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Coogee Bay Flood Study

Final Report | April 2013

Coogee Bay
Flood Study
Final Report

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Title :	Coogee Bay Flood Study – Final Report
Author :	Daniel Williams
Synopsis :	Report for the Coogee Bay Flood Study covering the development and calibration of computer models, establishment of design flood behaviour and flood mapping.

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EXECUTIVE SUMMARY

Introduction

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

The primary objective of the Flood Study is to define the flood behaviour of the local Coogee Bay catchments through the establishment of appropriate numerical models. The study has produced information on flood flows, velocities, levels and extents for a range of flood event magnitudes under existing catchment and floodplain conditions. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Undertaking a community consultation and participation program to identify local flooding concerns, collect information on historical flood behaviour and engage the community in the on-going floodplain management process;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design events including the 20% AEP, 5% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and extreme flood event; and
- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping.

Catchment Description

The study area catchments occupy a total area of 2.9km^2 and incorporate the majority of Coogee and parts of South Coogee and Randwick. The catchments drain to the east into Coogee Bay.

The natural creek systems have been heavily modified and the study area is now drained entirely by a stormwater pipe network. When the capacity of this network is exceeded, overland flow will occur along the alignments of the original creeks. Many of the old creek alignments are now located through developed properties, which presents a significant flood risk.

Land use within the study area primarily consists of urban development (90%), open recreational space (9%) and tree-covered land (1%). The urban development within the study area includes low, medium and high density residential development and commercial uses, including the Coogee CBD along the beachfront. Some of the developed areas would previously have been creek alignments.

Historical Flooding

There is a long history of flooding in Coogee, as it is an old suburb with development located on natural creek lines. Floods reported in available newspaper articles include 1959, 1989 and 1998. The October 1959 event is the largest recorded within the catchment, with a daily total of 265mm of rainfall recorded at Randwick Bowling Club, however, the duration of the event is understood to have been of the order of three and a half hours.

The most significant recent floods include the January 1999 and May 2009 events. The former is well documented by both the Coogee Oval and Bowling Club Flooding Assessment (PBP, 1999) and Assessment of Impacts from January 1999 Flooding (GBA, 1999). 74mm of rain were recorded on 24th January at Randwick Bowling Club, most of which is believed to have fallen in a 90 minute period. This would be equivalent to around a 10% AEP event.

The May 2009 event is one of the largest recent local flooding events within the catchment This was a localised storm event which primarily impacted the eastern suburbs of Sydney. Randwick Bowling Club recorded 77mm of rain on 3rd May, which was the highest recorded daily total by any gauge in the local area. Most of the rain fell within a 90 minute period, which would be equivalent to around a 10% AEP event.

Community Consultation

Community consultation undertaken during the study has aimed to collect information on historical flooding and previous flood experience, and inform the community about the development of the flood study and its likely outcome as a precursor to floodplain management activities to follow. The key element of the consultation process involved the distribution of a questionnaire relating to historical flooding.

Council mailed out the questionnaire to all residents and businesses located within the study area. Council received back almost 1000 responses, of which around 250 had comments relating to flooding. The comments relating to flooding that were received from the community provided valuable data for the calibration process.

Model Development

Development of hydrologic and hydraulic models has been undertaken to simulate flood conditions in the catchment. Hydrologic and hydraulic modelling has been undertaken using the TUFLOW two-dimensional (2D) software developed by BMT WBM and utilising a direct rainfall approach to model the catchment hydrology. The model simulates runoff routing, hydrological response, flood depths, extents and velocities. The 2D modelling approach is suited to model the complex interaction between channels and floodplains and converging and diverging of flows through structures and urban environments.

The floodplain topography is defined using a high resolution digital elevation model (DEM) derived from LiDAR survey for greater accuracy in predicting flows and water levels and the interaction of in-channel and floodplain areas. The stormwater drainage system was modelled, using survey details of pipe configuration, pipe sizes and invert levels. Land use surfaces wee derived largely from Council GIS layers, including individual building footprint polygons.

Model Calibration and Validation

The selection of suitable historical events for calibration of computer models is largely dependent on available historical flood information. Significant flooding in Coogee has occurred on numerous occasions, with the most severe events in recent times including 1959, 1989, 1998, 1999 and 2009.

The May 2009 event is considered the most suitable of the historical events for model calibration. The vast majority of the community questionnaire responses related to the May 2009 event. The availability of rainfall data and flood photographs provides a sound dataset to assist calibration of the model.

The January 1999 event was also selected for model calibration. It is similar in magnitude to the May 2009 event and is the next most recent significant flood event in the catchment. The October 1959 event has been selected for model validation purposes as although available data is limited, it is the largest event recorded within the study area.

A reasonable model calibration has been achieved given the available data for the catchment. The developed model is considered to provide a sound representation of the flooding behaviour of the catchment, as demonstrated through comparison of recorded peak water levels and known inundation areas for the historical events simulated.

Design Event Modelling and Output

The developed model has been applied to derive design flood conditions within the Coogee Bay catchments. Design rainfall depth is based on the generation of intensity-frequency-duration (IFD) design rainfall curves utilising the procedures outlined in AR&R (2001). A range of storm durations using standard AR&R temporal patterns were modelled in order to identify the critical storm duration for design event flooding in the catchments.

The design events considered in this study include the 20% AEP (5-year ARI), 5% AEP (20-year ARI), 1% AEP (100-year ARI), 0.5% AEP (200-year ARI), 0.2% AEP (500-year ARI) and PMF events. The model results for the design events considered have been presented in a detailed flood mapping series for the catchments. The flood data presented includes design flood inundation, peak flood depths and peak flood velocities.

Provisional flood hazard categorisation in accordance with Figure L2 of the NSW Floodplain Development Manual (2005) has been mapped for the events, in addition to the hydraulic categories (floodway, flood fringe and flood storage) for flood affected areas.

Sensitivity Testing

A series of sensitivity tests have been undertaken on the modelled flood behaviour of the Coogee Bay catchments. The tests provide a basis for determining the relative sensitivity of modelling results to adopted parameter values. The tests undertaken include:

- Structure blockages – structure blockage due to flood debris can result in significant increases to flood levels and redistributions of flood flows. A scenario of 100% blockage to the stormwater drainage network has been applied to identify locations for which the blockage conditions are significant;

- Design rainfall losses – a decrease in design rainfall losses has been simulated to adopt the standard 15mm initial loss recommended by AR&R. This provides for an increase in effective rainfall and therefore in increase in surface runoff for the design rainfall condition;

- Increased sea-level – the downstream boundary condition in Coogee Bay was raised to an extreme level, approximating a 0.5% AEP ocean flooding condition with a 0.9m climate change sea-level rise allowance; and

- Increased rainfall intensities – the 0.5% AEP and 0.2% AEP event results were compared with the 1% AEP results to assess the impact of a 10% and 25% increase to the 1% AEP design rainfall intensities. This is similar to the recommended approach for considering increased rainfall intensity as a potential impact of climate change.

Conclusions

The objective of the study was to undertake a detailed flood study of the local overland flow catchments of Coogee Bay and establish models as necessary for design flood level prediction. In simulating the design flood conditions for the local catchments in the study area, the following locations were identified as potential problem areas in relation to flood inundation extent and property affected:

- Alfreda Street and Coogee Oval;
- Brook Street;
- Coogee Bowling Club and Tennis Club;
- Coogee Street and Dolphin Street;
- Clyde Street;
- Oswald Street;
- Abbott Street;
- Bardon Park and Smithfield Avenue;
- Carr Street;
- Oberon Street; and
- Rainbow Street.

The flooding issues within the Coogee Bay study area are largely restricted to locations which were naturally creek/gully lines, but are now occupied by urban development. Along these alignments natural depressions in the topography and those created by man-made obstructions, such as roads and other land-raising activities, fill to significant depths during major design flood events. This type of flood behaviour is widespread throughout the study area.

Most of the study area drains to two large depressions – Coogee Oval and Rainbow Street. At Coogee Oval the higher ground of Arden Street and Goldstein Reserve is situated some 2m above the bottom of the Oval. During major flood events the available storage of the Oval will be exceeded and flood waters will spill across Arden Street and the reserve to the beach. The Rainbow Street depression is some 10m deep and as such the storage capacity will never be exceeded. In extreme flood conditions such as the PMF event or under a blocked stormwater drainage scenario, a significant flood risk to this area is posed, with possible flood depths of several metres.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

annual exceedance probability (AEP)	AEP (measured as a percentage) is a term used to describe flood size. It is a means of describing how likely a flood is to occur in a given year. For example, a 1% AEP flood is a flood that has a 1% chance of occurring, or being exceeded, in any one year. It is also referred to as the '100 year ARI flood' or '1 in 100 year flood'. The term 100 year ARI flood has been used in this study. See also average recurrence interval (ARI).
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
attenuation	Weakening in force or intensity
average recurrence interval (ARI)	ARI (measured in years) is a term used to describe flood size. It is the long-term average number of years between floods of a certain magnitude. For example, a 100 year ARI flood is a flood that occurs or is exceeded on average once every 100 years. The term 100 year ARI flood has been used in this study. See also annual exceedance probability (AEP).
catchment	The catchment at a particular point is the area of land that drains to that point.
design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100yr ARI or 1% AEP flood).
development	Existing or proposed works that may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.
discharge	The rate of flow of water measured in tems of vollume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
flood	A relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood behaviour	The pattern / characteristics / nature of a flood.
flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage.
flood hazard	The potential for damage to property or risk to persons during a flood. Flood hazard is a key tool used to determine flood severity and is used for assessing the suitability of future types of land use.The degree of flood hazard varies with circumstances across the full range of floods.

flood level	The height of the flood described either as a depth of water above a particular location (eg. 1m above a floor, yard or road) or as a depth of water related to a standard level such as Australian Height Datum (eg the flood level was 7.8 mAHD). Terms also used include flood stage and water level.
flood liable land	see flood prone land
floodplain	Land susceptible to flooding up to the probable maximum flood (PMF). Also called flood prone land. Note that the term flood liable land now covers the whole of the floodplain, not just that part below the flood planning level.
floodplain risk management study	Studies carried out in accordance with the Floodplain Development Manual (NSW Government, 2005) that assesses options for minimising the danger to life and property during floods. These measures, referred to as 'floodplain management measures / options', aim to achieve an equitable balance between environmental, social, economic, financial and engineering considerations. The outcome of a Floodplain Risk Management Study is a Floodplain Risk Management Plan.
floodplain risk management plan	The outcome of a Floodplain Risk Management Study.
flood planning levels (FPL)	The combination of flood levels and freeboards selected for planning purposes, as determined in Floodplain Risk Management Studies and incorporated in Floodplain Risk Management Plans. The concept of flood planning levels supersedes the designated flood or the flood standard used in earlier studies..
flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
flood stage	See flood level.
flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
flood study	A study that investigates flood behaviour, including identification of flood extents, flood levels and flood velocities for a range of flood sizes.
floodway	Those areas of the floodplain where a significant discharge of water occurs during floods. Floodways 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	A factor of safety usually expressed as a height above the adopted flood level thus determing the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.

high flood hazard	For a particular size flood, there would be a possible danger to personal safety, able-bodied adults would have difficulty wading to safety, evacuation by trucks would be difficult and there would be a potential for significant structural damage to buildings.
hydraulics	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrology	The term given to the study of the rainfall-runoff process in catchments.
low flood hazard	For a particular size flood, able-bodied adults would generally have little difficulty wading and trucks could be used to evacuate people and their possessions should it be necessary.
m AHD	metres Australian Height Datum (AHD).
m/s	metres per second. Unit used to describe the velocity of floodwaters.
m^3/s	Cubic metres per second or ‘cumecs’. A unit of measurement for creek or river flows or discharges. It is the rate of flow of water measured in terms of volume per unit time.
overland flow path	The path that floodwaters can follow if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads. Floodwaters travelling along overland flow paths, often referred to as ‘overland flows’, may or may not re-enter the main channel from which they left; they may be diverted to another water course.
peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
probable maximum flood (PMF)	The largest flood likely to ever occur. The PMF defines the extent of flood prone land or flood liable land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with the PMF event are addressed in the current study.
probability	A statistical measure of the likely frequency or occurrence of flooding.
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
stage	See flood level.
topography	The shape of the surface features of land
velocity	The term used to describe the speed of floodwaters, usually in m/s.
water level	See flood level.

1 INTRODUCTION

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

1.1 Study Location

The study area drains east to Coogee Bay, with a total area of some 2.9km^2 as shown in Figure 1-1. Around 80% of the study area forms a single catchment, which is drained via the stormwater pipe network and discharges to the sea at the northern end of Coogee Beach. Another 10% of the study area drains to a topographic depression located on Rainbow Street, which is drained by the stormwater pipe network. The remainder of the study area drains to the sea via smaller local pipe networks. The study area is predominantly urban and the natural creek systems have been heavily modified.

1.2 Study Background

Previous studies within the Coogee Bay catchments have focussed on response to the January 1999 flood event, which is one of the more significant recent floods in the study area. Hydrological models have been used to assess flooding in the Coogee Oval catchment, but a detailed hydraulic modelling investigation of the entire study area had not been carried out prior to the undertaking of the current study.

It is recognised that the runoff from local catchments can pose a significant flood risk to parts of the Coogee Bay catchments. The majority of the study area is serviced by an underground stormwater drainage system. However, these systems have a finite capacity and are generally designed to convey runoff for events of the order of 20% AEP to 10% AEP at best. For events of a larger magnitude that exceed the drainage system capacity, overland flows are generally conveyed along road networks or designated overland flow paths. In Coogee Bay there are a number of overland flow paths that are not aligned with the road system which flow through private property.

1.3 The Need for Floodplain Management at Coogee Bay

As evidenced in the recent May 2009 and January 1999 events, a significant flood risk from overland flow is posed to residents in parts of the Coogee Bay area. The existing development situated within historic creek and gully alignments are particularly at risk from flooding. This existing flood risk may be exacerbated by potential climate change impacts through increased storm intensities and therefore more catchment runoff. This may result in more frequent and more severe flooding in some locations within the study area.

There is likely to be a future increase in development pressures across the wider Randwick LGA, including Coogee to accommodate general population growth expectations. Whilst the majority of the study catchments are largely developed, infill development may see an intensification of the existing urban areas. This in time will increase the number of people potentially exposed to flood risk, many

Title:
Study Locality

Figure: 1-1

Rev: A

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Approx. Scale

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Filepath : K:\N1924_Coogee_Bay_Flood_Study\MI\Workspaces\DRG_001_100808_Study_Locality.WOR of whom would be oblivious to existing flood risk given no previous experience of flooding in the catchment

Floodplain risk management considers the consequences of flooding on the community and aims to develop appropriate floodplain management measures to minimise and mitigate the impact of flooding. This incorporates the existing flood risk associated with current development, and future flood risk associated with future development and changes in land use.

Accordingly, Council desires to approach local floodplain management in a considered and systematic manner. This study comprises the initial stages of that systematic approach, as outlined in the Floodplain Development Manual (NSW Government, 2005). The approach will allow for more informed planning decisions within Coogee.

1.4 The Floodplain Management Process

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

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

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

Stages of Floodplain Management

	Stage	Description
1	Flood Study	Determines the nature and extent of the flood problem.
2	Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed developments.
3	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
4	Implementation of the Floodplain Risk Management Plan	Construction of flood mitigation works to protect existing development. Use of environmental plans to ensure new development is compatible with the flood hazard.

This study represents Stage 1 of the above process and aims to provide an understanding of local catchment flood behaviour within the Coogee Bay catchments.

1.5 Study Objectives

The primary objective of the Flood Study is to define the flood behaviour of the local Coogee Bay catchments through the establishment of appropriate numerical models. The study has produced information on flood flows, velocities, levels and extents for a range of flood event magnitudes under existing catchment and floodplain conditions. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Undertaking a community consultation and participation program to identify local flooding concerns, collect information on historical flood behaviour and engage the community in the on-going floodplain management process;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design events including the 20% AEP, 5% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and extreme flood event; and
- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping.

The principal outcome of the flood study is the understanding of flood behaviour in the catchments and in particular design flood information that will underpin subsequent floodplain management activities.

1.6 About This Report

This report documents the Study's objectives, results and recommendations.

Section 1 introduces the study.

Section 2 provides an overview of the approach adopted to complete the study.

Section 3 outlines the community consultation program undertaken.

Section 4 details the development of the computer model.

Section 5 details the model calibration and validation process.

Section 6 presents the design flood conditions and sensitivity tests.

2 STUDY APPROACH

2.1 The Study Area

2.1.1 Catchment Description

The study area catchments occupy a total area of 2.9km^2 and incorporate the majority of Coogee and parts of South Coogee and Randwick. The catchments generally drain to the east into Coogee Bay.

The topography of the study area is shown in Figure 2-1. The northern 80% of the study area forms a single catchment, with the alignment of the natural gully line being similar to that of Dolphin Street. The southern 20% of the study area forms a number a smaller, less well-defined catchments, all of which drain east to the sea. The upper catchments are largely elevated above a level of 60m AHD, peaking at above 80m AHD in some locations. The topography is mostly steep, with slopes typically in the order of 5% to 10%.

The natural creek systems have been heavily modified and the study area is now drained entirely by a stormwater pipe network. When the capacity of this network is exceeded, overland flow will occur along the alignments of the original creeks. Many of the old creek alignments are now located through developed properties, which presents a significant flood risk.

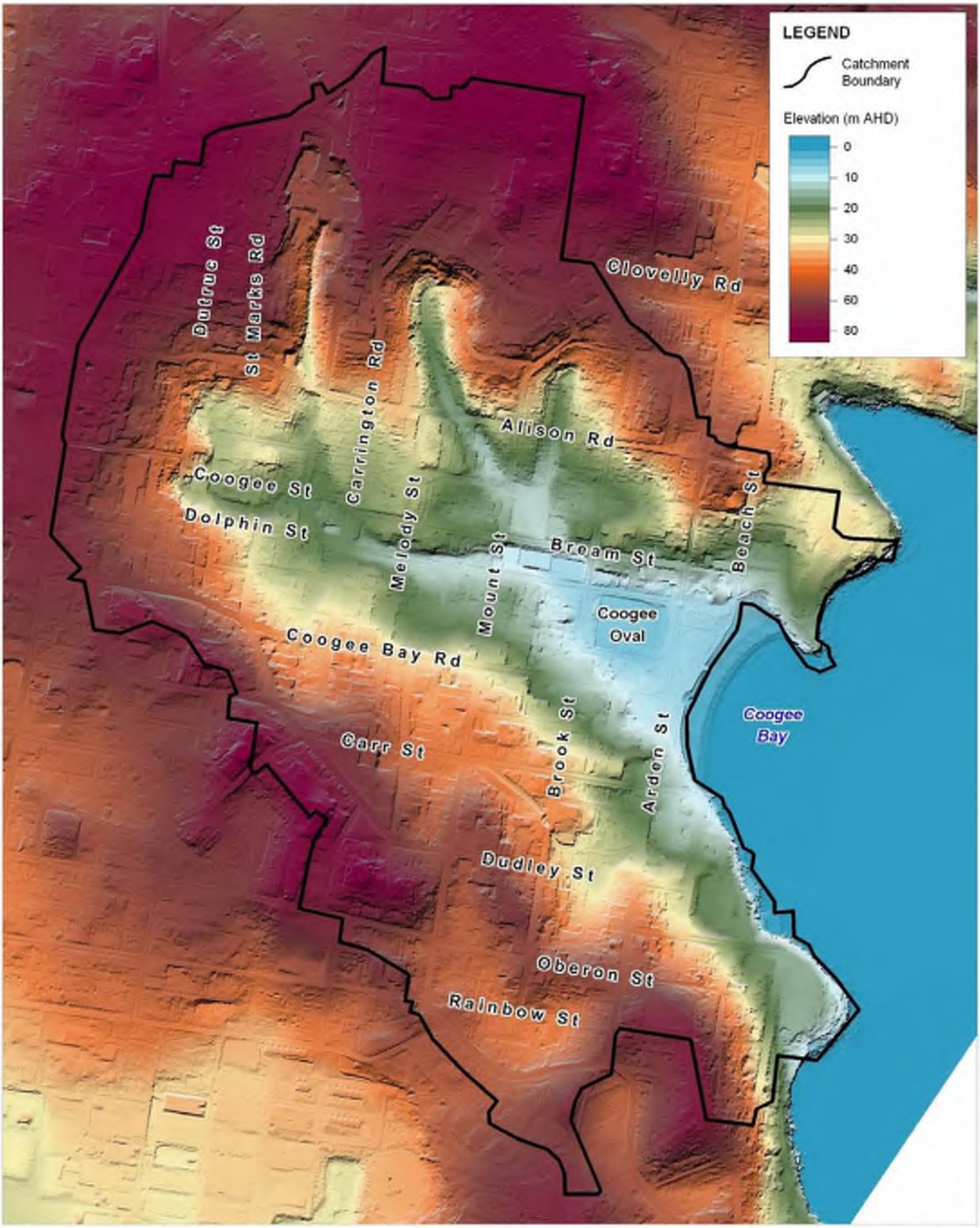
There are a number of localised depressions in the catchment topography, which will be liable to fill with water during flood events. Deep flood waters in these locations will not be uncommon once any local drainage capacity is exceeded. One such depression centred around Rainbow Street is a significant feature of the catchment topography. It is situated at the southern edge of the study area and has a catchment area of around 26ha (see Figure 2-1). The topography of this depression provides no natural outlet and is around 10m deep from the bottom of Rainbow Street to the lowest point along the catchment boundary. Drainage from the depression will be largely restricted to the capacity of the trunk drainage line and sub-surface infiltration.

Land use within the study area primarily consists of urban development (90%), open recreational space (9%) and tree-covered land (1%). The urban development within the study area includes low, medium and high density residential development and commercial uses, including the Coogee CBD along the beachfront. Some of the developed areas would previously have been creek alignments.

The study area is traversed by a number of roads, some of which run perpendicular to overland flow routes through the catchments. These include Alison Road, Coogee Street, Carrington Road, Mount Street, Brook Street and Arden Street. In certain locations these routes incorporate significant embankments across the overland flow routes that are evident in the catchment topography shown in Figure 2-1.

2.1.2 History of Flooding

There is a long history of flooding in Coogee, as it is an old suburb with development located on natural creek lines. Floods reported in available newspaper articles include 1959, 1989 and 1998. The articles typically reference flooding of Coogee Oval, including photographs and reported flood depths. Coogee Oval is situated in a natural depression of over 2m depth, located behind the higher



Title:
Topography of the Coogee Bay Catchment

Figure: 2-1

Rev: A

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Filepath : K:\N1924_Coogee_Bay_Flood_Study\MI\Workspaces\DRG_002_101221_DEM.WOR ground of Arden Street and the Coogee Bay foreshore area. As such it is prone to flooding and these occurrences are generally well documented.

The October 1959 event is the largest recorded within the catchment, with 265mm of daily rainfall recorded at Randwick Bowling Club. Mayoral records provided by Council related to this event suggest the total rainfall depth fell within a period of three and a half hours. This equates to around twice the rainfall of a 1% AEP event of similar duration.

The most significant recent floods include the January 1999 and May 2009 events. The former is well documented by both the Coogee Oval and Bowling Club Flooding Assessment (PBP, 1999) and Assessment of Impacts from January 1999 Flooding (GBA, 1999). 74mm of rain were recorded on 24th January at Randwick Bowling Club, most of which is believed to have fallen in a 90 minute period. This would be equivalent to around a 10% AEP event.

The May 2009 event is one of the largest recent local flooding events within the catchment This was a localised storm event which primarily impacted the eastern suburbs of Sydney. Randwick Bowling Club recorded 77mm of rain on 3rd May, which was the highest recorded daily total by any gauge in the local area. Most of the rain fell within a 90 minute period, which would be equivalent to around a 10% AEP event.

2.1.3 Previous Investigations

Previous investigations of the flooding characteristics of the study area were undertaken following the January 1999 flood event. These studies focused on specific locations within the catchment where flood damage had occurred during the event.

An assessment of flooding impacts at seven properties within Randwick LGA was undertaken by Gary Blumberg & Associates (1999). Of these, two properties are located within the study area. The report details the damage and likely flood mechanisms at each location.

A detailed investigation of flooding at Coogee Oval and Bowling Club was undertaken by Patterson Britton & Partners (1999). It included a hydrological assessment of the main catchment of the Coogee Bay study area. A local inspection of the drainage network and a hydraulic assessment were carried out for the area of concern.

Further details of these previous investigations and their relevance in the context of the current flood study are presented in Section 2.2.1.

2.2 Compilation and Review of Available Data

2.2.1 Previous Studies

2.2.1.1 Assessment of Impacts from January 1999 Flooding (GBA, 1994)

Following the flood event of 24th January 1999 and associated complaints from local residents, Council engaged Gary Blumberg & Associates to provide an engineering assessment of flooding impacts which occurred at seven properties. The properties were located across the wider Randwick LGA. Of these, two are located within the study area:

- Albi Place, Randwick; and

- Clyde Street, Randwick.

The study provides a description of the January 1999 storm event, including a 5-min interval recorded rainfall series at Little Bay (BoM station), in which 93mm of rain fell in one hour. It is stated that this may statistically be described as a 1 in 85 year ARI (or close to a 1% AEP event), as advised by Council at the time. However, the study found the storm recurrence interval to be lower for some local sub-catchments, based on the assessments undertaken.

Comments regarding the flooding at Albi Place suggest that runoff from the roadways to the north-west resulted in a scour hole being created behind the retaining wall at the rear of the property. At Clyde Street runoff from Pitt Street exceeded the gutter capacity, proceeding to flow through properties and into Clyde Street. Runoff from the northern end of Judge Street probably also contributed. A flood depth of 150mm to the rear of the property at Clyde Street is quoted.

2.2.1.2 Coogee Oval and Bowling Club Flooding Assessment – 24 January 1999 (PBP, 1999)

The Patterson Britton & Partners study focussed on flooding of Coogee Oval and the nearby bowling club. It included hydrologic and hydraulic investigations for the catchment using the RAFTS and RatHGL software packages. The modelling was done to assess the capacity of the stormwater network in the vicinity of Coogee Oval. Runoff exceeding the capacity of the stormwater drainage was routed to a detention basin representing Coogee Oval. Survey data of some of the pipes was collected as part of the study.

The January 1999 event was modelled using the rainfall data from Little Bay, which totalled 114mm over a two hour period. It is stated that this represents around a 1 in 60 year ARI storm event. Little Bay is located some 7km to the south of the Coogee Bay catchment. Inspection of the Randwick Bowling Club rain gauge, which is less than 1km away, shows a daily rainfall total of 74mm. The majority of the rainfall fell in a 90 minute period. A rainfall depth of 74mm over a 90 minute period would be closer to a 10% AEP event than the previously suggested 1 in 60 year ARI storm.

An observed peak flood level of around 5.4m AHD within Coogee Oval is specified within the report. The modelled peak level was over-estimated at 6.1m AHD. It is not apparent in the report why the Little Bay rainfall depth was adopted over the more local Randwick Bowling Club total, but this may explain the over-estimation of peak flood level, in addition to the modelling limitations cited in the report.

Recommendations were made regarding short-term and long-term measures to reduce flooding within the Coogee Bay catchment.

2.2.2 Historical Flood Levels

Available flood level records in the catchment are limited. Coogee Oval is the one location for which information relating to flood levels exists for a number of events. During significant storm events, excess runoff from the catchment collects in the Oval, which is situated in a natural depression of over 2m depth. Although no official flood level records were available at this location, the area can be inundated for several hours. As a result a number of flood photographs and additional anecdotal evidence is readily available, enabling estimation of peak flood levels in the Oval.

Flood photographs of Coogee Oval were available and identified for the following events:

- 6th January 1989;
- 24th January 1999; and
- 2nd May 2009.

For each of these events the peak flood level within Coogee Oval can consistently be determined to be around 5.4m AHD (approximately 1m depth). Daily rainfall totals recorded for the relevant dates at Randwick Bowling Club are 74mm, 74mm and 77mm respectively. It is likely that these events were in the same order of magnitude in terms of catchment runoff volume, and have resulted in similar peak flood levels within Coogee Oval being attained.

References within the Mayoral records and a newspaper article relating to a flood event on 29th October 1959 mention flood depths in Coogee Oval of around 10 feet. This indicates that a flood level of 7.5m AHD or more was reached within the Oval, which would also have involved substantial overtopping of Arden Street and the Coogee Bay foreshore area.

The records available for Coogee Oval were further supplemented by observed flood levels and photographs (largely relating to the May 2009 event) obtained through the community consultation process, as discussed in Section 3.2. Data obtained from historic records and the community consultation process is presented in Section 5.2.5, for the purposes of calibration.

2.2.3 Rainfall Data

There is an extensive network of rainfall gauges across the Sydney area, many of which are operated by the Bureau of Meteorology (BoM) and Sydney Water Corporation (SWC). There are no gauges located within the study area. The closest gauge to the Coogee Bay catchments is a BoM operated daily read gauge, located at Randwick Bowling Club. This gauge has a long period of record, from 1917, and is still operational. There are a further 16 rainfall gauges located within 5km of the study area, four of which are daily read gauges operated by BoM. The remainder are continuous gauges and are operated by SWC. The closest BoM-operated continuous gauge is located around 6km from the study area at Little Bay. A list of these rainfall stations with their respective period of record, including closed stations, is shown in Table 2-1. The location of the gauges is shown in Figure 2-2.

The May 2009 is the largest recent local catchment event in the study area. For this event RADAR rainfall data has also been acquired from BoM. A more detailed discussion of the rainfall data available for this and other events is discussed in Section 5.2.1.

2.2.4 Council Data

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

LiDAR (Light Detection and Ranging) land survey data covering the entire study area was acquired in 2005. LiDAR data is of good vertical accuracy (generally ~ +/- 0.1m) and provides data at around a 2m interval, providing excellent coverage over an extensive area. Flood behaviour is inherently dependent on the ground topography.

Title:
Rain Gauges in the Vicinity of Coogee Bay

Figure: 2-2

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Advanced GIS analysis also allows the LiDAR imagery to be assessed in concert with spatial 2-D flood model data, facilitating mapping, categorisation, and overall flood management.

Table 2-1 Summary of Rainfall Gauges in the Coogee Bay Locality

Station No.	Name	Operator	Type	Start Year	End Year
66051	Little Bay (The Coast Golf Club)	BoM	Pluvio	1925	current
566009	Rushcutters Bay Tennis Club	SWC	Pluvio	1998	current
566010	Cranbrook School at Bellvue Hill	SWC	Pluvio	1998	current
566028	Mascot Bowling Club	SWC	Pluvio	1973	current
566032	Paddington (Composite Site)	SWC	Pluvio	1961	current
566034	Pagewood	SWC	Pluvio	1959	1973
566043	Randwick (Army)	SWC	Pluvio	1956	1970
566077	Bondi (Dickson Park)	SWC	Pluvio	1989	2001
566088	Malabar STP	SWC	Pluvio	1990	current
566099	Randwick Racecourse	SWC	Pluvio	1991	current
566114	Waverley Bowling Club	SWC	Pluvio	1995	current
566115	Bondi Golf Club	SWC	Pluvio	1994	1995
566123	Maroubra Bowling Club	SWC	Pluvio	1995	1998
66052	Randwick Bowling Club	BoM	Daily	1917	current
66073	Randwick Racecourse	BoM	Daily	1937	current
66098	Rose Bay (Royal Sydney Golf Club)	BoM	Daily	1928	current
66160	Centennial Park	BoM	Daily	1900	current
66209	Dover Heights (Portland St)	BoM	Daily	2007	current

Details of stormwater drainage were provided in a GIS database format for the entire study area. The dataset included full survey details of the pipes and pits, which were collected over the previous five years. Details include pipe sizes, invert levels and pit inlet configuration and dimensions.

Flood information collated from a Council file and library search was also made available.

2.3 Site Inspections

A number of site inspections were undertaken during the course of the study to gain an appreciation of local features influencing flooding behaviour. Some of the key observations to be accounted for during the site inspections included:

- Presence of local structural hydraulic controls such as walls and kerbs that may have an impact on overland flooding behaviour;
- Confirmation of the location and configuration of the stormwater drainage pits and outlets;
- Location of existing development and infrastructure on the floodplain.

This visual assessment was useful for defining hydraulic properties within the hydraulic model and ground-truthing of topographic features identified from survey.

2.4 Community Consultation

The success of a floodplain management plan hinges on its acceptance by the community, residents within the study area, and other stake-holders. This can be achieved by involving the local community at all stages of the decision-making process. This includes the collection of their ideas and knowledge on flood behaviour in the study area, together with discussing the issues and outcomes of the study with them.

The key elements of the consultation process in undertaking the flood study have included:

- Issue of a questionnaire to obtain historical flood data and community perspective on flooding issues;

- Public exhibition of Draft Report and community information session (to be undertaken).

These elements are discussed in further detail in Section 3.

2.5 Development of Computer Models

2.5.1 Hydrological Model

Traditionally, for the purpose of the Flood Study, a hydrologic model is developed to simulate the rate of storm runoff from the catchment. The output from the hydrologic model is a series of flow hydrographs at selected locations such as at stormwater drainage pit inlets, which form the inflow boundaries to the hydraulic model.

In recent years the advancement in computer technology has enabled the use of the direct rainfall approach as a viable alternative. With the direct rainfall method the design rainfall is applied directly to the individual cells of the 2D hydraulic model. This is particularly useful for overland flow studies where model results are desired in areas with very small contributing catchments. This study has adopted the direct rainfall approach for modelling hydrology, details of which are discussed in Section 4.1.

2.5.2 Hydraulic Model

The TUFLOW hydraulic model (discussed in Section 4.2) developed for this study includes:

- two-dimensional (2D) representation of Coogee Bay covering an area of approximately 2.8 km^2 (complete coverage of the total catchment area); and
- one-dimensional (1D) representation of the stormwater pipe network.

The hydraulic model is applied to determine flood levels, velocities and depths across the study area for historical and design events.

2.6 Calibration and Sensitivity Testing of Models

The hydrodynamic model was primarily calibrated to the May 2009 flood event to establish the values of key model parameters and confirm that the models were capable of adequately simulating real flood events.

The following criteria are generally used to determine the suitability of historical events to use for calibration or validation:

- The availability, completeness and quality of rainfall and flood level event data;
- The amount of reliable data collected during the historical flood information survey; and
- The variability of events – preferably events would cover a range of flood sizes.

The available historical information highlighted only one flood with sufficient data to potentially support a calibration process – the May 2009 event. Flood information relating to Coogee Oval for the January 1999 and October 1959 events has also been used to aid the model calibration and validation process.

The calibration and validation of the model is presented in Section 5. A series of sensitivity tests were also carried out to evaluate the model. These tests were conducted to examine the performance of the models and determine the relative importance of different hydrological and hydrodynamic factors. The sensitivity testing of the model is detailed in Section 6.3.

2.7 Establishing Design Flood Conditions

Design floods are statistical-based events which have a particular probability of occurrence. For example, the 1% Annual Exceedance Probability (AEP) event, which is sometimes referred to as the 1 in 100 year Average Recurrence Interval (ARI) flood, is the best estimate of a flood with a peak discharge that has a 1% (i.e. 1 in 100) chance of occurring in any one year. For the Coogee Bay catchments, design floods were based on design rainfall estimates according to Australian Rainfall and Runoff (IEAust, 2001).

The design flood conditions form the basis for floodplain management in the catchment and in particular design planning levels for future development controls. The predicted design flood conditions are presented in Section 6.2.

2.8 Flood Result Presentation

Design flood result presentation is undertaken using output from the hydrodynamic model. Figures are produced showing water depth and velocity for each of the design events. The figures present the peak value of each parameter. Provisional flood hazard categories and hydraulic categories derived from the hydrodynamic model results are also presented. The flood model outputs are described in Section 6.2 and presented in Appendix A.

3 COMMUNITY CONSULTATION

3.1 The Community Consultation Process

The consultation has aimed to inform the community about the development of the flood study and its likely outcome as a precursor to subsequent floodplain management activities. It has provided an opportunity to collect information on their flood experience, in particular historical flood data related to overland flooding.

The key elements of the consultation process have been as follows:

- Distribution of a questionnaire to all landowners, residents and businesses within the study area; and
- Public exhibition of the draft Flood Study (to be undertaken).

These elements are discussed in detail below.

3.2 Community Questionnaire

A questionnaire was distributed to residents within the study area to collect information on their previous flood experience and flooding issues. The focus of the questionnaire was historical flooding information that may be useful for correlating with predicted flooding behaviour from the modelling.

