Duck Creek Flood Study

Final Report

Volume 1

Prepared for Wollongong City Council

31 May 2019

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The report has been prepared and reviewed by suitably qualified persons. The scope of the report is based on the client brief and/or the Rhelm written fee proposal and assumes information 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.

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 Office of Environment and Heritage (OEH), 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).

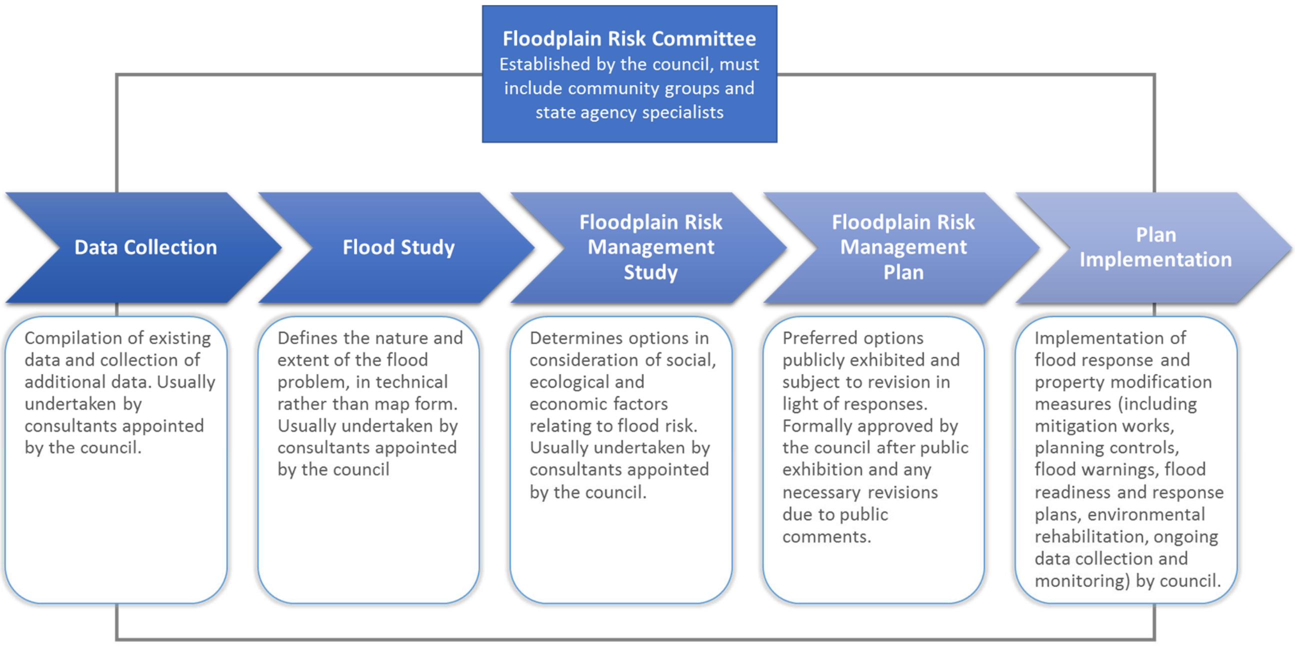

Figure F1 The Floodplain Risk Management Process (source: NSW Government, 2005)

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

Executive Summary

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

The Duck Creek catchment encompasses an area of approximately 19km^2 located in the Yallah region on the New South Wales South Coast. Duck Creek flows in a general east direction from its headwaters below the Illawarra Escarpment to its confluence with Lake Illawarra at Yallah (Figure i).

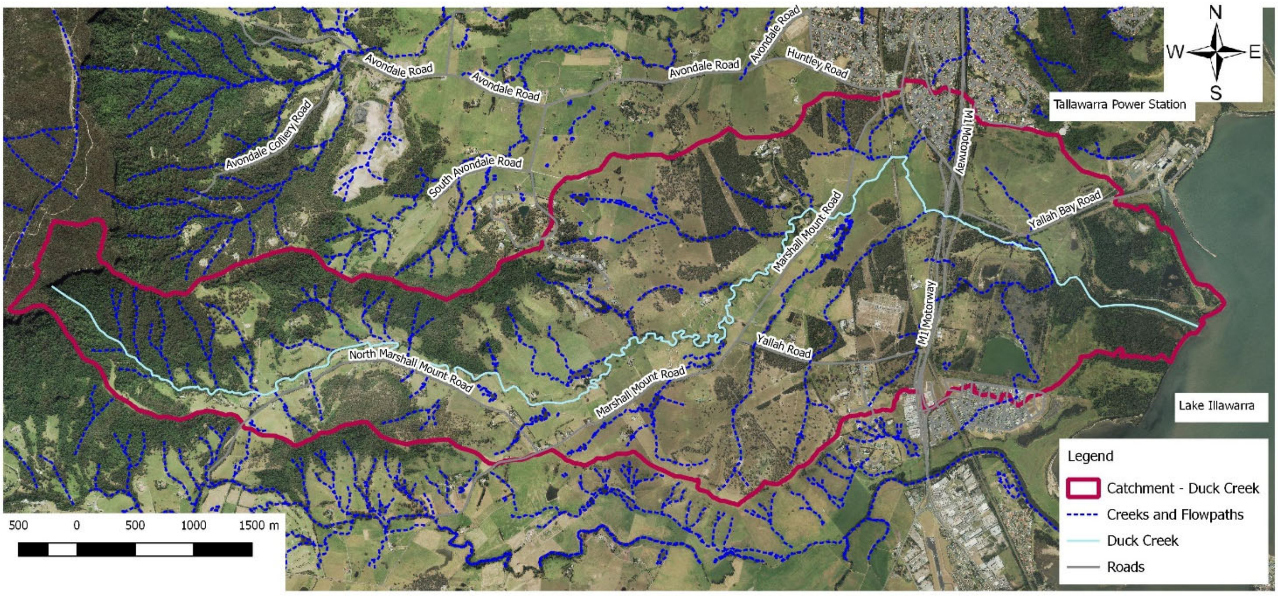

Figure i. Duck Creek Catchment

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

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

- Engaging agency and industry stakeholder to obtain details of historical flooding, survey data and other relevant data sets. Stakeholders were also been invited to provide feedback on the draft flood study during public exhibition.
- Community engagement has been undertaken through the mail out of an information brochure and brief survey. The purpose of the engagement was to raise awareness of the study and flood risk in the catchment, as well and obtain observations of historical flooding to assist in model calibration. Respondents were contacted for further information by phone and email, as required.
- The Flood Study has been overseen by the Southern Floodplain Risk Management Committee which includes representatives from community and state agencies.

- This document was placed on public exhibition for a period of four weeks. During this time Council sent letters to 104 residents and property owners in the catchment area inviting them to learn more about the draft Flood Study. An information session was held for community members to get information and ask questions. The webpage included information about the study, the draft documents and an opportunity to provide submissions. Submission could also be page at Council's Customer Service Centre and at the community information session.

Flood behaviour has been assessed using a WBNM hydrological model and TUFLOW hydraulic model. These models were originally developed as part of a flood study undertaken for the catchment in 2012 (BMT WBM). Minor modifications have been made to these models to account for changes in the catchment since 2012 and additional available survey data.

A calibration and validation of the hydraulic model has been undertaken for the March 2017, March 2011 and February 1984 events. The outcome of the calibration found that the model was able to represent the historical events to a reasonable level, providing confidence in the model to produce design flood event results.

The hydrological and hydraulic models were analysed for the Probable Maximum Flood (PMF), 0.2% AEP, 0.5% AEP, 1% AEP, 2% AEP, 10% AEP and 20% AEP events. The models were analysed for 90, 120, 360, 540 and 720 minute duration storms. These storm durations were identified based on initial model runs to understand the critical durations throughout the catchment.

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

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

It should be noted that a localised area of fill occurred at Haywards Bay which was not identified in the survey input to the models. This is shown in the various maps.

The upper part of the catchment is located within a relatively steep sided valley, with a large macro-channel that is bordered to the south by North Marshall Mount Road. Due to the relatively steep sides, the flow from Duck Creek is generally contained within the macro-channel up to and including the PMF, with no backwater reaching North Marshall Mount Road. Critical durations in the 1% AEP event through this area are generally 2 hours.

In the central floodplain the creeks and tributaries are generally less steep than the upper catchment, and there are more cross catchment flows that occur between the creeks.

There are three key tributaries that originate upstream (south) of Yallah Road. These tributaries cause flooding of Yallah Road in the 20% AEP event and above. Several tributaries cross the rail line, with overtopping occurring in the 0.2% AEP event.

There are three key waterway crossings of the M1 Motorway. Shallow overtopping of the north bound lanes starts to overtop in one location from the 20% AEP and increases to depths greater than 1 metre in the 10% AEP. The other crossings are only overtopped in the 0.5% AEP event and larger.

Downstream of the Princes Highway, the floodplain is primarily within low lying wetland areas, as well as the former Ash Ponds for the Tallawarra Power Station. These Ash Ponds have relatively high embankments that exclude overtopping in all flood events. A localised low point on the northern Ash Pond results in some overtopping in events greater than the 1% AEP flood event, although this is relatively minor.

To the north of Yallah Bay Road, a local tributary flows through farmland and is then held behind a former railway line embankment, before meeting with Yallah Bay Road. This starts to overtop in the 1% AEP event, with significant flooding of Yallah Bay Road occurring in the larger events.

In order to provide Council with an indication of future flood behaviour arising from further development within the catchment, a future development scenario was modelled. This scenario incorporated major works that are currently being planned or currently in construction, as well as a general assumption that all land within the catchment area would become fully developed in line with Council's planning controls. A preliminary assessment was undertaken representing the incorporation of these developments.

Three major developments within the study are currently in a planning stage, namely:

- West Dapto Masterplan;
- Tallawarra Concept Plan; and,
- Albion Park Rail Bypass.

Under the future development scenario, water level increases as a result of the developments were typically observed in the upstream portion of the catchment where development is proposed, as a result of increased impervious areas, and a higher riparian roughness due to revegetation works. The increases were generally contained within the development area. This in turn resulted in lower peak levels downstream, as a result of lower peak flows. The exception was the PMF, that saw further increases in the vicinity of the M1, due to the proposed bypass reducing conveyance.

Due to the generally confined nature of the flowpaths, the bulk of the catchment has overland escape routes available. There is one region in the central floodplain, along Marshall Mount Road upstream of the railway that is classed as flooded, isolated and submerged.

The major Duck Creek flowpath is classed as H5 and H6 with respect to hazard, as a result of both depths and flows. The tributaries are typically H1 and H2, with some pockets of H3 along the larger flowpaths, or deeper sections of ponding.

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 more sensitive to hydrological assumptions on flows, with levels potentially increasing up to 0.5 metres as a result of a 20% increase in flows in the 1% AEP event.

With respect to blockage, the results showed a generally minimal differences between the Risk and Design Scenarios of Council's new policy, with typical changes in the order of 0.1 metres. The key exception to this is around some of the tributaries and the smaller culverts, which experience higher blockage factors under the Risk Scenario and therefore higher differences. These increases are up to approximate 0.5 metres upstream of the rail line (where the Risk Scenario is higher than the Design Scenario).

The Risk Scenario results in levels that are generally up to 0.2 metres lower than the levels produced by applying the superseded policy. The key exception to this is the secondary culvert crossing of the rail line, where the tributary in that location has levels approximately 1.5 metres lower than the superseded blockage Policy, as this culvert was completely blocked under the superseded policy.

This report provides an understanding of the flood risk within the Duck Creek 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.

