Cardno
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Shaping the Future

Gosford CBD

Local Overland Flow Flood Study

Project W4816

Prepared for Gosford City Council

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Cardno (NSW/ACT) Pty Ltd
Trading as Cardno Lawson Treloar Pty Ltd
ABN 95 001 145 035

Level 9, The Forum
203 Pacific Highway
St Leonards New South Wales 2065
PO Box 19
St Leonards New South Wales 1590

Telephone: 02 9496 7700
Facsimile: 02 9439 5170
www.cardno.com.au

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Foreword

The NSW Government Flood Policy is directed towards providing solutions to existing flood 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.

Under the policy, the management of flood prone land is the responsibility of Local Government. The State Government subsidises flood management measures to alleviate existing flooding problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities. The Commonwealth Government also assists with the subsidy of floodplain management measures.

The Policy identifies the following floodplain management 'process' for the identification and management of flood risks:

1. Formation of a Committee -

    Established by a Local Government Body (Local Council) and includes community group representatives and State agency specialists.

2. Data Collection -

    The collection of data such as historical flood levels, rainfall records, land use, soil types etc.

3. Flood Study -

    Determines the nature and extent of the flood problem.

4. Floodplain Risk Management Study –

    Evaluates management options for the floodplain in respect of both existing and proposed development.

5. Floodplain Risk Management Plan –

    Involves formal adoption by Council of a management plan for the floodplain.

6. Implementation of the Plan –

    Implementation of actions to manage flood risks for existing and new development.

Gosford City Council has received funding from the Federal and State Governments under the Natural Disaster Mitigation Programme to undertake an Overland Flow Flood Study of the LGA. The Gosford CBD Local Overland Flow Flood Study is the first stage of the management process for the catchment. The Study, which has been prepared for Gosford City Council by Cardno Lawson Treloar Pty Ltd, defines flood behaviour for existing catchment conditions in the floodplain. The Flood Study will form the basis for future masterplanning and flood investigations in the catchment.

Executive Summary

The Local Overland Flow Flood Study has been undertaken to define the behaviour of local overland flows and flooding to properties in the study area. This Report comprises a pilot study on a small section of the LGA to evaluate the methodology and outcomes, prior to undertaking a similar study for the wider LGA.

This Study is intended to complement, rather than replace, Flood Studies and Plans previously adopted for the area:

- Brisbane Water Foreshore Flood Study, May 2009, Cardno Lawson Treloar
- Gosford CBD Drainage Investigation, February 1997, Bewsher Consulting
- East Gosford Catchment Study, August 1995, Bewsher Consulting
- Review of Lower Narara Creek Floodplain Management Study, December 1993, Kinhill Engineers
- Lower Narara Creek Floodplain Management Plan, September 1991, Kinhill Engineers

The study area incorporates the Greater Gosford CBD region comprising an area of about 4.9 km^2. It includes parts of the suburbs of Gosford, North Gosford, West Gosford and Point Frederick bounded by Narara Creek, Fagans Bay and The Gosford Broad Water. The study area comprises a variety of landuses such as residential, commercial, light industrial, and open space areas.

A draft of the Flood Study was placed on public exhibition in November 2010 inviting submissions for review of the Study.

The SOBEK 1D/2D model from WL|Delft Hydraulics Laboratory was used to model the catchment and to hydraulically route overland flood flows and street flow. Three modelling scenarios were assessed as a part of the study:

- Scenario 1 – The piped stormwater drainage systems are considered ineffective (ie blocked and is thus not included in the model) resulting in all flows conveyed overland.
- Scenario 2 – The main trunk drainage system, consisting of pipes 600mm diameter and larger, is included.
- Scenario 3 – Building footprints in the flowpath are incorporated into the model and the main trunk drainage system of Scenario 2 is included.

These scenarios represent different levels of complexity, with Scenario 1 being the simplest in terms of modelling effort and Scenario 3 being the most complex.

Two sub-catchment models were set-up – Gosford CBD representing about 2.8 km^2, and West Gosford representing about 3.3 km^2. A terrain grid of 2m by 2m cells was generated from Council's aerial laser scanning levels supplemented by detailed ground survey and work-as-executed drawings. The 1% probability of exceedance levels for Fagans Bay and The Gosford Broad Water were adopted as the downstream boundary conditions. Drainage inlets and pipelines / box culverts of size 600mm diameter and larger were included in the model for Scenario 2 and Scenario 3.

The hydrology of the direct rainfall method in the SOBEK models was verified by comparison to an XP-RAFTS hydrology model. The flood extents were verified to flooding hotspots identified in the previous reports, and assessment of model sensitivity to changes in the rainfall and roughness parameters.

Storm events of annual exceedance probability 1%, 2%, 5%, and 10% and the probable maximum flood were modelled. A storm event of 2 hours duration was determined to be the critical duration for flood levels in both sub-catchments.

The following table shows the number of property allotments with a depth of flooding greater than 0.2m in the Scenario 3 configuration for the 10% AEP, 1% AEP and PMF events.

Scenario 3 Model	Gosford CBD No. of Properties	West Gosford No. of Properties	Total No. of Properties
10% AEP	236	202	438
1% AEP	281	241	522
PMF	573	385	958

Flow behaviour in the Gosford CBD model zone is affected by the changes to the configuration of the grids and drainage systems for the three scenarios. The following table shows the number of properties which have a peak depth of flooding greater than 0.2m in the 1% AEP event for the three scenarios.

1% AEP Event Model	Gosford CBD No. of Properties	West Gosford No. of Properties	Total No. of Properties
Scenario 1	315	195	510
Scenario 2	255	195	450
Scenario 3	281	241	522

In summary, Scenario 3 results in a more refined representation of the overland flow behaviour than Scenario 1 and 2 as the effect to flow behaviour due to the influence of buildings is more detailed. The number of properties affected in the Gosford CBD is reduced due to the conveyance of the pipe system included in Scenario 2 (compared to Scenario 1). However, the properties affected in West Gosford is not reduced due to the different catchment conditions whereby the residential properties are in the upper part of the catchment draining towards the golf course and racecourse areas downstream. For both sub-catchments the inclusion of buildings within Scenario 3 results in an increase in the number of properties affected as flowpaths are more restricted and may spread across additional properties to convey downstream.

Therefore, for future overland flow studies, the following could be adopted:

- Scenario 1 – adopt this methodology for study areas when the stormwater infrastructure does not represent a major portion of the catchment or the capacity of the infrastructure is limited. Buildings within the floodplain do not represent major obstructions to flowpaths.
- Scenario 2 – applicable for study areas where buildings to not represent a major obstruction to flowpaths.
- Scenario 3 – adopt this for study areas where Scenario 1 and 2 are not applicable.

Provisional flood hazard determined from the 1% AEP results showed high hazard conditions are shown on several streets in the study area. In the Gosford CBD subcatchment, high provisional hazard areas include streets upstream of William Street, across the William Street pedestrian area to Mann Street, and at the Mann Street – Erina Street intersection. The channel from Rumbalara Reserve across Henry Parry Drive to Masons Parade is shown as provisional high hazard in some locations as well as some areas downstream of the open channel at Masons Parade and Dane Drive. High hazard conditions in the West Gosford subcatchment are shown on Moore Street and Fielders Lane, Batley Street North, and Showground Road north of Racecourse Road.

Hydraulic categories of floodway, flood storage, and flood fringe were determined from the 1% AEP results for the study area. Floodway is shown in the Gosford central business precinct, along the channel from Rumbalara Reserve to Dane Drive, and at Moore Street and Fielders Lane.

Changes to climate conditions are expected to have an adverse impact on sea levels and rainfall intensities. An assessment on the impact of climate change on flood behaviour in the Study Area has been undertaken for the following scenarios:

- Sea level increased by 0.2m, 0.4m and 0.9m;
- Rainfall increased by 10%, 20% and 30%; and
- Rainfall increased by 30%, combined with a sea level increase of 0.4m and 0.9m respectively.

Three increases to levels in Brisbane Water due to potential sea level rise impacts caused by climate change were modelled. Increases of 0.2m, 0.4m, and 0.9m were applied to the 1% PoE level at the downstream boundary for the 1% AEP 2 hour critical duration storm event. Some roads adjacent to the foreshore in the Gosford CBD subcatchment are at elevations below the increased Brisbane Water level, thus inundation at these locations is worsened. The conveyance capacity of pipelines discharging into Brisbane Water is also reduced, thus inundation to areas upstream is also worsened, such as the intersection of Mann Street and Erina Street. Similarly in the West Gosford subcatchment, flood inundation is worsened at some areas adjacent to the foreshore and Narara Creek that are below the raised Brisbane Water level. Peak flood levels increase in some of the roadways at low areas due to the reduced drainage capacity.

This Study defines local overland flow behaviour in the catchment. Flood modelling has enabled the generation of GIS layers for outputs including peak depth, peak water level, velocity and provisional hazard for a range of events and scenarios. The Study results can be used by Council to inform future masterplanning in the catchment, to identify property affectation criteria for development assessment, and to evaluate potential flood mitigation measures. A formal Floodplain Risk Management Study and Plan may be an appropriate next stage of the flood management process in the catchment.

Subsequent to the preparation of the Gosford CBD and West Gosford subcatchments, overland flow modelling has been undertaken for the adjacent suburb of Point Frederick and parts of East Gosford. Overland flood behaviour has been modelled in the approximately 114ha catchment for a range of recurrence intervals and scenarios. A summary report for this catchment is included as an appendix to this Report.

Table of Contents

Appendices

List of Tables

List of Figures

Glossary

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

Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average recurrence interval (ARI)	The long-term average number of years between the occurrence of a flood as big as or larger than the selected event. For example, floods with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
Creek Rehabilitation	Rehabilitating the natural 'biophysical' (i.e. geomorphic and ecological) functions of the creek.
Creek Modification	Widening or altering the creek channel in an environmentally compatible manner (i.e. including weed removal and stabilisation with suitable native endemic vegetation) to allow for additional conveyance.
Design flood	A significant event to be considered in the design process; various works within the floodplain may have different design events, e.g. some roads may be designed to be overtopped in the 1 year ARI flood event.

Development	Is defined in Part 4 of the EP&A Act. Infill development: refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development new development: refers to development of a completely different nature to that associated with the former land use. Eg, the urban subdivision of an area previously used for rural purposes. New developments involve re-zoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. Redevelopment: refers to rebuilding in an area. Eg, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either re-zoning or major extensions to urban services.
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
Flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
Flood fringe	The remaining area of flood-prone land after floodway and flood storage areas have been defined.
Flood hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low provisional hazard categories are provided in Appendix L of the Floodplain Development Manual (NSW Government, 2005).

Flood-prone land	Land susceptible to inundation by the probable maximum flood (PMF) event, i.e. the maximum extent of flood liable land.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
Flood planning area	The area of land below the FPL and thus subject to flood related development controls.
Flood planning levels	Are the combinations of flood levels (derived from significant historical flood events or floods of specific ARIs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans.
Flood Risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in the Floodplain Development Manual (Appendix G) is divided into 3 types, existing, future and continuing risks. They are described below: ▪ Existing flood risk: the risk a community is exposed to as a result of its location on the floodplain. ▪ Future flood risk: the risk a community may be exposed to as a result of new development on the floodplain. ▪ Continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

Flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas. See Section L3 of the Floodplain Development Manual.
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels. See Section L3 of the Floodplain Development Manual.
Freeboard	Provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. (See Section K5 of Floodplain Development Manual). Freeboard is included in the flood planning level.
Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
High hazard	Flood conditions that pose a possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty wading to safety; potential for significant structural damage to buildings. See Section L5 of the Floodplain Development Manual.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

Low hazard	Flood conditions such that should it be necessary, people and their possessions could be evacuated by trucks; able-bodied adults would have little difficulty wading to safety. See Section L5 of the Floodplain Development Manual.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
Major Drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purposes of the Floodplain Development Manual (Appendix C) major drainage involves: ▪ the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or ▪ Water depths generally in excess of 0.3m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or ▪ major overland flowpaths through developed areas outside of defined drainage reserves; and/or ▪ The potential to affect a number of buildings along the major flow path.
Management plan	A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. With regard to flooding, the objective of the management plan is to minimise and mitigate the risk of flooding to the community. It may also include description and discussion of various issues, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.
Mathematical/computer models	The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with rainfall, runoff, pipe and overland stream flow.

NPER	National Professional Engineers Register. Maintained by the Institution of Engineers, Australia.
Peak discharge	The maximum discharge occurring during a flood event.
Probable maximum flood	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
Probability	A statistical measure of the expected frequency or occurrence of flooding.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Stormwater flooding	Inundation by local runoff. Stormwater flooding can be caused by local runoff exceeding the capacity of an urban stormwater drainage system or by the backwater effects of mainstream flooding causing the urban stormwater drainage system to overflow.
Topography	A surface which defines the ground level of a chosen area.

Abbreviations

AAD	Average Annual Damage
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AWE	Average Weekly Earnings
BoM	Bureau of Meteorology
CPI	Consumer Price Index
DCP	Development Control Plan
DECCW	Department of Environment, Climate Change and Water (formerly the Department of Environment and Climate Change)
DNR	Department of Natural Resources (now DECCW)
FPL	Flood Planning Level
FRMC	Floodplain Risk Management Committee
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
GIS	Geographic Information System
GSDM	Generalised Short Duration Method
ha	hectare
IEAust	Institution of Engineers, Australia
IFD	Intensity Frequency Duration
km	kilometres
km^2	Square kilometres
LEP	Local Environment Plan
LGA	Local Government Area
m	metre
m^2	Square metres
m^3	Cubic metres

mAHD	Metres to Australian Height Datum
MHL	Manly Hydraulics Laboratory
MHWL	Mean High Water Level
mm	millimetre
m/s	metres per second
MSL	Mean Sea Level
NSW	New South Wales
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RAFTS	RAFTS proprietary software package
RTA	Roads and Traffic Authority
SEPP	State Environmental Planning Policy
SES	State Emergency Service

1 Introduction

1.1 Study Objectives

Gosford City Council has received funding from the Federal and State Governments under the Natural Disaster Mitigation Programme to undertake an Overland Flow Flood Study of the LGA. This Report comprises a pilot study on a small section of the LGA to evaluate the outcomes, prior to undertaking a similar study for the wider LGA.

The objective of the study is to define local overland flooding in accordance with the NSW Government's Floodplain Development Manual (2005). Gosford City Council seeks the following outcomes:

- Identify and map major overland flowpaths;
- Identify properties at risk from overland flows;
- Define local flood behaviour, including flows, flood levels and depths, and velocities; and,
- Assess provisional flood hazard for properties at risk.

This Study is not intended to replace, but to complement Flood Studies and Plans previously adopted.

1.2 Study Area Description

The study area incorporates the Greater Gosford CBD region comprising an area of about 4.9 km^2. It is shown in **Figure 1.1** and includes parts of the suburbs of Gosford, North Gosford, West Gosford and Point Frederick bounded by Narara Creek, Fagans Bay and The Gosford Broad Water.

The study area comprises a variety of landuses such as residential, commercial, light industrial, and open space areas. It includes "Bluetongue" Stadium, Gosford Hospital, Gosford Racecourse, large parklands, a golf course and other sporting venues as well as two high schools and the CBD of Gosford.

The study area rises from the foreshore to a ridgeline in the east with highest elevation about 160m AHD. A peak at about 113m AHD is located in the centre of the study area in Waterview Park. The area drains down to Narara Creek on the western side, and to the south at Fagans Bay and The Gosford Broad Water.

1.3 Public Exhibition

A draft of this Flood Study was placed on public exhibition for four weeks in November 2010 at Council's administration centre, Gosford library, and on Council's website. Comments and submissions were invited for review of the final report. No submissions were received on the draft Flood Study.

2 Catchment Data

Data adopted for this Study has been collated from a number of sources for application to the hydraulic model.

2.1 Gosford City Council Land Information

Gosford City supplied data and information for the Study including:

- GIS layer of cadastre and land-use zones
- GIS layer of drainage pipeline/culvert location and size
- Aerial photos
- GIS layer of building footprints for the CBD – additional areas in the catchment were prepared as part of this Study.

2.2 Previous Studies

2.2.1 Brisbane Water Foreshore Flood Study, May 2009, Cardno Lawson Treloar

This report describes the development of flood planning level parameters for the Brisbane Water Foreshore based on extensive data analysis and calibrated modelling systems. Downstream boundary water levels, the 1% Probability of Exceedance (PoE) levels, were determined for use in individual creek flooding studies. The 1% PoE levels represents the level that has a 99% chance that it will not be exceeded during any creek flood event. For the Gosford CBD Overland Flood Study, the relevant parameters are:

- Gosford = 0.72m AHD
- Narara Creek Entrance = 0.75m AHD

2.2.2 Gosford CBD Drainage Investigation, February 1997, Bewsher Consulting

This report describes the evaluation of the existing stormwater drainage network of the Gosford CBD and recommends potential improvement works. The study area covers the CBD catchment south to Broadview Avenue. It consists of two major trunk drainage systems, one covering about 96% of the area, and the other system located in the south near Vaughan Avenue. A pipeline system capacity assessment was undertaken by hydraulic and hydrologic modelling using ILSAX and a hydraulic grade line analysis model. Questionnaires were distributed to selected properties near trunk drainage lines, and responses indicated 16 instances of above floor flooding in the study area. The assessment indicates that the pipe systems in the study area have capacity below Council's standard requirement.

The summary of the questionnaire responses indicated that above floor flooding occurred in:

- Mann Street – commercial premises, predominant location recording most responses;
- Erina Street – commercial premises and public sector ownership;
- Donnison Street – commercial premises;
- Holden Street – public sector ownership.

The property on the south-east corner of Baker Street and Donnison Avenue is below street level and has experienced frequent inundation, up to 200mm above the step.

The Report indicated that most flooding problems in this catchment occur in the area downstream of the railway station and Henry Parry Drive. Significant flooding problems are noted at:

- Intersection of Mann Street and Erina Street (identified as the worst location for flooding in the study area);
- Between Mann Street and Mortimer Lane
- Sag point in Donnison Street – at the intersection with Baker Street;
- Streets surrounding Central Coast Leagues Club, such as Baker Street and Georgiana Terrace, particularly when the tide is high.

Upstream of the railway station and Henry Parry Drive, the catchment is relatively steep and overland flow is generally conveyed along roads. Significant flooding occurs at no. 131 Erina Street where the drainage line is situated under the property. Overfloor flooding is also noted for the adjoining property.

Significant drainage improvement works have been completed since this Report was prepared, thus the analysis results are not directly comparable to the Current Study. Works include the construction of the main trunkline along Mann Street – Donnison Street – Baker Street to The Gosford Broad Water. Other minor works may also have been completed since this time.

2.2.3 East Gosford Catchment Study, August 1995, Bewsher Consulting

This report describes the evaluation of the existing stormwater drainage system at East Gosford and recommends potential improvement works. The study area includes part of the area for the Gosford CBD Overland Flood Study, namely the CBD catchment itself, and extends to the east to cover areas contributing to Erina Creek. A pipeline system capacity assessment was undertaken by hydraulic and hydrologic modelling using ILSAX and a hydraulic grade line analysis model. Questionnaires were distributed to selected properties near trunk drainage lines, and responses indicated eight instances of above floor flooding in the study area.

The summary of the questionnaire responses indicated that above floor flooding occurred in the following locations within the Gosford CBD Overland Flood Study area:

- Albany Street - units
- Duke Street - house
- Masons Parade - units

Properties listed as inundated include 1 Duke Street (near intersection with Lynn Avenue), and properties adjacent to the open channel at Dane Drive / Masons Parade. This channel is noted as overtopping when heavy rain coincides with high tides, resulting in a 300mm depth of inundation recalled at the property to the north of the channel. Local drainage problems at 166 and 207 Albany Street may in part have been alleviated by works undertaken by Council following the study.

2.2.4 Review of Lower Narara Creek Floodplain Management Study, December 1993, Kinhill Engineers

This Report reviewed the Lower Narara Creek Floodplain Management Study and hydraulic model following severe flooding experienced during February 1992. This flood event resulted in significant flooding along Narara Creek, particularly from Glennie Street West along Showground Road to the bridge at Manns Road.

Several management options for flood mitigation in some areas were revised following this amended assessment.

This Report assessed the floodplain impacts primarily from inundation resulting from flows in Narara Creek. The current study models overland runoff from the local sub-catchment and does not allow for flows within Narara Creek from upstream contributing catchments. Thus the flood levels determined in this Report are not directly comparable to the Current Study.

2.2.5 Lower Narara Creek Floodplain Management Plan, September 1991, Kinhill Engineers

This Report evaluated the flood mitigation options identified in the Floodplain Management Study in preparation of this Management Plan.

The study area for this Report is divided into several sub-areas. The following descriptions for sites within the Gosford CBD Overland Flow Study extent include:

- Glennie Street West Industrial Area – during events in excess of 1% AEP, there will be minimal floodwater movement through building allotments with flows confined to the roads.
- Dwyer Street West – located south-west of Glennie Street West. A constriction in the Narara Creek valley is exacerbated by the sewage treatment works.
- Racecourse and Golfcourse Flood Storage Area – floodwater is stored at these locations due to floodwater spilling from Narara Creek and due to local surface drainage.
- West Gosford Industrial Area – located on the south-side of the racecourse. Flooding problems are generally noted on the western side of Narara Creek caused by water spilling from Narara Creek and local sub-catchment runoff.
- West Gosford Foreshore and Residential Flood Area – located between Fagans Bay and Pacific Highway. Some houses are just below the 1% AEP flood level, but no high velocities or depths are indicated near these houses.

2.3 Available Survey

2.3.1 Aerial Survey

Aerial survey (ALS) was provided by Gosford City Council. The survey was undertaken in 2007, and is therefore representative of the catchment at that time. While not explicitly reported with the data, typical accuracies of ALS or LiDAR data are in the order of +/- 0.15 metres in one standard deviation.

2.3.2 Bathymetry

Bathymetry of Brisbane Water (Fagans Bay and the Gosford Broad Water) was based on the bathymetry created for the Brisbane Water Foreshore Flood Study (Cardno Lawson Treloar, 2009).

2.3.3 Additional Survey

The need for additional survey was identified during the data review process. Two locations were identified:

- Masons Parade open channel (between Albany Street and Masons Parade). The channel at this location was not well defined in the aerial survey.
- Baker Street Carpark. The ground level of the carpark was not defined in the aerial survey information.

Council commissioned Cardno to undertake the survey, with the work being completed on 21 September 2009.

2.3.4 Dane Drive Information

The RTA has recently modified Dane Drive. As this occurred after the 2007 aerial survey information, additional details were required. The RTA supplied design drawings for Dane Drive on 17 September 2009. Work-as-Executed drawings were not available.

3 Flow Modelling

The SOBEK 1D/2D model from WL|Delft Hydraulics Laboratory was used to model the catchment and to hydraulically route overland flood flows and street flow. This modelling system dynamically couples the one-dimensional and two-dimensional flow in the floodplain. The Direct Rainfall ('rainfall on the grid') methodology was adopted for the study. In the model, rainfall is applied directly to the 2D terrain, and the hydraulic model automatically routes the flow determined by the elevation and roughness grids and the 1D pipeline network.

3.1 Modelling Scenarios

Three modelling scenarios were assessed as a part of the study:

- Scenario 1 – The piped stormwater drainage systems are considered ineffective (ie blocked and is thus not included in the model) resulting in all flows conveyed overland.
- Scenario 2 – The main trunk drainage system, consisting of pipes 600mm diameter and larger, is included.
- Scenario 3 – Building footprints in the flowpath are incorporated into the model and the main trunk drainage system of Scenario 2 is included.

These scenarios are depicted in **Figure 3.1**.

These scenarios represent different levels of complexity, with Scenario 1 being the simplest in terms of modelling effort and Scenario 3 being the most complex. There were two primarily drivers being these modelling scenarios:

- This study is a pilot study for future planned overland flow studies in Gosford LGA. Therefore, an understanding was required on the level complexity required to reasonably define the overland flooding behaviour within a study area. For example, if Scenario 1 demonstrated similar results to Scenario 3, then this would represent a more economical solution to future studies.
- While this study was being prepared, a masterplan was being developed for the Gosford CBD. As such, information was required on the overland flow characteristics within the study area in a relatively short timeframe. Preliminary results of each scenario were therefore progressively provided to Council throughout the study to facilitate the creation of the masterplan.

3.2 Model Zones

The Study Area has been divided into two discrete models, Gosford CBD and West Gosford, due to current computer limitations and run times. **Figure 3.2** shows the boundaries of the models.

A 2m by 2m grid was developed for the extents of the two model zones. The size of the model zones are:

- Gosford CBD – 2.8 km^2 represented by about 1.2 million grid cells
- West Gosford – 3.3 km^2 represented by about 1.7 million grid cells

3.3 Topography (2D)

A terrain grid was generated to represent ground elevations based on ALS data supplemented by detailed field survey of Masons Parade Channel and Baker Street carpark. **Figures 3.3** and **3.4** show the elevations of the Gosford CBD and West Gosford model zones respectively.

3.3.1 Building footprints

Scenario 3 includes the footprints of buildings as blocked elements within the terrain grid. Buildings outlines were determined from aerial photographs and their elevation increased 3m above the ground level from the ALS. These raised blocks represent the diversion of overland flow caused by the building structure. The resulting terrain grid, represented in the model as 2m x 2m grid cells, was reviewed to ensure flowpaths between buildings, which may be less than 2m in width, were still incorporated.

Some buildings are able to convey overland flow at ground level, thus are not incorporated in the model as raised cells. This includes the Baker Street multi-storey carpark which is open roadway on the ground level, rather than a full wall blocking flow. Arcades on Mann Street have also been assessed. Carbow Arcade, connecting Mann Street to the south side of the Baker Street multi-storey carpark, is retained as blocked out building (ie not flow through) due to the doors restricting flow. The book arcade, connecting Mann Street to the north side of the Baker Street multi-storey carpark, has a gated opening, thus potentially allowing flow through so a gap at ground level is retained.

Figure 3.5 shows the outlines of the buildings raised in the terrain grid of Scenario 3.

3.4 Roughness

Each cell of the 2D grid also has a roughness value applied to model the influence to flow behaviour of the particular land-use. The adopted roughness layout, shown in **Figure 3.6**, was based on aerial photographs, site inspections, and Council's land-use zonings. The roughness value applied for each land-use is listed in **Table 3.1**.

Table 3.1: 2D Grid Roughness Values

Land-use	Roughness Parameter
Road	0.02
Waterbody	0.02
Open Space	0.03
Channel	0.03
Properties	0.08
Bushland	0.10

3.5 1D Network

Piped drainage systems are incorporated into the SOBEK model as distinct 1D elements connected to the terrain grid for modelling Scenarios 2 and 3. Pipes 600mm in diameter and larger were incorporated into the model, representing the trunk drainage system only.

The location and size of pipes and culverts were determined based on Council's GIS data supplemented by design drawings and site inspections by Council staff. Inverts of pipes were assumed as a standard cover depth and surface levels were estimated based on aerial survey data.

Pit inlets were assumed to be pipe limiting, rather than controlled by the inlet itself. Given that only pipes 600mm and above are incorporated in the model, there would be a number of additional pits which would not be incorporated into the model. A standard pit inlet size method would not recognise allow for these additional pits.

The open channel section between Albany Street and Masons Parade was included as a distinct 1D channel element, but Narara Creek was represented in the 2D terrain grid.

Figure 3.7 shows the pipe and channel sections incorporated as 1D elements in the model. The lengths of the drainage system components for the two models are:

- Gosford CBD – 5.4km of pipeline, 3.5km of box culvert, 0.1km of open channel
- West Gosford – 3.9km of pipeline

Roughness values applied to the 1D elements are listed in **Table 3.2**.

Table 3.2: 1D Elements Roughness Values

Drainage Component	Roughness Parameter
Pipeline	0.018
Box Culvert	0.018
Open Channel	0.03

3.6 Hydrology

As the Direct Rainfall methodology was adopted, a separate hydrological model was not required.

Due to the small area of the catchment, uniform areal distribution of design storms has been assumed for the hydrologic component of the analysis. Design rainfall depths and temporal patterns for the modelling of 1% AEP, 2% AEP, 5% AEP, and 10% AEP were developed using standard techniques provided in Australian Rainfall and Runoff (1999).

The design Intensity-Frequency-Duration (IFD) parameters were obtained from the Bureau of Meteorology for the Central Coast Stadium located in the catchment. The IFD parameters are shown in **Table 3.3**.

Table 3.3: Design IFD Parameters

Parameter	Value
2-Years ARI 1-hour Intensity	37.34 mm/hr
2-Years ARI 12-hours Intensity	8.52 mm/hr
2-Years ARI 72-hours Intensity	2.73 mm/hr
50-Years ARI 1-hours Intensity	71.24 mm/hr
50-Years ARI 12-hours Intensity	17.79 mm/hr
50-Years ARI 72-hours Intensity	6.09 mm/hr
Skew	0.0
F2	4.3
F50	15.89
Temporal Pattern Zone	1

The Probable Maximum Precipitation (PMP) was estimated using the publication "The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method" (Commonwealth Bureau of Meteorology, 2003). The Study Area was split into two model zones, Gosford CBD and West Gosford, as detailed in **Section 3.2**. These two model zones are similar in area, about 2.3 to 2.8 km^2, thus the PMP rainfall depth determined for each catchment was the same. **Table 3.4** shows the data for the PMP calculations.

Table 3.4: PMP Calculation Values

Parameter	Value
Total area (km^2)	Gosford CBD = 2.3 km^2, West Gosford = 2.8 km^2
Moisture Adjustment Factor	0.71
Elevation Adjustment Factor	1.00
Percentage Rough	100%

Estimated average design storm rainfall intensities for the full ranges of storm events and durations are presented in **Table 3.5**.

The loss rates applied to the rainfall patterns based on the soil conditions of the catchment are listed in **Table 3.6**.

Table 3.5: Design Rainfall Intensities (mm/h)

Duration	10% AEP	5% AEP	2% AEP	1% AEP	PMP
15 min	108	123	143	158	640
30 min	77	88	103	114	480
45 min	63	72	83	92	400
1 hour	53	61	71	79	350
1.5 hours	42.6	48.9	57	63	300
2 hours	36.2	41.6	48.7	54	265
3 hours	28.6	33.0	38.8	43.2	213

Table 3.6: Rainfall Loss Parameters

Rainfall Loss	Value
Initial Loss	10mm
Continuing Loss Rate	1.5mm/h

3.7 Boundary Conditions

Downstream boundary conditions were adopted from the Brisbane Water Foreshore Flood Study (May 2009, Cardno Lawson Treloar) (described in **Section 2.2.1**). The 1% Probability of Exceedance (PoE) levels, being the level that one can be 99% confident will not be exceeded during any creek flood event, used in the modelling are:

- Gosford = 0.72m AHD
- Narara Creek Entrance = 0.75m AHD

Narara Creek was also incorporated into the modelling. The modelling assumes that no flooding is occurring within Narara Creek when a local event occurs in the local catchment. Given the size of Narara Creek Catchment, it would be expected that any flood peak would occur after the flood peak from the local catchment. Furthermore, the critical duration for the local catchment is generally in the order of a 2 hour event, while Narara Creek would be expected to have a longer critical duration. Therefore, a constant water level of 0.75m AHD was assumed along Narara Creek.

3.8 Model Verification

3.8.1 XP-RAFTS

As the Direct Rainfall (rainfall on the grid) methodology is still relatively new to the industry, it was verified against a traditional hydrological model. The verification was undertaken by comparing the results from a 1% AEP event for the Direct Rainfall Model with the results from a traditional hydrological model (XP- RAFTS). It is not always expected that the two models will exactly match (in fact, two separate traditional hydrological models with similar parameters can produce significantly different results). However, where there are differences some interpretation of the results can be made, and the models can be checked as to why this is the case.

