Coastal Lagoon Catchments
Overland Flood Study

Report MHL2590
June 2020

Department of Planning, Industry and Environment

Cover Photograph: Imagery of Cockrone, Wamberal, Avoca and Terrigal Lagoons source: Environment, Energy and Science website, https://www.environment.nsw.gov.au/topics/water/estuaries/estuaries-of-nsw/

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Foreword

NSW government's professional specialist advisor, Manly Hydraulics Laboratory (MHL) were commissioned by Central Coast Council (CCC) to undertake a flood study for the four coastal lagoons along CCC's local government area (LGA). These lagoons are Wamberal Lagoon, Terrigal Lagoon, Avoca Lagoon and Cockrone Lake.

The report was prepared by Scott Marshall, Matthieu Glatz and Bronson McPherson.

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Executive summary

The Coastal Lagoon Catchments Overland Flood Study has been prepared in accordance with the New South Wales Government's *Floodplain Development Manual* (2005). A flood study is the first step of the floodplain management process set up to reduce flood risks and private/public losses resulting from flood while using eco-friendly solution where possible.

Manly Hydraulic Laboratory (MHL) were engaged by Central Coast Council (Council) to undertake the Coastal Lagoon Catchments Overland Flood Study. The outcome of the study is to develop and calibrate hydrologic and hydraulic models for the estimation of overland and mainstream flood behaviour in the study area, taking into account the performance of the stormwater drainage network including overflows from the drainage network. The study outputs can 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. Each of these areas has different user groups, whose needs vary. Meeting the requirements of the identified end user groups, which have been tailored to the context of the flood situation, is a key objective of this study.

The study has been overseen and guided by the Waterways & Coastal Protection Unit of the Central Coast Council, which includes representatives from key stakeholder and end user groups.

The Coastal Lagoons Catchments Overland Flood Study has been completed to provide a detailed flooding assessment of Avoca Lagoon, Cockrone Lagoon, Terrigal Lagoon and Wamberal Lagoon. The objective of this study is to improve understanding of flood behaviour and impacts, and better inform management of flood risk in the study area. The study also provides a sound technical basis for any further flood risk management investigation in the area. The previous studies while providing relevant information that relates to the lagoon levels do not provide hazard information in the upper catchments. The lagoons levels are largely dependent upon the berm beach levels and are a key consideration in this project.

The key components of the flooding assessment included:

- Review of available data
- Community consultation
- Hydrological analysis and modelling
- Hydraulic analysis and modelling
- Sensitivity analysis including climate change impact
- Flood mapping
- Define flood planning area to determine flood control lots and hazard flood levels
- Description of consequences of flooding
- Development of a draft flood study followed by a final flood study

The flood maps appended to this report are presenting the flood levels, depths and velocities

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for the critical duration and rainfall pattern of a full set of events including the 50%, 20%, 10%, 5%, 2%, 1%, 1 in 200, 1 in 500 AEP and PMF events and represent an envelope of the critical duration/pattern of a selected representative upstream catchment and the critical duration/pattern at the lagoon. The upper catchments are very flashy with very short critical durations of less than 2h to reach the peak level while the downstream catchments (lagoons), have typical critical durations ranging between 2h and 9h. The mapping is also based on a non-mechanical breakout and on the assumption that the entrance berm is at the managed level, to consider the fact that mechanical opening of the lagoon may sometimes not be practical during severe storms.

Sensitivity analysis highlighted the following points:

- The lower catchments of the four lagoons are highly sensitive to the berm level at the time of the flood and maintaining the berm at a set level would minimise the risk of the lagoon reaching very high levels should mechanical opening of the berm not be possible during a storm.
- Tailwater conditions (including sea level rise) typically have minimal impact on most lagoons flooding given the managed berm elevations. Only very large increases in tailwater levels such as the 0.74m sea level rise scenario would influence the lagoon level. The exception is Terrigal Lagoon that has a relatively low managed berm level and changes in tailwater level would have significant impact on the lagoon level as elevated ocean levels would flow into the lagoon. This identifies a significant potential issue with flooding becoming more common in Terrigal with rising sea level.
- Increase in rainfall intensity due to climate change may exacerbate the overland flooding but would typically have a relatively low impact on the lagoon level.
- Changes in roughness or antecedent conditions of the catchment (wet/dry catchment leading to varying losses) could have minor to moderate impacts on the overland flooding.
- Blockages of structures can have severe impact in areas with no gravity flow that only relies on the drainage network (e.g. ponding area) and maintaining the pits and pipes network is essential to avoid exacerbating the flooding in such location.
- Intermittently Closed and Open Lakes and Lagoons (ICOLLs) entrance conditions are sensitive to ocean inundation. These processes need to be carefully considered in conjunction with this study.

The above results allowed the definition of the flood hazard (including provisional hazard and flood life hazard categories) and hydraulic categories in the four catchments. These have been created and mapped to inform development control planning.

Results of the model allow the identification of main flooding areas, key infrastructure impacted by flooding and road closures around the catchments. Key infrastructure typically may have access issues during severe flood events rather than flooding issues, except during the PMF event.

Similarly, road closures predominantly occur on secondary roads with most of the major road closures occurring for the PMF only. It is also noted that given the flashy behaviour of the catchment, flooding and road closure in the upper catchment would be of relatively short

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duration while flooding of the areas surrounding the lagoons may last for several hours.

A preliminary flood damage assessment was also completed, and it was found that close to 4,500 properties are impacted by the PMF flood event and over 9,400 properties are located within the PMF extent. The largest amount of damage occurs in Terrigal Lagoon catchment and the lowest amount in Cockrone Lagoon catchment. However, it is noted that limited floor level survey information was available from the previous Floodplain Risk Management Plans (FRMPs) of the four lagoons (approximately 825 properties), and it is recommended that a more detailed flood damage assessment be developed based on a floor level survey of the various properties located within the PMF extent during the next stage of the floodplain risk management process. It is also noted that the flood damages are based on the conservative modelling of the entrance berm assuming a non-mechanical entrance breakout. Although council has a mechanical opening policy, it may not always be possible due to various reasons such as rapid rainfall and severe weather conditions. The damage is therefore likely to reduce should the entrance be opened at a lower lagoon level. This is particularly true for Terrigal Lagoon given the very low level of the berm. It is also important to note that should the berm not be maintained to the managed level and build up to higher levels, higher lagoon levels would occur and therefore higher associated damages.

The results were also utilised to guide planning and emergency response by providing the flood planning area and preliminary emergency response classifications mapping to assist NSW SES during flood event. The majority of the properties are located in areas where evacuation by car or by foot is possible or where flooding does not occur, but access is cut.

Preliminary minimum floor levels were provided based on the sensitivity analysis and flood mapping. It considers the difference between overland and mainstream flooding as well as areas subject to berm sensitivity and climate change sensitivity.

An MHL Flood (and Coastal) Intelligence Tool (MHLFIT) flood warning system is being developed concurrently to this study and is based on the same information. This tool provides NSW SES access to predictive capabilities and would also greatly benefit from accurate floor levels and up-to-date information.

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1. Introduction

The Coastal Lagoon Catchments Overland Flood Study has been prepared in accordance with the New South Wales Government's *Floodplain Development Manual* (2005). The manual guides implementation of the NSW Government's *Flood Prone Land Policy* (2005), the primary objective of which 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."*

Under the policy, primary responsibility for floodplain risk management rests with local government. Financial and technical assistance is provided to councils by the NSW Government's Environment, Energy and Science group (EES).

Manly Hydraulic Laboratory (MHL) were engaged by Central Coast Council (Council) to undertake the Coastal Lagoon Catchments Overland Flood Study. The outcome of the study is to develop and calibrate hydrologic and hydraulic models for the estimation of overland and mainstream flood behaviour in the study area, taking into account the performance of the stormwater drainage network including overflows from the drainage network. The study outputs can 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. Each of these areas has different user groups, whose needs vary. Meeting the requirements of the identified end user groups, which have been tailored to the context of the flood situation, is a key objective of this study.

The study has been overseen and guided by the Waterways & Coastal Protection Unit of the Central Coast Council, which includes representatives from key stakeholder and end user groups. The key end-user groups that this study aims to support are:

- High-level strategic decision makers
- Community
- Flood risk management professionals
- Engineers involved in designing, constructing and maintaining mitigation works
- Emergency management planners
- Land-use planners (strategic planning and planning controls)
- Hydrologists and meteorologists involved in flood prediction and forecasting
- Insurers

1.1 Scope and objectives

The objective of this study is to improve understanding of flood behaviour and impacts, and better inform management of flood risk in the study area. The study also provides a sound technical basis for any further flood risk management investigation in the area. The current

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studies while providing relevant information that relates to the lagoon levels do not provide hazard information in the upper catchments. The lagoons levels are largely dependent upon the berm beach levels and are a key consideration in this project. Capability of that will verify the existing lagoon flood studies and provide further confidence to the flood risk management process. The key objectives of this study are to:

- Investigate mainstream and local overland flooding regimes including the capacity of the existing trunk drainage.
- Compare & review existing flood studies against current best practice.
- Determine flood levels, extents, velocities and flows catchment wide for a range of design events including consideration of climate change projections.
- Identify provisional hydraulic and hazard categories for a range of design events.
- Determine flood emergency response classification of communities.
- Determine an appropriate flood planning area including sensitivity to climate change.
- Consider the effects of the coastal processes on boundary conditions.
- Consider the sensitivity of flood behaviour to changes in flood producing rainfall events due to climate change and blockages at critical infrastructure.
- Consider the impediments of fences and buildings on overland flow.
- Determine the number of properties affected by the 1% & PMF flood extents and the depth of water over the property.
- Provide sufficient information that will inform a future Floodplain Risk Management Study and Plan.
- Provide outputs in a format that can be disseminated to a wide audience within Council's GIS environment.

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2. Background

2.1 Study area

The Coastal Lagoon Catchments study area is approximately 75 km north of Sydney and comprises four main catchments encompassing a total area of 39.1 km^2 (refer to **Figure 2-1**). Each catchment is characterised by residential, commercial and rural land draining to intermittently closed and open lakes and lagoons (ICOLLs).

The lagoons are characterised by sand berms that control the entrance conditions, this natural process is artificially control by Central Coast Council in an effort to reduce flooding in low-lying areas. The entrances are mechanically opened at predetermined trigger levels lower than that of a natural breakout level.

2.1.1 Wamberal Lagoon catchment

Wamberal Lagoon Catchment is the northernmost catchment and is 7.3 km^2 with the lagoon accounting for approximately 8% of this area (i.e. 0.6 km^2). The catchment consists of rural land in the north-west, residential in the north-east and south-west and the lagoon in the south-eastern corner. Some residential areas around the lagoon foreshores are low-lying and subject to flooding. The upper reaches rise to approximately 120 m AHD along the western boundary with the lower reaches at sea level. The coastal escarpment is at 10 m AHD to 30 m AHD and the only possible exit of the lagoon to the ocean is to the south. The main tributary flows south through the middle of the catchment and discharges to the lagoon. The banks of the tributary generally consist of low-lying bushland.

The bed level of the lagoon typically varies from +0.0 m AHD to +1.0 m AHD. The outlet to the Pacific Ocean is generally blocked by a sand bar or beach berm, thus the water level in the lagoon is generally not influenced by the tides.

2.1.2 Terrigal Lagoon catchment

Terrigal Lagoon Catchment is the second most northern catchment and is 10.3 km^2 with the lagoon accounting for approximately 3% of this area (i.e. 0.3 km^2). The catchment consists of rural land in the upper north-western and south-western reaches. The majority of the catchment is residential with some areas of commercial development particularly around Terrigal CBD in the south-east. Some residential areas around the lagoon foreshores are very low-lying and subject to flooding. The upper reaches rise to approximately 120 m AHD along the north-western boundary and 140 m AHD in the south-eastern corner.

There are two main tributaries which both flow in an easterly direction to the lagoon. A golf course lies at the limit of the northern arm of the lagoon. It is dissected by a creek herein termed North Arm. Upstream of Willoughby Road the catchment rises sharply into the hills and the creek splits into two branches. Willoughby Road is crossed by a two-cell culvert and concrete causeway. The West Arm of the lagoon is bounded by Brunswick Road and Terrigal Drive. Terrigal Lagoon is crossed by two bridges near the entrance - at Willoughby Road and at Ocean View Drive.

The average bed level of the lagoon varies from -0.5 m AHD to +0.5 m AHD although there are holes up to -3.0 m AHD or possibly deeper. The outlet to the Pacific Ocean is generally blocked by a sand bar or beach berm. While the berm typically reduces the tidal influence, it

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is relatively low, can be overtopped by waves and breaches regularly.

2.1.3 Avoca Lagoon catchment

Avoca Lagoon Catchment is the second most southern catchment and is 13.2 km^2 with the lagoon accounting for approximately 8% of this area (i.e. 1.0 km^2). The majority of the catchment consists of rural land and bushland in the western half of the catchment and along the southern boundary. The remaining catchment is residential with some areas of commercial development. Some residential areas around the lagoon foreshores are very low lying and subject to flooding. The upper reaches rise to approximately 200 m AHD along the north-western boundary and 100 m AHD on the south-western boundary.

A number of small tributaries discharge to each arm of the cross shaped lagoon. Saltwater creek is the largest of these and discharges to the western arm of the lagoon. The creek flows in an easterly direction adjacent to Avoca Drive. The upper catchment to the north-west discharges to the creek which passes under the Scenic Highway.

Avoca Lagoon is a shallow coastal lagoon located behind Avoca Beach. The centre of the lagoon (surroundings of the natural island) is deeper with a few areas with bed levels lower than -3.0 m AHD. The lagoon has a cruciform shape with three main arms and a narrow entrance some 300 metres long which crosses Avoca Beach. The entrance is usually closed to the ocean by the beach berm. The lagoon's normal water level is perched approximately 1.0 metres above mean sea level.

2.1.4 Cockrone Lagoon catchment

Cockrone Lagoon Catchment is the southernmost catchment and is 8.3 km^2 with the lagoon accounting for approximately 6% of this area (i.e. 0.5 km^2). The majority of the catchment is bushland with pockets of rural land in the western half of the catchment. To the east the catchment is mainly residential. Some residential areas around the lagoon foreshores are low-lying and subject to flooding. The upper reaches rise to approximately 90 m AHD along the western boundary and 180 m AHD in the south-western corner.

The two main tributaries include Cockrone Gully to the west and Merchants Gully to the north.

Cockrone Lagoon is a small, shallow coastal lagoon located behind MacMasters Beach. The entrance is usually closed to the ocean by the beach berm. The lagoon's normal water level is perched approximately 1.5 metres above mean sea level.

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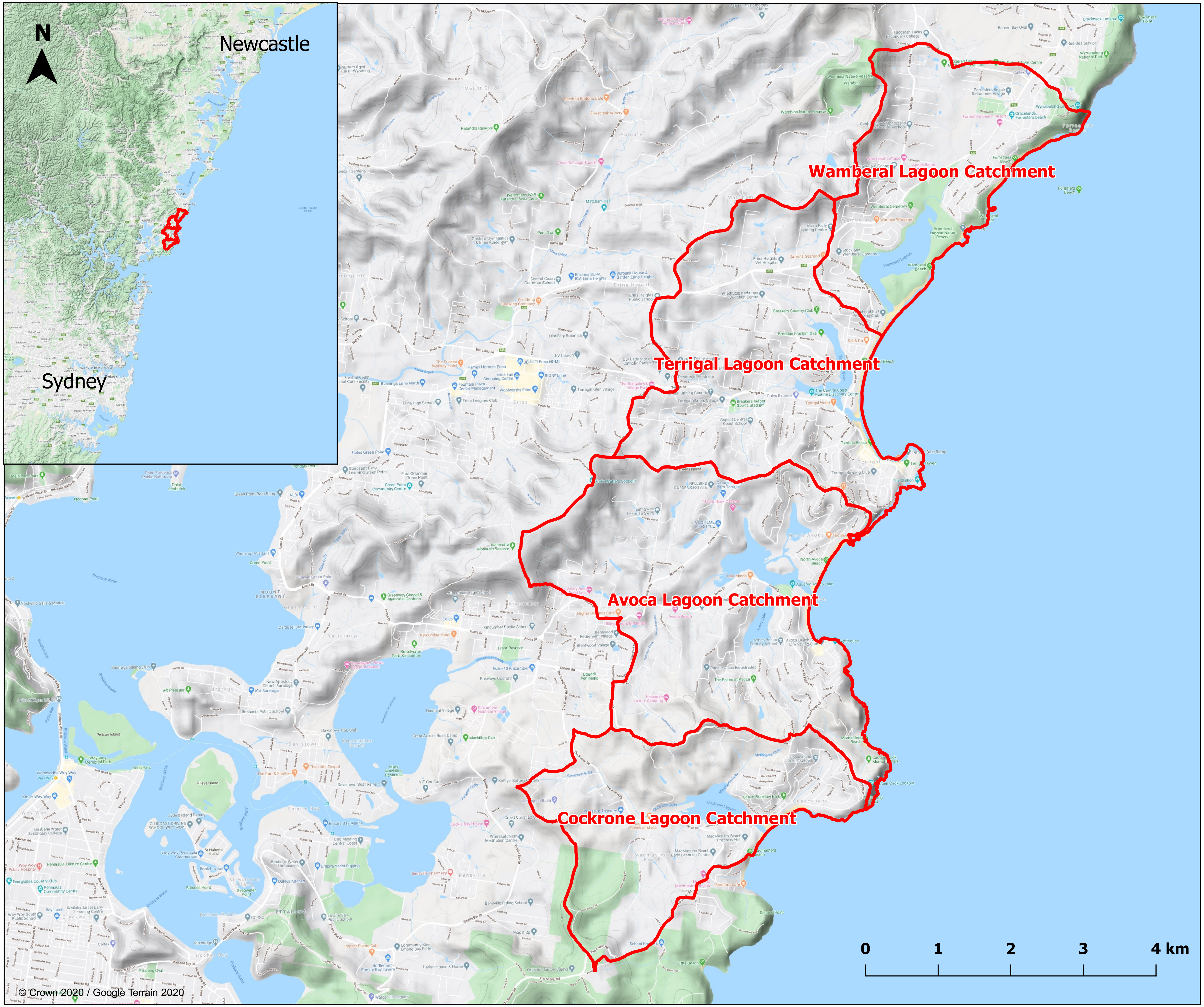

Figure 2-1

Study Area Location

Legend

Catchments

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2.2 Previous studies

Previous studies were reviewed and relevant information has been adopted in the development of this flood study. The following studies have been reviewed and are summarised below:

- Wamberal Lagoon Flood Study (WMA, 2001)
- Wamberal Lagoon Floodplain Management Study (WMA, 2001)
- Wamberal Lagoon Floodplain Management Plan (WMA, 2001)
- Terrigal Lagoon Flood Study (WMA, 2001)
- Terrigal Lagoon Floodplain Management Study (WMA, 2001)
- Terrigal Lagoon Floodplain Management Plan (WMA, 2001)
- Terrigal Valley Trunk Drainage Strategy (Kinhill Engineers, 1991)
- Terrigal Valley Trunk Drainage Strategy – Grasslands Ave & Riviera Catchments (WMA, 1995)
- Avoca Lagoon Flood Study (Patterson Consultants, 2008)
- Avoca Lagoon Floodplain Management Study (Patterson Consultants, 2008)
- Avoca Lagoon Floodplain Management Plan (Patterson Consultants, 2008)
- Cockrone Lagoon Flood Study (Patterson Consultants, 2008)
- Cockrone Lagoon Floodplain Management Study (Patterson Consultants, 2008)
- Cockrone Lagoon Flood Study-Addendum One McMasters Beach Drain (Patterson Consultants, 2007)
- Cockrone Lagoon Floodplain Management Plan (Patterson Consultants, 2008)
- The Entrance Dynamics of Wamberal, Terrigal, Avoca & Cockrone Lagoons (AWACS, 1994)
- Open Coast and Broken Bay Beaches Coastal Processes and Hazard Definition Study (Worley Parsons, 2014)
- Coastal Zone Management Plan for Gosford Lagoons (BMT WBM, 2015)

Wamberal Lagoon Flood Study (WMA, 2001)

The Wamberal Lagoon Flood Study constitutes the first stage of the management process and determines flood behaviour for Wamberal Lagoon and its catchment area.

A WBNM hydrological model was set up to cover the entire catchment draining to Wamberal Lagoon, as well as the lagoon itself. A RUBICON hydraulic model was structured to model the main drainage lines within the designated study area. The study area encompasses approximately two square kilometres loosely bounded by Crystal Street, Tumbi Road, The Entrance Road, Old Gosford Road and the Pacific Ocean.

A limited calibration (as a result of the lack of suitable data) of the hydrologic and hydraulic models was undertaken using the available historical data to ensure that they simulated recorded floods. For both models, parameter values from established texts and those found to be applicable in previous studies were adopted. The calibration was assisted by data from a mechanical breakout of the lagoon on 13 September 1993. These data provided the most comprehensive record of any lagoon openings on Wamberal Lagoon.

The primary objectives of this Flood Study were to:

- determine the flood behaviour of Wamberal Lagoon and its tributaries under existing conditions;
- set up a numerical model of the catchment to determine flood flows, velocities and levels for design events; and
- formulate the model such that the effects on flood behaviour of catchment development and flood mitigation options can be investigated.

The Flood Study does not consider local flooding which may result from inadequate urban drainage provisions. These issues were examined in other separate studies undertaken by Council.

Wamberal Lagoon Floodplain Management Study (WMA, 2001)

The Wamberal Lagoon Floodplain Management Study constitutes the second stage of the management process and examines a range of flood management options for Wamberal Lagoon and its catchment area.

Gosford City Council sought to examine the range of floodplain management measures which could be employed, firstly to protect existing development as far as possible, and secondly to ensure that any new development would be flood compatible.

Wamberal Lagoon Floodplain Management Plan (WMA, 2001)

The Wamberal Lagoon Floodplain Management Plan constitutes the third stage of the management process and provides a risk management approach managing flood risk through prevention, preparedness, response and recovery activities for Wamberal Lagoon and its catchment area.

This Plan incorporates a range of floodplain management measures to provide the optimal degree of protection within the constraints of practicability and cost effectiveness. Some components of the Plan apply to the whole floodplain within the study area while others relate to the specific areas.

The Floodplain Management Plan involves:

- Maintenance of Council's existing let-out policy.
- Maintenance of the beach berms.
- Adoption of the design one percent AEP flood plus 0.5 m freeboard as the "Flood Planning Level" through the study area. This follows Council's existing practice.
- Building and planning controls to set minimum floor levels and "allowable" building locations.

Terrigal Lagoon Flood Study (WMA, 2001)

The Terrigal Lagoon Flood Study constitutes the first stage of the management process and determines flood behaviour for Terrigal Lagoon and its catchment area.

The Flood Study does not consider local flooding which may result from inadequate urban drainage provisions.

A WBNM model was set up to cover the entire catchment draining to Terrigal Lagoon, as well as the lagoon itself. A RUBICON model was structured to model the main drainage lines within the designated study area. The study area encompasses approximately two square kilometres loosely bounded by Terrigal Drive, Brunswick Road, Weemala Crescent, Brush Road, Old Gosford Road and the Pacific Ocean.

A limited calibration (as a result of the lack of suitable data) of the hydrologic and hydraulic models was undertaken using the available historical data to ensure that they simulated recorded floods. For both models, parameter values from established texts and those found to be applicable in previous studies were adopted. The calibration was assisted by data from a mechanical breakout of the lagoon on 5 August 1993. These data provided the most comprehensive record of lagoon openings in the Gosford City area.

The primary objectives of this Flood Study were to:

- determine the flood behaviour of Terrigal Lagoon and its tributaries under existing conditions;
- set up a numerical model of the catchment to determine flood flows, velocities and levels for design events; and
- formulate the model such that the effects on flood behaviour of catchment development and flood mitigation options can be investigated.

The Flood Study does not consider local flooding which may result from inadequate urban drainage provisions. These issues were examined in other separate studies undertaken by Council.

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Gosford City Council sought to examine the range of floodplain management measures which could be employed, firstly to protect existing development as far as possible, and secondly to ensure that any new development would be flood compatible.

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The Terrigal Lagoon Floodplain Management Plan constitutes the third stage of the management process and provides a risk management approach managing flood risk through prevention, preparedness, response and recovery activities for Terrigal Lagoon and its catchment area.

This Plan incorporates a range of floodplain management measures to provide the optimal degree of protection within the constraints of practicability and cost effectiveness. Some

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components of the Plan apply to the whole floodplain within the study area while others relate to the specific areas.

The Floodplain Management Plan involves:

- Maintenance of Council's existing let-out policy.
- Maintenance of the beach berms.
- Adoption of the design one percent AEP flood plus 0.5 m freeboard as the "Flood Planning Level" through the study area. This follows Council's existing practice.
- Building and planning controls to set minimum floor levels and "allowable" building locations.

Terrigal Valley Trunk Drainage Strategy (Kinhill Engineers, 1991)

This report investigates the existing trunk stormwater drainage system in the catchment and predicts the effect that urbanization would have on the stormwater runoff.

A hydrologic model RAFTS was used to estimate peak flows in the catchment and a hydraulic model HEC-2 was used to determine peak flood levels. The models were calibrated using the February 1990 flood event.

A drainage strategy was investigated that restricted the 1% AEP flows and flood levels from the newly urbanized catchment to those of the existing catchment and also reduced existing flooding problems. Two detention basins are proposed within the study area with a formalized grass floodway between the basins and Terrigal Lagoon. Replacement of three existing road culverts is recommended together with the reconstruction of a short section of Terrigal Drive.

Terrigal Valley Trunk Drainage Strategy – Grasslands Ave & Riviera Catchments (WMA, 1995)

This study follows on from the Terrigal Valley Trunk Drainage Strategy (Kinhill Engineers, 1991). To obtain a clearer understanding of the drainage problem and solutions for the trunk drainage system, the Terrigal study area was sub-divided by Council into three main catchments; Grasslands Avenue, Riviera Avenue and Terrigal CBD. A hydrologic/hydraulic computer model was established for the three catchments and their drainage networks. The model was used to assess the existing drainage system behaviour, determine the design 1 in 20 and 1 in 100 AEP floods, and quantify the relative effects of alternative mitigation measures.

Avoca Lagoon Flood Study (Patterson Consultants, 2008)

The Avoca Lagoon Flood Study constitutes the first stage of the management process and determines flood behaviour for Avoca Lagoon and its catchment area.

The Flood Study addresses only those issues which relate to flooding of the foreshores and floodplain adjacent to the lagoon.

A hydrologic model of the catchment was established using the package RORB while the lagoon hydraulics were modelled using MIKE-11. The opening of the lagoon entrance on 14 September 1993 was simulated using the DAMBREAK module of the MIKE-11 hydraulic model. Calibration parameters determined for this simulation were adopted for modelling natural breakouts under design flood conditions.

Regional parameters were adopted for the RORB model because of insufficient data to enable hydrologic model calibration. The MIKE-11 hydraulic model was calibrated using data for three recent floods for which rainfall and flood level data were available. The model reproduced lagoon water levels and peak flood levels upstream of the lagoon within 0.15 metres of the levels.

For comparative purposes, a series of design flood levels were prepared and represent a maximum for the envelope of floods created by:

- water levels created by flood rainfall over the catchment;
- water levels created by ocean waves either over-washing the beach berm or propagating through an open entrance; and
- beach berm level assumed to be at RL 3.3 m AHD.

Avoca Lagoon Floodplain Management Study (Patterson Consultants, 2008)

The Avoca Lagoon Floodplain Management Study constitutes the second stage of the management process and examines a range of flood management options for Avoca Lagoon and its catchment area.

The management study draws on the results of the flood study and uses this information, together with additional data collected for the management study to assess feasible floodplain management options for Avoca Lagoon foreshore area and floodplain within the study area.

Preferred management options have been recommended based on a comparative evaluation of each option and a range of relevant criteria. These evaluation criteria include indicators of flood mitigation performance, economic considerations, environmental impacts and social issues.

Avoca Lagoon Floodplain Management Plan (Patterson Consultants, 2008)

The Avoca Lagoon Floodplain Management Plan constitutes the third stage of the management process and provides a risk management approach managing flood risk through prevention, preparedness, response and recovery activities for Avoca Lagoon and its catchment area.

This Plan incorporates a range of floodplain management measures to provide the optimal degree of protection within the constraints of practicability and cost effectiveness. The Floodplain Management Plan divides the Avoca Lagoon area into four management areas; Avoca Lagoon – Beach Berm, Avoca Lagoon – Entrance, Saltwater Creek and Avoca Lagoon and Foreshore.

Essentially, the Floodplain Management Plan involves:

- Maintenance of Council's existing let-out policy.
- Maintenance of the beach berms.
- Adoption of the design one percent AEP flood plus 0.5 m freeboard as the "Flood Planning Level" through the study area. This follows Council's existing practice.

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- Building and planning controls to set minimum floor levels and "allowable" building locations.

Cockrone Lagoon Flood Study (Patterson Consultants, 2008)

The Cockrone Lagoon Flood Study constitutes the first stage of the management process and determines flood behaviour for Cockrone Lagoon and its catchment area.

A hydrologic model of the catchment was established using the package RORB while the lagoon hydraulics were modelled using MIKE-11. The break-out process through the beach berm was simulated using the DAMBREAK module of MIKE-11.

Regional parameters were adopted for the RORB model because of insufficient data to enable hydrologic model calibration. The MIKE-11 hydraulic model was calibrated using data for three recent floods for which rainfall and flood level data were available. The model reproduced lagoon water levels and peak flood levels upstream of the lagoon within 0.11 metres of the historical levels.

For comparative purposes, a series of design flood levels were prepared and represent a maximum for the envelope of floods created by:

- water levels created by flood rainfall over the catchment;
- water levels created by ocean waves either over washing the beach berm or propagating through an open entrance; and
- beach berm level assumed to be at RL 3.8 m AHD.

Cockrone Lagoon Floodplain Management Study (Patterson Consultants, 2008)

The Cockrone Lagoon Floodplain Management Study constitutes the second stage of the management process and examines a range of flood management options for Cockrone Lagoon and its catchment area.

The management study draws on the results of the flood study and uses this information, together with additional data collected for the management study to assess feasible floodplain management options for Cockrone Lagoon foreshore area and floodplain within the study area.

Preferred management options have been recommended based on a comparative evaluation of each option and a range of relevant criteria. These evaluation criteria include indicators of flood mitigation performance, economic considerations, environmental impacts and social issues.

Cockrone Lagoon Flood Study-Addendum One McMasters Beach Drain (Patterson Consultants, 2007)

Flood behaviour in the lower section of the drain is dependent on the behaviour of Cockrone Lagoon. This Study relates to local runoff behaviour in the upper section.

Cockrone Lagoon Floodplain Management Plan (Patterson Consultants, 2008)

The Cockrone Lagoon Floodplain Management Plan constitutes the third stage of the management process and provides a risk management approach managing flood risk through prevention, preparedness, response and recovery activities for Cockrone Lagoon and its catchment area.

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This Plan incorporates a range of floodplain management measures to provide the optimal degree of protection within the constraints of practicability and cost effectiveness. The Floodplain Management Plan divides the Cockrone Lagoon area into six precincts; Cockrone Lagoon - Beach Berm, Cockrone Lagoon - Entrance Area, Cockrone Lagoon - Storage Area, Cockrone Lagoon - Floodway Area, Merchants Creek - Floodway Area and Newell Road Floodway.

Essentially, the Floodplain Management Plan involves:

- Maintenance of Council's existing let-out policy.
- Maintenance of the beach berms.
- Adoption of the design one percent AEP flood plus 0.5 m freeboard as the "Flood Planning Level" through the study area. This follows Council's existing practice.
- Building and planning controls to set minimum floor levels and "allowable" building locations.
- Construction of drainage works at Newell Road.

The Entrance Dynamics of Wamberal, Terrigal, Avoca & Cockrone Lagoons (AWACS, 1994)

This study was undertaken to:

- develop a time versus discharge relationship which would simulate the natural breakout of each lagoon during flood conditions; and
- estimate the likely flood inundation from ocean waves either overtopping or penetrating into the lagoon.

The study is summarised under the following headings:

- Berm Dimensions
- Lagoon Breakout Analysis
- Flood Inundation from Ocean Waves

Open Coast and Broken Bay Beaches Coastal Processes and Hazard Definition Study (Worley Parsons, 2014)

This study determines the coastal hazard such as run-up and coastal inundation along the coastline of the four lagoons. The coastal mapping highlights the properties that may potentially be affected by coastal inundation and these properties may be subject to higher inundation levels due to coastal inundation rather than catchment flooding.

Coastal Zone Management Plan for Gosford Lagoons (BMT WBM, 2015)

This CZMP provides potential management options to reaches a range of objectives such as improvement of water quality, natural environment and habitats, protection of threatened species, vegetation, wetland fauna, educational value, flood mitigation value, recreational swimming value, tourism value and indigenous cultural heritage.

A key recommendation in regard to flooding is the incorporation of climate change considerations into infrastructure asset management, planning processes and development

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controls as well as review the lagoon opening procedure and policy.

2.3 Discussion of relevant policies, legislation and guidance

The NSW Floodplain Risk Management Process

The Coastal Lagoon Catchments Overland Flood Study has been prepared in accordance with the New South Wales Government's *Floodplain Development Manual* (NSW Government, 2005). The manual guides implementation of the NSW Government's *Flood Prone Land Policy* (NSW Government, 2005), the primary objective of which 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."*

Under the policy, primary responsibility for floodplain risk management rests with local government. Financial and technical assistance is provided to councils by EES.

The *Floodplain Development Manual* defines the following steps in the Floodplain Risk Management Process:

- Formation of a Project Technical Group
- Data Collection
- Flood Study Preparation
- Floodplain Risk Management Study Preparation
- Floodplain Risk Management Plan Preparation
- Floodplain Risk Management Plan Implementation.

Completion of the Coastal Lagoon Catchments Overland Flood Study provides a detailed picture of flood behaviour and flood risk throughout the Coastal Lagoon Catchments. This information and the numerical flood model developed during the study will form the basis for the preparation of a Floodplain Risk Management Study and Plan (FRMS&P). During this subsequent phase of the process the potential economic, social and environmental impacts of flooding will be quantified and used as a basis to assess various options to manage flood risk. Management options can include flood modification measures (e.g. drainage upgrades and detention basins), property modification measures (e.g. flood-related development controls) and flood response modifications (e.g. emergency response and community education programs). Adoption of the FRMS&P will allow Council to apply for grant funding from the NSW Government to implement measures recommended in the plan including capital works.

By following the NSW Floodplain Risk Management Process, Central Coast Council is adopting a best practice, State supported pathway for the methodical identification, assessment and implementation of robust and effective flood risk management measures in order to reduce the impacts of flooding on the community and existing development, and to ensure that future development is compatible with flood risk. Councils following the NSW Floodplain Risk Management Process demonstrate duty of care with respect to the management of flood liable land and are exempted from liability under Section 733 of the Local Government Act 1993.

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Gosford Local Environmental Plan 2014

Council's local environmental plan (LEP) is available online on Council's website. The LEP provides land use maps separating the LGA into various land use zonings. The document outlines what development is allowed in each zoning as well as any special provisions. The plan includes definitions to give the community a greater understanding of what uses and building types are allowed on their land, and also outlines planning controls that may apply to a particular site, such as properties that have a heritage listing.

Gosford Beaches Coastal Zone Management Plan (Worley Parsons, 2017)

This report documents the Coastal Zone Management Plan (CZMP) for Gosford's Open Coast and Broken Bay Beaches.

This CZMP was prepared in accordance with the *Guidelines for Preparing Coastal Zone Management Plans* (OEH, 2013) and its development has been supported by funding under the NSW Coastal Management Program.

The primary purpose of this Plan is:

> *"to describe proposed actions to be implemented by Gosford City Council, other public authorities and by the private sector to address priority management issues in the coastal zone between 2015 and 2025. These issues include:*
>
> - *managing risks to public safety and built assets*
> - *pressures on coastal ecosystems, and*
> - *community uses of the coastal zone."*

The primary objective of this Plan is:

> *"to protect and preserve the beach environments, beach amenity, public access and social fabric of the Open Coast and Broken Bay beaches while managing coastal hazard risks to people and the environment".*

Coastal Zone Management Study for Gosford Lagoons (BMT WBM, 2014)

The Coastal Zone Management Study for Gosford Lagoons (BMT WBM, 2014) recognises the importance these ICOLs and the influence the contributing catchment has on water quality and quantity. This document has since been included into Council's DCP documents.

Lagoon Entrance Management Policy and Procedures (Salients, 2017)

Due to community concerns that human intervention is altering the ecological balance Council has recently completed a revision of the Lagoon Entrance Management Policy and Procedures (Salients, 2017). A draft Entrance Management Procedures have been prepared following consultation with key stakeholders with water level and monitoring being a key element within the procedures. Flood forecasting will provide critical input into the decision-making process.

2.4 Flood behaviour

Each of the lagoon catchments are susceptible to similar modes of flooding, including inundation from both the ocean and stormwater. Flood behaviour exhibited within the study is

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summarised as follows.

2.4.1 Mainstream flooding

Mainstream flooding is a result of relatively high-water flows which overtop the natural or artificial banks along any part of a watercourse (creeks, tributaries), lake, dam or lagoon. Floods in the tributary creeks draining to the lagoon result from intense and short duration storms, typically less than three hours. The steep terrain results in short catchment response time to rainfall. The short response time coupled with the confined nature of the creek channels leads to spilling of floodwaters onto the floodplain prior to a significant rise in lagoon water levels. Flooding around the lagoon foreshores results from rainfall of much longer durations, typically 6-12 hours or longer. The large surface area of the lagoons requires a considerable volume of runoff to raise the water level. The extent of water level rises in the lagoons is determined by conditions at the entrance.

With the entrance opened, floodwaters are able to discharge quickly with little resultant increase in lagoon water levels. On the other hand, with the entrance closed, floodwaters pond in the lagoons until the beach berm is overtopped or the lagoon entrance breaks out either artificially or naturally. For this reason, a berm management safety factor has been recommended on top of the normal freeboard as part of the minimum floor level in **Section 12.1**.

2.4.2 Overland flooding

Overland flooding is caused by heavy rainfall flowing across the ground or overflowing pipes, pits and gutters. It is inundation as a result of local runoff rather than inundation created by overbank flows discharging from a watercourse, lake or dam. Local overland flooding is often characterised by a rapid rise in flood levels, particularly where the local catchment is relatively steep and small. The nature of the catchments within the study area are susceptible to this type of flooding particularly in urbanised areas, on roads and through property.

2.4.3 Coastal inundation

Generally elevated ocean levels occur in combination with increased wave activity. The level in the lagoon could be raised as a result of wave runup and overtopping of the berm. However, this action it is also likely to lower the berm, reducing the water level in the lagoon. Furthermore, the volume of inflow likely to result from this mechanism would only be a small percentage of the total volume required to raise the lagoon level by a significant amount. Terrigal Lagoon may be more sensitive to this phenomenon due to the low berm level.

2.4.4 Combination of flood modes

These modes of flooding may occur in isolation or in combination with each other. For example, the floods in February 1981 resulted from intense local rain, in the absence of significant ocean activity and with only a slightly elevated lagoon level. In the May 1974 the storm produced only minor rainfall but was a major ocean event causing significant coastal damage. Whilst in January 1978 the storm produced high rainfalls as well as significant ocean activity. In most cases the only records of flood occurrences in the catchment are from elevated lagoon levels. Thus, major rainfall events which produced flooding of one catchment may have passed unnoticed on another catchment if the entrance was open and the lagoon level did not rise significantly.

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2.4.5 Observed flood prone areas

Details of specific flood prone areas have been collated from the previous studies outlined in **Section 2.2** and from new accounts obtained through the community consultation process undertaken for this flood study. The aim is to capture and convey the key areas within each lagoon catchment were flooding has been an issue in the past (Refer to **Figures 2-2 to 2-5**).

Wamberal Lagoon Catchment

- Remembrance Drive - This area may experience flooding as a result of ocean inundation. Ponding of water in front yards and the roadway has flooded. Debris was placed in front yards as a result of wave activity through the open entrance during the May 1974 storm. Waves were breaking inside the lagoon and running into the front yards of the properties.
- Loxton Avenue - A number of properties in Loxton Avenue have experienced above floor inundation in the past. However, improvements to drainage on Old Gosford Road (completed in 1990) has significantly improved flooding within the Loxton Avenue area as there were no reports of flooding in the February 1992 storm.
- Wamberal Park and Blue Bell Drive - Minor local drainage problems have been reported in the drain which is located between Blue Bell Drive and Tall Timbers Road. This has caused inundation of the yards of several properties and caused minor inconvenience. Flooding occurred due to inadequate capacity within the local drain and was not affected by elevated lagoon levels.
- Sections of Malkana Avenue and John Street, near Crystal Street – evidence of inundation during the February 1990 event. Flooding was caused by the North Arm creek overtopping its banks and flowing over Malkana Avenue. The water generally ponds in yards and dissipates slowly. Low-lying depressions in the yards are inundated for several days.
- Northern part of John Street - Poor local drainage has been indicated as a problem. No. 5 and No. 10 John Street were inundated above floor level in the February 1991 flood.

Terrigal Lagoon Catchment

- Terrigal Lagoon floodplain - Catchment runoff increases the lagoon water level resulting in significant flood problems around the foreshore and floodplain.
- Bundara Avenue - There have been numerous reports of flooding in the vicinity of Bundara Avenue in the community questionnaire responses. Properties in Renown Street, Arila Avenue, Lake View Road and Bundara Avenue have all been affected. The residents indicated that the degree of inundation in the past was dependent on if, and when, the lagoon was opened to the ocean.
- Northern End of Ocean View Drive Bridge - the southern part of this area (facing the lagoon) has been affected by waves running into the lagoon from the ocean. The Clan Motor Lodge experienced flooding over the veranda floor in either 1974 or 1978. This was caused by waves running into the lagoon, not elevated lagoon levels. Council has also indicated that above floor flooding has occurred in "one or two" residences in the past.

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- Farrand Crescent – At least three properties have experienced inundation above floor level.
- Golf Course – flooding of the golf course has occurred on several occasions.
- Windsor Road – Above floor flooding has been noted by at least one property on two to three occasions in the 10 years from 1984 to 1994. The residents in this area have generally indicated that the cause of flooding is from local runoff which concentrates at the two floodways, rather than from elevated lagoon levels.
- Upstream of Willoughby Road Causeway - Above floor flooding has been noted by at least one property on Brush Road (No.22) on January 1989. The creek runs through all the lots, the residents will likely have experienced inundation of their land and consequent drainage problems associated with the saturated ground as there is no sub-surface drainage system.

Avoca Lagoon Catchment

- Northern side of lagoon entrance - comprising seven properties in Bareena Avenue which are susceptible to inundation by wave action during ocean storms.
- North Avoca - comprising nine properties in Lake Street and in Tramway Road which back onto the lagoon.
- North Arm foreshore - comprising some eight properties in Leeside Road and three properties in Lake Shore Drive which are above lagoon flood levels but may suffer inundation due to blockages in the stormwater drainage systems. The properties in Lake Shore Drive experienced flooding due to blocked drainage in February 1989.
- Saltwater Creek floodplain - comprising a small number of rural properties which may be isolated by lagoon floodwaters over access roads.
- Avoca Drive/Scenic Highway intersection - unaffected by lagoon flooding but local runoff can cover Avoca Drive restricting access.
- South Arm foreshore - comprising the caravan park and three adjacent properties in the Round Drive and Avoca Beach Primary School grounds.
- Southern side of the lagoon entrance - comprising some 19 properties in Ficus Avenue and Avoca Drive which are susceptible to inundation by wave action during ocean storms.
- Open space areas bordering the lagoon which are flood prone.

Cockrone Lagoon Catchment

- Cockrone Lagoon Foreshore - Properties adjacent to the entrance channel may be flooded by ocean inundation. This occurred in March 1974 and July 1983 when high seas produced by severe ocean storms overtopped the beach berm and flowed into the lagoon.
- The northern side of lagoon entrance - comprising eight houses in Del Monte Place which are susceptible to inundation by lagoon floodwaters as well as wave action during severe ocean storms.
- Cockrone Gully floodplain - comprising rural land, opens space and public reserve;

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- Southern foreshore of the lagoon - comprising the bird sanctuary, open space and five houses susceptible to lagoon flooding.
- Newell Road, Three Points Avenue and Tudibaring Parade backing onto the open drain - unaffected by lagoon flooding but may be affected by local runoff in extreme storms.
- Southern side of the lagoon entrance - comprising four houses in Lakeside Drive and two houses in Three Points Avenue which are susceptible to lagoon flooding and wave action during severe ocean storms.

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Figure 2-2

Observed Flood Prone Areas in Wamberal Lagoon Catchment

Legend

Catchments
Locations of observed flood issues

Gauges

Rainfall
Water Level
Rainfall & Water Level

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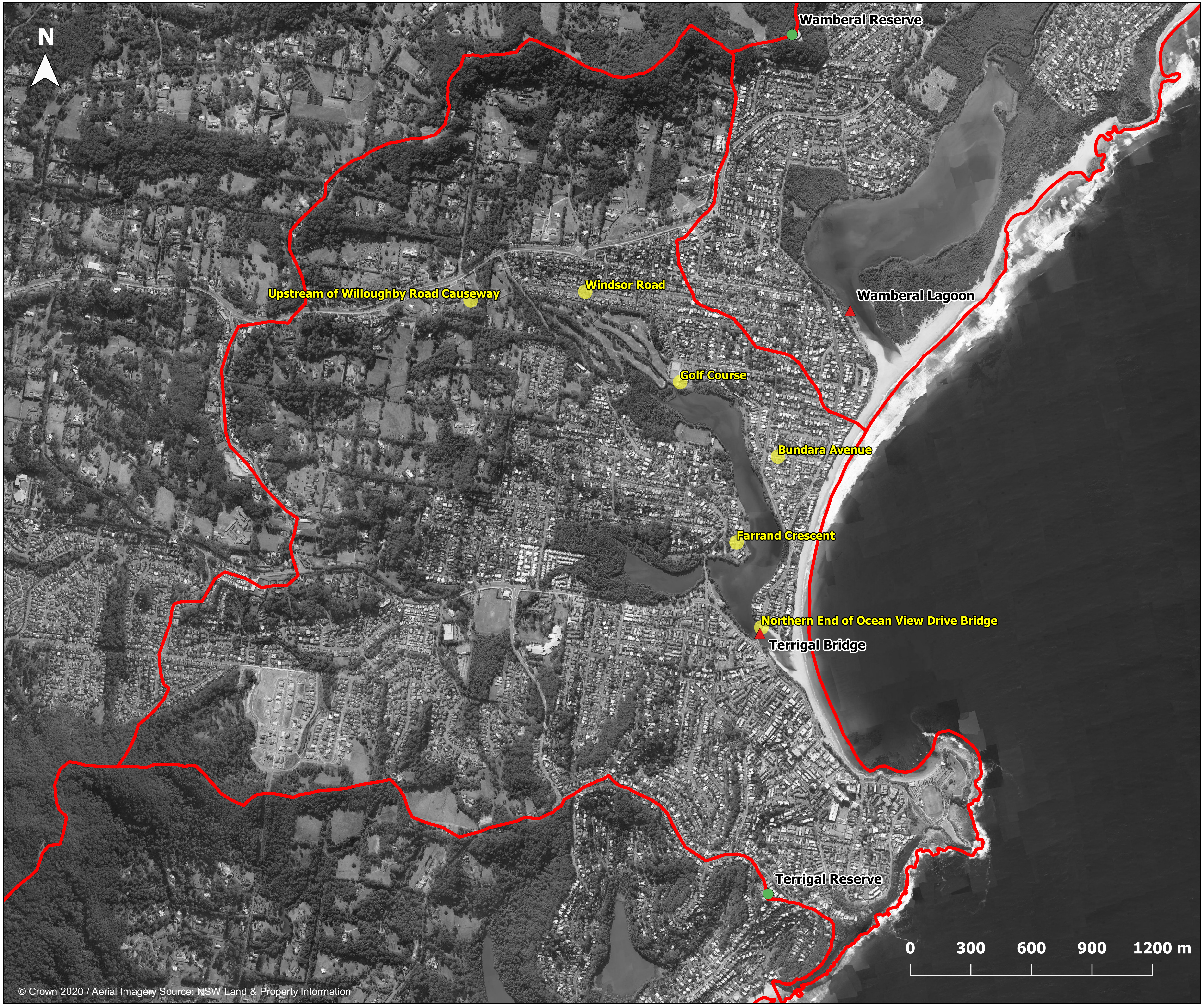

Figure 2-3

Observed Flood Prone Areas in Terrigal Lagoon Catchment

Legend

Catchments

Locations of observed flood issues

Gauges

Rainfall

Water Level

Rainfall & Water Level

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Coastal Lagoon Catchments Overland Flood Study

NSW GOVERNMENT Manly Hydraulics Laboratory

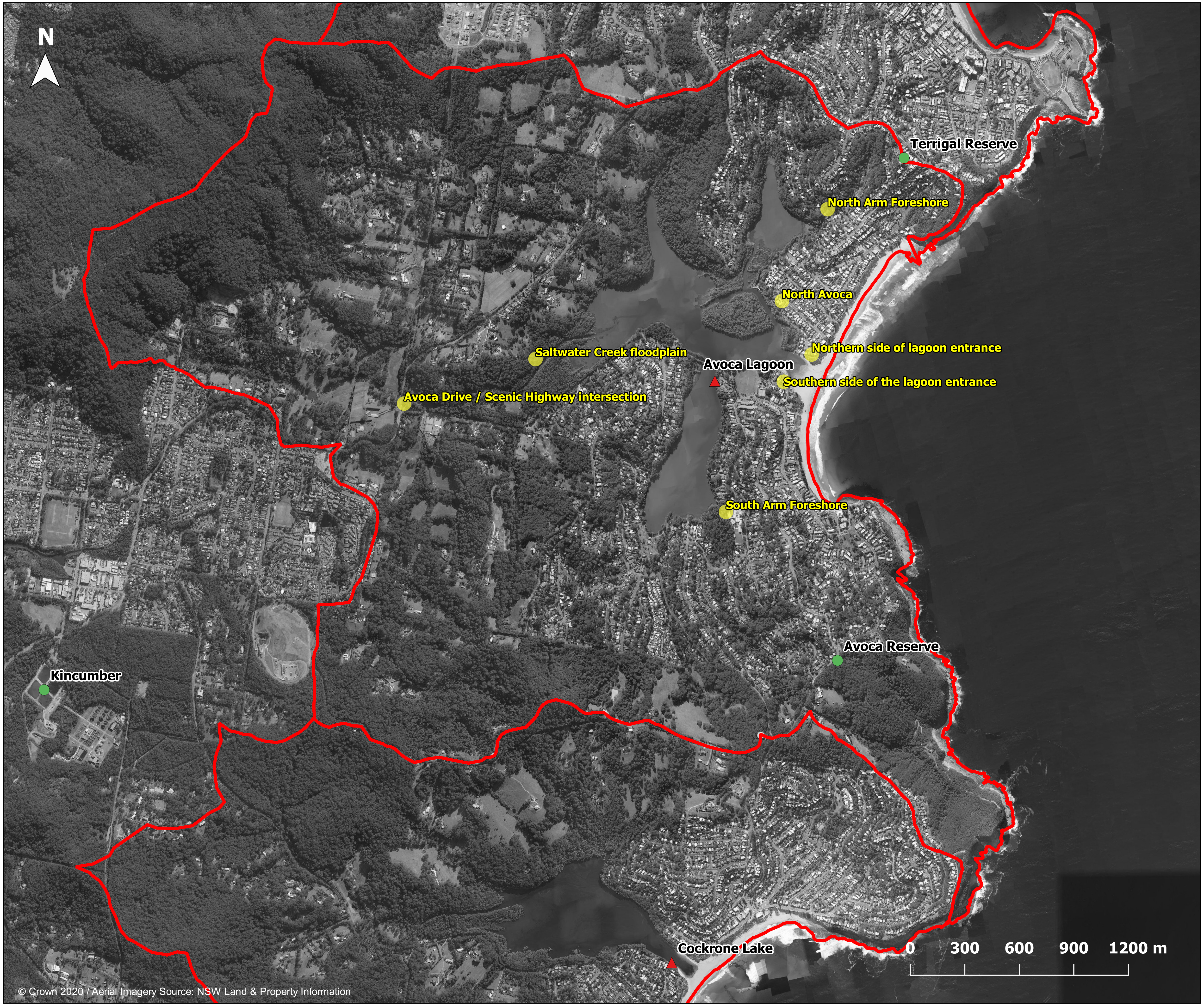

Figure 2-4

Observed Flood Prone Areas in Avoca Lagoon Catchment

Legend

Catchments

Locations of observed flood issues

Gauges

Rainfall

Water Level

Rainfall & Water Level

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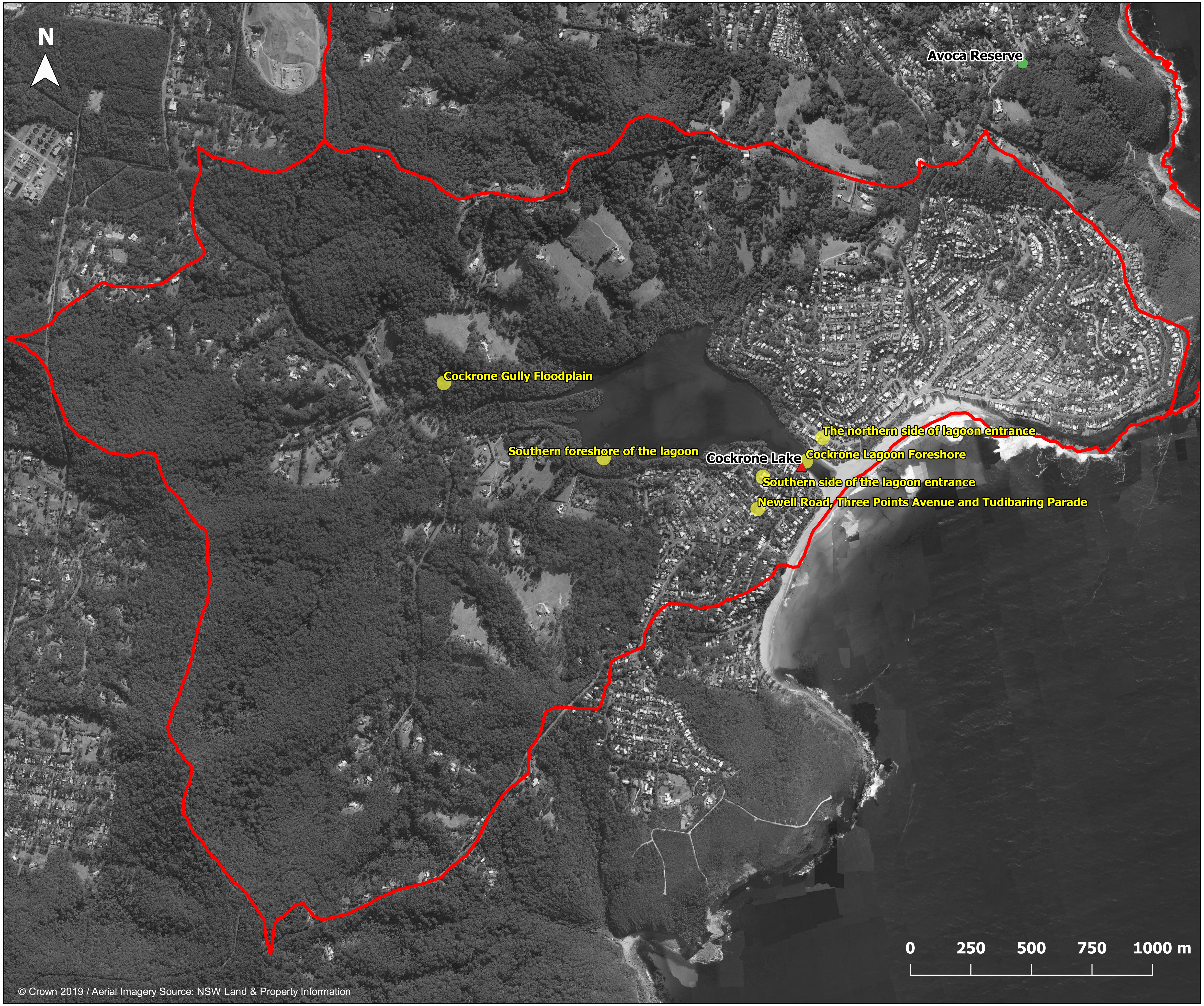

Figure 2-5

Observed Flood Prone Areas in Cockrone Lagoon Catchment

Legend

Catchments

Locations of observed flood issues

Gauges

Rainfall

Water Level

Rainfall & Water Level

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Coastal Lagoon Catchments Overland Flood Study

NSW GOVERNMENT | Manly Hydraulics Laboratory

3. Available data

3.1 Historic data

Significant storm events occurred over the study area on or around the following dates:

May/June 1974	January 1989	August 1998	June 2007	April 2013	March 2017
January 1978	February 1990	April 1999	April 2008	June 2013	February 2020
February 1981	February 1992	May 2001	March 2011	January 2015	
October 1985	June 1996	May 2003	January 2012	April 2015	
April 1988	May 1997	October 2004	January 2013	June 2016	

Although most storm events occur across all the catchments, the degree of flooding may differ between catchments. Storm events which produced flooding on one catchment may have passed unnoticed on another catchment if the entrance was open and the lagoon level did not rise significantly.