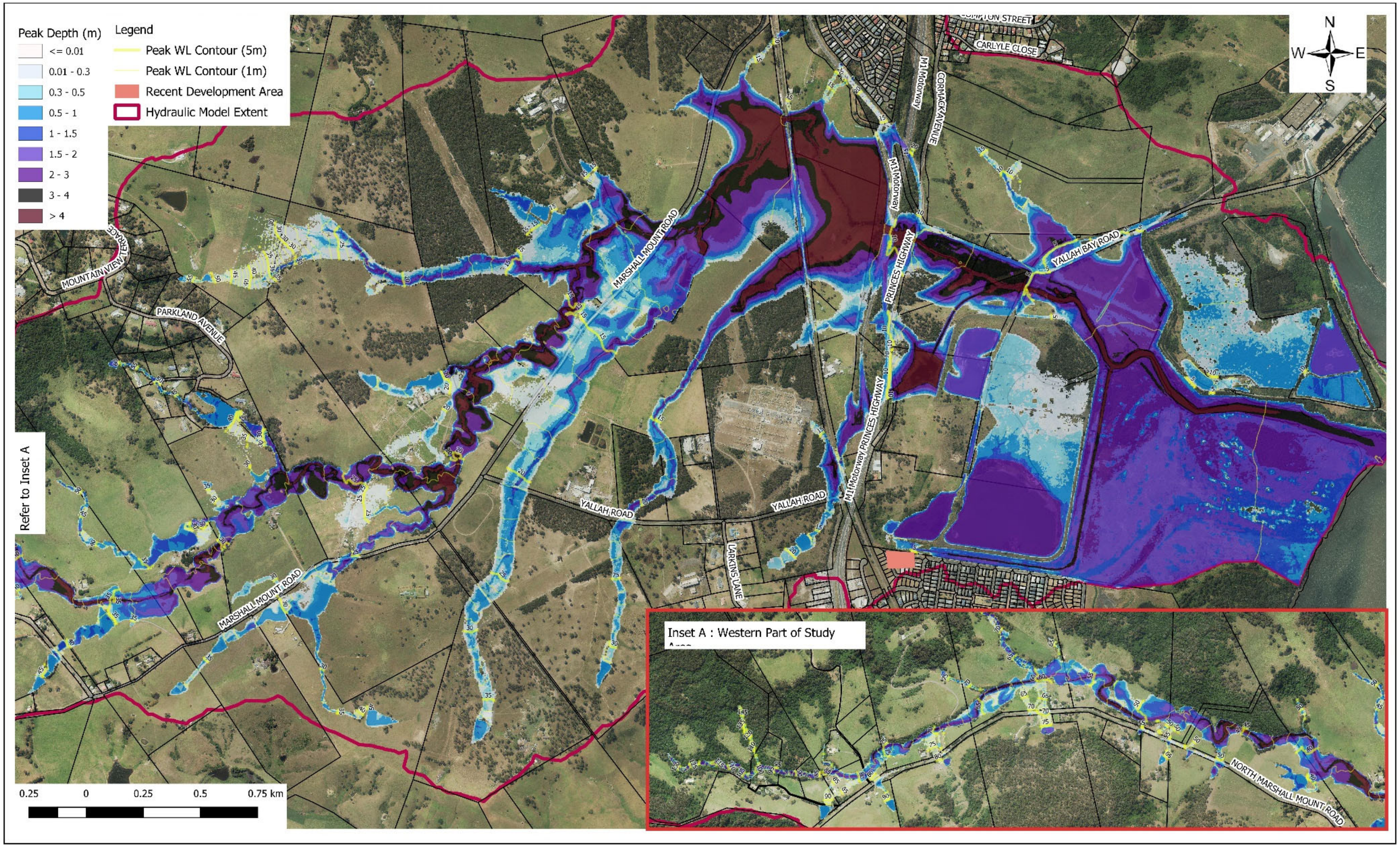

Figure ii. PMF Flood Depths and Water Levels – Risk Blockage Scenario

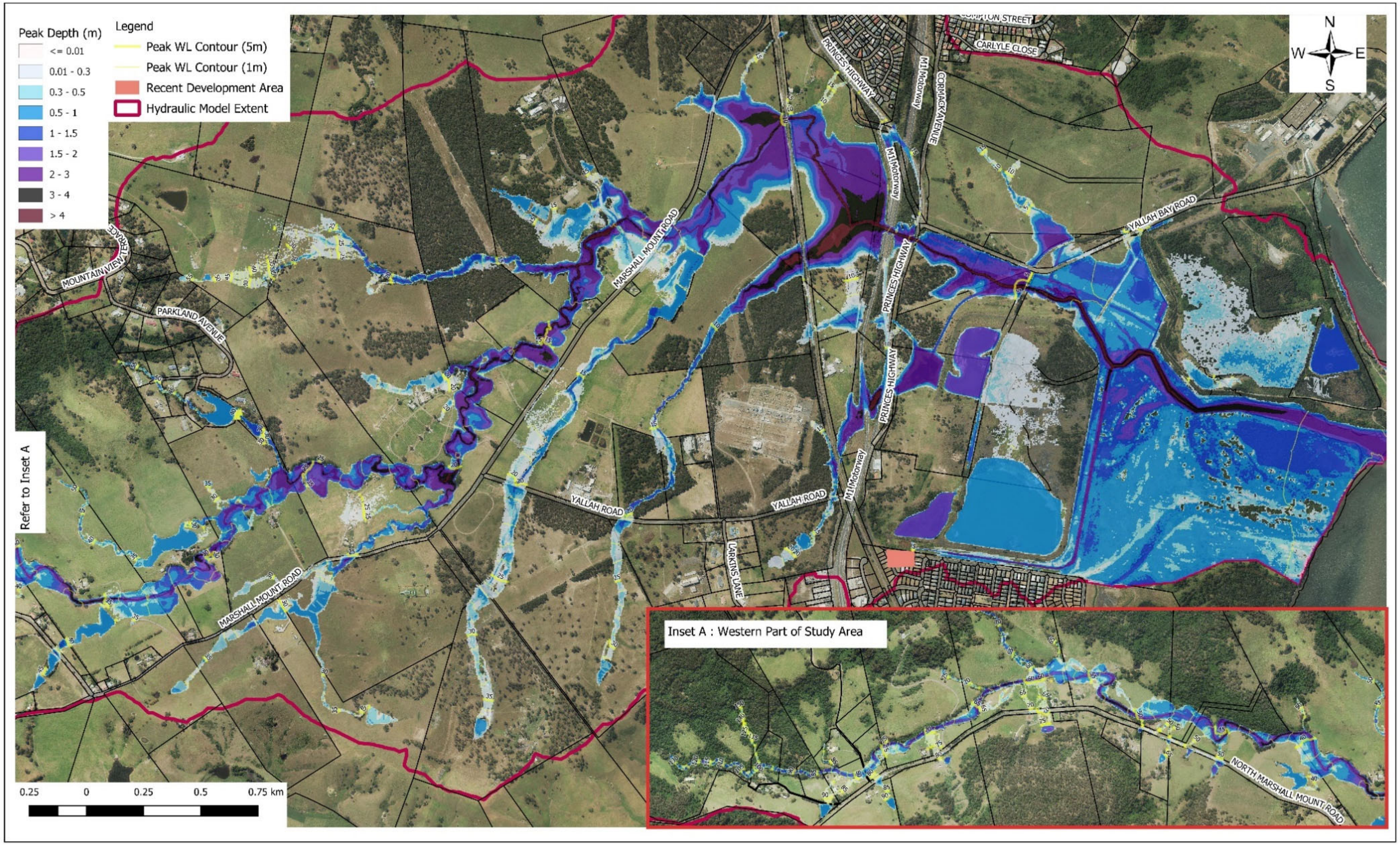

Figure iii. 1%AEP Flood Depths and Water Levels – Risk Blockage Scenario

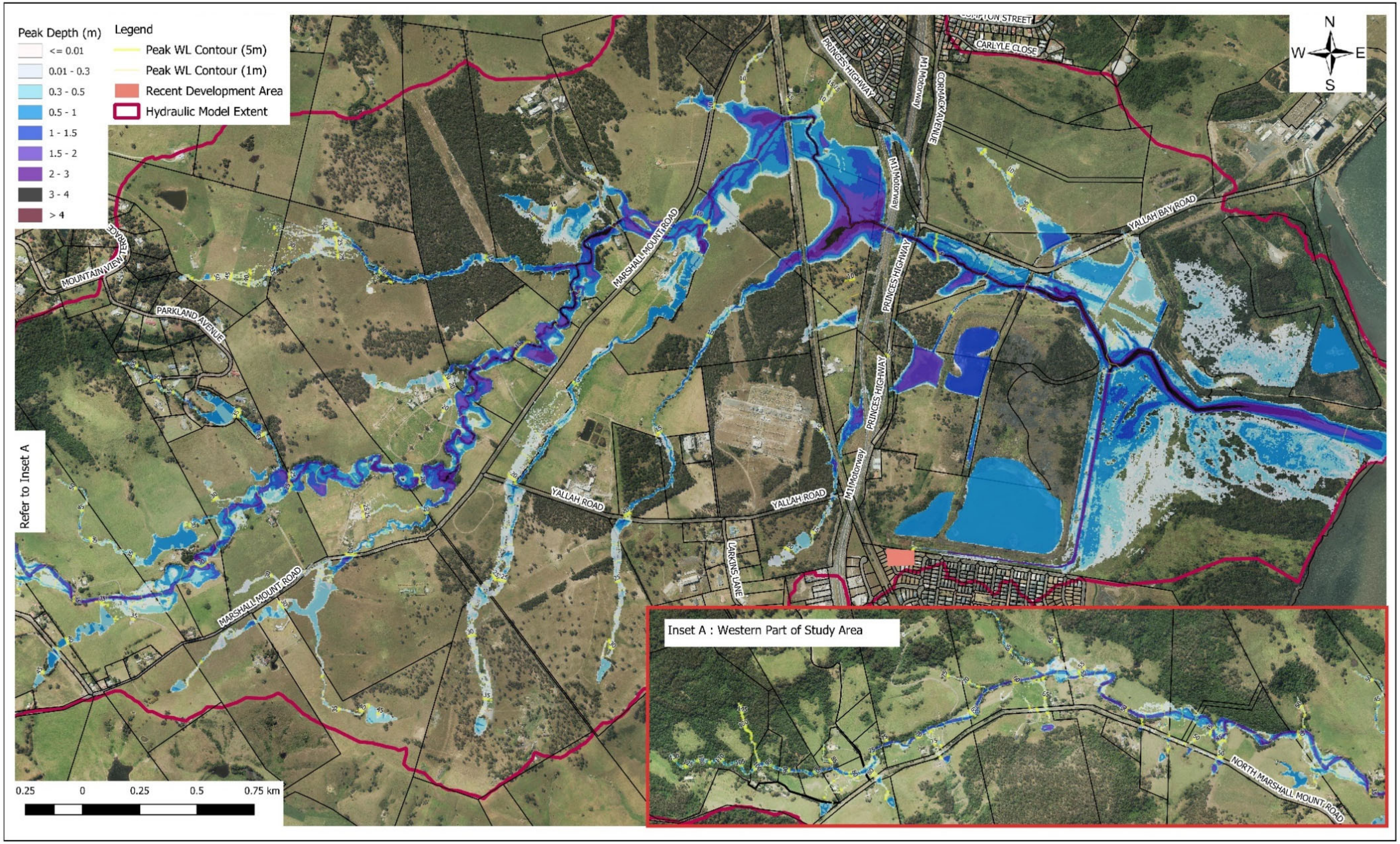

Figure iv. 20%AEP Flood Depths and Water Levels – Risk Blockage Scenario

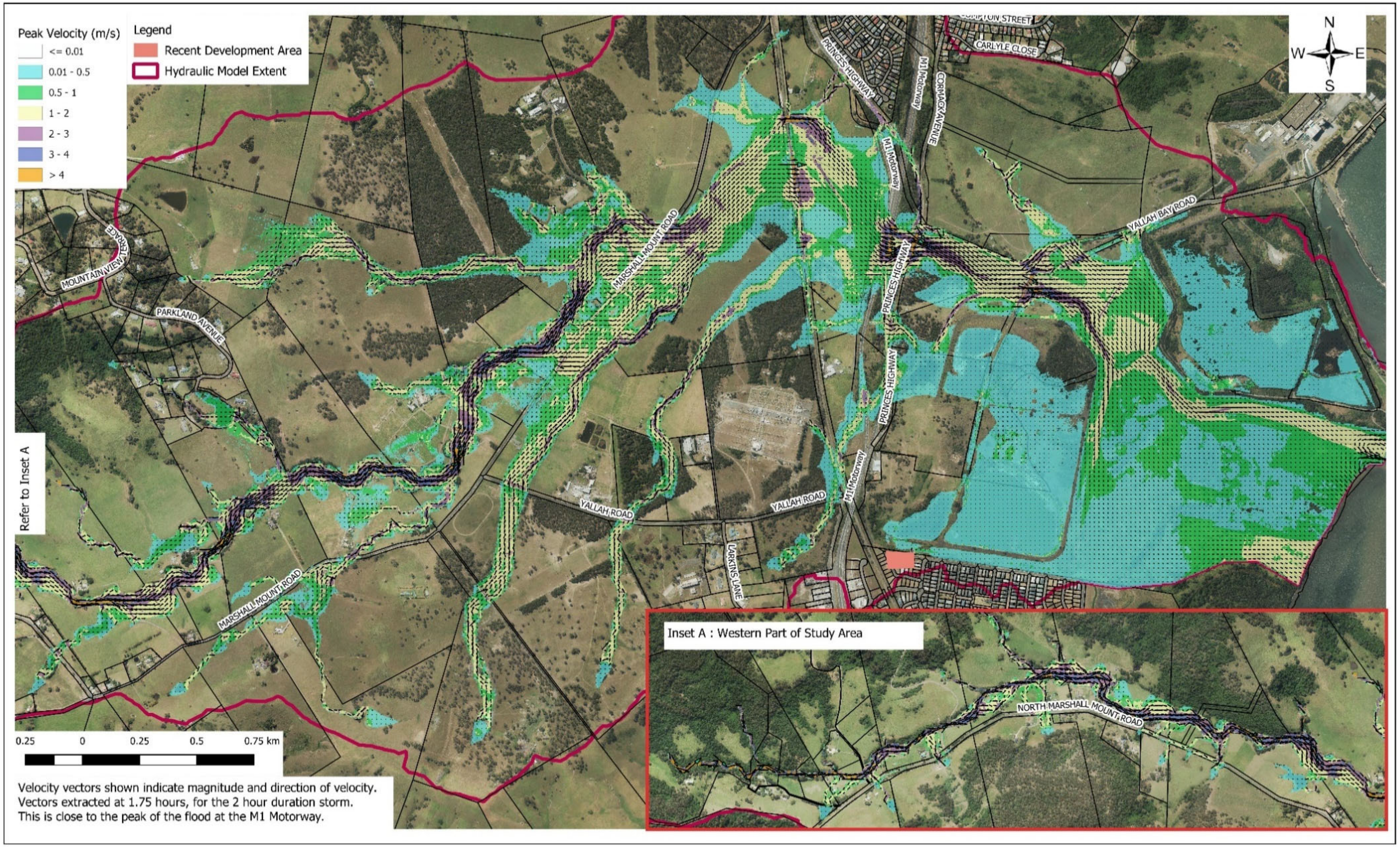

Figure v. PMF Peak Velocity – Risk Blockage Scenario

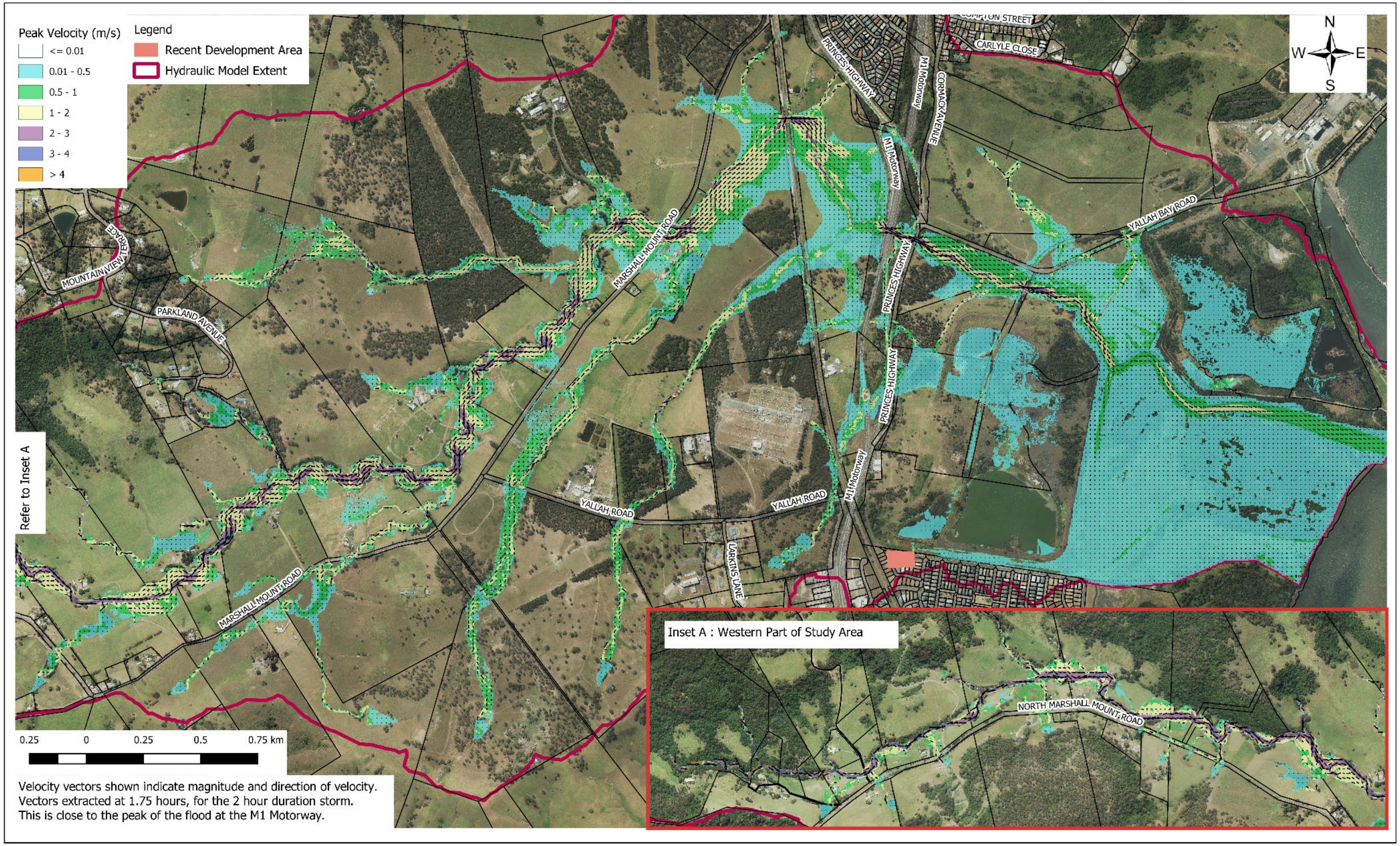

Figure vi. 1% AEP Peak Velocity – Risk Blockage Scenario

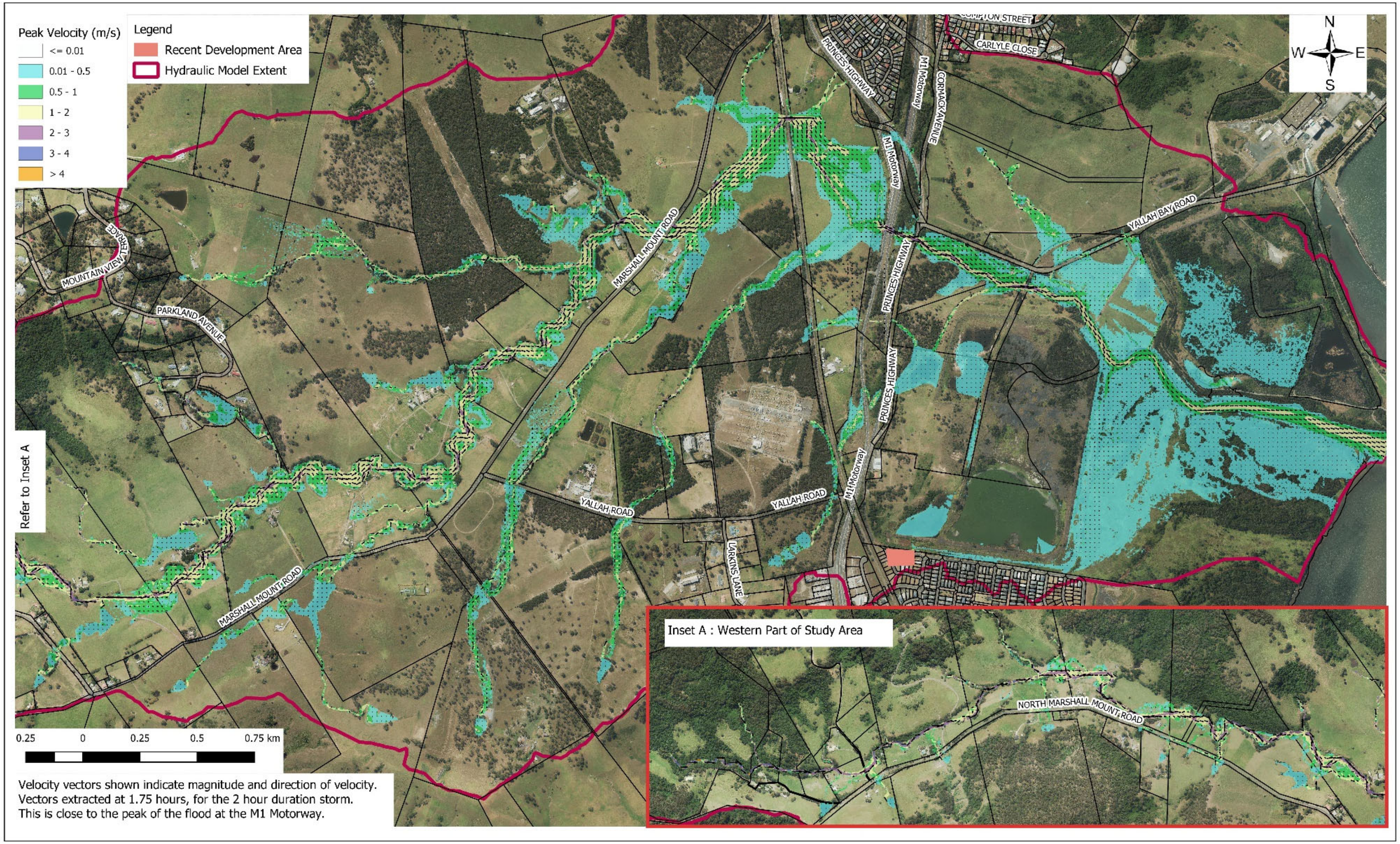

Figure vii. 20% AEP Peak Velocity – Risk Blockage Scenario

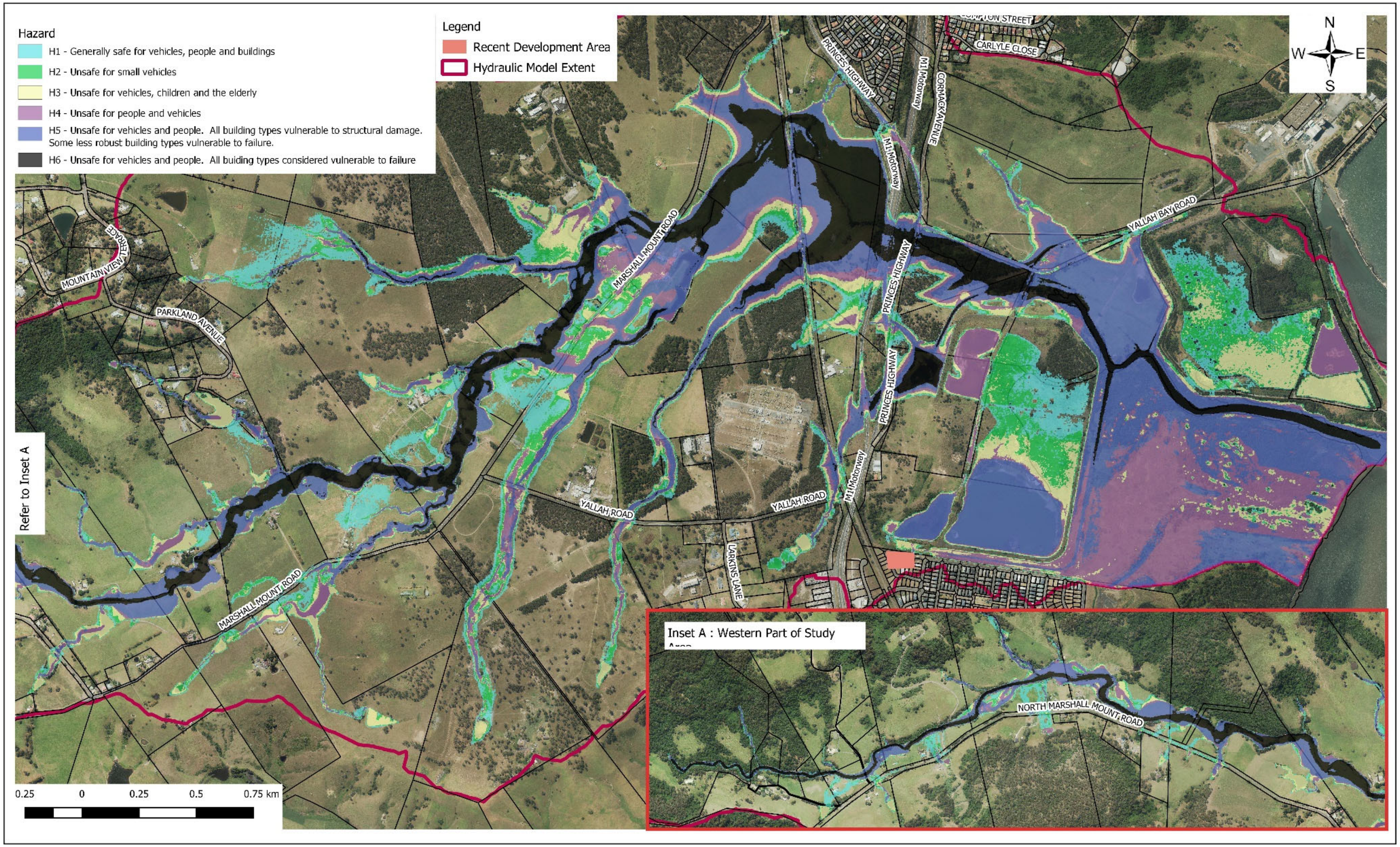

Figure viii. PMF Provisional Hazard – Risk Blockage Scenario

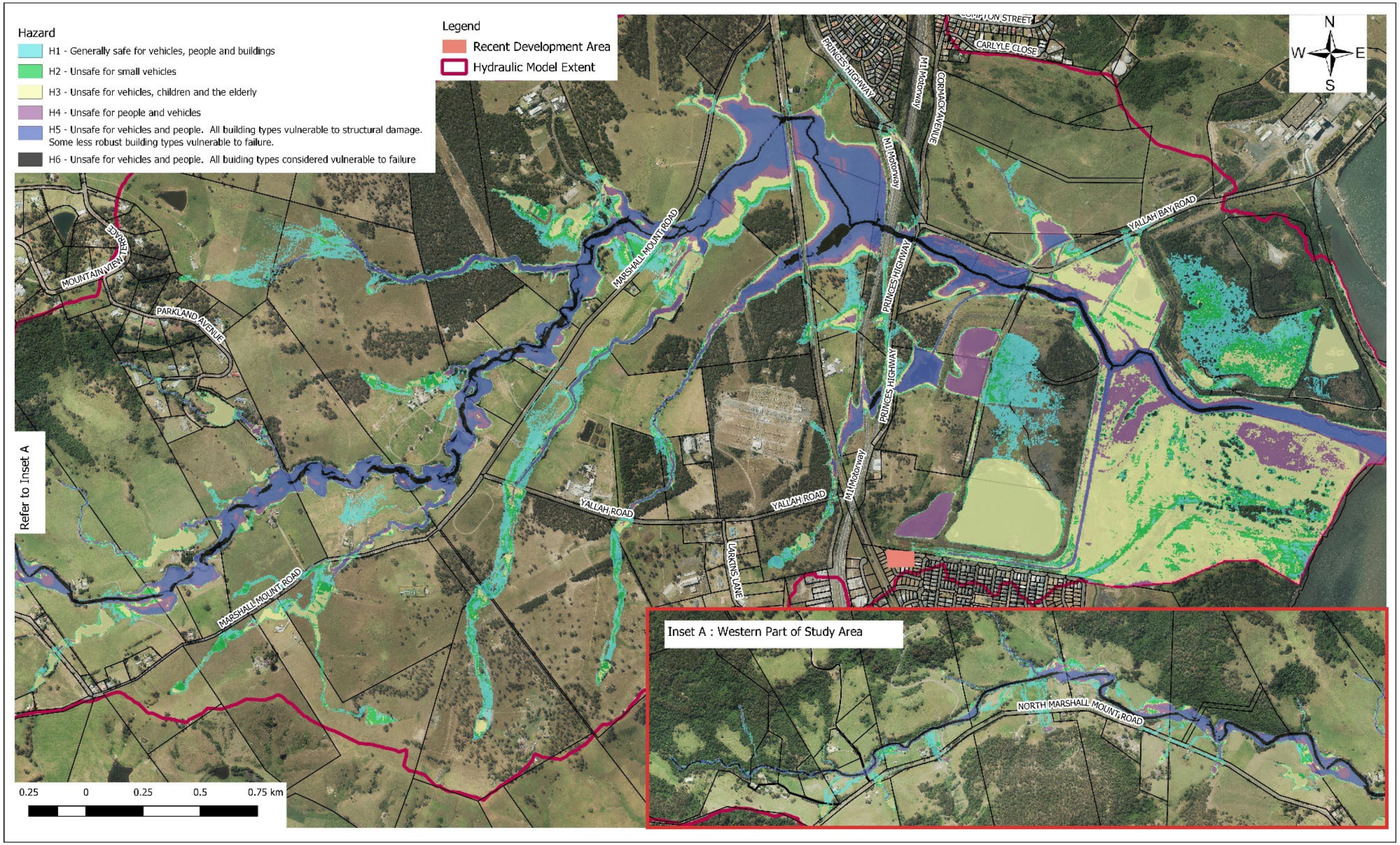

Figure ix. 1% AEP Provisional Hazard – Risk Blockage Scenario

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Volume 2 - Maps

These are provided as an attachment to this report.

