.25	14.02	16.24	16.93	19.03	22.06	23.34	**24.71**	19.09	19.79	16.96
6.01	1.42	1.70	1.76	1.65	1.64	2.14	**2.40**	2.33	1.65	1.46	1.08
7.01	0.50	0.66	0.69	0.64	0.61	0.76	**0.82**	0.75	0.51	0.46	0.33
7.02	1.56	1.92	1.95	1.93	2.10	2.47	3.02	**3.10**	2.30	2.03	1.61
8.01	1.34	1.59	1.66	1.57	1.59	2.05	**2.37**	2.30	1.64	1.45	1.08
9.01	1.73	2.35	2.54	2.57	2.76	3.23	3.51	**3.78**	2.93	2.58	2.10
10.01	1.19	1.54	1.84	2.15	2.56	2.76	2.82	**2.92**	2.36	2.91	2.55
11.01	0.69	0.97	1.18	1.25	1.39	1.61	1.62	**1.78**	1.40	1.38	1.20
12.01	0.69	0.86	0.89	0.86	0.93	1.10	**1.38**	1.35	1.03	0.90	0.70
12.02	1.81	2.22	2.63	2.69	2.99	3.40	3.62	**4.00**	3.11	2.80	2.38
12.03	4.33	5.93	7.04	7.39	8.21	9.47	9.89	**10.71**	8.33	7.94	6.73
12.04	7.62	10.17	11.99	12.74	14.63	16.77	17.80	**18.76**	14.47	14.86	12.59
12.05	8.13	10.89	12.91	13.71	15.76	18.05	19.12	**20.15**	15.62	16.08	13.59
13.01	0.29	0.36	0.38	0.36	0.35	0.46	**0.55**	0.53	0.38	0.34	0.26
13.02	1.61	2.10	2.34	2.44	2.63	3.00	3.23	**3.49**	2.76	2.45	2.02
13.03	2.43	3.27	3.86	4.03	4.43	5.11	5.34	**5.76**	4.52	4.24	3.61
14.01	1.29	1.51	1.68	1.59	1.79	1.97	**2.45**	2.41	1.91	1.73	1.45
14.02	2.25	2.65	3.24	3.20	3.49	4.09	**4.56**	4.55	3.49	3.55	3.00
14.03	2.56	3.06	3.76	3.77	3.96	4.74	5.14	**5.26**	3.96	4.07	3.45
14.04	3.16	4.02	4.75	4.93	5.22	6.25	6.61	**6.92**	5.26	5.35	4.53
15.01	0.24	0.31	0.39	0.44	0.51	0.57	0.58	**0.63**	0.48	0.55	0.49
16.01	0.49	0.66	0.77	0.80	0.89	1.01	1.06	**1.16**	0.92	0.83	0.71
17.01	0.63	0.69	0.78	0.74	0.84	0.93	**1.14**	1.11	0.89	0.83	0.71
18.01	0.79	0.87	1.00	0.93	1.03	1.17	**1.45**	1.40	1.10	0.99	0.82
18.02	1.05	1.19	1.33	1.41	1.58	1.76	2.03	**2.07**	1.65	1.54	1.31
19.01	0.37	0.52	0.65	0.72	0.81	0.91	0.93	**0.99**	0.77	0.86	0.76
20.01	0.95	1.26	1.58	1.81	2.11	2.34	2.37	**2.51**	1.97	2.29	2.02
20.02	1.25	1.75	2.20	2.55	3.17	3.50	3.54	**3.69**	2.96	3.61	3.15
20.03	1.41	1.98	2.47	2.84	3.54	3.91	3.96	**4.13**	3.32	4.00	3.52
20.04	1.58	2.20	2.71	3.12	3.91	4.30	4.37	**4.59**	3.72	4.38	3.91

Subcatchment ID	15 min	20 min	25 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min
20.05	1.62	2.27	2.82	3.26	4.08	4.51	4.60	**4.85**	3.95	4.59	4.13
20.06	2.56	3.64	4.39	5.03	6.20	6.70	6.93	**7.48**	6.09	7.01	6.40
21.01	0.13	0.16	0.21	0.23	0.27	0.30	0.30	**0.32**	0.25	0.30	0.26
21.02	0.57	0.69	0.74	0.78	0.86	0.95	1.11	**1.14**	0.92	0.85	0.76
21.03	0.90	1.18	1.38	1.42	1.58	1.80	1.92	**2.05**	1.61	1.57	1.37
21.04	0.99	1.33	1.61	1.76	2.14	2.41	2.46	**2.66**	2.13	2.31	2.13
22.01	0.12	0.15	0.17	0.19	0.26	0.31	0.36	0.39	0.38	0.36	**0.42**
23.01	1.98	2.59	2.88	2.98	3.24	3.69	4.08	**4.36**	3.42	3.04	2.51
23.02	2.76	3.73	4.32	4.83	5.40	6.07	6.33	**6.92**	5.38	5.30	4.53
23.03	4.85	6.66	7.84	8.59	10.07	11.44	12.05	**12.86**	9.88	10.34	8.75
23.04	5.08	7.01	8.21	8.94	10.67	12.11	12.81	**13.60**	10.45	11.08	9.36
23.05	5.34	7.38	8.74	9.39	11.52	13.13	13.86	**14.56**	11.26	12.19	10.32
23.06	5.61	7.75	9.33	9.88	12.30	14.09	14.92	**15.52**	12.04	13.17	11.21
23.07	5.78	7.88	9.46	10.13	12.59	14.52	15.10	**15.89**	12.44	13.60	11.67
23.08	5.83	7.96	9.59	10.30	12.69	14.81	15.36	**16.17**	12.77	13.88	12.09
23.09	6.15	8.41	10.44	11.11	13.61	16.09	16.70	**17.56**	14.06	15.21	13.45
23.10	6.32	8.64	10.69	11.41	14.00	16.75	17.49	**18.40**	14.92	15.88	14.28
23.11	6.62	9.17	11.20	12.03	15.00	18.03	18.83	**19.83**	16.36	17.34	15.74
24.01	1.29	1.61	1.76	1.86	2.12	2.37	2.72	**2.79**	2.21	2.06	1.78
24.02	1.62	2.21	2.45	2.76	3.15	3.50	3.78	**4.03**	3.17	3.11	2.67
25.01	0.26	0.31	0.33	0.31	0.30	0.39	**0.44**	0.42	0.30	0.27	0.20
26.01	0.20	0.25	0.28	0.26	0.24	0.31	**0.35**	0.31	0.22	0.20	0.14
27.01	0.54	0.67	0.75	0.69	0.63	0.85	**0.94**	0.83	0.60	0.53	0.39
28.01	0.30	0.39	0.40	0.38	0.36	0.47	**0.53**	0.48	0.34	0.30	0.22
29.01	0.72	0.70	0.82	0.77	0.64	0.87	**0.98**	0.88	0.60	0.53	0.40
29.02	1.23	1.50	1.59	1.69	1.68	1.98	2.13	**2.24**	1.68	1.58	1.30
30.01	0.58	0.59	0.68	0.64	0.54	0.73	**0.81**	0.73	0.50	0.44	0.33
31.01	0.96	0.97	1.14	1.06	0.90	1.27	**1.50**	1.31	1.00	0.88	0.68
31.02	1.39	1.45	1.66	1.54	1.53	1.94	**2.31**	2.16	1.69	1.48	1.17
33.01	0.23	0.22	0.25	0.23	0.22	0.26	**0.33**	0.29	0.24	0.25	0.23
34.01	0.59	0.77	0.82	0.76	0.72	0.98	**1.13**	1.04	0.77	0.68	0.51
35.01	0.22	0.23	0.27	0.24	0.28	0.31	**0.36**	0.34	0.28	0.34	0.30
35.02	0.85	0.88	0.99	0.93	0.90	1.03	1.23	**1.24**	0.97	1.00	0.91
36.01	0.54	0.70	0.82	0.86	0.97	1.10	1.19	**1.27**	1.01	0.93	0.80
36.02	1.03	1.14	1.21	1.27	1.43	1.64	1.80	**1.87**	1.49	1.43	1.24
36.03	1.09	1.23	1.30	1.34	1.52	1.74	1.92	**2.00**	1.56	1.53	1.32
36.04	3.13	3.24	3.55	3.34	3.38	4.02	4.57	**4.57**	3.58	3.46	2.94
36.05	3.20	3.32	3.62	3.41	3.45	4.10	4.64	**4.67**	3.64	3.54	2.99
36.06	3.28	3.39	3.71	3.49	3.52	4.20	4.72	**4.75**	3.71	3.62	3.05
36.07	4.99	5.83	6.16	5.85	6.12	7.44	8.46	**8.51**	6.51	6.22	5.17
37.01	0.88	0.84	0.95	0.89	0.74	0.97	**1.12**	1.01	0.75	0.70	0.59
38.01	0.51	0.49	0.59	0.55	0.46	0.62	**0.72**	0.64	0.50	0.47	0.39
38.02	0.63	0.64	0.76	0.71	0.61	0.82	**0.92**	0.87	0.64	0.60	0.50
39.01	0.49	0.48	0.58	0.53	0.43	0.60	**0.68**	0.62	0.44	0.39	0.30
40.01	0.62	0.77	0.82	0.85	0.91	1.07	1.25	**1.28**	0.99	0.86	0.69
40.02	0.88	1.13	1.20	1.25	1.37	1.57	1.80	**1.89**	1.46	1.28	1.05
40.03	0.95	1.28	1.39	1.44	1.58	1.81	2.01	**2.14**	1.66	1.51	1.27
40.04	1.81	2.46	2.60	2.47	2.66	3.30	3.73	**3.75**	2.84	2.60	2.11
41.01	0.59	0.79	0.82	0.76	0.73	0.94	**1.04**	0.94	0.67	0.59	0.44
41.02	0.83	1.05	1.11	1.04	1.00	1.31	**1.44**	1.36	0.97	0.86	0.63
41.03	0.88	1.20	1.24	1.18	1.17	1.50	**1.64**	1.59	1.18	1.04	0.79
42.01	0.93	0.91	0.98	0.93	0.79	0.99	**1.12**	1.03	0.73	0.71	0.65
42.02	1.15	1.26	1.20	1.18	1.12	1.35	1.44	**1.47**	1.12	1.20	1.08
43.01	0.34	0.53	0.64	0.68	0.76	0.87	0.88	**0.97**	0.75	0.77	0.67
43.02	0.39	0.58	0.69	0.76	0.90	1.02	1.04	**1.13**	0.88	0.93	0.79
44.01	0.39	0.58	0.72	0.76	0.86	0.98	0.99	**1.08**	0.85	0.86	0.75
45.01	0.45	0.61	0.66	0.67	0.72	0.85	0.94	**1.00**	0.77	0.68	0.55
46.01	0.32	0.44	0.48	0.48	0.51	0.61	0.69	**0.72**	0.55	0.48	0.38
46.02	0.46	0.60	0.65	0.63	0.67	0.82	0.93	**0.96**	0.73	0.65	0.51