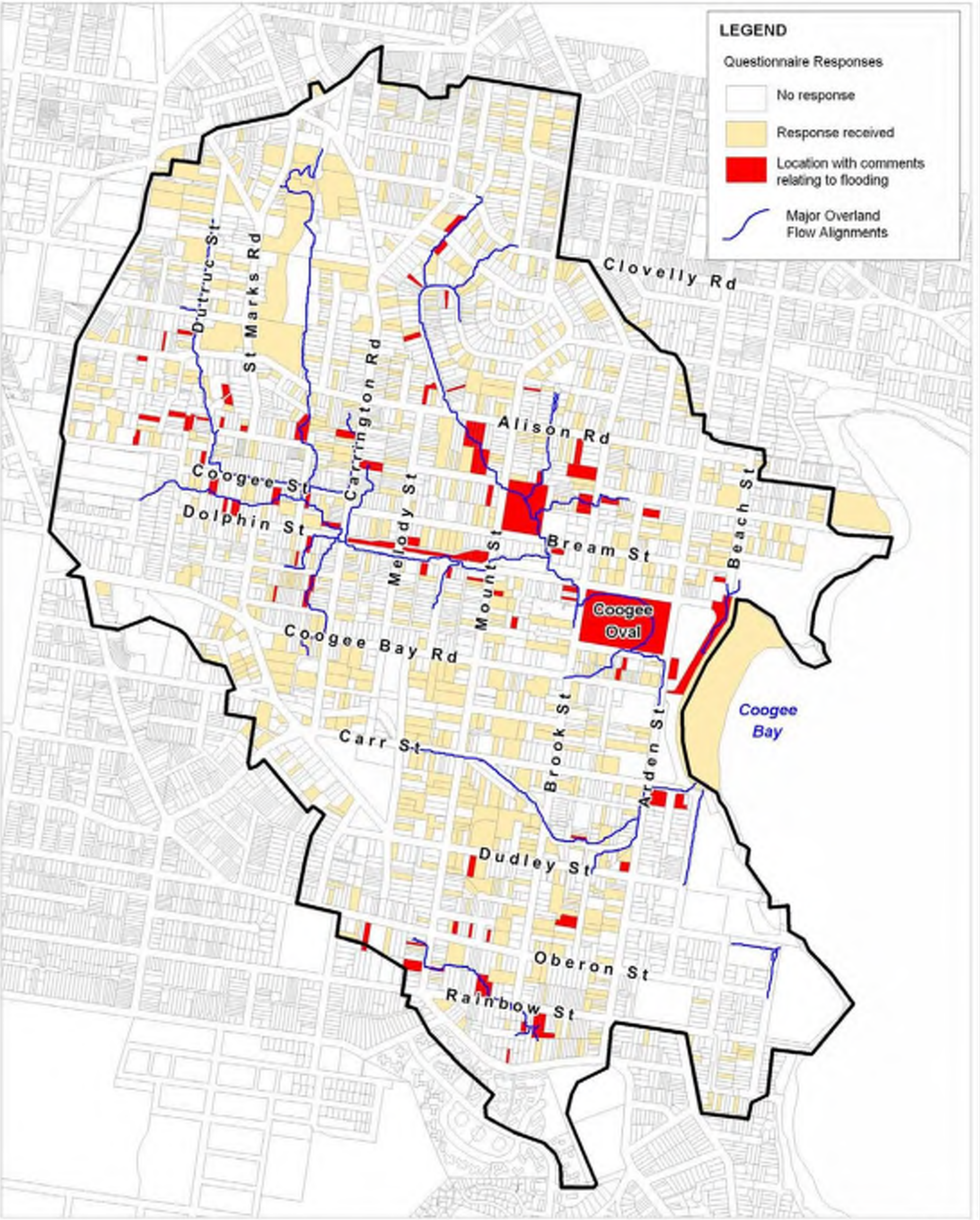
Council mailed out the questionnaire to all residents and businesses located within the study area. Council received back almost 1000 responses, of which around 250 had comments relating to flooding. The responses were compiled into a GIS layer by Council. A copy of the questionnaire is included in Appendix B.

The focus of the questionnaire was to gather relevant flood information from the community, including photographs, observed flood depths and descriptions of flood behaviour within the catchment. Thirteen responses included photographs showing flooding, flood damage or flood marks showing high water levels that occurred during the flood event.

Comments relating to flood behaviour contained within the responses were extracted where useful for model calibration purposes. Around 200 such comments were extracted, many of which included indicative flood depths. Most of these comments appeared to relate to the recent May 2009 flood event, with only a few relating to older events.

The distribution of questionnaire responses is presented in Figure 3-1. It can be seen that there is a fairly comprehensive coverage of responses across the study area. The locations of responses with comments relating to flooding have been highlighted. The two main flowpath alignments within the study area can be discerned, as can a cluster of comments from the local depression catchment centred on Rainbow Street.

The comments relating to flooding that were received from the community were an important part of the calibration process, which is discussed in Section 5.



Title:

Distribution of Responses to the Questionnaire

Figure: 3-1

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Many comments received related to local scour issues. These typically occur in areas with steep slopes over 10% grade. The high flood velocities coupled with sandy soils result in local scour and downstream deposition problems, even in areas of sheet flow where no substantial overland flow path has been generated. Comments of this nature were prominent in the south-east of the study area, such as Cairo Street.

A number of newspaper articles relating to storms in 1912, 1914, 1922 and 1933 were also provided through the community consultation process and are included in Appendix D. They contain some useful anecdotal evidence relating to flooding in the catchment. The 1922 storm in particular appears to have caused severe damage. It was an intense hailstorm, lasting only around 30 minutes, but caused extensive flooding. Unfortunately there is insufficient data available to use these events for model calibration purposes. Also, topographic modifications within the catchment over such timeframes may also have changed local flood behaviour.

3.3 Public Exhibition

The Draft Coogee Bay Flood Study was paced on public exhibition from Tuesday 19 February 2013 to Tuesday 26 March 2013.

Public displays were placed at the following locations:

- Bowen Library, 669-673 Anzac Parade, Maroubra;
- Randwick Library, Level 1 Royal Randwick Shopping Centre, Randwick; and
- Council's administration centre, 30 Frances Street, Randwick.

Exhibition material at the public displays included:

- Copies of the draft reports;
- Fact Sheets;
- Comment Sheets; and
- Comment Box.

Newspaper advertisements were placed in the Southern Courier on 19 February and 5 March providing details of the public exhibition. The public exhibition was also advertised on Council's website and included a copy of the draft Flood Study.

A letter was sent to all property owners identified as being below the 1% AEP flood plus freeboard or below the Probable Maximum Flood. A total of 7317 letters were sent to property owners providing details of the public exhibition and the community drop in session. A community drop in session was held at Bowen Library, 669-673 Anzac Parade, Maroubra on Monday 11 March between 6pm and 8pm. Staff from Council, BMT WBM and the Office of Environment and Heritage were available for the community to come along and find out about the study or ask questions.

A total of five written submissions were received during the public exhibition period. A summary of the feedback from residents during the public exhibition period is provided in Appendix E

4 MODEL DEVELOPMENT

Computer models are the most accurate, cost-effective and efficient tools to assess a catchment's flood behaviour. Traditionally, for the purpose of the Flood Study, a hydrologic model and a hydraulic model are developed.

The **hydrologic model** simulates the catchment rainfall-runoff processes, producing the stormwater flows which are used in the hydraulic model.

The **hydraulic model** simulates the flow behaviour of the drainage network and overland flow paths, producing flood levels, flow discharges and flow velocities.

In recent years the advancement in computer technology has enabled the use of the direct rainfall approach as a viable alternative. With the direct rainfall method the design rainfall is applied directly to the individual cells of the 2D hydraulic model. This is particularly useful for overland flow studies where model results are desired in areas with very small contributing catchments. This study has adopted the direct rainfall approach for modelling hydrology and therefore only a single TUFLOW model has been developed.

Information on the topography and characteristics of the catchments, drainage network and floodplains are built into the model. Recorded historical flood data, including rainfall and flood levels, are used to simulate and validate (calibrate and verify) the model. The model produces as output, flood levels, flows (discharges) and flow velocities.

Development of a hydraulic model follows a relatively standard procedure:

1. Discretisation of the catchment, drainage network, floodplain, etc.
2. Incorporation of physical characteristics (stormwater pipe details, floodplain levels, structures etc).
3. Establishment of hydrographic databases (rainfall, flood flows, flood levels) for historic events.
4. Calibration to one or more historic floods (calibration is the adjustment of parameters within acceptable limits to reach agreement between modelled and measured values).
5. Verification to one or more other historic floods (verification is a check on the model's performance without further adjustment of parameters).
6. Sensitivity analysis of parameters to measure dependence of the results upon model assumptions.

Once model development is complete it may then be used for:

- establishing design flood conditions;
- determining levels for planning control; and
- modelling development or management options to assess the hydraulic impacts.

4.1 Hydrological Model

The hydrologic model simulates the rate at which rainfall runs off the catchment. The amount of rainfall runoff from the catchment is dependent on:

- the catchment slope, area, vegetation and other characteristics;
- variations in the distribution, intensity and amount of rainfall; and
- the antecedent conditions (dryness/wetness) of the catchment.

Hydrological modelling is undertaken to establish inflow boundaries to the TUFLOW hydraulic model (flow hydrographs from external catchments and local rainfall directly on to the flood-prone area). A direct rainfall approach has been adopted for the study using the TUFLOW software. The runoff routing and hydrological response of the catchment within the model is driven by the surface type and underlying topography. Where appropriate, runoff is diverted into 1D pipe domains of the 2D/1D model (more detail is provided in Section 4.2). The general modelling approach and adopted parameters is discussed in the following sections.

4.1.1 Flow Path Mapping

The study catchments drain an area of approximately 2.9km^2 to their outlets in Coogee Bay. The extent of the study area hydrologic catchment is shown in Figure 4-1.

Flow path mapping and catchment delineation has been undertaken using the CatchmentSIM software. The generated DEM was imported into the software and following hydrologic conditioning (removal of flats and pits), flow paths and catchment boundaries were generated.

The delineation of the hydrologic catchment boundary was important for defining the limits of the hydraulic model extent and the associated direct rainfall input.

4.1.2 Rainfall Data

Rainfall information is the primary input and driver of the hydrological model which simulates the catchments response in generating surface run-off. Rainfall characteristics for both historical and design events are described by:

- Rainfall depth – the depth of rainfall occurring across a catchment surface over a defined period (e.g. 270mm in 36hours or average intensity 7.5mm/hr); and
- Temporal pattern – describes the distribution of rainfall depth at a certain time interval over the duration of the rainfall event.

Both of these properties may vary spatially across the catchment.

The procedure for defining these properties is different for historical and design events. For historical events, the recorded hyetographs at continuous rainfall gauges provide the observed rainfall depth and temporal pattern. Where only daily read gauges are available within a catchment, assumptions regarding the temporal pattern may need to be made.

Title:
Coogee Bay Catchment Boundary and Overland Flow Paths

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For design events, rainfall depths are most commonly determined by the estimation of intensity-frequency-duration (IFD) design rainfall curves for the catchment. Standard procedures for derivation of these curves are defined in AR&R (2001). Similarly AR&R (2001) defines standard temporal patterns for use in design flood estimation.

The rainfall inputs for the historical calibration/validation events are discussed in further detail in Section 5 and design events discussed in Section 6.

4.1.3 Surface Type Hydrologic Properties

The response of the catchment to the input rainfall data is dependent on the spatial distribution and hydrologic properties of the land use surface types. The properties assigned to each surface type (or material) within TUFLOW that influence the hydrologic response of the model are:

- Initial and continuing losses determine how much rainfall is lost to surface and soil storage etc. and therefore the effective rainfall contributing to surface runoff;
- Roughness parameters for sheet flow govern the speed with which the runoff will travel, influencing the hydrologic response of the model.

The material layers input to the model define these properties for each land use surface type within the catchment. Each material has initial loss, continuing loss and roughness parameters assigned to it. Along with the model topography, it is these parameters which determine the runoff routing and hydrological response of the model.

4.2 Hydraulic Model

The overland flow regime in urban environments is characterised by large and shallow inundation of urban development with interconnecting and varying flowpaths. Road networks often convey a considerable proportion of floodwaters due to the hydraulic efficiency of the road surface compared to developed areas (eg. blocked by fences and buildings), in addition to the underground pipe network draining mainly to open channels. Given this complex flooding environment, a 2D modelling approach is warranted for the overland flooding areas.

BMT WBM has applied the fully 2D software modelling package TUFLOW. TUFLOW was developed in-house at BMT WBM and has been used extensively for over fifteen years on a commercial basis by BMT WBM. TUFLOW has the capability to simulate the dynamic interaction of in-bank flows in open channels, major underground drainage systems, and overland flows through complex overland flowpaths using a linked 2D / 1D flood modelling approach.

4.2.1 Extents and Layout

Consideration needs to be given to the following elements in constructing the model:

- topographical data coverage and resolution;
- location of recorded data (eg. levels/flows for calibration);
- location of controlling features (eg. dams, levees, bridges);
- desired accuracy to meet the study's objectives;
- computational limitations.

With consideration to the available survey information and local topographical and hydraulic controls, a linked 1D/2D model was developed extending from the catchment outlets in Coogee Bay at the downstream limit, to the head of the catchments. The stormwater drainage network has been modelled as 1D branches underlying the 2D (floodplain) domain. This approach enables the hydraulic capacity of the pipe drainage to be accurately defined by true pipe dimensions, whilst enabling the overland flow to be represented in 2D. The model layout is presented in Figure 4-2.

The floodplain area modelled within the 2D domain comprises a total area of some 2.9km^2 (up to approximately 80m AHD) which includes the entire of the study catchments and the Coogee Beach area. A high resolution DEM was derived for the study area from the LiDAR data provided by Council. The ground surface elevation for the TUFLOW model grid points are sampled directly from the DEM.

A TUFLOW 2D domain model resolution of 2m was adopted for study area. It should be noted that TUFLOW samples elevation points at the cell centres, mid-sides and corners, so a 2m cell size results in DEM elevations being sampled every 1m. This resolution was selected to give necessary detail required for accurate representation of floodplain topography and its influence on overland flows.

4.2.2 Topography

A high resolution DEM has been derived for the study area from the LiDAR data provided by Council. The ground surface elevation for the TUFLOW model grid points are sampled directly from the DEM. It is a representation of the ground surface and does not include features such as buildings or vegetation.

In the context of the overland flow path study, a high resolution DEM is important to suitably represent available flow paths, such as roadway/gutter flows that are expected to provide significant flood conveyance within the study area. Experience has proved this to be a successful approach and enables detailed simulation of flooding from overland flow paths.

The ability of the model to provide an accurate representation of the overland flow distribution on the floodplain ultimately depends upon the quality of the underlying topographic model. For the Coogee Bay catchments, a high resolution DEM (0.5m grid) was derived from LiDAR survey provided by Council.

4.2.3 Hydraulic Roughness

The development of the TUFLOW model requires the assignment of different hydraulic roughness zones. These zones are delineated from aerial photography and cadastral data identifying different land-uses (eg. forest, cleared land, roads, urban areas, etc) for modelling the variation in flow resistance.

The hydraulic roughness is one of the principal calibration parameters within the hydraulic model and has a major influence on flow routing and flood levels. The roughness values adopted from the calibration process is discussed in Section 5.

Title:

Linked 1D/2D Model Layout

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4.2.4 Drainage Layer

The study requires the modelling of the drainage system in each catchment. Council provided information where available on the existing drainage system. This data comprised a GIS layer of pit/pipe locations, together with survey details including pipe sizes, invert levels and pit inlet structures. The review of the available stormwater drainage system found the data to be largely complete with only local gaps where survey access had not been possible.

In areas where no pipe survey was available pipe size details were assumed from upstream and downstream configurations. The invert levels were interpolated between known locations, maintaining the upstream and downstream pipe gradients where appropriate. These were then cross-checked against the DEM elevations to take account of any local topographic features and to maintain minimum cover levels.

For this study the entire trunk drainage network indicated by the council GIS data was modelled. The study area contains a number of locations that would drain poorly without the inclusion of the pipe network. Modelling all pipes ensures that the drainage of these areas is well represented.

A sample longsection of a modelled drainage line is shown in Figure 4-3. The figure shows the invert levels and obvert according to culvert dimension, the ground surface level as derived from the DEM, and a minimum cover level of 600mm.

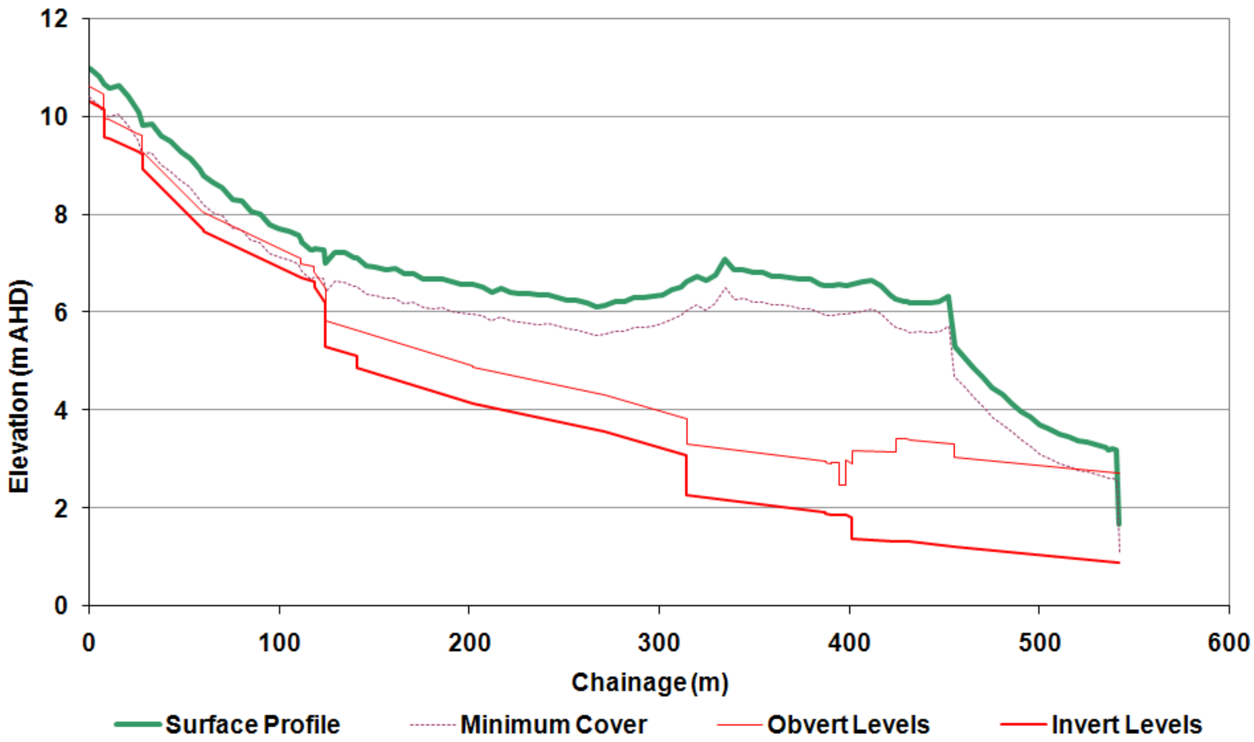


Figure 4-3 Sample Drainage Line Longsection

The pipe network, represented as a 1D layer in the model, is dynamically linked to the 2D domains at specified pit locations for inflow and surcharging. Pit inlet capacities have been modelled using dimensions contained within the GIS database. Pit inlet curves have been developed for sag pit configurations. The modelled pipe network, which consists of around 1400 pipes with a combined run length of approximately 25km, is shown in Figure 4-2.

For the magnitude of events under consideration in the study, the pipe drainage system capacity is expected to be well exceeded with the major proportion of flow conveyed in overland flow paths. For this study the pipe network data was of a high quality, providing for a good representation of the drainage system in the model. Nevertheless, any limitations in the available data or model representation of the drainage system may not have a significant affect on flooded area for the major flood events considered.

4.2.5 Boundary Conditions

The catchment runoff is determined through the hydrological component of the model and is applied directly to the TUFLOW model 2D domain, where it is routed as sheet flow until the runoff contribution is substantial enough to generate an overland flow path. Flow is automatically transferred to the 1D domain where sufficient pipe and inlet capacity is available. Surcharging will then occur from the 1D to the 2D domain once the pipe capacity becomes exceeded.

The downstream model limit corresponds to the water level in Coogee Bay. This has been set to a conservative level of 1m AHD but is insignificant in its influence on upstream flood levels. The adopted sea level boundary is discussed further in Section 6.3.2. Additional model boundaries have been included at a few locations where runoff will spill over the catchment boundary and exit the study area. In these instances constant water level boundaries have been applied in the 1D domain and QH relationships applied in the 2D domain. The impact of these boundaries is not significant in determining flood levels within the study area.

5 MODEL CALIBRATION

5.1 Selection of Calibration Events

The selection of suitable historical events for calibration of computer models is largely dependent on available historical flood information. Ideally the calibration and validation process should cover a range of flood magnitudes to demonstrate the suitability of a model for the range of design event magnitudes to be considered.

Significant flooding in Coogee has occurred on numerous occasions, with the most severe events in recent times including 1959, 1989, 1998, 1999 and 2009. The May 2009 event is considered the most suitable of the historical events for model calibration. The vast majority of the community questionnaire responses related to the May 2009 event. The availability of rainfall data and flood photographs provides a sound dataset to assist calibration of the model.

The January 1999 event was also selected for model calibration. It is similar in magnitude to the May 2009 event and is the next most recent significant flood event in the catchment. The October 1959 event has been selected for model validation purposes as although available data is limited, it is the largest event recorded within the study area.

The model calibration therefore is based on the historical data available for the three events. The available data, modelling approach and model results for each of these events are discussed in further detail in the following sections.

5.2 May 2009 Model Calibration

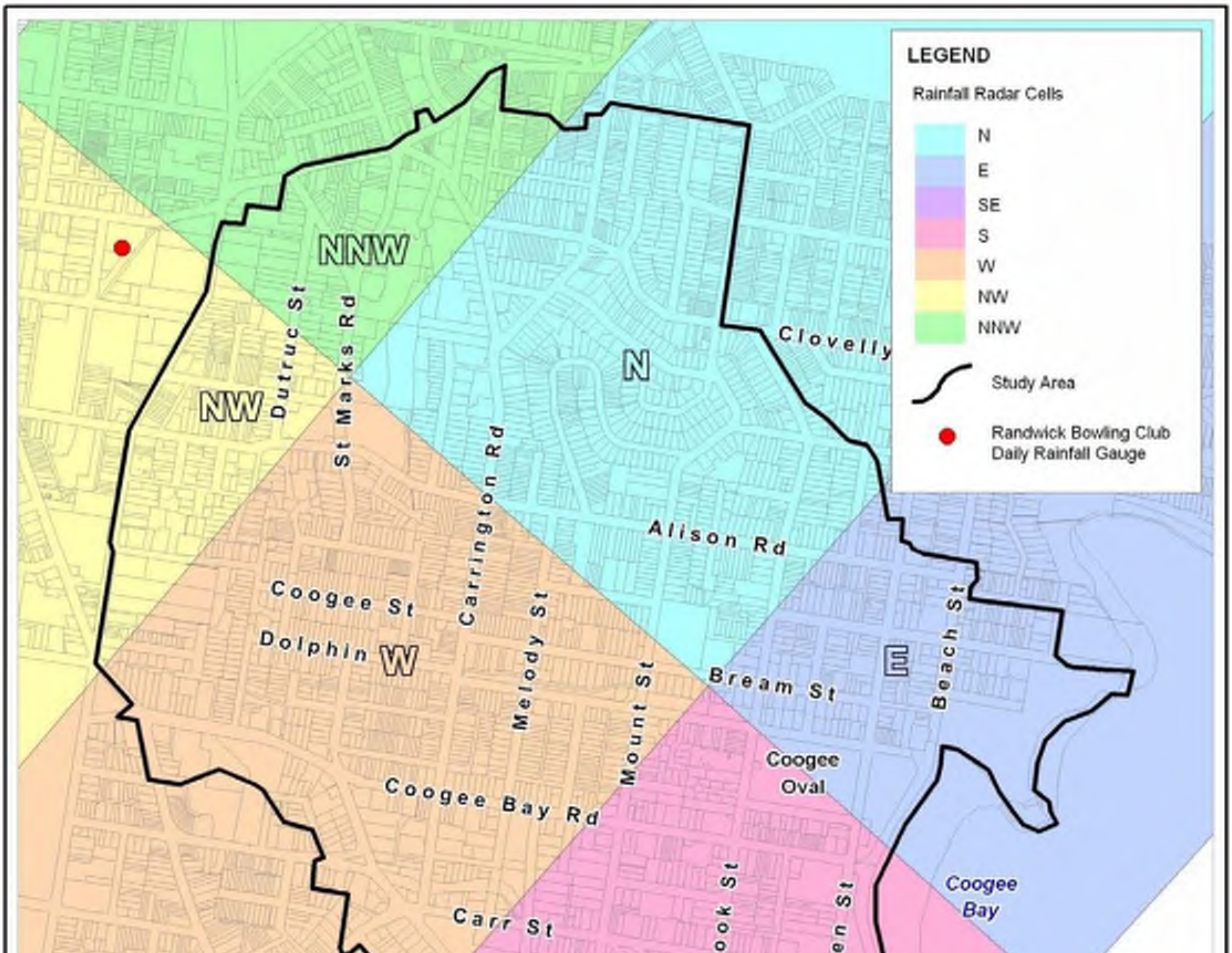
5.2.1 Rainfall Data

The distribution of rainfall gauge locations in the vicinity of the Coogee Bay catchments was shown in Figure 2-2 with their respective periods of record shown in Table 2-1. The closest gauge to the study area is located at Randwick Bowling Club, which records daily rainfall totals. It recorded a total rainfall depth of 76.6mm on 3rd May 2009.

The May 2009 storm was localised and intense and so rainfall depths and temporal patterns would have exhibited significant spatial variation. The best data source available to estimate the rainfall that fell on the catchments during the event is the rainfall radar data from the Sydney radar station, located at Terry Hills and operated by BoM. Data was acquired from this station for the May 2009 event.

A total of seven cells of the rainfall radar dataset intersected with the study area. These have been referred to as cells: N, E, SE, S, W, NW and NNW for the purposes of this study. The coverage of these cells in relation to the study area is shown in Figure 5-1. The radar data provides signal strength (dBZ) returns at 10 minute intervals, classified into 16 bands. These signal strengths can be converted to rainfall intensities in mm/h using the following equation:

$$Rainfall\ Rate\ (mm/h) = \left(\frac{10^{(dBZ/10)}}{200}\right)^{5/8}$$



Title:
Coogee Bay Rainall Radar Coverage

Figure: 5-1

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Table 5-1 shows the 16 radar intensity bands and their corresponding rainfall intensities.

Table 5-1 Conversion of Radar Reflectivity to Rainfall Intensity

Intensity Band	Signal Strength (dBZ)	Rainfall Intensity (mm/h)
0	0	0.0
1	12	0.2
2	23	1.0
3	28	2.1
4	31	3.2
5	34	4.9
6	37	7.5
7	40	11.5
8	43	17.8
9	46	27.3
10	49	42.1
11	52	64.8
12	55	99.9
13	58	153.8
14	61	236.8
15	64	364.6

The rainfall radar measures the reflectivity of rain clouds. This is strongly dependant on the size of raindrops in the cloud and not the amount of rain drops. Therefore, differences between rainfall totals estimated from radar data and those recorded at gauge sites are often experienced. The radar data gives a good indication of the temporal and spatial distribution of rainfall, but requires calibration to recorded gauge totals to provide accurate rainfall depth estimations. For this study the radar data has been used to provide the temporal pattern of the May 2009 storm and the spatial distribution of rainfall intensities within the catchment, in relation to the Randwick Bowling Club rainfall gauge location and recorded rainfall depth.

The calculated rainfall intensities for each cell and time interval were converted to rainfall depths and totalled for the 24 hours (09:00 – 09:00) of 3rd May. The total rainfall depth for cell NW, as captured by the radar data is 22.9mm. This is the cell in which the Randwick Bowling Club daily rainfall gauge is situated. The total rainfall depth recorded by the gauge was 76.6mm, or approximately 3.3 times as much as was indicated by the radar. The daily totals for each radar cell were therefore scaled by this amount, to match with the recorded gauge data. The rainfall totals for each radar cell are presented in Table 5-2. The data shows a trend of higher rainfall on the coast, decreasing to the west of the study area. The data suggests that higher rainfall intensities were experienced within the study catchments than at the Randwick Bowling Club gauge location. The May 2009 event was largely a coastal event, with localised high intensities.

Table 5-2 Daily Rainfall Totals for Each Radar Cell

Radar Cell	Calculated Daily Rainfall Total (mm)	Scaled Daily Rainfall Total (mm)	Area Within Study Catchment (ha)
N	31.9	106.9	58.6
E	34.6	115.9	28.9
SE	35.0	117.1	16.0
S	34.2	114.5	86.0
W	28.7	96.1	69.3
NW	22.9	76.6	18.0
NNW	25.1	84.1	16.5
Catchment Weighted	31.3	104.9	293

A representative rainfall profile for the catchment was then derived from the scaled radar rainfall intensities using an areal weighted approach. The area of each radar cell that intersects with the study catchment are also shown in Table 5-2 and were used to derive the areal weighted catchment average rainfall. The rainfall intensities calculated for each radar cell and the resultant scaled catchment weighted average intensity are presented in Figure 5-2. A total rainfall depth of 105mm was determined to have fallen on the catchment in the 24 hour period. However, the main event lasted around one hour, with a rainfall depth of around 62mm. Around 12mm fell in the three hours preceding the event, with a further 27mm within the six hours following the event.

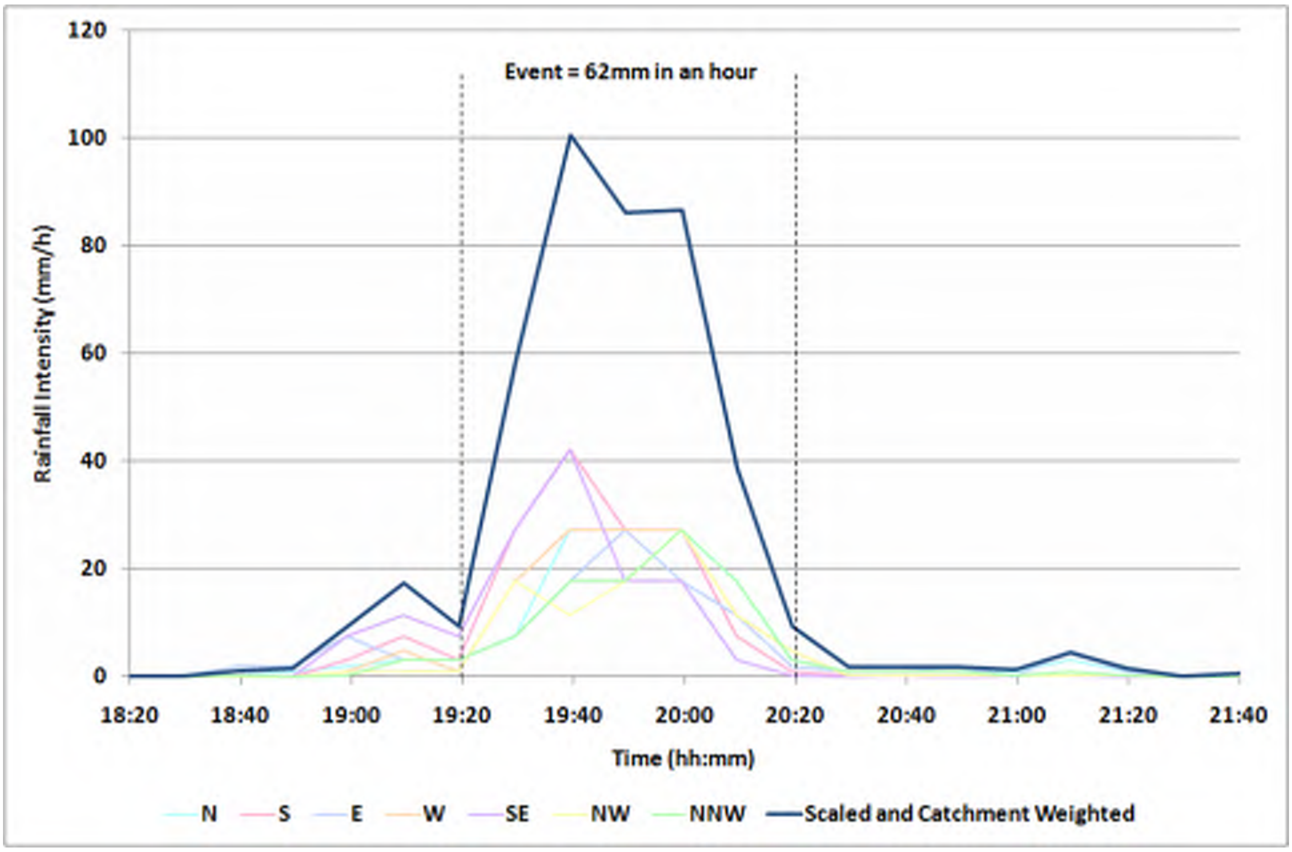


Figure 5-2 Rainfall Intensity Profiles for the May 2009 Event

To gain an appreciation of the relative intensity of the May 2009 event, the derived rainfall depths for various storm durations is compared with the design IFD data for Coogee as shown in Figure 5-3.

The derived depth vs. duration profile for the May 2009 event from the scaled catchment averaged radar data shows it generally tracking around the design 10% AEP (10-year ARI) rainfall for a one hour duration event.

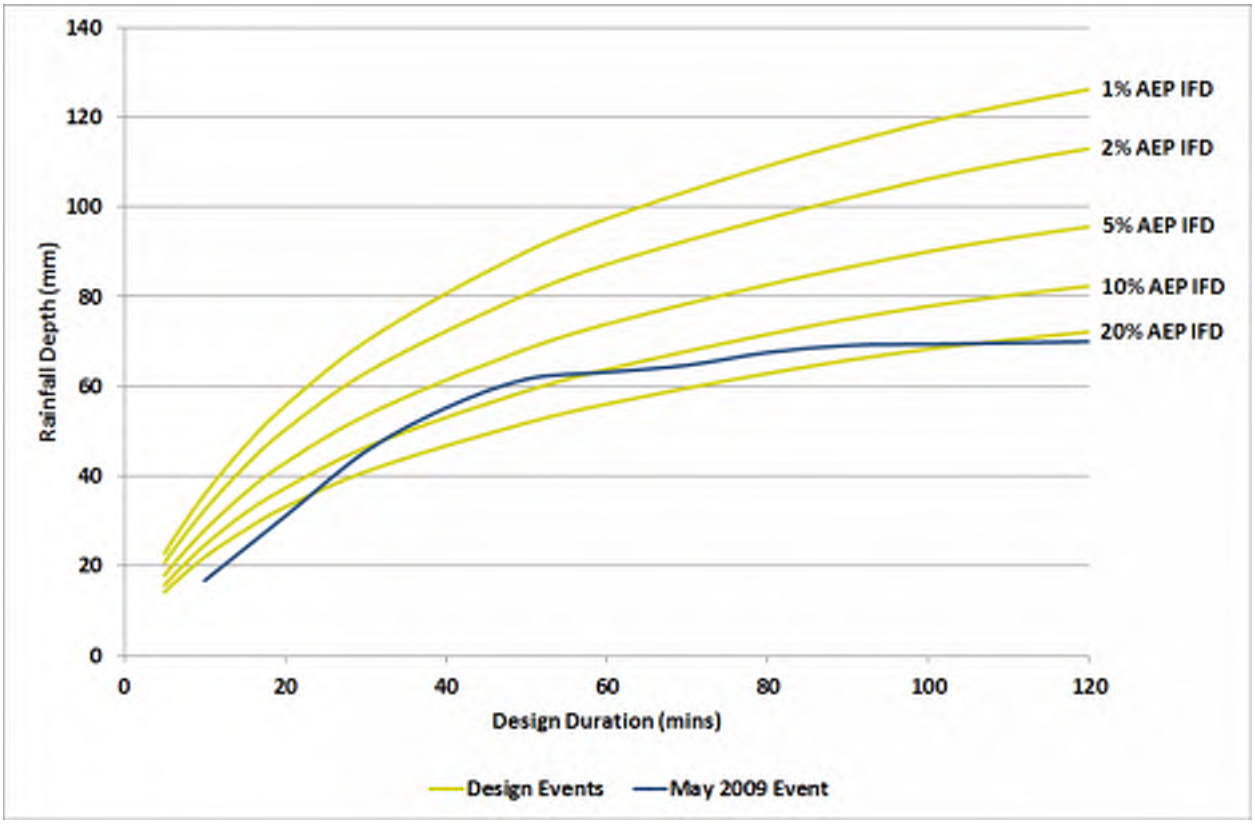


Figure 5-3 Comparison of Derived May 2009 Rainfall with IFD Relationships

5.2.2 Rainfall Losses

The initial loss-continuing loss model has been adopted in the TUFLOW model developed for the Coogee Bay catchments. The initial loss component represents a depth of rainfall effectively lost from the system and not contributing to runoff and simulates the wetting up of the catchment to a saturated condition. The continuing loss represents the rainfall lost through soil infiltration once the catchment is saturated and is applied as a constant rate (mm/hr) for the duration of the runoff event.

Typical design loss rates applicable for NSW catchments east of the western slopes are initial loss of 10 to 35 mm and continuing loss of 2.5mm/hr (AR&R, 2001). However, losses for the Coogee Bay catchments are likely to be higher due to the sandy nature of the soils. The Coogee Oval and Bowling Club Flooding Assessment – 24 January 1999 (PBP, 1999) adopted initial and continuing losses of 35mm and 5mm/h respectively. The flood level within Coogee Oval was substantially overestimated by the modelling and one of the reasons given for this was that the losses may be considerably higher. The initial loss was set at 35mm to remain within the recommendations given in AR&R.

Given the availability of flood records for Coogee Oval it was possible to assess the likely losses for the catchment. Being a flood storage area, the peak water levels within Coogee Oval are predominantly driven by the volume of runoff generated during an event. The volume of water entering the oval is dependent on the rainfall depth and the rainfall losses. The volume of water exiting the oval is restricted to the capacity of the stormwater drainage. Given the detailed survey information and hydraulic modelling of the stormwater drainage system, it is assumed that the outlet capacity is well represented. Provided that the adopted event rainfall is close to that of the actual event then the modelled flood level in the oval can be used to calibrate the rainfall losses.

Modelled flood levels in Coogee Oval for this event and the January 1999 event were used to iteratively determine appropriate initial and continuing loss parameters. These were found to be 50mm and 5mm/h respectively for pervious areas and 5mm and 0mm/h for impervious areas. These values are representative of the whole catchment, but may vary locally. Steep, rocky areas will likely have reduced soil infiltration and corresponding loss rates. Areas where the soils contain a higher proportion of loose sand may have a higher loss rate. The adopted rainfall loss parameters are higher than the standards in AR&R but are appropriate for Coogee Bay, which experiences a high rate of infiltration. However, despite this high infiltration the study area is still subject to flooding from high intensity rainfall, as evidenced by the design results in Section 6.2.

