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Kully Bay Overland Flow Study

Volume 1

Wollongong City Council | Flood Study | 23 October 2019

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Client Reference: Final Flood Study Report *provided by the client and sourced from other third parties is fit for purpose unless otherwise stated. The findings rely on a range of assumptions that are noted in the report.*

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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).

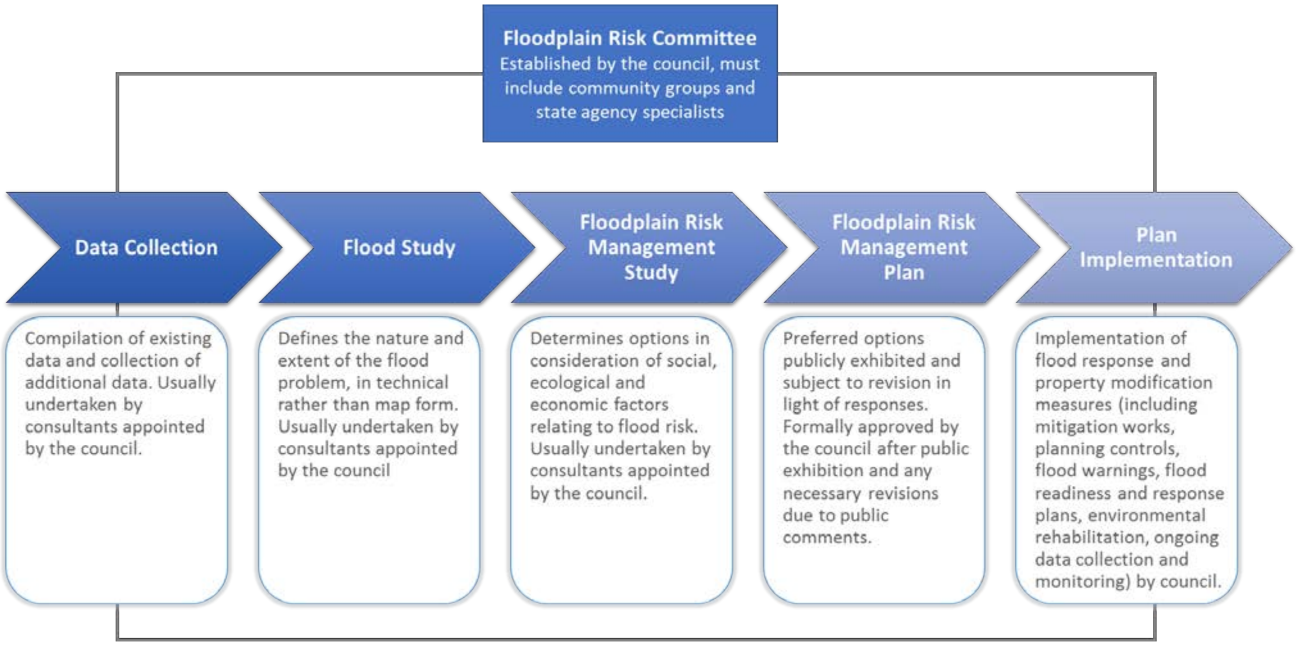

Figure F1 The Floodplain Risk Management Process (source: NSW Government, 2005)

Wollongong City Council is responsible for local land use planning in its service area, including in the Kully Bay 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 Kully Bay Overland Flow Study has been prepared for Wollongong City Council (Council) to define the existing flood behaviour in the Kully Bay catchment and to establish the basis for subsequent floodplain management activities.

The Kully Bay catchment is located in the suburb of Warrawong, in the Wollongong City LGA. The catchment covers an area of approximately 150 hectares and extends from the northern shores of Lake Illawarra in the south of the catchment to some 200m south of Wattle Street and Five Islands Road in the north.

The catchment area is largely comprised of residential development (primarily detached dwellings) and commercial development, with a significant commercial centre, Warrawong Plaza, in the downstream reaches of the catchment.

Figure i. Kully Bay Catchment

This project is an overland flow 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 overland flow 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 overland flow study during public exhibition.
- Community engagement has been undertaken through the mail out of an information brochure and brief survey. This was supplemented by door knocking of a number of residential properties to gain information directly from residents. 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.
- The Overland Flow Study has been overseen by the Southern Floodplain Risk Management Committee which includes representatives from community and state agencies.
- The Overland Flow 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.

A Tuflow model was developed for the study area, incorporating the direct rainfall methodology, so that the hydrology and hydraulics were assessed in a single model.

An indirect validation of the hydraulic model has been undertaken utilising historical rainfall intensities, community observations and comparisons to previous hydraulic models. The outcome of this validation identified that the model was suitable for use in defining the design flood event results.

The 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 60, 90, 120, and 360 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 overland flow 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**.

There are five major overland flowpaths through the catchment area, with varying degrees of flood severity. Three of these are located west of King Street. The first two run from Second Avenue, past First Avenue and into Bent Street. The first is then conveyed along Greene Street, while the second spreads widely through the multi-unit dwellings at Todd Street. Only the first flow path results in flows that cut road access, with depths of greater than 0.3m occurring at First Avenue in the 2% AEP event.

The third flowpath on the west runs from First Avenue in the north, across Bent Street and into King Street near the north of the catchment. Access along Bent Street is lost in events as small as the 20% AEP due to flows from this flowpath by depths of up to 0.5 metres.

On the east side of King Street are the two remaining overland flowpaths. The northernmost flowpath runs adjacent to Storey Street before crossing Robertson Street and then McGowen Street. At Shellharbour Road, the flow disperses, with some passing down Montgomery Avenue, and the rest spilling through residential blocks to Cowper Street. Along this flowpath, access is lost at both Robertson Street (>1% AEP) and Shellharbour Road (5% AEP).

The final overland flowpath conveys flow from the far east of the catchment. Flows commence upstream of Cowper Street, before flowing through residential zones across Forster Street and Shellharbour Road. It then passes along the northern side of Northcliffe Drive until the plaza, where it combines with the backwater from the lake and wetlands.

There are no creeks or rivers to convey flood water within the catchment area. When the stormwater drainage infrastructure capacity is exceeded, then primary flowpaths conveying water through the catchment are the road reserves, and the previously discussed urban overland flowpaths discharge into road reserves rather than creek channels.

The primary flowpath through the catchment is along King Street, which runs north-south through the centre of the catchment. With the exception of some overland flow from the far eastern and western sides, all flow within the catchment eventually reaches King Street. Other significant flows are conveyed along roads that run perpendicular to King Street – Cowper Street and Greene Street / Montgomery Avenue in particular (which then discharge into King Street). Between them, these three road reserves serve as the major flowpaths through the catchment.

Access along King Street is lost for much of its length during flood events. While the northern section is only affected in events of a 2% or 1% AEP magnitude, the lower sections, in particular around the Cowper Street intersection, are inundated in events as small as the 10% AEP. This serves to largely divide the catchment in half from an access perspective with a limited ability to cross from one side of the catchment to the other in events above a 5% AEP.

Downstream of Northcliffe Drive, the flooding is largely driven by backwater from Lake Illawarra. Access along Northcliffe Drive is lost at multiple locations within the study area. Aside from the intersection with First Avenue South, all of the intersections along Northcliffe Drive within the study area are inundated in events as small as the 20% AEP. The flooding is most pronounced east and west of the King Street intersection with depths of up to 1 metre in the 1% AEP.

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 +/- 0.2 metres arising from +/- 20% changes in roughness values. The model was also relatively insensitive to hydrological assumptions on flows, with levels changing by up to 0.05 metres as a result of a 20% increase in flows in the 1% AEP event.

With respect to blockage, the assessment showed that the impact of blockage in the catchment is generally limited, with the majority of water level changes within +/- 0.05m, and only for very limited areas of the catchment. The 20% AEP event showed a greater change in levels along the western length of Cowper Street than the 1% AEP event. This is likely due to the pipes running full in the 1% AEP event, so that pit capacity has less of an influence over peak flood levels.

This report provides an understanding of the flood risk within the Kully Bay catchment and provides Council with the tools for planning. This study provides a baseline against which a Floodplain Risk Management Study and Plan can be prepared.

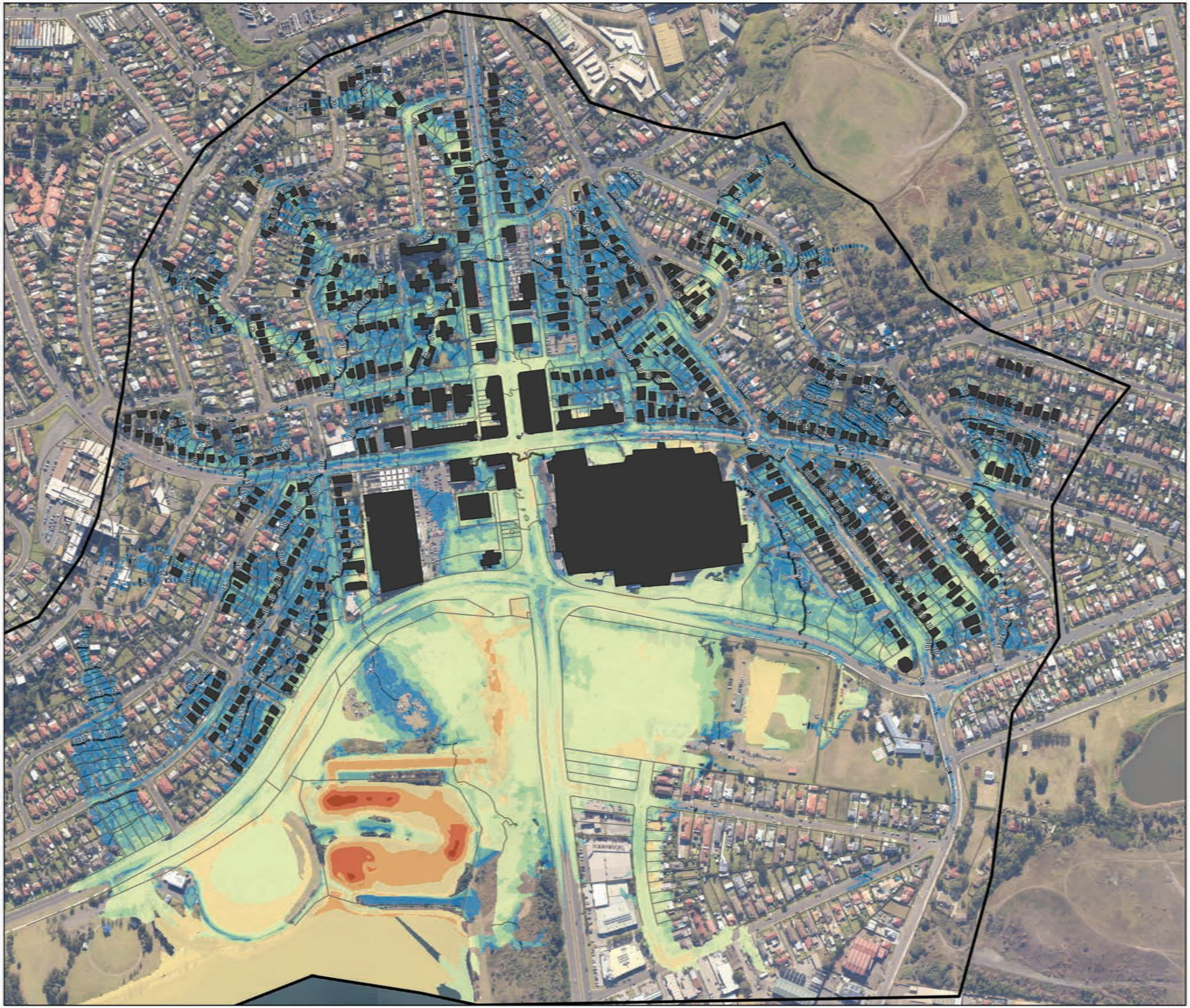

Figure i

Peak Depth & Water Level PMF

- Cadastre
- Model Extent
- Buildings

Depth (m)

- 0 - 0.15
- 0.15 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- >4

Scale : 1:5000@A3
Date : 14 August 2019
Revision : C
Created by : LRE
Coordinate System : MGA 56