PEAK DESIGN FLOOD DISCHARGES - 1% AEP

Subcatchment ID	15 min	20 min	25 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min
1.01	2.66	3.41	4.23	4.67	5.34	5.96	6.00	**6.53**	5.18	5.45	4.80
1.02	4.25	5.60	6.58	7.08	8.05	9.13	9.22	**10.03**	8.08	8.08	7.06
1.03	5.23	6.87	7.96	8.62	9.80	11.07	11.33	**12.40**	9.84	9.87	8.53
1.04	10.20	13.76	16.21	17.54	19.85	22.49	23.03	**25.05**	19.79	19.76	16.95
1.05	11.56	15.45	18.18	19.77	22.58	25.51	26.39	**28.41**	22.48	22.64	19.30
1.06	19.61	25.98	30.22	32.37	36.63	41.50	43.33	**46.65**	36.72	36.36	30.85
1.07	19.78	26.44	30.86	33.09	37.76	42.83	44.46	**47.75**	37.63	38.04	32.40
1.08	32.97	44.00	50.98	53.85	60.93	69.60	72.36	**77.29**	60.70	61.99	52.96
1.09	41.15	54.88	64.18	68.62	78.53	89.36	92.52	**98.28**	77.65	80.67	68.73
1.10	40.86	54.83	64.28	68.86	79.24	90.17	93.20	**99.02**	78.38	81.71	69.78
1.11	41.29	55.42	65.02	69.78	80.70	91.84	94.88	**100.79**	79.93	83.39	71.38
1.12	41.03	55.09	65.08	70.13	81.61	92.86	95.86	**101.78**	80.95	84.74	72.77
1.13	40.92	55.00	64.81	70.02	81.18	92.26	95.18	**101.83**	80.69	84.80	73.08
1.14	43.11	57.04	68.78	74.25	87.48	99.31	102.14	**109.14**	87.05	92.57	80.41
1.15	42.67	56.37	68.00	73.68	86.88	98.76	101.60	**108.48**	86.59	92.38	80.43
1.16	42.87	56.55	68.28	74.05	87.33	99.35	102.35	**109.23**	87.42	93.12	81.40
1.17	42.21	56.07	67.59	73.46	86.91	98.92	101.96	**108.71**	87.25	92.99	81.46
1.18	45.76	60.73	75.81	81.51	98.79	114.36	119.26	**127.12**	103.24	109.31	97.91
1.19	45.72	60.63	75.71	81.49	98.82	114.43	119.67	**127.61**	103.78	109.67	98.64
1.20	45.68	60.62	75.72	81.45	98.79	114.49	119.81	**127.79**	103.95	109.73	98.79
1.21	45.75	60.71	75.83	81.57	98.98	114.82	120.39	**128.47**	104.63	110.21	99.44
1.22	46.11	61.12	76.51	82.36	100.21	116.99	124.36	**132.95**	109.62	113.39	104.75
1.23	46.14	61.13	76.48	82.41	100.49	117.44	125.18	**133.92**	110.74	114.08	105.84
1.24	46.17	61.13	76.47	82.43	100.48	117.50	125.36	**134.15**	110.94	114.19	106.03
1.25	46.17	61.12	76.47	82.42	100.56	117.62	125.67	**134.53**	111.43	114.44	106.52
1.26	46.15	61.09	76.44	82.42	100.59	117.80	126.20	**135.17**	112.13	114.79	107.21
1.27	46.11	61.05	76.38	82.38	100.56	117.87	126.49	**135.54**	112.57	115.04	107.65
2.01	3.20	4.18	5.18	5.37	5.93	6.78	6.83	**7.49**	6.12	5.71	5.00
2.02	3.95	5.25	6.35	6.76	7.47	8.48	8.60	**9.46**	7.63	7.20	6.22
3.01	2.43	3.09	3.66	3.80	4.26	4.91	4.94	**5.50**	4.37	4.11	3.59
3.02	3.35	4.23	4.89	5.14	5.72	6.51	6.78	**7.46**	5.84	5.47	4.73
3.03	7.63	9.79	11.11	11.52	12.68	14.51	15.60	**16.75**	12.97	12.09	10.19
4.01	2.95	3.71	4.06	4.08	4.32	5.06	5.79	**6.02**	4.58	3.95	3.20
4.02	3.88	4.87	5.44	5.43	5.76	6.77	7.56	**7.90**	5.95	5.30	4.30
5.01	0.95	1.18	1.20	1.12	1.10	1.35	**1.47**	1.38	0.98	0.86	0.64
5.02	5.69	7.22	7.42	7.07	7.21	9.04	10.10	**10.17**	7.54	6.80	5.39
5.03	8.17	10.58	11.25	10.87	11.23	13.60	14.73	**15.41**	11.69	10.67	8.65
5.04	10.82	14.05	15.36	15.32	16.26	19.31	20.53	**21.74**	16.69	15.97	13.43
5.05	13.40	17.67	20.09	20.48	22.47	26.19	27.44	**29.21**	22.61	22.82	19.40
6.01	1.77	2.14	2.21	2.07	2.05	2.51	**2.73**	2.64	1.87	1.66	1.23
7.01	0.61	0.79	0.84	0.79	0.73	0.87	**0.93**	0.85	0.58	0.52	0.38
7.02	1.99	2.43	2.46	2.32	2.42	2.97	**3.58**	3.55	2.66	2.32	1.82
8.01	1.68	2.01	2.07	1.94	1.96	2.45	**2.70**	2.60	1.86	1.64	1.22
9.01	2.27	2.87	3.06	3.04	3.21	3.80	4.20	**4.46**	3.39	2.94	2.37
10.01	1.54	1.93	2.35	2.62	3.02	3.29	3.34	**3.50**	2.87	3.33	2.92
11.01	0.91	1.24	1.44	1.49	1.65	1.92	1.96	**2.15**	1.70	1.58	1.36
12.01	0.85	1.04	1.11	1.04	1.09	1.35	**1.60**	1.56	1.18	1.02	0.80
12.02	2.29	2.83	3.21	3.24	3.54	4.11	4.31	**4.74**	3.69	3.22	2.69
12.03	5.71	7.66	8.69	9.00	9.79	11.14	11.79	**12.60**	10.03	9.06	7.66
12.04	9.87	13.02	14.87	15.59	17.31	19.86	21.13	**22.19**	17.40	16.99	14.36
12.05	10.57	13.88	16.07	16.83	18.68	21.46	22.67	**23.99**	18.72	18.37	15.51
13.01	0.35	0.44	0.47	0.44	0.43	0.56	**0.65**	0.60	0.43	0.38	0.29
13.02	2.01	2.63	2.83	2.87	3.05	3.53	3.86	**4.11**	3.21	2.80	2.29
13.03	3.12	4.15	4.73	4.82	5.22	5.95	6.33	**6.80**	5.36	4.86	4.10
14.01	1.57	1.86	2.04	1.91	2.10	2.34	**2.95**	2.87	2.25	1.99	1.64
14.02	2.75	3.28	3.94	3.88	4.08	4.83	**5.42**	5.40	4.21	4.04	3.42
14.03	3.12	3.75	4.58	4.48	4.63	5.60	6.15	**6.28**	4.84	4.65	3.91
14.04	3.95	4.94	5.86	5.92	6.18	7.41	7.73	**8.22**	6.33	6.09	5.15
15.01	0.30	0.38	0.50	0.54	0.61	0.68	0.69	**0.75**	0.61	0.63	0.56
16.01	0.65	0.83	0.94	0.97	1.05	1.18	1.29	**1.38**	1.10	0.96	0.81
17.01	0.75	0.85	0.93	0.88	0.99	1.09	**1.36**	1.33	1.06	0.95	0.80
18.01	0.93	1.09	1.23	1.15	1.21	1.40	**1.72**	1.63	1.29	1.14	0.93
18.02	1.25	1.51	1.66	1.70	1.87	2.07	2.45	**2.45**	1.96	1.77	1.48
19.01	0.49	0.66	0.78	0.85	0.96	1.09	1.10	**1.20**	0.95	0.99	0.87
20.01	1.25	1.60	2.02	2.23	2.51	2.75	2.82	**3.01**	2.43	2.61	2.30
20.02	1.68	2.21	2.80	3.15	3.76	4.13	4.22	**4.43**	3.57	4.17	3.62
20.03	1.88	2.50	3.11	3.52	4.19	4.60	4.69	**4.97**	4.00	4.62	4.03
20.04	2.09	2.77	3.42	3.87	4.60	5.07	5.18	**5.51**	4.44	5.07	4.46

Subcatchment ID	15 min	20 min	25 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min
20.05	2.15	2.90	3.57	4.03	4.80	5.33	5.47	**5.83**	4.71	5.32	4.72
20.06	3.43	4.62	5.53	6.17	7.27	8.16	8.43	**9.07**	7.16	8.15	7.32
21.01	0.16	0.21	0.25	0.28	0.32	0.36	0.36	**0.39**	0.30	0.34	0.30
21.02	0.69	0.87	0.91	0.90	0.98	1.12	1.33	**1.35**	1.06	0.98	0.86
21.03	1.12	1.51	1.66	1.67	1.83	2.12	2.29	**2.42**	1.89	1.80	1.55
21.04	1.27	1.71	2.00	2.15	2.53	2.86	2.97	**3.17**	2.53	2.74	2.45
22.01	0.15	0.19	0.21	0.23	0.31	0.38	0.43	0.47	0.45	0.44	**0.50**
23.01	2.55	3.16	3.45	3.52	3.80	4.35	4.93	**5.20**	3.99	3.47	2.85
23.02	3.61	4.62	5.40	5.82	6.38	7.18	7.64	**8.27**	6.40	6.06	5.15
23.03	6.40	8.21	9.59	10.58	12.11	13.58	14.25	**15.14**	12.03	11.87	9.94
23.04	6.65	8.51	9.95	11.02	12.83	14.42	15.15	**15.97**	12.66	12.76	10.63
23.05	6.94	8.98	10.43	11.82	13.88	15.61	16.36	**17.10**	13.62	14.11	11.73
23.06	7.26	9.40	10.87	12.57	14.88	16.74	17.52	**18.22**	14.53	15.37	12.75
23.07	7.44	9.58	11.12	12.92	15.30	17.37	17.88	**18.70**	14.99	15.82	13.28
23.08	7.56	9.69	11.28	13.06	15.49	17.66	18.10	**19.09**	15.40	16.15	13.73
23.09	8.13	10.38	11.87	14.02	16.91	19.25	19.64	**20.71**	16.98	17.69	15.31
23.10	8.36	10.68	12.18	14.35	17.49	19.96	20.43	**21.67**	17.93	18.54	16.25
23.11	8.83	11.28	12.82	15.11	18.82	21.43	21.93	**23.34**	19.56	20.32	17.89
24.01	1.62	1.99	2.15	2.28	2.53	2.76	3.26	**3.28**	2.66	2.40	2.03
24.02	2.26	2.85	3.03	3.37	3.74	4.10	4.59	**4.77**	3.82	3.60	3.05
25.01	0.31	0.39	0.42	0.39	0.37	0.46	**0.51**	0.47	0.34	0.30	0.22
26.01	0.24	0.30	0.34	0.31	0.28	0.36	**0.39**	0.36	0.25	0.22	0.16
27.01	0.66	0.85	0.94	0.86	0.78	0.99	**1.07**	0.96	0.67	0.60	0.44
28.01	0.37	0.47	0.51	0.47	0.44	0.56	**0.61**	0.54	0.39	0.34	0.25
29.01	0.83	0.82	0.97	0.91	0.75	1.02	**1.13**	1.02	0.68	0.60	0.45
29.02	1.35	1.61	2.03	1.98	1.95	2.33	2.52	**2.66**	1.92	1.76	1.48
30.01	0.67	0.69	0.81	0.76	0.64	0.84	**0.93**	0.83	0.56	0.50	0.37
31.01	1.13	1.20	1.38	1.28	1.11	1.49	**1.72**	1.53	1.14	1.00	0.77
31.02	1.61	1.78	1.97	1.83	1.76	2.29	**2.69**	2.51	1.93	1.69	1.32
33.01	0.26	0.25	0.29	0.27	0.25	0.32	**0.38**	0.34	0.28	0.29	0.26
34.01	0.72	0.95	1.03	0.97	0.89	1.16	**1.30**	1.18	0.86	0.77	0.57
35.01	0.25	0.28	0.32	0.31	0.34	0.37	**0.43**	0.42	0.34	0.39	0.34
35.02	1.00	1.03	1.14	1.06	1.09	1.20	**1.49**	1.46	1.18	1.15	1.04
36.01	0.71	0.88	1.00	1.05	1.16	1.28	1.44	**1.50**	1.21	1.08	0.91
36.02	1.22	1.37	1.48	1.54	1.71	1.92	2.21	**2.24**	1.79	1.65	1.41
36.03	1.29	1.48	1.60	1.63	1.81	2.03	2.32	**2.38**	1.87	1.75	1.50
36.04	3.62	3.83	4.22	3.99	4.01	4.68	**5.51**	5.46	4.19	3.98	3.33
36.05	3.71	3.92	4.31	4.08	4.08	4.79	**5.60**	5.53	4.26	4.07	3.41
36.06	3.81	4.01	4.41	4.18	4.16	4.90	**5.69**	5.63	4.33	4.16	3.47
36.07	6.01	6.94	7.57	7.09	7.16	8.84	**10.05**	9.99	7.57	7.14	5.87
37.01	1.01	0.96	1.09	1.02	0.85	1.12	**1.32**	1.17	0.89	0.81	0.67
38.01	0.59	0.57	0.68	0.63	0.54	0.72	**0.85**	0.75	0.59	0.53	0.44
38.02	0.76	0.76	0.89	0.82	0.71	0.94	**1.07**	1.00	0.75	0.68	0.56
39.01	0.57	0.56	0.66	0.62	0.50	0.69	**0.78**	0.71	0.50	0.44	0.34
40.01	0.77	0.92	1.01	1.01	1.06	1.26	1.46	**1.50**	1.14	0.99	0.79
40.02	1.14	1.37	1.48	1.49	1.59	1.85	2.15	**2.22**	1.70	1.47	1.18
40.03	1.24	1.55	1.70	1.72	1.85	2.13	2.39	**2.50**	1.94	1.73	1.44
40.04	2.38	3.01	3.25	3.08	3.14	3.92	4.34	**4.36**	3.29	2.97	2.39
41.01	0.71	0.93	1.02	0.95	0.88	1.09	**1.18**	1.06	0.75	0.67	0.49
41.02	1.04	1.28	1.40	1.30	1.22	1.53	**1.65**	1.54	1.09	0.97	0.72
41.03	1.13	1.44	1.58	1.46	1.41	1.77	**1.90**	1.85	1.34	1.18	0.90
42.01	1.06	1.02	1.13	1.06	0.90	1.13	**1.30**	1.18	0.86	0.84	0.75
42.02	1.33	1.46	1.40	1.36	1.31	1.58	1.70	**1.75**	1.33	1.39	1.24
43.01	0.49	0.66	0.79	0.81	0.90	1.04	1.06	**1.16**	0.92	0.88	0.76
43.02	0.54	0.73	0.85	0.92	1.06	1.21	1.26	**1.35**	1.08	1.07	0.90
44.01	0.57	0.74	0.89	0.92	1.02	1.17	1.18	**1.28**	1.05	0.98	0.86
45.01	0.59	0.76	0.81	0.80	0.84	1.01	1.12	**1.17**	0.89	0.77	0.62
46.01	0.44	0.55	0.58	0.56	0.59	0.72	0.81	**0.84**	0.64	0.55	0.43
46.02	0.60	0.76	0.79	0.75	0.78	0.97	1.09	**1.11**	0.83	0.74	0.58