5.2.3 Downstream Boundary Condition

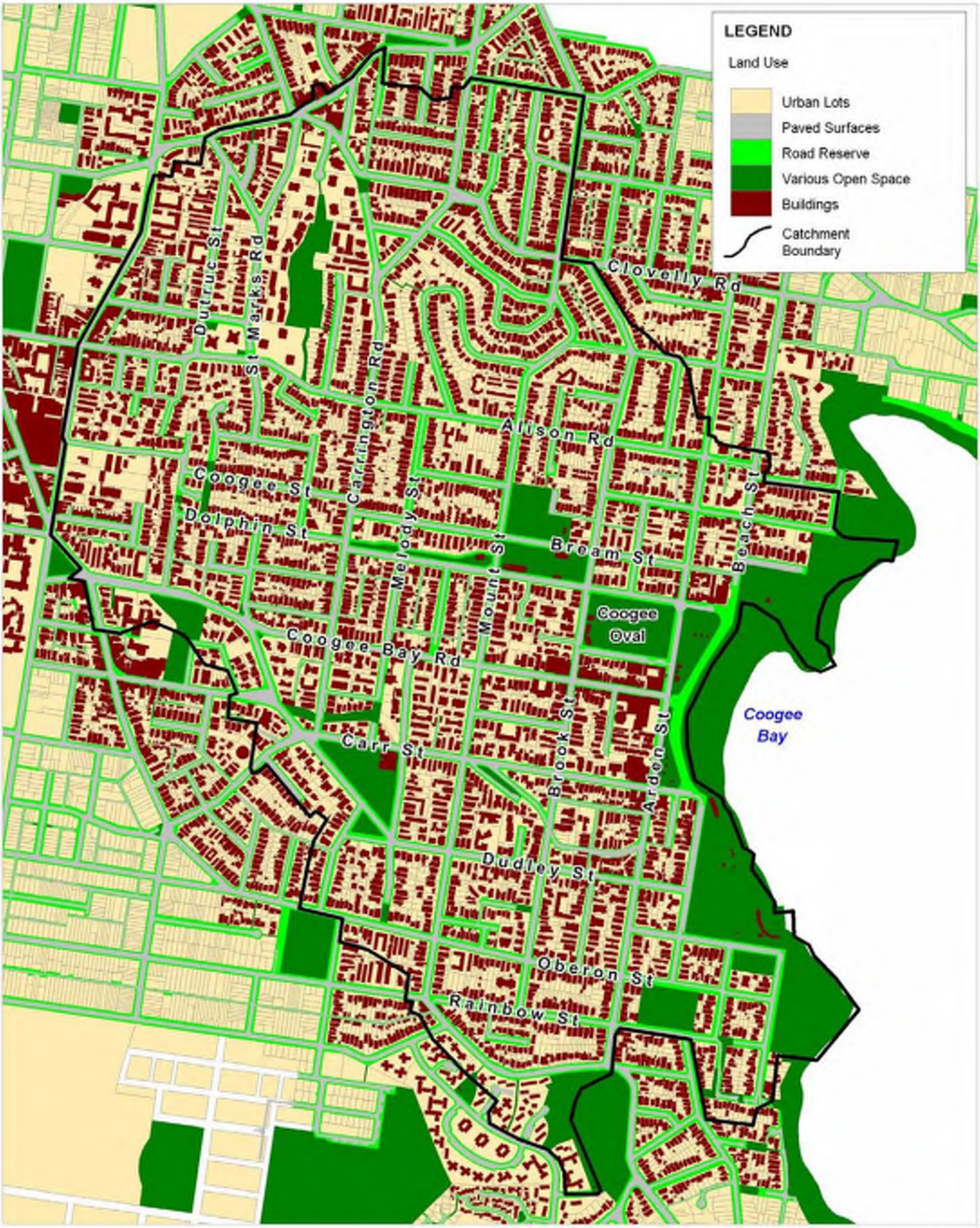
The downstream model limit corresponds to the water level in Coogee Bay. This has been set to a conservative level of 1m AHD but is insignificant in its influence on upstream flood levels. A lower boundary condition of 0m AHD was tested and found to have no impact on the modelled flood levels. Additional model boundaries have been included at a few locations where runoff will spill over the catchment boundary and exit the study area. In these instances constant water level boundaries have been applied in the 1D domain and QH relationships applied in the 2D domain. The impact of these boundaries is not significant in determining flood levels within the study area and so no event specific boundary conditions have been applied.

5.2.4 Adopted Model Parameters

The development of the TUFLOW model requires the assignment of different hydraulic roughness zones. These zones are delineated from aerial photography and cadastral data identifying different land-uses (eg. cleared land, scrub, roads, urban areas, etc) for modelling the variation in flow resistance. Council provided GIS layers representing different land use types including paved surfaces and building polygons.

The adopted hydraulic roughness (Manning's 'n') applied in the model according to land use type (material) is shown in Table 5-3. A roughness map for the study area is shown in Figure 5-4 illustrating the subdivision of the model area by land use type. A higher roughness value has been applied to the materials at shallow depths (<30mm) to represent sheet flow. This will provide a more realistic hydrologic response of the model to the direct rainfall inputs. For overland flow paths (depths >150mm) standard roughness values have been applied. Between these two depths a linear interpolation of the roughness value is applied.

The high Manning's value for residential/industrial buildings is adopted to account for inundation within buildings (accounting for storage) but not simulating significant flow through the building. A



Title:

Modelled Land Use Map

Figure: 5-4

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Filepath : K:\N1924_Coogee_Bay_Flood_Study\MI\Workspaces\DRG_017_110525_Materials.WOR lower roughness value is adopted for sheet flow on buildings to allow the rainfall to quickly "runoff" the building and on to the surrounding land.

Other obstructions to flow paths have been identified from site inspections undertaken during the model building phase. Preliminary flow path mapping was used to identify potential flow paths and impedance by existing on ground works such as fences. There are a variety of construction types whose structural integrity and subsequent flow impedance perform differently in flood events. Further complication is added by the presence of gaps at the bottom of fences allowing some through flow, albeit controlled. The general approach has been to only include solid walls as obstructions to flow, where located along flow paths and deemed to have a significant impact on local flood behaviour. The locations at which solid wall obstructions have been modelled have been guided by the model calibration process and includes both the Bowling and Tennis Clubs. The walls have been modelled at their correct heights, as observed on site and openings in the walls are accounted for where present. Figure 5-5 shows an example location where solid walls have been modelled and is presented with the modelled flood depths for the May 2009 calibration event.

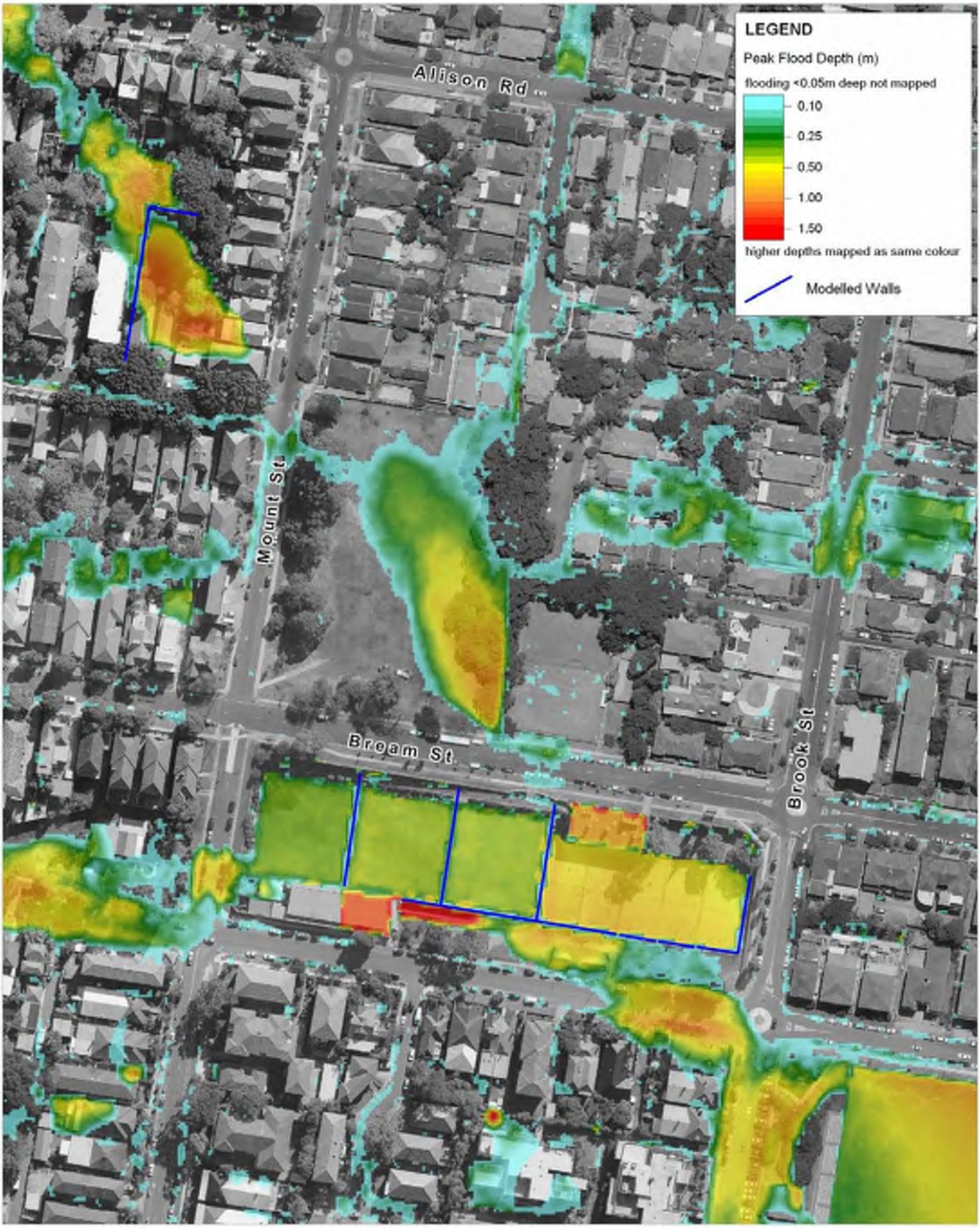
Table 5-3 Adopted Hydraulic Roughness Coefficients Based on Land Use

Material	'n' for Sheet Flow (depths <30mm)	'n' for Overland Flow (depths >150mm)
Urban Lots	0.1	0.05
Buildings	0.05	1.00
Road Reserve	0.05	0.03
Paved Areas	0.02	0.02
Maintained Grass	0.05	0.03
Unmaintained Grass	0.1	0.05
Light Vegetation	0.15	0.06
Medium Vegetation	0.25	0.08
Dense Vegetation	0.40	0.10
Sand	0.05	0.03

The model parameters that were adopted were shown to provide a reasonable calibration to observed data and so were not modified. Modifications to the model through the calibration process were restricted to the rainfall loss parameters and local modifications to the model topography to correctly represent significant hydraulic controls.

5.2.5 Observed and Simulated Flood Behaviour

There are no official water level records available for calibration within the study area. Alternatively, calibration data was derived through relevant comments and photographs from community questionnaire responses and other available resources. Comments relating to flood behaviour were compiled and compared with modelled outputs for the May 2009 event. These have been presented in Appendix C. Although most comments received relate to the May 2009 event, some do refer to other flood events, but have been included for completeness. The reliability of individual flood depth observations is highly variable. Some observers will be able to better assess flood depths than others. Also, there is typically no indication as to what the depth is referenced to, i.e. the gutter,



Title:

Example Location of Solid Wall Modelling

Figure: 5-5

Rev: A

N

0 37.5 75m

Approx. Scale

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Filepath : K:\N1924_Coogee_Bay_Flood_Study\MI\Workspaces\DRG_026_120217_Walls.WOR pavement, garden, floor, etc. The general pattern and magnitude of flooding indicated by the model results provides a good match with the comments received from the community. Specific calibration data for particular flooding hotspots is presented in more detail below.

5.2.5.1 Flood Photographs

For locations where flood photographs are available a more detailed assessment of model calibration is possible. Several such photographs were received from the community and other sources relating to the May 2009 event, the locations of which are indicated on Figure 5-6.

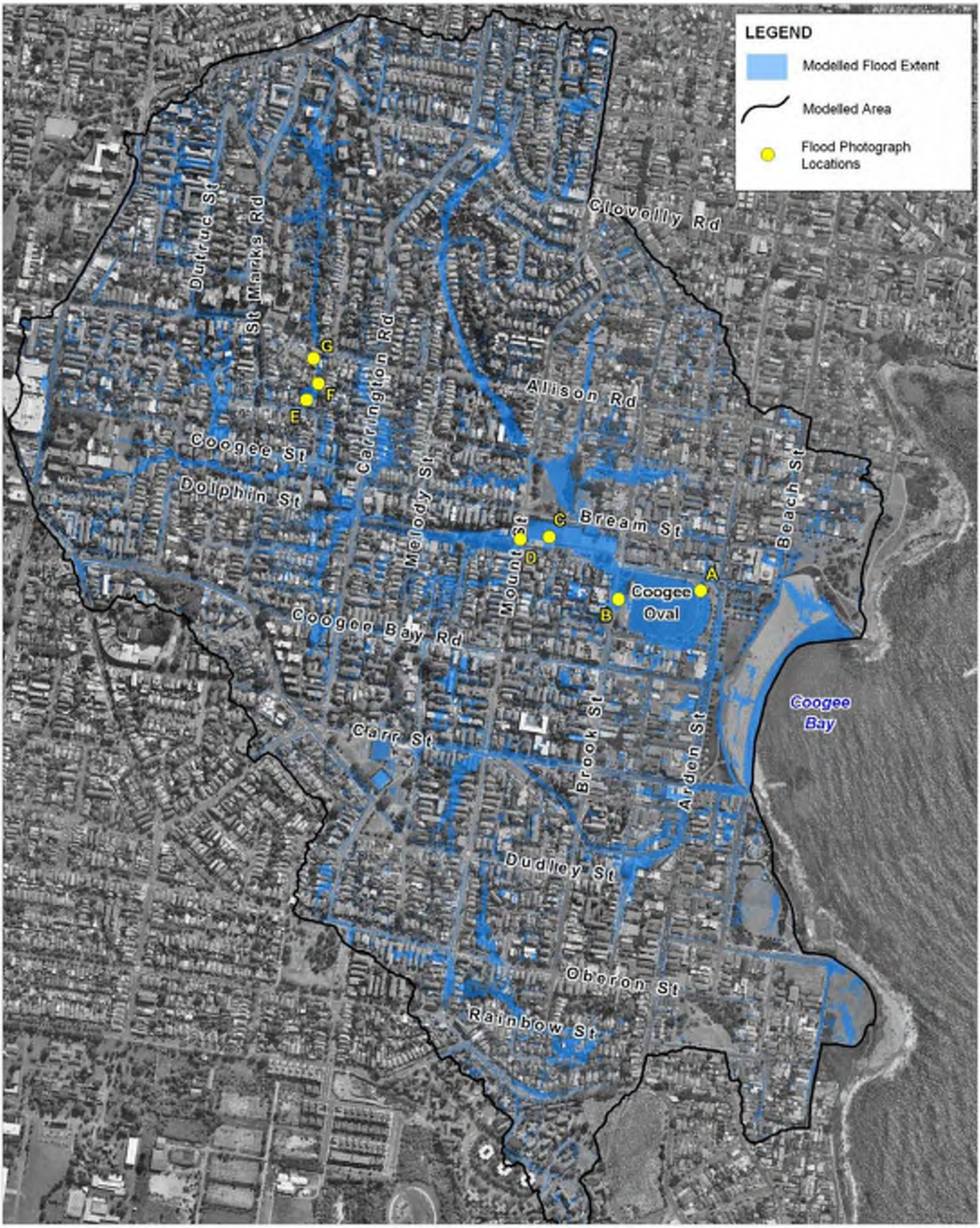
With the May 2009 event occurring during the evening the availability of flood photos for Coogee Oval was not as substantial as for other events. However, some flood photos were available, one of which is presented in Figure 5-7 (Location A on Figure 5-6). A flood level of around 5.4m AHD has been estimated from the photograph. However, it is not known whether the photograph was taken at the peak of the flood and so the peak level in the Oval may have been higher than this. The peak modelled flood level in Coogee Oval for the May 2009 flood event is around 5.7m AHD.

Another photo is available showing a flood mark on the door of the Senior Citizens Centre, located just to the west of the Oval on Brook Street and presented in Figure 5-8 (Location B). A flood level of around 6.8m AHD has been estimated from the photograph, based on the height of the flood mark above the local kerb level. A similar peak level was modelled by the May 2009 calibration event.

Photographs showing flood debris on the Bowling Green and a flood mark in the Bowling Club basement were included in a May 4th article by the Southern Courier and are presented in Figure 5-9 (Location C). The flood mark shows around a 1m peak flood depth within the basement, which based from site observations could represent a flood level of around 8.8m AHD. The modelled flood level here is close to this at around 9.0m AHD. A number of local hydraulic controls were incorporated into the model at this location to properly represent the local flood behaviour. These were based on site investigations and include wall structures between the bowling greens and around the tennis courts. The floor levels of the Bowling Club and Tennis Club are set below ground level.

A photograph showing flood waters flowing from Dolphin Street, down Mount Street and through to the Bowling Club was included in a May 4th article by the Sydney Morning Herald and is presented in Figure 5-10 (Location D). The depth of the water flowing through the area at the deepest location appears to be around the bonnet height of a car, or around 0.9m. This would require a flood level of around 10.8m AHD, which is closely matched by the modelled flood level of around 10.7m AHD.

Further up the catchment, there is a depression located behind the eastern end of Oswald Street which will fill with this excess runoff and result in significant flood depths. Figure 5-11 (Location E) shows a flood mark at Oswald Street indicating a flood depth of around 1m. At this location the ground level is around 22.1m AHD (based on the LiDAR data points), giving a flood level of around 23.1m AHD. The modelled flood level is higher, at around 23.8m AHD. This location is a topographic depression with no local drainage included in the model. As it is an isolated depression with no modelled connection to Council's drainage network, the flood level will be highly sensitive to the volume of water spilling into the depression. Council have indicated that a drain cover was removed at this location to help drain the water away and this may account for the lower water level than that which has been modelled.



Title:

May 2009 Flood Photograph Locations

Figure: 5-6

Rev: A

N

0 250 500m

Approx. Scale

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Figure 5-7 May 2009 Flood Photograph: Location A

Figure 5-8 May 2009 Flood Photograph: Location B

Figure 5-9 May 2009 Flood Photographs: Location C

Figure 5-10 May 2009 Flood Photograph: Location D

A property located behind Oswald Street, on Farnham Avenue, also reported flooding, providing flood photographs of the front and rear of the property, as shown in Figure 5-12 (Location F). The flood depths at the front and rear of the property can be judged to be around 0.1m and 0.5m respectively. Using elevations from the LiDAR data, flood levels of around 24.7m AHD at the front and 24.1m AHD at the rear of the property are appropriate. The model results indicate flood levels of 24.7m AHD and 23.8m AHD.

Another property, located on the Alison Road side of Farnham Avenue suffered from flood damage during the May 2009 event, a photograph of which is provided in Figure 5-13 (Location G). It appears from the photograph that local scouring has undermined the corner of the property, resulting in failure of the wall. Runoff from Alison Road will flow down a steep embankment and into the rear of the properties on Farnham Avenue. There are likely to be locally high velocities, which could result in scouring such as this. The flood mark of around a 0.7m depth is not evident further along the walled section of the building, or within internal photographs of the damaged room. The model has generated an overland flow path in the vicinity of this property.

Figure 5-11 May 2009 Flood Photograph: Location E

Figure 5-12 May 2009 Flood Photographs: Location F

Figure 5-13 May 2009 Flood Photograph: Location G

5.2.5.2 Rainbow Street Calibration

The model calibration results generally match well with those indicated by comments from the community and the available flood photographs. Rainbow Street was the only location for which the performance of the model did not initially correspond to the available information.

The bottom of Rainbow Street is situated within a topographic depression, with a depth of 10m and catchment area of 26ha. As such there is no natural outlet for catchment runoff and the stormwater drainage provides the only means for transfer of water out of the catchment. Once the capacity of the trunk drain is exceeded, the excess runoff will begin to fill the depression. This resulted in significant flooding being modelled for the May 2009, with a peak level of around 42.1m AHD. Information received a resident in this location suggested that the highest flood level experienced was closer to 41.6m AHD. It is also known that during the largest floods, the water drained away over the course of an afternoon It is therefore likely that local drainage infrastructure in the Rainbow Street depression connects into the Council stormwater network. A 300mm diameter pipe was added to the model to provide drainage from the lowest-lying lot. This reduced the modelled flood level to around 41.7m AHD.

5.3 January 1999 Model Calibration

The January 1999 event was used in conjunction with the May 2009 event to calibrate model parameters such as roughness values and rainfall losses. These parameters are consistent with those of the May 2009 calibration, as discussed in section 5.2.2 to section 5.2.4.

5.3.1 Rainfall Data

The distribution of rainfall gauge locations in the vicinity of the Coogee Bay catchments was shown in Figure 2-2 with their respective periods of record shown in Table 2-1. The closest gauge to the study area is located at Randwick Bowling Club, which records daily rainfall totals. It recorded a total rainfall depth of 73.8mm on 24th January 1999.

The temporal pattern for the January 1999 rainfall event has been derived from the recorded data at the Little Bay gauge, located 6km to the south of the study area. This data was adopted for use in the Coogee Oval and Bowling Club Flooding Assessment. The rainfall event recorded at Little Bay lasted approximately two hours, with a total recorded depth of 114mm. For the purposes of this study the data has been scaled to provide a total of 73.8mm, as recorded at Randwick Bowling Club. The recorded rainfall data from Little Bay and the adopted rainfall for the model calibration are shown in Table 5-4.

Table 5-4 Rainfall Data for the January 1999 Event

Time	Recorded at Little Bay (mm)	Scaled for Randwick Bowling Club (mm)
7:15	3	1.9
7:20	1	0.6
7:25	3	1.9
7:30	3	1.9
7:35	1	0.6
7:40	2	1.3
7:45	2	1.3
7:50	1	0.6
7:55	0	0
8:00	4	2.6
8:05	7	4.5
8:10	7	4.5
8:15	10	6.5
8:20	8	5.2
8:25	9	5.8
8:30	6	3.9
8:35	8	5.2
8:40	8	5.2
8:45	8	5.2
8:50	10	6.5
8:55	5	3.2
9:00	3	1.9

To gain an appreciation of the relative intensity of the May 2009 event, the derived rainfall depths for various storm durations is compared with the design IFD data for Coogee as shown in Figure 5-14.

The derived depth vs. duration profile for the January 1999 event from the adopted catchment rainfall shows it generally tracking between the design 20% AEP (5-year ARI) and 10% AEP (10-year ARI) rainfall for a one to two hour duration.

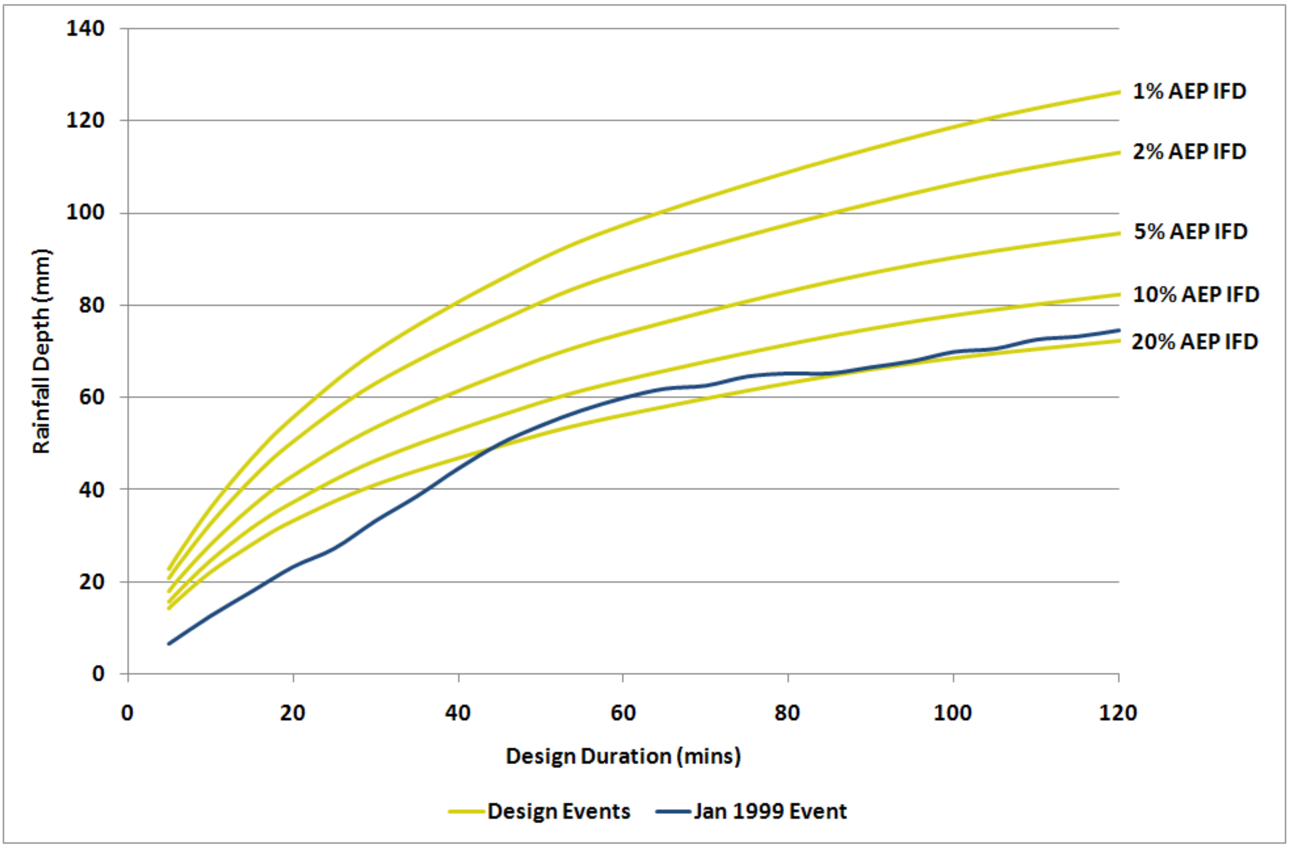


Figure 5-14 Comparison of Derived January 1999 Rainfall with IFD Relationships

5.3.2 Observed and Simulated Flood Behaviour

The January 1999 event was used in conjunction with the May 2009 event to assess appropriate rainfall losses for the catchment. The Coogee Oval and Bowling Club Flooding Assessment references a flood level of around 5.4m AHD in the Oval. This level is also supported by the available flood photographs taken of the Oval during the flood. Figure 5-15 shows vehicles parked along the southern side of Coogee Oval. At the deepest area of flooding the water level is at the level of the car bonnets, or around 0.9m deep. The ground elevation here is around 4.5m AHD, giving an approximate flood level of 5.4m AHD. The modelled flood level in Coogee Oval for the January 1999 calibration event is 5.5m AHD.

Figure 5-15 January 1999 Flood Photograph of Coogee Oval

5.4 October 1959 Model Validation

The October 1959 event is the largest on record within the study area. There is little data available to calibrate the model, but an indicative flood depth in Coogee Oval of 10 feet (referenced in the Mayoral records) was used to validate the performance of the calibrated model.

5.4.1 Rainfall Data

The distribution of rainfall gauge locations in the vicinity of the Coogee Bay catchments was shown in Figure 2-2 with their respective periods of record shown in Table 2-1. The closest gauge to the study area is located at Randwick Bowling Club, which records daily rainfall totals. It recorded a total rainfall depth of 265.4mm on 29th October 1959.

The Mayor’s minutes documenting flood damages from this event indicate a storm duration of around 3.5 hours. With no better available information, the three hour design event provided in AR&R has been adopted as the temporal pattern for the October 1959 event.

To gain an appreciation of the relative intensity of the October 1959 event, the derived rainfall depths for various storm durations is compared with the design IFD data for Coogee as shown in Figure 5-16.

The derived depth vs. duration profile for the October 1959 event from the adopted catchment rainfall shows it far exceeding the 0.2% AEP (500-year ARI) rainfall, being almost twice as large as the 1% AEP (100-year ARI) rainfall.

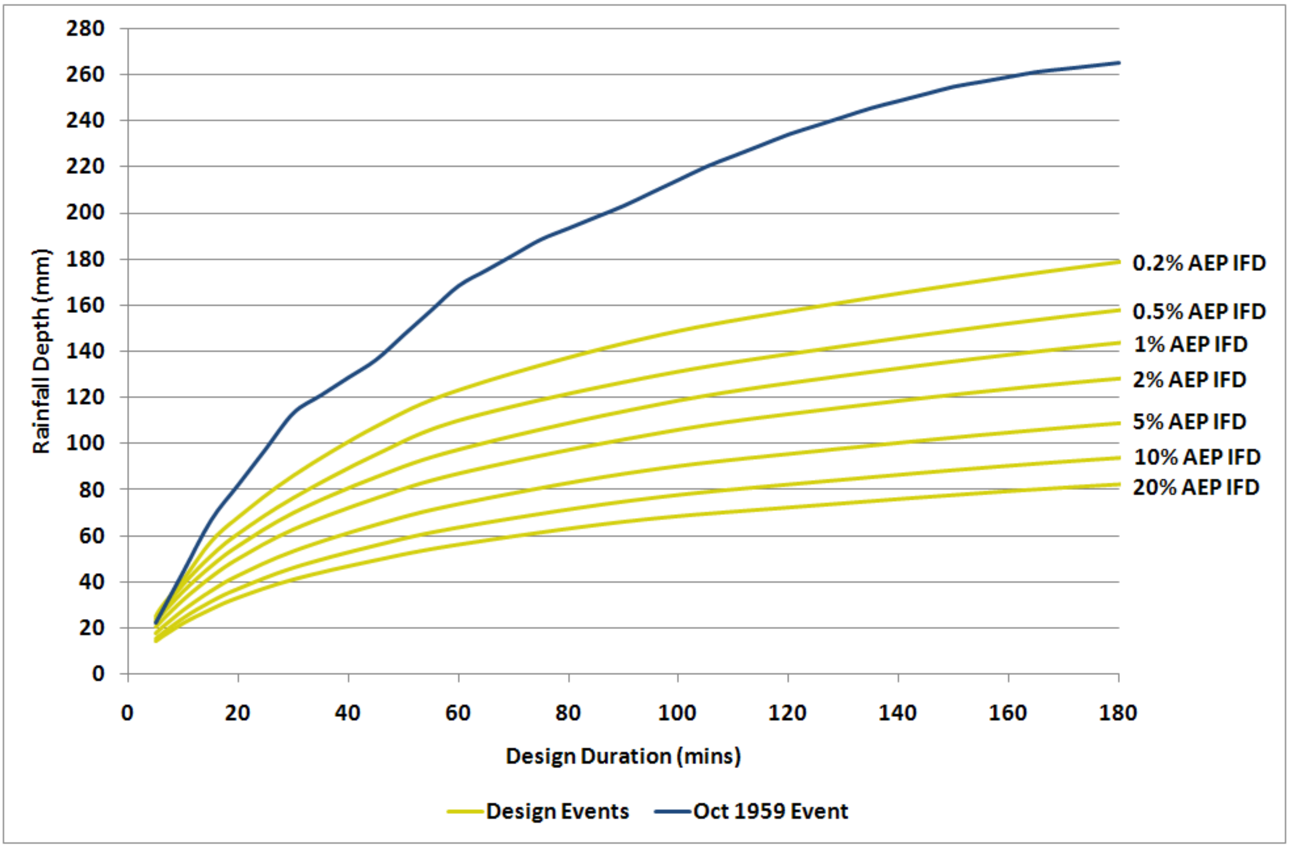


Figure 5-16 Comparison of Derived October 1959 Rainfall with IFD Relationships

5.4.2 Observed and Simulated Flood Behaviour

The only calibration data available for the October 1959 event is a reference in the Mayor's minutes to a flood depth of 10 feet on Coogee Oval (also referenced as 12 feet within a newspaper). A depth of this order would relate to a flood level of around 7.6m AHD. The model predicted flood level in Coogee Oval is 7.3m AHD. There is much uncertainty regarding the water level record, adopted rainfall pattern and changes to the catchment characteristics and so an exact match is not expected in this instance. However, the similarity of the reported and modelled flood depths within Coogee Oval suggests a reasonable model prediction.

6 DESIGN FLOOD CONDITIONS

Design floods are hypothetical floods used for planning and floodplain management investigations. They are based on having a probability of occurrence specified either as:

- Annual Exceedance Probability (AEP) expressed as a percentage; or
- Average Recurrence Interval (ARI) expressed in years.

This report uses the AEP terminology. Refer to Table 6-1 for a definition of AEP and the ARI equivalent.

Table 6-1 Design Flood Terminology

ARI[1]	AEP[2]	Comments
500 years	0.2%	A hypothetical flood or combination of floods which represent the worst case scenario likely to occur on average once every 500 years.
200 years	0.5%	As for the 0.2% AEP flood but with a 0.5% probability or 200 year return period.
100 years	1%	As for the 0.2% AEP flood but with a 1% probability or 100 year return period.
20 years	5%	As for the 0.2% AEP flood but with a 5% probability or 20 year return period.
5 years	20%	As for the 0.2% AEP flood but with a 20% probability or 5 year return period.
Extreme Flood / PMF[3]		A hypothetical flood or combination of floods which represent an extreme scenario.

1 Average Recurrence Interval (years)
2 Annual Exceedance Probability (%)
3 A PMF (Probable Maximum Flood) is not necessarily the same as an Extreme Flood.

In determining the design floods it is necessary to take into account the critical storm duration of the catchment. Small catchments are more prone to flooding during short duration storms while for large catchments longer durations will be more critical. For example, considering the relatively small size of the study area catchments, they are potentially more prone to higher flooding from intense storms extending over a few hours rather than a couple of days.

6.1 Design Rainfall

Design rainfall parameters are derived from standard procedures defined in AR&R (2001) which are based on statistical analysis of recorded rainfall data across Australia. The derivation of location specific design rainfall parameters (e.g. rainfall depth and temporal pattern) for Coogee Bay is presented below.

6.1.1 Rainfall Depths

Design rainfall depth is based on the generation of intensity-frequency-duration (IFD) design rainfall curves utilising the procedures outlined in AR&R (2001). These curves provide rainfall depths for various design magnitudes (up to the 1% AEP) and for durations from 5 minutes to 72 hours.

The Probable Maximum Precipitation (PMP) is used in deriving the Probable Maximum Flood (PMF) event. The theoretical definition of the PMP is “the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of year” (AR&R, 2001). The ARI of a PMP/PMF event ranges between 10^4 and 10^7 years and is beyond the “credible limit of extrapolation”. That is, it is not possible to use rainfall depths determined for the more frequent events (100 year ARI and less) to extrapolate the PMP. The PMP has been estimated using the Generalised Short Duration Method (GSDM) derived by the Bureau of Meteorology.

A range of storm durations were modelled in order to identify the critical storm duration for design event flooding in the catchment. Design durations considered included the 0.25-hour, 0.5-hour, 0.75-hour, 1-hour, 1.5-hour, 2-hour, 3-hour, 4.5-hour, 6-hour and 9-hour durations.

Table 6-2 shows the average design rainfall intensities based on AR&R adopted for the modelled events.

Table 6-2 Average Design Rainfall Intensities (mm/hr)

Duration (hours)	Design Event Frequency				
	20% AEP	5% AEP	1% AEP	0.5% AEP	0.2% AEP
0.25	112	145	187	205	229
0.5	82	107	140	153	172
0.75	66	87	114	127	143
1	56	74	97	110	123
1.5	43.9	58	76	84	96
2	36.1	47.8	63	69	79
3	27.4	36.3	47.9	53	60
4.5	20.8	27.3	36.0	39.8	45.0
6	17	22.4	29.5	32.7	36.9
9	12.7	16.7	22	24.7	27.9

Areal Reduction Factor

The areal reduction factor takes into account the unlikelihood that larger catchments will experience rainfall of the same design intensity (eg 1% AEP) over the entire area. Areal reduction factors typically apply to catchments significantly larger than those at Coogee Bay and no reduction factor is required for the study area catchment of 2.9km^2.

6.1.2 Temporal Patterns

The IFD data presented in Table 6-2 provides for the average intensity that occurs over a given storm duration. Temporal patterns are required to define what percentage of the total rainfall depth occurs over a given time interval throughout the storm duration. The temporal patterns adopted in the current study are based on the standard patterns presented in AR&R (2001).

The same temporal pattern has been applied across the whole catchment. This assumes that the design rainfall occurs simultaneously across each of the modelled sub-catchments. The direction of a storm and relative timing of rainfall across the catchment may be determined for historical events if sufficient data exists, however, from a design perspective the same pattern across the catchment is generally adopted.

6.1.3 Rainfall Losses

The rainfall losses adopted for the design floods were the same as those used for model calibration and verification. For the initial and continuing rainfall losses, values of 50mm and 5mm/h were used for pervious portions of the catchment, with 5mm and 0mm/h being used for impervious areas. These are higher than those generally recommended for design event losses in AR&R (2001), but are appropriate for well-draining sandy soils such as those of the Coogee Bay catchment. A sensitivity test using standard AR&R losses has been carried out and is discussed in Section 6.3.

