Minnegang Creek Flood Study

Volume 1

Wollongong City Council | Flood Study | 23 October 2019

Contact Information

Rhelm Pty Ltd
ABN: 55 616 964 517
Level 1, 50 Yeo Street
Neutral Bay NSW 2089
Australia

Lead Author:
Rhys Thomson
contact@rhelm.com.au

Document Control

Ver	Effective Date	Description of Revision	Prepared by:	Reviewed by:
0	22 July 2019	Executive Summary issued to Council	LRE	RST
1	15 August 2019	Internal Review	LRE	RST/ERM
2	16 August 2019	Issue of Draft Flood Study to Council	LRE	RST
3	9 October 2019	Executive Summary issues to Council	RST	RST
4	23 October 2019	Issue of Final Flood Study to Council	LRE	RST

Prepared For: Wollongong City Council

Project Name: Minnegang Creek Flood Study

Rhelm Reference: J1074

Document Location: C:\Dropbox (Rhelm)\Jobs\J1074 - Minnegang FS\4. Reports\R005 Minnegang Final Report\J1074_R004_Minnegang_Stage_4_Rev4_Vol-1.doc

Client Reference: Stage 4 Report Final Flood Study

Wollongong Council

41 Burelli Street, Wollongong

council@wollongong.nsw.gov.au

+612 4227 7111

Foreword

The primary objective of the New South Wales (NSW) Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible.

Through the NSW Department of Planning, Industry and Environment (DPIE), NSW Department of Planning and Environment (DPE) and the NSW State Emergency Service (SES), the NSW Government provides specialist technical assistance to local government on all flooding, flood risk management, flood emergency management and land-use planning matters.

The *Floodplain Development Manual* (NSW Government 2005) is provided to assist councils to meet their obligations through the preparation and implementation of floodplain risk management plans, through a staged process. **Figure F1**, taken from this manual, documents the process for plan preparation, implementation and review.

The *Floodplain Development Manual* (NSW Government 2005) is consistent with Australian Emergency Management Handbook 7: *Managing the floodplain: best practice in flood risk management in Australia* (AEM Handbook 7) (AIDR 2017).

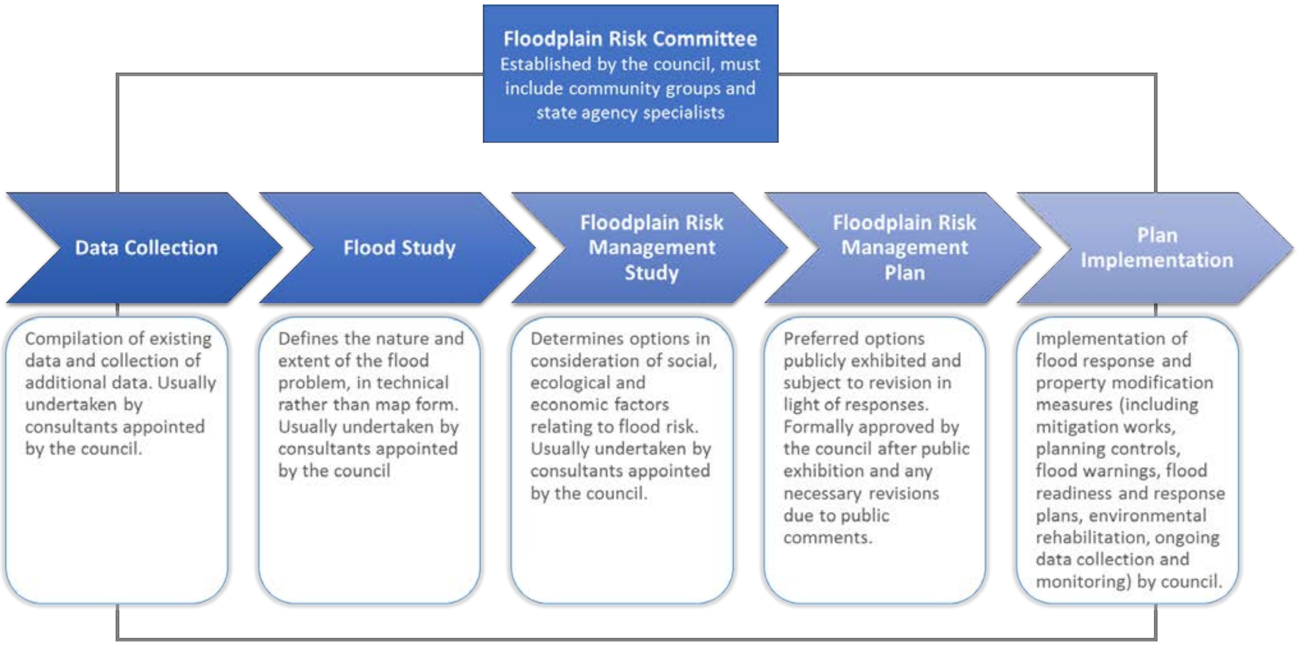


Figure F1 The Floodplain Risk Management Process (source: NSW Government, 2005)

Wollongong City Council is responsible for local land use planning in its service area, including in Minnegang Creek catchment and its floodplain. Through its Floodplain Risk Management Committee, Council has committed to prepare a comprehensive floodplain risk management plan for the study area in accordance with the NSW Government's *Floodplain Development Manual* (2005). This document relates to the flood study phase of the process.

Executive Summary

The Minnegang Creek Flood Study has been prepared for Wollongong City Council (Council) to define the existing flood behaviour in the Minnegang Creek catchment and to establish the basis for subsequent floodplain management activities.

The Minnegang Creek Catchment is located around 7km south of Wollongong. The Minnegang Creek Catchment is approximately 90 hectares in size and is largely developed and zoned as low density residential (roughly 80% of the catchment). The remaining part of the catchment comprises recreational and open-space areas, and some areas of bushland.

The catchment has a combination of natural open watercourses and piped drains. Minnegang Creek originates in the north west of the catchment. The creek is piped from Lake Heights Road through to the Barina Park Basin. Minnegang Creek continues to be piped to downstream of Barina Park Basin, discharging into a defined open channel downstream of Weringa Avenue. This remains as a defined open channel before passing through a culvert under Northcliffe Drive, and discharging into Lake Illawarra. A major tributary, originating from the north of Gilgandra Street, meets with Minnegang Creek at Barina Park

This project is a flood study, which is a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust floodplain risk management plan. It aims to provide a better understanding of the full range of flood behaviour and consequences. It involves consideration of the local flood history, available collected flood data, and the development of hydrologic and hydraulic models that are calibrated and verified, where possible, against historic flood events and extended, where appropriate, to determine the full range of flood behaviour.

A comprehensive engagement strategy was undertaken throughout the development of the flood study. This involved:

- Engaging agency and industry stakeholder to obtain details of historical flooding, survey data and other relevant data sets. Stakeholders have also been invited to provide feedback on the draft flood study during public exhibition.
- Community engagement has been undertaken through the mail out of an information brochure and brief survey. The purpose of the engagement was to raise awareness of the study and flood risk in the catchment, as well and obtain observations of historical flooding to assist in model calibration. Respondents were contacted for further information by phone and email, as required.
- Door knocking was also undertaken for selected properties identified based on preliminary review of the flood behaviour.
- The Flood Study has been overseen by the Southern Floodplain Risk Management Committee which includes representatives from community and state agencies.
- The Flood Study was placed on public exhibition from 26 August 2019 to 23 September 2019. During the exhibition period, letters were sent to residents and owners to inform them of the study. An information session was also provided on 7 September 2019.

Flood behaviour has been assessed using a TUFLOW hydraulic model incorporating the Direct Rainfall methodology.

A calibration and validation of the hydraulic model has been undertaken utilising historical rainfall intensities, community observations and comparisons to surveyed flood marks from events occurring in

1985, 1987, 1990 and 1998. The outcome of the calibration found that the model was able to represent the historical events to a reasonable level, providing confidence in the model to produce design flood event results.

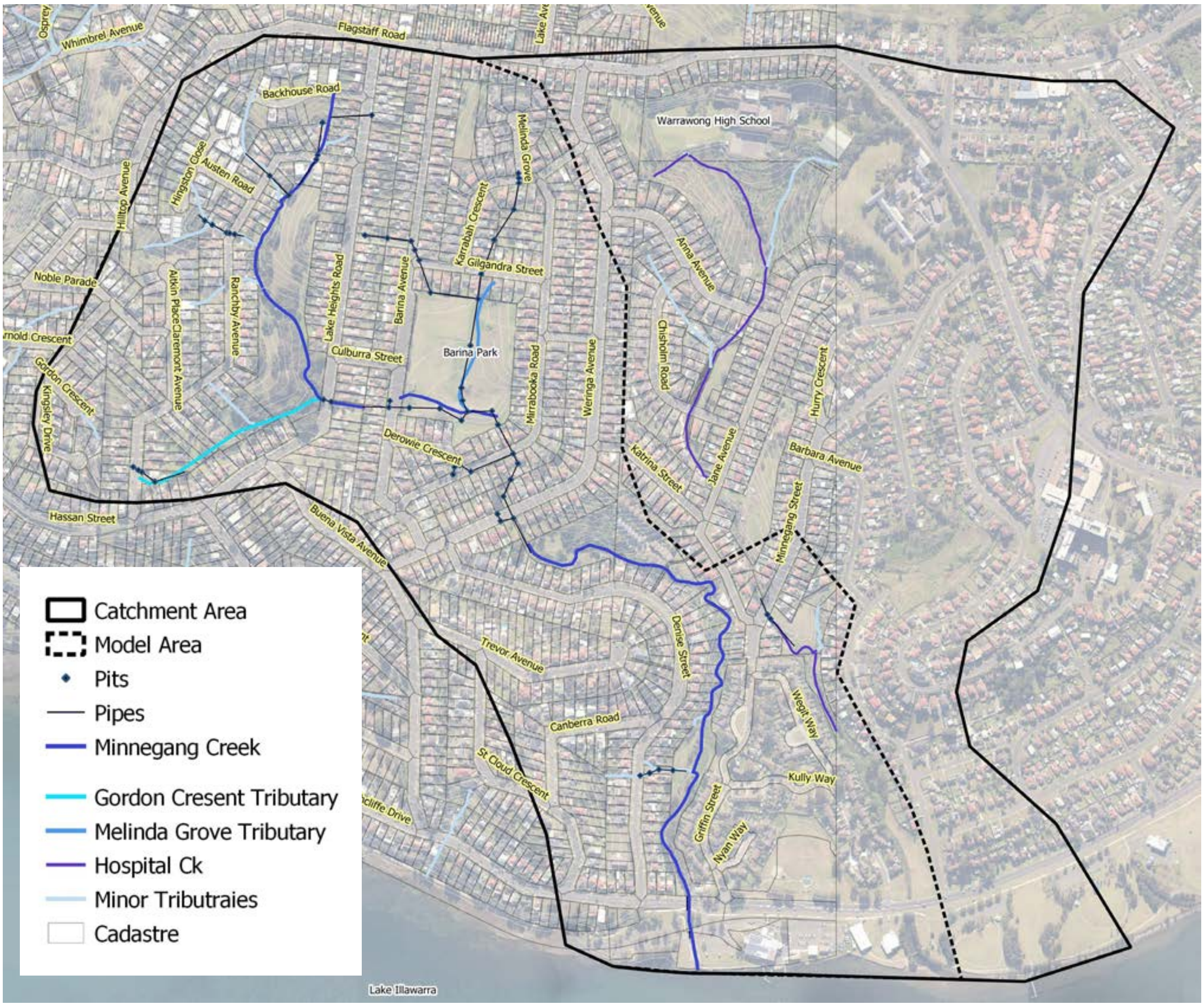


Figure i. Minnegang Creek Catchment

The hydrological and hydraulic models were analysed for the Probable Maximum Flood (PMF), 1% Annual Exceedance Probability (AEP), 2% AEP, 10% AEP and 20% AEP events. The models were analysed for 90 and 120 minute duration storms.

The models represent the catchment conditions at the time of survey, being 2017. This study represents the flood behaviour driven by catchment flooding. In the downstream areas of the study area, this flood study should be read in conjunction with the Lake Illawarra Flood Study (Lawson & Treloar, 2001) and the Lake Illawarra Floodplain Risk Management Study and Plan (Cardno Lawson Treloar, 2012).

An overview of the flood behaviour is provided for the PMF, 1% AEP and 20% AEP events in **Figures ii** to **ix**.

Minnegang Creek has two major tributaries. The Gordon Crescent Tributary commences in the far west of the catchment. Overland flows pass down Gordon Crescent, before flowing overland through residential properties to Ranchby Avenue. From Ranchby Avenue, flow again passes overland through residential lots, joining with Minnegang Creek immediately upstream of Lake Heights Road. A smaller unnamed overland flowpath commences in Claremont Avenue, flows overland across Ranchby Avenue, and joins the Gordon Creek Tributary 100m upstream of the Minnegang Creek tributary.

The Melina Grove Tributary commences in Melinda Grove, in the north eastern region of the study area. It flows directly south, crosses Karrabah Crescent, and flows overland through residential lots until it crosses Gilgandra Street and discharges into Barina Park Basin.

Minnegang Creek begins in the north west of the catchment area. Minnegang Creek, and two unnamed tributaries, convey water from this region, through the public recreation zone between Ranchby Avenue and Lake Heights Road, before crossing Lake Heights Road and Barina Avenue, and discharging into Barina Park Basin. In the PMF event, an additional overland flowpath is activated when flow breaks out of Lake Heights Road, and flows south-east across residential lots into Barina Avenue.

The flows along much of the upstream reaches are generally well contained with little change in extent between 20% AEP and 1% AEP and a minor increase in width in the PMF.

The Barina Park Basin lies in the centre of the catchment area, and intercepts flow from Minnegang Creek and Melinda Grove Tributary. It also indirectly intercepts flow from Gordon Crescent Tributary as this flowpath merges with Minnegang Creek upstream of Barina Park Basin.

The Barina Park Basin first overtops in the 10% AEP, though only engages a portion of the embankment. The embankment is fully engaged for events from the 5% AEP to the 1% AEP. The PMF results in additional overtopping of the embankment to both the east and the west of the designated spillway.

Downstream of Weringa Avenue, Minnegang Creek becomes a defined open channel. Flows are generally well contained within the channel for events up to the 1% AEP, although the rear of some properties are inundated. In the PMF, some overbank flows begin to occur, inundating the rear of adjacent properties. A number of overland flowpaths convey runoff from the developed areas to the west of the creek. These overland flows result in ponding along Denise Street, which loses access in the 20% AEP, though the duration is short, with flooding clearing in under an hour.

Immediately to the east of Minnegang Creek is Hospital Creek, which drains the adjacent catchment area. While Hospital Creek does not form a part of this study, it was included in the modelling in order to assess whether any breakout flows occur from Hospital Creek to Minnegang Creek in larger events. At Jane Avenue, where the creeks are approximately 100m apart, some break out flow was observed in the PMF event. It was driven by the constriction of Hospital Creek flows when it passes through the culvert under Minnegang Street. At this location, flow backs up upstream of the culvert, and breaks out over the western bank, crosses Jane Avenue and flows into Minnegang Creek. The breakout occurred in both the design blockage and risk blockage scenarios. Along and downstream of Northcliffe Drive, the flooding is largely driven by backwater from Lake Illawarra.

Similar to other areas of the catchment, there was little change in extent between the 20% AEP and the 1% AEP, while the PMF extent was substantially larger, inundating much of the area. These changes are commensurate with the change in downstream boundary, which sees lake levels rise from 1.81m for the 1% AEP design runs to 2.24m for the PMF.

Sensitivity testing was undertaken on model roughness, inflows and blockage. It was found that overall, the model is relatively insensitive to model roughness assumptions, with potential variation in water levels in the order of +/- 0.05 metres arising from +/- 20% changes in roughness values. The model was more sensitive to hydrological assumptions on flows, with levels changing by up to 0.3 metres in the downstream reaches of Minnegang Creek as a result of a 20% increase in flows in the 1% AEP event.

With respect to blockage, the sensitivity testing showed that the impact of blockage in the catchment is generally limited, with the majority of water level changes within +/- 0.05m between blocked (risk scenario) and unblocked cases, and only for very limited areas of the catchment. The most significant change is immediately upstream of Barina Avenue, where risk scenario blockages resulted in increases of up to 0.2 metres in the 1% AEP and 0.1 metres in the 20% AEP occurring between Barina Avenue and Lake Heights Road.

This report provides an understanding of the flood risk within the Minnegang Creek catchment and may be used to inform planning. This study provides a baseline against which a Floodplain Risk Management Study and Plan can be prepared.

Figure i

Peak Depth & Water Level PMF

Cadastre
Model Area
Study Area
Buildings
Depth (m)
0 - 0.15
0.15 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 4
>4
Contour 1m
Contour 5m

Scale : 1:6000@A3
Date : 15 August 2019
Revision : B
Created by : LRE
Coordinate System : MGA 56

Rhelm

N
W E
S

Figure ii

Peak Depth & Water Level 1% AEP

- Cadastre
- Model Area
- Study Area
- Buildings

Depth (m)
- 0 - 0.15
- 0.15 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- >4
- Contour 1m
- Contour 5m

Scale : 1:6000@A3
Date : 15 August 2019
Revision : B
Created by : LRE
Coordinate System : MGA 56

Rhelm

Figure iii

Peak Depth & Water Level 20% AEP

Scale : 1:6000@A3
Date : 15 August 2019
Revision : B
Created by : LRE
Coordinate System : MGA 56

Rhelm

Figure iv

Peak Velocity PMF

Scale : 1:6000@A3
Date : 15 August 2019
Revision : B
Created by : LRE
Coordinate System : MGA 56

Rhelm

Figure v

Peak Velocity
1% AEP

Scale : 1:6000@A3
Date : 15 August 2019
Revision : B
Created by : LRE
Coordinate System : MGA 56

Rhelm

Figure vi

Peak Velocity
20% AEP

Cadastre
Model Area
Study Area
Buildings
Velocity (m/s)
<=0.01
0.01 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 4
> 4

Scale : 1:6000@A3
Date : 15 August 2019
Revision : B
Created by : LRE
Coordinate System : MGA 56

Rhelm

Figure vii

Peak Hazard
PMF

Figure viii

Peak Hazard
1% AEP

Cadastre
Model Area
Study Area
Buildings

Hazard
H1 - Generally safe for vehicles, people & buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for vehicles and people
H5 - Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure
H6 - Unsafe for vehicles and people. All building types considered vulnerable to failure

Scale : 1:6000@A3
Date : 15 August 2019
Revision : B
Created by : LRE
Coordinate System : MGA 56

Rhelm

Table of Contents

Tables

Figures

Appendices

Maps

These are provided in Volume 2.

G101	Study Area Location
G201	Catchment Area Features
G301	Additional Survey
G302	Historic Survey Marks
G303	Rainfall Gauges
G501	Subcatchments
G502	Tuflow Model Setup
G503	Roughness Zones
G601	Historical Data Points
G602	1985 Validation
G603	1987 Validation
G604	1990 Validation
G605	1998 Validation
G606	Mike-11 Comparison
G701-D-1	PMF Peak Depth & Water Level – Design Scenario
G701-D-2	1% AEP Peak Depth & Water Level – Design Scenario
G701-D-3	2% AEP Peak Depth & Water Level – Design Scenario
G701-D-4	5% AEP Peak Depth & Water Level – Design Scenario
G701-D-5	10% AEP Peak Depth & Water Level – Design Scenario
G701-D-6	20% AEP Peak Depth & Water Level – Design Scenario
G701-R-1	PMF Peak Depth & Water Level – Risk Scenario
G701-R-2	1% AEP Peak Depth & Water Level – Risk Scenario
G701-R-3	2% AEP Peak Depth & Water Level – Risk Scenario
G701-R-4	5% AEP Peak Depth & Water Level – Risk Scenario
G701-R-5	10% AEP Peak Depth & Water Level – Risk Scenario
G701-R-6	20% AEP Peak Depth & Water Level – Risk Scenario
G702-D-1	PMF Peak Velocity – Design Scenario
G702-D-2	1% AEP Peak Velocity – Design Scenario
G702-D-3	2% AEP Peak Velocity – Design Scenario
G702-D-4	5% AEP Peak Velocity – Design Scenario
G702-D-5	10% AEP Peak Velocity – Design Scenario
G702-D-6	20% AEP Peak Velocity – Design Scenario
G702-R-1	PMF Peak Velocity – Risk Scenario
G702-R-2	1% AEP Peak Velocity – Risk Scenario
G702-R-3	2% AEP Peak Velocity – Risk Scenario

Glossary

Annual exceedance probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (i.e. a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year. (See also average recurrence interval).
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
Attenuation	Weakening in force or intensity.
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 design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. (See also annual exceedance probability).
Catchment	The catchment, at a particular point, is the area of land that drains to that point.
Design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100 year ARI or 1% AEP flood).
Development	Is defined in Part 4 of the AP&A Act as: - Infill Development: development of vacant blocks of land that are generally surrounded by developed properties. - New Development: development of a completely different nature to that associated with the former land use. - Redevelopment: Rebuilding in an area with similar development.
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).
Flood	Relatively high river or creek flows, which overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
Flood Awareness	Awareness is an appreciation of the likely effects of flooding and knowledge of the relevant flood warning, response ad evacuation procedures.
Flood Education	Education that seeks to provide information to raise awareness of the flood problem to enable individuals to understand how to manage themselves and their property in a flood event.
Flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage.
Flood hazard	The potential risk to life and limb and potential damage to property

	resulting from flooding. The degree of flood hazard varies with circumstances across the full range of floods.
Flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as "stage".
Floodplain	Area of land which is subject to floods up to and including the probable maximum flood.
Floodplain risk management plan	A document outlining a range of actions aimed at improving floodplain management. The plan is the principal means of managing the risks associated with the use of the floodplain. A floodplain risk management plan needs to be developed in accordance with the principles and guidelines contained in the NSW Floodplain Development Manual. The plan usually contains both written and diagrammatic information describing how particular areas of the floodplain are to be used and managed to achieve defined objectives.
Flood planning levels (FPLs)	Flood planning levels selected for planning purposes are derived from a combination of the adopted flood level plus freeboard, as determined in floodplain management studies and incorporated in floodplain risk management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also consider the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of land use and for different flood plans. The concept of FPLs supersedes the "standard flood event". As FPLs do not necessarily extend to the limits of flood prone land, floodplain risk management plans may apply to flood prone land beyond that defined by the FPLs.
Flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
Flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
Floodway	A flow path (sometimes artificial) that carries significant volumes of floodwaters during a flood.
Freeboard	A factor of safety usually expressed as a height above the adopted flood level thus determining the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
Gauging (tidal and flood)	Measurement of flows and water levels during tides or flood events.
Hazard	A source of potential harm or a situation with a potential to cause loss.
Historical flood	A flood that has actually occurred.
Hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems, in particular the evaluation of flow parameters such as water level and velocity.
Hydrograph	A graph showing how a river or creek's discharge changes with time.
Hydrologic	Pertaining to rainfall-runoff processes in catchments.

Hydrology	The term given to the study of the rainfall-runoff process in catchments, in particular, the evaluation of peak flows and flow volumes. .
Isohyet	Equal rainfall contour.
Peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
Pluviometer	A rainfall gauge capable of continuously measuring rainfall intensity.
Probable maximum flood (PMF)	An extreme flood deemed to be the maximum flood that could conceivably occur.
Probability	A statistical measure of the likely frequency or occurrence of flooding.
Riparian	The interface between land and waterway. Literally means "along the river margins".
Runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
Stage	See flood level.
Stage hydrograph	A graph of water level over time.
Topography	The shape of the surface features of land.
Velocity	The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, i.e. the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.

Terminology in this Glossary has been adapted from the NSW Government Floodplain Development Manual, 2005, where available.

Abbreviations

1D	One Dimensional
2D	Two Dimensional
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ALS	Aerial Laser Survey
ARI	Average Recurrence Interval
ARF	Areal Reduction Factor
ARR	Australian Rainfall and Runoff
ARR87	The 1987 Edition of Australian Rainfall and Runoff
ARR2016	The 2016 Edition of Australian Rainfall and Runoff
BoM	Bureau of Meteorology
DCP	Development Control Plan
DEM	Digital Elevation Model
DFE	Defined Flood Extent
DPE	Department of Planning and Environment
DPIE	Department of Planning, Industry and Environment
IFD	Intensity Frequency Duration
FPL	Flood Planning Level
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
FPRMSP	Floodplain Risk Management Study & Plan
ha	Hectare
km	Kilometres
km^2	Square kilometres
LEP	Local Environment Plan
LGA	Local Government Area
LiDAR	Light Detection and Ranging
m	Metre
m^2	Square metres
m^3	Cubic metres
mAHD	metres to Australian Height Datum
MHL	Manly Hydraulics Laboratory

mm	Millimetres
m/s	metres per second
NSW	New South Wales
OEH	Office of Environment and Heritage (NSW)
PMF	Probable Maximum Flood
SCA	Sydney Catchment Authority
SES	State Emergency Service (NSW)
STP	Sewerage Treatment Plant
SWC	Sydney Water Corporation
TWG	Technical Working Group

1 Introduction

The Minnegang Creek Flood Study has been prepared for Wollongong City Council (Council) to define the existing flood behaviour in the Minnegang Creek catchment and to establish the basis for subsequent floodplain management activities.