The comparison was undertaken on relatively small sub-catchments, as the larger the sub-catchment, the more likely significant hydraulic controls, such as culverts, would not be included in the hydrological model. In addition, the primary aim of this comparison is to ensure that the timing and peak flows from the direct rainfall hydraulic model (SOBEK) are reasonable, with the focus on the runoff areas rather than the mainstream areas.

The comparison is also useful to testing appropriate roughness and loss parameters in the hydraulic model for generating catchment runoff.

Four sub-catchments within the Gosford CBD model zone were modelled in XP-RAFTS to assess the flows generated in the SOBEK model. The sub-catchments, shown in **Figure 3.8**, are located in the upper areas of the catchment. Details of the sub-catchments are listed in **Table 3.7.**

Table 3.7: XP-RAFTS Subcatchments

Subcatchment	Details
C1A	Area 14.2 ha, Impervious 15%
C1B	Area 26.7 ha, Impervious 7%
C2	Area 25.3 ha, Impervious 23%
C3	Area 12.2 ha, Impervious 32%

Table 3.8 shows results for three variations of the soil loss rates applied to the SOBEK model for the 1% AEP storm and the RAFTS model. The varied loss rates, initial loss (IL) in mm and continuing loss rates (CLR) in mm/hr, were modelled with a preliminary bushland roughness value of 0.06. **Figure 3.9** shows the flow hydrographs for the modelled variations.

The total volume results show a significant difference for the variation in the applied loss rates for the SOBEK model. Runoff storage areas, resulting from variations in the terrain grid profile through natural depressions and the like, would be expected to result in lesser volumes at the sub-catchment outlet in the SOBEK model compared to the RAFTS model. The hydrographs show that flows occur earlier in the RAFTS model due to the small storages occurring in the terrain grid retaining water in the SOBEK model.

Table 3.8: Verification - Soil Loss Parameters

Model	Peak Flow (m^3/s)	Total Volume (m^3)	Volume Difference (%)
Subcatchment 1A			
SOBEK IL5CLR1	14.3	25,238	7.4
SOBEK IL10CLR1.5	13.1	23,201	-1.2
SOBEK IL20CLR2.5	9.8	18,693	-20.4
RAFTS	11.6	23,492	--
Subcatchment 1B			
SOBEK IL5CLR1	12.0	17,072	-9.6
SOBEK IL10CLR1.5	11.9	15,865	-16.0
SOBEK IL20CLR2.5	11.2	12,943	-31.5
RAFTS	9.6	18,890	--
Subcatchment 2			
SOBEK IL5CLR1	11.1	17,321	8.4
SOBEK IL10CLR1.5	11.1	15,792	-1.2
SOBEK IL20CLR2.5	10.6	13,859	-13.3
RAFTS	9.6	15,982	--
Subcatchment 3			
SOBEK IL5CLR1	5.4	8,931	4.0
SOBEK IL10CLR1.5	5.2	8,313	-3.2
SOBEK IL20CLR2.5	4.6	7,202	-16.2
RAFTS	5.7	8,590	--

The effect of the roughness parameter in the SOBEK model was assessed by varying the value of roughness for the bushland zone, which comprises a large proportion of the sub-catchments modelled in RAFTS. Results are shown in **Table 3.9** for three variations of this roughness parameter for the 1% AEP event with an initial loss of 10mm and continuing loss of 1.5mm/hr.

Table 3.9: Verification - Bushland Roughness Parameter

Model	Peak Flow (m^3/s)	Total Volume (m^3)	Volume Difference (%)
Subcatchment 1A			
SOBEK-Bushland 0.06	13.1	23,197	-1.3
SOBEK-Bushland 0.08	12.5	23,175	-1.4
SOBEK-Bushland 0.1	12.0	23,132	-1.5
RAFTS	11.6	23,492	--
Subcatchment 1B			
SOBEK-Bushland 0.06	11.9	15,865	-16.1
SOBEK-Bushland 0.08	12.3	15,867	-16.0
SOBEK-Bushland 0.1	12.4	15,782	-16.5
RAFTS	9.6	18,890	--
Subcatchment 2			
SOBEK-Bushland 0.06	11.1	15,792	-1.2
SOBEK-Bushland 0.08	10.9	15,701	-1.8
SOBEK-Bushland 0.1	10.7	15,661	-2.0
RAFTS	9.6	15,982	--
Subcatchment 3			
SOBEK-Bushland 0.06	5.19	8,313	-3.2
SOBEK-Bushland 0.08	5.16	8,312	-3.2
SOBEK-Bushland 0.1	5.15	8,316	-3.2
RAFTS	5.71	8,590	--

The results show limited effect on the volumes generated from the varied roughness parameters, which is to be expected, but the peak flows are more influenced by the changes in the roughness. A roughness value of 0.1 within the bushland areas would appear to provide a comparable peak flow to RAFTS. This roughness value is a reasonable 2D roughness value for bushland areas.

Variations in the calculation methodology and data used in the RAFTS and SOBEK models are likely to result in the difference in results for the differences in the sub-catchments for the altered parameters.

Based on these comparisons and site details, the following parameters were selected for the SOBEK modelling:

- Initial loss 10mm, continuing loss rate 1.5mm/hr
- Bushland roughness 0.1.

3.8.2 Previous Studies

Previous studies completed in the Study Area are described in **Section 2.2**.

The Gosford CBD Drainage Investigation (Bewsher Consulting, 1997) highlighted several locations as being particularly flood affected. These locations are also shown as having significant flood depths for the 1% AEP SOBEK modelling (detailed in **Section 4**):

- Intersection of Mann Street and Erina Street
- Between Mann Street and Mortimer Lane – particularly Mortimer Lane south of William Street
- Streets surrounding Central Coast Leagues Club – particularly intersection of Dane Drive and Georgiana Terrace
- Flowpath across number 131 Erina Street

The 1997 Report also included a large proportion of questionnaire responses noting flooding problems to commercial properties in Mann Street. This area was shown in the SOBEK model to be a problem area around Erina Street and William Street.

The East Gosford Catchment Study (1995, Bewsher Consulting) highlighted several locations as particularly flood affected. These locations are also shown as having significant flood depths for the 1% AEP SOBEK modelling (detailed in **Section 4**):

- 1 Duke Street – near intersection with Lynn Avenue
- Open channel near Dane Drive / Masons Parade – the 1% AEP SOBEK results show a depth of flooding around 0.35m on the property to the north of the channel

The review of the Lower Narara Creek Floodplain Management Study (1993, Kinhill Engineers) was prepared in response to the February 1992 flood event which resulted in significant flooding from Glennie Street West along Showground Road to the bridge at Manns Road. The 1% AEP SOBEK modelling shows flooding adjacent to Showground Road to the north of Racecourse Road.

The Lower Narara Creek Floodplain Management Plan (1991, Kinhill Engineers) described flooding problems that occur in several areas within the study area. The descriptions of flooding from the Plan were compared to the 1% AEP SOBEK results:

- Glennie Street West Industrial Area – flooding depths above 0.2m are generally confined to the roadways and the un-developed areas on the northern side adjacent to the creek
- Racecourse and Golfcourse – both are shown as inundated in the 1% AEP SOBEK results

- West Gosford Industrial Area – in this area the flooding is concentrated at the intersection of Pacific Highway and Racecourse Road.

4 Flood Model Results

Flood modelling was completed for a series of Annual Exceedance Probabilities (AEP) – 1%, 2%, 5%, 10% AEP and for the Probable Maximum Flood (PMF). Three modelling scenarios were completed:

- Scenario 1 – The piped stormwater drainage systems are considered ineffective (ie blocked and is thus not included in the model) resulting in all flows conveyed overland.
- Scenario 2 – The main trunk drainage system, consisting of pipes 600mm diameter and larger, is included.
- Scenario 3 – Building footprints in the flowpath are incorporated into the model and the main trunk drainage system of Scenario 2 is included.

These scenarios are depicted in **Figure 3.1**.

4.1 Critical Duration

The Gosford CBD and West Gosford catchments were modelled in Scenario 1 format for the 10% AEP, 1% AEP and PMF events for the following durations:

- 10% AEP and 1% AEP - 15 minutes, 30, 60, 90, 120, and 180 minutes
- PMF - 15 minutes, 30, 45, 60 and 90 minutes

The peak water levels for the 10% AEP and 1% AEP in Scenario 1 configuration resulted from the 15 minutes, 90, and 120 minutes duration storms. These durations were used for the modelling of the 1% AEP, 2%, 5% and 10% AEP events for all three scenarios.

A further assessment of the results from the scenarios shows that the representative critical duration is the 120 minute duration as it resulted in peak water levels which are within 0.01m of the other storms.

The peak water levels for the PMF event in Scenario 1 configuration resulted from the 15 minutes, 30, and 45 minutes durations. These durations were used for the modelling of the PMF events for all three scenarios.

For the Gosford CBD catchment, the 15 minute duration event is critical in the higher elevations while downstream areas tend to have the 30 minute duration as resulting in peak water levels. The PMF storm durations resulting in the peak water levels varies across the catchment for the 15, 30 and 45 minute storms.

4.2 Design Event Results

The SOBEK flood models were run for the 1% AEP, 2%, 5%, and 10% AEP and the PMF events. Peak flood depths for Scenario 3 are shown in the following figures:

- Figure 4.1 and 4.2 – 10% AEP event for the Gosford CBD model zone and West Gosford model zone respectively
- Figure 4.3 and 4.4 – 1% AEP event for the Gosford CBD model zone and West Gosford zone respectively

- Figure 4.5 and 4.6 - PMF event for the Gosford CBD model zone and West Gosford model zone respectively

The peak water levels for the 1% AEP event for the Gosford CBD and West Gosford catchments respectively are shown in the following figures:

- **Figure 4.7 and 4.8** – Scenario 1
- **Figure 4.9 and 4.10** – Scenario 2
- **Figure 4.11 and 4.12** – Scenario 3

Table A.1 in **Appendix A** lists the peak water level at the reference locations shown in **Figure 4.13** for the 1% AEP, 2%, 5%, 10%, and 20% AEP and the PMF events in the Scenario 3 configuration.

Peak flow rates at locations shown in **Figure 4.14** for the 1% AEP 2 hour critical duration storm are listed in **Table 4.1.**

Table 4.1: Peak Flow Rates – 1% AEP 2 hour Scenario 3

Section	Peak Flow (m^3/s)
Gosford CBD	
GA-1	2.7
GA-3	7.3
GA-2	1.1
GA-4	4.9
GA-5	1.9
GA-6	3.7
GA-7	7.3
West Gosford	
WA-1	6.1
WA-2	1.6
WA-3	5.6

Table 4.2 shows the number of property allotments with a depth of flooding greater than 0.2m in the Scenario 3 configuration for the 10% AEP, 1% AEP and PMF events. The properties inundated with depth greater than 0.3m in the 1% AEP event are also listed. Minor areas of localised ponding within a single property, such as at small depressions occurring in the terrain grid, have been excluded from the assessment.

Table 4.2: Properties Inundated – Scenario 3

Scenario 3 Model	Gosford CBD No. of Properties	West Gosford No. of Properties	Total No. of Properties
Inundation >0.2m			
10% AEP	236	202	438
1% AEP	281	241	522
PMF	573	385	958
Inundation >0.3m			
1% AEP	199	167	366

4.2.1 Comparison of Scenarios 1, 2, and 3

Figures 4.15 and 4.16 show the difference in flood extents for the Scenario 3 and Scenario 2 model configuration in the 1% AEP event. Note that the extents are filtered for depths >0.1m and velocity-depth product >0.1m^2/s. **Figures 4.17 and 4.18** show the difference in flood extents for the Scenario 3 and Scenario 1 model configuration in the 1% AEP event.

Table A.2 in **Appendix A** lists the peak water levels at the reference locations shown in **Figure 4.13** for the 1% AEP event for the three scenarios and the difference to the Scenario 3 configuration.

Flow behaviour in the Gosford CBD model zone is affected by the changes to the configuration of the grids and drainage systems for the three scenarios. The peak water level at Location GC-9 is unaffected by the change in the Scenarios as there are no buildings or piped drainage located in the contributing catchment area upstream. However, the flows downstream of Henry Parry Drive to Masons Parade show significant variation with the inclusion of the buildings in Scenario 3 (compared to Scenario 2). Flows across Dane Drive – Masons Parade are not affected by the change from Scenario 3 to Scenario 2. The exclusion of pipes from Scenario 1 results in higher flows across Henry Parry Drive (Location GC-10) and Dane Drive (GC-12).

Flows from Mann Street to The Gosford Broad Water are significantly affected by the inclusion of building footprints in the elevation grid of Scenario 3. In Scenarios 1 and 2, the flow travels overland across properties from Mann Street toward Baker Street, which are blocked out in Scenario 3. Levels at the intersection of Mann Street and Erina Street (Location of GC-3) are increased in Scenario 3 compared to Scenario 2, as the buildings block the passage of flow. However, the level at GC-3 is reduced for Scenario 2 to Scenario 1 due to the conveyance of water in piped drainage system.

At Location GC-2, the buildings in Scenario 3 result in more water ponding on the roadway compared to Scenarios 2 and 1.

In the West Gosford model zone, the peak water levels for the reference locations (in **Table A.2**) indicate a variation of up to 0.05m between the Scenarios. At Glennie Street West, the water level at Location WG-2 is unchanged for Scenario 3 to Scenario 2 as flows in this area are generally conveyed in the roadways and thus unaffected by the inclusion of buildings. Flow depths for Scenario 1 are higher as the piped drainage included in Scenarios 2 and 3 convey flow from this location.

Peak water levels are higher in the area just to the north of Gosford High School (near WG-3) for Scenarios 3 and 2 compared to Scenario 1, as the pipelines under Showground Road convey flow westward instead of overland going to the north.

Flow behaviour across properties from Faunce Street to Sinclair Street to Racecourse Road is influenced by the inclusion of buildings in Scenario 3. Comparison to the other Scenarios shows that the buildings change the path of flow, however flow is still directed across the properties.

Table 4.3 shows the number of properties which have a peak depth of flooding greater than 0.2m in the 1% AEP event for the three scenarios. Scenario 2 shows less properties inundated compared to Scenario 1 as a proportion of the flow is conveyed in the pipeline. Scenario 3 shows a higher number of properties inundated as runoff is retained on more properties due to the building structures and as runoff previously flowing over properties is conveyed in roadways adjacent to the buildings on properties.

Table 4.3: Properties Inundated >0.2m – 1% AEP Scenarios

1% AEP Event Model	Gosford CBD No. of Properties	West Gosford No. of Properties	Total No. of Properties
Scenario 1	315	195	510
Scenario 2	255	195	450
Scenario 3	281	241	522

In summary, Scenario 3 results in a more refined representation of the overland flow behaviour than Scenario 1 and 2 as the effect to flow behaviour due to the influence of buildings is more detailed. The number of properties affected in the Gosford CBD is reduced due to the conveyance of the pipe system included in Scenario 2 (compared to Scenario 1). However, the properties affected in West Gosford is not reduced due to the different catchment conditions whereby the residential properties are in the upper part of the catchment draining towards the golf course and racecourse areas downstream. For both sub-catchments the inclusion of buildings within Scenario 3 results in an increase in the number of properties affected as flowpaths are more restricted and may spread across additional properties to convey downstream.

Therefore, for future overland flow studies, the following could be adopted:

- **Scenario 1** – adopt this methodology for study areas when the stormwater infrastructure does not represent a major portion of the catchment or the capacity of the infrastructure is limited. Buildings within the floodplain do not represent major obstructions to flowpaths.
- **Scenario 2** – applicable for study areas where buildings do not represent a major obstruction to flowpaths.
- **Scenario 3** – adopt this for study areas where Scenario 1 and 2 are not applicable.

4.3 Provisional Hazard

Flood hazard can be defined as the risk to life and limb and damage caused by a flood. The hazard caused by a flood varies both in time and place across the floodplain. The Floodplain Development Manual (NSW Government, 2005) describes various factors to be considered in determining the degree of hazard. These factors are:

- Size of the flood,
- Depth and velocity of floodwaters,
- Effective warning time,
- Flood awareness,
- Rate of rise of floodwaters,
- Duration of flooding,
- Evacuation problems,
- Access.

Hazard categorisation based on all the above factors is part of establishing a Floodplain Risk Management Plan. The scope of the present study calls for determination of provisional flood hazards only, which when considered in conjunction with the above listed factors provides comprehensive analysis of the flood hazard.

Provisional flood hazard is determined through a relationship developed between the depth and velocity of floodwaters as detailed in the Floodplain Development Manual (NSW Government, 2005). The provisional hazard is defined as either High or Low and the transition zone between high and low is assumed as high hazard. Provisional hazard for the 1% AEP event in Scenario 3 configuration are shown in **Figures 4.19 and 4.20** for the Gosford CBD and West Gosford subcatchments respectively.

Provisional high hazard conditions are shown on several streets in the Gosford CBD catchment. Flows conveyed along streets upstream of William Street show high hazard flow conditions. Runoff is directed from these streets towards Kibble Park on Henry Parry Drive, with flow conveyed overland across the William Street pedestrian area to Mann Street. High hazard flows are shown at this location as well as at the Mann Street – Erina Street intersection.

Flows in the channel from Rumbalara Reserve across Henry Parry Drive to Masons Parade are shown as provisional high hazard in some locations. Dane Drive and Masons Parade have high provisional hazard flow conditions in some areas downstream of the open channel.

The flows occurring on the Pacific Highway and Racecourse Road in the West Gosford catchment are generally of provisional low hazard condition. High hazard conditions are shown on Moore Street and Fielders Lane, Batley Street North, and Showground Road north of Racecourse Road.

4.4 Hydraulic Categories

Hydraulic categorisation of the floodplain is used in the development of the Floodplain Risk Management Plan. The Floodplain Development Manual (2005) defines flood prone land to be one of the following three hydraulic categories:

- **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.

Floodways were determined for the 1% AEP event of Scenario 3 by considering those model branches that conveyed a significant portion of the total flow. These branches, if blocked or removed, would cause a significant redistribution of the flow. The criteria used to define the floodways are described below (based on Howells et al, 2003).

As a minimum, the floodway was assumed to follow the creekline from bank to bank. In addition, the following depth and velocity criteria were used to define a floodway:

- Velocity x Depth product must be greater than 0.25 m^2/s and velocity must be greater than 0.25 m/s; OR
- Velocity is greater than 1 m/s.

Flood storage was defined as those areas outside the floodway, which if completely filled would cause peak flood levels to increase by 0.1 m and/or would cause peak discharge anywhere to increase by more than 10%. The criteria were applied to the model results as described below.

Previous analysis of flood storage in 1D cross sections assumed that if the cross-sectional area is reduced such that 10% of the conveyance is lost, the criteria for flood storage would be satisfied To determine the limits of 10% conveyance in a cross-section, the depth was determined at which 10% of the flow was conveyed. This depth, averaged over several cross-sections, was found to be 0.2 m (Howells et al, 2003). Thus the criteria used to determine the flood storage is:

- Depth greater than 0.2m
- Not classified as floodway.

All areas that were not categorised as Floodway or Flood Storage, but still fell within the flood extent, where the depth is greater than 0.1 m, are represented as Flood Fringe.

The hydraulic categories for the 1% AEP event in Scenario 3 configuration based on the peak depth and velocity from local catchment runoff determined in the flood model, are shown in **Figures 4.21 and 4.22** for the Gosford CBD and West Gosford subcatchments respectively.

Flow conditions categorised as floodway are shown in several areas of the Gosford CBD subcatchment, particularly Erina Street East through Henry Parry Drive to the pedestrian walkway at Mann Street and along the channel from Rumbalara Reserve to Dane Drive. In the West Gosford Subcatchment, floodway area is noted at Gosford Golf Course and at Moore Street and Fielders Lane.

4.5 Sensitivity Analysis

The sensitivity of the model was tested to demonstrate the range of uncertainty in the model results for changes in key parameters. The following variables were tested for sensitivity in the Scenario 3 configuration for the 1% AEP 2 hour critical duration event:

- Catchment rainfall – increased and decreased by 20%
- Catchment roughness – increased and decreased by 20%

The effect of potential blockage of the piped drainage system can be assessed by comparison of the Scenario 1 and Scenario 2 configurations. Changes to flood behaviour due to the adopted boundary condition at Fagans Bay and The Gosford Broad Water is assessed in the climate change analysis described in **Section 4.5**.

4.5.1 Rainfall

Peak water levels for the catchment reference points (see **Figure 4.13**) are listed in **Table A.3** in **Appendix A** for the cases of a 20% increase and decrease to the rainfall intensity.

Changes to the rainfall intensities show changes in peak water levels above 0.1m in some locations. For Gosford CBD, runoff ponds at locations GC-1, GC-3, and GC-11 and thus the increased rainfall volume results in the changes to peak water levels. Location GC-9 is located in a well-defined channel where flows concentrate, thus the increased rainfall results in a higher depth of flow (and vice versa).

In the West Gosford model zone, the changes to rainfall result in minor changes to peak water levels (<0.05m) in most locations. Changes between 0.05m to 0.10m occur in the Racecourse and Showground / Greyhound Track where water ponds, and in the central depression of the Golf Course where flows are concentrated as it is conveyed to Narara Creek.

4.5.2 Roughness

Peak water levels for the catchment reference points are listed in **Table A.4** in **Appendix A** for the cases of a 20% increase and decrease to the roughness grid.

In the Gosford CBD model zone, the case of roughness down 20% shows decreases in peak water levels in the upstream areas and increases in downstream areas. Upstream of Henry Parry Drive shows a decrease, whilst areas such as the Mann Street-Erina Street intersection and near Central Coast Leagues show an increase. For the case of roughness up 20%, the opposite occurs and increases result to peak levels upstream and decreases to downstream areas. The difference in peak water levels to the base case is less than 0.10m for both variations in roughness parameter cases.

Peak water levels in the West Gosford model zone show variations of less than 0.03m in scattered locations for the varied roughness cases. Increases in the roughness parameter on the grid results in an increase in peak water levels, compared to a 20% decrease in the roughness parameter which shows a decrease. Overall, there is limited variation for the changed roughness, generally less than 0.03m and no change to levels at the reference points.

In general, only relatively small changes in peak water levels are observed for changes in model roughness.

4.6 Climate Change

Changes to climate conditions are expected to have an adverse impact on sea levels and rainfall intensities. An assessment on the impact of climate change on flood behaviour in the Study Area has been undertaken for the following scenarios:

- Sea level increased by 0.2m, 0.4m and 0.9m;
- Rainfall increased by 10%, 20% and 30%; and
- Rainfall increased by 30%, combined with a sea level increase of 0.4m and 0.9m respectively.

The 1% AEP 2 hour critical duration storm for Scenario 3 configuration was used as a base case to assess the potential impacts.

4.6.1 Sea Level Increase

The Brisbane Water Foreshore Flood Study (2009) noted that a rise in the offshore tidal level would generally result in an equivalent rise in estuary level. Increases of 0.2m, 0.4m, and 0.9m were applied to the 1% PoE boundary condition in the models. The modelled downstream boundary levels are shown in **Table 4.4.**

Table 4.4: Boundary Conditions – Climate Change Scenarios

Description	Base Case 1% PoE	Plus 0.2m	Plus 0.4m	Plus 0.9m
Gosford CBD – level at The Broad Water	0.72	0.92	1.12	1.62
West Gosford – level at Narara Creek entrance in Fagans Bay	0.75	0.95	1.15	1.65

Changes in the peak water levels for the sea level rise scenarios at the reference locations (shown in **Figure 4.13**) are listed in **Table A.5** in **Appendix A**.

The difference in peak water levels of the climate change condition with boundary condition plus 0.9m compared to the base case (1% AEP 2 hour event) are shown in **Figures 4.23**

and 4.24 for the two modelled catchments. The differences in flood extent for the 0.9m sea level rise scenario are shown in **Figures 4.25 and 4.26**.

A 0.9m increase to the boundary level at The Gosford Broad Water results in an increase to peak water levels in several areas in the Gosford CBD catchment. Dane Drive and Masons Parade near the open channel have an elevation around 1.5m AHD, which is below the 1.62m AHD water level in The Gosford Broad Water for the scenario. Properties adjacent to the open channel experience an increase in peak water level of up to 0.05m. The increase in flood level at this location is influenced by the increased water level downstream which reduces the conveyance capacity within the channel itself.

Dane Drive / Pacific Highway along the foreshore between the railway and Vaughan Avenue, has sections with elevation below 1.5m AHD, resulting in an increase in peak water level of up to 0.17m in the 0.9m elevated scenario. Streets around the leagues club, including Georgiana Terrace, are also below 1.5m AHD and thus also show increased peak water levels. The intersection of Donnison Street and Baker show an increase in peak water level, though it has an elevation above 2.2m AHD, due to the reduced conveyance of water from the location through the pipe system and increased backwater levels. The decreased capacity of the drainage system results in increases of up to 0.38m at the lowpoint between Baker Street multi-storey carpark and up to 0.05m at the intersection of Mann Street and Erina Street.

Several areas within the West Gosford model zone show an increase in peak water levels resulting from the 0.9m increase to the level in Narara Creek and Fagans Bay. The Pacific Highway at the intersection with Racecourse Road, and surrounding areas, such as Adcock Avenue and Racecourse Road, have an elevation below 1.5m AHD which are inundated in the raised water level scenario. Similarly inundated are the Racecourse, which has an elevation around 0.8m AHD, and the Golf Course which has areas below the raised water level of 1.65m AHD. In the Glennie Street West Industrial Area, roads around the intersection of Glennie Street West and Tatura Avenue, which have an elevation above 1.8m AHD, experience a 0.03m increase to peak water levels due to the reduced drainage capacity.

4.6.2 Rainfall Increase

The NSW Department of Environment and Climate (DECC, now DECCW) guideline, Practical Consideration of Climate Change (2007), provides advice for consideration of climate change in flood investigations. The guideline recommends sensitivity analysis is done for rainfall intensity increases of 10%, 20%, and 30%.

Peak water levels listed in **Table A.6** (in **Appendix A**) shows that some locations in Gosford CBD experience a significant increase of water level as rainfall increases. For example, the water level at the reference point GC-1 increases by 0.51m as rainfall increases by 30%. However, it appears that an increase of rainfall up to 30% results in a limited impact on water levels in West Gosford Catchment.

Figures 4.27 and 4.28 show the flood extent for the 30% rainfall increase scenario and the base case for Gosford CBD and West Gosford respectively. Note that the extents shown have been filtered for depths >0.1m and velocity-depth product >0.1m^2/s. The area around

Baker Street in Gosford CBD shows a significant expansion in flood extent for the 30% rainfall increase scenario. In West Gosford, there is an increase in extents to flood affected locations but not the substantial increase in a particular road that is evident in Gosford CBD.

4.6.3 Increase of Rainfall and Sea Level

Two scenarios of both increase to rainfall and sea level were modelled to evaluate the potential effect of these climate change impacts. A rainfall increase of 30% was modelled with increases of 0.4m and 0.9m to the downstream boundary level.

Table A.7 (in **Appendix A**) lists the resultant peak water levels for the scenarios at the reference locations (shown in **Figure 4.13**). **Figures 4.29 and 4.30** show the comparative flood extents for the 1% AEP 2hour event with 30% rainfall increase and 0.9m sea level rise.

5 Conclusion

Flood modelling using the SOBEK 1D/2D hydraulic model was completed for a series of storm events, from 10% AEP to PMF, for the Gosford CBD and West Gosford catchments. Flow behaviour was modelled for three different scenarios of detail included in the model:

- **Scenario 1 –** The piped stormwater drainage systems are considered ineffective (ie blocked and is thus not included in the model) resulting in all flows conveyed overland.
- **Scenario 2 –** The main trunk drainage system, consisting of pipes 600mm diameter and larger, is included.
- **Scenario 3 –** Building footprints in the flowpath are incorporated into the model and the main trunk drainage system of Scenario 2 is included.

The modelling showed that the different configurations of data input to the model can have a significant effect on flood results. For both catchments modelled, the Scenario 3 configuration is the most refined representation of results and is potentially the best indication of flood behaviour. Scenario 2 configuration is less data-intensive but the nature of development within individual areas would determine its applicability. Flood modelling in Scenario 1 configuration may be suited to less-urbanised catchments which have less infrastructure.

This Study defines local overland flow behaviour in the catchment. Flood modelling has enabled the generation of GIS layers for outputs including peak depth, peak water level, velocity and provisional hazard for a range of events and scenarios. These GIS layers are provided for Council to incorporate into their mapping system and the flood models are provided to enable evaluation of other scenarios.

The Study results can be used by Council to inform future masterplanning in the catchment, to identify property affectation criteria for development assessment, and to evaluate potential flood mitigation measures. A formal Floodplain Risk Management Study and Plan may be an appropriate next stage of the flood management process in the catchment.