Historical data was collated from various sources. Data from the previous flood study concentrated on the period since the mid 1970’s to 2001, as data prior to that time the data are generally of insufficient quality and quantity for model calibration. Data for the period since the previous flood studies was collated from community consultation and water level records.

3.2 Water level and rainfall data

EES owns a number of rainfall and water level gauges within the vicinity of the study area which are operated by Manly Hydraulics Laboratory (MHL) and are outlined in **Table 3-1** and illustrated on **Figures 2-2 to 2-5.** The data was collated and reviewed to confirm flood events identified in previous studies and to identify flood events which have occurred since the previous studies. Water level and rainfall time series plots are provided in **Figures 3-1 and 3-2.**

A flood frequency analysis based on the available data at the four lagoon’s water level gauges was applied using the Annual Maximum Series approach. Results of this flood frequency analysis are presented in **Figure 3-3**. It is noted that the flood frequency analysis is highly influenced by the berm level at the lagoon.

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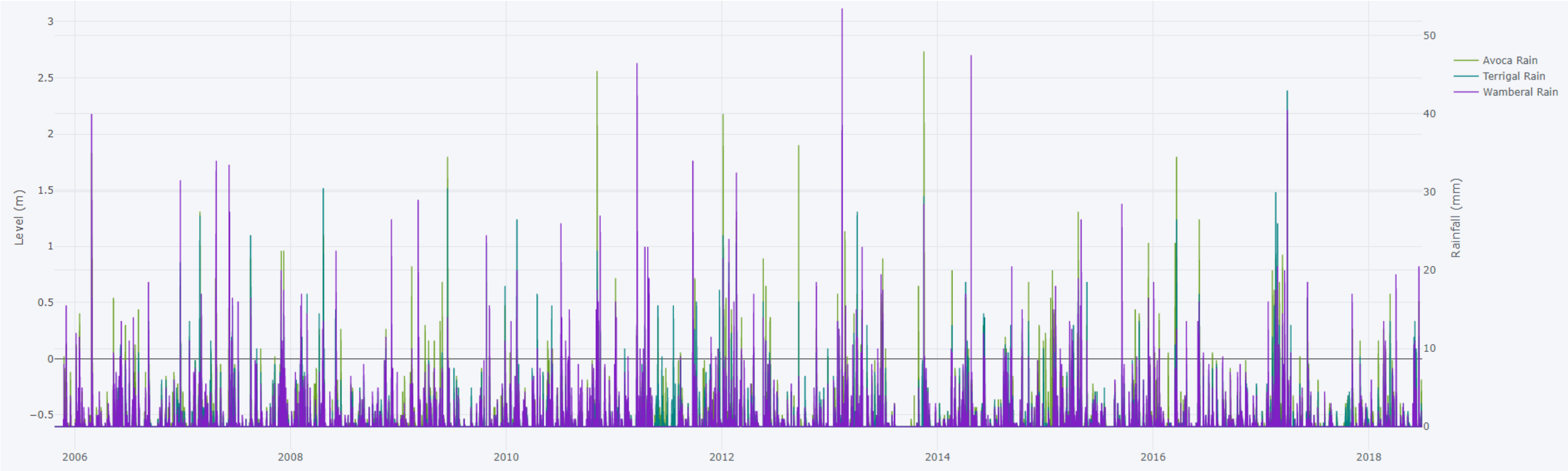

Figure 3-1 Rainfall Data at Avoca, Terrigal and Wamberal Rainfall Stations

Figure 3-2 Water Levels gauges within Avoca, Cockrone, Terrigal and Wamberal Lagoons

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Table 3-1 Rainfall and water level gauges within the vicinity of the study area

Station number	Name	Type	Owner
561078	Kulnura	R	EES
561147	Wamberal Reserve	R	CCC
561138	Terrigal Reserve	R	CCC
561139	Avoca Reserve	R	CCC
561077	Kincumber	R	EES
561148	Kincumba Mountain	R	CCC
561144	Bensville	R	CCC
561145	Paul Oval Erina Heights	R	CCC
212452	Avoca Lagoon	L	EES
212429	Gunderman Caravan Park	L	EES
212455	Terrigal Bridge	L	EES
212450	Wamberal Lagoon	L	EES
212408	Webbs Creek	L	EES
212431	Spencer	L	EES
212453	Cockrone Lake	L	EES

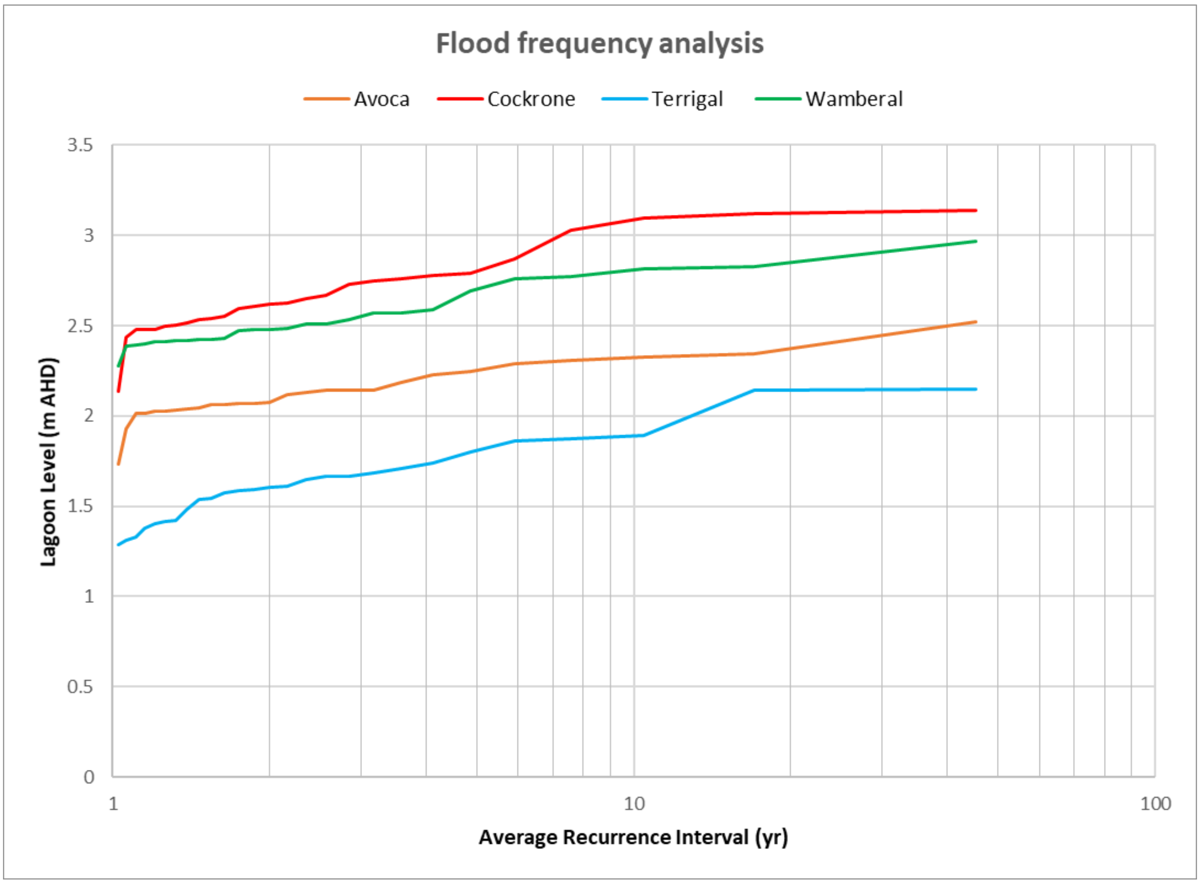

Figure 3-3 – Flood frequency analysis of the four lagoons

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3.3 Pit and pipe data

Council's 'pit and pipe' GIS layers were reviewed for completeness and quality for flood modelling purposes. The review identified missing data required for modelling the stormwater network. Missing data is summarised in **Table 3-2**.

Table 3-2 Summary of missing pit and pipe data

Item	Total	Missing inlet dimensions / diameters		Missing Invert Levels		Missing Depths	
Pipes	6399	413	6%	6399	100%	4288	67%
Box culverts	243	0	0%	243	100%	108	44%
Pits	5890	5020	85%	5890	100%	4030	68%
Headwalls	1041	10	1%	1018	98%	599	58%
GPTs	15	12	80%	15	100%	15	100%

For the purpose of modelling, missing data was supplemented by estimates based on the following:

- Estimate pit invert levels using Lidar, pipe dimensions, standard cover and pit depths – Council's DCP identifies a minimum cover of 0.7m (Central Coast Council, 2017).
- Check available drawings to confirm information in key sample location
- Update pit and pipe data to be consistent with modelling requirements:
  - Add pits or headwalls to end of pipes which do not have one
  - Split up pipes which continue through pits
  - Consolidate multiple identical parallel pipes and culverts
  - Remove dummy pipes and amend network to make sense
  - Other modifications to get network to run in TUFLOW
- Undertake site investigation to confirm estimated data at some key sample locations.
- Additional analysis to ensure all:
  - Pipe sizes are greater than or equal to upstream pipes
  - Pipe inverts are less than upstream inverts

Pit and Pipe Inspections at Sample Locations

Pits and pipes were inspected at sample locations to develop an understanding of the accuracy of the provided information and estimated information used to model the pits and pipes. Primarily this involved measuring pit depths and comparing them with values adopted for the model based on the methodology outlined above.

A comparison and map of sample locations are provided in **Appendix A**. The comparison indicates that there are significant differences between modelled and measured pit depths. This is evident for both the available and estimated values.

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It is noted that a number of the measured pit depths were less than the 0.7m pipe cover assumed in calculating the estimated pit depths. This may be that the pipes are either concrete encased or were constructed prior to the release of council's DCP where this is specified.

Whilst some pipe diameters were also sampled, the majority of pipe diameters were available in council's GIS data. Hence less emphasis has been placed on this information. The few pipes which were measured were generally in good agreement with the available information.

It was found that Terrigal CBD trunk drainage did not reflect the drawings and had to be amended into the model.

3.4 Lagoon entrances behaviour

3.4.1 Overview

A typical natural opening and closing sequence in New South Wales follows these steps (Gordon, 1990):

- A closed lagoon fills following flows from the catchment;
- When the water level in the lagoon reaches the crest level of the barrier across the entrance, flow overtops and begins to scour a channel down the ocean face of the berm;
- The scoured channel gradually widens, lowers and flattens, resulting in increasing flow as the breach gathers pace;
- The scoured channel reaches its maximum extent. At this stage, the lagoon is open and under the influence of tides, which flow freely in and out of the entrance;
- With full tidal connectivity, and the influence of waves and alongshore currents, sand is carried into the entrance channel, which gradually fills until the sub-tidal region of the channel is filled with sand;
- Following closure of the sub-tidal entrance channel, the process of wave run-up acts further to carry sand into the scoured channel, depositing sand above the sub-tidal region.
- Additional sand is deposited above the limit of wave run-up through aeolian processes (i.e. wind)

A typical breakout comprises three distinct stages:

- The initiation channel stage (Froude No. < 1)
- The weir/hydraulic jump stage (Froude No. > 1)
- The river flow stage (Froude No. < 1)

These breakout stages are presented in **Figure 3-4**.

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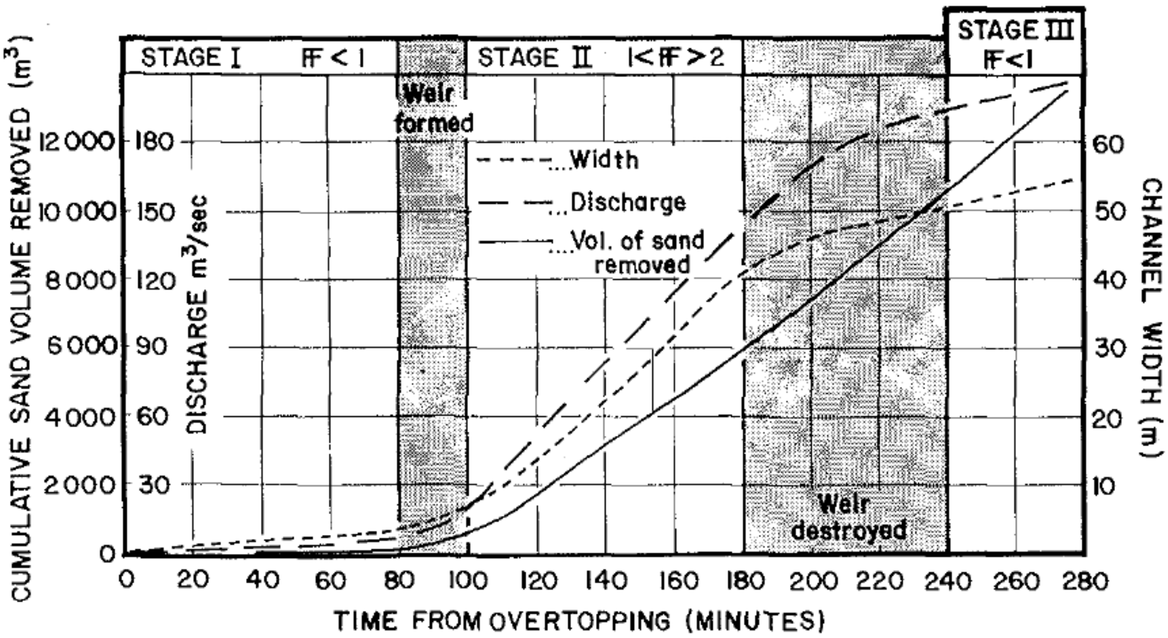

Figure 3-4 Three-staged Behaviour of Breakout

Source: (Gordon, 1990)

3.4.2 Council records

Council maintains a "lagoon book" which contains data for the four coastal lagoons - Cockrone, Avoca, Wamberal and Terrigal. This book contains data regarding the number of openings, tide, lagoon levels, etc. A notation is made in the book generally when a breakout occurs (natural or mechanical). The book does not necessarily provide the peak level reached by the lagoon. Council also has a photographic record of some lagoon openings.

3.4.3 Previous studies

Information regarding lagoon entrances was collated from numerous sources including the Gosford Lagoon and Creek Entrance - Management Review: Phases 1 and 2 (Salients, Coastal Environment, the University of Newcastle, 2017).

Details are summarised in **Table 3-3** and **Table 3-4**.

Table 3-3 Summary of Key Lagoon Entrance Information

Source: Gosford Lagoon and Creek Entrance - Management Review: Phases 1 and 2 (Salients, Coastal Environment, the University of Newcastle, 2017) and The Entrance Dynamics of Wamberal, Terrigal, Avoca and Cockrone Lagoons (AWACS, 1994)

Lagoon	Let Out Level (m AHD)	Mean water level (m AHD)	Breach width	Berm Breadth
Wamberal	2.40	1.59	30 to 80 m (70-80 most likely)	50 to 70 m
Terrigal	1.23	0.89	30 to 50 m	40 to 80 m
Avoca	2.09	1.26	60 to 90 m	40 to 130 m

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Lagoon	Let Out Level (m AHD)	Mean water level (m AHD)	Breach width	Berm Breadth
			(80-90 most likely)	
Cockrone	2.53	1.73	60 to 100 m (60-80 most likely)	60 to 80 m

Table 3-4 Entrance Management Levels compared to "Natural" Barrier Levels (Salients, Coastal Environment, the University of Newcastle, 2017)

Lagoon	Present "Trigger" Level (m AHD)	Present Barrier Maintenance Level (m AHD)	Typical "Natural" Barrier Height (m AHD)	Potential "Natural" Barrier Height (m AHD)
Wamberal	2.40	2.6-2.7	3.0	3.6
Terrigal	1.23	1.7	2.1	2.8-3.0
Avoca	2.09	2.7-2.8	2.5-3.0	3.5
Cockrone	2.53	3.3-3.5	3.0	3.5

Additional data from Salients, Coastal Environment, the University of Newcastle (2017) are provided below for each lagoon.

Wamberal Lagoon Entrance

- Typically opened artificially ~3 times/yr at a water surface elevation of 2.4m AHD. Breaching is initiated at high tide.
- Barrier Elevations naturally around 3.0m AHD but managed at 2.6 to 2.7m for flood purposes.
- The entrance faces towards the south east (bearing ~135 degrees) and has a beach face slope of around 0.09. The barrier sands have a median grain size of around 0.42mm (Hanslow, 2000).
- Ultimately, a breach channel of 30 to 50m width develops, but this can close quickly if wave and ocean levels are right (e.g. overnight). The water level in the Lagoon can fall by 1m in 4 to 6 hours following artificial breaching (WMA, 2001)
- Once closed, the minimum barrier elevation is monitored at least once a month by Council. If that elevation is found to exceed 2.6 to 2.7m AHD, a section of the barrier, at least 2m wide is lowered using earth moving equipment to an elevation that is halfway between the barrier monitoring elevation and the let-out level (i.e. to around ~2.5m AHD).

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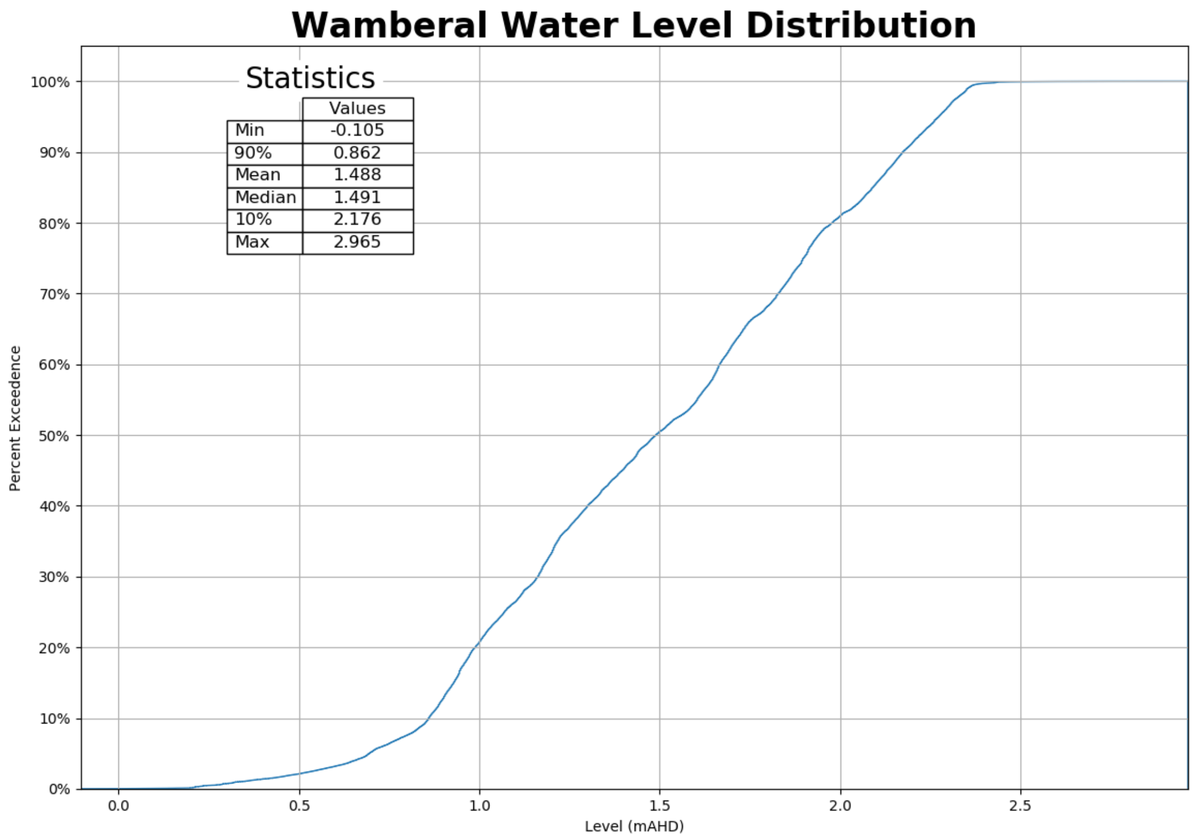
- The simulated peak of the 1% AEP flood fell from 3.5m to 3.1m AHD when the simulated berm level was lowered from 3.0 to 2.7m AHD.
- The current adopted Minimum Floor Level (MFL) is 3.6m AHD for the main body of the lagoon based on the existing Wamberal Lagoon Floodplain Management Plan.
- Water level statistics are provided in **Figure 3-5**.

Figure 3-5 Water Level Distribution for Wamberal Lagoon (data analysed between 15/07/1993 and 19/02/2019)



Terrigal Lagoon Entrance

- Typically opened artificially ~12-13 times/yr at a very low (relatively) water surface elevation of 1.23m AHD. Breaching is initiated at high tide and it typically remains open for around 8 days, but variable.
- Barrier Elevations naturally around 2.1m AHD but managed at 1.7m for flood purposes.
- The barrier sands have a median grain size of around 0.36mm (Hanslow, 2000).
- Ultimately, a breach channel of 30 to 50m width develops but this can close within hours, or overnight.
- Once closed, the minimum barrier elevation is monitored at least once a month by Council survey (official council procedure) or line of sight marks (WMA, 2001). If that elevation is found to exceed 1.7m AHD, a section of the barrier, at least 2m wide is lowered using earth moving equipment to achieve an elevation that is halfway between the barrier monitoring elevation and let out level (i.e. to around 1.45m AHD).

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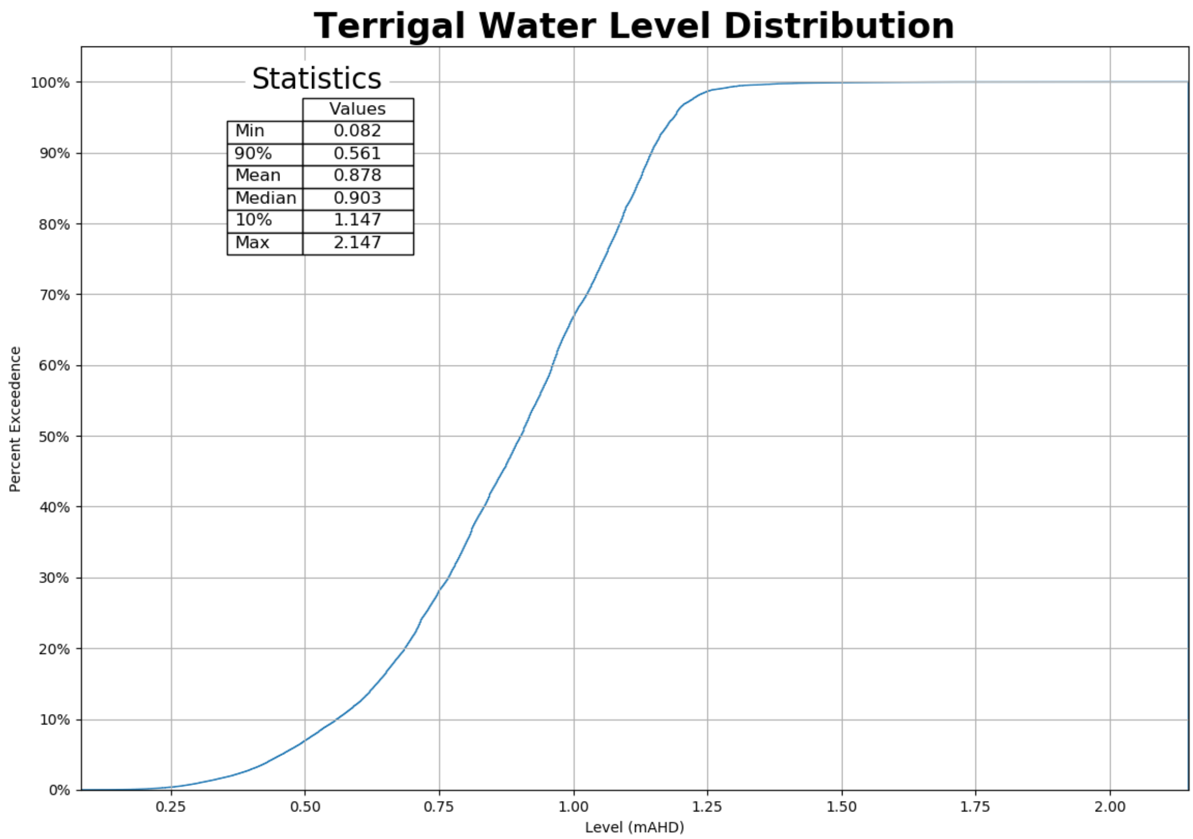
- The flood planning level at Terrigal Lagoon was based on the simulated 1% AEP flood plus 0.5m of freeboard. The simulated lagoon water level with an initial lagoon level of 1.2m AHD, and a berm elevation of 2.5m AHD provide a peak 1% AEP flood level of 2.9m AHD. The flood study simulations adopted a barrier width (shore normal) of 40m, and it should be recognised that wider barriers contribute to a slower drawdown of water levels during flood conditions and hence exacerbation of the flood risk if lagoon inflows are high.
- The current adopted MFL is 3.4m AHD for the main body of the lagoon based on the existing Terrigal Lagoon Floodplain Management Plan.
- Water level statistics are provided in **Figure 3-6**.

Figure 3-6 Water Level Distribution for Terrigal Lagoon (data analysed between 25/06/1993 and 19/02/2019)



Avoca Lagoon Entrance

- Typically opened artificially ~3-4 times/yr at a water surface elevation of 2.09m AHD. Breaching is typically initiated such that breaching coincides with a rising tide, aiming to reduce drainage, entrance scour and the impacts on surrounding wetlands.
- Barrier elevations naturally around 2.5-3.0m AHD but managed at 2.7 to 2.8m for flood purposes.
- The entrance faces, approximately, towards the east (bearing ~110 degrees) and has a slope of around 0.07. The barrier sands have a median grain size of around 0.34mm (Hanslow, 2000).
- Ultimately, a breach channel of around 70-80m length needs to develop and the

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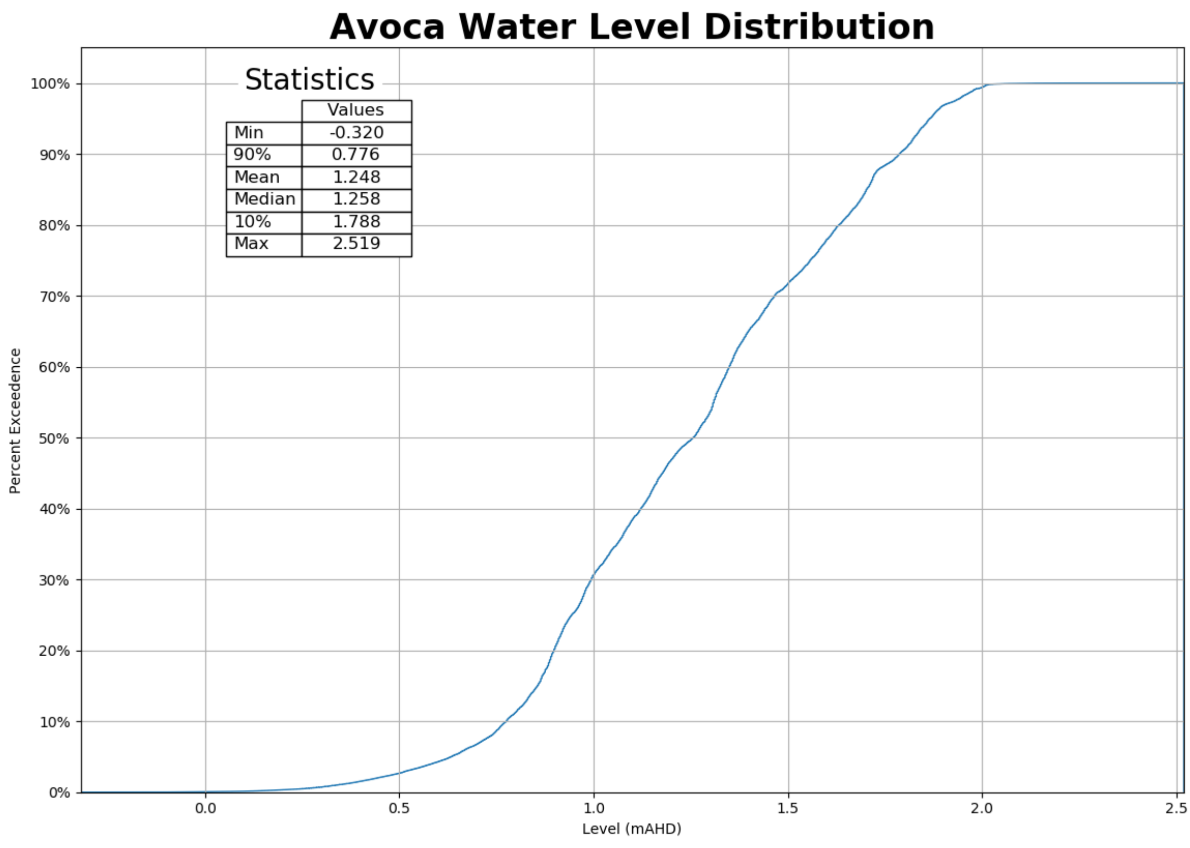
opening process takes around 8-12 hours (Patterson Consultants, 2008).

- Once closed, the minimum barrier elevation is monitored at least once a month by survey. If that elevation is found to exceed 2.7-2.8m AHD, a section of the barrier, at least 2m wide is lowered using a beach tractor to achieve an elevation that is halfway between the barrier monitoring elevation and let out level (i.e. to around 2.4m AHD).
- The flood study (Patterson Consultants, 2008) does not indicate the initial water level adopted in the design flood simulations. It does note that the initial water level has some effect, but that the adopted berm elevation is by far the most significant factor affecting flood levels.
- The current adopted MFL is 3.7m AHD for the main body of the lagoon based on the existing Avoca Lagoon Floodplain Management Plan and a level of 4.2m AHD was encouraged.
- Water level statistics are provided in **Figure 3-7**.

Figure 3-7 Water Level Distribution for Avoca Lagoon (data analysed between 24/06/1993 and 30/06/2018)



Cockrone Lagoon Entrance

- Typically opened artificially ~2-3 times/yr at a water surface elevation of 2.53m AHD. Breaching is typically initiated such that breaching coincides with a rising tide, aiming to reduce drainage and the potential for subsequent eutrophication and fish kills. The lagoon typically stays open for 9 days.
- Barrier Elevations naturally around 3.0m AHD and managed such that it does not

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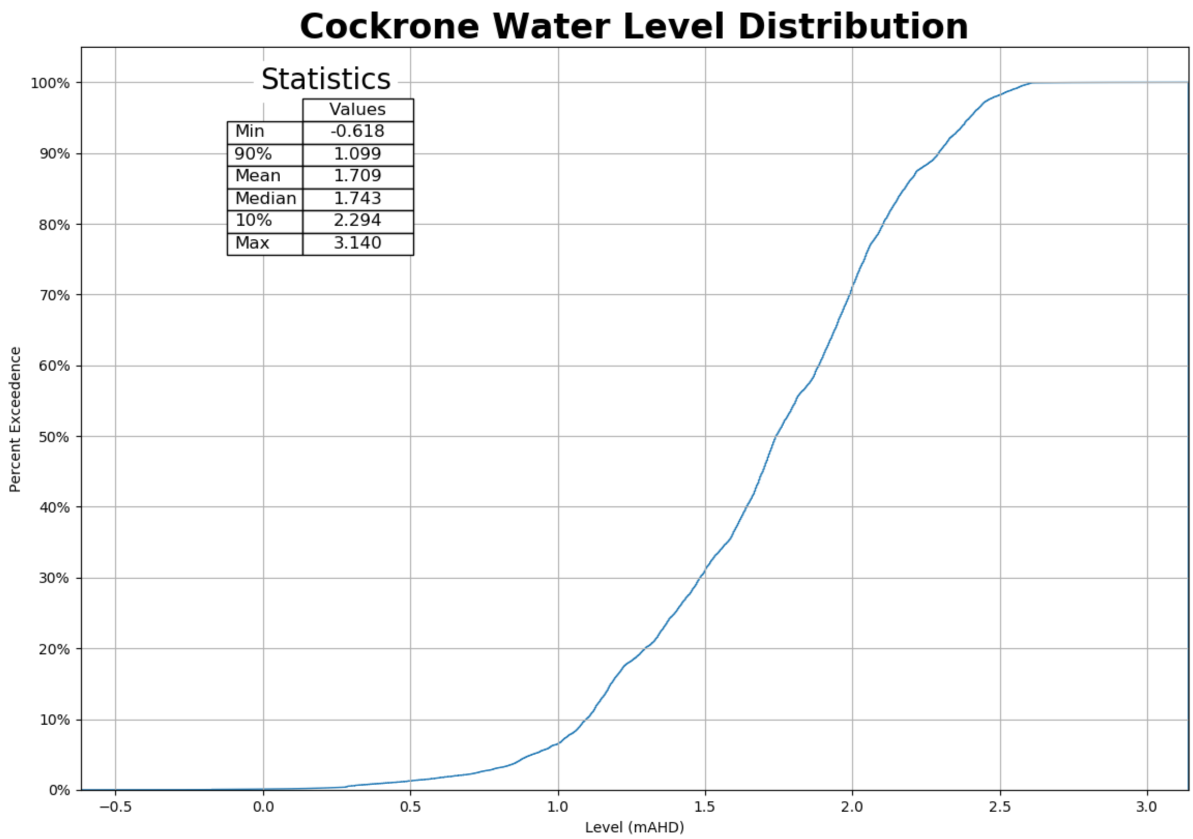
exceed 3.3 to 3.5m for flood purposes.

- The entrance faces towards the south east (bearing ~130 degrees) and is relatively steep, with a beach face slope of around 0.16. The barrier sands have a median grain size of around 0.38mm (Hanslow, 2000).
- Ultimately, a breach channel of around 65m width develops (Patterson Consultants, 2008).
- Once closed, the minimum barrier elevation is monitored at least once a month by survey. If that elevation is found to exceed 3.3-3.5m AHD, a section of the barrier, at least 2m wide, is lowered using earth moving equipment to achieve an elevation that is halfway between the barrier monitoring elevation and let out level (i.e. to around 3.0m AHD).
- As for other lagoons, modelling has indicated that the adopted beach berm elevation is a key determinant of estimated flood levels. In this instance, a beach berm level of 3.8m AHD was adopted, with the flood study (Patterson Consultants, 2008) indicating that such a berm elevation would be exceeded for 10% of the time.
- The current adopted MFL is 4.3m AHD for the main body of the lagoon based on the existing Cockrone Lagoon Floodplain Management Plan and a level of 4.6m AHD was encouraged.
- Water level statistics are provided in **Figure 3-8**.

Figure 3-8 Water Level Distribution for Cockrone Lagoon (data analysed between 25/06/1993 and 30/06/2018)



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3.5 Information from site visit

A site visit was undertaken on the 15 February 2018 by MHL (Bronson McPherson and Scott Marshall) in conjunction with CCC (Robert Baker). All four coastal lagoon catchments were visited with specific visual inspection and discussion based around key areas. Key areas where identified through prior review of previous reports and information and also noted by CCC throughout the visit. Such areas included:

- Entrances / beach berms for each lagoon
- Levees, e.g. Three Points Ave Cockrone and Willoughby Rd Terrigal
- Key trunk drainage, e.g. Terrigal CBD
- Areas of new and proposed developments, e.g. Kings Estate and the Basketball Stadium
- Observed flood prone areas (discussed in **Section 2.4.5**)

These site observations allowed the development of an improved understanding of the flood behaviour at key locations of the study area.

3.6 Topographic and aerial survey and imagery

Aerial imagery provided by Council has been taken in 2014.

Digital Elevation Model (DEM) was developed from Lidar survey completed by LPI in July 2017.

Bathymetric data from previous studies were provided for each lagoon. Avoca Lagoon data are dated 1998, Wamberal 2003 and Cockrone/Terrigal 2009.

Building footprints were supplied by PSMA in June 2018.

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4. Community and stakeholders consultation

4.1 Methodology

Consultation provides an opportunity for various stakeholders, particularly the community, to collaborate together in developing the Coastal Lagoon Catchments Overland Flow Flood Study. Engaging the community throughout the process provides both an opportunity to garner useful information regarding past flood events, community flood awareness and attitudes to flood risk, and to increase community acceptance of the Flood Study.

The community consultation program for the Flood Study included the following activities:

- At the commencement of the study Council published a brief newspaper article informing the community of the study, the parties involved and the key objectives, with input provided by MHL. The content of this media release is provided in **Appendix B**.
- Meetings were held with the project technical group (including personnel from Council, DPIE and SES) at the commencement, during and at the end of the study.
- A project website was developed, and a link was provided for inclusion into Council's YourVoiceOurCoast.com website.
- Letter, information brochure and questionnaire for property owners were prepared.

4.1.1 Media release

A media release was published in July 2018. The content of this media release is provided in **Appendix B**.

4.1.2 Website

A website was developed to provide information about the study including a link to the online community questionnaire (**Figure 4-1**).

4.1.3 Community letter, brochure and questionnaire

General Approach

Early July 2018, a total of 4,391 letters were distributed to all property owners (excluding Council or Government) identified as being flood affected based on the preliminary 1% AEP flood event. The letter alerted the residents and businesses of the online survey that was available to complete. A copy of the letter is included in **Appendix B** of this report.

An online survey was made available until end of August seeking community input about historic flood flooding and ideas about floodplain management options in the study area. The survey is included in **Appendix B**. A hardcopy of the survey was mailed to a number of residents at the same time as the community letter.

The online survey has been using the SurveyMonkey platform.

Questionnaire Results

A total of 776 responses were received. This represents a response rate of 17.6%. A total of 127 responses were provided using the online questionnaire and 649 hard-copies responses were submitted. Results of the survey are provided in **Appendix B**.

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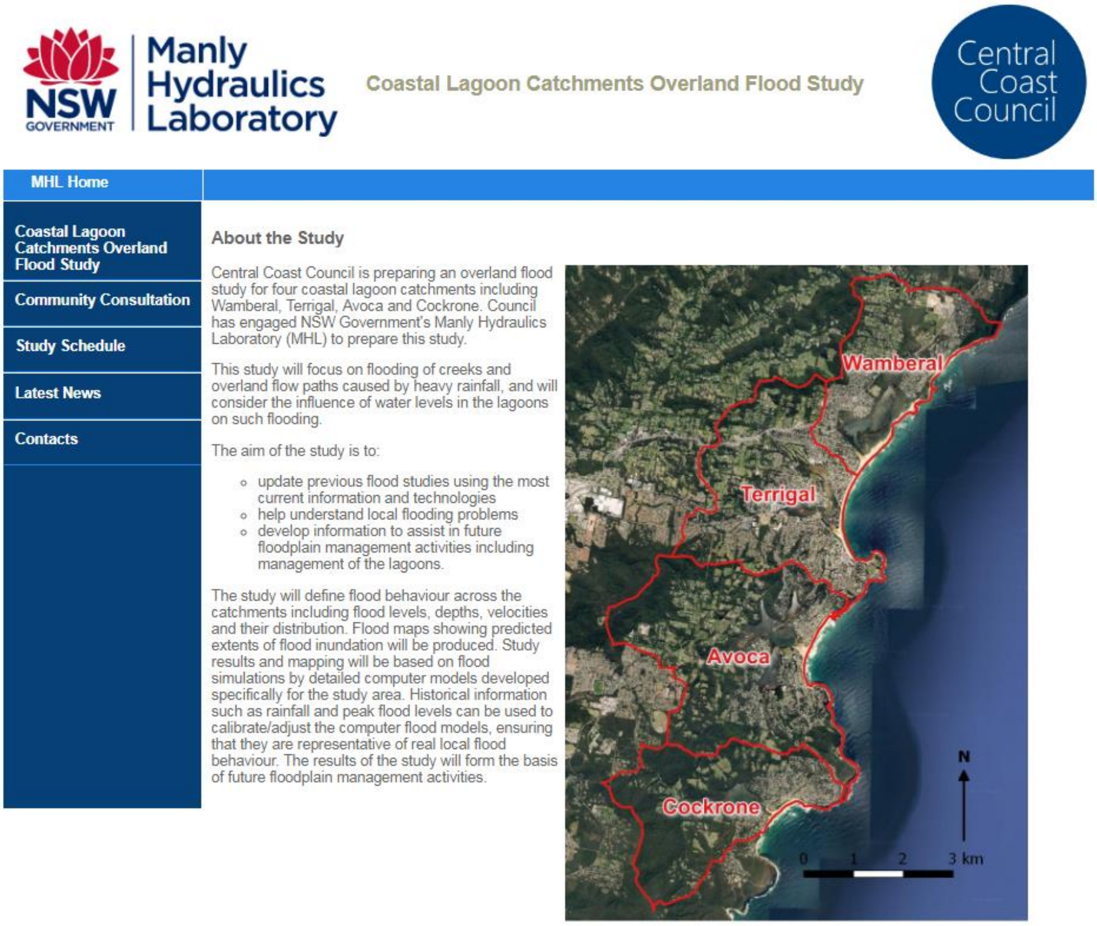

Figure 4-1 Project Website Home Page

The following key observation were made out of the community survey:

- The vast majority of respondent have a residential property (over 93.1%) with only 2.7% of farming/rural, 1.3% of commercial and less than 1% of vacant land and industrial.
- Over 85% of properties are owner occupied.
- Many residents have been living there for a long time (26.2% lived between 10-20 years, about 36.6% have lived there for over 20 years and only 22.2% lived there for less than 5 years).
- Only about 25.6% of the respondent mentioned that their property was affected by flooding. It is important to note the personal interpretation of flood affectation (i.e. flooding of property vs. flooding of building).
- 191 respondents provided one or multiple example of flood events (total of 427 entries). The most commonly impacted part of the property included the ground (~53%), the garage/shed (~22%) and the building (~17%).
- Observed flood depth were typically described as less than 0.5 m (~60% under 0.25 m and ~18% between 0.25 and 0.50 m). However, a number of properties mentioned depth larger than 0.5 m (~16%).
- Flooding durations range between less than 1 hour to several weeks.

- The flood water was relatively evenly described between stationary, walking pace and running pace with slightly more running pace descriptions.
- The main sources of flooding were described as the overflow from neighbouring properties (~28%) and water flowing down the roads (~27%), followed by rising lagoon level (~12%) and ponding of water within property (~13%).
- A number of residents provided photographs as well as other flood information. Example of photographs are provided in **Figure 4-2** and **Figure 4-3**.

Figure 4-2 Flooding at Wamberal Lagoon on 5 June 2016

Source: Courtesy of K. Stucke

Figure 4-3 Entrance break out at Avoca Lagoon in June 2016

Source: Snapshot extracted from video, courtesy of M. Hoskin

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5. Hydrological analysis

The direct rainfall method was employed in this study. This method applies rainfall directly to the 2D hydraulic model cells which then determine the quantity, direction and velocity of flow on a highly local scale based on detailed surface material and topographic information. Therefore, development of a traditional hydrologic model was not required to complete the study.

Although the direct rainfall method negates the need for hydrological models, hydrological models were still developed to:

- Provide verification of the direct-rainfall method;
- Identify critical design duration/pattern hyetographs from the ensemble of events specified by AR&R 2019; and
- Potentially be utilised at a later stage in the floodplain management process, such as flood warning systems or flood information tools (e.g. MHLFIT).

5.1 Hydrologic controls in catchment and changes overtime

To consider the change in flood behaviour in different location of the catchment, two critical durations were simulated to consider the upper and lower catchment separately. The lower catchment critical duration was defined according to the AR&R 2019 guidelines in relation to the flow out of each lagoon. The upper catchment critical duration was based on a selected sub-catchment considered representative of the majority of the upper catchment.

The lower catchment typically has a longer duration than the upper catchment. The design mapping in this study represents an envelope of the results for these two durations.

These two durations take into consideration the difference between overland and mainstream flooding. Overland Flooding is the inundation by local runoff rather than overbank discharge from a waterway. This flooding is often called flash flooding as it occurs rapidly and with little to no warning. Mainstream flooding is the inundation of normally dry land occurring when water overflows the natural or artificial banks of a waterway. This type of flooding typically requires longer rainfall duration, particularly in the case of large water body such as lakes, dams or lagoons.

5.2 Model selection

The hydrological model selected for this study is WBNM (version 2017). This model is very robust and has been validated against numerous catchments in NSW.

Moreover, this version of the model has been developed to include the AR&R 2019 guideline requirements.

5.3 Model setup

5.3.1 Catchment delineation

Catchment boundaries were obtained from Council as GIS layers and were confirmed by

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comparing with topographic Lidar data.

Sub-catchments were derived from previous flood studies (discussed in **Section 2.2**). The sub-catchments were reviewed, and it was noted that:

- Some of the Avoca Lagoon sub-catchments are elongated but this was found to not have a significant impact;
- The sub-catchments were compared against the topography and appeared reasonable. Some minor misalignments were noted but are not expected to influence the outcome of the hydrological model which is to identify the critical temporal pattern.

The sub-catchments of each lagoon are presented in **Figure 5-1**.

5.3.2 Spatial patterns

AR&R 2019 guidelines mention that catchments with areas up to and including 20 km^2 are sufficiently small that there is little available data to derive a spatial pattern. For these catchments, it is usually acceptable to adopt a uniform spatial pattern. However, if there is sufficient density of continuously rainfall gauges that have recorded a number of rainfall events, using this data to derive alternative (non-uniform) design spatial patterns may be considered.

Since all four sub-catchments are less than 20 km^2, a single uniform spatial pattern was adopted for the design events.

However, for the purpose of calibrating the model, the various rainfall gauges data surrounding the lagoons were used to represent the recorded spatial pattern and each sub-catchment was applied an average rainfall based on a Thiessen Polygon approach (i.e. each rainfall gauge was applied a weight based on the distance between the gauge and the centroid of the sub-catchment).

5.3.3 Entrance breakout representation

The entrance was modelled as a scourable weir into the WBNM model. Typical dimensions of the berm as described in (AWACS, 1994) were used to estimate a volume of erodible sand. Water level data were analysed to estimate a discharge rate, a time over which the entrance opens and a typical low point following scour. The berm was assumed to scour from the managed berm level (**Table 3-4**) down to 0.25m AHD in approximately 90 min. This assumption allowed the definition of a scour erosion rate for the berm of each lagoon.

5.3.4 Initial water level

The initial water level within the lagoon was set at the respective trigger level (**Table 3-4**).

5.4 Design events

The design events modelled in this study include:

- Frequent events - 50% AEP, 20% AEP and 10% AEP;
- Rare events - 5% AEP, 2% AEP and 1% AEP;
- Very rare events - 1 in 200 AEP and 1 in 500 AEP; and
- Extreme event - Probable Maximum Flood (PMF).

The terminology of these events is defined as per the AR&R 2019 guidelines presented in

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Table 5-1. All events but the PMF events are using the patterns and durations provided by the AR&R 2019 Data Hub. The method is further described in **Section 5.7**.

The PMF determination is detailed in the next section.

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
Very Frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
Frequent	0.69	50	2	1.44
	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	20
	0.02	2	50	50
	0.01	1	100	100
Very Rare	0.005	0.5	200	200
	0.002	0.2	500	500
	0.001	0.1	1000	1000
	0.0005	0.05	2000	2000
Extreme	0.0002	0.02	5000	5000
			↓	
			PMP/ PMPDF	

Table 5-1 Preferred Event Terminology as per AR&R 2019

5.5 Probable Maximum Flood event

The PMP rainfall depth has been estimated using the Generalised Short Duration Method (GSDM) derived by the Bureau of Meteorology. Durations of up to 6-hours have been considered for the PMP in accordance with the GSDM.

The temporal patterns used to derive the probable maximum flood (PMF) should be selected from an ensemble of patterns appropriate for use with the Generalised Probable Maximum Precipitation (PMP). Similarly to the other design event, an envelope of two critical duration has been applied for the PMF calculation, one shorter duration to consider flashy sub-catchments and a longer duration for the lagoon.

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At present, the best source of ensemble temporal patterns for use with short duration Very Rare to Extreme events are those derived by Jordan et al. (2005); these patterns were derived specifically from storms associated with thunderstorm or deeply convective events.

These ten patterns were therefore adopted in this study and applied to the calculated PMP rainfall depth. The critical pattern was determined as per the typical AR&R 2019 guidelines applied to the other design events.

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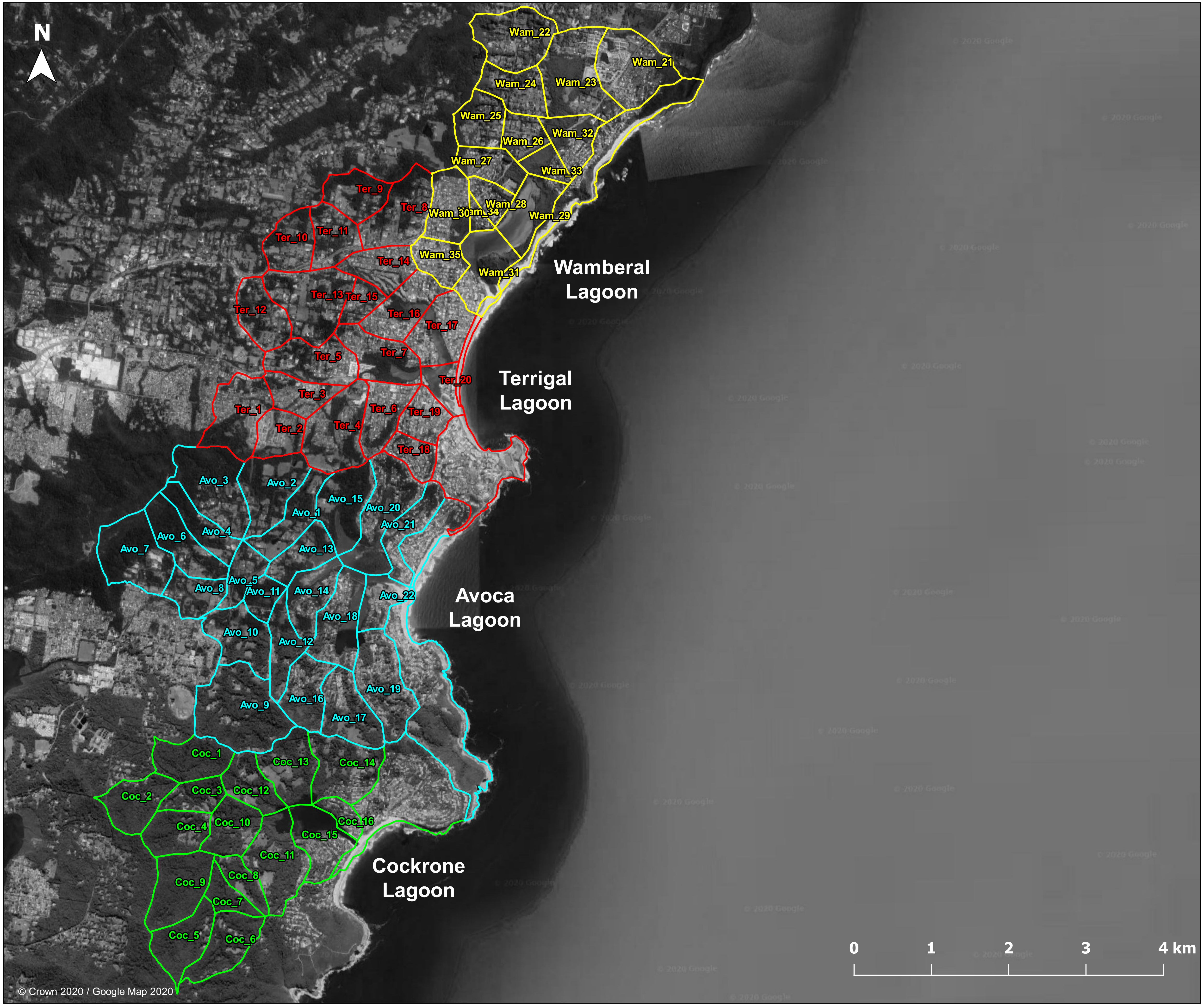

Figure 5-1

WBNM Sub-Catchments

Legend

WBNM Sub-catchments

- Wamberal
- Terrigal
- Avoca
- Cockrone

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5.6 Model parameter selection

Parameters required by the WBNM model include sub-catchment area and linkage, % pervious, % impervious, runoff lag factor (pervious and impervious), stream routing lag factor, rainfall input, initial loss (pervious and impervious) and continuing loss (pervious). Adopted parameters are presented in **Table 5-2**. Due to the close proximity of the four lagoons, the same parameters were used in the design event for all lagoons.

Table 5-2 Adopted WBNM hydrologic model parameters

Parameter	Value	Comment
Initial loss (pervious surface)	15 mm (design events) 0-40 mm (calibration)	Determined separately for calibration and design events
Initial loss (impervious surface)	1 mm	
Continuing loss (pervious surfaces)	2.9 mm/hr	Per AR&R 2019 with modification to improve calibration
C (Lag parameter)	1.29	Adopted from previous flood study at Wamberal and Terrigal Lagoons.
Stream routing factor	1.0	Natural channel routing factor of 1.0

5.6.1 Impervious areas

Impervious areas were derived by adopting impervious percentages for various land uses defined by Councils GIS layer for LEP zoning. Based on land use areas, a weighted average was calculated for each sub-catchment.