1.1 Study Objectives

The overall objective of this study is to improve understanding of flood behaviour and impacts, and better inform management of flood risk in the study area through consideration of the available information, and relevant standards and guidelines. The study will also provide a sound technical basis for any further flood risk management investigations in the area.

The project is a Flood Study Review, which is a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust floodplain risk management plan. It aims to provide a better understanding of the full range of flood behaviour and consequences. It involves consideration of the local flood history, available collected flood data, and the development of hydrologic and hydraulic models that are calibrated and verified, where possible, against historic flood events and extended, where appropriate, to determine the full range of flood behaviour.

The project will re-evaluate the design flood discharges, velocities, flood levels, hydraulic categories and other flood related information for the Minnegang Creek catchment. The study will incorporate the latest available data and Council's revised Blockage Policy (2016).

The outputs of the study will assist this by:

- providing a better understanding of the:
  - variation in flood behaviour, flood function, flood hazard and flood risk in the study area;
  - risks on the existing and future community;
  - impacts of climate on flood risk; and,
  - emergency response situation and limitations.
- facilitating information sharing on flood risk across government and with the community.

The study outputs will also inform decision making for investing in the floodplain; managing flood risk through prevention, preparedness, response and recovery activities; pricing insurance, and informing and educating the community on flood risk and response to floods.

1.2 Study Location

The Minnegang Creek Catchment is located approximately 7km south of Wollongong. The Minnegang Creek Catchment is approximately 90 hectares in size and is largely developed and zoned as low density residential (roughly 80% of the catchment). The remaining part of the catchment comprises recreational and open-space areas, and some areas of bushland.

The catchment has a combination of natural open watercourses and piped drains. Minnegang Creek originates in the north west of the catchment. Downstream of Lake Heights Road, the creek is piped through to Barina Park Detention Basin. Downstream of Barina Park Basin, Minnegang Creek discharges from a culvert into a defined open channel downstream of Weringa Avenue. This remains as a defined open channel before passing under Northcliffe Drive through a culvert and discharging into Lake Illawarra.

A secondary tributary, originating from the north of Gilgandra Street, meets with Minnegang Creek at the Detention Basin.

The study area location is shown in **Map G101**.

1.3 Study Background and Context

The Minnegang Creek Flood Study (KBR) was completed in 2002, followed by a subsequent Floodplain Risk Management Study and Plan (KBR) in 2004.

More recently, a breach and consequence assessment was undertaken for the Barina Park Basin by GHD in 2017.

The Floodplain Development Manual (NSW Government 2005) recommends that a flood study should be reviewed regularly (approximately every five years) or a review may be triggered earlier for a variety of reasons including the occurrence of a significant flood event, changes to relevant policy, legislation or guidelines or development occurring or proposed in the catchment.

It has been determined that a review of the flood study from 2002 for Minnegang is warranted on the basis of a number of changes to policy, guidelines, modelling approaches and development in the catchment which have occurred since its adoption, namely:

- Implementation of Council's New Blockage Policy, May 2016 (as outlined in the Final Technical Report – Review of Conduit Blockage Policy, May 2016);
- The effect of climate change on the catchment both increasing rainfall and ocean level;
- The availability of ALS data and greater detailed ground survey / LiDAR data
    - AAM Hatch (2005) and LPI (2011-2013) ALS was not available for the original study;
    - Additional ground, pit and pipe survey has also been undertaken as part of the Flood Study Review.
- Advances in modelling technology (particularly in 2D modelling);
- Implementation of flood mitigation measures from the 2004 Flood Risk Management Plan;
- Information available from subsequent flood events since the initial studies were finalised; and,
- The changes to development and proposed development within the catchment.

2 Study Area

2.1 Catchment Description

The Minnegang Creek catchment is located in the suburb of Lake Heights, in the Wollongong LGA. The catchment covers an area of approximately 90 hectares and extends from the northern shore of Lake Illawarra in the south to Flagstaff Road in the north. The catchment is characterised by relatively steep hills, with elevations falling from 80mAHD in the upper catchment to 2mAHD adjacent to the Lake.

The waterway system in the catchment is comprised of natural open watercourses and piped drains. Minnegang Creek is the only major creek in the system, and is fed by a number of small tributaries, primarily in the upper catchment. Minnegang Creek flows from the north-west of the catchment to the south-east where it discharges into Lake Illawarra. The Creek is approximately 2km long, with grades in the order of 5% in the upper catchment, and 2% in the lower.

There are two primary tributaries to Minnegang Creek, referred to in this report as Gordon Crescent Tributary and Melinda Grove Tributary. Gordon Crescent tributary commences in the west, from Gordon Crescent and flows across Ranchby Avenue, joining with Minnegang Creek upstream of Lake Heights Road. Melinda Grove Tributary flows from the north of the catchment, follows Melinda Grove and then passes across Gilgandra Street, joining with Minnegang Creek upstream of Mirrabooka Road. The site of this confluence is Barina Park, which also serves as a detention basin, intercepting flows from both Minnegang Creek and Melinda Grove Tributary.

The catchment is principally comprised of low density residential development, which covers 80% of the catchment area. The remaining 20% is largely open recreational space, including Barina Park, as well as some areas of bushland. There are no commercial or industrial precincts in the catchment area.

There are two major road corridors in the catchment area. Flagstaff Road is a major road that runs along the ridge that forms the northern boundary of the catchment area. As such, it does not experience flooding from Minnegang Creek. The second major road, Northcliffe Drive, runs near the southern boundary of the catchment, adjacent to Lake Illawarra. Within the study area there are a number of municipal roads, a number of which cross Minnegang Creek and its tributaries.

In addition to these crossings, Minnegang Creek also passes through two piped reaches that pass under residential properties. These regions have little provision for overland flow and have a history of reports relating to flood affectation. These reaches are:

- Between Lake Heights Road and Barina Avenue, downstream of the Gordon Crescent Tributary confluence; and
- Between Mirrabooka Road and Weringa Avenue, downstream of the Melinda Grove Tributary.

The catchment area and its features are shown in **Map G201**.

2.2 Historical Flooding

Council had previously collected flood marks for events in 1985, 1987, 1990 and 1998. These were made available as part of this study. In addition, community records and recollections of historical flooding were collected as part of the door knocking undertaken as part of this study. The results of the door knocking are detailed in **Section 4.4**.

3 Review of Available Data

3.1 Site Inspections

Site inspections of the catchment were undertaken at the inception of the project (20 November 2017 and 12 December 2017). The site inspection was attended by Rhelm, Council and DPIE staff, and aimed to provide an overview of the catchment, and an appreciation of key features impacting flood behaviour.

3.2 Previous Studies and Reports

3.2.1 Lake Illawarra Flood Study (Cardno Lawson & Treloar, 2001)

Completed in 2001, the Lake Illawarra Flood Study defined the flood behaviour for the Lake Illawarra system. The study developed a RAFTS hydrological model and a MIKE-11 hydraulic model to define the flood behaviour. The Flood Study considered the 50%, 20%, 10%, 2% and 1% AEP events, and an extreme event of the order of a PMF.

The study found that the 36 hour event was critical for the Lake. This is significantly longer than the 2 hour critical duration of the Minnegang Creek catchment (refer **Section 7.5**).

An overview of the flood extents for flooding associated with Lake Illawarra for the 1% AEP and the PMF is provided in **Figure 3-1** and **Figure 3-2** respectively. The figures show that flooding in the 1% AEP event from Lake Illawarra inundates Northcliffe Drive at the outlet of Minnegang Creek with backwater extending approximately 50 metres up Minnegang Creek. In the PMF event, peak levels are approximately 1 metre higher. The terrain restricts lateral expansion of the flood extent, but inundation extends further inland, and backwater effects extend approximately 100 metres up Minnegang Creek.

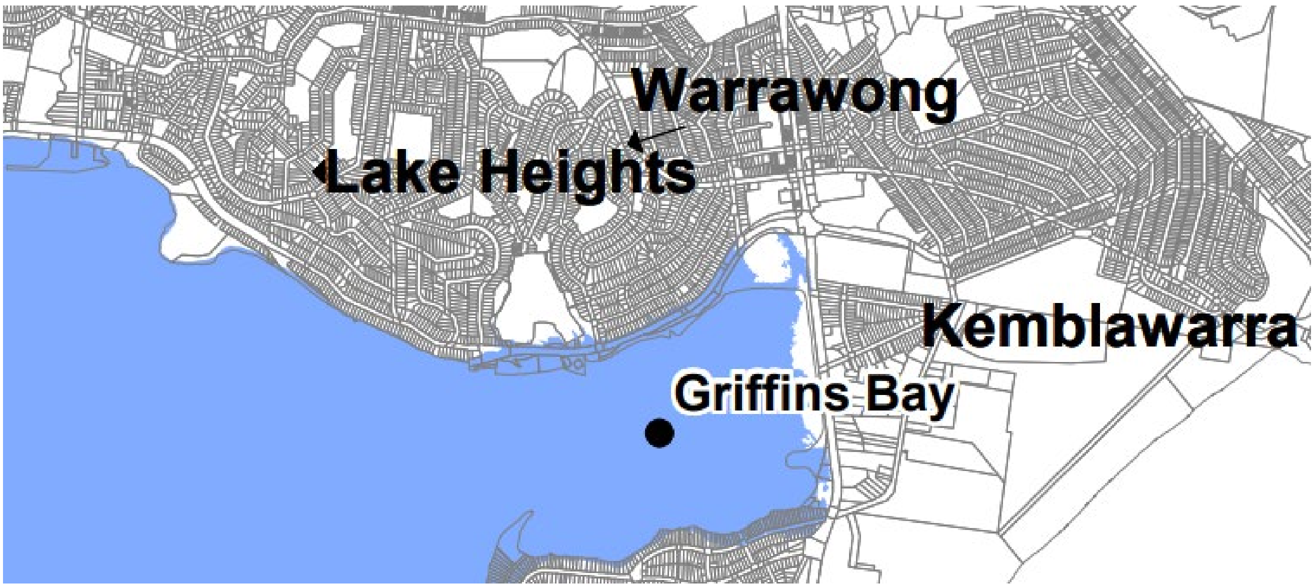


Figure 3-1 1% AEP Lake Illawarra Flood Extent (adapted from Cardno Lawson & Treloar, 2001)

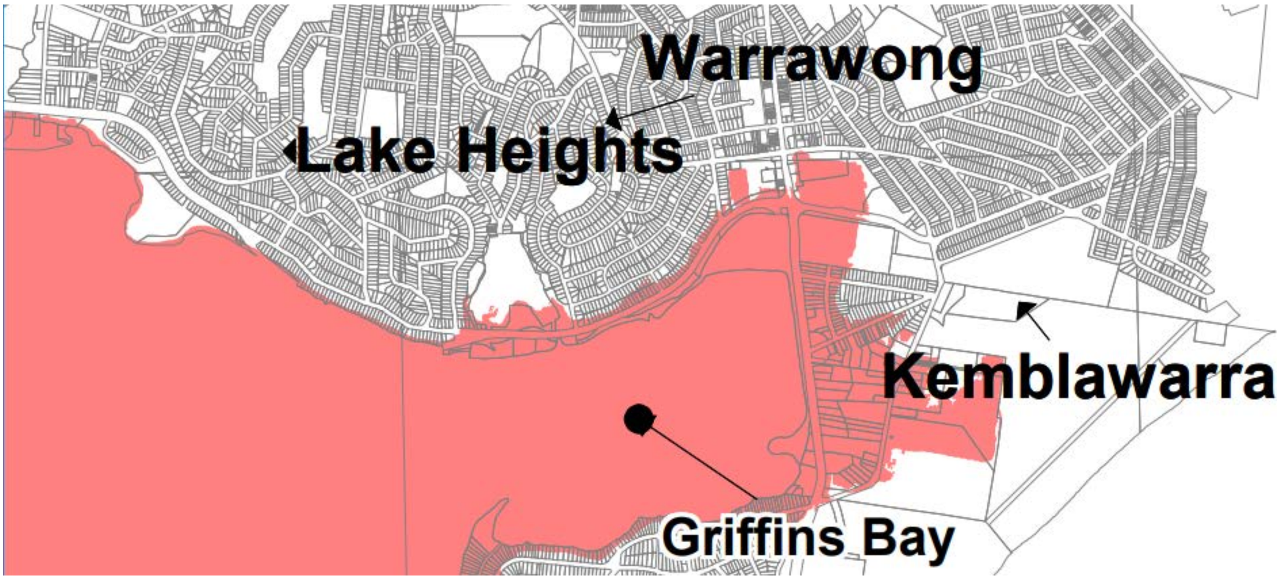


Figure 3-2 PMF Lake Illawarra Flood Extent (adapted from Cardno Lawson & Treloar, 2001)

3.2.2 Minnegang Creek Flood Study (KBR, 2002)

In 2002, Council undertook a Flood Study for Minnegang Creek. The objective of the study, undertaken by KBR, was to define the extent and behaviour of flooding in the catchment. A RAFTS hydrological model and a MIKE-11 hydraulic model were prepared, both of which covered the entire catchment area.

Due to the scarcity of available historical data, a limited validation was undertaken using historic levels taken from an event in 1998 which was in the order of a 50% AEP. A larger event would have provided a more robust validation, but no suitable data was available.

The study examined the 20%, 5%, 2% and 1% AEP events and the PMF event. A critical duration of 2 hours was found to be applicable to all storm events. The 1% AEP extent and risk precincts are shown in **Figure 3-3**.

The study found that flooding was relatively well contained in the upper reaches of the catchment but increasing amounts of overbank flows occurred as the flood progressed downstream.

3.2.3 Minnegang Creek Floodplain Risk Management Study and Plan (KBR, 2004)

Following on from the above Flood Study, a subsequent Floodplain Risk Management Study and Plan was prepared for Minnegang Creek in 2004 by KBR. The study adopted the results from the preceding Flood Study. No changes were made to either the hydrological or the hydraulic models. The Risk Management Study sought to identify suitable measures to mitigation and manage the flood risks within the Minnegang Creek catchment.

The study prepared two catchment wide management schemes that incorporated, to varying extents:

- House raising;
- Voluntary purchase;
- Detention basins;
- Community education;
- Creek management and rehabilitation; and,
- Emergency management and data transfer to SES.

The Voluntary Purchase scheme was implemented and is ongoing, with Council having purchased two of the six properties included in the scheme.

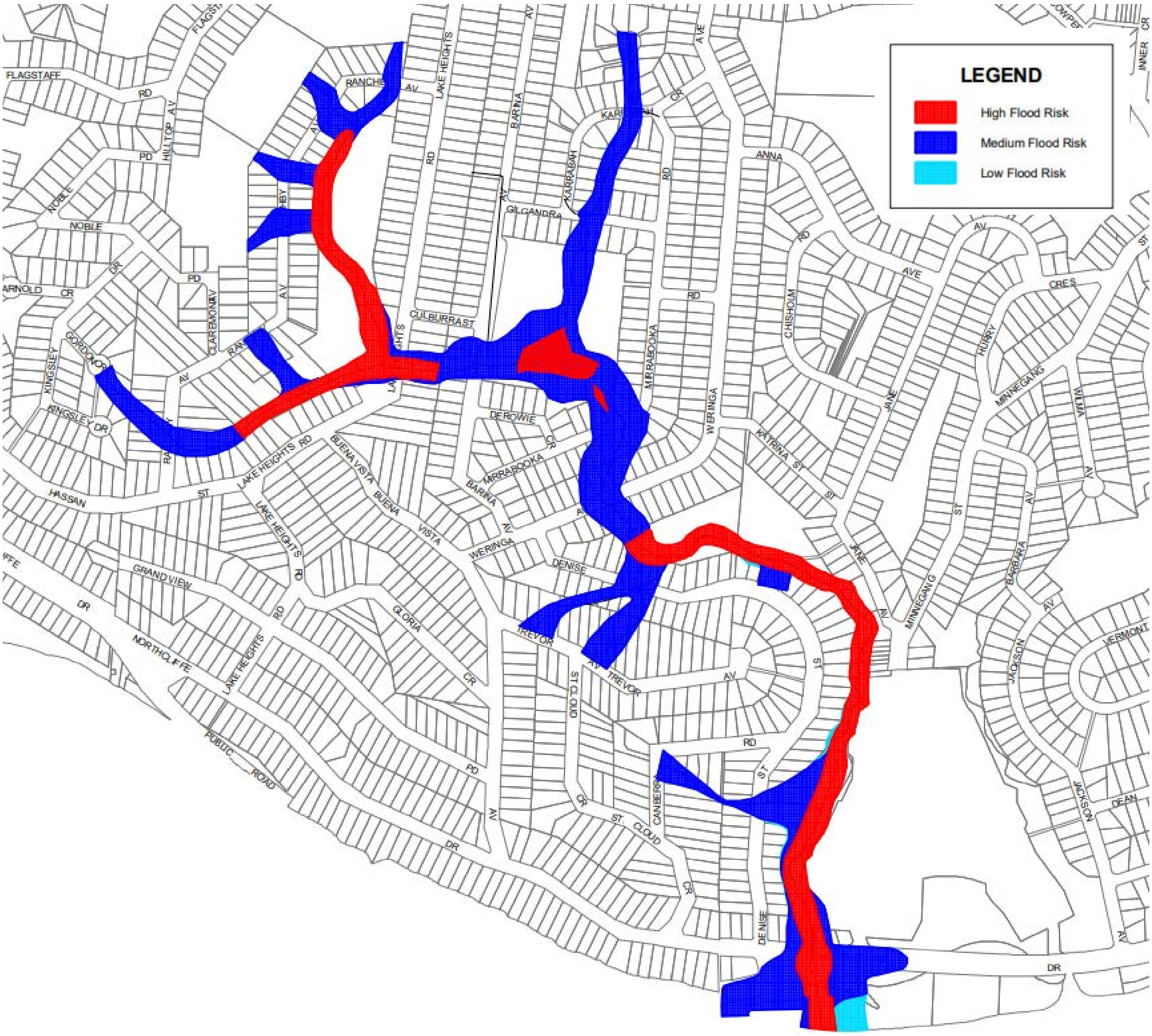


Figure 3-3 1% AEP Extents and Risk Precincts (adapted from KBR, 2002)

3.2.4 Lake Illawarra Floodplain Risk Management Study and Plan (Cardno, 2012)

Following on from the Flood Study undertaken in 2001, the Lake Illawarra Floodplain Risk Management Study and Plan sought to define mitigation and management options to address the flood risks in the Lake Illawarra catchment.

The key aspect of this study that feeds into the current Minnegang Creek study, is that the 1% AEP model was updated to a Delft 3D model, to better define the entrance behaviour of the Lake. As a result, peak 1% AEP flood levels were revised as part of this study.

The changes to the 1% AEP peak flood levels were minor, with reductions of 0.06m through much of the Lake, and a decrease of 0.28 in the entrance channel. The only site to experience increases was Windang Bridge, where peak 1% AEP levels increased by 0.08m in the Delft 3D model.

For the current Minnegang Creek study, these updated peak levels have been adopted for the downstream boundary of the study area.

3.2.5 Barina Park Basin Breach and Consequence Category Assessment (GHD, 2017)

An assessment on the consequences of failure of the Barina Park Basin was undertaken in 2017. The study was prepared in accordance with the requirements of the NSW Dam Safety Committee (DSC) and the ANCOLD guidelines, where relevant, and sought to define the consequences of basin failure, and the consequence category.

As part of the study, a Tuflow hydraulic model was constructed, utilising the KBR RAFTS model for hydrology, and flood events from the 1 EY to the PMF were investigated. The models covered the full catchment area. Inflows from the RAFTS model were applied as point sources within the Tuflow model.

Barina Park Basin was assigned a consequence category of "significant", based on a Population at Risk (PAR) of 36.4 and a Potential Loss of Life (PLL) of 0.184.

3.3 Previous Hydrological and Hydraulic Models

As part of the 2002 study (KBR) a RAFTS hydrological model and a MIKE-11 hydraulic model were prepared to define the flood behaviour of the study area.

The RAFTS model covers the full catchment area and has been delineated to allow inflow hydrographs to be applied to the MIKE-11 model at sub-catchment outlets.

The hydrological model was validated against peak flow estimates from Probabilistic Rational Method calculations, and the hydraulic model was calibrated against recorded peak flood levels from a flood event in August 1998. While flood level data was available for other events (namely 1985, 1987 and 1990), sufficient rainfall data could not be sourced for these other events.

The hydrological model was found to be largely suitable for use in the current study, subject to some minor subcatchment revisions, and an update to the land use breakdown to reflect current catchment conditions.

With regard to the hydraulic model, it was elected to construct a new, 1D/2D hydraulic model using Tuflow. While the approach taken for the previous study was suitable given modelling approaches at the time of the 2002 study, it is no longer appropriate given advances in hydraulic modelling. For example, the original report notes that the model was unable to accurately define the flood behaviour in the lower reaches of the catchment, due to the backwater effects from Lake Illawarra.

The 1D nature of the MIKE-11 model required all overland flow paths and river breakouts to be identified in advance of running the model. The approach is prone to issues relating to the accurate identification of overland flow paths, which is a difficult task.

Furthermore, changes to the catchment as a result of ongoing development are likely to alter the flood behaviour in some regions of the catchment.

As a result of the above, the creation of a new 1D/2D model to define flood behaviour is warranted.

A comprehensive review of the previous modelling is provided in **Appendix A**.

3.4 Local Policies and Emergency Management Plans

A variety of relevant planning documents, where available, were also reviewed and considered as part of the study. These documents are listed in **Table 3-1**.

Table 3-1 Policy and Planning Documents

Document	Relevance to the Study
Wollongong Development Control Plan (WCC 2009)	This Flood Study needs to produce outputs that allow users to assess developments in accordance with the DCP.
Wollongong Local Environmental Plan (WCC 1990 & 2009)	The LEP 1990 applies to areas outside of the study area, so is not applicable to this study. The LEP 2009 applies to those areas not covered by the LEP 1990. The flood related controls in this LEP apply to land identified as "Flood planning area" on the Flood Planning Map, and other land at or below the flood planning level. It is assumed that the outcomes of this Flood Study would be used to inform the mapping contained within the relevant LEPs. The updated flood planning area mapping is discussed in **Section 8.2**.
Wollongong Local Flood Plan (SES 2010)	This plan covers preparedness measures, the conduct of response operations and the coordination of immediate recovery measures from flooding within the Wollongong City Council area. It covers operations for all levels of flooding within the Council area. The general characteristics of flooding for each catchment is provided in the Flood Plan. No details are currently included for the Minnegang Creek Catchment. The information presented in this Flood Study can be used to update this. This Flood Study would be used to update Annex B of the Local Flood Plan including: • Critical storm duration • Possible road closures Further details on road closures can be updated in Annex C from the information presented in **Section 8.2**.
Conduit Blockage Policy (WCC, 2002)	The superseded conduit blockage policy was adopted by Council in 2002 and required that flood modelling of large events (100 year Average Rainfall Intensity (ARI)) should assume bridge and culverts with a diagonal opening span less than 6 m should be assumed completely blocked, and the bottom 25% of the area of larger openings should be assumed blocked. Although there was significant uncertainty about the amount of blockage to apply, and whether this blockage would always occur to the same degree in subsequent floods, the policy as it was implemented was effective in identifying and planning for flood risks at locations potentially sensitive to blockage.
Revised Conduit Blockage Policy (WCC 2016)	Since adoption of the previous blockage policy in 2002, there have been several developments in industry practices for modelling, assessing, and planning for flood risk. There have also been developments in the way design flood modelling is used, for example within the insurance industry. In light of these developments it was appropriate to consider updating and refining Council's blockage policy to reflect current practices. Based on the outcomes of the policy review, data compilation and probabilistic modelling analysis, it was recommended that Council's blockage policy be revised. The main changes to blockage factors generally resulted in a reduction in blockage percentages. The number of Classes of Conduit size was increased from 2 to 4 and two different sets of blockage factors were determined based on two different uses of the flooding information "Risk Management" and "Design".

3.5 Survey Information

3.5.1 Aerial Survey

LiDAR data was captured for the study area over the period 2011 to 2014. This data was acquired from the NSW Government spatial services department and is available online via public portals (http://elevation.fsdf.org.au/index.html). This data has been converted into a 1 metre DEM, and the accuracies are provided relative to the DEM rather than the raw LIDAR data and are shown in **Table 3-2**. The accuracies are reported on open hard surfaces (such as roads).