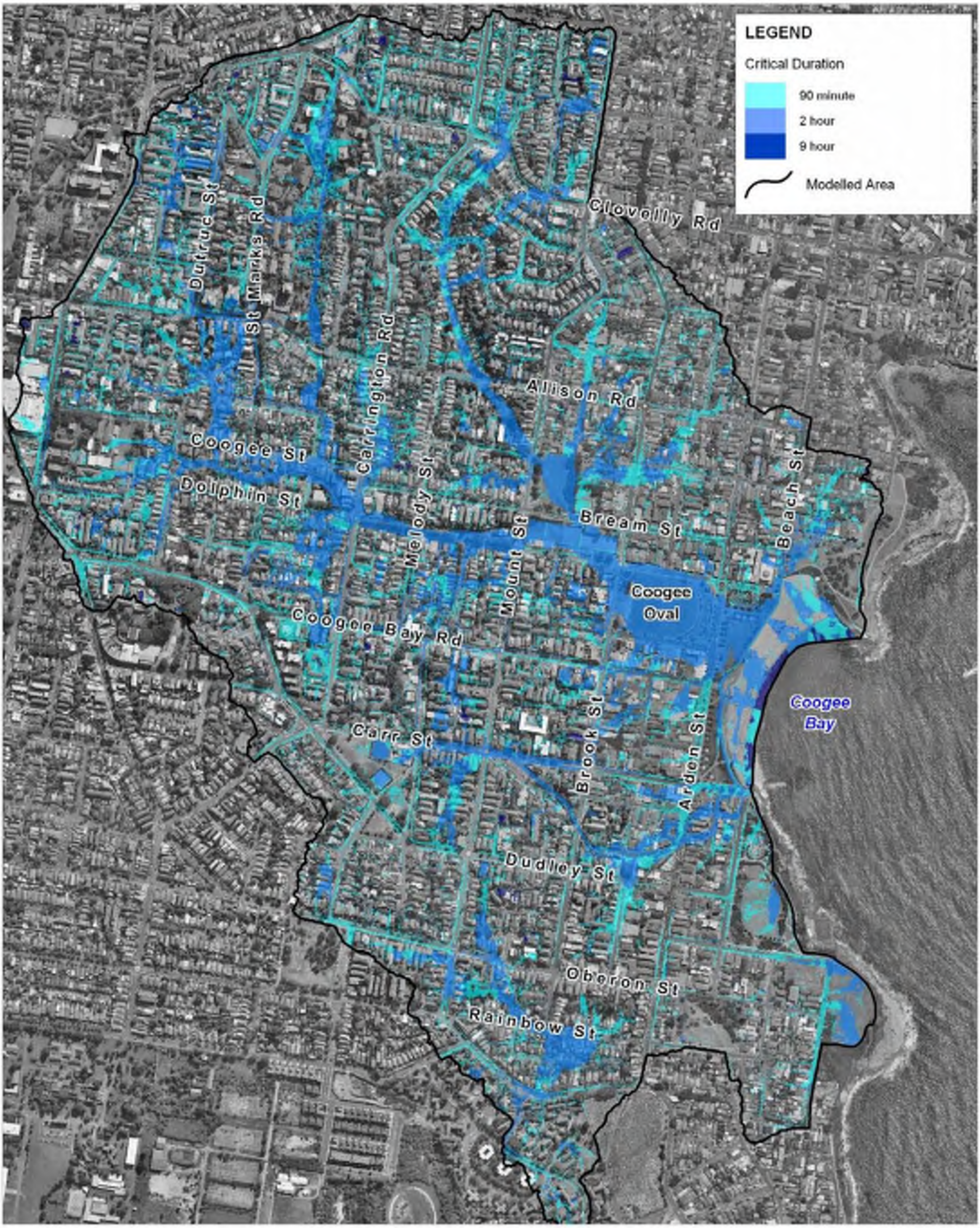
6.2 Design Flood Results

A range of design event durations were simulated to determine the critical duration for flooding throughout the study area. In general, the model simulations indicated the peak water levels in most areas corresponded to the 90-minute or two-hour durations. For local depression storage areas the critical conditions are flood volume driven for which a longer duration is required. In these areas the 9-hour duration (which was the longest duration considered) is the critical duration. The design flood results are the maximum condition from the combined 90-minute, 2-hour and 9-hour duration events, for which the distribution at the 1%AEP event is presented in Figure 6-1. For the PMF event, the critical durations (and those from which the results have been derived) are the 15-minute, 30-minute, 45-minute and 4.5-hour durations.

The design flood results are presented in a flood mapping series in Appendix A. For the key simulated design events including the 20% AEP (5-year ARI), 5% AEP (20-year ARI), 1% AEP (100-year ARI), 0.5% AEP (200-year ARI), 0.2% AEP (500-year ARI), and PMF events, a map of peak flood depth, velocity and hydraulic hazard is presented covering the modelled area.

6.2.1 Peak Flood Levels, Depths and Velocities

The flood extents for the 1% AEP design event have been presented in Figure 6-2. The figure also shows the distribution of 15 reporting locations that are referenced in the design flood level summary Table 6-3. The alignment of a flood long section (presented in Figure 6-3) is also indicated on the figure. Five distinct sub-catchment areas can be distinguished from the flood model results and the boundaries of these have also been identified on Figure 6-2. The main sub-catchment is that draining to Coogee Oval, which is some 200ha in size. The Rainbow Street sub-catchment is located at the south of the study area. It is around 26ha in size and drains to a depression centred around 303 Rainbow Street. Located between these two sub-catchments is a smaller 19ha sub-catchment centred around the Havelock Avenue alignment, which drains to Coogee Bay near the Surf Life-saving Club. The Beach Street sub-catchment covers only 10ha and includes the urban area around Beach Street and the Goldstein Reserve, draining to Coogee Bay via Coogee Beach. The remaining sub-catchment is around 16ha in size and covers the headland area to the south of Coogee Beach that drains directly to Coogee Bay over the cliffs in Grant Reserve and Trenerry Reserve.



Title:

Critical Durations for the 1% AEP Event

Figure: 6-1

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Approx. Scale

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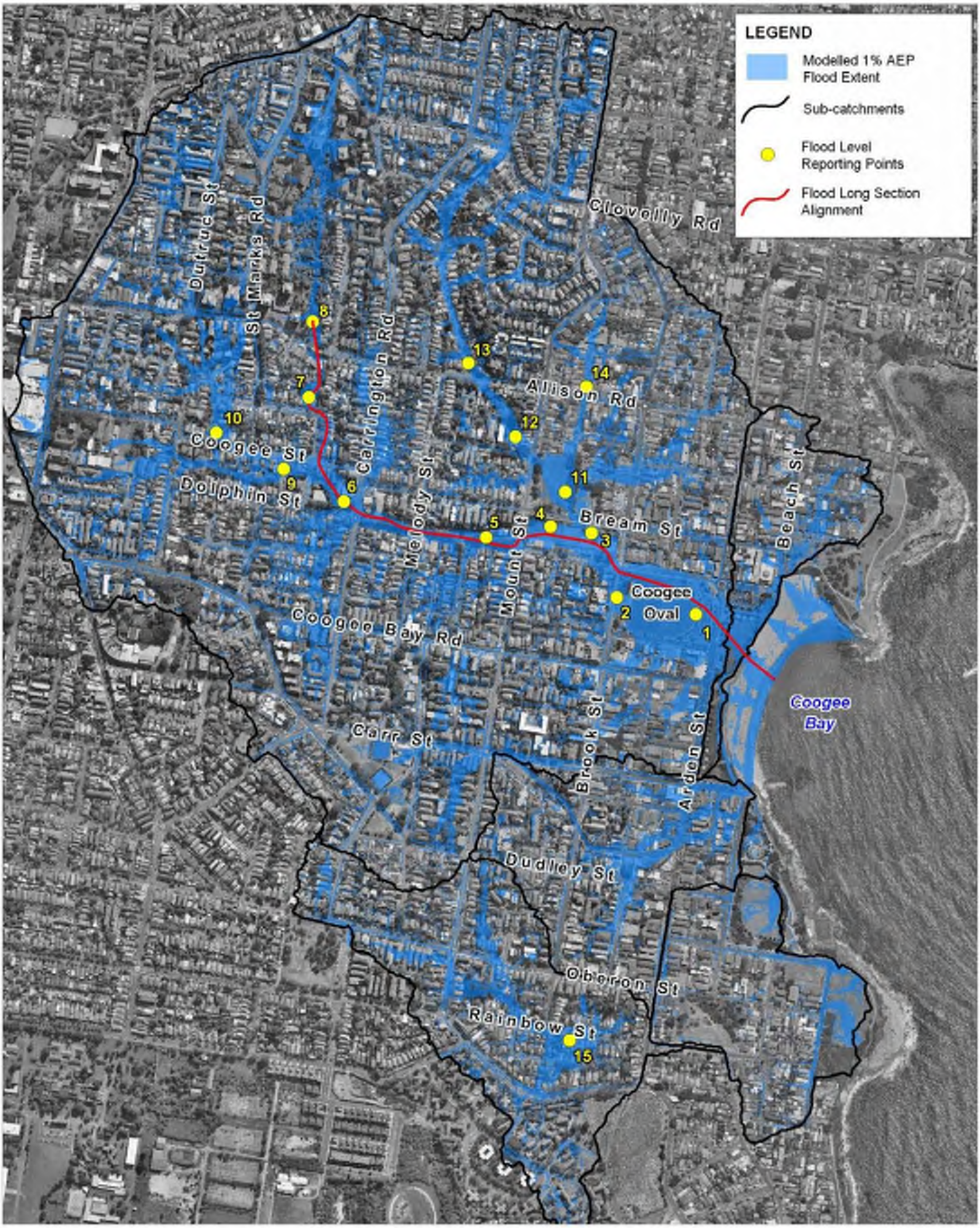

Title:

Distribution of Design Result Reporting Locations

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Table 6-3 Summary of Design Flood Levels

ID	Location	Design Event Flood Level (m AHD)					
		20% AEP	5% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
1	Coogee Oval	5.4	6.1	6.9	7.0	7.1	7.8
2	Brook Street	6.6	6.8	7.0	7.1	7.2	8.1
3	Coogee Tennis Club	7.9	8.1	8.2	8.3	8.4	9.2
4	Coogee Bowling Club	8.9	9.0	9.1	9.1	9.2	10.1
5	Dolphin Street	12.2	12.3	12.4	12.5	12.6	13.5
6	Carrington Road	17.2	18.4	19.0	19.2	19.3	20.3
7	Oswald Street	23.8	23.9	24.1	24.2	24.2	25.2
8	Glen Avenue	28.2	29.1	30.3	30.7	31.4	32.6
9	32 Coogee Street	20.1	20.2	20.7	20.8	20.9	21.6
10	9 Coogee Street	25.3	25.8	26.0	26.1	26.2	26.9
11	Bardon Park	12.5	12.7	13.0	13.1	13.3	13.9
12	Mount Street	13.8	14.4	15.0	15.1	15.2	16.0
13	Pauling Avenue	17.2	17.7	18.0	18.1	18.2	18.9
14	Leeton Avenue	19.4	19.6	19.8	19.8	19.9	20.1
15	Rainbow Street	42.1	42.4	42.8	43.0	43.3	47.6

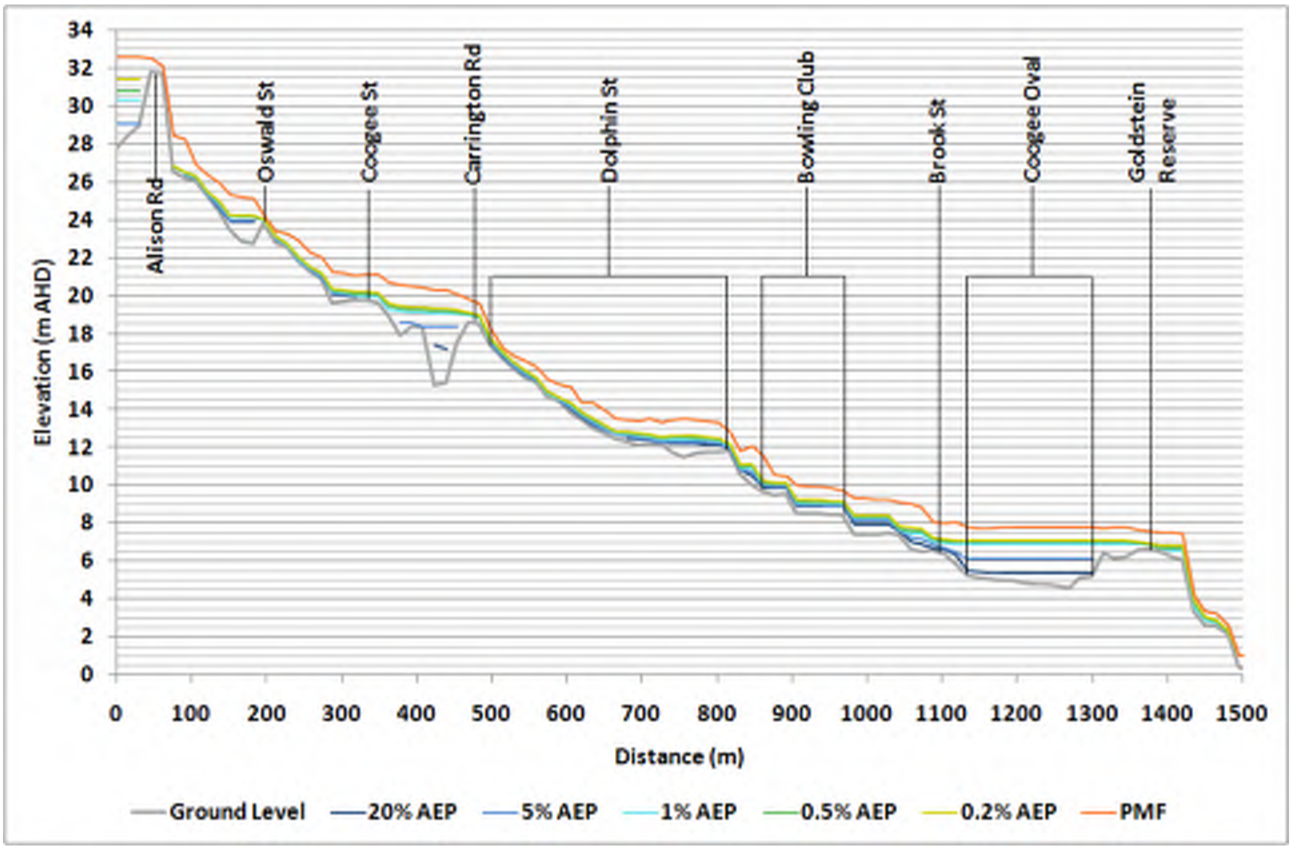


Figure 6-3 Design Flood Level Long Section

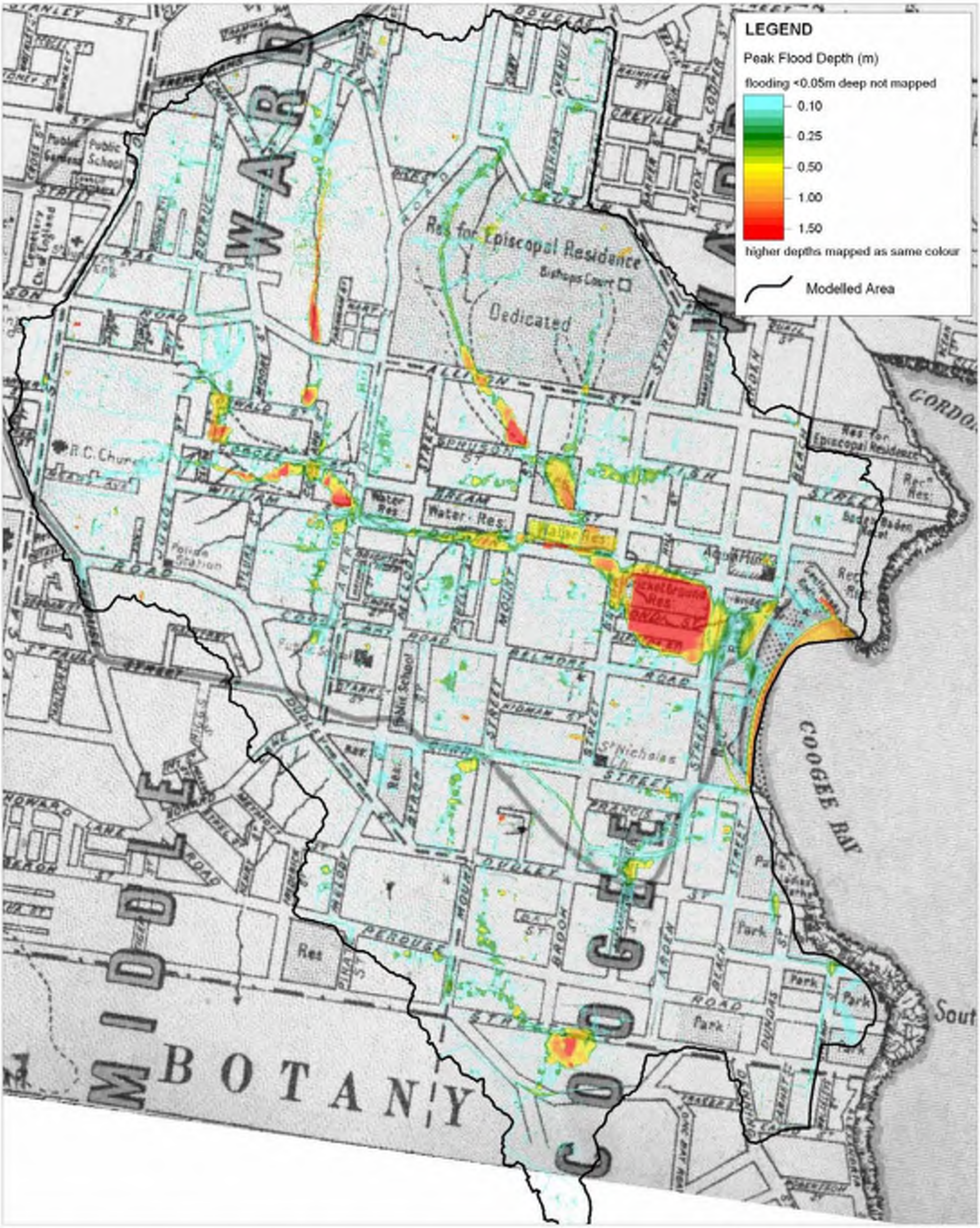
The main flowpath of the Coogee Oval catchment is aligned with Dolphin Street from Carrington Road to Arden Street. This corresponds to the areas designated as “Water Reserve” on a historic map of Randwick by Higinbotham and Robinson, dating from c.1885. This map is shown in Figure 6-4, overlain by the 1% AEP modelled flood depth results. The creek alignment along Dolphin Street and through the Coogee Bowling Club site is evident and corresponds well with the alignment of the modelled overland flow path. Flood depths in this area are driven by local obstructions to the flow. Depressions in Dolphin Street and Brook Street flood to depths of around 0.5m for the 20% AEP event, rising to around 1m for the 1% AEP event. Flood depths at the bowling club (at green level) are around 0.3m for the 20% AEP event and 0.5m for the 1% AEP event. The deepest flood depths are experienced in the Coogee Oval depression, which is separated from the sea by the higher ground of Arden Street and Goldstein Reserve. Here flood depths are around 0.5m for the 5% AEP event, rising to over 2m for the 1% AEP flood. Properties that are likely to be impacted by flooding include those located immediately to the south of the oval, those near the Dolphin Street – Brook Street intersection and the bowling and tennis clubs.

There are two main tributaries that contribute to the main flowpath, both aligned in a roughly north-south direction. The first tributary flowpath is generated from the catchment area to the north of Coogee Bay Road and west of Carrington Road. It includes a remnant creek alignment upstream of Alison Road. This was marked on the historic map and still exists today. Downstream of Alison Road it is conveyed through a series of underground culverts. The flood depths upstream of Alison Road are driven by the volume of runoff and are around 0.3m for the 20% AEP event, rising to around 2m by the 1% AEP event. The events up to the 0.2% AEP are not sufficient enough to overtop Alison Road. Downstream of Alison Road the flood depths are locally high in natural depressions in the topography. These depressions correspond to the creek and flow path alignments identified in 1885 The three most significant of these depressions are:

- Upstream of the Courland Street – Oswald Street intersection. Flood depths here are over 1.5m for the 20% AEP event and almost 2m for the 1% AEP event;
- Between Clyde Street and Coogee Street. Flood depths here are around 0.5m for the 20% AEP event and 1.2m for the 1% AEP event;
- Upstream of the Dolphin Street – Carrington Road intersection. Flood depths here are up to 2m for the 20% AEP event and almost 4m for the 1% AEP event.

Properties that are likely to be impacted by flooding include those at the locations mentioned above, some additional properties located on Coogee Street and some located between Coogee Bay Road and Dolphin Street.

The second tributary flowpath is generated from the catchment area to the north of Bream Street and east of Carrington Road. It contains two main flowpaths which converge on Bardon Park. The approximate alignment of these is marked on the historic map. One originates from Clovelly Road, progressing through Marcel Avenue and then along Pauling Avenue. The other originates from around Division Street, flowing along Leeton Avenue. Flood depths in this area are most significant upstream of the Abbott Street – Mount Street intersection, where flood depths of around 1m are modelled for the 20% AEP event, rising to 2m by the 1% AEP event. Flooding is also significant in a depression at the bottom of Pauling Avenue and on Bardon Park. Flood depths are around 1m for both location in the 1% AEP event, being 0.2m and 0.5m respectively for the 20% AEP event. Another flowpath into Bardon Park is also significant. It is aligned approximately along Hill Lane and



Title:

Comparison of Design Flood Results with Historic Map

Figure: 6-4

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Smithfield Avenue. Flood depths are typically shallow for the 20% AEP event, rising to over 0.5m for the 1% AEP event. Properties that are likely to be impacted by flooding include those located between Alison Road and Abbott Street and those located along Smithfield Avenue or between Arcadia Street and Hill Lane.

Elsewhere in the Coogee Oval catchment, flooding is generally less substantial. Perhaps the most significant flooding other than the issues already discussed occurs between Carr Street and Dudley Street, where local flood depths can exceed 0.5m.

The Rainbow Street catchment consists primarily of two overland flow alignments. One begins at the Oberon Street – Hendy Avenue intersection and flows east, the other from the Dudley Street - Mount Street intersection and flowing south. The flood depths on these alignments are typically shallow but are locally higher than 0.5m in topographic depressions. The flood waters collect in the bottom of the catchment depression on Rainbow Street, which is relieved to some extent by the capacity of the stormwater drainage network. The stormwater pipe runs along Rainbow Street and under Blenheim Park, where it is buried over 30m underground. The flood depths in the Rainbow Street depression are typically around 0.3m for the 20% AEP event and 1m for the 1% AEP event. The depths are around 1m greater than this in the deepest part of the depression. Properties likely to be impacted by flooding are located in the areas described above, predominantly on Oberon Street and Rainbow Street, and particularly those situated within the Rainbow Street depression.

Elsewhere in the study area the flow paths are confined largely to the roadways, with only some localised flooding issues.

Flood velocities within the study area vary significantly due to local conditions. They are typically lower than 0.5m/s in flood storage locations, such as the depressions but are significantly higher in the roadways. Typical flood velocities in the road alignments are over 1m/s for the 20% AEP event, rising to over 2m/s for the 1% AEP event.

6.2.2 Hydraulic Categorisation

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringes. Descriptions of these terms within the Floodplain Development Manual (NSW Government, 2005) are essentially qualitative in nature. Of particular difficulty is the fact that a definition of flood behaviour and associated impacts is likely to vary from one floodplain to another depending on the circumstances and nature of flooding within the catchment.

The hydraulic categories as defined in the Floodplain Development Manual are:

- **Floodway -** Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- **Flood Storage -** Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.

- **Flood Fringe -** Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant affect on the flood pattern or flood levels.

A number of approaches were considered when attempting to define flood impact categories across Coogee Bay. Approaches to define hydraulic categories that were considered for this assessment included partitioning the floodplain based on:

- Peak flood velocity;
- Peak flood depth;
- Peak velocity * depth (sometimes referred to as unit discharge);
- Cumulative volume conveyed during the flood event; and
- Combinations of the above.

The definition of flood impact categories that was considered to best fit the application within Coogee Bay was ultimately provided by Council and was based on a combination of velocity*depth, velocity and depth parameters. The adopted hydraulic categorisation is defined in Table 6-4.

The hydraulic category map is included in Appendix A. It is also noted that mapping associated with the flood hydraulic categories may be amended in the future, at a local or property scale, subject to appropriate analysis that demonstrates no additional impacts (e.g. if it is to change from floodway to flood storage).

Table 6-4 Hydraulic categories

Floodway	Defined at the 1% AEP event using the following criteria: Velocity * Depth > 0.3 OR Velocity > 0.5 m/s	Areas and flowpaths where a significant proportion of floodwaters are conveyed (including all bank-to-bank creek sections).
Flood Storage	Defined at the 1% AEP event where Depth > 0.15 metres	Areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.
Flood Fringe	Defined at the PMF event where Depth > 0.15 metres	Areas that are low-velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.

6.2.3 Provisional Hazard

The NSW Government's Floodplain Development Manual (2005) defines flood hazard categories as follows:

- **High hazard** – possible danger to personal safety; evacuation by trucks is difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings; and

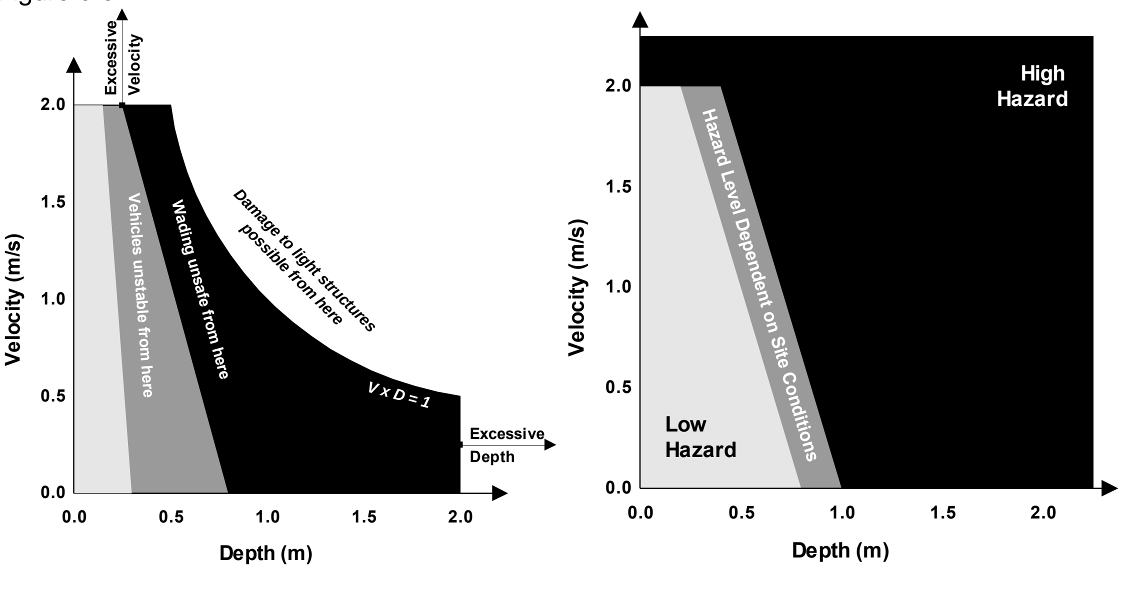
- **Low hazard** – should it be necessary, trucks could evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.

The key factors influencing flood hazard or risk are:

- Size of the Flood
- Rate of Rise - Effective Warning Time
- Community Awareness
- Flood Depth and Velocity
- Duration of Inundation
- Obstructions to Flow
- Access and Evacuation

The provisional flood hazard level is often determined on the basis of the predicted flood depth and velocity. This is conveniently done through the analysis of flood model results. A high flood depth will cause a hazardous situation while a low depth may only cause an inconvenience. High flood velocities are dangerous and may cause structural damage while low velocities have no major threat.

Figures L1 and L2 in the Floodplain Development Manual (NSW Government, 2005) are used to determine provisional hazard categorisations within flood liable land. These figures are reproduced in Figure 6-5.



Velocity Depth Relationships

Provisional Hazard Categories

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Figure 6-5 Provisional Flood Hazard Categorisation

The provisional hydraulic hazard is included in the mapping series for each simulated design event provided in Appendix A.

6.3 Sensitivity Tests

A number of sensitivity tests have been undertaken on the modelled flood behaviour in Coogee Bay. These tests consider blockage of the stormwater drainage system, reduction in rainfall losses and increased sea level. The details of the sensitivity tests and results of the modelled scenarios are presented below.

6.3.1 Stormwater Drainage Blockage

For the overland flows, the blockage considerations are mainly associated with the underground stormwater drainage network.

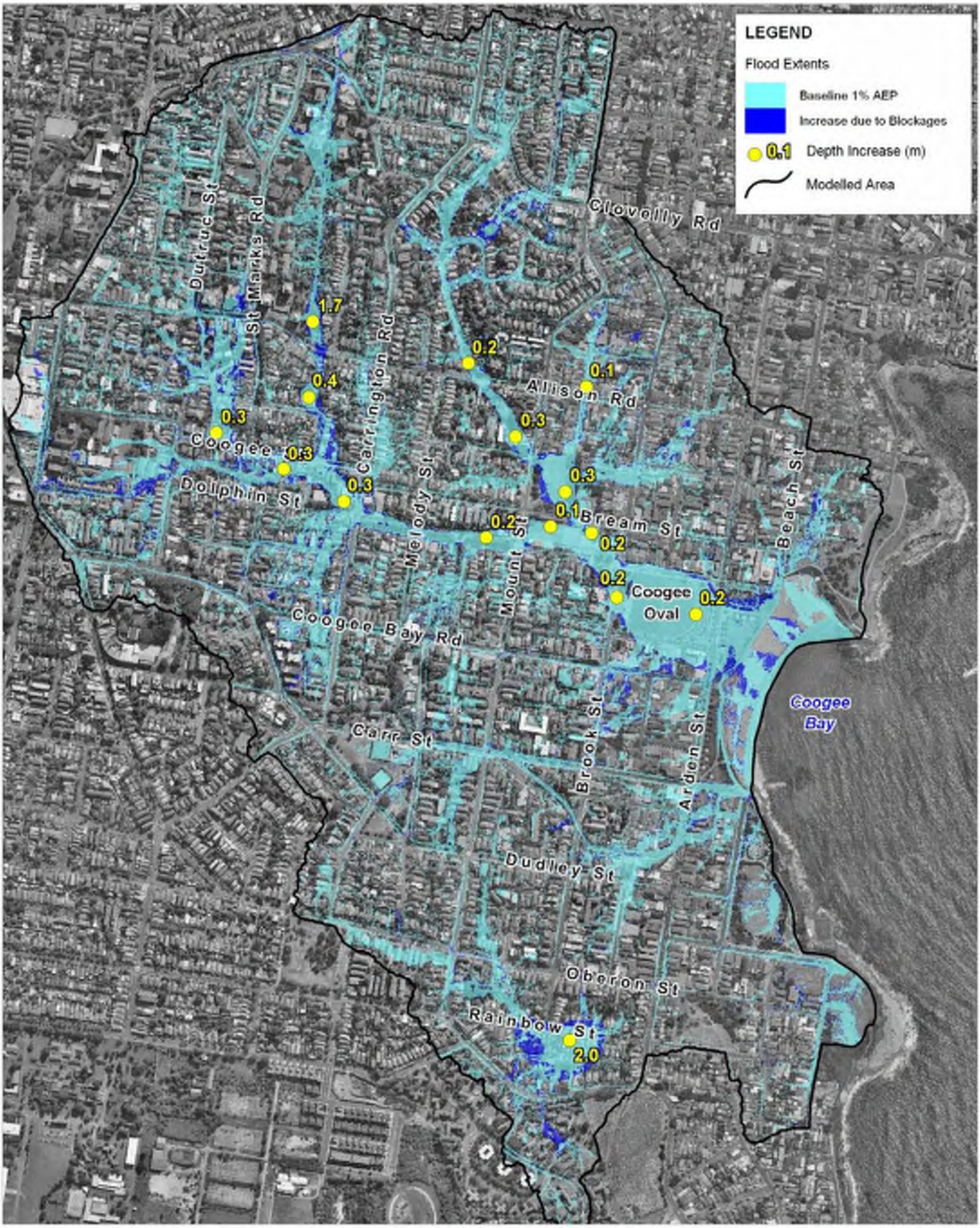
A 100% blockage assumption was applied to all pipes in the modelled subsurface network, thereby eliminating pipe flow. This results in all of the runoff remaining in the 2D model domain as overland flow. Blockage scenarios were undertaken using the 1% AEP event for both the 90-minute, 2-hour and 9-hour storm durations. The results of the blockage scenario simulation are presented in Figure 6-6 and Table 6-5.

Table 6-5 Summary of Blockage Sensitivity Results

ID	Location	Modelled Flood Level (m AHD)		Flood Level Increase (m)
		Baseline 1% AEP	1% AEP with Blockages	
1	Coogee Oval	6.9	7.1	0.2
2	Brook Street	7.0	7.2	0.2
3	Coogee Tennis Club	8.2	8.4	0.2
4	Coogee Bowling Club	9.1	9.2	0.1
5	Dolphin Street	12.4	12.6	0.2
6	Carrington Road	19.0	19.3	0.3
7	Oswald Street	24.1	24.5	0.4
8	Glen Avenue	30.3	32.0	1.7
9	32 Coogee Street	20.7	21.0	0.3
10	9 Coogee Street	26.0	26.3	0.3
11	Bardon Park	13.0	13.3	0.3
12	Mount Street	15.0	15.3	0.3
13	Pauling Avenue	18.0	18.2	0.2
14	Leeton Avenue	19.8	19.9	0.1
15	Rainbow Street	42.8	44.6	1.8

The key findings of the stormwater drainage blockage sensitivity test are summarised below:

- Blockage impacts are greatest upstream of significant topographic obstructions, which restrict the progression of overland flow.
- The largest flood level increase was around 1.8m above base case conditions. This increase occurs in the depression of the Rainbow Street catchment. Here the only flow outlet is via the pipe network and so there is a significant increase in flood level. The peak flood level represents the total volume of runoff from the local catchment.
- A flood level increase of 1.7m was simulated in the remnant creek line upstream of Alison Road. Here the road forms around a 3m high obstruction, serviced by a 2.5m x 2.0m cross-drainage



Title:
Impact of Stormwater Pipe Blockage on 1% AEP Event

Figure: 6-6

Rev: A

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Filepath : K:\N1924_Coogee_Bay_Flood_Study\MI\Workspaces\DRG_020_110701_Blockage_Impacts.WOR capacity. The blockage of the stormwater drainage network provides no outlet from the upstream depression until a flood level of over 31.7m AHD is reached. Overtopping of Alison Road occurs during the blockage scenario but not under baseline conditions.

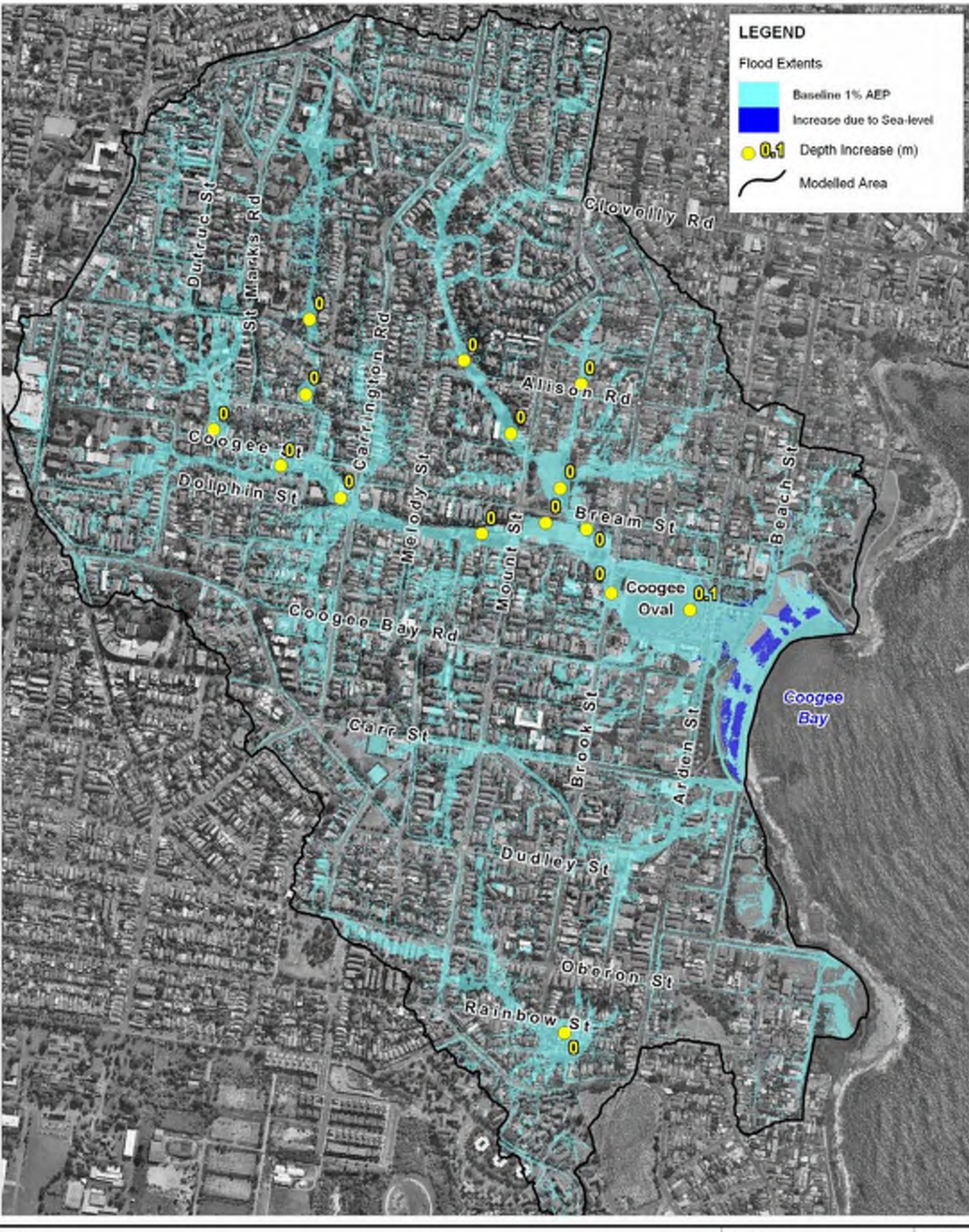
- Flood level increases of around 0.2m to 0.3m were typically simulated in areas located along the major flowpath alignments, i.e. the previous creek/gully locations. Larger increases were not experienced for any of the topographic depressions other than those specifically mentioned above. This is because the baseline 1% AEP event is substantial enough to fill the remaining depressions.
- Elsewhere, blockage impacts were 10cm or less. Areas where larger impacts were simulated have been marked on Figure 6-6.