Glossary[1]

Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m3 /s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m3 /s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m3 /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).
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
Emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
Flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
Flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.

[1] Definitions from the Floodplain Development Manual (2005)

Flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
Flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
Flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
Floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
Floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
Flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the flood liable land concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL's are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the standard flood event in the 1986 manual.
Flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
Flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
Flood readiness	Flood readiness is an ability to react within the effective warning time.

Flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. • existing flood risk: the risk a community is exposed to as a result of its location on the floodplain. • future flood risk: the risk a community may be exposed to as a result of new development on the floodplain. • continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
Flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
Freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
Hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
Hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
Hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
Hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
Local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
Local drainage	Smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.

Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
Mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
Merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the States rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.
Minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. Moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. Major flooding: appreciable urban areas are flooded, and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
Modification measures	Measures that modify either the flood, the property or the response to flooding.
Peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.

Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
Probability	A statistical measure of the expected chance of flooding (see AEP).
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
Stage	Equivalent to water level. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
Water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.

Abbreviations

1D	One Dimensional
2D	Two Dimensional
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ARF	Areal Reduction Factor
ARR	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
DCP	Development Control Plan
DECCW	Department of Environment, Climate Change & Water (now OEH)
DEM	Digital Elevation Model
DPE	Department of Planning and Environment
EPI	Environmental Planning Instrument
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
mm	millimetres
m/s	metres per second
NSW	New South Wales
OSD	On-site Stormwater Detention
OEH	Office of Environment and Heritage (NSW)
PMF	Probable Maximum Flood

SES	State Emergency Service (NSW)
SWC	Sydney Water Corporation
WBNM	Watershed Bounded Network Model
WCC	Wollongong City Council

1 Introduction

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

1.1 Study Location

The Duck Creek catchment encompasses an area of approximately 19km^2 located in the Yallah region on the New South Wales South Coast as shown in **Figure 2-1**. Duck Creek flows in a general east direction from its headwaters below the Illawarra Escarpment to its confluence with Lake Illawarra at Yallah.

The extent of existing development in the catchment is somewhat limited. The catchment is extensively undeveloped rural floodplain, with minor pockets of development around Yallah and Haywards Bay. Other rural residential property is scattered through the catchment largely along the main access roads including Yallah Road, Marshall Mount Road and North Marshall Mount Road.

The higher concentrations of development, predominantly in the lower reach of the catchment are generally located on higher ground. Most of the existing property with significant flood risk is rural property that potentially becomes isolated in major flooding events.

The upper slopes of the catchment remain natural bushland, with the middle and lower reaches predominantly consisting of rural pasture with small pockets of forested areas.

1.2 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 study will update the previous 2012 Flood Study (BMT WBM 2012) to current industry best practise through incorporating Council's recently adopted blockage policy and the latest available data for the catchment.

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

The 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, and 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 outlined in **Sections 7 to 10** 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;
    - impacts and costs for a range of flood events or risks on the existing and future community;
    - impacts of changes in development and climate on flood risk;
    - emergency response situation and limitations; and
    - effectiveness of current management measures.
- 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.

1.3 Study Background

A flood study for Duck Creek was completed in 2012 (BMT WBM 2012). The *Floodplain Development Manual* (NSW Government 2005) recommends that a flood study should be reviewed regularly (approximately every five years) or a review may be triggered earlier for a variety of reasons including the occurrence of a significant flood event, changes to relevant policy, legislation or guidelines or development occurring or proposed in the catchment.

In addition to a period of more than 5 years having elapsed since the flood study was complete, changes to policy, guidelines, modelling approaches and development in the catchment have also occurred. As such, Wollongong City Council (Council) determined that a review and update of the Duck Creek Flood Study (BMT WBM 2012) was required. In July 2017 Council commissioned Rhelm to undertake this review and update. The findings and outcomes of the flood study review are presented in this document.

The following changes, which have occurred since the adoption of the 2012 Flood Study, and additional issues that have been assessed in this revised Flood Study include:

- The effect of climate change on the catchment both increasing rainfall and ocean level;
- The availability of newer survey data and greater detailed ground survey / LiDAR data;
- Advances in computational capacity and modelling technology (particularly in the 2D modelling sector);
- Information available from subsequent flood events since the initial studies were finalised;
- The changes to development and proposed development within the catchment;
- The standard of all study results submitted in the WaterRide™ format;
- Change in AR&R guidance in 2016 (e.g. IFD’s, temporal patterns, ARF etc.) which will be further investigated at in the next stage of the Floodplain Risk Management process; and
- Implementation of Council’s New Blockage Policy, May 2016 (as outlined in the Final Technical Report – Review of Conduit Blockage Policy, May 2016).

2 Study Area

2.1 Catchment Description

The Duck Creek catchment encompasses an area of approximately 19km^2, extending from the Illawarra escarpment, and flowing generally east to its confluence with Lake Illawarra at Haywards Bay (refer to **Figure 2-1** and **Figure 2-2)**.

The upper portion of the Duck Creek catchment is dominated by bushland and steep ephemeral streams characteristic of the Illawarra Escarpment. From an elevation of around 600m AHD at the top of the catchment, the topography grades steeply from the upper slopes to the broader and flatter floodplain approximately 4.5km downstream.

The catchment is principally drained by Duck Creek and a series of minor tributaries. The watercourses (including Duck Creek) in the upper and middle catchments are typically small with heavily vegetated riparian corridors. The main channel of Duck Creek is fed by minor steep ephemeral streams that drain the sides of the valley and by sheet flow from the surrounding agricultural land. Downstream of the M1 Motorway and Princes Highway Bridges, the creek widens and deepens along the lower floodplain to the confluence with Lake Illawarra.

Land use within the catchment primarily consists of rural pasture (69%), bushland (30%) and urban development (1%). The floodplain area principally remains undeveloped and largely occupied by rural farming. However, rezoning, neighbourhood planning and major road infrastructure projects are being planned (**Section 3.7**).

The main urban communities within the catchment are parts of South Dapto and Haywards Bay. Other residential property is scattered through the catchment largely along the main access roads including Yallah Road, Marshall Mount Road and North Marshall Mount Road. The main urban communities are generally located on higher ground. Most of the existing property with significant flood risk is rural property that potentially becomes isolated in major flooding scenarios.

The Duck Creek catchment is traversed by a number of major transport corridors. These are predominantly located in the lower catchment and include the M1 Motorway, Princes Highway and the South Coast (Illawarra) Rail Line. In order to provide transport routes with a degree of flood immunity, most of the transport routes are elevated above the natural floodplain levels, constructed on embankments with major waterway openings (bridges/culverts) at appropriate cross drainage locations.

The structures associated with these transport routes spanning Duck Creek and its floodplain have a significant influence on the flooding behaviour in the Duck Creek catchment. The significant length of embankment for some of the transport lines provides impedance to out-of-bank floodplain flows in major flood events. In addition, the potential for blockage at major hydraulic structures may exacerbate flood risk to upstream property. Given the major structures are located on the lower floodplain with relatively flat topography; the extent of backwater influence is extensive.

2.2 Historical Flooding

Details of historical flooding in Duck Creek catchment are limited. Most of the historical events identified in the catchment coincide with the larger regional events experienced in the Wollongong/Illawarra Region including the events of March 1978, February 1984, March 2011 and the more recent March 2017 event. Apart from the March 2011 and March 2017 event, availability of historical flood data is limited for the Duck Creek catchment.

2.3 Future Development

While the catchment is largely undeveloped at present, development is expected to occur over the following years, including:

- Albion Park Rail Bypass – this is a Roads and Maritime Services project and will involve an upgrade of the M1 Motorway and A1 Princes Highway in a portion of the catchment (refer **Section 3.7.3**);
- West Dapto Masterplan – a draft zoning has been prepared for the West Dapto area, inclusive of the Duck Creek Catchment (refer **Section 3.7.1**). This zoning envisages up to 4,000 dwellings over time. An overview of the draft zoning is provided in **Map G201**.
- Tallawarra Concept Plan – this covers the lands currently owned by Energy Australia and was developed by the Department of Planning (now Department of Planning and Environment) (refer **Section 3.7.2**). This zoning envisages up to 1000 new dwellings in the Duck Creek catchment over time. An overview of the concept plan prepared on behalf of the Department of Planning is provided in **Figure 3-4**.

Further details on these future developments are provided in **Section 3.7**.

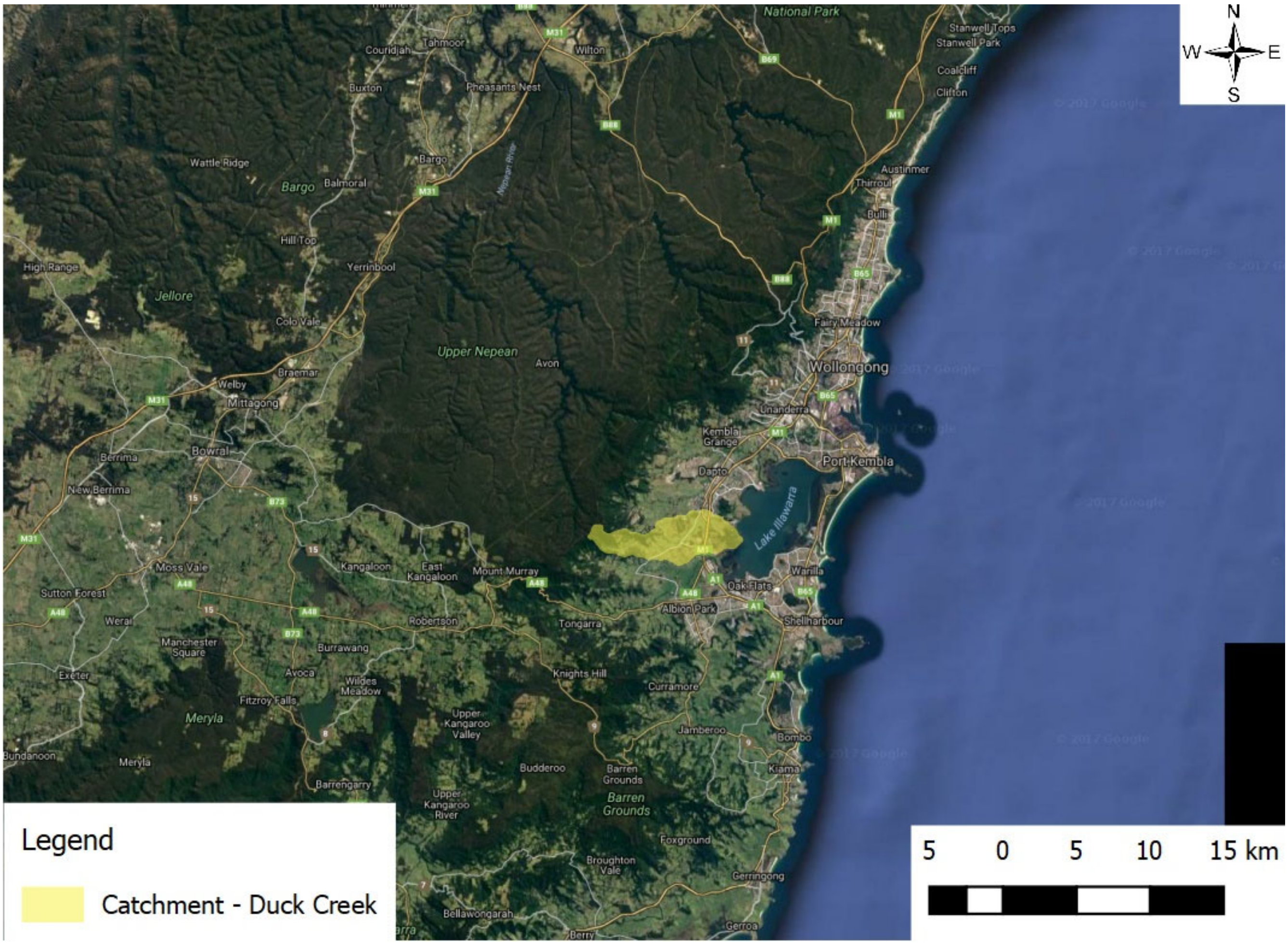

Figure 2-1. Study Area Locality

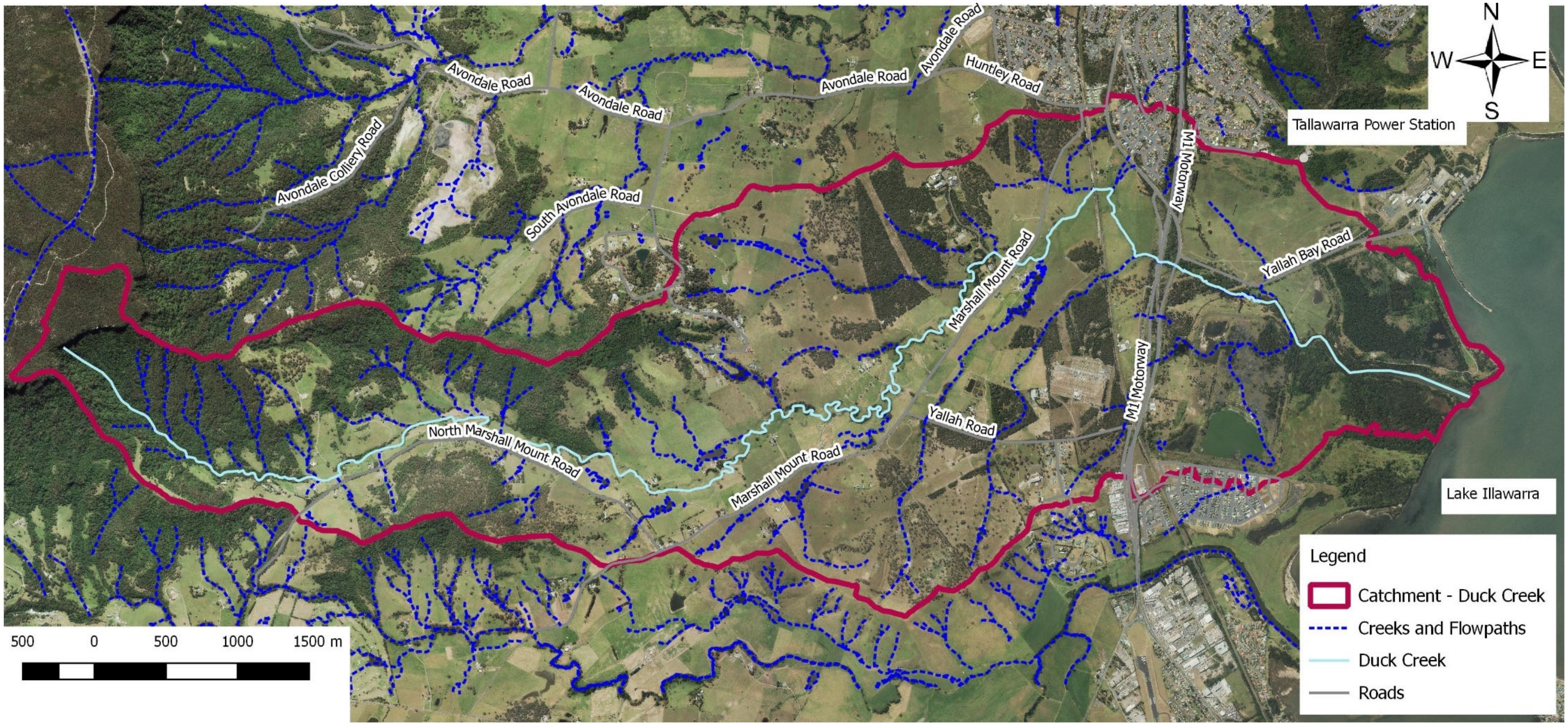

Figure 2-2. Study Area

3 Review of Available Data

3.1 Site Inspections

Site inspections of the catchment were undertaken at the inception of the project over two days (5 – 6 July 2017). The site inspections were attended by Rhelm, OEH and Council staff and aimed to provide an overview of the catchment, an appreciation of key features impacting flood behaviour and identify any flood marks (e.g. debris or damage) from the recent minor flood event in March 2017.

The locations inspected, field notes and key site photos are provided in **Appendix A**.

3.2 Previous Studies and Reports

3.2.1 Duck Creek Flood Study (BMT WBM 2012)

This project is a review and update of the 2012 Flood Study, and therefore this reference is a key input to the study. The information and data used from the 2012 Flood Study is identified throughout this report. A detailed review of the hydrological and hydraulic modelling presented in the 2012 Flood Study is provided in **Appendix D**.

3.2.2 Duck Creek Flood Study (Cardno Forbes Rigby [CFR] 2007)

To facilitate the preparation of a local environmental plan (LEP) and local environment study (LES) for land owned by TRUenergy Australia Pty Ltd at Tallawarra, Cardno Forbes Rigby (CFR) was engaged to prepare a flood study of the land in 2006 (CFR 2007). The Tallawarra site is located on the western foreshore of Lake Illawarra, north of Haywards Bay, in the lower Duck Creek catchment.

The objectives of the study were to predict the extent of flooding from Duck Creek throughout the Tallawarra site for a range of ARIs, under both existing and post-development (comprising developments as per the TRUenergy Master Plan and the ultimate development scenario in the upper catchment) conditions; and assess the provisional flood hazard across the Tallawarra site for the 1% AEP and PMF events.

A limited calibration was undertaken of the developed hydrologic (WBNM) and hydraulic (HECRAS) models using a single peak flood level for the March 1978 flood upstream of the Princes Highway Bridge over Duck Creek.

Unlike the 2012 Flood Study, the WBNM model adopted three representative design rainfall IFDs across the catchment (an upper, middle and lower IFD). This is in recognition of the spatial variation in rainfall that occurs in the vicinity of the Illawarra escarpment.

The reach of Duck Creek represented in the one-dimensional (1D) hydraulic model was originally restricted to the downstream side of the Princes Highway Bridge over Duck Creek and subsequently extended to the confluence of Duck Creek and Lake Illawarra. The model was further extended to include the Princes Highway/F6 Freeway (now M1 Motorway) and railway bridges to ascertain the effect these structures have on attenuating flood peaks.

The results of the hydraulic modelling indicate that floodwaters are confined to the channel of Duck Creek upstream of the historical bridge for all design events simulated (including the PMF event).

3.2.3 Tallawarra Lands Flood Risk Assessment (Bewsher, 2010)

The Tallawarra Lands Flood Risk Assessment was undertaken for TRUEnergy to inform the flood risks and constraints for the proposed Tallawarra Lands development. This study generally correlates with the proposed concept plan prepared for the Department of Planning (now Department of Planning and Environment) shown in **Figure 3-4**.

Bewsher undertook a review of the CFR (2007) flood study, and generally agreed with the approach adopted. However, for this particular study, Bewsher (2010) developed a more refined Tuflow 1D/2D hydraulic model, and also developed their own WBNM model.

The WBNM model that was developed was similar to the one reported by CFR (2007). However, the key difference is that the CFR (2007) study included a number of flood storages to represent the storages upstream of the key bridges in the catchment, while the Bewsher (2010) study did not include these. These flood storages represent the storages that are formed upstream of the hydraulic structures, such as the TAFE bridge upstream. It's not clear why the Bewsher (2010) study did not include these, although given the dynamic nature of these storages, and their minor volume relative to the large upstream flows, it may be that these were not significant enough to consider beyond the catchment routing already in-built within WBNM.

For the rainfall intensities for the design events, the Bewsher (2010) study adopted similar upper, middle and lower representative rainfalls across the catchment to the CFR (2007) study. Similar to the CFR (2007) study, the Bewsher (2010) study identified that the 6 hour duration rainfall was critical for the catchment.

The Tuflow (1D/2D) model was developed through a combination of survey sources:

- A DTM prepared by Land Team;
- Where the AAM Hatch LiDAR data was 0.2m lower than the levels above, this was adopted instead;
- Duck Creek bathymetry from the CFR (2007) study; and
- Outside of the Tallawarra lands site, the AAM Hatch LiDAR data was adopted.

The resulting model provided a greater definition of the flood behaviour compared with the CFR (2007) HEC-RAS model. **Figure 3-1** shows the flood depths from the 1% AEP event for that model, together with the limits of the model. It only extended a short distance upstream of the railway line (given the focus of this modelling was on the areas downstream of the M1 Motorway).