6 References

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Figures

FIGURE 1.1
STUDY AREA LOCALITY

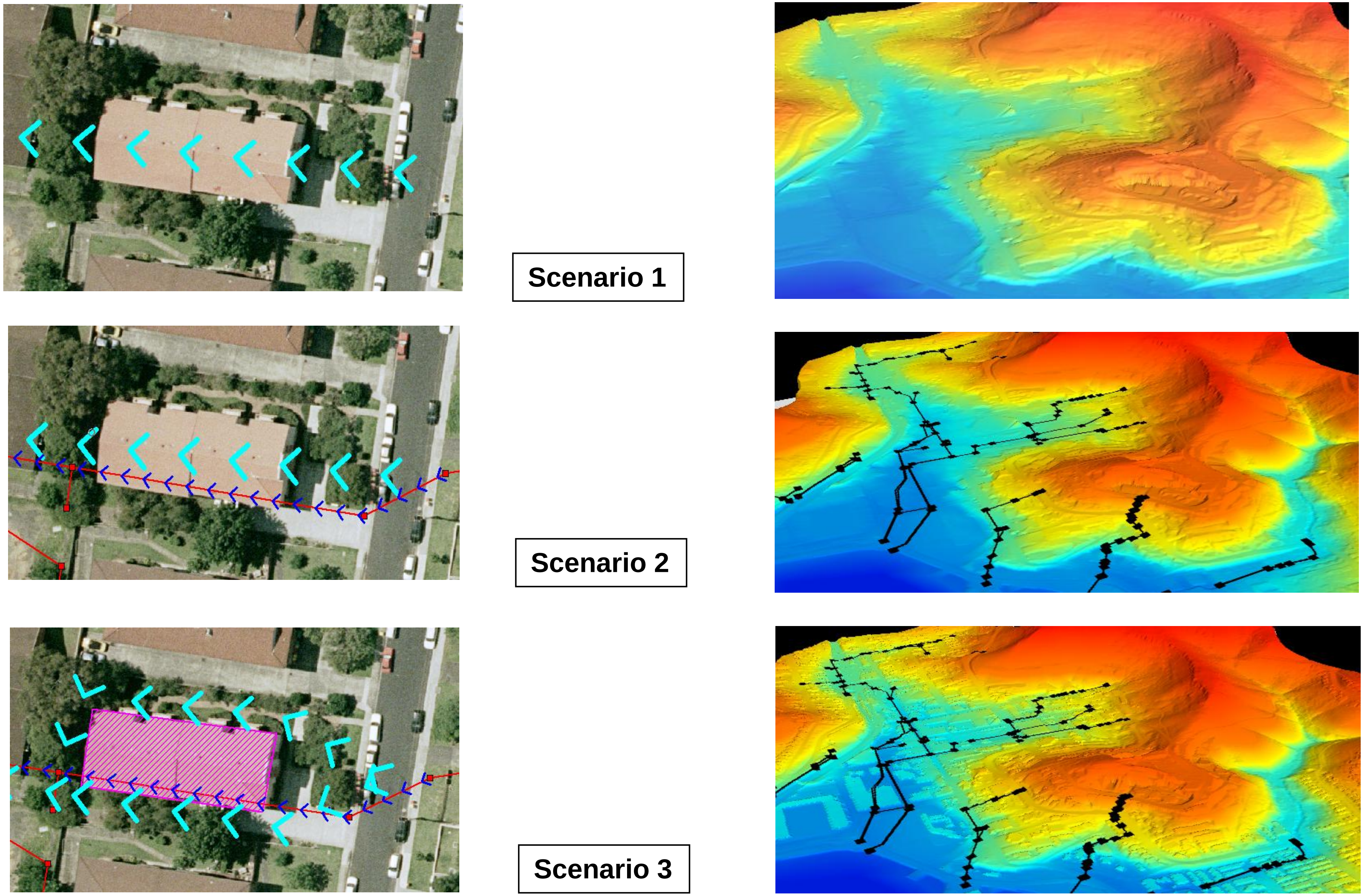
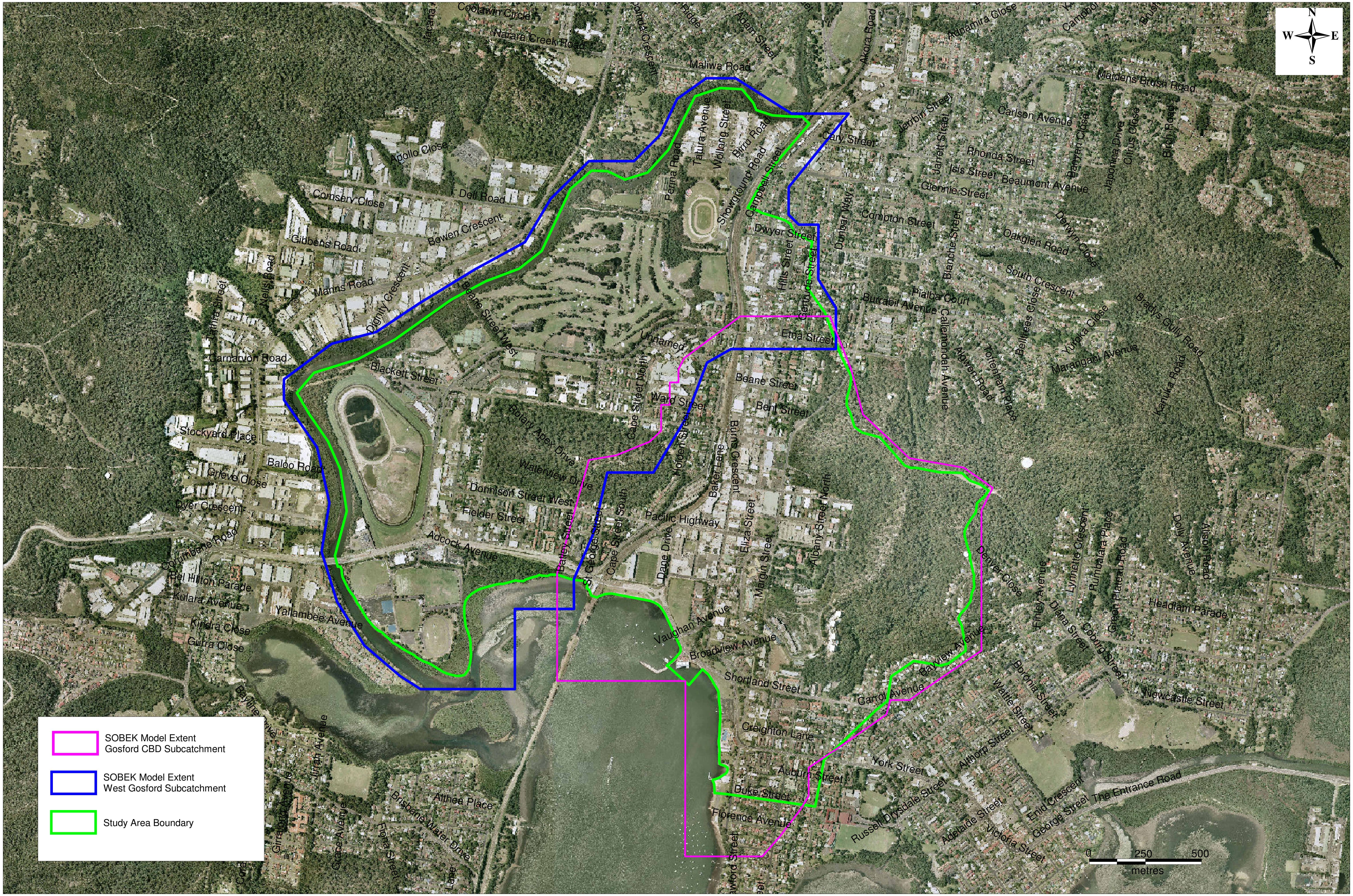


FIGURE 3.1
SCENARIO SCHEMATICS



W4816/V4
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FIGURE 3.2
SUBCATCHMENT MODEL LAYOUT

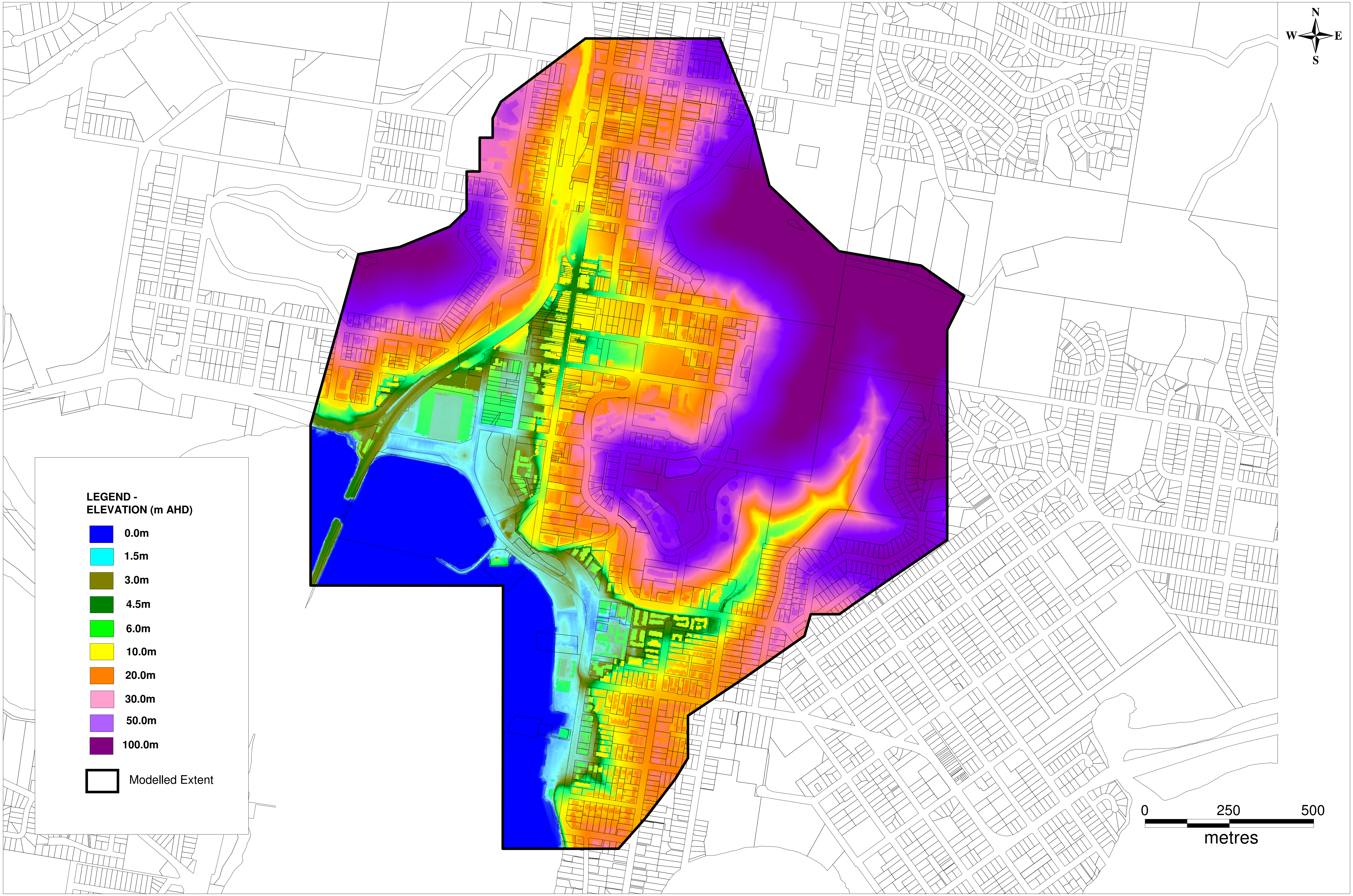

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FIGURE 3.3
GROUND ELEVATION-GOSFORD CBD MODEL

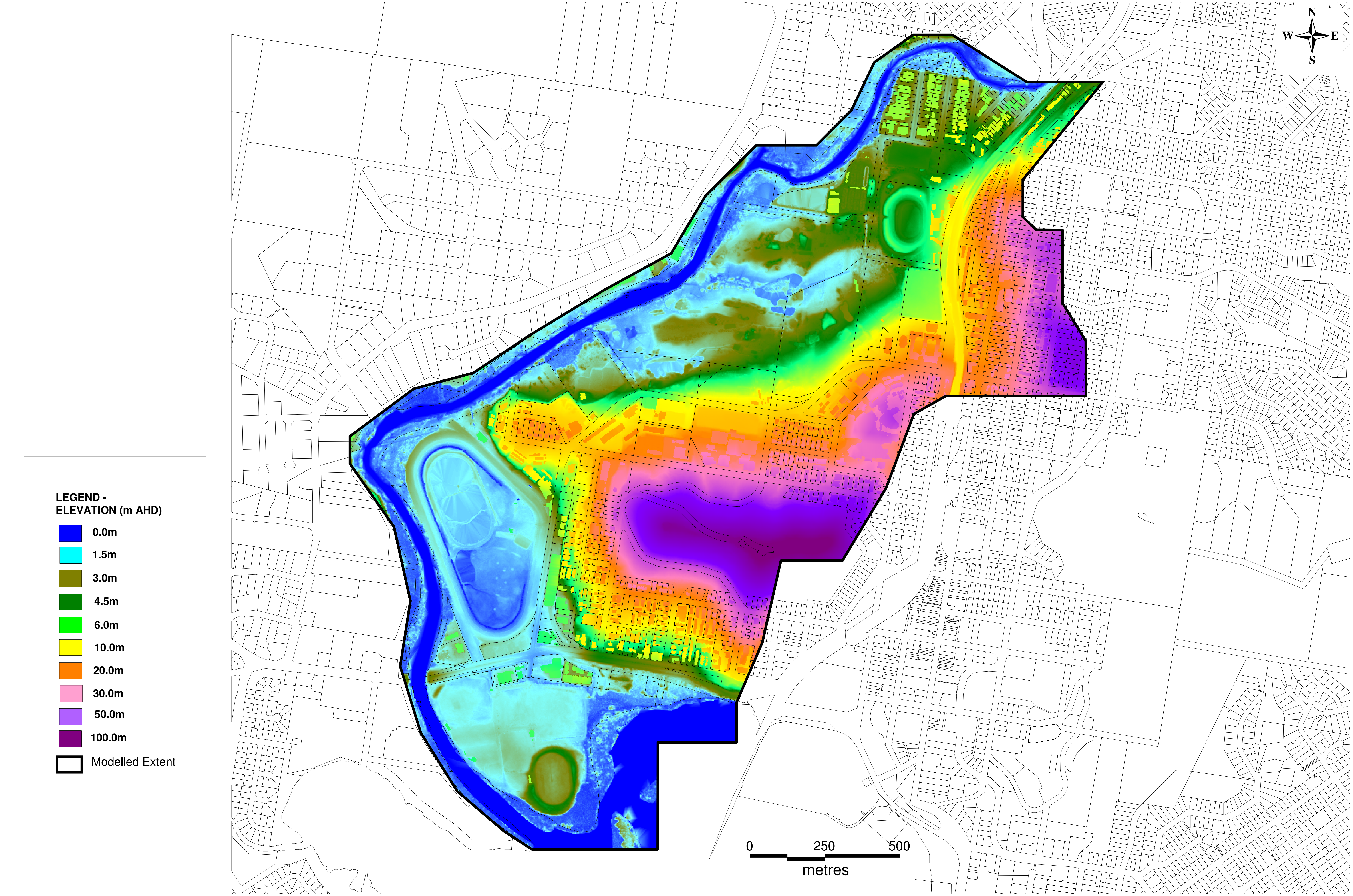

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FIGURE 3.4
GROUND ELEVATION- WEST GOSFORD MODEL

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FIGURE 3.5
SOBEK MODEL SCENARIO 3 - BUILDING OUTLINES

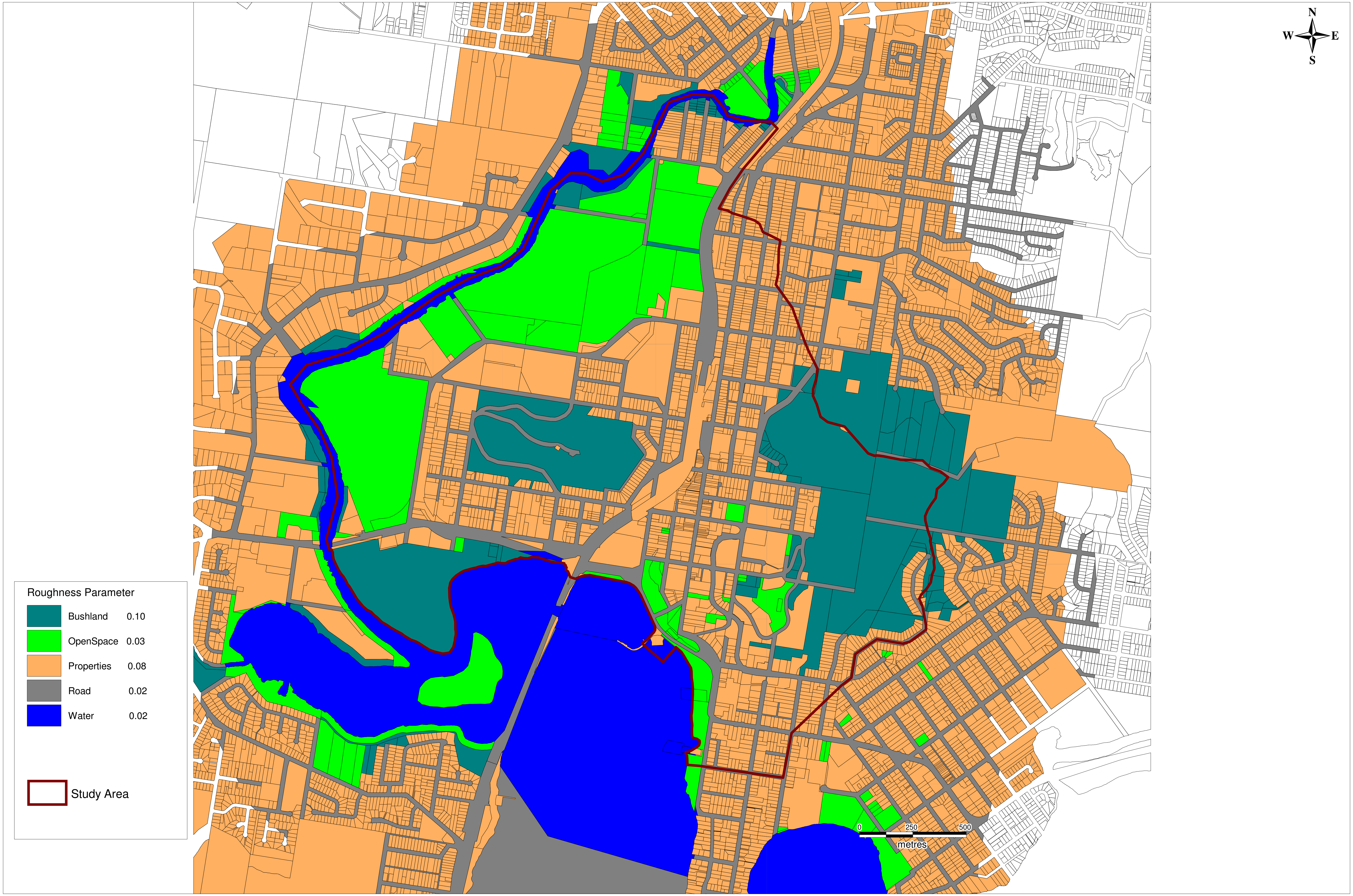

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FIGURE 3.6
SOBEK MODEL - ROUGHNESS LAYOUT

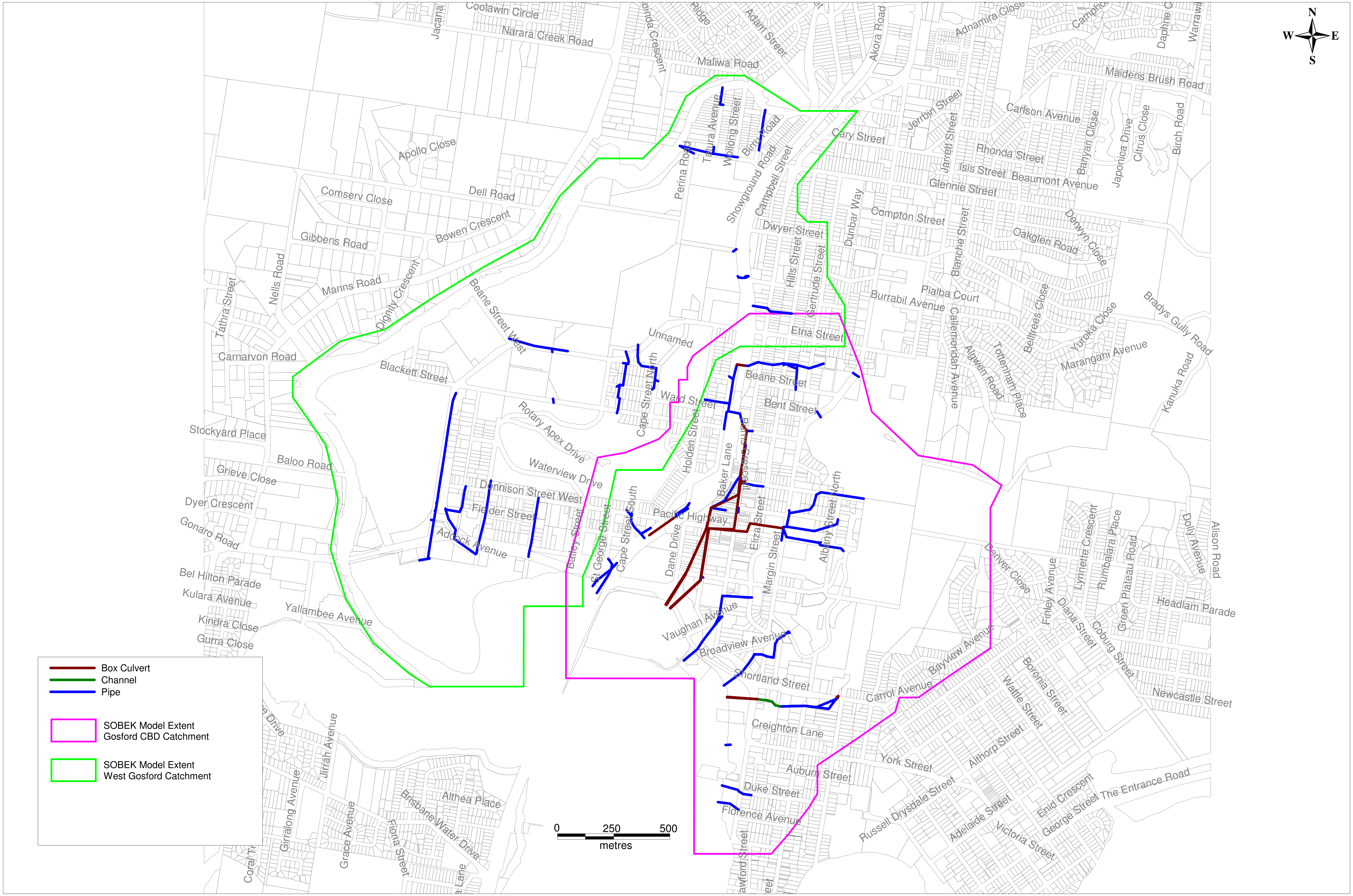

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FIGURE 3.7
SOBEK MODEL - 1D DRAINAGE SYSTEM

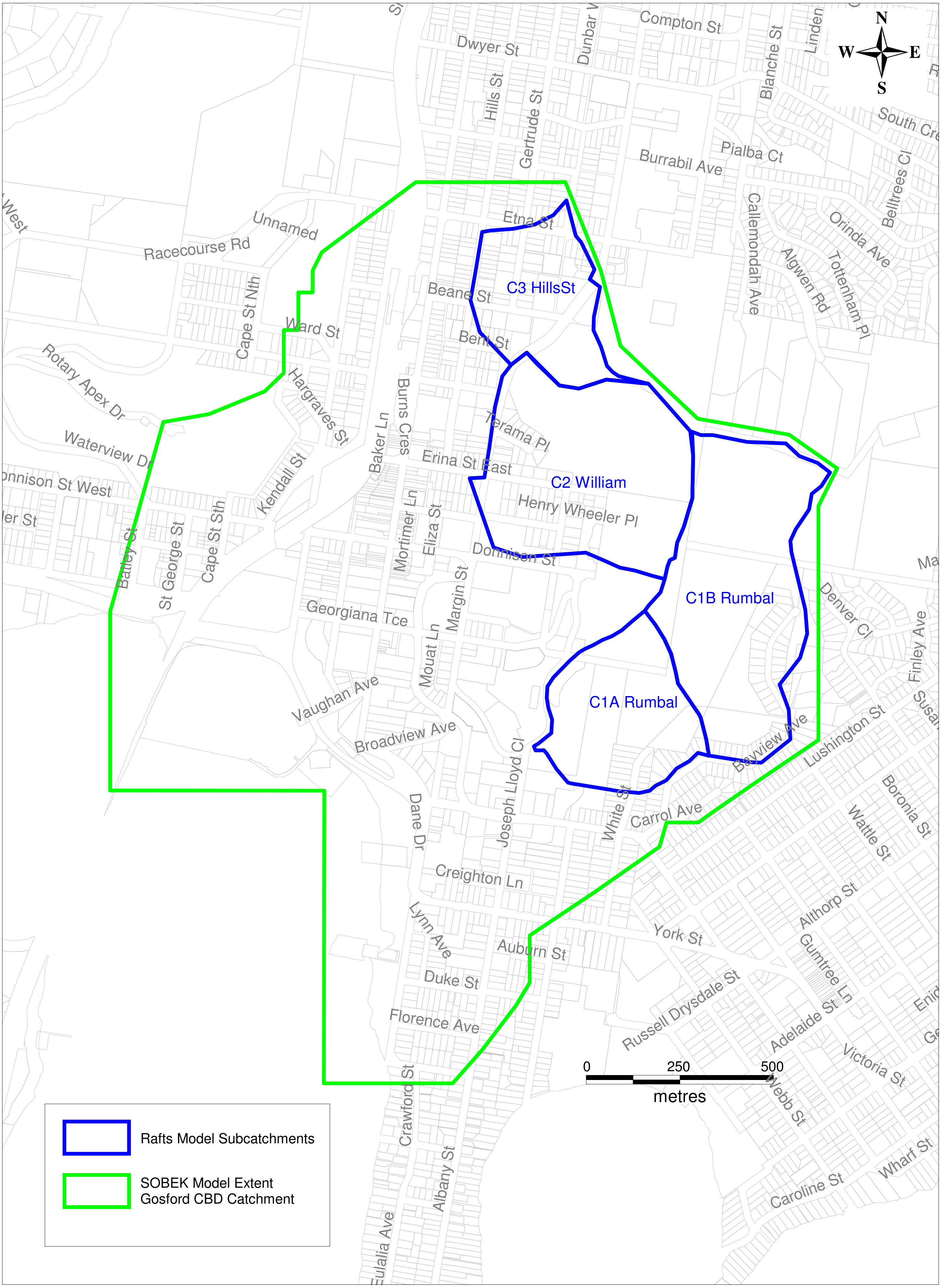

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FIGURE 3.8
RAFTS MODEL - SUBCATCHMENTS

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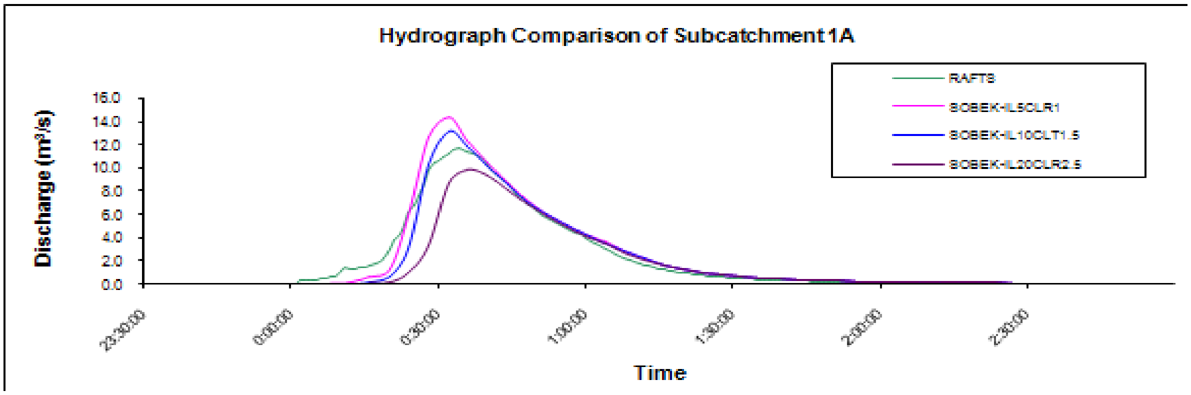