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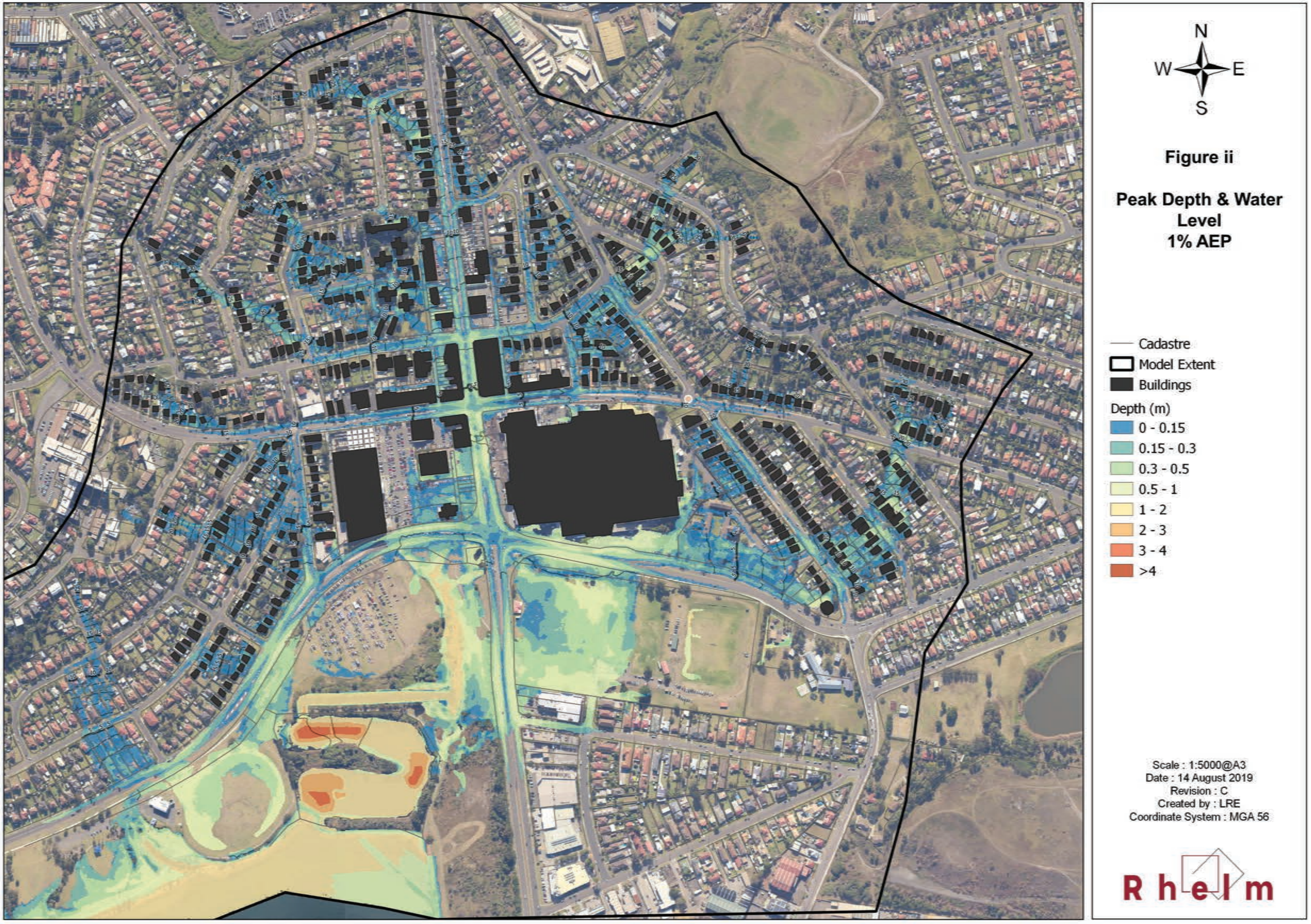
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Figure ii
Peak Depth & Water Level 1% AEP
Cadastre
Model Extent
Buildings
Depth (m)
0 - 0.15
0.15 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 4
>4
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Figure iii
Peak Depth & Water Level
20% AEP
Cadastre
Model Extent
Buildings
Depth (m)
0 - 0.15
0.15 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 4
>4
Scale : 1:5000@A3
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Figure iv

Peak Velocity
PMF

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

Scale : 1:5000@A3
Date : 14 August 2019
Revision : C
Created by : LRE
Coordinate System : MGA 56

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Figure v
Peak Velocity
1% AEP
Cadastre
Model Extent
Buildings
Velocity (m/s)
<=0.01
0.01 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 4
> 4
Scale : 1:5000@A3
Date : 14 August 2019
Revision : C
Created by : LRE
Coordinate System : MGA 56
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N
W E
S

Figure vi

Peak Velocity
20% AEP

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

Scale : 1:5000@A3
Date : 14 August 2019
Revision : C
Created by : LRE
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Figure vii

Peak Hazard
PMF

Scale : 1:5000@A3
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Figure viii

Peak Hazard 1% AEP

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Maps

Maps are provided in Volume 2 of this report

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 Kully Bay Overland Flow Study has been prepared for Wollongong City Council (Council) to define the existing flood behaviour in the Kully Bay 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 an overland flow 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.

The overall project provides an understanding of, and information on, flood behaviour and associated risk to inform:

- relevant government information systems;
- government and strategic decision makers on flood risk;
- the community and key stakeholders on flood risk;
- flood risk management planning for existing and future development;
- emergency management planning for existing and future development;
- strategic and development scale land-use planning to manage growth in flood risk; and
- decisions on insurance pricing (where the information is utilised by insurance companies).

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 Kully Bay catchment is located in the suburb of Warrawong, in the Wollongong City LGA. The catchment covers an area of approximately 150 hectares and extends from the northern shores of Lake Illawarra in the south of the catchment to some 200m south of Wattle Street and Five Islands Road in the north.

The catchment area is largely comprised of residential development (primarily detached dwellings) and commercial development, with a significant commercial centre, Warrawong Plaza, in the downstream reaches of the catchment.

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

1.3 Study Background and Context

The management of flood risks and hazards within townships is the responsibility of the Local Council. The Wollongong LGA has a history of flooding, with a number of significant events occurring over the last decade. Council is proactive in responding to these risks and is continuing to increase understanding of the flood behaviour and risks within the LGA.

The Kully Bay catchment has a reported history of flooding, which affects both residential and commercial development. However, to date, no flood study in accordance with the Floodplain Development Manual has been prepared by Council to define the flood behaviour of the study area. Some previous flood analysis has been undertaken as a part of some proposed developments in parts of the catchment, and this has highlighted the potential flood risks in the catchment.

In light of these risks, and the lack of any detailed flood information, Council has elected to undertake the Kully Bay Overland Flow Study. The study defines the current flood behaviour for a range of flood events and provides an indication of the risks to local development that arises from this behaviour. The study forms an important initial step in the wider floodplain management process, which will ultimately deliver Council tools and recommendations to manage the flood risks in the Kully Bay catchment.

2 Study Area

2.1 Catchment Description

Drainage through the catchment is largely by way of piped systems, with excess flow traveling via overland flowpaths. Upstream of Northcliffe Drive, there are no creeks or formal open channels. South of Northcliffe Drive the catchment drains to Lake Illawarra via a series of constructed channels and a major constructed wetland (Kully Bay Wetland), which also drain the reclaimed land adjacent to Kully Bay Oval.

The catchment is principally comprised of low density residential development surrounding a commercial development area located in the centre of the catchment. This commercial development is extensive and incorporates Warrawong Plaza and Bunnings. The commercial development is largely located between Cowper Street and Northcliffe Drive, with a narrow band of commercial development running up King Street. Upstream of Northcliffe Drive, there are few areas of open space or extensive vegetation. Downstream of Northcliffe Drive is largely reclaimed open space.

There are two major road corridors in the catchment area. King Street runs north-south through the centre of the catchment. Northcliffe Drive runs east-west through the lower catchment along the edge of Lake Illawarra. Observations by residents and Council suggests that both these roads are subject to flooding.

Port Kembla Hospital is located within the catchment area, on the western ridge that forms the boundary to the catchment. Given its location on high ground, it is not directly affected by flooding, but access to it during flood events is restricted as a result of the inundation of major access roads.

Kemblawarra Public School and Kindergarten are located in the south-east corner of the study area. Like the hospital, they are located on the catchment boundary, so are not directly impacted by catchment flows.

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

2.2 Historical Flooding

Council had previously collected flood marks for events in 1975 and 1984. 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 the Stage 1 consultations. The results of the door knocking are detailed in **Section 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). The site inspection was attended by Rhelm and Council 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 Kully Bay catchment (refer **Section 7.4**).

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 has minor impacts on the study area. Some inundation occurs in the wetlands and open space south of Northcliffe Drive, but this does not impact roadways or development.

In the PMF event, peak levels are approximately 1 metre higher. Flooding from the PMF event inundates both Northcliffe Drive and King Street. In the north, PMF lake flooding affects Warrawong Plaza and other commercial properties along Northcliffe Drive. It also affects commercial and industrial properties to the east of King Street in Kemblawarra, though this flooding is outside of the study area. The extent of the eastern inundation is significant, reaching up to 400 metres from the lake in some areas.

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

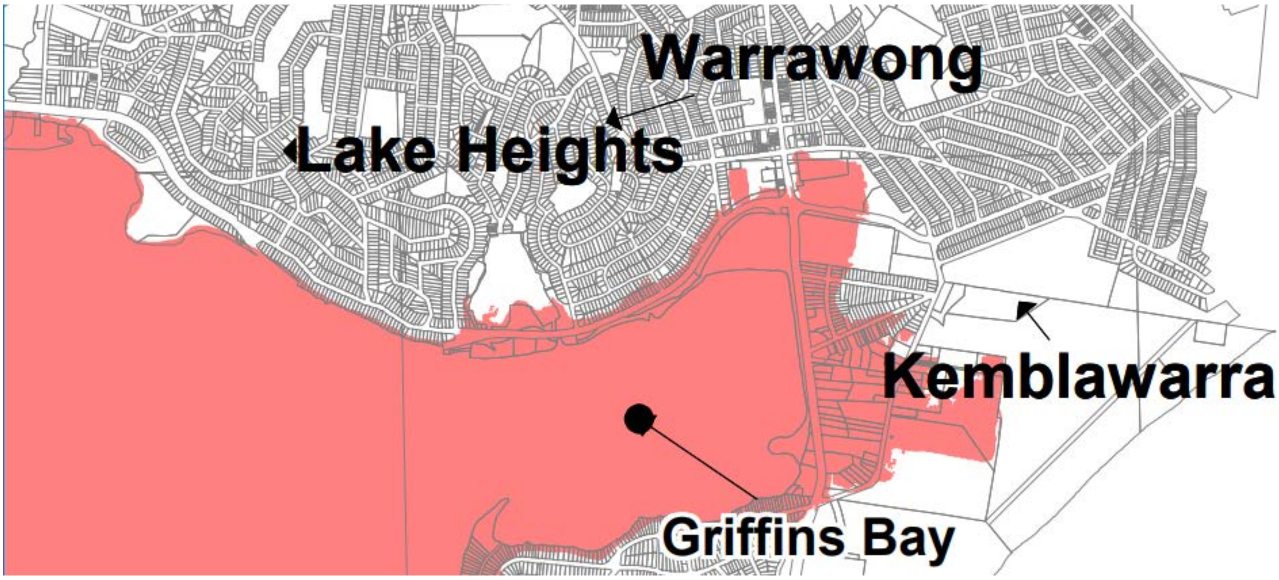


Figure 3-2 PMF Lake Illawarra Flood Extent (adapted from Cardno Lawson & Treloar, 2001)

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

Following on from the Flood Study undertaken in 2001, the 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 Kully Bay 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 Kully Bay study, these updated peak levels have been adopted for the downstream boundary of the study area.

3.2.3 Proposed Development at Warrawong Plaza (Rhelm, 2017a)

The study was undertaken for WINIM Developments to assess a proposed development for the extension of a portion of the Warrawong Plaza shopping centre.

As part of the study, a SOBEK model was developed for the catchment area. The model utilised direct rainfall, so no separate hydrological model was constructed. Buildings within the CBD were modelled as blockages, while a higher roughness value across the full lot was used to account for buildings in the wider catchment area.

The model was run for the 5% and 1% AEP events, and the PMF event.

The results demonstrated that there were confined overland flowpaths in the upper catchment areas, although some overland flow paths did impact residential areas. The majority of the flow was conveyed along King Street and Cowper Street. At the intersection of these streets in the CBD, numerous commercial premises were impacted by flooding in the 5% AEP event.

Northcliffe Drive also experienced flooding, with access lost in the 5% AEP event.

Downstream of Northcliffe Drive, flooding was largely contained within open space regions.

3.2.4 Warrawong CBD Flood Study (Rhelm, 2017b)

The study was undertaken to assess the development of a new Community Centre and Library in the Warrawong Central Business District. Council had identified three development alternatives for the site, and the study aimed to determine which was most appropriate from a flooding perspective.

The study adopted the model previously developed for the Proposed Development at Warrawong Plaza (refer Section 3.2.3). Aside from assessing the various design alternatives, the key change to the hydraulic model was the incorporation of additional ground survey that was made available, primarily covering Cowper Street and King Street, as well as the areas around the proposed Community Centre and Library.

3.2.5 Warrawong Pedestrian Upgrade Works (Rhelm, 2018)

The study was undertaken to assess the impact on flood behaviour of proposed streetscape works along Cowper Street, Warrawong. The works involved widening the northern and southern sides of Cowper Street. The study adopted the Warrawong CBD Sobek model, and incorporated additional survey of Cowper Street and a refinement of the DTM at the King Street and Cowper Street intersection.