5.6.2 Losses

For the initial and continuing rainfall losses, values of 15 mm and 2.9 mm/hr were used for pervious areas and 1 mm and 0 mm/hr for impervious areas. The AR&R 2019 data hub values were 48 mm and 2.9mm/hr for pervious area. The large initial loss is considering the presence of a preburst (storm rainfall that occurs before the main rainfall burst). Following analysis of rainfall and water level data recorded at the four lagoons during multiple storm, it was found that initial loss of 15 mm/hr were more appropriate.

5.6.3 Lag

A lag parameter C = 1.29 was adopted as per previous flood study WBNM models for Wamberal and Terrigal.

A stream lag routing Type R with a value of 1 was adopted. This is the natural channel routing.

5.6.4 Intensity-Frequency-Duration

The Intensity-Frequency-Duration (IFD) from the Bureau of Meteorology following the AR&R 2019 guidelines were used as inputs to the WBNM model to determine the design events. The IFDs for the four lagoons are presented in **Figure 5-2**. All four lagoons have similar IFD with only minor changes of a few millimetres.

5.7 Model results

The results of the WBNM model were processed using the Storm Injector software that allows a quick determination of the critical duration and critical patterns for each design storm event for both the upper and lower catchments.

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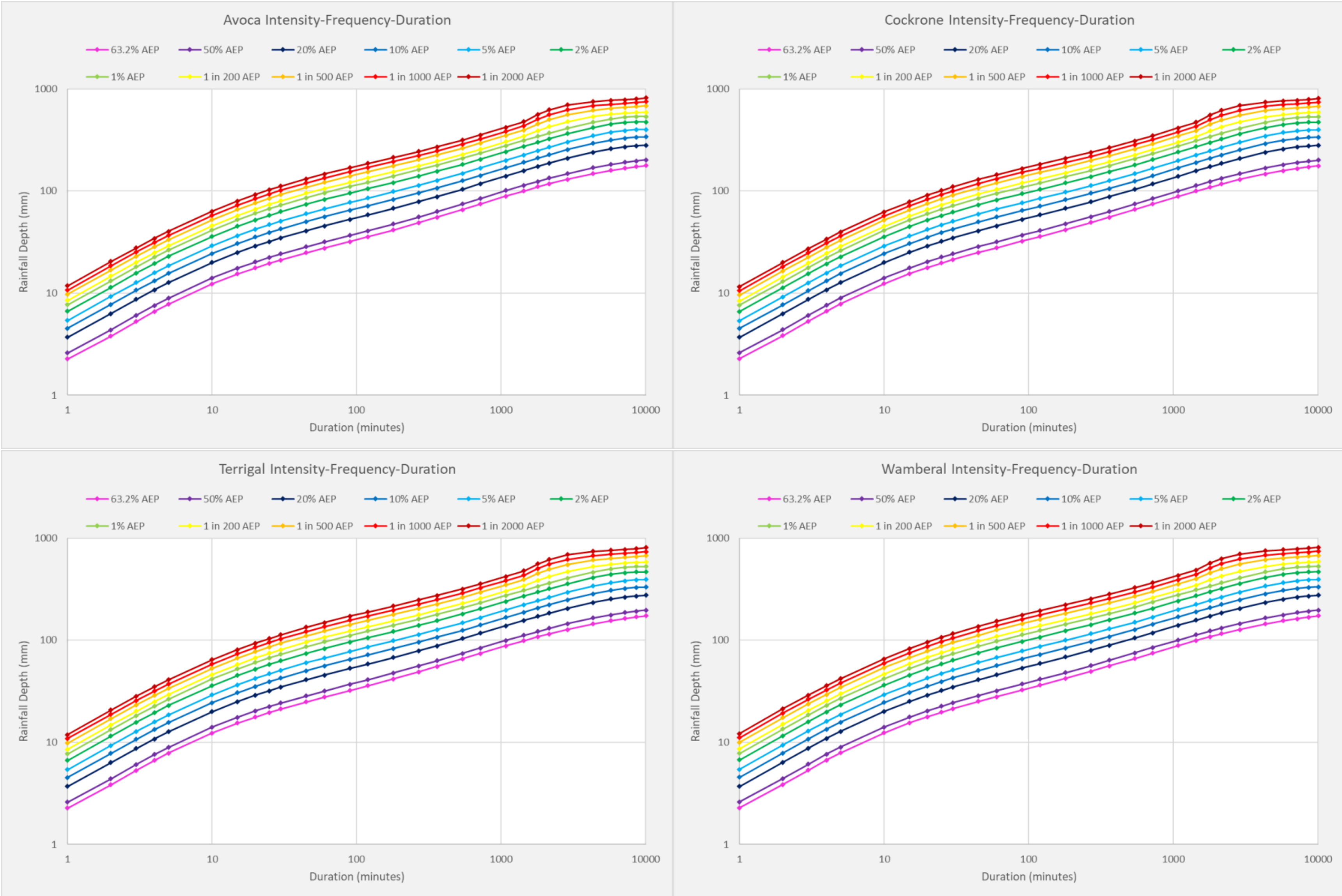

Figure 5-2 Intensity-Frequency-Duration diagrams for the four lagoons

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The selection of the critical duration for the lower catchment was based on the peak flow out of the lagoon rather than the peak inflow into the lagoon. This approach was adopted to consider the significant effect of the storage on attenuating flows through the lagoon. This would be equivalent to considering the peak water level into the lagoon (since the outflow of the lagoon is directly dependent on the water level).

Each design event was modelled for 24 different duration ranging from 10 minutes to 168 hours (except for the PMF that was modelled for eight durations from 15 minutes to 6 hours). Each duration was run for 10 patterns as recommended by AR&R 2019. A typical critical duration box chart obtained, and a typical hydrograph set allowing selection of the critical pattern are presented in **Figure 5-3**. This chart shows the results for the 1% AEP lower catchments at Avoca. On this box chart, the blue dots are the results of each scenario, the blue line represents the critical pattern for each duration and the critical duration is highlighted in yellow (here, 4.5 hr). Critical durations are presented in **Table 5-3**.

It can be noticed that short duration events do not generate enough volume of water for the lagoon to fill up and for the entrance to break out. This is even more pronounced for lower intensity events such as the 50% AEP.

Summaries of results are presented in **Appendix C**.

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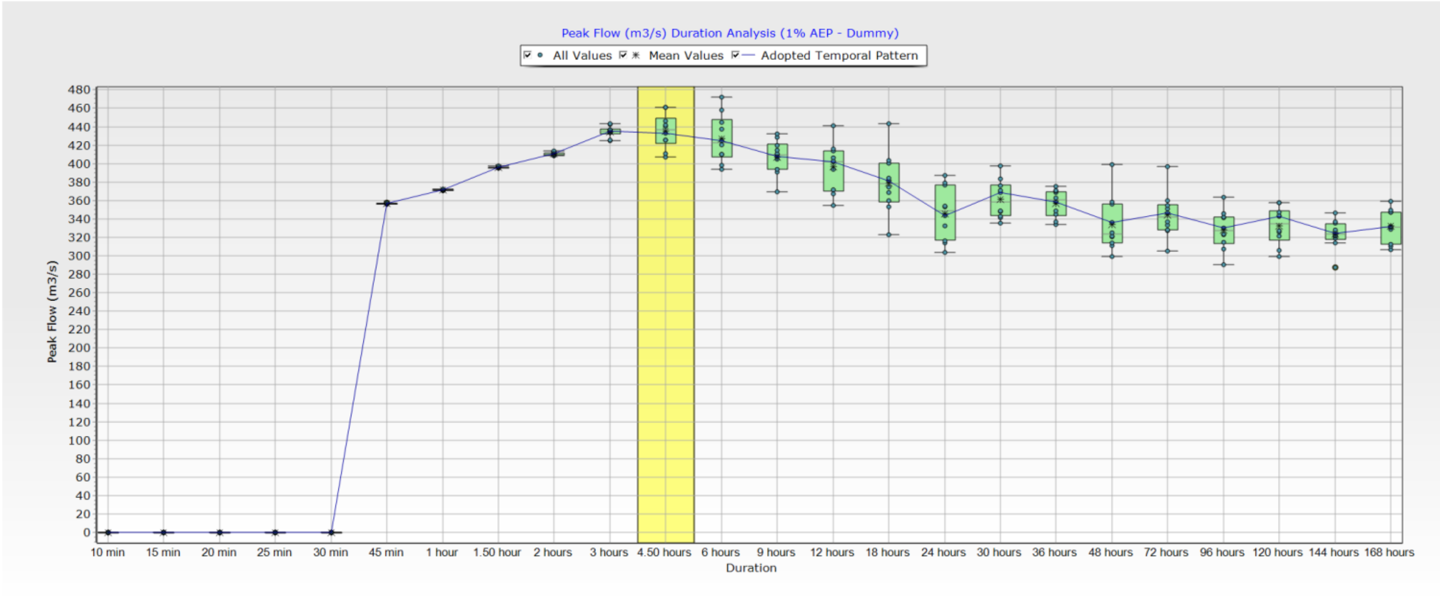

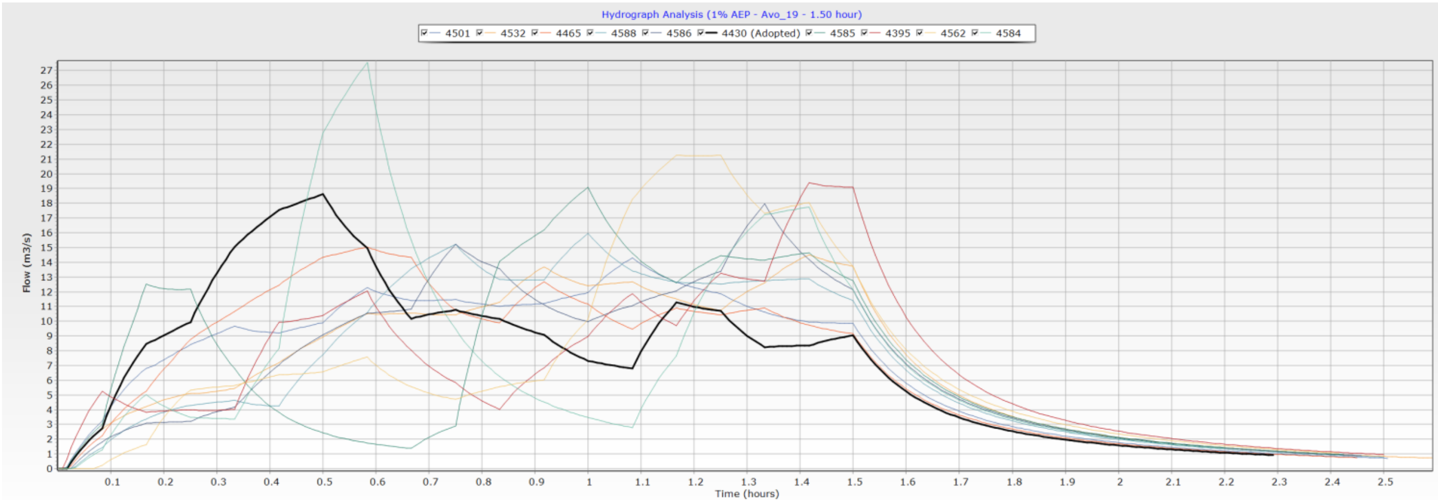

Figure 5-3 Example of critical duration selection box chart for Avoca Lagoon Lower Catchment for the 1%AEP (yellow highlight, top) and example of critical patterns selection for the 1%AEP 90min event (black line, bottom)

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Table 5-3 Critical durations for each event

Lagoon	Catchment	Event	Adopted Critical Duration	Event Rainfall Depth (mm)
Wamberal	Upper	50% AEP	2 hr	40
		20% AEP	45 min	38
		10% AEP	45 min	47
		5% AEP	20 min	38
		2% AEP	20 min	47
		1% AEP	20 min	55
		1 in 200 AEP	20 min	60
		1 in 500 AEP	20 min	69
		PMF	30 min	230
	Lower	50% AEP	4.5 hr	55
		20% AEP	4.5 hr	77
		10% AEP	4.5 hr	94
		5% AEP	3 hr	95
		2% AEP	2 hr	100
		1% AEP	2 hr	116
		1 in 200 AEP	2 hr	129
		1 in 500 AEP	1.5 hr	133
		PMF	2 hr	510
Terrigal	Upper	50% AEP	45 min	26
		20% AEP	45 min	37
		10% AEP	45 min	46
		5% AEP	45 min	54
		2% AEP	45 min	67
		1% AEP	45 min	77
		1 in 200 AEP	45 min	85
		1 in 500 AEP	45 min	97
		PMF	1 hr	330
	Lower	50% AEP	9 hr	73
		20% AEP	4.5 hr	76
		10% AEP	4.5 hr	92
		5% AEP	3 hr	92
		2% AEP	3 hr	113
		1% AEP	2 hr	112
		1 in 200 AEP	2 hr	123
		1 in 500 AEP	2 hr	139
		PMF	2 hr	500

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Lagoon	Catchment	Event	Adopted Critical Duration	Event Rainfall Depth (mm)
Avoca	Upper	50% AEP	45 min	26
		20% AEP	45 min	37
		10% AEP	20 min	30
		5% AEP	20 min	36
		2% AEP	20 min	44
		1% AEP	20 min	51
		1 in 200 AEP	20 min	56
		1 in 500 AEP	20 min	64
		PMF	30 min	220
	Lower	50% AEP	*144 hr**	*195*
		20% AEP	9 hr	101
		10% AEP	6 hr	103
		5% AEP	6 hr	121
		2% AEP	4.5 hr	130
		1% AEP	4.5 hr	150
		1 in 200 AEP	3 hr	138
		1 in 500 AEP	3 hr	156
		PMF	2 hr	490
Cockrone	Upper	50% AEP	90 min	35
		20% AEP	1 hr	43
		10% AEP	1 hr	52
		5% AEP	1 hr	62
		2% AEP	45 min	67
		1% AEP	45 min	77
		1 in 200 AEP	45 min	85
		1 in 500 AEP	45 min	96
		PMF	1 hr	340
	Lower	50% AEP	*168 hr**	*200*
		20% AEP	9 hr	102
		10% AEP	6 hr	103
		5% AEP	4.5 hr	108
		2% AEP	4.5 hr	131
		1% AEP	4.5 hr	150
		1 in 200 AEP	3 hr	139
		1 in 500 AEP	3 hr	158
		PMF	2 hr	510

** The very long duration of the 50% AEP event for the lower catchment is due to the low intensity of rainfall and the need for a large volume of flood water to fill up the lagoon to a level allowing a breakout of the entrance. Such event would only reach the berm level in the lagoon.*

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It is noted that varying time critical peaks can, in some catchments, represent vastly differing temporal patterns as determined by AR&R. This is because the methodology uses an averaging approach based on an ensemble of differing pattern. There are 30 pre-determined temporal patterns for each catchment area. These consist of three event characteristics with 10 frequent temporal patterns, 10 intermediate temporal patterns and 10 rare temporal patterns. The varying sets of patterns may generate different results in the averaging leading to the selection of a different critical rainfall pattern and hence, a different flood behaviour from one event to the next may occur (e.g. front-loaded storm, back-loaded storm or long low intensity storm).

5.8 Comparison with AR&R 1987

The 1987 and 2016 Intensity-Frequency-Duration charts (IFD) were compared for the coastal lagoon study area. **Figure 5-4** presents an overlay of both sets of IFD. It can be noted that the rainfall intensity of events more frequent than 10% AEP generally reduced. For event rarer than the 10% AEP, the rainfall intensity generally remained similar except for shorter durations of less than one hour where the intensity increased. WBNM was run for the 1987 IFD and the resulting flows have been compared to the 2016 IFD flows. The resulting hydrographs for the downstream and upstream catchments are presented in **Figure 5-5** and **Figure 5-6** respectively. While some timing differences are noticeable, a good match in shape and volume was observed between the two sets of IFD for the downstream catchments. Regarding the upstream catchments, the shape of the hydrograph generally differs due to the AR&R 2019 pattern ensemble allowing different behaviour than the single temporal pattern from AR&R 1987. However, the peaks are typically in the same order of magnitude and the volumes appear consistent.

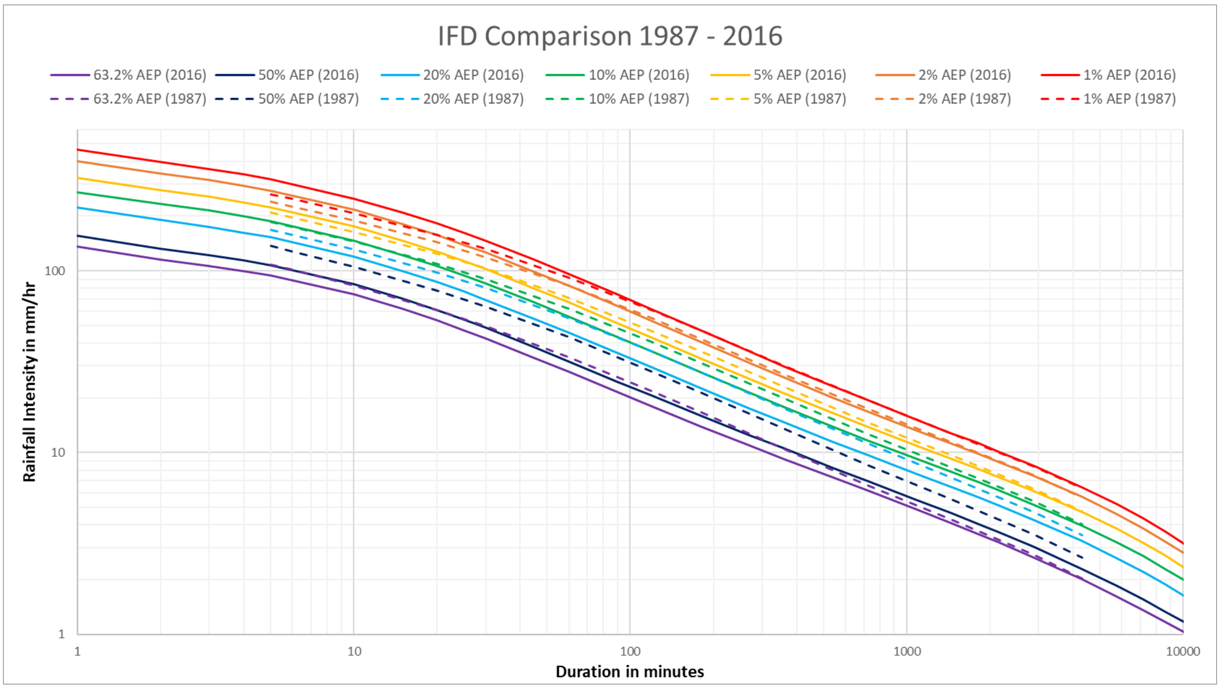

Figure 5-4 – Comparison between the 1987 and 2016 IFDs

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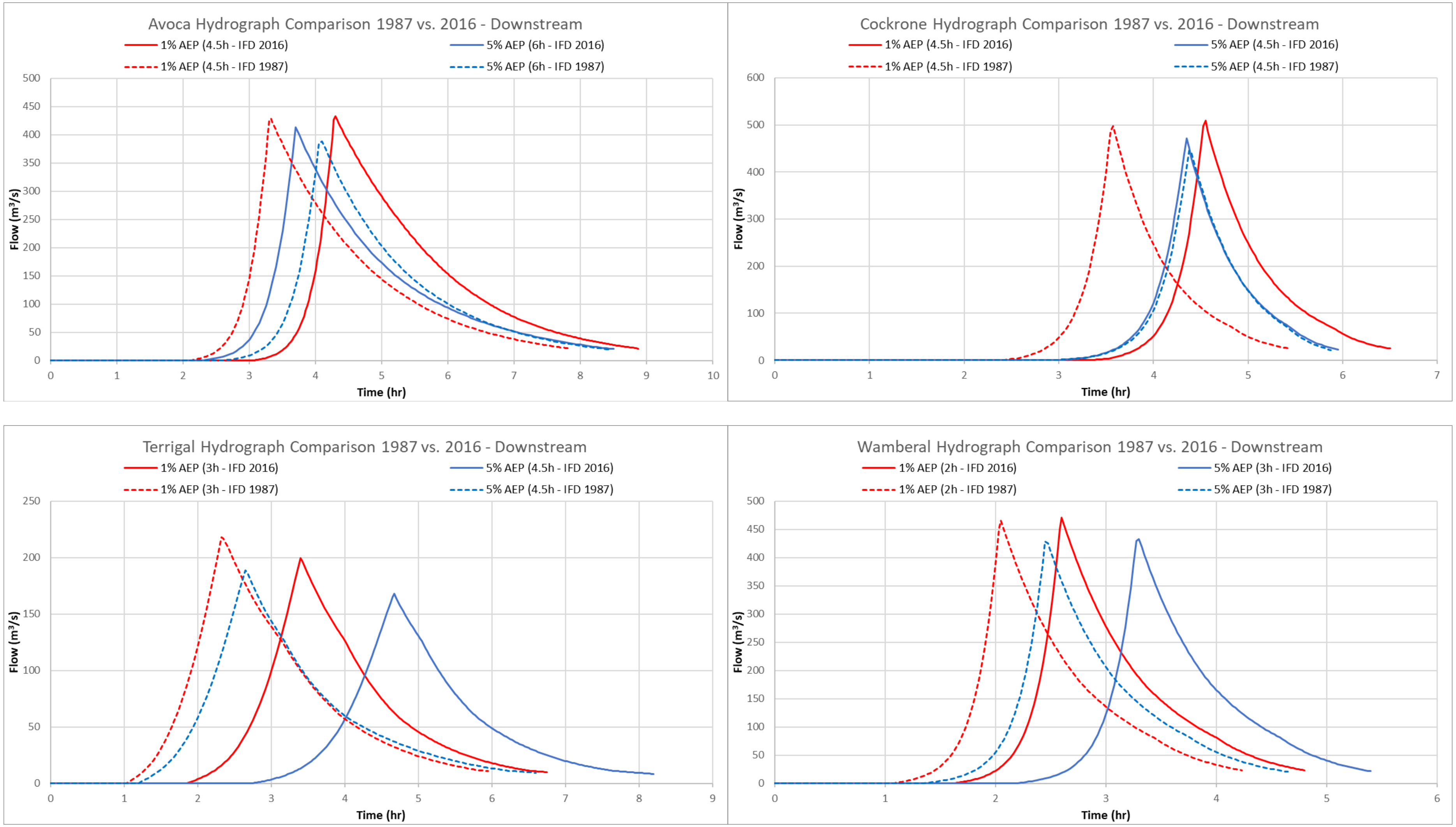

Figure 5-5 – WBNM Hydrograph for the downstream catchment for the 1% and 5% AEP flood events using 1987 and 2016 IFDs

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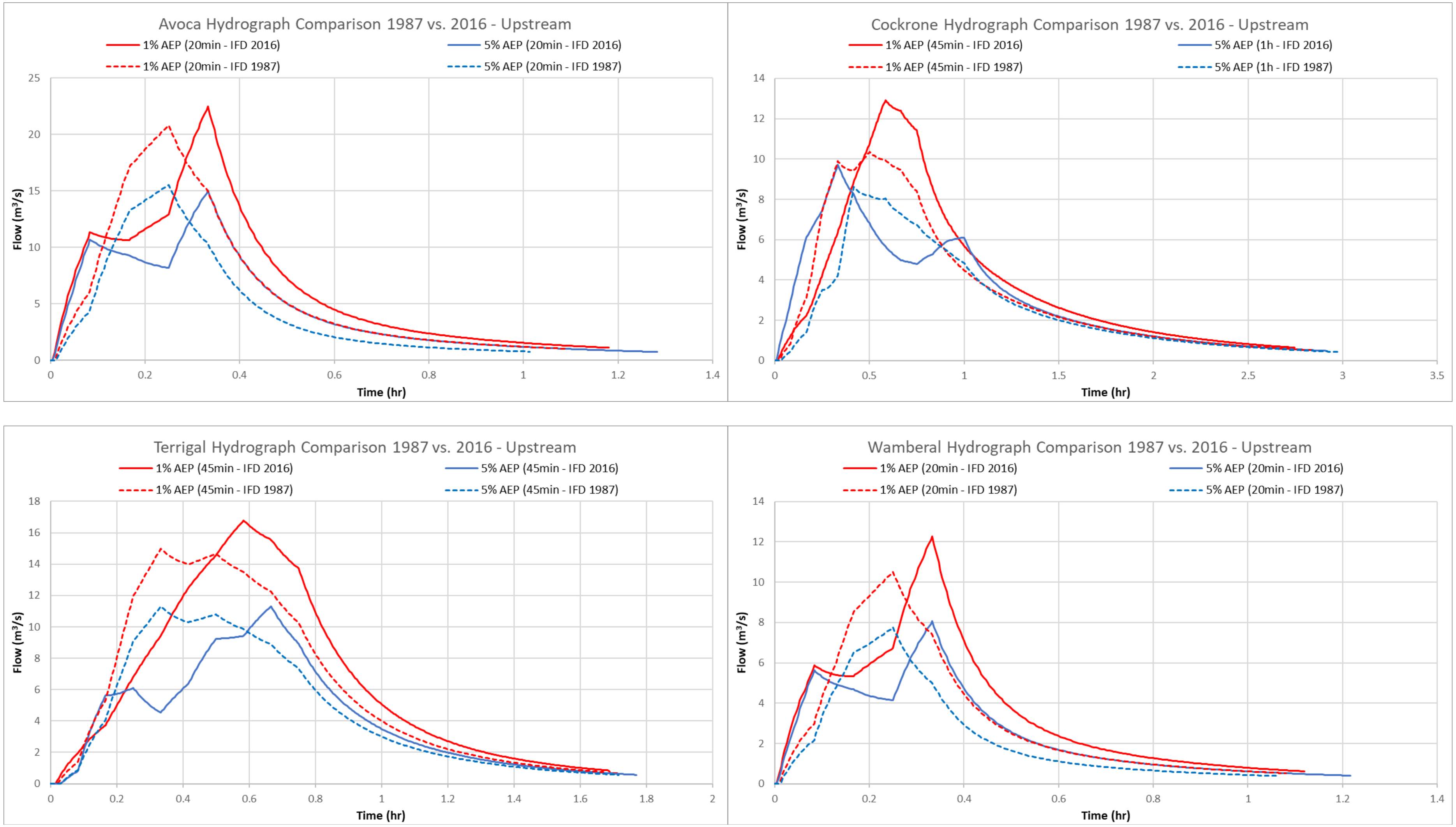

Figure 5-6 – WBNM Hydrograph for the upstream catchments for the 1% and 5% AEP flood events using 1987 and 2016 IFDs

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6. Hydraulic analysis

6.1 Model selection

TUFLOW HPC has been used for hydraulic modelling in this study to simulate flood behaviour across the study area. TUFLOW is robust and widely accepted unsteady-state flood simulation software with combined 1D and 2D capabilities. The use of a TUFLOW model allows integrated investigation of local overland flow flooding, mainstream creek flooding, foreshore flooding and tidal influences, and the inclusion of stormwater drainage infrastructure.

The GIS data layers and control files used to drive the model can be easily modified for future use in the Floodplain Risk Management Study (including modelling the impact of mitigation measures) or assessment of development applications.

TUFLOW has suitable functionality to model each of the catchment characteristics identified in the brief and is considered suitable for this study. Catchment characteristics include:

- Accumulation of sand berm at Entrance to Ocean in each lagoon
- Maintenance of entrance berm under management protocol in each lagoon
- Major Roads – Hydraulic Structures – Recent upgrades
- Ocean Inundation
- Levees
- Fences, Buildings, Watercourses

MHL flood modelling processes follow guidance provided in AR&R 2019.

The dynamically linked 1D/2D model requires a number of GIS data layers to represent the study area. These include, for example:

- 1D Domain
  - Pits & headwalls GIS layer
  - Pipe network GIS layer
  - Culverts and 1D bridges GIS layer
  - Open channel GIS layers (including cross-sections, stream alignment and connection to 2D overbank areas)
- 2D Domain
  - 2D grid / digital elevation model (DEM)
  - Topographic modifications and break lines (e.g. to incorporate detail survey into the DEM)
  - Materials layer (specifies surface roughness and infiltration)
  - Rainfall on the grid
  - Layered flow constrictions layer for 2D bridges

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- Tidal boundary condition
- Initial water level polygons

6.2 Model setup

A number of parameters are required to setup a TUFLOW model. These parameters are discussed below.

6.2.1 Grid size

A grid cell size of 2.0m by 2.0m was found to be suitable to define the overland flow in a relatively built-up environment. This size allows an appropriate representation of the features of the catchment while keeping the run time reasonable.

6.2.2 Modelling approach

MHL applied the following modelling approach to the development of a detailed, calibrated and reliable 2D/1D TUFLOW hydraulic model for the study area:

- Extent of the study area and 2D hydraulic model was determined in consultation with Council based on available elevation data.
- Boundary conditions consist of tidal water levels at the Tasman Sea, and a relevant coincident flood event as per the EES guidelines (OEH, 2015).
- Direct rainfall method was adopted.
- A preliminary model was developed at the commencement of the study prior to the initial site inspection in order to improve understanding of flood behaviour, key hydraulic features and areas to be targeted by the inspection. This preliminary model was also used to determine the extent of the community consultation mailout area.
- Detail survey and additional information from the site inspection and previous studies were incorporated using 2D topographic modifications and 1D elements as appropriate.
- Stormwater Infrastructure: All pipes in Council's GIS of 375 mm diameter and larger were included in the model.
- Blockages: The blockage applied to the pits and pipes system has been established by following the method described in the blockage assessment form provided in AR&R 2019 and AR&R Project 11: Blockage of Hydraulic Structures.
- Hydraulic Roughness: a materials layer was delineated from Council's cadastre, zoning and aerial photography along with site observations. Initial material categories and associated depth-varying Manning's roughness coefficients were adopted from similar studies.
- Buildings: A layer of the building locations acquired by Council was provided, and this was applied as a layer with a larger roughness.
- Fences: given significant uncertainty and variation in fence type, hydraulic behaviour and permanency throughout the study area, and a lack of verification of hydraulic modelling capabilities to represent them, MHL did not specifically model fences. Rather a 'lumped' hydraulic roughness approach was adopted.
- Undertake thorough model calibration, validation, verification by alternative methods

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and quality assurance checks.

6.2.3 Hydraulic roughness

Hydraulic roughness coefficients (Manning's 'n') are used to represent the resistance to flow of different surface materials. Hydraulic roughness has a major influence on flow behaviour and is one of the primary parameters in hydraulic model calibration.

Spatial variation in hydraulic roughness is represented in TUFLOW by delineating the catchment into zones of similar hydraulic properties. The hydraulic roughness zones adopted in this study have been delineated based on consideration of Council LEP zoning, cadastral data, aerial photography and site observations. Factors affecting resistance to flow were of primary importance including surface material, vegetation type and density, and the presence and density of flow obstructions such as buildings, fences and garden beds. Manning's 'n' values assigned to each zone were determined based on site observations, with reference to standard values recommended by Chow (1959). As resistance to flow due to surface and form roughness varies with depth (e.g. Chow 1959, Institution of Engineers Australia 1987), variable depth-dependent hydraulic roughness values have been adopted for this study.

The delineation of hydraulic roughness zones applied in the TUFLOW model is shown in **Figure 6-1**, and associated Manning's 'n' roughness coefficients provided in **Table 6-1**. The higher Manning's values are applied at depths below the specified depth range of variable roughness, and the lower Manning's values applied at depths above the specified depth range. At flow depths within the range of variable roughness, applied Manning's values are determined by linear interpolation.

The effect of buildings on flow behaviour has been represented in the model by applying a high Manning's 'n' value across building footprints to impede flow. Buildings have been modelled as zones of depth-varying roughness, with low hydraulic roughness at shallow depths to represent rapid runoff from roofs, and high hydraulic roughness at higher depths to represent obstruction to flow.

Table 6-1 Adopted Manning's 'n' Hydraulic Roughness Coefficients and Losses for all lagoons

Material	Range of depth variable roughness (m)	Manning's 'n'	Initial Loss (mm)	Continuing Loss (mm)
Lagoon	0.1 - 0.5	0.030 - 0.013	0	0
Beach/foreshore	0.1 - 0.5	0.100 - 0.060	15	2.9
Residential – Medium density	0.1 - 0.5	0.150 - 0.075	15	2.9
Residential – high density	0.2 - 1.0	0.300 - 0.150	15	2.9
Open Space	0.1 - 0.5	0.075 - 0.030	15	2.9
Vegetation – medium density	0.2 - 1.0	0.100 - 0.060	15	2.9
Vegetation – high density	0.4 - 2.0	0.150 - 0.080	15	2.9
Roadways	0.04 - 0.20	0.030 - 0.020	0	0
Buildings	0.03 - 0.10	0.100 - 10.000	1	0
Cliff / steep areas	NA	0.300	15	2.9
Concrete Open Channels	NA	0.012	1	0

N.B.: Concrete conduits represented in 1D were assigned a constant Manning's value of 0.011.

Cliff/steep area high roughness have been used for improvement of TUFLOW model stability.

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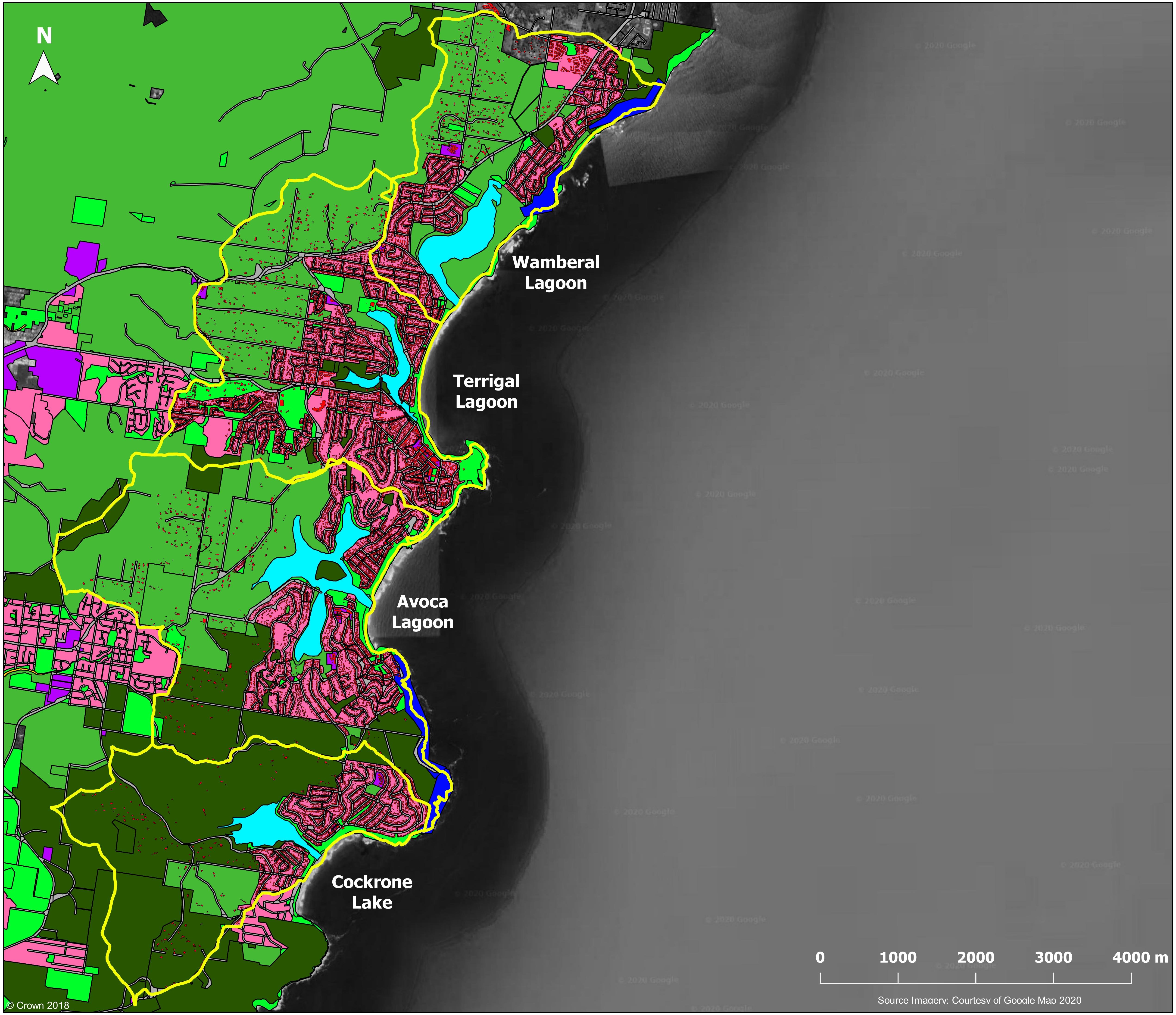

Figure 6-1

Hydraulic Roughness Zones

Legend

Study area

Catchment Areas

Material Type

- Lagoon
- Beach/Foreshore
- Medium Density Development
- High Density Development
- Open Space
- Medium Density Vegetation
- High Density Vegetation
- Road
- Increased roughness in cliff areas
- Building

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6.2.4 Boundary conditions

Rainfall

Rainfall on a grid using hyetographs. Design hyetographs were identified and defined in the hydrological analysis (**Section 5**).

Tailwater

Tailwater levels were defined as the ocean levels. The adopted values were based on the *Floodplain Risk Management Guide – Modelling the interaction of catchment flooding and oceanic inundation in coastal waterways (OEH, 2015).* Based on these guidelines, ICOLLs are classified as Waterway Entrance Type C and are highly impacted by wave setup. **Table 6-2** and **Table 6-3** summarise the tailwater levels and peak design levels recommended by EES (OEH, 2015).

Table 6-2 Combination of catchment flooding and oceanic inundation scenarios

***Source: Table 8.1 of EES* (OEH, 2015)**

Design AEP for peak levels/velocities	Catchment Flood Scenario	Ocean Water Level Boundary Scenario	Comment/ Reference
50% AEP	50% AEP	HHWS(SS)	Dynamic hydrograph can be taken from Appendix C with peak flood to coincide with HHWS(SS) highest peak for highest water levels Peak HHWS(SS) 1.25m AHD
20%	20% AEP	HHWS(SS)	
10%	10% AEP	HHWS(SS)	
5%	5% AEP	HHWS(SS)	
2%	2% AEP	5% AEP	Dynamic ocean water level boundary hydrograph Appendices A or B for relevant waterway type
1% Envelope level	5% AEP	1% AEP	Envelope provides 1% AEP design flood estimate
1% Envelope level	1% AEP	5% AEP	Dynamic ocean water level boundary hydrograph Appendices A or B for relevant waterway type
1% Envelope velocity	1% AEP	ISLW	Dynamic hydrograph can be taken from Appendix C with peak flood to coincide with ISLW lowest trough for peak velocities in entrance. Fixed ISLW approx. -0.95m AHD
0.5%	0.5% AEP	1% AEP	Dynamic ocean water level boundary hydrograph Appendices A or B for relevant waterway type
0.2%	0.2% AEP	1% AEP	
PMF	PMF	1% AEP	
1% Catchment	1%	HHWS(SS)	Suggested envelopes for analysis of catchment flooding only
PMF Catchment	PMF	HHWS(SS)	

***Note:** Individual projects are likely to specify the use of only a select number of AEPs outlined in the table.*

Table 6-3 Summary of peak design levels for various categories and locations

***Source: Table 5.2 of EES* (OEH, 2015)**

Classification	Peak Design Ocean Water Level (m AHD)			
	South of Crowdy Head		North of Crowdy Head	
	1% AEP	5% AEP	1% AEP	5% AEP
Waterway Entrance Type A	1.45	1.40	1.55	1.50
Waterway Entrance Type B	2.00	1.90	2.10	2.00
Waterway Entrance Type C	2.55	2.35	2.65	2.45

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Initial Lagoon Water Level

The initial water level in the four lagoons adopted for catchment derived flood events is the respective trigger level (**Table 3-4**). This water level corresponds to the water level at which a mechanical Lagoon breakout should be initiated.

Berm Level

The berm level of the lagoons was set at the respective managed berm level (**Table 3-4**).

6.2.5 Entrance behaviour

The entrance breakout was modelled as a varying berm level in the TUFLOW model. This allows the input of a change in geometry from the existing elevation value to a scoured value over a set period of time. More details are provided about the entrance behaviour in the calibration **Section 7.3.2** and the model sensitivity **Section 8.3**.

6.2.6 Blockage

Bridges and culverts are cross-drainage structures that carry roads, railways, pipelines or other infrastructure across watercourses. These structures can be affected by a number of different types of blockage mechanisms, resulting in consequences including increased flood levels, changes to stream flow patterns, changes to erosion and deposition patterns in channels, and physical damage to the structure. Blockage of these structures is discussed in AR&R 2019.

The procedure initially involves a series of decisions leading to estimation of the likely magnitude of debris reaching a structure in a 1% AEP event and the most likely blockage level that would develop at the structure under consideration. Subsequent adjustments are then made to reflect the most likely design blockage levels in lesser or greater AEP events and to establish the associated most likely blockage mechanism. This procedure provides an approach to the assessment of an appropriate level of blockage for the simulation of design flood behaviour but may not reflect specific conditions in an equivalent historical event. Such is the random nature of the many variables controlling blockage behaviour.

This AR&R 2019 blockage procedure presented in the Blockage Assessment Form was followed. Cross-drainage structures were identified from Council GIS and included the four bridges present in the study area.

Each cross drainage was assigned a “High”, “Medium” or “Low’ rating for the following AR&R 2019 attributes:

- Debris Availability – This rating was based on aerial imagery to assess the upstream catchment and the availability of debris.
- Debris Mobility – This rating was defined using contours based on steepness of the source area and proximity of source area to streams.
- Debris transportability – based on stream dimension in comparison to potential debris as well as stream shape.
- Debris Length L_{10} : AR&R 2019 defines this value as:
    - the average length of the longest 10% of the debris reaching the site and should preferably be estimated from sampling of typical debris loads. However, if such data is not available, it should be determined from an inspection of debris on the

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floor of the source area, with due allowance for snagging and reduction in size during transportation to the structure.

- In an urban area the variety of available debris can be considerable with an equal variability in L_{10}. In the absence of a record of past debris accumulated at the structure, an L_{10} of at least 1.5 m should be considered as many urban debris sources produce material of at least this length such as palings, stored timber, sulo bins and shopping trolleys."
- Hence, a value of 1.5 m has been adopted for L_{10} for all blockage structures in the model.

Regarding all other pits and pipes that were not identified as cross drainage structure, a 50% design blockage was adopted. This value was developed based on the design blockages described in Table 7.1 of AR&R Project 11 – Blockage of Hydraulic Structures Stage 2.

6.3 Model limitations and assumptions

The flood model is subject to the following limitations and assumptions:

- The selected 2m by 2m resolution of the model is adequate for representing flood behaviour but would have a limited representation of details smaller than the resolution.
- Buildings have been removed from the elevation DEM and modelled as high roughness based on a building footprint layer provided by Council and created by PSMA in June 2018. This can lead to observed flooding on the maps where large buildings are in place (e.g. Terrigal CBD). Such phenomenon should have limited impact on the flooding but should be considered at the time of encoding of properties as flood affected.
- Limited information about drainage and survey elevation was available for some large subdivisions such as the Forrester Beach Retirement Village and local flooding behaviour may vary depending on actual drainage and elevation at the site.

The model files are following the structure presented in **Figure 6-2** for each lagoon.

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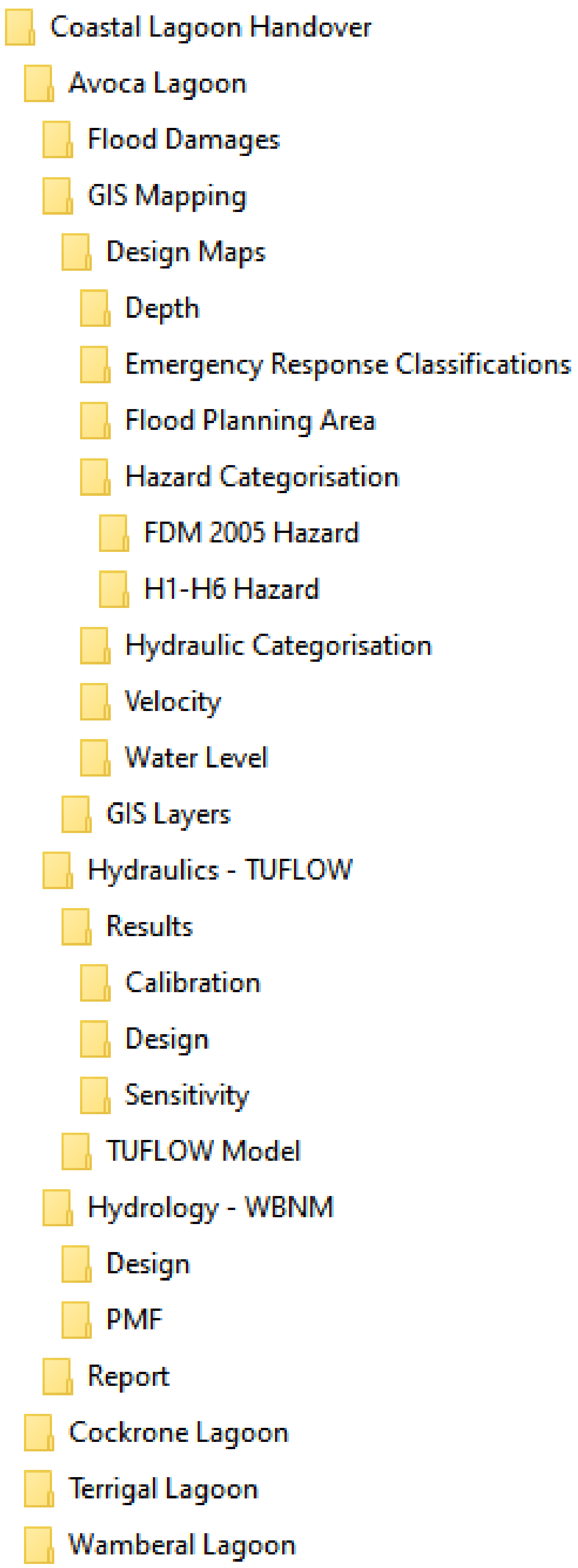

Figure 6-2 Modelling files folder structure

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7. Model calibration and validation

7.1 Methodology

Model calibration is an essential step in the flood modelling process to confirm that the model can adequately simulate historical flood events. In order to carry out model calibration it is necessary to have available suitable recorded data sets against which to evaluate model results. Selection of appropriate historical events for model calibration is therefore largely dependent on the availability of relevant flood data.

The most reliable recorded flood data available in the study area are the records from the various water level and rainfall gauges described in **Section 3.2**. Although recorded depth and flow data are not available higher in the catchment, calibration against each lagoon water level gauge would indicate that overall model behaviour in the four coastal lagoon catchments is reliable and provides confidence in the model parameters and data being adopted throughout the study area. The water level record of each lagoon, together with recorded rainfall data from the neighbouring gauges, therefore act as the primary basis for model calibration, with anecdotal flood depth data collected through community consultation also utilised.

As no recorded flow data was available, MHL undertook additional model verification through comparison of flow hydrographs computed by TUFLOW with those produced by the WBNM hydrologic model.

The calibration was also completed using a two-staged approach:

- Stage 1 – Flow and Volume: This stage focuses on the “rising limb” of the water level timeseries (**Figure 7-1**). It assumes a closed lagoon entrance and aim at matching the time and value of the peak water level in the lagoon.
- Stage 2 – Entrance Breakout Behaviour: This stage focuses on the “falling limb” of the water level timeseries when the entrance breaks out (**Figure 7-1**). It aims at obtaining a reasonable match for the entrance opening behaviour and associated drop in water level in the lagoon.

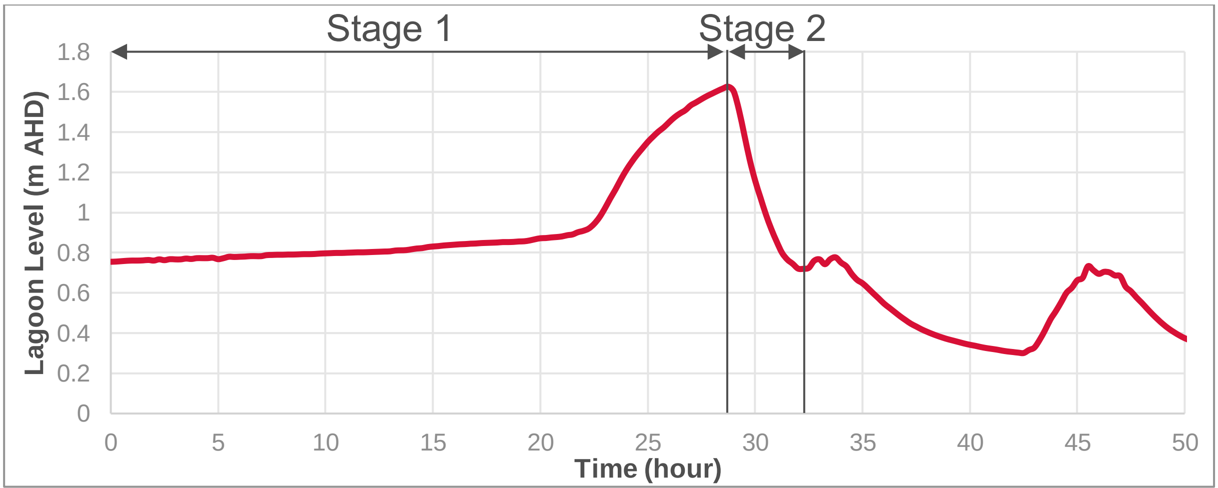

Figure 7-1 Two-Staged Calibration

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7.2 Calibration Stage 1 – Flow and volume

7.2.1 Event selection

Suitable historical calibration and validation events were determined through considering the following criteria:

- the availability of appropriate water level and continuous rainfall data at the lagoon;
- the historical significance of recorded rainfall;
- the influence of recorded rainfall on water levels; and
- the availability of flood depth data collected through community consultation.

Community consultation highlighted a large number of storms with significant storms impact various properties occurring almost every year since the 1990s. The most commonly mentioned storms were the June 2016 event, March-April 2017 event and the April 2015 events.

Review of the available historical information highlighted that a number of events had apparent inconsistencies between the recorded water level and rainfall data. This was found to be the result of wave impact generated wave pump up into the lagoon or potential partial opening behaviour of the entrances by manual intervention. Therefore, events impacted by such phenomenon were not appropriate for use in the hydraulic model calibration.

Three events were used for each lagoon (2 calibration events and 1 validation event). These events include both closed entrances and opening entrances. The selected events for each lagoon are listed below:

- Wamberal Lagoon: August 2007, June 2014 and June 2016
- Terrigal Lagoon: June 2009, January 2013 and March 2017
- Avoca Lagoon: April 2012, January 2013 and June 2016
- Cockrone Lake: April 2012, April 2015 and June 2016

7.2.2 Key parameter selection

In this stage, the entrance was assumed as closed. The continuing losses from the AR&R 2019 Data Hub of 2.9 mm/hr were used and the initial losses were adjusted for each event and each lagoon due to the high variability of the rainfall behaviour around the study area. Values between 0 and 40 mm were adopted which is consistent with the AR&R 2019 data hub recommendation of 48 mm with some antecedent rainfall. Manning's n as described in **Section 6.2.3** were adopted for the TUFLOW model. This roughness has been applied to all four lagoons.

7.2.3 Flow and volume

The flows and volumes were compared using the following approach:

- Flows and volumes of the downstream catchment of the lagoon was completed by comparing the timeseries of the flood level within the lagoon resulting from TUFLOW with the measured flood level within the lagoon for the selected calibration events.
- Given the lack of calibration data in the upper catchment, flows and volumes were checked by comparing the hydrographs generated by TUFLOW and WBNM at typical sub-catchments.

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7.3 Calibration Stage 2 – Entrance breakout behaviour

Once the above Calibration Stage 1 completed, the events followed by an entrance breakout were further analysed to obtain a typical entrance behaviour for each lagoon and define general opening stage.

7.3.1 Modelling approach

The entrance breakout was modelled as a varying berm level in the TUFLOW model. This allows the input of a change in geometry from the existing elevation value to a scoured value over a set period of time.

7.3.2 Entrance conditions

As described in **Section 3.4**, the four lagoons were found to have an unusual behaviour of the entrance due to the partial opening by manual intervention and the opening capacity of the entrance is relatively large in comparison to the catchment inflow. These conditions make the lagoon flood level highly sensitive to the timing and the duration of the entrance opening.

It was therefore necessary to undertake some sensitivity analysis on the opening duration and trigger levels. Communication with the Council Officer responsible for the lagoon entrance was required to obtain an improved understanding of the opening behaviour and usual mechanical opening process.

Entrance breach widths applied for the calibration were typically consistent with the available literature and did not exceed the values presented in **Table 3-3**.

The berm level was set to the managed level (or Present Barrier Maintenance Level in **Table 3-4**) and following observation of the lagoon water level data, a level of 0.25 m AHD was adopted as the level reached by scour of the entrance during a storm event.

Opening durations were found to range between 1.0 and 2.5 hours.

Example of the sensitivity of the breakout behaviour to the channel width and duration is illustrated in **Figure 7-2**. In this figure, entrances ranging between 10 and 30 m as well as opening duration ranging between 1.0 and 1.5 hour are compared to the recorded water level in the lagoon.

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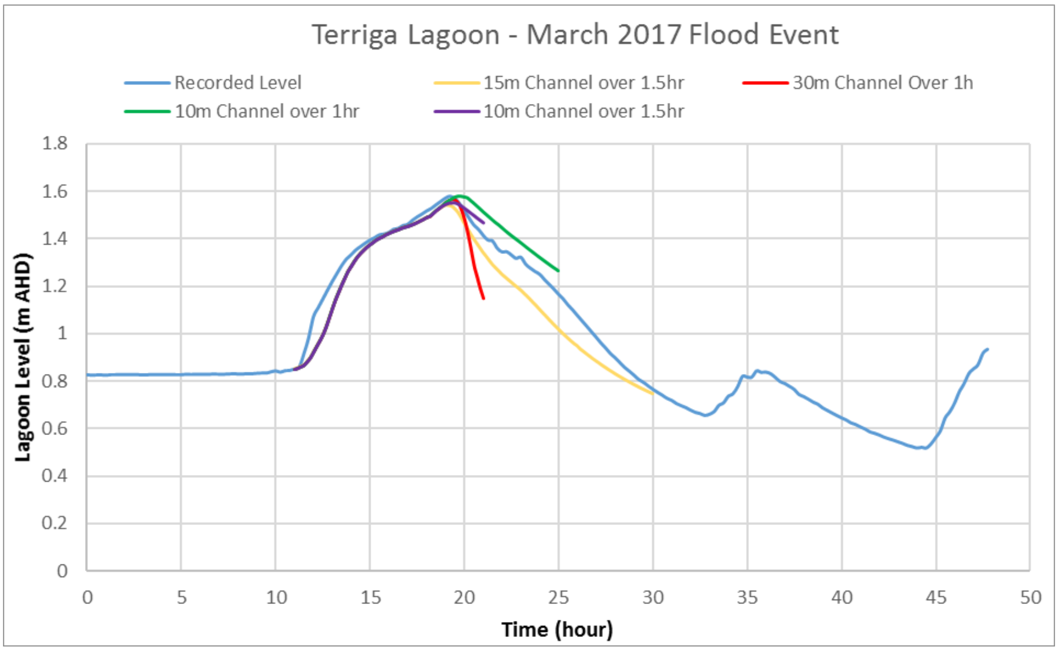

Figure 7-2 Sensitivity of Terrigal Lagoon entrance behaviour to channel width and opening duration during March 2017 event

7.4 Calibration results

Results of the calibration are presented in **Figure 7-3** to **Figure 7-6** for each of the four lagoons respectively and tabulated in **Table 7-1**.