A comparison was undertaken between the LiDAR data and the ground survey collected by surveyors. A series of points (16 in total) were taken along roadways across the extent of the available ground survey and were compared against the LiDAR. The comparison showed that the LiDAR generated slightly higher results than the ground survey data, by an average of 0.04m. The level difference was consistent, ranging from 0.03 to 0.07m. This is within the reported accuracy of the LiDAR, as well as general expected accuracy of lidar which is typically +/-0.15m on hard surfaces to one standard deviation.

Table 3-2 Reported Accuracy of 2011 – 2014 LiDAR data

LiDAR Date	Vertical Accuracy(m)	Horizontal Accuracy (m)
Various from 2011 to 2014	0.3	0.8

3.5.2 Existing Ground Survey

Existing ground survey was available from two primary sources, the 2002 Flood Study, and the 2017 assessment of the Barina Park detention basin.

As part of the 2002 flood study, cross sections were taken of Minnegang Creek and its tributaries. Bridge structures and culverts were also surveyed. Some general terrain data was also collected to assist in determining the locations of the overland flow paths.

Given the amount of time elapsed since the survey was obtained, there was the potential that there may have been some changes particularly along the defined open channel areas. Therefore, some further survey was collected to verify this older survey. This is discussed further in **Section 3.5.3**.

The second source of existing terrain data was the Barina Park Basin Breach Assessment, undertaken in 2017.

The survey from this study focused on Barina Park, and collected detailed survey of the basin invert, crest level and discharge structures.

This data was incorporated into the DEM built for the current flood study (**Section 5**).

3.5.3 Additional Ground Survey

Further survey data was collected as part of this study to gain more detailed information on:

- Pit locations and inverts;
- Pipe locations and sizes;
- Creek and channel cross sections; and,
- Heights of basin embankments and road crests.

The survey was collected by KFW Surveyors between March and September 2018.

The survey collected is shown in **Map G301**.

3.6 Historical Flood Marks

Council has collected historical flood marks for a number of prior flood events. Flood marks were collected for:

- August 1998 (four marks);
- December 1990 (two marks);
- October 1987 (27 marks); and
- December 1985 (28 marks).

The majority of these marks were focused on the residential areas surrounding Barina Park, with only one mark from the 1998 event located outside of this region.

The location of these flood marks is shown in **Map G302**.

3.7 Rainfall Data

There is an extensive network of rainfall gauges (current and discontinued) across the wider Lake Illawarra area operated by the Bureau of Meteorology (BoM), Sydney Water Corporation (SWC) and Manly Hydraulics Laboratory (MHL). A list of gauges for the area surrounding the catchment is shown in **Table 3-3, Table 3-4** and **Table 3-5,** together with key information on whether they are pluviometer or daily gauges, and whether they were operational during the historical storm events in the catchment. The locations of these gauges are shown in **Map G303**.

There are no rainfall gauges within the study area catchment. Beyond the catchment boundary, there is an extensive network of daily read rainfall gauges. Between both discontinued and existing gauges, a long period of daily rainfall record is available. The closest gauges to the study area are the Berkeley (Northcliffe Drive) gauge (approx. 1km west) and Port Kembla (BSL Central Lab) gauge (approx. 2km northeast), both operated by the BoM. Neither gauge has pluviometer data, and only record daily rainfall.

There is also an extensive network of continuous rainfall gauges operated by MHL in the vicinity of the catchment. The stations generally have data from the early 1980's, such that their period of record covers significant rainfall events in the catchment, including the 1984 flood event.

Further discussion on recorded rainfall data for historical events is presented with the calibration and validation of the models developed for the study in **Section 5**.

Table 3-3 MHL Rain Gauges

			Operational During Storm Events				
Site	**Name**	**Pluvio**	**Dec-85**	**Oct-87**	**Dec-90**	**Aug-98**	**Mar-11**
568308	Cleveland Road	Y	Y	Y	Y	Y	Y
568311	Huntley Colliery	Y	Y	Y	Y	Y	Y
214467	Little Lake Entrance	Y	N	N	N	N	N
568316	Port Kembla	Y	Y	Y	Y	Y	Y
568309	Darkes Road	Y	N	N	N	Y	Y
568307	Dombarton	Y	Y	Y	Y	Y	Y
568314	Mount Kembla	Y	Y	Y	Y	Y	Y
568229	Mount Pleasant	Y	N	N	N	Y	Y

Table 3-4 Sydney Water Rain Gauges

Site	Name	Pluvio	Operational During Storm Events Dec-85	Oct-87	Dec-90	Aug-98	Mar-11
568071	Upper Avon	Y	Y	N	N	N	N
568102	Mount Murray	Y	Y	N	N	N	N
568119	Shellharbour STP	Y	Y	Y	Y	Y	Y
568136	Wollongong STP	Y	Y	Y	Y	Y	Y
568159	Kanahooka SPS1113	Y	N	N	N	N	Y
568171	Albion Park Bowling Club	Y	N	N	N	N	Y
568180	Dapto Citizens Bowling Club	Y	N	N	N	N	Y
568185	Wongawilli	Y	N	N	N	N	Y

Table 3-5 Bureau of Meteorology Rain Gauges

Site	Name	Start	End	Pluvio	Operational During Storm Events Dec-85	Oct-87	Dec-90	Aug-98	Mar-11
68110	BERKELEY (NORTHCLIFFE DRIVE)	Jan-64	Jul-17	N	Y	Y	Y	Y	Y
68022	DAPTO BOWLING CLUB	Jan-06	Feb-17	N	N	N	N	N	Y
68023	DAPTO WEST (STANE DYKES)	Jan 1898	Aug-87	N	Y	N	N	N	N
68237	KEMBLA GRANGE RACECOURSE	Feb-94	Jun-03	N	N	N	N	Y	N
68131	PORT KEMBLA (BSL CENTRAL LAB)	May-63	Mar-17	N	Y	Y	Y	Y	Y
68053	PORT KEMBLA SIGNAL STATION	Jun-50	Jun-77	N	N	N	N	N	N
68104	TALLAWARRA POWER STATION	Jan-62	Apr-00	N	Y	Y	Y	Y	N
68060	UNANDERRA	Jan-03	Apr-69	N	N	N	N	N	N
68123	WINDANG BOWLING CLUB	Dec-62	Apr-17	N	Y	Y	Y	Y	Y
68240	WINDANG KRUGER AVE	Sep-95	Dec-01	N	N	N	N	Y	N
68121	YALLAH	Nov-62	Nov-73	N	N	N	N	N	N

3.8 Flow Data

There is no current or historic stream gauges on Minnegang Creek.

3.9 Water Level Data

Water level information was available for Lake Illawarra. However, given the hydraulic models adopted downstream levels taken from the *Lake Illawarra Flood Study* (Lawson and Treloar, 2000) and the *Lake Illawarra Floodplain Risk Management Study and Plan* (Cardno, 2012), the time series data was not utilised in the current study.

3.10 GIS Data

Digitally available information such as aerial photography, cadastral boundaries, topography, watercourses, drainage networks, land zoning, vegetation communities and soil landscapes were provided by Council in the form of GIS datasets.

4 Consultation

Consultation with the community and stakeholders is a critical part of undertaking any flood study. Consultation provides an opportunity to obtain information relating to specific flooding experiences within the study area and allow the respondents to provide input and feedback to the study.

Since the previous consultation was undertaken in 2002 as part of the preceding flood study, there have been several flood events in the catchment (including events in 2011 and 2017). The current study aimed to collect information on these more recent events and also engage with community members and stakeholders who were unable to provide input in 2002.

4.1 Consultation Strategy

The consultation strategy outlined in **Table 4-1** describes the approach to consultation in accordance with the IAP2 framework and the requirements of the NSW Governments Floodplain Development Manual (2005).

Table 4-1 Consultation Strategy Outline

IAP2 Engagement Strategy Guide	Engagement Strategy
Context ***The internal and external drivers, pressures and other background information that is of relevance to the consultation strategy, and in particular how these may influence how the community receives and responds to the consultation program.***	The context of the consultation has been defined by the following: • Floodplain Development Manual • Council's policies. • Flood behaviour (e.g. flash flooding, flooding from Lake Illawarra, blockages). • Past flooding experiences and local, regional and national media on flooding. • Consultation undertaken as part of previous flood related studies (it is important to build on this rather than just repeat or supersede it).
Scope ***The scoping statements are based on the project context and articulate why the consultation is being undertaken for this project, what the desired outcomes would be, and what the limitations of the engagement are.***	The scope of the consultation strategy is to engage with stakeholders and the community to better understand the flood risks within the study area and to develop community understanding and ownership of the study outcomes.
Stakeholders ***This section provides an overview of the different categories of stakeholders, and their relative level of interest, influence and impact.*** ***This process is useful in identifying the level of engagement under the IAP2 Consultation Spectrum that may be suitable for different types of stakeholders.***	A stakeholder matrix has been provided in **Table 4-2**. This informed the selection of appropriate consultation methods.

IAP2 Engagement Strategy Guide	Engagement Strategy
Purpose ***The purpose relates to the purpose of the consultation not the overall project.*** ***Stakeholders will be linked to each purpose and the goals within each purpose for each stakeholder will be identified.***	The purpose of the consultation is to: ▪ Inform the community and stakeholders of the study; ▪ Gain an understanding of the community and stakeholders' concerns relating to flooding in the study area; ▪ Gather information from the community by participation; ▪ Obtain feedback on the Draft Flood Study; and ▪ Develop and maintain community confidence and collaboration with the study results.
Methods	A methods selection and associated goals are provided in **Section 4.1.2**.

4.1.1 Stakeholder Matrix

A stakeholder matrix has been developed to provide an overview of the different categories of stakeholders, and their relative level of interest, influence and impact on the Flood Study Review.

Table 4-2 Preliminary Stakeholder Matrix

Stakeholder	Level of Impact	Level of Interest	Level of Influence	Recommended Type of Consultation
Impacted Agency Stakeholders				
Wollongong City Council	High	High	High	Empower
Office of Environment and Heritage	Moderate	Moderate	Moderate	Empower
Technical Working Group (TWG)	High	High	High	Collaborate
Floodplain Risk Management Committee (FRMC)	High	High	High	Collaborate
NSW State Emergency Services	High	High	Moderate	Collaborate
Roads and Maritime Service	High	High	Moderate	Involve
Endeavour Energy	Moderate	Moderate	Moderate	Consult
Jemena Gas Networks (NSW) Ltd	Moderate	Moderate	Moderate	Consult
NBN	Moderate	Moderate	Moderate	Consult
Optus	Moderate	Moderate	Moderate	Consult
Sydney Water	Moderate	Moderate	Moderate	Consult
Telstra	Moderate	Moderate	Moderate	Consult

Stakeholder	Level of Impact	Level of Interest	Level of Influence	Recommended Type of Consultation
Interested Agency Stakeholders				
Wollongong City Council – departments not directly involved in the preparation of the Flood Study Review (e.g. asset managers)	Moderate	Moderate	Moderate	Involve
Wollongong City Councillors	Unknown	Moderate	Moderate	Involve
Impacted Community Stakeholders				
Flood affected property owners	High	High	Low	Consult
Flood affected residents	High	High	Low	Consult
Flood affected business owners	High	High	Low	Consult
Residents and owners of properties not affected by flooding but within the study area (e.g. impacted by flood access)	Moderate	Moderate	Low	Consult
Users of the area (e.g. impacted by flood access)	Moderate	Low	Low	Consult
Interested Community Stakeholders				
General community	Low	Low	Low	Consult

4.1.2 Engagement Methods Selection

A list of engagement methods has been developed based on the project requirements, the objectives of the consultation (identified in the consultation strategy outline) and the level of consultation identified for each of the stakeholders (in the stakeholder matrix). The key goals of each method have also been provided.

Table 4-3 Preliminary Engagement Methods Selection

Method	Stakeholders	Example Goals	Timing	Responsibility / Details
Website, media and social media updates.	▪ All stakeholders. ▪ Wider community.	▪ To inform stakeholders of the study. ▪ To capture stakeholders (e.g. visitors and users of the area) not targeted by other consultation	Following project inception (March 2018). Prior to and during public exhibition.	Council currently uses their own website, local media and social media to engage with the community. Rhelm has assisted Council in the preparation of media updates for this purpose.

Method	Stakeholders	Example Goals	Timing	Responsibility / Details
		methods.		
Information sheet	▪ All flood impacted land owners, business owners and residents. ▪ Wider community	▪ Inform. ▪ Gain interest and improve likelihood of participation during the public exhibition period. ▪ Gather input.	Following project inception (March 2018).	A brief information sheet was prepared for the study area. This was used to assist in discussions held during community door knocking. The information sheet provided an overview of the study area, the purpose of the study and how the community can provide input.
Online Survey	▪ All flood impacted land owners, business owners and residents. ▪ Wider community	▪ Gather input	Following project inception (March 2018).	Rhelm provided questions to Council to be inputted to an online survey, hosted by Council's Have Your Say page.
Door knocking	▪ Flood affected residents and business owners	▪ Inform. ▪ Gain interest and improve likelihood of participation during the public exhibition period. ▪ Gather input.	Project inception (March 2018)	Door knocking of flood affected residents and businesses was undertaken over a period of 2 days by Rhelm and Council staff. The intent of this method was to gain an appreciation of people's flooding experiences and knowledge. Responses received during this period were compiled by Rhelm.
Email and phone calls	▪ All agency stakeholders. ▪ Community groups (if required).	▪ To inform stakeholders of the study. ▪ To identify any additional relevant documents or data sets to be included in the data analysis and review.	Following data review (May 2018).	Rhelm contacted relevant agency and community stakeholders to inform them of the purpose of the study and how they can provide input. Each email targeted specific data gaps identified in Stage 1. Follow up was undertaken by Rhelm by email or by phone as required.
Public Exhibition Period	▪ All stakeholders	▪ Provide an opportunity for feedback on the	Following completion of the Draft	Rhelm has provided documents and posters and provided input to media releases regarding the public exhibition

Method	Stakeholders	Example Goals	Timing	Responsibility / Details
		Draft Study.	Study.	period.
Public information sessions for community consultation	▪ Impacted Community Stakeholders. ▪ Interested Community Stakeholders.	▪ Provide an overview of the study purpose, methodology and outcomes. ▪ Provide location specific information to attendees (via one on one sessions). ▪ Provide an opportunity for feedback on the Draft Study.	Following completion of the Draft Study.	Rhelm prepared posters and animations to demonstrate the flood behaviour of the study area Rhelm participated in one on one discussions at community information sessions.
Technical Working Group meetings	▪ Technical working group	▪ Inform the TWG of the study scope, objectives, methodology and outcomes. ▪ Receiving feedback and clarifying technical matters.	Four meetings have been allowed for. The timing of these meetings will be discussed with Council.	Rhelm prepared the materials for discussion and facilitate and participate in discussions.
Floodplain Risk Management Committee Meeting	▪ Floodplain Risk Management Committee	▪ Inform the Committee of the study scope, objectives, methodology and outcomes. ▪ Receiving feedback.	Two meetings have been allowed for. The timing of these meetings will be discussed with Council.	Rhelm prepared the materials for discussion and facilitated and participated in discussions.

4.2 Website and Media

Council utilised their website, social media and local newspapers throughout the project to engage with the wider community. Copies of released media are provided in **Appendix B**.

4.3 Community Update and Survey

A two-page community update was distributed to 495 dwellings within the Minnegang Creek catchment. The recipients were identified where they were within the PMF flood extent from the 2002 Flood Study. The update was also available online.

The update also included a short survey intended to canvas the community for their experiences of flooding. The survey questions were provided on the back page of the mail out and were also provided as an online survey.

A total of 14 responses were received via mail and online. This represents only 3 percent of the surveys distributed. However, an extensive door knocking program was also undertaken (**Section 4.4**), which may have reduced the number of written submissions received.

A copy of the community update is provided in **Appendix B**.

A summary of the responses is provided in **Table 4-4**. From the information received, several flood observations provided useful data to verify the flood models, other observations such as dense vegetation in channels and blockage of culverts will be useful in the development of sensitivity testing of the models.

Table 4-4 Community Survey Responses

Question	Responses
How long have you lived, worked or visited in the catchment?	Range of responses: 1 – 60 Years Average: 25 Years
Are you aware of flooding in the study area?	Not aware: 21% (3) Some Knowledge: 14% (2) Aware: 64% (9)
Have you ever seen flooding in the catchment?	Yes: 72% (10) No: 28% (4)
Flooding dates observed by respondents.	1959 Early 1980s October 1987 December 1990 1998 March 2011 2002 – 2004 (uncertain of exact dates) 2014 June 2016 16 March and July 2017 January and February 1975

Question	Responses
Flood behaviour observed.	The descriptions and locations of survey and door knocking responses are shown on **Appendix C**. • Minnegang Creek over topping its banks. Several observations of flooding of Council reserve, some of the rear of private properties flooding. • High flows in Minnegang Creek causing erosion of creek banks and encroachment into private properties. • Flooding of Northcliff Drive. Fairly regularly closed to traffic. • Flooding in Minnegang Creek observed to be worsened by blockage of the channel by debris and vegetation and blockage of downstream culverts (under Northcliff Drive). • Flooding of Yacht Club, mostly due to elevated lake levels.
Have you seen water pond in the Barina Park sports fields?	Only one respondent had observed flooding in Barina Park.

4.4 Door Knocking

Door knocking was undertaken over two days (14^{th} – 15^{th} March 2018) by Rhelm and Council staff. Properties targeted for door knocking were initially identified through a desk top review of topography, location of waterways and historic flooding issues. These properties were further refined in the field during the door knocking process as a result of site inspections and responses provided by residents. Fifty-five properties were approached, of these 38 properties answered the door, representing an engagement rate of 69 percent.

Residents were asked if they had observed any flooding or were aware of any flooding issues in the catchment. In some cases, Rhelm and Council staff inspected the locations of interest, often located in the back yard.

The information compiled from the door knocking was collated into a map for use in verifying the flood model results. No ground survey was undertaken as a result of the door knocking. A summary of all survey and door knocking responses are provided in **Appendix C.**

The door knocking program was considered highly effective for the following reasons:

- The engagement rate (69%) was considerably higher than for previous Council engagement on flood studies and considerably higher than the engagement rate with the paper and online survey.
- It was able to target those properties most at risk of flooding and increase flood awareness for those people who are most likely to have to respond to flooding.
- It was able to target those residents most likely to have observed flooding (i.e. properties located in close proximity to flow paths and watercourses).
- Council and Rhelm staff were able to discuss flood observations with residents and business owners onsite and gain a good understanding of the flow behaviour observed.

4.5 Agency Consultation

There are many agencies with flood-related interests in the LGA. To best approach these agencies, initial contact with most agencies was undertaken following the completion of the data collation and review (Stage 1) to address data gaps and better target agencies.

The agencies contacted as part of this consultation are listed in **Table 4-5** along with the outcomes of the consultation.

All agency stakeholders will be contacted prior to the public exhibition of the draft Flood Study to request their feedback on the document.

Table 4-5 Agency Consultation

Agency Stakeholder	Outcome of Consultation
Wollongong City Council: Floodplain Management Engineer	Council's project manager has provided project guidance and review throughout the project duration.
Wollongong City Council: Community Engagement Officer	Council community engagement officer has been involved in: • the review and distribution of the mailout and survey; • the Have Your Say page; and • the development of the door knocking program.
Office of Environment and Heritage	A DPIE representative has provided input to the project, as requested by Council. Including provision of data and review of reports.
Manly Hydraulics Laboratory	A DPIE representative provided liaison with MHL regarding the provision of data required for the project.
NSW State Emergency Service	An SES representative is on the floodplain management committee and has be provided with project updates by Council's project manager. SES was also contacted directly by Rhelm and invited to provide input to the project, however, no response was received.
Roads and Maritime Services	An RMS representative is on the floodplain management committee and has be provided with project updates by Council's project manager. RMS was also contacted directly by Rhelm and invited to provide input to the project, however, no response was received.
Department of Planning and Environment	DP&E were contact by email and advised that although they would like to be kept informed of the public exhibition and the project status, DPIE that is best placed to provide technical and policy advice on flood planning and catchment issues from a NSW Government perspective.
NSW Dams Safety Committee (DSC)	DSC was contacted by email and advised on the project, particularly with regards to the detention basin at Barina Park. No response was received.

Agency Stakeholder	Outcome of Consultation
Endeavour Energy	Locations of services provided in maps and photos. No reports were able to be identified on past remediation works relating to flood damages of assets. Endeavour Energy advised that all the outputs from the Council's flood studies are valuable to Endeavour Energy's operations, from the initial design of the network to the flood response plans. Endeavour Energy does not currently have flood information / mapping. The flooding information for environmental assessments is based on enquiries to Council and in some situations the engagement of consultants to prepare specific flood studies for a project / site. Endeavour Energy's System Control Branch refer to the Council's flood studies to assist in the preparation and implementation of their flood response plans.
NBN	NBN confirmed that they have assets in the study areas that may be prone by flooding. They provided locations in images. NBN advised that they use the 1 in 100 year flood data received from Councils and State Governments to evaluate the best areas to place nodes and to best minimise flood risks. However due to restrictions on distances that we are able to be away from Copper Pillars, we aren't able to avoid flood prone areas completely. NBN were unaware of any past remediation in these areas related to flooding in these areas.
Optus	No contact was able to be established for liaison regarding this project. However, it is noted that the only Optus infrastructure shown on the DBYD maps is an underground cable, which is not likely to be prone to flood damage.
Sydney Water	Sydney Water did not advise of any key assets within the study area. No records of any past flood impacts or remediation of flood-related damages. We have no major infrastructure in the Minnegang Creek study area. In terms of flood study outputs of value – extents, depths, velocities, durations and hazard classification are all useful.
Telstra	No response received.

4.6 Public Exhibition

The Draft Flood Study was placed on exhibition from 26 August to 23 September 2019.

During the exhibition period:

- Council sent letters to more than 1,000 residents and property owners in the catchment area inviting them to learn more about the Study.
- Customer service information was included in the three most commonly-spoken languages in this area other than English; Macedonian, Italian and Arabic. The additional information let the community know that Council and the National Relay Service could provide language assistance if needed.

- Emails with this information were sent to community, education, Register of Interest (flood), business, government and emergency services' stakeholders. The information was also available at Council's Customer Service Centre.
- Copies of the draft report, a Frequently Asked Questions sheet and Feedback Form were made available at Warrawong Library, and at the information session at Warrawong Community Centre from 7 September 2019. They were also included on the project webpage, which also included a Google Translate feature to assist with online translation.
- Notices of the exhibition were published in the Advertiser on 28 August and 4 September 2019.
- The community were invited to provide feedback via Council's website, Customer Service Centre and at the community information session.

There were no submissions made during the exhibition period, however some comments were provided at the drop-in information session which was attended by a total of 3 community members, including SES volunteers and a floodplain committee member.

Feedback themes related to general interest about flood risk in the catchment. There was interest in Council's proposal to manage erosion of the creek at Denise St, Lake Heights. Photos were provided of this creek area. There was some understanding of the risk of flooding to people's properties, with an interest in finding out further details specific to individual properties and what Council might do to reduce the risk. There was discussion on the next steps of the floodplain management process, which was to look at possible options to alleviate flooding e.g. creek modification and Voluntary House Raising or Voluntary Purchase in some cases where properties were quite severely flood-affected and where nominated criteria were met. Experiences of historical flooding were shared.

5 Flood Modelling

5.1 Modelling Approach Overview

As part of a previous 2002 flood study, a RAFTS hydrological model and a MIKE-11 hydraulic model were developed for the study area. A comprehensive review of the previous modelling is provided in **Appendix A**. Overall, the RAFTS model was found to be largely suitable for continued use, but the hydraulic model was upgraded to a 1D/2D model to more accurately define the flood behaviour of the site.

For the current study, the Direct Rainfall methodology was adopted, so that both hydrology and hydraulics were modelled in the Tuflow model. The RAFTS model was utilised to validate the flow occurring in the hydraulic model. Minor modifications were made to the RAFTS model to reflect current catchment conditions. These are detailed in **Section 5.2**.

A new 1D/2D hydraulic model was developed for the study, using the TUFLOW flood model software. Key structure and cross sections details were extracted from the previous MIKE-11 model and were supplemented by additional survey collected as part of this study. The development of the TUFLOW model is discussed in **Section 5.3**. It was assumed in the Tuflow model that the Barina Park basin wall remained functional throughout the storm event. An assessment of the consequences of failure of this basin wall have been assessed in a separate study (refer **Section 3.2.5**).