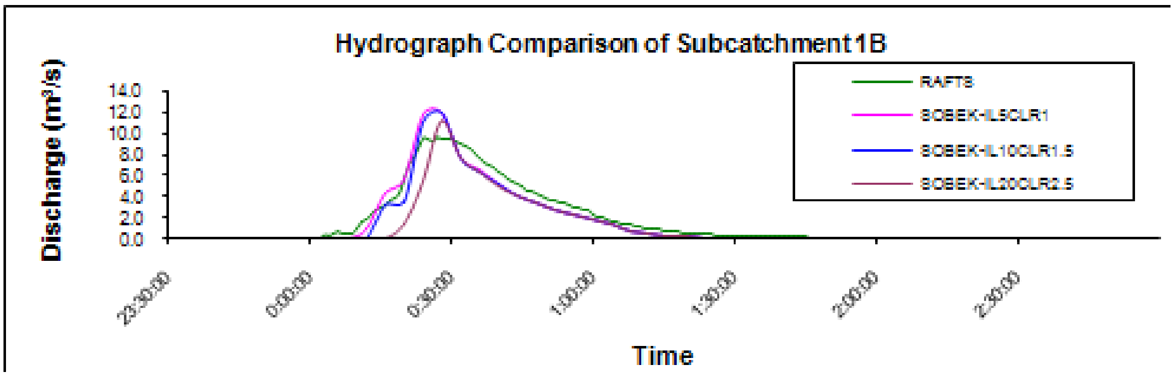

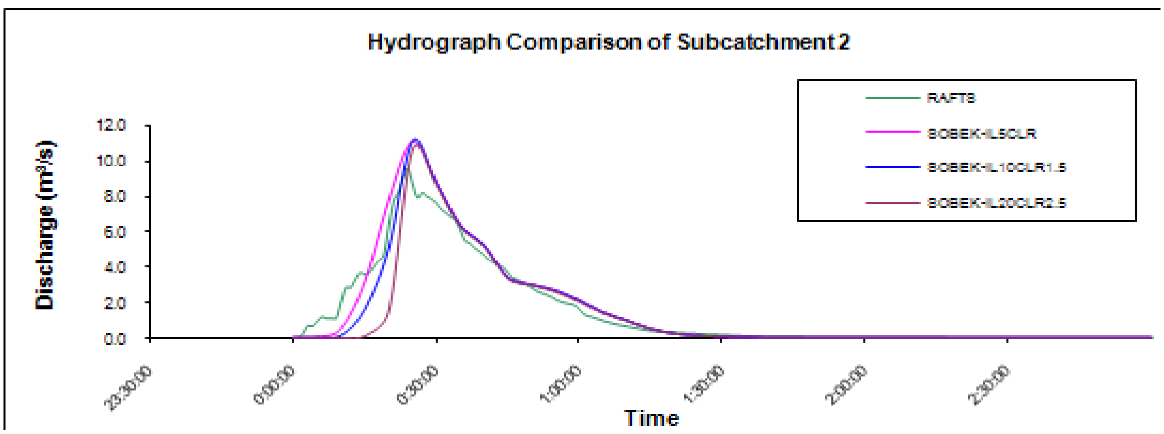

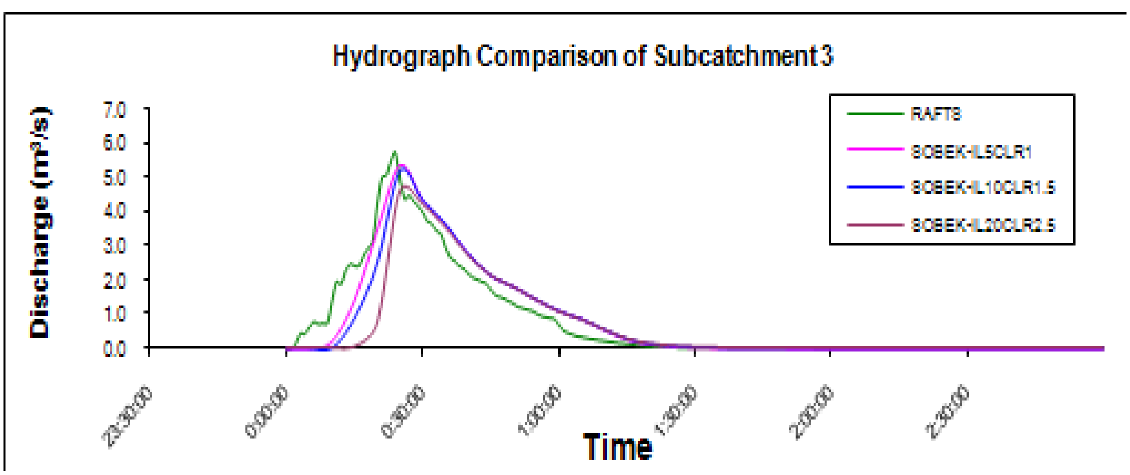

FIGURE 3.9

RAFTS HYDROGRAPHS FOR LOSS RATES

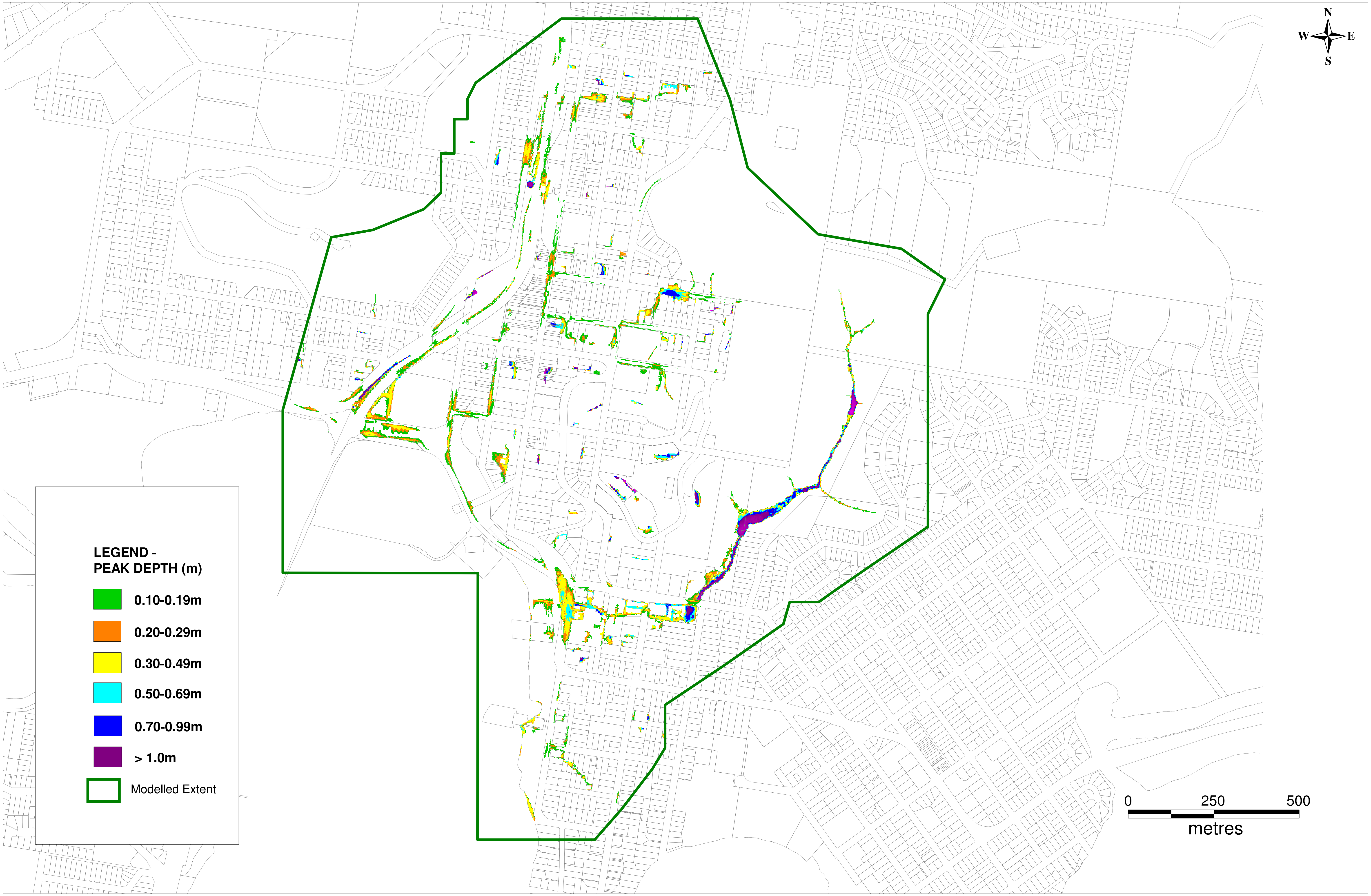

FIGURE 4.1
PEAK FLOOD DEPTHS - GOSFORD CBD 10% AEP SCENARIO 3

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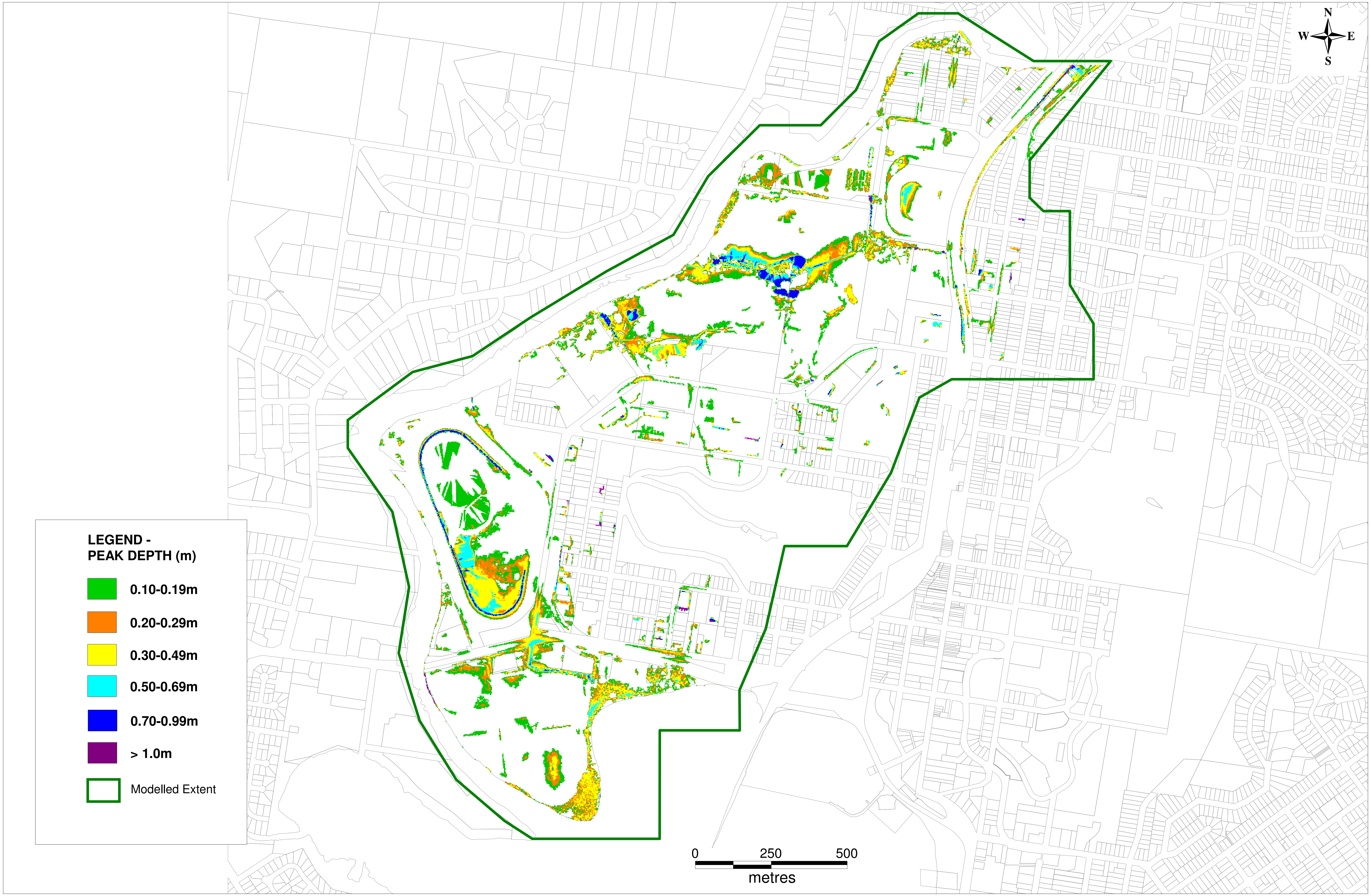

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FIGURE 4.2
PEAK FLOOD DEPTHS - WEST GOSFORD 10% AEP SCENARIO 3

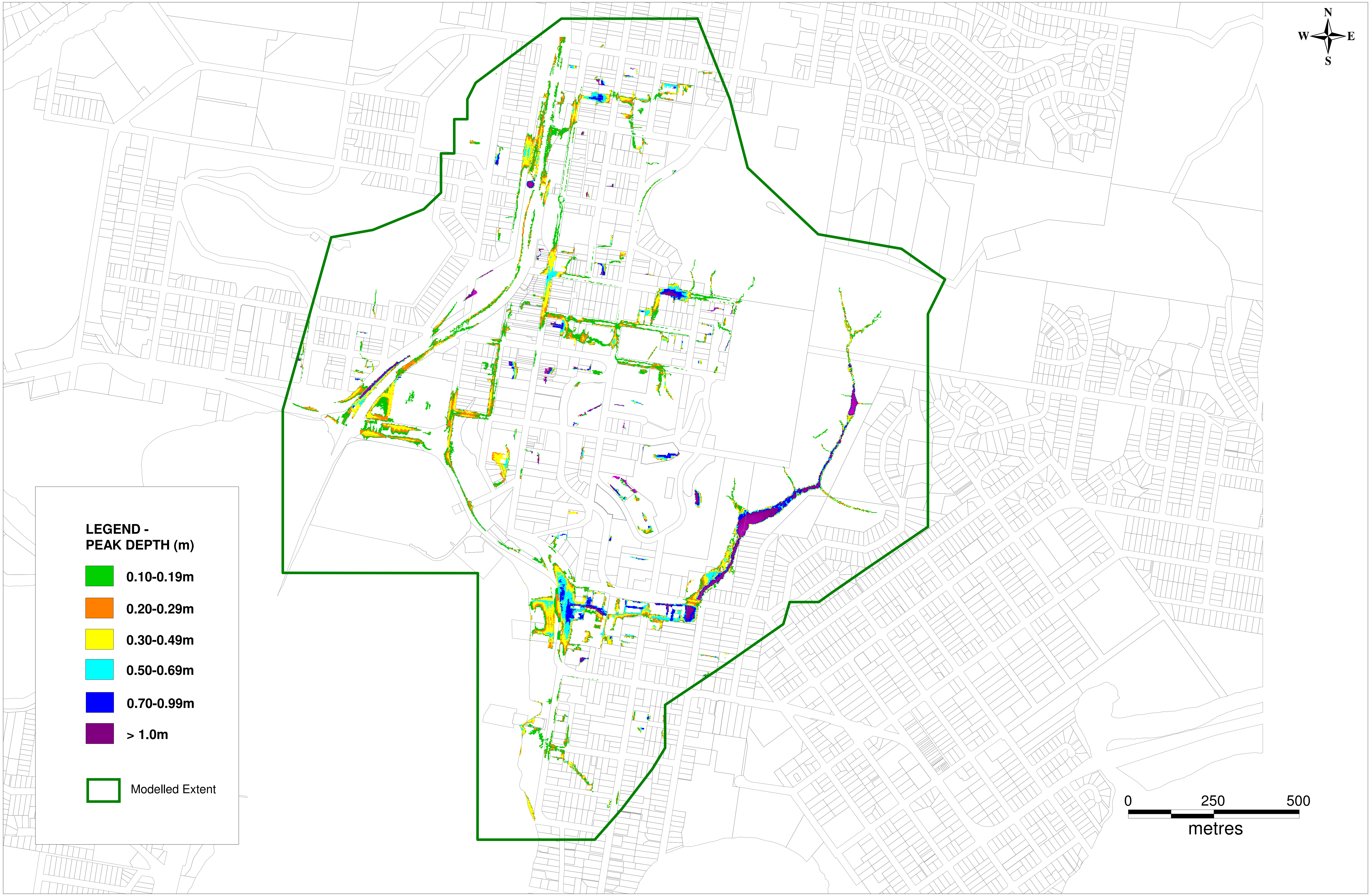

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FIGURE 4.3
PEAK FLOOD DEPTHS - GOSFORD CBD 1% AEP SCENARIO 3

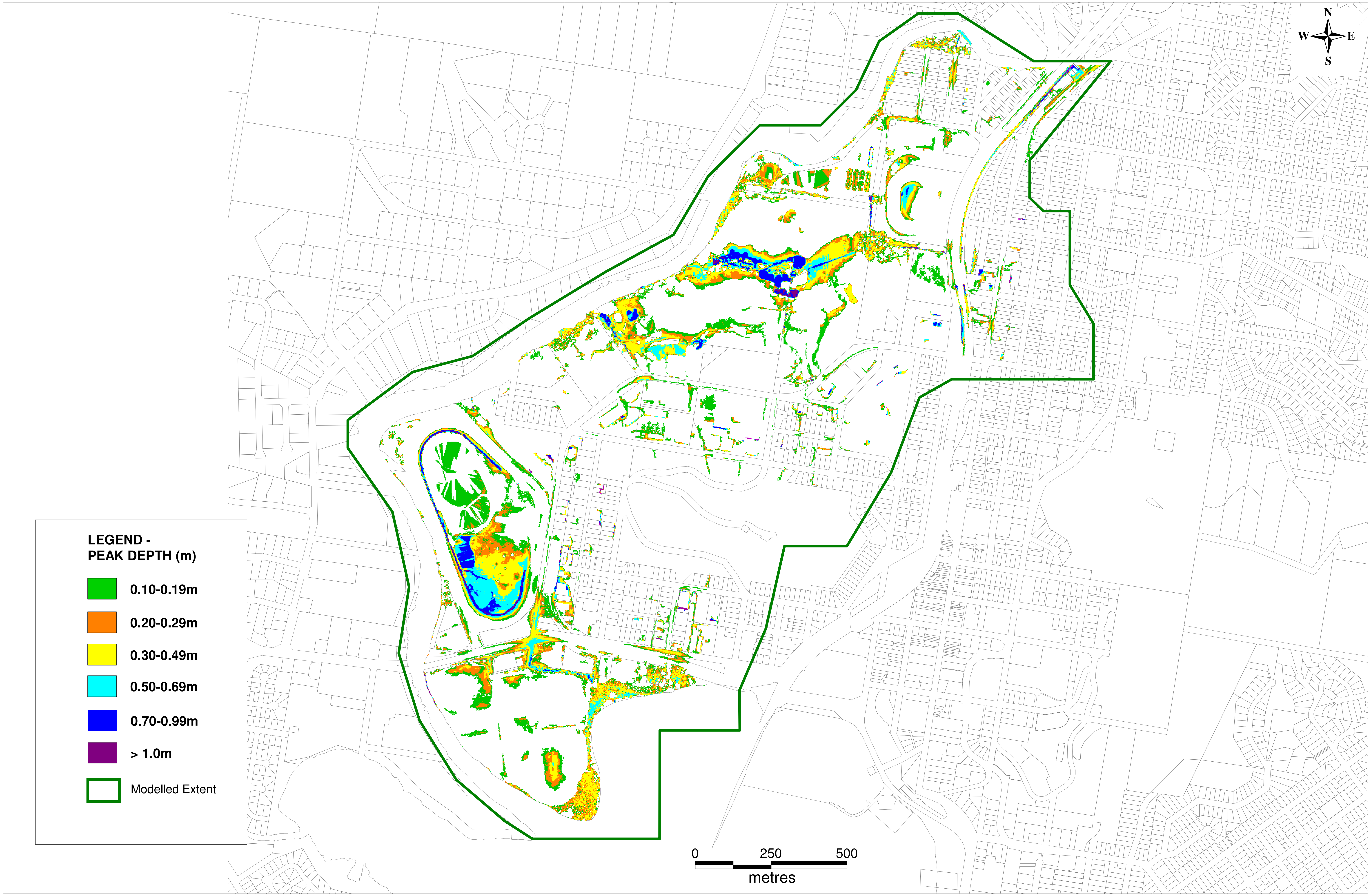

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FIGURE 4.4
PEAK FLOOD DEPTHS - WEST GOSFORD CBD 1% AEP SCENARIO 3

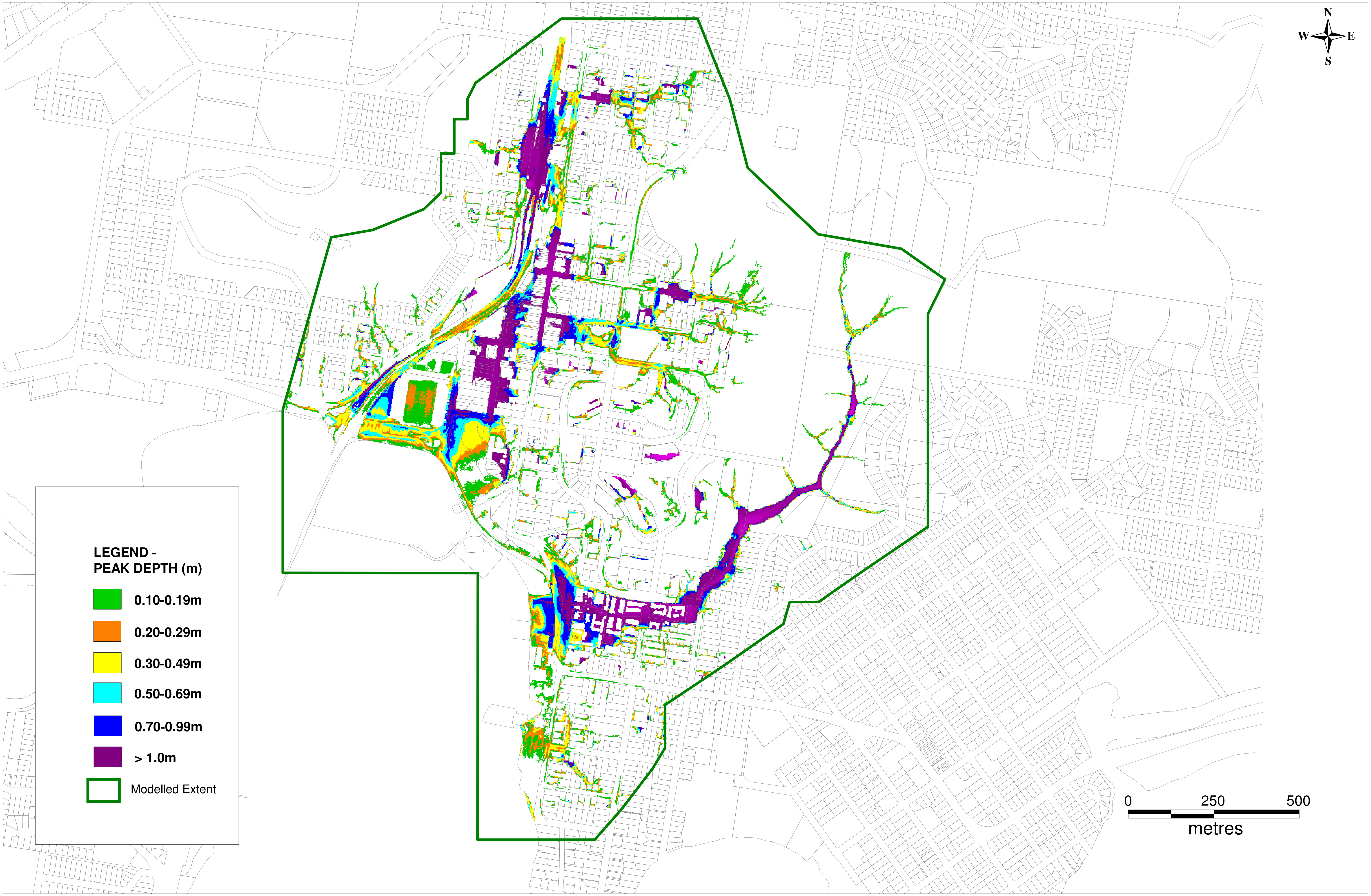

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FIGURE 4.5
PEAK FLOOD DEPTHS - GOSFORD CBD PMF SCENARIO 3

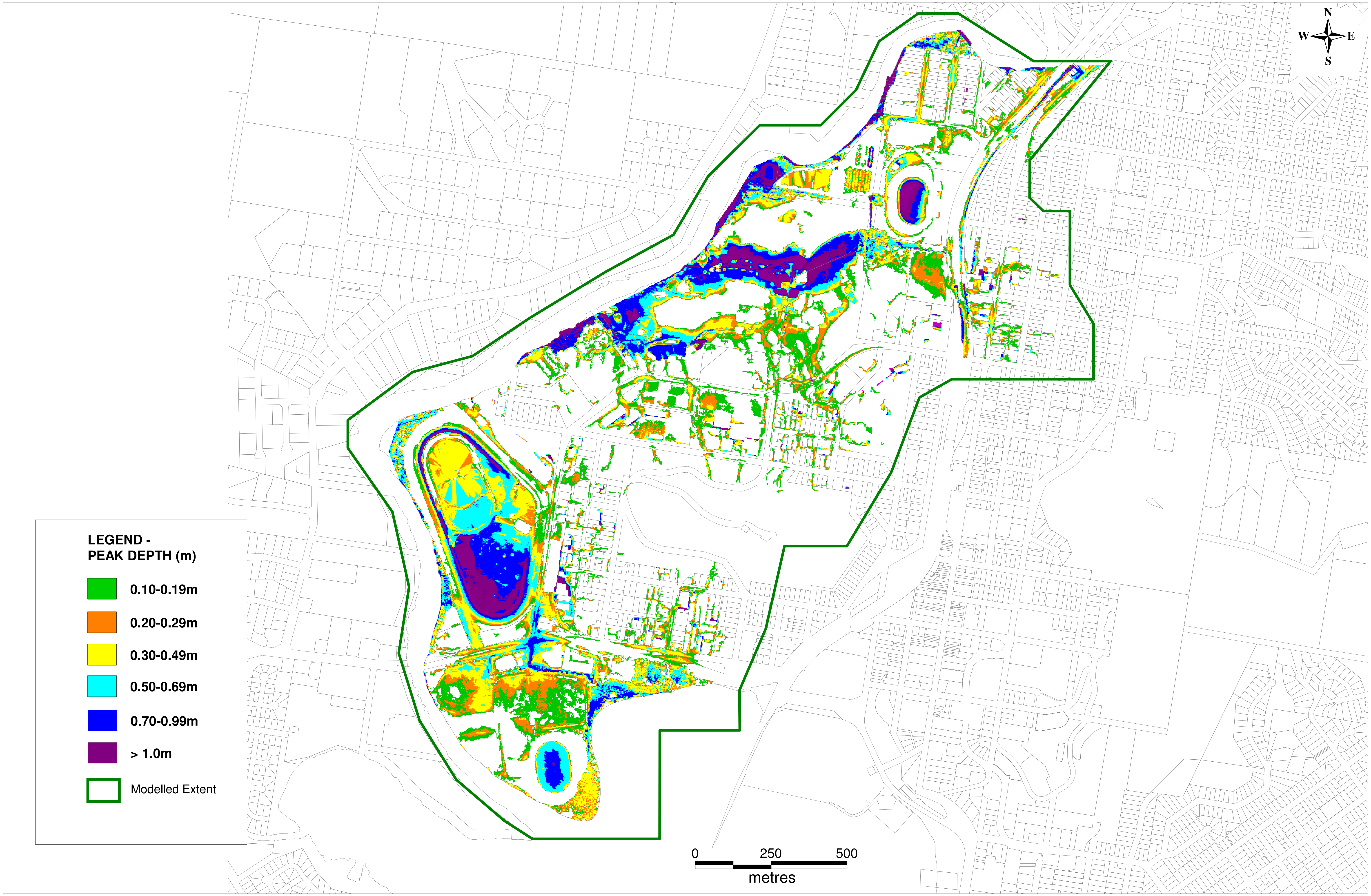

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FIGURE 4.6
PEAK FLOOD DEPTHS - WEST GOSFORD PMF SCENARIO 3

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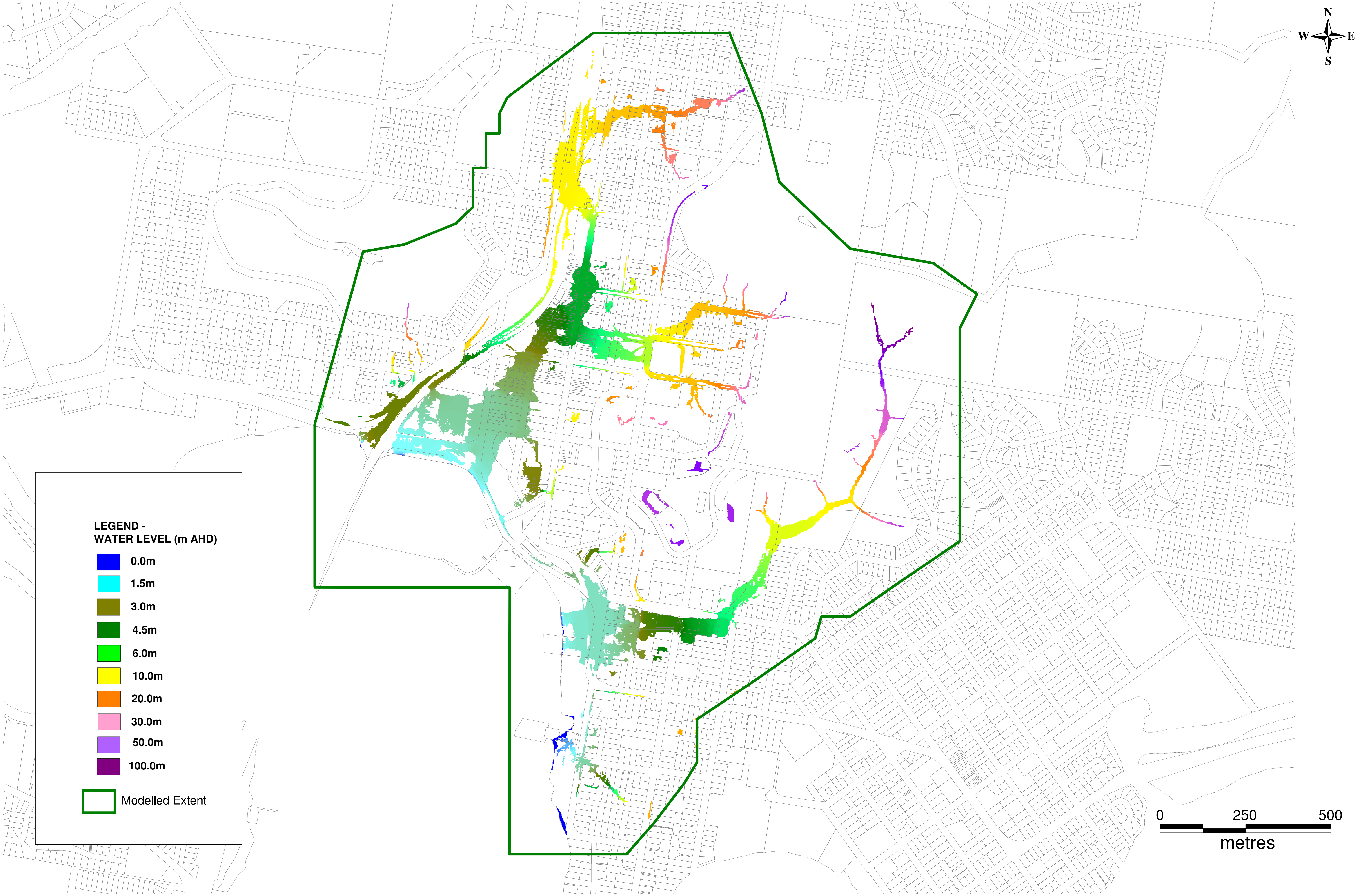

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FIGURE 4.7
GOSFORD CBD CATCHMENT-PEAK WATER LEVEL-1% AEP SCENARIO 1

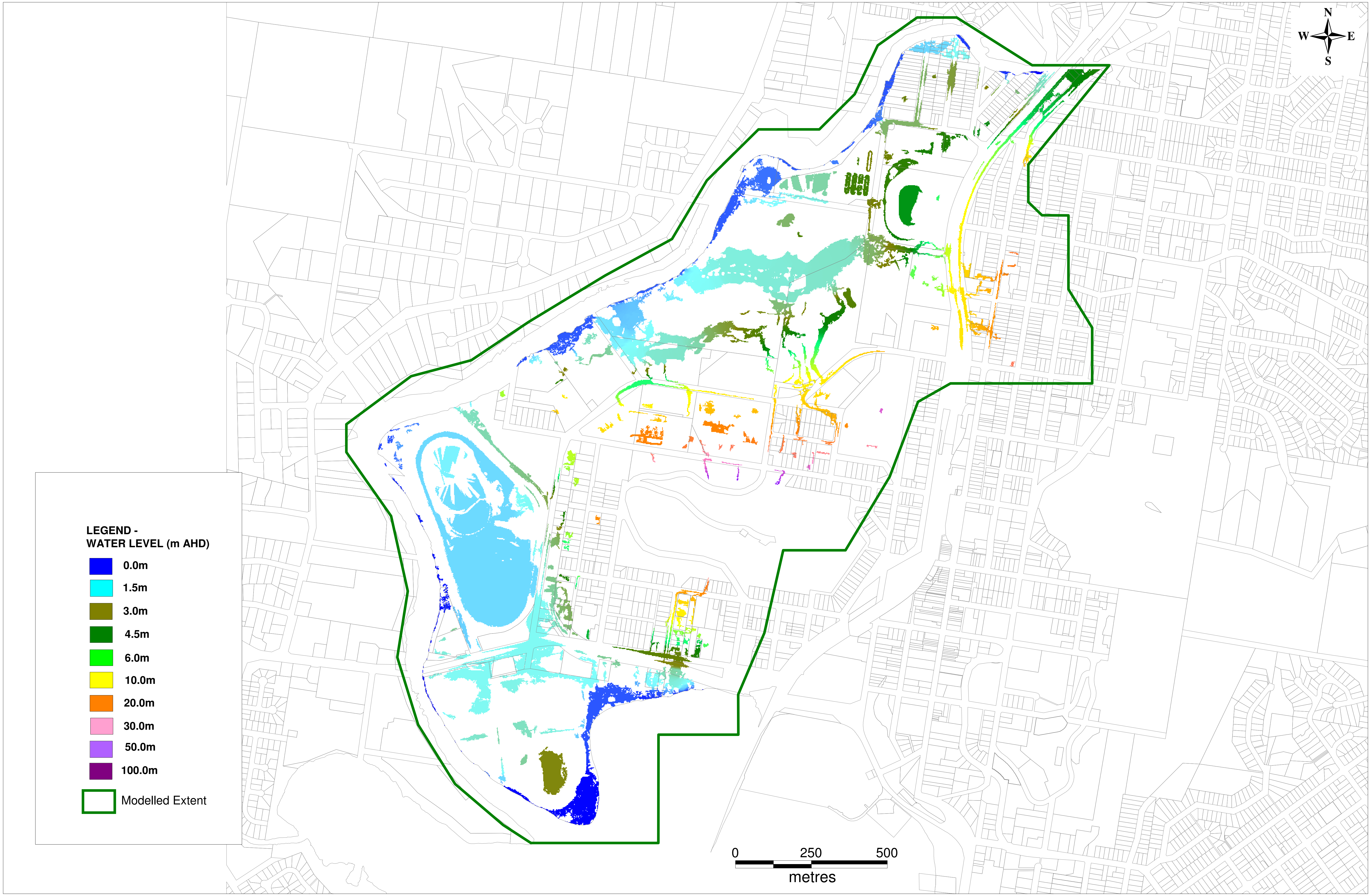

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FIGURE 4.8
WEST GOSFORD CATCHMENT-PEAK WATER LEVEL-1% AEP SCENARIO 1