Table 7-1 Summary of Calibration

Lagoon	Event Date	Breach Width (m)	Breach Duration (hour)	Peak Water Level (m AHD)		Difference	
				Measured	Modelled	(m)	(%)
Wamberal	Aug-07	70	1.5	2.57	2.58	+0.01	+0.4
	Jun-14	N/A	N/A	2.33	2.36	+0.03	+1.3
	Jun-16	80	1.0	2.70	2.71	+0.01	+0.4
Terrigal	Jun-09	30	1.0	1.68	1.70	+0.02	+1.2
	Jan-13	30	1.0	1.89	1.83	-0.06	-3.2
	Mar-17	10	1.0	1.58	1.58	+0.00	+0.0
Avoca	Apr-12	N/A	N/A	1.65	1.64	-0.01	-0.6
	Jan-13	N/A	N/A	2.00	1.97	-0.03	-1.5
	Jun-16	40	1.5	2.35	2.36	+0.01	+0.4
Cockrone	Apr-12	N/A	N/A	1.98	1.97	-0.01	-0.5
	Apr-15	N/A	N/A	2.78	2.71	-0.07	-2.5
	Jun-16	80	1.0	3.14	3.20	+0.06	+1.9

It can be observed that the peak flow of each event is fairly well represented. The general shape of the modelled water level behaviour in the different lagoons typically gives a reasonable match with the recorded data which provides confidence in the representation of the flood behaviour within the downstream catchments.

It is noted that Terrigal Lagoon presents a minor lag in the response of the water level. This is due to the representation of potential partial opening of the entrance using increased losses parameters.

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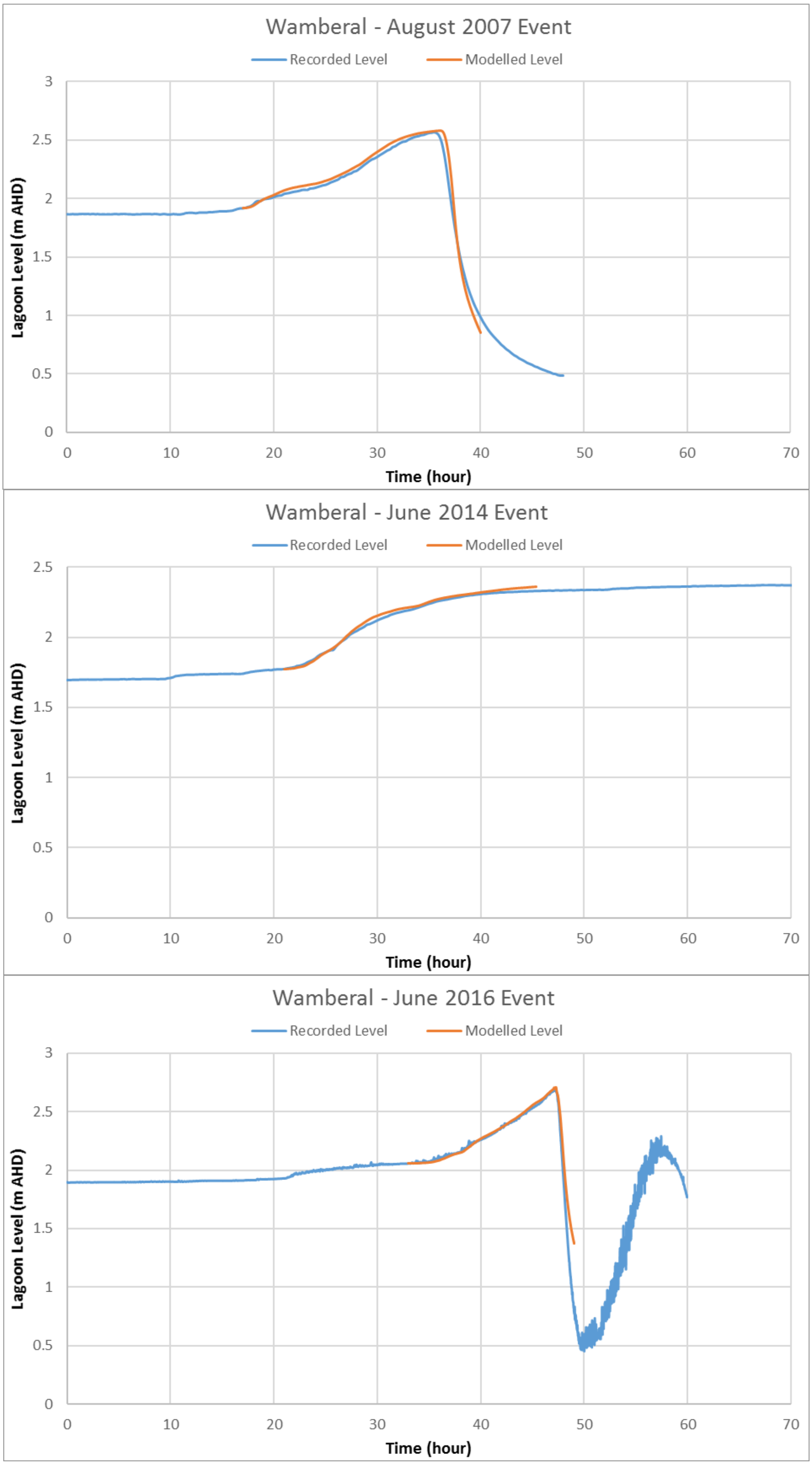

Figure 7-3 Calibration Results for Wamberal Lagoon

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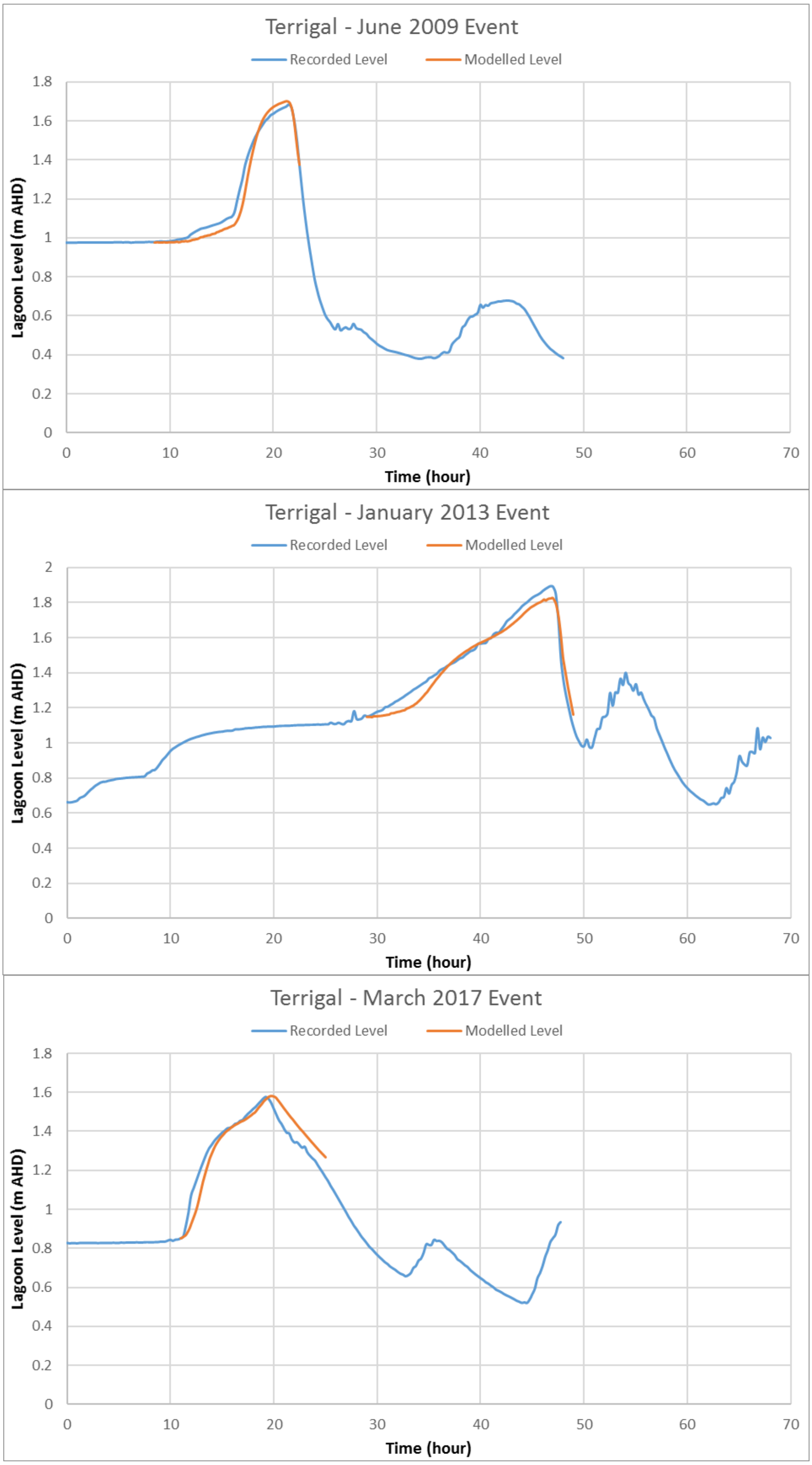

Figure 7-4 Calibration Results for Terrigal Lagoon

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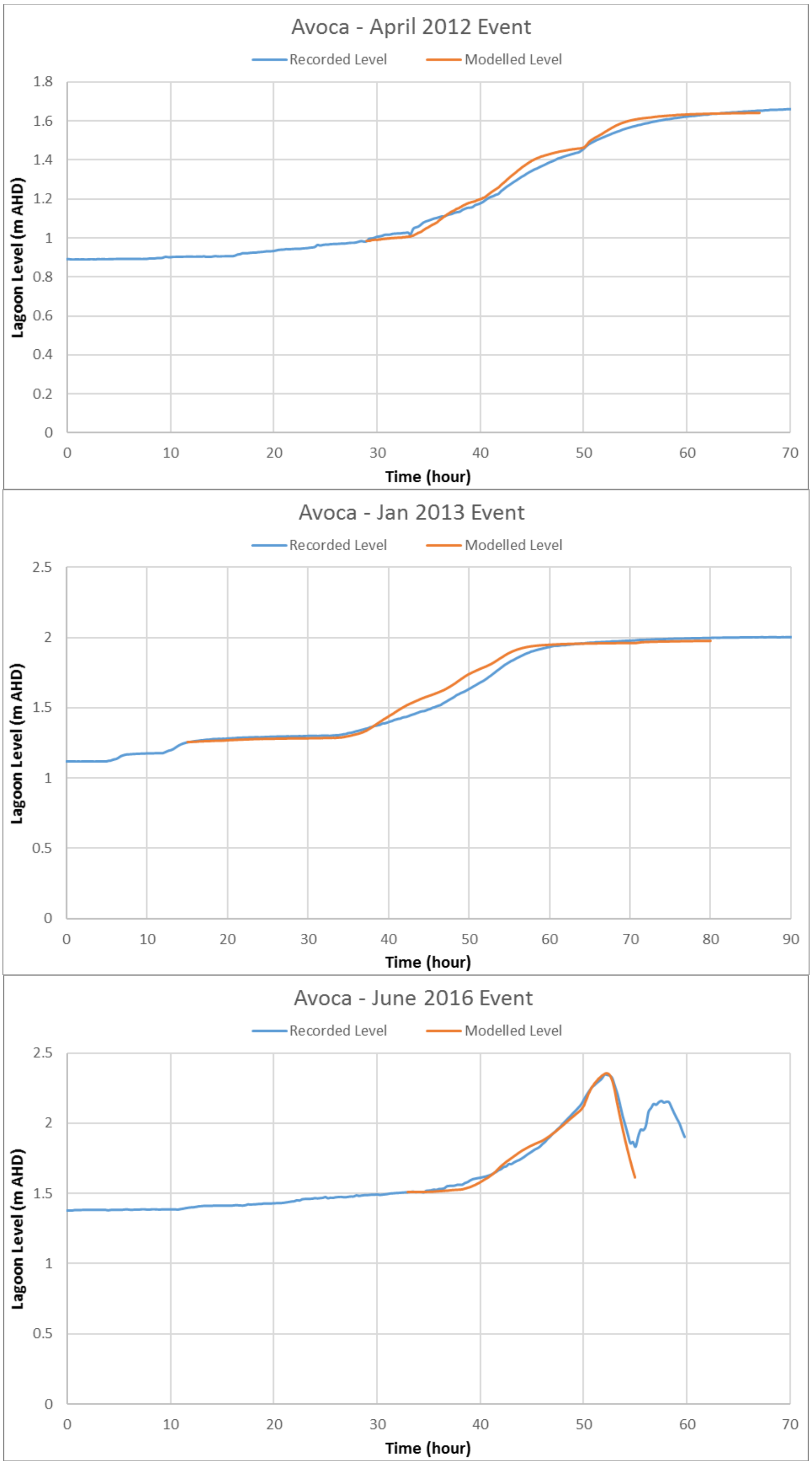

Figure 7-5 Calibration Results for Avoca Lagoon

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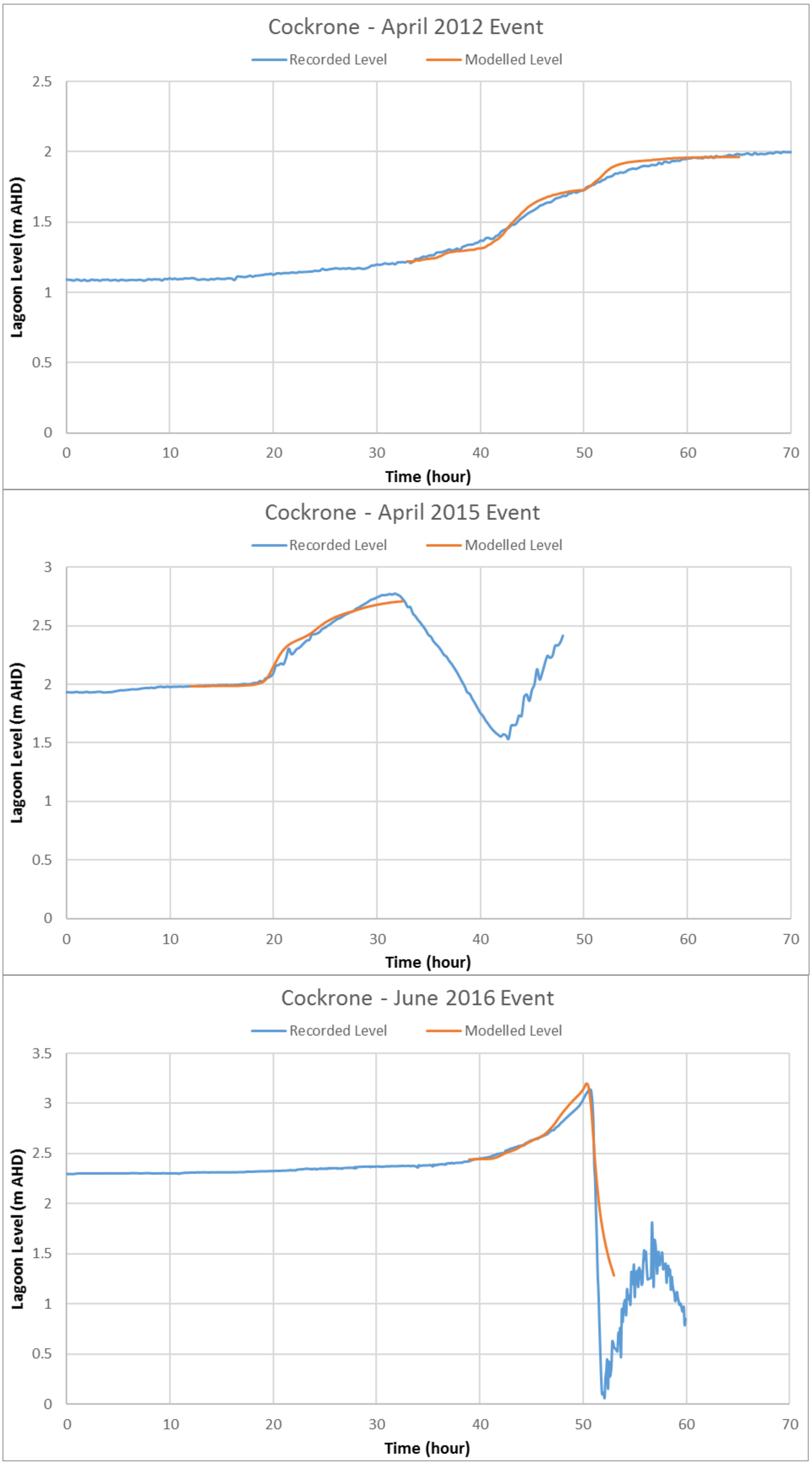

Figure 7-6 Calibration Results for Cockrone Lake

Comparison of the WBNM and TUFLOW hydrographs was completed for a key calibration event. The results for typical upper sub-catchments located in upper catchment and mid-catchments for each lagoon are presented in **Figure 7-7** to **Figure 7-10**. Cockrone appears slightly peakier in the TUFLOW model than in the WBNM model. The TUFLOW model also includes less of the flows at the very start of the model due to the two-dimensional losses generated by the direct rainfall methodology. In general, volumes are typically consistent between the two software with differences of 3 to 13% during the peak flow. This provides confidence in the representation of the upstream catchment flows.

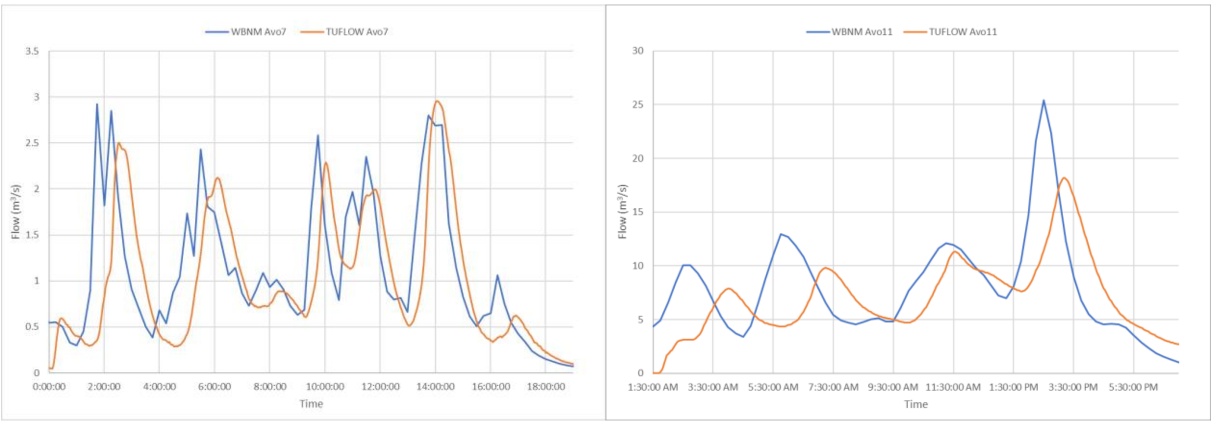

Figure 7-7 WBNM and TUFLOW hydrographs comparison for typical upper catchment of Avoca Lagoon on 4-5 June 2016

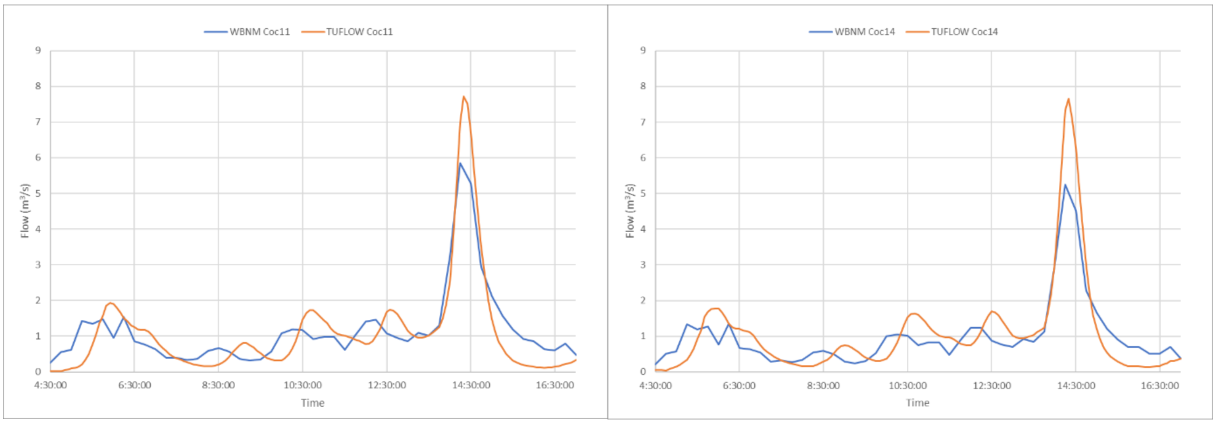

Figure 7-8 WBNM and TUFLOW hydrographs comparison for typical upper catchment of Cockrone Lagoon on 4-5 June 2016

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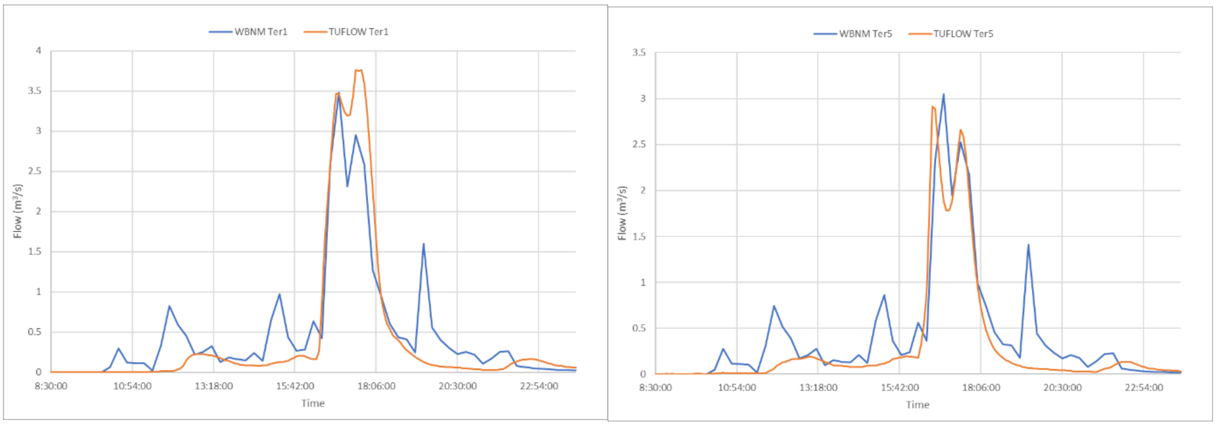

Figure 7-9 WBNM and TUFLOW hydrographs comparison for typical upper catchment of Terrigal Lagoon on 16-17 June 2009

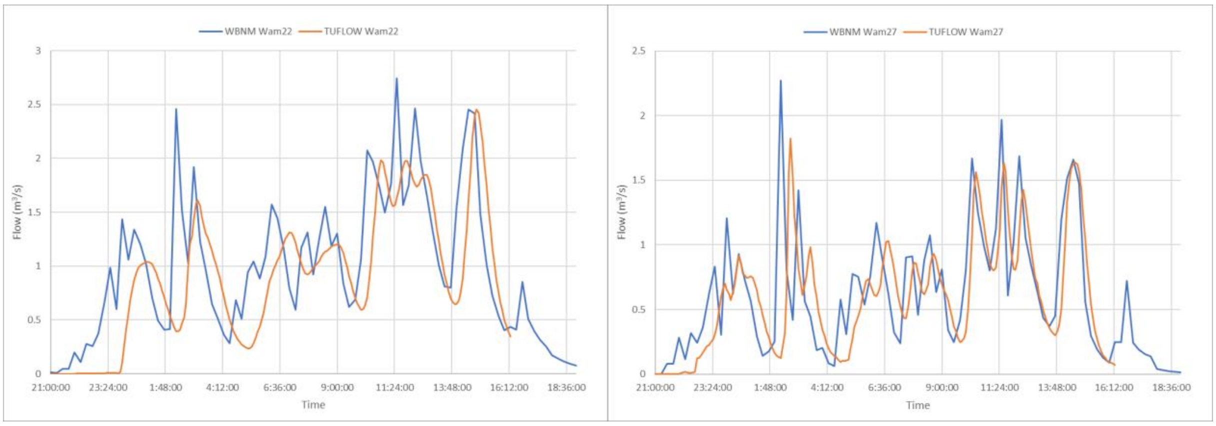

Figure 7-10 WBNM and TUFLOW hydrographs comparison for typical upper catchment of Wamberal Lagoon on 4-5 June 2016

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8. Model sensitivity

A number of factors require some sensitivity analysis prior to completing the design runs. These factors include:

- Entrance breakout behaviour: adopted berm level, initial water level in the lagoon, breach width and duration all have a crucial impact on the final design flood level.
- Tailwater level: a number of different tailwater conditions are recommended to be investigated by EES (OEH, 2015).
- Losses: impacts of reduced and increased losses were investigated.
- Roughness: impacts of reduced and increased losses were investigated.
- Blockage: AR&R 2019 recommends running two blockage sensitivity scenarios including double design blockage and no blockage.
- Climate change: Impact of changes in sea level and rainfall intensity have been investigated.

The sensitivity of the model results to the above factors is described in the following sections.

8.1 Entrance breakout behaviour and tailwater conditions

8.1.1 Preliminary entrance breakout analysis

The lagoons are intermittently closed and open lake or lagoons (ICOLLs) and the lagoon levels are largely dependent upon the berm beach levels.

MHL reviewed and compared a number of ICOLL flood studies along the NSW coastline. Typical ICOLLs around NSW surrounded with developments include a much larger catchment and ICOLLs with similar catchment size are typically only including a few properties (and therefore do not require any major flood study).

A typical modelling approach consist of starting the model with the water level at trigger level and assuming that the breakout commences at the start of the model.

This approach was found to provide non-conservative results as flows would start discharging from the lagoon prior to the peak of the storm. Hence, water level would already have reduced significantly by the time the peak of the flow reaches the entrance. This was observed during a preliminary sensitivity analysis of the entrance as presented in **Figure** 8-1. This graph compares four versions of the 1% AEP storm event for Cockrone Lake including:

- Scenario 1 (blue): Start of model with berm at managed level (i.e. 3.4 m), let out level at trigger level (i.e. 2.53 m AHD) and initial level of the lake at trigger level.
- Scenario 2 (green): Start of model with berm at managed level (i.e. 3.4 m), let out level at trigger level (i.e. 2.53 m AHD) and initial level of the lake at mean lake level (~2.1 m AHD).
- Scenario 3 (yellow): Start of model with berm at managed level (i.e. 3.4 m), let out level 200mm above trigger level (i.e. 2.73 m AHD) and initial level of the lake at trigger level.

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- Scenario 4 (red): Start of model with berm at natural level (i.e. 3.0 m), let out level at natural level (i.e. 3.20 AHD – 200mm above natural berm level) and initial level of the lake at trigger level.

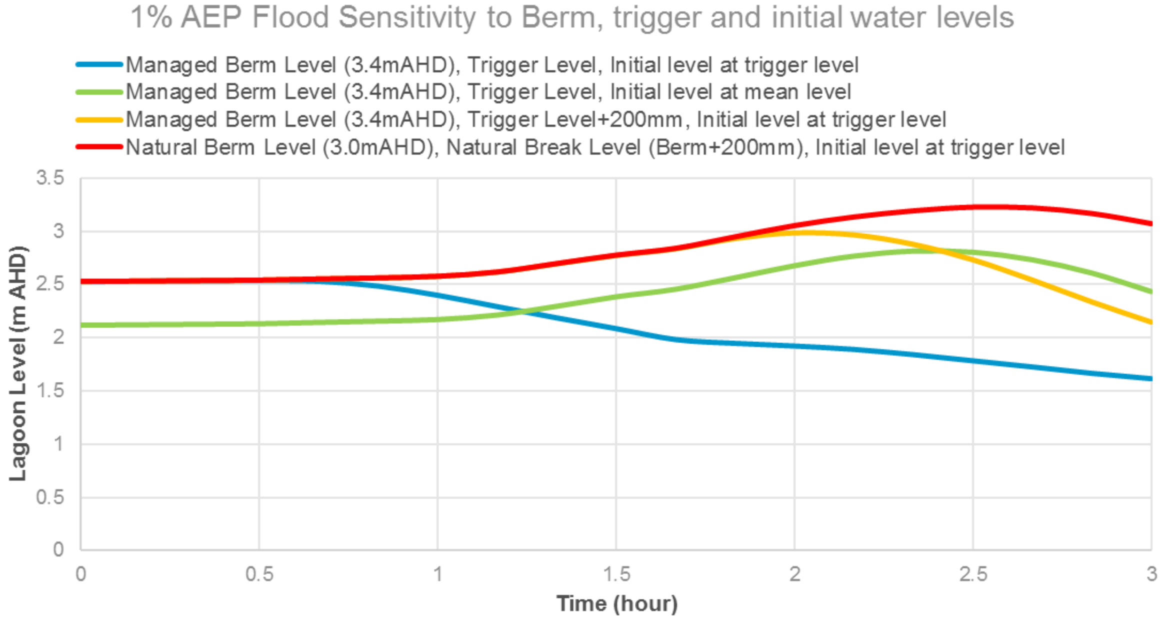

Figure 8-1 Preliminary sensitivity analysis to berm, trigger and initial water levels at Cockrone Lake

It can be observed that the first scenario is non-conservative as the flow discharges before the peak flow reaches the entrance about 2.0-2.5 hr after the start of the storm.

This can be explained by the fact that the four lagoons have a unique opening behaviour where the entrance channel scour is large when compared to the relatively small catchments feeding the lagoons.

These particular entrance conditions allow outflow from the lagoon to exceed the catchment inflows, making the design flood level highly sensitive to the berm level and timing of the entrance opening.

Therefore, MHL utilised in-house custom-built entrance model algorithms based on the real-time entrance modelling in the MHLFIT flood prediction tools. The custom-built algorithms utilise sediment characteristics, scour velocity and physical considerations to represent the outbreak behaviour. An important component was to analyse the actual event data and understand the physical aspects of the particular lagoon including opening constraints and common historical berm heights.

Following analysis of real events captured by the rainfall and water level gauges available around the study area, a typical two-staged opening behaviour was developed. This two-staged opening was developed to consider stage 1 and 2 of the typical 3-staged opening behaviour described in Gordon (Gordon, 1990) as observed along the NSW coastline (**Figure 3-4**). Stage 1 represents the beginning of the break out when the entrance starts to be overtopped by flood water and a small pilot channel starts to form. Stage 2 represents the actual breakout when the scour of the berm occurs. Stage 3 represents the behaviour of the flood once the berm is almost fully eroded. At this time the entrance is large enough to allow significantly more flow to discharge from the lagoon than there are inflows into the lagoon.

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This stage was therefore not represented as, once this configuration occurs, the lagoon rapidly discharges, and water levels drop in a relatively short time. The peak water level (and hence peak of flood extent) typically occurs during Stage 2 just before the inflows to the lagoon become lower than the outflows.

Figure 8-2 presents a typical storm event behaviour at Avoca Lagoon. The volume of flow presented on this graph (orange line) represents the incremental flow difference calculated using the water level measured at the water level gauge and the hypsometric data derived from the available Lidar data. It is important to note that it is an incremental flow and is not an actual outflow from the lagoon. The blue line illustrates the water level of the lagoon. Positive flows represent outflow from the lagoon through the entrance. Discharge from the lagoon commences when the flow difference is zero (black diamond on the left). The flow then increases slowly (Stage 1) until it reaches between 5 and 20 m^3/s (Orange dots represents the 5, 10 and 20 m^3/s). In this case, 20 m^3/s appears representative of the transition to Stage 2. The flow then increases significantly until reaching the peak flow (black diamond on the right). Once this point has been reached, the entrance is open sufficiently to allow a larger outflow through the entrance than the inflow from the catchment and the head difference (and hence the flow) start to reduce.

Numerous flood event similar to the one illustrated in **Figure 8-2** were analysed to determine a typical opening duration, timing and flows for Stage 1 and Stage 2. Results of the typical opening duration analysis are provided in **Table 8-1** along with the adopted duration of both stages for each lagoon.

As expected, the higher the initial level in the lagoon at the start of the opening, the larger the flow and the shorter the opening time. This is due to the larger flows increasing the erosion rate of the entrance and accelerating the opening process.

A number of storm event were found to not have any visible Stage 1 when the inflow to the lagoon is significant. This is particularly true for Terrigal Lagoon. These events are skewing the Stage 1 duration results in **Table 8-1** towards lower values.

Flows out of each lagoon were then analysed and compared to the results of a number of runs completed to estimate the flow capacity through the entrance for a range of head difference and entrance width. Results of this sensitivity of the flow to the entrance width and head difference is summarised in **Figure 8-3**. These data were used to estimate appropriate entrance channel width during the breakout. Adopted widths were selected with consideration of the observed historical widths and are presented in **Table 8-2**.

The entrance breakout was modelled assuming a natural breakout scenario rather than a mechanical opening scenario to consider time when mechanical opening is not possible. This natural breakout scenario would trigger when the berm (set at managed level) is overtopped.

In the TUFLOW model, Stage 1 commences with the creation of a 5 m wide channel when the water level reaches the berm level and Stage 2 follows directly from Stage 1 with the adopted channel width for each lagoon.

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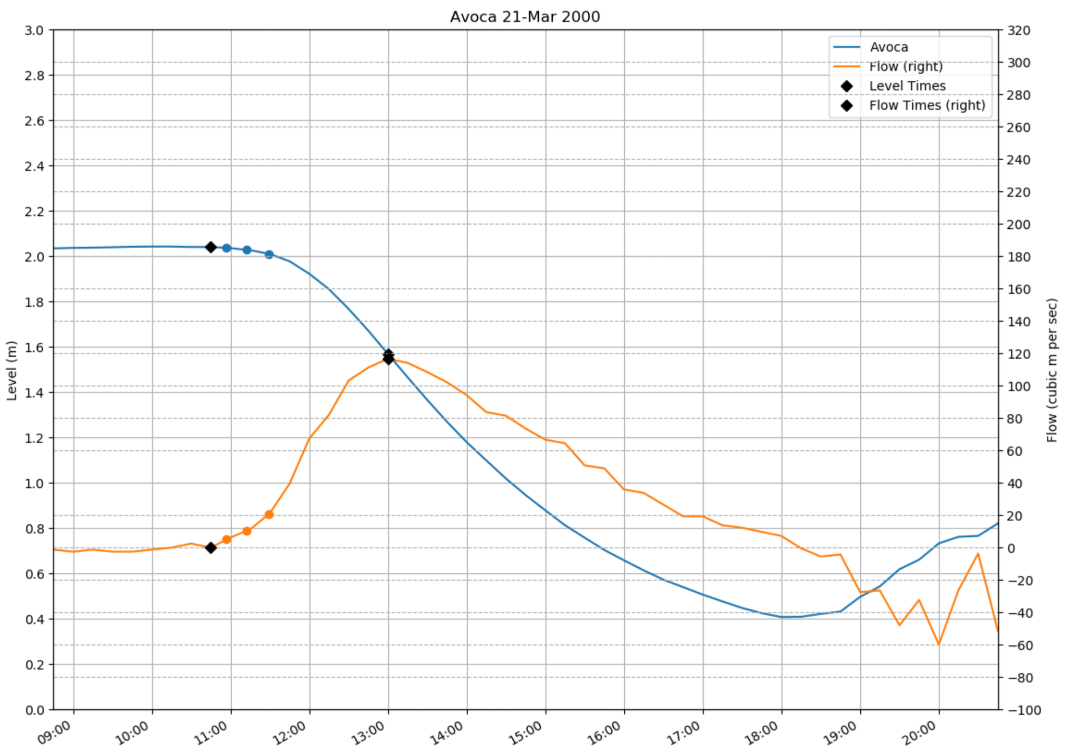

Figure 8-2 Avoca Lagoon level and estimated outflow on 21 March 2000

Table 8-1 Entrance breakout analysis results

Stage	Lagoon	Stage Duration in Minutes						
		Min	5%ile	Median	Average	95%ile	Max	Adopted
Stage 1	Wamberal	0	13	38	42	89	133	**45**
	Terrigal	0	0	30	37	95	180	**45**
	Avoca	16	18	44	54	113	120	**45**
	Cockrone	13	16	36	51	131	175	**45**
Stage 2	Wamberal	40	44	72	81	148	175	**80**
	Terrigal	21	29	59	67	124	165	**60**
	Avoca	44	57	84	87	133	157	**90**
	Cockrone	29	30	55	61	104	140	**60**

Table 8-2 Adopted Entrance Widths

Lagoon	Adopted Entrance Breakout Width (m)
Wamberal	70
Terrigal	50
Avoca	60
Cockrone	60

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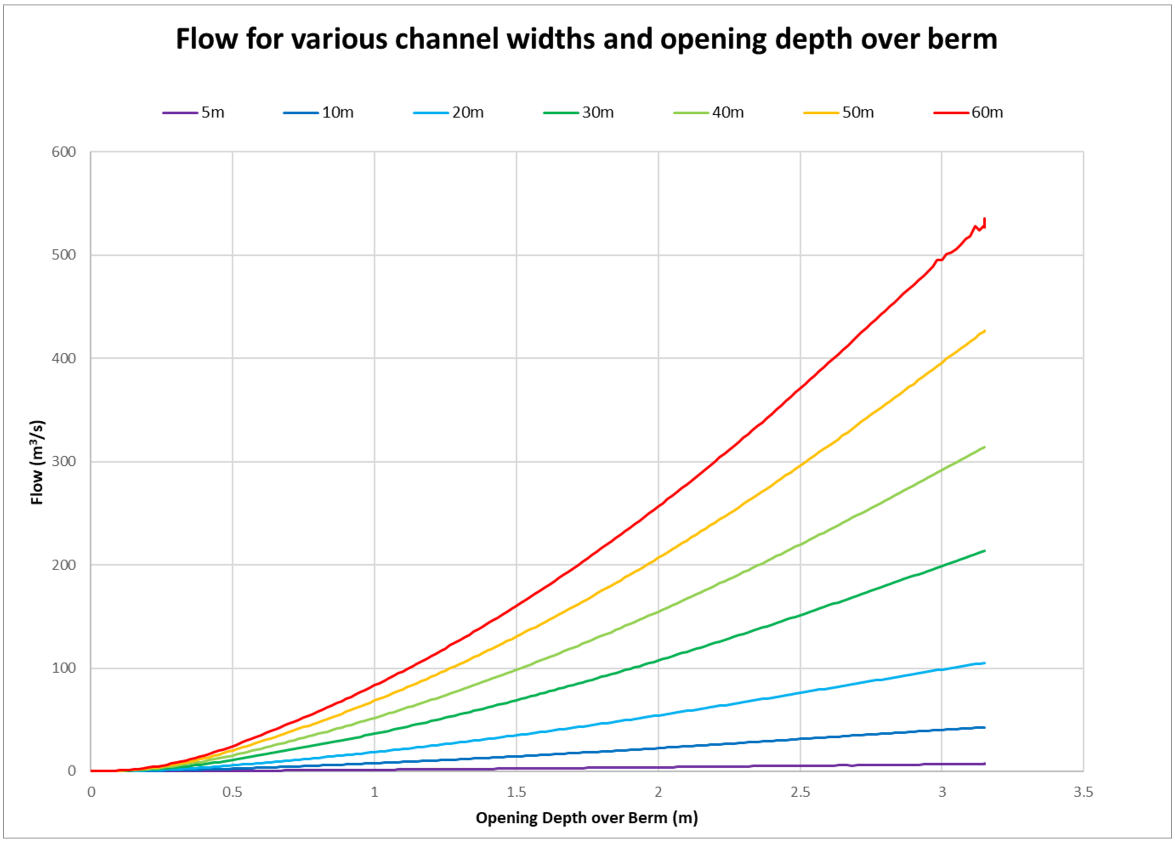

Figure 8-3 Flow for a range of berm openings and entrance channel widths assuming a constant lagoon level of 3.4m AHD at Cockrone Lake

8.1.2 Entrance behaviour and tailwater condition sensitivity analysis

To understand the impact of entrance behaviour and tailwater conditions, the following scenarios have been modelled for each lagoon and compared to the design conditions:

- Breakout level at berm level equal to the typical natural barrier height described in **Table 3-4** for the 1% AEP and PMF events.
- Breakout level at berm level equal to present "Trigger" level described in **Table 3-4** for the 1% AEP and PMF events.
- Tailwater peak occurring 3 hours before and after the catchment flooding peak for both 1% AEP and PMF flood events.
- HHWS tailwater conditions during a 1% AEP flood event.

Afflux maps showing the difference with the design conditions are presented in **Appendix D**.

The following observations can be made:

- For all four lagoons, an elevated berm level would lead to higher level in the lagoons during a large flood event as well as exacerbated flooding while a lower berm level would reduce flood levels into the lagoon.
- The results highlight the importance of opening the lagoons prior to reaching the natural level to significantly reduce flood levels in the lagoon. Maintaining the berm level at a certain height would also ensure that the berm does not build up too high and

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hence allowing higher flood levels into the lagoons.

- For Avoca, Cockrone and Wamberal Lagoons, the tailwater conditions have negligible influence on the flood levels within the lagoon as the berm level is typically higher than the tailwater level.
- For Terrigal Lagoon, given the low level of the berm, the tailwater conditions can have a significant impact on the flood level of the entire lagoon.

8.2 Losses and roughness sensitivity analysis

In order to analyse the influence of losses and roughness on the flood behaviour, the following scenarios were modelled for each of the four lagoons:

- No loss scenario with neither continuing losses nor initial losses in the pervious areas for the 1% AEP flood event.
- High loss scenario with 4.0mm/hr continuing losses and 30mm initial losses in the pervious areas for the 1%AEP flood event.
- Low roughness scenario with roughness reduced by 20% for the PMF and 1% AEP flood events.
- High roughness scenario with roughness increased by 20% for the PMF and 1% AEP flood events.

Afflux maps showing the difference with the design conditions are presented in **Appendix E**.

The following observations can be made:

- Scenarios with no losses can increase the flood levels by over 0.2m in the upper catchments during a 1% AEP flood event where there are a more significant amount of pervious areas and less developments. Key locations with elevated levels are:
  - The area upstream of Scenic Highway in the Avoca Lagoon catchment where flood levels increase by over 0.2m.
  - The area upstream of the southern branch of Avoca Lagoon with flood level increasing by 0.1-0.2m.
  - The area directly north of Wamberal Lagoon with level increasing by 0.05-0.10m.
  - The area upstream of the southern branch of Terrigal Lagoon with level increasing by 0.1-0.2m.
  - The area upstream of The Entrance Road, north of Terrigal Lagoon where levels increase by over 0.2m.
  - Lagoon levels are increasing in the order of 0.02-0.05m for all four lagoons.
- Scenarios with high losses can reduce the flood levels by over 0.2m in the upper catchments during a 1% AEP flood event. As expected, this as the opposite effect from the scenarios with no losses and key locations with reduced levels are the same areas.
- Scenarios with roughness decreased by 20% typically lead to reductions in flood levels by up to 0.1m during a 1% AEP flood event and by over 0.2m during a PMF event. However, a number of small areas where water is ponding can show slight increase in

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flood level due to the water filling the area faster than the water can drain out. This was observed:

  - At the back of the northern end of Avoca Beach during a PMF event.
  - Directly upstream of The Entrance Road, north of Terrigal Lagoon, at Terrigal Bowling Club, at Terrigal Football Club Oval and near Terrigal Lagoon entrance during a 1% AEP flood event.
  - At a few places along the upper catchment of the southern arm of Terrigal Lagoon.

- Scenarios with roughness increased by 20% typically lead to reductions in flood levels by up to 0.1m during a 1% AEP flood event and by over 0.2m during a PMF event. The areas where water is ponding as listed for the reduced roughness scenarios are presenting small decrease in flood level due to the water taking longer to fill the area and allowing than the flood water to drain out.

8.3 Blockage sensitivity analysis

In order to analyse the influence of blockage on the flood behaviour, the following scenarios were modelled for each of the four lagoons:

- No blockage scenario for both the 1% AEP and the PMF flood events. These scenarios assumed that all the pits and pipes were free of blockage.
- Double design blockage scenario for both the 1% AEP and the PMF flood events. These scenarios consider the double design blockage for the cross-drainage structures as recommended by AR&R 2019 and the severe blockage value of 100% blockage for the pits and pipes system as described in AR&R 2019 Project 11.

Afflux maps showing the difference with the design conditions are presented in **Appendix F**.

The following observations can be made:

- The no blockage scenarios typically reduce the flood levels in the upper catchment and in ponding areas such as ovals and other detention basins. Reductions are typically low (i.e. less than 0.05-0.10m) with some localised areas reducing the flood level by up to 0.1-0.2m.
- The no blockage scenarios also show some slight increases in flood level along main flowpath, directly downstream of larger cross-drainage culverts such as:

  - The culvert under The Entrance Road in Terrigal increase the flooding of the area directly downstream.
  - The creek flowing between Kings Avenue and the southern arm of Terrigal Lagoon.

  This was observed during the 1% AEP flood event and not the PMF as the incremental difference during such extreme event becomes negligible.

- The double design blockage scenarios typically increase the flood levels in the upper catchment and in ponding areas such as ovals and other detention basins. Increases are typically in the order of 0.05-0.20m.

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- However, a number of locations show significant impacts during the double design blockage scenarios with some localised areas increasing the flood level by up to 0.2-0.5m and a couple of location increasing by over 0.5m. These high increase areas include:
    - The area upstream of Scenic Highway in the Avoca Lagoon catchment where flood levels increase by over 0.2m during a PMF event.
    - The southern end of Tudibaring Parade, south of Cockrone Lagoon entrance where there is no gravity flow and some low flow can accumulate to over 0.2m if the pits and pipes are fully blocked.
    - Bluewave Crescent, Forrester Beach where there is no gravity flow and some low flow can accumulate to over 0.5m if the pits and pipes are fully blocked.
    - The area directly south of Wamberal Lagoon entrance where levels increase by over 0.2m.
    - The area along the southern bank near Terrigal Lagoon Entrance where increase in level of over 0.2m.
    - The section of the Terrigal Bowling Club allowing flows to accumulate and overflow toward Terrigal CBD.
- The double design blockage scenarios also show some slight decreases in flood level along main flowpath, directly downstream of larger cross-drainage culverts such as:
    - The culvert under The Entrance Road in Terrigal increase the flooding of the area directly downstream.
    - The creek flowing between Kings Avenue and the southern arm of Terrigal Lagoon.

  This was observed during the 1% AEP flood event and not the PMF as the incremental difference during such extreme event becomes negligible.

This sensitivity analysis of the blockages highlights the significance of maintaining the drainage network to minimise blockages particularly in the Terrigal CBD area and in ponding areas with no gravity flows that only relies on pipe system to drain the flood water.

8.4 Climate change sensitivity analysis

In order to analyse the influence of climate change on the flood behaviour, the following scenarios were modelled for each of the four lagoons:

- Scenarios with rainfall intensity increases by 10%, 20% and 30% during the 1% AEP flood event.
- Scenarios with sea level rise of 0.20m, 0.39m and 0.74m during the 1% AEP and PMF flood events.

Afflux maps showing the difference with the design conditions are presented in **Appendix G**.

The following observations can be made:

- The increased rainfall intensity scenarios typically increase the flood levels in the upper catchments by about 0.05-0.10m with a 10% increase in rainfall intensity increasing to over 0.2m with a 30% increase in rainfall intensity.

- Ponding areas such a ovals and detention basin are also impacted by these increases in rainfall intensity.
- Lagoon levels increase by up to 0.05m with a 10% increase in rainfall intensity and this increase can reach 0.10-0.20m with a 30% increase in rainfall intensity.
- During sea level rise scenarios:
  - Cockrone is not affected by any of the sea level rise of 0.20m, 0.39m and 0.74m due to the high level of the beach berm.
  - Avoca and Wamberal Lagoons are not affected by the sea level rises of 0.20m and 0.39m.
  - In the 0.74m sea level rise scenario at Avoca Lagoon, the PMF level increases by 0.02-0.05m and slightly reduces during a 1% AEP flood event. This slight decrease in level is due to the ocean water filling the lagoon earlier leading to an early breakout of the berm.
  - In the 0.74m sea level rise scenario at Wamberal Lagoon, the PMF level increases by 0.20-0.50m and by 0.10-0.20m during a 1% AEP flood event.
  - For Terrigal Lagoon, given the low level of the berm, the increase in flood level within the lagoon is approximately equivalent to the increase in sea level during a 1% AEP flood event. During a PMF event, the increase in flood level within the lagoon remains significant although the impact is slightly reduced due to already elevated flood levels within the lagoon during such extreme event.

All lagoons are impacted by the increase in rainfall intensity. Perched lagoons such as Cockrone Lagoon are not influenced by sea level rise. Lagoons with relatively high berm levels such as Avoca and Wamberal Lagoons are only impacted by very high tailwater levels and lagoons with low berm levels such as Terrigal Lagoon are impacted by increase in flood levels proportional to the sea level increase.

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9. Flood modelling results

9.1 Flood modelling description

The TUFLOW hydraulic model was run for nine (9) flood events including the 50%, 20%, 10%, 5%, 2%, 1%, 1 in 200, 1 in 500 and PMF flood events.

Two durations representing the upstream and downstream critical durations as described in **Table 5-3** were modelled and an envelope of these two durations was produced to represent the flooding for each event.

9.2 Flood mapping

9.2.1 Mapping filtering

The flood extents were filtered to remove shallow depths area generated by the direct rainfall methodology. The criteria used to filter these shallow depths consisted of keeping areas where:

- Depth > 0.10 m; OR
- Depth > 0.05 m AND Velocity x Depth > 0.025 m^2/s; OR
- Velocity > 2 m/s

Further to these criteria, “puddles” of less than 100m^2 were also removed from the extent.

This filtering criteria have been developed in collaboration with Council and are based on a recent study completed within the LGA and communication between Council and a number of consultants.

9.2.2 Flood maps

Flood mapping presenting the envelop of each event is provided as follows:

- **Appendix H** presents the flood levels, flood depths and flood velocities for each of the nine flood events at Avoca Lagoon.
- **Appendix I** presents the flood levels, flood depths and flood velocities for each of the nine flood events at Cockrone Lagoon.
- **Appendix J** presents the flood levels, flood depths and flood velocities for each of the nine flood events at Terrigal Lagoon.
- **Appendix K** presents the flood levels, flood depths and flood velocities for each of the nine flood events at Wamberal Lagoon.
- **Figure R.1** to **Figure R.16** in **Appendix R** present 1:5,000 scale maps of the 1% AEP and PMF flood levels and depth for each of the four lagoons

9.3 Flood levels in the lagoon

The peak design flood levels in the four lagoons have been summarised in **Table 9-1**. A small discrepancy can be observed between the 1% AEP and the 1 in 200 AEP flood levels. This is due to the selection of the critical rainfall pattern out of 10 patterns as described by

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AR&R 2019 leading to different critical durations and critical pattern selection for each flood event.

The peak flood values were taken at the centre of the lagoon and higher levels can occur at the upstream end of the various arms of the lagoons.

It is also important to note that these design levels are largely dependent on the berm conditions adopted and it is therefore important to maintain the berm.

Table 9-1 Summary of Peak Flood Levels in the Four Coastal Lagoon

Flood Event	Peak Lagoon Flood Level (m AHD)			
	Avoca Lagoon	Cockrone Lagoon	Terrigal Lagoon	Wamberal Lagoon
50% AEP	2.75	3.22	1.86	2.66
20% AEP	2.77	3.40	1.92	2.76
10% AEP	2.80	3.43	1.95	2.83
5% AEP	2.86	3.45	2.00	2.87
2% AEP	2.95	3.60	2.41	2.91
1% AEP	3.00	3.62	2.48	2.94
1 in 200 AEP	2.98	3.64	2.68	2.96
1 in 500 AEP	3.04	3.65	2.72	2.98
PMF	4.32	4.78	4.18	3.94

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10. Post processing of results

10.1 Preamble

Once the flood mapping completed for the main parameters (water level, depth and velocity), it was possible to determine the flood function, flood hazard and flood emergency response classification resulting from these data. Development of such categorisations is described in this section.

10.2 Flood hazard

A starting point for the assessment of Flood Life Hazard categories is to better understand the flood hazard. National Best Practice Guidelines present a set of hazard vulnerability curves shown in **Figure 10.1**.This shows how flood depths, velocities and depth-velocity product threaten the stability of vehicles, pedestrians and buildings.

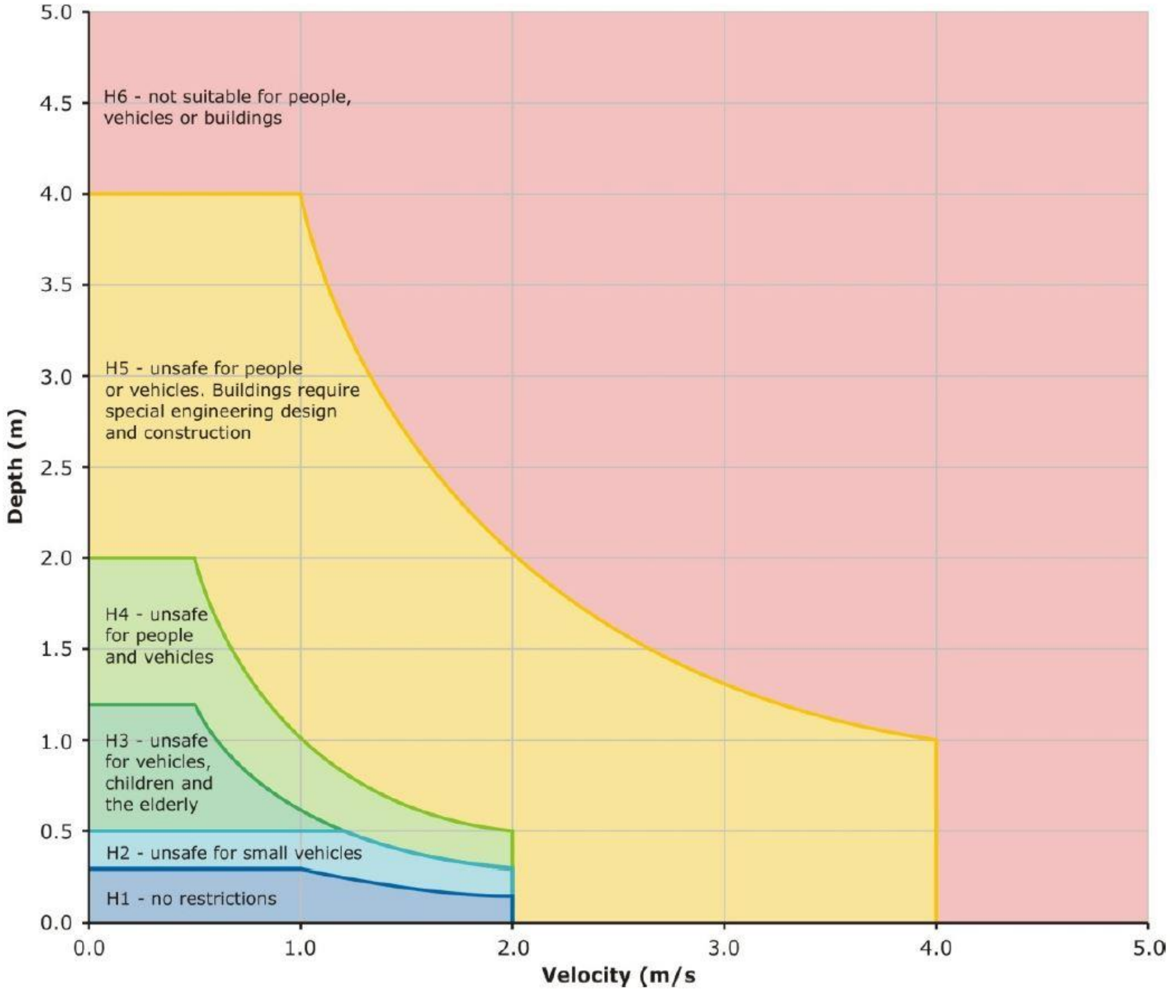

Figure 10.1 – General flood hazard vulnerability curves

Source: Technical flood risk management guideline: Flood hazard (Australian Institute for Disaster Resilience, 2012)

The above hazard vulnerability categories have been mapped for the 1% AEP and the PMF event for the entire study area and are presented in **Appendix L** for each of the four

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lagoons. Maps at 1:5,000 scale of the 1% AEP and PMF H1-H6 flood hazard for each of the four lagoons are presented in **Figure R.17** to **Figure R.24** of **Appendix R.**

During a 1% AEP flood event, the vast majority of the developed areas is classified as Hazard H1 to H2 with some occasional small areas of H3 hazard. Hazard condition H5 and H6 are typically observed within the lagoons, main natural/concrete channels or open spaces acting as retention basins as would be expected. Hazard conditions H3 and H4 can be observed at a few locations where ponding occurs, in the vicinity of existing streams or channels and along a number of roadways.