5.2 Hydrologic Model Development

A RAFTS hydrological model was developed which covered the full catchment area of Minnegang Creek. The model from the previous study was largely adopted. The key changes made were:

- A revision of the land use breakdown (and fraction impervious) as a result of development within the study area;
- The splitting of some of the larger subcatchments into smaller subcatchments to better define flow behaviour;
- The addition of the adjacent Hospital Creek catchment in order to generate flows to assess potential cross-catchment flows;
- The inclusion of the Barina Park detention basin in the hydrological model. The basin crest levels and stage storage relationship were extracted from the survey data. A flow diversion was applied to Minnegang Creek as it enters Barina Park Basin from the west, so that flow up to 6.5 m^3/s bypasses Barina Park Basin. This represents the pipe flow. Flow in excess of this amount is diverted into Barina Park Basin and represents the overland flow. The primary purpose for inclusion of Barina Park Basin was for rapid assessments to be undertaken in the model development and also to assist in future modelling of ARR2016 (**Section 7.1**).

The subcatchment breakdown for the model is shown in **Map G501**. In addition to the Minnegang Creek catchment, the adjacent Hospital Creek catchment was also included. The catchment breakdown was coarser than that used for Minnegang Creek, as Hospital Creek was only included to investigate reports that cross catchment flows may occur in larger events in the vicinity of Jane Avenue and Minnegang Street.

Inputs to the model and the data sources for those inputs are summarised in **Table 5-1**. Subcatchment parameters are summarised in **Appendix D**.

Table 5-1 Hydrological Model Input Data

Parameter	Data Source
Sub-catchment area and slope	LiDAR data was available for the full catchment area at a resolution of 1m. This data, along with the subcatchments, is shown in **Map G501**.
Percentage impervious	Percentage impervious areas are largely a factor of development intensity and were determined from aerial imagery. High resolution aerial imagery was provided by Council and was supplemented by freely available online imagery and land use maps. No changes were made to the percentage impervious values as part of this study. The only changes made were to the development extents, to reflect the current land use. The impervious percentages adopted were: ▪ Residential 60% ▪ Road corridors 100% ▪ Open Space 10% ▪ Vegetated areas 0%
Roughness	Roughness parameters influence how quickly runoff occurs in a sub-catchment. Similar to the percentage impervious, the values were determined from an examination of aerial imagery and were largely dependent on land use. Delineation of roughness zones also referred to Council's LEP mapping, particularly in areas that are undergoing development or redevelopment. The roughness values adopted were consistent with the previous study, with the roughness extents updated to reflect current development. Roughness values adopted for the catchments were: ▪ Roads / carparks 0.015 / 0.02 ▪ Parks and open space 0.030 ▪ Riparian Vegetation 0.070 ▪ Residential development 0.100 The catchment roughness map is shown in **Map G503**.
Runoff routing	Routing refers to the transfer of flows from one sub-catchment to another. This routing can be done in XP-RAFTS through either specifying a lag time between sub-catchments (10mins for example) or inputting a typical cross section, roughness and length and allowing XP-RAFTS to compute the lag time based on the flow volume. For this model, lag links were used to define the routing. Lag times were determined based on the stream velocity, which was estimated based on the subcatchment grade using Book 4 of ARR2016, which provides approximate stream velocities for given slopes. This was revised from the previous model, which assumed a constant 1 minute delay between all subcatchments.

Parameter	Data Source
Rainfall losses	Rainfall intensities and hyetographs for the design storms were based on ARR87, using data sourced from the BOM. Values for rainfall losses were based on previous modelling and the validation of the hydraulic model. The rates adopted were: • Roads and carparks 2mm IL 0mm CL • Parks and open space 10mm IL 2.5mm CL • Riparian Vegetation 10mm IL 2.5mm CL • Residential development 5mm IL 1mm CL

5.3 Hydraulic Model

5.3.1 Digital Terrain Model

Digital Elevation Models (DEMs) have been developed for input into the hydraulic model. The DEM have been based on the survey data collected, including the LiDAR, ground survey and Council data.

One of the important components in the development of hydraulic models is to ensure that key hydraulic controls and features are defined appropriately within the DEM. This includes features such as embankment crest details, road levels where roads overtop etc. These have been incorporated these where appropriate through the use of breaklines and other features using the software 12d.

The following data sets have been used in the development of the DEM:

- 2011 – 2014 LiDAR Survey;
- Collected ground survey (refer **Section 3.5.3**);
- Collected bridge and culvert survey (refer **Section 3.5.3**); and,
- Culvert details provided by Council.

The DEM and 2D domain were also extended near the downstream boundary to better represent cross catchment flows and flooding along Northcliffe Drive.

5.3.2 Model Development

The purpose of the Minnegang Creek model is to define the mainstream and primary overland flows in the study area. In addition to Minnegang Creek, the hydraulic model also covers the adjacent Hospital Creek catchment area, in order to assess the potential for cross catchment flows in larger events.

The focus of the model area is on incorporating creeks and flowpaths that are likely to pose a risk to urban and developed areas within the floodplain. These flowpaths and creeks have been incorporated through a combination of 1D and 2D elements. The model area has been refined following site inspections and discussions with Council. The model features discussed below are shown in **Map G502**.

Grid Cell Resolution

The urban area for the Minnegang Creek catchment suggests that a higher resolution grid domain would be more appropriate. A grid cell resolution of 2 metres has been adopted for this study to achieve a reasonable balance in model run times and representation of flow behaviour.

1D Components

Key structures within the study area have been included within the 1D portion of the model, with the channel and overbank areas defined in the 2D domain. Stormwater drainage, to a minimum pipe diameter of 600mm, has been included where it is available in Council's data sets. Some smaller pipe reaches were included in order to extend the pipe network to road sag points.

Some regions of the pipe network had missing data for both inverts and pipe sizes. This data was infilled based on the following assumptions:

- 600mm cover of pipes and culverts, unless otherwise suggested by nearby survey.
- Missing pipe sizes were assumed to the same as the largest of any upstream pipes.
- For a reach of pipes with missing data where sizes increased dramatically between known upstream and downstream sizes, a stepped increase was assumed through the missing reach.

Buildings

There are a number of ways that buildings can be incorporated within a hydraulic model. Council does not have building outlines in a GIS format. Buildings within flowpaths were incorporated as nulled cells, based on aerial photography, which effectively removes them from the model domain. The flowpaths were identified based on preliminary runs of the PMF event. Buildings were raised only within the flood extents.

Fences

There are numerous ways to incorporate fences within a 2D hydraulic model. While the techniques can be quite advanced, the reality is that the behaviour of fences in flooding can be quite uncertain and difficult to represent appropriately. Fences have been incorporated in the model through a property averaged roughness value.

Interaction with lake processes

The downstream boundary conditions of the Hydraulic model are governed by the water levels in Lake Illawarra. The adoption of lake levels for design events is discussed in detail in **Section 7.2**.

6 Calibration and Validation

As identified in Section 3.7, there is a lack of historical pluviometers within the catchments. The nearest pluviometer gauge is located at Port Kembla (run by MHL). An analysis of the rainfall data (see **Section 6.1**) suggests that this rainfall gauge may not be representative of the local rainfall events within the catchment for the observed historical events.

Due to the lack of suitable historic pluvio data within the study area, a full calibration against historical events was not possible. In order to provide Council with confidence in the model, a number of alternative validation assessments have been undertaken, namely:

- A review of the historical rainfall intensities for those events with water level data recorded;
- A comparison of the design events against the historic water level data;
- A comparison of the design events against the previous Mike-11 model; and
- A comparison of the design events against the modelling undertaken for Barina Park by GHD.

Details of these data sources are provided in **Section 3**.

These assessments and comparisons are discussed below.

6.1 Rainfall Intensity Assessment

The nearest rainfall gauge to the study area with pluvio data available is the Port Kembla gauge, run by MHL (refer to **Section 3.7** and **Map G303** for gauge details and location). This gauge is approximately 3 km from the catchment, to the north east. It is much closer to the coastline than the catchment and may not necessarily represent local rainfall that falls on the catchment. Unfortunately, the next nearest pluviometer for the historical events that were identified was at Dapto Bowling Club, which is approximately 10.5 km away from the catchment. This makes it difficult to determine any localised movement of the rainfall during the period of that storm event.

An assessment was undertaken on the rainfall intensities for the Port Kembla gauge for the four historical events for which flood marks are available. ARR87 IFD data for design events was sourced from the BoM and are summarised in **Table 6-1**. Average rainfall intensities were determined for each of the four historical events for durations ranging from 15 minutes to 3 hours. The results are summarised in **Table 6-2** and plotted in **Figure 6-1**.

For the 90 – 120 minute durations which are critical for Barina Park Basin, and the downstream reaches of Minnegang Creek, the historical storms were smaller than a 50%, based on the average rainfall intensities at Port Kembla, although August 1998 was significantly smaller than a 50% AEP. However, it is possible that these storms were localised around the catchment and were more significant at the catchment location.

An analysis was also undertaken on the full rainfall record for the Port Kembla rainfall gauge, for the 1 hour duration. The results of this are provided in **Table 6-3**. There have been a number of significant rainfall events at the rainfall gauge, but what is of interest is that few of these events were identified in the previous historical data or recollected by residents during the community survey. This would suggest that there is variability in the local rainfall patterns particularly for short duration storms, therefore the rainfall at the Port Kembla gauge is not always representative of the rainfall in the catchment and should be considered on a case by case basis in future studies.

Table 6-1 ARR 87 Design Rainfalls(mm)

Duration	Design Event (AEP)					
	50%	20%	10%	5%	2%	1%
15 min	17.1	24.4	29.8	35.6	43.9	50.8
30 min	23.2	33.1	40.4	48.2	59.3	68.5
60 min	30.5	43.1	52.4	62	75.7	86.9
90 min	35.8	50.3	60.8	71.7	86.9	99.2
120 min	40.3	56.4	68	79.8	96.1	109
180 min	48	67	80.4	93.8	112	127

Table 6-2 Historical Event Intensity Analysis

Duration	Average Intensity (mm/hr)				Approximate AEP			
	14-Dec-85	23-Oct-87	16-Dec-90	17-Aug-98	14-Dec-85	23-Oct-87	16-Dec-90	17-Aug-98
15 min	10.75	11	13	5.25	<50%	<50%	<50%	<50%
30 min	17.5	18	17.5	9	<50%	<50%	<50%	<50%
60 min	33	32	27	14	50-20%	50-20%	<50%	<50%
90 min	42	45	36	19.5	50-20%	50-20%	50-20%	<50%
120 min	46	50	44	24	50-20%	50-20%	50-20%	<50%
180 min	51	54	63	33	50-20%	50-20%	50-20%	<50%

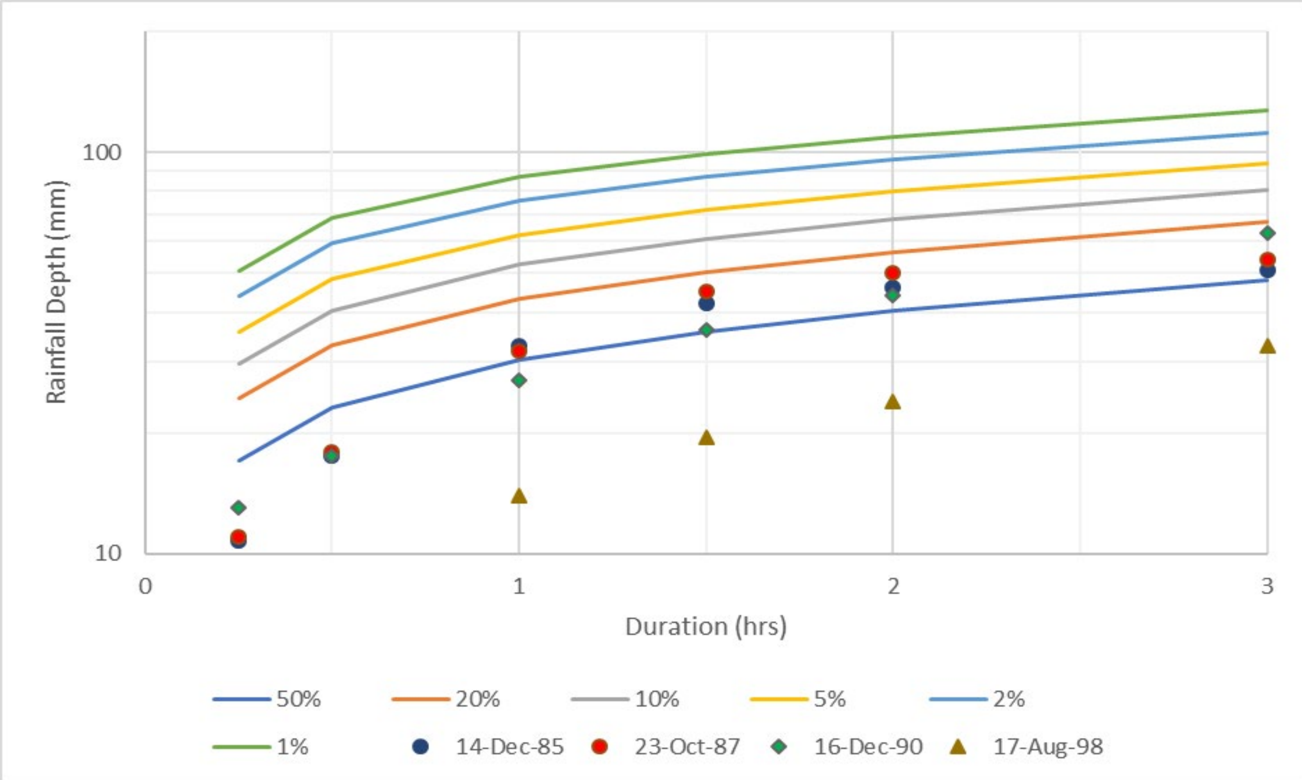


Figure 6-1 Historical Event Intensity Compared to ARR87 Intensity

Table 6-3 Analysis of Port Kembla Gauge Rainfall Record

Event	Rainfall (mm)	Approximate AEP	Mentioned by Community in Survey
March 1994	97.5	>1%	No
May 1983	55.5	10% - 5%	Council recorded flood marks, newspaper articles and the Barina Park detention basin design drawings refer to the 1985 and 1987 events. There is little evidence of a localised flood event in 1983.
February 2012	51.5	~10%	No
November 1984	49.5	20% - 10%	Council recorded flood marks, newspaper articles and the Barina Park detention basin design drawings refer to the 1985 and 1987 events. There little evidence of a localised flood event in 1983.
April 2004	49.5	20% - 10%	Indirectly (comment was 2002-2004)
November 2013	49	20% - 10%	No
May 1989	45.5	~20%	No
April 2009	44.5	~20%	No
March 2017	44.5	~20%	Yes

6.2 Comparison of Model Results with Historical Flood Data

A number of historical flood levels and locations had previously been collected by Council, and were supplied as part of this study, for four historical events (refer **Section 3.6**), namely:

- December 1985 (27 locations);
- October 1987 (25 locations);
- December 1990 (two locations); and
- August 1998 (four locations).

All of these locations are shown in **Map G601**.

The map shows that all of the flood marks save one are within the 5% AEP extent, and the majority are within the 20% AEP extent. Overall, this suggests that the model is demonstrating flood extents comparable with the historical record. The fact that most of the points are within the 20% AEP also suggests that the extents are reasonable, given the relatively small sizes of the historical events for the critical duration of the catchment, assuming that the rainfall data is representative.

Maps G602 to **G605** show the individual historical marks for each event, with the marks colour coded to show how their level compares with the design events.

Figure 6-2 to **Figure 6-6** show long-sections through Minnegang Creek, Melinda Grove and Gordon Crescent Tributary respectively, along with the individual historical marks for each event. **Figure 6-3** and **Figure 6-4** show a more detailed view of **Figure 6-2**.

No data was available on the source of the survey data (flood marks, debris lines, community recollection, etc), so it was not possible to comment on the likely accuracy of the survey data recorded. The data was first reported in the 2002 Flood Study, but this report makes no note of the sources of the individual flood marks.

Some points on the long sections are shown as being below ground level. While it is assumed that the elevation was inaccurately surveyed, it has been assumed that the location is correct.

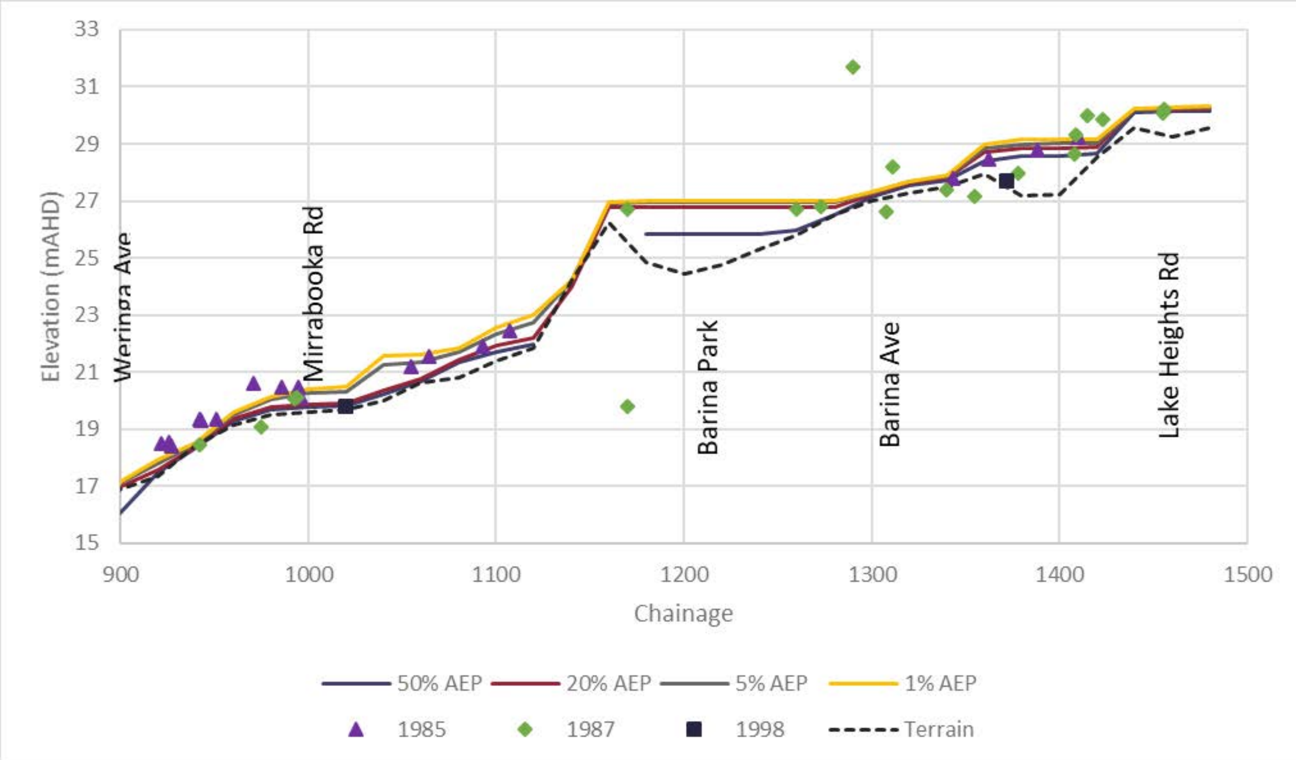


Figure 6-2 Minnegang Creek Long-section (CH0 at Northcliffe Drive)

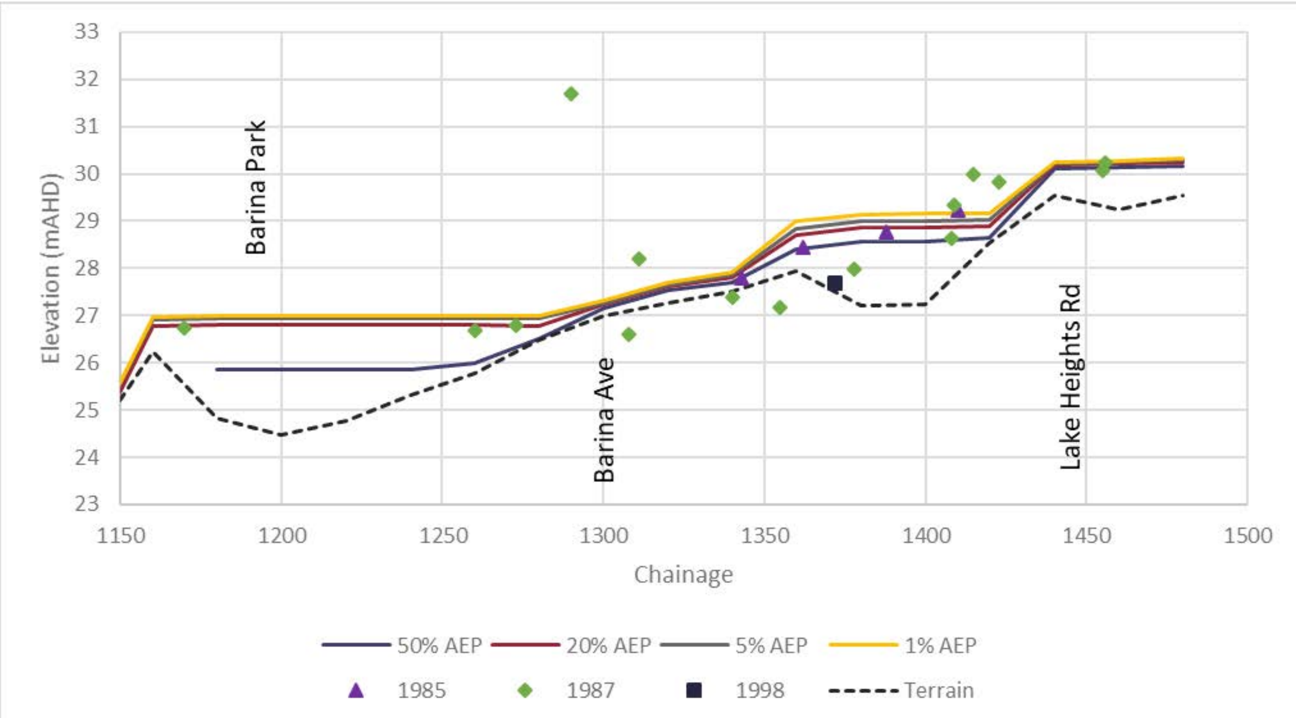


Figure 6-3 Minnegang Creek Long-section (CH0 at Northcliffe Drive) – upstream of Barina Park Basin

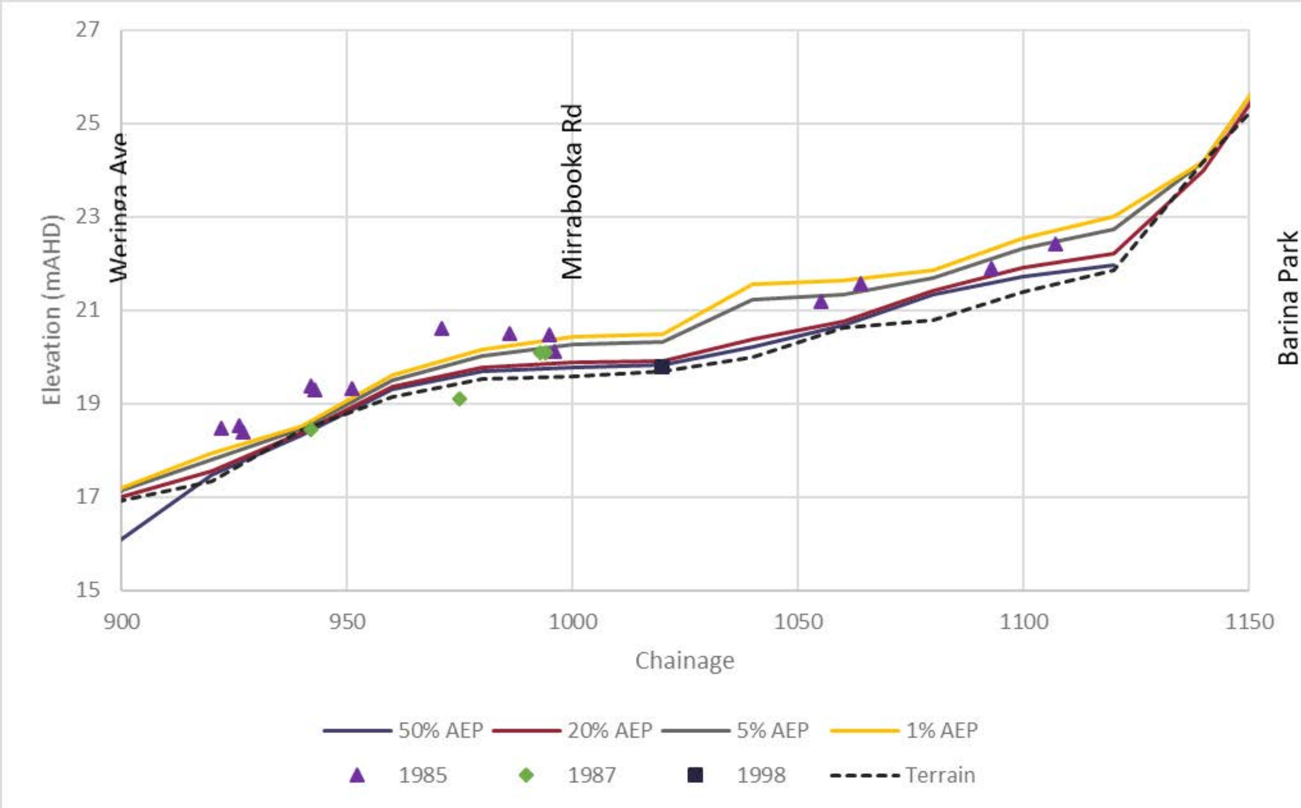


Figure 6-4 Minnegang Creek Long-section (CH0 at Northcliffe Drive) – downstream of Barina Park Basin