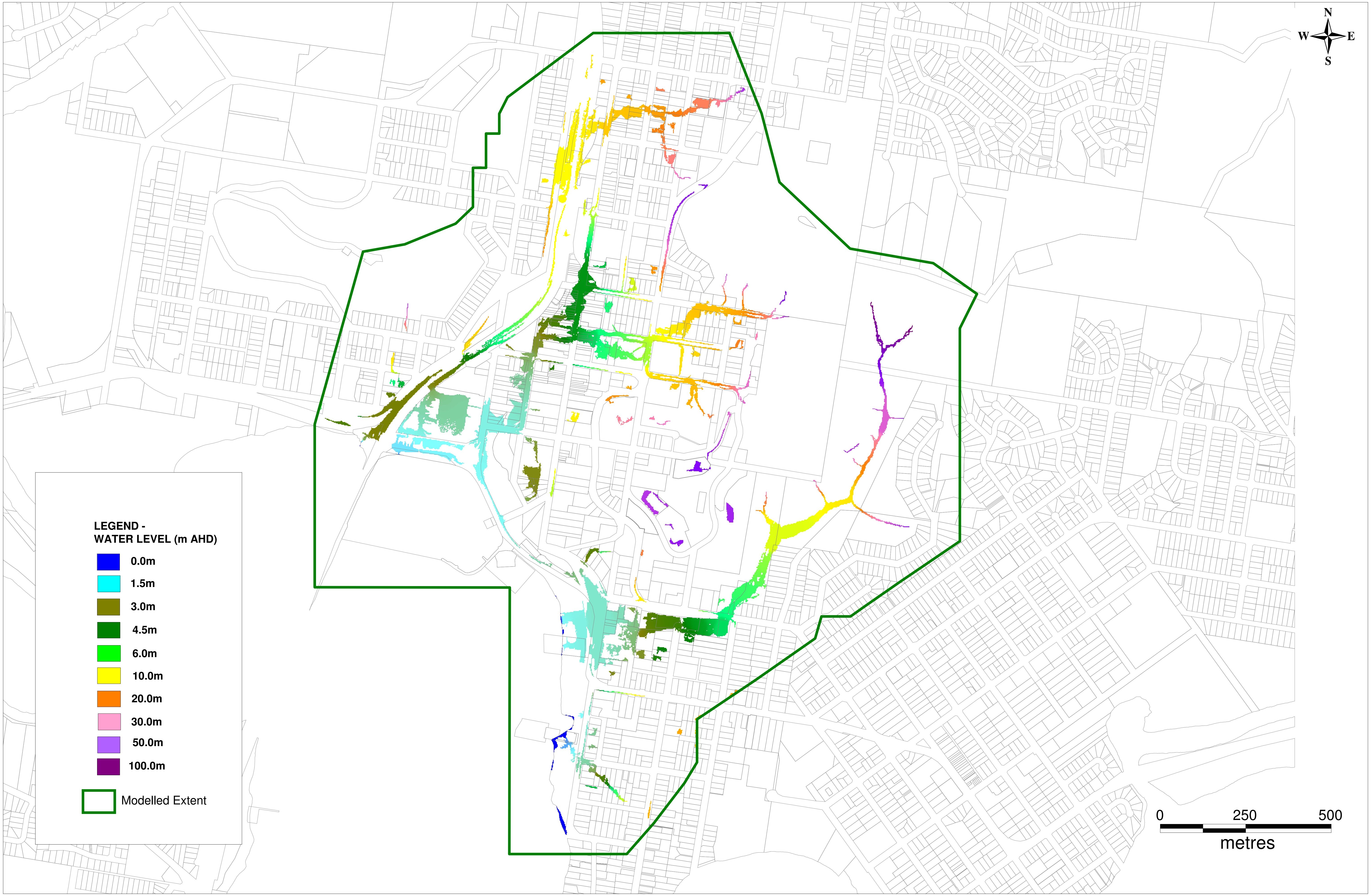

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FIGURE 4.9
GOSFORD CBD CATCHMENT-PEAK WATER LEVEL-1% AEP SCENARIO 2

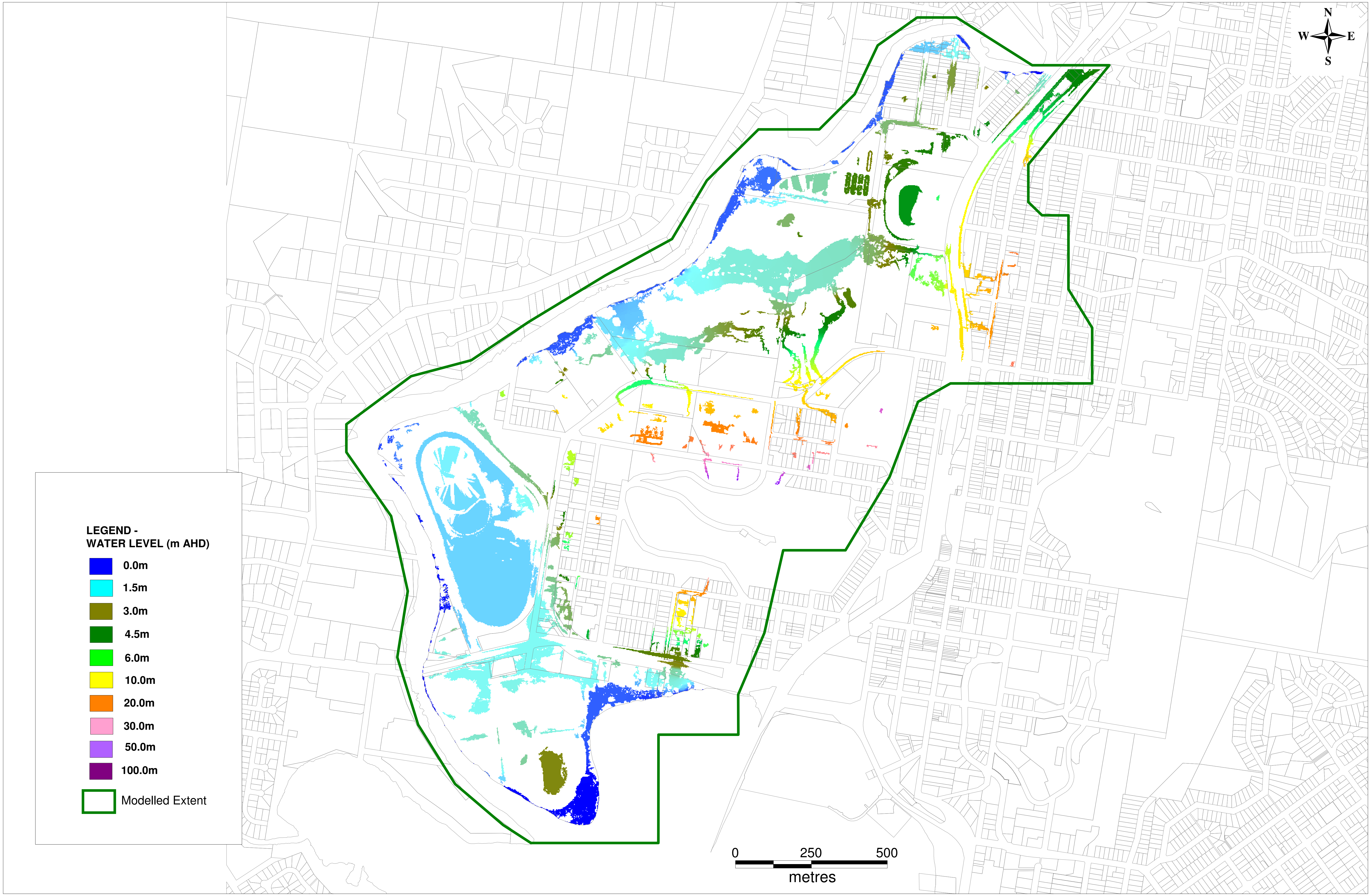

FIGURE 4.10
WEST GOSFORD CATCHMENT-PEAK WATER LEVEL-1% AEP SCENARIO 2

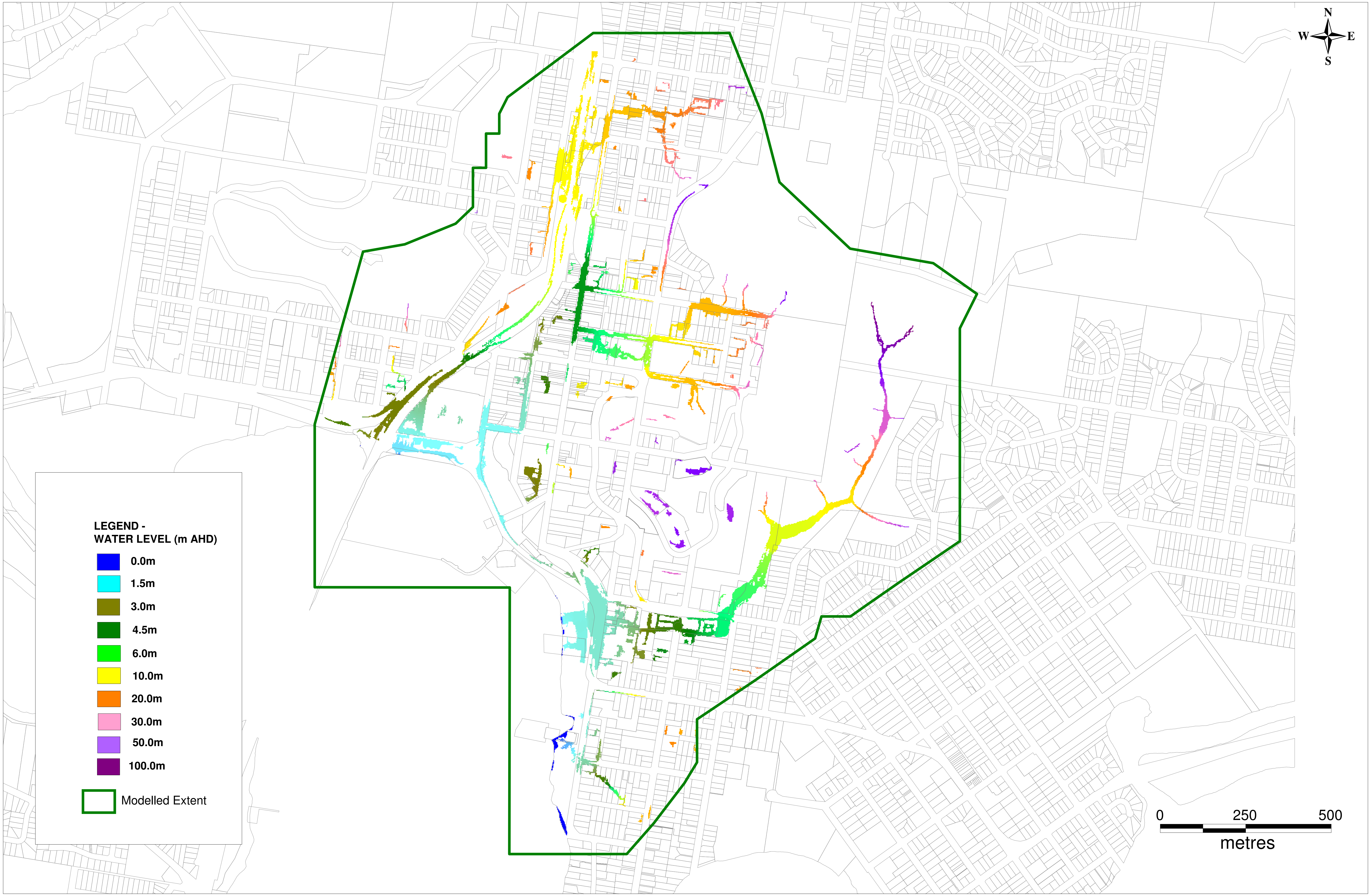

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FIGURE 4.11
PEAK WATER LEVEL - GOSFORD CBD 1% AEP SCENARIO 3

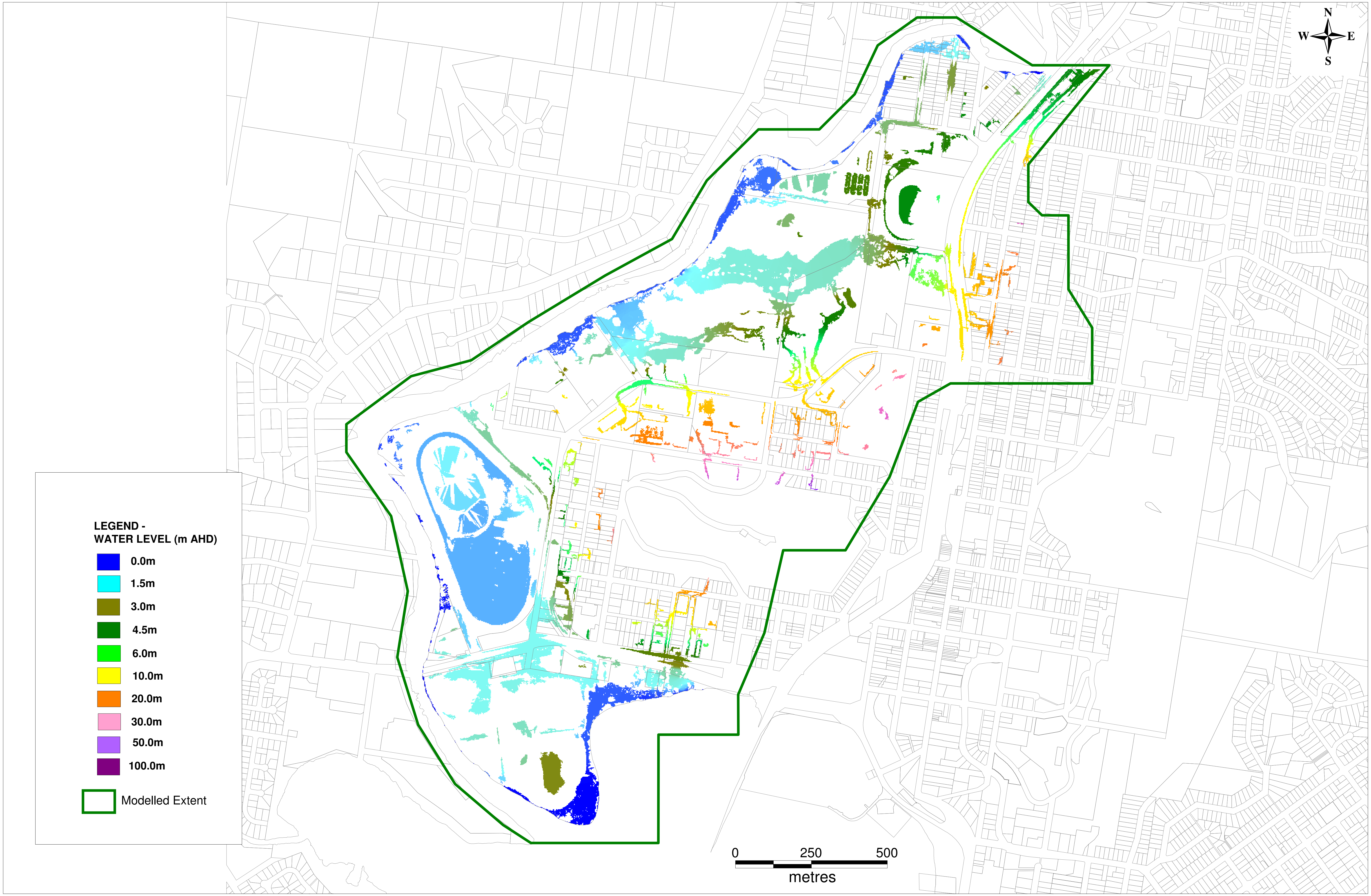

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FIGURE 4.12
PEAK WATER LEVEL - WEST GOSFORD 1% AEP SCENARIO 3

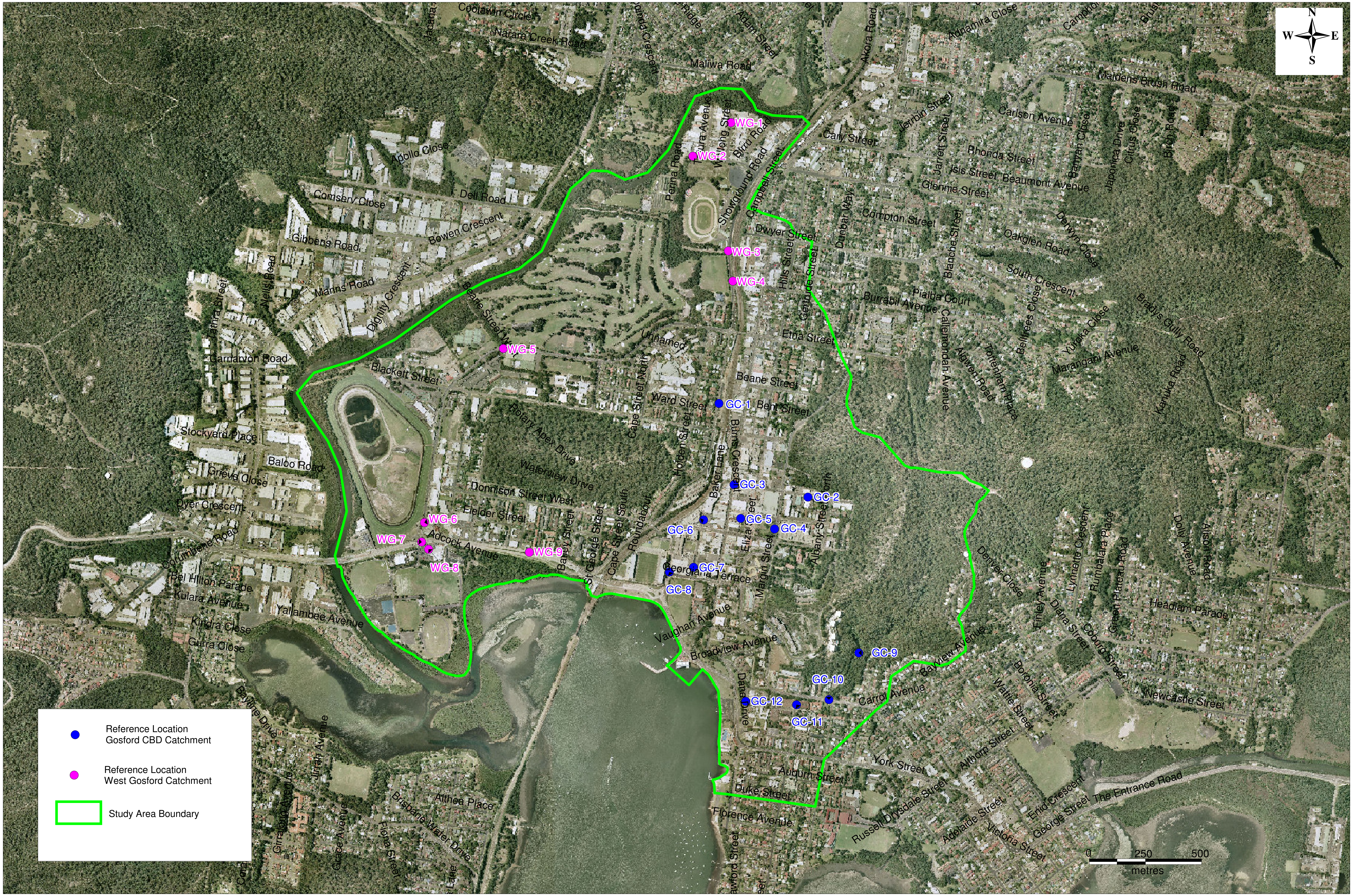

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FIGURE 4.13
RESULTS REFERENCE LOCATIONS - PEAK WATER LEVELS

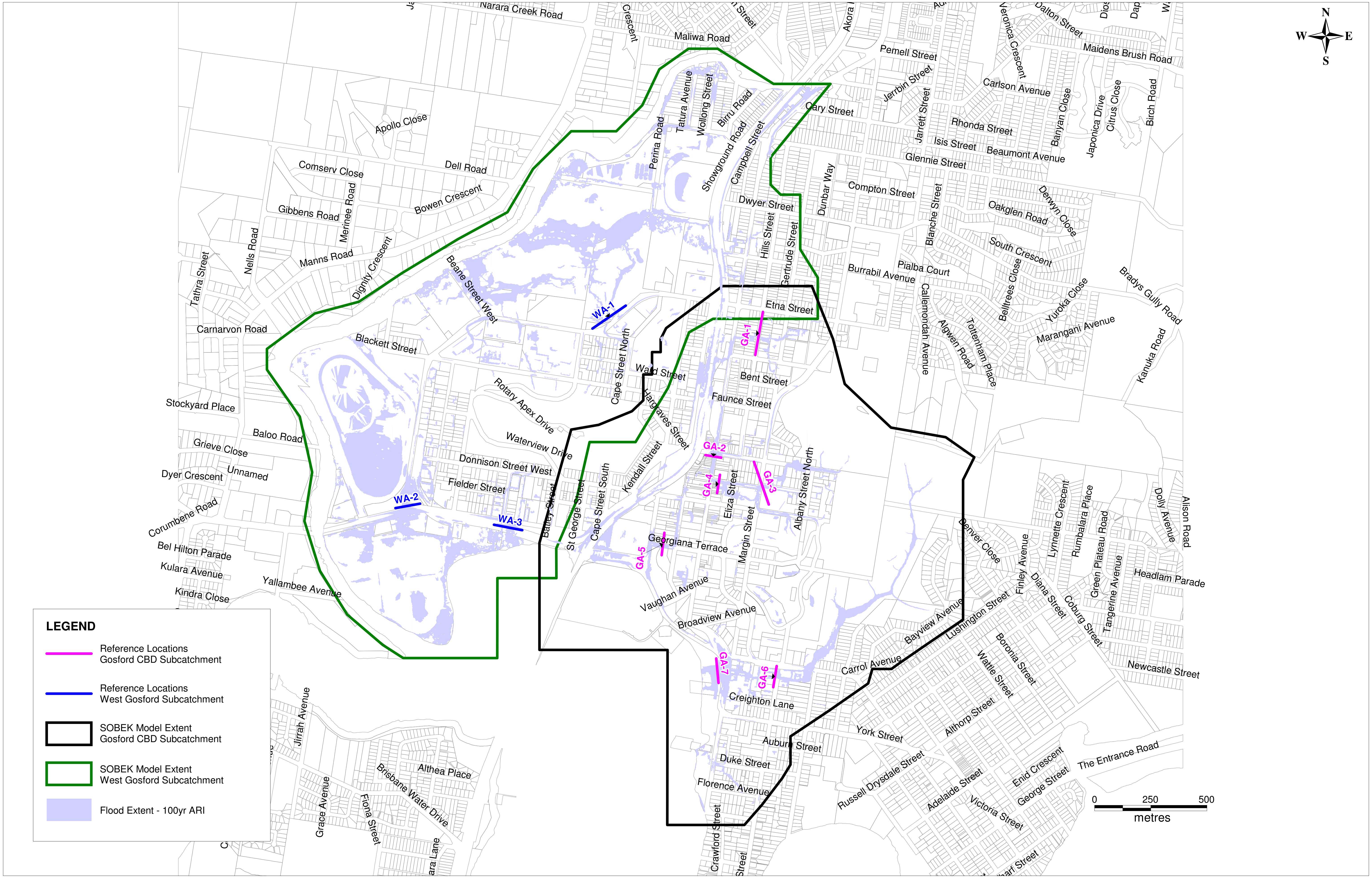

FIGURE 4.14
RESULTS REFERENCE LOCATIONS - PEAK FLOW RATES

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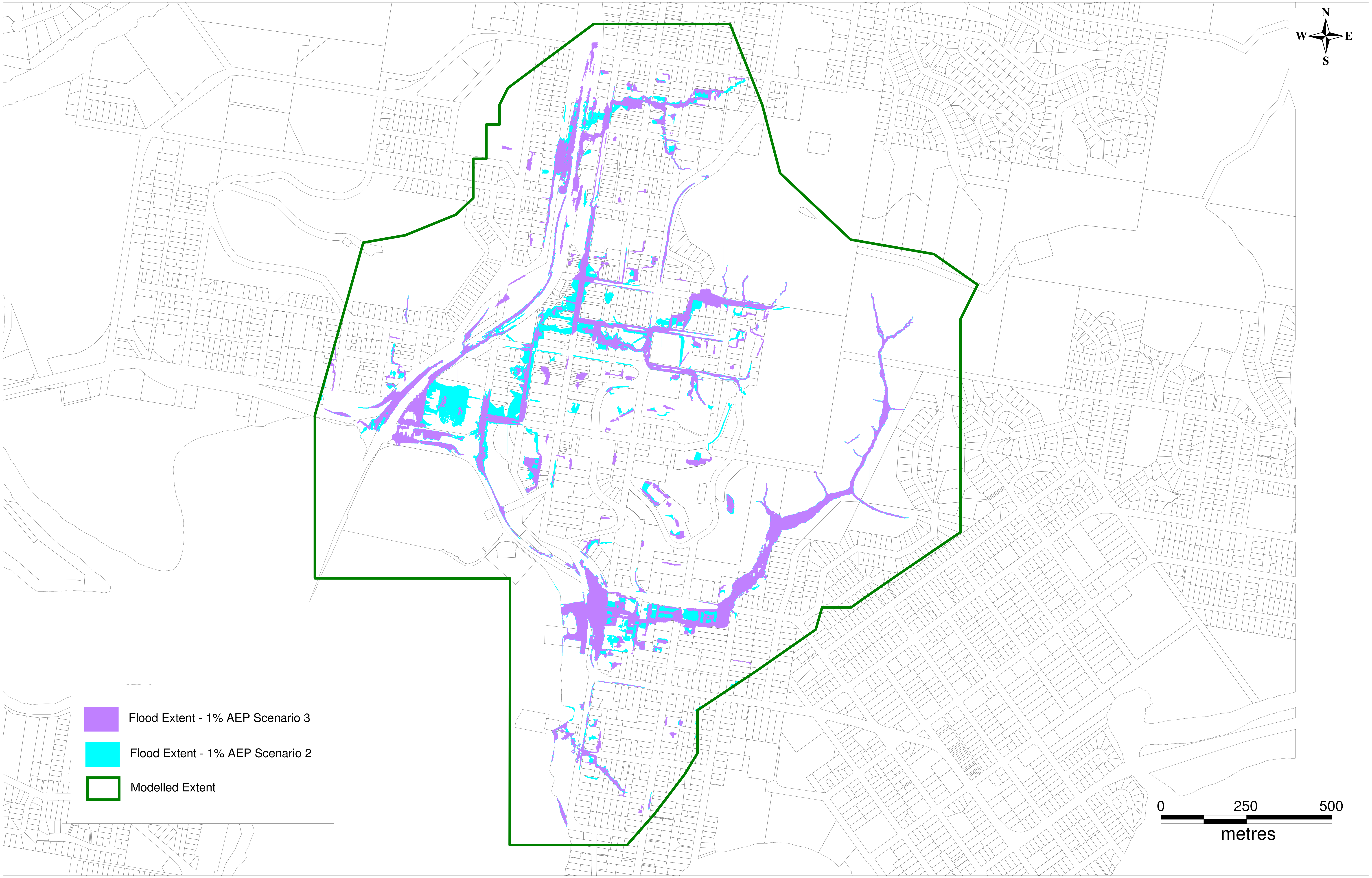

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FIGURE 4.15
GOSFORD CBD - EXTENT COMPARISON SCENARIO 3 AND SCENARIO 2
1% AEP

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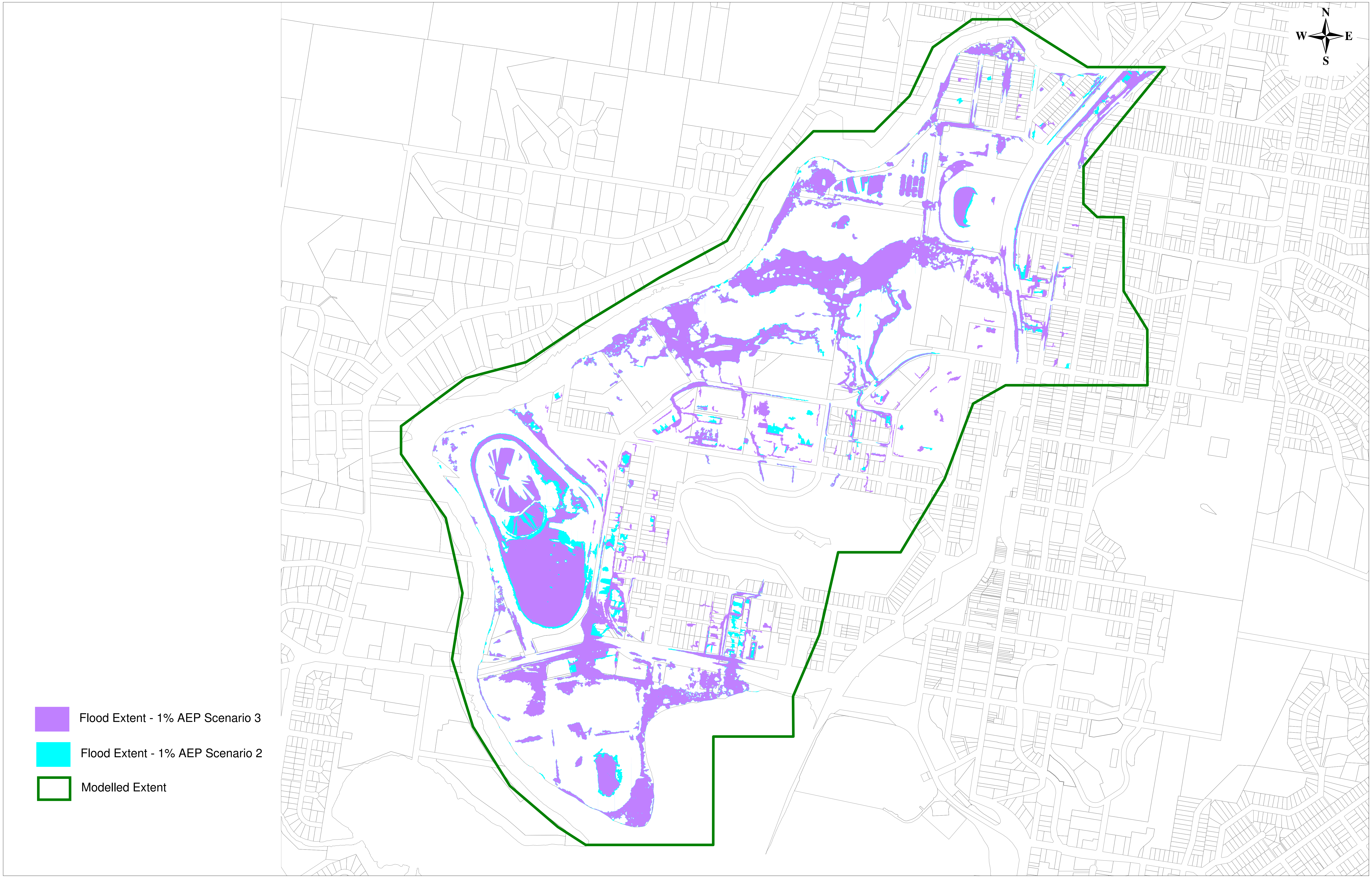

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FIGURE 4.16
WEST GOSFORD- EXTENT COMPARISON SCENARIO 3 AND SCENARIO 2
1% AEP

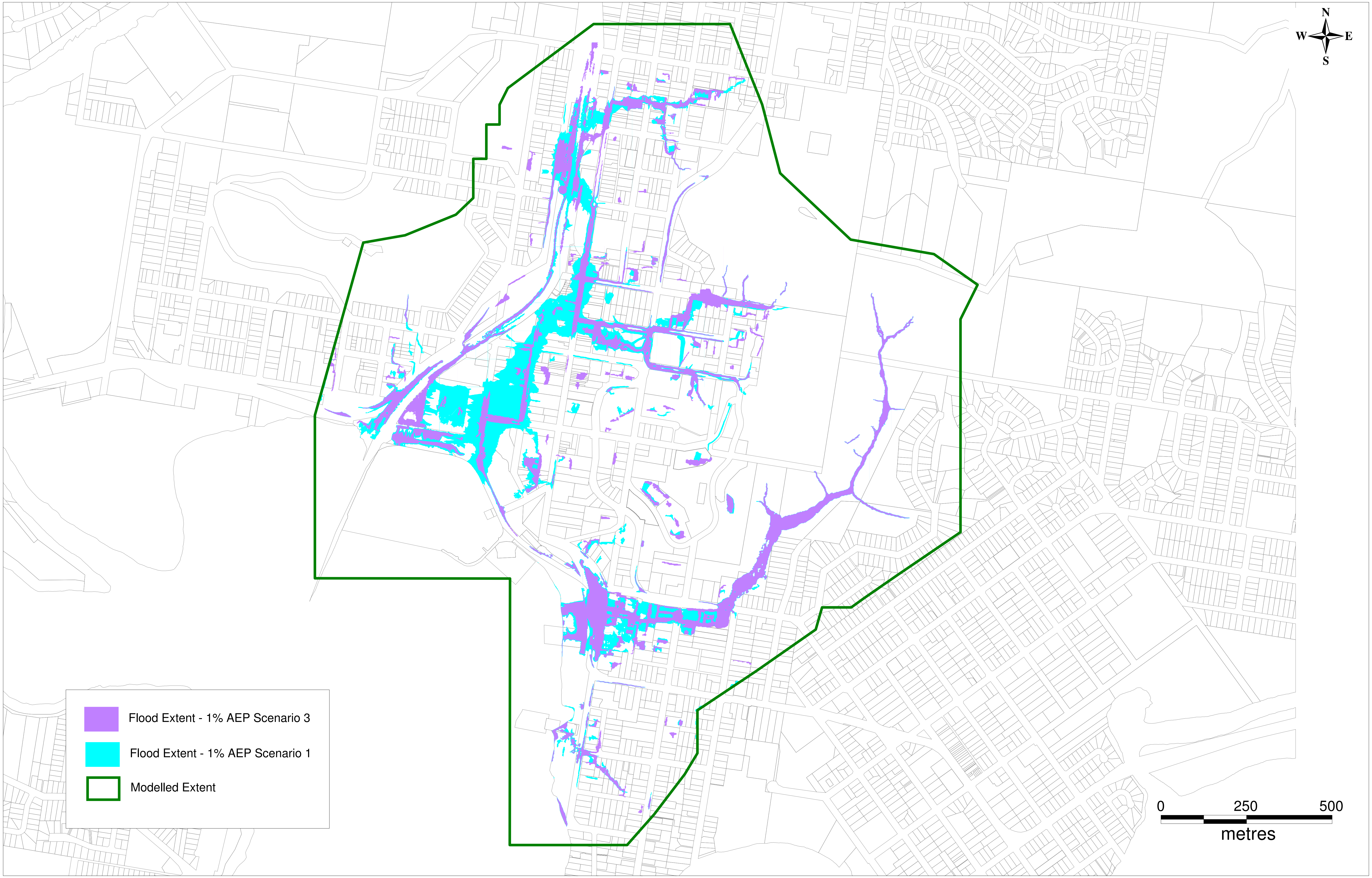

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FIGURE 4.17
GOSFORD CBD - EXTENT COMPARISON SCENARIO 3 AND SCENARIO 1
1% AEP