PEAK DESIGN FLOOD DISCHARGES - 0.5% AEP

Subcatchment ID	15 min	20 min	25 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min
1.01	3.29	4.24	5.22	5.56	6.21	7.01	7.04	**7.65**	6.23	6.16	5.43
1.02	5.40	6.84	8.06	8.50	9.37	10.67	10.88	**11.86**	9.52	9.15	8.01
1.03	6.56	8.32	9.63	10.36	11.43	12.96	13.53	**14.62**	11.55	11.15	9.66
1.04	13.00	16.98	19.51	20.85	23.10	26.16	27.30	**29.44**	23.23	22.34	19.17
1.05	14.59	19.15	22.01	23.49	26.27	29.74	31.12	**33.33**	26.30	25.60	21.82
1.06	24.57	32.05	36.38	38.32	42.58	48.40	51.07	**54.51**	42.88	41.14	34.82
1.07	24.78	32.55	37.19	39.24	43.94	49.93	52.27	**55.86**	44.00	43.15	36.60
1.08	41.01	53.76	61.21	63.66	70.70	81.08	84.37	**89.85**	70.76	70.34	59.84
1.09	51.07	67.15	76.72	81.21	91.29	104.32	108.05	**114.30**	90.26	91.58	77.57
1.10	50.97	66.97	76.83	81.55	92.23	105.27	108.87	**115.21**	91.14	92.81	78.78
1.11	51.50	67.70	77.76	82.60	93.94	107.25	110.83	**117.18**	92.87	94.76	80.58
1.12	51.19	67.48	77.93	83.15	95.10	108.52	111.42	**117.79**	94.06	96.30	82.17
1.13	51.05	67.16	77.13	82.39	94.59	108.61	111.46	**117.94**	93.67	96.17	82.38
1.14	52.87	70.42	81.73	88.00	102.02	116.92	120.04	**127.14**	101.12	105.07	90.70
1.15	52.35	69.53	80.85	87.08	101.53	116.30	119.33	**126.36**	100.77	104.86	90.76
1.16	52.55	69.80	81.18	87.42	102.09	117.00	120.19	**127.42**	101.74	105.72	91.83
1.17	52.05	69.01	80.39	86.84	101.65	116.50	119.71	**126.84**	101.56	105.65	91.95
1.18	56.55	76.76	89.87	96.75	116.95	135.88	140.79	**149.84**	120.77	124.10	110.47
1.19	56.50	76.64	89.76	96.72	116.95	136.12	141.31	**150.42**	121.54	124.54	111.32
1.20	56.45	76.65	89.80	96.67	116.96	136.16	141.46	**150.55**	121.79	124.60	111.49
1.21	56.53	76.76	89.92	96.82	117.23	136.61	142.16	**151.31**	122.59	125.15	112.22
1.22	56.94	77.39	90.74	97.75	118.86	139.78	147.03	**156.59**	128.67	128.89	118.22
1.23	56.95	77.37	90.83	97.93	119.27	140.39	148.10	**157.78**	130.03	129.67	119.47
1.24	56.97	77.32	90.81	97.88	119.26	140.44	148.22	**157.94**	130.25	129.79	119.69
1.25	56.97	77.36	90.85	97.95	119.35	140.65	148.69	**158.45**	130.85	130.09	120.24
1.26	56.95	77.32	90.81	97.95	119.41	140.94	149.29	**159.13**	131.71	130.51	121.04
1.27	56.91	77.26	90.74	97.88	119.40	141.06	149.62	**159.53**	132.25	130.80	121.58
2.01	3.99	5.34	6.12	6.32	6.96	7.86	8.15	**8.93**	7.18	6.46	5.62
2.02	4.96	6.62	7.55	7.96	8.73	9.84	10.25	**11.19**	8.88	8.14	6.99
3.01	2.98	3.79	4.43	4.58	5.07	5.68	6.03	**6.45**	5.23	4.64	4.03
3.02	4.11	5.18	5.85	6.12	6.72	7.56	8.15	**8.72**	6.91	6.20	5.31
3.03	9.46	11.95	13.24	13.54	14.68	16.91	18.43	**19.48**	15.09	13.72	11.46
4.01	3.69	4.51	4.82	4.73	4.94	5.86	6.71	**6.87**	5.24	4.48	3.59
4.02	4.83	5.97	6.44	6.33	6.62	7.84	8.77	**9.05**	6.79	5.99	4.82
5.01	1.12	1.38	1.42	1.33	1.30	1.54	**1.65**	1.55	1.09	0.97	0.72
5.02	6.88	8.59	9.00	8.44	8.54	10.48	11.45	**11.49**	8.63	7.66	6.04
5.03	9.89	12.69	13.32	12.82	13.04	15.81	16.86	**17.61**	13.36	12.03	9.71
5.04	13.28	16.94	18.30	18.05	18.79	22.36	23.62	**24.91**	19.23	18.08	15.13
5.05	16.50	21.42	23.96	24.19	26.03	30.38	31.74	**33.66**	26.23	25.88	21.90
6.01	2.12	2.57	2.65	2.51	2.43	2.86	**3.06**	2.96	2.09	1.86	1.37
7.01	0.73	0.92	1.01	0.95	0.84	0.99	**1.05**	0.96	0.65	0.58	0.42
7.02	2.40	2.89	3.01	2.82	2.77	3.56	**4.08**	4.01	3.01	2.62	2.04
8.01	2.04	2.48	2.54	2.39	2.36	2.80	**3.02**	2.91	2.07	1.84	1.37
9.01	2.80	3.42	3.65	3.57	3.70	4.39	4.91	**5.13**	3.85	3.31	2.66
10.01	1.85	2.30	2.80	3.07	3.49	3.85	3.92	**4.16**	3.43	3.76	3.29
11.01	1.13	1.51	1.73	1.78	1.96	2.20	2.31	**2.49**	2.01	1.79	1.53
12.01	1.04	1.29	1.34	1.25	1.24	1.58	**1.83**	1.77	1.33	1.15	0.89
12.02	2.80	3.49	3.88	3.80	4.05	4.74	5.02	**5.47**	4.24	3.65	3.02
12.03	7.01	9.34	10.41	10.50	11.28	12.95	13.52	**14.60**	11.53	10.24	8.61
12.04	12.08	15.87	17.96	18.45	20.12	23.22	24.41	**25.83**	20.29	19.18	16.18
12.05	12.97	16.89	19.42	19.88	21.74	25.12	26.19	**27.90**	21.86	20.72	17.48
13.01	0.45	0.56	0.58	0.54	0.52	0.68	**0.73**	0.67	0.49	0.43	0.32
13.02	2.57	3.18	3.34	3.32	3.47	4.08	4.50	**4.74**	3.65	3.15	2.57
13.03	3.92	5.08	5.57	5.62	6.00	6.89	7.36	**7.85**	6.16	5.49	4.60
14.01	1.83	2.17	2.37	2.22	2.41	2.79	**3.42**	3.28	2.60	2.25	1.84
14.02	3.23	4.05	4.66	4.45	4.70	5.71	6.22	**6.29**	4.93	4.57	3.84
14.03	3.77	4.62	5.32	5.24	5.42	6.58	7.07	**7.29**	5.65	5.23	4.41
14.04	4.77	5.87	7.01	6.89	7.22	8.64	8.92	**9.58**	7.32	6.87	5.80
15.01	0.38	0.51	0.60	0.64	0.71	0.81	0.81	**0.87**	0.73	0.71	0.63
16.01	0.81	1.02	1.10	1.12	1.20	1.37	1.52	**1.61**	1.26	1.10	0.91
17.01	0.86	1.00	1.13	1.06	1.15	1.30	**1.61**	1.54	1.23	1.08	0.90
18.01	1.10	1.30	1.43	1.31	1.37	1.66	**1.99**	1.89	1.48	1.29	1.05
18.02	1.49	1.85	1.97	1.96	2.16	2.42	2.87	**2.88**	2.28	2.00	1.67
19.01	0.62	0.78	0.96	1.01	1.13	1.28	1.29	**1.40**	1.15	1.12	0.98
20.01	1.49	1.96	2.41	2.58	2.90	3.23	3.28	**3.52**	2.88	2.95	2.59
20.02	2.01	2.70	3.38	3.74	4.39	4.85	4.94	**5.22**	4.19	4.74	4.09
20.03	2.29	3.04	3.75	4.16	4.90	5.43	5.51	**5.85**	4.71	5.27	4.56
20.04	2.53	3.37	4.10	4.53	5.42	6.05	6.12	**6.51**	5.27	5.82	5.05