During a PMF flood event, the majority of the study area is classified as Hazard H1 to H3. Hazard conditions H5 and H6 are observed in most flow paths but typically still within the main channels and waterways. Hazard conditions H3 and H4 are much more common and extend further from the existing streams or channels, particularly at the downstream end of the various flow paths and at the properties located along the lagoon foreshore.

The provisional hazard as described in the NSW Government's Floodplain Development Manual (2005) was also calculated for comparison with the latest flood life hazard categories. The transition hazard has been included in the high provisional hazard. It was found that the extent of the high provisional hazard category was slightly less than the H3 category extent and therefore, the high provisional hazard appears to generally be equivalent to a flood life hazard category located between H3 and H4. Therefore, the H1 to H3 categories could potentially be used as an alternative for the previous low provisional hazard category and the H4 to H6 categories could be used as an alternative to the previous high provisional hazard categories.

10.3 Flood function (or hydraulic categorisation)

Hydraulic categorisation is a useful tool in assessing the suitability of land use and development in flood-prone areas. The Australian Disaster Resilience Handbook (Australian Institute for Disaster Resilience, 2017) describes the following three hydraulic categories of flood-prone land:

- **Floodway / Flow Conveyance** – Flow conveyance areas are defined as those areas where a significant flow of water occurs. They typically flow continuously from the upper reaches of waterways and flow paths within the catchment to the outlet during a flood. These flows often align with naturally defined channels. They are areas that, even if only partially blocked by changes in topography or development, cause a significant redistribution of flood flow or a significant increase in flood levels. They are often, but not necessarily, areas of deeper flow or areas where higher velocities occur. In the DFE, they generally extend beyond the waterway banks.
- **Flood Storage** – During a flood event, significant amounts of floodwater can also extend into, and be temporarily stored in, areas of the floodplain. This water flows downstream as the flood recedes. Where storage is important in attenuating downstream flood flows and levels, areas storing this water are classified as flood storage areas. Filling of flood storage areas reduces their ability to attenuate downstream flood flows and, as a result, flood flows and flood levels may increase.
- **Flood Fringe** – Flood-fringe areas make up the remainder of the flood extent for the

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particular event. It is the area where the effects on flood function are not a constraint. Developing in flood-fringe areas is unlikely to significantly alter flood behaviour, beyond the broader impact of changes to run-off because of urbanisation within the catchment. However, other flood-related constraints may exist in flood-fringe areas.

These qualitative descriptions do not prescribe specific thresholds for determining the hydraulic categories in terms of model outputs, and such definitions may vary between floodplains depending on flood behaviour and associated impacts. For the purposes of the Coastal Lagoons Catchment Overland Flood Study, hydraulic categories have been defined as per the criteria in **Table 10.1**. These criteria have previously been developed in collaboration with Central Coast Council during the Northern Lakes FRMSP. The floodway criterion has been selected as it provides improved continuity of flow along the various flow paths and considers areas of deeper flows. The flood storage criteria were selected as they have been commonly applied on various recent overland studies around NSW and considers areas with deep flood depth allowing storage of flood water.

Hydraulic category mapping for the PMF and 1% AEP design events is presented in **Appendix M**. Maps at 1:5,000 scale of the 1% AEP and PMF flood hydraulic categories for each of the four lagoons are presented in **Figure R.25** to **Figure R.32** of **Appendix R.**

Table 10.1 – Hydraulic category criteria

Hydraulic Category	Criteria	Description
Floodway	Velocity x Depth > 0.25 m^2/s	Flowpaths and channels where a significant proportion of flood flows are conveyed
Flood Storage	Depth > 0.5 m, Not Floodway	Areas that temporarily store floodwaters and attenuate flood flows
Flood Fringe	Depth < 0.5 m, Not Floodway or Flood Storage	Generally shallow, low velocity areas within the floodplain that have little influence on flood behaviour

11. Consequences of flooding on the community

11.1 Preamble

The impact of flooding on the community is described in this section. The first step of understanding the impact of flooding on the community is to define the flood behaviour within the catchment and identify key problem areas. Flood impact, road closure and flood damages can then be assessed, and more details are provided in this section.

11.2 Flood behaviour

Avoca Lagoon catchment comprises of a number of small urbanised catchments leading to the northern and southern arms of the lagoon where overland flow flooding can occur and a few larger and more rural catchments leading to the western arm of the lagoon.

Similarly, Terrigal Lagoon catchment comprises of numerous small urbanised catchments around the lagoon and the creek leading to the southern arm of the lagoon. A larger and more rural catchment is leading to the northern arm of the lagoon.

Wamberal Lagoon catchment comprises of small urban catchments and a few small rural catchments in the northern western quarter of the catchment.

Cockrone includes a few urbanised catchments along the coastline and the rest of the catchment is mostly rural.

The nature and impact of flooding differs throughout the area, associated largely with differences in the size and topography of the various catchments, as well as the nature of development and effectiveness of drainage infrastructure.

Flooding in the upper catchments is ‘flashy’ in nature, with flood levels rising rapidly in response to relatively short durations of high intensity rainfall as opposed to extended periods of rainfall of lower intensity. This is confirmed by the critical duration ranging between 20 min and 3 hr as shown in **Table 5-3**. The lower catchment remains relatively flashy in nature during the rare and extreme event with only a couple of hours to react. This was represented by the analysis of two critical durations as part of the design event modelling: a longer duration for the main lagoon and a shorter duration for the flashy catchments.

The potential for rapid inundation of properties and numerous roads in response to short durations of rainfall means that time available to disseminate flood warning is limited, and that emergency response may occur after the event. Flood waters generally recede quite quickly following the simulated storms except in some low-lying areas (such as areas around the lagoons) where flooding persists for a number of hours.

The study area contains various small, steep catchments which drain rapidly toward receiving waters through small well-defined valleys. The impact of flooding in such catchments is generally low except where development has encroached upon these natural drainage lines.

Potential key issue areas include:

- Avoca Lagoon catchment:

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  - Burns Street, Avoca Beach
  - Southern end of Picketts Valley Road and directly upstream of the intersection of Scenic Highway and Avoca Drive, Avoca
  - The southern bank of Avoca Lagoon entrance channel
  - Southern end of Tramway Road, Surf Rider Avenue, Leeside Road and Elgata Avenue, North Avoca
- Cockrone Lagoon catchment:
  - Tudibaring Parade, MacMasters Beach
  - The natural drainage channel upstream of the corner of Del Monte Place and Del Rio Drive, Copacabana
  - Both bank of Cockrone Lagoon entrance channel
- Terrigal Lagoon catchment
  - Intersection of Campbell Crescent and Scenic Highway, Terrigal
  - Flowpath linking Trevally Close to Terrigal lagoon via Chantell Avenue and Ena Street
  - Farrand Crescent, Yarang Close and Grasslands Avenue, Terrigal
  - Bundara Avenue, Lake View Road, Arila Avenue, Minell Close and Windsor Road, Wamberal
- Wamberal Lagoon catchment
  - Dover Road, Loxton Avenue and Lucinda Avenue, Wamberal
  - Bluewave Crescent, Malkana Avenue and John Street, Forresters Beach

A number of these key issue location appear to commence being impact from relatively frequent events like the 20% AEP.

11.3 Key infrastructures

There are two main types of key infrastructures as presented below:

- The first type includes facilities that are occupied by emergency responders such as police stations, fire stations or SES Centres.
- The second type includes facilities with particularly vulnerable residents such as schools, childcare centres, aged care facilities and hospitals.

The locations of these key infrastructures have been sourced from publicly available information (e.g. google map) and are illustrated in **Figure 11.1**. A list of these facilities is also provided in **Table 11.1** along with a brief description of the flood affectation of each infrastructure.

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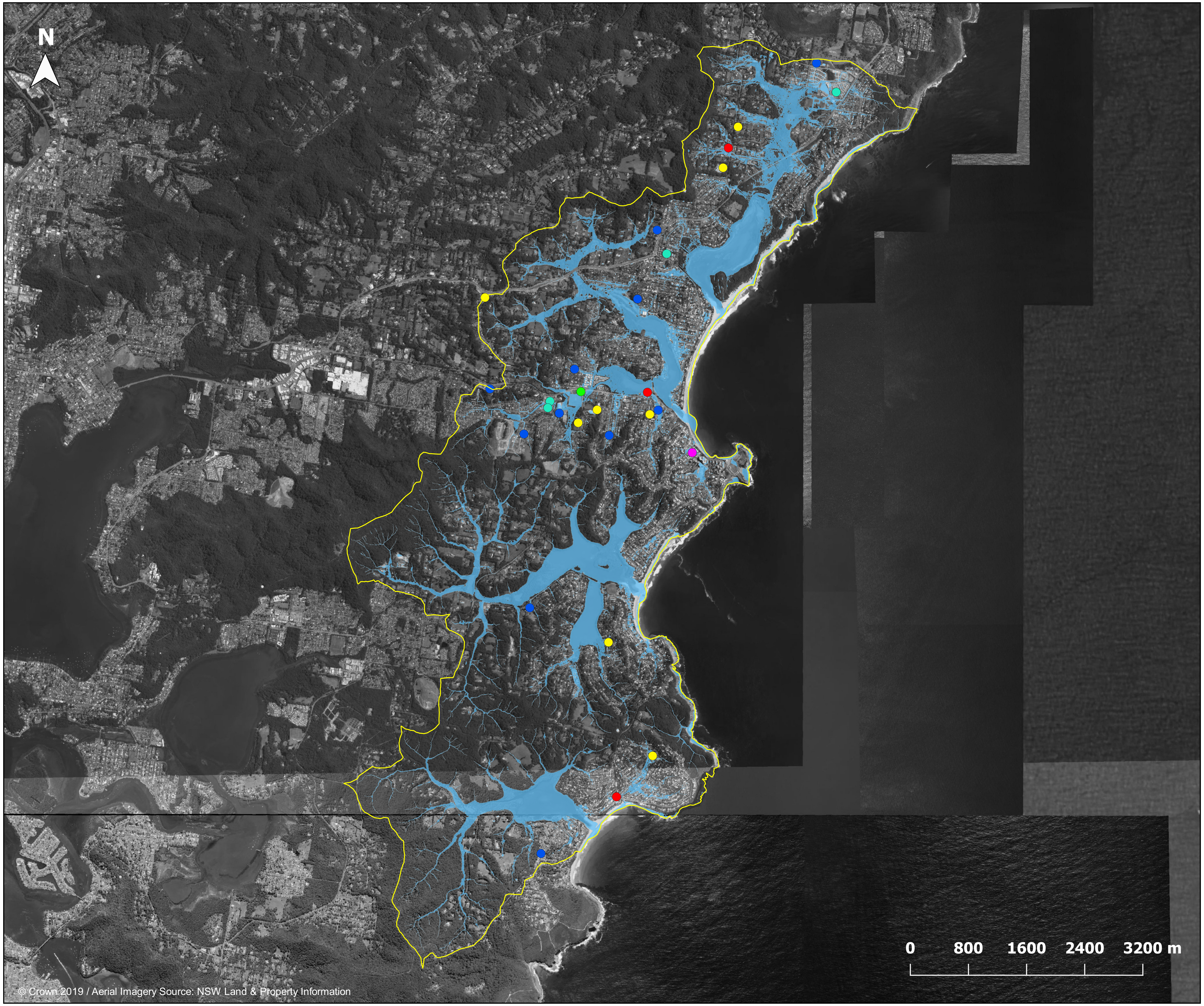

Figure 11.1

Key Infrastructure Location

Legend

Study area

1% AEP Flood Extent

Key Infrastructure

- Ambulance Station
- Child Care / Preschool
- Fire Station
- Police Station
- Age Care Facilities / Retirement Village
- School

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Table 11.1 – List of Key Infrastructures

Location	Comments on Flood Risk
Police and Fire Stations	
Copacabana Rural Fire Brigade	The fire station is located within the PMF extent.
Fire and Rescue NSW Terrigal Fire Station	The fire station is located within the PMF extent and access becomes limited above the 1% AEP event.
Wamberal Rural Fire Brigade	The fire station is located within the PMF extent and access may become limited above the 1% AEP event.
Terrigal Police Station	Terrigal Police Station is within the 1 in 200 AEP flood extent and access to the station may be restricted from the 1% AEP flood event.
SES Centres	
SES	There are no SES facilities located within the study area
Hospital and Ambulance Stations	
Terrigal Ambulance Station	The ambulance station is located within the PMF extent and access from the station may become limited from the 1 in 200 AEP flood event.
Hospitals	There are no hospitals located within the study area
Schools	
Central Coast Montessori School	The school is outside of the PMF extent but access to school may be limited in such event.
Wamberal Public School	The school is outside of the PMF extent but access to school may be limited in such event.
Junior at Wamberal	The school is outside of the PMF extent but access to school may be limited in such event.
Terrigal Public School	The school is outside of the PMF extent but access to school may be limited in such event.
Terrigal High School	The school is outside of the PMF extent but access may become limited from the 1 in 200 AEP flood event.
Aspect Central Coast School	The school is outside of the PMF extent but access may become limited from the 1 in 200 AEP flood event.
Erina Heights Public School	The school is outside of the PMF extent and access remains during the PMF.
Avoca Beach Public School	The school is partly within the PMF extent and access may become limited during such event.
Copacabana Public School	The school is within the 2% AEP flood extent and can become partly flooded during events as frequent as the 10% AEP flood event. Access may cut from the 2% AEP flood event.
Childcare Facilities and Preschools	
Alkira Early Learning Centre	The learning centre is outside the PMF extent and access to centre remains during PMF.
Pippies at Wamberal	The learning centre is outside the PMF extent and access to centre remains during PMF.

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Location	Comments on Flood Risk
Shine Eary Learning Centre	The learning centre starts becoming flooded from the 20% AEP flood event.
Dinky Di Childrens Learning Centre	The learning centre starts becoming flooded from the 20% AEP flood event.
Ladybug Academy	The pre-school is within the PMF extent and access may become limited from the 5% AEP flood event
Little Miracles Terrigal	The childcare is within the PMF extent and some minor ponding may occur during more frequent events. Access is unaffected.
Terrigal Childrens Centre	The childcare is outside of the PMF extent but access may become restricted during such event
Explore & Develop Terrigal – Early Learning Centre	The childcare is outside of the PMF extent and access remains during the PMF.
Keleah's Early Learning & Development	The childcare is outside of the PMF extent but access may become restricted during such event
Hillside Preschool	The childcare is outside of the PMF extent but access may become restricted during such event
MacMasters Beach Early Learning Centre	The childcare is outside of the PMF extent and access remains during the PMF.
Aged Care Facilities and Retirement Villages	
Terrigal Waters Village	This retirement village starts flooding from the 1% AEP and becomes largely flooded during the PMF. Access remains during such event.
Terrigal Sands	This retirement village starts flooding from the 1% AEP and becomes largely flooded during the PMF. Access may become restricted during such event.
Wamberal Gardens Retirement Village	This village is outside the PMF extent and access remains during this event.
Forresters Beach Retirement Village	This village is within the PMF extent. However, it is noted that the provided DEM at this location appears to differ from the existing configuration and flooding at this location may be misrepresented.

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11.4 Road closure

An assessment of the frequency and hazard of road inundation is important for understanding the risk of vehicles becoming unstable, posing a risk to life for their drivers and passengers. It is also important for understanding evacuation risks, informing the classification of communities according to flood emergency response planning considerations. Measures to increase the flood immunity of critical roads could be considered as a result of this assessment.

Figure 11.2 describes the flood events required to first generate road closure in the four lagoon catchments. Road closure was assumed as occurring when the depth reaches over 0.3m which is the depth that can start mobilising cars. **Table 11.2** summarises the peak depth, duration of flooding over 0.3m and time to depth above 0.3m for each location presented on **Figure 11.2**.

It can be noted from the flood mapping that a large number of locations get some water over road very rapidly in the study area, although it may not become a significant issue every time. This is fairly common during overland flooding events.

In the 1% AEP flood, the majority of roads that are inundated are minor roads with secondary access by-passing the flooded area. During PMF events a number of larger roads are cut off as well as numerous small roads.

Larger roads that are impacted include The Scenic Road in Cockrone Lagoon catchment, Avoca Drive and Scenic Highway in Avoca Lagoon catchment, Terrigal Drive and The Entrance Road in Terrigal Lagoon catchment as well as Ocean View Drive and Central Coast Highway in Wamberal Lagoon catchment.

While the majority of the roads cut by the flood are due to overland flooding, the following roads are relatively low lying and would be overtopped when the lagoon level rise:

- Within Avoca Lagoon catchment, Ficus Avenue, Avoca Drive and Tramway Road are subject to water over road from 2.64, 3.15-3.20 and 2.98m AHD respectively.
- Within Cockrone Lagoon catchment, Lakeside Drive, Del Monte Place, The Scenic Road and Three Points Avenue are subject to water over road from 3.17, 3.22, 3.23 and 3.62m AHD respectively.
- Within Terrigal Lagoon catchment:
  - Between the lagoon and the ocean, Bundara Avenue, Arila Avenue, Lake View Road and Ocean View Drive are subject to water over road from 1.63, 1.65, 1.32 and 2.54m AHD respectively.
  - West of the lagoon, Terrigal Drive and Willoughby Road are subject to water over road from 2.3m and 3.12m AHD respectively near the western bridge while Ogilvie Street and Farrand Crescent are overtopped from 2.40m and 1.83m AHD.
- Within Wamberal Lagoon catchment, Remembrance Drive and Ocean View Drive are subject to water over road from 2.52 and 3.40m AHD respectively.

These roads may become impracticable once a depth of 0.30m is present across the road.

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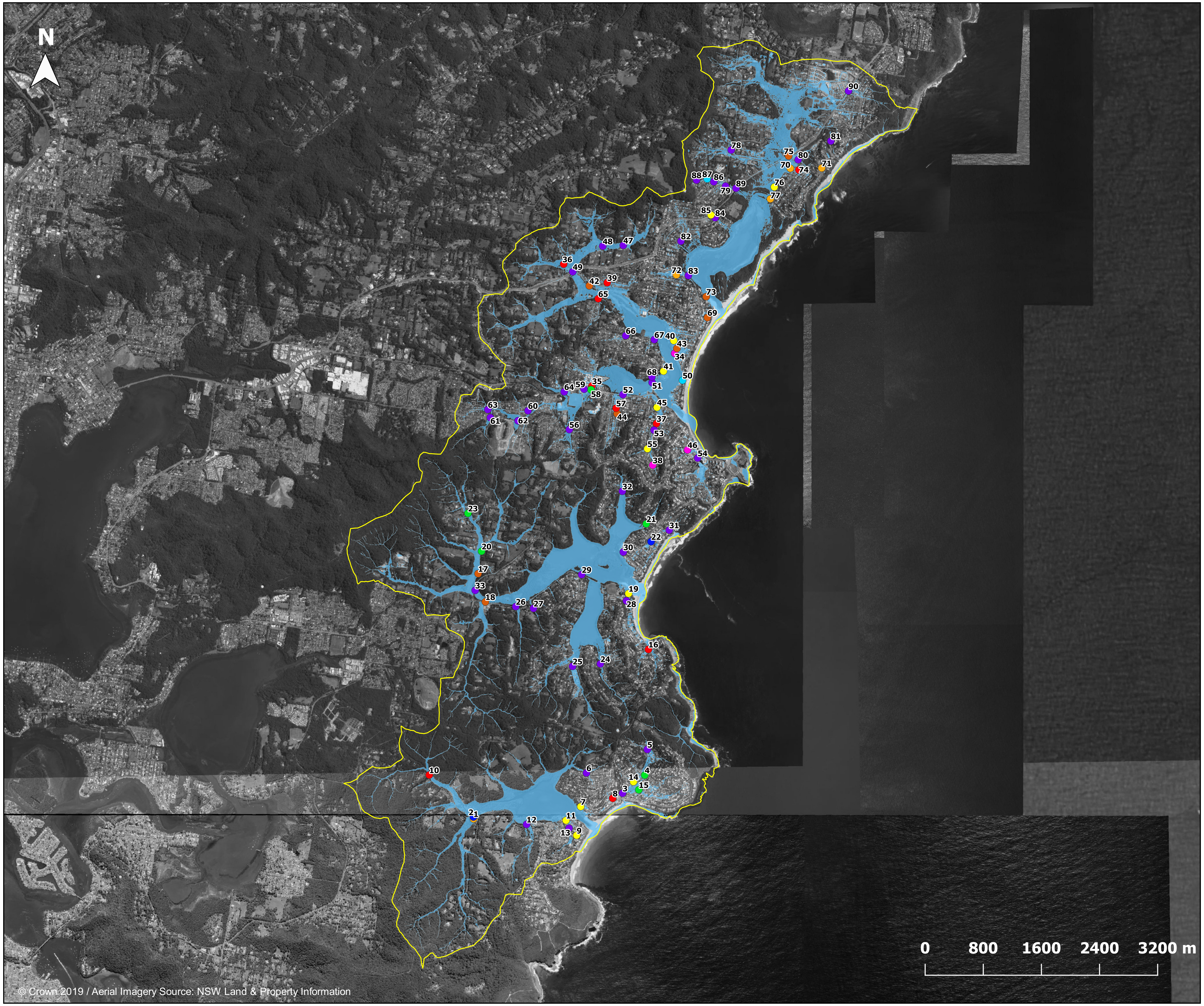

Figure 11.2

Road Closure Locations

Legend

- 1% AEP Flood Extent
- Study area

Road Closure from

- PMF
- 1 in 500 AEP
- 1 in 200 AEP
- 1% AEP
- 2% AEP
- 5% AEP
- 10% AEP
- 20% AEP
- 50% AEP

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Table 11.2 – Peak depth, duration of flooding over 0.3m and time to depth above 0.3m at road closure location

Road ID	First AEP to flood	Catchment	Peak Depth (m)									Duration of Flooding over 0.3 m (hr)									Time to Depth above 0.3 m (hr)								
			PMF	1 in 500 AEP	1 in 200 AEP	1% AEP	2% AEP	5% AEP	10% AEP	20% AEP	50% AEP	PMF	1 in 500 AEP	1 in 200 AEP	1% AEP	2% AEP	5% AEP	10% AEP	20% AEP	50% AEP	PMF	1 in 500 AEP	1 in 200 AEP	1% AEP	2% AEP	5% AEP	10% AEP	20% AEP	50% AEP
1	5%	Cockrone	1.35	0.62	0.55	0.49	0.41	0.30	0.26	0.22	0.00	1.92	2.08	1.42	0.58	0.33	0.08	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	1in500	Cockrone	1.52	0.33	0.28	0.24	0.19	0.13	0.11	0.09	0.00	1.50	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.23	0.27	0.28	0.32	0.37	0.58	0.75	1.75
3	PMF	Cockrone	1.69	0.20	0.18	0.16	0.14	0.08	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	1.50	1.92	2.08	2.17	3.08	4.58	0.00	0.00
4	1%	Cockrone	0.77	0.36	0.33	0.32	0.29	0.25	0.23	0.21	0.15	1.75	0.33	0.33	0.17	0.00	0.00	0.00	0.00	0.00	0.42	1.42	2.00	2.08	2.08	0.00	0.00	0.00	0.00
5	PMF	Cockrone	0.43	0.18	0.16	0.14	0.12	0.10	0.07	0.00	0.00	1.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.93	1.58	1.67	1.67	2.42	3.67	0.00	0.00
6	PMF	Cockrone	0.36	0.18	0.15	0.14	0.12	0.11	0.08	0.06	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	2%	Cockrone	1.50	0.37	0.36	0.34	0.33	0.17	0.15	0.13	0.00	1.58	0.50	0.42	0.42	0.33	0.00	0.00	0.00	0.00	0.17	0.33	0.38	0.00	0.00	0.00	0.00	0.00	0.00
8	20%	Cockrone	0.98	0.66	0.63	0.61	0.57	0.51	0.47	0.41	0.18	2.25	2.83	2.17	3.00	2.08	1.50	0.58	0.83	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	2%	Cockrone	1.49	0.54	0.47	0.42	0.37	0.26	0.26	0.21	0.14	3.83	2.25	1.92	0.83	0.50	0.00	0.00	0.00	0.00	0.21	0.37	0.40	0.43	0.00	0.00	0.00	0.00	0.00
10	20%	Cockrone	1.43	0.76	0.69	0.65	0.58	0.43	0.40	0.31	0.11	2.00	2.00	1.58	0.58	0.42	0.25	0.25	0.08	0.00	0.29	0.67	1.75	2.42	3.75	0.00	4.17	0.00	0.00
11	2%	Cockrone	1.54	0.42	0.41	0.39	0.37	0.25	0.25	0.17	0.06	2.08	1.33	1.67	1.08	0.92	0.00	0.00	0.00	0.00	0.29	0.65	0.87	2.25	2.50	2.00	4.00	0.00	0.00
12	PMF	Cockrone	0.35	0.13	0.11	0.11	0.09	0.07	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	2.17	3.08	0.00	0.00	0.00	0.00	0.00	0.00
13	PMF	Cockrone	1.16	0.27	0.26	0.26	0.25	0.23	0.23	0.21	0.18	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	2.83	3.25	4.25	4.67	0.00	0.00	0.00	0.00
14	2%	Cockrone	2.12	0.49	0.44	0.41	0.36	0.29	0.26	0.22	0.12	2.17	0.67	0.50	0.50	0.33	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	1%	Cockrone	2.09	0.42	0.37	0.33	0.29	0.21	0.17	0.13	0.07	2.00	0.42	0.33	0.25	0.00	0.00	0.00	0.00	0.00	1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	20%	Avoca	1.25	0.73	0.67	0.62	0.55	0.43	0.44	0.42	0.22	2.50	2.92	2.92	3.58	2.92	1.67	0.83	0.46	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	10%	Avoca	3.13	1.97	1.85	1.65	1.13	0.60	0.69	0.00	0.00	2.50	3.17	3.00	3.83	3.50	2.50	1.50	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	10%	Avoca	2.35	0.56	0.45	0.38	0.36	0.26	0.32	0.12	0.00	2.33	2.17	1.83	2.08	1.42	0.00	0.50	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	2%	Avoca	1.44	0.42	0.36	0.38	0.35	0.26	0.20	0.16	0.15	2.42	1.00	0.83	0.83	1.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	1%	Avoca	1.91	0.64	0.52	0.30	0.00	0.00	0.00	0.00	0.00	2.50	1.92	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	1%	Avoca	1.04	0.41	0.34	0.29	0.21	0.07	0.00	0.07	0.00	1.58	0.17	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	1in500	Avoca	0.57	0.29	0.25	0.24	0.18	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	1%	Avoca	1.04	0.41	0.37	0.33	0.26	0.12	0.11	0.10	0.00	1.58	0.17	0.13	0.08	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	PMF	Avoca	0.51	0.22	0.19	0.18	0.14	0.07	0.00	0.06	0.00	1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.33	0.33	0.42	0.42	0.33	0.83	0.75	0.00
25	PMF	Avoca	0.61	0.10	0.08	0.07	0.00	0.00	0.06	0.00	0.00	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	2.58	2.75	4.17	4.58	0.00	0.00	0.00	0.00
26	PMF	Avoca	0.70	0.16	0.14	0.13	0.12	0.09	0.05	0.05	0.00	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	PMF	Avoca	0.39	0.21	0.20	0.19	0.19	0.15	0.13	0.14	0.09	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.67	0.75	0.83	0.92	1.92	0.00	0.00	0.00
28	PMF	Avoca	0.94	0.18	0.17	0.15	0.13	0.11	0.00	0.00	0.00	1.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58	0.58	0.67	0.00	0.00	0.00	0.00	0.00
29	PMF	Avoca	0.95	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	PMF	Avoca	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.42	0.50	0.50	0.58	0.00	0.00	0.00	0.00
31	PMF	Avoca	0.64	0.16	0.14	0.13	0.12	0.10	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	PMF	Avoca	0.84	0.16	0.14	0.12	0.10	0.08	0.05	0.06	0.00	1.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.25	0.27	0.30	0.33	0.38	0.45	0.75	0.00
33	PMF	Avoca	0.66	0.17	0.13	0.06	0.00	0.00	0.00	0.00	0.00	1.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58	0.58	0.67	0.00	0.00	0.00	0.00	0.00
34	50%	Terrigal	2.77	1.31	1.27	1.07	1.00	0.60	0.55	0.52	0.45	2.75	4.00	4.00	3.67	4.50	1.67	2.00	1.83	5.25	0.33	0.50	0.50	0.58	0.58	0.50	1.00	1.00	0.00
35	20%	Terrigal	2.24	1.02	0.91	0.82	0.56	0.51	0.41	0.36	0.14	2.75	3.17	3.08	2.92	3.08	2.33	2.17	1.17	0.00	0.25	0.42	0.50	0.50	0.58	0.00	0.00	0.00	0.00
36	20%	Terrigal	2.02	0.48	0.46	0.44	0.41	0.37	0.34	0.30	0.21	2.67	1.42	1.17	1.08	2.00	1.00	0.25	0.04	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37	20%	Terrigal	1.34	0.73	0.68	0.64	0.59	0.52	0.46	0.40	0.28	2.42	2.00	1.75	1.67	2.58	1.50	0.67	0.46	0.00	0.33	0.50	0.58	0.58	0.67	0.00	0.00	0.00	0.00
38	50%	Terrigal	1.36	0.93	0.89	0.86	0.80	0.72	0.67	0.66	0.56	2.67	2.33	2.25	2.08	3.00	2.50	4.00	3.33	1.25	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	20%	Terrigal	1.68	0.59	0.55	0.52	0.47	0.40	0.35	0.30	0.16	2.83	1.75	1.42	1.25	0.71	0.50	0.29	0.08	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	2%	Terrigal	2.21	0.75	0.71	0.51	0.44	0.09	0.00	0.00	0.00	2.50	3.33	3.25	2.00	2.08	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41	2%	Terrigal	2.30	0.84	0.81	0.61	0.54	0.26	0.22	0.15	0.00	2.67	3.50	3.42	2.67	3.00	0.00	0.00	0.00	0.00	0.21	0.33	0.38	0.38	0.50	0.00	0.00	0.00	0.00
42	10%	Terrigal	1.79	1.07	0.98	0.87	0.50	0.40	0.33	0.29	0.17	2.50	2.50	2.25	2.08	2.50	1.83	1.00	0.00	0.00	0.58	1.00	1.04	0.00	0.00	0.00	0.00	0.00	0.00
43	10%	Terrigal	2.41	0.95	0.91	0.71	0.64	0.33	0.31	0.28	0.19	2.75	3.92	3.67	3.17	4.00	1.17	0.83	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44	10%	Terrigal	1.19	0.50	0.47	0.45	0.41	0.37	0.33	0.30	0.12	2.00	1.17	0.92	0.58	0.46	0.33	0.21	0.00	0.00	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	2%	Terrigal	1.35	0.61	0.52	0.45	0.36	0.22	0.13	0.11	0.00	2.33	0.92	0.75	0.67	0.38	0.00	0.00	0.00	0.00	1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	50%	Terrigal	2.22	0.96	0.90	0.85	0.77	0.68	0.62	0.54	0.39	2.83	4.25	3.50	3.17	3.25	2.67	3.17	2.00	0.54	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47	PMF	Terrigal	0.37	0.13	0.12	0.11	0.10	0.09	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48	PMF	Terrigal	0.22	0.10	0.09	0.09	0.07	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	PMF	Terrigal	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Road ID	First AEP to flood	Catchment	Peak Depth (m)									Duration of Flooding over 0.3 m (hr)									Time to Depth above 0.3 m (hr)								
			PMF	1 in 500 AEP	1 in 200 AEP	1% AEP	2% AEP	5% AEP	10% AEP	20% AEP	50% AEP	PMF	1 in 500 AEP	1 in 200 AEP	1% AEP	2% AEP	5% AEP	10% AEP	20% AEP	50% AEP	PMF	1 in 500 AEP	1 in 200 AEP	1% AEP	2% AEP	5% AEP	10% AEP	20% AEP	50% AEP
50	1in200	Terrigal	1.90	0.44	0.40	0.20	0.13	0.00	0.00	0.00	0.00	2.33	1.33	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.83	2.08	2.25	0.00	0.00	0.00	0.00	0.00
51	PMF	Terrigal	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.33	0.38	0.42	0.46	0.50	0.58	0.75	0.00
52	PMF	Terrigal	1.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
53	PMF	Terrigal	0.52	0.19	0.17	0.16	0.14	0.10	0.08	0.06	0.00	1.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	PMF	Terrigal	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.21	0.21	0.25	0.25	0.25	0.25	0.46	0.58
55	2%	Terrigal	1.02	0.45	0.41	0.38	0.34	0.29	0.26	0.25	0.10	1.83	0.54	0.46	0.46	0.29	0.00	0.00	0.00	0.00	0.21	0.33	0.33	0.38	0.42	0.46	0.50	0.71	0.00
56	PMF	Terrigal	0.41	0.15	0.13	0.12	0.11	0.09	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.75	0.79	1.04	1.13	0.00	0.00	0.00	0.00
57	20%	Terrigal	1.20	0.62	0.57	0.54	0.49	0.43	0.38	0.34	0.25	2.25	1.50	1.42	1.33	1.75	0.83	0.42	0.29	0.00	0.21	0.38	0.38	0.42	0.46	0.54	0.67	0.83	0.00
58	1%	Terrigal	1.81	0.54	0.41	0.31	0.11	0.08	0.00	0.00	0.00	2.25	0.58	0.33	0.08	0.00	0.00	0.00	0.00	0.00	0.29	0.33	0.33	0.54	0.54	2.17	3.17	3.83	7.00
59	PMF	Terrigal	1.37	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	PMF	Terrigal	1.14	0.12	0.11	0.11	0.10	0.09	0.08	0.08	0.00	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.50	0.54	0.54	0.58	0.67	0.79	1.00	0.00
61	PMF	Terrigal	1.00	0.14	0.13	0.13	0.12	0.00	0.00	0.00	0.00	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.46	0.50	0.54	0.58	0.67	0.79	1.04	0.00
62	PMF	Terrigal	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.29	0.29	0.33	0.38	0.46	0.54	0.71	0.83
63	PMF	Terrigal	0.65	0.17	0.15	0.15	0.14	0.12	0.11	0.00	0.00	1.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.63	0.71	0.75	0.88	0.00	0.00	0.00	0.00
64	PMF	Terrigal	0.49	0.20	0.19	0.18	0.16	0.13	0.06	0.05	0.00	1.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
65	20%	Terrigal	0.55	0.37	0.36	0.35	0.34	0.32	0.31	0.30	0.24	2.00	0.92	0.92	0.58	0.38	0.25	0.17	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66	PMF	Terrigal	0.29	0.13	0.11	0.11	0.10	0.08	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.71	0.75	0.79	0.83	0.96	1.17	0.00	0.00
67	PMF	Terrigal	1.56	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.50	0.54	0.58	0.67	0.00	0.00	0.00	0.00
68	PMF	Terrigal	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.33	0.38	0.42	0.46	0.54	0.63	0.00	0.00
69	10%	Wamberal	1.19	0.76	0.70	0.65	0.61	0.53	0.36	0.29	0.17	2.75	2.00	2.50	2.00	1.50	1.50	0.42	0.00	0.00	0.25	0.42	0.46	0.54	0.58	2.17	4.00	0.00	0.00
70	5%	Wamberal	2.13	0.76	0.68	0.59	0.48	0.36	0.21	0.20	0.18	2.50	1.33	1.25	1.17	0.92	0.58	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
71	5%	Wamberal	2.31	0.77	0.66	0.59	0.51	0.42	0.23	0.19	0.00	2.75	1.92	1.50	1.42	1.17	1.08	0.00	0.00	0.00	0.13	0.20	0.23	0.28	0.32	0.00	0.00	0.00	0.00
72	5%	Wamberal	1.09	0.57	0.57	0.53	0.49	0.40	0.24	0.18	0.10	2.58	1.50	1.17	1.08	0.92	0.92	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
73	10%	Wamberal	1.32	0.45	0.43	0.41	0.38	0.35	0.31	0.24	0.14	1.92	0.83	0.92	0.83	0.92	1.50	1.08	0.00	0.00	0.17	0.32	0.35	0.00	0.00	0.00	0.00	0.00	0.00
74	20%	Wamberal	1.87	0.74	0.74	0.71	0.68	0.62	0.50	0.46	0.37	2.83	2.08	2.67	2.58	2.67	2.33	3.33	2.42	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
75	10%	Wamberal	1.26	0.55	0.53	0.51	0.47	0.42	0.31	0.22	0.11	2.42	1.33	1.50	1.42	1.25	1.17	0.67	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
76	2%	Wamberal	1.90	0.56	0.50	0.42	0.33	0.22	0.00	0.00	0.00	2.33	1.08	0.92	0.75	0.33	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
77	5%	Wamberal	1.50	0.61	0.56	0.50	0.41	0.31	0.10	0.00	0.00	2.42	1.25	1.17	1.00	0.75	0.25	0.00	0.00	0.00	1.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
78	PMF	Wamberal	0.52	0.15	0.13	0.12	0.10	0.07	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
79	PMF	Wamberal	0.53	0.17	0.14	0.13	0.12	0.08	0.08	0.08	0.05	1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	PMF	Wamberal	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	1.25	1.83	1.92	1.83	2.67	0.00	0.00	0.00
81	PMF	Wamberal	0.55	0.20	0.18	0.16	0.15	0.13	0.11	0.10	0.00	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.27	0.30	0.32	0.37	1.83	0.71	0.00	0.00
82	PMF	Wamberal	0.31	0.13	0.11	0.10	0.09	0.06	0.06	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.42	0.48	0.57	1.50	2.17	0.00	0.00	0.00
83	PMF	Wamberal	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.28	0.32	0.35	1.42	2.08	0.00	0.00	0.00
84	PMF	Wamberal	0.58	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
85	2%	Wamberal	0.67	0.50	0.47	0.45	0.40	0.30	0.28	0.25	0.13	1.92	1.08	0.50	0.42	0.33	0.00	0.00	0.00	0.00	0.25	0.42	0.46	0.46	0.50	0.58	0.63	0.00	0.00
86	PMF	Wamberal	0.54	0.25	0.21	0.19	0.16	0.13	0.12	0.11	0.08	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
87	1in200	Wamberal	0.74	0.34	0.30	0.28	0.25	0.20	0.18	0.17	0.00	1.50	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
88	PMF	Wamberal	0.45	0.29	0.27	0.25	0.22	0.19	0.15	0.15	0.10	1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
89	PMF	Wamberal	0.49	0.27	0.24	0.23	0.21	0.18	0.12	0.10	0.00	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	1.33	1.92	2.00	1.92	2.83	0.00	0.00	0.00
90	PMF	Wamberal	0.54	0.20	0.17	0.15	0.13	0.09	0.07	0.06	0.00	1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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11.5 Preliminary flood damage assessment

11.5.1 General approach

The flood damage assessment has been undertaken using a step-by-step approach:

- Some floor level information was provided by Council (included in data handover). This information included 825 floor levels taken at the time of the previous FRMPs of the various lagoons.
- A number of properties located within the PMF extent did not have any floor level survey information and the floor level was therefore estimated by selecting the highest ground level for each building and assuming two 0.15m steps to the floor level (i.e. 0.30m).
- Building of less than 50m^2 were not included in the analysis as they are typically garages or sheds which would not have the same level of damages as a residential building.
- Some sensitivity was completed on the floor level by providing the flood damages assuming a single step to the floor level and three steps to the floor level.

It is noted that the provided flood damages are preliminary, and it is recommended to undertake a detailed floor level survey to provide a more accurate flood damage assessment as part of the floodplain risk management study.

11.5.2 Type of flood damage

The definitions and methodology used in estimating flood damages are well established. **Figure 11.2** summarises all the types of flood damages examined in this study. The two main categories are tangible and intangible damages. Tangible flood damages are those that can be more readily evaluated in monetary terms. Intangible damages relate to the social cost of flooding and therefore are much more difficult to quantify.

Tangible flood damages are divided further into direct and indirect damages. Direct flood damages relate to the loss or loss in value of an object or a piece of property caused by direct contact with floodwaters, flood-borne debris or sediment deposited by the flood. Indirect flood damages relate to loss in production or revenue, loss of wages, additional accommodation and living expenses, and any extra outlays that occur because of the flood.

11.5.3 Basis of flood damages calculations

Flood damages have been estimated by applying one of several stage-damage curves to every property included in the database. These curves relate the amount of flood damage that would potentially occur at different depths of inundation, for a particular property type, whether residential or commercial/industrial.

Residential damages

In October 2007, the then Department of Environment and Climate Change (now EES) released Guidelines to facilitate a standard methodology for assessing residential flood damages. This involves tailoring stage-damage data for the particular floodplain of interest and is recommended for use throughout NSW so that the results from one floodplain can be compared with another.

Inputs for the Coastal Lagoons study area are listed in **Table 11.3**, together with explanations for each selection. The resultant stage-damage data are provided in **Appendix N** of this report.

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It is noted that the EES residential stage-damage curves make allowance for both clean-up costs ($4,000 per flooded house) and the cost of time in alternative accommodation. Based on previous experience on past studies, an allowance of 5% has been applied for additional indirect costs for the residential sector for this study. The flood damages curve of low set properties was adjusted to start generating damages from 100mm below floor level instead of 500mm.

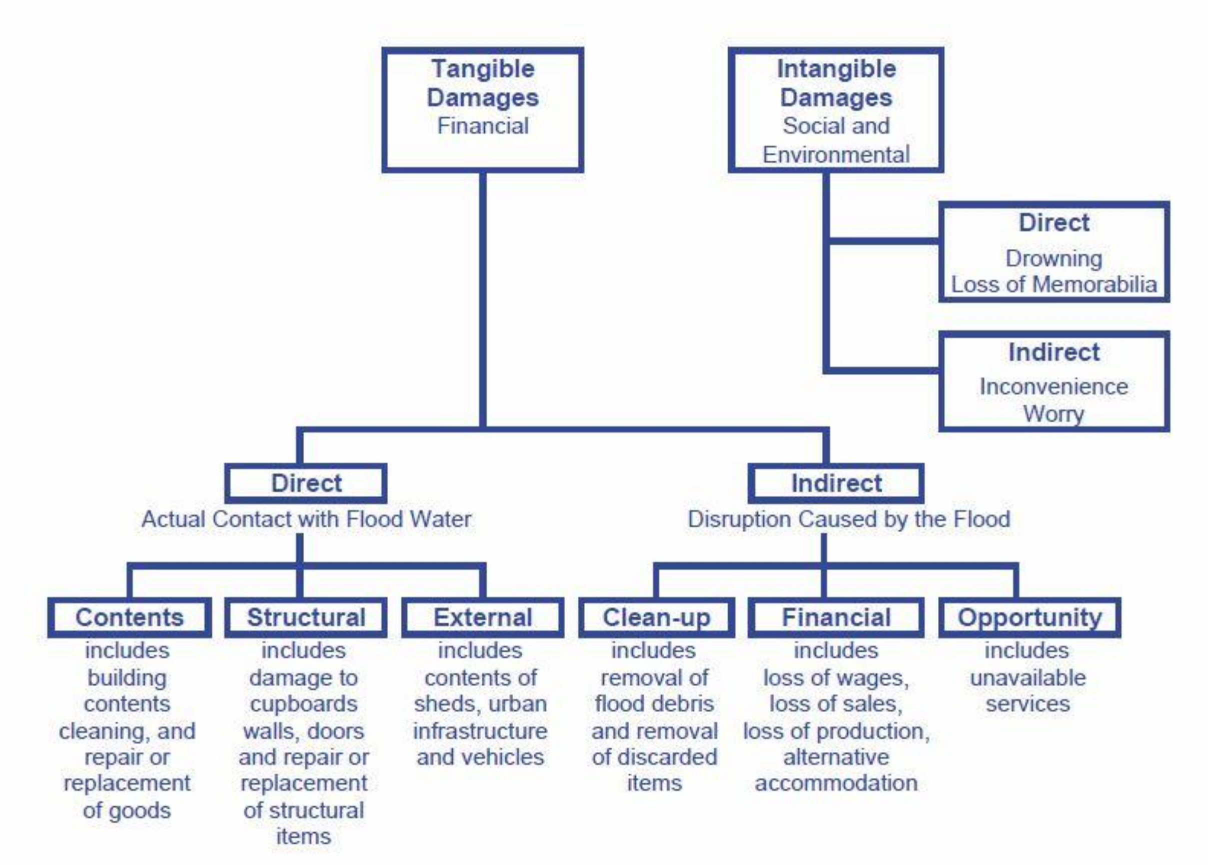

Figure 11.2 – Types of flood damage
Source: Floodplain Development Manual (NSW Government, 2005)

Table 11.3 - Input variables for residential damages assessment

Input	Value	Explanation
Regional Cost Variation Factor	1.0	Rawlinsons
Post late 2001 adjustments	1.83	Changes in AWE from Nov 2001 to May 2019
Post Flood Inflation Factor	1.40	Regional city
Typical Duration of Immersion	1 hour	Flash flooding scenario
Building Damage Repair Limitation Factor	0.85	Short duration
Typical House Size	210 m^2 (Avoca) 225 m^2 (Terrigal) 180 m^2 (Cockrone) 220 m^2 (Wamberal)	Based on median size of the properties
Contents Damage Repair Limitation Factor	0.75	Short duration

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Level of Flood Awareness	Low	
Effective Warning Time	0 hour	Flash flooding scenario with small catchments
Typical Table/Bench Height	0.90	Standard
External Damage	$6,700	Standard
Clean-up costs	$4,000	Standard
Likely Time in Alternative Accommodation	3 weeks	Typically shallow flooding
Additional Accommodation Costs	$220	Standard

Commercial/Industrial damages

No standard stage-damage curves have been issued for commercial and industrial damages. The stage-damage relationships used to estimate these damages in this study are based on investigations by Water Studies (1992) and incorporated into waterRIDE. Stage-damage data were factored up to 2019 values using changes in Average Weekly Earnings (AWE). The stage-damage data are reported in $/m^2 for each of six value categories (see **Appendix N**). Research suggests that commonly adopted commercial and industrial stage-damage data may err on the low side, particularly for places where there are several specialist stores likely to contain higher-value contents that the shops – predominantly from inland NSW towns – where the damage data was first derived.

Based on previous experience on past studies, an allowance of 50% for indirect costs for the commercial sector – covering clean-up costs and disruption to trade – was deemed appropriate.

The buildings selected as commercial/industrial were estimated from the aerial photograph and Google Earth information. They typically include the main commercial areas and CBDs, however, a number of additional properties may be classified as commercial and the commercial damages are therefore indicative only.

Other damages

In some previous floodplain risk management studies, EES has advised that damages to infrastructure (roads, etc.) be estimated as 15% of total direct residential and commercial/ industrial damages. This allowance has been included as a separate item for this study.

A number of studies also include basic stage-damage assumptions to cater for damage to motor vehicles. However, EES has made clear that damages to vehicles should not influence the BCR of potential flood reducing measures, which are particularly intended to address damages to houses and to a lesser extent, businesses (and associated livelihoods). Accordingly, no allowance has been made to assess damage to vehicles for this study.

Flooding can have various impacts on people's health, both physical and emotional. These include stress-related ailments, influenza, viral infections, heart problems and back problems (from lifting and cleaning). Although it is difficult to quantify the cost of disruption, illness, injury and hospitalisation, in keeping with advice previously received from EES, social damages have been estimated (as a separate item) as 25% of 'total damages', which are interpreted as the sum of direct residential damages and direct non-residential damages.

Damage mapping

Maps summarising the results of the flood damage assessment for both residential and commercial/industrial are presented in **Appendix N**. The damages are colour coded and

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results are provided for the AAD at each lagoon. These maps identify key areas where high damage is occurring and hence, highlights areas where future management options are likely to have a significant beneficial impact.

11.5.4 Economic analysis

An economic appraisal is required for all proposed capital works in NSW, including flood mitigation measures, in order to attract funding from the State Government's Capital Works Program. The NSW Government has published two Treasury Policy Papers to guide this process: *NSW Government Guidelines for Economic Appraisal* (NSW Treasury, 2007) and a summary in *Economic Appraisal Principles and Procedures Simplified* (NSW Treasury, 2007).

An economic appraisal is a systematic means of analysing all the costs and benefits of a variety of proposals. In terms of flood mitigation measures, benefits of a proposal are generally quantified as *the avoided costs associated with flood damages*. The avoided costs of flood damage are then compared to the capital (and on-going) costs of a particular proposal in the economic appraisal process.

Average annual damage (AAD) is a measure of the cost of flood damage that could be expected each year by the community, on average. It is a convenient yardstick to compare the economic benefits of various proposed mitigation measures with each other and the existing situation. **Figure 11.3** describes how AAD relates to actual flood losses recorded over a long period. For the current study, AAD is assessed using the potential damages derived for each design event and represents the area under the curve generated by these potential damages illustrated in **Figure 11.4**. It is assumed that damages to buildings can commence at the 50% AEP event; the PMF is set to an ARI of once in 100,000 years.

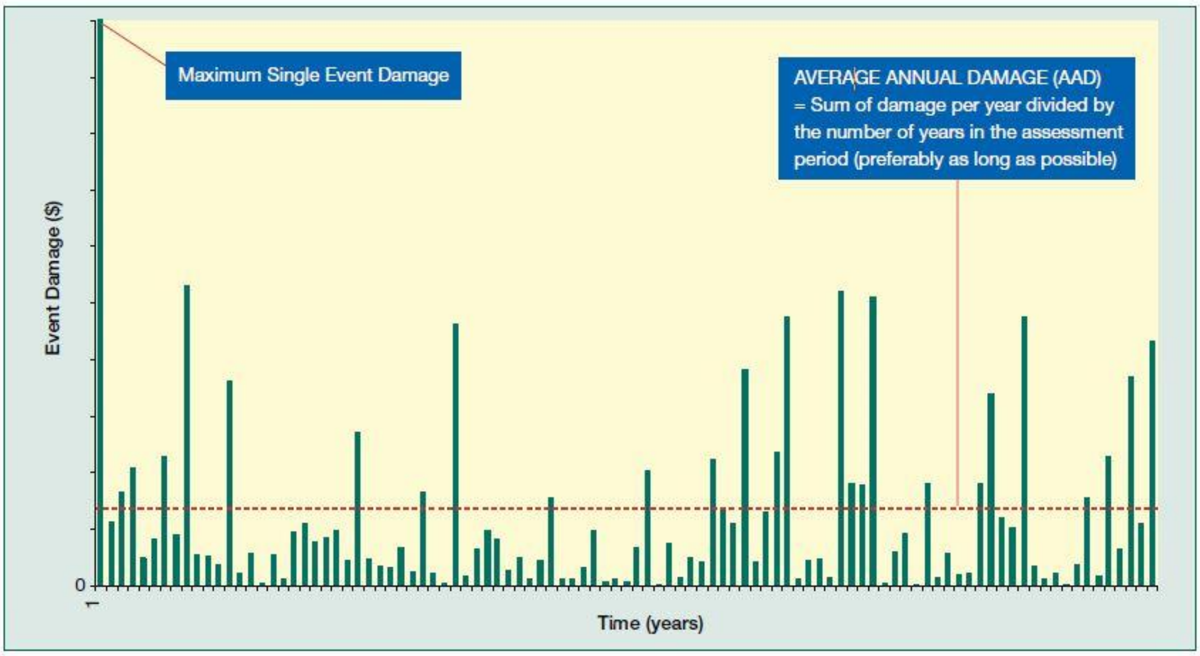

Figure 11.3 – Randomly occurring flood damage as annual average damage

Source: *Managing Flood Risk through Planning Opportunities* (HNFMSC, 2006)

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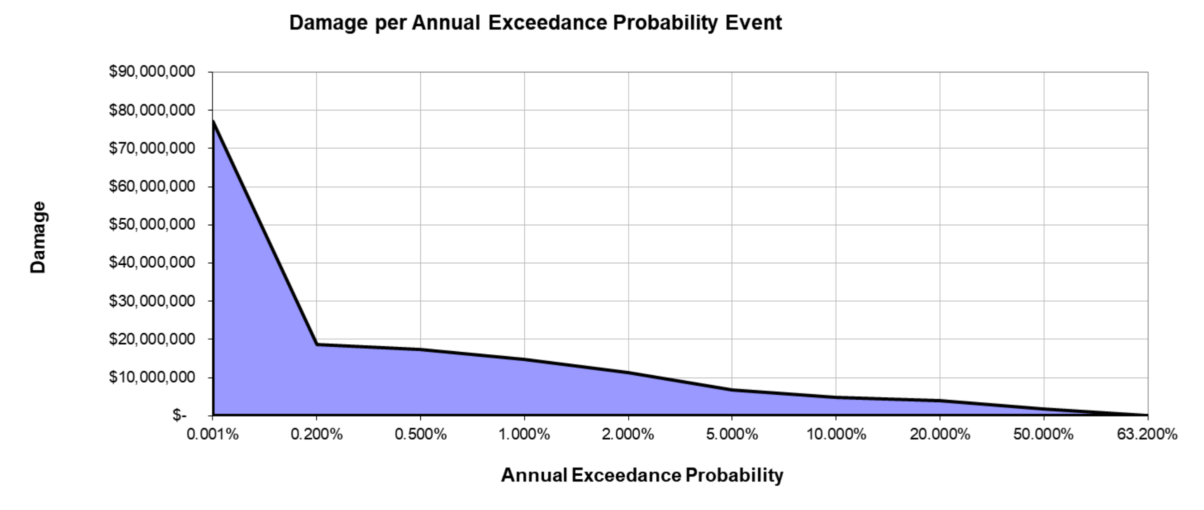
Figure 11.4 – Example of AAD estimation based on events annual exceedance probability and associated damages at Wamberal



The present value of flood damage is the sum of all future flood damages that can be expected over a fixed period (usually 50 years) expressed as a cost in today's value. The present value is determined by discounting the future flood damage costs back to the present-day situation, using a discount rate (typically 7%).