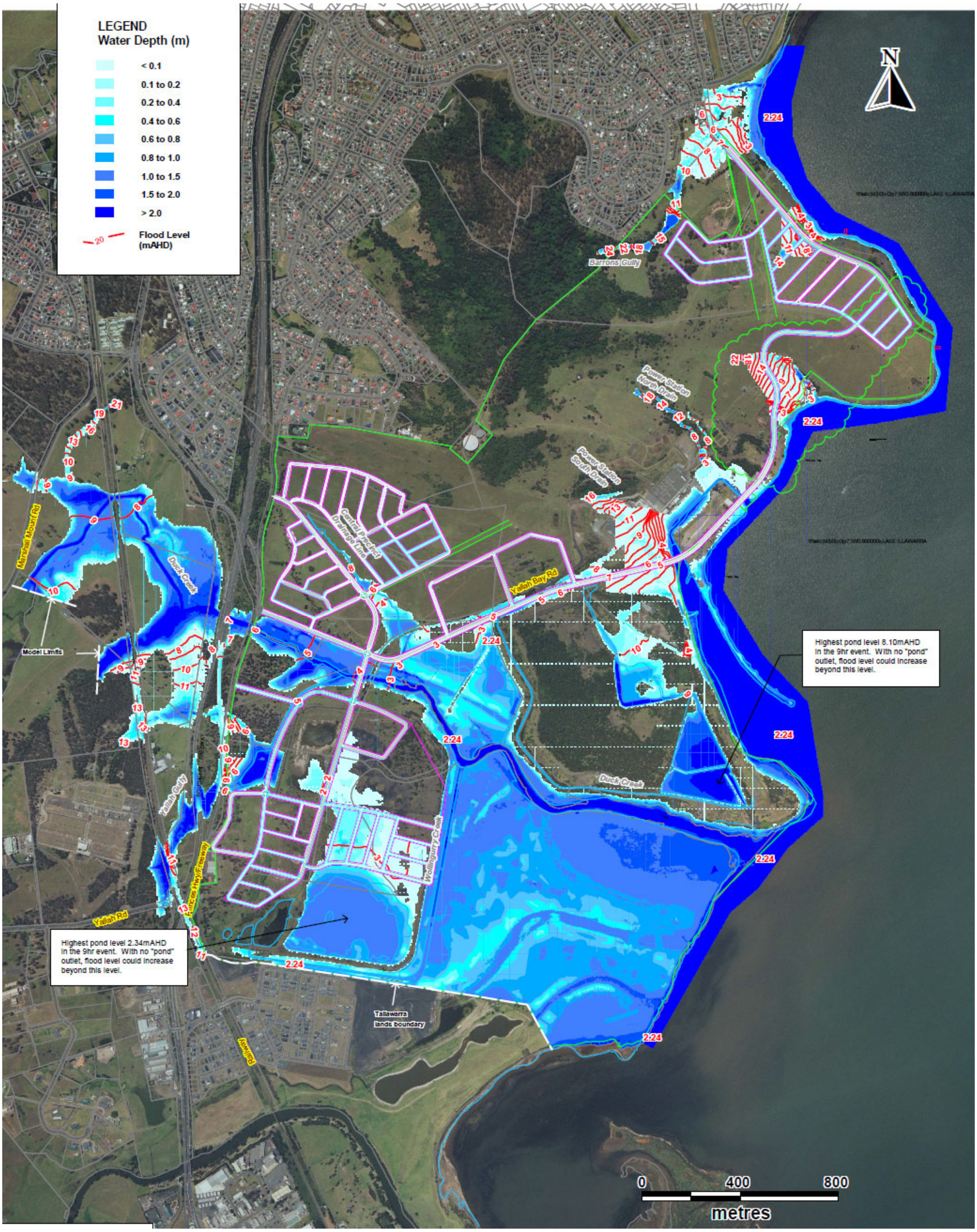

Figure 3-1. 1% AEP Flood Depths (Source: Bewsher 2010)

3.2.4 Lake Illawarra Flooding

Lake Illawarra forms the downstream boundary of the study area, and the lower portions of the study area are influenced by backwater flooding from the Lake. The key information to be considered with regards to Lake Illawarra flooding for the Duck Creek Flood Study is to understand the potential flooding mechanisms for the Lake, and how these may influence the local flood behaviour of Duck Creek.

Two previous studies have been undertaken for Lake Illawarra, namely:

- Lake Illawarra Flood Study (Lawson & Treloar 2001); and
- Lake Illawarra Floodplain Risk Management Study and Plan (Cardno Lawson Treloar 2012).

Hydrologic calculations for these studies were undertaken using the RAFTS software for the full 270km^2 catchment (of which Duck Creek is a part). The hydrological model identified that the 36 hour duration rainfall event was critical when considering the Lake Illawarra catchment in its entirety, whereas the critical duration for Duck Creek on its own is much shorter (2 – 6 hours BMT WBM 2012).

The 2001 Flood Study adopted a 1D MIKE11 hydraulic model to define the flood behaviour in the lake. This was subsequently updated for the 100 year ARI event for the Floodplain Risk Management Study (Cardno Lawson Treloar 2012), where a detailed Delft 3D hydrodynamic model was developed. Therefore, the Floodplain Risk Management Study recommends the use of a combination of the MIKE11 results, and the Delft 3D results for flood planning purposes, with the Delft 3D results being used for the 100 year ARI event.

A joint probability analysis was undertaken on historical data that was available. Based on this assessment, a downstream boundary in the ocean of Mean High Water Springs (MHWS) was adopted (0.6m AHD). A sensitivity analysis was undertaken on this water level by increasing to 1.2m AHD, which suggested a resulting increase in model results in the order of 0.2 metres within the lake.

A summary of peak flood levels in the lake for planning purposes is provided in **Table 3-1**. The relevant level for the Duck Creek Catchment is the Tallawarra Power Station (Location 2).

An overview of the flood extents for flooding within the Duck Creek catchment associated with Lake Illawarra is provided in **Figure 3-2** and **Figure 3-3** for the 1% AEP and PMF respectively. It shows that the inundation from Lake Illawarra flooding effectively extends up to the Princes Highway within the Duck Creek catchment.

Table 3-1 Flood Levels from the Lake Illawarra Floodplain Risk Management Study & Plan

Lake Illawarra Floodplain Risk Management Study
Prepared for Lake Illawarra Authority, Wollongong City Council & Shellharbour City Council

Table 16.2 Design Flood Levels to be used for Planning Purposes

	Location*	Peak Flood Level (m AHD)								
		100 Year ARI	100 Year ARI (2050 SLR)	100 Year ARI (2100 SLR)	50 Year ARI	20 Year ARI	10 Year ARI	5 Year ARI	2 Year ARI	Extreme Event (PMF)
	Modelling	Delft3D (2008)	Delft3D (2008)	Delft3D (2008)	MIKE11 (2001)	MIKE11 (2001)	MIKE11 (2001)	MIKE11 (2001)	MIKE11 (2001)	MIKE11 (2001)
1	Griffins Bay	2.24	2.63	3.04	2.03	1.81	1.57	1.40	1.11	3.24
2	Tallawarra Power Station	2.24	2.63	3.04	2.03	1.81	1.57	1.40	1.11	3.24
3	Horsley Inlet	2.24	2.63	3.04	2.03	1.81	1.57	1.40	1.11	3.24
4	Cudgeree Island Channel	2.24	2.64	3.04	1.99	1.81	1.54	1.40	1.08	3.19
5	Windang Bridge	2.15	2.55	3.01	1.83	1.63	1.42	1.26	0.99	2.98
6	Entrance Channel	1.71	2.25	2.32	1.74	1.55	1.35	1.20	0.95	2.84

** Locations illustrated on Figures 5.1 – 5.2.*
** Note: FPL = Design Flood Level + Freeboard (0.5m)*

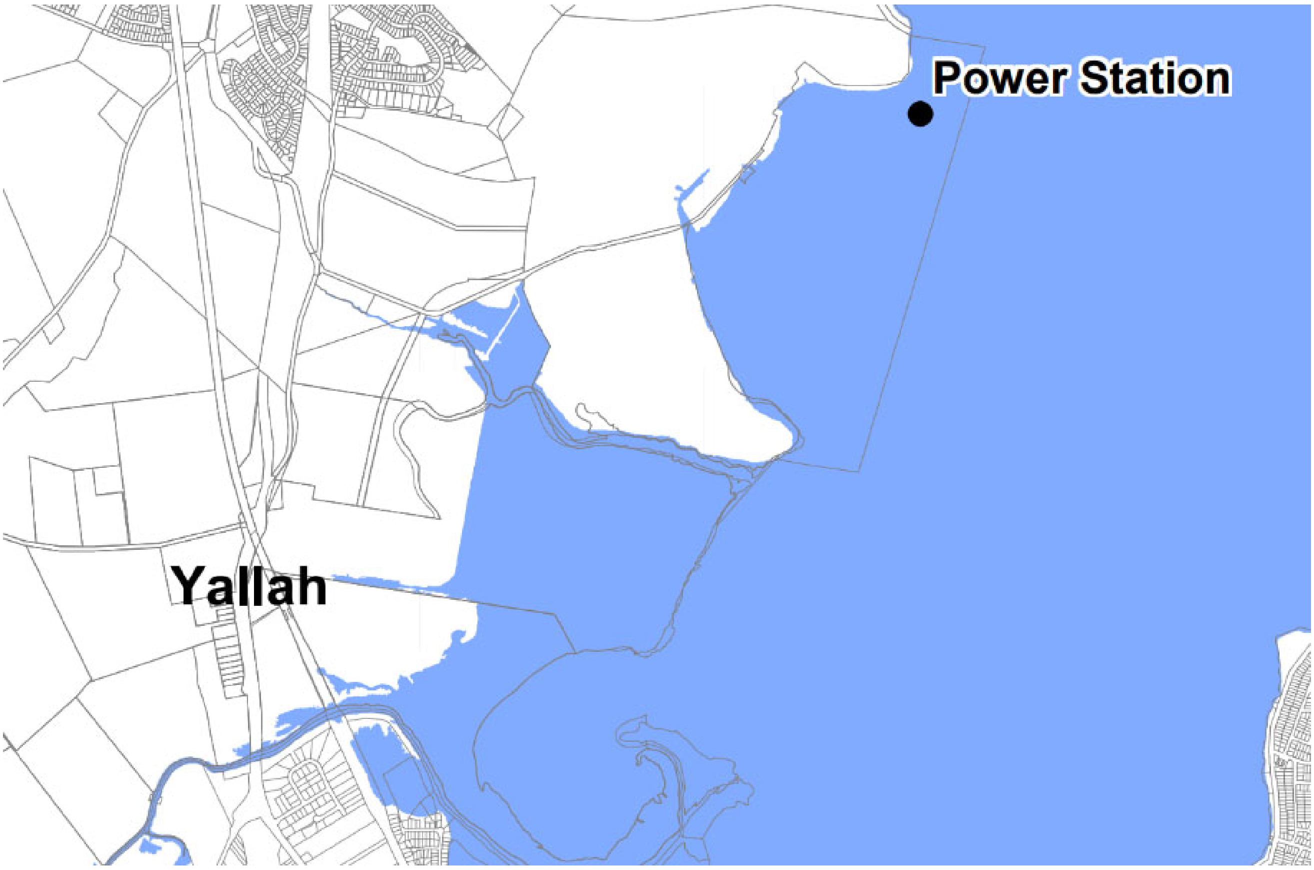

Figure 3-2. 1% AEP Flood Extent – Lake Illawarra FPRMSP (map excerpt from Cardno Lawson Treloar, 2012)

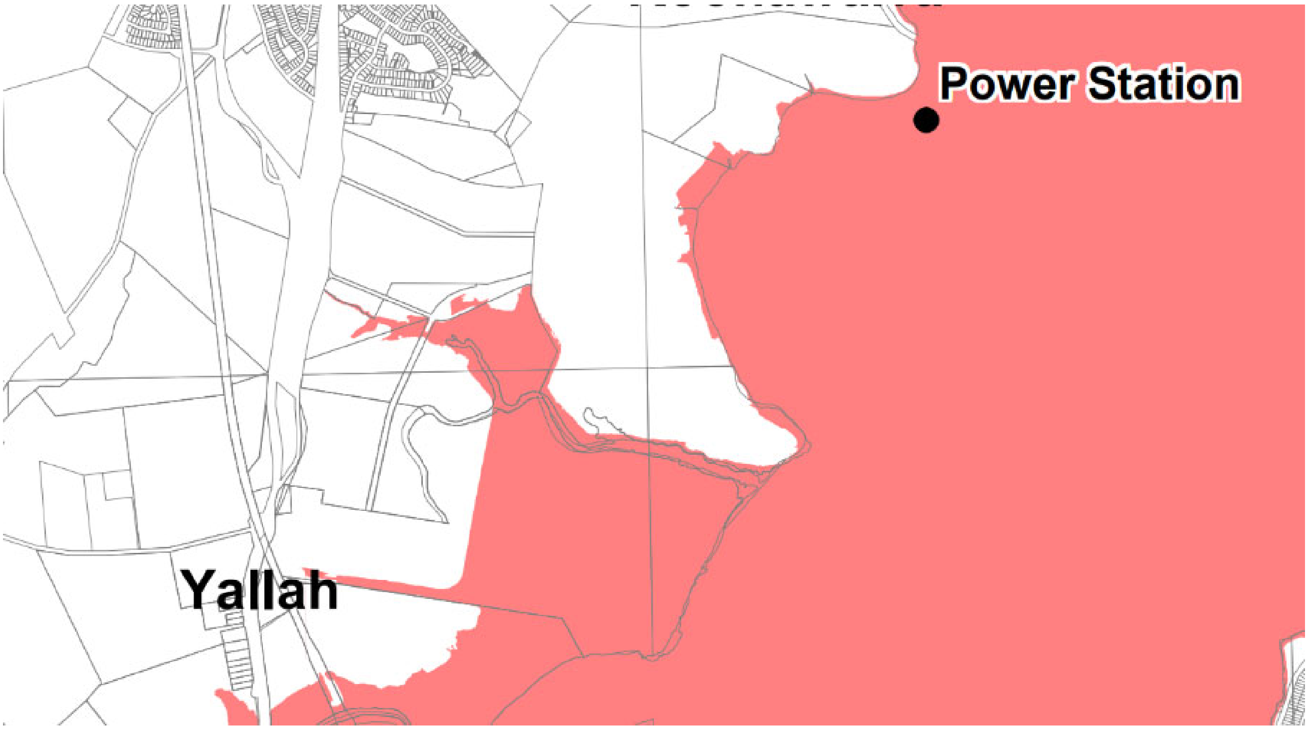

Figure 3-3. PMF Flood Extent – Lake Illawarra FPRMSP (map excerpt from Cardno Lawson Treloar, 2012)

3.3 Local Policies and Emergency Management Plans

A variety of relevant planning documents, where available, were reviewed and considered as part of the study. These documents are listed in **Table 3-2**.

Table 3-2 Policy and Planning Documents

Document	Relevance to the Study
Wollongong Development Control Plan (WCC 2009)	This Flood Study needs to produce outputs that allow users to assess developments in accordance with the requirements of the DCP.
Wollongong Local Environmental Plan (WCC 1990 & 2009)	The LEP 1990 Applies to Marshall Mount and parts of Huntley and Yallah. This LEP provides controls for development on flood prone land. Flood prone land is defined in the LEP as land indicated as flood prone on the map marked "Wollongong Local Environmental Plan 1990 (Amendment No 235)—Flood Prone Land Map". 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. No flood planning area is currently shown on the Flood Planning Maps for the Duck Creek catchment.
Wollongong Local Flood Plan (SES 2010)	This plan covers preparedness measures, the conduct of response operations and the coordination of immediate recovery measures from flooding within the Wollongong City Council area. It covers operations for all levels of flooding within the Council area. The general characteristics of flooding for each catchment is provided in the Flood Plan. No details are currently included for the Duck Creek Catchment. The information presented in this Flood Study can be used to update this. This Flood Study would be used to update Annex B of the Local Flood Plan including: • Critical storm duration – see **Section 8** • Possible road closures – see **Section 8.7**. Further details on road closures can be updated in Annex C from the information presented in **Section 8.7**.
Conduit Blockage Policy (WCC, 2002) - *superseded*	The superseded conduit blockage policy applied to all design events was adopted by Council in 2002 and required that flood modelling 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

Document	Relevance to the Study
	implemented was effective in identifying and planning for flood risks at locations potentially sensitive to blockage. The 2012 Duck Creek Flood Study utilised this blockage policy for design flood modelling.
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". Further details of the revised blockage policy and how it has been applied in this study are provided in **Section 7.3.3**.
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 will be considered when evaluating the impact of increased development (Scenario 5).

3.4 Survey Information

3.4.1 Aerial Survey

Two sets of aerial survey (LiDAR) were available for the project. One set was flown from 2005 – 2007 and represents a compilation of data collated for that period. This data was collected by AAMHatch. The second set of 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).

A comparison of these data sets is provided in **Appendix B**. Based on this assessment, it is recommended to adopt the 2005 – 2007 LiDAR data set, as it generally provides a better representation of the Duck Creek floodplain. Based on a comparison of ground survey data with the LiDAR data set, the accuracy is approximately within +/- 0.15m to one standard deviation. Further details are provided in **Appendix B**.

This data set is the key input to the establishment of the digital elevation model (DEM) for the project.

3.4.2 Existing Ground Survey

There were a number of key ground survey data sources that were available. These are summarised in **Table 3-3**.

Table 3-3 Existing Survey Sources

Source	Information Available
Flood Study (BMT WBM 2012)	Cross sections and structures (e.g. bridges and culverts) were surveyed as a part of this study, across most of the study area. Limited data was collected in the Tallawarra lands outside of the creekline corridor, where LiDAR was relied upon to define the floodplain area. The spacing of the cross sections, particularly upstream of the M1 Motorway, is quite far apart. Largely, the capacity of the creekline would be reasonable defined from the LiDAR survey, however, there are some areas where additional cross sectional data would be of benefit.
Cardno Forbes Rigby (2007)	Ground survey was collected on the Tallawarra lands for this study. This included creekline bathymetry, as well as a number of spot heights across the Tallawarra owned lands. This data is more extensive in this location than the 2012 Flood Study.
LandTeam	Ground survey was provided by LandTeam on the 4 January 2018. This survey was undertaken for the Tallawarra owned lands. It is a combination of LiDAR and ground survey information covering the Tallawarra Lands. There is some uncertainty on the source of the individual survey elements, as it is understood to be a compilation of survey that has been undertaken over the years and combined with LiDAR data.
Council	Survey of Marshall Mount Road and Yallah Road was provided by Council. This survey was collected as a part of earlier work undertaken for the land release area.

3.4.3 Additional Survey

Following site inspections and a review of the existing survey available, additional ground survey was identified to provide greater definition of the floodplain. This survey was collected by Council's surveyors in September 2017. Primarily, this included additional cross sections, particularly where the spacing of cross sections from the existing data sets was too large, or where dense vegetation would limit the reliability of the LiDAR data.

A summary of the surveyed cross sections is provided in **Map G301**.

3.5 Historical Flood Marks

3.5.1 March 2017 Event

During the site inspections at the commencement of the study (see **Section 3.1**), a number of debris marks were visually identified. While the site inspection was undertaken in July 2017, there was still evidence of the flooding from March 2017. The project team identified a number of key locations, and Council's surveyors collected these flood marks in July 2017. A total of 12 flood marks were collected. These flood marks are shown in **Map G302**.

3.5.2 March 2011 Event

BMT WBM undertook post-event reconnaissance after the March 2011 event as a part of the 2012 Flood Study. During this, key flow paths and inundation extents were identified for the event. A total of 22 peak flood levels were identified throughout the catchment for the March 2011 flood event.

This data is shown in **Map G303**.

3.5.3 February 1984

One historic flood level was identified from the February 1984 event in Cardno Forbes Rigby (2007). This level was recorded in Duck Creek, at the Yallah TAFE site.

A further two historic flood levels were identified from the community questionnaire that was undertaken in the 2012 Flood Study. These two flood levels were reported on a private property on North Mount Marshall Road. However, it was identified that the locality of these points was not certain, and given the grades in this area, the potential variation in water level is high.

This data is shown in **Map G304**.

3.5.4 March 1978 event

A single historic flood level was identified for the March 1978 flood event in the Cardno Forbes Rigby (2007) study. This level was identified upstream of the Princes Highway bridge over Duck Creek.

This data is shown in **Map G304**.

3.6 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), WaterNSW (formerly Sydney Catchment Authority (SCA)), Sydney Water Corporation (SWC) and Manly Hydraulics Laboratory (MHL). A list of gauges for the area surrounding the catchment is shown in

Table 3-4**, Table 3-5** and **Table 3-6,** together with key information on whether they are pluviometer or daily gauges, and whether they were operational during the historical storm events in the catchment. The location of these gauges is shown in **Map G305**.

There are five rainfall gauges within or close to the boundary of the Duck Creek catchment, including the discontinued BoM rainfall gauges at Tallawarra Power Station, Yallah (Ianwyn) and Yallah; and two continuous rainfall gauges operated by MHL at Huntley and Calderwood (still in operation).