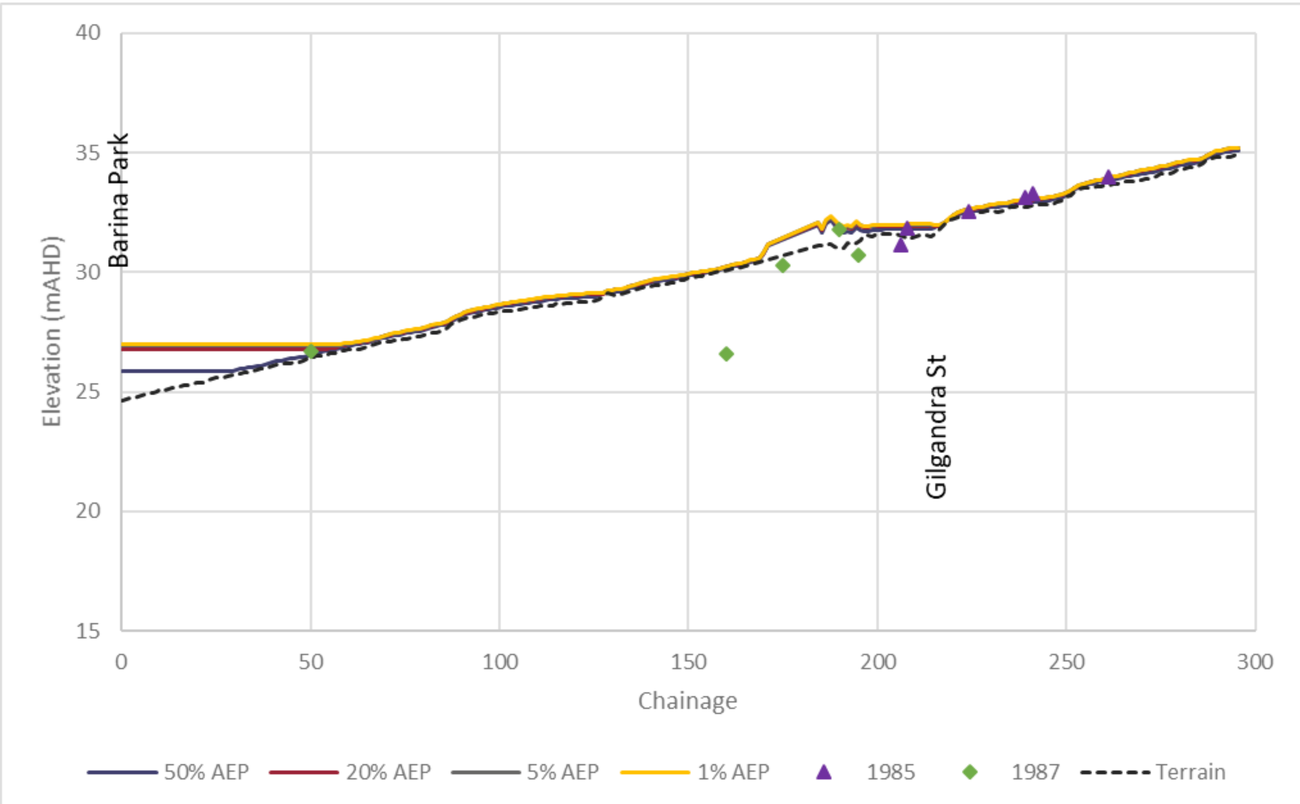


Figure 6-5 Melinda Grove Tributary Long-section (CH0 at Minnegang Creek confluence)

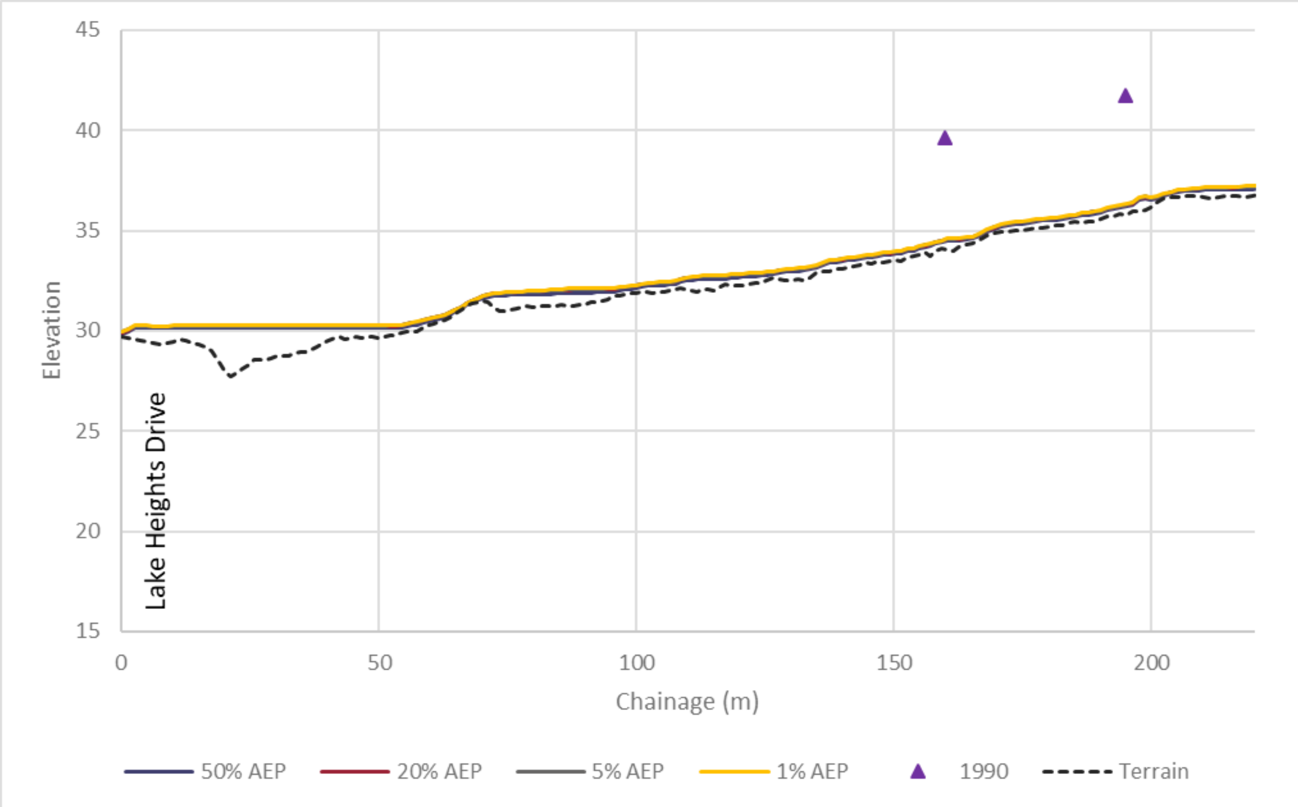


Figure 6-6 Gordon Crescent Tributary Long-section (CH0 at Minnegang Creek confluence)

The 1985 event had 27 flood marks recorded, the majority of which were between Barina Park and Weringa Avenue. The points showed a wide range of results from levels less than the 50% AEP to greater than the 1% AEP, some in immediate proximity to each other. This was reviewed in detail, with the following key points to note:

- A review of the data showed that for all the locations with observed levels above the 5% AEP, the difference between the 1% and the 20% AEP was less than 0.3m. This is likely to be within the observation error from the observed levels from the event.
- There may be some inconsistencies between observations by the community and what occurred;
- In some locations, the levels appear significantly higher than the 1% AEP and it is difficult to reconcile this significant increase relative to the flood level variances between the events. For example, in areas downstream of Barina Park basin.
- local obstructions or influences may create localised differences in flood levels.

The 1987 event had 25 flood marks recorded, with the majority of points recorded between Lake Heights Road and Barina Park. The majority of the points show that the recorded flood levels are less than the 50% AEP, although the observed levels near Barina Park Basin were in the 50 – 20% AEP range.

However, there were a number of locations that had recorded flood levels greater than the 1% AEP design flood level. In some instances, these levels were immediately adjacent to other recorded levels that were less than the 20% or 50% AEP events. A review of the data showed that these points had recorded flood levels 1 – 4m above the 1% AEP levels. Given the proximity of these points to others with lower values, and the fact that the majority of the points are in the 50 – 20% AEP range, which also corresponds to the rainfall intensity results, it is suggested that there is something anomalous with these observed points.

The 1990 event was the largest of the four historical events based on the available rainfall data. However, as only two observed levels were available from this event it may not have been as significant at the Minnegang catchment. The two observed levels available were near to each other, mid-way up Gordon Crescent Tributary. The location of the marks corresponds well with the model results. There is some concern however that the levels were recorded at the wrong location, as the recorded water levels are 5m higher than the design 1% AEP. Without any additional data on the original mark surveyed, it has been assumed that the location is correct, but that the levels recorded are in error.

The 1998 event had four locations available, and all of these had levels below the 50% AEP. The 1998 event was the smallest of the four events, and this result is consistent with the rainfall intensities observed.

Based on the number of observed points alone, it would generally appear that the 1985 and 1987 rainfall events were more significant in the catchment. This is broadly in agreement with the AEP analysis from the Port Kembla gauge.

6.3 Comparison with Community Survey Descriptions

As a part of the community survey and door knocking (**Section 4**), there was a lot of information obtained on general flood behaviour. This was not always specific to a particular event, or in many cases a general period was recalled. However, it provides useful information on the flood behaviour. The generalised descriptions of flood behaviour, together with the modelled behaviour, is provided in **Appendix C**. This indicates a general level of consistency between the modelling and the observations from the community.

6.4 Comparison of Model Results with Previous Flood Study Results

As part of the preceding flood study, undertaken in 2002 (refer **Section 3.2.2**), a 1D Mike-11 model was developed to assess the flood behaviour of Minnegang Creek. Peak water levels for the design events were compared against the results from the current study.

There are a number of differences between the previous modelling that was undertaken in 2002 and the current updated flood model. These include:

- The use of LiDAR data to define a detailed terrain for the floodplain. This compares with the previous work that relied on ground surveyed cross sections alone. Levels between the cross sections were interpolated.
- Changes in landuse, particularly upstream of Barina Park Basin where additional development has occurred.

Given the potential differences between the 1D model and the 2D model the comparison between the models is more of a check and verification.

The comparison points were taken along the main reach of Minnegang Creek, from Lake Heights Road to Northcliffe Drive. These locations are areas where the flow is more confined within the channels, and it is likely that the 1D model would provide a reasonable representation in these locations. In areas dominated by 2D flow, there are likely to be differences between the models due to the differences in approach and the more detailed terrain information available in the current model.

It is also important to note that the modelling results available from the 2002 flood study are for an envelope of the blocked and unblocked scenario, using Council's previous blockage policy. The results are not specifically reported for the unblocked scenario but scaling of longitudinal profiles provided suggest that the unblocked scenario is approximately 0.1 – 0.2m lower than the blocked scenario.

A comparison of the results is shown in **Map G606**.

The results show a good correlation between the two studies, with the differences all within 0.2m, and generally within 0.1m. This aligns with the results of the unblocked modelling undertaken by KBR, suggesting that levels would reduce by this order of magnitude for the unblocked scenario in these locations.

For the 5% AEP event, levels were typically 0.1 – 0.2m lower than the Mike-11 model, save for a location adjacent to Canberra Avenue, which was 0.16m higher. The 1% AEP results demonstrated a closer match with all levels within 0.1m of the Mike-11 model results.

6.5 Comparison of Model Results with Previous Barina Park Assessment

A comparison was undertaken between Barina Park Basin levels reported in the Barina Park Dam Break Assessment (GHD, 2017) and those from the Minnegang Creek Tuflow Model. They are summarised on **Table 6-4**.

The comparison showed that for the 20% and 1% AEP events, the levels were 0.05m different. It is worth noting that at these levels, the basin embankment is overtopping, so the similarity is largely due to both models having the same crest height, and to a lesser extent, similar overtopping flows.

The 50% AEP event in the Minnegang Creek model was 0.68m lower that the level in the dam break study. The level was also lower than the 1 EY level reported in the dam break study of 25.93mAHD.

A review of the dam break model showed some differences in the model setup that are expected to have contributed to this difference. Firstly, the dam break study assumed that all pipes were 35% blocked. No blockage factor was applied to pipes in the Minnegang Tuflow model for the validation.

Secondly, the rating curve for the large inlet structure in Barina Park Basin is substantially difference between models. The inlet is a 4m by 1.5m grated letterbox inlet. The Minnegang Creek Tuflow rating curve has a flow of 3.6 m^3/s at 0.5m of depth above the inlet, while the dam break model only has 0.5 m^3/s. This is relatively low compared with the expected capacity for an inlet of this size. It is worth noting that the actual flow will also depend on pipe capacity (i.e. in some cases the pipe downstream will control the inflow to the inlet).

The Tuflow model was re-run with the blockage rates and rating curves from the Barina Park assessment to understand the potential influences of the dam break model assumptions. Under these conditions, the Minnegang Creek Tuflow model, and the Barina Park Dam Break model resulted in similar peak levels in the Barina Park basin.

Table 6-4 Comparison with Dam Break Tuflow Model

Event	Dam Break Model Level (mAHD)	Minnegang Creek Tuflow Model Level (mAHD)	Revised Minnegang Creek Tuflow Model Level (mAHD)
50% AEP	26.53	25.85	26.43
20% AEP	26.74	26.79	26.75
1% AEP	26.96	27.01	26.99

6.6 Outcomes

Modelled flood extents followed similar patterns to the collected historical flood marks, and the design flood levels generally aligned with the expected size of the historical events, based on the rainfall assessment. As noted above, some of the recorded levels appear to be unreasonable, but without the original data source, further investigation of these anomalies is not possible.

The comparison between the two prior hydraulic models also indicated the Tuflow model is performing in a similar manner. The comparison of peak flood levels for the 5% and 1% AEP events are similar across all three models, and well within the tolerance limits of the various approaches adopted.

The outcomes of the above assessments indicate that the Tuflow model behaviour is reasonable, and that the model is suitable for use in defining the design flood events for the catchment.

6.7 RAFTS Validation

A comparison of the 1% AEP peak flows reported from the Rafts hydrological model and the Tuflow hydraulic model was undertaken for a selection of subcatchments. The comparison is shown in **Table 6-5** (with locations of the subcatchments shown in Map G501). The table shows that the flows from each model were generally similar, with RAFTS reporting flows 5 – 10% higher than the Tuflow model, which is in the order of magnitude accuracy of the two models.

Table 6-5 Comparison of Peak Flows

Subcatchment	Rafts Peak Flow (m^3/s)	Tuflow Peak Flow (m^3/s)	% Difference
MH52	5.1	4.8	6%
MHCa	10.9	9.4	9%
MHCc	18.7	16.9	4%
MC2	29.8	27.9	6%

7 Design Flood Modelling

7.1 Australian Rainfall and Runoff

Australian Rainfall and Runoff 2016 (Ball et al, 2016) (ARR2016) was developed in draft form and released in 2016. This guideline updates the previous Australian Rainfall and Runoff 1987 (Pilgrim et al, 1987) (ARR87).

Through various studies and testing, some localised features of Wollongong have resulted in the need to review and update some of the guidance in the draft ARR2016. These updates and review are ongoing, with additional testing being undertaken by Council.

In light of this, ARR87 was adopted for this study and the results presented in this report are based on that guidance.

7.2 Coincident Lake Illawarra Flooding

The downstream portion of the study area can be influenced by flooding from both the Minnegang Creek catchment as well as backwater from Lake Illawarra. Lake Illawarra has a significantly larger catchment (which includes the Minnegang Creek catchment), and a floodplain which requires much longer duration rainfall to achieve a peak flood level. It is also influenced by ocean levels and these effects on the lake.

These different flood mechanisms can result in a large flood occurring in the Lake, while there is only a relatively small event in the Minnegang Creek catchment. Applying a 1% AEP in Lake Illawarra at the same time as a 1% AEP in Minnegang Creek is likely to be overly conservative and represent a far less frequent event.

The OEH (2015) guide *Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* was used to inform the approach for modelling of the Lake Illawarra downstream boundary for the model. In discussion with Council, the approach adopted was to rely on the Lake Illawarra Flood Study and Floodplain Risk Management Study to define the flood planning levels for the lake and foreshore. Therefore, the focus was on catchment driven flooding and the appropriate level to adopt for the local catchment driven flood behaviour.

The adopted Lake Illawarra levels for each of the events is shown in **Table 7-1**. Flood levels for the Lake were adopted from Cardno Lawson Treloar (2012) for the Griffins Bay reporting location in the report.

It is important to note that the results in this report only represent the peak flood behaviour from the local catchment. For the downstream area of this model, it is important to reference the Cardno Lawson Treloar (2012) study, as the levels from Lake Illawarra may be higher in some locations and the highest level should be adopted.

Table 7-1 Adopted Lake Illawarra Events

Design Event	Catchment	Lake AEP	Lake Level
PMF	PMF	1%	2.24
1%	1%	5%	1.81
2%	2%	5%	1.81
10%	10%	HHWS[1]	0.23
20%	20%	HHWS	0.23

[1] High High Water Springs

7.3 Blockage Policy

Wollongong Council undertook a review of their hydraulic structure blockage policy in 2016, with the review summarised in WMAwater (2016). This reviewed the existing blockage policy for Council at the time and looked at the latest research and information. The outcomes of this review resulted in two blockage scenarios:

- Design Scenario – this scenario is intended to represent a "best estimate" of the likely blockage during an event, recognising that this can be highly uncertain and variable. It is intended to be used for applications such as:
    - Estimation of design flood levels for flood studies;
    - Flood hazard and hydraulic categories;
    - Infrastructure design;
    - Estimating flood damages; and
    - Assessment of risk to life and evacuation considerations.
- Risk Management Scenario – this scenario is intended to have a higher factor of safety, in recognition of the high uncertainty, for "high regret" decisions, such as;
    - Setting of flood planning levels; and
    - Determining medium and low flood risk precincts.

In addition to these scenarios, refinement was undertaken on the level of blockage for different "classes" of structure. These classes of structure are provided in **Table 7-2**. The level of blockage to be applied for each class of structure is provided in **Table 7-3**.

These blockage factors were applied in the TUFLOW model and both scenarios have been analysed. These blockage scenarios have only been applied for culverts, bridges and for the headwall inlets of pipes (and not on the complete pipe network). The results represented in this report are noted as either "Risk" or "Design", with these results being the envelope of the respective blockage scenario and an unblocked scenario.

In addition to the above, Wollongong Council has a separate policy relating to the blockage of pits for hydraulic modelling. Chapter E14 of Council's DCP states that blockages to be applied to pit inlets are 20% blockage for on-grade pits and 50% blockage for sag pits.

To understand the changes of the new blockage policy in relation to the old blockage policy, a sensitivity analysis was undertaken and is discussed further in **Section 9.3**.

Table 7-2 Classes of Structure - Wollongong Council Blockage Policy

Class	Structure
1	Pipes 1.2 m internal diameter or smaller. Box culverts or bridges with a diagonal opening less than 1.5 m, and a width or height less than 0.9 m.
2	Pipes greater than 1.2 m internal diameter. Box culverts or bridges with a diagonal opening of more than or equal to 1.5 m, less than 3 m and minimum dimension of 0.9 m for both width and height.
3	Box culverts or bridges with a diagonal opening of more than or equal to 3 m, less than 6 m, and a minimum dimension of 1.2 m for both width and height.
4	Box culverts or bridges with a diagonal opening greater than or equal to 6 m, and a minimum dimension of 2.5 m for both width and height.

Table 7-3 Blockage Policy and Blockage Factors

Blockage Factors	Class 1	Class 2	Class 3	Class 4	Fences/ Railings
Risk Management	95%	75%	60%	15%	75%
Design	70%	50%	40%	10%	50%
Previous Council Policy	100%	100%	100%	25%	100%

7.4 Hospital Creek

Hospital Creek is the adjacent catchment area to the east. While outside the study area, it has been included in the model to determine if cross catchment flows occur in large events. While regions of Hospital Creek have been included in the mapping it should be noted that detailed survey or the channel and structures has not been undertaken. As such, the flood results, while suitable for the purposes of this study (assessment of cross-catchment flows) they are not as robust as the results for Minnegang Creek and should not be used for planning or flood information.

7.5 Design Flood Events

Using the parameters as identified above, the hydrological and hydraulic models were analysed for the PMF, 1% AEP, 2% AEP, 10%AEP and 20%AEP events. Each event was run for durations from 30 minutes to three hours to determine the critical duration for each event. The dominant critical durations for each event are summarised in **Table 7-4**.

Table 7-4 Event Critical Durations

Design Event	Critical Duration
PMF	60 min
1%	120 min
2%	120 min
5%	120min
10%	60 min
20%	90 min

As the modelling utilised rainfall on grid, it was necessary to filter the results, as the raw results have flood depths showing on every grid cell. The models were filtered on the following parameters:

- Depth greater than 0.15m OR velocity depth product greater than 0.1 m^2/s. The velocity depth product filter was included in order to capture fast moving but shallow flow that may occur, such as within the road reserves.
- Flood islands of less than $200m^2$ were deleted.

The results for the modelling are presented as a series of maps attached to this report, as noted in **Table 7-5**. A summary of peak water levels and discharges at key locations in the model are provided in **Appendix E**.

Table 7-5 Design Flood Event Result Maps

Results	Design Scenario Maps	Risk Scenario Maps
Peak Depth and Water Level	G701-D-1 to G701-D-6	G701-R-1 to G701-R-6
Peak Velocity	G702-D-1 to G702-D-6	G702-R-1 to G702-R-6

Long sections along Minnegang Creek, Melinda Grove Tributary and Gordon Crescent Tributary are shown in, **Figure 7-1, Figure 7-2** and **Figure7-3** respectively.

In the upper catchment the long sections show that there is very little difference in peak water level across all the design events, up to and including the PMF. This is particularly true of the Melinda Grove Tributary. The Gordon Crescent Tributary also exhibits this behaviour, although there is a larger increase between the 1% AEP and the PMF for this flowpath.

Through Minnegang Creek, peak levels from the 20% AEP to the 1% AEP are similar, with the PMF showing noticeably higher levels, in particular downstream of Barina Park Basin.

Flood behaviour within the study area is discussed in **Section 8**.