A flood mitigation proposal may be considered to be potentially worthwhile if the benefit–cost ratio (the present value of benefits divided by the present value of costs) is greater than 1.0. In other words, the present value of benefits (in terms of flood damage avoided) exceeds the present value of (capital and on-going) costs of the project.

However, whilst this direct economic analysis is important, it is not unusual to proceed with urban flood mitigation schemes largely on social grounds, that is, on the basis of the reduction of intangible costs and social and community disruption. In other words, the benefit–cost ratio could be calculated to be less than 1.0.

11.6 Summary of flood damages

Calculated flood damages and AAD for the Coastal Lagoons study area are presented in **Table 11.4** to **Table 11.11**. Sensitivity analysis of the flood damages using 1 and 3 steps to floor level is presented in **Appendix N**. Results are described below:

Avoca Lagoon

- The 20% AEP flood is expected to cause damages of $6.4 million;
- The 1% AEP flood is expected to cause damages just over $23.0 million;
- The annual average damage within the study area is about $3.51 million, which is a measure of the cost of flood damage that could be expected each year, on average, by the community;
- The flood with the highest contribution to the AAD is the 20% AEP flood event followed by the 10% AEP flood event;
- The net present value of damages (discounted at 7% over a 50-year period) is $52.0 million, which represents the maximum sum that could be spent on flood mitigation

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measures if an economic benefit/cost ratio of 1.0 is required and all flood damages can be avoided. The reality is that mitigation works to address damages from events as rare as the PMF are rarely pursued;

- The largest contributor to flood damages is direct residential damage that contributes 65% of the damages followed by social damage that contributes 17%.
- It is important to note that conservative assumptions have been adopted for the floor level (i.e. 300mm above ground level). Following the sensitivity analysis with 1 step and 3 steps, the AAD ranges between $2.13M and $6.44M and the NPV between $31.5M and $95.3M.

Cockrone Lagoon

- The 20% AEP flood is expected to cause damages of $2.9 million;
- The 1% AEP flood is expected to cause damages just over $9.5 million;
- The annual average damage within the study area is about $1.66 million, which is a measure of the cost of flood damage that could be expected each year, on average, by the community;
- The flood with the highest contribution to the AAD is the 20% AEP flood event followed by the 10% AEP flood event;
- The net present value of damages (discounted at 7% over a 50-year period) is $24.6 million, which represents the maximum sum that could be spent on flood mitigation measures if an economic benefit/cost ratio of 1.0 is required and all flood damages can be avoided. The reality is that mitigation works to address damages from events as rare as the PMF are rarely pursued;
- The largest contributor to flood damages is direct residential damage that contributes 69% of the damages followed by social damage that contributes 17%.
- It is important to note that conservative assumptions have been adopted for the floor level (i.e. 300mm above ground level). Following the sensitivity analysis with 1 step and 3 steps, the AAD ranges between $0.85M and $3.79M and the NPV between $12.6M and $56.1M.

Terrigal Lagoon

- The 20% AEP flood is expected to cause damages of $13.6 million;
- The 1% AEP flood is expected to cause damages just over $37.1 million;
- The annual average damage within the study area is about $7.53 million, which is a measure of the cost of flood damage that could be expected each year, on average, by the community;
- The flood with the highest contribution to the AAD is the 20% AEP flood event followed by the 10% AEP flood event;
- The net present value of damages (discounted at 7% over a 50-year period) is $111.5 million, which represents the maximum sum that could be spent on flood mitigation measures if an economic benefit/cost ratio of 1.0 is required and all flood damages can be avoided. The reality is that mitigation works to address damages from events as

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rare as the PMF are rarely pursued;

- The largest contributor to flood damages is direct residential damage that contributes 63% of the damages followed by social damage that contributes 17%.
- It is important to note that conservative assumptions have been adopted for the floor level (i.e. 300mm above ground level). Following the sensitivity analysis with 1 step and 3 steps, the AAD ranges between $4.95M and $13.33M and the NPV between $73.3M and $197.3M.

Wamberal Lagoon

- The 20% AEP flood is expected to cause damages of $5.8 million;
- The 1% AEP flood is expected to cause damages just over $21.3 million;
- The annual average damage within the study area is about $3.37 million, which is a measure of the cost of flood damage that could be expected each year, on average, by the community;
- The flood with the highest contribution to the AAD is the 20% AEP flood event followed by the 10% AEP flood event;
- The net present value of damages (discounted at 7% over a 50-year period) is $49.9 million, which represents the maximum sum that could be spent on flood mitigation measures if an economic benefit/cost ratio of 1.0 is required and all flood damages can be avoided. The reality is that mitigation works to address damages from events as rare as the PMF are rarely pursued;
- The largest contributor to flood damages is direct residential damage that contributes 69% of the damages followed by social damage that contributes 17%.
- It is important to note that conservative assumptions have been adopted for the floor level (i.e. 300mm above ground level). Following the sensitivity analysis with 1 step and 3 steps, the AAD ranges between $1.53M and $10.09M and the NPV between $22.6M and $149.4M.

General observation

- Residential damages are typically the largest contributor to the total flood damages.
- Terrigal is the lagoon with the largest amount of damage with almost double of the damage generated by the second lagoon (Wamberal) and Cockrone Lagoon has the lowest amount of damage.
- The large damage obtained in Terrigal is largely due to the entrance conditions being conservative and assuming inability for Council to proceed with the opening of the lagoon due to severe weather or other potential reason.
- The assumed floor level has a significant impact on the flood damages, particularly for the residential damages. Changing the floor level by ±0.15m can almost half or double to damage value. It is therefore important to complete a detailed floor level survey to obtain more accurate flood damage results as part of the next step of the floodplain risk management process.

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Table 11.4 ‑ Summary of flood damage by design event for Avoca Lagoon catchment assuming 2 steps to floor level where no floor level data was available

Flood Event	Number of Impacted Properties+		Direct Damage Only ($2019)		Total Predicted Actual Damage ($2019)#	Total Average Annual Damage ($2019)*	Total Net Present Value of Damage ($2019)*
	Residential	Commercial	Residential	Commercial			
PMF	892	104	$68.1M	$5.1M	$108.4M	$0.14M	$2.0M
1 in 500 AEP	238	39	$17.1M	$2.4M	$29.4M	$0.08M	$1.2M
1 in 200 AEP	209	30	$14.7M	$2.2M	$25.5M	$0.12M	$1.8M
1% AEP	181	25	$13.1M	$2.1M	$23.0M	$0.21M	$3.0M
2% AEP	144	16	$10.1M	$1.8M	$18.1M	$0.42M	$6.2M
5% AEP	94	9	$6.6M	$0.1M	$9.7M	$0.42M	$6.2M
10% AEP	66	9	$4.8M	$0.1M	$7.1M	$0.67M	$10.0M
20% AEP	63	7	$4.3M	$0.1M	$6.4M	$1.30M	$19.3M
50% AEP	22	0	$1.6M	$0.0M	$2.3M	$0.15M	$2.2M
TOTAL	**892**	**104**	**$140.4M**	**$13.9M**	**$230.0M**	**$3.51M**	**$52.0M**

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years
# Includes residential direct and indirect, commercial direct and indirect, infrastructure and social damages
+ Residential properties have been separated into building where multiple buildings are on the same property and commercial properties into separate businesses. However, where commercial buildings are the same company (e.g. industrial area with 5 warehouse or caravan park) the damages were consolidated as one property.

Table 11.5 – Components of flood damage for Avoca Lagoon catchment assuming 2 steps to floor level where no floor level data was available (AAD)

	Damage Component	Method Assessed	Number of Impacted Properties	Cost ($2019)	
A.	Direct Residential Damage	DECC (2007) curves	892	$2,294K	65%
B.	Indirect Residential Damage	5% of A	892	$115K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	104	$97K	3%
D.	Indirect Commercial Damage	50% of C	104	$48K	1%
E.	Infrastructure Damage	15% of (A + C)	N/A	$359K	10%
F.	Social Damage	25% of (A + C)	N/A	$598K	17%
	TOTAL AAD			**$3,511K**	100%

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Table 11.6 - Summary of flood damage by design event for Cockrone Lagoon catchment assuming 2 steps to floor level where no floor level data was available

Flood Event	Number of Impacted Properties+		Direct Damage Only ($2019)		Total Predicted Actual Damage ($2019)#	Total Average Annual Damage ($2019)*	Total Net Present Value of Damage ($2019)*
	Residential	Commercial	Residential	Commercial			
PMF	506	7	$36.1M	$0.3M	$52.8M	$0.07M	$1.0M
1 in 500 AEP	155	0	$9.5M	$0.0M	$13.8M	$0.04M	$0.6M
1 in 200 AEP	128	0	$7.7M	$0.0M	$11.2M	$0.05M	$0.8M
1% AEP	112	0	$6.6M	$0.0M	$9.5M	$0.09M	$1.3M
2% AEP	88	0	$5.2M	$0.0M	$7.6M	$0.19M	$2.9M
5% AEP	62	0	$3.7M	$0.0M	$5.4M	$0.24M	$3.6M
10% AEP	50	0	$2.9M	$0.0M	$4.3M	$0.36M	$5.3M
20% AEP	36	0	$2.0M	$0.0M	$2.9M	$0.57M	$8.4M
50% AEP	10	0	$0.6M	$0.0M	$0.9M	$0.06M	$0.9M
TOTAL	**506**	**7**	**$74.4M**	**$0.3M**	**$108.4M**	**$1.66M**	**$24.6M**

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years
# Includes residential direct and indirect, commercial direct and indirect, infrastructure and social damages
+ Residential properties have been separated into building where multiple buildings are on the same property and commercial properties into separate businesses. However, where commercial buildings are the same company (e.g. industrial area with 5 warehouse or caravan park) the damages were consolidated as one property.

Table 11.7 – Components of flood damage for Cockrone Lagoon catchment assuming 2 steps to floor level where no floor level data was available (AAD)

	Damage Component	Method Assessed	Number of Impacted Properties	Cost ($2019)	
A.	Direct Residential Damage	DECC (2007) curves	506	$1,145K	69%
B.	Indirect Residential Damage	5% of A	506	$57K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	7	$0.3K	0%
D.	Indirect Commercial Damage	50% of C	7	$0.1K	0%
E.	Infrastructure Damage	15% of (A + C)	N/A	$172K	10%
F.	Social Damage	25% of (A + C)	N/A	$286K	17%
	TOTAL AAD			**$1,660K**	100%

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Table 11.8 – Summary of flood damage by design event for Terrigal Lagoon catchment assuming 2 steps to floor level where no floor level data was available

Flood Event	Number of Impacted Properties+		Direct Damage Only ($2019)		Total Predicted Actual Damage ($2019)#	Total Average Annual Damage ($2019)*	Total Net Present Value of Damage ($2019)*
	Residential	Commercial	Residential	Commercial			
PMF	1891	56	$159.7M	$8.8M	$248.3M	$0.30M	$4.5M
1 in 500 AEP	473	16	$36.0M	$1.6M	$55.2M	$0.15M	$2.3M
1 in 200 AEP	402	16	$30.4M	$1.5M	$46.9M	$0.21M	$3.1M
1% AEP	319	9	$24.2M	$1.1M	$37.1M	$0.34M	$5.0M
2% AEP	253	6	$19.5M	$0.9M	$30.1M	$0.75M	$11.2M
5% AEP	172	4	$13.1M	$0.6M	$20.2M	$0.88M	$13.0M
10% AEP	126	3	$9.5M	$0.6M	$14.9M	$1.43M	$21.1M
20% AEP	114	3	$8.7M	$0.5M	$13.6M	$3.04M	$45.0M
50% AEP	55	2	$4.0M	$0.5M	$6.6M	$0.44M	$6.5M
TOTAL	**1891**	**56**	**$305.1M**	**$16.0M**	**$472.9M**	**$7.53M**	**$111.5M**

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years
# Includes residential direct and indirect, commercial direct and indirect, infrastructure and social damages
+ Residential properties have been separated into building where multiple buildings are on the same property and commercial properties into separate businesses. However, where commercial buildings are the same company (e.g. industrial area with 5 warehouse or caravan park) the damages were consolidated as one property.

Table 11.9 – Components of flood damage for Terrigal Lagoon catchment assuming 2 steps to floor level where no floor level data was available (AAD)

	Damage Component	Method Assessed	Number of Impacted Properties	Cost ($2019)	
A.	Direct Residential Damage	DECC (2007) curves	1891	$4,779K	63%
B.	Indirect Residential Damage	5% of A	1891	$239K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	56	$319K	4%
D.	Indirect Commercial Damage	50% of C	56	$159K	2%
E.	Infrastructure Damage	15% of (A + C)	N/A	$765K	10%
F.	Social Damage	25% of (A + C)	N/A	$1,274K	17%
	TOTAL AAD			**$7,535K**	100%

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Table 11.10 – Summary of flood damage by design event for Wamberal Lagoon catchment assuming 2 steps to floor level where no floor level data was available

Flood Event	Number of Impacted Properties[+]		Direct Damage Only ($2019)		Total Predicted Actual Damage ($2019)[#]	Total Average Annual Damage ($2019)*	Total Net Present Value of Damage ($2019)*
	Residential	Commercial	Residential	Commercial			
PMF	1016	5	$77.2M	$1.2M	$114.1M	$0.14M	$2.1M
1 in 500 AEP	321	1	$18.7M	$0.7M	$28.4M	$0.08M	$1.2M
1 in 200 AEP	252	0	$17.4M	$0.0M	$25.3M	$0.12M	$1.7M
1% AEP	215	0	$14.7M	$0.0M	$21.3M	$0.19M	$2.8M
2% AEP	164	0	$11.4M	$0.0M	$16.5M	$0.39M	$5.8M
5% AEP	101	0	$6.7M	$0.0M	$9.7M	$0.41M	$6.1M
10% AEP	71	0	$4.7M	$0.0M	$6.8M	$0.63M	$9.4M
20% AEP	61	0	$4.0M	$0.0M	$5.8M	$1.24M	$18.4M
50% AEP	26	0	$1.7M	$0.0M	$2.4M	$0.16M	$2.4M
TOTAL	**1016**	**5**	**$156.5M**	**$1.8M**	**$230.3M**	**$3.37M**	**$49.9M**

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years
[#] Includes residential direct and indirect, commercial direct and indirect, infrastructure and social damages
[+] Residential properties have been separated into building where multiple buildings are on the same property and commercial properties into separate businesses. However, where commercial buildings are the same company (e.g. industrial area with 5 warehouse or caravan park) the damages were consolidated as one property.

Table 11.11 – Components of flood damage for Wamberal Lagoon catchment assuming 2 steps to floor level where no floor level data was available (AAD)

	Damage Component	Method Assessed	Number of Impacted Properties	Cost ($2019)	
A.	Direct Residential Damage	DECC (2007) curves	1016	$2,319K	69%
B.	Indirect Residential Damage	5% of A	1016	$116K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	5	$3K	0%
D.	Indirect Commercial Damage	50% of C	5	$1K	0%
E.	Infrastructure Damage	15% of (A + C)	N/A	$348K	10%
F.	Social Damage	25% of (A + C)	N/A	$581K	17%
	TOTAL AAD			**$3,368K**	100%

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12. Information to support decisions on activities in the floodplain and managing flood risk

12.1 Flood planning area

The flood planning area (FPA) is the area of land subject to flood related development controls and as such determines whether a parcel of land is a flood control lot. It was defined as a combination of the extent of the 1% AEP flood event including an increase in rainfall intensity of 30% (for the overland flooding) and the 1% AEP flood level with a freeboard of 500mm (for the mainstream flooding). This criterion was adopted following discussion with Council and is based on analysis completed in previous studies such as the Northern Lakes Floodplain Risk Management Study and Plan currently being finalised and other studies completed within Central Coast Council LGA.

The 1% AEP with an increase in rainfall intensity of 30% criteria appears more appropriate than adding a 0.5m freeboard followed by stretching of the elevated water level in the upper reaches as the majority of the 1% AEP flooding is relatively shallow and stretching this elevated flood level would significantly alter the extent of the flood planning area and may propagate it beyond the PMF extent.

The FPA is mapped for each lagoon in **Figures O.1 to O.4** in **Appendix O**. Maps at 1:5,000 scale of the flood planning area for each of the four lagoons are presented in **Figure R.33** to **Figure R.36** of **Appendix R.** It is noted that the mapped extents are subject to the same filtering as all design event mapping as described in **Section 9.2.1** and that ocean foreshore have not been included in the FPA.

Once the FPA defined, a freeboard of 0.3 to 0.5m can then be applied by Council on the 1% AEP design event to obtain a minimum floor level (MFL) or floor hazard level (FHL) for properties within the FPA. A 0.5m freeboard can be applied to the mainstream flooding area (i.e. the lagoons propagating to the confluences of the tributaries) and the 0.3m freeboard can be applied for overland flooding.

For this study, the mainstream flooding was defined as the extent reached by the flood level in the lagoon during a 1% AEP event with a freeboard of 500mm. The rest of the catchment would be considered as overland.

The FHL is also influenced by a number of other factors including:

- Berm levels: managed berm levels have a significant influence on the flood levels in the lagoons as highlighted in **Section 8.1**. An additional freeboard of 0.2m was added to the FHL and was considered a realistic accuracy of the managed berm level.
- Climate change: in accordance to Council's existing climate change policy, a 0.2m additional freeboard should be added to consider climate change for residential developments in areas subject to climate change influence. **Section 8.4** highlights that flood levels within Terrigal Lagoon are largely influenced by climate change.

While more detailed FHL will be defined as part of the floodplain risk management study stage, a preliminary differentiation between the two freeboard is illustrated in **Figures O.5 to O.8** in **Appendix O**. Maps at 1:5,000 scale of the preliminary freeboard recommendation for

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each of the four lagoons are presented in **Figure R.37** to **Figure R.40** of **Appendix R.** It is noted that the ocean foreshore has not been included in these figures. **Table 12.1** summarises the changes in MFL/FHL between the past FRMP studies and the current study for each of the four lagoons. It is noted that the MFL/FHL remains similar within the four lagoons.

The following comments should also be considered when defining FHL:

- It is recommended to set the FHL of properties with flood emergency response classification categorised as “low flood islands” and “low trapped perimeters” (as defined in the following section) to the PMF level.
- This study focused on flooding level in the four lagoons’ catchments which does not include oceanic or coastal inundation extents. As such, FHL in areas described as impacted by “ocean inundation” in the existing floodplain management plans should not be modified.

Table 12.1 – Lagoon MFL/FHL comparison between current study and past FRMP studies

Lagoon	Current Study FHL* (m AHD)	Past FRMP MFL** (m AHD)
Avoca Lagoon	3.70	3.70
Cockrone Lagoon	4.32	4.30
Terrigal Lagoon	3.38	3.40
Wamberal Lagoon	3.64	3.60

** Includes freeboard and additional freeboard due to sensitivity to climate change and berm level.*

*** minimum floor level for catchment related event within the lagoon, excluding increased values due to oceanic inundation near the lagoon entrance.*

12.2 Flood emergency response classification

In order to assist in the planning and implementation of response strategies, the NSW SES in conjunction with EES developed guidelines to classify communities according to the ease of evacuation (DECC, 2007). The guidelines classify communities as either ‘Flood Islands’ (either ‘High Flood Island’ if isolated but not flooded or ‘Low Flood Island’ if first isolated then flooded), ‘Trapped Perimeter’ (either ‘High’ if isolated but not flooded or ‘Low’ if first isolated then flooded), ‘Overland Escape Route’ (people can walk to nearby road or refuge above flood level), Rising Road Access or Indirectly Affected areas.

Some consideration has been given to building locations on a block affected by flooding, but no consideration has been given to building styles. A raised building effectively represents a Low Flood Island if the floor level is not above PMF. Or a raised building may facilitate shelter-in-place where the floor level is above PMF and the structure can withstand PMF forces (effectively representing a High Flood Island). Mapping Flood Emergency Response Planning classes is to a degree a subjective exercise. Nevertheless, it serves to highlight areas most at risk in the event of severe flooding where people fail to evacuate early or shelter in houses is unsuitable for that purpose.

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Summary of the Flood Emergency Response Classification is presented in **Appendix P**. It can be noted that the vast majority of the flood affected properties have a rising road classification or overland escape route classification. This is primarily due to the fact the study area is relatively low-lying and overland flows generate shallow ponding. Such shallow depths allow local residents to evacuate either by car or by foot should the depth increase. A number of properties are also classified as high trapped perimeter areas during a 1%AEP and PMF due to access roads being cut during large to extreme event.

12.3 Land-use planning considerations

A key objective of the study is to provide better flood information to support land use planning activities in the study area.

Use of the latest hydraulic categories and hazard information would allow a more informed decision on potential land uses based on existing constraints.

Two main types of flooding occur within the four coastal lagoons catchments: overland flooding and lagoon flooding.

It has become more common to vary the freeboard to be used to define the floor planning level based on the type of flooding and the type of land use. Potential land use type that could have different freeboard may include:

- Critical and Vulnerable Uses: such land use may require stricter freeboard or planning restriction
- Subdivision and all Residential Uses: this type of use can use the more typical freeboard values with potentially slightly lower freeboard values for overland flooding rather when compared to lagoon flooding.
- Business and Industrial Uses: type of commercial land use should be considered. For example, driveways, loading docks and other equivalent trafficked areas may not require strict freeboard restriction.
- Recreational and Environmental Uses: Reduced freeboard may be applied to such uses (e.g. parks, ovals)
- Concessional Uses: Such land use type may be treated separately should the certain properties require specific freeboard due to special use requiring more or less protection.

Climate change should also be taken into consideration when planning the land use. It is noted that the areas subject to overland flooding may be impacted by slightly elevated levels due to increase in rainfall intensities while properties subject of the lagoon flooding may be more impacted by rising sea level (particularly around Terrigal Lagoon).

12.4 Pipe capacity

Pipe capacity was mapped to informed decision-makers in Council to understand were the drainage network could be improved. Pipe capacity maps for all design event for all four lagoons are provided in **Appendix Q**. It can be noted that some areas are reaching capacity of the pipe in events as early as the 50% AEP flood event (particularly in the lower sections of the catchment) and that the general network starts to be strained from the 5% to 2% AEP flood events for all lagoons.

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12.5 Rate of rise and timing of flooding

Rate of rise and timing of flooding is an important information for emergency services to understand how much response time is available for the community. The average rate of rise and time to peak for the 1% AEP was calculated for each lagoon for both the shorter (overland) and longer (mainstream) durations. Results are mapped in **Appendix S**. Given the large number of properties in the four catchments, a spreadsheet presenting the key timing parameters at the various building located within the four lagoons catchments has been provided as a stand-alone document.

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13. Peer review

13.1 Summary of the review

Peer review was completed internally all along the development of the study and at the end of the study. The objective of the peer review was to assess key assumptions, procedures and conclusions.

To achieve this, the following flood study attributes were reviewed:

- Hydrological
  - Hydrological Model
  - Sub-Catchments
  - Rainfall IFD
  - Losses
  - Impervious Areas
  - Critical Durations
- Hydraulic
  - Hydraulic Model
  - Digital Elevation Model (DEM)
  - Model grid size
  - Roughness values
  - Major structures
  - Blockages
  - Boundary conditions
  - Time Step
  - Mass Error
  - Calibration / Validation of Model
- Hazard and Hydraulic categories
- Emergency Response Classifications
- Flood Planning Area
- Preliminary Flood Damage Assessment

13.2 Results of the review

13.2.1 Hydrological model

Model selection

The 2017 version of WBNM was applied. This model was the latest available at the time and is suitable for such hydrologic modelling as it includes the rainfall pattern ensembles capabilities as per the AR&R2019 guidelines.

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Sub-catchments

The models utilise 22 sub-catchments for Avoca Lagoon, 16 for Cockrone Lagoon, 20 for Terrigal Lagoon and 15 for Wamberal Lagoon. The number of sub-catchments and their sizes is considered suitable for rainfall representation over the catchments.

Rainfall IFD

Intensity-Frequency-Duration (*IFD*) parameters were obtained from the Bureau of Meteorology (BoM) via the use of the Storm Injector software. This would have been based on the latest IFD available as per AR&R2019 recommendations. Limited information was provided on the comparison between the 1987 and 2016 IFDs. This was added into the report.

Losses

Continuing losses of 2.9mm/hr were applied for this study. This rate of losses is reasonable and are values recommended by the AR&R2019 Data Hub. Initial losses of 15mm were used. While this differs from the Data Hub values, it has been selected based on available rainfall and water level data which is a suitable approach for losses determination. Both initial and continuing losses lead to appropriate calibration of the model and are therefore considered adequate for this study. However, it was found that losses of Terrigal downstream catchments have been mis-entered in the hydrological model which lead to longer critical durations. This was corrected and the model and associated mapping was adjusted accordingly.

Impervious areas

Catchments with no urban areas were assigned 0% impervious and catchments with urban areas were assigned a % impervious accordingly. This was appropriate considering the catchment changes since the original model.

Critical durations

Two critical duration were selected for each lagoon. One longer duration based on the downstream end of the catchment to represent the lagoon critical duration and one shorter duration based on a selected representative “flashy” and urban upstream catchment. This approach was deemed appropriate to represent overland and mainstream flooding. The representative catchment selection was reviewed, and the original Terrigal upstream catchment was found to not be the most representative. This was corrected to a more appropriate catchment with flashy behaviour.

13.2.2 Hydraulic model

Model selection

1D/2D hydraulic model TUFLOW was used to model the study area. TUFLOW is a widely renowned and utilised model for flood studies. The original model was constructed using the original TUFLOW. Given the very long run-times and the latest improvement in the HPC (heavily parallelised compute) version of TUFLOW, the model was converted into an HPC model to make run-time more manageable, particularly during the calibration process. The latest version of TUFLOW available at the time was used for the four lagoon models.

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Digital elevation model (DEM)

The elevation data used in the four lagoon models was Lidar survey completed in July 2017. This appears adequate for overland flow representation. It was noted that some areas may have been developed since then and this has been mentioned in the report.

Model grid size

A grid size of 2m by 2m was adopted for this study. This is commonly used for overland flood studies as it is a size balancing run time and representation of floodplain features. It is considered appropriate.

Roughness values

Roughness values used in this study are varying based on depth of flooding and values adopted are consistent with common flood modelling practice.

Major structures

Key culverts and bridges were reviewed. Major bridges have been modelled as losses which is common practice in TUFLOW models and considered appropriate. Review highlighted that a culvert under The Entrance Road was misrepresented and flow capacity was reduced. This was corrected accordingly. Moreover, one key pit downstream of the CBD area in Terrigal Lagoon catchment was found to have an erroneous invert leading to some reduction in drainage capacity and this was corrected accordingly.

Blockages

Blockages of the pits and pipes system were found to be misrepresented.

Blockages were adjusted using blockage conditions based on AR&R 2019 and the AR&R Project 11. The first document provides a blockage assessment form that suggests blockages for major cross-structure. Other pits and pipes structures have been applied a blockage as described in Project 11.

Boundary conditions

Boundary conditions were using direct rainfall methodology and varying tailwater conditions. Direct rainfall has been using the rainfall obtained from the hydrologic model. Tailwater conditions have been using the OEH 2015 recommendations. Both approaches are standard practice and appropriate for such flood study.

The berm initial condition was a key factor in the flood behaviour of the lagoons and was originally defined as a single trigger opening. As a result of the peer review, the entrance conditions were adjusted to include a staged breakout behaviour to better represent the opening of the lagoon.

Time steps

Time steps are flexible and controlled by TUFLOW HPC. The timestep typically reduces to about 10 time the initial timestep that was set between 0.5 and 1s for the different lagoons. The timestep appears to remain above this value for most runs with the time step occasionally dropping to lower values for brief periods of time before increasing again. This is happening particularly during extreme events such as the PMF event. Overall the timestep appears adequate.

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Mass error

Cumulative mass error at the end of the simulation were typically of less than 0.04% with a few longer duration runs (downstream 50% AEP or 20% AEP) reaching errors between 0.07% and 0.12%. It is expected that even these highest values should not significantly impact the model.

Calibration/Validation of model

Calibration and validation were completed using three events for each lagoon and results of the calibration appeared to indicate that the four lagoons models were appropriate for the purpose of this study. Limited information was provided on the flow and volume calibration. This was corrected.

Climate change modelling

Climate change was modelled using two main criteria: increase in rainfall intensity (by 10%, 20% and 30%) and increase in sea levels (by 0.2m, 0.39m and 0.74m). Analysed of each component of climate change separately provides a clear indication of the influence of each factor.

13.2.3 Modelling results

Hazard and Hydraulic categories

Hazard categories have been defined using both the NSW Floodplain Development Manual categories (Low and High) and the latest Flood Life Hazard categories (H1-H6). These approaches are the latest standards in hazard definition and results map appeared appropriate. Hydraulic categories have been defined using criteria consistent with the Northern Lakes FRMSP which is a similar type of catchment with Central Coast Council.

Preliminary Flood Damage Assessment

Preliminary flood damages assessment was completed assuming a 2 step (or 0.30m) between the ground and the floor level for properties with no floor level information. Given the uncertainty, it was suggested to provide some sensitivity using 1 and 3 steps in addition to the 2 steps approach.

Flood Planning Area

Flood planning area was defined as the 1% AEP flood event with an increase in rainfall intensity of 30%. This method is becoming more and more used by Councils around NSW for overland flood studies and is deemed appropriate. Minimum floor levels and freeboard requirements have been developed in close communication with Council. It was recommended to use the 500mm freeboard for the 1% AEP lagoon level in combination to the 1% AEP with 30% increase in rainfall intensity and the FPA maps have been updated accordingly.

Emergency Response Classifications

The emergency response classifications (ERC) have been completed using the 2007 Floodplain Emergency Response Planning Classification of Community Floodplain Risk Management Guideline from the then Department of Environment & Climate Change (DECC). While these guidelines are being replaced by the Australian Institute for Disaster Resilience Flood Emergency Response Classification of the Floodplain guidelines (2014),

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the various categories from the 2007 guidelines represent the same categories as the 2014 guidelines with different names and more granularity. For example, low flood island or low trapped perimeter in the 2007 guidelines are both Flooded Isolated and Submerged (FIS) in the 2014 guidelines. A number of categories were adjusted and the overall classifications appear sensible.

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14. Conclusions

The Coastal Lagoons Catchments Overland Flood Study has been completed to provide a detailed flooding assessment of Avoca Lagoon, Cockrone Lagoon, Terrigal Lagoon and Wamberal Lagoon. The key components of the flooding assessment included:

- Review of available data
- Community consultation
- Hydrological analysis and modelling
- Hydraulic analysis and modelling
- Sensitivity analysis including climate change impact
- Flood mapping
- Description of consequences of flooding
- Development of a draft flood study following by a final flood study

The flood maps appended to this report are presenting the flood levels, depths and velocities for the critical duration and rainfall pattern of a full set of events including the 50%, 20%, 10%, 5%, 2%, 1%, 1 in 200, 1 in 500 AEP and PMF events and represent an envelope of the critical duration/pattern of a selected representative upstream catchment and the critical duration/pattern at the lagoon. The upper catchments are very flashy with very short critical durations of less than 2h to reach the peak level while the downstream catchments (lagoons), have typical critical durations ranging between 2h and 12h. The mapping is also based on a non-mechanical breakout and on the assumption that the entrance berm is at the managed level, to consider the fact that mechanical opening of the lagoon may sometimes not be practical during severe storms.

Sensitivity analysis highlighted the following points:

- The lower catchments of the four lagoons are highly sensitive to the berm level at the time of the flood and maintaining the berm at a set level would minimise the risk of the lagoon reaching very high levels should mechanical opening of the berm not be possible during a storm.
- Tailwater conditions (including sea level rise) typically have minimal impact on most lagoons flooding given the managed berm elevations. Only very large increases in tailwater levels such as the 0.74m sea level rise scenario would influence the lagoon level. The exception is Terrigal Lagoon that has a relatively low managed berm level and changes in tailwater level would have significant impact on the lagoon level as elevated ocean levels would flow into the lagoon. This identifies a significant potential issue with flooding becoming more common in Terrigal with rising sea level.
- Increase in rainfall intensity due to climate change may exacerbate the overland flooding but would typically have a relatively low impact on the lagoon level.
- Changes in roughness or antecedent conditions of the catchment (wet/dry catchment leading to varying losses) could have minor to moderate impacts on the overland

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flooding.

- Blockages of structures can have severe impact in areas with no gravity flow that only relies on the drainage network (e.g. ponding area) and maintaining the pits and pipes network is essential to avoid exacerbating the flooding in such location.

The above results allowed the definition of the flood hazard (including provisional hazard and flood life hazard categories) and hydraulic categories in the four catchments. These have been created and mapped to inform development control planning.

Results of the model allow the identification of main flooding areas, key infrastructure impacted by flooding and road closures around the catchments. Key infrastructure typically may have access issues during severe flood events rather than flooding issues, except during the PMF event.

Similarly, road closures predominantly occur on secondary roads with most of the major road closures occurring for the PMF only. It is also noted that given the flashy behaviour of the catchment, flooding and road closure in the upper catchment would be of relatively short duration while flooding of the areas surrounding the lagoons may last for several hours.

A preliminary flood damage assessment was also completed, and it was found that close to 4,400 properties are located within the PMF extent. The largest amount of damage occurs in Terrigal Lagoon catchment and the lowest amount in Cockrone Lagoon catchment. However, it is noted that limited floor level survey information was available, and it is recommended that a more detailed flood damage assessment be developed based on a floor level survey of the various properties located within the PMF extent during the next stage of the floodplain risk management process. It is also noted that the flood damages are based on the conservative modelling of the entrance berm assuming a non-mechanical entrance breakout. Although council has a mechanical opening policy, it may not always be possible due to various reasons such as rapid rainfall and severe weather conditions. The damage is therefore likely to reduce should the entrance be opened at a lower lagoon level. This is particularly true for Terrigal Lagoon given the very low level of the berm. It is also important to note that should the berm not be maintained to the managed level and build up to higher levels, higher lagoon levels would occur and therefore higher associated damages.

The results were also utilised to guide planning and emergency response by providing the flood planning area and preliminary emergency response classifications mapping to assist NSW SES during flood event. The majority of the properties are located in areas where evacuation by car or by foot is possible or where flooding does not occur, but access is cut.

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15. Recommendations

The following actions are recommended:

- Information, outcomes and results of this study should be incorporated in future entrance opening strategies and protocols.
- Modelling results will allow predictive tools such as the MHLFIT to more accurately account for inflows.
- Existing Floodplain Risk Management Plans are to be reviewed with respect to minimum floor levels i.e. flood hazard levels (FHL).
- Flood hazard levels defined as:
  - Overland flow FHL: 1%AEP plus 0.30 m freeboard
  - Mainstream FHL: 1% AEP plus 0.50 m freeboard plus 0.20 m berm management for all lagoons plus an additional 0.20 m (minimum) for SLR up to 0.74 m commensurate to the asset life - refer Brisbane Water Foreshore Floodplain Risk Management Plan (Cardno, 2015).
- Flood Control Lots are to be determined by the Flood Planning Areas (FPA) for the Overland, Mainstream durations and PMF.
- Council to consider seeking funding to complete and implement a flood education strategy that would incorporate a flood audit of individual properties that would include floor level acquisition or update from DA and education response using predictive tools such as the existing MHLFIT.
- Future flood risk management plan to update damages AAD based on more accurate information.
- Council to review asset management program to ensure pipe capacity is optimized in the drainage network.
- Continue operational funding for water recorders and MHLFIT tools, including review and training of staff and state agencies such as SES.
- Community education of entrance openings and consequences of inappropriate opening regimes or ad hoc timing should be included in overall education.
- Council to ensure that the berm level of each lagoon is kept at the maintenance level.

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17.Glossary

Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. Eg, if a peak flood discharge of 500 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 events occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrence of a flood as big as or larger than the selected event. For example, floods with a discharge as great as or greater than the 20-year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Berm Level/Berm Height	Level of the sand at the entrance of a waterbody
Design Blockage	Blockage is an obstruction which makes movement of flood water or flow through a drainage system difficult or impossible. Design blockage is the blockage obtained following the Australian Rainfall and Runoff 2019 recommendations. Blockage is defined as a percentage of reduction in flow capacity through a drainage structure (e.g. pit, pipe, culvert, bridge, etc.)
Double Design Blockage	Minimum of double of the design blockage or 100% blockage (i.e. fully blocked)
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.
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.
Consent Authority	The council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the council, however legislation or an EPI may specify a Minister or public authority (other than a council), or the Director General of OEH, as having the function to determine an application.
Defined flood event (DFE)	The flood event selected for the management of flood hazard for the location of specific development as determined by the appropriate authority.

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Defined flood level (DFL)	The flood level associated with a defined flood event (DFE) relative to a specified datum. The DFL plus the freeboard determines the extent of the flood hazard area.
Development	"Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). Infill Development: refers to development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. New Development: refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. Redevelopment: refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services."
Disaster Plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (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 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.
ESD	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act, 1993. The use of sustainability and sustainable in this manual relate to ESD.
Finished floor level	The uppermost surface of the finished floor, not including any floor covering such as carpet, tiles and the like.
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.

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Flood Awareness	Awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
Flood Control Lot	Property (or Lot) located within the flood planning area and subject to flood-related development controls.
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 Hazard Area (FHA)	the area (whether or not mapped) encompassing land lower than the flood hazard level (FHL) which has been determined by the appropriate authority. The area relates to that part of the allotment on which a building stands or is to be erected.
Flood Hazard Level (FHL)	The flood level used to determine the height of floors in a building and represents the defined flood level (DFL) plus the freeboard.
Flood Liable Land	Is synonymous with flood prone land, i.e., land susceptible to flooding by the PMF event. Note that the term flood liable land covers the whole floodplain, not just that part below the FPL (see flood planning area).
Flood Planning Area	Area that defines when a property is classified as a flood control lot.
Flood Planning Levels (FPLs)	Are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans.
Flood Prone Land	Land susceptible to flooding by the PMF event. Flood prone land is synonymous with flood liable land.
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 Readiness	Readiness is an ability to react within the effective warning time.
Flood Risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. Existing Flood Risk: the risk a community is exposed to as a result of its location on the floodplain. Future Flood Risk: the risk a community may be exposed to as a result of new development on the floodplain. Continuing Flood Risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

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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.
Flood Study	Is a technical investigation of flood behaviour in the study area. It describes the extent, depth and velocity of flood waters as well as the variation in flood hazard during a range of historical as well as hypothetical 'design' floods. The 'design' floods are based on statistical analysis of flooding that has occurred in the past.
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.
Floodway Areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Freeboard	Provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
Hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this study the hazard is flooding which has the potential to cause damage to the community.
Historical Flood	A flood which has actually occurred.
Hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
Hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
Hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
Local Drainage	Smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
Local Overland Flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

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Mainstream Flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
Major Drainage	"Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purposes of this manual major drainage involves: The floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or Water depths generally in excess of 0.3m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or Major overland flowpaths through developed areas outside of defined drainage reserves; and/or The potential to affect a number of buildings along the major flow path."
Managed Berm Level	Level at which the sand berm is managed by Council to prevent continuous build up to levels that may exacerbate flood risk to residents around the lagoon.
Minimum Floor Level (MFL)	Minimum floor level at which a building should be constructed. Also named Flood Hazard Level (FHL).
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.
Probability	A statistical measure of the expected chance of flooding (see annual exceedance probability).
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

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	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.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
Stage	Equivalent to water level (both measured with reference to a specified datum).
Stage Hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
Survey Plan	A plan prepared by a registered surveyor.
TUFLOW	A 1-dimensional and 2-dimensional flood simulation software. It simulates the complex movement of floodwaters across a particular area of interest using mathematical approximations to derive information on floodwater depths, velocities and levels.
Velocity	The speed or rate of motion (distance per unit of time, e.g., metres per second) in a specific direction at which the flood waters are moving.
Water Surface Profile	A graph showing the flood stage at any given location along a watercourse at a particular time.

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Appendix A – Pits and pipes inspection

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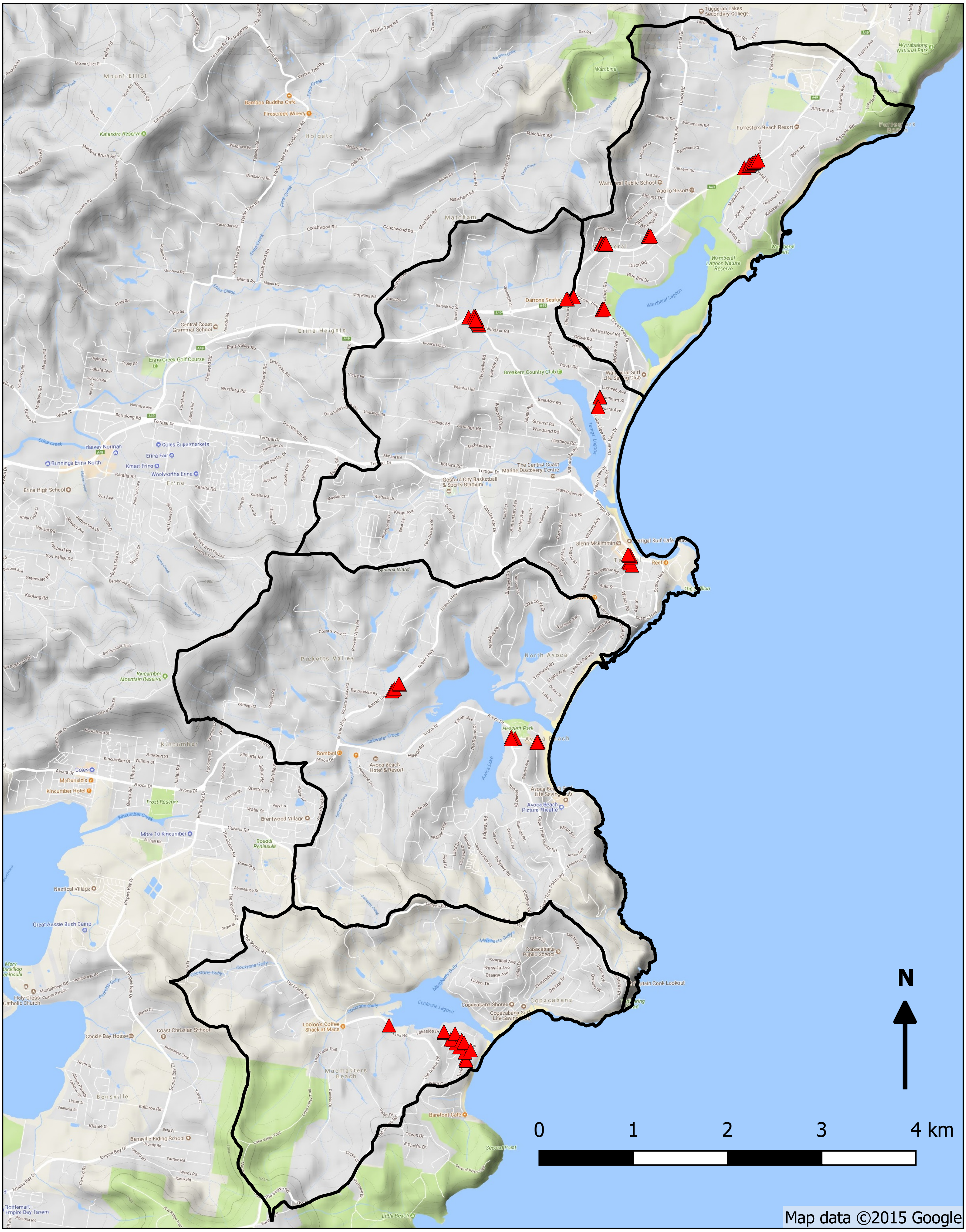

Coastal Lagoon Catchments - Overland Flood Study

Legend

▲ Inspected Pits & Pipes

Figure XXXX

Pit & Pipe Inspection

Pit and Pipe Inspection Comparison - Sample Locations Only

Coastal Lagoon Catchments Overland Flood Study

	Pit Depths				Pipe Diameters		
ID	Modelled (Provided)	Modelled (Estimated)	Measured	% Difference (modelled to measured)	Modelled (Provided)	Measured	% Difference (modelled to measured)
HW_4100		1.23				450	
Pits_15583	1.00		0.70	143%	450	450	100%
HW_7997		1.45				700x1500	
HW_4097		1.45				225	
HW_5705_1		1.30				(2x) 1500x750	
HW_7996_1		1.30				(3x) 1500x750	
Pits_6212	0.90		2.00	45%	450		
Pits_13470	0.90		0.50	180%	450		
Pits_6216	0.70		0.70	100%	375	375	100%
Pits_15584	0.60		0.90	67%	375	450	83%
Pits_16807		1.08	0.70	154%	375		
Pits_12302		1.08	0.50	215%	375		
Pits_2210		1.08	0.50	215%	375	250	150%
Pits_6856		1.08	0.75	143%	375	375	100%
Pits_11851	1.00		1.10	91%	450	450	100%
Pits_11852	1.00		1.30	77%	450	525	86%
Pits_11853	1.00		1.50	67%	600	525	114%
Pits_3387	3.00		3.00	100%	600		
Pits_11854	3.00		2.70	111%	600		
Pits_10458	2.00		2.25	89%	600		
Pits_937	2.00		2.35	85%	450		
Pits_10455	2.00		2.20	91%	600		
Pits_10456	2.00		2.25	89%	600		
Pits_4214	2.00		2.40	83%	600		
Pits_15672	2.00		1.10	182%	600		
Pits_11295	2.00		1.15	174%	600	375	160%
Pits_11297		1.08	1.10	98%	375		
Pits_11296		1.08	1.15	93%	375		
Pits_10454		1.08	0.70	154%	375		
Pits_935		1.08	0.45	239%	375		
Pits_15726		1.23	0.52	236%	525		
Pits_6813		1.23	0.60	204%	375		
Pits_13765		1.23	0.55	223%	525	375	140%
Pits_13767		1.23	0.60	204%	525		
Pits_6777		1.08	0.95	113%	375	375	100%
Pits_6778	1.00		1.75	57%	450		
Pits_6781	1.00		1.10	91%	600		
Pits_6784	1.00		1.15	87%	600		
Pits_18083		1.15	0.95	121%	375		
Pits_18082	2.72		2.50	109%	750		
Pits_18081	2.82		2.65	106%	525		
Pits_18080	1.84		1.75	105%	525		
Pits_6587	1.70		1.50	113%	750		
Pits_18079	1.43		1.30	110%	450		
Pits_6588	1.70		1.50	113%	750		
Pits_18086	1.70		1.65	103%	750		
Pits_18085	3.61		3.55	102%	900		
Pits_6592	1.00		3.30	30%	900		
Pits_18089	2.66		3.50	76%	1050		
Pits_18088	2.58		2.55	101%	1050		
Pits_15663	2.58		2.60	99%	1050		

Pits_20991		1.15	1.50	77%	450		
Pits_20992		1.15	1.60	72%	450		
Pits_6545	1.87		1.15	163%	450		
Pits_15651		1.08	0.80	134%	375		
Pits_20644		1.08	1.35	80%	375		
Pits_20645		1.08	1.20	90%	375		
Pits_20592		1.08	1.30	83%	375		
Pits_20589		1.08	1.20	90%	375		
Pits_20586		1.08	1.10	98%	375		
Pits_20584		1.08	1.20	90%	375		
Pits_13643	2.00		0.50	400%	375		
Pits_31532	1.85		0.80	231%	375		
Pits_31533	2.04		1.30	157%	375		
Pits_39584		1.08			375		
Pits_39583		1.08	1.10	98%	375		
Pits_39582		1.08	1.25	86%	375		
Pits_39575		0.93	1.00	93%	225		
Pits_39581		1.08	1.60	67%	375		
Pits_39574		1.08	1.20	90%	375		
Pits_39586		1.08	1.00	108%	375		
Pits_39580		1.08	2.00	54%	375		
Pits_39579		1.08	1.20	90%	375		
Pits_39647		1.75	1.90	92%	1050		
Pits_39576		1.08	2.65	41%	375		
Pits_39577		1.08	0.70	154%	375		
Pits_39578		1.08	1.10	98%	375		

Pit and Pipe Inspection Comparison - Sample Locations Only

Coastal Lagoon Catchments Overland Flood Study

	Pit Depths				Pipe Diameters		
ID	Modelled (Available)	Modelled (Estimated)	Measured	% Difference (modelled to measured)	Modelled (Available)	Measured	% Difference (modelled to measured)
HW_4100		1.23				450	
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Pits_13470	0.90		0.50	180%	450		
Pits_6216	0.70		0.70	100%	375	375	100%
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Pits_11851	1.00		1.10	91%	450	450	100%
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Pits_18089	2.66		3.50	76%	1050		
Pits_18088	2.58		2.55	101%	1050		
Pits_15663	2.58		2.60	99%	1050		

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Pits_20991		1.15	1.50	77%	450			
Pits_20992		1.15	1.60	72%	450			
Pits_6545	1.87		1.15	163%	450			
Pits_15651		1.08	0.80	134%	375			
Pits_20644		1.08	1.35	80%	375			
Pits_20645		1.08	1.20	90%	375			
Pits_20592		1.08	1.30	83%	375			
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Pits_20586		1.08	1.10	98%	375			
Pits_20584		1.08	1.20	90%	375			
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Pits_39577		1.08	0.70	154%	375			
Pits_39578		1.08	1.10	98%	375			

Appendix B – Community consultation material

Media release

Flood Study to understand the impact of coastal 'flash' flooding

Central Coast Council is undertaking an overland flood study for each of the contributing catchments that flow into the coastal lagoons of Wamberal, Terrigal, Avoca and Cockrone.

The study, which is concurrent to a study already underway in Green Point, West Gosford, Point Clare, Koolewong and Woy Woy Bay will identify flash flooding 'trouble spots' and assess what measures are required to reduce the risk of flooding during significant storm events.

Council Acting Director – Assets, Infrastructure and Business, Boris Bolgoff, said Council was seeking the community's help to collect information on past flooding experiences and local flood knowledge to help with the selection of flood reduction measures.

"These suburbs have been identified as priority areas and this study will focus on stormwater that overwhelms the drainage network causing flash flooding and inundation from elevated water levels," Mr Bolgoff said.

"Local knowledge and experience in times of flash flooding is critical to the success of this study.

"We would really like as many residents in these affected areas as possible to contribute to this study by completing the questionnaire, sharing their stories, photos or videos of flood events so we can gain a complete understating of flooding in these local areas."

Residents in areas covered by the study will receive a letter from Council containing a paper based survey and a reply-paid envelope. Residents can either complete and post this survey or complete online at www.yourvoiceourcoast.com.

The study survey is now open and will close on Friday 10 August 2018.

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Community letter and questionnaire

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#####################
15 ########### Street
LONG ######## 2261

Dear ################,

Coastal Lagoon Catchments Overland Flood Study
Community Questionnaire

Central Coast Council is preparing an overland flood study for four coastal lagoon catchments including Wamberal, Terrigal, Avoca and Cockrone. Council has engaged NSW Government's Manly Hydraulics Laboratory (MHL) to prepare this study.

This study will focus on flooding of creeks and overland flow paths caused by heavy rainfall, and will consider the influence of water levels in the lagoons on such flooding.

The aim of the study is to:

- update previous flood studies using the most current information and technologies
- help understand local flooding problems
- develop information to assist in future floodplain management activities including management of the lagoons.

How can I contribute?

Community involvement is essential to the success of the floodplain risk management process. It enables the community to:

- contribute local knowledge of flood behaviour
- express concerns and ideas for flood management.

Please take a few minutes to complete the hard copy questionnaire and return by **Friday 10 August 2018** using the enclosed reply-paid envelope (no postage stamp required) or through the website at www.yourvoiceourcoast.com/Coastal Lagoon Catchments - Overland Flood Study or at www.surveymonkey.com/r/LL86KXZ

All survey information is confidential and will be used only for floodplain risk management purposes.

What are the flood risks?

Flooding in the catchments can come from three main sources:

- high creek levels
- high water levels in the lagoons
- excess stormwater flowing overland.

The dominant cause of creek and overland flooding is intense rainfall, while foreshore flooding from the lagoons can be driven by elevated ocean conditions (tide and storm surge), long durations of rainfall, and local wind waves. This study will focus on flooding of creeks and overland flow paths caused by heavy rainfall, and will consider the influence of water levels in the lagoons on such flooding.

What does the study involve?

The study will define flood behaviour across the catchments including flood levels, depths, velocities and their distribution. Flood maps showing predicted extents of flood inundation will be produced. Study results and mapping will be based on flood simulations by detailed computer models developed specifically for the study area. Historical information such as rainfall and peak flood levels can be used to calibrate/adjust the computer flood models, ensuring that they are representative of real local flood behaviour. The results of the study will form the basis of future floodplain management activities.

Where can I find out more?

To stay informed and contribute to future developments of this study, please provide your details on the questionnaire provided. Should you wish to obtain further information on the study, please contact Central Coast Council's Robert Baker on (02) 43047087 or email FloodManagement@centralcoast.nsw.gov.au

Alternatively visit the consultant's study website:
http://www.mhl.nsw.gov.au/users/CoastalLagoonCatchments

Yours sincerely,

P. Sheath

Peter Sheath
Section Manager Waterways

QUESTIONNAIRE

To complete this Questionnaire, please tick the appropriate boxes and make comments where required. You may tick more than one box if applicable. Please return the completed questionnaire using the provided reply paid envelop (no postage required) by **Friday 10th August 2018.**

This questionnaire is also available online and can be completed by visiting: www.surveymonkey.com/r/LL86KXZ

Contract Information *(This information will only be used to complete the Flood Study)*

Name:

………………………………………………………………………………………………….......

Address: …………………………………………………………………………………………………

Address of your Property (if different from the address above)

....…..........................

Telephone: ……………………….... Email: …………………………………………….....................

I wish to receive information for the duration of the study: ☐ Yes ☐ No

1 What is the type of your property?

☐ Residential ☐ Vacant land ☐ Industrial

☐ Commercial ☐ Farming/Rural ☐Other (Please specify) ...…………………………

2 What is the status of property?

☐ Owner-occupied ☐ Leased to rental tenants

☐ Other (Please specify) ……………………………

3 How long have you lived or operated a business at this address?

☐ 0-5 years ☐ 6-10 years ☐ 10-20 years ☐ More than 20 years

4 As far as you are aware, has your property ever been affected by flooding?

☐ Yes ☐ No (if you answered No, please go to question 6)

Date/s your property has been affected by floods, if known? (Date, Month, Year) (if more than one, please list all dates)			
What **part/s of your property** were affected by flooding (select more than one if appropriate) **1 = Ground** **2 = Garage/Shed** **3 = Building** **4 = Other (please specify)**			
Depth of Flooding (in cms) Please provide details of the location of this depth (e.g. a sketch)			
Duration of Flooding (Hours/Days)			

What was the velocity of the flood waters at the peak/worst of the flooding? 1 = Stationary 2 = Walking Pace 3 = Running Pace			

5 What was the source of the floodwaters?

☐ Creek (floodwaters rising in the creek)

☐ Lagoon (levels rising in lagoon)

☐ Water flowing down the roads

☐ Ponding of water within property

☐ Ponding of water on roads

☐ Overflow from neighbouring properties

☐Other (Please describe) ……………………………………………………………………........