Subcatchment ID	15 min	20 min	25 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min
20.05	2.63	3.53	4.28	4.72	5.67	6.35	6.44	**6.86**	5.57	6.11	5.34
20.06	4.22	5.56	6.56	7.15	8.69	9.69	9.92	**10.72**	8.59	9.39	8.30
21.01	0.19	0.25	0.31	0.33	0.38	0.42	0.42	**0.47**	0.36	0.39	0.34
21.02	0.86	1.04	1.08	1.05	1.12	1.30	1.55	**1.57**	1.21	1.12	0.97
21.03	1.41	1.77	1.96	1.99	2.13	2.45	2.69	**2.79**	2.17	2.04	1.75
21.04	1.59	2.11	2.44	2.57	2.96	3.33	3.51	**3.70**	2.94	3.15	2.78
22.01	0.18	0.22	0.24	0.28	0.39	0.47	0.52	0.56	0.53	0.54	**0.57**
23.01	3.15	3.80	4.08	4.11	4.33	5.05	5.87	**5.97**	4.57	3.92	3.19
23.02	4.38	5.61	6.53	6.75	7.30	8.41	8.98	**9.50**	7.36	6.85	5.79
23.03	7.85	10.32	11.75	12.40	13.93	15.68	16.04	**17.05**	13.89	13.41	11.24
23.04	8.18	10.83	12.35	13.11	14.79	16.66	16.98	**17.92**	14.65	14.40	12.01
23.05	8.52	11.35	13.37	14.11	16.11	18.07	18.33	**19.12**	15.83	15.92	13.36
23.06	8.87	11.91	14.27	15.04	17.33	19.41	19.63	**20.28**	16.97	17.33	14.51
23.07	9.10	12.07	14.37	15.38	17.88	20.05	20.21	**20.79**	17.56	17.98	15.11
23.08	9.22	12.14	14.34	15.46	18.24	20.41	20.57	**21.20**	17.97	18.39	15.61
23.09	9.67	12.72	15.06	16.51	19.89	22.22	22.29	**22.93**	19.81	20.47	17.42
23.10	9.91	13.00	15.39	16.87	20.57	23.14	23.32	**24.00**	20.81	21.55	18.48
23.11	10.36	13.58	16.08	17.72	22.15	24.89	25.07	**25.82**	22.59	23.75	20.32
24.01	1.88	2.35	2.56	2.65	2.90	3.18	**3.82**	3.81	3.06	2.71	2.27
24.02	2.71	3.41	3.69	3.91	4.30	4.78	5.22	**5.39**	4.41	4.06	3.44
25.01	0.38	0.48	0.50	0.47	0.44	0.54	**0.59**	0.53	0.38	0.34	0.25
26.01	0.31	0.36	0.39	0.36	0.33	0.41	**0.44**	0.40	0.28	0.25	0.18
27.01	0.79	0.98	1.07	1.01	0.89	1.12	**1.20**	1.08	0.75	0.67	0.49
28.01	0.44	0.57	0.62	0.57	0.53	0.64	**0.69**	0.61	0.43	0.38	0.28
29.01	0.95	0.97	1.13	1.05	0.89	1.18	**1.26**	1.16	0.75	0.67	0.50
29.02	2.02	2.27	2.32	2.31	2.31	2.68	2.93	**3.06**	2.22	1.93	1.65
30.01	0.78	0.82	0.95	0.89	0.75	0.97	**1.05**	0.95	0.63	0.56	0.42
31.01	1.30	1.39	1.56	1.47	1.28	1.73	**1.96**	1.75	1.28	1.12	0.86
31.02	1.85	2.12	2.30	2.17	2.05	2.66	**3.09**	2.87	2.17	1.90	1.48
33.01	0.29	0.30	0.35	0.32	0.30	0.37	**0.44**	0.39	0.32	0.32	0.29
34.01	0.87	1.13	1.21	1.14	1.05	1.34	**1.47**	1.33	0.97	0.86	0.64
35.01	0.30	0.33	0.37	0.35	0.39	0.44	**0.51**	0.50	0.41	0.44	0.39
35.02	1.15	1.20	1.30	1.23	1.26	1.42	**1.69**	1.64	1.37	1.29	1.17
36.01	0.87	1.08	1.17	1.23	1.33	1.48	1.69	**1.77**	1.40	1.22	1.02
36.02	1.40	1.65	1.74	1.81	1.99	2.21	2.26	**2.45**	2.10	1.86	1.59
36.03	1.49	1.77	1.87	1.90	2.10	2.35	2.37	**2.58**	2.20	1.98	1.69
36.04	4.18	4.51	4.79	4.56	4.60	5.54	**6.10**	6.06	4.90	4.49	3.75
36.05	4.29	4.60	4.91	4.66	4.69	5.64	**6.17**	6.14	4.97	4.59	3.83
36.06	4.42	4.70	5.02	4.76	4.78	5.77	**6.27**	6.24	5.04	4.69	3.91
36.07	6.97	8.41	8.93	8.40	8.18	10.36	**11.26**	11.24	8.73	8.05	6.60
37.01	1.14	1.09	1.25	1.17	0.98	1.28	**1.53**	1.35	1.04	0.93	0.76
38.01	0.70	0.66	0.77	0.72	0.62	0.82	**0.99**	0.87	0.68	0.60	0.49
38.02	0.89	0.87	1.01	0.94	0.81	1.07	**1.22**	1.15	0.86	0.77	0.63
39.01	0.68	0.64	0.76	0.70	0.58	0.79	**0.89**	0.80	0.56	0.49	0.38
40.01	0.96	1.13	1.21	1.17	1.22	1.44	1.69	**1.72**	1.29	1.12	0.88
40.02	1.40	1.69	1.78	1.71	1.80	2.15	2.48	**2.54**	1.92	1.66	1.33
40.03	1.53	1.91	2.02	1.98	2.11	2.47	2.78	**2.90**	2.22	1.96	1.61
40.04	2.84	3.70	3.90	3.65	3.67	4.57	4.98	**4.99**	3.75	3.35	2.68
41.01	0.84	1.11	1.21	1.13	1.03	1.25	**1.33**	1.19	0.84	0.75	0.55
41.02	1.24	1.54	1.64	1.53	1.44	1.73	**1.85**	1.74	1.22	1.08	0.80
41.03	1.35	1.74	1.86	1.75	1.66	2.05	**2.16**	2.07	1.49	1.32	1.01
42.01	1.21	1.14	1.27	1.20	1.02	1.28	**1.49**	1.33	1.01	0.97	0.85
42.02	1.53	1.67	1.59	1.55	1.50	1.82	1.97	**2.05**	1.56	1.60	1.41
43.01	0.61	0.81	0.94	0.97	1.07	1.21	1.24	**1.34**	1.08	0.99	0.86
43.02	0.69	0.90	1.02	1.12	1.26	1.42	1.49	**1.57**	1.26	1.21	1.02
44.01	0.70	0.91	1.04	1.08	1.19	1.35	1.38	**1.51**	1.23	1.11	0.96
45.01	0.73	0.91	0.97	0.93	0.97	1.16	1.29	**1.34**	1.02	0.87	0.70
46.01	0.55	0.65	0.70	0.67	0.69	0.84	0.94	**0.97**	0.72	0.62	0.49
46.02	0.76	0.89	0.95	0.90	0.92	1.12	1.26	**1.27**	0.94	0.83	0.65

PEAK DESIGN FLOOD DISCHARGES - PMP

Subcatchment ID	15 min	30 min	45 min	60 min	90 min	120 min	150 min	180 min	240 min	300 min	360 min
1.01	26.86	**33.64**	32.74	30.95	27.92	25.06	22.13	20.32	17.85	15.99	14.53
1.02	42.67	**50.07**	48.28	45.80	41.07	36.76	32.45	29.81	26.25	23.65	21.47
1.03	53.12	**61.45**	59.13	55.90	50.48	45.30	40.01	36.78	32.38	29.24	26.46
1.04	111.70	**127.19**	122.08	113.70	102.95	92.06	81.51	75.18	66.25	59.86	53.88
1.05	125.73	**145.30**	140.07	130.13	118.34	106.17	94.02	86.69	76.36	68.95	61.95
1.06	211.62	**237.70**	227.84	210.31	191.11	170.89	151.56	140.00	123.64	111.68	100.14
1.07	214.73	**246.63**	237.99	221.33	201.75	181.06	160.60	148.05	130.47	117.84	105.84
1.08	337.73	**392.77**	381.54	356.36	326.28	294.46	262.45	240.53	211.13	191.10	172.18
1.09	418.90	**504.02**	494.11	462.28	424.02	382.65	341.43	312.82	274.59	248.05	223.36
1.10	420.88	**510.49**	502.14	470.12	431.58	389.54	347.74	318.68	279.63	252.48	227.27
1.11	425.26	**519.78**	513.62	481.36	442.37	399.20	356.57	326.86	286.68	258.70	232.88
1.12	422.72	**524.06**	521.92	490.24	451.22	408.28	364.77	334.57	292.98	264.33	237.87
1.13	421.72	**524.88**	524.12	492.72	453.66	410.73	366.91	336.65	294.75	265.84	239.23
1.14	447.34	569.83	**574.89**	542.81	501.96	455.83	407.81	374.62	327.01	294.31	264.88
1.15	444.53	569.36	**575.55**	543.81	503.16	457.14	409.10	375.84	328.00	295.10	265.57
1.16	446.50	573.12	**581.13**	549.93	509.57	463.15	414.79	381.04	332.61	299.16	269.23
1.17	442.99	571.52	**581.51**	551.28	511.16	464.87	416.52	382.64	333.97	300.26	269.92
1.18	506.29	666.40	**696.07**	666.90	622.35	568.75	509.60	469.16	409.60	367.23	329.81
1.19	505.98	666.97	**699.38**	672.13	627.93	574.16	515.02	473.94	414.03	371.09	333.23
1.20	505.94	667.28	**700.25**	673.20	629.42	575.52	516.45	475.13	415.21	372.14	334.14
1.21	506.99	669.28	**703.84**	677.89	634.43	580.25	521.10	479.26	419.01	375.47	337.10
1.22	512.68	682.66	**733.98**	714.87	672.71	617.45	555.24	511.10	447.43	400.41	359.25
1.23	512.77	685.63	**740.13**	723.04	681.33	625.73	563.24	518.48	454.09	406.22	364.41
1.24	513.37	685.34	**741.20**	724.23	683.03	627.24	564.82	519.86	455.41	407.39	365.45
1.25	513.16	686.28	**743.61**	727.67	686.84	631.04	568.45	523.12	458.46	410.06	367.78
1.26	513.15	686.87	**746.61**	732.86	692.66	636.52	573.98	528.14	463.10	414.12	371.41
1.27	512.24	687.31	**749.10**	736.11	696.71	640.57	577.89	531.65	466.42	417.00	373.95
2.01	34.64	**38.08**	36.20	33.62	30.04	26.53	23.61	21.83	19.27	17.43	15.65
2.02	43.91	**48.15**	45.74	42.27	37.98	33.63	29.93	27.68	24.43	22.08	19.80
3.01	26.47	**28.40**	27.01	24.85	22.26	19.64	17.51	16.21	14.29	12.96	11.61
3.02	36.02	**37.74**	35.93	32.76	29.50	26.03	23.21	21.52	19.01	17.24	15.40
3.03	80.44	**82.55**	77.92	70.66	63.53	56.23	50.21	46.65	41.41	37.37	33.34
4.01	**28.78**	27.02	24.83	22.39	19.47	17.38	15.62	14.56	12.95	11.61	10.31
4.02	**38.33**	36.23	33.17	30.04	26.26	23.43	21.06	19.65	17.40	15.59	13.85
5.01	**6.23**	5.44	4.81	4.24	3.72	3.38	3.06	2.83	2.47	2.17	1.93
5.02	**43.93**	42.03	38.33	34.99	30.39	27.10	24.42	22.85	20.29	18.03	16.12
5.03	**67.06**	65.85	60.98	55.79	49.15	43.51	39.02	36.42	32.39	28.94	25.93
5.04	93.69	**98.05**	92.67	85.90	78.16	70.88	63.28	58.04	50.83	46.17	41.83
5.05	125.84	**141.03**	136.08	127.11	116.43	105.66	94.40	86.64	75.55	68.46	61.90
6.01	**11.86**	10.42	9.23	8.14	7.12	6.48	5.86	5.43	4.72	4.17	3.70
7.01	**3.86**	3.29	2.87	2.55	2.26	2.07	1.84	1.70	1.47	1.29	1.14
7.02	**14.87**	14.13	13.08	11.91	10.25	9.15	8.22	7.71	6.87	6.11	5.45
8.01	**11.55**	10.33	9.17	8.08	7.04	6.38	5.79	5.37	4.69	4.15	3.68
9.01	**20.15**	19.03	17.53	15.89	13.74	12.29	11.04	10.29	9.14	8.17	7.28
10.01	15.04	**20.14**	20.02	19.00	17.56	15.98	14.14	12.94	11.29	10.09	9.10
11.01	10.49	**10.94**	10.37	9.44	8.47	7.47	6.67	6.18	5.46	4.95	4.42
12.01	**6.56**	6.31	5.77	5.22	4.49	4.03	3.60	3.37	3.01	2.68	2.39
12.02	19.11	**20.49**	19.43	17.38	15.20	13.53	12.07	11.20	9.93	8.96	8.03
12.03	53.92	**57.44**	54.24	49.26	43.73	38.77	34.56	31.98	28.35	25.55	22.96
12.04	93.30	**105.32**	100.25	93.11	83.36	74.39	65.93	60.83	53.98	48.50	43.72
12.05	100.84	**114.73**	109.28	101.36	90.85	81.09	71.88	66.33	58.80	52.83	47.61
13.01	**2.65**	2.43	2.15	1.90	1.65	1.49	1.36	1.26	1.10	0.98	0.87
13.02	**17.81**	17.70	16.46	14.92	12.94	11.54	10.33	9.60	8.54	7.66	6.86
13.03	29.48	**30.66**	28.85	26.22	23.29	20.62	18.39	17.02	15.16	13.62	12.26
14.01	11.41	**12.17**	11.68	10.53	9.24	8.18	7.28	6.72	6.06	5.45	4.88
14.02	22.67	**24.99**	23.85	22.10	19.52	17.27	15.34	14.14	12.60	11.25	10.14
14.03	25.87	**28.84**	27.41	25.51	22.56	19.98	17.73	16.34	14.55	13.00	11.73
14.04	34.07	**38.21**	36.14	33.60	29.88	26.48	23.49	21.68	19.23	17.23	15.51
15.01	3.09	**3.87**	3.76	3.56	3.21	2.88	2.55	2.34	2.05	1.84	1.67
16.01	**6.68**	6.67	6.25	5.62	4.96	4.40	3.93	3.66	3.24	2.93	2.61
17.01	5.20	**5.75**	5.63	5.18	4.54	4.02	3.57	3.29	2.95	2.67	2.40
18.01	6.57	**6.94**	6.69	5.99	5.25	4.65	4.14	3.82	3.44	3.10	2.78
18.02	10.17	**10.94**	10.48	9.46	8.39	7.43	6.61	6.11	5.47	4.92	4.43
19.01	5.40	**6.43**	6.18	5.83	5.28	4.69	4.15	3.82	3.35	3.02	2.73
20.01	14.64	**17.60**	17.02	15.96	14.55	13.04	11.55	10.65	9.30	8.37	7.54
20.02	20.86	**26.91**	26.69	25.03	23.53	21.39	19.07	17.47	15.18	13.62	12.20
20.03	23.53	**30.13**	29.94	28.10	26.24	23.93	21.37	19.58	17.01	15.27	13.68
20.04	25.98	33.35	**33.35**	31.36	29.12	26.62	23.80	21.83	18.95	17.01	15.25
20.05	27.04	34.95	**35.17**	33.16	30.87	28.16	25.20	23.14	20.08	18.02	16.16