3.3 Previous Hydrological and Hydraulic Models

A hydraulic model has been prepared for the catchment as part of the Warrawong CBD Flood Study (Rhelm, 2017b), which was an update to the previous hydraulic model used in the Warrawong Plaza flood study (Rhelm, 2017a). For this study, a SOBEK model was developed that covered the catchment area drainage to Lake Illawarra. It incorporated the majority of the study area for the Kully Bay catchment, with only some portions to the south east and south west that were not part of the model. The model utilised the direct rainfall methodology, so no separate hydrological model was required. However, a WBNM model was built for the catchment draining to the intersection of King and Cowper Streets to validate the flows observed in the hydraulic model.

The details of the hydraulic model schematisation and summarised and discussed in **Table 3-1**.

Table 3-1 SOBEK Setup Parameters

Data	Comment
Survey, Pipes and Structures	LiDAR survey data was acquired from AAM Hatch on 6 March 2017 for the local catchment area (Map G201). This data was collected in 2013, and therefore represents the catchment conditions at that time. A review of the data would suggest that it generally aligns with the conditions within the catchment at present. Additional survey data was supplied by Council which covered the driveway and carpark areas fronting King Street, together with a portion of Cowper Street and the small carpark on the northern side of the property fronting Cowper Street as well as a small section of the property fronting Northcliffe Drive. The model is 2D only and does not incorporate the pit and pipe network (effectively assuming that they are completely blocked).
Hydrologic Inputs	Design rainfalls for the study area were based on Australian Rainfall and Runoff 1987 (ARR1987). The 5% and 1% AEP events and the PMF event were assessed.

Data	Comment
Downstream Boundary	In order to be conservative, a constant tailwater level of 3.04m AHD was adopted, which reflects the 1% AEP level in Lake Illawarra for the 2100 sea level rise scenario. The backwater from Lake Illawarra at this level extends to Northcliffe Drive and the intersection with King Street and Northcliffe Drive. However, it does not influence the flooding behaviour at King Street in the vicinity of where the assessment was being undertaken for that project. This same boundary level was adopted for both the local 1% AEP and PMF analysis. This was considered a conservative adopted level for both events. It was concluded that the approach to coincident flooding be revised for the current study, in accordance with the DPIE guidance provided in *Floodplain Risk Management Guide: Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* (OEH, 2015). This approach resulted in 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 Kully Bay event. This is important as this study focuses on the full Kully Bay catchment, unlike previous studies which were focused on the CBD in the middle of the catchment, which is not influenced by Lake Illawarra flooding.
Roughness	Manning's 'n' values were determined based on field inspections, the ground survey and reference texts. The typical values adopted were: • Roads and surfaces 0.015 • Industrial Development 0.02 • Commercial Development 0.1 • Residential Development 0.1 • Open Space 0.03 • Wetlands 0.06

3.3.1 Calibration / Validation

Due to the lack of historic flood data and the scope of the work undertaken, calibration of the models was not possible. Validation was undertaken through comparing the flows from the WBNM hydrological model and Rational Method with the SOBEK hydraulic model results to ensure that the flow estimation was appropriate. This was undertaken on King Street, immediately downstream of the Montgomery Street intersection. The WBNM model used was a simplified singular catchment model and assumes all the catchment upstream of the intersection arrives at the intersection. However, some of this flow is directed down the nearby laneway, and similarly some of the flow on Montgomery Avenue is directed south down Taurus Avenue and other flowpaths. Therefore, it is expected that the WBNM model would have a higher peak flow than the SOBEK model.

The comparisons that were provided in Rhelm (2017) are reproduced in **Table 3-2**. This shows a general reasonable consistency, particularly considering the coarseness of the Rational Method and WBNM model that was used.

Table 3-2 Peak Flow Validation - SOBEK Model

	SOBEK	Rational	WBNM
Peak Flow (m3/s)	18	15	23

3.3.2 Design Runs

Modelling was only undertaken for the 5%, 1% AEP events and the PMF events as part of this study.

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 3-3**.

Table 3-3 Policy and Planning Documents

Document	Relevance to the Study
Wollongong Development Control Plan (WCC 2009)	This Overland Flow Study has produced 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 Overland Flow 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. The information presented in this Overland Flow Study can be used to update this. This Overland Flow 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 8.3**.
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

Document	Relevance to the Study
	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".
Riparian Corridor Management Study (DIPNR, 2004)	The Riparian Corridor Management Study was prepared in response to the 1999 Commission of Inquiry into the "Long Term Planning and Management of the Illawarra Escarpment". The study area includes all of the Wollongong Local Government Area. Three categories of riparian environmental objectives were developed for the streams in the study area. For each of the categories, the recommended minimum width of the riparian zone varies in order to achieve the functioning identified by the objective being sought. The requirements of this study have been considered when evaluating the impact of increased development (Scenario 5).

3.5 Survey Information

3.5.1 Aerial Survey

LiDAR data was captured 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 3-4**. It should also be noted that these are reported to the 95% confidence level. 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 (12 in total) were taken along Cowper Street and King 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 0.06m. The level difference was consistent, ranging from 0.02 to 0.08m. 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 3-4 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

Ground survey data was provided by Council for the purposes of this assessment. The ground survey covered the intersection of King and Cowper Streets, and extended approximately 250m along both King Street and Cowper Street from the intersection.

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; and,
- Pipe locations and sizes.

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 two prior flood events. Flood marks were collected for:

- March 1975 (two marks); and,
- February 1984 (one mark).

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

All of the flood marks are south of Northcliffe Drive and west of King Street, in the open space surrounding the wetland. The 1975 and 1984 events were widespread and resulted in flooding of Lake Illawarra. The location of the marks suggest that they were the result of Lake Illawarra flooding, rather than local catchment flows.

As a result, the flood marks are not suitable for calibration or validation of the Kully Bay model.

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 3-5, Table 3-6** and **Table 3-7,** together with key information on whether they are pluviometer or daily gauges, and whether they were operational during the historical storm events identified by Council. 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. Many of these stations are discontinued, however, between both discontinued and existing gauges, a long period of daily rainfall record is available. The closest gauges operated by the Bureau of Meteorology to the study area are the Berkeley (Northcliffe Drive) gauge (approx. 3km west) and Port Kembla (BSL Central Lab) gauge (approx. 2km northeast), both operated by the BoM. Neither gauge has pluviometer data, they 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. A pluviometer operated by MHL is located at Port Kembla, approximately 1.5km north of the catchment.

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 6**.

Table 3-5 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 3-6 Sydney Water Rain Gauges

			Operational During Storm Events				
Site	**Name**	**Pluvio**	**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 3-7 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 are currently no stream gauges in operation within the Kully Bay catchment area.

3.9 Water Level Data

Water level information was available for Lake Illawarra. However, given the flood model has adopted constant downstream levels taken from the *Lake Illawarra Flood Study* (Lawson and Treloar, 2000), the time series data was not utilised in the Kully Bay Overland Flow Study (refer **Section 7.2**).

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.

4.1 Consultation Strategy

The consultation strategy outlined in **Table 4-1** describes the adopted 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.
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 has informed the selection of appropriate consultation methods.
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 Overland Flow Study; and ▪ Develop and maintain community confidence and collaboration with the study results.
Methods	A methods selection and associated goals are provided in **Table 4.3**.

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 Overland Flow Study.

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
Interested Agency Stakeholders				
Wollongong City Council – departments not directly involved in the preparation of the 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

Stakeholder	Level of Impact	Level of Interest	Level of Influence	Recommended Type of Consultation
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 methods.	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.
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.

Method	Stakeholders	Example Goals	Timing	Responsibility / Details
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 has 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 Draft Study.	Following completion of the Draft Study.	Rhelm has provided documents and posters and provided input to media releases regarding the public exhibition period.
Public information session 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	Following completion of the Draft Study.	Rhelm prepared posters and animations detailing flood behaviour across the study area. Rhelm participated in one on one discussions at community information sessions.

Method	Stakeholders	Example Goals	Timing	Responsibility / Details
		one on one sessions). ▪ Provide an opportunity for feedback on the Draft Study.		
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 throughout the study process.	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 A**.

4.3 Community Update and Survey

A two-page community update was distributed to 455 dwellings within the Kully Bay catchment. The recipients were identified where they were in the vicinity of preliminary flood mapping of the likely PMF extent undertaken by Council. The community 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 13 responses were received via mail and online. This represents only 3 percent of the surveys delivered. 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 A**.

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: 28 Years
Are you aware of flooding in the study area?	Not aware: 38% (5) Some Knowledge: 15% (2) Aware: 46% (6)
Have you ever seen flooding in the catchment?	Yes: 46% (6) No: 46% (6) No response: 8% (1)
Flooding dates observed by respondents.	Every year (2006 – 2018) 1970 November / December 1999 February 2012 June 2016 March 2017 January 2018
Flood behaviour observed.	The descriptions and locations of survey responses are shown in Appendix A). • Flooding at North end of Carlotta Crescent (road, carpark and football ground). • Flooding on Northcliff Drive and King Street and impacting Warrawong Plaza. • Flooding at Warrawong Shopping centre due to blocked inlet drainage pit. • Flooding in old K-mart carpark and along King Street (now Bunnings area). • Flooding up to shop entrances along King Street, flooding rises and falls quickly. • Flooding into medical centre entrance on Cowper Street.
Have you seen flood or storm water enter businesses or shops in the Warrawong CBD?	Yes: 54% (7) No: 38% (5) No response: 8% (1)

4.4 Door Knocking

Door knocking was undertaken over two days (14th – 15th 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 45 properties answered the door. This represents an engagement rate of 80 percent.

Residents and businesses 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, as no clear information was gained on flood observations and a related storm event. Further information on the door knocking results is presented in **Appendix B**.

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

- The engagement rate (80%) 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 were contacted prior to the public exhibition of the draft report 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.

Agency Stakeholder	Outcome of Consultation
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.
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.

Agency Stakeholder	Outcome of Consultation
Sydney Water	Sydney Water advised that they have a pumping station (SP0177) in the study area at the south-east corner of Northcliffe Dr and King St, Warrawong. No records of any past flood impacts or remediation of flood-related damages. We have no major infrastructure in the study area. In terms of study outputs of value – extents, depths, velocities, durations and hazard classification are all useful.
Telstra	No response received.

4.6 Public Exhibition

The Kully Bay Overland Flow Study was placed on Public Exhibition from 26 August to 23 September 2019.

During the pubic 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 on 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 public 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 also interest in the flood gates at the entrance of Warrawong Mall.

5 Flood Modelling

5.1 Modelling Approach Overview

While a SOBEK model was previously prepared for an earlier study (Rhelm, 2017), the decision was made in conjunction with Council to construct a new Tuflow model for this assessment. The primary reason for this was to provide consistency with other Council studies, including the Minnegang Creek Flood Study that is being undertaken in parallel by Rhelm.

5.2 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 the Wollongong LGA 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.

5.3 Hydrological Model

As per the SOBEK model (Rhelm, 2017), the Tuflow model was run using the Direct Rainfall methodology, where rainfall is directly applied to the 2D domain, so no separate hydrological model was utilised in the hydraulic model. This methodology is typically adopted where there are complex flowpaths, and an understanding of the smaller flowpaths within the catchment are required.

The design rainfall intensities adopted for the modelling are identified in **Table 5-1**.

An initial and continuing loss approach was adopted to estimate the rainfall excess. The parameters for the initial and continuing loss are provided in **Table 5-2**. The land use areas correspond with the roughness land uses that were adopted (**Section 5.4**) and are shown in **Map G502**.

Table 5-1 ARR 87 Design Rainfalls(mm)

Duration	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 5-2 Initial and Continuing Loss

	Assumed % Impervious	Initial Loss (mm)	Continuing Loss (mm/hr)
Pervious Areas	0	10	2.5
Impervious Areas	100	2	0
Carpark	100	2	0
Roads	100	2	0

	Assumed % Impervious	Initial Loss (mm)	Continuing Loss (mm/hr)
Residential	60	5	1
Open Space/ Parkland	10	9.2	2.4
Riparian & Medium vegetation	0	10	2.5
Water	-	0	0

5.4 Hydraulic Model

5.4.1 Digital Elevation Model

A Digital Elevation Model (DEMs) has 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 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; and
- Collected ground survey (refer **Section 3.5**).

5.4.2 Model Development

The purpose of the Kully Bay model is to define the mainstream and primary overland flows in the study area.

The focus of the model area is on incorporating creeks, stormwater infrastructure 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 G501**.

Grid Cell Resolution

The extent of urban area across the catchment suggests that a higher resolution grid domain would be more appropriate to represent flow paths through built up areas and along roadways. 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.

Roughness

Roughness values were determined based on land use mapping and aerial photography. The values adopted are summarised in **Table 5-3** and shown in **Map G502**.

Table 5-3 Adopted Roughness Values

Land Use	Manning's 'n'
Residential	0.1
Open Space / Parklands	0.03
Vegetation	0.05
Roads	0.015

Land Use	Manning's 'n'
Carparks	0.02
Water / Lakes	0.0

1D Components

Key stormwater infrastructure 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 and from the available survey data. Some smaller pipe reaches were included in order to extend the pipe network to road sag points, or where they provided a localised connection to an inlet pit.