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.

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

Further discussion on recorded rainfall data for historical events is presented with the calibration and validation of the models developed for the study in **Section 6**.

Table 3-4 Bureau of Meteorology Rain Gauges

					Operational During Storm Events				
Site	**Name**	**Start**	**End**	**Pluvio**	**Mar-78**	**Feb-84**	**Feb-08**	**Mar-11**	**Mar-17**
68129	ALBION PARK (PARKVALE)	Nov-62	Jan-67	N	N	N	N	N	N
68241	ALBION PARK (WOLLONGONG AIRPORT)	Jun-99	Aug-17	Y	N	N	Y	Y	Y
68000	ALBION PARK POST OFFICE	Apr 1892	Jul-17	N	N	N	N	N	N
68110	BERKELEY (NORTHCLIFFE DRIVE)	Jan-64	Jul-17	N	Y	Y	Y	Y	Y
68246	BLACKBUTT (TAMMAR PLACE)	Jan-02	Aug-17	N	N	N	Y	Y	Y
68022	DAPTO BOWLING CLUB	Jan-06	Feb-17	N	N	N	Y	Y	N
68023	DAPTO WEST (STANE DYKES)	Jan 1898	Aug-87	N	Y	N	N	N	N
68113	DUNMORE (KURRAWONG)	Nov-62	Jul-74	N	N	N	N	N	N
68237	KEMBLA GRANGE RACECOURSE	Feb-94	Jun-03	N	N	N	N	N	N
68242	KIAMA (BOMBO HEADLAND)	Dec-01	Aug-17	Y	N	N	Y	Y	Y
68004	MOUNT WARRIGAL (REDDALL PARADE)	May-99	Dec-08	N	N	N	Y	N	N
68199	OAK FLATS (THE BOULEVARDE)	Mar-74	Jun-05	N	Y	Y	N	N	N
68115	OCEAN VIEW (ROBERTSON)	Nov-62	Mar-69	N	N	N	N	N	N
68116	PHEASANTS GROUND	Nov-62	Nov-69	N	N	N	N	N	N
68131	PORT KEMBLA (BSL CENTRAL LAB)	May-63	Mar-17	N	Y	Y	Y	Y	N
68053	PORT KEMBLA SIGNAL STATION	Jun-50	Jun-77	N	N	N	N	N	N
68224	ROBERTSON (THE PIE SHOP)	Sep-85	Aug-17	N	N	N	Y	Y	Y
68104	TALLAWARRA POWER STATION	Jan-62	Apr-00	N	Y	Y	N	N	N
68155	THE HILL	Sep 1895	Sep-1919	N	N	N	N	N	N
68060	UNANDERRA	Jan-03	Apr-69	N	N	N	N	N	N
68061	VIADUCT CREEK	Jan-42	Oct-68	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	N	N
68121	YALLAH	Nov-62	Nov-73	N	N	N	N	N	N
68130	YALLAH (IANWYN)	Nov-62	Jan-81	N	Y	N	N	N	N

Table 3-5 MHL Rain Gauges

			Operational During Storm Events				
Site	**Name**	**Pluvio**	**Mar-78**	**Feb-84**	**Feb-08**	**Mar-11**	**Mar-17**
568308	Cleveland Road	Y	N	N	Y	Y	Y
568311	Huntley Colliery	Y	N	Y	Y	Y	Y
214467	Little Lake Entrance	Y	N	N	N	N	Y
568315	North Macquarie	Y	N	N	Y	Y	Y
568316	Port Kembla	Y	N	Y	Y	Y	Y
568319	Upper Calderwood	Y	N	N	Y	Y	Y
568320	Wongawilli	Y	N	Y	Y	Y	Y

Table 3-6 Sydney Water Rain Gauges

			Operational During Storm Events				
Site	**Name**	**Pluvio**	**Mar-78**	**Feb-84**	**Feb-08**	**Mar-11**	**Mar-17**
568071	Upper Avon	Y	N	Y	N	N	N
568102	Mount Murray	Y	N	Y	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	Y	Y	Y
568171	Albion Park Bowling Club	Y	N	N	Y	Y	Y
568180	Dapto Citizens Bowling Club	Y	N	N	Y	Y	Y
568185	Wongawilli	Y	N	N	Y	Y	Y

3.7 Future Development Information

3.7.1 West Dapto Structure Plan

Council provided GIS data of the draft structure plan for the West Dapto Masterplan (file name: Draft_structure_Plan_V1_2014, provided on 7 July 2017). This GIS file provides the draft proposed zonings for the area. An overview of this zoning plan is provided in **Map G201**.

3.7.2 Tallawarra Lands Concept Plan

A concept structure plan was prepared for the Tallawarra Lands (owned by Energy Australia) by the Department of Planning (now the Department of Planning and Environment) in 2009. A series of reports and planning documents were also prepared as a part of this process[2]. An overview of the concept plan and zoning is provided in **Figure 3-4**.

[2] Submission details available from http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=3362

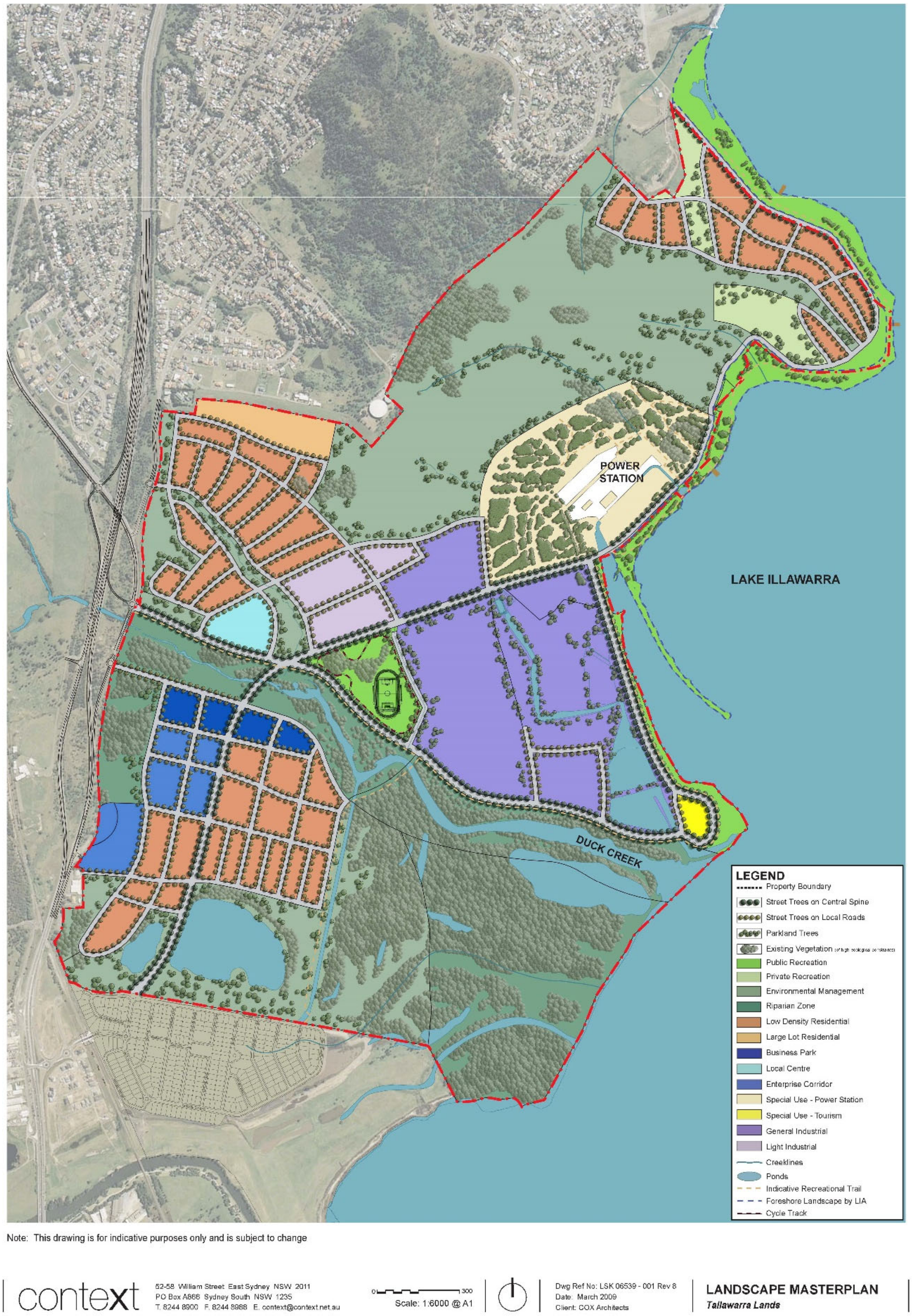

Figure 3-4. Tallawarra Concept Plan (Context, 2009)

3.7.3 Albion Park Rail By-Pass

The Albion Park Rail By-Pass involves a modification to the freeway with the northern end starting within Duck Creek catchment. The hydraulic modelling undertaken for the By-Pass was based on the earlier 2012 Duck Creek Flood Study Tuflow model, and updated to reflect the proposed By-Pass works. The model was provided to Rhelm on 19 January 2019. This has been used as an input to the future scenario modelling discussed in Section 7.5.

3.8 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.

The consultation undertaken as part of this Flood Study has been built on the consultation undertaken as part of the 2012 Duck Creek Flood Study. Since the previous consultation was undertaken in 2010 there have been several flood events in the catchment (including events in 2011 and 2017). The current study will aim to collect information on these more recent events and also engage with community members and stakeholders who were unable to provide input in 2010.

4.1 Consultation Strategy

A consultation strategy was developed in the preliminary stages of the project. Details of the strategy are provided in **Table 4-1**.

Table 4-1 Consultation Strategy

Method	Stakeholders	Example Goals	Timing	Details
Letter of introduction to the study and follow up phone calls and emails	▪ 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.	Project inception.	Rhelm prepared a letter of introduction to be sent to relevant agency and community stakeholders to inform them of the purpose of the study and how they could provide input. This letter was sent via email. Follow up was undertaken via email and phone. The outcomes of this engagement are summarised in **Table 4-2.**
Newsletter and questionnaire	▪ 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.	Project inception.	A newsletter and questionnaire were sent to all flood affected properties in the Duck Creek catchment. The newsletter provided information about the purpose and scope of the study. The survey requested input from residents regarding their experiences of flooding and any concerns they might have regarding flood risk. Further details are provided in **Section 4.3**.
Councillor Briefing	▪ Councillors.	▪ Inform Councillors of the draft Flood Study Review. ▪ Gain approval for public exhibition of the draft document.	Prior to public exhibition.	The draft Flood Study will be presented to the Councillors to obtain approval for the document to be released for public exhibition.
Public Exhibition Period	▪ All stakeholders.	▪ Provide an opportunity for feedback on the Draft Study.	Following completion of the Draft Study.	The draft Flood Study will be placed on public exhibition for a minimum period of four (4) weeks. During this time the community and other stakeholders will be encouraged to review the document and provide feedback. The document will be available online and in hard copy from Council admin and the library. The submissions received during the public exhibition period will inform the finalisation of the study.

Method	Stakeholders	Example Goals	Timing	Details
Public information sessions for community consultation	▪ Impacted Community Stakeholders. ▪ Interested Community Stakeholders.	▪ Provide an overview of the study purpose, methodology and outcomes. ▪ Provide location specific information to attendees (via one on one sessions). ▪ Provide an opportunity for feedback on the Draft Study.	Following completion of the Draft Study.	A community information session will be undertaken during the public exhibition period to present the draft Flood Study to the community, answer any questions that may be raised and the gain feedback to assist in the finalisation of the 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.	Project inception. Completion of Stages 1, 2 and 3.	Technical working group meetings have been undertaken throughout the duration of the study to review key technical aspects of the study and ensure the methodology and assumptions are robust and peer reviewed.
Southern Floodplain Risk Management Committee Meeting	▪ Floodplain Risk Management Committee.	▪ Inform the Committee of the study scope, objectives, methodology and outcomes. ▪ Receiving feedback.	29 March 2018	Committee meetings were undertaken in accordance with the committee meeting program. One meeting has occurred since the project inception. A progress report for the study was provided at each meeting and provided an opportunity for key stakeholders to contribute to the study.

4.2 Agency Consultation

There are many agencies with flood-related interests in the Duck Creek Catchment. A letter of introduction to the study was sent to the key stakeholder agencies with an invitation to be involved in the project. The letter also included requests for any relevant data or information that they may have.

The agencies contacted as part of this consultation are listed in **Table 4-2** along with the outcomes of the consultation.

All agency stakeholders were contacted prior to the public exhibition of the draft Flood Study to request their feedback on the document. No responses were received.

Table 4-2 Agency Consultation

Agency Stakeholder	Outcome of Consultation
Wollongong City Council: Senior Stormwater Development Engineer	Provided information on the proposed West Dapto Urban Development. Attended the inception meeting and initial site inspections. Ongoing liaison throughout the data collection stage of the project with the project team.
Wollongong City Council: Senior Development Project Officer	Provided relevant contact details at Energy Australia.
Wollongong City Council: Civil Coordinator – South Works, City Works and Services	Provided input on historical flood damage to Council infrastructure.
Office of Environment and Heritage	Provided ongoing guidance on best practice guidelines, policy, technical and project management advice throughout the project.
Manly Hydraulics Laboratory	No consultation undertaken. All relevant MHL data has been accessed and provided by OEH (the owner of the data collected by MHL).
NSW State Emergency Service	The relevant response unit was contacted but no historical flood photos or other information could be obtained. SES has a representative on the Floodplain Management Committee and will continue to be involved in the project for its duration.
Roads and Maritime Services	Provided existing ground survey obtained as part of the Albion Park Rail Bypass investigations, culvert design details.
RailCorp	Advised that RailCorp has not had any serious issues with floods in the Duck Creek catchment that have affected the Illawarra Line. The rail bridge over Duck Creek has good clearance and there have never been any reports of flood damage. However, the culverts further south of the main Duck Creek channel have been known to overflow from time to time and this could affect rail corridor access roads. There has been some recent work extending and upgrading the culverts.
Department of Planning and Environment	Supportive of the study being undertaken due to proposed development in the catchment. Did not have any additional information regarding rezoning or development that was not already held by Council.

Agency Stakeholder	Outcome of Consultation
Energy Australia (Owner of Tallawarra Power Station)	Contact was attempted via several avenues; however, no response has been received.
Elton Consulting (Consultant to Energy Australia)	No response received.
LandTeam (Consultant to Energy Australia)	Contacted regarding Tallawarra Lands survey. They advised that permission would need to be granted by Energy Australia before the data can be released. No permission has been obtained to date.
TAFE NSW	They observed in March 2017 that the water level in the creek was approximately 1 foot below the bridge.
Conservation Volunteers Australia	No response received.

Other asset owners with utilities in the area include:

- National Broadband Network
- Endeavour Energy
- Jemena Gas
- NextGen Networks
- Telstra
- Optus/Uecomm.

These asset owners were advised of the draft flood study exhibition (see **Section 4.4**).

4.3 Community Newsletter and Survey

A community newsletter and survey was distributed to property and business owners, as well as residents within the Duck Creek catchment. The newsletter and survey were also made available on Council's website. A copy of the newsletter and survey is provided in **Appendix C**.

The newsletter provided information on the purpose and scope of the Duck Creek Flood Study and the survey sought information about historical flooding events and other flooding concerns within the community.

The survey was delivered to approximately 87 recipients. The mail out included owners, occupiers, businesses and public agencies affected by the PMF:

- 39 addressed to "the occupant"
- 16 addressed to businesses, churches or public agencies.
- 32 duplicate mail outs related to a parcel i.e. the Owner and the occupant.

A summary was also provided in a media release, informing the community of the Flood Study and advertising that the survey was being undertaken.

From the distribution and availability of the survey on the website, two responses were received, representing a return of only 2% of direct distribution. A return rate of 10% is typical for these types of mail-outs. It is noted, however, that the 100 recipients included everyone within the PMF extent, many of whom have buildings outside of the flood extent. There are significantly less residences in the floodplain and this may explain the lower response rate.

The submissions received provided information and photos on historical flooding. Follow up was undertaken with the respondents to clarify the data received. Ground level survey was captured for several locations for the 2011 flood event based on information derived from the submissions. The ground survey provides flood levels for the calibration of the hydraulic model.

4.4 Southern Floodplain Management Committee

The Flood Study has been overseen by the Southern Floodplain Risk Management Committee which includes representatives from community groups and State agencies including:

- Wollongong City Council
- Office of Environment and Heritage
- State Emergency Service
- Manly Hydraulic Laboratory
- Roads and Maritime Services
- Rail Corp.

The committee has met once during the progress of the Flood Study. Project updates have been provided to the committee at these meetings by Council's project manager. In addition, email updates have been provided to the committee throughout the project.

At the Southern Area Floodplain Risk Management Committee meeting on 19 March 2019, the public exhibition of the Duck Creek Flood Study Review was unanimously supported. The outcomes of the exhibition and resulting amendments to the Study will be reported to the Southern Area Floodplain Risk Management Committee and Council in view of adopting it in 2019.

4.5 Public Exhibition

The draft Flood Study was placed on Public Exhibition (1 April 2019 to 14 May 2019) to allow the community and other stakeholders to review and comment on the report prior to it being finalised and adopted by Council.

Council sent letters to 104 residents and property owners in the catchment area inviting them to learn more about the draft Flood Study (**Appendix C**). The information was also provided to Council's Customer Service Centre. A Frequently Asked Questions sheet (**Appendix C**) and Feedback Form (**Appendix C**) was provided at the information session at Dapto Ribbonwood Centre on 8 April 2019 and on the project webpage. The webpage also included the draft report and attachments. Notices of the exhibition were published in the Advertiser on 3 April and 1 May 2019. The community were invited to provide feedback via Council's website, Customer Service Centre and at the community information session.

Six people attended the drop-in information session, including two NSW State Emergency Services representatives, and a representative of Neighbourhood Forum 8 and Dapto Chamber of Commerce. All were generally supportive of Council's flood risk management work for the catchment. Some noted that not much had changed since the last Study.

No other submissions were received.

Details of the number of participants for each engagement activity are presented in **Table 4-3**.

Table 4-3 Public Exhibition Engagement Participation Results

Engagement Activities	Participation
Drop-in Community Information Session	6
Online Participation • Aware – Total number of users who viewed the project page • Informed – Total number of users who clicked a hyperlink, e.g. to download a document • Engaged – Total number of users who actively contributed to the project, e.g. submitted feedback via the online form	 77 27 0

5 Model Development

5.1 Hydrologic Model

The 2012 Flood Study developed a hydrological model using WBNM software that provides for simulation of the rainfall-runoff process using the catchment characteristics of Duck Creek and historical and design rainfall data.

The previous model was found to be largely suitable for use in the current study. Some minor changes were made to imperviousness to ensure that the model was reflective of current catchment conditions.

The Duck Creek catchment drains an area of approximately $19km^2$ to its point of discharge into Lake Illawarra. For the hydrologic model the catchment area has been delineated into 127 sub-catchments as shown in **Map 501**. The underlying DEM is shown in **Map 502**. The sub-catchment delineation provides for the generation of flow hydrographs at key confluences or inflow points to the hydraulic model.

There was no flow gauging available within the Duck Creek Catchment, and therefore a direct calibration of the hydrological model could not be undertaken. However, an indirect calibration was undertaken through the hydraulic model and comparison to observed flood levels within the catchment (**Section 6**).

As a check on the hydrological model, a verification was undertaken by comparing the flows derived in the current study with those of the 2010 Bewsher Study. The results of this verification are provided in **Table 5-1**.

As noted above, the 2012 hydrological model was setup so that flow routing occurs within the hydraulic model, rather than the hydrologic model. As such, the 2012 hydraulic model flows have been shown for verification purposes.

The model shows a reasonable agreement between the 2012 hydraulic model results and the 2010 Bewsher study, suggesting that the hydrological modelling approach adopted is comparable.

Table 5-1 Hydrological Model Verification

Location	100 Year ARI Peak Flow (m3/s)		
	Current Model	2012 Hydraulic Model (6 hour duration)	2010 Bewsher Study
F6 Freeway (downstream)	253	233	237.1
Duck Creek Outlet	290	NA	289.0

Further details on the development of the hydrological model are provided in **Appendix D**.

5.2 Hydraulic Model

A TUFLOW model was developed by WBM as part of the 2012 Duck Creek Flood Study. The model developed was primarily a 2D model of the floodplain and channels. 1D components of the model were limited to hydraulic structures (culverts). Bridges were represented through the 2D component of TUFLOW. The culverts and bridges are shown in **Map 503**. The adopted model roughness is shown in **Map 504**.

The previous model was found to be largely suitable for use in the current study. Some minor changes were made to ensure that the model was reflective of current catchment conditions, namely:

- Update of culvert details based on new survey data;
- Update of previous survey based on field verification of current conditions;

- Update of bridge crossings based on new survey and field verification;
- Incorporation of additional cross sections to better define the creek areas; and
- Update of the roughness values to ensure they represent current conditions.