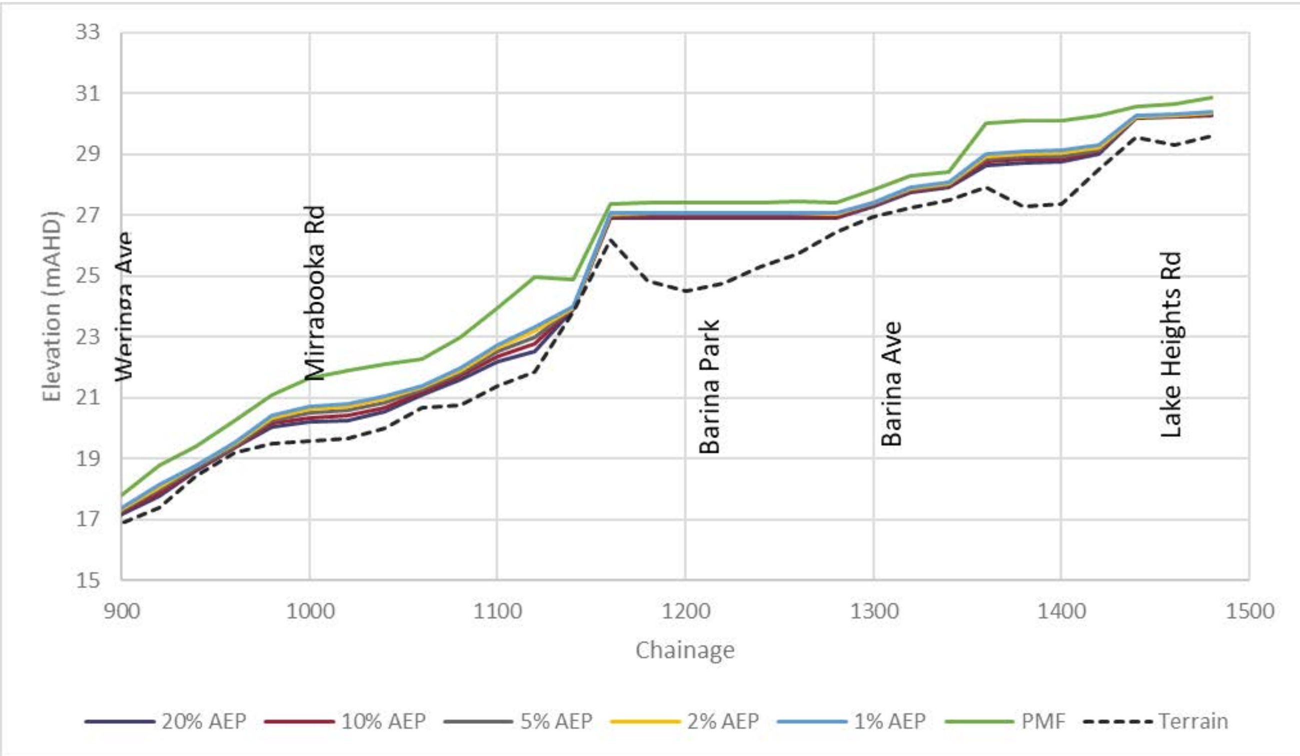


Figure 7-1 Minnegang Creek Long-section (CH0 at Northcliffe Drive)

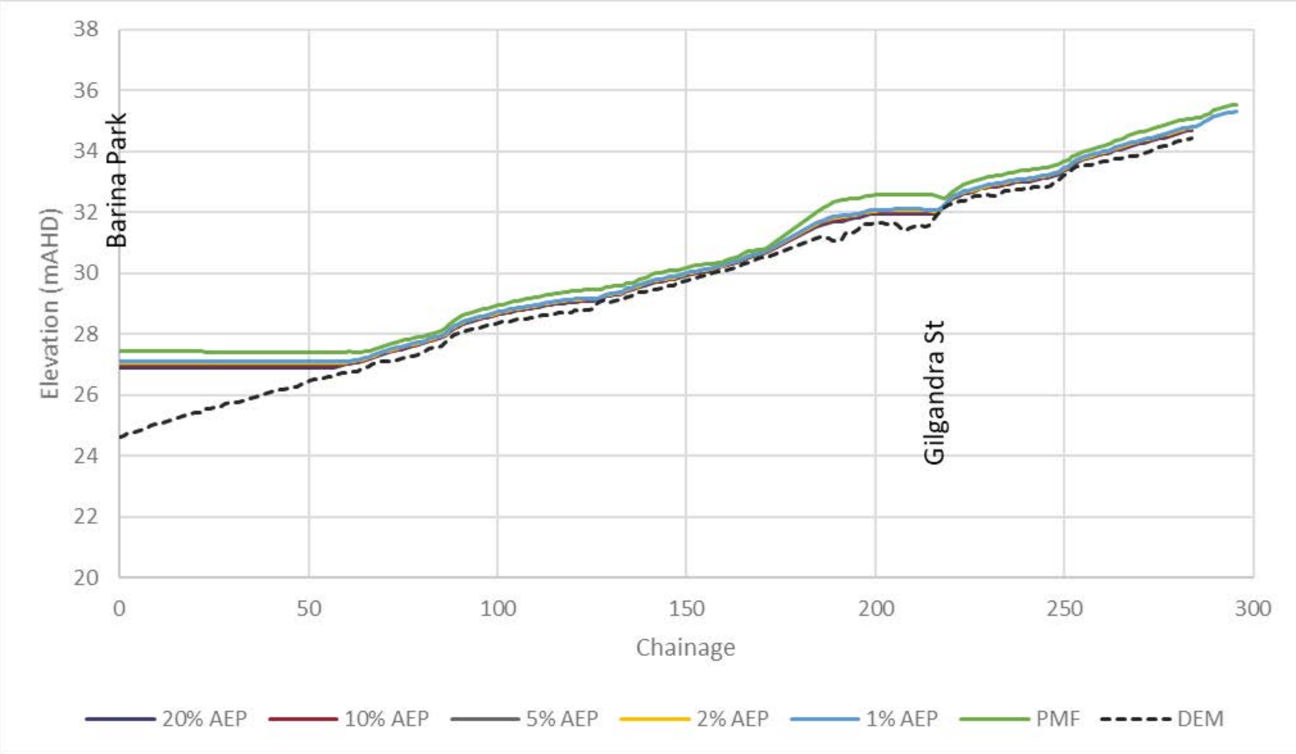


Figure 7-2 **Melinda Grove Tributary Long-section (CH0 at Minnegang Creek confluence)**

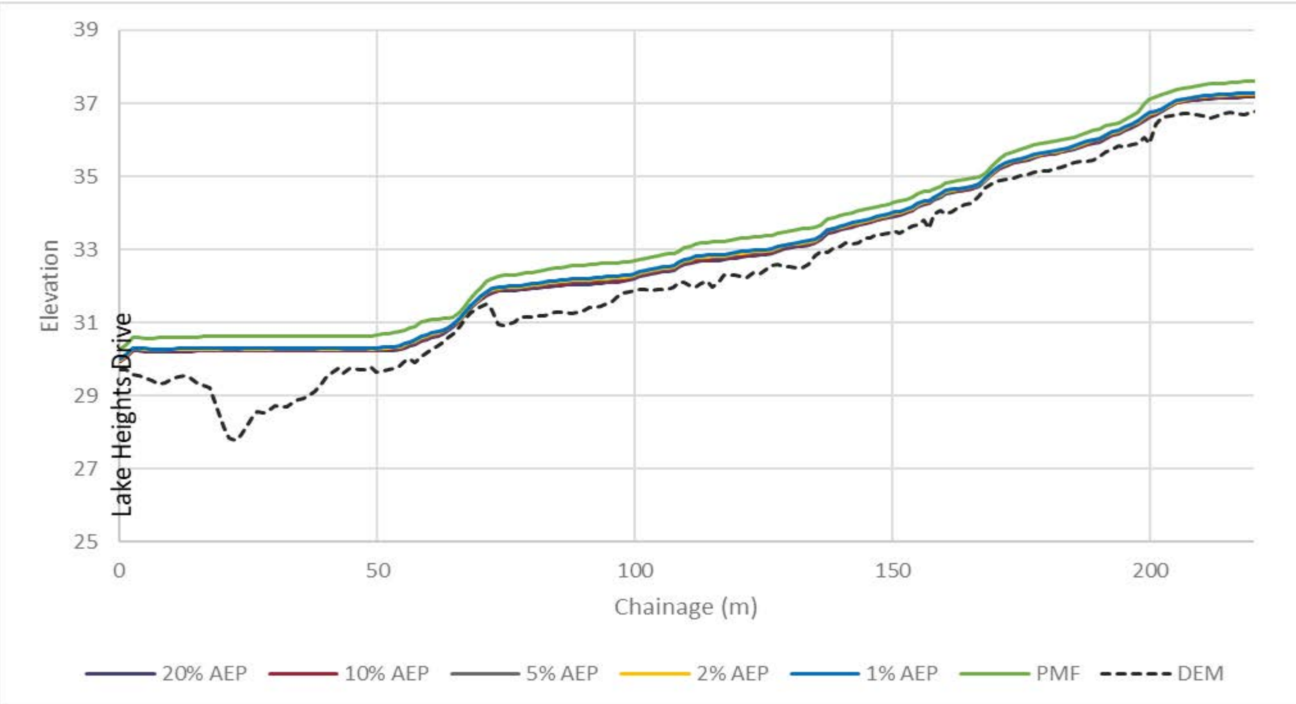


Figure 7-3 **Gordon Crescent Tributary Long-section (CH0 at Minnegang Creek confluence)**

7.6 Flood Hazard

Flood hazard varies with flood severity (i.e. for the same location, the rarer the flood the more severe the hazard) and location within the floodplain for the same flood event. This varies with both flood behaviour and the interaction of the flood with the topography.

It is important to understand the varying degree of hazard and the drivers for the hazard, as these may require different management approaches. Flood hazard can inform emergency and flood risk management for existing communities, and strategic and development scale planning for future areas.

The hazard categories mapped are summarised in **Table 7-6** and **Figure 7-4**. These are based on the categories as defined in the AIDR (2017) Guideline.

Flood hazard mapping is provided for the 1% AEP and PMF events in **Maps G703-D-1** to **2** for the Design Scenario and **Maps G703-R-1** to **2** for the Risk Scenario.

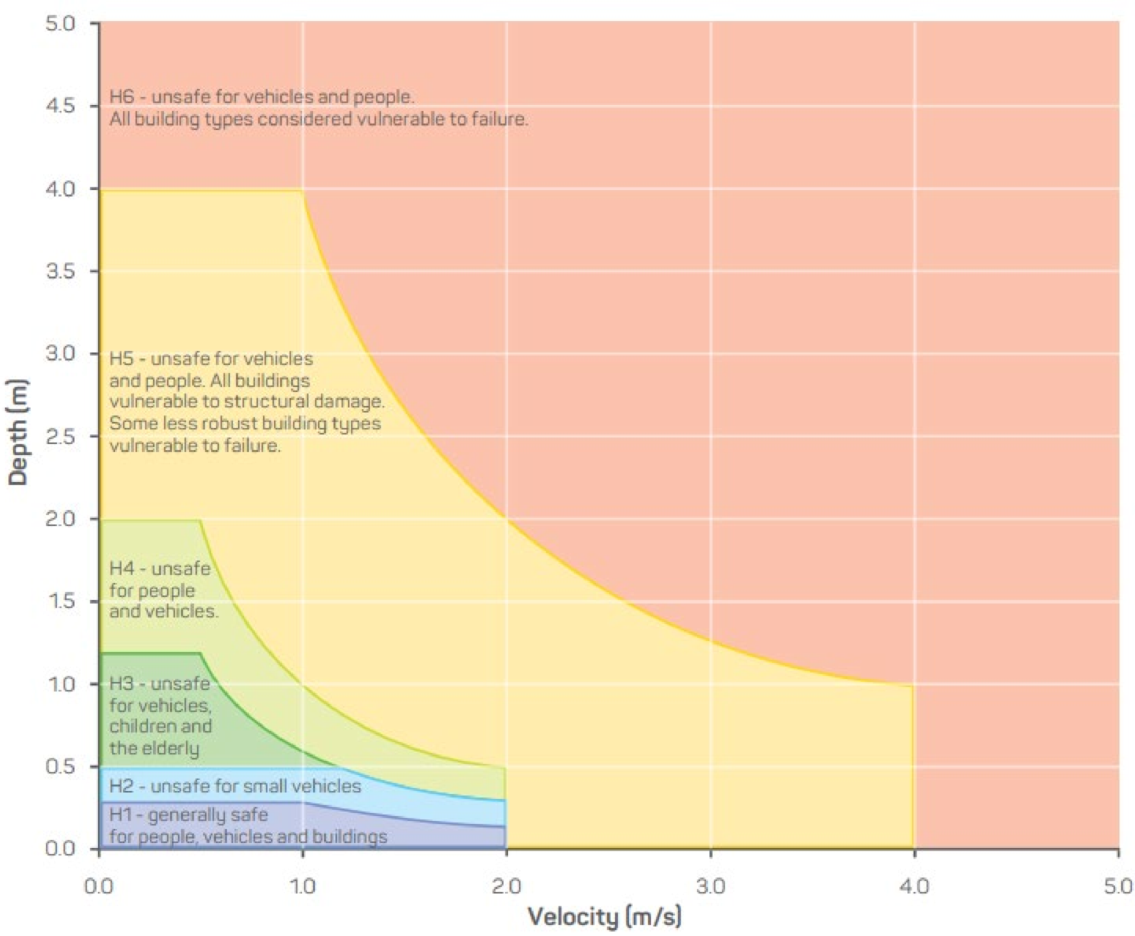


Figure 7-4 Flood Hazard Categories (AIDR, 2017)

Table 7-6 Hazard Categories

Hazard Category	Description
H1	Generally safe for vehicles, people and buildings
H2	Unsafe for small vehicles
H3	Unsafe for vehicles, children and the elderly
H4	Unsafe for vehicles and people
H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure

7.7 Flood Function

Identifying the flood functions of the floodplain is a key objective of best practice in flood risk management in Australia, because it is essential to understanding flood behaviour. The flood function across the floodplain will vary with the magnitude in an event. An area which may be dry in small floods may be part of the flood fringe or flood storage in larger events and may become an active flow conveyance area in an extreme event. In general flood function is examined in the defined flood event (DFE), so it can be accommodated as part of floodplain development, and in the PMF so changes in function relative to the DFE can be considered in flood risk management.

The hydraulic categories (also known as flood function), as defined in the Floodplain Development Manual (2005), are:

- Floodway - areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- Flood Storage - areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges.
- Flood Fringe - remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

An initial categorisation was undertaken based on recent work that was undertaken for Duck Creek (Rhelm, 2019). The criteria adopted is as follows:

- Floodway – VelocityxDepth Product is greater than 0.5m^2/s;
- Flood Storage – VelocityxDepth product is less than 0.5m^2/s and depth is greater than 0.5m; and
- Flood Fringe – areas in the flood extent outside of the above criteria.

It is noted that there is no “one size fits all approach” to hydraulic category / flood function definition. Thomas & Golaszewski (2012) investigated a number of different approaches in some case study catchments, and some of these adopted similar criteria to those identified in the Duck Creek Study. However, it was emphasised in this paper to test the underlying assumptions through methods such as “encroachment”, testing the impact of reducing or increasing the floodway.

On the basis of the outcomes of the testing described, the above criteria was adopted for the hydraulic category mapping. The mapping is provided in **G704-D-1 to 2** for the Design Scenario for the PMF and 1% AEP. Similarly, the Risk Scenario is provided in **G704-R-1 to 2**.

7.8 Lake Illawarra Flooding

As identified in **Section 7.2**, the Lake Illawarra Flood Study (Lawson and Treloar, 2001) and the Lake Illawarra Floodplain Risk Management Study and Plan define the flood behaviour of the Lake Illawarra Floodplain. The downstream portion of the Minnegang Creek catchment is also influenced by flooding from Lake Illawarra. The areas affected are shown in **Figure 3-1** and **Figure 3-2** for the 1% AEP and PMF respectively. For flood levels in these areas, the Lake Illawarra previous flood analysis should be consulted in conjunction with the results of this report.

8 Catchment Flooding

8.1 Flood Behaviour

The flood behaviour along the major flowpaths through the catchment is discussed below. A comparison between the peak flood extents for the 20% AEP, 5% AEP, 1% AEP and the PMF are shown in **Map G801-R-1**.

8.1.1 Gordon Crescent Tributary

The Gordon Crescent Tributary commences in the far west of the catchment. Overland flows pass down Gordon Crescent, before flowing overland through residential properties to Ranchby Avenue. From Ranchby Avenue, flow again passes overland through residential lots, joining with Minnegang Creek immediately upstream of Lake Heights Road. A smaller unnamed overland flowpath commences in Claremont Avenue, flows overland across Ranchby Avenue, and joins the Gordon Creek Tributary 100m upstream of the Minnegang Creek tributary.

There is very little change in flood extent between the 20% AEP and the 1% AEP. In the PMF event, additional breakouts of overland flow are observed through properties adjacent to the main flowpath.

Both the Gordon Crescent Tributary and the overland flowpath result in overtopping of Ranchby Avenue in events as small as the 20% AEP (refer **Table 8-1** and **Figure 8-1**). In the 1% AEP, road overtopping hazard is classed as H5, which is driven by the relatively high velocities from the steep terrain.

Table 8-1 Gordon Crescent Tributary Road Overtopping

ID	Location	Event Overtopped
GC1	Ranchby Avenue south	20% AEP
GC2	Ranchby Avenue north	20% AEP

Figure 8-1 Gordon Crescent Tributary Road Overtopping Locations (with 1% AEP Risk Scenario)

8.1.2 Melinda Grove Tributary

The Melina Grove Tributary commences in Melinda Grove, in the north eastern region of the study area. It flows directly south, crosses Karrabah Crescent, and flows overland through residential lots until it crosses Gilgandra Street and discharges into Barina Park Basin.

Similar to the Gordon Crescent Tributary, there was little difference in flood extent from the 20% AEP to the 1% AEP. The PMF showed slightly wider extents on the main flowpath, and the activation of additional overland flowpaths in the upstream of the catchment. There was also some additional breakout flow from Karrabah Crescent.

The flows crossing both Karrabah Crescent and Gilgandra Street resulted in a loss of access in events as small as the 20% AEP (refer **Table 8-2** and **Figure 8-2**).

Table 8-2 Melinda Grove Tributary Road Overtopping

ID	Location	Event Overtopped
MG1	Karrabah Crescent	20% AEP
MG2	Gilgandra Street	20% AEP

Figure 8-2 Melinda Grove Tributary Road Overtopping Locations (with 1% AEP Risk Scenario)

8.1.3 Minnegang Creek Upstream

Minnegang Creek begins in the north west of the catchment area. Minnegang Creek, and two unnamed tributaries, convey water from this region, through the public recreation zone between Ranchby Avenue and Lake Heights Road, before crossing Lake Heights Road and Barina Avenue, discharging into Barina Park Basin. In the PMF event, an additional overland flowpath is activated when flow breaks out of Lake Heights Road and flows south-east across residential lots into Barina Avenue.

Minnegang Creek and its upstream tributaries cross Ranchby Avenue at three locations. All locations lose access in events as small as 20% AEP (refer **Table 8-3** and **Figure 8-3**), though the time of overtopping is short, with flood waters clearing within 1 hour.

The flow along much of the upstream reaches are generally well contained with little change in extent between 20% AEP and 1% AEP and a minor increase in width in the PMF.

The flow across Lake Heights Road and Barina Avenue is significant, with overtopping depths of 0.6 metres and 0.7 metres respectively in the 20% AEP event.

Table 8-3 Minnegang Creek Upstream Road Overtopping

ID	Location	Event Overtopped
MC-US1	Ranchby Avenue west	20% AEP
MC-US2	Ranchby Avenue central	20% AEP
MC-US3	Ranchby Avenue east	20% AEP
MC-US4	Lake Heights Road	20% AEP
MC-US5	Barina Avenue	20% AEP

Figure 8-3 Minnegang Creek Upstream Road Overtopping Locations (with 1% AEP Risk Scenario)

8.1.4 Barina Park Basin

Barina Park Basin lies in the centre of the catchment area, and intercepts flow from Minnegang Creek and Melinda Grove Tributary. It also indirectly intercepts flow from Gordon Crescent Tributary as this flowpath merges with Minnegang Creek upstream of Barina Park Basin.

The basin has a crest level of 26.5 mAHD, and has a storage of approximately 5,400 m^3 at this level.

Barina Park Basin first overtops in the 10% AEP, though only engages a portion of the embankment. The embankment is fully engaged for events from the 5% AEP to the 1% AEP. The PMF results in additional overtopping of the embankment to both the east and the west.

Flow over the embankment flows overland through residential lots, crossing first Mirrabooka Road then Weringa Avenue before entering the open channel downstream of Weringa Avenue. Access along these roads is lost in the 20% AEP event (refer **Table 8-4** and **Figure 8-4**).

Downstream of Barina Park Basin, both Mirrabooka Road and Weringa Avenue are overtopping in events as small as the 20% AEP event.

Table 8-4 Barina Park Basin Road Overtopping

ID	Location	Event Overtopped
BP1	Mirrabooka Road	20% AEP
BP2	Weringa Avenue	20% AEP

Figure 8-4 Barina Park Road Overtopping Locations (with 1% AEP Risk Scenario)

8.1.5 Minnegang Creek Downstream

Downstream of Weringa Avenue, Minnegang Creek becomes a defined open channel. Flows are generally well contained within the channel for events up to the 1% AEP, although some properties along Denise Street are inundated. In the PMF, some overbank flows begin to occur, inundating the rear of adjacent properties. A number of overland flowpaths convey runoff from the developed areas to the west of the creek. These overland flows result in ponding along Denise Street, which loses access in the 20% AEP (refer **Table 8-5** and **Figure 8-5**), though the duration is short, with flooding clearing in under an hour.

Immediately to the east of Minnegang Creek is Hospital Creek, which drains the adjacent catchment area. While Hospital Creek does not form a part of this study, it was included in the modelling in order to assess whether any breakout flows occur from Hospital Creek to Minnegang Creek in larger events. At Jane Avenue, where the creeks are approximately 100m apart, some break out flow was observed in the PMF event. It was driven by the constriction of Hospital Creek flows when it passes through the culvert under Minnegang Street. At this location, flow backs up upstream of the culvert, and breaks out over the western bank, crosses Jane Avenue and flows into Minnegang Creek.

Table 8-5 Minnegang Creek Downstream Road Overtopping

ID	Location	Event Overtopped
MC-DS1	Denise Avenue	20% AEP
MC-DS2	Denise Avenue	20% AEP
MC-DS3	Denise Avenue	20% AEP
MC-DS4	Denise Avenue	20% AEP

Figure 8-5 Minnegang Creek Downstream Road Overtopping Locations (with 1% AEP Risk Scenario)

8.1.6 Northcliffe Drive

Along and downstream of Northcliffe Drive, the flooding is largely driven by backwater from Lake Illawarra (refer **Section 7.2**).

Similar to other areas of the catchment, there was little change in extent between the 20% AEP and the 1% AEP, while the PMF extent was substantially larger, inundating much of area. These changes are commensurate with the change in downstream boundary, which sees lake levels rise from 1.81m for the 1% AEP design runs to 2.24m for the PMF.

Access is lost along Northcliffe Drive in events as small as the 20% AEP (refer **Table 8-5** and **Figure 8-5**). The overtopping depths are significant, with depths of 0.8 metres occurring on Northcliffe Drive in the 20% AEP event.

Table 8-6 Minnegang Creek Downstream Road Overtopping

ID	Location	Event Overtopped
NC1	Northcliffe Drive	20% AEP

Figure 8-6 Northcliffe Drive Road Overtopping Locations (with 1% AEP Risk Scenario)

8.2 Flood Planning Area

The Interim Flood Planning Area was mapped for the catchment based on the 1% AEP event for the Risk Management Scenario. The Flood Planning Area represents the 1% AEP flood extent plus a freeboard of 0.5 metres. Where the 1% AEP +0.5m extent was wider than the PMF extent, the Flood Planning Area was limited to the PMF extent.

The results of the analysis are provided in **Map G802**.

8.1 Emergency Response Classification

Flood Emergency Response Classification aims to categorise the floodplain based upon differences in isolation due to the potential for entrapment of an area by floodwaters, potentially in combination with impassable terrain. It also considers the potential ramifications for an isolated area based upon its potential to be completely submerged in the probable maximum flood (PMF) or a similar extreme flood (AIDR, 2014).

Flood Emergency Response Classification mapping is a useful tool emergency services and evacuation planning for a floodplain.

AIDR (2014) provides guidance on mapping response classification mapping, which is intended to be undertaken at the community or precinct scale (i.e. not at the lot scale). A summary of the classifications is provided in **Table 8-7**. They are presented in **Map G803-R-1.** It is noted that the Flood Free category was not shown on the map.

Table 8-7 Emergency Response Classifications (AIDR, 2014)

Primary Classification	Description	Secondary Classification	Description	Tertiary Classification	Description
Flooded (F)	The area is flooded in the PMF	Isolated (I)	Areas that are isolated from community evacuation facilities (located on flood-free land) by floodwater and/or impassable terrain as waters rise during a flood event up to and including the PMF. These areas are likely to lose electricity, gas, water, sewerage and telecommunications during a flood.	Submerged (FIS)	Where all the land in the isolated area will be fully submerged in a PMF after becoming isolated.
				Elevated (FIE)	Where there is a substantial amount of land in isolated areas elevated above the PMF.
		Exit Route (E)	Areas that are not isolated in the PMF and have an exit route to community evacuation facilities (located on flood-free land).	Overland Escape (FEO)	Evacuation from the area relies upon overland escape routes that rise out of the floodplain.
				Rising Road (FER)	Evacuation routes from the area follow roads that rise out of the floodplain.
Not Flooded (N)	The area is not flooded in the PMF			Indirect Consequence (NIC)	Areas that are not flooded but may lose electricity, gas, water, sewerage, telecommunications, and transport links due to flooding.
				Flood Free (NFA)	Areas that are not flood affected and are not affected by indirect consequences of flooding.