Blockage has been applied to inlet pits and culverts. A detailed discussion of the blockage methodology is provided in **Section 7.3**.

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 be 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 several 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 null objects, based on aerial imagery, which effectively removes them from the model domain. The flowpaths were identified based on preliminary runs of the PMF event. Buildings were raised only nulled within the flood extents (see **Map G501**). Rainfall inputs to the model were scaled appropriately to take into account the nulled areas.

Warrawong Plaza was assumed to be completed impervious to flow. It is noted that there is some additional storage in the basement of the plaza that would be activated during a flood event. However, given this is a regional overland flow assessment, this area was conservatively not included in this model.

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

In a typical flood study, a calibration is undertaken by comparing observed flood behaviour, including recorded flood levels where available, against the flood behaviour determined from the flood model. This is done by obtaining or estimating the historical rainfall on the catchment for a particular historical flood event, and then reviewing the flood behaviour in the flood model to determine if it is consistent with observations. This provides greater confidence in the flood model results and assists in understanding the level of potential uncertainty.

In Kully Bay, 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), approximately 1.5 kilometres from the catchment. While this is not a significant distance from the catchment, 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 known historical events within the catchments.

In addition to the rainfall data, many of the historical flood observations from the community (**Section 4**) were not specific to a particular date or flood event. In many cases, residents recalled a general period of time (for example, around 15 – 20 years ago), or a general frequency (for example, inundation of a particular area occurs every few years). This makes it difficult to assign a particular flood behaviour that was observed against a particular historical storm event.

Due to these challenges, it was agreed with Council that a full calibration against historical events would not be undertaken. Instead, an indirect calibration was undertaken on the modelling. This was undertaken in two ways; through a comparison of the model behaviour for design events against the observations, and a comparison of the model behaviour against the previous SOBEK model (Rhelm, 2017). This section of the report has three key components:

- A review of the historical rainfall intensities – this provides an indication of the frequency and magnitude of historical events within the catchment (**Section 6.1**);
- A comparison of the modelled design events against the observations by the community (**Section 6.2**); and,
- A comparison of the design events against the previous SOBEK model (Rhelm, 2017) (**Section 6.3**).

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

6.1 Rainfall Intensity Assessment

An assessment of rainfall data can provide an indication of the magnitude of the rainfall events that may have been experienced within the catchment. The nearest rainfall gauge to the study area with pluviometer data available is the Port Kembla (MHL) gauge (refer to **Section 3.7** and **Map G303** for gauge details and location). This gauge is approximately 1.5 km from the catchment to the north and an analysis of the rainfall may not necessarily represent local rainfall that falls on the catchment due to the variable nature of rainfall patterns in this area.

A common approach when there is no gauge within a catchment is to review surrounding rainfall gauges to understand how a storm event may have moved across the catchment and allow for an interpolation of the likely rainfall that fell on the catchment. Unfortunately, the next nearest pluviometer for the historical events that were identified was at Dapto Bowling Club, which is approximately 12 km away from the catchment. This makes it difficult to determine any localised movement of the rainfall during the period of a storm event.

An alternative is to use daily rainfall gauges. However, Kully Bay typically responds to short duration rainfall events (i.e. less than 6-hour events). Understanding how these rainfall events move across a catchment is difficult to represent through a daily read rainfall gauge. Further, as identified on Map G303, the nearest daily read gauge is nearly 3 kilometres to the west at Berkeley, again making it difficult to represent potential changes in rainfall patterns across a catchment for a short duration storm.

To provide an indication of the general magnitude of historical rainfall events that were identified by the community (**Section 4**), an analysis of the Port Kembla (MHL) gauge was undertaken. Design rainfalls for ARR87 IFD data for design events was sourced from the BoM and are summarised in **Table 5-1**. Average rainfalls were determined for each of the historical events for durations ranging from 30 minutes to 3 hours. These historical events coincide with those identified by the community or from previous studies (such as those that were identified for the Minnegang Flood Study currently being undertaken by Rhelm). The results are shown in **Figure 6-1**.

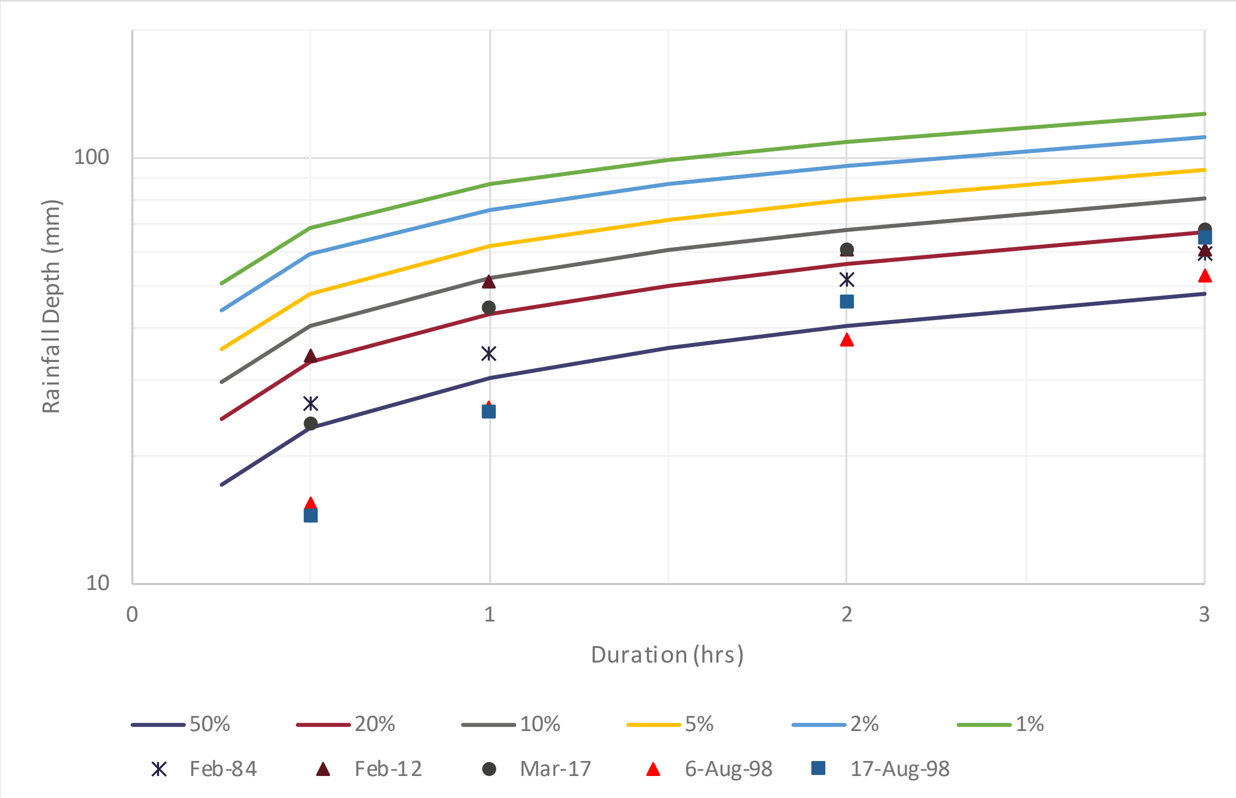


Figure 6-1 Port Kembla Gauge Historical Event Intensity Compared to ARR87 Intensity

For the March 2017 event, at the critical duration (2 hours), the rainfall is roughly a 20% AEP. For the February 2012, this appeared to be more significant, with it being closer to a 10% AEP for a 1 hour duration, and therefore may have been more significant in some areas of the catchment. The February 1984 event, which was regionally significant for the Wollongong LGA, was only between a 50% AEP and 20% AEP at the Port Kembla (MHL) gauge.

1998 was identified as a year when flooding occurred by a number of community members during door knocking, with community members either recalling specifically 1998 or an event approximately 20 years ago. There were two rainfall events in August 1998 which were a few weeks apart. One event around the 6 August 1998, and the other around the 17 August 1998. An analysis of the rainfall suggests that for short durations, these events were smaller than a 50% AEP, but the 17 August 1998 was closer to a 20% AEP for the 3 hour event. However, the available observations from residents suggested that this event was perhaps larger than this, which may have meant that the rainfall over the catchment was more intense than at the Port Kembla Gauge.

An analysis was also undertaken on the full rainfall record for the Port Kembla (MHL) rainfall gauge, for the 2 hour duration. The results of this are provided in **Table 6-1** below. 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 Analysis of Port Kembla (MHL) Rainfall Record for a 2 hour critical duration

Event	Rainfall Depth (mm)	Approximate AEP	Mentioned by Community in Survey/ Door Knocking
March 1994	106.5	~1%	No
May 1983	99.0	2% - 1%	No
April 2009	69	~10%	No
February 2012	61.5	~10%	Yes
March 2017	61	20% - 10%	Yes
November 1984	59.0	20% - 10%	No
November 2013	55.5	~20%	No
April 2004	53	50% - 20%	No
May 1989	47.5	50% - 20%	No

6.2 Comparison with Community Survey Descriptions

As a part of the community survey and door knocking (refer **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 in the study area.

An indirect verification of the modelling was undertaken by comparing the flood behaviour in the model for the design rainfall events (50%AEP, 20% AEP, 5% AEP and 1% AEP) against the observations from the community (refer **Map G601**). The design events provide an indication of the frequency and the level of magnitude of that frequency. By reviewing the potential magnitude of the events (where an event is identified by the community), it is possible to compare the general model behaviour for that event against the community observation.

The generalised descriptions of flood behaviour, together with the modelled behaviour, is provided in **Appendix B**. This indicates a general level of consistency between the modelling and the observations from the community.

6.3 Comparison with previous SOBEK model

A SOBEK model was prepared for the study area as part of an earlier study undertaken by Rhelm (2017) (refer **Section 3.2**). A comparison was undertaken between the 1% AEP results from the earlier SOBEK model and the Tuflow model built for this study. It is noted that the SOBEK model did not include stormwater drainage infrastructure (pipes) within the model, assuming conservatively that these were blocked. Therefore, in order to undertake the comparison, the Tuflow model was analysed without the stormwater infrastructure.

The comparison is shown in **Map G602**.

The map shows that the models generally resulted in comparable levels. Throughout the central area of the model along King Street the model results are within 0.1 metres of each other, which was the focus of the SOBEK model.

There were some areas that showed some difference in levels between the models. In the south western and south eastern regions of residential developments, the Tuflow model showed increased flooding around these properties. This was a direct result of blocking out these properties in the model. In the SOBEK model, this area was represented by a high residential roughness, with no raised buildings, as the raising was restricted to the central business district and major northern flowpaths which were the focus of the previous study. As the current study is focused on the catchment as a whole, additional buildings were raised along this southern flowpath, resulting in the increases in flood levels observed.

The reductions in flood levels south of Northcliffe Drive are a result of the more conservative downstream boundary assumption that was adopted for Lake Illawarra in the SOBEK model. As the SOBEK model was more concerned with areas around King Street and Cowper Street, the levels adopted for Lake Illawarra were less important and a conservative level was adopted. This level was considered to be too conservative for Council planning purposes and inconsistent with DPIE guidance (**Section 7.2**).

The western end of Cowper Street is observed to have some of the larger changes in water level along roads. The steepness of this area, and the difference in sampling of the terrain between the models, may lead to some of these differences.

The SOBEK model also provides a method to undertake a verification of the hydrological analysis of the Tuflow model. A comparison was undertaken between peak flows in the model. The comparison was undertaken at King Street, immediately upstream of the Cowper Street intersection. Flow in this region is well contained, and the flowpath is significant. The results for the 5% and 1% AEP events are shown in **Table 6-2**.

For both events, Tuflow reports slightly lower peak flows, although the differences are less than 5% in both cases. This suggests that the Tuflow model is consistent in peak flow estimation with the SOBEK model.

Table 6-2 Peak Flow Comparison

Event	Sobek (cumecs)	Tuflow (cumecs)	Difference
20% AEP	13.3	12.9	-3%
1% AEP	18.0	17.1	-4%

6.4 Outcomes

The validation of the model was based on an indirect comparison of the model behaviour with the observed flood behaviour from the community, and a comparison of the flood model against the previous SOBEK model (Rhelm, 2017) that was developed within the study area.

The results indicate that the flood model is generally producing results consistent with the previous SOBEK model, and generally in line with the observations from the community.

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.

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 Kully Bay catchment as well as backwater from Lake Illawarra. Lake Illawarra has a significantly larger catchment (which includes the Kully Bay catchment), and a floodplain which requires much longer duration rainfall to achieve a peak flood level. It is also influenced by ocean levels and the associated 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 Kully Bay catchment. Applying a 1% AEP in the Lake Illawarra at the same time as a 1% AEP in Kully Bay 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.

Within the Kully Bay catchment, there were no hydraulic structures (e.g. bridges, culverts) that would be subject to the blockage policy within the model area. There is a small bridge crossing the Kully Bay Wetlands, but as flooding in this region is driven by backwater from Lake Illawarra, blockage of this structure was not analysed. As such, it has not been necessary to apply this policy to the Kully Bay modelling.