The details of the hydraulic model developed for the current study are provided in **Appendix D**.

6 Calibration and Validation

The selection of suitable historical events for calibration of the computer models is largely dependent on available historical flood information. Based on the information collected from both the 2012 Flood Study and the data collection for this update of the flood study, there are five potential events that could be used for the calibration and validation of the model:

- March 1978
- February 1984
- February 2008
- March 2011
- March 2017

Of these events, March 2011 and March 2017 have the largest collection of observed flood levels for the calibration of the model.

March 1978, while a large event, did not have any nearby pluviometers, which means that it is not possible to directly estimate the rainfall on the catchment. Given its magnitude, a review of the 1978 event was also undertaken.

The February 2008 event was a significantly smaller event than the others, and only had three observed levels (two of which were identified as being potentially uncertain due to steep grades in that area). Therefore, February 2008 was not included in the calibration and validation of the model.

A calibration and validation of the model has been undertaken for the March 2017, March 2011 and February 1984 events.

An overview of the calibration is provided below, further details are provided in **Appendix D**.

March 2017

March 2017 - The model generally aligns well with the observed levels from the event, with modelled levels typically within +/-0.2m of the observed levels. However, it is important to note that there is uncertainty in the observed levels. The calibration results are shown in **Map 601**. Some commentary of the comparisons, particularly where larger differences occur, are provided in **Appendix D**.

March 2011

March 2011 - In general, the model provides a reasonable match to the observed flood levels from March 2011. The modelled levels are higher in the vicinity of the Freeway and Princes Highway, with the observed levels being closer to the lower estimate of rainfall for the event. This may indicate that the lower estimate rainfall may be more appropriate for this area. However, these points are in very close proximity to the structures in this area, which may lead to localised effects that may affect the results.

There are also some larger differences in the upper part of the catchment. However, the terrain and water level gradient in this area is relatively steep. Therefore, any error in the horizontal location of an observed point in this area can lead to relatively large differences in vertical height.

The calibration results are shown in **Map 602**.

February 1984

February 1984 – there was only one historical observation for this event near where the current TAFE access road exists (but was not in this location during the 1984 event). The model showed a higher level in this location. However, there is a fair degree of uncertainty, related to:

- The rainfall pattern. The assessment as noted was based on the Calderwood Gauge, and weighted according to 48 hour rainfall. The analysis of the March 2011 and 2017 event suggests that there can be significant variation on hourly or less increments in this area;
- There has been significant change in the area surrounding the observed point in vegetation. It is uncertain as to potential changes in terrain. While a representative terrain was included in the model by removing the road and the bridge, it is difficult to know what exactly was there at the time.

The calibration results are shown in **Map 603**.

March 1978

The 1978 event was a large event in the catchment, with one observed level being available. However, the key challenge for this event is that the closest pluviometer rainfall gauges are at Shellharbour STP (around 13km away from the catchment) and Wollongong STP (around 19km away from the catchment). Analysis of other events (2017, 2011 and 1984) suggests that there would be large differences in rainfall volume and pattern between these locations at Duck Creek.

This results in a difficulty in generating a local rainfall pattern for the Duck Creek catchment in order to undertake the calibration. The 2012 Flood Study utilised an artificial temporal pattern derived from ARR87 from the 72 hour duration storm. This approach leads to significant uncertainty, and in some part may explain the large difference in modelled level versus observed level from that report.

Given these uncertainties, the 1978 event has not been utilised for the calibration of the model. However, to understand the potential magnitude of this event relative to the other historical events, the single observed level has been compared with the other events to provide an indication of how large the event was. The observed levels from the different events in the vicinity of the Princes Highway are provided in **Table 6-1**. This suggests that the March 1978 event may have been similar in magnitude to the March 2011 event.

Table 6-1 Comparison of Observed Levels

Flood Event	Observed Level (m AHD)
March 1978	4.5
March 2011	4.5
March 2017	5.1 – 5.6

7 Design Flood Modelling

7.1 Australian Rainfall and Runoff

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

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

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

7.2 Hydrology

The hydrological model, as described in **Section 5.1**, was adopted for the design flood event modelling. The parameters identified for the calibration provided a reasonable performance in the modelling, and these same parameters were adopted for the design event modelling.

The catchment extends from the coastal plains in the east adjacent to Lake Illawarra, up to the escarpment. As identified in the rainfall analysis for the calibration (**Section 6**), the escarpment can result in significant variations in rainfall behaviour.

As a result of this significant variation, four representative rainfall locations were applied in the WBNM model. These were applied as points, with a linear (Thiessen polygon) interpolation undertaken between them. The location of these points is provided in **Figure 7-1**. A comparison of the 1% AEP and 20% AEP rainfall depths for Location A and D is provided in **Figure 7-2**, indicating the significant variability within the study area. As an indication, the 1% AEP 6 hour duration rainfall at location A (western edge of catchment, at the escarpment) is approximately twice that at location D (eastern edge of catchment, at Lake Illawarra).

A summary of other catchment parameters, as per the previous section of this report, are provided in **Table 7-1**.

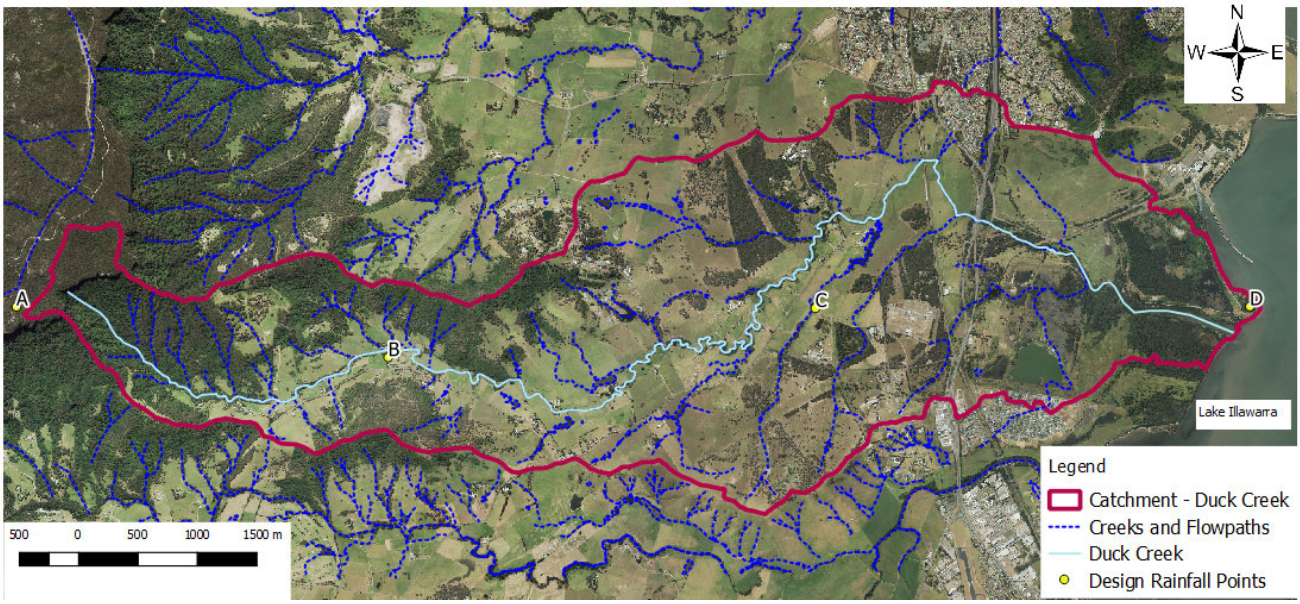

Figure 7-1 Design Rainfall Locations for Hydrological Model

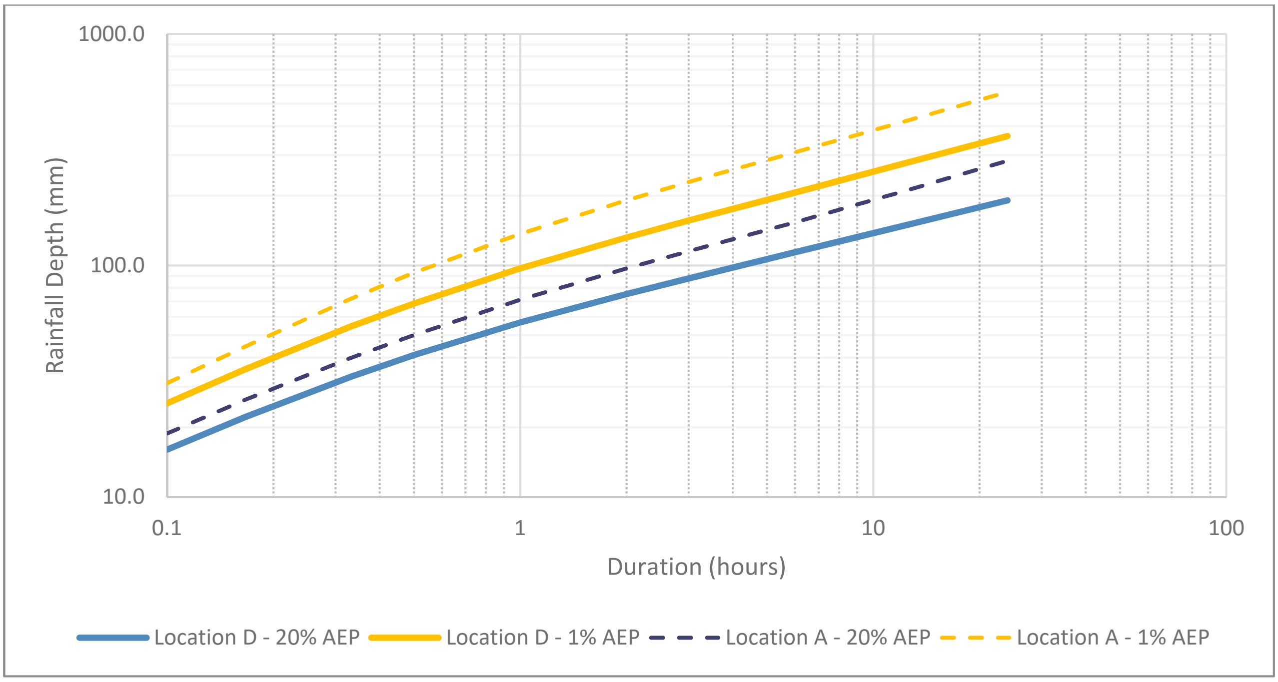

Figure 7-2. Design Rainfall IFDs

Table 7-1 Adopted WBNM Values - Summary

Parameter	Value	Comment
Initial Loss (mm)	20	Adopted consistent as per the 2012 flood study, and as per calibration. Refer Section 5 and 6.
Continuing Loss (mm)	2.5	Adopted as per 2012 flood study and calibration results.
WBNM Lag Parameter	1.6	Refer Appendix D.
WBNM Stream Lag Factor	1.0	Refer Appendix D.

7.3 Hydraulic Modelling

7.3.1 Model Parameters

The hydraulic model parameters, as identified in **Appendix D**, were adopted for the design event modelling.

7.3.2 Coincident Lake Illawarra Flooding

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

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

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

The adopted Lake Illawarra levels for each of the design event boundary conditions are shown in **Table 7-2**. Flood levels for the Lake were adopted from Cardno Lawson Treloar (2012) for the Tallawarra Power Station reporting location in the report. High High Water Springs (HHWS) was estimated based on MHL (2012) for Koonawarra Bay, which is the closest reporting location to the downstream boundary of Duck Creek.

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 7-2 Adopted Lake Illawarra Events

Design Event	Catchment	Lake AEP	Lake Level
PMF	PMF	1%	2.3
0.20%	0.20%	1%	2.3
0.50%	0.50%	1%	2.3
1%	1%	5%	1.81
2%	2%	5%	1.81
10%	10%	HHWS	0.23
20%	20%	HHWS[3]	0.23

7.3.3 Structure 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.

[3] High High Water Springs

In addition to these scenarios, refinement was undertaken on the level of blockage for different "classes" of structure. These classes of structure are provided in **Table 7-3**. The level of blockage to be applied for each class of structure is provided in **Table 7-4**.

These blockage factors were applied in the TUFLOW model and both scenarios have been analysed. The results represented in this report are noted as either "Risk" or "Design", with these results being the envelope of the respective blockage scenario and an unblocked scenario.

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

Table 7-3 Classes of Structure - Wollongong Council Blockage Policy

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

Table 7-4 Blockage Policy and Blockage Factors

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

7.4 Design Flood Events

Using the parameters as identified above, the hydrological and hydraulic models were analysed for the PMF, 0.2% AEP, 0.5% AEP, 1% AEP, 2% AEP, 10% AEP and 20% AEP events. The models were analysed for 90, 120, 360, 540 and 720 minute duration storms. These storm durations were identified based on initial model runs to understand the critical durations throughout the catchment.

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

Table 7-5 Design Flood Event Result Maps

Results	Design Scenario Maps	Risk Scenario Maps
Peak Depth and Water Level	701-D-1 to 701-D-7	701-R-1 to 701-R-7
Peak Velocity	702-D-1 to 702-D-7	702-R-1 to 702-R-7

The models analysed represent the catchment conditions at the time of survey, being 2017. A localised area of fill occurred at Haywards Bay which was not identified in the LiDAR. This is shown in the various maps.

Further description and discussion on the flood behaviour within the catchment are provided in **Section 8**.

7.5 Future Development

In order to provide Council with an indication of future flood behaviour arising from further development within the catchment, a future development scenario was modelled.

This scenario incorporated major works that are currently being planned or constructed, as well as a general assumption that all land within the catchment area would become fully developed in line with Council's planning controls.

Three major developments within the study are currently in a planning stage, namely:

- West Dapto Masterplan;
- Tallawarra Concept Plan; and,
- Albion Park Rail Bypass.

For the remaining areas, Council's current zoning was used to determine the extent of possible future development.

The revised future land use areas are shown in **Figure 7-3**.

Figure 7-3 Future Land Use

7.5.1 Updates to hydrological model

Under the Future Development scenario, increased impervious areas are expected across the catchment. The impervious area percentages previously adopted for the study were retained for the future development scenario. Each subcatchment within the model was then updated accordingly. All other catchment parameters remained identical to the design scenario.

7.5.2 Updated to hydraulic model

Following the development of revised subcatchment hydrographs, the terrain and roughness details of the hydraulic model were revised.

The land uses defined in **Figure 7-3** were used to define updated roughness layers for the hydraulic model. Roughness values were adopted from the design scenario where applicable, and new categories were add as required.

The roughness values adopted, in line with the zones shown on **Figure 7-3**, are shown in **Table 7-6**.

Changes to the model terrain were also undertaken in line with expected future development. Terrain updates are summarised in **Table 7-7**.

It is noted that this is a preliminary representation of the future development. No designs were available for the masterplan areas, which are likely to incorporate detention and other flood mitigating structures. Therefore, the results from this modelling should be considered preliminary only.

Table 7-6 Future Development Scenario Roughness Parameters

Land Use Zone	Manning's 'n'
Pasture / Grass	0.05
Roads and Pavements	0.02
Heavy Vegetation	0.10
Ponds / Dams	0.03
Duck Creek Downstream – Mainstream, lower channel	0.05
Steep bushland	0.15
Duck Creek Channel	0.06
Riparian Vegetation	0.07
Median Vegetation	0.07
Fence Blockage	0.10
Mixed Use Development	0.10
Medium Industrial	0.08
Light Industrial	0.06
Low Density Residential	0.08
Medium Density Residential	0.10
Highway	0.015
Upstream Revegetation	0.10

Table 7-7 Future Development Scenario Terrain Updates

Development	Model Revision
Albion Park Rail By-Pass	A Tuflow model of the Albion Park bypass has already been prepared. This model was supplied to Rhelm, and the relevant layers incorporated into the future scenario model. The design included design terrain, cross drainage and bridge structures.
Tallawarra Estate Development	A concept plan has been prepared for the Tallawarra Development, as shown in **Figure 7-4**. The development covers much of the floodplain downstream of the highway. A this stage, no formal terrain data was available. Where the concept showed drainage channels, these were incorporated into the terrain. For the developed areas, the terrain was lifter to 0.5m above the 1% AEP level. The open space and retained water bodies were retained as per the design scenario.
West Dapto Masterplan	At present, the only data available for the West Dapto Masterplan was a proposed land use map. For areas outside of the masterplan extent, current zoning was assumed to be retained. It was assumed that the local creeks would be revegetated as part of these works, and so a higher roughness has been incorporated into the creeks throughout the masterplan area.
General Development	

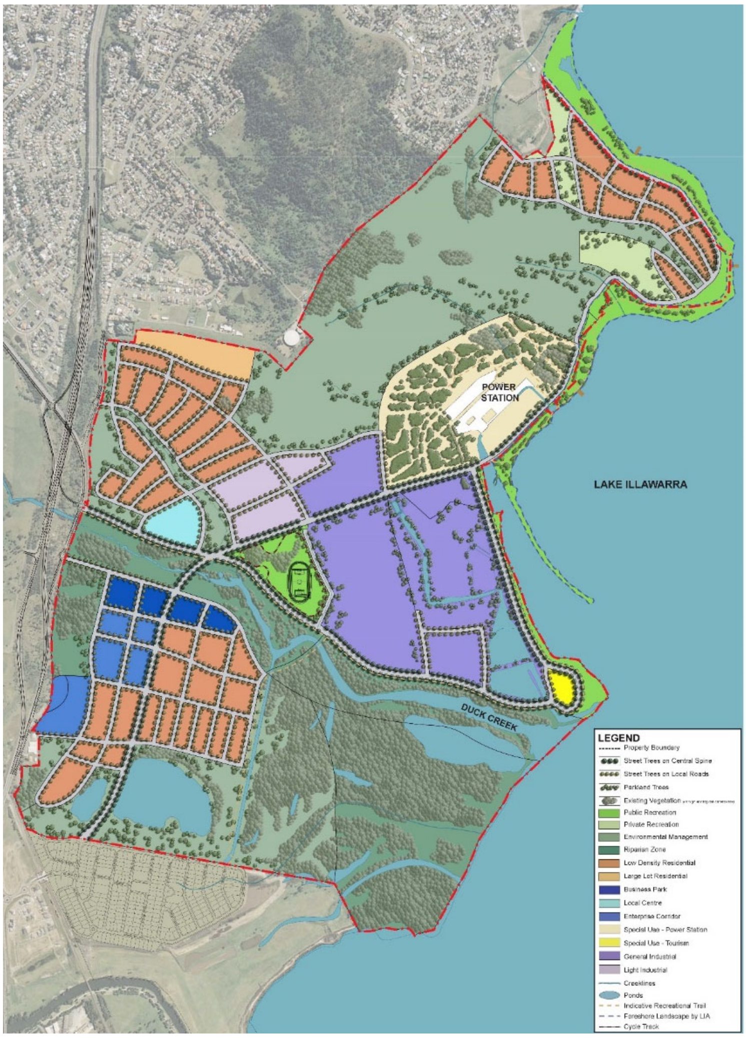

Figure 7-4 Tallawarra Land Concept Design

7.5.3 Future Scenario Results

The future scenario was run for the full set of design events, for unblocked, design blockage and risk blockage scenarios. Similar to the design events, a flood envelope was created for design blockage and unblocked results, and risk blockage and unblocked results.

The results for the 20% AEP, 1% AEP and PMF events are presented as a series of Maps attached to this report, as noted in **Table 7-8**.

Table 7-8. Future Development Scenario Flood Event Result Maps

Results	Design Scenario	Risk Scenario
Peak Depth and Water Level	706-D-1, 706-D-4, 706-D-7	706-R-1, 706-R-4, 706-R-7
Water Level Difference (relative to the existing scenario modelling)	707-D-1, 707-D-4, 707-D-7	707-R-1, 707-R-4, 707-R-7

For all event, the results show increases of 0.2 – 0.5m in the upstream reaches where future development and subsequent creek revegetation is proposed. These increases are generally within the proposed development area. These increases transition to reductions in the vicinity of the Duck Creek crossing of Marshal White Road. In events up to and including the 1% AEP, these reductions, typically in the order of 0.05 – 0.2m, extend all the way downstream to the model boundary.

A comparison of the hydrograph at the M1 for the 1% AEP event, shown in Figure 7-5, demonstrate that there are two factors driving these reductions. The first is that the higher impervious areas in the future result in a higher initial flow rate, that passes through the system in advance of the peak flow from the larger catchment. Secondly, as a result of the higher riparian roughness's in the future scenario, water is being held back in the upper catchment, leading to a slight decrease in the flood peak. This reduction is in the order of 3%; not hugely significant, but enough to translate into 0.05 – 0.1m lower peak water levels.

Based on the outcomes of this preliminary analysis, it is suggested that detention be investigated further for the West Dapto masterplan. It is understood that detention systems would likely be incorporated within the development. However, these should be reviewed to ensure that they achieve the best outcome both in terms of flood levels within and downstream of the proposed development area.