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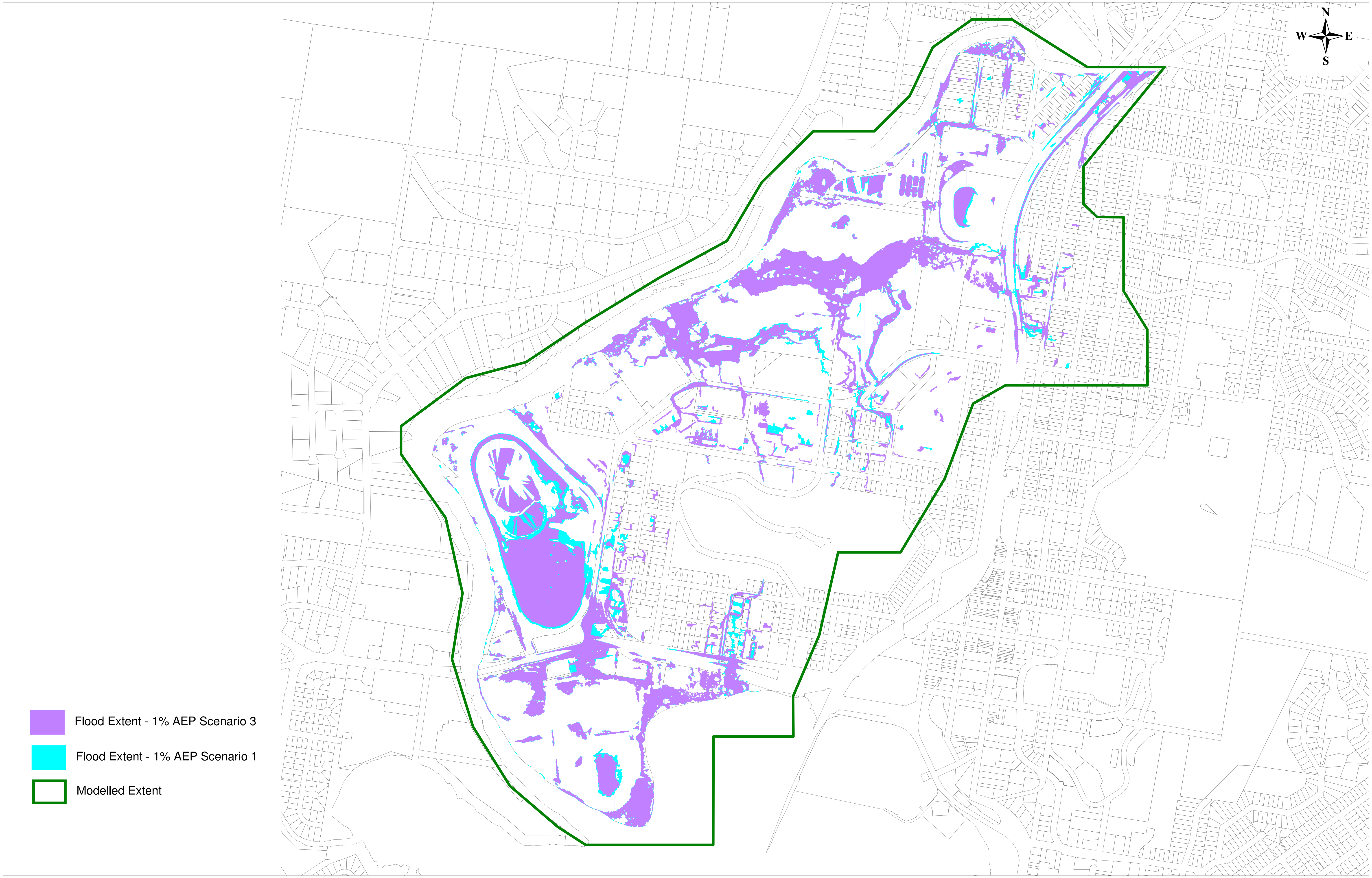

FIGURE 4.18
WEST GOSFORD- EXTENT COMPARISON SCENARIO 3 AND SCENARIO 1
1% AEP

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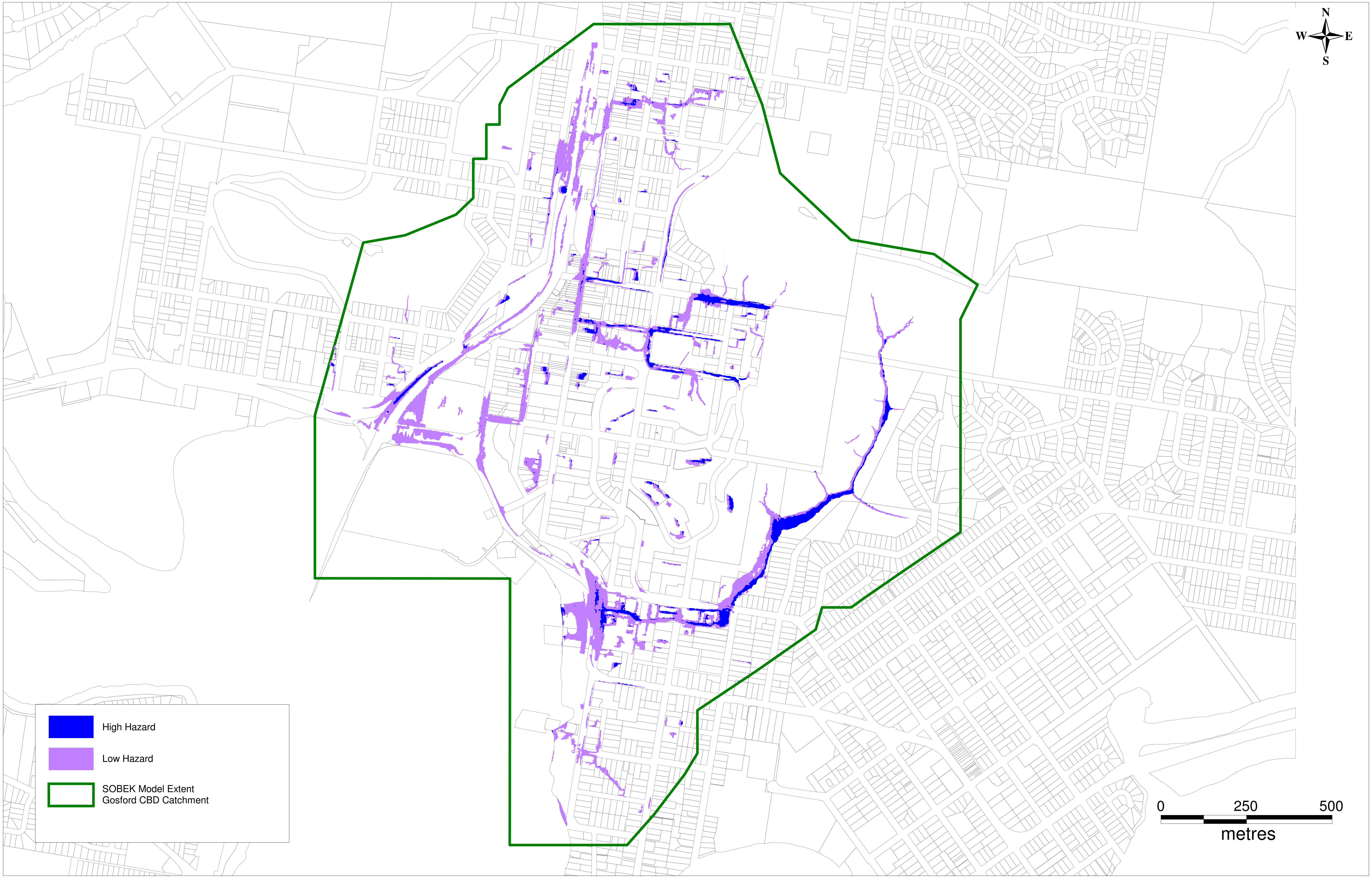

FIGURE 4.19
GOSFORD CBD PROVISIONAL HAZARD 1% AEP

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W4816/V4
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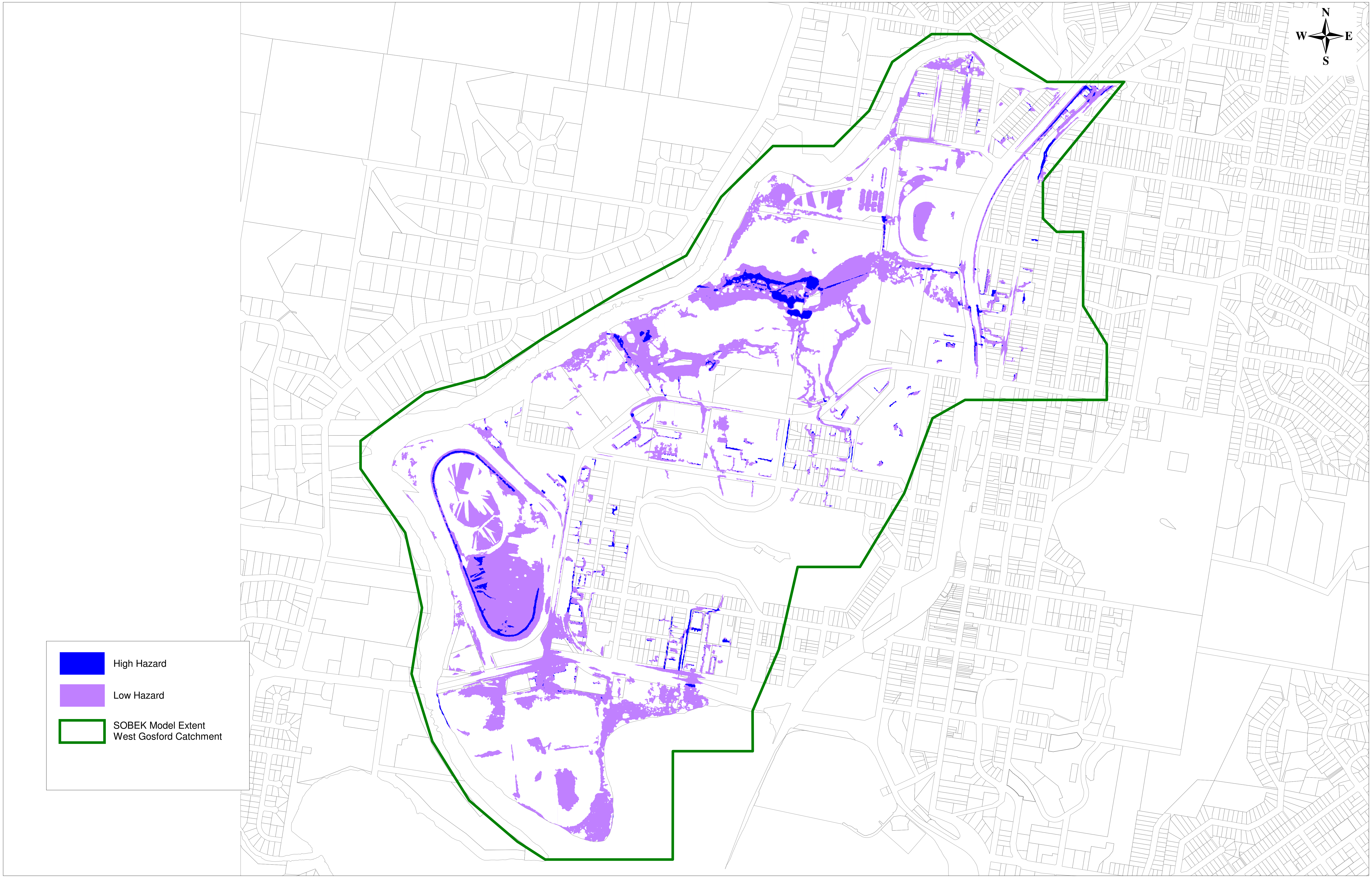

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FIGURE 4.20
WEST GOSFORD PROVISIONAL HAZARD 1% AEP

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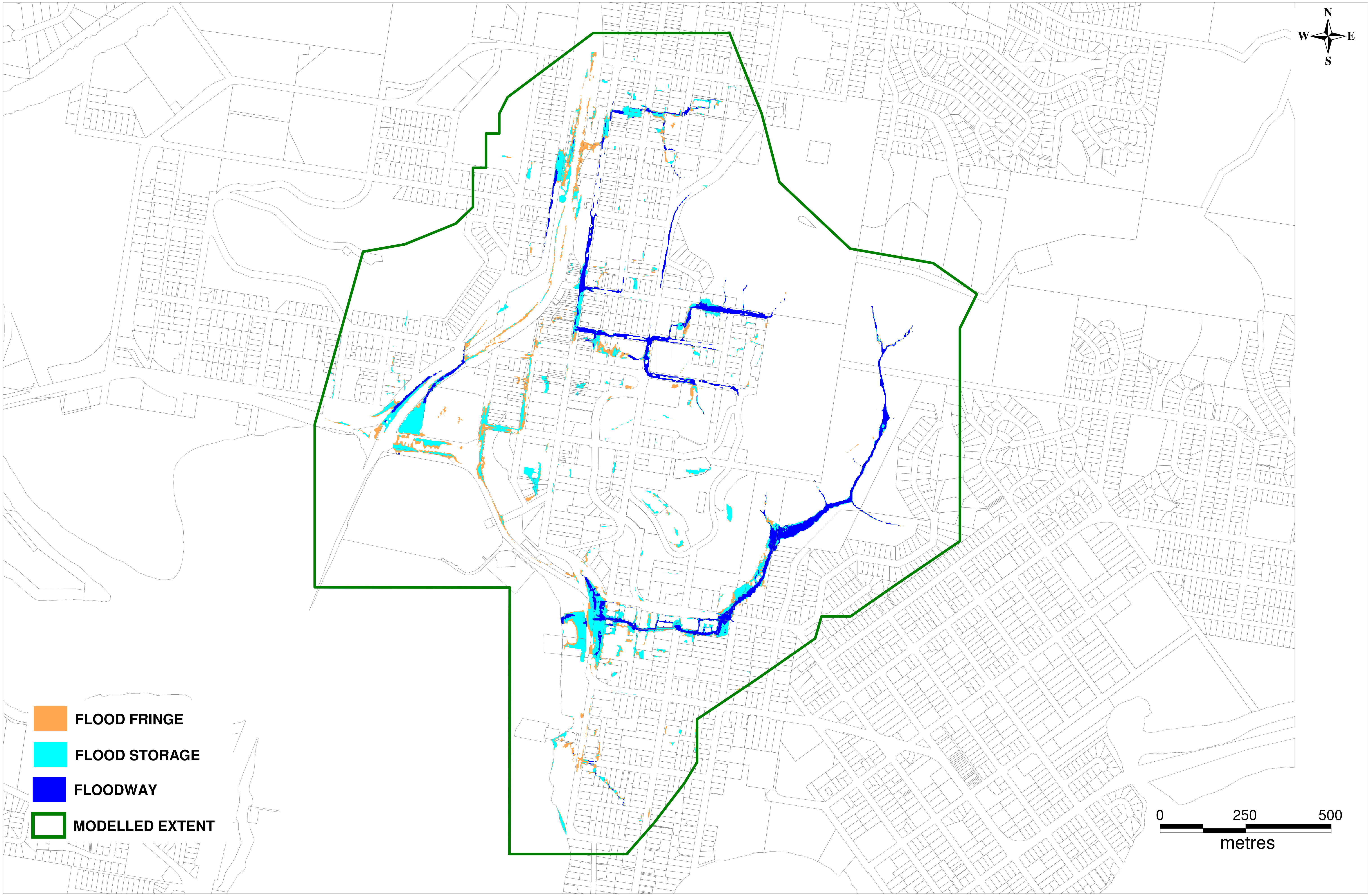

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FIGURE 4.21
GOSFORD CBD HYDRAULIC CATEGORIES 1% AEP SCENARIO 3

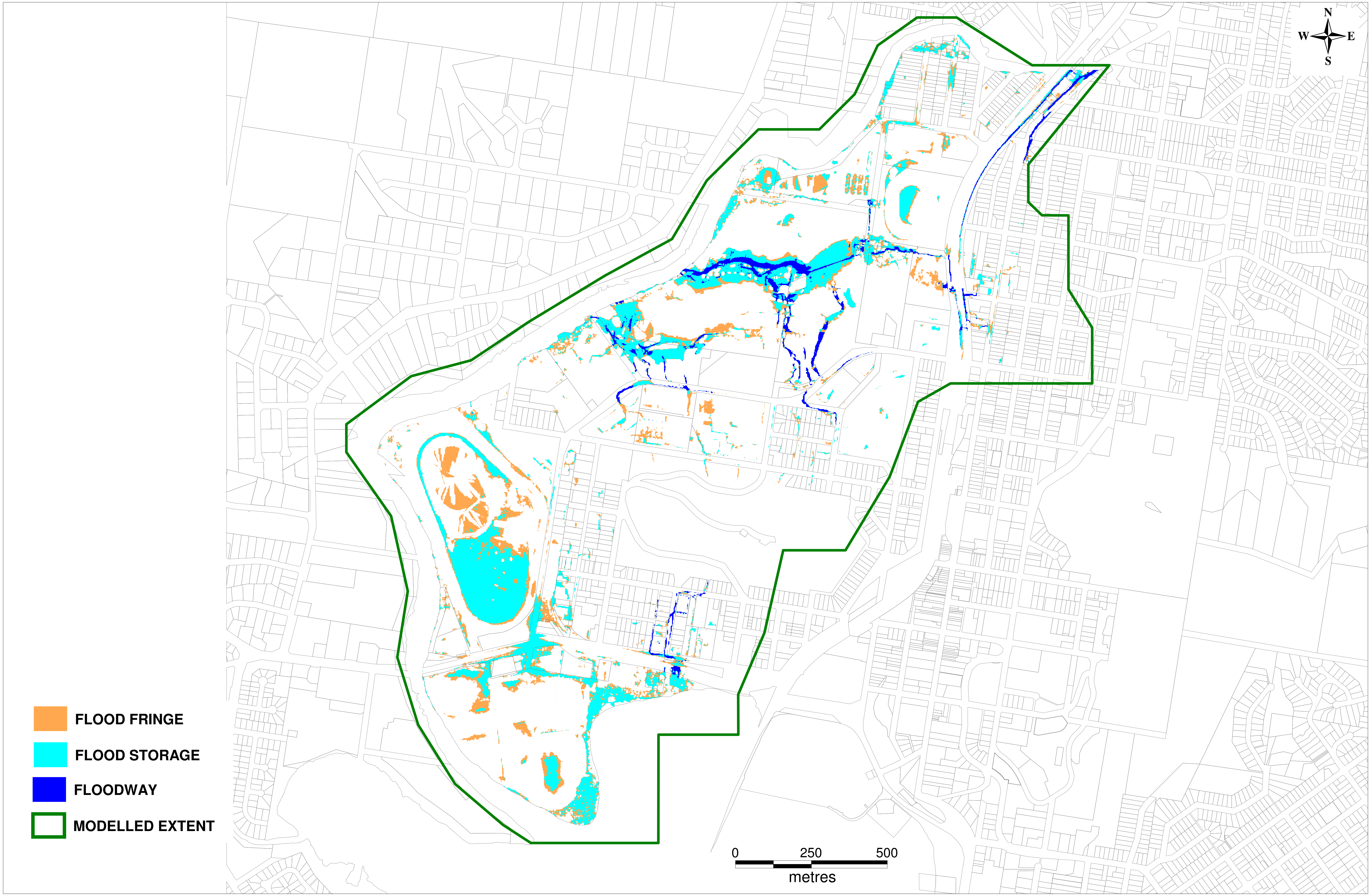

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FIGURE 4.22
WEST GOSFORD HYDRAULIC CATEGORIES 1% AEP SCENARIO 3

Gosford CBD Local Overland Flow Flood Study

FIGURE 4.23
CLIMATE CHANGE PEAK LEVEL COMPARISON GOSFORD CBD
1% AEP 2 HOUR 0.9m SEA LEVEL RISE

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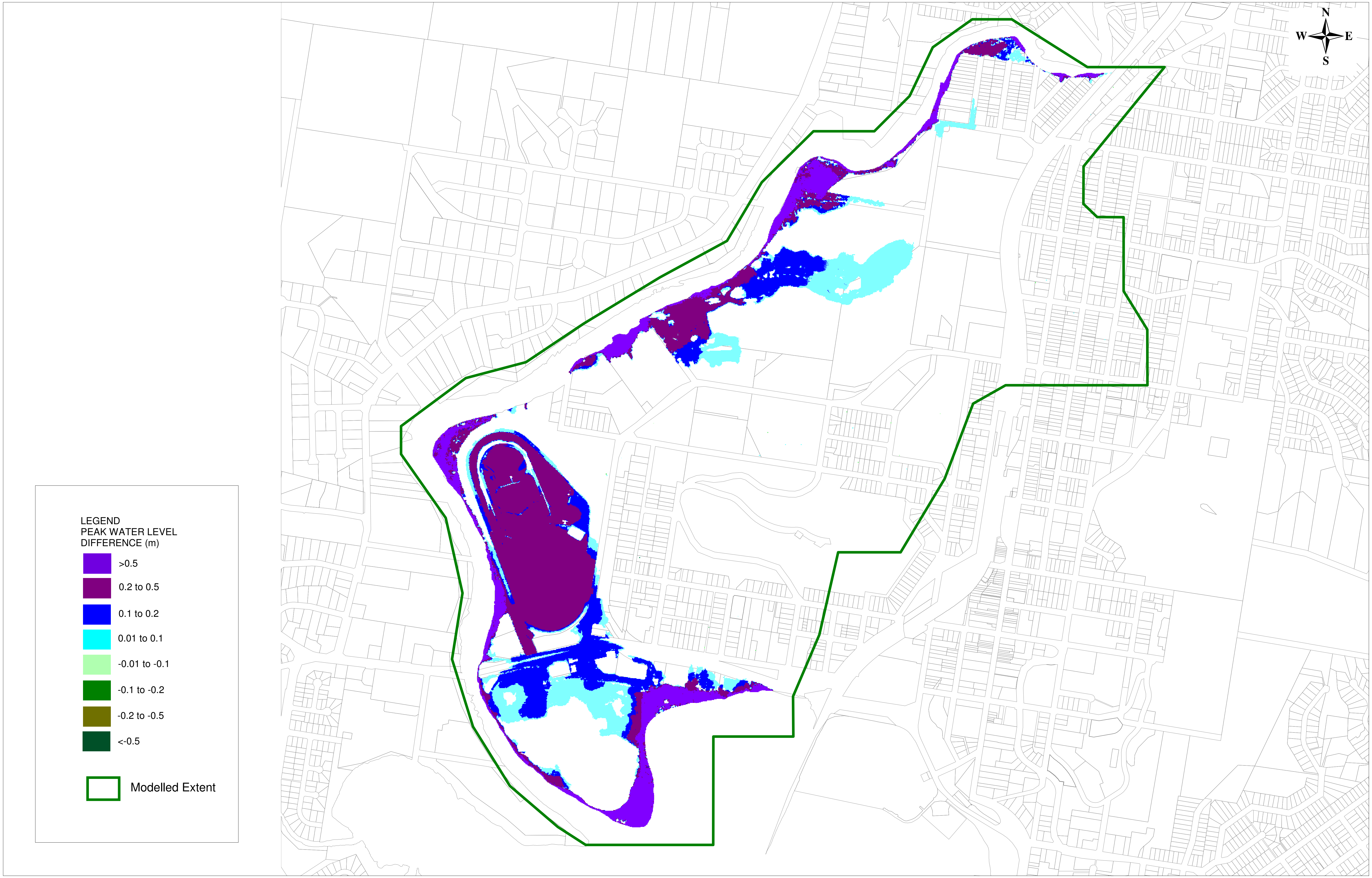

Gosford CBD Local Overland Flow Flood Study

FIGURE 4.24
CLIMATE CHANGE PEAK LEVEL COMPARISON WEST GOSFORD
1% AEP 2 HOUR 0.9m SEA LEVEL RISE

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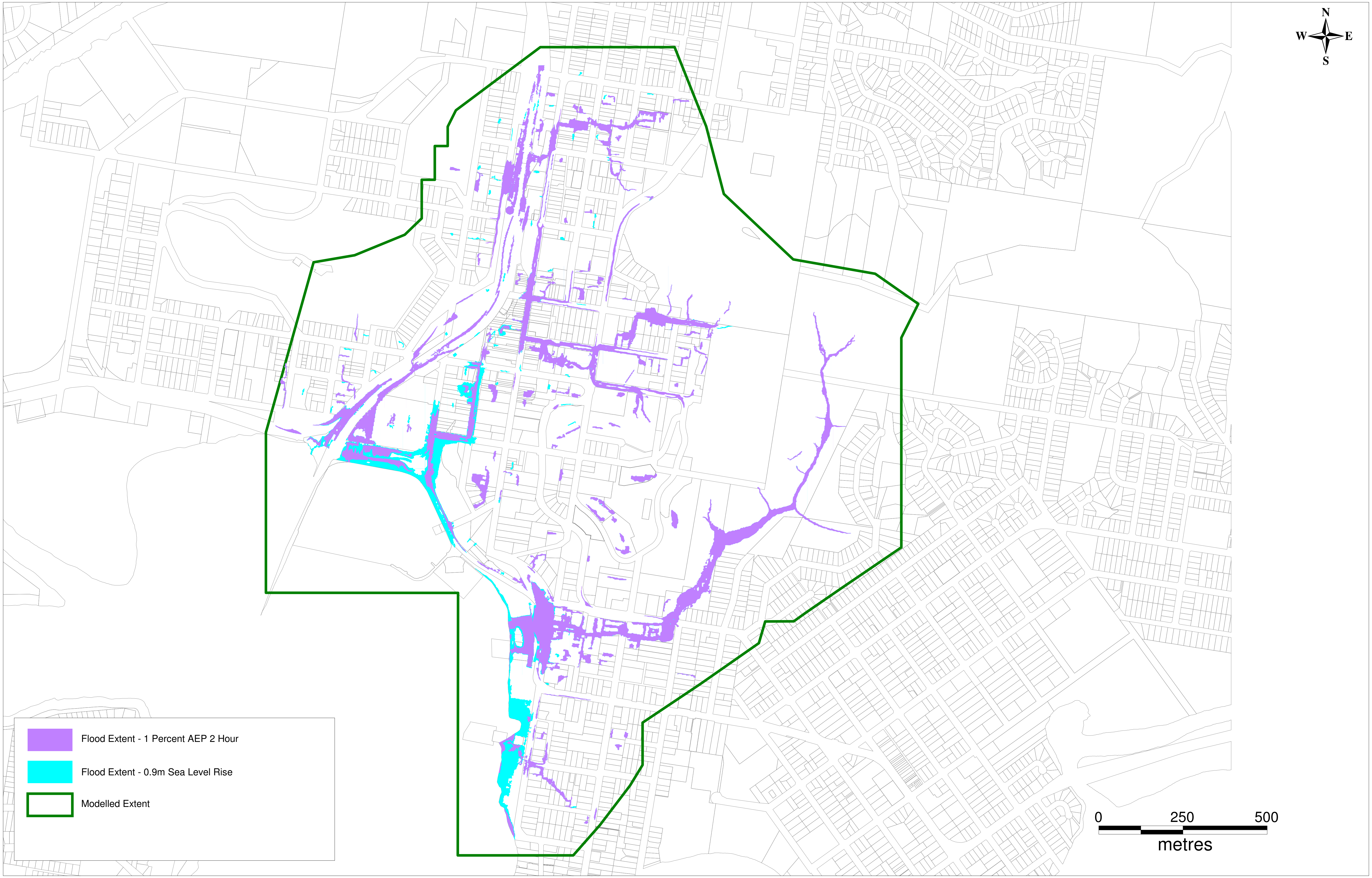

FIGURE 4.25
CLIMATE CHANGE EXTENT COMPARSION GOSFORD CBD
1% AEP 2 HOUR - 0.9m SEA LEVEL RISE

Gosford CBD Local Overland Flow Flood Study

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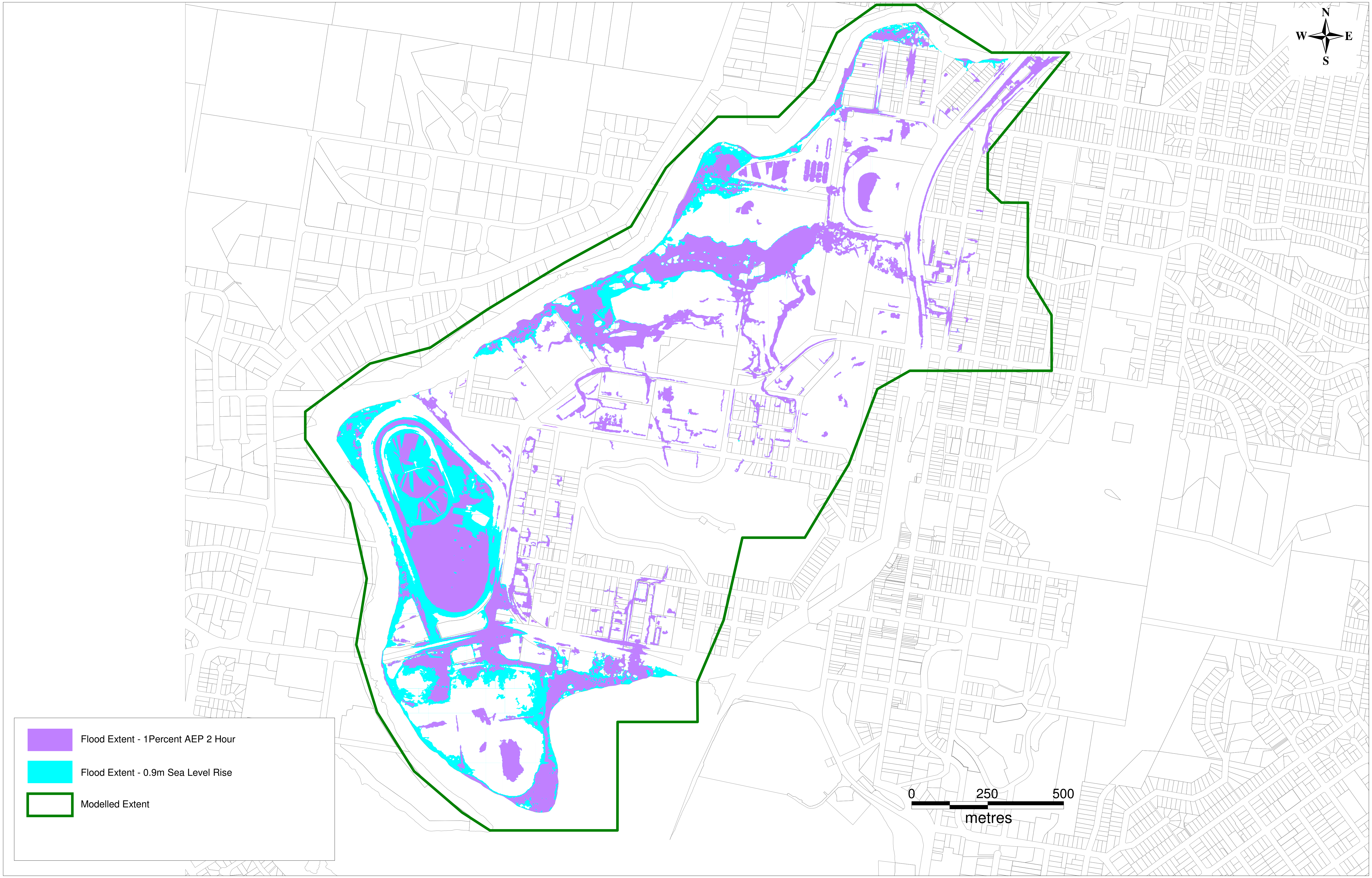
January 2011