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.

For each design event, models were run for a blockage scenario, incorporating the above pit blockage factors, and an unblocked scenario, with no blockage applied. The results reported in this study are an envelope of these scenarios, unless noted otherwise.

7.4 Design Flood Events

Using the parameters as identified above, the hydrological and hydraulic models were analysed for the PMF, 1% AEP, 2% AEP, 5% 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 critical durations that dominate for each event are summarised in **Table 7-2**.

Table 7-2 Event Critical Durations

Design Event	Critical Duration
PMF	90 min
1%	90 min
2%	120 min
10%	120 min
20%	120 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 in **Maps G701-1** to **G701-6** for peak depth and water levels, and **Maps G702-1** to **G702-6** for peak velocity. These maps are provided in **Volume 2** of this report. A summary of peak water levels and peak discharges at key locations in the model are provided in **Appendix C**.

Long sections along King Street and Cowper Street are shown in **Figure 7-1** and **Figure 7-2** respectively.

Cross sections have been taken at the King Street / Cowper Street intersection, at the locations shown in **Figure 7-3**. These cross sections are shown in **Figure 7-4** and **Figure 7-5**.

The long section and cross section figures show that there is little difference in peak levels for events from the 20% AEP to the 1% AEP event.

The long sections show that levels in the PMF were higher along the full length of King Street. The relatively steep grades along the western and eastern ends of Cowper Street resulted in the PMF having similar peak levels to other design events along these steeper sections, although a marked increase in PMF levels was observed at the low point of the Cowper Street – King Street intersection.

The cross section plots show that all the modelled events resulted in the inundation of the adjacent footpaths for both King Street and Cowper Street. Flooding in the PMF was noticeably higher than the other design events, reaching 0.29m higher than the 1% AEP at King Street and up to 0.46m higher at Cowper Street.

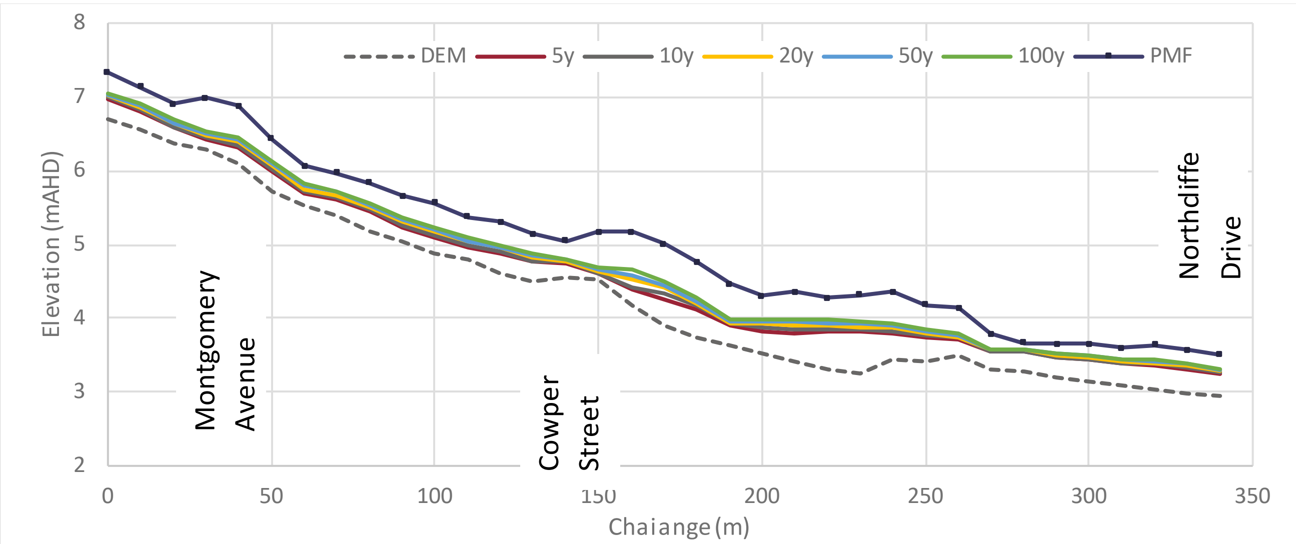


Figure 7-1 King Street Long Section

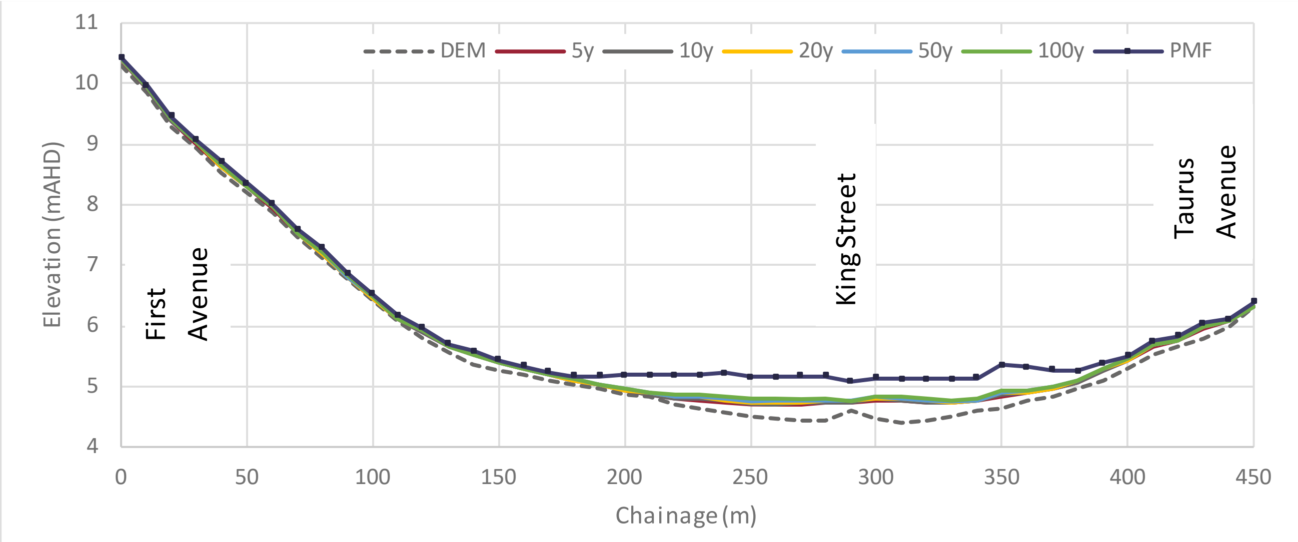


Figure 7-2 **Cowper Street Long Section**

Figure 7-3 **Cross Section Locations**

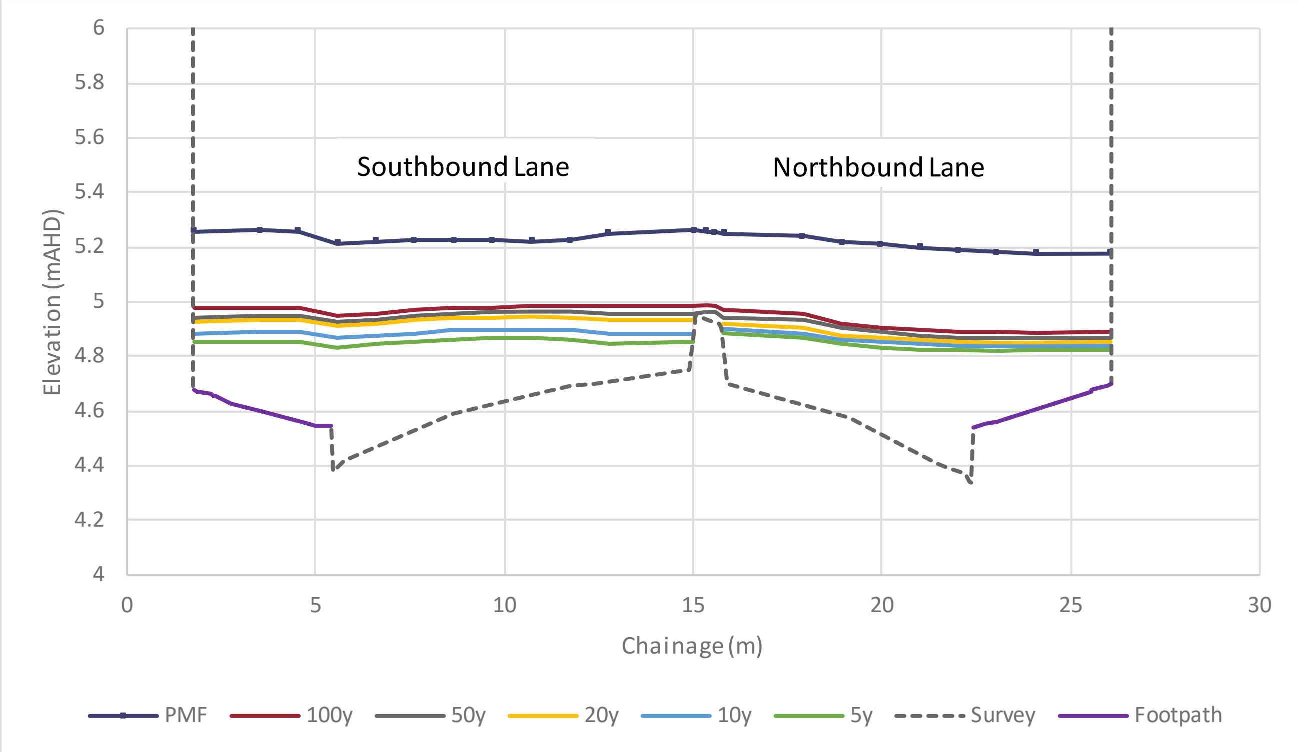


Figure 7-4 **King Street Cross Section**

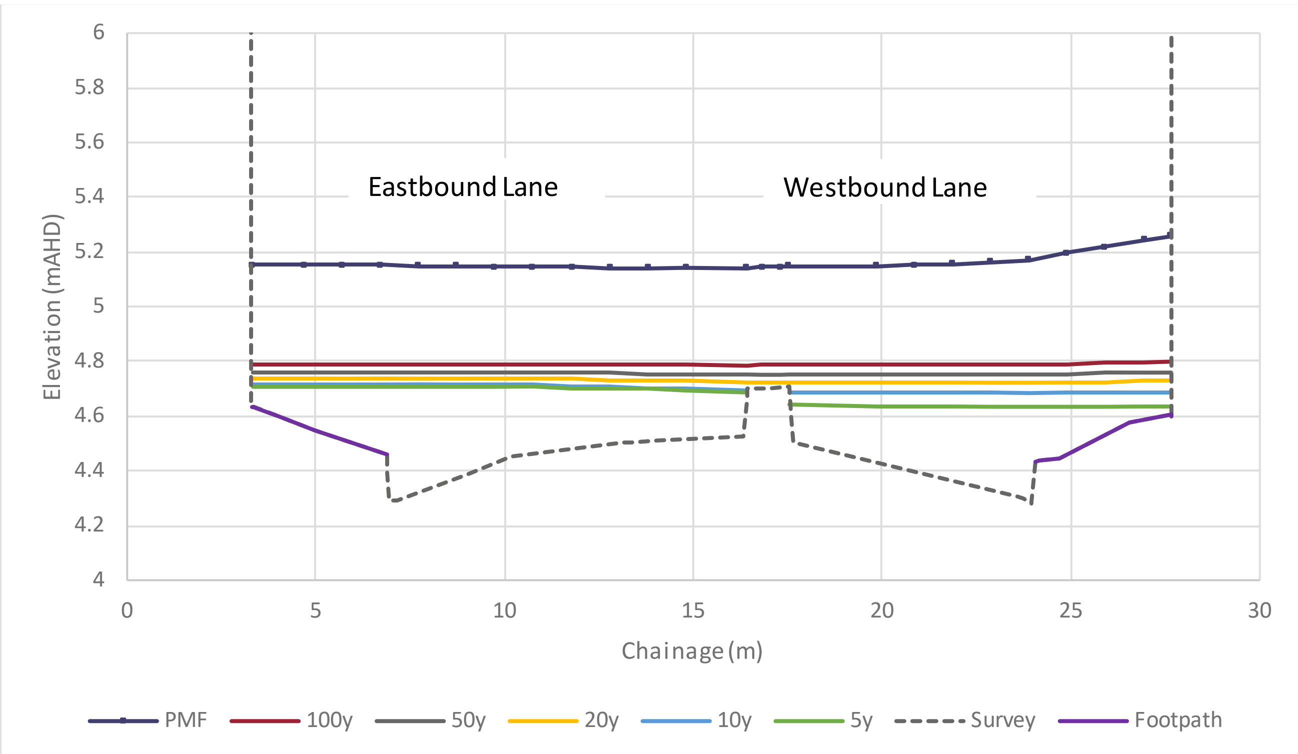


Figure 7-5 **Cowper Street Cross Section**

7.5 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.

Hazards have been mapped based on the criteria set out in *Australian Disaster Resilience Guideline 7-3: Technical flood risk management guideline: Flood hazard* (Australian Institute for Disaster Resilience, 2017).