6.3.2 Sea Level

The model developed for this study adopted a fixed water level boundary of 1m AHD to represent the sea level in Coogee Bay. This is similar to a conservative spring tide level, but is unlikely to have any impact of the model results in the study area as the lowest-lying areas are situated a few metres above this at around 4.5m AHD. Higher sea-level conditions could coincide with a flood event if for example local catchment flooding occurred during a significant coastal flood. Future climate change predictions also suggest a 0.9m increase in sea-levels by 2100. To test the influence of higher sea-level conditions on flood levels within the study area an extreme water level of 3.5m AHD was adopted. This would be similar to a 0.5% coastal flood event with a 0.9m increase for climate change. The results of the increased sea-level scenario simulation are presented in Figure 6-7 and Table 6-6,

Table 6-6 Summary of Sea-level Sensitivity Results

ID	Location	Modelled Flood Level (m AHD)		Flood Level Increase (m)
		Baseline 1% AEP	1% AEP with 3.5m AHD Sea-level	
1	Coogee Oval	6.9	7.0	0.1
2	Brook Street	7.0	7.0	0.0
3	Coogee Tennis Club	8.2	8.2	0.0
4	Coogee Bowling Club	9.1	9.1	0.0
5	Dolphin Street	12.4	12.4	0.0
6	Carrington Road	19.0	19.0	0.0
7	Oswald Street	24.1	24.1	0.0
8	Glen Avenue	30.3	30.3	0.0
9	32 Coogee Street	20.7	20.7	0.0
10	9 Coogee Street	26.0	26.0	0.0
11	Bardon Park	13.0	13.0	0.0
12	Mount Street	15.0	15.0	0.0
13	Pauling Avenue	18.0	18.0	0.0
14	Leeton Avenue	19.8	19.8	0.0
15	Rainbow Street	42.8	42.8	0.0



Title:
Impact of Increased Sea-level on 1% AEP Event

Figure: 6-7

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The key findings of the sea-level rise sensitivity test are summarised below:

- The sea-level conditions have a minimal impact of upstream flooding conditions;
- Coogee Oval and Goldstein Reserve is the only area (other than the beach itself) that is impacted by the sea-level rise scenario. Here a flood level increase of around 0.1m is modelled, due to the slight reduction in drainage outlet capacity;
- Elsewhere the impacts are negligible.

6.3.3 Rainfall Losses

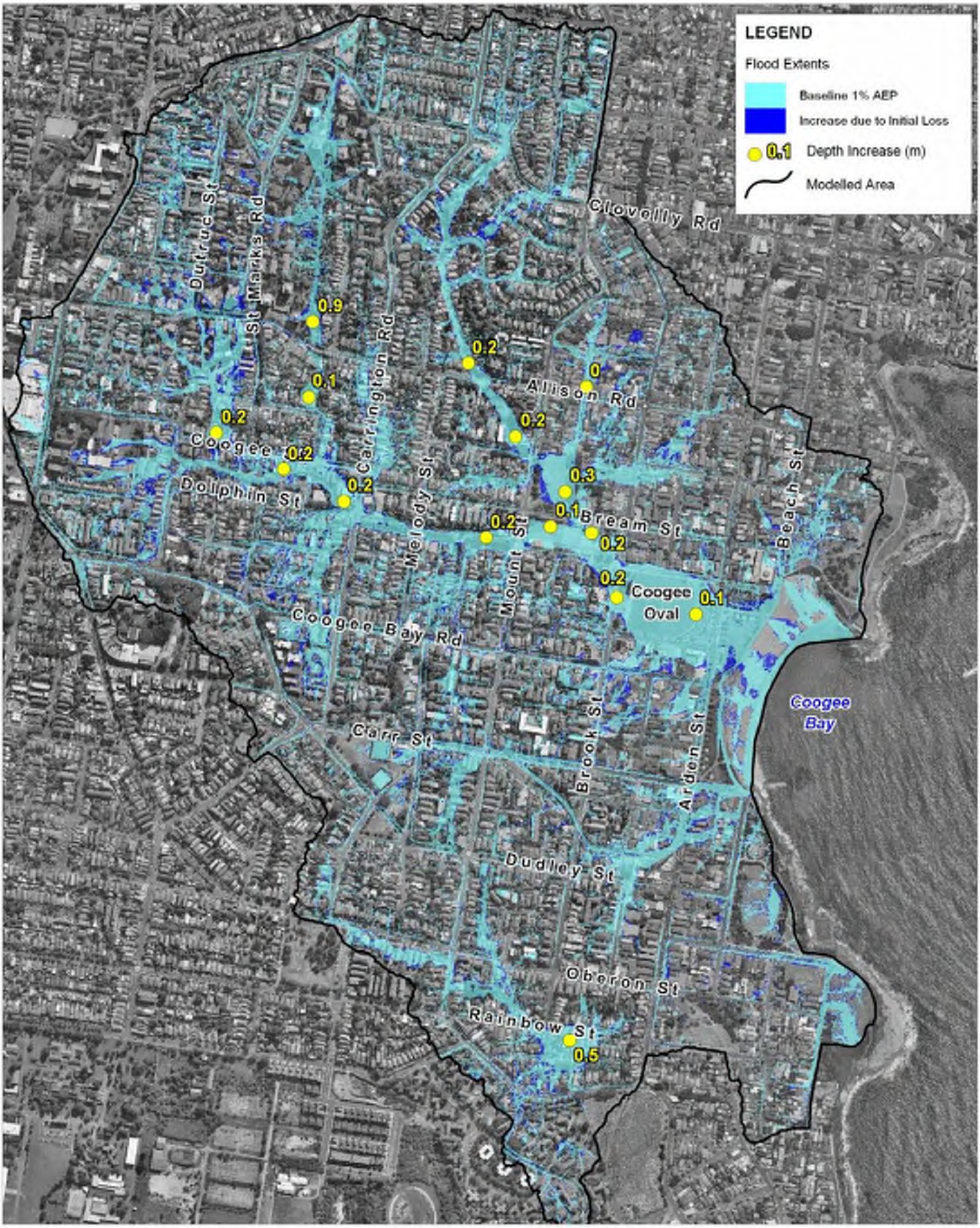
The rainfall losses that were determined through the calibration process found an initial loss of 50mm to be appropriate for the study area. This is outside of the normal range recommended by AR&R, but is reasonable for well-draining sandy soils. The sensitivity of the 1% AEP design results was tested by adopting the standard recommended initial loss for eastern NSW of 15mm. The results of the decreased initial rainfall loss scenario simulation are presented in Figure 6-8 and Table 6-7.

Table 6-7 Summary of Initial Loss Sensitivity Results

ID	Location	Modelled Flood Level (m AHD)		Flood Level Increase (m)
		Baseline 1% AEP	1% AEP with 15mm Loss	
1	Coogee Oval	6.9	7.0	0.1
2	Brook Street	7.0	7.2	0.2
3	Coogee Tennis Club	8.2	8.4	0.2
4	Coogee Bowling Club	9.1	9.2	0.1
5	Dolphin Street	12.4	12.6	0.2
6	Carrington Road	19.0	19.2	0.2
7	Oswald Street	24.1	24.2	0.1
8	Glen Avenue	30.3	31.2	0.9
9	32 Coogee Street	20.7	20.9	0.2
10	9 Coogee Street	26.0	26.2	0.2
11	Bardon Park	13.0	13.3	0.3
12	Mount Street	15.0	15.2	0.2
13	Pauling Avenue	18.0	18.2	0.2
14	Leeton Avenue	19.8	19.8	0.0
15	Rainbow Street	42.8	43.2	0.4

The key findings of the reduced initial rainfall loss sensitivity test are summarised below:

- As for the blockage scenario, initial loss impacts are greatest upstream of significant topographic obstructions, which restrict the progression of overland flow. This is because the peak flood levels in such locations are driven by volumes rather than peak flows;
- The largest flood level increase was around 0.9m above base case conditions. This increase occurs in the remnant creek line upstream of Alison Road. Here the road forms around a 3m high



Title:

Impact of Decreased Initial Rainfall Loss on 1% AEP Event

Figure: 6-8

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- A flood level increase of 0.4m was simulated in the depression of the Rainbow Street catchment. This is due to the increased runoff volume from the local catchment which drives the peak flood level in the depression.
- Flood level increases of around 0.2m were typically simulated in areas located along the major flowpath alignments, i.e. the previous creek/gully locations. Larger increases were not experienced for any of the topographic depressions other than those specifically mentioned above. This is because the baseline 1% AEP event is substantial enough to fill the remaining depressions.
- Elsewhere, initial loss impacts were 10cm or less. Areas where larger impacts were simulated have been marked on Figure 6-8.

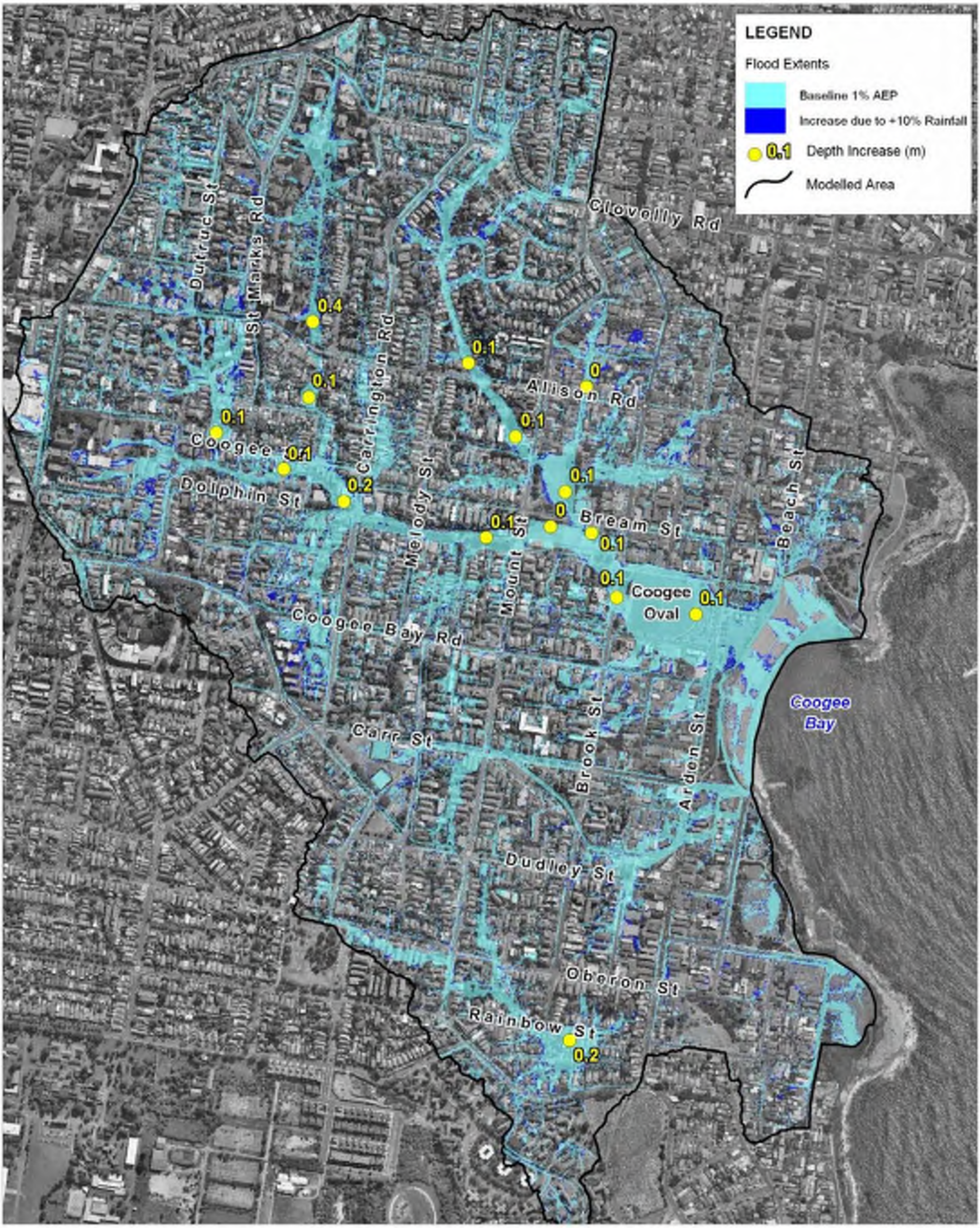
6.3.4 Climate Change

Current practice in floodplain management generally requires consideration of the impact of potential climate change scenarios on design flood conditions. For the Coogee Bay catchments this requires investigation of increases in design rainfall intensities. Typically climate change sensitivity tests in this regard consider increases in design rainfall intensity of 10%, 20% or 30% in accordance with DECCW Practical Consideration of Climate Change Guideline for Floodplain Risk Management (2007).

Specific climate change simulations were not undertaken as part of this study but the 0.5% AEP and 0.2% AEP design results can be used, when compared to the 1% AEP results, to give an indication as to the potential magnitude of climate change impacts. The 0.5% AEP design rainfall depth is approximately 10% greater than that of the 1% AEP and the 0.2% AEP design rainfall depth is approximately 25% greater than that of the 1% AEP. Comparing results of the 0.5% AEP and 0.2% AEP events to the 1% AEP event is comparable to considering a 10% or 25% increase in design rainfall depths to the 1% AEP event respectively. As discussed previously, these are similar increases typically considered for climate change assessments.

The assessment of the 10% increase in rainfall intensity scenario is presented in Figure 6-9 and Table 6-8. The assessment of the 25% increase in rainfall intensity scenario is presented in Figure 6-10 and Table 6-9. The key findings of the potential climate change impacts are summarised below:

- As for the blockage and initial loss scenarios, increased rainfall impacts are greatest upstream of significant topographic obstructions, which restrict the progression of overland flow. This is because the peak flood levels in such locations are driven by volumes rather than peak flows;
- The largest flood level increase was around 0.4m above base case conditions for the 10% rainfall increase scenario and 1.1m for the 25% rainfall increase scenario. This increase occurs in the remnant creek line upstream of Alison Road. Here the road forms around a 3m high obstruction, serviced by a 2.5m x 2.0m cross-drainage capacity. The increased rainfall considerations of +10% and +25% significantly increases the flood level here, but overtopping of Alison Road does not occur.



Title:

Impact of 10% Rainfall Increase on 1% AEP Event

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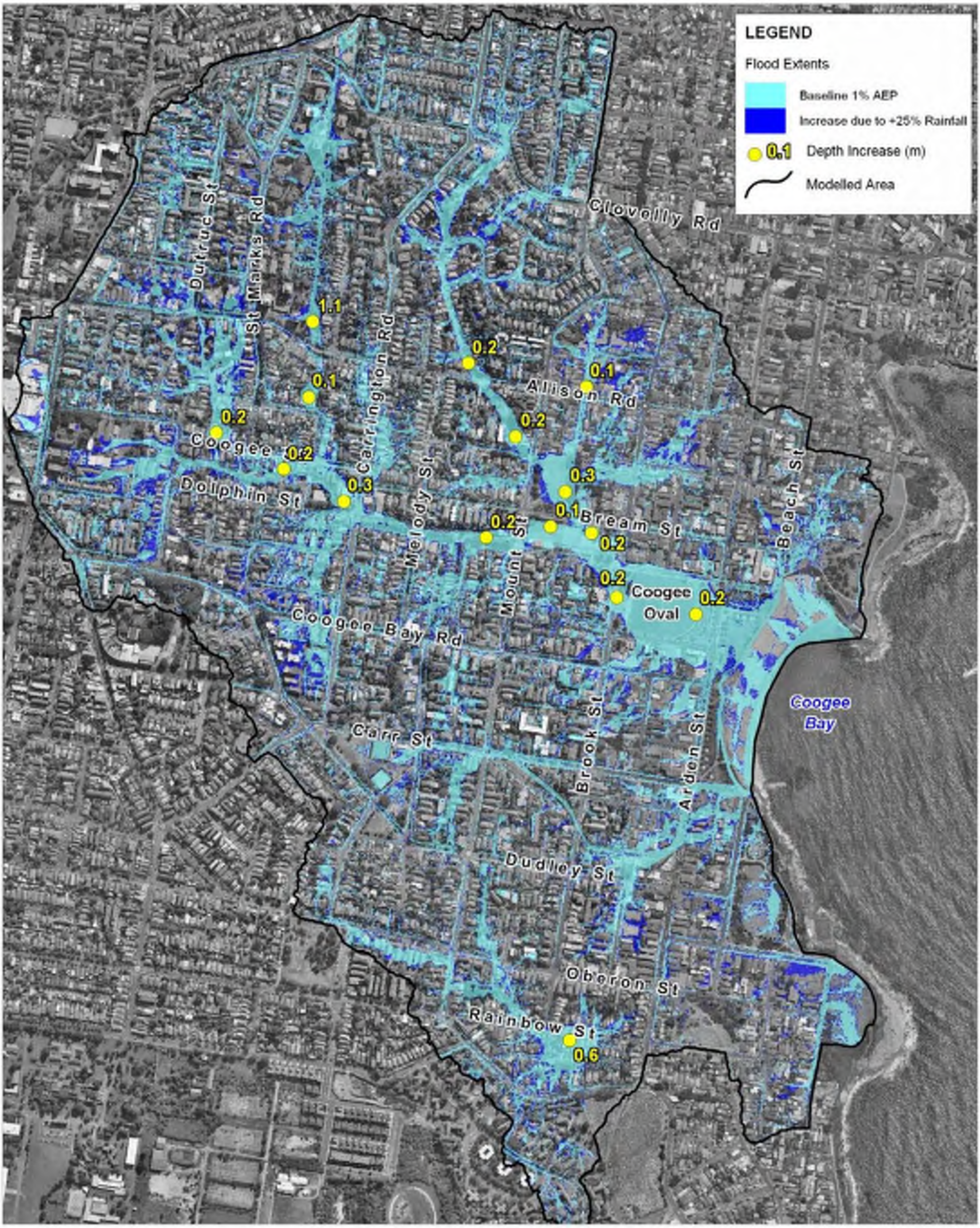

Title:

Impact of 25% Rainfall Increase on 1% AEP Event

Figure: 6-10

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Filepath : K:\N1924_Coogee_Bay_Flood_Study\MI\Workspaces\DRG_024_110701_+25%Rainfall_Impacts.WOR

Table 6-8 Summary of 10% Increased Rainfall Assessment

ID	Location	Modelled Flood Level (m AHD)		Flood Level Increase (m)
		1% AEP	0.5% AEP	
1	Coogee Oval	6.9	7.0	0.1
2	Brook Street	7.0	7.1	0.1
3	Coogee Tennis Club	8.2	8.3	0.1
4	Coogee Bowling Club	9.1	9.1	0
5	Dolphin Street	12.4	12.5	0.1
6	Carrington Road	19.0	19.2	0.2
7	Oswald Street	24.1	24.2	0.1
8	Glen Avenue	30.3	30.7	0.4
9	32 Coogee Street	20.7	20.8	0.1
10	9 Coogee Street	26.0	26.1	0.1
11	Bardon Park	13.0	13.1	0.1
12	Mount Street	15.0	15.1	0.1
13	Pauling Avenue	18.0	18.1	0.1
14	Leeton Avenue	19.8	19.8	0
15	Rainbow Street	42.8	43.0	0.2

Table 6-9 Summary of 25% Increased Rainfall Assessment

ID	Location	Modelled Flood Level (m AHD)		Flood Level Increase (m)
		1% AEP	0.2% AEP	
1	Coogee Oval	6.9	7.1	0.2
2	Brook Street	7.0	7.2	0.2
3	Coogee Tennis Club	8.2	8.4	0.2
4	Coogee Bowling Club	9.1	9.2	0.1
5	Dolphin Street	12.4	12.6	0.2
6	Carrington Road	19.0	19.3	0.3
7	Oswald Street	24.1	24.2	0.1
8	Glen Avenue	30.3	31.4	1.1
9	32 Coogee Street	20.7	20.9	0.2
10	9 Coogee Street	26.0	26.2	0.2
11	Bardon Park	13.0	13.3	0.3
12	Mount Street	15.0	15.2	0.2
13	Pauling Avenue	18.0	18.2	0.2
14	Leeton Avenue	19.8	19.9	0.1
15	Rainbow Street	42.8	43.3	0.5

- A flood level increase of 0.2m occurs in the depression of the Rainbow Street catchment for the +10% rainfall scenario, with a 0.5m increase for the +25% rainfall scenario. This is due to the increased runoff volume from the local catchment which drives the peak flood level in the depression.
- Flood level increases of around 0.1m and 0.2m (for the +10% and +25% scenarios respectively) are typical in areas located along the major flowpath alignments, i.e. the previous creek/gully locations. Larger increases were not experienced for any of the topographic depressions other than those specifically mentioned above. This is because the baseline 1% AEP event is substantial enough to fill the remaining depressions.
- Elsewhere, increased rainfall impacts are 10cm or less. Areas where larger impacts were simulated have been marked on Figure 6-9 and Figure 6-10.

7 CONCLUSIONS

The objective of the study was to undertake a detailed flood study of the local overland flow catchments of Coogee Bay and establish models as necessary for design flood level prediction.

In completing the flood study, the following activities were undertaken:

- Collation of historical flood information for the study area;
- Consultation with the community to acquire additional historical flood information;
- Development of a 2D/1D hydrodynamic model (using TUFLOW software) to simulate hydrology and flood behaviour in the catchment;
- Calibration of the developed model using the available flood data, primarily relating to the May 2009 event;
- Prediction of design flood conditions in the catchments and production of design flood mapping series.

In simulating the design flood conditions for the local catchments in the study area, the following locations were identified as potential problem areas in relation to flood inundation extent and property affected:

- Alfreda Street – the properties located immediately to the south of Coogee Oval are liable to be flooded during significant flood events. This will be from flood waters ponding behind Arden Street and Goldstein Reserve. The car parking areas situated around the Oval will also be affected (as well as the oval itself);
- Brook Street – properties situated along Brook Street near the Dolphin Street intersection are in a local depression which is separated from the oval to the east by an area of higher ground;
- Coogee Bowling Club and Tennis Club – these clubs are situated on the traditional creek alignment of the Coogee Oval catchment. As such they will experience frequent flooding and significant flooding during major flood events. Some of the property is situated below ground level, which will exacerbate the problem;
- Coogee Street and Dolphin Street – the properties situated between these two roads and to the west of Carrington Road are located on an old creek alignment. Locally deep flooding will occur on some properties, particularly adjacent to Carrington Road, which is a substantial obstruction to overland flows. Some properties to the south of Dolphin Street will also be impacted;
- Clyde Street – properties located here between Oswald Street and Coogee Street are impacted by flood levels building in local depressions, particularly behind Coogee Street, which forms a significant obstruction to overland flow and has limited cross-drainage capacity;
- Oswald Street – properties located between here and Alison Road are on a traditional creek alignment and as such are at risk of flooding when the available stormwater drainage capacity is exceeded, particularly those located in the depression adjacent to Oswald Street;

- Abbott Street – properties situated between Abbott Street and Alison Road are located within an historic creek alignment and are liable to flooding, particularly those in a depression that sits behind Mount Street;
- Bardon Park – properties situated on around Bardon Park are within overland flow alignments, including those located between the park and Leeton Avenue and those to the east along Smithfield Avenue;
- Carr Street – properties situated between here and Dudley Street are located on an overland flowpath and may experience locally deep flooding in depressions;
- Oberon Street – properties situated south of Oberon Street, between Hendy Avenue and Mount Street are located on an overland flowpath and may experience locally deep flooding in depressions. This is also the case for properties situated to the north of Oberon, around Cox Street and Bay Street;
- Rainbow Street – a large depression in the topography (some 10m deep) is situated between Rainbow Street and Marian Street, and to the east of Brook Street. The location is liable to significant flood depths when the available capacity of the stormwater drainage is exceeded.

The flooding issues within the Coogee Bay study area are largely restricted to locations which were naturally creek/gully lines, but are now occupied by urban development. Along these alignments natural depressions in the topography and those created by manmade obstructions, such as roads and other land-raising activities, fill to significant depths during major design flood events. Stormwater drainage networks are typically designed to around a 20% AEP standard. Once the available drainage capacity is exceeded the depressions will quickly fill with excess runoff, acting as local flood storages. For large flood events such as the 1% AEP these storages are filled to capacity and water flooding progresses via the lowest adjoining point in the topography. This type of flood behaviour is widespread throughout the study area.

Most of the study area drains to two large depressions – Coogee Oval and Rainbow Street. The surrounding higher land prevents progression of overland flow and flood waters rise as the available storage volume is filled. Both are serviced by Council's stormwater network but when the drainage capacity is exceeded the flood levels rise. At Coogee Oval the higher ground of Arden Street and Goldstein Reserve is situated some 2m above the bottom of the Oval. During major flood events the available storage of the Oval will be exceeded and flood waters will spill through here and on to the beach. The Rainbow Street depression is some 10m deep and as such the storage capacity will never be exceeded. In extreme flood conditions such as the PMF event or under a blocked stormwater drainage scenario, a significant flood risk to this area is posed, with possible flood depths of several metres.

The potential impacts of future climate change are relatively insignificant in the study area for the 1% AEP event, with negligible impacts from sea-level rise and only locally significant flood depth increases under increased rainfall intensity conditions.

The flood study will form the basis for the subsequent floodplain risk management activities, being the next stage of the floodplain management process.

8 REFERENCES

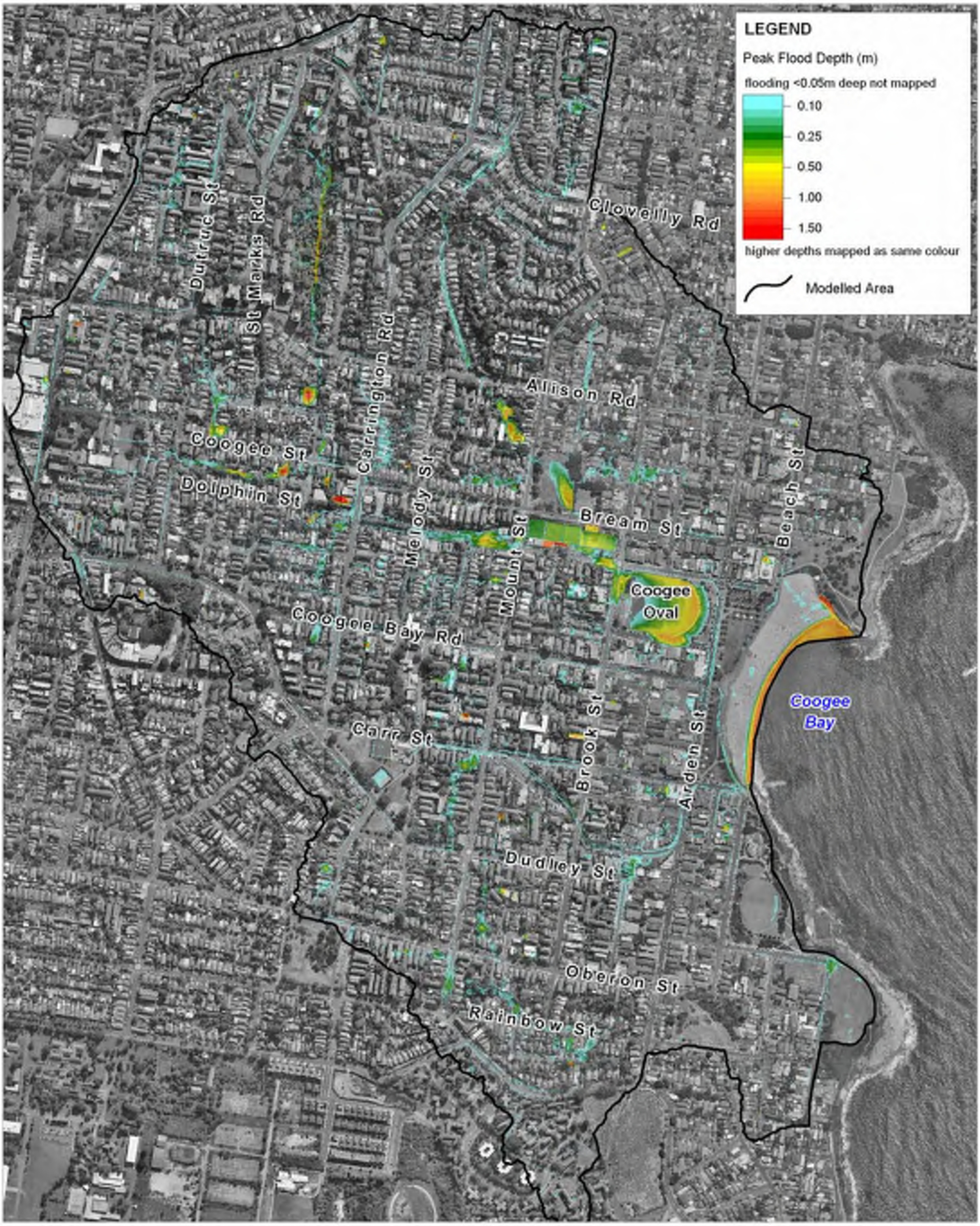
Department of Environment and Climate Change (DECC) (2007) *Floodplain Risk Management Guideline – Practical Consideration of Climate Change.*

Gary Blumberg and Associates (1999) *Assessment of Impacts from January 1999 Flooding*.

NSW Department of Infrastructure, Planning and Natural Resources (DIPNR) (2005) *Floodplain Development Manual.*

Patterson Britton and Partners (1999) *Coogee Oval and Bowling Club – Flood Assessment for 24 January 1999*.

APPENDIX A: DESIGN FLOOD MAPPING



Title:

Coogee Bay Flood Study
Peak Flood Depths: 20% AEP Event

Figure: A-1

Rev: A

N

0 250 500m

Approx. Scale

BMT WBM

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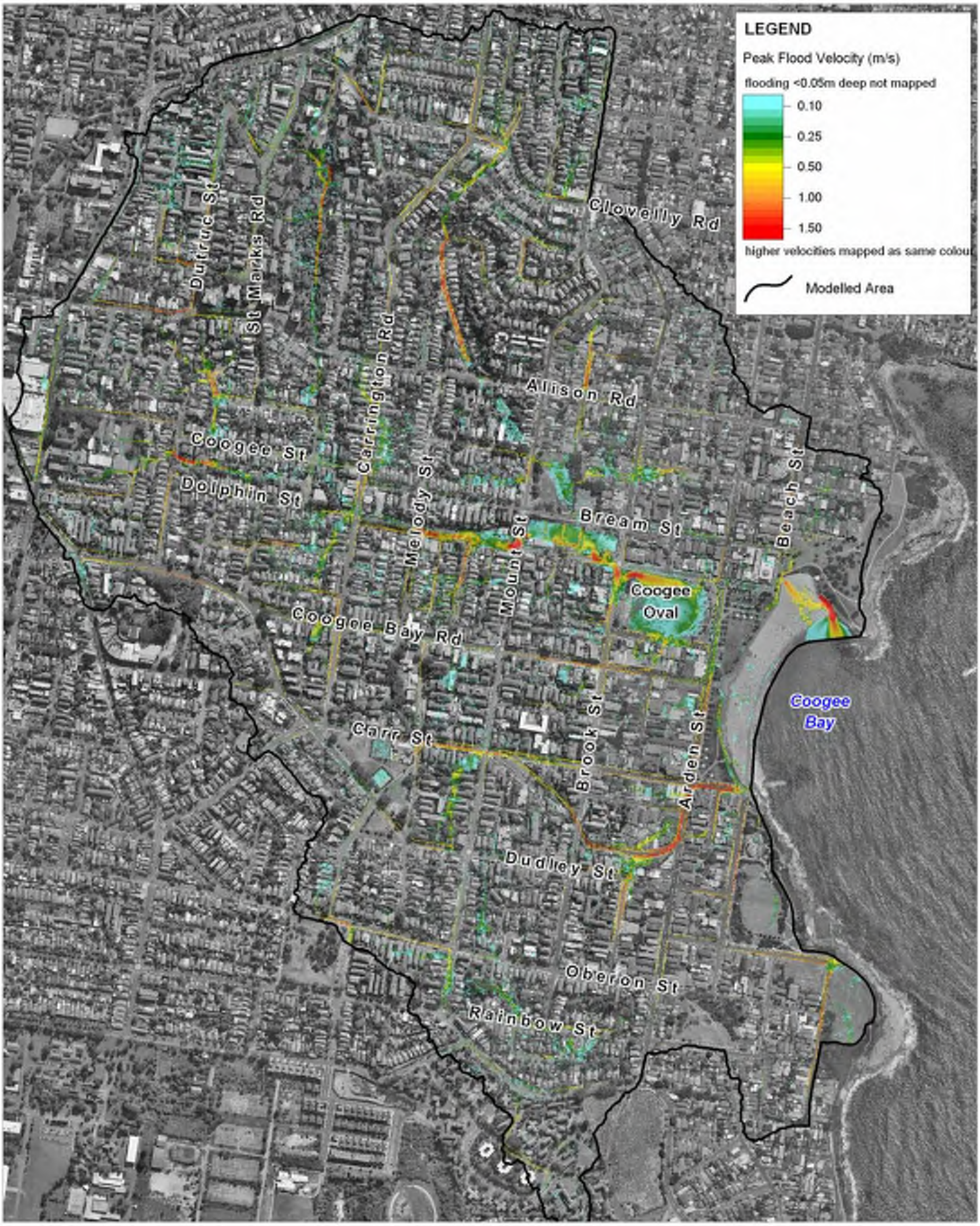

Title:

Coogee Bay Flood Study
Peak Flood Velocities: 20% AEP Event

Figure: A-2

Rev: A

N

0 250 500m

Approx. Scale

BMT WBM

www.bmtwbm.com.au

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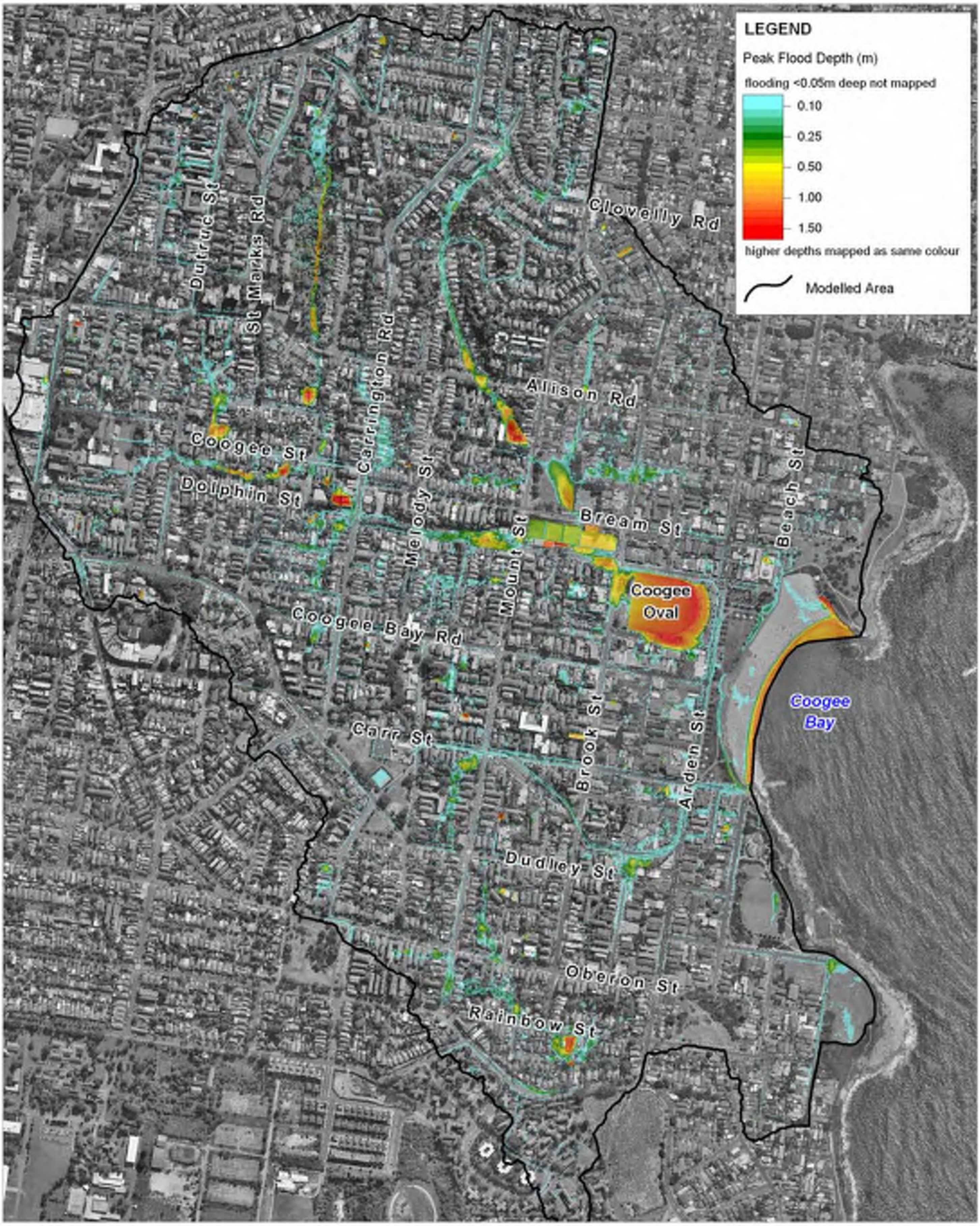

Title:

Coogee Bay Flood Study
Peak Flood Depths: 5% AEP Event

Figure: A-3

Rev: A

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Approx. Scale

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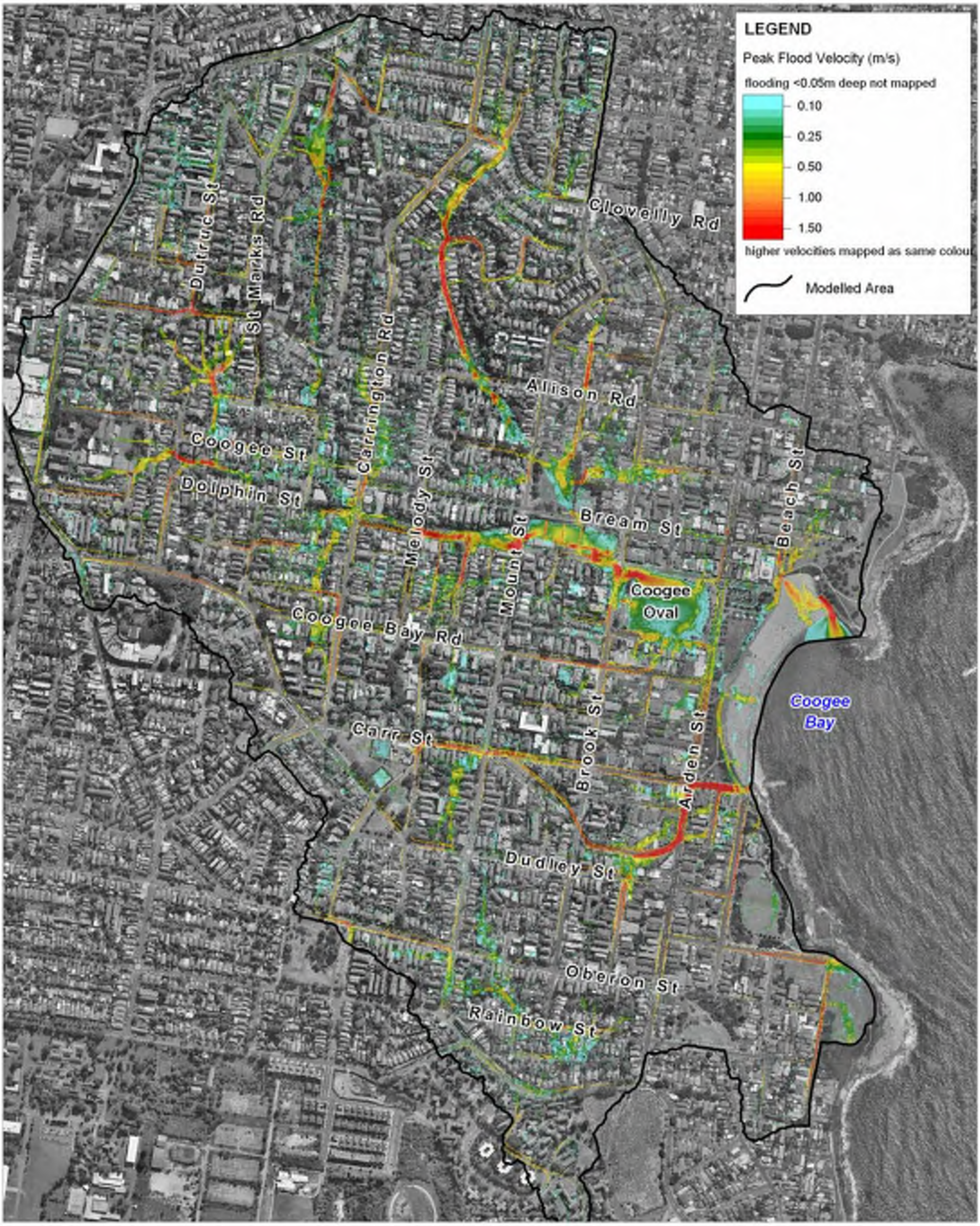

Title:

Coogee Bay Flood Study
Peak Flood Velocities: 5% AEP Event

Figure: A-4

Rev: A

N

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Approx. Scale

BMT WBM

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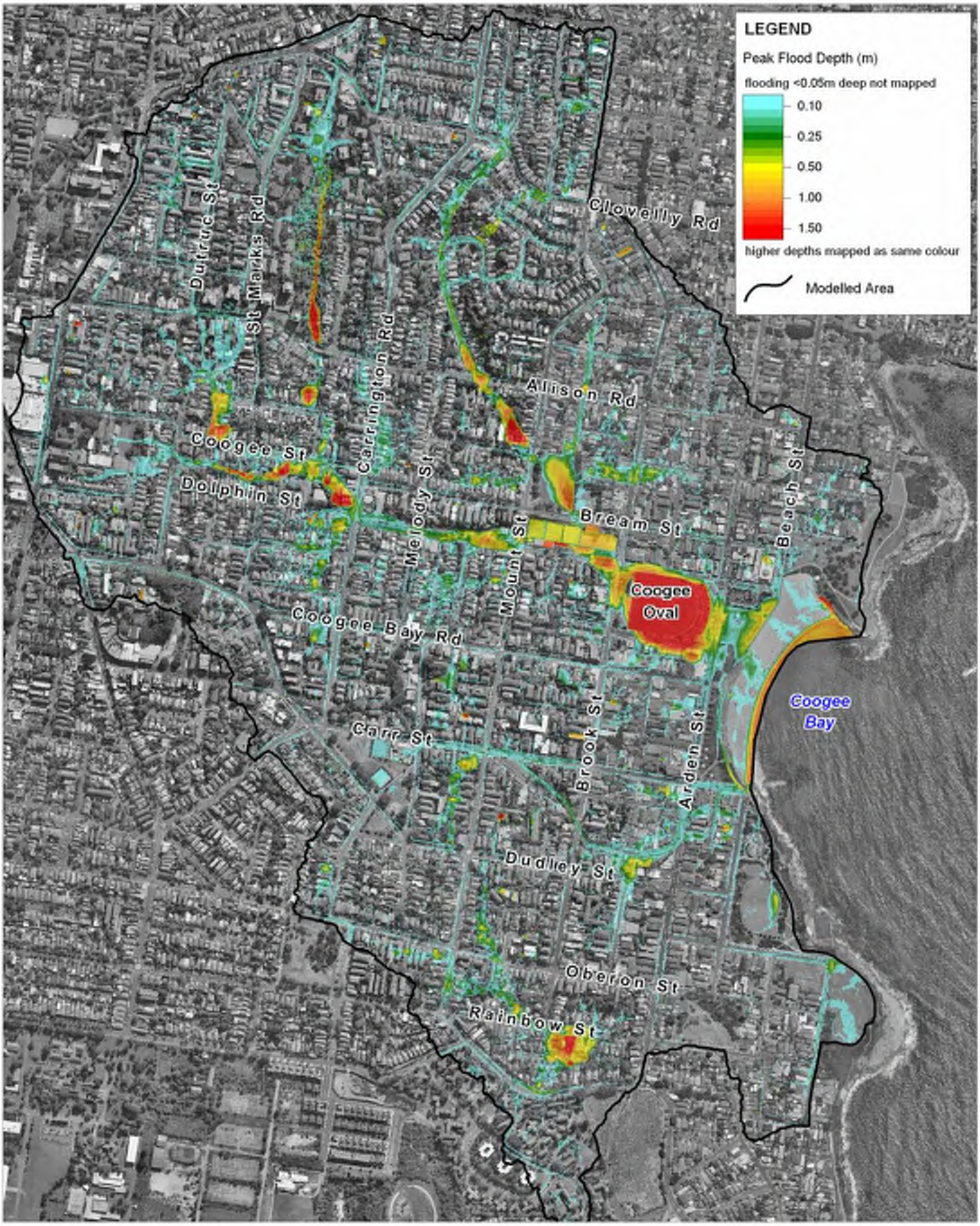

Title:

Coogee Bay Flood Study
Peak Flood Depths: 1% AEP Event

Figure: **A-5**

Rev: **A**

N

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Approx. Scale

BMT WBM

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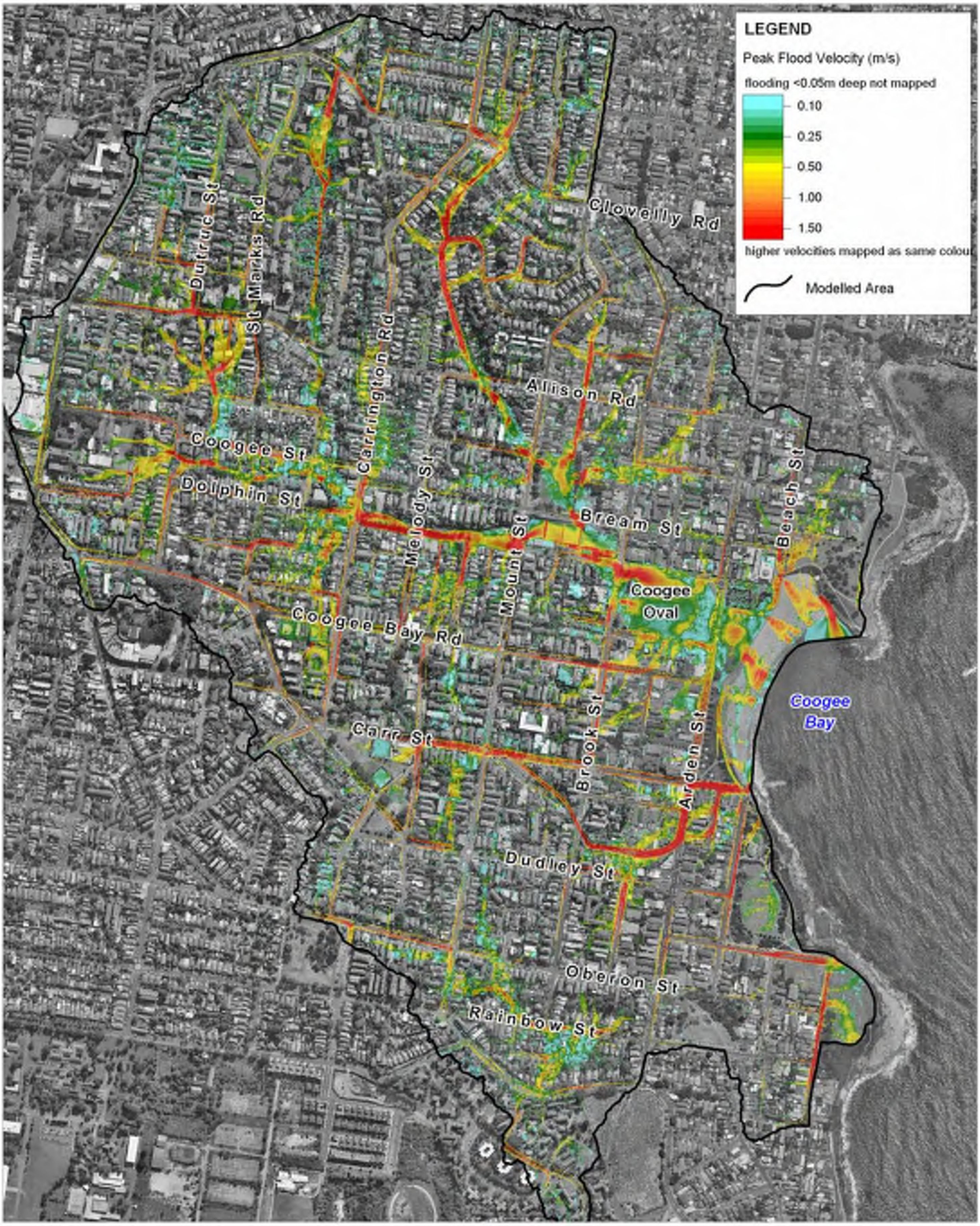

Title:

Coogee Bay Flood Study
Peak Flood Velocities: 1% AEP Event

Figure: A-6

Rev: A

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Approx. Scale

BMT WBM

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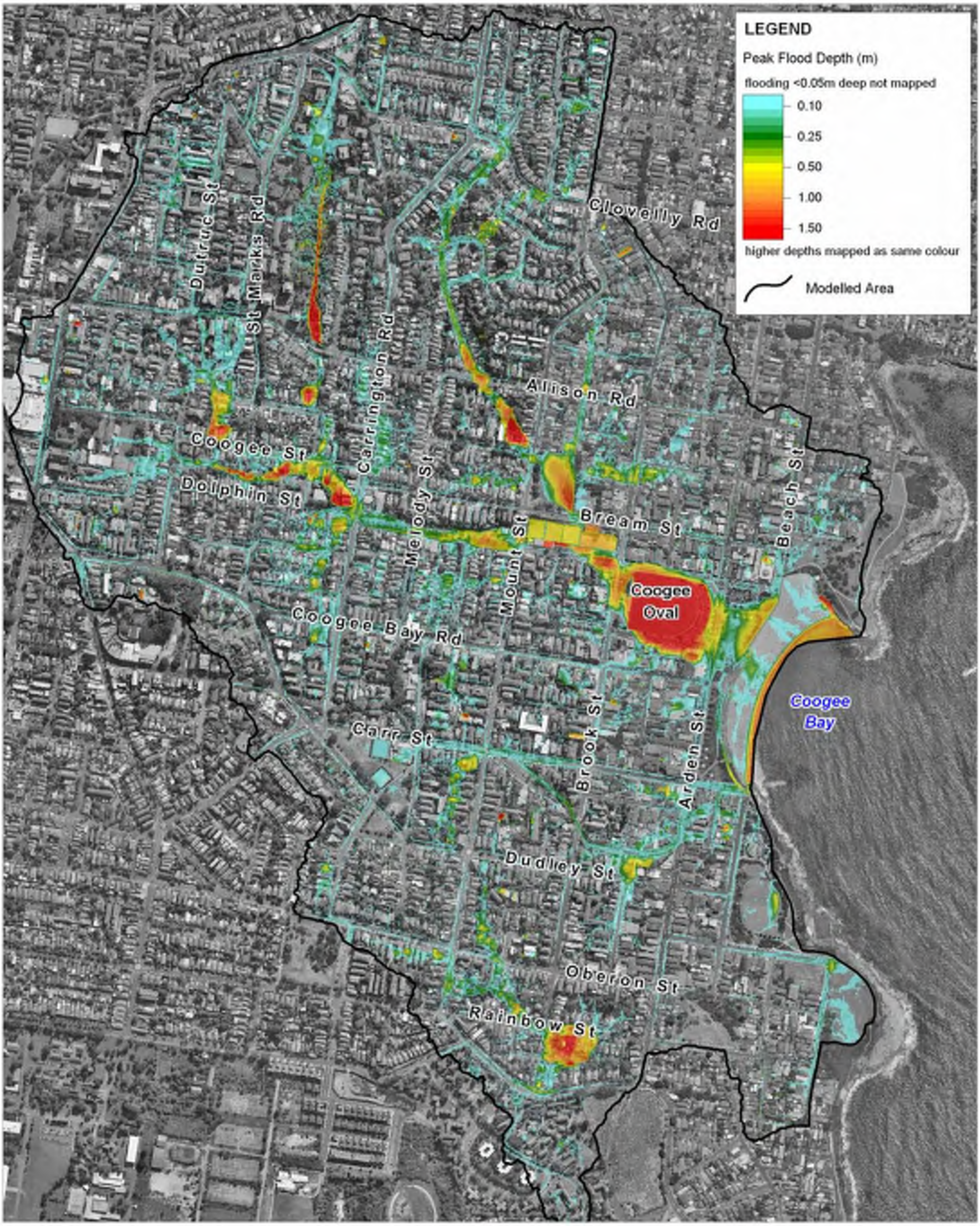

Title:

Coogee Bay Flood Study
Peak Flood Depths: 0.5% AEP Event

Figure: A-7

Rev: A

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0 250 500m

Approx. Scale

BMT WBM

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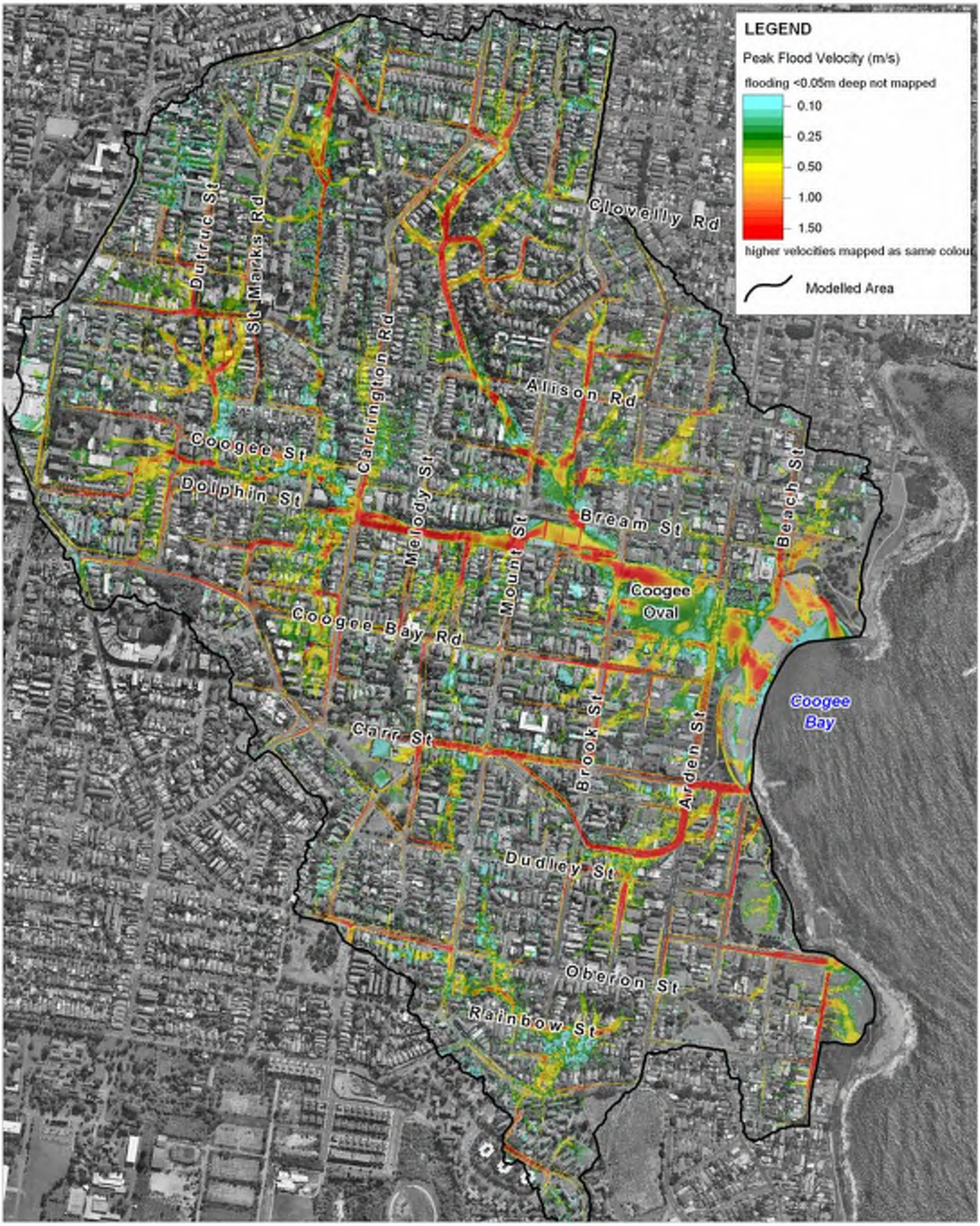

Title:

Coogee Bay Flood Study
Peak Flood Velocities: 0.5% AEP Event

Figure: A-8

Rev: A

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Approx. Scale

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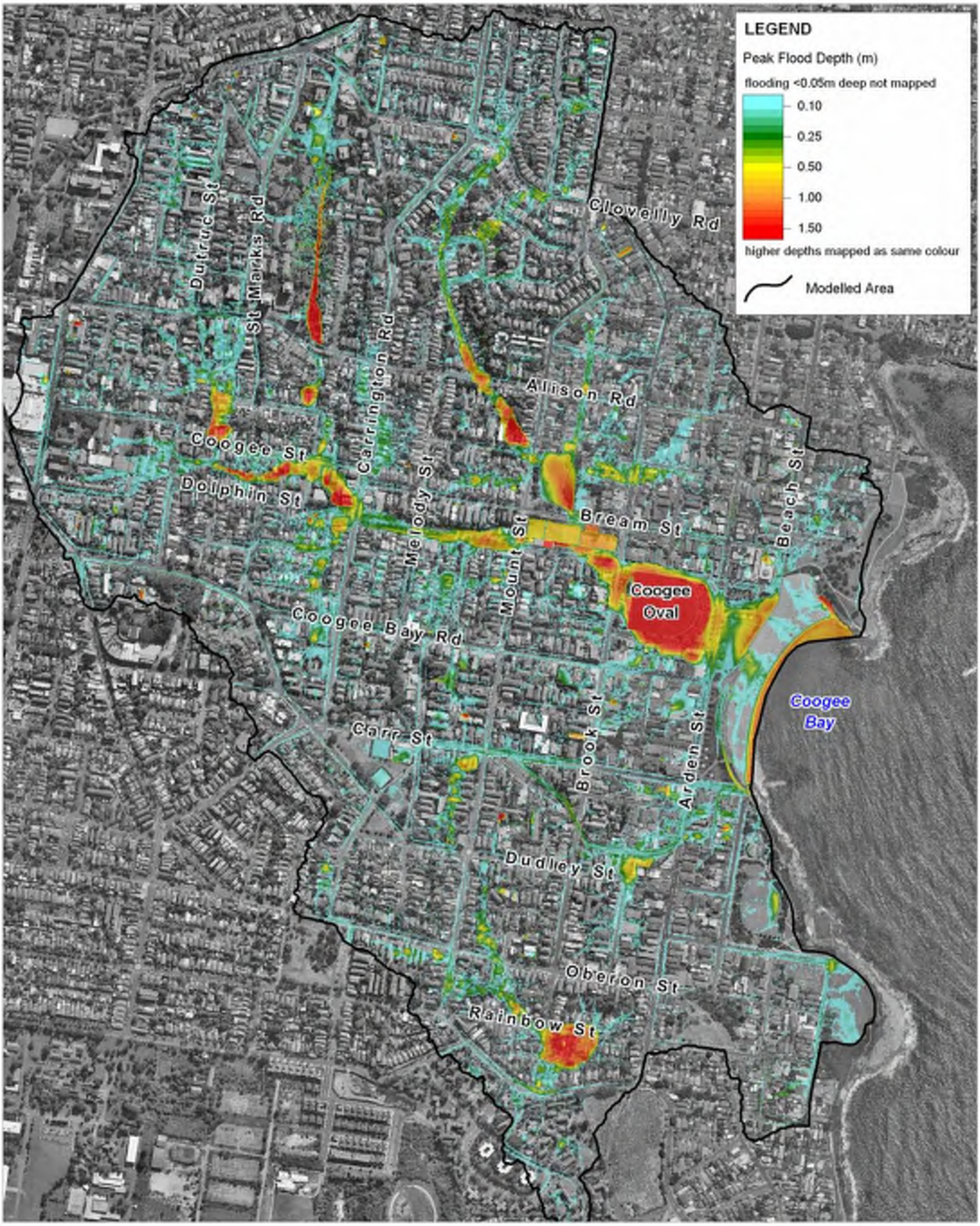

Title:

Coogee Bay Flood Study
Peak Flood Depths: 0.2% AEP Event

Figure: A-9

Rev: A

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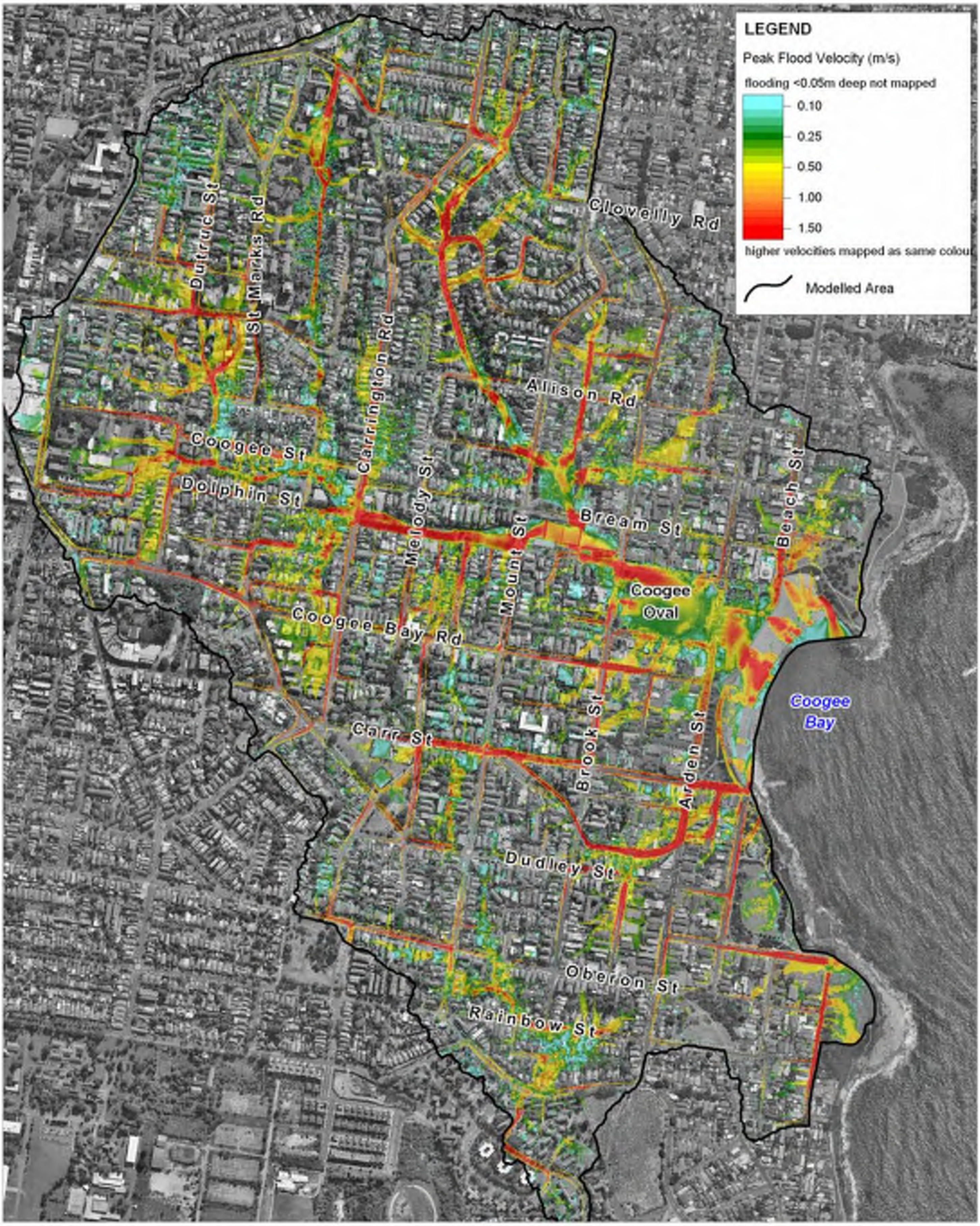

Title:

Coogee Bay Flood Study
Peak Flood Velocities: 0.2% AEP Event

Figure: A-10

Rev: A

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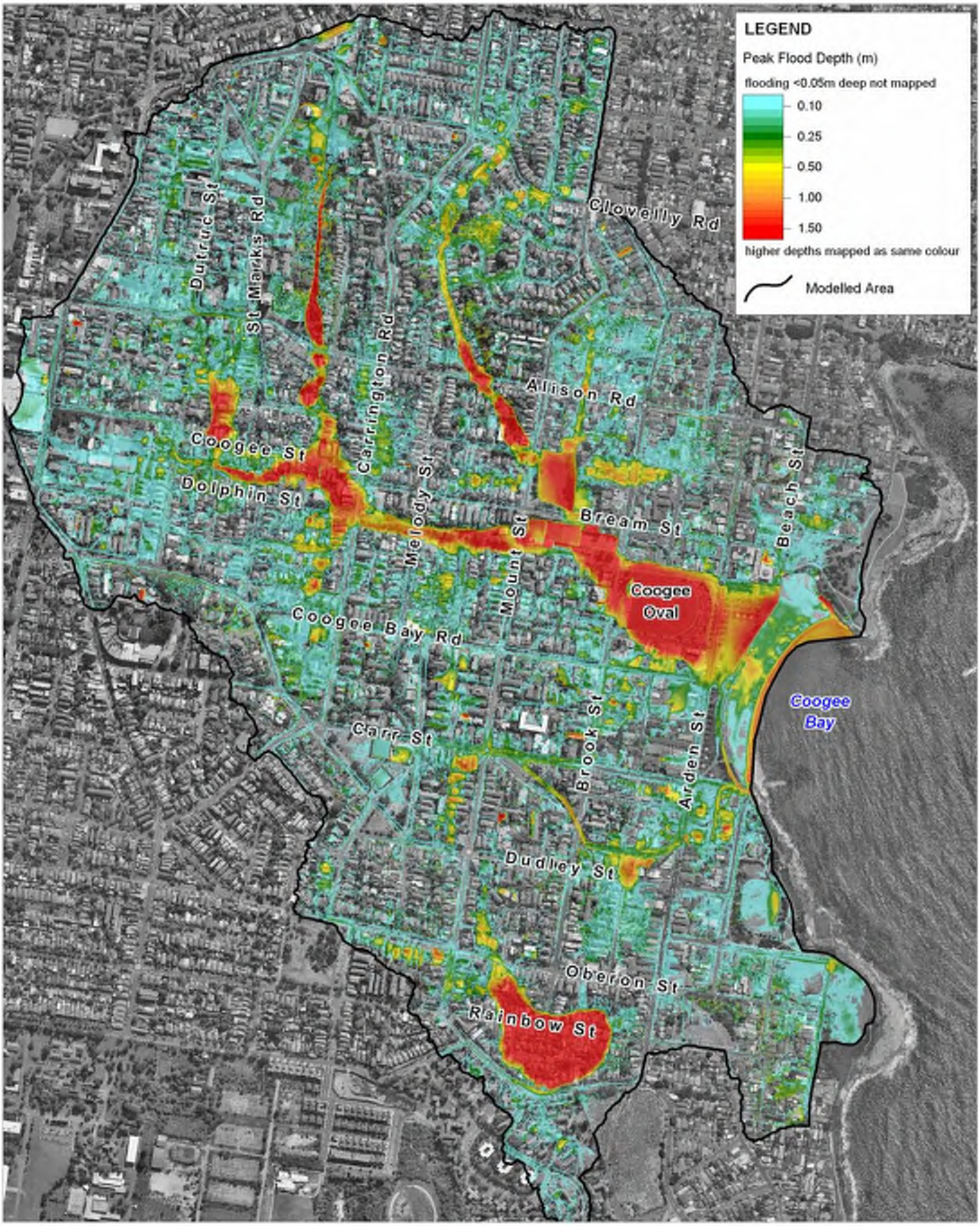

Title:

Coogee Bay Flood Study
Peak Flood Depths: PMF Event

Figure: **A-11**

Rev: **A**

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Approx. Scale

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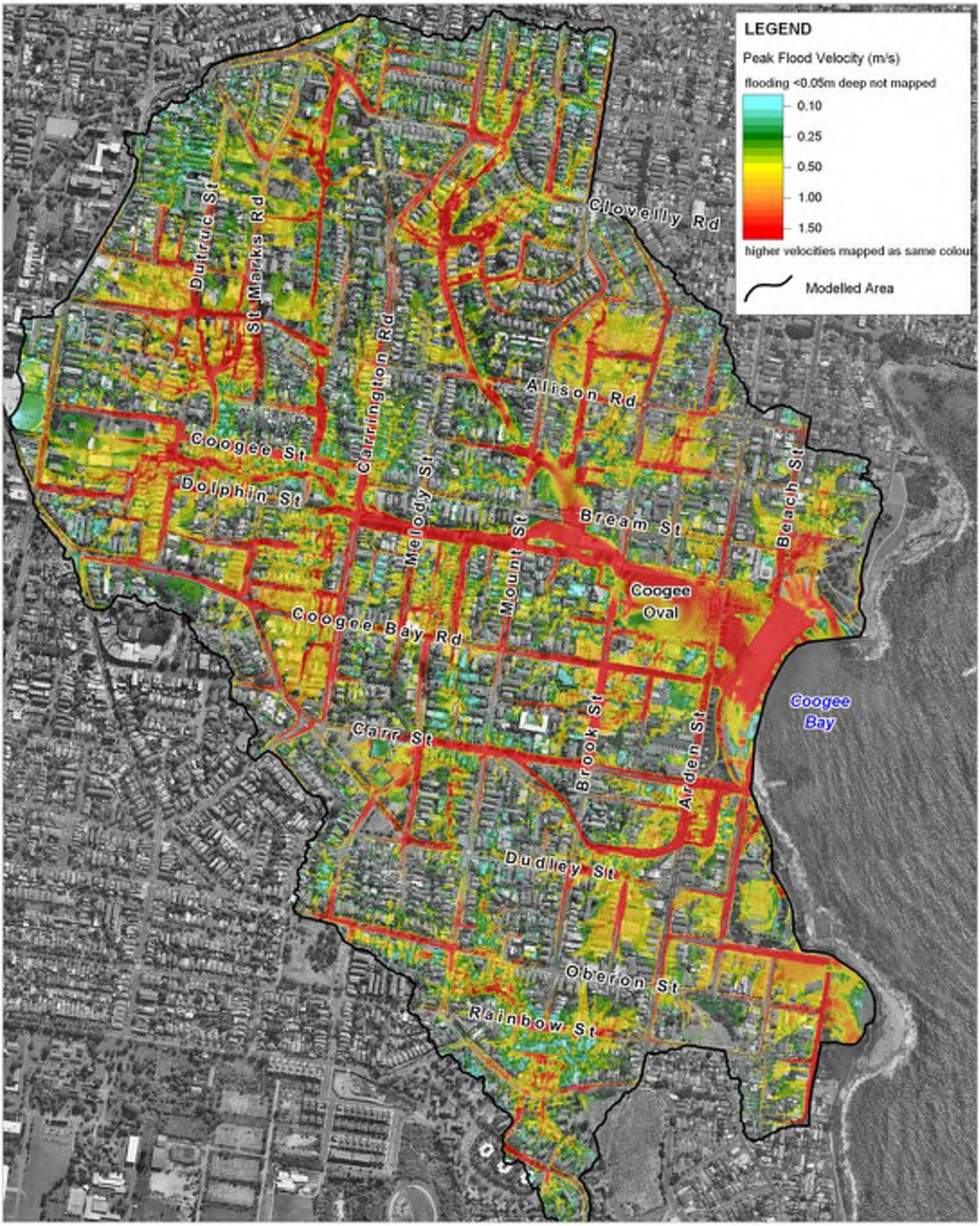

Title:

Coogee Bay Flood Study
Peak Flood Velocities: PMF Event

Figure: A-12

Rev: A

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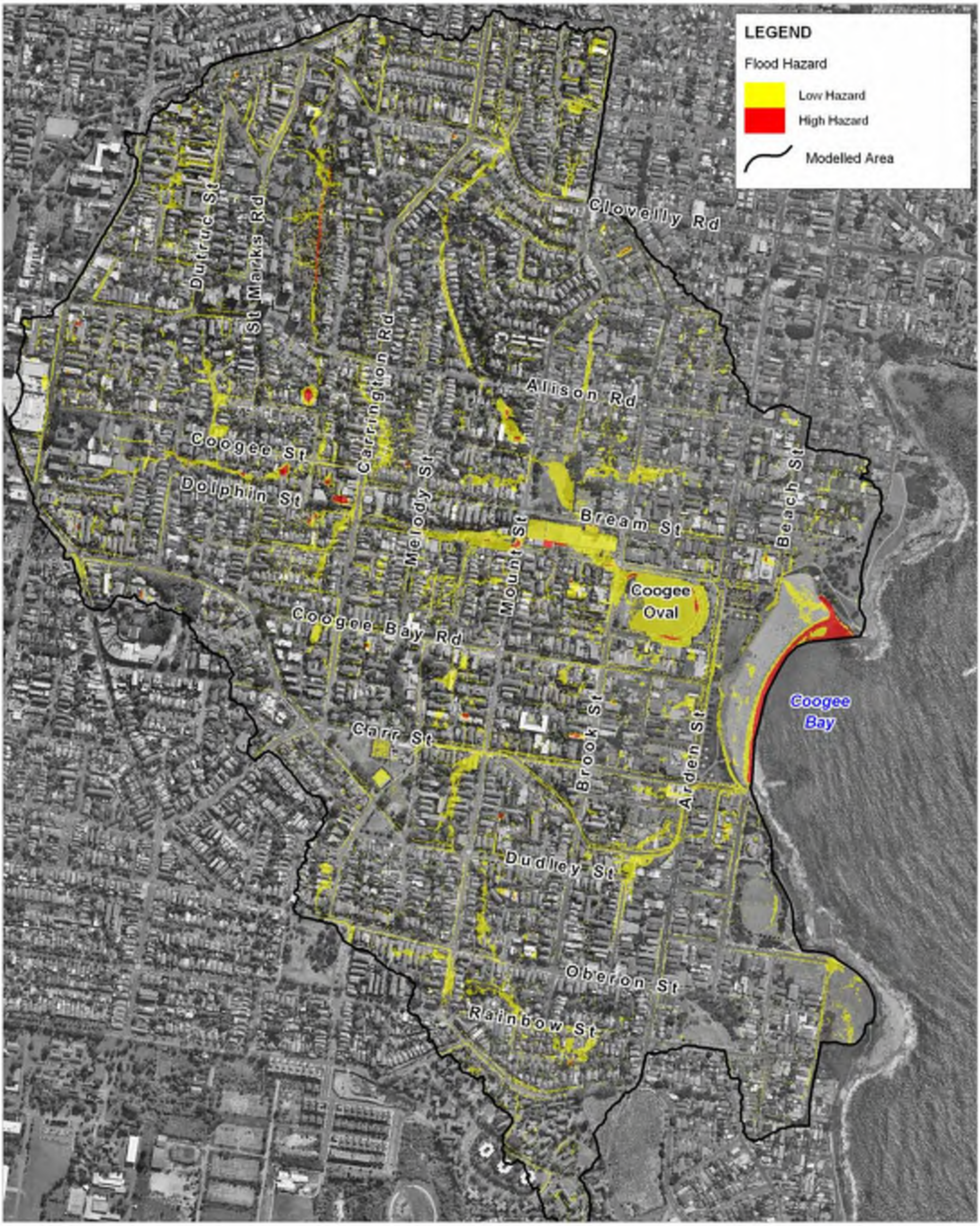

Title:

Coogee Bay Flood Study
Provisional Hazard: 20% AEP Event

Figure: A-13

Rev: A

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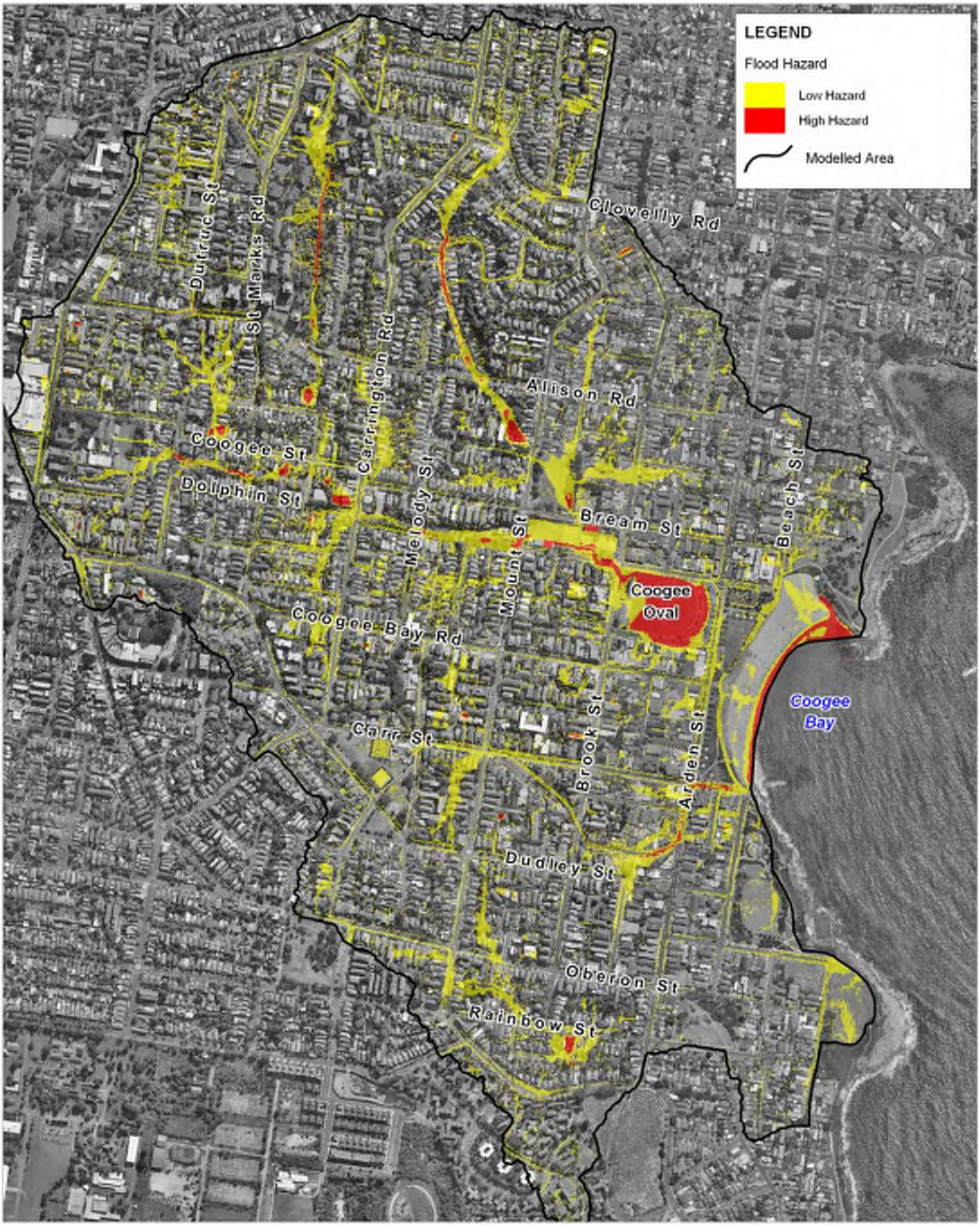

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Coogee Bay Flood Study
Provisional Hazard: 5% AEP Event

Figure: A-14

Rev: A

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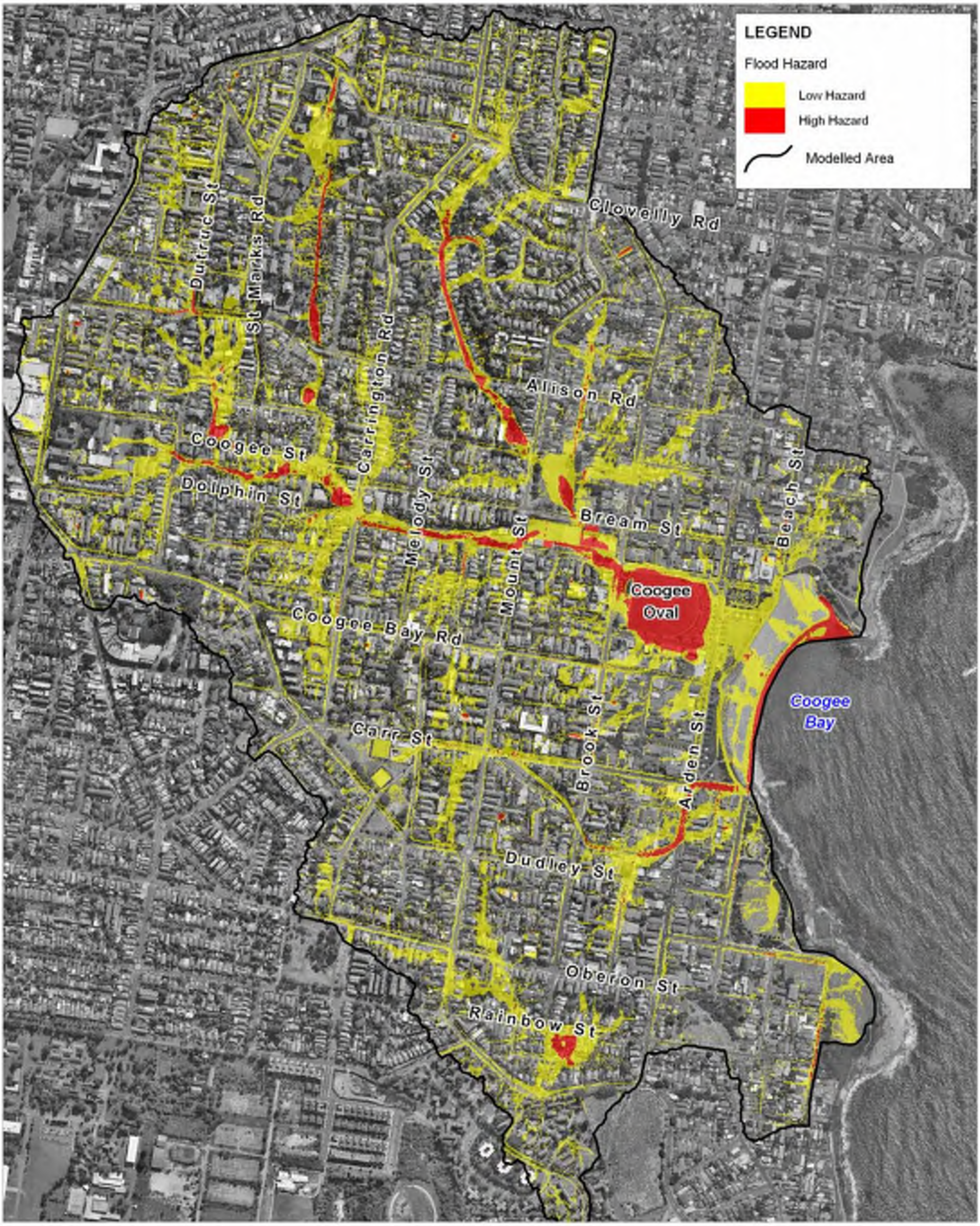

Title:

Coogee Bay Flood Study
Provisional Hazard: 1% AEP Event

Figure: **A-15**

Rev: **A**

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N

0 250 500m

Approx. Scale

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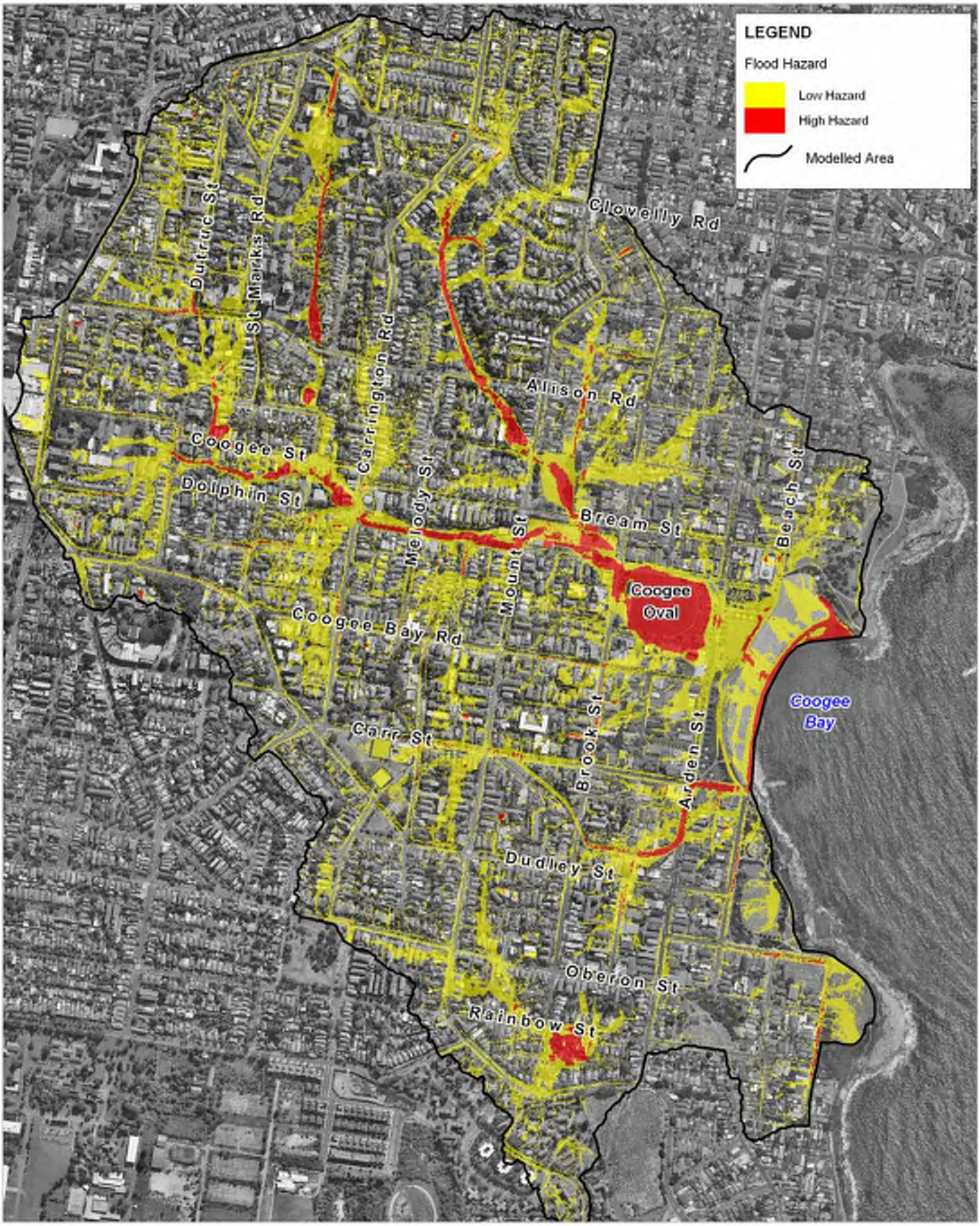

Title:

Coogee Bay Flood Study
Provisional Hazard: 0.5% AEP Event

Figure: A-16

Rev: A

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0 250 500m

Approx. Scale

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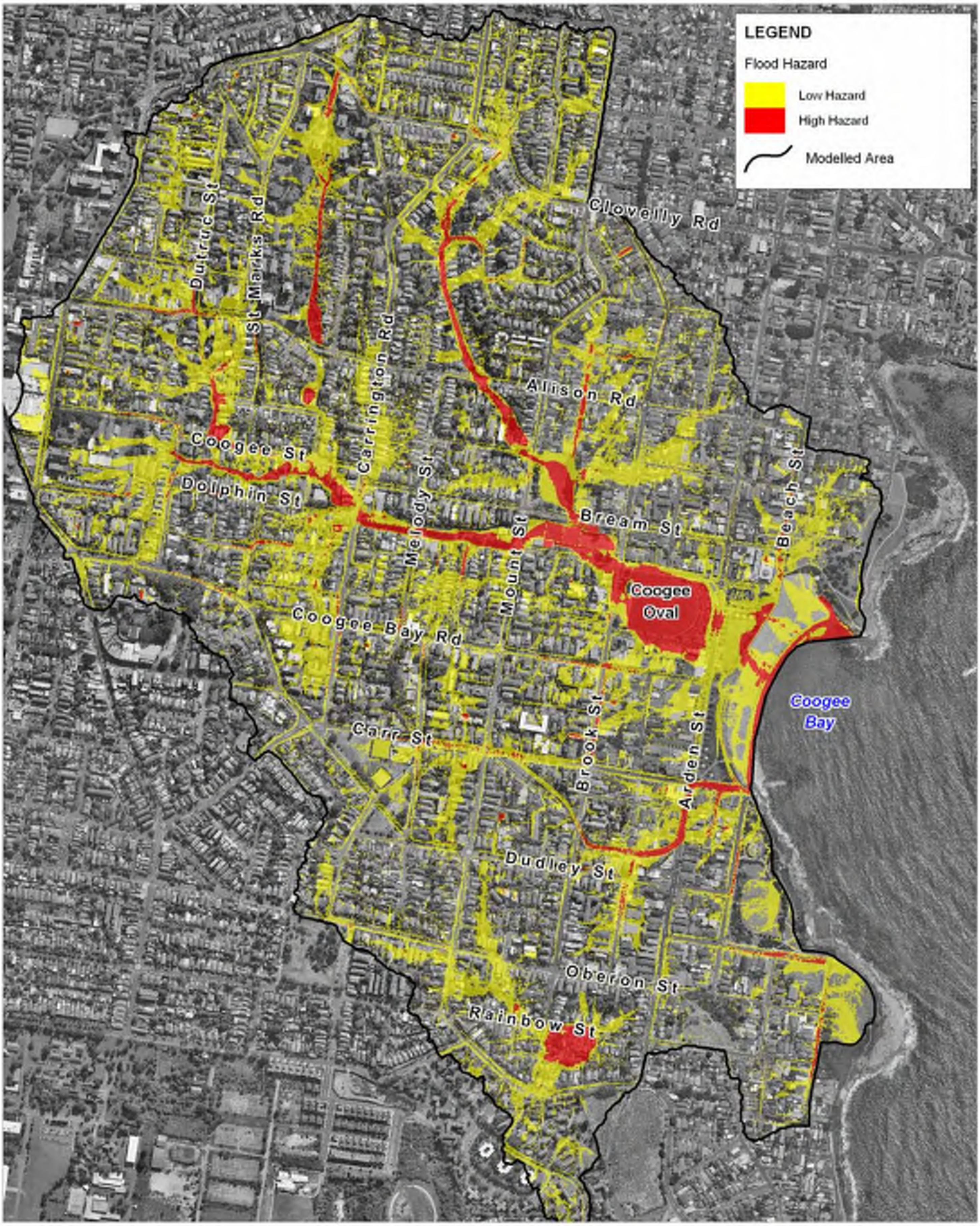

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Coogee Bay Flood Study
Provisional Hazard: 0.2% AEP Event

Figure: A-17

Rev: A

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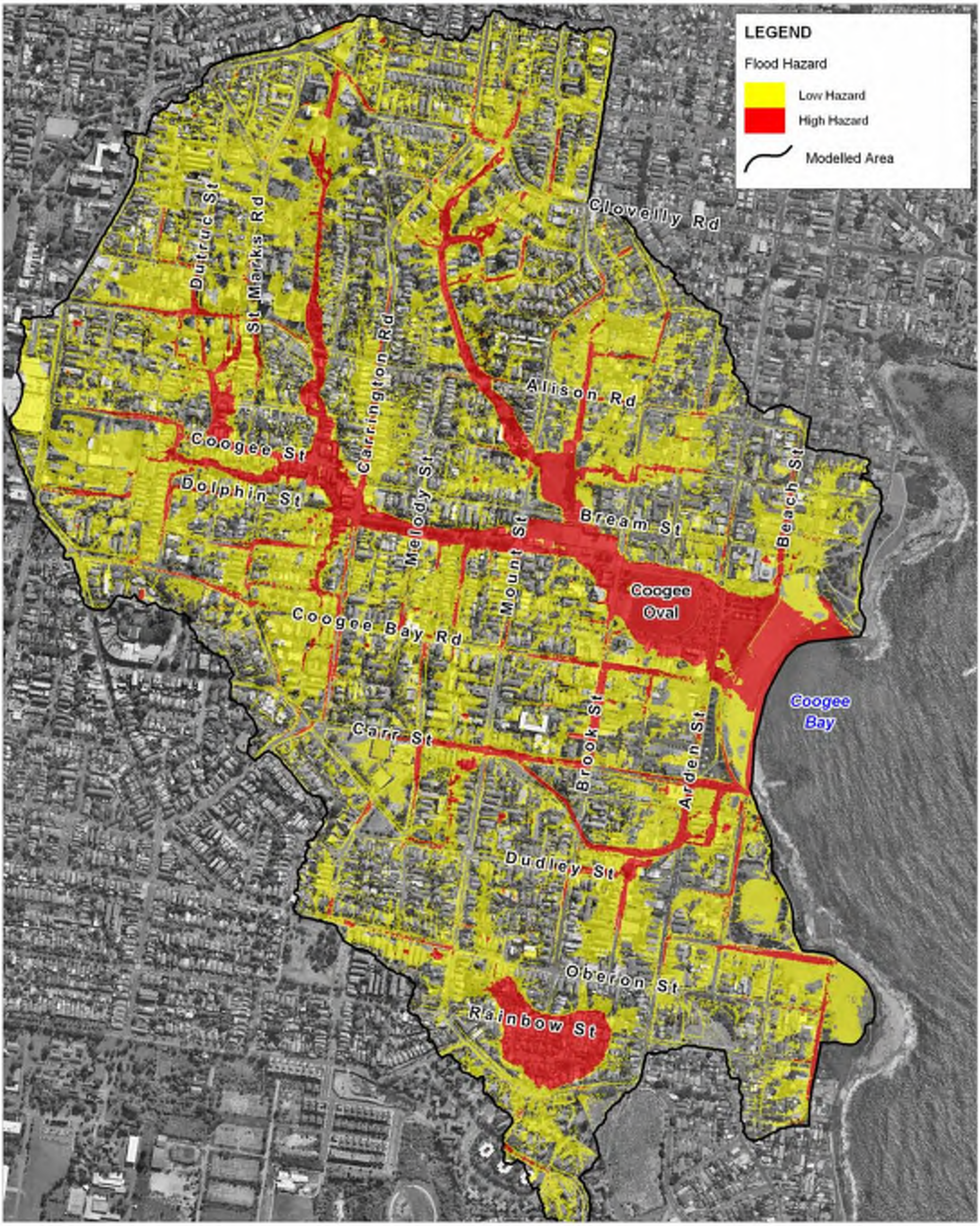

Title:

Coogee Bay Flood Study
Provisional Hazard: PMF Event

Figure: A-18

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N

0 250 500m

Approx. Scale

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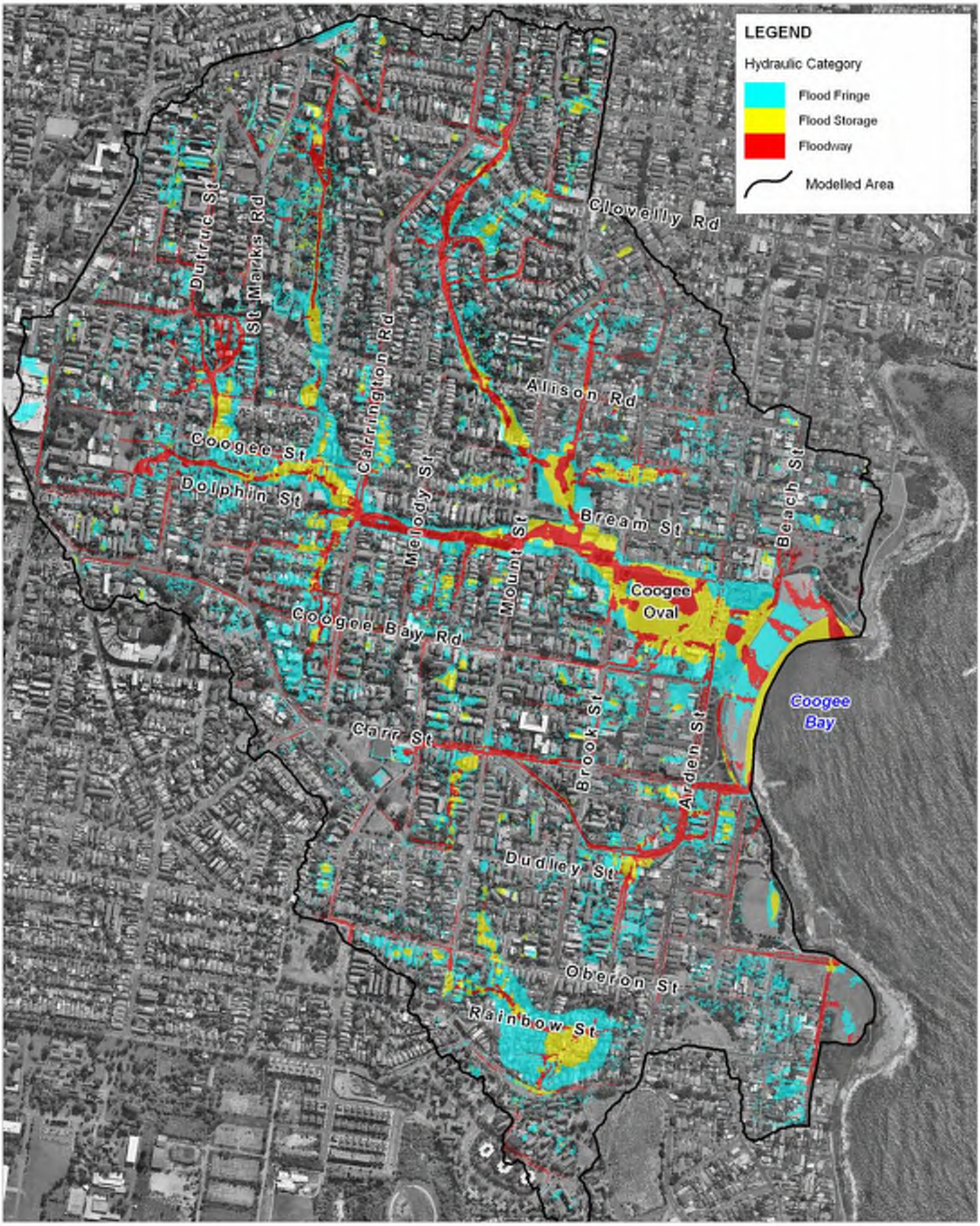

Title:

Coogee Bay Flood Study
Provisional Hydraulic Categories

Figure: **A-19**

Rev: **A**

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0 250 500m

Approx. Scale

BMT WBM

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Filepath : K:\N1924_Coogee_Bay_Flood_Study\MI\Workspaces\DRG_125_120217_Hydcats.WOR

APPENDIX B: COMMUNITY QUESTIONNAIRE

COOGEE BAY FLOOD STUDY

Randwick City Council is undertaking a detailed flood study of the Coogee Bay catchment to help identify flooding problem areas. We are seeking the community's help by collecting information on any flooding or drainage problems that you may have experienced in the past. Please take a minute or two to read through these questions and provide responses wherever you can. Please return this form to Randwick City Council in the enclosed envelope (no stamp required).

Coogee Oval 24 January 1999

Do you have any photographs or video of flooding that you are willing to share with Council?

Contact details:

Name:……………………………………………………………………

Address:…………………………………………………………………

Phone or email:………………………………………………………

Q1: Have you experienced flooding on your property? Please provide the date(s) if known.

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Q2: Are you able to indicate the depth that flood waters reached on your property or elsewhere such as roads?

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Q3: A map is provided on the back, please mark up your property or known flooding areas. Additional space is provided to add other comments.

Q4: Do you want to be kept informed of the study progress? (please tick)

☐ Yes ☐ No

Project Contacts

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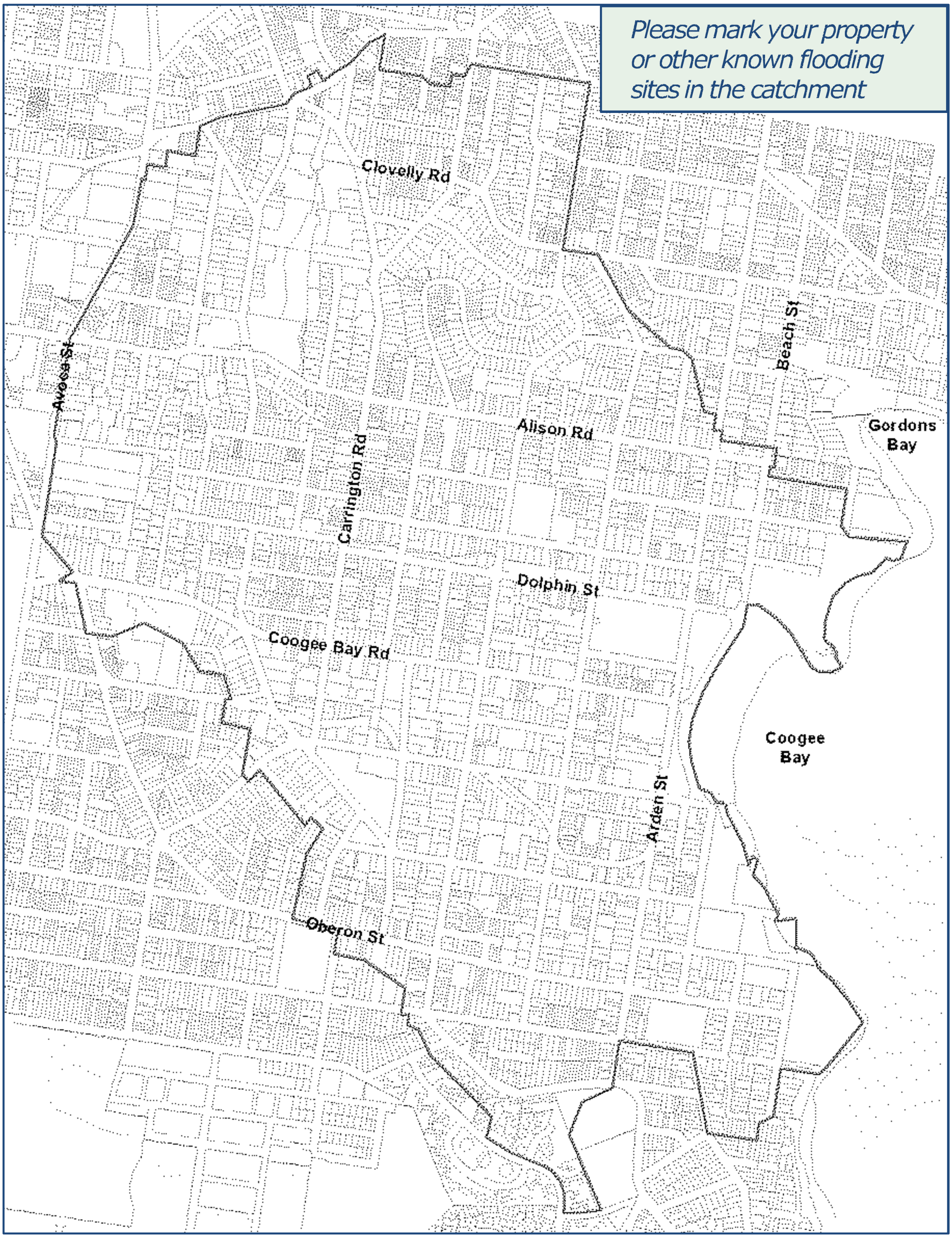
Darren.Lyons@bmtwbm.com.au

Terry Kefalianos (Randwick City Council)
Ph: 02 9399 0525
Terry.Kefalianos@randwick.nsw.gov.au

BMT WBM

Randwick City Council
a sense of community



Please provide any additional comments or information that you think will help the study

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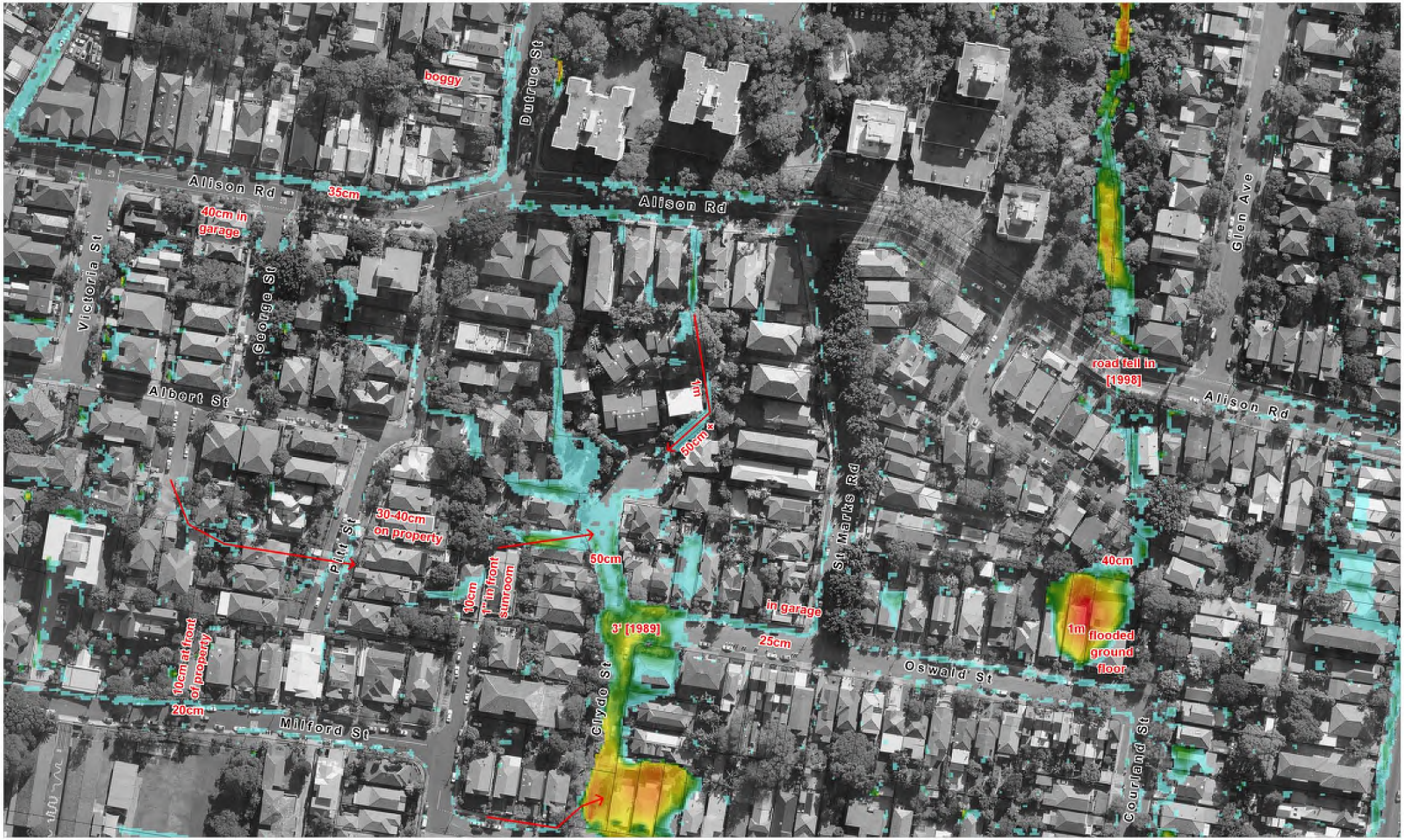
APPENDIX C: CALIBRATION DATA



LEGEND

Peak Flood Depth (m)

- 0.10 flooding <0.05m deep not mapped
- 0.25
- 0.50
- 1.00
- 1.50 higher depths mapped as same colour

Title:

Coogee Bay Flood Study
May 2009 Event Calibration

Figure: **C-1**

Rev: **A**

N

0 25 50m
Approx. Scale

BMT WBM
www.bmtwbm.com.au

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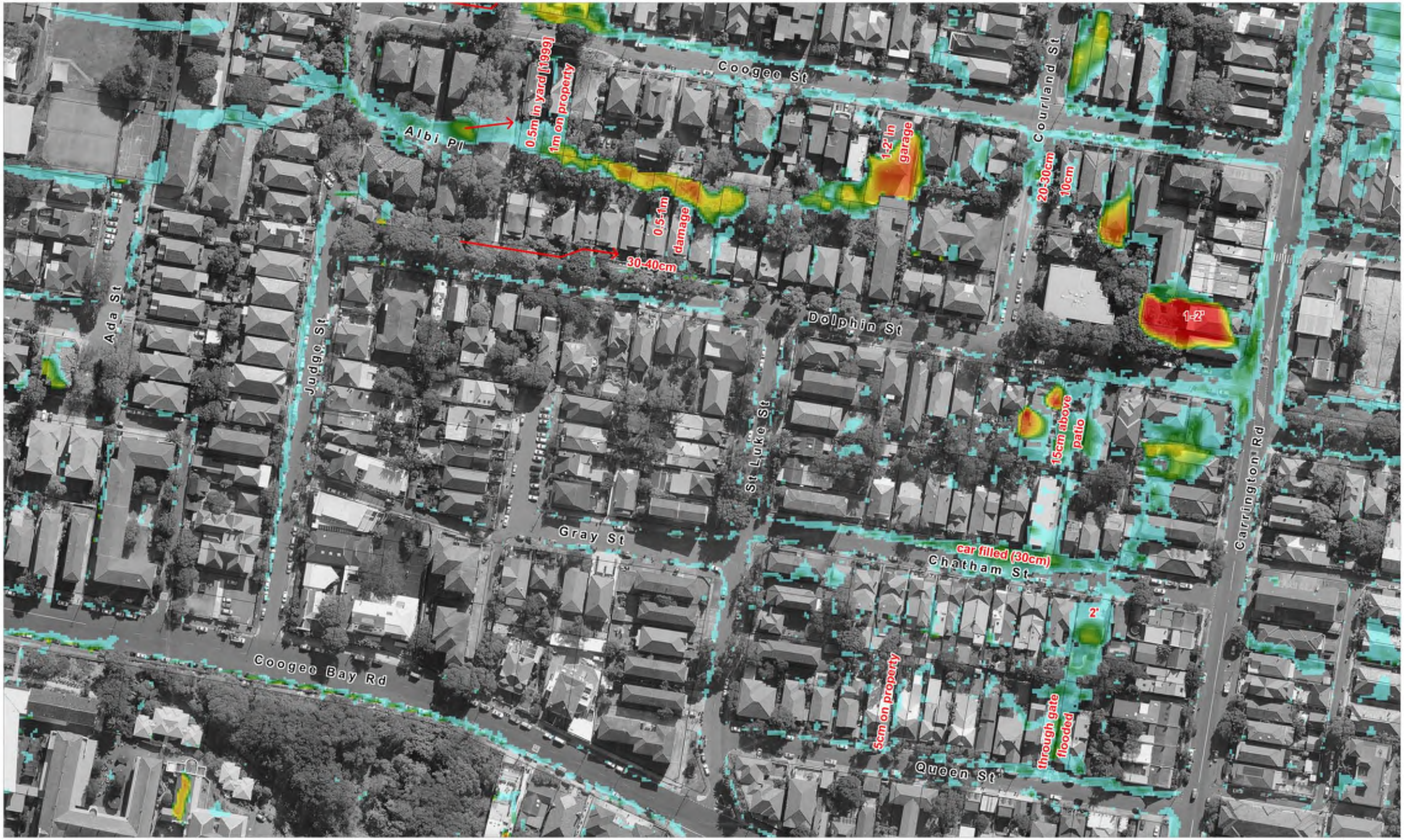

LEGEND

Peak Flood Depth (m)

- 0.10 flooding <0.05m deep not mapped
- 0.25
- 0.50
- 1.00
- 1.50 higher depths mapped as same colour

Title:

Coogee Bay Flood Study
May 2009 Event Calibration

Figure: C-2

Rev: A

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N

0 25 50m

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N1924_Coogee_Bay_Flood_Study\MI\Workspaces\DRG_004_110329_Calibration2.WOR

LEGEND

Peak Flood Depth (m)

- 0.10 flooding <0.05m deep not mapped
- 0.25
- 0.50
- 1.00
- 1.50 higher depths mapped as same colour

Title:

Coogee Bay Flood Study
May 2009 Event Calibration

N

0 25 50m
Approx. Scale

Figure: C-3

Rev: A

BMT WBM
www.bmtwbm.com.au

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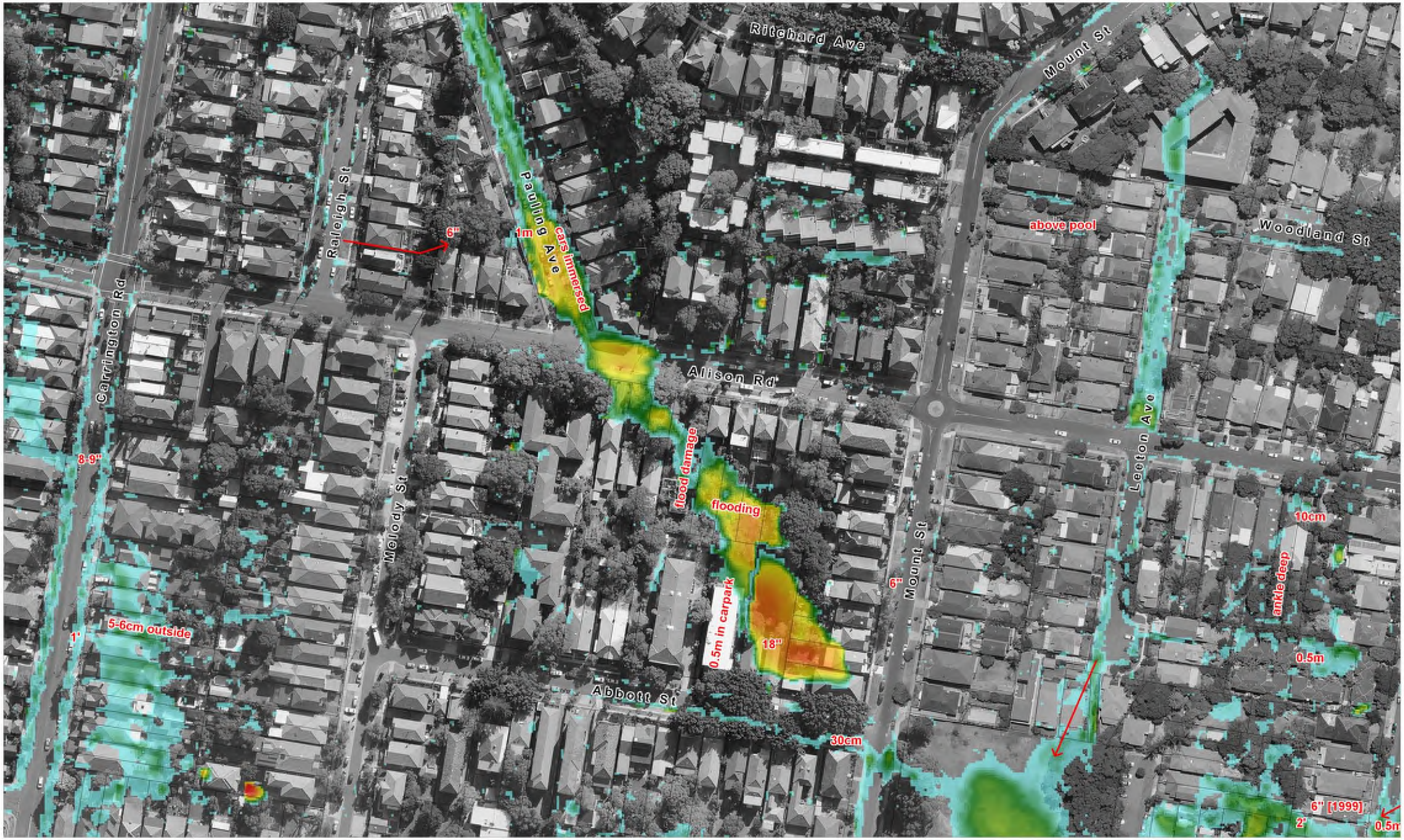