Subcatchment ID	15 min	30 min	45 min	60 min	90 min	120 min	150 min	180 min	240 min	300 min	360 min
20.06	41.59	52.78	**53.43**	50.55	47.27	43.26	38.91	35.88	30.93	27.70	24.92
21.01	1.98	**2.33**	2.25	2.11	1.92	1.71	1.52	1.40	1.23	1.11	1.00
21.02	6.52	**6.60**	6.31	5.94	5.39	4.80	4.24	3.89	3.43	3.16	2.83
21.03	11.74	**12.12**	11.46	10.60	9.63	8.59	7.59	6.99	6.21	5.66	5.06
21.04	14.21	16.97	**17.07**	16.21	15.37	14.21	12.82	11.92	10.34	9.10	8.18
22.01	1.33	2.35	2.91	3.18	**3.25**	3.11	2.91	2.73	2.42	2.15	1.91
23.01	**22.84**	22.45	20.96	18.91	16.40	14.61	13.10	12.17	10.88	9.74	8.70
23.02	36.10	**38.98**	36.90	33.91	30.36	26.87	23.90	22.13	19.67	17.69	15.86
23.03	68.44	**77.40**	73.77	67.98	61.11	54.46	48.42	44.75	39.55	35.60	31.85
23.04	71.42	**82.55**	79.01	72.97	65.68	58.61	52.07	48.09	42.49	38.19	34.17
23.05	75.57	**90.02**	86.80	80.47	72.76	65.19	57.86	53.36	47.06	42.24	37.86
23.06	79.55	**96.59**	93.92	87.44	79.15	71.18	63.14	58.19	51.28	45.97	41.21
23.07	81.25	**99.86**	97.91	91.35	82.86	74.62	66.19	60.96	53.67	48.10	43.14
23.08	81.61	**102.10**	101.28	94.74	86.34	77.68	69.00	63.51	55.84	50.04	44.88
23.09	85.58	111.67	**112.66**	106.03	97.12	87.29	77.70	71.44	62.71	56.12	50.34
23.10	87.38	116.64	**119.36**	112.80	104.03	93.33	83.37	76.59	67.14	60.03	53.85
23.11	91.31	126.18	**131.23**	124.68	115.21	103.87	92.88	85.25	74.63	66.65	59.78
24.01	15.49	**16.08**	15.48	13.99	12.44	10.97	9.78	9.06	8.06	7.32	6.53
24.02	22.73	**24.43**	23.23	21.09	19.11	16.87	15.03	13.92	12.30	11.14	9.94
25.01	**2.34**	2.00	1.76	1.55	1.36	1.25	1.12	1.04	0.90	0.80	0.70
26.01	**1.73**	1.50	1.31	1.15	1.01	0.94	0.84	0.78	0.68	0.60	0.53
27.01	**4.18**	3.74	3.30	2.91	2.54	2.35	2.10	1.95	1.70	1.49	1.32
28.01	**2.48**	2.16	1.91	1.68	1.48	1.36	1.22	1.13	0.98	0.86	0.76
29.01	**4.11**	3.74	3.31	2.91	2.51	2.36	2.13	1.96	1.70	1.50	1.33
29.02	10.64	**10.99**	10.61	9.55	8.26	7.33	6.60	6.13	5.41	4.88	4.39
30.01	**3.47**	3.13	2.76	2.43	2.12	1.98	1.78	1.64	1.42	1.25	1.11
31.01	**6.24**	6.07	5.57	4.99	4.29	3.82	3.49	3.30	2.89	2.57	2.29
31.02	**10.62**	10.22	9.38	8.62	7.42	6.62	5.99	5.61	4.97	4.43	3.95
33.01	1.34	1.68	**1.70**	1.64	1.51	1.37	1.21	1.10	0.96	0.85	0.79
34.01	**5.13**	4.77	4.25	3.76	3.26	2.94	2.69	2.50	2.19	1.93	1.72
35.01	1.65	2.31	**2.32**	2.21	2.05	1.85	1.64	1.50	1.31	1.17	1.06
35.02	5.30	6.63	**6.65**	6.38	5.99	5.41	4.82	4.40	3.82	3.40	3.09
36.01	6.15	**6.66**	6.42	5.86	5.17	4.58	4.07	3.76	3.34	3.02	2.72
36.02	7.89	**10.08**	9.69	9.06	8.03	7.11	6.30	5.81	5.14	4.63	4.15
36.03	8.31	**10.73**	10.26	9.63	8.56	7.59	6.72	6.19	5.49	4.94	4.43
36.04	21.20	**23.63**	22.81	21.22	19.06	16.94	14.98	13.76	12.23	11.08	9.97
36.05	21.54	**24.17**	23.31	21.69	19.53	17.38	15.36	14.11	12.55	11.35	10.21
36.06	22.00	**24.68**	23.81	22.11	19.95	17.77	15.71	14.43	12.83	11.60	10.43
36.07	40.60	**42.29**	40.43	37.18	33.49	29.71	26.27	24.21	21.75	19.59	17.60
37.01	4.53	**4.70**	4.68	4.37	3.81	3.36	2.97	2.72	2.47	2.24	2.01
38.01	3.03	**3.17**	3.12	2.83	2.46	2.17	1.93	1.77	1.62	1.46	1.30
38.02	4.08	**4.08**	3.95	3.60	3.18	2.81	2.49	2.32	2.10	1.88	1.68
39.01	**2.84**	2.72	2.45	2.19	1.88	1.68	1.55	1.45	1.27	1.13	1.00
40.01	**6.27**	6.13	5.68	5.15	4.44	3.97	3.55	3.30	2.95	2.64	2.36
40.02	9.07	**9.14**	8.44	7.68	6.66	5.93	5.31	4.94	4.40	3.94	3.53
40.03	10.48	**10.77**	10.10	9.19	8.14	7.22	6.44	5.96	5.32	4.78	4.30
40.04	**18.54**	18.14	16.80	15.37	13.48	11.93	10.69	10.01	8.92	7.97	7.15
41.01	**4.72**	4.20	3.69	3.26	2.85	2.65	2.36	2.19	1.90	1.67	1.48
41.02	**6.82**	6.00	5.37	4.74	4.15	3.80	3.42	3.16	2.75	2.42	2.15
41.03	**8.16**	7.35	6.61	5.89	5.13	4.67	4.21	3.90	3.41	3.03	2.69
42.01	4.47	4.78	**4.84**	4.75	4.34	3.90	3.45	3.15	2.73	2.47	2.26
42.02	6.76	7.67	**7.91**	7.60	7.32	6.61	5.93	5.43	4.70	4.21	3.84
43.01	4.92	**5.52**	5.26	4.93	4.38	3.88	3.44	3.17	2.81	2.53	2.29
43.02	5.40	**6.55**	6.38	5.93	5.31	4.77	4.23	3.89	3.44	3.08	2.78
44.01	5.50	**6.17**	5.89	5.52	4.91	4.34	3.85	3.55	3.14	2.83	2.56
45.01	**5.05**	4.85	4.48	4.07	3.51	3.14	2.82	2.62	2.33	2.09	1.86
46.01	**3.62**	3.42	3.15	2.86	2.46	2.21	1.99	1.85	1.64	1.46	1.31
46.02	**4.85**	4.56	4.16	3.79	3.27	2.93	2.64	2.46	2.18	1.94	1.73

APPENDIX F

PROBABILISTIC RATIONAL METHOD RESULTS

PROBABILISTIC RATIONAL METHOD
PEAK DESIGN FLOOD DISCHARGES - 1% AEP

C10 = 0.79
FFy= 1.50
Cy= 1.185

Subcatchment ID	Contributing Catchment Area (Ha)	Tc (min)	Design Intensity (mm/hr)	PRM Discharge (m3/s)	XP-RAFTS Discharge (m3/s)
1.01	26.3	26	108.4	7.9	6.5
1.02	38.6	32	96.8	12.3	10.0
1.03	47.1	34	93.0	14.4	12.4
1.04	93.4	44	80.3	24.7	25.0
1.05	107.2	47	77.9	27.5	28.4
1.06	170.5	56	70.3	39.5	46.7
1.07	181.5	57	69.3	41.4	47.8
1.08	301.4	69	61.6	61.2	77.3
1.09	395.0	77	57.9	75.3	98.3
1.10	402.6	77	57.6	76.4	99.0
1.11	413.4	78	57.2	77.9	100.8
1.12	423.4	79	56.9	79.4	101.8
1.13	426.2	79	56.8	79.8	101.8
1.14	473.7	82	55.4	86.5	109.1
1.15	475.4	82	55.4	86.7	108.5
1.16	482.8	83	55.2	87.7	109.2
1.17	485.1	83	55.1	88.0	108.7
1.18	597.4	90	52.4	103.1	127.1
1.19	604.2	90	52.3	104.0	127.6
1.20	606.0	90	52.2	104.3	127.8
1.21	611.8	91	52.1	105.0	128.5
1.22	655.1	93	51.3	110.6	132.9
1.23	660.8	93	51.2	111.3	133.9
1.24	662.8	94	51.1	111.6	134.1
1.25	667.4	94	51.0	112.2	134.5
1.26	674.5	94	50.9	113.1	135.2
1.27	679.6	94	50.8	113.7	135.5
2.01	26.6	26	107.2	8.2	7.5
2.02	33.4	30	99.7	11.0	9.5
3.01	19.1	24	111.5	7.0	5.5
3.02	25.3	27	105.5	8.8	7.5
3.03	54.8	36	90.0	16.3	16.8
4.01	16.7	23	114.4	6.3	6.0
4.02	22.5	26	108.3	7.9	7.9
5.01	3.3	12	153.1	1.7	1.5
5.02	28.1	28	103.3	9.6	10.2
5.03	45.5	34	93.6	14.0	15.4
5.04	75.1	40	85.1	20.1	21.7
5.05	110.8	47	77.4	28.2	29.2
6.01	6.4	12	153.4	1.7	2.7
7.01	2.0	10	167.1	1.1	0.9
7.02	9.4	19	127.4	4.0	3.6
8.01	6.3	16	136.9	2.9	2.7
9.01	12.4	21	121.1	4.9	4.5
10.01	16.6	23	114.6	6.3	3.5
11.01	7.2	16	135.5	3.0	2.1

Subcatchment ID	Contributing Catchment Area (Ha)	Tc (min)	Design Intensity (mm/hr)	PRM Discharge (m3/s)	XP-RAFTS Discharge (m3/s)
12.01	4.1	12	155.6	1.5	1.6
12.02	14.0	22	118.3	5.5	4.7
12.03	40.4	32	95.9	12.8	12.6
12.04	78.0	41	83.5	21.5	22.2
12.05	84.6	43	82.1	22.9	24.0
13.01	1.5	9	174.5	0.9	0.6
13.02	11.9	20	122.0	4.8	4.1
13.03	21.5	25	108.9	7.7	6.8
14.01	8.5	18	129.8	3.6	3.0
14.02	18.0	24	112.8	6.7	5.4
14.03	20.9	25	109.6	7.5	6.3
14.04	27.7	28	103.6	9.4	8.2
15.01	3.0	12	155.4	1.6	0.7
16.01	4.2	14	146.9	2.0	1.4
17.01	4.2	14	147.1	2.0	1.4
18.01	4.8	14	143.5	2.3	1.7
18.02	7.8	17	132.0	3.4	2.5
19.01	4.7	14	144.1	2.2	1.2
20.01	12.7	21	120.5	5.0	3.0
20.02	21.1	25	109.4	7.6	4.4
20.03	23.6	26	106.9	8.3	5.0
20.04	26.4	28	104.6	9.1	5.5
20.05	28.2	28	103.3	9.6	5.8
20.06	44.4	33	94.1	13.8	9.1
21.01	1.7	10	171.3	0.9	0.4
21.02	4.7	14	144.4	2.2	1.4
21.03	8.5	18	130.0	3.6	2.4
21.04	15.1	22	116.6	5.8	3.2
22.01	3.8	13	150.0	1.9	0.5
23.01	14.8	22	117.0	5.7	5.2
23.02	27.6	28	103.7	9.4	8.3
23.03	54.8	36	90.7	15.9	15.1
23.04	59.1	37	88.6	17.3	16.0
23.05	66.0	39	86.6	18.8	17.1
23.06	72.2	40	84.9	20.2	18.2
23.07	75.9	41	84.0	21.0	18.7
23.08	79.3	42	83.2	21.7	19.1
23.09	89.7	44	81.0	24.0	20.7
23.10	96.5	45	79.8	25.4	21.7
23.11	107.9	47	77.8	27.7	23.3
24.01	10.6	19	124.7	4.4	3.3
24.02	16.4	23	114.9	6.2	4.8
25.01	1.1	8	182.1	0.7	0.5
26.01	0.8	7	191.1	0.5	0.4
27.01	2.3	11	163.1	1.2	1.1
28.01	1.3	9	178.0	0.8	0.6
29.01	2.3	11	162.9	1.2	1.1
29.02	7.6	17	132.4	3.3	2.7
30.01	1.9	10	168.0	1.0	0.9
31.01	3.9	13	148.8	1.9	1.7
31.02	6.8	16	135.2	3.0	2.7
32.01	0.0	1	258.6	0.0	0.4