The hazard categories mapped are summarised in **Table 7-3** and **Figure 7-6**.

Flood hazard mapping is provided for the PMF and 1% AEP events in **Maps G703-1** to **G703-2**. These maps are provided in **Volume 2** of this report.

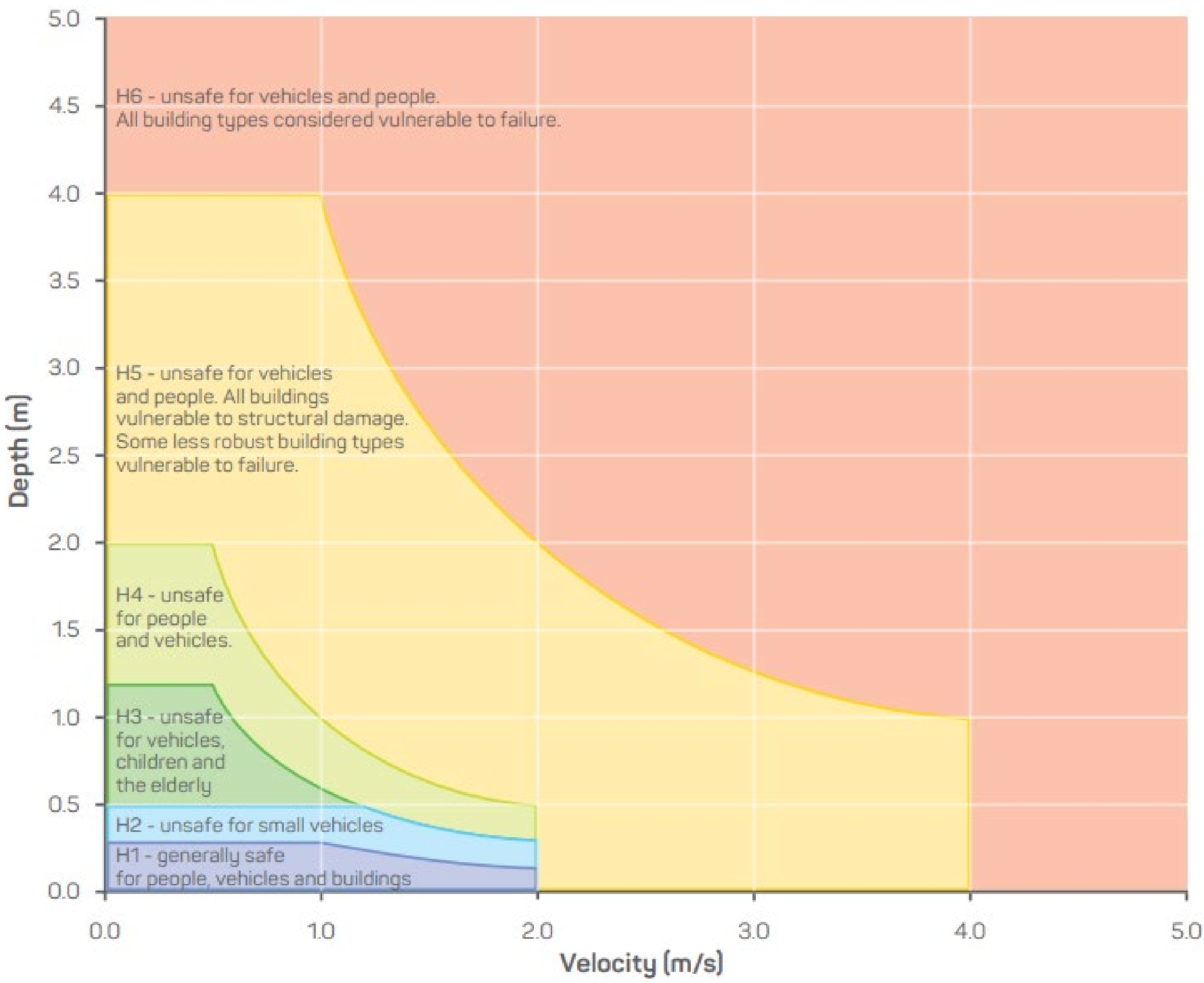


Figure 7-6 Flood Hazard Categories (AIDR, 2017)

Table 7-3 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

7.6 Flood Function

Identifying the flood functions is common in many flood studies to understand areas of key conveyance and important storage areas. In the Kully Bay study area it was found that the majority of floodways are constrained to road reserves, which represent some of the key flowpaths. Further, the majority of the flow is overland flow, and may not be appropriate to define floodways in the traditional sense. Therefore, flood function was not included in this study.

7.7 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 Kully Bay 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

Within the catchment area, there were three broad categories of flooding:

- Overland flow through the urban regions of the upper catchment;
- Flows within the vicinity of King Street, Cowper Street and Montgomery Avenue, which convey the bulk of the flood; and
- Flooding downstream of Northcliffe Drive, driven by a combination of catchment flow and elevated lake levels.

A comparison between the peak flood extents for the 20% AEP, 5% AEP, 1% AEP and the PMF are shown in **Map G801**.

8.1.1 Overland Flowpaths

Flood extents are generally similar for events up to and including the 1% AEP. However, there is a marked increase in flood extent in the PMF, with additional overland flowpaths activating between buildings in the event.

There are five major overland flowpaths through the catchment area, with varying degrees of flood severity. A summary of road overtopping arising from these flowpaths is presented in **Table 8-1**.

Three of these overland flowpaths are located west of King Street. The first two run from Second Avenue, past First Avenue and into Bent Street. The first is then conveyed along Greene Street, while the second spreads widely through the multi-unit dwellings at Todd Street. Only the first flow path results in flows that limit road access, with depths of greater than 0.3m occurring at First Avenue in the 2% AEP event.

The third flowpath on the west runs from First Avenue, across Bent Street and into King Street near the north of the catchment. Access along Bent Street is lost in events as small as the 20% AEP due to flows from this flowpath by depths of up to 0.5 metres.

On the east side of King Street are the two remaining overland flowpaths.

The northernmost flowpath runs adjacent to Storey Street before crossing Robertson Street and then McGowen Street. At Shellharbour Road, the flow disperses, with some passing down Montgomery Avenue, and the rest spilling through residential blocks to Cowper Street. Along this flowpath, vehicle access is lost at both Robertson Street (>1% AEP) and Shellharbour Road (5% AEP).

The final overland flowpath conveys flow from the far east of the catchment. Flows commence upstream of Cowper Street, before flowing through residential zones across Forster Street and Shellharbour Road. It then passes along the northern side of Northcliffe Drive until the plaza, where it combines with the backwater from the lake and wetlands. This flowpath results in access being lost along both Foster Street and Shellharbour Road in events as small as the 20% AEP.

Table 8-1 Urban Overland Flow Road Overtopping

ID	Location	Event Overtopped
UO1	First Avenue North	2% AEP
UO2	Bent Street	20% AEP
UO3	Robertson Street	>1% AEP
UO4	Shellharbour Road (north)	5% AEP
UO5	Forster Street	20% AEP
UO6	Shellharbour Road (south)	20% AEP

Figure 8-1 Location of Urban Overland Reporting Locations (with 1% AEP Flood Depths)

8.1.2 Flooding Along Major Roads

There are no creeks or rivers to convey flood water within the catchment area. When the stormwater drainage infrastructure capacity is exceeded, road reserves become the primary flowpaths conveying water through the catchment, and the previously discussed urban overland flowpaths discharge into road reserves rather than creek channels.

The primary flowpath through the catchment is along King Street, which runs north-south through the centre of the catchment. With the exception of some overland flow from the far eastern and western sides, all flow within the catchment eventually reaches King Street. Other significant flows are conveyed along roads that run perpendicular to King Street – Cowper Street and Greene Street / Montgomery Avenue in particular (which then discharge into King Street). Between them, these three road reserves serve as the major flowpaths through the catchment.

Within the road reserves of King Street, Cowper Street and Montgomery Avenue there was little difference in extent between the 20% AEP and the PMF. This is due the flow being primarily contained to the road reserve despite the increasing depth. Along King Street this is primarily a result of the dense commercial buildings on each side of the road constraining the active flow. The PMF does show additional flow breaking out of the road reserve and flowing between buildings in the CBD in the block south of Greene Street and Montgomery Avenue.

Vehicle access along King Street is lost for much of its length during flood events. While the northern section is only affected in events of a 2% or 1% AEP magnitude, the lower sections, in particular around the Cowper Street intersection, are inundated in events as small as the 10% AEP. This serves to largely divide the catchment in half from an access perspective with limited ability to cross from one side of the catchment to the other in events above a 5% AEP.

The extent of lost access is not as pronounced for the roads crossing King Street. East-west roads largely remain trafficable, including in large events up to the 1% AEP, with access lost only for 50-60 metres from the King Street intersections.

Peak depths along King Street remain below 0.5m for all flood events for flooding north of Greene Street / Montgomery Avenue. However, depths increase substantially for larger events at the Cowper Street intersection with modelled depths of up to 1.1 metres in the PMF event and 0.7m in the 1% AEP event.

Depths across Northcliffe Drive were substantial for a larger range of flood events, with depths of over 0.8m observed at the King Street intersection in events as small as the 10% AEP.

Table 8-2 Road Reserve Overtopping

ID	Location	Event Overtopped
MR1-N	King Street, northbound, corner of Turpin Avenue	1% AEP
MR1-S	King Street, southbound, corner of Turpin Avenue	2% AEP
MR2-N	King Street, northbound	10% AEP
MR2-S	King Street, southbound	1% AEP
MR3-N	King Street, northbound, corner of Greene Street	5% AEP
MR3-S	King Street, southbound, corner of Montgomery Avenue	5% AEP
MR4-N	King Street, northbound, corner of Cowper Street	10% AEP
MR4-S	King Street, southbound, corner of Cowper Street	10% AEP
MR5	Montgomery Avenue, corner of Churchill Avenue	1% AEP
MR6	Cowper Street, west of King Street	5% AEP
MR7	Cowper Street, corner of Taurus Avenue	>1% AEP

Figure 8-2 Location of Major Road Reporting Locations (with 1% AEP Flood Depths)

8.1.3 Downstream Flooding

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 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 (refer **Section 7.2**).

Access along Northcliffe Drive is lost at multiple locations within the study area. A summary of road overtopping along Northcliffe Drive is presented in **Table 8-3**. The summary shows that aside from the intersection with First Avenue South, all of the intersections along Northcliffe Drive within the study area are inundated in events as small as the 20% AEP. The flooding is most pronounced east and west of the King Street intersection with depths of up to 1 metre in the 1% AEP.

Shown in **Table 8-4** is a comparison between peak flood levels from the catchment model and the Lake Illawarra Flood Model. For the 5% AEP event, catchment flooding results in greater peak water levels along all of Northcliffe Drive. In the 1% AEP, lake flooding is more severe at those two locations closest to the lake. In the PMF event, lake flooding is more severe than catchment flooding across Northcliffe Drive for all locations, save the final location (NC 5), which is located furthest from the lake.

Table 8-3 Urban Overland Flow Road Overtopping

ID	Location (Corner of Northcliffe Drive and ...)	Event Overtopped
NC1	Walker Street	20% AEP
NC 2	Margaret Street	20% AEP
NC 3	First Avenue South	2% AEP
NC 4	King Street (west of intersection)	20% AEP
NC 5	King Street (east of intersection)	20% AEP

Table 8-4 Comparison of Flood Levels Arising from Catchment and Lake Flooding

ID	Kully Bay Overland Flow Study			Lake Illawarra Flood Study		
	5% AEP	1% AEP	PMF	5% AEP	1% AEP	PMF
NC1	1.98	2.06	2.52	1.81	2.24	3.24
NC 2	2.11	2.16	2.70			
NC 3	2.62	2.66	2.91			
NC 4	2.91	2.95	3.23			
NC 5	3.08	3.11	3.33			