LEGEND

Peak Flood Depth (m)

- 0.10 flooding <0.05m deep not mapped
- 0.25
- 0.50
- 1.00
- 1.50 higher depths mapped as same colour

Title:

Coogee Bay Flood Study
May 2009 Event Calibration

Figure: **C-4**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

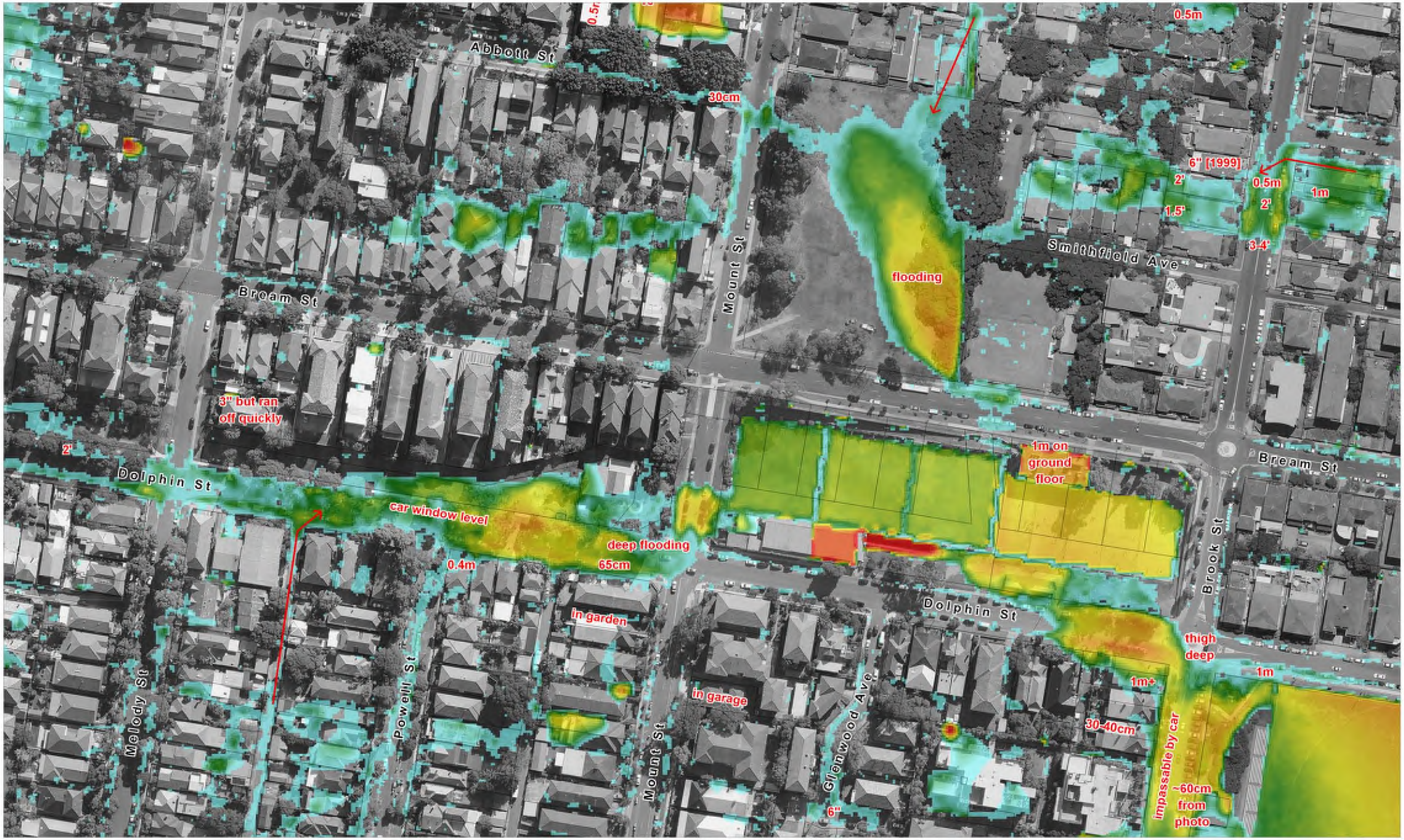
0 25 50m

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N1924_Coogee_Bay_Flood_Study\MI\Workspaces\DRG_006_110329_Calibration4.WOR



LEGEND

Peak Flood Depth (m)

Depth (m)	
0.10	flooding <0.05m deep not mapped
0.25	
0.50	
1.00	
1.50	higher depths mapped as same colour

Title:

Coogee Bay Flood Study
May 2009 Event Calibration

Figure: C-5

Rev: A

N

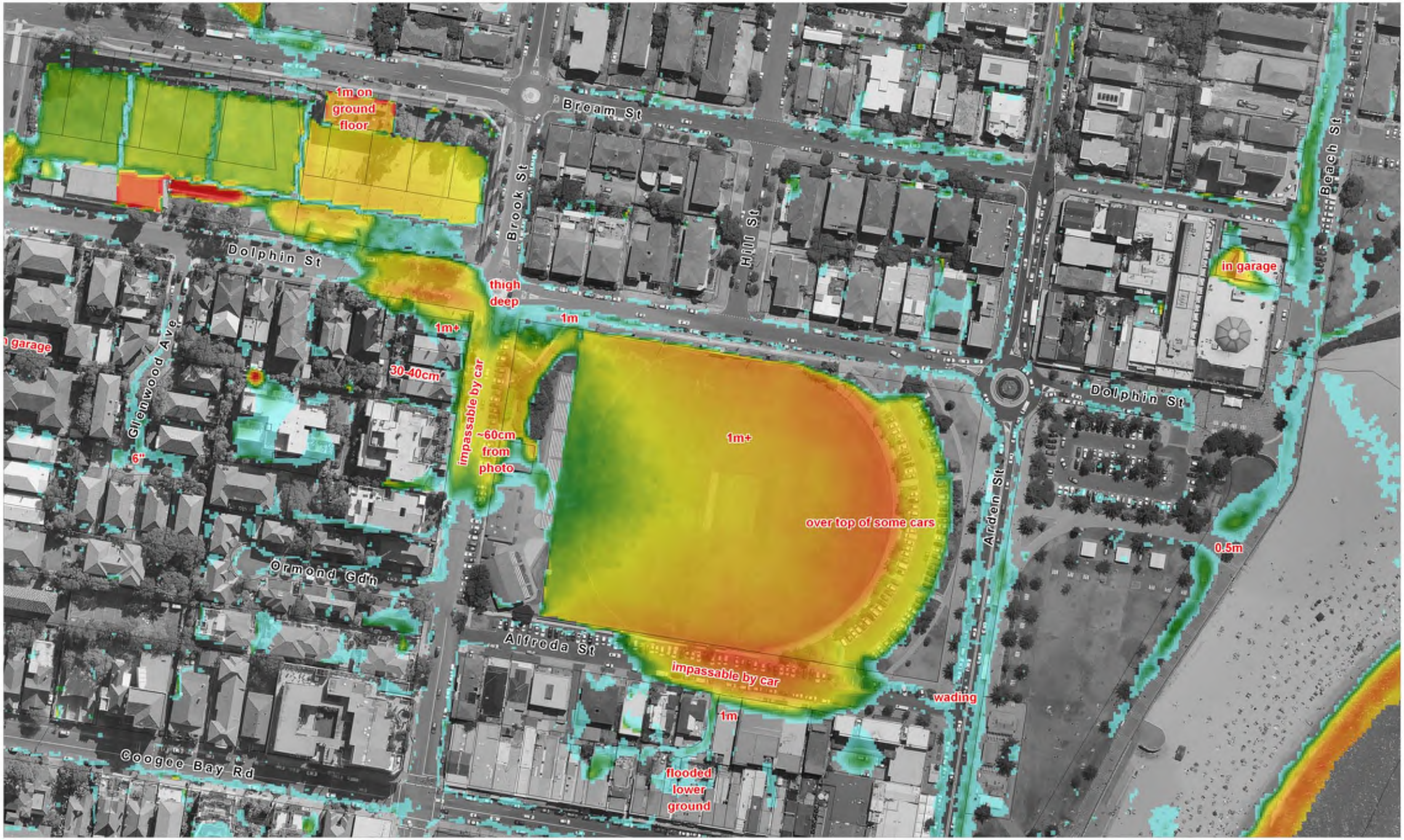
0 25 50m

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N1924_Coogee_Bay_Flood_Study\MI\Workspaces\DRG_007_110329_Calibration5.WOR



LEGEND

Peak Flood Depth (m)

- 0.10 flooding <0.05m deep not mapped
- 0.25
- 0.50
- 1.00
- 1.50 higher depths mapped as same colour

Title:

Coogee Bay Flood Study
May 2009 Event Calibration

Figure: C-6

Rev: A

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N

0 25 50m

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N1924_Coogee_Bay_Flood_Study\MI\Workspaces\DRG_008_110329_Calibration6.WOR

LEGEND

Peak Flood Depth (m)

- 0.10 flooding <0.05m deep not mapped
- 0.25
- 0.50
- 1.00
- 1.50 higher depths mapped as same colour

Title:

Coogee Bay Flood Study
May 2009 Event Calibration

Figure: C-7

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

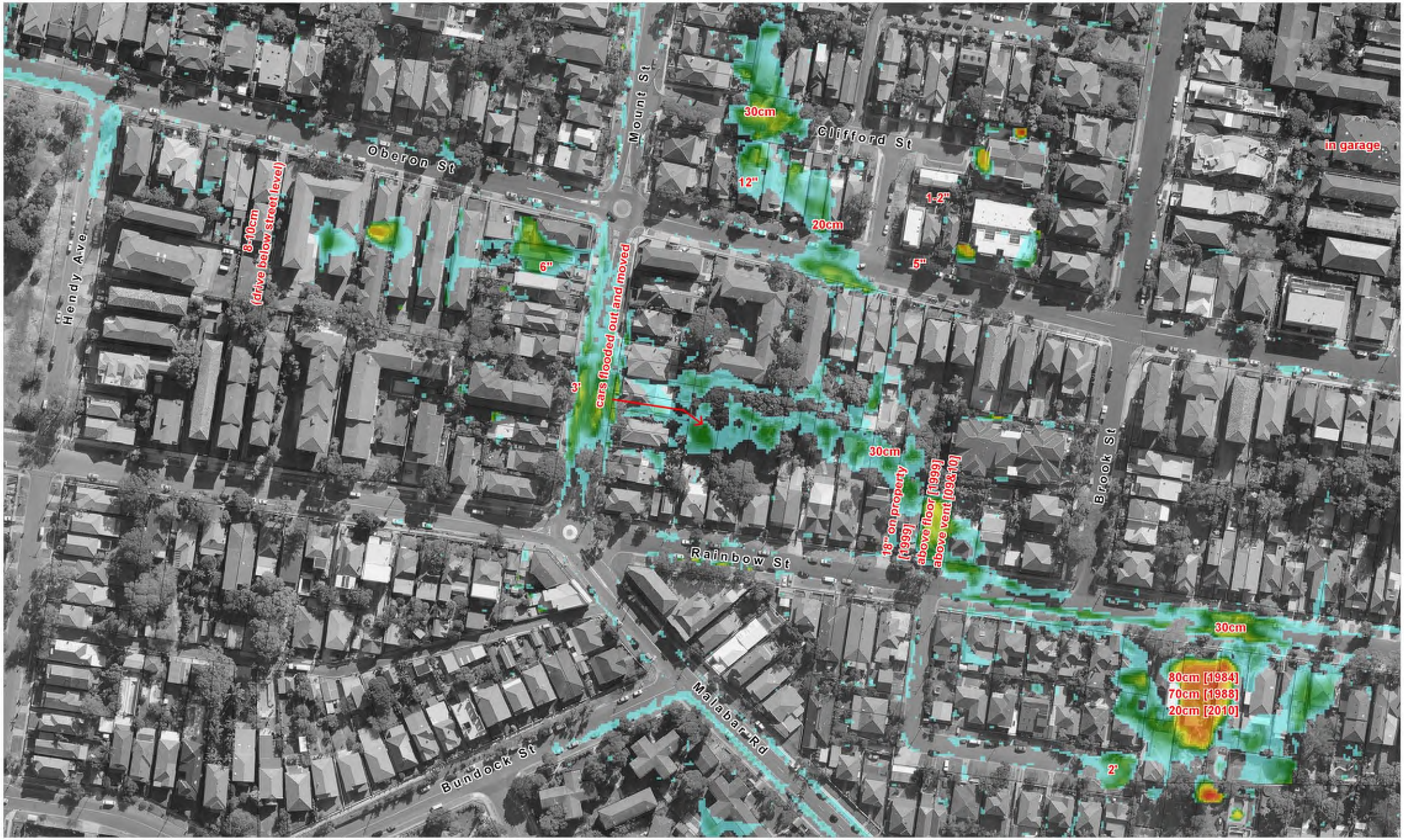
0 25 50m

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N1924_Coogee_Bay_Flood_Study\MI\Workspaces\DRG_009_110329_Calibration7.WOR



LEGEND

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Title:

Coogee Bay Flood Study
May 2009 Event Calibration

Figure: C-8

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 25 50m

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N1924_Coogee_Bay_Flood_Study\MI\Workspaces\DRG_010_110329_Calibration8.WOR

APPENDIX D: HISTORIC NEWSPAPER ARTICLES

GREAT STORM.

HAVOC IN HARBOUR

FIFTEEN CAPSIZES.

FERRY COLLISION NARROWLY AVERTED.

TERRIFIED PASSENGERS.

DANGER BY LIGHTNING.

A most remarkable storm, causing considerable damage and several accidents, passed over Sydney yesterday afternoon.

The conditions which followed at night will long be remembered from the fact that the point of saturation (100 per cent. humidity) was actually reached. During the day the atmosphere was enervating to a degree. What little breeze there was came from the east and east-north-east. There were one or two light thunderstorms in the early morning, but they were nothing to what followed. The day humidity reached 78 per cent., only 7 degrees below the maximum temperature. Something had to happen, and the crash came with startling suddenness at 5 o'clock.

The storm started in the north-west, and worked due west to south-west. As a matter of fact, it shifted around to all points of the compass.

The change, which brought gusts, accompanied by blinding rain from the southward, was most violent. Claps of thunder were incessant, and the lightning, sheet and forked, was very vivid. The atmospheric conditions thickened until the harbour was enveloped in what had the appearance of a thick fog. Thunder-squalls were beating on the water. The rain fell in torrents. Hunter's Hill had 204 points up to 7 p.m. At the Lavender Bay steps the water poured down in hissing streams, and carried with it all sorts of debris, including road metal. The waiting-room was several inches thick with stones and mud. Tram-wheels were half covered in the low-lying parts of the city. King-street was running a "banker." Circular Quay was a quagmire. For a time it looked as if it would be impossible to continue the running, but when the heaviest of the rain was over (at 6.30) the drainage was found to be equal to requirements.

The full fury of the storm was experienced by the small pleasure craft on the harbour, and the sailing boats made haste to run for home out of the fierce gusts and driving rain. It was an emergency in which the fast-moving motor propelled launches showed to advantage over their more stately but less mobile white-winged companion craft, being able to make direct for shelter without any beating about, while the passengers had the further advantage of being protected by awnings and windows from the rain and wind.

The scene in Port Jackson was an unusual

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one. The lightning played about continuously in the sky, and the thunder boomed and reverberated like artillery close at hand.

There were quite a number of capsizes, and narrow escapes on the part of the occupants who were thrown into the water. One overturned sailing boat was towed into Mosman Bay by a motor launch, the sail being flat on the surface of the water, while one of the crew was riding on the upturned side to steady the craft. A number of rowing boats, caught in mid-stream, sheltered under the lee of ocean liners till the squall had spent itself, the crews escaping with a drenching. Other rowing boats dropped their killicks where the storm struck them, and weathered the pelting rain and the furious wind through riding at anchor.

Article text, suitable for copy and paste

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GREAT DELUGE.

AT COOGEE.

EXTENSIVE DAMAGE.

Traffic Held Up.

A severe rainstorm occurred at Coogee last night. Hail and rain began to fall at 6.10 p.m., and within 10 minutes five trams had been derailed between Allison-road and the terminus.

Traffic was suspended for several hours, and at a late hour only a single-line service had been installed.

The damage to property cannot be estimated at present; but with the innumerable windows broken, fences and gates carried away, furniture injured by water, and new buildings undermined and damaged, the amount is estimated to run into thousands of pounds.

In Dunning-street a channel five feet deep was quickly cut by the rushing flood, and an electric light pole fell across the street. A new house, almost completed, in Mount-street, had several feet of earth carried away, and the foundations were precariously exposed. At 6.25, during the height of the storm, articles of furniture, gates, portions of fences, and all manner of debris, were washed down Arden-road towards the tram-terminus. At the intersection of Arden and Belmore roads hundreds of tons of sand blocked up the tram-way for a distance of a hundred yards. At the terminus itself a tram was isolated, and it was not expected that it would be released until this morning. Gangs of men had begun digging at 10 p.m. last night.

The dining-room of Coogee Bay Hotel had a foot of water in it a few minutes after the deluge commenced, and in the cellar some damage was done by the water, which poured in to a depth of 2ft. The Boomerang Picture Theatre, in Carr-street, was also flooded out, and at the foot of this street, amongst the debris, was a pillar-box, dislodged from somewhere on the heights. At the north end of the beach the foundations of the old Coogee sea wall, which was built 30 years ago, are now exposed for the first time in 17 years. In several streets the kerbing and guttering were washed away, and four large pits, 3ft deep, and several yards across, were scooped out on the slope of Arden-road, leading to the beach.

The Ambulance Station had 3ft of water in it within a very few minutes, and the officer in charge said that in the casualty room the medical appurtenances were in water.

The most extraordinary features of the storm were the suddenness and short duration. By 6.45 the storm had spent itself, and at 8 o'clock the streets were almost dry.

At Maroubra, the sand silted across the

o'clock the streets were almost dry.

At Maroubra, the sand silted across the tramway, and traffic was held up.

"One can look upon the occurrence of such a severe storm," said the State Meteorologist (Mr. D. J. Mares) last night, "as the local intensification of the thundery conditions which set in towards sundown. On the morning weather chart the various wind controls, or pressure systems, were so distributed as to cause a convergence of winds of different directions, and of different character, in respect of temperature and humidity. The storm doubtless occurred at the point of convergence. The huge cumulo-nimbus clouds—the progenitors of thunderstorms—were observed towards sundown in a southerly direction. The general appearance of the clouds, with their rugged formation and prodigious size, marked the storm as one of exceptional violence. The thunderstorm was the product of the very extensive tropical depression which has been causing rain in Queensland and in the northern parts of this State."

Article text, suitable for copy and paste

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The Sydney Morning Herald (NSW : 1842 - 1954), Tuesday 24 January 1933, page 11

Article text, suitable for copy and paste

STORM DISASTERS.

Camping Family Overwhelmed

EIGHT PERSONS PERISH ON

SOUTH COAST.

Six of the Bodies Swept Out to Sea.

PARENTS' HEROIC EFFORTS END IN

TRAGEDY.

Family Buried by Landslide; One Boy

Killed.

One of the worst flood disasters in the history of Illawarra occurred early yesterday morning, when a man, his wife, and children, and two young visitors to their camp were swept to death.

One daughter, a girl of 16, was saved by the heroic efforts of three

rescuers, who brought her to safety from a perilous position.

The total fatalities on the South Coast numbered eight, and it is almost certain that a ninth victim of the flood, a car driver who is missing, has been drowned in a creek near Scarborough. His wrecked car has

been found.

Graphic details have been obtained of the overwhelming of the family by flood waters at Stanwell Park camping area, and of the desperate but unsuccessful efforts of the father and mother to bring their children to safety.

Six of the bodies of the members of this party were carried out into the boiling surf, and four of them have so far not been recovered.

A boy of 15 was killed when a family of ten was caught in a land- slide which buried their rude hut at Bulgoa Beach, near Helensburgh.

A young man was killed by lightning at Young.

The Sydney Morning Herald (NSW : 1842 - 1954), Wednesday 25 January 1933, page 11

STORM'S TOLL.

ANOTHER DEATH.

Repairing the Damage.

STATE AID PROBABLE.

The discovery of a body in a creek near Bathurst yesterday revealed another victim of Monday's storms. Latest reports also indicated that losses of stock were heavy.

Following further heavy rains, there is danger of extensive floods on south coastal river systems, south from the Hawkesbury. A further warning has been issued by the Weather Bureau.

Isolated violent storms occurred at many places in the State yesterday, with hail, wind, and lightning. Considerable damage was done. The forecast for to-day indicates further heavy falls of rain.

At to-day's meeting of the State Cabinet, consideration will be given to the provision of relief in municipalities following on the extensive floods during the last few days. Ministers have been asked by the Premier (Mr. Stevens) to obtain reports concerning the extent of the damage. Unemployment relief funds will be made available to enable work to be commenced at once.

The damage caused to the Lady Carrington Drive through National Park was more serious than was at first thought. The National Park Trust has applied to the Unemployment Relief Council for a grant of £10,000 to recondition the drive, which is closed to traffic. Long strips of the road have been washed into the Port Hacking River, and other parts are strewn with trees and debris. It is estimated that it will take several weeks to effect repairs.

The damage done in the municipality of Randwick is estimated at £3000. Coogee oval is covered with silt to a depth of six inches, and its removal will cost £300. The Mayor (Alderman Paine) stated at last night's meeting of the council that much work had been done in urgent cases. A lot of damage had been done to private property, and a number of legal claims had been made.

The body of James Hemmings, aged 64 years, a well-known resident, was found suspended on a wire fence in the bed of the Vale Creek, two miles from Bathurst, yesterday afternoon. Apparently Hemmings was washed out of his camp by flood waters and drowned.

PRAISE FOR BRAVE RESCUER.

The formerly picturesque camping site at Stanwell Park, the scene of the flood disaster early on Monday morning, seemed desolate and forbidding yesterday. Flood waters had changed a fine stretch of sand, well known to holiday makers, into a tangle of boulders, huge logs, mud, and debris. A large sedan motor car was wedged between rocks and logs, evidence of the terrific force of the water that rushed down the gorge upon the campers. It had been carried 150 yards.

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Mr. O. Riches, whose family was camped in the valley on Sunday night, and who assisted in the rescue of Laurel Davis, said that the action of Gordon Tonkin, in swimming the flooded stream with a rope to her assistance was the bravest thing he ever saw, and it deserved some form of recognition.

"I offered to go," said Mr. Riches, "but Tonkin said, 'I am taller than you,' and took the rope with scarcely another word. The stream was bringing down trees faster than a man could run. It was a miracle that Miss Davis was alive at all. One end of the rope, which was tied to one of her wrists, was caught in the roots of a floating tree, and she would certainly have been swept out to sea if that tree had not been caught in the branches of a standing tree. Our greatest fear was that one of the logs coming down the stream would catch our rope, as Tonkin took it across. I had to go out into the stream up to my waist, holding the rope above my head, so that the logs and other floating debris would pass underneath. Tonkin not only had to swim against a terrific rush of water, but had to dodge trees and rocks. He risked death a dozen times."

Mr. Riches said the first real intimation he received of the seriousness of the flood was a dull booming sound, due to the earth round a culvert at the head of the valley giving way. In a few seconds a roaring torrent was racing down the valley. He was making his way through water almost up to his waist, carrying one child and leading another, and accompanied by his wife, who was carrying their baby, when he saw Mr. Davis and his two boys in the stream. He caught a glimpse of upturned faces, by the light of a hurricane lantern, and they were swept past him. He heard terrible screams, which ceased abruptly in a few minutes.

SURVIVOR'S STORY.

Mrs. Michel, of Granville, who was rescued from the flood which overwhelmed the Davis family, said that she heard a roar, and was horrified to see a great wall of water rushing down on the camp. She threw off her coat, and the next second was swept off her feet. The water carried her away swiftly. She managed to grab a signpost, but was swept away. Her cries were heard by three campers, who groped their way to where they expected Mrs. Michel to be carried, and when she was within their reach they seized her.

CAR DRIVER STILL MISSING.

A search for the body of Geoffrey Walton, of Thirroul, who is believed to have been drowned when attempting to cross a creek near Scarborough, was made yesterday without success. It is assumed that the flood waters carried the body out to sea. A careful watch is being kept on the beaches. None of the bodies of the four victims swept out to sea in the major tragedy at Stanwell Park has been recovered.

LOSSES OF STOCK.

Reports from many country centres indicate heavy losses of stock.

Near Wellington, after a heavy downpour, flood waters rushing down Pile Creek swept away 400 merino sheep, the property of Mr. H. A. Taylor. The sheep were being removed to another paddock at the time.

Settlers at Perthville, near Bathurst, report the loss of many sheep, cattle, and pigs, which were washed down Vale Creek. Poultry losses were also severe.

At Barellan several valuable horses owned by Messrs. P. Quade and D. Bahnsen were killed by lightning. A camel depasturing on Quade's property, was also killed.

FLOOD PRECAUTIONS.

Although police at many south coastal

FLOOD PRECAUTIONS.

Although police at many south coastal centres made reassuring reports last night, extensive floods were expected on the Moruya River at midnight, the Hawkesbury was running a banker at Windsor, and the Nepean was in flood at Penrith. Moruya police reported at 8.30 p.m. that a heavy storm was raging. Lakes had formed, and the river was running strongly. Windsor police said that the river was very close to the tops of the banks. Lowlying land on the Sydney side of the town was under water. At Camden and Penrith the Nepean was slowly receding there. South Creek bridge, St. Marys, was under water, which blocked traffic. Many cars were towed through by a horse.

HAIL AND WIND DAMAGE.

At Narrabri yesterday a terrifying storm was experienced. Hundreds of exposed windows on the northern side of the town were smashed, and few residences escaped the loss of glass. Water tanks were perforated by the hail. The hailstones were the largest ever seen in Narrabri. A strong gale accompanied the hail, causing considerable damage. A bakehouse was unroofed. The roof of a shed was blown 100ft. Two beds and a dressing table were swept from the first story of the Namoi Hotel, crashed through a verandah railing, and fell in the street below.

At Medlow Bath early yesterday afternoon guests sitting at lunch in the dining-room were stampeded when huge hailstones smashed windows and fell on the guests. It is estimated that 75 windows were smashed.

TRAIN SERVICES.

Full train services to the South Coast, using a single track, were restored at midnight last night, but the Railway Department has cancelled several of to-morrow's holiday trains.

Trains were held up at Taree owing to a washaway between Wauchope and Kendall. The Brisbane express left four hours 44 minutes late, the North Coast mail was three hours late, and the Kempsey passenger train two hours late.

Two washaways occurred eight miles south of Cooma yesterday and the Cooma train was delayed at Bunyan for 30 minutes. Repairs will be completed to-day. The Moss Vale to Port Kembla line is still closed.

FLOODS IN QUEENSLAND.

BRISBANE, Tuesday.

The Condamine River at Pittsworth has fallen considerably, though the water is still over the rails near Pampas.

Pilot L. J. Brain, the Qantas airman, arrived at [illegible] to-day and said that he had flown through storms from [illegible] River. At various places the ground had been covered with water.

A heavy storm south of Roma unroofed the residence of the Robertson Brothers.

The dry spell was broken in the Winton district with a [illegible] downpour which [illegible] up to [illegible] inches [illegible]. Further falls [illegible] the district from a [illegible] plight.

Article text, suitable for copy and paste

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"I offered to "go," said Mr Riches, "but Ton- kin said I am taller than you.' and took the rope with scarcely another word. The stream was bringing down trees faster than a man could run. It was a miracle that Miss Davis was alive at all. One end of the rope, which was tied to one of her wrists was caught in the roots of a floating tree and she would certainly have been swept out to sea if that tree had not been caught in the branches of a standing tree. Our greatest fear was that one of the logs coming down the stream would catch our rope, as Tonkin took it across. I had to go out into the stream up to my waist holding the rope above my head so that the logs and other floating debris would pass underneath. Tonkin not only had to swim against a terrific rush of water, but had to dodge trees and rocks. He risked death a

dozen times "

Mr Riches said the first real intimation he received of the seriousness of the flood was a dull booming sound, due to the earth round a culvert at the head of the valley giving way. In a few seconds a roaring torrent was racing down the valley. He was making his way through water almost up to his waist carrying one child and leading another, and accom- panied by his wife, who was carrying their baby, when he saw Mr. Davis and his two boys in the stream. He caught a glimpse of upturned faces by the light of a hurricane lantern, and they were swept past him. He heard terrible screams, which ceased abruptly

in a few minutes.

SURVIVOR'S STORY.

Mrs. Michel, of Granville, who was rescued from the flood which overwhelmed the Davis family, said that she heard a roar, and was horrified to see a great wall of water rushing down on the camp. She threw off her coat and the next second was swept off her feet. The water carried her away swiftly. She managed to grab a signpost but was swept away. Her cries were heard by three campers, who groped their way to where they expected Mrs. Michel to be carried, and when she was within their reach they seized her.

CAR DRIVER STILL MISSING.

A search for the body of Geoffrey Walton of Thirroul, who Is believed to have been drowned when attempting to cross a creek near Scarborough, was made yesterday without success. It is assumed that the flood waters carried the body out to sea. A careful watch is being kept on the beaches. None of the bodies of the four victims swept out to sea in the major tragedy at Stanwell Park has been

recovered.

LOSSES OF STOCK.

Reports from many country centres indicate

heavy losses of stock.

Near Wellington, after a heavy downpour, flood waters rushing down Pile Creek swept away 400 merino sheep, the property of Mr. H. A. Taylor. The sheep were being removed to another paddock at the time.

Settlers at Perthville, near Bathurst, report the loss of many sheep, cattle, and pigs which were washed down Vale Creek. Poultry losses

were also severe.

At Barellan several valuable horses owned by Messrs P. Quade and D. Bahnsen were killed by lightning. A camel depasturing on Quade's property, was also killed.

FLOOD PRECAUTIONS.

Although police at many south coastal centres made reassuring reports last night, extensive floods were expected on the Moruya River at midnight, the Hawkesbury was run- ning a banker at Windsor, and the Nepean was in flood at Penrith. Moruya police reported at 8.30 p.m. that a heavy storm was raging. Lakes had formed and the river was running strongly. Windsor police said that the river was very close to the tops of the banks. Lowlying land on the Sydney side of the town was under water. At Camden and Penrith the Nepean was slowly receding there. South Creek bridge St Marys, was under water which blocked traffic. Many cars were towed through by a horse.

HAIL AND WIND DAMAGE.

At Narrabri yesterday a terrifying storm was experienced. Hundreds of exposed win- dows on the northern side of the town were smashed and few residences escaped the loss of glass. Water tanks were perforated by the hail. The hailstones were the largest ever seen in Narrabri. A strong gale accompanied the hail causing considerable damage. A bake- house was unroofed. The roof of a shed was blown 160ft. Two beds and a dressing table were swept from the first story of the Namoi Hotel, crashed through a verandah railing and fell in the street below.

At Medlow Bath early yesterday afternoon guests sitting at lunch in the dining-room were stampeded when huge hailstones smashed windows and fell on the guests. It is esti- mated that 78 windows were smashed.

TRAIN SERVICES

Full train services to the South Coast, using a single track, were restored at midnight last night, but the Railway Department, has, cancelled several of to-morrow's holiday trains.

Trains were held up at Taree owing to a washaway between Wauchope and Kendall.

The Brisbane express left four hours 44 minutes late, the North Coast mail was three hours late, and the Kempsey passenger train

two hours late.

Two washaways occurred eight miles south of Cooma yesterday and the Cooma train was delayed at Bombala for 30 minutes. Repairs will be completed to-day. The Moss Vale to Port Kembla line is still closed.

FLOODS IN QUEENSLAND.

BRISBANE Tuesday

The Condamine River at Pittsworth has fallen consIderably though the water is still over the tails near Pampas.

Pilot L. J. Brain, the Quants airman, ar- rived at Longreach to-day and said that he had flown through storms from Alice River. At various places the ground had been covered

with water.

A heavy storm south of Roma unroofed the residence of the Schenman Brothers.

The dry spell was broken in the Winton district with a thunderstorm which yielded up to an inch and a half of rain. Further falls alone can save the district from a desperate

plight.

FLOODS AT KENSINGTON.

Kensington, Randwick, and Coogee appear to have suffered most from the rainstorm. A good deal of damage was done. In Eastern-avenue, between Abbotsford-street and Allison-road, the water was 3ft deep in places. A large quantity of silt and stones was washed up over the tramlines, and caused a Long Bay car to be derailed. The water was over the footboards, and the passengers were compelled to remain in the car until the water subsided. The whole of the traffic to Long Bay, Maroubra, and Kensington was hung up.

A Coogee-bound car left the rails at Carr-street, Randwick, and the Randwick and Coogee services were also held up for a considerable period.

The tramline in Illawarra-road, Marrickville, was completely blocked with debris.

CASINO.—During the last few days several showers of rain have fallen throughout the district. There is every sign of a fine spring, and the clover is springing up all over the district. The various dairy herds are milking well.

DUNGOG.—Heavy rain set in on Wednesday, and continued during the night. The river and creeks broke over the banks, flooding all the low-lying lands; 300 points being recorded to 9 a.m. on Thursday. Rain is still falling heavily, with every indication of a record flood.

KEMPSEY.—Another [illegible] points of rain were registered on Wednesday, making [illegible] since Saturday. Already paddocks and farm lands on the lower river are covered with water. So far, not much rain has fallen on the upper portion of the Macleay River, or a serious flood must have resulted. Rain is still falling heavily.

PEAK HILL.—Steady soaking rain began to fall on Wednesday night, and it is still coming down. The rain came from the east, and appears to have been fairly general throughout this district, although lighter south from Peak Hill. On Thursday morning at Peak Hill 35 points had been registered, and the same at McPhail, Tomingley, and Nungery, whilst up to 40 points were recorded in other portions. There is every appearance of the rain continuing, and if it does the pastures will benefit as well as the crops. A good yield of wheat is now assured here.

SINGLETON.—The dry spell has been effectively broken. So far this week 170 points have fallen. It is still showery. This timely change puts a different aspect on the agricultural outlook. The pastures will greatly benefit. Many creeks in the district are uncrossable.

WINDSOR.—Rain has fallen throughout the Hawkesbury, which looked very well, and now has a good season assured. Down the river over 2in have been recorded since Saturday.

Article text, suitable for copy and paste

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APPENDIX E: SUMMARY OF PUBLIC EXHIBITION SUBMISSIONS

Issue	Action
Resident Experience of flooding in 1984 and 1988 on Rainbow Street in the vicinity of Marian Street.	A review of information from the Coogee Bay Flood Study indicates that the resident's experience is consistent with the flooding simulated by the hydraulic modelling.
Resident experience with flooding in Marian Street.	
Resident claims to have not experienced flooding at their block of units in Mount Street.	Flooding at this location is a minor overland flow path at the rear of the property in the 1% AEP flood. The frequency of such storms and the nature of the "flooding" are likely reasons for the resident not witnessing such events previously.
Request that stormwater drains in Marian Street are cleaned on a regular basis	Council has an established drainage maintenance program that includes the cleaning of stormwater pits. The stormwater network will be inspected and cleaned as required.
Concern that Marian Street is omitted as a potential problem area for flood inundation in page iv of the Executive Summary	Marian Street is part of a broader trapped low area located on Rainbow Street which is mentioned in this section
Comment that drains on Malabar Road and Marian Street do not have capacity to cope with extreme flood events.	Potential measures to manage the impacts of extreme flood events will be considered as part of the Coogee Bay Floodplain Risk Management Study.
Question regarding whether there are any recommendations for property blocks, particularly those in flood prone areas.	Potential measures to manage the impacts of extreme flood events will be considered as part of the Coogee Bay Floodplain Risk Management Study. Council's Flooding Advice and Flood Related Development Controls Policy provides advice on how to deal with the interim period until the study is complete.
Complaint regarding drainage at the bottom of the stairs in Cairo Street	Council will investigate options to modify the stairway to improve accessibility and use of the stairway. A by product of this will be the improvement of drainage at the bottom of the stairs
Complain regarding local discharges from a development on Denning Street	Drainage of the development was reviewed and found to comply with the appropriate standards.
Concern over the potential impact of the study on insurance premiums.	Flooding insurance is progressively becoming available in Australia. Insurance companies undertake their own studies and use their own methodologies independent of Council to determine premiums. The flood study is part of the process undertaken in good faith and

	aims to determine methods of minimising private and public losses. The identification of areas at risk of flooding is necessary to achieve this and does not change any property owners actual risk but does enable them to become informed of the risk.