6 Are there any flood marks on or near your property?

☐ Yes ☐ No

If you answered Yes, do we have your permission for surveyors to access your property and will surveyors be able to do so? (Please ensure you have completed the contact details above so we can contact you)

☐ Yes ☐ No

7 Do you have or know of any photographs or records of these flood events?

☐ Yes ☐ No

If Yes, would it be possible for Council to make copies of this data to contribute to the Flood Study?

☐ Yes ☐ No

If Yes, please indicate if the holder of this information is someone other than you.

....

Fig 1: Study Area

8 Do you have any suggestions for resolving the flooding or drainage problems in your area or do you have any comments you wish to make in addition to the questions in the Survey? Please attach additional pages for any further information, if needed.

…………………………………………………………………
…………………………………………………………………
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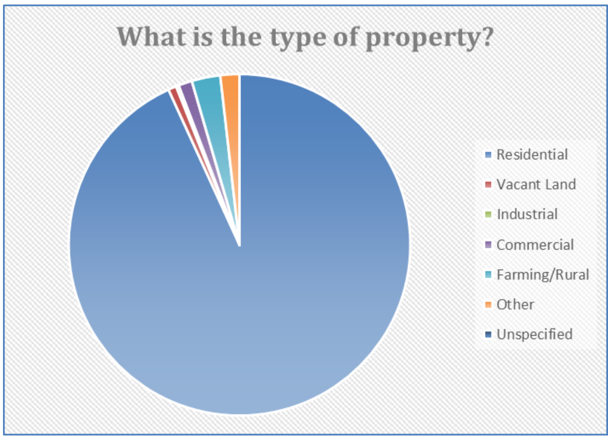
…………………………………………………………………
…………………………………………………………………

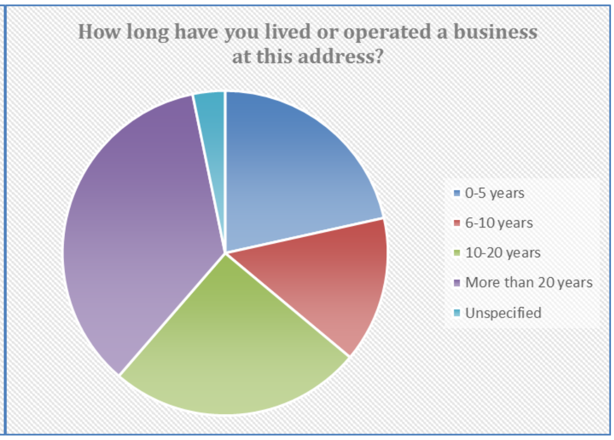
For any specific information relating to the questionnaire, please contact: **Scott Marshall (**Project Manager)

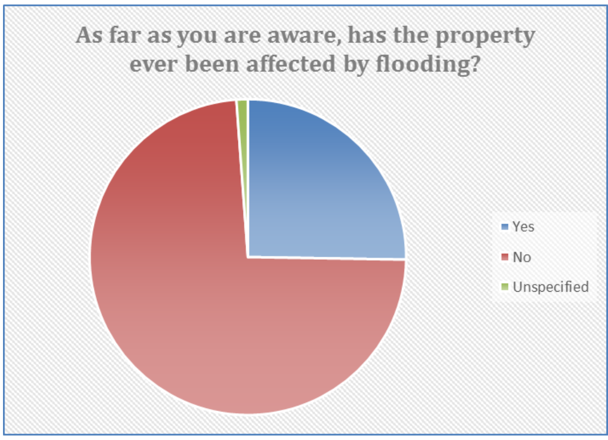
contact-us@mhl.nsw.gov.au

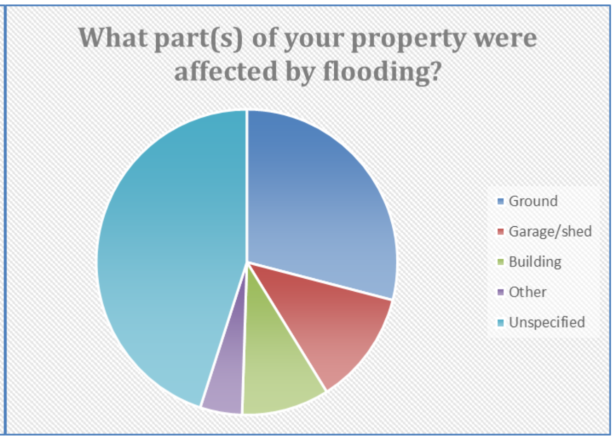
Community questionnaire results

General Questions









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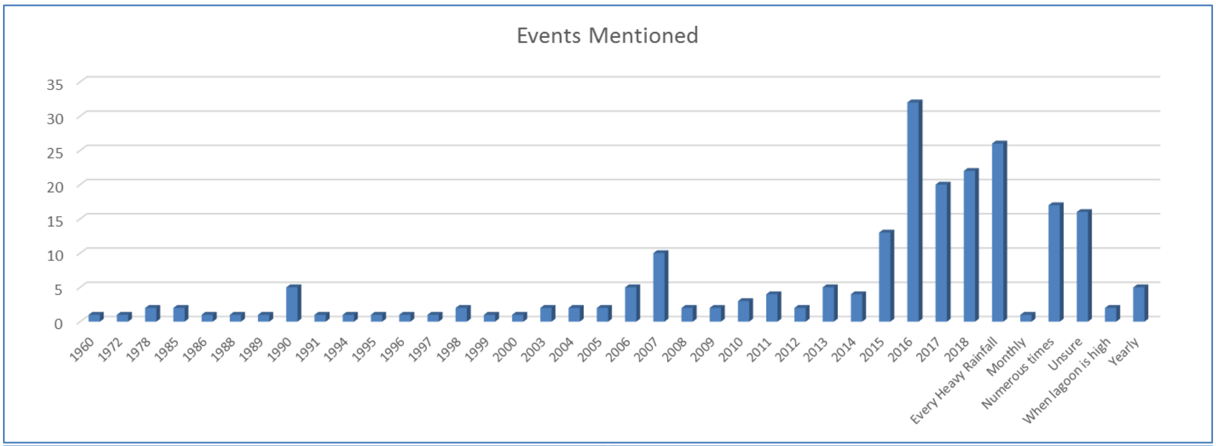
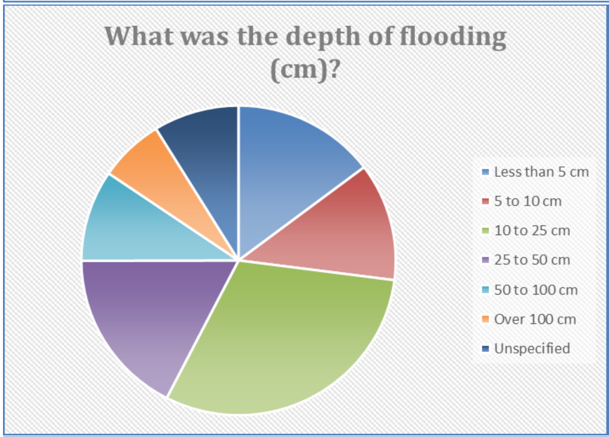
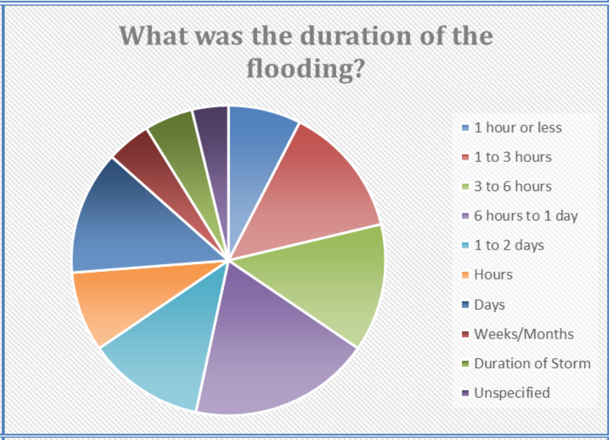
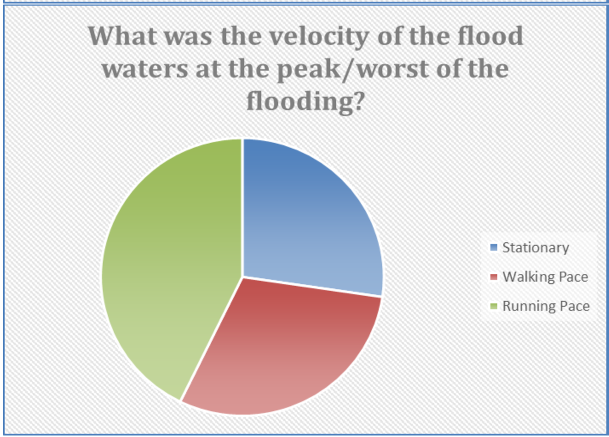
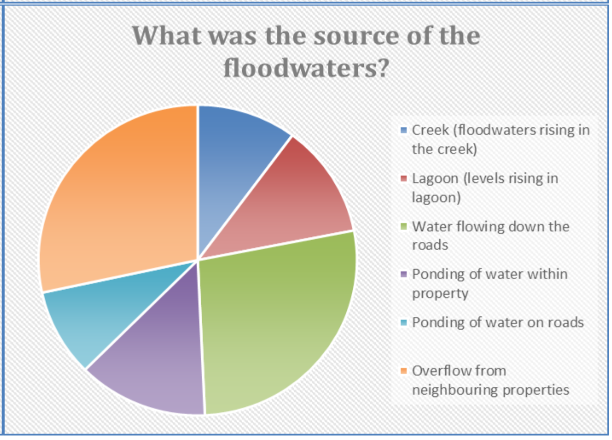
Flood Events Summary



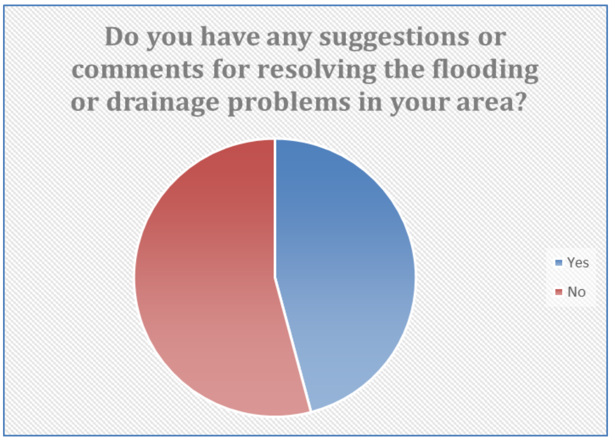








Comments and Suggestions



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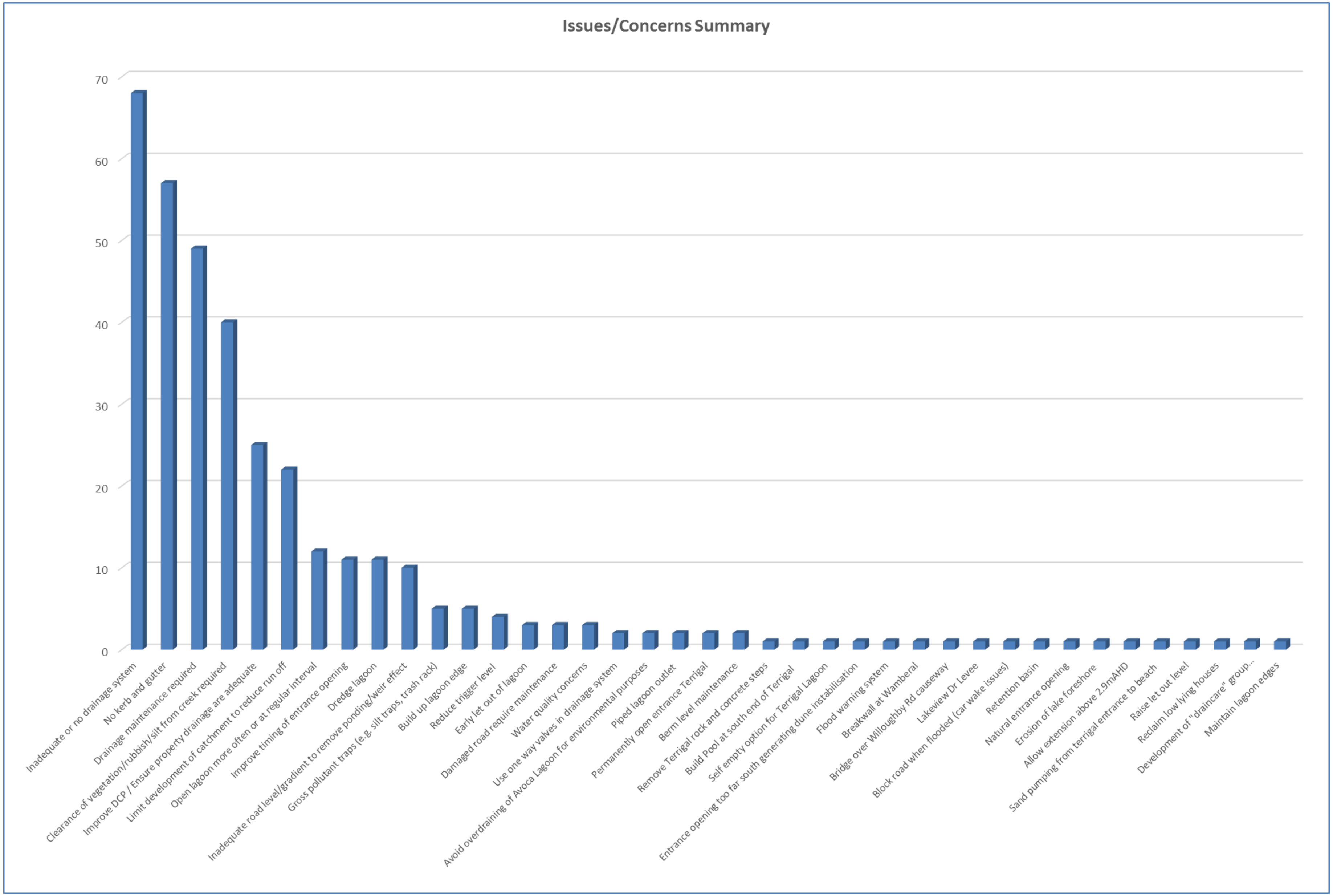

Issues/Concerns Summary
70
60
50
40
30
20
10
0
Inadequate or no drainage system
No kerb and gutter
Drainage maintenance required
Clearance of vegetation/rubbish/silt from creek required
Improve DCP / Ensure property drainage are adequate
Limit development of catchment to reduce run off
Open lagoon more often or at regular interval
Improve timing of entrance opening
Dredge lagoon
Inadequate road level/gradient to remove ponding/weir effect
Gross pollutant traps (e.g. silt traps, trash rack)
Build up lagoon edge
Reduce trigger level
Early let out of lagoon
Damaged road require maintenance
Water quality concerns
Use one way valves in drainage system
Avoid overdraining of Avoca Lagoon for environmental purposes
Piped lagoon outlet
Permanently open entrance Terrigal
Berm level maintenance
Remove Terrigal rock and concrete steps
Build Pool at south end of Terrigal
Self empty option for Terrigal Lagoon
Entrance opening too far south generating dune instabilisation
Flood warning system
Breakwall at Wamberal
Bridge over Willoughby Rd causeway
Lakeview Dr Levee
Block road when flooded (car wake issues)
Retention basin
Natural entrance opening
Erosion of lake foreshore
Allow extension above 2.9mAHD
Sand pumping from terrigal entrance to beach
Raise let out level
Reclaim low lying houses
Development of "draincare" group...
Maintain lagoon edges

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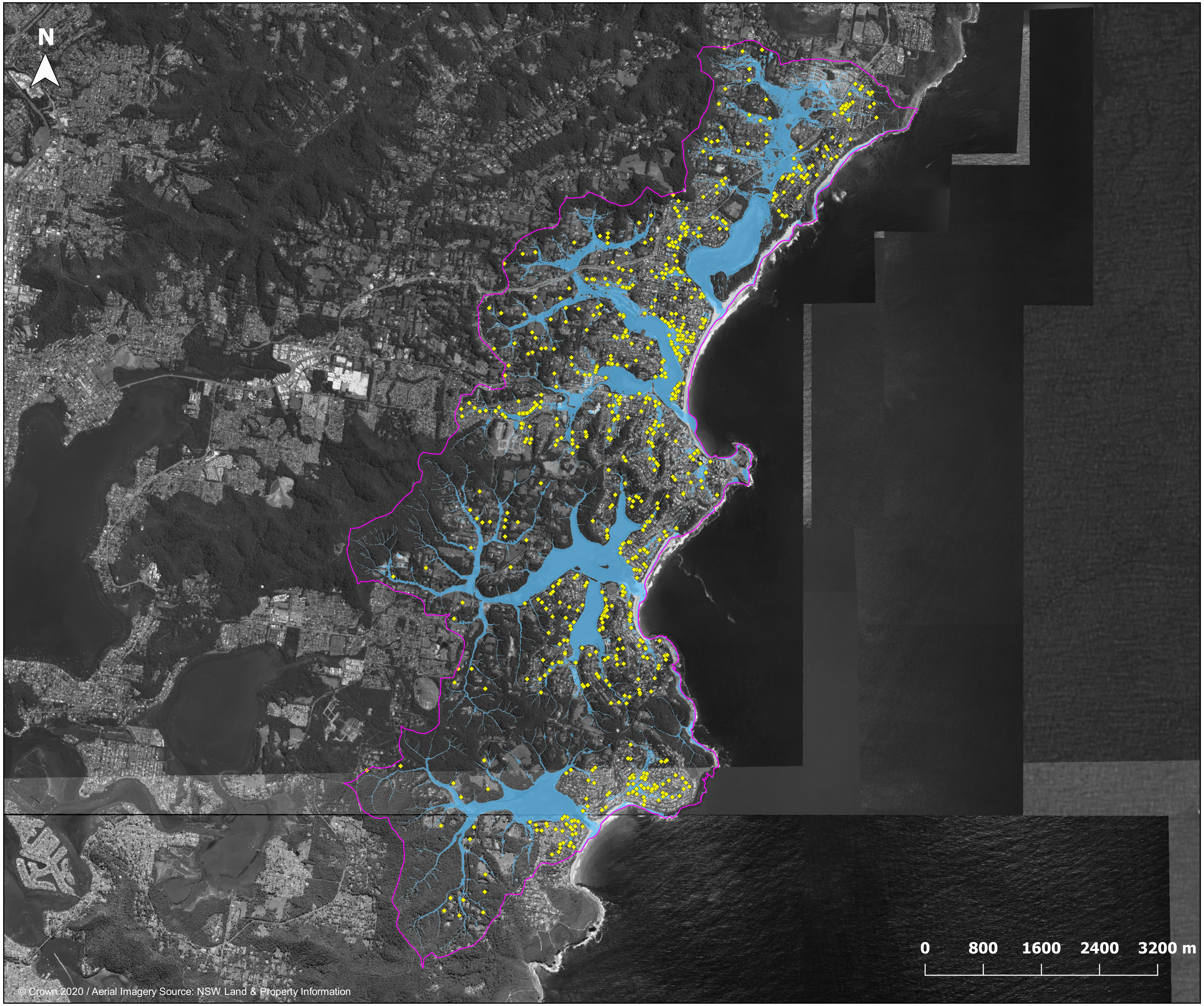


Figure B.1

Community Consultation Survey Respondents

Legend

- 1% AEP Flood Extent
- Study area
- Community Consultation Survey Respondent

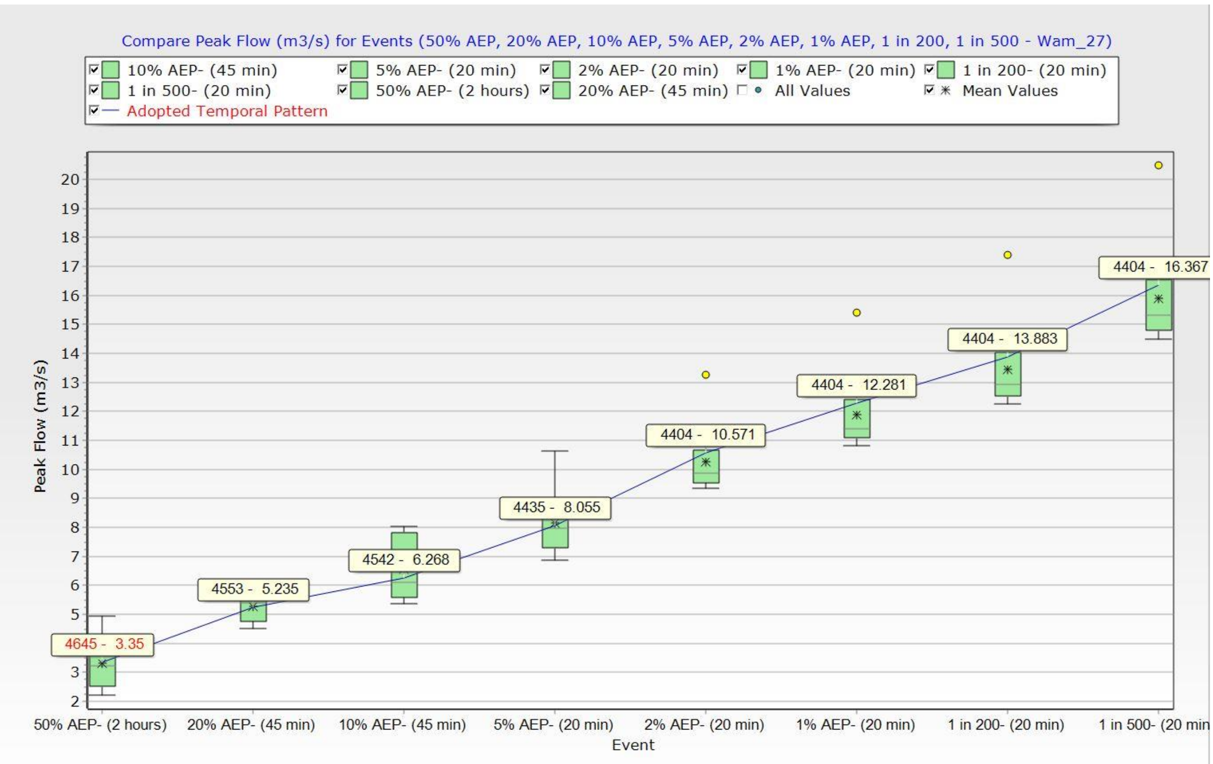
Report MHL2590

Coastal Lagoon Catchments Overland Flood Study

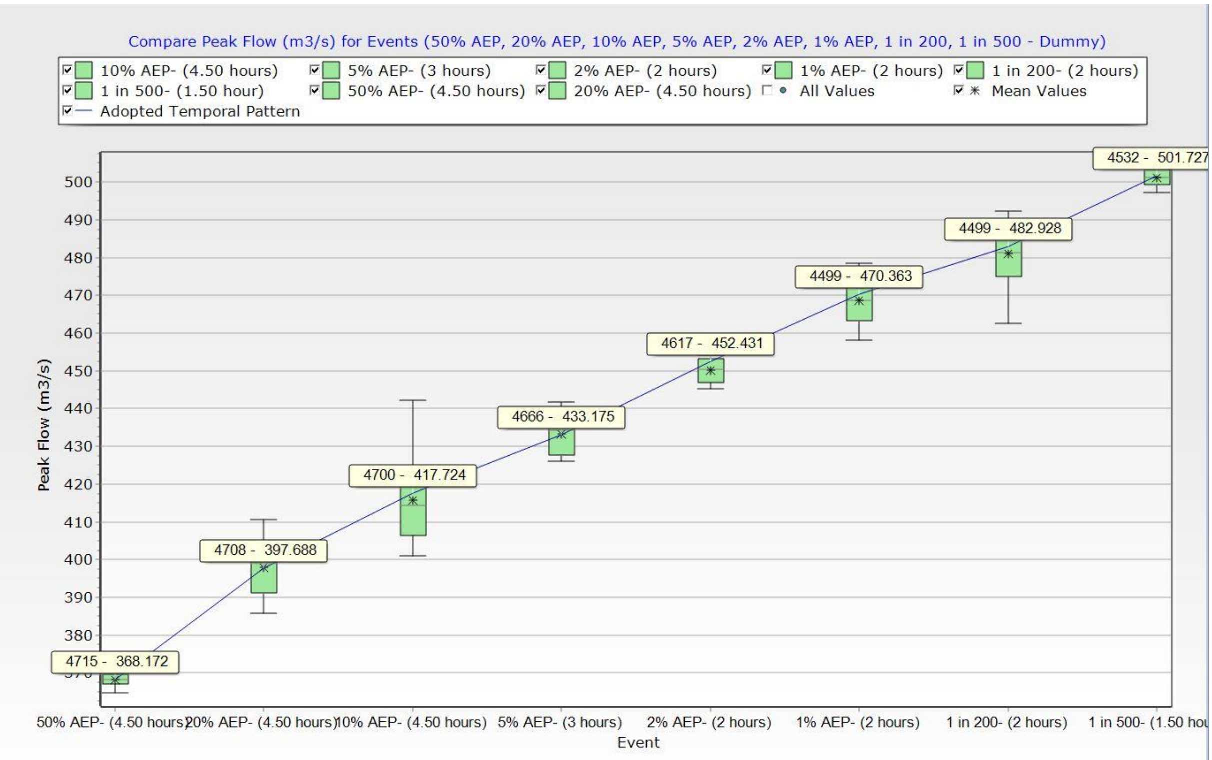
NSW GOVERNMENT | Manly Hydraulics Laboratory

Appendix C – Hydrological model results

Wamberal Upper Catchments – Critical Patterns and Durations



Wamberal Lower Catchments – Critical Patterns and Durations



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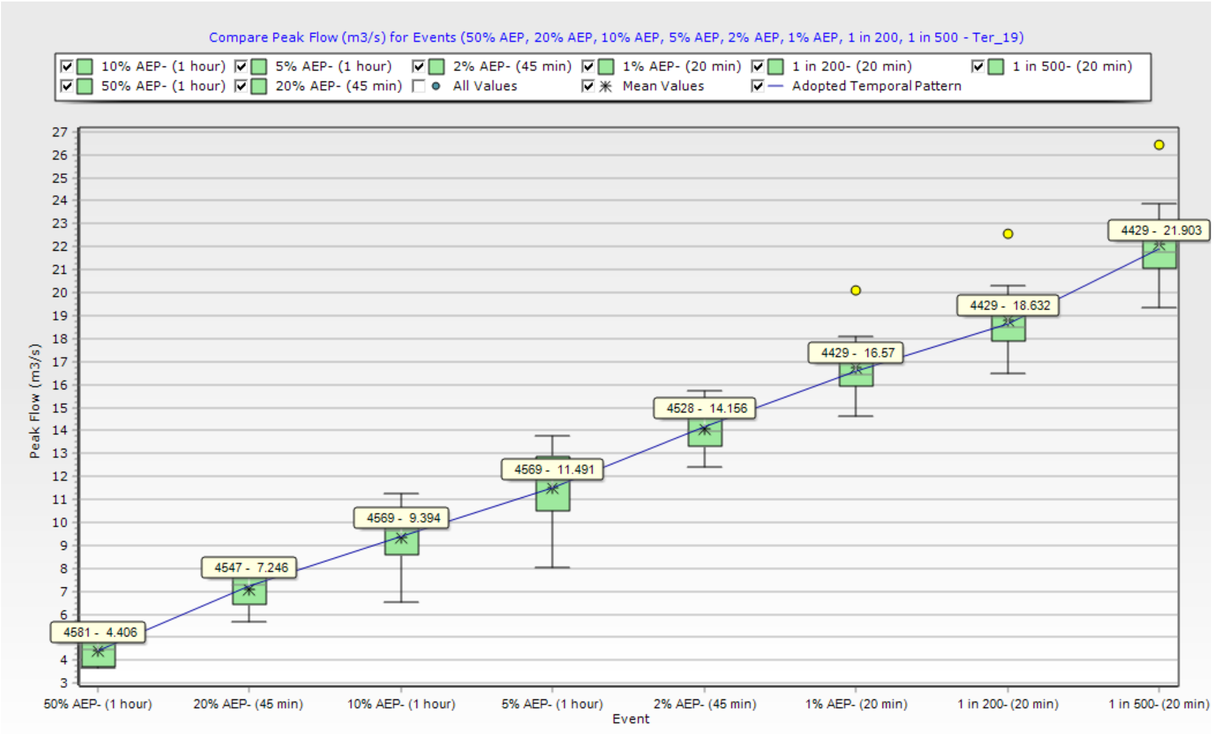
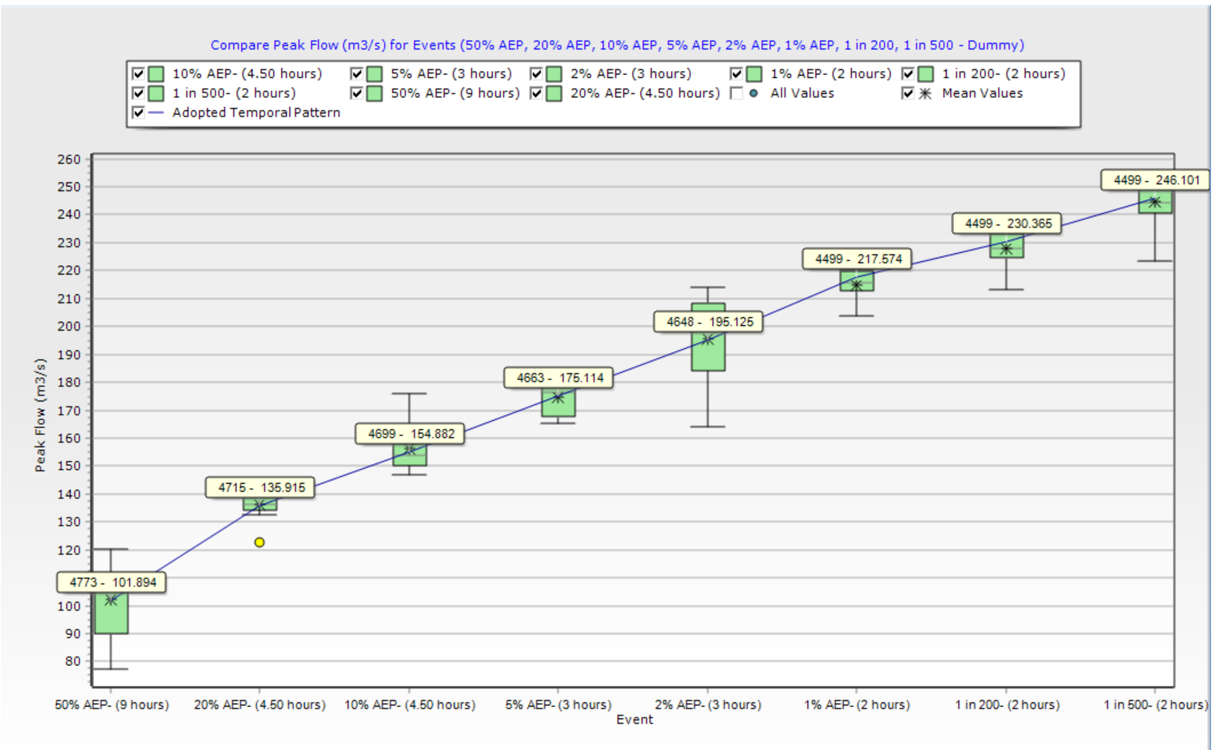
Terrigal Upper Catchments – Critical Patterns and Durations



N.B.: Analysis of the various temporal patterns of the individual events showed that the 45-minute duration for 1% and 1 in 200 AEP gave larger flows and the 45-minute duration was adopted. Given the majority of 45-minutes durations, similarity of results between the various durations and to avoid discrepancies in mapping due to varying durations, a 45-minute duration was adopted for all events.

Terrigal Lower Catchments – Critical Patterns and Durations



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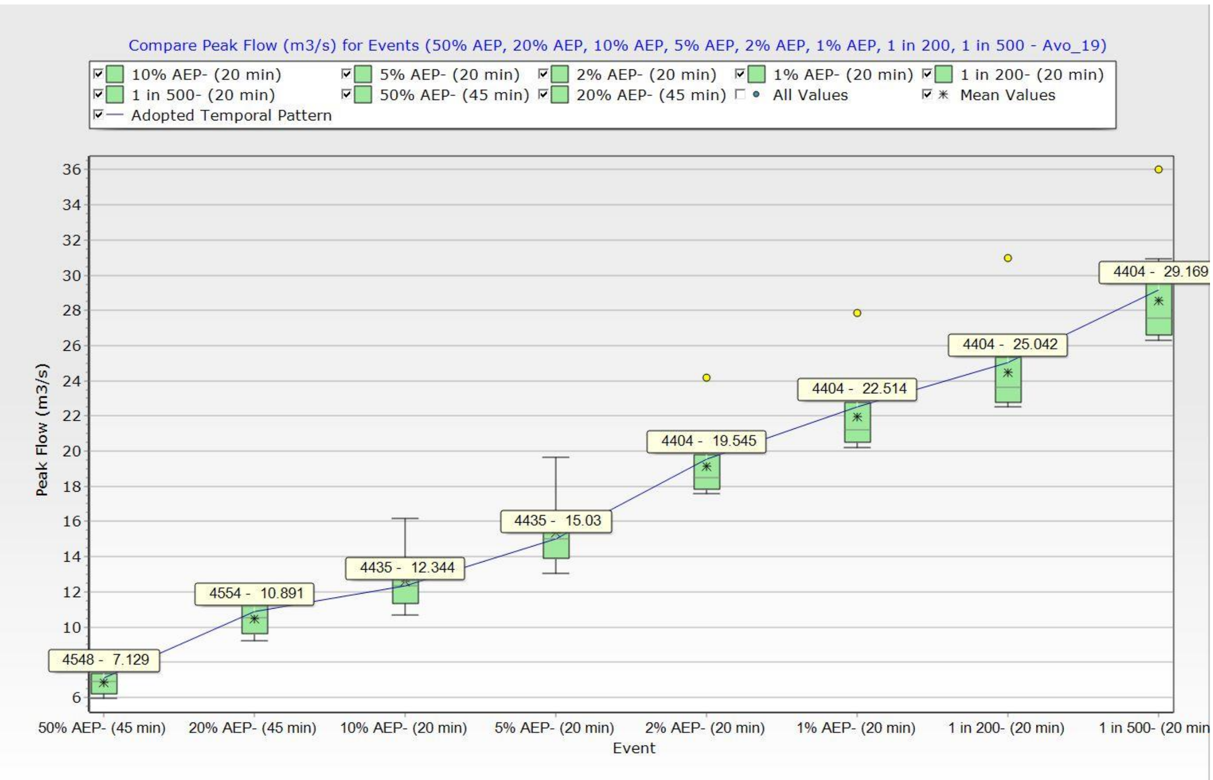
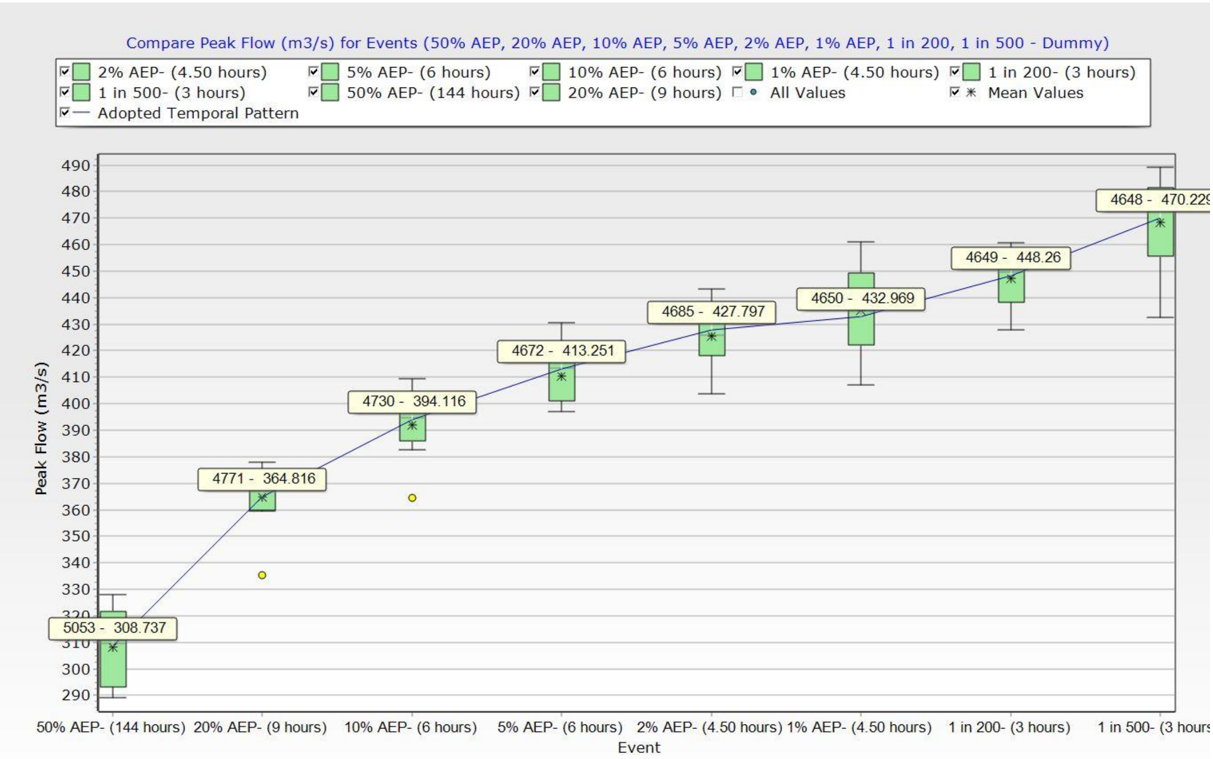
Avoca Upper Catchments – Critical Patterns and Durations



Avoca Lower Catchments – Critical Patterns and Durations



N.B.: The very long duration of the 50% AEP event for the lower catchment is due to the low intensity of rainfall and the need for a large volume of flood water to fill up the lagoon to a level allowing a breakout of the entrance. Such event would only reach the berm level in the lagoon.

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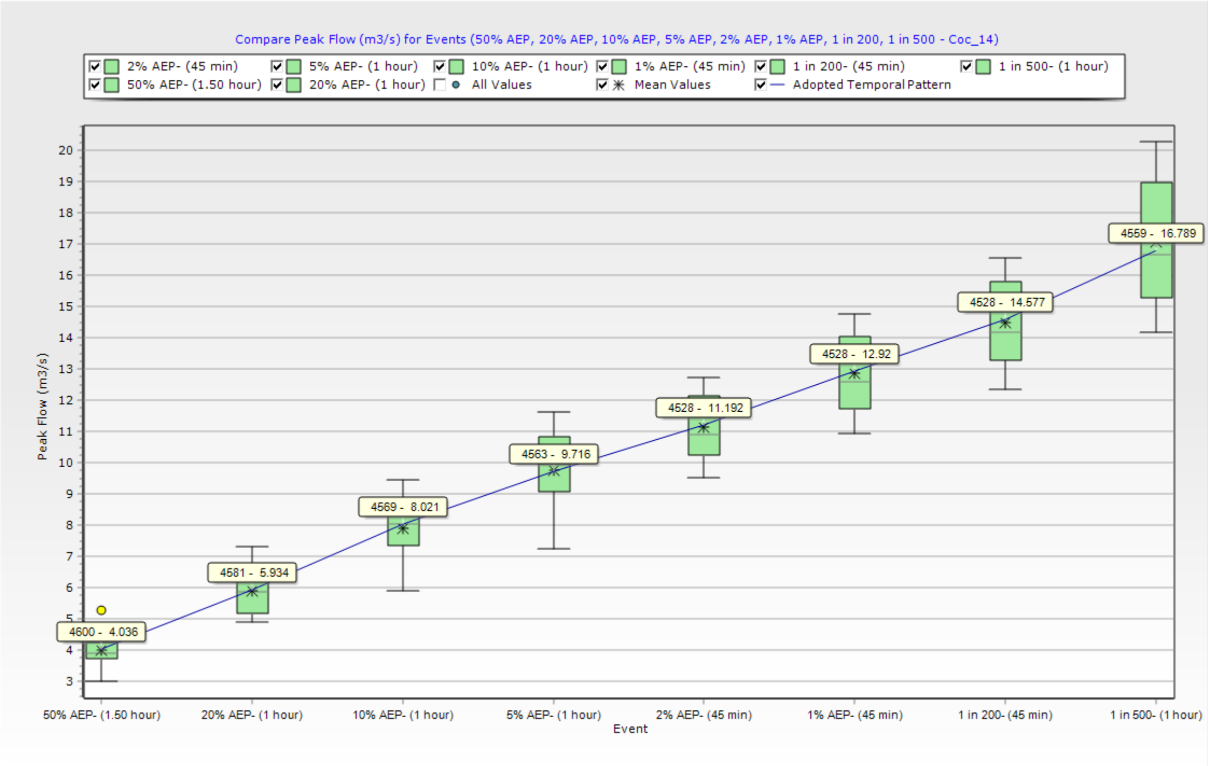
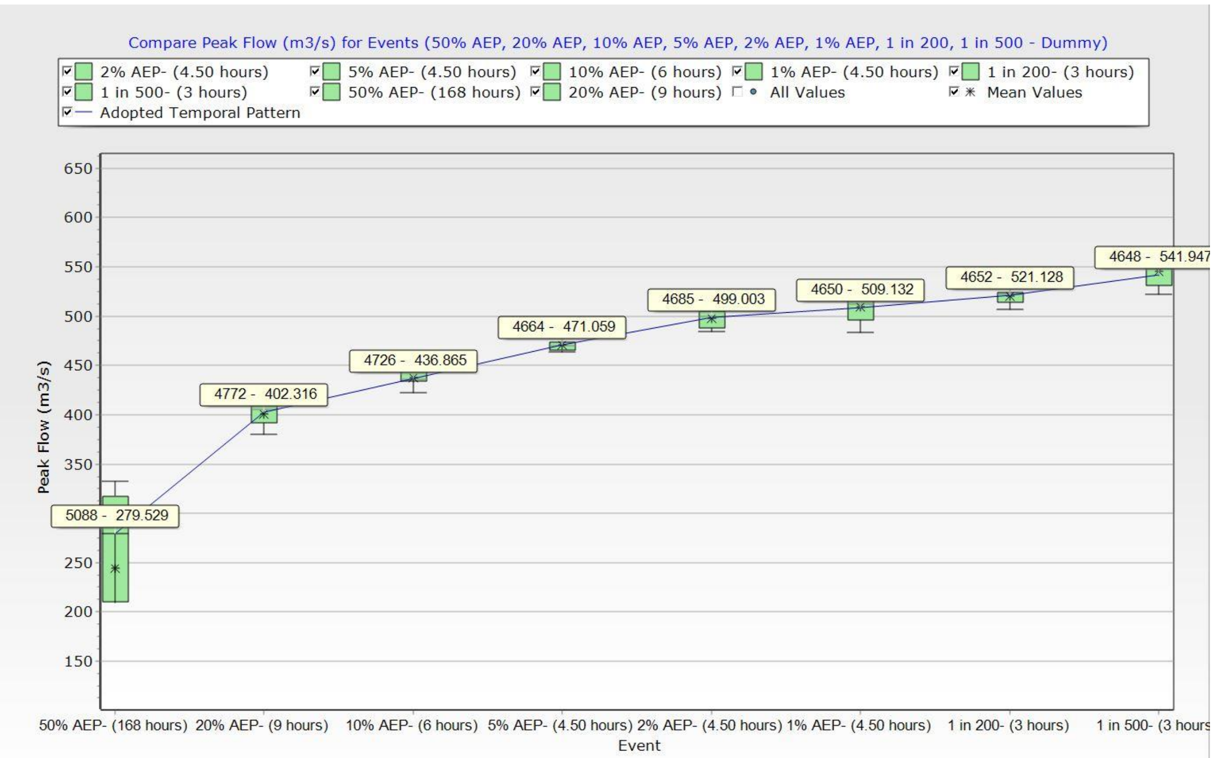
Cockrone Upper Catchments – Critical Patterns and Durations



Cockrone Lower Catchments – Critical Patterns and Durations



N.B.: The very long duration of the 50% AEP event for the lower catchment is due to the low intensity of rainfall and the need for a large volume of flood water to fill up the lagoon to a level allowing a breakout of the entrance. Such event would only reach the berm level in the lagoon.

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Appendix D – Entrance and tailwater conditions sensitivity

Figure D.1 Avoca Lagoon Probable Maximum Flood Sensitivity – Natural Breakout
Figure D.2 Avoca Lagoon Probable Maximum Flood Sensitivity – Let-Out Level Breakout
Figure D.3 Avoca Lagoon 1% AEP Flood Sensitivity – Natural Breakout
Figure D.4 Avoca Lagoon 1% AEP Flood Sensitivity – Let-Out Level Breakout
Figure D.5 Avoca Lagoon Probable Maximum Flood Sensitivity – Tailwater Peak plus 3 hours
Figure D.6 Avoca Lagoon Probable Maximum Flood Sensitivity – Tailwater Peak minus 3 hours
Figure D.7 Avoca Lagoon 1% AEP Flood Sensitivity – Tailwater Peak plus 3 hours
Figure D.8 Avoca Lagoon 1% AEP Flood Sensitivity – Tailwater Peak minus 3 hours
Figure D.9 Avoca Lagoon 1% AEP Flood Sensitivity – HHWS Tailwater
Figure D.10 Cockrone Lagoon Probable Maximum Flood Sensitivity – Natural Breakout
Figure D.11 Cockrone Lagoon Probable Maximum Flood Sensitivity – Let-Out Level Breakout
Figure D.12 Cockrone Lagoon 1% AEP Flood Sensitivity – Natural Breakout
Figure D.13 Cockrone Lagoon 1% AEP Flood Sensitivity – Let-Out Level Breakout
Figure D.14 Cockrone Lagoon Probable Maximum Flood Sensitivity – Tailwater Peak plus 3 hours
Figure D.15 Cockrone Lagoon Probable Maximum Flood Sensitivity – Tailwater Peak minus 3 hours
Figure D.16 Cockrone Lagoon 1% AEP Flood Sensitivity – Tailwater Peak plus 3 hours
Figure D.17 Cockrone Lagoon 1% AEP Flood Sensitivity – Tailwater Peak minus 3 hours
Figure D.18 Cockrone Lagoon 1% AEP Flood Sensitivity – HHWS Tailwater
Figure D.19 Terrigal Lagoon Probable Maximum Flood Sensitivity – Natural Breakout
Figure D.20 Terrigal Lagoon Probable Maximum Flood Sensitivity – Let-Out Level Breakout
Figure D.21 Terrigal Lagoon 1% AEP Flood Sensitivity – Natural Breakout
Figure D.22 Terrigal Lagoon 1% AEP Flood Sensitivity – Let-Out Level Breakout
Figure D.23 Terrigal Lagoon Probable Maximum Flood Sensitivity – Tailwater Peak plus 3 hours
Figure D.24 Terrigal Lagoon Probable Maximum Flood Sensitivity – Tailwater Peak minus 3 hours
Figure D.25 Terrigal Lagoon 1% AEP Flood Sensitivity – Tailwater Peak plus 3 hours
Figure D.26 Terrigal Lagoon 1% AEP Flood Sensitivity – Tailwater Peak minus 3 hours
Figure D.27 Terrigal Lagoon 1% AEP Flood Sensitivity – HHWS Tailwater
Figure D.28 Wamberal Lagoon Probable Maximum Flood Sensitivity – Natural Breakout
Figure D.29 Wamberal Lagoon Probable Maximum Flood Sensitivity – Let-Out Level Breakout
Figure D.30 Wamberal Lagoon 1% AEP Flood Sensitivity – Natural Breakout
Figure D.31 Wamberal Lagoon 1% AEP Flood Sensitivity – Let-Out Level Breakout
Figure D.32 Wamberal Lagoon Probable Maximum Flood Sensitivity – Tailwater Peak plus 3 hours
Figure D.33 Wamberal Lagoon Probable Maximum Flood Sensitivity – Tailwater Peak minus 3 hours
Figure D.34 Wamberal Lagoon 1% AEP Flood Sensitivity – Tailwater Peak plus 3 hours
Figure D.35 Wamberal Lagoon 1% AEP Flood Sensitivity – Tailwater Peak minus 3 hours
Figure D.36 Wamberal Lagoon 1% AEP Flood Sensitivity – HHWS Tailwater

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Appendix E – Losses and roughness sensitivity

Figure E.1	Avoca Lagoon 1% AEP Flood Sensitivity – No Losses
Figure E.2	Avoca Lagoon 1% AEP Flood Sensitivity – High Losses
Figure E.3	Avoca Lagoon Probable Maximum Flood Sensitivity – Roughness minus 20%
Figure E.4	Avoca Lagoon Probable Maximum Flood Sensitivity – Roughness plus 20%
Figure E.5	Avoca Lagoon 1% AEP Flood Sensitivity – Roughness minus 20%
Figure E.6	Avoca Lagoon 1% AEP Flood Sensitivity – Roughness plus 20%
Figure E.7	Cockrone Lagoon 1% AEP Flood Sensitivity – No Losses
Figure E.8	Cockrone Lagoon 1% AEP Flood Sensitivity – High Losses
Figure E.9	Cockrone Lagoon Probable Maximum Flood Sensitivity – Roughness minus 20%
Figure E.10	Cockrone Lagoon Probable Maximum Flood Sensitivity – Roughness plus 20%
Figure E.11	Cockrone Lagoon 1% AEP Flood Sensitivity – Roughness minus 20%
Figure E.12	Cockrone Lagoon 1% AEP Flood Sensitivity – Roughness plus 20%
Figure E.13	Terrigal Lagoon 1% AEP Flood Sensitivity – No Losses
Figure E.14	Terrigal Lagoon 1% AEP Flood Sensitivity – High Losses
Figure E.15	Terrigal Lagoon Probable Maximum Flood Sensitivity – Roughness minus 20%
Figure E.16	Terrigal Lagoon Probable Maximum Flood Sensitivity – Roughness plus 20%
Figure E.17	Terrigal Lagoon 1% AEP Flood Sensitivity – Roughness minus 20%
Figure E.18	Terrigal Lagoon 1% AEP Flood Sensitivity – Roughness plus 20%
Figure E.19	Wamberal Lagoon 1% AEP Flood Sensitivity – No Losses
Figure E.20	Wamberal Lagoon 1% AEP Flood Sensitivity – High Losses
Figure E.21	Wamberal Lagoon Probable Maximum Flood Sensitivity – Roughness minus 20%
Figure E.22	Wamberal Lagoon Probable Maximum Flood Sensitivity – Roughness plus 20%
Figure E.23	Wamberal Lagoon 1% AEP Flood Sensitivity – Roughness minus 20%
Figure E.24	Wamberal Lagoon 1% AEP Flood Sensitivity – Roughness plus 20%

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Appendix F – Blockage sensitivity

Figure F.1	Avoca Lagoon Probable Maximum Flood Sensitivity – No Blockage
Figure F.2	Avoca Lagoon Probable Maximum Flood Sensitivity – Double Design Blockage
Figure F.3	Avoca Lagoon 1% AEP Flood Sensitivity – No Blockage
Figure F.4	Avoca Lagoon 1% AEP Flood Sensitivity – Double Design Blockage
Figure F.5	Cockrone Lagoon Probable Maximum Flood Sensitivity – No Blockage
Figure F.6	Cockrone Lagoon Probable Maximum Flood Sensitivity – Double Design Blockage
Figure F.7	Cockrone Lagoon 1% AEP Flood Sensitivity – No Blockage
Figure F.8	Cockrone Lagoon 1% AEP Flood Sensitivity – Double Design Blockage
Figure F.9	Terrigal Lagoon Probable Maximum Flood Sensitivity – No Blockage
Figure F.10	Terrigal Lagoon Probable Maximum Flood Sensitivity – Double Design Blockage
Figure F.11	Terrigal Lagoon 1% AEP Flood Sensitivity – No Blockage
Figure F.12	Terrigal Lagoon 1% AEP Flood Sensitivity – Double Design Blockage
Figure F.13	Wamberal Lagoon Probable Maximum Flood Sensitivity – No Blockage
Figure F.14	Wamberal Lagoon Probable Maximum Flood Sensitivity – Double Design Blockage
Figure F.15	Wamberal Lagoon 1% AEP Flood Sensitivity – No Blockage
Figure F.16	Wamberal Lagoon 1% AEP Flood Sensitivity – Double Design Blockage

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Appendix G – Climate change sensitivity

Figure G.1	Avoca Lagoon 1% AEP Flood Sensitivity – 10% Increase in Rainfall Intensity
Figure G.2	Avoca Lagoon 1% AEP Flood Sensitivity – 20% Increase in Rainfall Intensity
Figure G.3	Avoca Lagoon 1% AEP Flood Sensitivity – 30% Increase in Rainfall Intensity
Figure G.4	Avoca Lagoon Probable Maximum Flood Sensitivity – Sea Level Rise of 200mm
Figure G.5	Avoca Lagoon Probable Maximum Flood Sensitivity – Sea Level Rise of 390mm
Figure G.6	Avoca Lagoon Probable Maximum Flood Sensitivity – Sea Level Rise of 740mm
Figure G.7	Avoca Lagoon 1% AEP Flood Sensitivity – Sea Level Rise of 200mm
Figure G.8	Avoca Lagoon 1% AEP Flood Sensitivity – Sea Level Rise of 390mm
Figure G.9	Avoca Lagoon 1% AEP Flood Sensitivity – Sea Level Rise of 740mm
Figure G.10	Cockrone Lagoon 1% AEP Flood Sensitivity – 10% Increase in Rainfall Intensity
Figure G.11	Cockrone Lagoon 1% AEP Flood Sensitivity – 20% Increase in Rainfall Intensity
Figure G.12	Cockrone Lagoon 1% AEP Flood Sensitivity – 30% Increase in Rainfall Intensity
Figure G.13	Cockrone Lagoon Probable Maximum Flood Sensitivity – Sea Level Rise of 200mm
Figure G.14	Cockrone Lagoon Probable Maximum Flood Sensitivity – Sea Level Rise of 390mm
Figure G.15	Cockrone Lagoon Probable Maximum Flood Sensitivity – Sea Level Rise of 740mm
Figure G.16	Cockrone Lagoon 1% AEP Flood Sensitivity – Sea Level Rise of 200mm
Figure G.17	Cockrone Lagoon 1% AEP Flood Sensitivity – Sea Level Rise of 390mm
Figure G.18	Cockrone Lagoon 1% AEP Flood Sensitivity – Sea Level Rise of 740mm
Figure G.19	Terrigal Lagoon 1% AEP Flood Sensitivity – 10% Increase in Rainfall Intensity
Figure G.20	Terrigal Lagoon 1% AEP Flood Sensitivity – 20% Increase in Rainfall Intensity
Figure G.21	Terrigal Lagoon 1% AEP Flood Sensitivity – 30% Increase in Rainfall Intensity
Figure G.22	Terrigal Lagoon Probable Maximum Flood Sensitivity – Sea Level Rise of 200mm
Figure G.23	Terrigal Lagoon Probable Maximum Flood Sensitivity – Sea Level Rise of 390mm
Figure G.24	Terrigal Lagoon Probable Maximum Flood Sensitivity – Sea Level Rise of 740mm
Figure G.25	Terrigal Lagoon 1% AEP Flood Sensitivity – Sea Level Rise of 200mm
Figure G.26	Terrigal Lagoon 1% AEP Flood Sensitivity – Sea Level Rise of 390mm
Figure G.27	Terrigal Lagoon 1% AEP Flood Sensitivity – Sea Level Rise of 740mm
Figure G.28	Wamberal Lagoon 1% AEP Flood Sensitivity – 10% Increase in Rainfall Intensity
Figure G.29	Wamberal Lagoon 1% AEP Flood Sensitivity – 20% Increase in Rainfall Intensity
Figure G.30	Wamberal Lagoon 1% AEP Flood Sensitivity – 30% Increase in Rainfall Intensity
Figure G.31	Wamberal Lagoon Probable Maximum Flood Sensitivity – Sea Level Rise of 200mm
Figure G.32	Wamberal Lagoon Probable Maximum Flood Sensitivity – Sea Level Rise of 390mm
Figure G.33	Wamberal Lagoon Probable Maximum Flood Sensitivity – Sea Level Rise of 740mm
Figure G.34	Wamberal Lagoon 1% AEP Flood Sensitivity – Sea Level Rise of 200mm
Figure G.35	Wamberal Lagoon 1% AEP Flood Sensitivity – Sea Level Rise of 390mm
Figure G.36	Wamberal Lagoon 1% AEP Flood Sensitivity – Sea Level Rise of 740mm