A review of the West Dapto masterplan area would suggest that the flood extents are largely convened within the areas zoned as "revegetation", as per Figure 7-3.

In the PMF event however, additional areas of water level increases are observed between the rail line and the M1. These increases are driven by the reduction through the M1 as a result of the proposed bypass. The bypass cross drainage had been designed to conserve flow conveyance in the 1% AEP, which it has done based on these results. However, the additional bridges and culverts installed have a greater influence on flow in events larger than the 1% AEP, leading to a building up of water between the M1 and railway. These impacts then extend approximately 500m downstream from the M1, adjacent to the proposed Tallawarra estate development.

In the uppermost reaches of the catchment, beyond the extent of future development, there were no changes for any of the events.

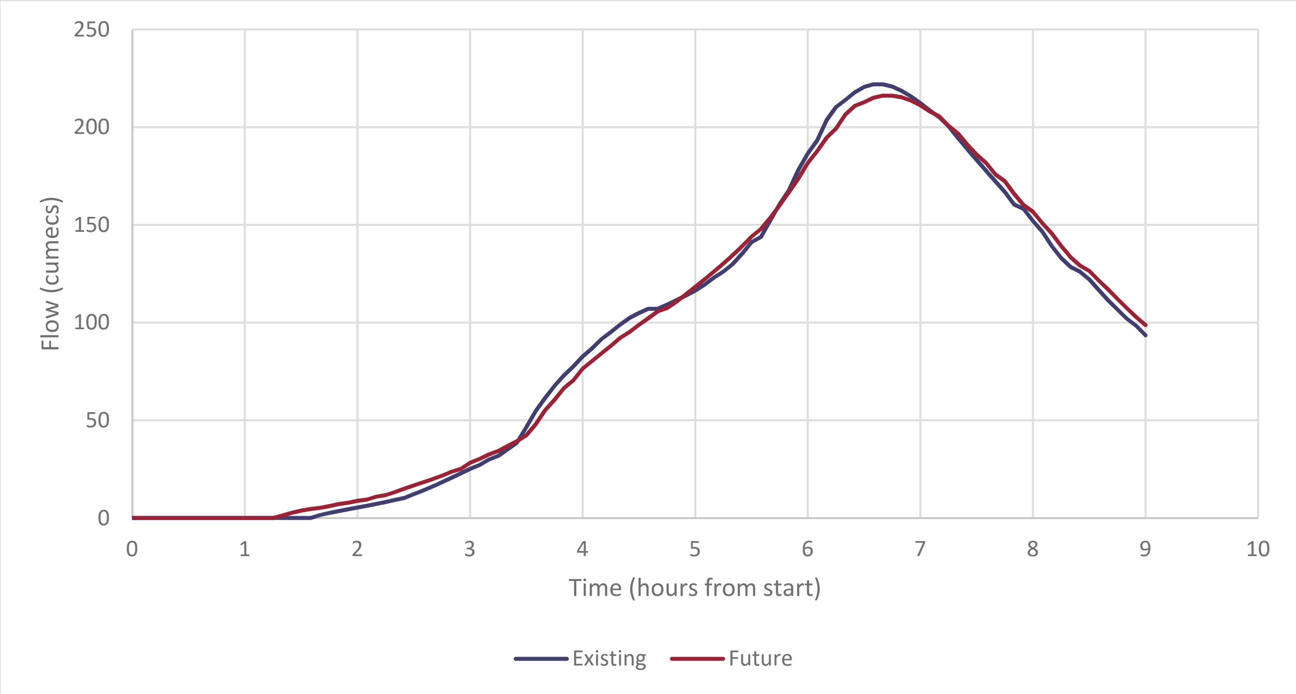

Figure 7-5 1% AEP Flow at M1: Comparison between Existing and Future Scenarios

7.6 Flood Hazard

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

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

Flood hazard mapping is provided for the 1% AEP and PMF events in **Maps G801-D-1 to 2** for the Design Scenario and **Maps G801-R-1 to 2** for the Risk Scenario.

7.7 Flood Function

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

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

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

The 2012 Flood Study defined hydraulic categories in the following way:

- Floodway – VelocityxDepth Product is greater than 0.5m2/s;
- Flood Storage – VelocityxDepth product is less than 0.5m2/s and depth is greater than 0.5m; and
- Flood Fringe – areas in the flood extent outside of the above criteria.

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

The 2012 Flood Study criteria was used as an initial starting point for the mapping undertaken in this current flood study. Further testing was then undertaken on the following basis:

- Testing of the floodway using the 2012 Flood Study criteria to understand the potential changes in flood levels in the main channel. This testing suggested that the criteria was generally appropriate for Duck Creek.
- An assessment on a selection of representative cross sections in the study area and assessing the unit flows across these areas to estimate the proportion of flow contained within the floodway. The testing suggested that the flows were typically 80% or greater of the total flow across the floodplain, and a review of the unit flows suggested that the majority of the flow was through the floodway.

On the basis of the outcomes of the testing described above, the 2012 Flood Study criteria was adopted for the hydraulic category mapping. The mapping is provided in **G802-D-1 to 2** for the Design Scenario for the PMF and 1% AEP. Similarly, the Risk Scenario is provided in **G802-R-1 to 2**.

7.8 Lake Illawarra Flooding

As identified in Section 3.2.4, 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 Duck Creek catchment is also influenced by flooding from Lake Illawarra. The areas affected are shown in Figure 3-2 and Figure 3-3. For flood levels in these areas, then the Lake Illawarra previous flood analysis should be consulted in conjunction with the results of this report.

8 Flood behaviour

The following sections provide a brief discussion on the general flood behaviour at a number of key locations within the catchment. Key locations discussed are referenced in figures of the 1% AEP depth for each location. Reference should also be made to **Figure 8-8**, which provides a comparison of the flood extents for the different events for the central area of the catchment to understand the overtopping of structures and roads between events, as well as key cross catchment flows that occur in the larger events.

8.1 Upper Catchment

The upper part of the catchment is located within a relatively steep sided valley, with a large macro-channel that is bordered to the south by North Marshall Mount Road (see **Figure 8-1**). Due to the relatively steep sides, the flow from Duck Creek is generally contained within the macro-channel up to and including the PMF, with no backwater reaching North Marshall Mount Road. Critical durations in the 1% AEP event through this area are generally 2 hours.

Overtopping does occur however from a number of smaller tributaries that cross North Marshall Mount Road (for example, UC1, UC2 and UC3). This will generally occur for relatively short periods of time during the flood event. While some of these overtopping points may be trafficable in a 1% AEP event, there are areas of H2 and greater hazard (see **Section 7.6**) which may result in hazardous conditions particularly for smaller vehicles.

Further downstream, a larger un-named tributary joins with Duck Creek in the vicinity of Yallah Road. Approximately 0.75km upstream of this junction, this tributary crosses Marshall Mount Road (UC4). Overtopping of the road occurs in the 20% AEP event and above and is likely not to be trafficable in a 1% AEP event.

Table 8-1 Structure/ Road Overtopping

Structure/ Road	**Location ID**	**Event Overtopped**
North Marshall Mount Road	Various	Various
Marshall Mount Road	UC4	20% AEP

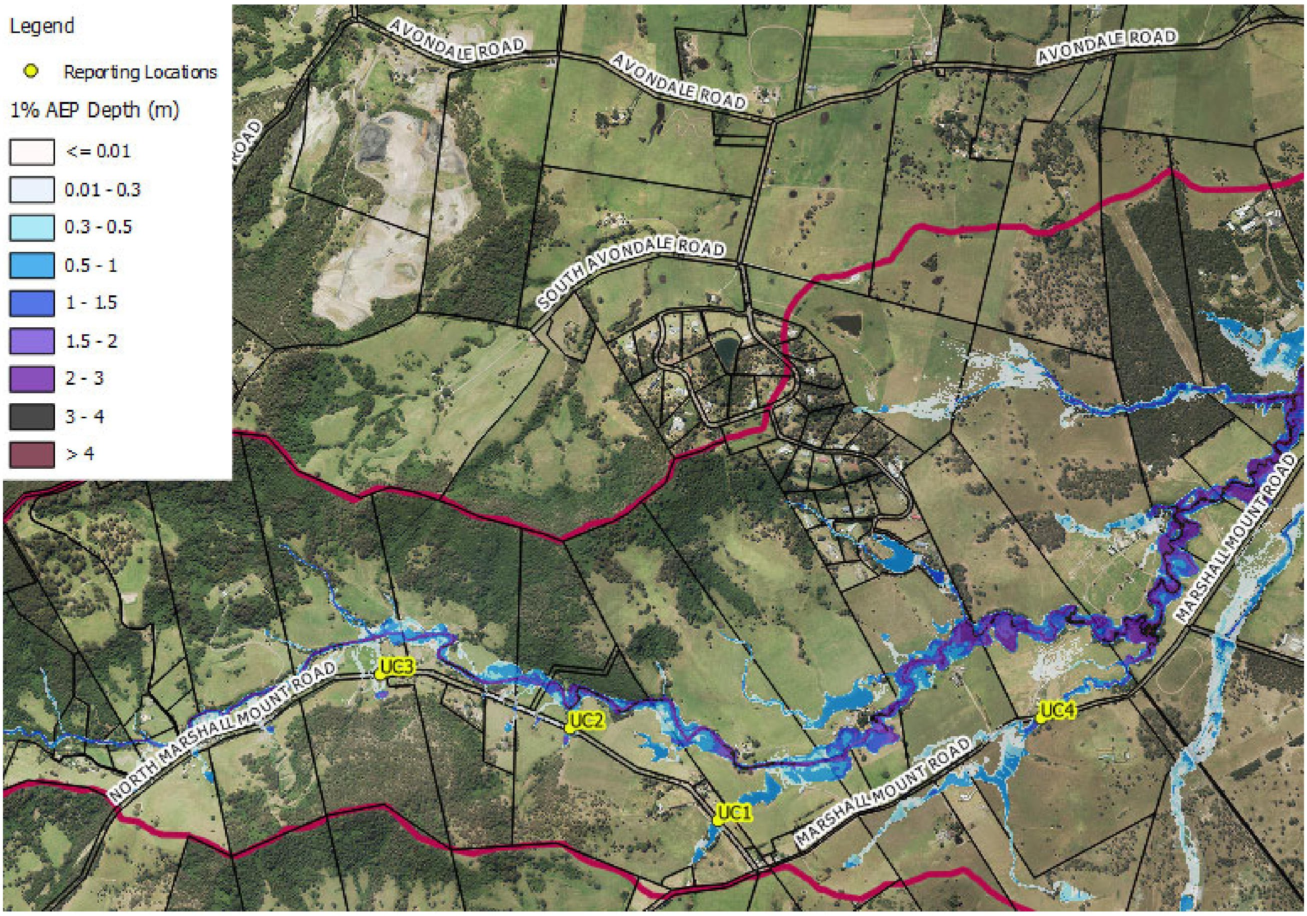

Figure 8-1. 1% AEP Flood Depth - Upper Catchment

Figure 8-2. Typical View of Duck Creek in the Upper Catchment

8.2 Central Floodplain

For the purposes of this report, the Central Floodplain has been defined as the area from Yallah Road downstream to the rail line (**Figure 8-5**). In this area, the creeks and tributaries are generally less steep than the upper catchment, and there are more cross catchment flows that occur between the creeks.

Downstream of Yallah Road, Duck Creek follows parallel to Marshall Mount Road until crossing the TAFE access road (CF1). Flows along this length are generally contained within the macro channel up to the 1% AEP event, although some overtopping occurs into the wider floodplain and farmland. Along this section, Marshall Mount Road acts as a divide between Duck Creek and a tributary to the east which originates south of Yallah Road. Limited overtopping of Marshall Mount Road occurs along this section (except near the TAFE Road) until the PMF, when the majority of Marshall Mount Road between Yallah Road and the TAFE road sees cross catchments flows (CF2). Some larger depths of flow at several locations along this overtopping result in high hazard conditions along the road.

Figure 8-3. March 2011 Flooding of Duck Creek in the area between Yallah Road and the TAFE Bridge

The TAFE Road bridge over Duck Creek (CF1), together with the culverts on the same road further north west across the small tributary (CF3), have around a 20% AEP capacity, with overtopping of both occurring in a 10% AEP event. This road is subject to high hazard conditions in a 1% AEP event at these locations.

Marshall Mount Road crosses Duck Creek at two bridges downstream of the TAFE Bridge (CF4). Overtopping of the road in this vicinity occurs somewhere between a 10% AEP event and a 2% AEP event. In the 2% AEP event, overtopping is primarily confined to the area around the two bridges. Backwater from Duck Creek, both upstream and downstream of the TAFE bridge inundate areas to the east toward Marshall Mount Road. In larger events (including the 1% AEP event), this results in a wider area to the south of the two bridges being overtopped.

Downstream of Marshall Mount Road, the Duck Creek floodplain is much wider and spreads out, controlled by the railway embankment (CF5). Overtopping of the rail embankment in this location does not occur until events larger than the 0.2% AEP event, where flows overtop south of the main bridge under the rain line.

Figure 8-4. Duck Creek downstream of Marshall Mount Road (left), Marshall Mount Road crossing of Duck Creek (right)

A smaller tributary joins Duck Creek west of the main rail bridge, crossing Marshall Mount Road via a small box culvert. This culvert has a capacity of approximately 20% AEP, with overtopping occurring in events larger than this.

Table 8-2 Structure/ Road Overtopping

Structure/ Road	Location ID	Event Overtopped
Marshall Mount Road, between Yallah Road and south of TAFE Road	CF2	>0.2% AEP
TAFE Road	CF1, CF3	>20% AEP
Marshall Mount Road near Duck Creek Crossing and TAFE Road	CF4	>10% AEP
Rail Crossing of Duck Creek	CF5	>0.2% AEP
Marshall Mount Road, small tributary	CF6	>20% AEP

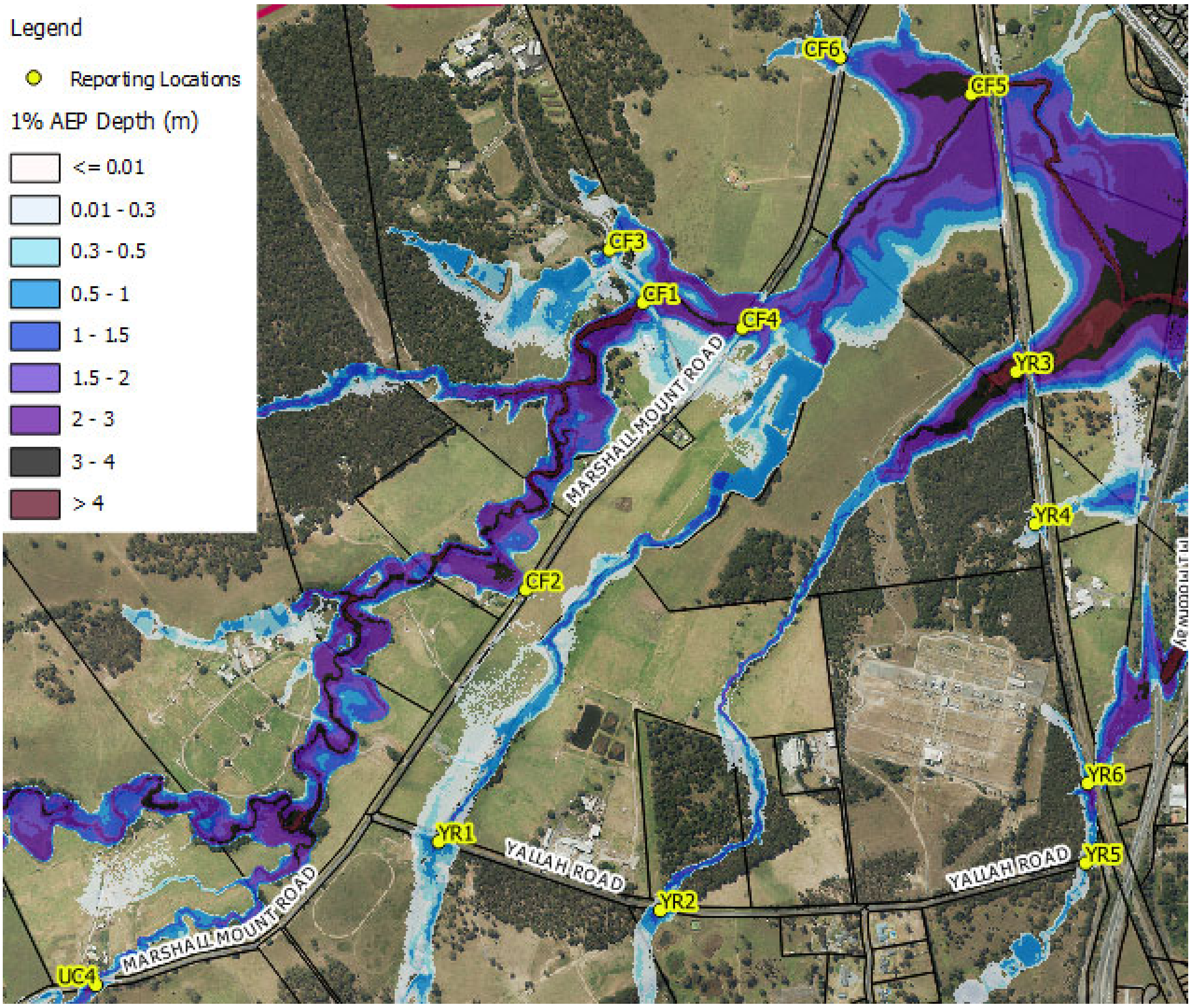

Figure 8-5. 1% AEP Flood Depth - Central Catchment and Yallah Rd Tributaries

8.3 Yallah Road Tributaries

There are three key tributaries that originate upstream (south) of Yallah Road (**Figure 8-5**). The most westerly of these crosses Yallah Road near Marshall Mount Road (YR1). Overtopping of the road in this area occurs at a low point to the west of the culvert, in the 20% AEP event and above. This tributary then follows in parallel with Duck Creek and Marshall Mount Road, as discussed above.

The second tributary cross Yallah Road approximately half way along Yallah Road (YR2), which overtops in a 20% AEP. This tributary passes to the west of the power sub-station and is generally contained within the macro-channel. This tributary crosses the rail line (YR3), but overtopping only occurs here and to the north (CF5) in events greater than a 0.2% AEP event.

To the south of this location, a small tributary (originating from the power sub-station) crosses the rail line (YR4). This tributary also overtops the rail line in events greater than the 0.2% AEP.

The final tributary from Yallah Road originates on the eastern end of Yallah Road, crossing Yallah Road near the rail embankment (YR5). The culvert in this location has a very low capacity, and overtopping occurs in the

20% AEP event. This tributary crosses the rail line a short distance downstream (YR6). Overtopping of the rail line occurs in events greater than the 0.2% AEP event.

Table 8-3 Structure/ Road Overtopping

Structure/ Road	Location ID	Event Overtopped
Yallah Road	YR1	20% AEP
Yallah Road	YR2	20% AEP
Rail Line at tributary	YR3	>0.2%AEP
Rail line at power sub-station tributary	YR4	>0.2% AEP
Yallah Road	YR5	20%AEP
Rail line at tributary	YR6	>0.2% AEP

8.4 Railway Line to Downstream Boundary

The floodplain from the railway line downstream to Lake Illawarra is shown in **Figure 8-7**. There are three key waterway crossings of the M1 Motorway; Duck Creek (D1), the smaller tributary originating from the power sub-station (D2), and the third tributary from Yallah Road (D3). The third tributary, crossing to the south of the others, overtops in events less than a 0.5% AEP. Shallow overtopping of the north bound lanes starts to overtop in this area from the 20% AEP and increases to depths greater than 1 metre in the 10% AEP. The crossings at D1 and D2 are overtopped in the 0.5% AEP event and larger.

This same tributary also overtops the south bound lane, with the south bound land effectively channelizing this flow in a northern direction to meet with Duck Creek (D4).

North of this location, Duck Creek only overtops the M1 Motorway and the Princes Highway in events larger than a 0.2% AEP.

Downstream of the Princes Highway, the floodplain is primarily within low lying wetland areas, as well as the former Ash Ponds for the Tallawarra Power Station. These Ash Dams have relatively high embankments that exclude overtopping in all flood events. A localised low point on the northern Ash Pond results in some overtopping in events greater than the 1% AEP (D6), although this is relatively minor.

To the north of Yallah Bay Road, a local tributary flows through farmland and is then held behind a former railway line embankment (D5), before meeting with Yallah Bay Road. This starts to overtop in the 1% AEP event, with significant overtopping occurring in the larger events.