Catchment Simulation Solutions

Subcatchment ID	Contributing Catchment Area (Ha)	Tc (min)	Design Intensity (mm/hr)	PRM Discharge (m3/s)	XP-RAFTS Discharge (m3/s)
33.01	1.4	9	175.6	0.8	1.3
34.01	3.0	12	156.1	1.5	0.4
35.01	2.0	10	166.9	1.1	1.5
35.02	5.8	15	139.2	2.6	1.5
36.01	4.8	14	143.9	2.3	2.2
36.02	7.4	17	133.1	3.3	2.4
36.03	7.9	17	131.5	3.4	5.5
36.04	17.7	24	113.1	6.6	5.6
36.05	18.2	24	112.6	6.7	5.7
36.06	18.6	24	112.1	6.9	10.0
36.07	31.1	29	101.2	10.4	1.3
37.01	3.5	13	151.7	1.8	0.8
38.01	2.3	11	163.1	1.2	1.1
38.02	3.0	12	156.1	1.5	0.8
39.01	1.7	10	170.7	1.0	1.5
40.01	4.1	14	147.8	2.0	2.2
40.02	6.1	16	138.1	2.7	2.5
40.03	7.5	17	132.7	3.3	4.4
40.04	12.5	21	121.0	5.0	1.2
41.01	2.5	11	160.1	1.3	1.6
41.02	3.7	13	150.5	1.8	1.9
41.03	4.6	14	144.7	2.2	1.3
42.01	4.1	14	147.7	2.0	1.7
42.02	7.1	17	134.1	3.1	1.2
43.01	4.1	13	147.9	2.0	1.4
43.02	5.0	15	142.7	2.4	1.3
44.01	4.5	12	158.7	1.4	1.2
45.01	3.2	12	153.9	1.6	0.8
46.01	2.3	11	163.3	1.2	1.1
46.02	3.0	12	155.9	1.5	

Catchment Simulation Solutions

APPENDIX G

HYDRAULIC CATEGORY VERIFICATION

HYDRAULIC CATEGORY VERIFICATION

Floodway

By definition, a floodway is an area that if only partially blocked would produce a significant impact on upstream water levels and/or would divert water from existing flowpaths resulting in the development of new flowpaths (NSW Government, 2005). Accordingly, the suitability of the delineated floodways was verified by partially blocking the floodways and quantifying the impact that this blockage had on peak 1% AEP flood levels and the distribution of flood flows. This approach is in accordance with recommendations outlined in the Office of Environment and Heritage's (formerly Department of Environment and Climate Change) 'Floodway Definition' guideline (2007).

The TUFLOW hydraulic model was updated to include partial blockage of the delineated floodways at several locations across the catchment and was re-run for the 1% AEP event. The peak flood level, depth and velocity results were interrogated and compared against 'existing' model results to quantify the impact of the blockage of the floodway.

Peak 1% AEP depth and velocity results for selected blockage areas are shown in **Plate G1** and **Plate G3**. The Peak 1% AEP flood levels were also compared against 'existing' 1% AEP flood levels to create flood level difference maps (i.e., maps showing the location and magnitude of changes in flood level). The difference maps are shown in **Plate G2** and **Plate G4**.

Plate G1 and **Plate G3** show that the blockages cause are significant redistribution of flood flows. Specifically, water is forced laterally around the blockage resulting in the formation of new, high velocity flowpaths around the blockage. Accordingly, the blockages appear to be diverting water from existing flowpaths resulting in the development of new flowpaths, in accordance with the *'Floodplain Development Manual'* definition (NSW Government, 2005).

Plate G2 and **Plate G4** show that the blockages typically increase peak 1% AEP flood levels by between 0.2 and 0.3 metres with a localised maximum flood level increase of 0.5 metres. This is considered to be a 'significant impact' on upstream water levels.

Accordingly, the partial blockage of the delineated floodways is predicted to produce significant impacts on upstream water levels and would divert water from existing flowpaths resulting in the development of new flowpaths. Therefore it is considered that the delineated floodway extents conform to the *'Floodplain Development Manual'* definitions and are suitable for application across the Nattai River catchment.

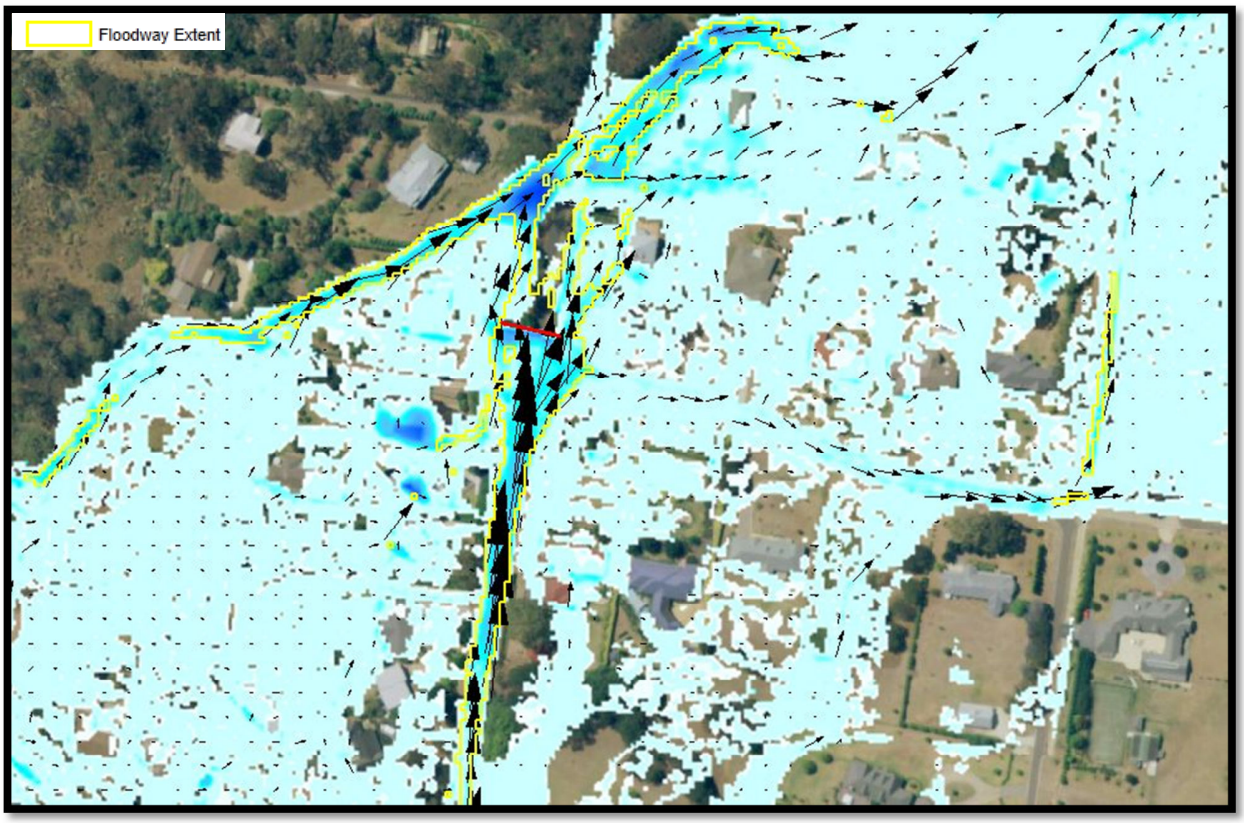


Plate G1 1% AEP Depths and Velocities in the vicinity of a floodway blockage (red line) located at the intersection of Nero St and Oxley Drive, Mittagong.

Plate G2 1% AEP Flood Level Differences in the vicinity of a floodway blockage (black line) located at the intersection of Nero St and Oxley Drive, Mittagong.

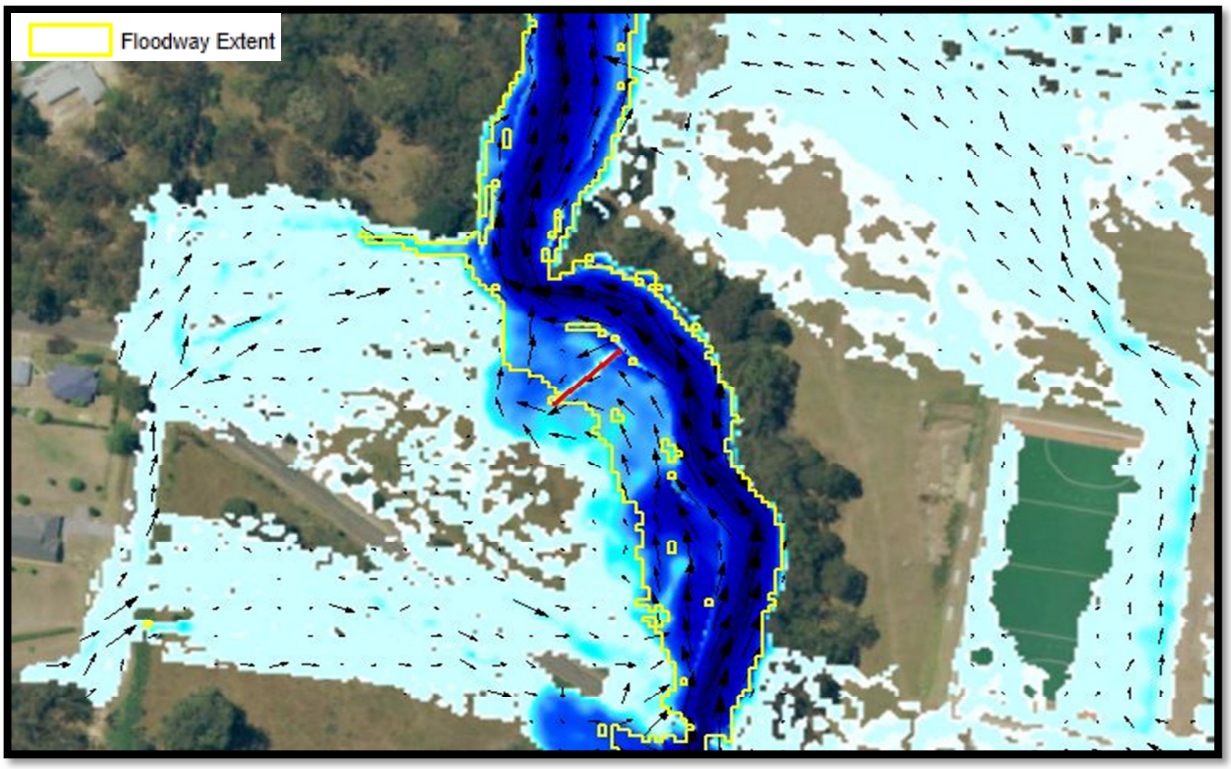


Plate G3 1% AEP Depths and Velocities in the vicinity of a floodway blockage (red line) located downstream of the Range Road crossing of Nattai River.

Plate G4 1% AEP Flood Level Differences in the vicinity of a floodway blockage (black line) located downstream of the Range Road crossing of Nattai River.

Flood Storage

Flood storage areas are important for the temporary storage of floodwaters during the passage of a flood. They are areas that typically coincide with deep, slow moving water. Therefore, the suitability of the delineated flood storage extents was verified by significantly increasing the Manning's 'n' roughness of flood storage areas. As flood storage areas coincide with areas of slow moving water, a significant increase in Manning's 'n' should not produce a large increase in peak flood level. Accordingly, the TUFLOW hydraulic model was updated to include a Manning's 'n' roughness coefficient of 0.2 across all flood storage areas and was re-run for the 1% AEP flood.

Peak 1% AEP flood levels were compared against 'existing' 1% AEP flood levels and the resulting difference mapping is shown in **Plate H5** and **Plate H6**. The difference maps indicate a typical flood level increase in the range of 0.05-0.15m. Given the large increase in Manning's 'n' across these areas (typically > 5x increase), increases in peak flood level of this magnitude are considered to be minor.

Accordingly, it is considered that the extent of the delineated flood storage extents is appropriate and suitable for application across the Nattai River catchment.