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Appendix H – Avoca Lagoon flood mapping

Figure H.1 Avoca Lagoon Probable Maximum Flood Level
Figure H.2 Avoca Lagoon 1 in 500 AEP Flood Level
Figure H.3 Avoca Lagoon 1 in 200 AEP Flood Level
Figure H.4 Avoca Lagoon 1% AEP Flood Level
Figure H.5 Avoca Lagoon 2% AEP Flood Level
Figure H.6 Avoca Lagoon 5% AEP Flood Level
Figure H.7 Avoca Lagoon 10% AEP Flood Level
Figure H.8 Avoca Lagoon 20% AEP Flood Level
Figure H.9 Avoca Lagoon 50% AEP Flood Level
Figure H.10 Avoca Lagoon Probable Maximum Flood Depth
Figure H.11 Avoca Lagoon 1 in 500 AEP Flood Depth
Figure H.12 Avoca Lagoon 1 in 200 AEP Flood Depth
Figure H.13 Avoca Lagoon 1% AEP Flood Depth
Figure H.14 Avoca Lagoon 2% AEP Flood Depth
Figure H.15 Avoca Lagoon 5% AEP Flood Depth
Figure H.16 Avoca Lagoon 10% AEP Flood Depth
Figure H.17 Avoca Lagoon 20% AEP Flood Depth
Figure H.18 Avoca Lagoon 50% AEP Flood Depth
Figure H.19 Avoca Lagoon Probable Maximum Flood Velocity
Figure H.20 Avoca Lagoon 1 in 500 AEP Flood Velocity
Figure H.21 Avoca Lagoon 1 in 200 AEP Flood Velocity
Figure H.22 Avoca Lagoon 1% AEP Flood Velocity
Figure H.23 Avoca Lagoon 2% AEP Flood Velocity
Figure H.24 Avoca Lagoon 5% AEP Flood Velocity
Figure H.25 Avoca Lagoon 10% AEP Flood Velocity
Figure H.26 Avoca Lagoon 20% AEP Flood Velocity
Figure H.27 Avoca Lagoon 50% AEP Flood Velocity

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Appendix I – Cockrone Lagoon flood mapping

Figure I.1 Cockrone Lagoon Probable Maximum Flood Level
Figure I.2 Cockrone Lagoon 1 in 500 AEP Flood Level
Figure I.3 Cockrone Lagoon 1 in 200 AEP Flood Level
Figure I.4 Cockrone Lagoon 1% AEP Flood Level
Figure I.5 Cockrone Lagoon 2% AEP Flood Level
Figure I.6 Cockrone Lagoon 5% AEP Flood Level
Figure I.7 Cockrone Lagoon 10% AEP Flood Level
Figure I.8 Cockrone Lagoon 20% AEP Flood Level
Figure I.9 Cockrone Lagoon 50% AEP Flood Level
Figure I.10 Cockrone Lagoon Probable Maximum Flood Depth
Figure I.11 Cockrone Lagoon 1 in 500 AEP Flood Depth
Figure I.12 Cockrone Lagoon 1 in 200 AEP Flood Depth
Figure I.13 Cockrone Lagoon 1% AEP Flood Depth
Figure I.14 Cockrone Lagoon 2% AEP Flood Depth
Figure I.15 Cockrone Lagoon 5% AEP Flood Depth
Figure I.16 Cockrone Lagoon 10% AEP Flood Depth
Figure I.17 Cockrone Lagoon 20% AEP Flood Depth
Figure I.18 Cockrone Lagoon 50% AEP Flood Depth
Figure I.19 Cockrone Lagoon Probable Maximum Flood Velocity
Figure I.20 Cockrone Lagoon 1 in 500 AEP Flood Velocity
Figure I.21 Cockrone Lagoon 1 in 200 AEP Flood Velocity
Figure I.22 Cockrone Lagoon 1% AEP Flood Velocity
Figure I.23 Cockrone Lagoon 2% AEP Flood Velocity
Figure I.24 Cockrone Lagoon 5% AEP Flood Velocity
Figure I.25 Cockrone Lagoon 10% AEP Flood Velocity
Figure I.26 Cockrone Lagoon 20% AEP Flood Velocity
Figure I.27 Cockrone Lagoon 50% AEP Flood Velocity

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Appendix J – Terrigal Lagoon flood mapping

Figure J.1 Terrigal Lagoon Probable Maximum Flood Level
Figure J.2 Terrigal Lagoon 1 in 500 AEP Flood Level
Figure J.3 Terrigal Lagoon 1 in 200 AEP Flood Level
Figure J.4 Terrigal Lagoon 1% AEP Flood Level
Figure J.5 Terrigal Lagoon 2% AEP Flood Level
Figure J.6 Terrigal Lagoon 5% AEP Flood Level
Figure J.7 Terrigal Lagoon 10% AEP Flood Level
Figure J.8 Terrigal Lagoon 20% AEP Flood Level
Figure J.9 Terrigal Lagoon 50% AEP Flood Level
Figure J.10 Terrigal Lagoon Probable Maximum Flood Depth
Figure J.11 Terrigal Lagoon 1 in 500 AEP Flood Depth
Figure J.12 Terrigal Lagoon 1 in 200 AEP Flood Depth
Figure J.13 Terrigal Lagoon 1% AEP Flood Depth
Figure J.14 Terrigal Lagoon 2% AEP Flood Depth
Figure J.15 Terrigal Lagoon 5% AEP Flood Depth
Figure J.16 Terrigal Lagoon 10% AEP Flood Depth
Figure J.17 Terrigal Lagoon 20% AEP Flood Depth
Figure J.18 Terrigal Lagoon 50% AEP Flood Depth
Figure J.19 Terrigal Lagoon Probable Maximum Flood Velocity
Figure J.20 Terrigal Lagoon 1 in 500 AEP Flood Velocity
Figure J.21 Terrigal Lagoon 1 in 200 AEP Flood Velocity
Figure J.22 Terrigal Lagoon 1% AEP Flood Velocity
Figure J.23 Terrigal Lagoon 2% AEP Flood Velocity
Figure J.24 Terrigal Lagoon 5% AEP Flood Velocity
Figure J.25 Terrigal Lagoon 10% AEP Flood Velocity
Figure J.26 Terrigal Lagoon 20% AEP Flood Velocity
Figure J.27 Terrigal Lagoon 50% AEP Flood Velocity

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Appendix K – Wamberal Lagoon flood mapping

Figure K.1 Wamberal Lagoon Probable Maximum Flood Level
Figure K.2 Wamberal Lagoon 1 in 500 AEP Flood Level
Figure K.3 Wamberal Lagoon 1 in 200 AEP Flood Level
Figure K.4 Wamberal Lagoon 1% AEP Flood Level
Figure K.5 Wamberal Lagoon 2% AEP Flood Level
Figure K.6 Wamberal Lagoon 5% AEP Flood Level
Figure K.7 Wamberal Lagoon 10% AEP Flood Level
Figure K.8 Wamberal Lagoon 20% AEP Flood Level
Figure K.9 Wamberal Lagoon 50% AEP Flood Level
Figure K.10 Wamberal Lagoon Probable Maximum Flood Depth
Figure K.11 Wamberal Lagoon 1 in 500 AEP Flood Depth
Figure K.12 Wamberal Lagoon 1 in 200 AEP Flood Depth
Figure K.13 Wamberal Lagoon 1% AEP Flood Depth
Figure K.14 Wamberal Lagoon 2% AEP Flood Depth
Figure K.15 Wamberal Lagoon 5% AEP Flood Depth
Figure K.16 Wamberal Lagoon 10% AEP Flood Depth
Figure K.17 Wamberal Lagoon 20% AEP Flood Depth
Figure K.18 Wamberal Lagoon 50% AEP Flood Depth
Figure K.19 Wamberal Lagoon Probable Maximum Flood Velocity
Figure K.20 Wamberal Lagoon 1 in 500 AEP Flood Velocity
Figure K.21 Wamberal Lagoon 1 in 200 AEP Flood Velocity
Figure K.22 Wamberal Lagoon 1% AEP Flood Velocity
Figure K.23 Wamberal Lagoon 2% AEP Flood Velocity
Figure K.24 Wamberal Lagoon 5% AEP Flood Velocity
Figure K.25 Wamberal Lagoon 10% AEP Flood Velocity
Figure K.26 Wamberal Lagoon 20% AEP Flood Velocity
Figure K.27 Wamberal Lagoon 50% AEP Flood Velocity

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Appendix L – Flood hazard categories

Figure L.1 Avoca Lagoon Probable Maximum Flood Hazard H1-H6
Figure L.2 Avoca Lagoon 1% AEP Flood Hazard H1-H6
Figure L.3 Cockrone Lagoon Probable Maximum Flood Hazard H1-H6
Figure L.4 Cockrone Lagoon 1% AEP Flood Hazard H1-H6
Figure L.5 Terrigal Lagoon Probable Maximum Flood Hazard H1-H6
Figure L.6 Terrigal Lagoon 1% AEP Flood Hazard H1-H6
Figure L.7 Wamberal Lagoon Probable Maximum Flood Hazard H1-H6
Figure L.8 Wamberal Lagoon 1% AEP Flood Hazard H1-H6
Figure L.9 Avoca Lagoon Probable Maximum Flood Hazard
Figure L.10 Avoca Lagoon 1% AEP Flood Hazard
Figure L.11 Cockrone Lagoon Probable Maximum Flood Hazard
Figure L.12 Cockrone Lagoon 1% AEP Flood Hazard
Figure L.13 Terrigal Lagoon Probable Maximum Flood Hazard
Figure L.14 Terrigal Lagoon 1% AEP Flood Hazard
Figure L.15 Wamberal Lagoon Probable Maximum Flood Hazard
Figure L.16 Wamberal Lagoon 1% AEP Flood Hazard

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Appendix M – Flood hydraulic categories

Figure M.1 Avoca Lagoon Probable Maximum Flood Hydraulic Categories
Figure M.2 Avoca Lagoon 1% AEP Flood Hydraulic Categories
Figure M.3 Avoca Lagoon 5% AEP Flood Hydraulic Categories
Figure M.4 Avoca Lagoon 20% AEP Flood Hydraulic Categories
Figure M.5 Cockrone Lagoon Probable Maximum Flood Hydraulic Categories
Figure M.6 Cockrone Lagoon 1% AEP Flood Hydraulic Categories
Figure M.7 Cockrone Lagoon 5% AEP Flood Hydraulic Categories
Figure M.8 Cockrone Lagoon 20% AEP Flood Hydraulic Categories
Figure M.9 Terrigal Lagoon Probable Maximum Flood Hydraulic Categories
Figure M.10 Terrigal Lagoon 1% AEP Flood Hydraulic Categories
Figure M.11 Terrigal Lagoon 5% AEP Flood Hydraulic Categories
Figure M.12 Terrigal Lagoon 20% AEP Flood Hydraulic Categories
Figure M.13 Wamberal Lagoon Probable Maximum Flood Hydraulic Categories
Figure M.14 Wamberal Lagoon 1% AEP Flood Hydraulic Categories
Figure M.15 Wamberal Lagoon 5% AEP Flood Hydraulic Categories
Figure M.16 Wamberal Lagoon 20% AEP Flood Hydraulic Categories

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Appendix N – Preliminary flood damages assessment

Residential Stage-Damage Data (assuming low set and 2 steps to floor level)

Above Floor Depth (m)	Avoca Lagoon Damage	Cockrone Lagoon Damage	Terrigal Lagoon Damage	Wamberal Lagoon Damage
-5.00	$0	$0	$0	$0
-1.50	$0	$0	$0	$0
-1.40	$0	$0	$0	$0
-1.30	$0	$0	$0	$0
-1.20	$0	$0	$0	$0
-1.10	$0	$0	$0	$0
-1.00	$0	$0	$0	$0
-0.90	$0	$0	$0	$0
-0.80	$0	$0	$0	$0
-0.70	$0	$0	$0	$0
-0.60	$0	$0	$0	$0
-0.50	$0	$0	$0	$0
-0.40	$0	$0	$0	$0
-0.30	$0	$0	$0	$0
-0.20	$0	$0	$0	$0
-0.10	$0	$0	$0	$0
0.00	$37,347	$33,763	$39,139	$38,541
0.10	$73,226	$65,735	$76,971	$75,723
0.20	$76,556	$68,590	$80,540	$79,212
0.30	$79,886	$71,444	$84,108	$82,701
0.40	$83,217	$74,299	$87,676	$86,189
0.50	$86,547	$77,153	$91,244	$89,678
0.60	$89,877	$80,008	$94,812	$93,167
0.70	$93,207	$82,862	$98,380	$96,656
0.80	$96,538	$85,717	$101,948	$100,145
0.90	$99,868	$88,571	$105,516	$103,634
1.00	$103,198	$91,426	$109,084	$107,122
1.10	$106,528	$94,280	$112,653	$110,611
1.20	$109,859	$97,135	$116,221	$114,100
1.30	$113,189	$99,989	$119,789	$117,589
1.40	$116,519	$102,844	$123,357	$121,078
1.50	$119,849	$105,698	$126,925	$124,566
1.60	$123,180	$108,553	$130,493	$128,055
1.70	$126,510	$111,407	$134,061	$131,544
1.80	$129,840	$114,262	$137,629	$135,033
1.90	$133,170	$117,116	$141,197	$138,522
2.00	$136,501	$119,970	$144,766	$142,011
2.10	$137,429	$120,766	$145,760	$142,983
2.20	$138,357	$121,562	$146,755	$143,955
2.30	$139,285	$122,357	$147,749	$144,928
2.40	$140,213	$123,153	$148,743	$145,900
2.50	$141,141	$123,948	$149,738	$146,872
2.60	$142,070	$124,744	$150,732	$147,845
2.70	$142,998	$125,540	$151,727	$148,817
2.80	$143,926	$126,335	$152,721	$149,790
2.90	$144,854	$127,131	$153,716	$150,762
3.00	$145,782	$127,926	$154,710	$151,734
3.50	$150,423	$131,904	$159,683	$156,596
4.00	$155,064	$135,882	$164,655	$161,458
4.50	$159,705	$139,860	$169,628	$166,320
5.00	$164,346	$143,838	$174,600	$171,182

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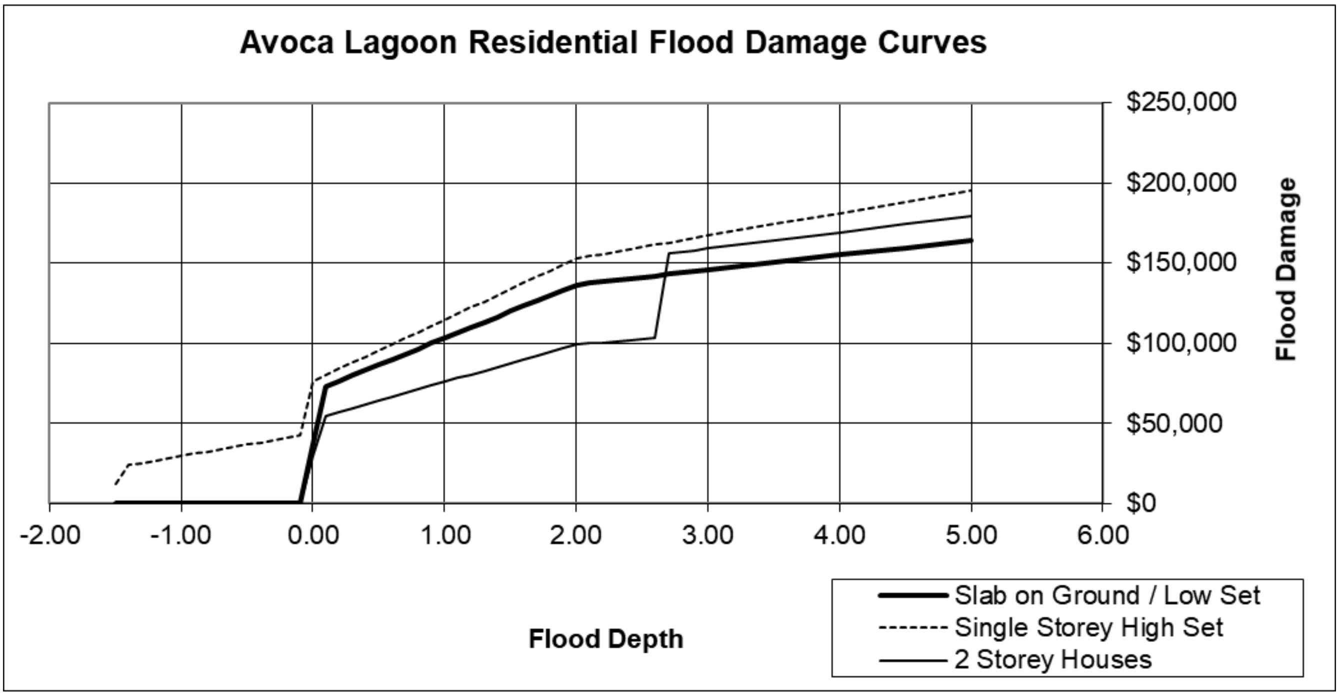
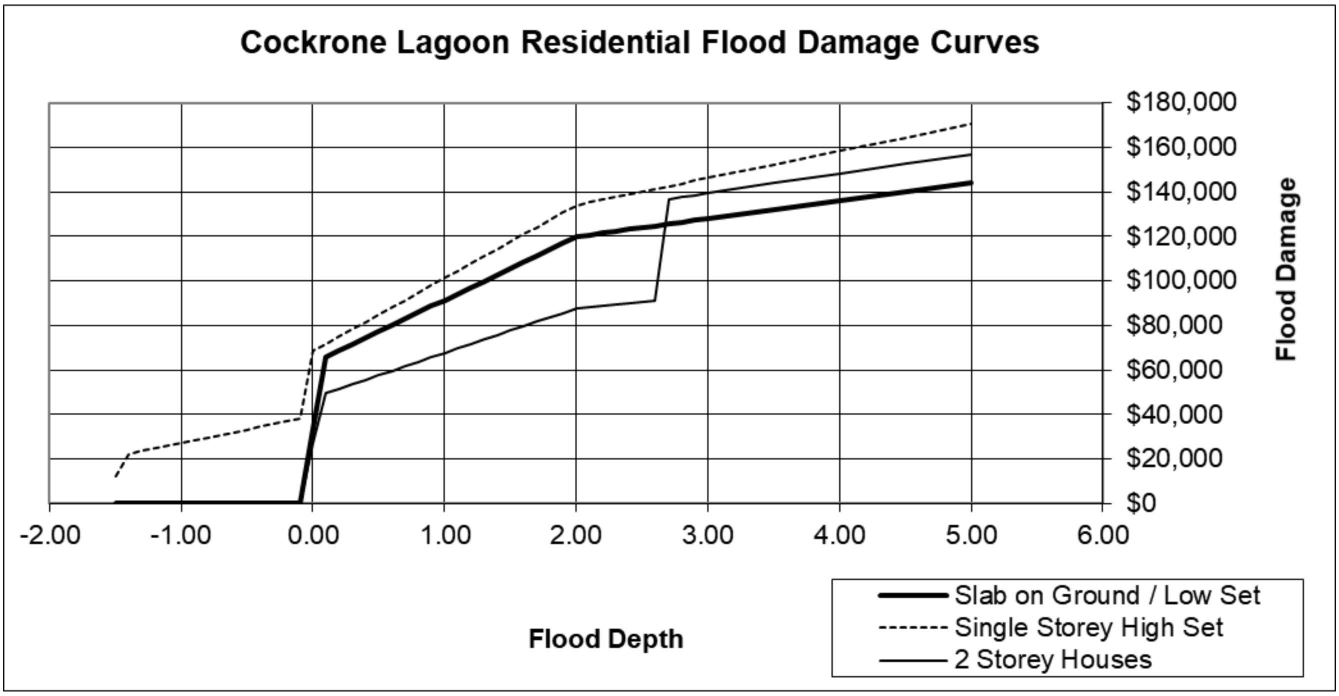

Avoca Lagoon Residential Flood Damage Curves
$250,000
$200,000
$150,000
$100,000
$50,000
$0
Flood Damage
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Flood Depth
Slab on Ground / Low Set
Single Storey High Set
2 Storey Houses


Cockrone Lagoon Residential Flood Damage Curves
$180,000
$160,000
$140,000
$120,000
$100,000
$80,000
$60,000
$40,000
$20,000
$0
Flood Damage
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Flood Depth
Slab on Ground / Low Set
Single Storey High Set
2 Storey Houses

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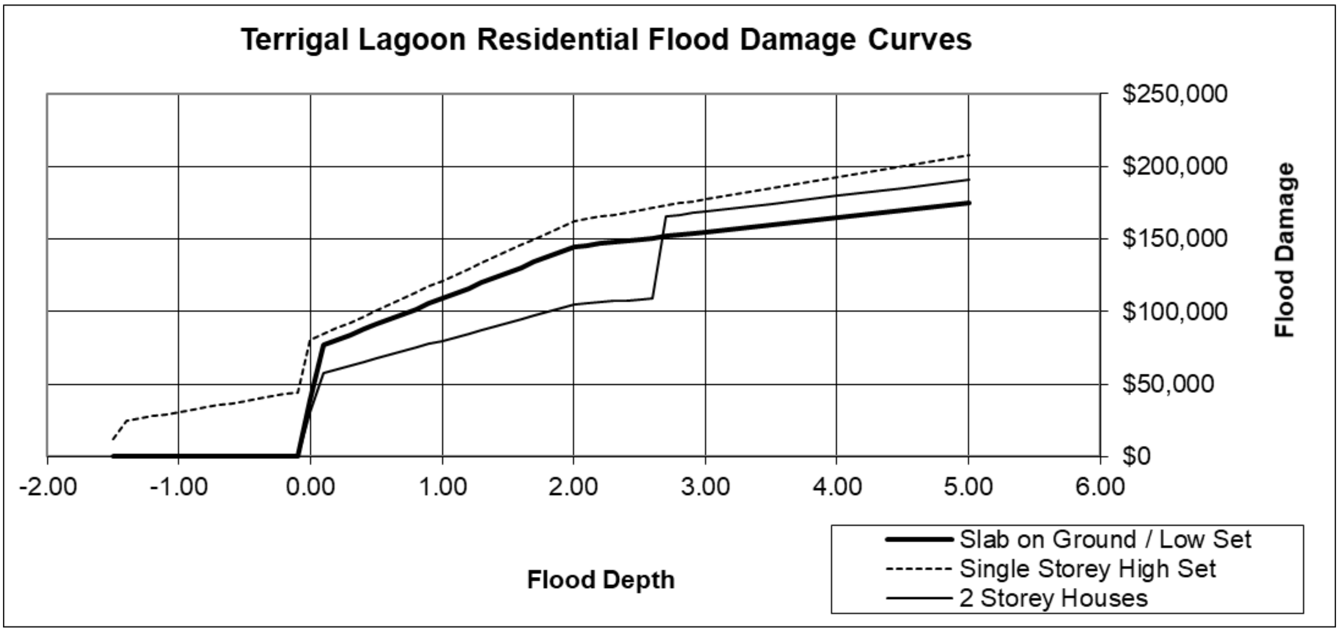
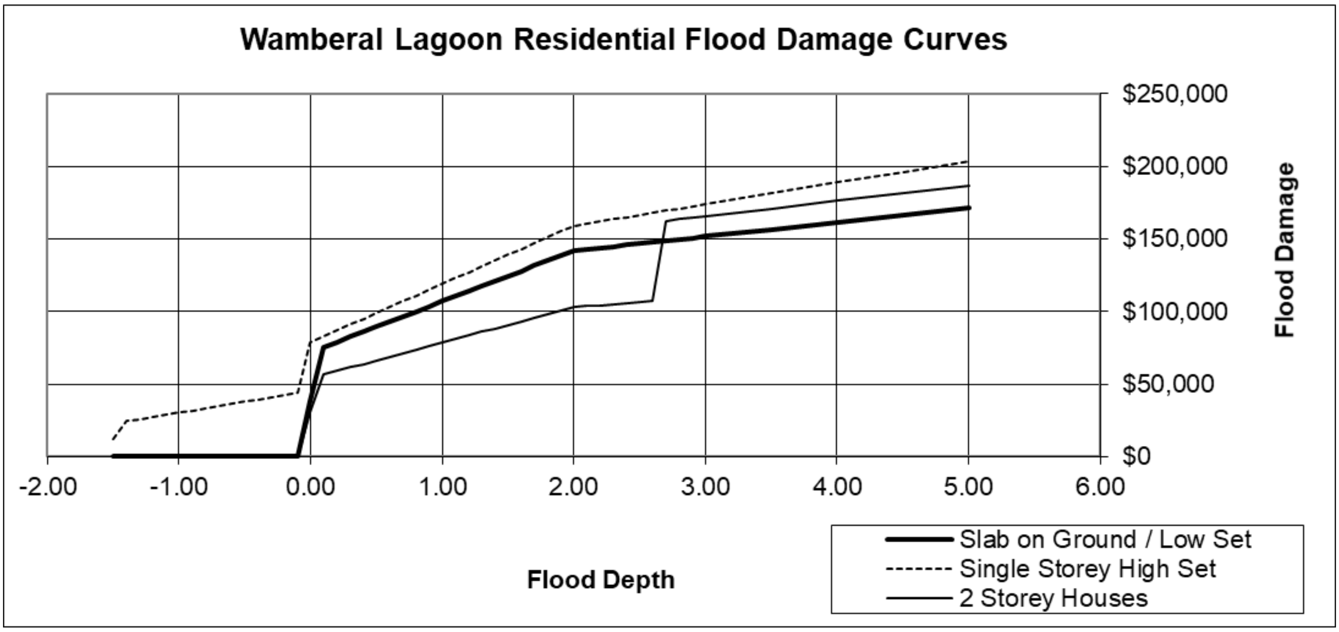


Terrigal Lagoon Residential Flood Damage Curves
$250,000
$200,000
$150,000
$100,000
$50,000
$0
Flood Damage
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Flood Depth
Slab on Ground / Low Set
Single Storey High Set
2 Storey Houses



Wamberal Lagoon Residential Flood Damage Curves
$250,000
$200,000
$150,000
$100,000
$50,000
$0
Flood Damage
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Flood Depth
Slab on Ground / Low Set
Single Storey High Set
2 Storey Houses

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Commercial-Industrial Damages – All four lagoons

Depth (m)	Commercial Low	Commercial Medium	Commercial High	Industrial Low	Industrial Medium	Industrial High
	WS-C-low	WS-C-med	WS-C-high	WS-I-low	WS-I-med	WS-I-high
-999	0	0	0	0	0	0
0.10	$117	$205	$438	$117	$205	$934
0.20	$117	$205	$438	$117	$205	$934
0.30	$137	$272	$585	$151	$282	$1,032
0.50	$175	$409	$876	$220	$438	$1,227
0.60	$187	$444	$970	$236	$502	$1,308
0.75	$205	$496	$1,110	$263	$599	$1,432
1.00	$234	$540	$1,241	$292	$716	$1,636
1.50	$278	$569	$1,418	$322	$818	$1,986
2.00	$292	$599	$1,577	$351	$905	$2,308

Damage per square metre in May 2019 dollars

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Summary of flood damage by design event for Avoca Lagoon catchment assuming 1 step to floor level

Flood Event	Number of Impacted Properties+		Direct Damage Only ($2019)		Total Predicted Actual Damage ($2019)#	Total Average Annual Damage ($2019)*	Total Net Present Value of Damage ($2019)*
	Residential	Commercial	Residential	Commercial			
PMF	1225	124	$96.6M	$5.7M	$150.9M	$0.20M	$2.9M
1 in 500 AEP	362	74	$26.9M	$3.2M	$45.1M	$0.13M	$1.9M
1 in 200 AEP	308	62	$22.8M	$2.9M	$38.6M	$0.19M	$2.7M
1% AEP	287	51	$21.1M	$2.5M	$35.4M	$0.32M	$4.7M
2% AEP	230	35	$16.8M	$2.1M	$28.4M	$0.68M	$10.1M
5% AEP	154	25	$11.2M	$0.3M	$16.9M	$0.76M	$11.2M
10% AEP	126	23	$8.9M	$0.3M	$13.5M	$1.30M	$19.3M
20% AEP	122	22	$8.4M	$0.2M	$12.5M	$2.57M	$38.0M
50% AEP	46	5	$3.1M	$0.1M	$4.6M	$0.30M	$4.5M
TOTAL	**1225**	**124**	**$215.7M**	**$17.5M**	**$346.0M**	**$6.44M**	**$95.3M**

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years
# Includes residential direct and indirect, commercial direct and indirect, infrastructure and social damages
+ Residential properties have been separated into building where multiple buildings are on the same property and commercial properties into separate businesses. However, where commercial buildings are the same company (e.g. industrial area with 5 warehouse or caravan park) the damages were consolidated as one property.

Components of flood damage for Avoca Lagoon catchment assuming 1 step to floor level (AAD)

	Damage Component	Method Assessed	Number of Impacted Properties	Cost ($2019)	
A.	Direct Residential Damage	DECC (2007) curves	1225	$4,202K	65%
B.	Indirect Residential Damage	5% of A	1225	$210K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	124	$181K	3%
D.	Indirect Commercial Damage	50% of C	124	$90K	1%
E.	Infrastructure Damage	15% of (A + C)	N/A	$657K	10%
F.	Social Damage	25% of (A + C)	N/A	$1,096K	17%
	TOTAL AAD			**$6,437K**	100%

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Summary of flood damage by design event for Avoca Lagoon catchment assuming 3 steps to floor level

Flood Event	Number of Impacted Properties+		Direct Damage Only ($2019)		Total Predicted Actual Damage ($2019)#	Total Average Annual Damage ($2019)*	Total Net Present Value of Damage ($2019)*
	Residential	Commercial	Residential	Commercial			
PMF	571	91	$43.5M	$4.7M	$72.0M	$0.09M	$1.3M
1 in 500 AEP	139	24	$9.9M	$2.2M	$18.4M	$0.05M	$0.8M
1 in 200 AEP	117	19	$8.4M	$2.0M	$16.0M	$0.08M	$1.1M
1% AEP	110	12	$7.8M	$1.9M	$15.0M	$0.13M	$2.0M
2% AEP	85	9	$6.0M	$1.8M	$12.0M	$0.27M	$3.9M
5% AEP	55	4	$3.9M	$0.0M	$5.7M	$0.25M	$3.6M
10% AEP	39	4	$2.8M	$0.0M	$4.1M	$0.39M	$5.8M
20% AEP	36	3	$2.5M	$0.0M	$3.7M	$0.77M	$11.4M
50% AEP	14	0	$1.0M	$0.0M	$1.5M	$0.10M	$1.4M
TOTAL	**571**	**91**	**$85.8M**	**$12.7M**	**$148.4M**	**$2.13M**	**$31.5M**

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years
\# Includes residential direct and indirect, commercial direct and indirect, infrastructure and social damages
\+ Residential properties have been separated into building where multiple buildings are on the same property and commercial properties into separate businesses. However, where commercial buildings are the same company (e.g. industrial area with 5 warehouse or caravan park) the damages were consolidated as one property.

Components of flood damage for Avoca Lagoon catchment assuming 3 steps to floor level (AAD)

	Damage Component	Method Assessed	Number of Impacted Properties	Cost ($2019)	
A.	Direct Residential Damage	DECC (2007) curves	571	$1,364K	64%
B.	Indirect Residential Damage	5% of A	571	$68K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	91	$78K	4%
D.	Indirect Commercial Damage	50% of C	91	$39K	2%
E.	Infrastructure Damage	15% of (A + C)	N/A	$216K	10%
F.	Social Damage	25% of (A + C)	N/A	$361K	17%
	TOTAL AAD			**$2,126K**	100%

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Summary of flood damage by design event for Cockrone Lagoon catchment assuming 1 step to floor level

Flood Event	Number of Impacted Properties+		Direct Damage Only ($2019)		Total Predicted Actual Damage ($2019)#	Total Average Annual Damage ($2019)*	Total Net Present Value of Damage ($2019)*
	Residential	Commercial	Residential	Commercial			
PMF	674	9	$49.3M	$0.4M	$72.2M	$0.10M	$1.4M
1 in 500 AEP	246	5	$16.2M	$0.2M	$23.8M	$0.07M	$1.0M
1 in 200 AEP	225	2	$14.2M	$0.1M	$20.7M	$0.10M	$1.5M
1% AEP	204	1	$12.9M	$0.0M	$18.8M	$0.17M	$2.5M
2% AEP	170	0	$10.6M	$0.0M	$15.4M	$0.41M	$6.1M
5% AEP	133	0	$8.3M	$0.0M	$12.1M	$0.54M	$8.1M
10% AEP	109	0	$6.7M	$0.0M	$9.7M	$0.83M	$12.3M
20% AEP	81	0	$4.8M	$0.0M	$7.0M	$1.41M	$20.8M
50% AEP	29	0	$1.7M	$0.0M	$2.4M	$0.16M	$2.4M
TOTAL	**674**	**9**	**$124.7M**	**$0.6M**	**$182.0M**	**$3.79M**	**$56.1M**

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years
# Includes residential direct and indirect, commercial direct and indirect, infrastructure and social damages
+ Residential properties have been separated into building where multiple buildings are on the same property and commercial properties into separate businesses. However, where commercial buildings are the same company (e.g. industrial area with 5 warehouse or caravan park) the damages were consolidated as one property.

Components of flood damage for Avoca Lagoon catchment assuming 1 step to floor level (AAD)

	Damage Component	Method Assessed	Number of Impacted Properties	Cost ($2019)	
A.	Direct Residential Damage	DECC (2007) curves	674	$2,612K	69%
B.	Indirect Residential Damage	5% of A	674	$131K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	9	$1.0K	0%
D.	Indirect Commercial Damage	50% of C	9	$0.5K	0%
E.	Infrastructure Damage	15% of (A + C)	N/A	$392K	10%
F.	Social Damage	25% of (A + C)	N/A	$653K	17%
	TOTAL AAD			**$3,790K**	100%

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Summary of flood damage by design event for Cockrone Lagoon catchment assuming 3 steps to floor level

Flood Event	Number of Impacted Properties+		Direct Damage Only ($2019)		Total Predicted Actual Damage ($2019)#	Total Average Annual Damage ($2019)*	Total Net Present Value of Damage ($2019)*
	Residential	Commercial	Residential	Commercial			
PMF	335	6	$24.9M	$0.2M	$36.4M	$0.04M	$0.6M
1 in 500 AEP	74	0	$4.7M	$0.0M	$6.8M	$0.02M	$0.3M
1 in 200 AEP	62	0	$3.8M	$0.0M	$5.5M	$0.03M	$0.4M
1% AEP	54	0	$3.2M	$0.0M	$4.7M	$0.04M	$0.6M
2% AEP	43	0	$2.5M	$0.0M	$3.6M	$0.09M	$1.4M
5% AEP	30	0	$1.7M	$0.0M	$2.5M	$0.11M	$1.6M
10% AEP	21	0	$1.3M	$0.0M	$1.9M	$0.16M	$2.4M
20% AEP	17	0	$1.0M	$0.0M	$1.4M	$0.31M	$4.6M
50% AEP	8	0	$0.5M	$0.0M	$0.7M	$0.04M	$0.7M
TOTAL	**335**	**6**	**$43.5M**	**$0.2M**	**$63.4M**	**$0.85M**	**$12.6M**

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years
# Includes residential direct and indirect, commercial direct and indirect, infrastructure and social damages
+ Residential properties have been separated into building where multiple buildings are on the same property and commercial properties into separate businesses. However, where commercial buildings are the same company (e.g. industrial area with 5 warehouse or caravan park) the damages were consolidated as one property.

Components of flood damage for Cockrone Lagoon catchment assuming 3 steps to floor level (AAD)

	Damage Component	Method Assessed	Number of Impacted Properties	Cost ($2019)	
A.	Direct Residential Damage	DECC (2007) curves	335	$586K	69%
B.	Indirect Residential Damage	5% of A	335	$29K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	6	$0.2K	0%
D.	Indirect Commercial Damage	50% of C	6	$0.1K	0%
E.	Infrastructure Damage	15% of (A + C)	N/A	$88K	10%
F.	Social Damage	25% of (A + C)	N/A	$147K	17%
	TOTAL AAD			**$850K**	100%

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Summary of flood damage by design event for Terrigal Lagoon catchment assuming 1 step to floor level

Flood Event	Number of Impacted Properties+		Direct Damage Only ($2019)		Total Predicted Actual Damage ($2019)#	Total Average Annual Damage ($2019)*	Total Net Present Value of Damage ($2019)*
	Residential	Commercial	Residential	Commercial			
PMF	2563	71	$220.4M	$10.7M	$339.8M	$0.43M	$6.3M
1 in 500 AEP	772	19	$59.4M	$1.7M	$89.4M	$0.25M	$3.7M
1 in 200 AEP	666	19	$50.8M	$1.6M	$76.7M	$0.35M	$5.2M
1% AEP	569	12	$42.8M	$1.3M	$64.7M	$0.59M	$8.7M
2% AEP	468	10	$34.9M	$1.0M	$52.5M	$1.33M	$19.7M
5% AEP	322	6	$23.9M	$0.7M	$36.0M	$1.55M	$23.0M
10% AEP	234	4	$17.3M	$0.6M	$26.2M	$2.54M	$37.6M
20% AEP	216	4	$16.2M	$0.6M	$24.6M	$5.50M	$81.4M
50% AEP	106	3	$7.7M	$0.5M	$12.1M	$0.80M	$11.8M
TOTAL	**2563**	**71**	**$473.3M**	**$18.8M**	**$722.0M**	**$13.33M**	**$197.3M**

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years
# Includes residential direct and indirect, commercial direct and indirect, infrastructure and social damages
+ Residential properties have been separated into building where multiple buildings are on the same property and commercial properties into separate businesses. However, where commercial buildings are the same company (e.g. industrial area with 5 warehouse or caravan park) the damages were consolidated as one property.

Components of flood damage for Terrigal Lagoon catchment assuming 1 step to floor level (AAD)

	Damage Component	Method Assessed	Number of Impacted Properties	Cost ($2019)	
A.	Direct Residential Damage	DECC (2007) curves	2563	$8,737K	65%
B.	Indirect Residential Damage	5% of A	2563	$437K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	71	$349K	3%
D.	Indirect Commercial Damage	50% of C	71	$175K	1%
E.	Infrastructure Damage	15% of (A + C)	N/A	$1,363K	10%
F.	Social Damage	25% of (A + C)	N/A	$2,272K	17%
	TOTAL AAD			**$13,332K**	100%

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Summary of flood damage by design event for Terrigal Lagoon catchment assuming 3 steps to floor level

Flood Event	Number of Impacted Properties+		Direct Damage Only ($2019)		Total Predicted Actual Damage ($2019)#	Total Average Annual Damage ($2019)*	Total Net Present Value of Damage ($2019)*
	Residential	Commercial	Residential	Commercial			
PMF	1240	39	$108.1M	$6.0M	$168.2M	$0.20M	$3.0M
1 in 500 AEP	283	15	$22.3M	$1.5M	$35.2M	$0.10M	$1.4M
1 in 200 AEP	236	12	$18.5M	$1.2M	$29.2M	$0.13M	$1.9M
1% AEP	190	6	$14.8M	$1.0M	$23.4M	$0.22M	$3.2M
2% AEP	159	4	$12.4M	$0.9M	$19.6M	$0.49M	$7.2M
5% AEP	102	3	$8.0M	$0.6M	$12.8M	$0.56M	$8.3M
10% AEP	75	3	$5.9M	$0.5M	$9.6M	$0.91M	$13.5M
20% AEP	68	3	$5.3M	$0.5M	$8.7M	$2.03M	$30.0M
50% AEP	36	1	$2.8M	$0.4M	$4.8M	$0.32M	$4.7M
TOTAL	**1240**	**39**	**$198.2M**	**$12.7M**	**$311.5M**	**$4.95M**	**$73.3M**

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years
# Includes residential direct and indirect, commercial direct and indirect, infrastructure and social damages
+ Residential properties have been separated into building where multiple buildings are on the same property and commercial properties into separate businesses. However, where commercial buildings are the same company (e.g. industrial area with 5 warehouse or caravan park) the damages were consolidated as one property.

Components of flood damage for Terrigal Lagoon catchment assuming 3 steps to floor level (AAD)

	Damage Component	Method Assessed	Number of Impacted Properties	Cost ($2019)	
A.	Direct Residential Damage	DECC (2007) curves	1240	$3,018K	61%
B.	Indirect Residential Damage	5% of A	1240	$151K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	39	$304K	6%
D.	Indirect Commercial Damage	50% of C	39	$152K	3%
E.	Infrastructure Damage	15% of (A + C)	N/A	$498K	10%
F.	Social Damage	25% of (A + C)	N/A	$830K	17%
	TOTAL AAD			**$4,953K**	100%

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Summary of flood damage by design event for Wamberal Lagoon catchment assuming 1 step to floor level

Flood Event	Number of Impacted Properties+		Direct Damage Only ($2019)		Total Predicted Actual Damage ($2019)#	Total Average Annual Damage ($2019)*	Total Net Present Value of Damage ($2019)*
	Residential	Commercial	Residential	Commercial			
PMF	1584	14	$124.5M	$1.8M	$184.0M	$0.25M	$3.7M
1 in 500 AEP	703	4	$43.3M	$1.0M	$64.6M	$0.19M	$2.9M
1 in 200 AEP	618	3	$43.5M	$0.9M	$64.8M	$0.30M	$4.5M
1% AEP	542	3	$38.0M	$0.9M	$56.7M	$0.51M	$7.5M
2% AEP	439	1	$30.3M	$0.7M	$45.2M	$1.12M	$16.5M
5% AEP	286	1	$19.2M	$0.7M	$29.2M	$1.26M	$18.6M
10% AEP	222	0	$14.5M	$0.0M	$21.0M	$1.95M	$28.8M
20% AEP	188	0	$12.3M	$0.0M	$17.9M	$3.96M	$58.6M
50% AEP	97	0	$5.9M	$0.0M	$8.5M	$0.56M	$8.3M
TOTAL	**1584**	**14**	**$331.6M**	**$5.9M**	**$492.0M**	**$10.09M**	**$149.4M**

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years
# Includes residential direct and indirect, commercial direct and indirect, infrastructure and social damages
+ Residential properties have been separated into building where multiple buildings are on the same property and commercial properties into separate businesses. However, where commercial buildings are the same company (e.g. industrial area with 5 warehouse or caravan park) the damages were consolidated as one property.

Components of flood damage for Wamberal Lagoon catchment assuming 1 step to floor level (AAD)

	Damage Component	Method Assessed	Number of Impacted Properties	Cost ($2019)	
A.	Direct Residential Damage	DECC (2007) curves	1584	6,889K	68%
B.	Indirect Residential Damage	5% of A	1584	$344K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	14	$54K	1%
D.	Indirect Commercial Damage	50% of C	14	$27K	0%
E.	Infrastructure Damage	15% of (A + C)	N/A	$1,041K	10%
F.	Social Damage	25% of (A + C)	N/A	$1,736K	17%
	TOTAL AAD			**$10,092K**	100%

Summary of flood damage by design event for Wamberal Lagoon catchment assuming 3 steps to floor level

Flood Event	Number of Impacted Properties[+]		Direct Damage Only ($2019)		Total Predicted Actual Damage ($2019)[#]	Total Average Annual Damage ($2019)*	Total Net Present Value of Damage ($2019)*
	Residential	Commercial	Residential	Commercial			
PMF	552	2	$42.0M	$0.7M	$62.2M	$0.07M	$1.1M
1 in 500 AEP	126	0	$7.9M	$0.0M	$11.5M	$0.03M	$0.5M
1 in 200 AEP	95	0	$7.1M	$0.0M	$10.3M	$0.05M	$0.7M
1% AEP	80	0	$6.1M	$0.0M	$8.8M	$0.08M	$1.2M
2% AEP	64	0	$4.9M	$0.0M	$7.1M	$0.18M	$2.6M
5% AEP	46	0	$3.3M	$0.0M	$4.7M	$0.20M	$3.0M
10% AEP	33	0	$2.3M	$0.0M	$3.3M	$0.29M	$4.4M
20% AEP	28	0	$1.8M	$0.0M	$2.6M	$0.55M	$8.2M
50% AEP	11	0	$0.7M	$0.0M	$1.1M	$0.07M	$1.1M
TOTAL	**552**	**2**	**$76.0M**	**$0.7M**	**$111.5M**	**$1.53M**	**$22.6M**

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years
[#] Includes residential direct and indirect, commercial direct and indirect, infrastructure and social damages
[+] Residential properties have been separated into building where multiple buildings are on the same property and commercial properties into separate businesses. However, where commercial buildings are the same company (e.g. industrial area with 5 warehouse or caravan park) the damages were consolidated as one property.

Components of flood damage for Wamberal Lagoon catchment assuming 3 steps to floor level (AAD)

	Damage Component	Method Assessed	Number of Impacted Properties	Cost ($2019)	
A.	Direct Residential Damage	DECC (2007) curves	552	$1,053K	69%
B.	Indirect Residential Damage	5% of A	552	$53K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	2	<$1K	0%
D.	Indirect Commercial Damage	50% of C	2	<$1K	0%
E.	Infrastructure Damage	15% of (A + C)	N/A	$158K	10%
F.	Social Damage	25% of (A + C)	N/A	$263K	17%
	TOTAL AAD			**$1,528K**	100%

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Appendix O – Flood planning area

Figure O.1 Avoca Lagoon Flood Planning Area (1% AEP + 30% Increase in Rainfall Intensity)
Figure O.2 Cockrone Lagoon Flood Planning Area (1% AEP + 30% Increase in Rainfall Intensity)
Figure O.3 Terrigal Lagoon Flood Planning Area (1% AEP + 30% Increase in Rainfall Intensity)
Figure O.4 Wamberal Lagoon Flood Planning Area (1% AEP + 30% Increase in Rainfall Intensity)
Figure O.5 Avoca Lagoon Preliminary Freeboard Recommendations for Flood Hazard Levels
Figure O.6 Cockrone Lagoon Preliminary Freeboard Recommendations for Flood Hazard Levels
Figure O.7 Terrigal Lagoon Preliminary Freeboard Recommendations for Flood Hazard Levels
Figure O.8 Wamberal Lagoon Preliminary Freeboard Recommendations for Floor Hazard Levels

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Appendix P – Emergency response classifications

Figure P.1 Avoca Lagoon Probable Maximum Flood Emergency Response Categories
Figure P.2 Avoca Lagoon 1% AEP Flood Emergency Response Categories
Figure P.3 Avoca Lagoon 5% AEP Flood Emergency Response Categories
Figure P.4 Avoca Lagoon 10% AEP Flood Emergency Response Categories
Figure P.5 Avoca Lagoon 20% AEP Flood Emergency Response Categories
Figure P.6 Cockrone Lagoon Probable Maximum Flood Emergency Response Categories
Figure P.7 Cockrone Lagoon 1% AEP Flood Emergency Response Categories
Figure P.8 Cockrone Lagoon 5% AEP Flood Emergency Response Categories
Figure P.9 Cockrone Lagoon 10% AEP Flood Emergency Response Categories
Figure P.10 Cockrone Lagoon 20% AEP Flood Emergency Response Categories
Figure P.11 Terrigal Lagoon Probable Maximum Flood Emergency Response Categories
Figure P.12 Terrigal Lagoon 1% AEP Flood Emergency Response Categories
Figure P.13 Terrigal Lagoon 5% AEP Flood Emergency Response Categories
Figure P.14 Terrigal Lagoon 10% AEP Flood Emergency Response Categories
Figure P.15 Terrigal Lagoon 20% AEP Flood Emergency Response Categories
Figure P.16 Wamberal Lagoon Probable Maximum Flood Emergency Response Categories
Figure P.17 Wamberal Lagoon 1% AEP Flood Emergency Response Categories
Figure P.18 Wamberal Lagoon 5% AEP Flood Emergency Response Categories
Figure P.19 Wamberal Lagoon 10% AEP Flood Emergency Response Categories
Figure P.20 Wamberal Lagoon 20% AEP Flood Emergency Response Categories

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Appendix Q – Pipe capacity

Figure Q.1 Avoca Lagoon Probable Maximum Flood Pipe capacity
Figure Q.2 Avoca Lagoon 1 in 500 AEP Flood Pipe capacity
Figure Q.3 Avoca Lagoon 1 in 200 AEP Flood Pipe capacity
Figure Q.4 Avoca Lagoon 1% AEP Flood Pipe capacity
Figure Q.5 Avoca Lagoon 2% AEP Flood Pipe capacity
Figure Q.6 Avoca Lagoon 5% AEP Flood Pipe capacity
Figure Q.7 Avoca Lagoon 10% AEP Flood Pipe capacity
Figure Q.8 Avoca Lagoon 20% AEP Flood Pipe capacity
Figure Q.9 Avoca Lagoon 50% AEP Flood Pipe capacity
Figure Q.10 Cockrone Lagoon Probable Maximum Flood Pipe capacity
Figure Q.11 Cockrone Lagoon 1 in 500 AEP Flood Pipe capacity
Figure Q.12 Cockrone Lagoon 1 in 200 AEP Flood Pipe capacity
Figure Q.13 Cockrone Lagoon 1% AEP Flood Pipe capacity
Figure Q.14 Cockrone Lagoon 2% AEP Flood Pipe capacity
Figure Q.15 Cockrone Lagoon 5% AEP Flood Pipe capacity
Figure Q.16 Cockrone Lagoon 10% AEP Flood Pipe capacity
Figure Q.17 Cockrone Lagoon 20% AEP Flood Pipe capacity
Figure Q.18 Cockrone Lagoon 50% AEP Flood Pipe capacity
Figure Q.19 Terrigal Lagoon Probable Maximum Flood Pipe capacity
Figure Q.20 Terrigal Lagoon 1 in 500 AEP Flood Pipe capacity
Figure Q.21 Terrigal Lagoon 1 in 200 AEP Flood Pipe capacity
Figure Q.22 Terrigal Lagoon 1% AEP Flood Pipe capacity
Figure Q.23 Terrigal Lagoon 2% AEP Flood Pipe capacity
Figure Q.24 Terrigal Lagoon 5% AEP Flood Pipe capacity
Figure Q.25 Terrigal Lagoon 10% AEP Flood Pipe capacity
Figure Q.26 Terrigal Lagoon 20% AEP Flood Pipe capacity
Figure Q.27 Terrigal Lagoon 50% AEP Flood Pipe capacity
Figure Q.28 Wamberal Lagoon Probable Maximum Flood Pipe capacity
Figure Q.29 Wamberal Lagoon 1 in 500 AEP Flood Pipe capacity
Figure Q.30 Wamberal Lagoon 1 in 200 AEP Flood Pipe capacity
Figure Q.31 Wamberal Lagoon 1% AEP Flood Pipe capacity
Figure Q.32 Wamberal Lagoon 2% AEP Flood Pipe capacity
Figure Q.33 Wamberal Lagoon 5% AEP Flood Pipe capacity
Figure Q.34 Wamberal Lagoon 10% AEP Flood Pipe capacity
Figure Q.35 Wamberal Lagoon 20% AEP Flood Pipe capacity
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Appendix R – 1:5,000 maps

Figure R.0 Lagoons reference maps
Figure R.1 Avoca Lagoon 1% AEP Flood Level
Figure R.2 Avoca Lagoon Probable Maximum Flood Level
Figure R.3 Cockrone Lagoon 1% AEP Flood Level
Figure R.4 Cockrone Lagoon Probable Maximum Flood Level
Figure R.5 Terrigal Lagoon 1% AEP Flood Level
Figure R.6 Terrigal Lagoon Probable Maximum Flood Level
Figure R.7 Wamberal Lagoon 1% AEP Flood Level
Figure R.8 Wamberal Lagoon Probable Maximum Flood Level
Figure R.9 Avoca Lagoon 1% AEP Flood Depth
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Figure R.12 Cockrone Lagoon Probable Maximum Flood Depth
Figure R.13 Terrigal Lagoon 1% AEP Flood Depth
Figure R.14 Terrigal Lagoon Probable Maximum Flood Depth
Figure R.15 Wamberal Lagoon 1% AEP Flood Depth
Figure R.16 Wamberal Lagoon Probable Maximum Flood Depth
Figure R.17 Avoca Lagoon 1% AEP Flood Hazard H1-H6
Figure R.18 Avoca Lagoon Probable Maximum Flood Hazard H1-H6
Figure R.19 Cockrone Lagoon 1% AEP Flood Hazard H1-H6
Figure R.20 Cockrone Lagoon Probable Maximum Flood Hazard H1-H6
Figure R.21 Terrigal Lagoon 1% AEP Flood Hazard H1-H6
Figure R.22 Terrigal Lagoon Probable Maximum Flood Hazard H1-H6
Figure R.23 Wamberal Lagoon 1% AEP Flood Hazard H1-H6
Figure R.24 Wamberal Lagoon Probable Maximum Flood Hazard H1-H6
Figure R.25 Avoca Lagoon 1% AEP Flood Hydraulic Categories
Figure R.26 Avoca Lagoon Probable Maximum Flood Hydraulic Categories
Figure R.27 Cockrone Lagoon 1% AEP Flood Hydraulic Categories
Figure R.28 Cockrone Lagoon Probable Maximum Flood Hydraulic Categories
Figure R.29 Terrigal Lagoon 1% AEP Flood Hydraulic Categories
Figure R.30 Terrigal Lagoon Probable Maximum Flood Hydraulic Categories
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Figure R.32 Wamberal Lagoon Probable Maximum Flood Hydraulic Categories
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Figure R.37 Avoca Lagoon Preliminary Freeboard Recommendations for Flood Hazard Levels
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Figure R.39 Terrigal Lagoon Preliminary Freeboard Recommendations for Flood Hazard Levels
Figure R.40 Wamberal Lagoon Preliminary Freeboard Recommendations for Flood Hazard Levels

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Appendix S – Rate of rise and time to peak

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