Gosford CBD Local Overland Flow Flood Study

FIGURE 4.26
CLIMATE CHANGE EXTENT COMPARSION WEST GOSFORD
1% AEP 2 HOUR - 0.9m SEA LEVEL RISE

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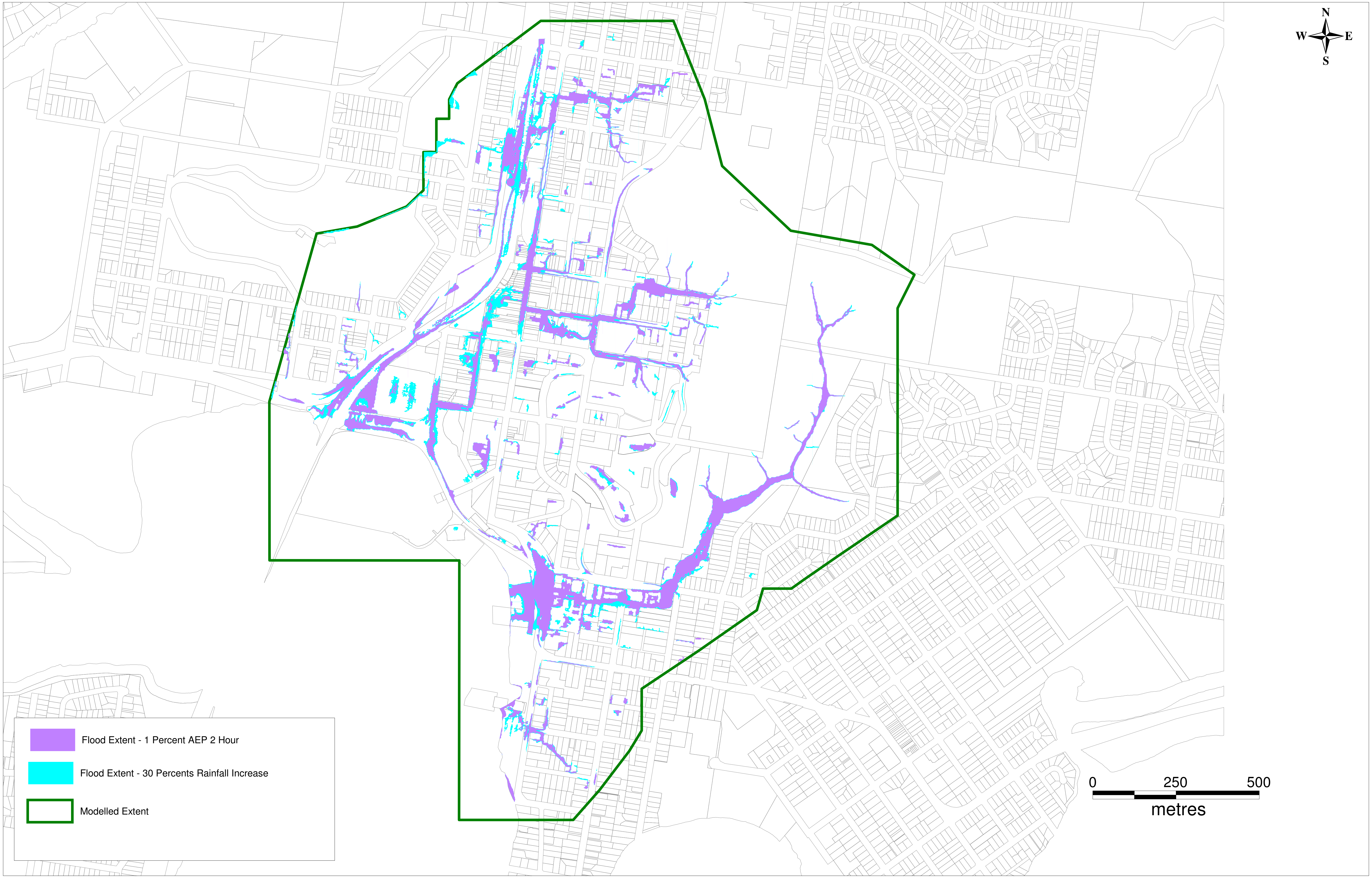

Gosford CBD Local Overland Flow Flood Study

FIGURE 4.27
CLIMATE CHANGE EXTENT COMPARSION GOSFORD CBD
1% AEP 2 HOUR 30% RAINFALL INCREASE

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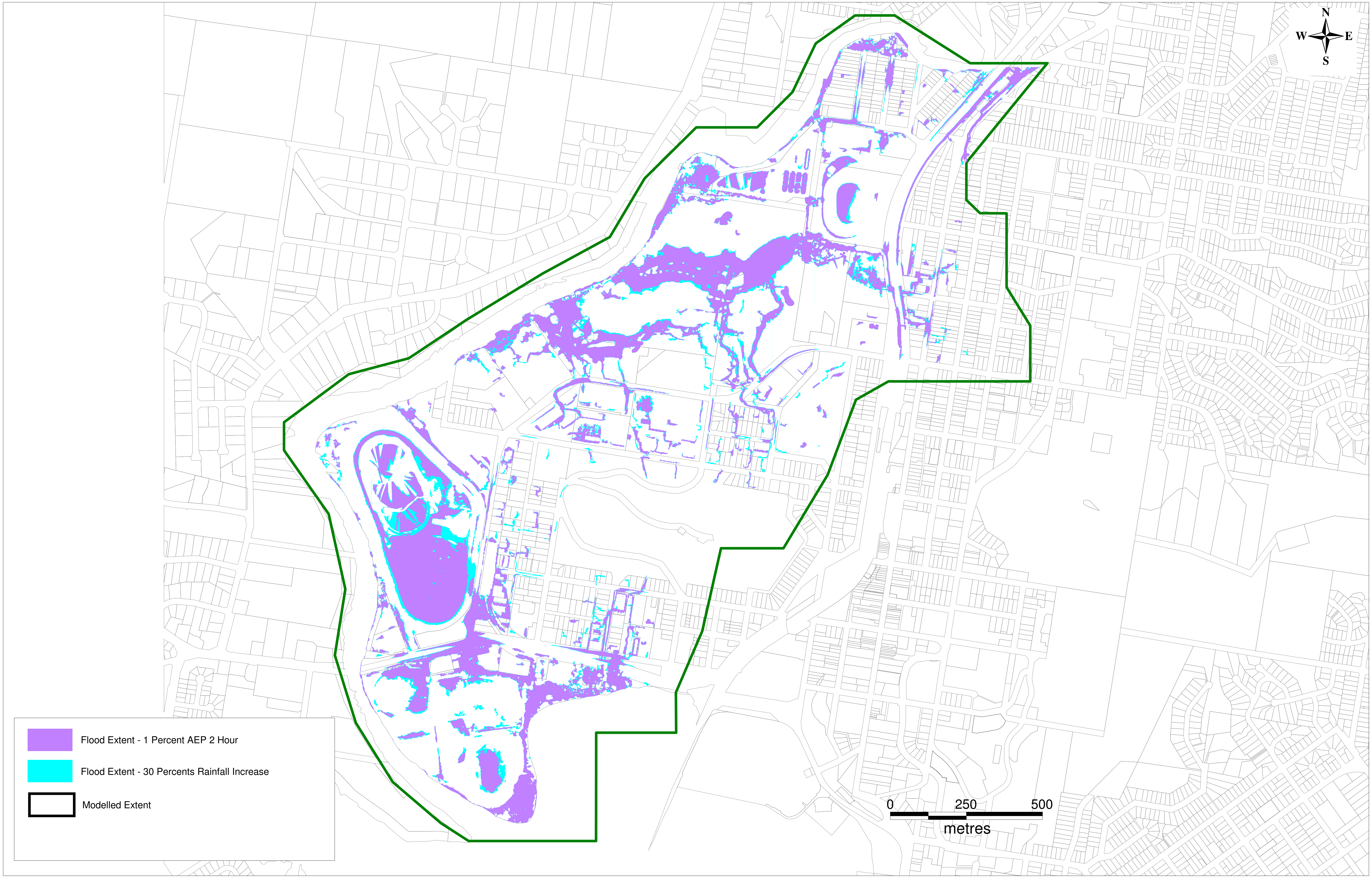

Gosford CBD Local Overland Flow Flood Study

FIGURE 4.28
CLIMATE CHANGE EXTENT COMPARSION WEST GOSFORD
1% AEP 2 HOUR 30% RAINFALL INCREASE

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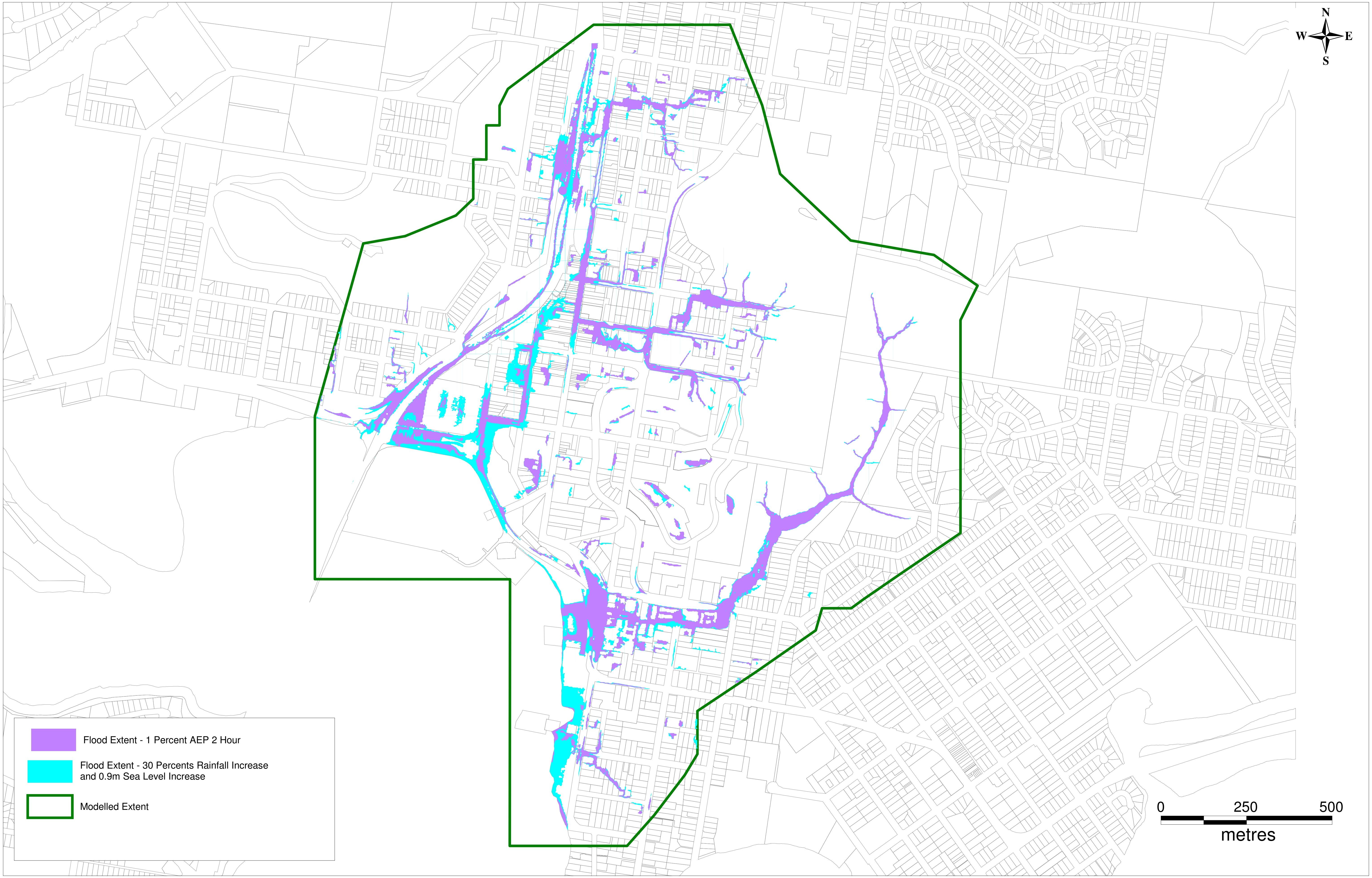

Gosford CBD Local Overland Flow Flood Study

FIGURE 4.29
CLIMATE CHANGE EXTENT COMPARSION GOSFORD CBD
1% AEP 2 HOURS SCENARIO 3- RAINFALL INCREASED BY 30%
AND SEA LEVEL INCREASED BY 0.9m

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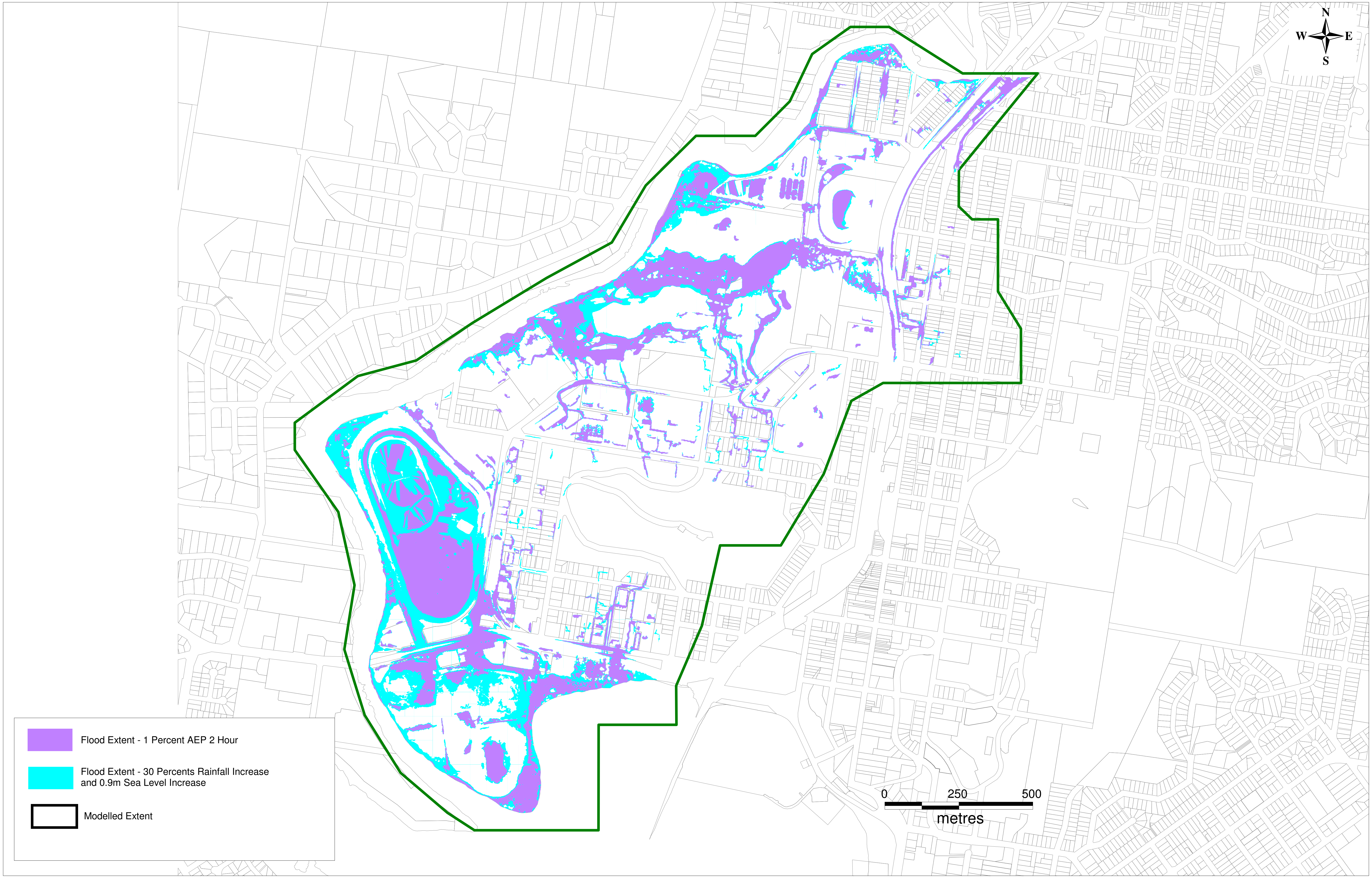
W4816/V4
January 2011



Gosford CBD Local Overland Flow Flood Study

FIGURE 4.30
CLIMATE CHANGE EXTENT COMPARSION WEST GOSFORD
1% AEP 2 HOURS SCENARIO 3- RAINFALL INCREASED BY 30%
AND SEA LEVEL INCREASED BY 0.9m

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January 2011

Appendix A

Reference Results Tables

Table A.1: Scenario 3 –Peak Water Level (m AHD)

Location	Grid Elevation	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Gosford CBD						
GC-1	9.71	10.10	10.14	10.17	10.26	11.90
GC-2	14.43	15.36	15.43	15.49	15.54	16.22
GC-3	4.18	4.40	4.56	4.67	4.78	6.65
GC-4	7.89	8.35	8.41	8.44	8.47	8.96
GC-5	5.07	5.70	5.79	5.86	5.92	6.99
GC-6	2.35	2.60	2.61	2.61	2.62	4.11
GC-7	1.28	1.76	1.78	1.80	1.82	3.52
GC-8	1.17	1.45	1.47	1.51	1.55	2.33
GC-9	7.08	9.16	9.29	9.41	9.49	10.46
GC-10	5.69	5.93	5.97	6.00	6.02	7.11
GC-11	3.47	3.76	3.82	3.88	3.97	5.67
GC-12	1.09	1.53	1.68	1.74	1.78	2.22
West Gosford						
WG-1	2.24	2.61	2.63	2.64	2.66	2.83
WG-2	1.88	2.26	2.30	2.33	2.36	2.60
WG-3	8.84	9.09	9.11	9.13	9.14	9.25
WG-4	10.65	10.99	11.04	11.08	11.10	11.41
WG-5	6.06	6.46	6.47	6.47	6.48	6.57
WG-6	1.00	1.52	1.53	1.55	1.57	1.82
WG-7	1.02	1.52	1.54	1.56	1.57	1.82
WG-8	1.24	1.52	1.54	1.56	1.57	1.82
WG-9	2.97	3.27	3.29	3.30	3.31	3.37

Table A.2: 1% AEP Scenarios –Peak Water Level (m AHD)

Location	Grid Elevation	Scenario 3	Scenario 2	Difference (m) [1]	Scenario 1	Difference (m) [1]
Gosford CBD						
GC-1	9.71	10.26	10.35	0.09	10.93	0.67
GC-2	14.43	15.54	14.95	-0.59	15.01	-0.52
GC-3	4.18	4.78	4.72	-0.06	5.03	0.25
GC-4	7.89	8.47	8.50	0.03	8.78	0.31
GC-5	5.07	5.92	5.59	-0.33	5.81	-0.11
GC-6	2.35	2.62	2.79	0.17	3.31	0.69
GC-7	1.28	1.82	1.82	0.00	2.19	0.37
GC-8	1.17	1.55	1.67	0.11	2.07	0.52
GC-9	7.08	9.49	9.48	-0.01	9.50	0.01
GC-10	5.69	6.02	6.02	0.00	6.04	0.02
GC-11	3.47	3.97	3.85	-0.12	4.05	0.08
GC-12	1.09	1.78	1.78	0.00	1.87	0.09
West Gosford						
WG-1	2.24	2.66	2.66	0.01	2.67	0.01
WG-2	1.88	2.36	2.36	0.00	2.41	0.05
WG-3	8.84	9.14	9.11	-0.03	9.15	0.02
WG-4	10.65	11.10	11.08	-0.03	11.10	0.00
WG-5	6.06	6.48	6.48	0.00	6.48	0.00
WG-6	1.00	1.57	1.56	0.00	1.57	0.00
WG-7	1.02	1.57	1.56	0.00	1.57	0.00
WG-8	1.24	1.57	1.56	0.00	1.57	0.00
WG-9	2.97	3.31	3.32	0.01	3.32	0.01

[1] Difference in peak water level to Scenario 3

Table A.3: Sensitivity Results – Rainfall Peak Water Level (m AHD)

Location	Grid Elevation	Base Case 1% AEP 2h	Rainfall Less 20%	Difference (m)	Rainfall Plus 20%	Difference (m)
Gosford CBD						
GC-1	9.71	10.26	10.14	-0.12	10.60	0.34
GC-2	14.43	15.54	15.42	-0.11	15.63	0.09
GC-3	4.18	4.78	4.54	-0.24	5.10	0.32
GC-4	7.89	8.47	8.40	-0.07	8.52	0.05
GC-5	5.07	5.92	5.78	-0.14	6.03	0.11
GC-6	2.35	2.62	2.60	-0.02	2.73	0.11
GC-7	1.28	1.82	1.78	-0.04	1.89	0.07
GC-8	1.17	1.55	1.47	-0.08	1.64	0.09
GC-9	7.08	9.49	9.29	-0.20	9.63	0.14
GC-10	5.69	6.02	5.97	-0.05	6.07	0.05
GC-11	3.47	3.97	3.83	-0.14	4.23	0.26
GC-12	1.09	1.78	1.68	-0.10	1.83	0.06
West Gosford						
WG-1	2.24	2.66	2.63	-0.03	2.68	0.02
WG-2	1.88	2.36	2.30	-0.06	2.40	0.04
WG-3	8.84	9.14	9.11	-0.02	9.15	0.01
WG-4	10.65	11.10	11.04	-0.07	11.15	0.04
WG-5	6.06	6.48	6.47	-0.02	6.50	0.01
WG-6	1.00	1.57	1.54	-0.03	1.59	0.03
WG-7	1.02	1.57	1.54	-0.03	1.59	0.03
WG-8	1.24	1.57	1.54	-0.03	1.60	0.03
WG-9	2.97	3.31	3.29	-0.02	3.32	0.01

Table A.4: Sensitivity Results – Roughness Peak Water Level (m AHD)

Location	Grid Elevation	Base Case 1% AEP 2h	Roughness Less 20%	Difference (m)	Roughness Plus 20%	Difference (m)
Gosford CBD						
GC-1	9.71	10.26	10.34	0.08	10.23	-0.03
GC-2	14.43	15.54	15.52	-0.02	15.56	0.02
GC-3	4.18	4.78	4.84	0.06	4.75	-0.03
GC-4	7.89	8.47	8.47	0.00	8.48	0.01
GC-5	5.07	5.92	5.93	0.01	5.90	-0.01
GC-6	2.35	2.62	2.62	0.00	2.63	0.01
GC-7	1.28	1.82	1.83	0.01	1.82	0.00
GC-8	1.17	1.55	1.58	0.03	1.53	-0.02
GC-9	7.08	9.49	9.46	-0.03	9.51	0.02
GC-10	5.69	6.02	6.00	-0.02	6.04	0.02
GC-11	3.47	3.97	3.99	0.03	3.95	-0.02
GC-12	1.09	1.78	1.79	0.01	1.78	0.00
West Gosford						
WG-1	2.24	2.66	2.65	0.00	2.66	0.00
WG-2	1.88	2.36	2.36	0.00	2.36	0.00
WG-3	8.84	9.14	9.14	0.00	9.13	0.00
WG-4	10.65	11.10	11.11	0.00	11.10	0.00
WG-5	6.06	6.48	6.48	0.00	6.48	0.00
WG-6	1.00	1.57	1.56	0.00	1.57	0.00
WG-7	1.02	1.57	1.57	0.00	1.57	0.00
WG-8	1.24	1.57	1.57	0.00	1.57	0.00
WG-9	2.97	3.31	3.31	0.00	3.31	0.00

Table A.5: Climate Change Scenarios (Sea Level Rise) - Peak Water Level (m AHD)

Location	Base Case 1% AEP 2h	Level Plus 0.2m	Difference (m)	Level Plus 0.4m	Difference (m)	Level Plus 0.9m	Difference (m)
Gosford CBD							
GC-1	10.26	10.26	0.00	10.26	0.00	10.26	0.00
GC-2	15.54	15.54	0.00	15.54	0.00	15.54	0.00
GC-3	4.78	4.78	0.00	4.80	0.02	4.82	0.04
GC-4	8.47	8.47	0.00	8.48	0.00	8.47	0.00
GC-5	5.92	5.92	0.00	5.92	0.00	5.92	0.00
GC-6	2.62	2.62	0.00	2.62	0.00	2.62	0.00
GC-7	1.82	1.84	0.02	1.88	0.06	2.06	0.24
GC-8	1.55	1.60	0.05	1.67	0.11	1.86	0.30
GC-9	9.49	9.49	0.00	9.49	0.00	9.49	0.00
GC-10	6.02	6.02	0.00	6.02	0.00	6.02	0.00
GC-11	3.97	3.97	0.00	3.97	0.00	3.97	0.01
GC-12	1.78	1.79	0.01	1.80	0.02	1.83	0.05
West Gosford							
WG-1	2.66	2.66	0.00	2.66	0.00	2.66	0.00
WG-2	2.36	2.36	0.00	2.37	0.01	2.38	0.02
WG-3	9.14	9.14	0.00	9.14	0.00	9.14	0.00
WG-4	11.10	11.10	0.00	11.11	0.00	11.10	0.00
WG-5	6.48	6.48	0.00	6.48	0.00	6.48	0.00
WG-6	1.57	1.57	0.00	1.57	0.00	1.71	0.15
WG-7	1.57	1.57	0.00	1.57	0.00	1.71	0.14
WG-8	1.57	1.57	0.00	1.57	0.00	1.71	0.14
WG-9	3.31	3.31	0.00	3.31	0.00	3.31	0.00

Table A.6: Climate Change Scenarios (Rainfall Increase) - Peak Water Level (m AHD)

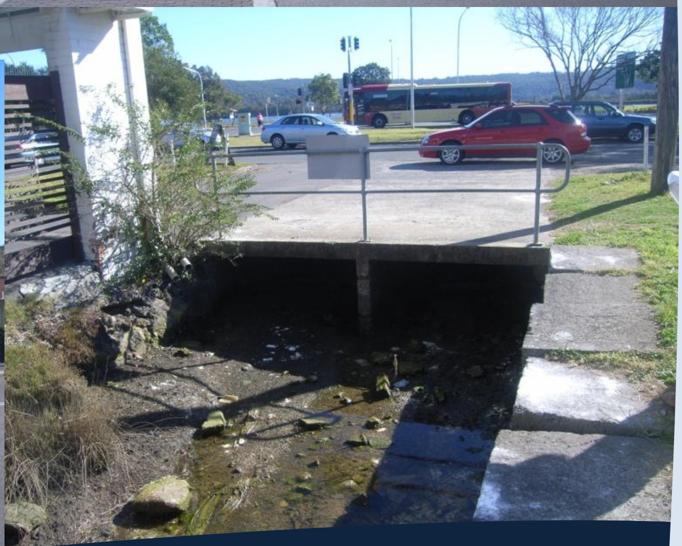
Location	Base Case 1% AEP 2h	Rainfall Plus 10%	Difference (m)	Rainfall Plus 20%	Difference (m)	Rainfall Plus 30%	Difference (m)
Gosford CBD							
GC-1	10.26	10.4	0.14	10.6	0.34	10.77	0.51
GC-2	15.54	15.59	0.05	15.63	0.09	15.67	0.13
GC-3	4.78	4.94	0.16	5.1	0.32	5.23	0.45
GC-4	8.47	8.49	0.02	8.52	0.05	8.54	0.07
GC-5	5.92	5.97	0.05	6.03	0.11	6.07	0.15
GC-6	2.62	2.64	0.02	2.73	0.11	2.8	0.18
GC-7	1.82	1.85	0.03	1.89	0.07	1.93	0.11
GC-8	1.55	1.6	0.05	1.64	0.09	1.67	0.12
GC-9	9.49	9.56	0.07	9.63	0.14	9.68	0.19
GC-10	6.02	6.04	0.02	6.07	0.05	6.08	0.06
GC-11	3.97	4.1	0.13	4.23	0.26	4.33	0.36
GC-12	1.78	1.81	0.03	1.83	0.05	1.86	0.08
West Gosford							
WG-1	2.66	2.67	0.01	2.68	0.02	2.69	0.03
WG-2	2.36	2.38	0.02	2.4	0.04	2.41	0.05
WG-3	9.14	9.14	0	9.15	0.01	9.16	0.02
WG-4	11.10	11.13	0.03	11.15	0.05	11.16	0.06
WG-5	6.48	6.49	0.01	6.5	0.02	6.5	0.02
WG-6	1.57	1.58	0.01	1.59	0.02	1.61	0.04
WG-7	1.57	1.58	0.01	1.59	0.02	1.61	0.04
WG-8	1.57	1.58	0.01	1.6	0.03	1.61	0.04
WG-9	3.31	3.32	0.01	3.32	0.01	3.33	0.02

Table A.7: Climate Change Scenarios (Rainfall & Sea Level Increase) - Peak Water Level (m AHD)

Location	Base Case 1% AEP 2h	Rainfall Plus 30% & Level Plus 0.4m	Difference (m)	Rainfall Plus 30% & Level Plus 0.9m	Difference (m)
Gosford CBD					
GC-1	10.26	10.78	0.52	10.78	0.52
GC-2	15.54	15.67	0.13	15.67	0.13
GC-3	4.78	5.25	0.47	5.26	0.48
GC-4	8.47	8.54	0.07	8.54	0.07
GC-5	5.92	6.07	0.15	6.07	0.15
GC-6	2.62	2.81	0.19	2.82	0.2
GC-7	1.82	2.01	0.19	2.13	0.31
GC-8	1.55	1.76	0.21	1.89	0.34
GC-9	9.49	9.68	0.19	9.68	0.19
GC-10	6.02	6.09	0.07	6.08	0.06
GC-11	3.97	4.33	0.36	4.33	0.36
GC-12	1.78	1.87	0.09	1.89	0.11
West Gosford					
WG-1	2.66	2.69	0.03	2.69	0.03
WG-2	2.36	2.42	0.06	2.42	0.06
WG-3	9.14	9.16	0.02	9.16	0.02
WG-4	11.10	11.16	0.06	11.16	0.06
WG-5	6.48	6.5	0.02	6.5	0.02
WG-6	1.57	1.6	0.03	1.74	0.17
WG-7	1.57	1.61	0.04	1.74	0.17
WG-8	1.57	1.61	0.04	1.74	0.17
WG-9	3.31	3.33	0.02	3.33	0.02

Appendix B

Point Frederick – East Gosford



Gosford CBD

Local Overland Flow Flood Study
Addendum – Point Frederick & East Gosford

Project W4816

Prepared for Gosford City Council

18 September 2013

Cardno (NSW/ACT) Pty Ltd
Trading as Cardno Lawson Treloar Pty Ltd
ABN 95 001 145 035

Level 9, The Forum
203 Pacific Highway
St Leonards New South Wales 2065
PO Box 19
St Leonards New South Wales 1590

Telephone: 02 9496 7700
Facsimile: 02 9439 5170
www.cardno.com.au

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6	Copyright amendment	18 September 2013	Daniel Wood	DW	Andrew Reid	AR

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Table of Contents

Appendices

List of Tables

List of Figures

1 Introduction

1.1 Study Objectives

Gosford City Council has received funding from the Federal and State Governments under the Natural Disaster Mitigation Programme to undertake an Overland Flow Flood Study of the LGA. This addendum comprises a pilot study on a small section of the LGA following the assessment of the Gosford CBD catchments to evaluate the outcomes, prior to undertaking a similar study for the wider LGA.