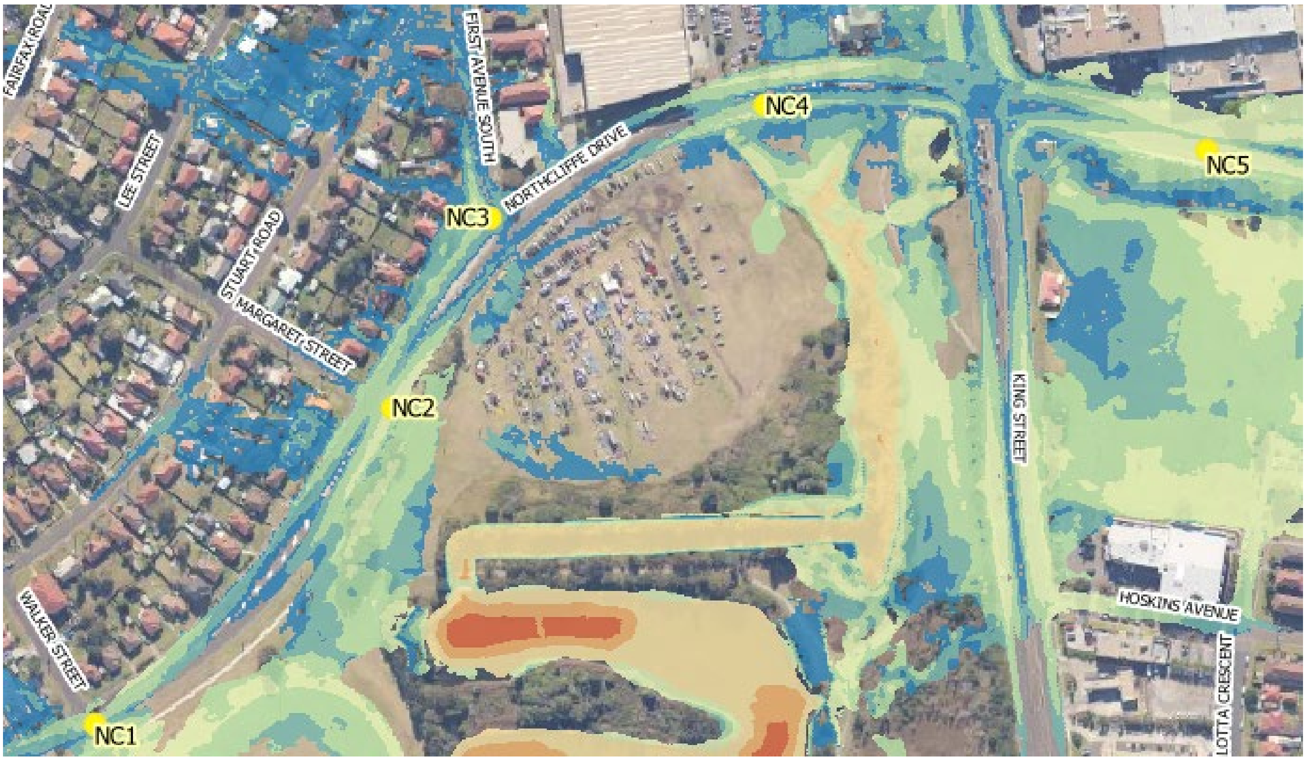


Figure 8-3 Location of Downstream Reporting Locations (with 1% AEP Flood Depths)

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. If the 1% AEP +0.5m extended beyond the PMF extent, the Flood Planning Area was limited to the PMF extent.

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

8.3 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 8-5** for both the PMF and 1% AEP events.

The table shows that the catchment is primarily driven by flash flooding, with all roads inundated within 0.5 hours of the storm commencing. The majority of 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 begin to fall.

Table 8-5 Road Overtopping

Location	1% AEP		PMF	
Location	Time to Overtopping (hrs)	Time of Overtopping (hrs)	Time to Overtopping (hrs)	Time of Overtopping (hrs)
Urban Overland Flowpaths				
UO1	<0.5	1.5	<0.5	2.5
UO2	<0.5	>3	<0.5	>3
UO3	<0.5	0.5	<0.5	1
UO4	<0.5	1.5	<0.5	>3
UO5	<0.5	2.5	<0.5	>3
UO6	<0.5	2.5	<0.5	>3 *
Road Reserve Flooding				
MR1	<0.5	1	<0.5	1
MR2	<0.5	1	<0.5	1.5
MR3	<0.5	1.5	<0.5	2.5
MR4	<0.5	1.5	<0.5	>3 *
MR5	<0.5	0.5	<0.5	1
MR6	<0.5	0.5	<0.5	1
MR7	<0.5	0.5	<0.5	0.5
Northcliffe Drive Flooding				
NC1	<0.5	>3	<0.5	>3 *
NC 2	<0.5	>3	<0.5	>3 *
NC 3	<0.5	1	<0.5	1
NC 4	<0.5	>3	<0.5	>3 *
NC 5	<0.5	>3	<0.5	>3 *

** The timings of these crossings are governed by 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;
- Model Inflows; and
- Blockage assumptions.

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

Sensitivity testing was undertaken for the 1% AEP. Climate change was assessed for the 1% AEP and the PMF.

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 G901-1** to **G901-2**.

Increases in model roughness result in increases in peak water level of up to 0.1 metres, but generally less than 0.05 metres.

The model was more sensitive to reductions in roughness than increases. Increased roughness values resulted in widespread but minor increases of 0.01 – 0.03 metres through much of the catchment upstream of Northcliffe Drive, including the overland flowpaths, and the major flowpaths along King and Cowper Streets. As a result of this delaying the flow of water across the catchment, levels in the downstream wetland reduced by up to 0.3m.

Under the decreased roughness scenario, the overland flowpaths saw minor reductions of 0.01 – 0.02 metres. The increased runoff resulted in increased water levels along Cowper Street, west of King Street, of up to 0.1m. Increases along King Street and the eastern side of Cowper Street were not as significant, with increases observed of 0.05 – 0.08 metres. Along Northcliffe Drive, and through the downstream wetland, increases were more pronounced with increases of up to 0.2 metres along Northcliffe Drive and 0.3 metres through the wetland.

This suggests that the model is insensitive to model roughness, with a change in levels of typically less than 0.05 metres arising as a result of a 20% change in model roughness in the 1% AEP event.

9.2 Model Inflows

The inflows to the model were tested by increasing and decreasing the inflows 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 G902-1 to G902-2**.

Increases in rainfall intensity of 20% resulted in increases in peak water level of generally less than 0.05 metres throughout the catchment area. Increases of up to 0.08 metres were observed at the major King Street intersections. Downstream of Northcliffe Drive, some levels increased by 0.1 metres, but these changes did not impact any development. Rainfall intensity reductions were similar, with reductions of less than 0.05 metres throughout the catchment, with higher reductions of up to 0.07 metres at the King Street intersections.

This suggests that the model is insensitive to hydrological assumptions on flows, with a change in levels of typically less than 0.05 metres arising as a result of a 20% change in rainfall intensity in the 1% AEP event.

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 blockage scenario against the unblocked scenario. The results of this analysis are provided in **Map G903-1** and **G903-2**.

This assessment shows that the impact of blockage in the catchment is generally limited, with the majority of water level changes within +/- 0.05m, and only for very limited areas of the catchment. The 20% AEP event showed a greater change in levels along the western length of Cowper Street than the 1% AEP event. This is likely due to the pipes running full in the 1% AEP event, so that pit capacity has less of an influence over peak flood levels.

Overall, the results indicate that pit blockage has very little impact on flood behaviour within the catchment.

9.4 Climate Change

Climate change has the potential to influence flood behaviour. In the Kully Bay 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.

The analysis was undertaken for the 1% AEP and PMF events. The results are provided in **G904-1 to G904-4**. A summary of climate change impacts at key locations is provided in **Table 9-1**.

Due to both the 2050 and 2100 having identical rainfall increases, the impacts occurring upstream of Northcliffe Drive are the same under both 2050 and 2100 scenarios (i.e. upstream of the impacts of Lake Illawarra levels). Only the downstream region of the model, within the wetlands adjacent to the lake, showed a difference between the 2050 and 2100 scenarios, due to the differences in the assumed lake level.

The results show that the impacts arising from climate change were relatively minor on Northcliffe Drive. Increases along the overland flowpaths range from 0.02 metres to 0.08 metres in the 1% AEP.

Along the major roads, impacts are still typically less than 0.05m, though at the King Street intersections with Greene Street / Montgomery Avenue and Cowper Street, increases of up to 0.06 and 0.08m are observed respectively.

Downstream of Northcliffe Drive, impacts are largely driven by changes in lake levels. The downstream wetland experienced increases of 0.4 metres in the 2050 scenario and 0.9 metres in the 2100 scenario. These increases did not extend beyond Northcliffe Drive at the King Street intersection but did extend across Northcliffe Drive west of the First Avenue intersection in the 2050 scenarios. In the 2100 PMF event, these increases were observed to extend across the King Street intersection.

Table 9-1 Water Level Changes Under Climate Change Scenarios

Location	2050 PMF	2050 1% AEP	2100 PMF	2100 1%AEP
Urban Overland Flowpaths				
UO1	0.05	0.01	0.05	0.02
UO2	0.06	0.03	0.06	0.03
UO3	0.05	0.03	0.05	0.03
UO4	0.06	0.02	0.06	0.02
UO5	0.08	0.04	0.08	0.04
UO6	0.04	0.02	0.04	0.02
Road Reserve Flooding				
MR1	0.02	0.02	0.02	0.03
MR2	0.05	0.02	0.05	0.02
MR3	0.11	0.05	0.11	0.05
MR4	0.11	0.02	0.12	0.02
MR5	0.02	0.03	0.02	0.03
MR6	0.07	0.05	0.08	0.05
MR7	0.02	0.03	0.02	0.03
Northcliffe Drive Flooding				
NC1	1.01	0.52	1.43	1.22
NC 2	0.35	0.12	1.31	0.80
NC 3	0.11	0.04	0.95	0.41
NC 4	0.09	0.03	0.12	0.04
NC 5	0.09	0.03	0.11	0.03

9.5 Low Tailwater Condition

The flood model was analysed with a low tailwater condition for Lake Illawarra as described in **Section 7.2**.

A sensitivity analysis was undertaken by analysing a lower tailwater condition, being the Indian Spring Low Water (ISLW) level which is 0.085m AHD. The particular focus of this analysis was to understand the potential changes in peak velocity, and any associated change in flood hazard in this area. The model was run for the 2-hour duration (critical at the outlet) for the unblocked scenario.

The results show that the lower tailwater resulted in minor velocity changes of less than +/- 0.5 m/s, and that all changes were contained within the Kully Bay wetland. Due to the minor impacts, no mapping of these results is provided.

Due to the impacts being relatively minor, the provisional hazard is unaltered with a low tailwater condition.

10 Conclusions and Recommendations

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

This project is an overland flow 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 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 hydraulic model was analysed for the Probable Maximum Flood (PMF), 1% AEP, 2% AEP, 10% AEP and 20% AEP events. The models were analysed for 60, 90, 120, 180 and 360 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.

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

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

Rhelm (2017a) *Proposed Development at Warrawong Plaza*, prepared for Wollongong City Council

Rhelm (2017b) *Warrawong CBD Flood Study*, prepared for Wollongong City Council

Rhelm (2018) *Warrawong Pedestrian Upgrade Works*, prepared for Wollongong City Council

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

Community Consultation Material

Wollongong City Council February 2018

Kully Bay Catchment Flood Study

Community Update

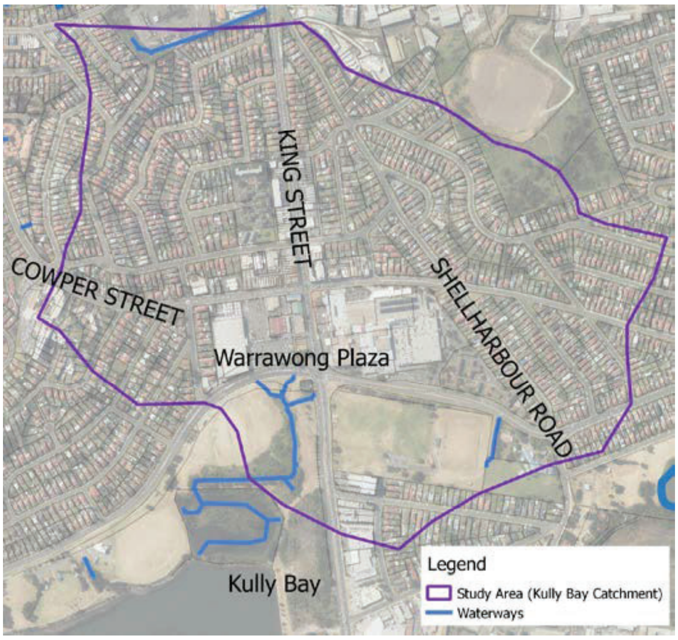
Wollongong City Council is currently undertaking a Flood Study for the Kully Bay catchment (Warrawong CBD area) to assist managing flood risk to people, property, infrastructure and assets.

No flood study has been prepared previously for the catchment to identify flood risk.

Properties in the Kully Bay Catchment have experienced relatively frequent flooding along King Street, Warrawong.

Initial estimates suggest more than 90 properties within the Kully Bay catchment could be affected by flooding.

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



Kully Bay Catchment is located within the suburbs of Warrawong and Port Kembla.

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 map shows the Kully Bay catchment. Areas within this catchment are subject to flooding from overland flows (flows across the ground and the road) and surcharging of the stormwater drainage system.

The flood study will provide design flood information for the Kully Bay catchment. It is also hoped that data collected during recent rainfall events (including the storm of March 2017) can be used to verify the flood models used in this study.

Do you have any records of local knowledge of flooding in the Kully Bay 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

Kully Bay Catchment Flood Study

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?

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 flood or storm water enter businesses or shops in the Warrawong CBD?