8.2 Transport Infrastructure

There are a number of key access routes through the study area. Understanding when these routes are overtopped by floodwaters and the duration in which they are flooded is useful, particularly for emergency response planning.

An analysis was undertaken on both duration of overtopping on key routes throughout the study area, as well as the earliest time in which they are overtopped, both measured where the depth exceeds 0.1 metres. The earliest time of overtopping is measured from the commencement of the storm event.

This information is presented **Table 8-7** for both the PMF and 1% AEP events.

The table shows that flooding is the catchment is driven by flash flooding, with all roads inundated within 0.5 hours of the storm commencing. Most roads also clear quickly, the exception being Northcliffe Drive, where flooding is also driven by lake levels. It is expected that this overtopping would subside as lake levels fall.

Table 8-8 Road Overtopping

Location	1% AEP		PMF	
Location	Time to Overtopping (hrs)	Time of Overtopping (hrs)	Time to Overtopping (hrs)	Time of Overtopping (hrs)
Gordon Crescent Tributary				
GC1	<0.5	<1	<0.5	<1
GC2	<0.5	<1	<0.5	<1
Melinda Grove Tributary				
MG1	<0.5	1	<0.5	1.5
MG2	<0.5	2	<0.5	2.5
Minnegang Creek Upstream				
MC-US1	<0.5	<1	<0.5	<1
MC-US2	<0.5	<1	<0.5	<1
MC-US3	<0.5	<1	<0.5	<1
MC-US4	<0.5	<1	<0.5	<1
MC-US5	<0.5	2	<0.5	3
Barina Park Basin				
BP1	<0.5	2	<0.5	2
BP2	<0.5	3	<0.5	3
Minnegang Creek Downstream				
MC-DS1	<0.5	<1	<0.5	<1
MC-DS2	<0.5	<1	<0.5	<1
MC-DS3	<0.5	<1	<0.5	<1
MC-DS4	<0.5	<1	<0.5	<1
Northcliffe Drive Flooding				
NC1	<0.5	>3	<0.5	>3 *

** The timings of this crossing is governed Lake Illawarra flooding (refer Cardno, 2012)*

9 Model Sensitivity

Sensitivity analysis is a useful tool in understanding the potential variability of model results with different parameter assumptions. The following sensitivity analyses have been undertaken:

- Model Roughness;
- Rainfall Intensity; and
- Blockage assumptions.

In addition to these analyses, an assessment of the potential impacts of climate change has also been undertaken.

9.1 Model Roughness

The roughness in the model was tested by increasing and decreasing the roughness by 20%. The results of this analysis are presented in **Maps G901-R-1** to **G901-R-2**.

A 20% roughness increase resulted in level changes of 0.02 – 0.05 metres across all flowpaths, with a slightly higher increase of 0.07 metres occurring in the downstream reaches of Minnegang Creek.

Decreases of a similar magnitude were observed for roughness reductions; generally, less than 0.05 metres, with a slightly greater decrease of 0.08m immediately upstream of Northcliffe Drive.

The results showed that the model is relatively insensitive to changes in roughness values.

9.2 Rainfall

The inflows to the model were tested by increasing and decreasing the rainfall intensity by 20%. This sensitivity assessment assesses the sensitivity of the model to the hydrological assumptions, including rainfall and design rainfall losses. The results of this analysis are presented in **Maps G902-R-1 to 2**.

The results showed that the model was more sensitive to changes in rainfall than changes in roughness. In the upper catchment (upstream of Barina Park Basin) and along the minor tributaries, level differences were minor, and within +/- 0.05 metres.

Within Barina Park Basin, flood levels change by + 0.05 / - 0.07 metres as a result of the +/-20% rainfall intensity change. These differences increased to +/- 0.3 metres downstream of Weringa Avenue and +/- 0.2 metres upstream of Northcliffe Drive.

This suggests that the model is relatively sensitive to hydrological assumptions on flows, with levels potentially changing by up to 0.3 metres as a result of a 20% change in rainfall intensity in the 1% AEP event, particularly in the downstream reaches.

9.3 Blockage

The approach adopted for the result analysis was to envelope the unblocked and blocked scenarios together (as discussed in **Section 7.3**). However, it is useful to understand the change in flood behaviour that can occur as a result of pit blockages, and key areas that are influenced by these. An analysis was undertaken on the 1% AEP and 20% AEP events, by comparing both the risk blockage scenario against the unblocked scenario. The results of this analysis are provided in **Map G903-R-1** to **G903-R-2**.

This assessment shows that the impact of blockage in the catchment is generally limited, with the majority of water level changes within +/- 0.05m. The most significant change is immediately upstream of Barina

Avenue, where risk scenario blockages resulted in increases of up to 0.2 metres in the 1% AEP and 0.1 metres in the 20% AEP occurring between Barina Avenue and Lake Heights Road.

With the exception of the above location, the results indicate that blockage has relatively little impact on flood behaviour across the catchment.

9.4 Climate Change

Climate change has the potential to influence flood behaviour. In the Minnegang Creek catchment this is most likely to occur through impacts on rainfall and / or sea level rise. Following discussions with Council, it was determined that a sensitivity analysis on rainfall and the downstream boundary was the most appropriate approach to assess the potential changes to the flood behaviour as a result of climate change. This sensitivity analysis is useful to understand the potential variance in flood levels, flood behaviour and associated planning under climate change conditions.

Two scenarios were assessed in the analysis:

- 0.4 metre increase in Lake Illawarra Levels and a 20% increase in rainfall; and
- 0.9 metre increase in Lake Illawarra Levels and a 20% increase in rainfall.

It is noted that these scenarios also provide a useful tool to assess the sensitivity of the model to alternative boundary condition assumptions. The analysis was undertaken for the 1% AEP and PMF events. The results are provided in **G904-D-2** and **G904-D-4** for the Design Scenario, and **G904-R-2** and **G904-R-4** for the Risk Scenario.

A summary of climate change impacts at key locations is provided in **Table 9-1** for selected locations as shown in **Map G801**.

Due to both the 2050 and 2100 have identical rainfall increases, the impacts occurring upstream of Northcliffe Drive are the same under both 2050 and 2100 scenarios. Only the downstream region of the model, between Northcliffe Drive and Lake Illawarra, showed a difference between the 2050 and 2100 scenarios, due to the differences in the assumed lake level.

Upstream of Barina Park Basin, changes were relatively minor, generally less than 0.05 metres in the 1% AEP and less than 0.08 metres in the PMF. Between Lake Heights Road and Barina Avenue, level increases were up to 0.13 metres and 0.16 metres for the 1% AEP and PMF events. Peak levels within Barina Park Basin remained similar, with a change in level of less than 0.05 metres in the 1% AEP and 0.08 metres in the PMF.

Downstream of Barina Park Basin, level increases were more pronounced. Immediately downstream of Barina Park Basin, increases of up to 0.15 metres were observed in both events. Within the open channel between Waringa Avenue and Northcliffe Drive, levels increased by 0.1 – 0.3 metres, with larger increases occurring over a greater area in the PMF event.

Overtopping of Northcliffe Drive at Minnegang Creek increased by 0.08 metres in 2050 and 0.09 metres in 2100 for the 1% AEP. Further east, at Hospital Creek, greater increases were observed across Northcliffe Drive of up to 0.2 metres in the 2100 scenario.

Table 9-1 Water Level Changes Under Climate Change Scenarios

Location	2050 PMF	2050 1% AEP	2100 PMF	2100 1%AEP
Gordon Crescent Tributary				
GC1	0.11	0.03	0.11	0.03
GC2	0.02	0.02	0.02	0.02
Melinda Grove Tributary				
MG1	0.05	0.03	0.05	0.03
MG2	0.15	0.10	0.15	0.10
Minnegang Creek Upstream				
MC-US1	0.03	0.02	0.03	0.02
MC-US2	0.02	0.02	0.02	0.02
MC-US3	0.04	0.03	0.04	0.03
MC-US4	0.16	0.13	0.16	0.13
MC-US5	0.10	0.07	0.10	0.07
Barina Park Basin				
BP1	0.15	0.13	0.15	0.13
BP2	0.16	0.12	0.16	0.12
Minnegang Creek Downstream				
MC-DS1	0.02	0.02	0.02	0.02
MC-DS2	0.02	0.02	0.02	0.02
MC-DS3	0.01	0.01	0.01	0.01
MC-DS4	0.05	0.03	0.05	0.03
Northcliffe Drive Flooding				
NC1	0.10	0.07	0.10	0.09

10 Conclusions and Recommendations

The Minnegang Flood Study has been prepared for Wollongong City Council to define the existing flood behaviour in the Minnegang catchment and establish the basis for subsequent floodplain management activities.

This project is a flood study, which is a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust floodplain risk management plan. It aims to provide a better understanding of the full range of flood behaviour and consequences. It involves consideration of the local flood history, available collected flood data, and the development of hydrologic and hydraulic models that are calibrated and verified, where possible, against historic flood events and extended, where appropriate, to determine the full range of flood behaviour.

Flood behaviour has been assessed using a TUFLOW model.

A calibration and validation of the hydraulic model has been undertaken by examining historical rainfall intensities, a comparison of modelled results with observations by the community, and a comparison against previous modelling.

The hydrological and hydraulic models were analysed for the Probable Maximum Flood (PMF), 1% AEP, 2% AEP, 10% AEP and 20% AEP events. The models were analysed for 90- and 120-minute duration storms. These storm durations were identified based on initial model runs to understand the critical durations throughout the catchment. Details and descriptions of the flood behaviour associated with these events has been provided.

In order to provide Council with an indication of future flood behaviour arising from climate change, two climate change scenarios were modelled. These scenarios incorporated rainfall intensity increases and sea level rise.

From the results developed, planning and emergency response data has been prepared for use by Council and emergency services.

11 References

Australian Institute for Disaster Resilience [AIDR] (2017). *Managing the Floodplain : A Guide to Best Practice in Flood Risk Management in Australia*, Handbook 7.

Cardno Lawson Treloar (2012). *Lake Illawarra Floodplain Risk Management Study*, prepared for Lake Illawarra Authority, Version 12, January.

GHD (2017) *Barina Park Basin Breach and Consequence Category Assessment*, prepared for Wollongong City Council

KBR (2002) *Minnegang Creek Flood Study*, prepared for Wollongong City Council

KBR (2004) *Minnegang Creek Floodplain Risk Management Study and Plan*, prepared for Wollongong City Council

Lawson & Treloar (2001). *Lake Illawarra Flood Study*, Version 7.

NSW Government (2005). *Floodplain Development Manual*.

SES (2010). *Wollongong City Local Flood Plan*.

WCC (2002) Conduit Blockage Policy

WMAWater (2016). *Review of Conduit Blockage Policy Summary Report*, prepared for Wollongong City Council, May.

Appendix A

Existing Hydrological and Hydraulic Model Review

Appendix A: Previous Hydrological and Hydraulic Model Review

As part of the 2002 study (KBR) a RAFTS hydrological model and a MIKE-11 hydraulic model were prepared to define the flood behaviour of the study area.

The RAFTS model covers the full catchment area and has been delineated to allow inflow hydrographs to be applied to the MIKE-11 model at sub-catchment outlets.

The hydrological model was validated against peak flow estimates from Probabilistic Rational Method calculations, and the hydraulic model was calibrated against recorded peak flood levels from a flood event in August 1998. While flood level data was available for other events, sufficient rainfall data could not be sourced for these other events.

A review of the models prepared as part of the 2002 study is provided below.

A.1 RAFTS Hydrological Model

A.1.1 Model Setup

The details of the hydrological model schematisation and summarised and discussed in **Table A-1**.

Table A-1 RAFTS Setup Parameters

Data	Comment
Catchment Delineation	For the 2002 study, the 90ha catchment area was broken down into 64 sub-catchments based on 1:2000 contour maps and 1982 and 1993 aerial photography. The sub-catchment delineation appears to have been governed by the method of application of the flows to the hydraulic model. This has resulted in some irregularly shaped sub-catchments and varying sizes.
Flow Routing	Flow routing in RAFTS can be done either by a simple 'lag' link, whereby flows are delayed between sub-catchments for a user-specified period or RAFTS can also automatically calculate lag times if the user enters a channel cross section. The 2002 study adopted lag times of between 1min and 2min for all sub-catchments, depending on sub-catchment size and land use. A more detailed assessment of lag times was not undertaken, as the primary purpose of the hydrological model was to define sub-catchment flows for the hydraulic model. Flow routing between sub-catchments was primarily undertaken in the hydraulic model. For a similar reason (that routing was undertaken in the hydraulic model) the hydrological model did not include the Barina Park detention basin.
Impervious Area	The impervious area was calculated individually for each sub-catchment. The impervious area was calculated by measuring the area of roads and developed areas in the sub-catchments. Roads were considered to be 95% impervious and developed areas (largely medium density residential) were considered to be 40% impervious. Given the nature of the development in the catchment, these values are reasonable. Impervious areas were found to be appropriate for the land use within the

<table>
<tr><th>Data</th><th>Comment</th></tr>
<tr><td></td><td>subcatchments.</td></tr>
<tr><td>Roughness</td><td>Based on recommendations outlines in the RAFTS user manual (WP Software, 1994) standard roughness values of 0.015 for impervious surfaces and 0.025 for pervious surfaces was adopted. It is noted that a more detailed roughness layer was utilised in the hydraulic model. For the purposes of hydrological modelling, these values are reasonable.</td></tr>
<tr><td>Losses</td><td>Rainfall losses were applied through an initial and continuing loss method. The values adopted in the 2002 study were:
• Impervious Areas: 1.5mm IL / 0mm/hr CL
• Pervious Areas: 15mm IL / 2.5mm/hr
Sensitivity testing was undertaken on the loss parameters. The assessment found that the model was relatively insensitive to changes in rainfall losses with flows changing by less than 10%, as a result of a 25% change in losses.
These values are within typical ranges for ARR87.</td></tr>
<tr><td>Rainfall</td><td>For calibration, 5 minute rainfall data, for the storm event on 17 August 1998, was taken from three rain gauges. These gauge stations were: Berkeley B44 (Berkeley Sports and Social Club), Port Kembla SPS 176 (Foreshore Rd, Port Kembla) and Manly Hydraulics Laboratory Port Kembla gauge. These gauges are sufficiently close to the catchment to define historical rainfall intensity for the 1998 event.
For design events, intensity-frequency-duration (IFD) data for the Wollongong area was used for storm durations of 30 minutes, 60 minutes, 2 hours, 3 hours and 6 hours. The intensities for the 90 minute storm events were derived in RAFTS using the IFD coefficients for Wollongong. Temporal patterns for all storm durations were generated by RAFTS in accordance with methods described in AR&R (1987).
A check of the IFD parameters was undertaken using the online BoM tool (http://www.bom.gov.au/cgi-bin/hydro/has/CDIRSWebBasic). The table below shows that the parameters used in the study area a close match for those provided by the BoM tool.
<table>
<tr><th rowspan="2">Source</th><th colspan="3">2-hour Duration Intensity (mm)</th></tr>
<tr><th>20% AEP</th><th>5% AEP</th><th>1% AEP</th></tr>
<tr><td>2002 Study</td><td>38.9</td><td>51.2</td><td>67.5</td></tr>
<tr><td>BoM IFD Tool</td><td>38.3</td><td>50.4</td><td>66.2</td></tr>
</table>
</td></tr>
</table>

A.1.2 Calibration / Validation

Due to the lack of streamflow gauges in the catchment, it was not possible to calibrate the RAFTS model to discharge estimates. A validation exercise was undertaken by comparing the RAFTS flows with peak flow estimates calculated using the Probabilistic Rational Method (PRM). To allow a valid comparison between the RAFTS flows and the PRM flows, the RAFTS model was modified so that each sub-catchment area was pervious (with 5% imperviousness) to represent the Minnegang Creek catchment in an undeveloped (rural) state.

The assessment found that PRM peak flows were typically within 10% of the peak RAFTS flows. Estimates were closer for larger flood events.

Further validation was undertaken through comparison of the hydraulic model results with observed flood levels.

A.1.3 Outcomes of Hydrological Model Review

The hydrological model developed for the catchment utilised appropriate parameters and methodologies and is suitable for defining the hydrology of the study area.

Some minor changes may be warranted to ensure sub-catchment boundaries and impervious fractions are representative of current conditions, but no major revisions are required.

A.2 Hydraulic Model

A.2.1 Model Setup

The details of the hydraulic model schematisation and summarised and discussed in **Table A-2**.

Table A-2 MIKE-11 Setup Parameters

Data	Comment
Survey, Pipes and Structures	The hydraulic model made use of 137 cross sections, 14 culverts and 14 weirs. These details were all collected via ground survey. The Minnegang Creek sections were collected as part of this study, while other sections, and the structures, were sourced from previous survey undertaken in 2000 and 2001.
Hydrologic Inputs	Inflow hydrographs were taken directly from the RAFTS model and applied at sub-catchment outlets in the hydraulic model, with routing undertaken by the hydraulic model.
Downstream Boundary	Minnegang Creek discharges into Lake Illawarra. The files for all calibration events and design events were provided for the models for this review. However, the raw data (i.e. the water level gauge data for Lake Illawarra) was not available. In reviewing the flood study report, the design levels adopted from Lake Illawarra were from the Lake Illawarra Flood Study (Lawson & Treloar, 2001). The 2002 study adopted a static downstream level for the design runs, assuming a similar recurrence interval in Lake Illawarra as for the local catchment; i.e. a 1% AEP Lake Illawarra level for a 1% AEP local catchment event. Given the large disparity in catchment size between Lake Illawarra and Minnegang Creek, this approach is conservative; as was noted in the report. Sensitivity testing was undertaken, and it was found that changes in Lake levels did not propagate far upstream, as a result of the catchment terrain. Changes in flood level were largely focused on the region surrounding Northcliffe Drive. Given the long duration flooding from Lake Illawarra, a static boundary is not unreasonable. It is recommended however that the approach to

Data	Comment
	coincident flooding be revised, in accordance with the OEH guidance provided in *Floodplain Risk Management Guide: Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* (OEH, 2015). This approach would see a lower recurrence interval adopted in Lake Illawarra, compared to the catchment event. For example, a 5% AEP level in Lake Illawarra for a 1% AEP Minnegang Creek event.
Roughness	Manning's 'n' values were determined for each cross section based on field inspections, the ground survey and reference texts. The typical values adopted were: • Roads and surfaces 0.018 • Short length grass 0.035 • Long length grass 0.04 – 0.06 • Main creek channel 0.04 – 0.07 • Vegetated overbank 0.05 – 0.08 • Residential blocks 0.1

A.2.2 Calibration / Validation

The hydraulic model was validated to a single event from August 1998. The event was in the order of a 50% AEP event for the Minnegang Creek Catchment according to the Flood Study. There were four recorded flood levels for this event within the catchment area.

The MIKE-11 model showed a reasonably good match to these levels. The higher differences were at structures, where the 2002 study hypothesised that adopted blockage rates may be influencing the results.

Overall the validation was considered reasonable, and the model was deemed suitable for use in the design runs. It is noted that calibrating to such a small flood event only provides a smaller level of certainty for larger flood events (such as the 1% AEP).

A.2.3 Design Runs

Modelling was undertaken for the 20%, 5%, 2% and 1% AEP events and the PMF event, for the 30min, 60min, 90min, 2hr, 3hr and 6hr duration storms. An analysis of the results demonstrated that the 2hr storm was critical for the catchment. Given the catchment size and terrain, a critical duration of this magnitude is reasonable.

A.2.4 Outcomes of the Hydraulic Model Review

While the approach taken was suitable given modelling approaches at the time of the 2002 study, it is no longer appropriate given advances in hydraulic modelling. The original report notes that the model was unable to accurately define the flood behaviour in the lower reaches of the catchment, due to the backwater effects from Lake Illawarra.

Furthermore, the 1D nature of the MIKE-11 model required all overland flow paths and river breakouts to be identified in advance of running the model. The approach is prone to issues relating to the accurate identification of overland flow paths, which is a difficult task. The rainfall on grid methodology proposed for the Flood Study Review will resolve this issue by allowing the hydraulic model to automatically route flows based on terrain and roughness parameters.

Furthermore, changes to the catchment as a result of ongoing development are likely to alter the flood behaviour in some regions of the catchment.

As a result of the above, the creation of a new 1D/2D model to define flood behaviour is warranted.

Appendix B

Community Consultation

Wollongong City Council February 2018

Minnegang Creek Flood Study Review

Community Update

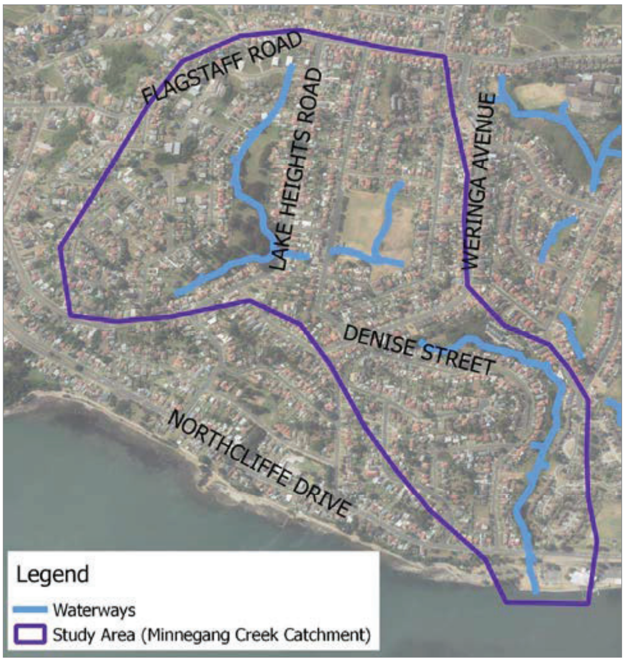
Wollongong City Council is currently undertaking a Flood Study for the Minnegang Creek catchment (Lake Heights and Warrawong) to assist with managing flood risk to people, property & infrastructure.

In 2002 Council undertook a Flood Study for Minnegang Creek. This study is currently being updated.

The Minnegang Creek catchment and floodplain has experienced a number of floods in the past.

More than 80 homes within the Minnegang Creek catchment could be affected by flooding.

Council is asking the community to provide details of any flooding they have experienced or are aware of.



Minnegang Creek Catchment is located in the suburb of Lake Heights and a small portion of Warrawong. Minnegang Creek has two main tributaries and discharges into Lake Illawarra.

At Wollongong City Council we know some parts of the Local Government Area (LGA) are more prone to flooding than others and we're committed to finding solutions to reduce the social and economic damages of flooding.

The Minnegang Creek Flood Study was completed by Council in 2002. This study identified flood risk within the Minnegang Creek catchment.

The map shows the Minnegang Creek catchment. Areas within this catchment are subject to flooding from overland flows and overtopping of drainage channels.

The updated flood study that's underway will incorporate the revised national guidelines and blockage policy and updated ground survey to define the nature and extent of flooding in the catchment. It is also expected that data collected during recent rainfall events will be used to verify the flood models used in this study.

Do you have any records of local knowledge of flooding in the Minnegang Creek Catchment?

Council would like to hear from you. There is a survey on the back or you can fill in the online "Have your Say" survey. You can also phone or email us. Your responses will help us understand the local flooding problems in more detail. Local knowledge and personal experiences of flooding are an invaluable source of data.

Submissions can be provided online, email or post

Online:
www.haveyoursaywollongong.com.au

For more information phone:
(02) 4227 7111

Email: council@wollongong.nsw.gov.au
Mail: 41 Burelli Street Wollongong

Submissions should be provided by 23rd March 2018

Wollongong City Council February 2018

Minnegang Creek Flood Study Review

Community Update

wollongong
city of innovation

Community Feedback Form

Contact details

Name ____

Address ____

Email ____

Best Contact Phone Number____

How long have you lived, worked or visited in the catchment? ______ years

Are you aware of flooding in the study area? (please select one)

Aware

Some knowledge

Not aware

Have you ever seen flooding in the catchment? (e.g. March 2017; March 2011; Aug 1998; Dec 1995; Dec 1990; Oct 1987)

Yes/No

Please describe the flooding you saw?

Date and time (as best as can be remembered) _________________

Location ____

Description of flooding (e.g. flooded the road outside my house or work, went into the house, went up to the front step, went part way up the yard, went into the garage

____

____

____

Have you seen water pond in the Barina Park sports fields?

Yes/No

Do you have any photos of flooding in the catchment?

Yes/No

Do you have any more information you think might help in relation to the Review of the Minnegang Creek Flood Study?

____

____

____

____

____

____

Can Council or our consultant contact you for further information relating to your responses to this survey?