Table 8-4 Structure/ Road Overtopping

Structure/ Road	Location ID	Event Overtopped
M1 Motorway over Duck Creek	D1	>0.5% AEP
M1 Motorway, tributary	D2	>0.5% AEP
M1 Motorway, tributary	D3	20% AEP
Princes Hwy (Duck Creek)	D4	>0.2% AEP

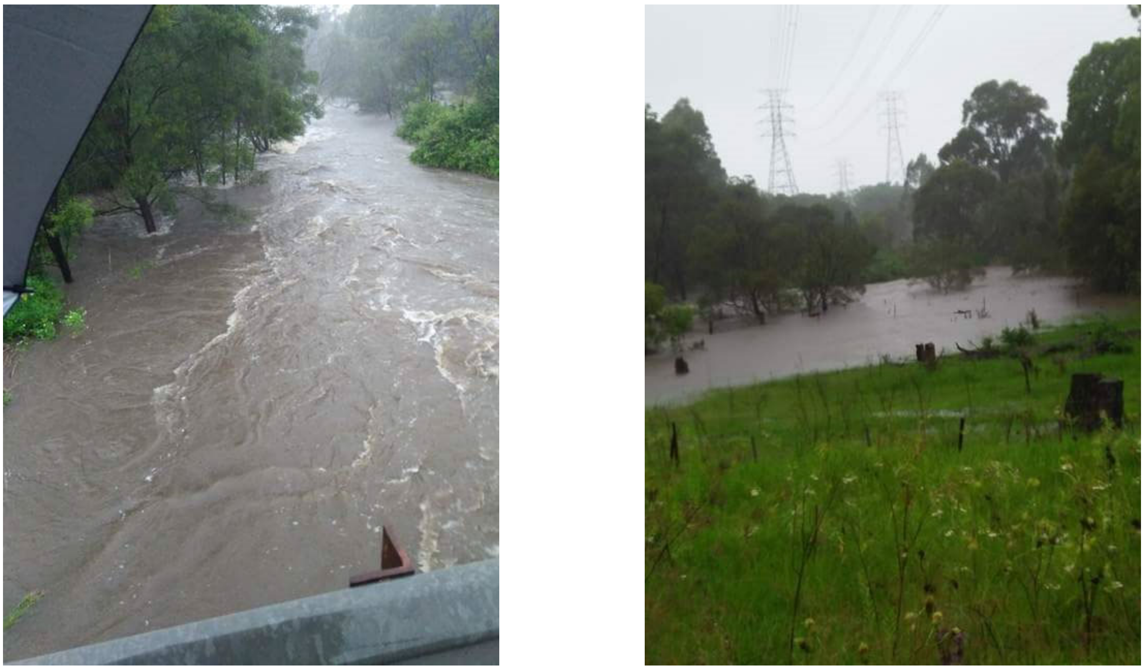

Figure 8-6. Flooding in March 2016 (Downstream of Princes Hwy on left, farming land in low lying areas downstream)

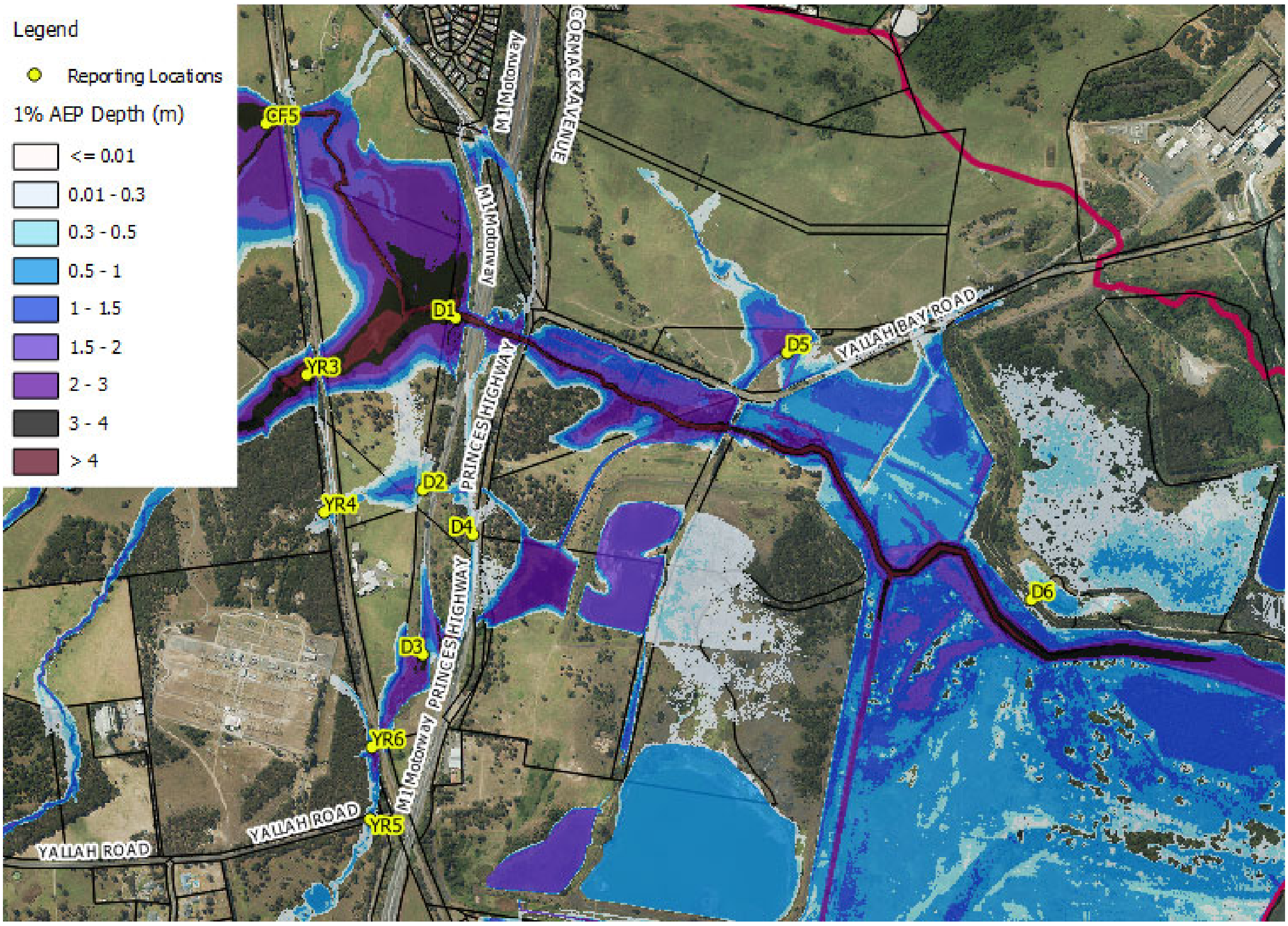

Figure 8-7. 1% AEP Flood Depth - Rail Line to Downstream

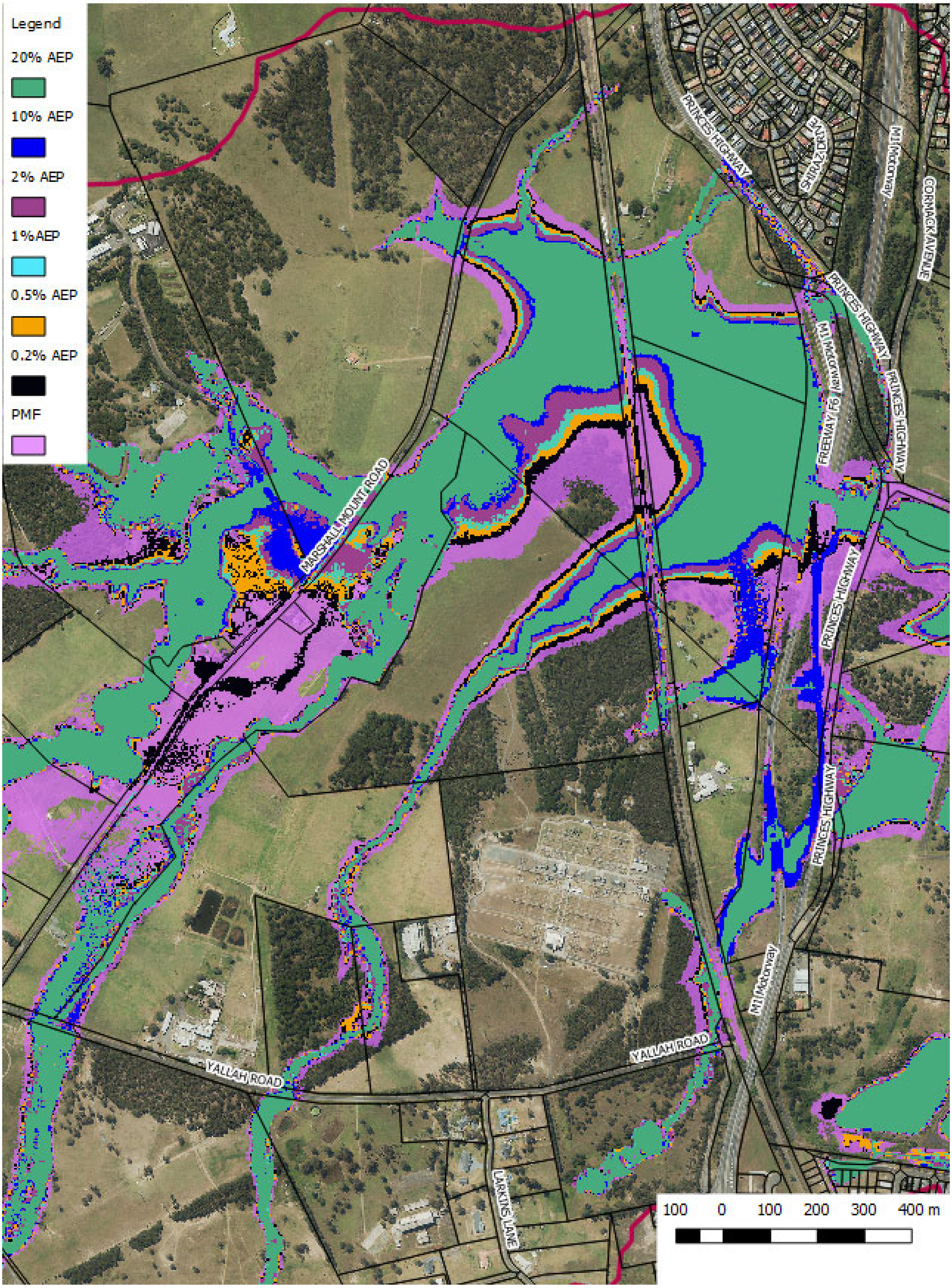

Figure 8-8. Comparison of Flood Extents - Central Floodplain and Yallah Road

8.5 Interim 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. The results of the analysis are provided in **Map G901-R-1**.

8.6 Emergency Response Classification

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

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

AIDR (2014) provides guidance on mapping response classification mapping, which is intended to be undertaken at the community or precinct scale (i.e. not at the lot scale). A summary of the classifications is provided in Table 8-5. These are presented in **Map G902-D-1** and **Map G902-R-1** for the design and risk scenarios respectively. It is noted that the Flood Free category was not shown on the map.

Table 8-5 Emergency Response Classifications (AIDR, 2014)

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

8.7 Transport Infrastructure

There are a number of transportation routes through the study area, both major arterials (such as the M1 Motorway and the rail line) and secondary roads providing access to properties (such as North Marshall Mount Road). 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. Note that the earliest time for overtopping may not coincide with the same event as the maximum duration of overtopping (e.g. the 2 hour duration may result in the earliest time for overtopping, but the 6 hour duration may result in the longest duration of overtopping).

The earliest time of overtopping is measured from the commencement of the rainfall burst associated with that event. Design rainfall events represent a burst that is typically “embedded” within a longer period of rainfall. Therefore, the earliest time of overtopping represents more an indication of the amount of time that might be available for evacuation.

This information is presented in **Map G903-R-1 and G903-R-2** for both the PMF and 1% AEP Risk Management Scenarios.

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.

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 G704-R-1 to 4**.

Increases in model roughness result in increases in peak water level of up to 0.2 metres, but generally less than 0.1 metres in the 1% AEP event. For increases in roughness, the peak water level increases are less than 0.2 metres.

In the PMF event, decreases in roughness result in reductions in peak water level of up to 0.2 metres. Increases in roughness result in increases in water levels of generally up to 0.2 metres, with some localised areas downstream of the Princes Highway with increases in water level of up to 0.3 metres.

Overall, the model is relatively insensitive to model roughness assumptions, with potential variation in water levels in the order of +/- 0.2 metres.

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 G704-R-5 to 8**.

In the 1% AEP event, increases in peak flows of 20% result in increases in in peak water level of generally up to 0.3 metres, although there are areas in excess of this adjacent to and upstream of the rail line and the motorway, with increases in these location in the order of 0.4 to 0.5 metres. The model is similarly sensitive to reductions in peak flow.

This suggests that the model is sensitive to hydrological assumptions on flows, with levels potentially increasing up to 0.5 metres as a result of a 20% increase in flows 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 7.3.3**). However, it is useful to understand the change in flood behaviour that can occur as a result of culvert and bridge blockages, and key areas that are influenced by these. An analysis was undertaken on the 1% AEP event, by comparing both the Risk blockage scenario against the unblocked case. The results of this analysis are provided in **Map G704-R-11**.

This assessment shows that the impact of blockage in the catchment under the Risk Scenario increases flood levels generally in the order of 0.2 to 0.3 metres, with the rail line and freeway the most sensitive to blockages of structures given the significant control that these represent. There are areas however with increases up to 0.8 metres around the smaller culverts under the rail line and motorway, due to the larger blockages applied to these structures (compared with the bridges).

Council's blockage policy incorporates two scenarios, the Risk and the Design scenario. To understand the differences between these scenarios, a comparison was undertaken between the peak water levels and this is shown in **Map G704-R-12**.

The results of this analysis show generally minimal differences between the Risk and Design Scenarios, with typical changes in the order of 0.1 metres. The key exception to this is around some of the tributaries and the smaller culverts, which experience higher blockage factors under the Risk Scenario and therefore higher differences. These increases are up to approximate 0.5 metres upstream of the rail line (where the Risk Scenario is higher than the Design Scenario).

The new blockage policy supersedes the previous blockage policy that had been widely used in Wollongong LGA over a number of years and was the benchmark for flood planning in the LGA. To understand the changes that have occurred between the old blockage policy and the new policy, a comparison of the Risk Scenario with the Old Blockage Policy was undertaken and presented in **Map G704-R-13**.

The Risk Scenario results in levels that are generally up to 0.2 metres lower than the levels produced by applying the Old Blockage policy. The key exception to this is the secondary culvert crossing of the rail line, where the tributary in that location has levels approximately 1.5 metres lower than the Old Blockage Policy, as this culvert was completely blocked under the old policy.

9.4 Climate Change

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

Two scenarios were assessed in the analysis:

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

It is noted that these scenarios also provide a useful tool to assess the sensitivity of the model to alternative boundary condition assumptions. The analysis was undertaken for the 1% AEP and PMF events. The results are provided in **G705-D-1 to 2** for the Design Scenario, and **G705-R-1 to 2** for the Risk Scenario.

A summary of climate change impacts at key locations is provided in **Table 9-1** for selected locations as shown in **Figure 9-1**. The table reports the changes occurring under the 'Risk Management' blockage scenario. There were minimal differences between this scenario and the 'Design' blockage scenario (<0.02m).

Due to both the 2050 and 2100 have identical rainfall increases, the impacts occurring in the upper and central catchments, as well as the tributaries, are the same under both 2050 and 2100 scenarios. Only the most downstream point on Duck Creek showed a difference between the 2050 and 2100 scenarios, due to the differences in the assumed lake level.

The results show that impacts arising from climate change impact the main channel significantly more than the tributaries. All climate change impacts along the tributaries, up to and including the 2100 PMF were less than or equal to 0.1m.

The primary Duck Creek channel showed increases ranging from 0.13m to 0.5m in the 2100 1% AEP event. Generally, increases along Duck Creek were within 0.1 – 0.3m. Higher increases were observed upstream of structures, where the higher flow rates coupled with structure blockages lead to increased upstream ponding. As previously noted, higher increases were also observed in the downstream reaches of Duck Creek, as a result of increased lake levels.

Table 9-1 Water Level Changes Under Climate Change Scenarios (Risk Management Blockage)

Location	2100 PMF	2100 1% AEP	2050 PMF	2050 1%AEP
Duck Creek Main Channel				
DC_1	0.22	0.13	0.22	0.13
DC_2	0.40	0.25	0.40	0.25
DC_3	0.24	0.30	0.24	0.30
DC_4	0.13	0.26	0.13	0.26
DC_5	0.25	0.21	0.25	0.21
DC_6	0.19	0.44	0.19	0.44
DC_7	0.30	0.41	0.30	0.41
DC_8	0.47	0.50	0.34	0.22
Tributaries				
T_1	0.03	0.01	0.03	0.01
T_2	0.04	0.03	0.04	0.03
T_3	0.02	0.02	0.02	0.02
T_4	0.10	0.05	0.10	0.05
T_5	0.06	0.04	0.06	0.04
T_6	0.06	0.04	0.06	0.04
T_7	0.09	0.04	0.09	0.04

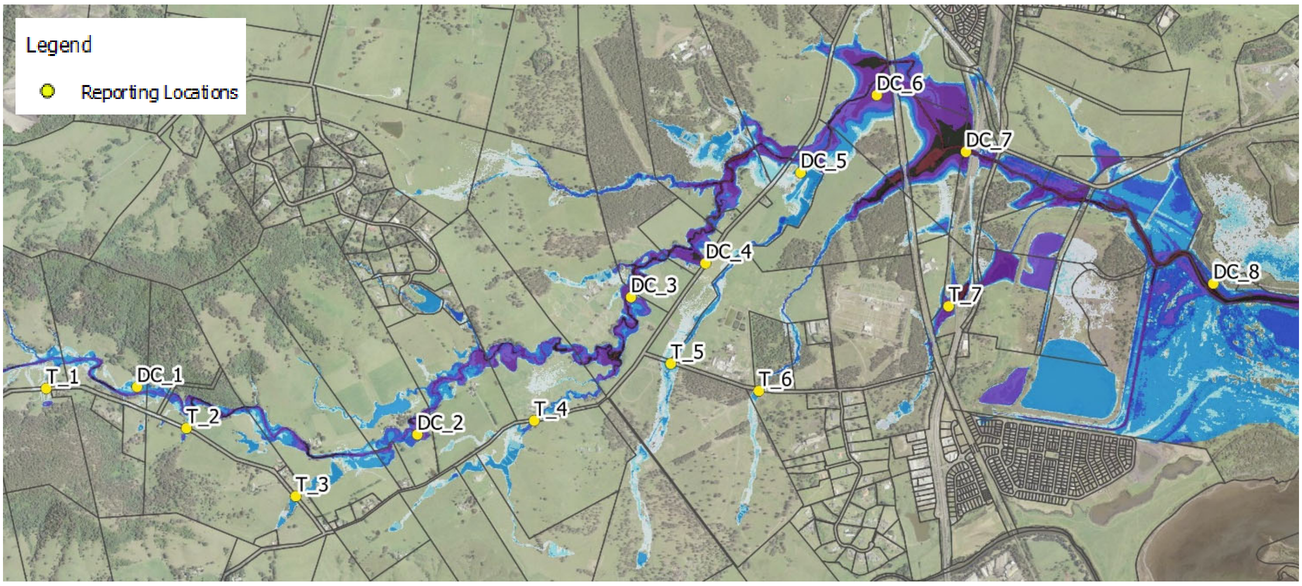

Figure 9-1. Climate Change Comparison Locations

9.5 Low Tailwater Condition

The flood model was analysed with an associated tailwater condition for Lake Illawarra as described in Section 7.3.2.

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 6-hour duration (critical at the outlet) for the unblocked scenario. The impacts on peak velocity are provided in **Map G708-U-1**.

The results show that the lower tailwater results in increased velocities at the outlet and extending approximately 200m upstream. The increases are in the order of 0.2m/s, representing an increase from 1.4m/s to 1.6m/s at the outlet as a result of the lower tailwater.

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

10 Conclusions

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

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

Flood behaviour has been assessed using a WBNM hydrological model and TUFLOW hydraulic model. These models were originally developed as part of a flood study undertaken for the catchment in 2012 (BMT WBM). Minor modifications have been made to these models to account for changes in the catchment since 2012 and additional available survey data.

A calibration and validation of the hydraulic model has been undertaken for the March 2017, March 2011 and February 1984 events. The outcome of the calibration found that the model was able to represent the historical events to a reasonable level, providing confidence in the model to produce design flood event results.

The hydrological and hydraulic models were analysed for the Probable Maximum Flood (PMF), 0.2% AEP, 0.5% AEP, 1% AEP, 2% AEP, 10% AEP and 20% AEP events. The models were analysed for 90, 120, 360, 540 and 720 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 further development within the catchment, a future development scenario was modelled. This scenario incorporated major works that are currently being planned or constructed, as well as a general assumption that all land within the catchment area would become fully developed in line with Council's planning controls.

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