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 Kully Bay 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

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

Figure B1
Community Survey Responses

Legend

- Survey Responses
- Catchment

Scale : 1:5500@A4
Date : 2 May 2018
Revision : 0
Created by : ERM
Coordinate System : Map Grid of Australia 94

Rhelm

Appendix B

Door knocking Information Summary

APPENDIX C
Community Observations and Model Behaviour

ID	Observation	Model Behaviour
1	Flooding occurs regularly on King Street after heavy rain.	Flooding shown at location in events as small as the 50% AEP.
2	Corner gets flooded. Worst seen had water over the footpath	Flooding of intersection occurs in 50% AEP. Footpath inundated in 5% AEP.
3	Cowper St floods before King Street. Flow backs up Cowper Street in large flood events	Evidence of backwater effects seen in 5% and 1% AEP events
4	Flooding observed 10 times in last 6 years. Sometimes takes p whole left lane. Drains quickly.	Flooding shown at location in events as small as the 50% AEP.
5	Flooding observed regularly	Flooding shown at location in events as small as the 50% AEP.
6	Shallow flooding through property	Model shows a flowpath through property that has depths greater than 0.15m in the 20%
7	Flooding observed	Some minor ponding was shown at this location for all design events, but was removed in
8	No flooding observed in last 30 years	Road flows well confined, so likely would not be seen as "flooding". Results suggest some flow from upstream of the property in the 5% AEP.
9	Water ponds on Bent Street.	Ponding shown in model for all design events.
10	No flooding observed in last 20 years	Flows well contained within road reserve even for large events. Unlikely to be viewed as
11	Flooding about 0.3m deep 20 years ago (assume 1998).	Location at edge of 20% AEP event.
12	Flooding observed about 18 years ago (2000) on road	Flooding on road in the 20% AEP event and larger
13	Seen flooding on road twice, once was in 1998. Water no higher than footpath.	Location is on the edge of the 1% AEP extent. Suggest resident may have observed flooding further down the road as a flood of this magnitude has not occurred in the catchment
14	Shallow flow down driveway a couple of times a year	Model shows a minor flowpath through the property
15	Have observed flooding at rear of property and through base of house	Model shows a minor flowpath through the property
16	Flow comes across paddock, over the road, and then down driveway	Model replicates this behaviour.
17	Flow from street came down driveway and through garage.	Model replicates this behaviour.
18	In 1983 water was 0.2m deep at fence	Water ponds at lowpoint in the road outside this property
19	Street pit surcharges during large storms	Water ponds at lowpoint in the road outside this property
20	Ankle deep flow through backyard in very heavy rain	A minor flowpath passes through this property
21	Flow observed through backyard	A minor flowpath passes through this property
22	Ponding of water seen on road. Never above gutter height.	Location outside of 1% AEP. Suggest resident may have seen ponding further down the road
23	Flow used to come off street and down driveway. Hasn't occurred in last 10 years.	Model replicates this behaviour.

Map GAB101

Door Knocking

Legend

- Community Observations
- 5% AEP Extent
- Cadastre

50 0 50 100 m

Scale : 1:4000@A3
Date : 19 December 2018
Revision : A
Created by : LRE
Coordinate System : MGA 56

Rhelm

engineering | environmental | economics | engagement

Appendix C

Design Flood Model Results

Peak Water Levels (mAHD) at Reporting Locations

Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
1	12.96	12.98	13.00	13.02	13.03	13.16
2	10.57	10.58	10.59	10.61	10.62	10.79
3	20.08	20.10	20.12	20.14	20.15	20.33
4	4.73	4.74	4.76	4.79	4.81	5.18
5	3.81	3.84	3.86	3.88	3.91	4.20
6	8.03	8.05	8.07	8.08	8.09	8.19
7	6.38	6.40	6.43	6.46	6.48	6.86
8	3.05	3.07	3.09	3.11	3.13	3.35
9	2.90	2.92	2.93	2.95	2.96	3.26
10	3.43	3.45	3.47	3.48	3.50	3.71
11	3.23	3.25	3.27	3.28	3.30	3.50
12	5.68	5.69	5.69	5.69	5.70	5.74
13	25.15	25.16	25.18	25.19	25.21	25.33
14	10.36	10.37	10.37	10.38	10.39	10.41
15	5.43	5.43	5.44	5.44	5.45	5.49
16	7.62	7.63	7.64	7.65	7.67	7.82
17	13.52	13.53	13.54	13.55	13.56	13.69
18	15.43	15.43	15.44	15.45	15.45	15.55
19	7.58	7.60	7.61	7.62	7.63	7.74
20	8.74	8.76	8.77	8.78	8.81	8.93
21	17.71	17.73	17.76	17.78	17.83	18.14
22	17.86	17.89	17.91	17.93	17.94	18.14
23	8.97	8.98	8.99	8.99	9.00	9.08

Peak Model Flows (m^3/s) at Reporting Locations

Blocked						
Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q_1	2.4	2.8	3.2	3.6	4.1	11.3
Q_2	4.2	4.9	6.0	6.8	7.9	22.1
Q_3	2.9	3.3	3.8	4.2	4.6	8.9
Q_4	2.3	2.7	3.2	3.7	4.2	11.2
Q_5	2.9	3.4	3.9	4.5	5.1	20.0
Q_6	8.8	10.4	12.6	14.3	16.4	43.0
Q_7	2.1	2.5	2.9	3.4	3.9	7.7
Q_8	1.2	1.5	1.9	2.2	2.5	7.5
Q_9	2.3	2.6	3.2	3.6	4.1	11.4
Q_10	1.7	1.9	2.3	2.5	2.8	7.0
Q_11	1.6	1.8	2.1	2.3	2.6	5.8
Q_12	12.5	14.2	16.4	18.6	21.2	64.0
Q_13	2.6	3.4	4.0	5.4	6.3	13.5
Q_14	2.7	3.1	3.6	4.0	4.6	20.1
Q_15	3.3	3.9	4.5	5.0	5.5	11.0
Q_16	3.2	3.9	4.6	5.2	6.1	17.8
Q_17	2.8	3.2	3.8	4.2	4.8	14.4
Q_18	8.9	10.5	12.7	14.4	16.4	42.6
Q_19	2.3	2.6	2.9	3.2	3.7	13.1
Q_20	0.6	0.7	1.0	1.2	1.7	5.4
Q_21	2.2	2.5	2.9	3.4	3.8	10.5
Q_22	2.7	3.1	3.6	4.0	4.4	12.7
Q_23	1.7	2.0	2.4	2.7	3.3	8.3
Q_24	2.5	2.9	3.4	3.8	4.6	12.6
Q_25	3.0	3.4	4.1	4.7	5.8	16.3
Q_26	1.5	1.7	2.0	2.2	2.5	5.1
Q_27	1.0	1.2	1.4	1.5	1.7	4.1
Q_28	1.1	1.3	1.5	1.6	1.8	4.0
Q_29	1.0	1.1	1.3	1.5	1.9	4.3
Q_30	1.2	1.4	1.7	1.9	2.2	5.5
Q_31	1.4	1.5	1.9	2.1	2.4	6.6
Q_32	0.8	1.0	1.1	1.3	1.4	3.4

Peak Model Flows (m^3/s) at Reporting Locations

Unblocked						
Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q_1	2.4	2.7	3.2	3.5	3.9	11.2
Q_2	4.2	5.0	6.0	6.8	7.8	21.8
Q_3	2.8	3.3	3.8	4.2	4.5	8.9
Q_4	2.3	2.7	3.3	3.7	4.2	11.2
Q_5	2.9	3.4	3.9	4.4	5.1	20.0
Q_6	8.8	10.4	12.6	14.3	16.2	42.9
Q_7	2.0	2.4	2.9	3.3	3.8	7.6
Q_8	1.3	1.5	1.9	2.1	2.5	7.5
Q_9	2.3	2.6	3.1	3.6	4.1	11.3
Q_10	1.6	1.9	2.2	2.5	2.8	7.0
Q_11	1.6	1.8	2.1	2.3	2.5	5.8
Q_12	12.4	14.1	16.3	18.5	20.7	63.9
Q_13	3.1	3.7	4.7	5.7	6.4	14.0
Q_14	2.7	3.1	3.5	3.9	4.5	20.1
Q_15	3.2	3.8	4.5	4.9	5.4	11.0
Q_16	3.2	3.9	4.6	5.2	6.0	17.8
Q_17	2.7	3.2	3.7	4.2	4.7	14.5
Q_18	8.9	10.5	12.6	14.3	16.2	42.6
Q_19	2.2	2.5	2.9	3.2	3.6	13.1
Q_20	0.6	0.7	0.9	1.2	1.5	5.4
Q_21	2.1	2.4	2.9	3.3	3.8	10.4
Q_22	2.7	3.1	3.6	4.0	4.4	12.7
Q_23	1.7	2.0	2.4	2.6	3.0	8.3
Q_24	2.4	2.9	3.4	3.8	4.3	12.6
Q_25	3.0	3.4	4.1	4.7	5.4	16.3
Q_26	1.5	1.7	2.0	2.2	2.4	5.1
Q_27	1.0	1.2	1.4	1.5	1.7	4.1
Q_28	1.1	1.3	1.5	1.6	1.8	4.0
Q_29	1.0	1.1	1.3	1.5	1.7	4.3
Q_30	1.2	1.4	1.7	1.9	2.2	5.5
Q_31	1.4	1.5	1.9	2.1	2.4	6.6
Q_32	0.8	1.0	1.1	1.3	1.4	3.4

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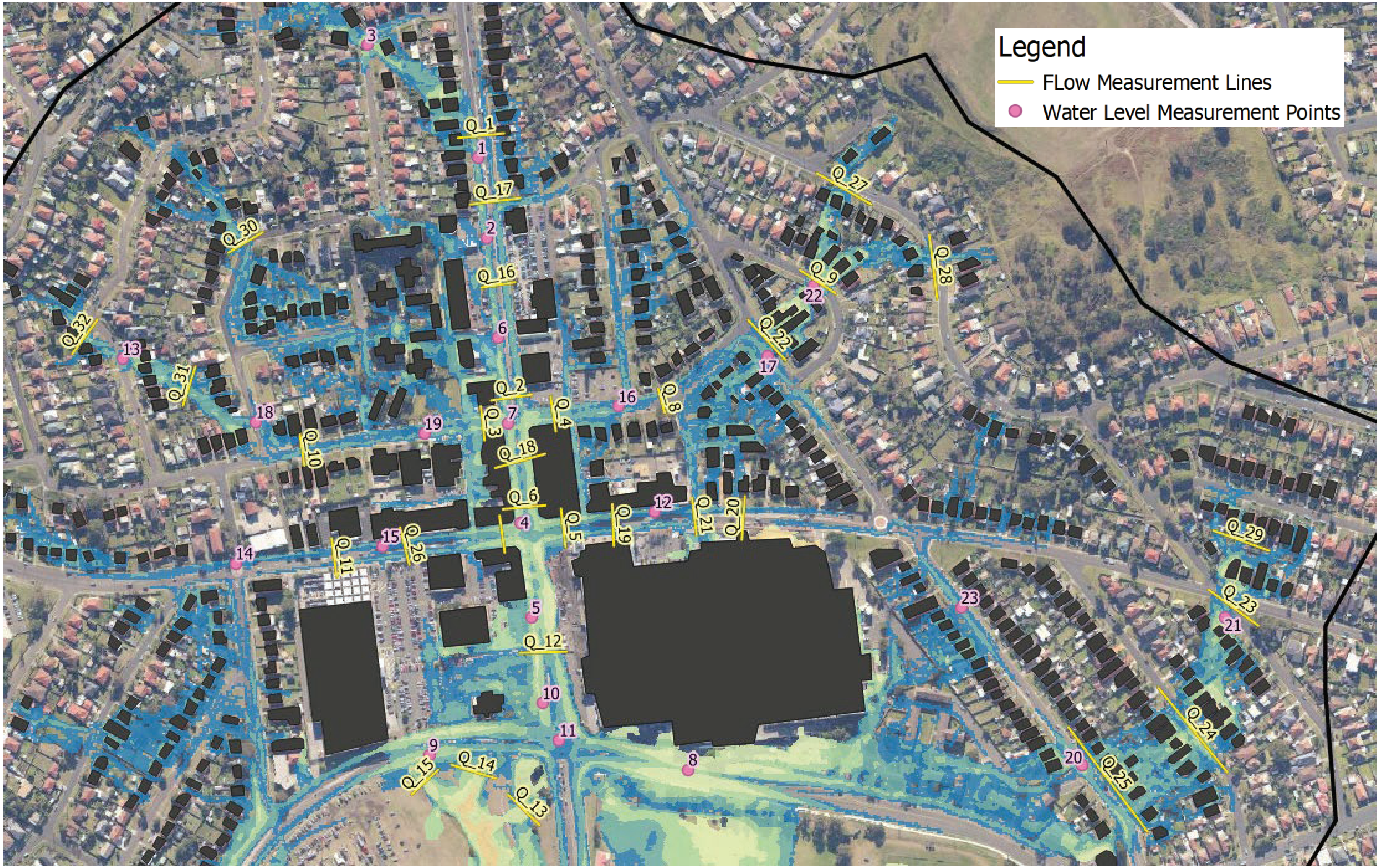
Key Reporting Locations



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