Yes/No

Submissions can be provided online, email or post

Online:
www.haveyoursaywollongong.com.au

Email: council@wollongong.nsw.gov.au
Mail: 41 Burelli Street Wollongong

For more information phone:
(02) 4227 7111

Submissions should be provided by 23rd March 2018

Appendix C

Door Knocking Responses

APPENDIX C
Community Observations Model Behaviour

ID	Observation	Model Behaviour
1	2017 water reached just above bottom of club house	This flooding would be governed by Lake Illawarra rather than from the local catchment
2	1980s part way up the south east /corner of the building	This flooding would be governed by Lake Illawarra
3	16.3.2017 Northclif Dr flooded from /west of ambulance station to /west of Yacht club.	Ambulance station further east from study area. However, flooding generally extends from Minnegang Creek (western edge) near Yacht Club and to the east across this low lying area.
4	Northcliff Dr closed 1980s and 2017	General inundation of Northcliffe Drive even in a 50% AEP, suggesting that this area would be exposed to regular flooding consistent with observations
5	Flooding in March 2017 up to back step and flooded back shed	Model shows breakout from Minnegang Creek upstream of the culvert, spreading across this area and inundating Northcliffe Drive. Depths in the order of 0.5m in a 20% AEP.
6	Since 1950 never had flooding on the property.	Consistent with the model results, with no inundation in a 1% AEP
7	Since 2001, flooding from creek has risen several times up to the north-east corner of No. 248	Model shows similar behaviour. The majority of the property is flood free in all events, but the back corner of the property is inundation in a 50% AEP
8	Northcliffe Drive often flooded and closed to traffic	Consistent with model results showing flooding even in 50% AEP
9	Flooding from Northcliffe Drive backed up to the speed hump on Griffin Street in March 2017	Flood model shows inundation up to the speed hump in the 50% AEP and above. Does not extend significantly further up the road even in 1% AEP
10	Local flow floods front yard regularly, but not backyard	flooding appears to only reach back boundary, not backyard. front yard flooding may be local drainage
11	Vegetation forms a dam in creek.Flooding observed up to property boundary.	model shows inundation up to back boundary of the fence up to the 1% AEP
12	No flow every experienced through the property. Pit at front of property has surcharged into the street	Model shows an overland flow path coming into the rear of neighbouring property and between buildings. Possible it may be largely contained to neighbouring property. Ponding on the street at the pit
13	Flow occassionally comes off the street. Clears quickly and is shallow.	Model shows an overland flowpath through this area. Depths up to approximately 0.2m
14	Flooding observed in Council reserve during period of heavy rain. Has not impacted property (since 1963)	Generally agrees with model behaviour, showing creek flooding inundating reserve but not reaching property up to and incl 1% AEP
15	2011, 2014 & 2017 flooded lower garden	Model shows flooding up into the lower part of the property to a small degree in 50% AEP, and more in 20% AEP.
16	2002 - 2004 creek flooded, did not impact house	model shows no inundation of the property

APPENDIX C
Community Observations Model Behaviour

ID	Observation	Model Behaviour
17	No flooding observed in last 8 years	Flooding appears to be confined to the creek corridor up to the 1% AEP
18	Resident since 1970, never seen the water in the creek above the lower fence	Generally agrees with the behaviour of the model up to the 1% AEP
19	Concrete lined channel along boundary has never come over channel and into backyard.	model of Hospital Creek shows inundation of this area in 50% AEP. Not clear on length of duration of living at property
20	low point on driveway accumulates flow from the street and property. Flow goes under the fence into No13 and under the house.	Model shows ponding on street in this area (shallow) across all events, and flow through properties in this area (shallow)
21	25m of fence washed away	Model in larger events shows relatively high velocity flow and depth through this area
22	1980s and 90s this property, property /acros the road and next door were /all submerged	This agrees with the model behaviour for 5% AEP and larger events, when more significant overtopping of the basin occurs
23	Major flooding through No. 98, 100 & 99 during the 1980s. 101 was also affected but not as badly. Some water through the back of the garage of 102, but not as deep	This agrees with the modelling, for larger events when the basin is overtopping
24	Flow from road overtops driveway at No 63. Depth of water can get to step above ground level at No. 61	approximately 1.2m of ponding on the road in a 1% AEP, with flow through the properties on the downstream side
25	Pit has been seen to surcharge. No flow observed through No 46. Flow comes along the eastern boundary of No 44	Flow is mainly contained on 44, flowing between the boundary as well between 46 and 44.
26	Residents downstream have seen embankment overtop several times in 1980s and 1990s, but not since then	Overtopping occurs in events between 50% AEP and 20% AEP. Possible that events after 1990s less than 20% AEP.
27	The park was observed to "fill up" by a resident regularly before 2000, but not anymore	It is possible that events in the 2000s were less than 20% AEP for the catchment
28	During heavy rain water ponds in the low point of the road and has been observed coming into front yard of No 66	ponding and backwater through this area consistent with these observations
29	last time creek was observed to overtop was more than 10 years ago. Resulted in approximately 1 foot of depth through the properties	Flooding through this area approximately 0.3m depth in a 50% AEP
30	Creek overtops banks and floods approx half of the backyard. Drains away fairly quickly	general widespread overtopping through this area once culvert capacity and channel capacity exceeded. It is likely to drain quickly in this area after the peak of the rainfall.

APPENDIX C
Community Observations Model Behaviour

ID	Observation	Model Behaviour
31	Flow from creek upstream of road has been observed in last 10 years to overtop and then re-enter creek downstream of the road	Overtopping of the road generally occurs in 20% AEP and above
32	Some flow observed down the driveway	Shallow overland flow observed through the vicinity of this property
33	No ponding observed on road by long term residents	Limited ponding in this area up to and including 1% AEP event.
34	Ponding on street observed when pit blocks	Modelling was not undertaken with pit blockage - shows limited ponding
35	Flow often seen in channel downstream of this location. 2016 flow came into backyard of No 9. 1998 event probably the worst in the last 50 years. Approximately 0.5m deep	Depth approximately 0.5m near boundary of property around1% AEP. Flows occurs in the channel normally. Flow seen into backyard for 50% AEP, but may be contained to some degree by fencing.
36	Flooding of Council reserve at this location. Has entered the backyard of No 7	Ponding shown in the back of No.7
37	No observations of flooding in 30 years	Flow down driveway of neighbouring property, but flooding not shown on this property. Small ponding on street out the front at low point.
38	Stormwater pit surcharges. Pressure has pushed up pit cover. Ponding of flood water on road to gutter height	Ponding up to 0.5 - 0.7m, controlled by level of kerb/ footpath downstream. Given gradients, possible to have surcharging pits in this area
39	Flow down street has come down driveway and built up against garage door	Model shows flow down driveway and up to garage
40	Unit 2 had water come through the back wall in March 2017	no overland flow shown in this location. This may be local stormwater issues
181	local flows flooded backyard /1998 and June 2016	Model shows inundation of this area.
182	1998 and June 2016 flooding of rear of Denise St properties	Flooding through this area in the model

N
W E
S

Figure GAC101

Community Observations

Legend

1% AEP Extent

Community Observations

50 0 50 100 150 200 m

Scale : 1:5000@A4
Date : 17 December 2018
Revision : A
Created by : RST
Coordinate System : MGA 56

Rhelm

Appendix D

RAFTS Catchment Parameters

Table D1 RAFTS Catchment Parameters

ID	Area	%Imp
MHB	28,261	65.4
MHA	16,144	61.8
S005	37,096	53.8
MH001A	6,777	59.1
MH60	9,315	41.1
MH56	7,233	64.0
MH54	7,136	52.4
MH50	10,969	63.2
MH50A	17,825	64.5
MH52	1,576	85.5
MH48	7,827	68.9
MH52C	21,537	28.9
MH69A	22,632	18.9
MH70	7,953	16.5
MH78	16,470	67.7
MH28	8,335	69.4
MH27	873	70.6
MH30	9,451	64.2
MH29	1,076	80.6
MH27A	8,855	36.1
OUT	10,562	34.2
MH134	1,465	90.4
MH132	12,328	62.9
MHG	25,107	50.5
MC4	26,039	49.9
S055	17,381	71.5
MH110	31,661	63.7
MC3	21,003	46.7
MH104	12,739	75.1
MH115	1,767	94.9
MH114	11,490	65.3
MC2	24,580	37.8
MC1	6,707	48.7
MH98	18,938	64.3
MHF	10,742	51.7
MH100	17,739	63.2
MH95	1,499	90.0
MH26A	2,501	60.0
MH26	3,382	71.3

S007	8,623	63.1
MH24	5,101	66.6
MH25	976	82.5
MH23	1,029	85.3
MH21	21,738	71.4
MH43	12,501	67.6
MH41	28,950	65.6
MH46	15,542	65.2
MH31	6,728	68.2
MH68	4,422	86.9
MHE	8,720	60.0
MH32	1,679	84.2
MHD	14,895	71.0
MHCa	41,324	39.8
MH72	13,392	69.2
MH96	6,859	72.6
MH87	7,358	79.1
MH80	3,832	93.6
MH77	17,317	67.2
MH76	2,112	90.1
MH79	21,009	65.3
MH53	13,988	69.6
MH94	869	93.7
MH36	2,968	84.3
MH67	37,600	64.9
MH62	13,583	69.1
MHCb	32,183	61.4
MHCc	20,136	29.3

Appendix E

Peak Flow and Water Level Summary

Peak Model Flows (m³/s) at Reporting Locations - Risk Blockage						
Location	20% AEP	20% AEP	5% AEP	2% AEP	1% AEP	PMF
Q_1	0.8	1.0	1.2	1.3	1.5	3.5
Q_2	1.0	1.2	1.5	1.7	1.9	4.3
Q_3	0.7	0.9	1.1	1.3	1.5	4.8
Q_4	2.5	2.8	3.2	3.5	3.9	10.5
Q_5	4.9	5.6	6.5	7.2	7.9	20.4
Q_6	1.4	1.6	1.9	2.2	2.5	6.1
Q_7	3.7	4.3	5.0	5.6	6.2	15.9
Q_8	8.9	10.7	12.7	14.6	16.4	42.1
Q_9	8.3	9.8	12.0	14.5	16.7	44.7
Q_10	1.8	2.1	2.5	2.8	3.3	8.0
Q_11	2.5	3.0	3.5	4.0	4.4	12.6
Q_12	2.1	2.5	2.9	3.3	3.7	11.1
Q_13	1.1	1.3	1.7	1.9	2.1	5.3
Q_14	6.7	11.0	15.2	17.9	21.9	60.5
Q_15	7.3	9.9	15.8	19.8	22.7	70.4
Q_16	6.3	11.1	14.3	20.1	24.4	78.8
Q_17	11.6	14.8	21.0	24.9	28.8	86.6
Q_18	11.7	14.9	20.8	24.7	30.5	102.2
Q_19	1.4	1.6	2.0	2.2	2.5	5.5
Q_20	12.3	16.2	20.7	26.3	30.3	114.6
Q_21	0.7	0.9	1.1	1.2	1.4	3.5
Q_22	4.1	4.7	5.4	6.0	6.6	17.2
Q_23	5.3	6.2	7.2	8.0	8.9	22.4
Q_24	5.6	6.5	7.7	8.6	9.6	24.1
Q_25	2.0	2.2	2.6	2.9	3.2	8.4
Q_26	2.3	2.6	3.1	3.4	3.8	9.7
Q_27	3.4	3.9	4.6	5.1	5.7	14.6
Q_28	11.4	15.2	20.9	25.3	28.5	94.3
Q_29	11.4	15.6	19.8	25.7	29.9	97.2
Q_30	11.6	15.6	19.9	25.6	30.3	98.5
Q_31	11.7	15.3	20.5	25.4	30.5	101.0
Q_32	12.1	16.1	21.2	26.0	29.9	113.2
Q_33	19.6	22.7	27.9	31.9	36.0	100.9
Q_34	17.2	19.4	21.7	24.4	26.8	54.3
Q_35	19.4	23.2	27.7	31.2	34.9	98.0
Q_36	10.7	12.4	14.5	16.5	18.9	53.2
Q_37	9.7	11.5	13.7	15.5	17.6	48.1
Q_38	8.1	9.4	11.2	12.7	14.5	39.0
Q_39	6.8	8.0	9.6	10.9	12.4	32.7

Peak Model Flows (m^3/s) at Reporting Locations - Design Blockage						
Location	20% AEP	20% AEP	5% AEP	2% AEP	1% AEP	PMF
Q_1	0.8	0.9	1.1	1.3	1.5	3.4
Q_2	1.0	1.2	1.5	1.6	1.9	4.3
Q_3	0.7	0.9	1.1	1.3	1.5	4.9
Q_4	2.5	2.8	3.2	3.5	3.9	10.5
Q_5	4.9	5.6	6.5	7.2	7.9	20.4
Q_6	1.3	1.5	1.9	2.1	2.4	6.1
Q_7	3.7	4.3	5.0	5.6	6.2	15.9
Q_8	8.6	10.2	12.3	14.0	15.8	41.1
Q_9	7.7	9.0	10.9	12.8	14.8	42.5
Q_10	1.8	2.1	2.5	2.8	3.2	8.0
Q_11	2.4	2.9	3.5	4.0	4.4	12.6
Q_12	2.0	2.4	2.9	3.3	3.7	11.1
Q_13	1.0	1.2	1.6	1.9	2.2	5.3
Q_14	6.4	10.5	14.8	17.2	21.1	59.8
Q_15	7.0	9.6	15.4	19.1	22.1	69.9
Q_16	6.1	10.6	14.2	19.4	23.9	78.3
Q_17	11.4	14.7	20.8	24.8	28.5	86.4
Q_18	11.6	14.7	20.6	24.3	30.3	102.2
Q_19	1.4	1.6	2.0	2.2	2.5	5.5
Q_20	12.1	16.0	20.5	26.2	30.2	114.5
Q_21	0.6	0.8	1.0	1.2	1.4	3.4
Q_22	4.1	4.7	5.4	6.0	6.6	17.2
Q_23	5.2	6.1	7.1	7.9	8.9	22.4
Q_24	5.4	6.4	7.6	8.5	9.6	24.1
Q_25	2.0	2.2	2.6	2.9	3.2	8.4
Q_26	2.3	2.6	3.1	3.4	3.8	9.7
Q_27	3.4	3.9	4.6	5.1	5.7	14.6
Q_28	11.2	15.0	20.8	25.1	28.5	94.0
Q_29	11.3	15.4	19.7	25.5	29.8	97.2
Q_30	11.5	15.3	19.9	25.4	30.2	98.5
Q_31	11.6	15.1	20.3	25.1	30.3	100.9
Q_32	12.0	15.9	21.0	25.9	29.6	113.1
Q_33	19.6	22.7	28.0	32.0	36.1	101.0
Q_34	17.2	19.5	21.8	24.4	26.9	54.4
Q_35	19.4	23.3	27.8	31.3	35.1	98.2
Q_36	10.7	12.4	14.5	16.5	18.9	53.2
Q_37	9.7	11.5	13.7	15.5	17.6	48.1
Q_38	8.1	9.4	11.2	12.7	14.5	39.0
Q_39	6.8	8.0	9.6	10.9	12.4	32.7
Q_40	1.0	1.2	1.4	1.6	1.8	4.4

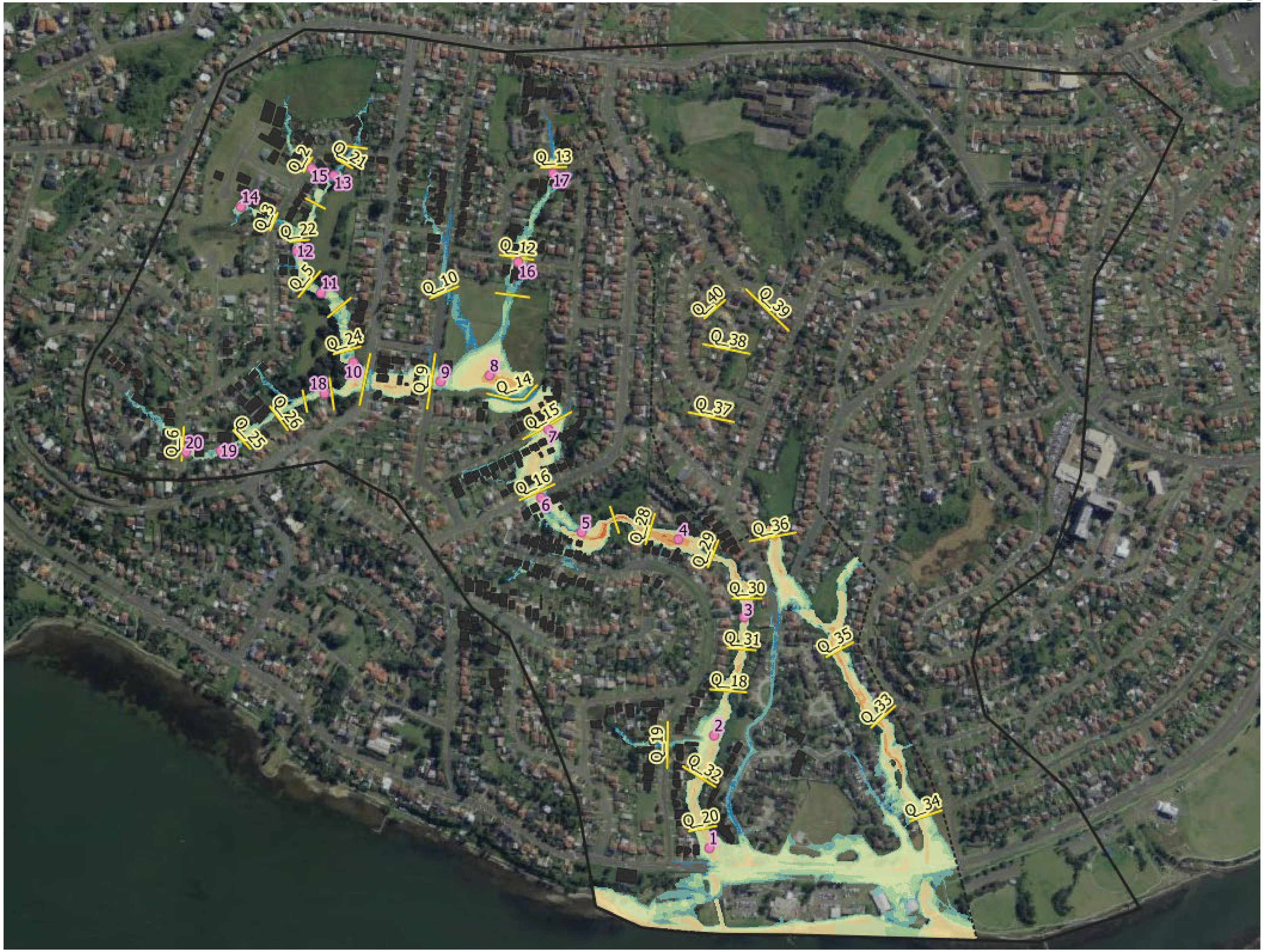
Peak Model Flows (m^3/s) at Reporting Locations - Unblocked						
Location	20% AEP	20% AEP	5% AEP	2% AEP	1% AEP	PMF
Q_1	0.8	0.9	1.2	1.3	1.5	3.4
Q_2	1.0	1.2	1.5	1.6	1.9	4.3
Q_3	0.7	0.9	1.1	1.3	1.5	4.8
Q_4	2.5	2.8	3.2	3.5	3.9	10.5
Q_5	4.9	5.5	6.5	7.2	7.9	20.4
Q_6	1.3	1.5	1.9	2.2	2.5	6.1
Q_7	3.7	4.3	5.0	5.6	6.2	15.9
Q_8	8.6	10.3	12.5	14.3	16.1	41.6
Q_9	7.7	9.1	11.5	13.7	15.7	43.5
Q_10	1.8	2.1	2.5	2.8	3.3	8.0
Q_11	2.4	2.8	3.5	4.0	4.4	12.6
Q_12	2.0	2.4	2.9	3.3	3.7	11.1
Q_13	1.0	1.2	1.7	1.9	2.1	5.3
Q_14	6.4	10.7	15.0	17.5	21.4	60.1
Q_15	7.0	9.5	15.6	19.4	22.4	70.1
Q_16	6.1	10.8	14.4	19.8	24.1	78.6
Q_17	11.4	14.6	20.9	24.9	28.6	86.5
Q_18	11.6	14.7	20.7	24.5	30.3	102.2
Q_19	1.4	1.6	2.0	2.2	2.5	5.5
Q_20	12.1	16.0	20.7	26.2	30.2	114.6
Q_21	0.6	0.8	1.1	1.2	1.4	3.5
Q_22	4.1	4.7	5.4	6.0	6.6	17.2
Q_23	5.2	6.1	7.2	8.0	8.9	22.4
Q_24	5.4	6.4	7.7	8.6	9.6	24.1
Q_25	2.0	2.3	2.6	2.9	3.2	8.4
Q_26	2.3	2.6	3.1	3.4	3.8	9.7
Q_27	3.4	3.9	4.6	5.1	5.7	14.6
Q_28	11.2	14.9	20.8	25.2	28.5	94.1
Q_29	11.3	15.4	19.8	25.6	29.8	97.2
Q_30	11.5	15.4	19.9	25.5	30.2	98.5
Q_31	11.6	15.2	20.4	25.2	30.4	101.0
Q_32	12.0	15.9	21.1	25.9	29.7	113.2
Q_33	19.6	22.8	28.0	31.9	36.0	100.9
Q_34	17.2	19.4	21.7	24.4	26.8	54.3
Q_35	19.4	23.2	27.7	31.2	34.9	98.0
Q_36	10.7	12.4	14.5	16.5	18.9	53.2
Q_37	9.7	11.5	13.7	15.5	17.6	48.1
Q_38	8.1	9.4	11.2	12.7	14.5	39.0
Q_39	6.8	8.0	9.6	10.9	12.4	32.7
Q_40	1.0	1.2	1.4	1.6	1.8	4.4

Peak Water Levels (mAHD) at Reporting Locations

Risk Blockage						
Location	20% AEP	20% AEP	5% AEP	2% AEP	1% AEP	PMF
1	3.637	3.037	2.978	2.905	2.824	2.747
2	5.821	4.534	4.431	4.309	4.164	4.037
3	9.464	8.241	8.131	7.997	7.804	7.615
4	14.376	13.302	13.188	13.054	12.89	12.727
5	16.605	15.585	15.568	15.548		
6	20.233	19.638	19.584	19.529	19.439	19.369
7	22.998	21.999	21.924	21.83	21.718	21.619
8	27.433	27.096	27.065	27.026	26.973	26.917
9	27.865	27.441	27.414	27.385	27.36	27.338
10	30.776	30.367	30.34	30.315	30.284	30.258
11	34.995	34.667	34.639	34.613	34.575	34.545
12	37.95	37.647	37.618	37.593	37.554	37.521
13	44.591	44.503	44.495	44.487	44.474	44.463
14	44.891	44.677	44.651	44.613	44.584	44.536
15	45.107	45.003	44.993	44.986	44.97	44.964
16	32.594	32.105	32.073	32.046	32.007	31.972
17	41.187	41.043	41.027	41.014	40.993	40.976
18	32.292	31.999	31.971	31.947	31.916	31.888
19	39.315	39.136	39.12	39.107	39.089	39.077
20	41.258					

Peak Water Levels (mAHD) at Reporting Locations

Design Blockage						
Location	20% AEP	20% AEP	5% AEP	2% AEP	1% AEP	PMF
1	3.628	3.026	2.967	2.895	2.814	2.74
2	5.821	4.532	4.428	4.307	4.163	4.036
3	9.464	8.239	8.128	7.995	7.802	7.613
4	14.376	13.3	13.185	13.053	12.888	12.725
5	16.605	15.584	15.567	15.547		
6	20.231	19.634	19.579	19.526	19.437	19.366
7	22.993	21.992	21.915	21.826	21.714	21.616
8	27.431	27.093	27.062	27.024	26.971	26.915
9	27.854	27.428	27.403	27.379	27.356	27.334
10	30.774	30.365	30.337	30.313	30.282	30.256
11	34.995	34.667	34.639	34.612	34.574	34.543
12	37.95	37.647	37.618	37.592	37.553	37.519
13	44.591	44.503	44.495	44.488	44.474	44.463
14	44.883	44.656	44.629	44.592	44.556	44.504
15	45.106	45.003	44.993	44.986	44.97	44.964
16	32.594	32.105	32.073	32.046	32.007	31.972
17	41.187	41.043	41.027	41.014	40.993	40.976
18	32.292	31.999	31.971	31.947	31.916	31.888
19	39.315	39.136	39.12	39.107	39.089	39.077
20	41.258					



Key Reporting Locations

Rhelm

engineering | environmental | economics | engagement

Rhelm Pty Ltd

ABN 55 616 964 517

ACN 616 964 517

Head Office

Level 1, 50 Yeo Street

Neutral Bay NSW 2089

contact@rhelm.com.au

+61 2 9098 6998

www.rhelm.com.au