Plate G5 **Flood level differences associated with increase in Manning's 'n' across flood storage areas (green polygons) on the MG1 tributary (between Payten and Colo Streets, Mittagong).**

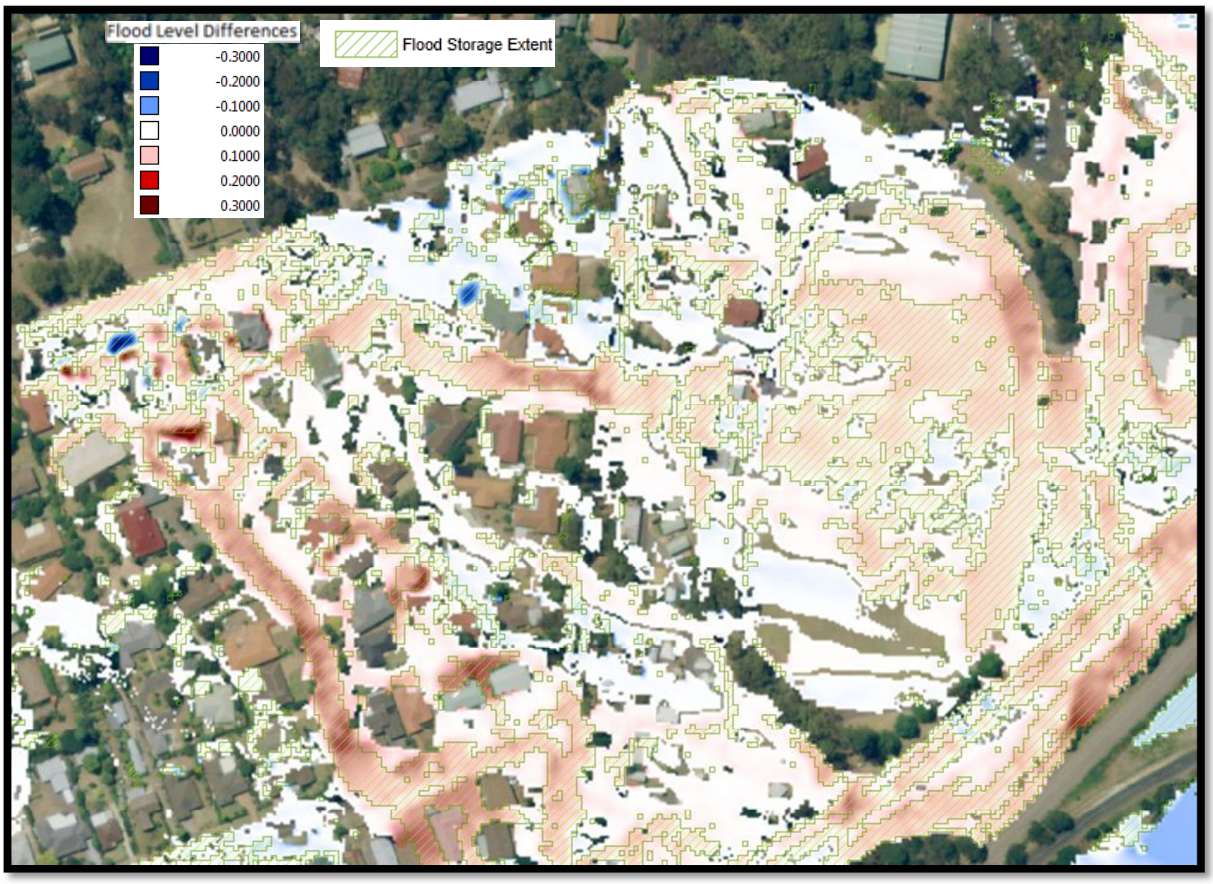


Plate G6 **Flood level differences associated with increase in Manning's 'n' across flood storage areas (green polygons) in the vicinity of the Old Hume highway and Beatrice Street, Mittagong.**

Flood Fringe

Flood Fringe areas are the remaining sections of flood-affected land after floodway and flood storage areas have been defined. They are areas that, if filled, would not have a snificiant impact on the pattern of flood flow and/or flood levels. Accordingly, verification of the delineated flood fringe extents was completed by filling all flood fringe areas, re-running the 1% AEP event and quantifying the impact that the filling had on flood behaviour.

Flood level difference mapping was prepared and is shown in **Plate H7** for a section of the Nattai River catchment. It shows that filling of all flood fringe areas will typically increase peak flood level by less than 0.1 metres. This is considered to be a minor impact on peak flood levels.

Accordingly, it is considered that the delineated flood fringe extents conform to the *'Floodplain Development Manual'* definitions and are suitable for application across the Nattai River catchment.

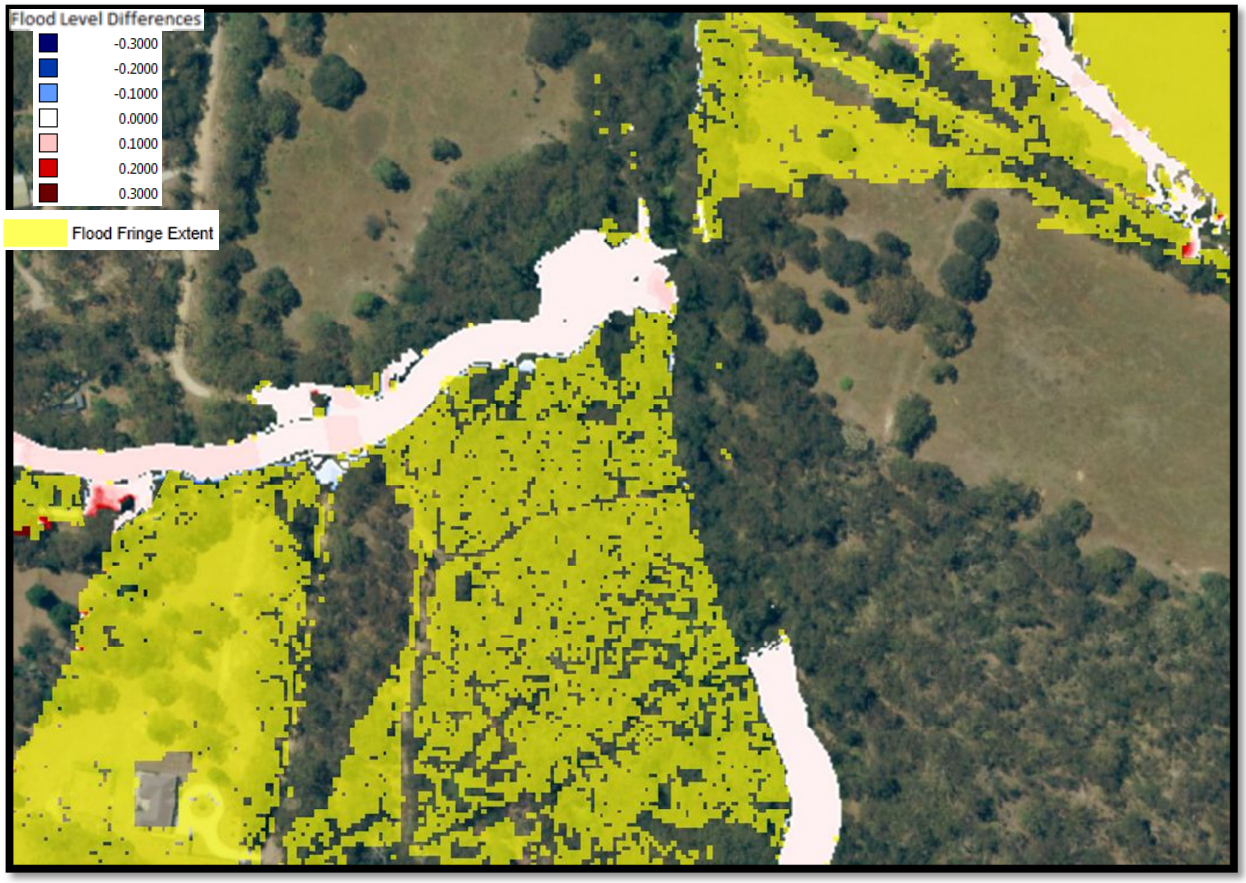


Plate G7 **Flood Level Differences caused by the complete filling of flood fringe areas (yellow polygons) along Nattai River in the vicinity of Elmo and Foots Rd.**

APPENDIX H

XP-RAFTS MODEL RESULTS FOR CLIMATE CHANGE ASSESSMENT

CLIMATE CHANGE ASSESSMENT SUMMARY - 1% AEP

Subcatchment ID	Peak Discharge (m^3/s)			
	Existing	10% Increase in Rainfall Intensity	20% Increase in Rainfall Intensity	30% Increase in Rainfall Intensity
1.01	6.53	7.54	8.56	9.63
1.02	10.03	11.69	13.39	15.02
1.03	12.40	14.41	16.43	18.40
1.04	25.05	29.02	32.90	36.80
1.05	28.41	32.87	37.09	41.44
1.06	46.65	53.76	60.71	67.56
1.07	47.75	55.06	62.10	69.26
1.08	77.29	88.59	99.68	110.91
1.09	98.28	112.71	127.01	140.80
1.10	99.02	113.63	128.11	141.90
1.11	100.79	115.56	130.35	144.50
1.12	101.78	116.15	131.05	145.40
1.13	101.83	116.25	130.90	144.44
1.14	109.14	125.31	140.84	155.61
1.15	108.48	124.58	140.04	154.69
1.16	109.23	125.56	141.21	155.95
1.17	108.71	125.06	140.51	155.24
1.18	127.12	147.43	164.60	181.48
1.19	127.61	147.99	165.28	182.23
1.20	127.79	148.18	165.42	182.44
1.21	128.47	148.94	166.25	183.31
1.22	132.95	154.16	172.20	189.79
1.23	133.92	155.27	173.41	191.23
1.24	134.15	155.50	173.63	191.37
1.25	134.53	155.94	174.10	192.01
1.26	135.17	156.64	174.84	192.76
1.27	135.54	157.06	175.34	193.26
2.01	7.49	8.79	9.93	11.09
2.02	9.46	11.01	12.42	13.83
3.01	5.50	6.35	7.22	8.11
3.02	7.46	8.60	9.72	10.86
3.03	16.75	19.21	21.54	23.88
4.01	6.02	6.78	7.54	8.31
4.02	7.90	8.93	9.94	10.94
5.01	1.47	1.63	1.80	1.97
5.02	10.17	11.35	12.64	13.90
5.03	15.41	17.39	19.23	21.22
5.04	21.74	24.60	27.31	30.24
5.05	29.21	33.23	37.18	41.26
6.01	2.73	3.03	3.34	3.65
7.01	0.93	1.04	1.14	1.25
7.02	3.58	4.04	4.50	4.95
8.01	2.70	2.99	3.29	3.59
9.01	4.46	5.07	5.62	6.17
10.01	3.50	4.10	4.71	5.33
11.01	2.15	2.45	2.75	3.06
12.01	1.60	1.80	2.02	2.23
12.02	4.74	5.40	6.03	6.65
12.03	12.60	14.39	15.96	18.01
12.04	22.19	25.47	28.35	31.97
12.05	23.99	27.51	30.68	34.46
13.01	0.65	0.72	0.80	0.87
13.02	4.11	4.68	5.23	5.78
13.03	6.80	7.75	8.68	9.63
14.01	2.95	3.38	3.78	4.18
14.02	5.42	6.19	7.11	7.92
14.03	6.28	7.18	8.17	9.11
14.04	8.22	9.43	10.66	11.78
15.01	0.75	0.86	0.98	1.12
16.01	1.38	1.59	1.79	1.99
17.01	1.36	1.58	1.78	1.99

Subcatchment ID	Peak Discharge (m^3/s)			
	Existing	10% Increase in Rainfall Intensity	20% Increase in Rainfall Intensity	30% Increase in Rainfall Intensity
18.01	1.72	1.97	2.21	2.45
18.02	2.45	2.84	3.21	3.58
19.01	1.20	1.38	1.56	1.77
20.01	3.01	3.47	3.93	4.40
20.02	4.43	5.14	5.88	6.61
20.03	4.97	5.76	6.60	7.43
20.04	5.51	6.40	7.33	8.28
20.05	5.83	6.76	7.72	8.72
20.06	9.07	10.54	12.05	13.61
21.01	0.39	0.46	0.53	0.59
21.02	1.35	1.54	1.72	1.95
21.03	2.42	2.76	3.08	3.46
21.04	3.17	3.65	4.14	4.66
22.01	0.50	0.56	0.62	0.69
23.01	5.20	5.90	6.56	7.23
23.02	8.27	9.37	10.52	11.66
23.03	15.14	16.86	19.57	21.74
23.04	15.97	17.76	20.62	22.86
23.05	17.10	18.98	22.16	24.73
23.06	18.22	20.18	23.79	26.57
23.07	18.70	20.67	24.53	27.36
23.08	19.09	21.07	25.01	27.90
23.09	20.71	22.83	27.11	30.25
23.10	21.67	23.89	28.34	31.56
23.11	23.34	25.72	30.45	33.92
24.01	3.28	3.76	4.26	4.74
24.02	4.77	5.31	6.09	6.80
25.01	0.51	0.58	0.65	0.70
26.01	0.39	0.43	0.47	0.52
27.01	1.07	1.19	1.30	1.43
28.01	0.61	0.69	0.75	0.82
29.01	1.13	1.25	1.37	1.49
29.02	2.66	3.02	3.38	3.73
30.01	0.93	1.04	1.14	1.24
31.01	1.72	1.94	2.13	2.33
31.02	2.69	3.05	3.40	3.76
33.01	0.38	0.43	0.48	0.54
34.01	1.30	1.46	1.60	1.75
35.01	0.43	0.50	0.57	0.65
35.02	1.49	1.67	1.89	2.13
36.01	1.50	1.74	1.96	2.19
36.02	2.24	2.39	2.79	2.99
36.03	2.38	2.52	2.93	3.15
36.04	5.51	6.03	6.77	7.39
36.05	5.60	6.09	6.87	7.50
36.06	5.69	6.20	6.98	7.61
36.07	10.05	11.15	12.44	13.68
37.01	1.32	1.51	1.68	1.85
38.01	0.85	0.97	1.11	1.22
38.02	1.07	1.20	1.36	1.51
39.01	0.78	0.88	0.98	1.07
40.01	1.50	1.69	1.88	2.09
40.02	2.22	2.51	2.78	3.06
40.03	2.50	2.87	3.19	3.52
40.04	4.36	4.94	5.49	6.05
41.01	1.18	1.32	1.45	1.57
41.02	1.65	1.83	2.03	2.22
41.03	1.90	2.14	2.36	2.58
42.01	1.30	1.47	1.68	1.85
42.02	1.75	2.02	2.28	2.59
43.01	1.16	1.32	1.51	1.70
43.02	1.35	1.55	1.77	1.96
44.01	1.28	1.48	1.70	1.92

Subcatchment ID	Peak Discharge (m^3/s)			
	Existing	10% Increase in Rainfall Intensity	20% Increase in Rainfall Intensity	30% Increase in Rainfall Intensity
45.01	1.17	1.33	1.47	1.62
46.01	0.84	0.96	1.06	1.16
46.02	1.11	1.26	1.39	1.53

APPENDIX I

TUFLOW MODEL RESULTS FOR CLIMATE CHANGE ASSESSMENT

CLIMATE CHANGE ANALYSIS SUMMARY - 1% AEP

Tributary and Location		Peak 1% AEP Water Elevation (mAHD)			
		'Base' Case	10% Increase in Rainfall	20% Increase in Rainfall	30% Increase in Rainfall
Nattai River	Old South Road	753.88	753.92	753.95	753.98
	Range Road	640.05	640.26	640.42	640.56
	Games Field	634.73	634.90	635.06	635.21
	Colo Street	628.80	628.89	628.97	629.04
	Mittagong Maltings	624.42	624.53	624.68	624.78
	Ferguson Crescent	622.23	622.47	623.27	623.41
	Main Southern Railway	621.83	621.97	622.09	622.23
	Old Hume Highway	621.60	621.67	621.73	621.79
	US Swimming Pool	618.48	618.60	618.79	618.95
	DS Swimming Pool	616.42	616.58	616.76	616.84
MG1	Unnamed Driveway	649.16	649.20	649.23	649.27
	Webb Street	643.48	643.52	643.56	643.60
	Payton Street	635.52	635.56	635.59	635.62
	16 Evans Street	630.28	630.34	630.40	630.45
	Colo Street	628.68	628.72	628.76	628.79
Unnamed Tributaries	Oxley Drive	690.78	690.81	690.86	690.88
	Robinson Street	650.89	650.93	650.97	651.00
	Range Road	659.65	659.67	659.69	659.71

APPENDIX J

XP-RAFTS MODEL RESULTS FOR SENSITIVITY ANALYSES

SENSITIVITY ASSESSMENT SUMMARY - 1% AEP

Subcatchment ID	Peak Discharge (m^3/s)				
	Existing	0mm/hr Pervious, 0mm/hr Impervious Initial Loss	30mm/hr Pervious, 3mm/hr Impervious Initial Loss	1.5mm/hr Pervious, 0mm/hr Impervious Continuing Loss	3.5mm/hr Pervious, 1mm/hr Impervious Continuing Loss
1.01	6.53	7.97	5.16	6.60	6.46
1.02	10.03	12.09	7.59	10.11	9.93
1.03	12.40	14.68	9.10	12.47	12.30
1.04	25.05	29.14	18.27	25.25	24.82
1.05	28.41	32.78	20.73	28.63	28.14
1.06	46.65	53.20	33.32	47.05	46.20
1.07	47.75	54.45	34.54	48.18	47.28
1.08	77.29	87.39	56.00	78.03	76.46
1.09	98.28	111.12	72.30	99.23	97.19
1.10	99.02	112.03	73.05	100.00	97.91
1.11	100.79	113.93	74.45	101.79	99.65
1.12	101.78	114.88	75.50	102.82	100.63
1.13	101.83	115.00	75.62	102.87	100.68
1.14	109.14	124.72	82.01	110.30	107.85
1.15	108.48	124.22	81.74	109.63	107.20
1.16	109.23	125.20	82.36	110.43	107.93
1.17	108.71	124.85	82.15	109.96	107.41
1.18	127.12	146.65	95.78	128.83	125.60
1.19	127.61	147.24	96.11	129.35	126.09
1.20	127.79	147.34	96.20	129.45	126.28
1.21	128.47	148.05	96.69	130.14	126.95
1.22	132.95	153.26	100.60	134.76	131.31
1.23	133.92	154.33	101.38	135.81	132.25
1.24	134.15	154.48	101.53	135.96	132.45
1.25	134.53	154.93	101.85	136.43	132.82
1.26	135.17	155.52	102.35	137.06	133.40
1.27	135.54	155.92	102.62	137.42	133.76
2.01	7.49	9.08	5.41	7.57	7.41
2.02	9.46	11.10	6.81	9.56	9.36
3.01	5.50	6.57	3.90	5.56	5.43
3.02	7.46	8.68	5.17	7.53	7.38
3.03	16.75	18.70	11.87	16.91	16.59
4.01	6.02	6.48	4.32	6.06	5.96
4.02	7.90	8.42	5.76	7.97	7.83
5.01	1.47	1.55	1.25	1.47	1.46
5.02	10.17	10.76	8.04	10.24	10.09
5.03	15.41	16.30	12.04	15.53	15.28
5.04	21.74	23.54	16.49	21.93	21.55
5.05	29.21	32.47	21.64	29.50	28.90
6.01	2.73	2.92	2.36	2.75	2.72
7.01	0.93	0.99	0.82	0.94	0.93
7.02	3.58	3.85	2.69	3.60	3.55
8.01	2.70	2.86	2.29	2.71	2.68
9.01	4.46	4.72	3.28	4.50	4.42
10.01	3.50	4.49	3.01	3.55	3.46
11.01	2.15	2.45	1.49	2.17	2.12
12.01	1.60	1.71	1.18	1.61	1.59
12.02	4.74	5.08	3.36	4.78	4.70
12.03	12.60	13.81	9.23	12.71	12.49
12.04	22.19	24.90	16.09	22.40	21.96
12.05	23.99	26.82	17.30	24.22	23.74
13.01	0.65	0.68	0.51	0.65	0.64
13.02	4.11	4.45	3.06	4.14	4.07
13.03	6.80	7.45	4.99	6.86	6.73
14.01	2.95	3.40	2.01	2.97	2.93
14.02	5.42	6.15	3.89	5.46	5.36
14.03	6.28	7.03	4.49	6.33	6.22
14.04	8.22	9.13	5.81	8.29	8.14
15.01	0.75	0.93	0.59	0.76	0.74
16.01	1.38	1.56	0.98	1.39	1.36
17.01	1.36	1.63	0.91	1.37	1.35
18.01	1.72	1.96	1.22	1.73	1.71
18.02	2.45	2.91	1.72	2.47	2.43
19.01	1.20	1.45	0.93	1.21	1.19
20.01	3.01	3.64	2.44	3.04	2.97
20.02	4.43	5.45	3.63	4.48	4.37
20.03	4.97	6.12	4.04	5.03	4.91
20.04	5.51	6.82	4.42	5.58	5.44
20.05	5.83	7.16	4.64	5.90	5.76
20.06	9.07	11.08	7.04	9.17	8.97
21.01	0.39	0.48	0.31	0.40	0.39
21.02	1.35	1.56	0.98	1.36	1.34
21.03	2.42	2.69	1.72	2.44	2.40

Subcatchment ID	Peak Discharge (m^3/s)				
	Existing	0mm/hr Pervious, 0mm/hr Impervious Initial Loss	30mm/hr Pervious, 3mm/hr Impervious Initial Loss	1.5mm/hr Pervious, 0mm/hr Impervious Continuing Loss	3.5mm/hr Pervious, 1mm/hr Impervious Continuing Loss
21.04	3.17	3.72	2.32	3.20	3.13
22.01	0.50	0.58	0.43	0.51	0.49
23.01	5.20	5.75	3.68	5.25	5.15
23.02	8.27	9.14	5.84	8.34	8.18
23.03	15.14	16.80	11.01	15.26	15.00
23.04	15.97	17.90	11.74	16.11	15.81
23.05	17.10	19.44	12.87	17.24	16.93
23.06	18.22	20.87	13.87	18.37	18.03
23.07	18.70	21.44	14.30	18.86	18.51
23.08	19.09	21.73	14.54	19.26	18.89
23.09	20.71	23.59	15.90	20.89	20.49
23.10	21.67	24.58	16.54	21.87	21.43
23.11	23.34	26.41	17.83	23.55	23.07
24.01	3.28	3.95	2.23	3.30	3.25
24.02	4.77	5.50	3.35	4.81	4.72
25.01	0.51	0.54	0.43	0.52	0.51
26.01	0.39	0.40	0.33	0.39	0.39
27.01	1.07	1.09	0.91	1.07	1.06
28.01	0.61	0.63	0.50	0.61	0.60
29.01	1.13	1.14	0.96	1.13	1.12
29.02	2.66	2.90	1.90	2.68	2.64
30.01	0.93	0.94	0.80	0.93	0.92
31.01	1.72	1.80	1.36	1.73	1.71
31.02	2.69	2.91	1.92	2.71	2.67
33.01	0.38	0.46	0.29	0.39	0.38
34.01	1.30	1.34	1.01	1.31	1.29
35.01	0.43	0.57	0.35	0.43	0.43
35.02	1.49	1.80	1.09	1.50	1.48
36.01	1.50	1.76	1.05	1.52	1.49
36.02	2.24	2.47	1.57	2.26	2.22
36.03	2.38	2.61	1.66	2.41	2.36
36.04	5.51	6.28	4.08	5.54	5.47
36.05	5.60	6.32	4.19	5.63	5.56
36.06	5.69	6.42	4.28	5.73	5.65
36.07	10.05	11.10	7.66	10.11	9.97
37.01	1.32	1.51	1.09	1.33	1.31
38.01	0.85	0.98	0.67	0.85	0.84
38.02	1.07	1.22	0.87	1.07	1.06
39.01	0.78	0.81	0.66	0.79	0.78
40.01	1.50	1.61	1.08	1.51	1.49
40.02	2.22	2.40	1.60	2.23	2.20
40.03	2.50	2.73	1.82	2.53	2.49
40.04	4.36	4.71	3.42	4.37	4.33
41.01	1.18	1.23	0.99	1.19	1.18
41.02	1.65	1.74	1.39	1.66	1.64
41.03	1.90	2.00	1.58	1.91	1.88
42.01	1.30	1.53	1.11	1.30	1.28
42.02	1.75	2.10	1.38	1.76	1.73
43.01	1.16	1.33	0.83	1.17	1.14
43.02	1.35	1.56	0.99	1.37	1.34
44.01	1.28	1.52	0.93	1.30	1.27
45.01	1.17	1.23	0.86	1.18	1.16
46.01	0.84	0.89	0.63	0.85	0.84
46.02	1.11	1.17	0.85	1.12	1.10

APPENDIX K

TUFLOW MODEL RESULTS FOR SENSITIVITY ANALYSES

SENSITIVITY ANALYSIS SUMMARY - 1% AEP

Tributary and Location		Peak 1% AEP Water Elevation (mAHD)				
		'Base' Case	0% Blockage	100% Blockage	Mannings 'n' Increase of 20%	Mannings 'n' Decrease of 20%
Nattai River	Old South Road	753.88	753.77	753.95	753.88	753.87
	Range Road	640.05	639.83	641.03	640.09	640.08
	Games Field	634.73	634.74	634.75	634.86	634.61
	Colo Street	628.80	628.78	629.05	628.85	628.75
	Mittagong Maltings	624.42	624.43	624.59	624.52	624.32
	Ferguson Crescent	622.23	622.08	624.01	622.24	622.25
	Main Southern Railway	621.83	621.71	623.85	621.83	621.85
	Old Hume Highway	621.60	621.53	621.85	621.60	621.60
	US Swimming Pool	618.48	618.48	618.56	618.62	618.95
	DS Swimming Pool	616.42	616.44	616.48	616.59	616.18
MG1	Unnamed Driveway	649.16	649.16	649.18	649.17	649.16
	Webb Street	643.48	643.36	643.61	643.49	643.47
	Payton Street	635.52	635.49	635.52	635.55	635.51
	16 Evans Street	630.28	630.12	630.44	630.30	630.26
	Colo Street	628.68	628.57	628.77	628.71	628.66
Unnamed Tributaries	Oxley Drive	690.78	690.67	690.89	690.78	690.82
	Robinson Street	650.89	650.93	650.82	651.05	650.87
	Range Road	659.65	659.65	659.66	659.66	659.65