This addendum report undertakes an investigation into the local overland flooding present in the vicinity of Point Frederick and Gosford East. This report should be read in conjunction with *Gosford CBD – Local Overland Flow Flood Study – February 2011*.

The objective of the study is to define local overland flooding in accordance with the NSW Government's Floodplain Development Manual (2005). Gosford City Council seeks the following outcomes:

- Identify and map major overland flow paths;
- Identify properties at risk from overland flows;
- Define local flood behaviour, including flows, flood levels and depths, and velocities, and
- Assess provisional flood hazard for properties at risk.

This Study is not intended to replace, but to complement Flood Studies and Plans previously adopted.

This Report summarises the background, methodology and results for the modelled scenarios. Electronic results files compatible with Council's GIS from the models detailing parameters, such as peak water and velocity, are compiled to enable a more detailed assessment of overland flow inundation than can be presented within this report.

1.2 Study Area Description

The study area incorporates the area of Point Frederick, Gosford East and the surrounding region comprising an area of about 1.1 km^2. It is shown in **Figure 1.1** and includes parts of the suburbs Point Frederick and Gosford East bounded by The Gosford Broad Water and Caroline Bay.

The study area comprises a variety of land uses such as residential, commercial, and open space areas. It includes large parklands, areas of dense vegetation and mangroves as well as three high schools

The study area rises from the foreshore to a ridgeline in the north with highest elevation about 100m AHD. The area drains down to Caroline Bay and The Gosford Broad Water.

1.3 Public Exhibition

A draft of this Flood Study was placed on public exhibition for four weeks May and June 2012 at Council's Administration Centre, Gosford Library, Erina Library and on Council's website. Comments and submissions were invited for review of the final report. The information documents advising of the exhibition are attached in **Appendix D**, including the advertisement for the Central Coast Express Advocate from 11 May to 30 May 2012.

Three submissions were received and are described in **Table 1.1**. Copies of the responses are included in **Appendix E**. The responses particularly relate to information and future involvement for the next stage of the flood management process with the application of the Study results for future masterplanning and flood risk management study.

Table 1.1: Submissions during Public Exhibition

Respondent	Description	Response
Resident of Melbourne Street	Storm runoff behaviour has changed over time due to development in the area. This includes the roundabout at the intersection of Webb St & Adelaide St and the cultural centre.	Recommend that resident is included in future consultation for next stage of flood management process.
Resident of Bay View Avenue	Improved management of storm runoff from Bay View Ave (at the top of the catchment) may be beneficial to properties lower in the catchment.	To be noted for next stage of flood management process.
Gosford residents group	Request for extension to public exhibition period to allow more residents to review Study results with respect to sea level rise and potential application of results by Gosford City Council.	The objective of this Flood Study is to define overland flood behaviour in the catchment. Recommend that respondent is included in future consultation for the next stage that relates Council's application of the results for masterplanning purposes and flood risk management study.

2 Catchment Data

Data adopted for this Study has been collated from a number of sources for application to the hydraulic model.

2.1 Gosford City Council Land Information

Gosford City supplied data and information for the Study including:

- GIS layer of cadastre and land-use zones
- GIS layer of drainage pipeline/culvert location and size
- Aerial photos

A copy of the data sharing agreement is included as **Appendix A**.

2.2 Previous Studies

2.2.1 Brisbane Water Foreshore Flood Study, May 2009, Cardno Lawson Treloar

This report describes the development of flood planning level parameters for the Brisbane Water Foreshore based on extensive data analysis and calibrated modelling systems. Downstream boundary water levels, the 1% Probability of Exceedance (PoE) levels, were determined for use in individual creek flooding studies. The 1% PoE levels represents the level that has a 99% chance that it will not be exceeded during any creek flood event. For the Point Frederick Flood Study, the relevant parameters are:

- Gosford = 0.72m AHD
- Caroline Bay = 0.72m AHD

2.2.2 East Gosford Catchment Study, August 1995, Bewsher Consulting

This report describes the evaluation of the existing stormwater drainage system at East Gosford and recommends potential improvement works. This study investigated trunk drainage in the East Gosford Catchment. A pipeline system capacity assessment was undertaken by hydraulic and hydrologic modelling using ILSAX and a hydraulic grade line analysis model. Questionnaires were distributed to selected properties near trunk drainage lines, and responses indicated eight instances of above floor flooding in the study area.

Two lines of stormwater water (lines 6 and 9 within the report) that are present within the study area were investigated in this report. From this analysis the following areas which suffer from flood are:

- The intersection of Frederick and Auburn St
- Properties on the western side of Line 9 (Melbourne Road)

2.2.3 Gosford CBD Local Overland Flow Flood Study, February 2011, Cardno

This report describes the local flooding present within the Gosford CBD study area. This study was undertaken by applying rainfall directly to the active 2D model (direct rainfall). As part of the study, several sensitivity analyses were undertaken to indentify suitable parameters and methodology in order to obtain an accurate representation of catchment flooding in this area.

2.3 Available Survey

2.3.1 Aerial Survey

Aerial survey (ALS) was provided by Gosford City Council. The survey was undertaken in 2007, and is therefore representative of the catchment at that time. While not explicitly reported with the data, typical accuracies of ALS or LiDAR data are in the order of +/- 0.15 metres in one standard deviation.

2.3.2 Bathymetry

Bathymetry of Brisbane Water (Caroline Bay and the Gosford Broad Water) was based on the bathymetry created for the Brisbane Water Foreshore Flood Study (Cardno Lawson Treloar, 2009).

2.3.3 Additional Survey

The need for additional survey was identified during the data review process. Three locations were identified:

- The three outlet channels entering into Caroline Bay. Due to the dense foliage in the area, the channels have not been well defined in the aerial survey information

Council commissioned Cardno to undertake the survey, with the work being completed on 16 December 2011. A copy of the additional survey is included as **Appendix B**.

3 Flow Modelling

The SOBEK 1D/2D model from WL|Delft Hydraulics Laboratory was used to model the catchment and to hydraulically route overland flood flows and street flow. This modelling system dynamically couples the one-dimensional and two-dimensional flow in the floodplain. The Direct Rainfall ('rainfall on the grid') methodology was adopted for the study. In the model, rainfall is applied directly to the 2D terrain, and the hydraulic model automatically routes the flow determined by the elevation and roughness grids and the 1D pipeline network.

3.1 Modelling Scenario

The following scenario was assessed as a part of the study:

- The main trunk drainage system, consisting of pipes 600mm diameter and larger, is included. Where buildings are likely to significantly impact the overland flow path, the building footprints are incorporated into the model.

This modelling scenario was chosen based on the previous investigations undertaken in the *Gosford CBD Local Overland Flow Flood Study* (Cardno, 2011). This report should be referred to while reading this addendum.

3.2 Model Extent

The model extent for the catchment covering about 1.1 km^2 is shown in **Figure 1.1**. A 2m by 2m grid was developed for the Study Area comprising about 400,000 grid cells.

3.3 Topography (2D)

A terrain grid was generated to represent ground elevations based on ALS data supplemented by detailed field survey of downstream drains discharging to Caroline Bay. **Figure 3.1** shows the elevations Point Frederick study area.

3.3.1 Building footprints

Some buildings in the study area, shown in **Figure 3.2**, were modelled as blocked obstructions similar to Scenario 3 of the Gosford CBD and West Gosford models. The extent of the building footprint is raised by 3m above the ground elevation in the terrain grid. Buildings at St Josephs College, near York and Wells Streets, and houses at Melbourne and Webb Streets (near Russell Drysdale Street) were raised due to their vicinity to an overland flowpath and potential to restrict flow conveyance.

3.4 Roughness

Each cell of the 2D grid also has a roughness value applied to model the influence to flow behaviour of the particular land-use. The adopted roughness layout, shown in **Figure 3.2**, was based on aerial photographs, site inspections, and Council's land-use zonings. The roughness value applied for each land-use is listed in **Table 3.1**.

Table 3.1: 2D Grid Roughness Values

Land-use	Roughness Parameter
Road/Carpark	0.02
Waterbody	0.02
Open Space	0.03
Channel	0.03
Properties	0.08
Bushland/Mangroves	0.10
Building/Commercial	0.5
School Building Areas	0.45
Light Vegetation	0.06

3.5 1D Network

Piped drainage systems are incorporated into the SOBEK model as distinct 1D elements connected to the terrain grid for modelling. All pipes that were considered significant to the function of the drainage network were incorporated into the model.

The location and size of pipes and culverts were determined based on Council's GIS data supplemented by design drawings and site inspections by Council staff. Design drawings provided by council and levels identified in *East Gosford Catchment Study* (Bewsher Consulting, 1995) were used to determine invert levels of the pipes. Where there was no available invert level data, inverts of pipes were assumed as a standard cover depth and surface levels were estimated based on aerial survey data.

Pit inlets were assumed to be pipe limiting, rather than controlled by the inlet itself.

The channel outlets located at the downstream end of the catchment were modelled within a 1D section. Within this area it was regarded that the bushland in the area was too dense to obtain an accurate representation of the channel. Field survey was used to define the channel in these locations.

Figure 3.3 shows the pipe and channel sections incorporated as 1D elements in the model. The lengths of the drainage system components for the model are:

- Gosford East Study Area – 4.9 km of pipeline, 0.08 km of box culvert, 0.28 km of open channel

Roughness values applied to the 1D elements are listed in **Table 3.2**.

Table 3.2: 1D Elements Roughness Values

Drainage Component	Roughness Parameter
Pipeline	0.018
Box Culvert	0.018
Open Channel	0.03

3.6 Hydrology

As the Direct Rainfall methodology was adopted, a separate hydrological model to determine flows was not required. The direct rainfall method, or rainfall-on-grid approach, is advantageous for defining overland flowpaths as runoff is not conveyed along pre-determined paths but is routed based on calculations for each grid cell. This methodology was verified to results from an XP-RAFTS hydrology model as discussed in Section 3.8 of the Gosford CBD study report.

Due to the small area of the catchment, uniform areal distribution of design storms has been assumed for the hydrologic component of the analysis. Design rainfall depths and temporal patterns for the modelling of 1% AEP, 2% AEP, 5% AEP, and 10% AEP were developed using standard techniques provided in Australian Rainfall and Runoff (1999).

The design Intensity-Frequency-Duration (IFD) parameters were obtained from the Bureau of Meteorology for Point Frederick located in the catchment. The IFD parameters are shown in **Table 3.3**.

Table 3.3: Design IFD Parameters

Parameter	Value
2-Years ARI 1-hour Intensity	38.74 mm/hr
2-Years ARI 12-hours Intensity	8.65 mm/hr
2-Years ARI 72-hours Intensity	2.71 mm/hr
50-Years ARI 1-hours Intensity	75.77 mm/hr
50-Years ARI 12-hours Intensity	17.9 mm/hr
50-Years ARI 72-hours Intensity	6.03 mm/hr
Skew	0.0
F2	4.3
F50	15.89
Temporal Pattern Zone	1

The Probable Maximum Precipitation (PMP) was estimated using the publication "The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method" (Commonwealth Bureau of Meteorology, 2003. **Table 3.4** shows the data for the PMP calculations.

Table 3.4: PMP Calculation Values

Parameter	Value
Total area (km^2)	Gosford East = 1.1 km^2,
Moisture Adjustment Factor	0.71
Elevation Adjustment Factor	1.00
Percentage Rough	100%

Estimated average design storm rainfall intensities for the full ranges of storm events and durations are presented in **Table 3.5**.

The loss rates applied to the rainfall patterns based on the soil conditions of the catchment are listed in **Table 3.6**.

Table 3.5: Design Rainfall Intensities (mm/h)

Duration	10% AEP	5% AEP	2% AEP	1% AEP	PMP
15 min	100.6	128.7	149.6	165.3	680
30 min	81.1	93.0	108.4	120.1	500
45 min	65.7	75.5	88.2	97.9	413
1 hour	56.2	64.7	75.8	84.2	360
1.5 hours	44.6	51.4	60.2	67.0	313
2 hours	37.7	43.4	51.0	56.8	270
3 hours	29.6	34.2	40.3	44.9	220

Table 3.6: Rainfall Loss Parameters

Rainfall Loss	Value
Initial Loss	10 mm
Continuing Loss Rate	1.5 mm/h

3.7 Boundary Conditions

Downstream boundary conditions were adopted from the Brisbane Water Foreshore Flood Study (May 2009, Cardno Lawson Treloar) (described in **Section 2.2.1**). The 1% Probability of Exceedence (PoE) levels, being the level that one can be 99% confident will not be exceeded during any creek flood event, used in the modelling are:

- Gosford = 0.72m AHD
- Caroline Bay = 0.72m AHD

3.8 Model Verification

Refer to *Gosford CBD Local Overland Flow Flood Study* (Cardno, 2011) Section 3.8 for verification of the modelling technique.

4 Flood Model Results

Flood modelling was completed for a series of Annual Exceedance Probabilities (AEP) – 1%, 2%, 5%, 10% AEP and for the Probable Maximum Flood (PMF). The study area was modelled for the 10% AEP, 1% AEP and PMF events for the following durations:

- 10% AEP and 1% AEP - 15 minutes, 30, 60, 90 and 120 minutes
- PMF - 15 minutes, 30, 45, 60 and 90 minutes

The peak water levels for the 10% AEP and 1% AEP resulted from the 15 minutes, 90, and 120 minutes duration storms. A further assessment of the results from the scenarios shows that the representative critical duration is the 120 minute duration as it resulted in peak water levels which are within 0.01m of the other storms. This duration was used for the modelling of the 2% and 5% AEP.

The peak water levels for the PMF event resulted from the 15 minutes and 30 minutes durations.

4.1 Design Event Results

The SOBEK flood models were run for the 1% AEP, 2%, 5%, and 10% AEP and the PMF events. Peak flood depths are shown in the following figures:

- Figure 4.1 10% AEP event
- Figure 4.2 1% AEP event
- Figure 4.3 PMF event

Note that the extents shown have been filtered for depths >0.1m or velocity-depth product >0.1m^2/s. Detailed results outputs are provided to Council in GIS format to allow more detailed review of overland flow inundation. The rainfall-on-grid modelling methodology applies rainfall to all locations of the grid which results in the isolated ponding in localised depressions.

Figure 4.4 shows the peak water level obtained during the 1% AEP event. **Table C.1** in **Appendix C** lists the peak water level at the reference locations shown in **Figure 4.5** for the 1% AEP, 2%, 5%, and 10% AEP and the PMF events

Peak flow rates at locations shown in **Figure 4.6** for the 1% AEP 2 hour critical duration storm are listed in **Table 4.1.**

Table 4.1: Peak Flow Rates – 1% AEP 2 Hour Event

Section	Peak Flow (m3/s)
GE-1	1.05
GE-2	2.49
GE-3	0.92
GE-4	3.56
GE-5	5.40
GE-6	0.09
GE-7	3.55

Table 4.2 shows the number of property allotments with a depth of flooding greater than 0.2m for the 10% AEP, 1% AEP and PMF events. The properties inundated with depth greater than 0.3m in the 1% AEP event are also listed.

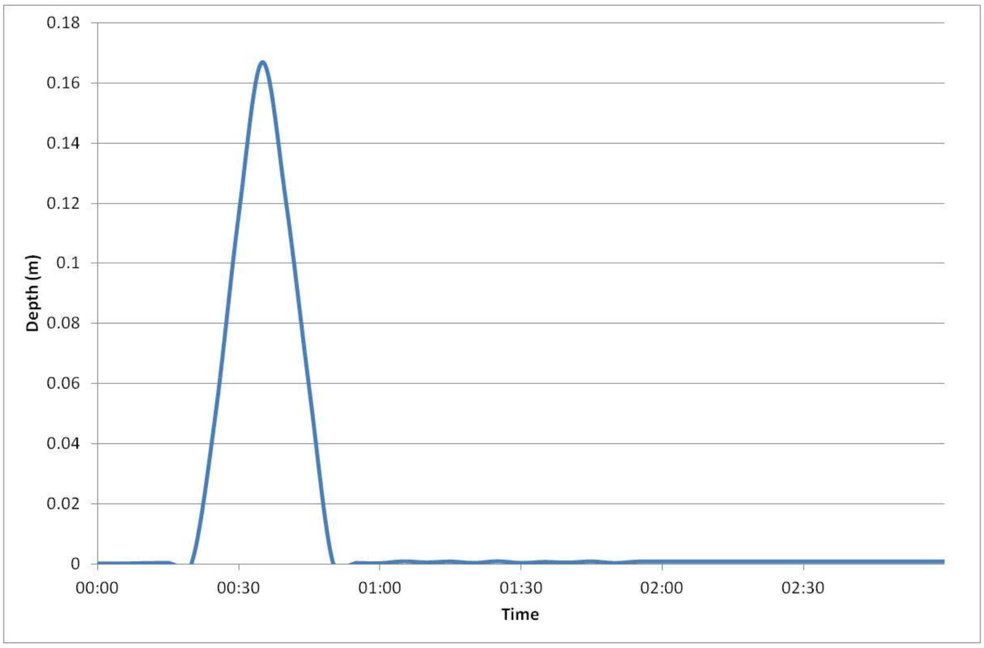
Table 4.2: Properties Inundated

ARI Event	East Gosford No. of Properties
Flooding Greater than 0.2	
10% AEP	79
1% AEP	104
PMF	138
Flooding Greater than 0.3 m	
1% AEP	54

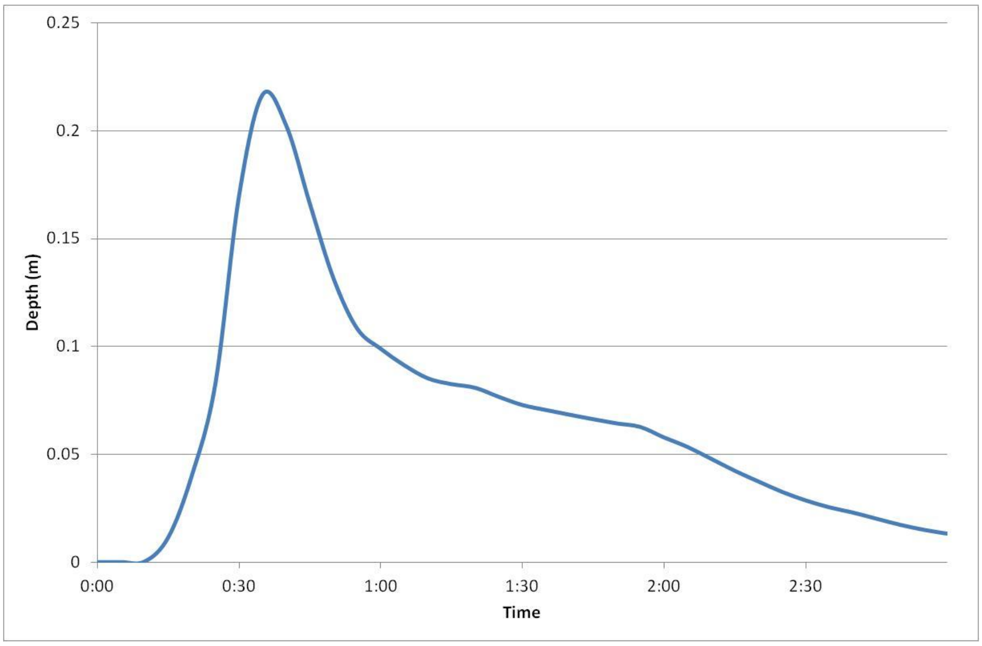
Time of flood inundation at three locations is shown in the following graphs of:

- **Graph 4.1** - York Street near Webb Street, reference location EG-12 (of Figure 4.5)
- **Graph 4.2** – Webb Street between Russell Drysdale Street and Adelaide Street, reference location EG-9
- **Graph 4.3** – Arts Centre carpark off Webb Street, near reference location EG-4.

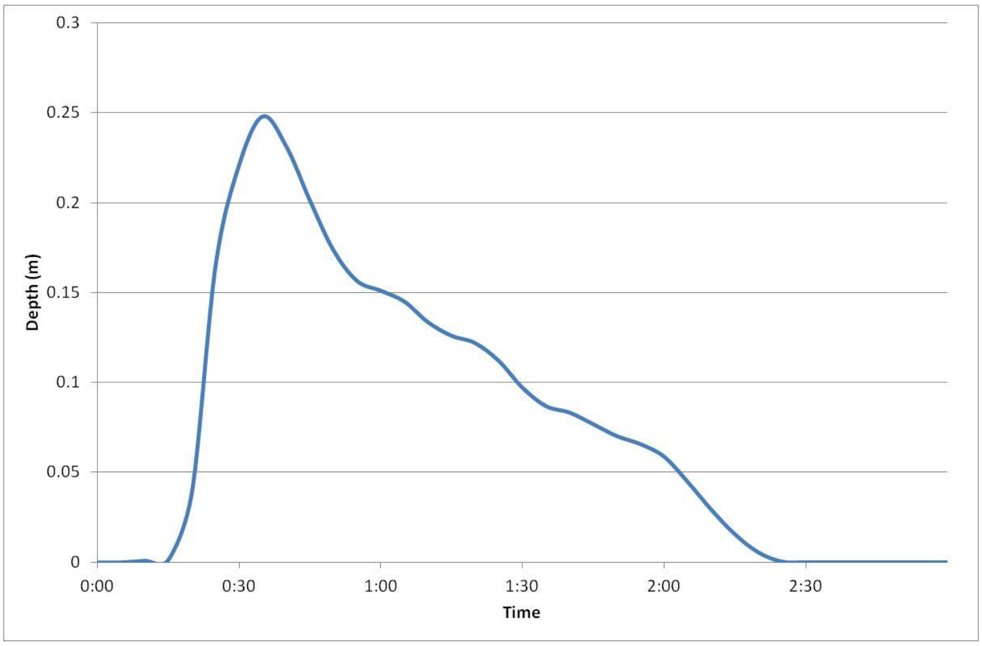
The inundation graphs show relatively short durations of exposure to significant flood depths. Flood depths in York Street show a comparatively quicker time of drawdown than the other two locations.



Graph 4.1: Depth of inundation at York Street (near Webb Street)



Graph 4.2: Depth of inundation at Webb Street (between Russell Drysdale St and Adelaide St)



Graph 4.3: Depth of inundation at Arts Centre carpark (off Webb Street)

4.2 Provisional Hazard

Flood hazard can be defined as the risk to life and limb and damage caused by a flood. The hazard caused by a flood varies both in time and place across the floodplain. The Floodplain Development Manual (NSW Government, 2005) describes various factors to be considered in determining the degree of hazard. These factors are:

- Size of the flood,
- Depth and velocity of floodwaters,
- Effective warning time,

- Flood awareness,
- Rate of rise of floodwaters,
- Duration of flooding,
- Evacuation problems,
- Access.

Hazard categorisation based on all the above factors is part of establishing a Floodplain Risk Management Plan. The scope of the present study calls for determination of provisional flood hazards only, which when considered in conjunction with the above listed factors provides comprehensive analysis of the flood hazard.

Provisional flood hazard is determined through a relationship developed between the depth and velocity of floodwaters as detailed in the Floodplain Development Manual (NSW Government, 2005). The provisional hazard is defined as either High or Low and the transition zone between high and low is assumed as high hazard. Provisional hazard for the 1% AEP event in is shown in **Figure 4.7**.

Provisional high hazard conditions in relatively localised areas along several streets within the Gosford East Catchment. At the corner of Webb and York St, there is a section of high hazard as the main flow path encounters a large change in elevation. At Lushington St there is also an area of high hazard, as similarly a large change in elevation is experienced.

Large areas at the downstream section of the model, in the mangrove areas are also subject to high hazard. In this location the high hazard is based on the depth of flooding, as the water outlets to the ocean along incised channels in this area.

In general, there are only small areas within the catchment which are subject to high hazard in the 1% AEP. Of these areas, the majority are either contained within the roadway or are located outside residential lots.

4.3 Hydraulic Categories

Hydraulic categorisation of the floodplain is used in the development of the Floodplain Risk Management Plan. The Floodplain Development Manual (2005) defines flood prone land to be one of the following three hydraulic categories:

- **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.

Floodways were determined for the 1% AEP event by considering those model branches that conveyed a significant portion of the total flow. These branches, if blocked or removed, would cause a significant redistribution of the flow. The criteria used to define the floodways are described below (based on Howells et al, 2003).

As a minimum, the floodway was assumed to follow the creekline from bank to bank. In addition, the following depth and velocity criteria were used to define a floodway:

- Velocity x Depth product must be greater than 0.25 m^2/s and velocity must be greater than 0.25 m/s; OR
- Velocity is greater than 1 m/s.

Flood storage was defined as those areas outside the floodway, which if completely filled would cause peak flood levels to increase by 0.1 m and/or would cause peak discharge anywhere to increase by more than 10%. The criteria were applied to the model results as described below.

Previous analysis of flood storage in 1D cross sections assumed that if the cross-sectional area is reduced such that 10% of the conveyance is lost, the criteria for flood storage would be satisfied. To determine the limits of 10% conveyance in a cross-section, the depth was determined at which 10% of the flow was conveyed. This depth, averaged over several cross-sections, was found to be 0.2 m (Howells et al, 2003). Thus the criteria used to determine the flood storage is:

- Depth greater than 0.2m
- Not classified as floodway.

All areas that were not categorised as Floodway or Flood Storage, but still fell within the flood extent, where the depth is greater than 0.1 m, are represented as Flood Fringe.

The hydraulic categories for the 1% AEP based on the peak depth and velocity from local catchment runoff determined in the flood model is shown in **Figure 4.8**.

Flow conditions categorised as floodway are shown in several areas of the East Gosford subcatchment, particularly along Wells, Webb and York Streets.

4.4 Sensitivity Analysis

Sensitivity of the model methodology to the adopted rainfall and roughness parameters is discussed in Section 4.4 of *Gosford CBD Local Overland Flow Flood Study* (Cardno, 2011).

The effect on flood behaviour of pipe blockage in the Point Frederick-East Gosford catchment was modelled by excluding the 1D pit and pipe elements. Differences in the peak water level for the 1% AEP 2 hour critical duration event area are listed in **Table C.2** in **Appendix C**.

Peak water levels in Russell Drysdale Street near the College show significant increases as runoff is concentrated and ponds in this area as it does not have the piped drainage system to convey runoff to the bay. Similarly on the Lushington Street to York Street flowpath, the increase in peak water level is highest on York Street as runoff ponds due to the exclusion of the underground pipe network.

4.5 Climate Change

Changes to climate conditions are expected to have an adverse impact on sea levels and rainfall intensities. An assessment on the impact of climate change on flood behaviour in the Study Area has been undertaken for the following scenarios:

- Sea level increased by 0.2 m and rainfall increased by 10%
- Sea level increased by 0.4 m and rainfall increased by 20%
- Sea level increased by 0.9 m and rainfall increased by 30%
- Sea level increased by 0.9
- Rainfall increased by 30%

The 1% AEP 2 hour critical duration storm was used as a base case to assess the potential impacts.

4.5.1 Sea Level Increase

The Brisbane Water Foreshore Flood Study (2009) noted that a rise in the offshore tidal level would generally result in an equivalent rise in estuary level. Increases of 0.2m, 0.4m, and 0.9m were applied to the 1% PoE boundary condition in the models. The modelled downstream boundary levels are shown in **Table 4.3.**

Table 4.3: Boundary Conditions – Climate Change Scenarios

Description	Base Case 1% PoE	Plus 0.2m	Plus 0.4m	Plus 0.9m
Level at Caroline Bay and Gosford Broadwater	0.72	0.92	1.12	1.62

Changes in the peak water levels for the sea level rise scenarios at the reference locations (shown in **Figure 4.5**) are listed in **Table C.3** in **Appendix C**.

The difference in peak water levels of the climate change condition with boundary condition plus 0.9m compared to the base case (1% AEP 2 hour event) are shown in **Figure 4.9**. The differences in flood extent for the 0.9m sea level rise scenario are shown in **Figure 4.10**. The extents were filtered to a depth of greater than 0.1 m in this scenario.

A 0.9 m increase to sea level results in an increase to peak water levels in the low lying areas of the catchment. Albert Street is particularly affected by the increased sea level, as the ground surface at this location is near or around the sea level. George St is similarly affected with the bushland on the south side of the road now completely inundated. At Point Frederick, properties backing onto Caroline Bay along Albany St experience significant impacts on all low lying areas.

4.5.2 Rainfall Increase

The NSW Department of Environment and Climate (DECC, now OEH) guideline, Practical Consideration of Climate Change (2007), provides advice for consideration of climate change in flood investigations. The guideline recommends sensitivity analysis is done for rainfall intensity increases of 10%, 20%, and 30%.

Peak water levels listed in **Table C.4** (in **Appendix C**) shows that some locations in the catchment experience an increase of water level as rainfall increases. For example, the water level at the reference point EG-2 increases by 0.10m as rainfall increases by 30%.

Figure 4.11 shows the flood extent for the 30% rainfall increase scenario. Note that the extents shown have been filtered for depths >0.1m. Downstream of Webb Street shows a significant expansion in flood extent for the 30% rainfall increase scenario. The downstream area of the catchment entering Caroline Bay is also impacted from increased rainfall intensity due to the bowl-like topography of the catchment which converges at this location.

4.5.3 Increase of Rainfall and Sea Level

Three scenarios of both increases to rainfall and sea level were modelled to evaluate the potential effect of these climate change impacts. They were used to evaluate the impact of low medium and high climate change scenarios.

Table C.5 (in **Appendix C**) lists the resultant peak water levels for the scenarios at the reference locations (shown in **Figure 4.5**). The following figures show comparative flood extents for the 1% AEP 2 hour event climate change scenarios:

- **Figure 4.12 -** 30% rainfall increase and 0.9m sea level rise
- **Figure 4.13 -** 20% rainfall increase and 0.4m sea level rise
- **Figure 4.14 -** 10% rainfall increase and 0.2m sea level rise

5 Conclusion

The modelling procedures assessed for the Gosford CBD catchments can be generally applied to other catchments in the Gosford LGA. Particular parameters will need to be reviewed on an individual catchment basis for adoption of model scenario, rainfall IFD, surface roughnesses and boundary conditions. Detailed survey would likely be required for specific location which may influence flow behaviour.

This Report summarises the background, methodology and results for the modelled scenarios. Electronic results files compatible with Council's GIS from the models detailing parameters, such as peak water and velocity, are compiled to enable a more detailed assessment of overland flow inundation than can be presented within this report.

Modelling of the Point Frederick – East Gosford Catchment identified that there are several areas which experience significant impacts due to flooding. The corner of York and Wells Street, along with the area along Webb Street south of this, is particularly susceptible to flooding. This is due to the majority of the upstream catchment area concentrating at this location. In combination with varying topography, this results in an area which experiences both high velocity and significant flood depths.

Climate Change scenarios show that due to the nature of this catchment, it is vulnerable to both increased sea level rise and increased rainfall intensity. This is due to the bowl-like nature of the catchment coupled with the low lying areas downstream adjacent to Brisbane Water.

6 Recommendations

This Study defines local overland flow behaviour in the Point Frederick – East Gosford catchment. Flood modelling has enabled the generation of GIS layers for outputs including peak depth, peak water level, velocity and provisional hazard for a range of events and scenarios. These GIS layers are provided for Council to incorporate into their mapping system and the flood models are provided to enable evaluation of other scenarios.

The Study results can be used by Council to inform future masterplanning in the catchment, to identify property affectation criteria for development assessment, and to evaluate potential flood mitigation measures. A formal Floodplain Risk Management Study and Plan may be an appropriate next stage of the flood management process in the catchment.

References

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Figures

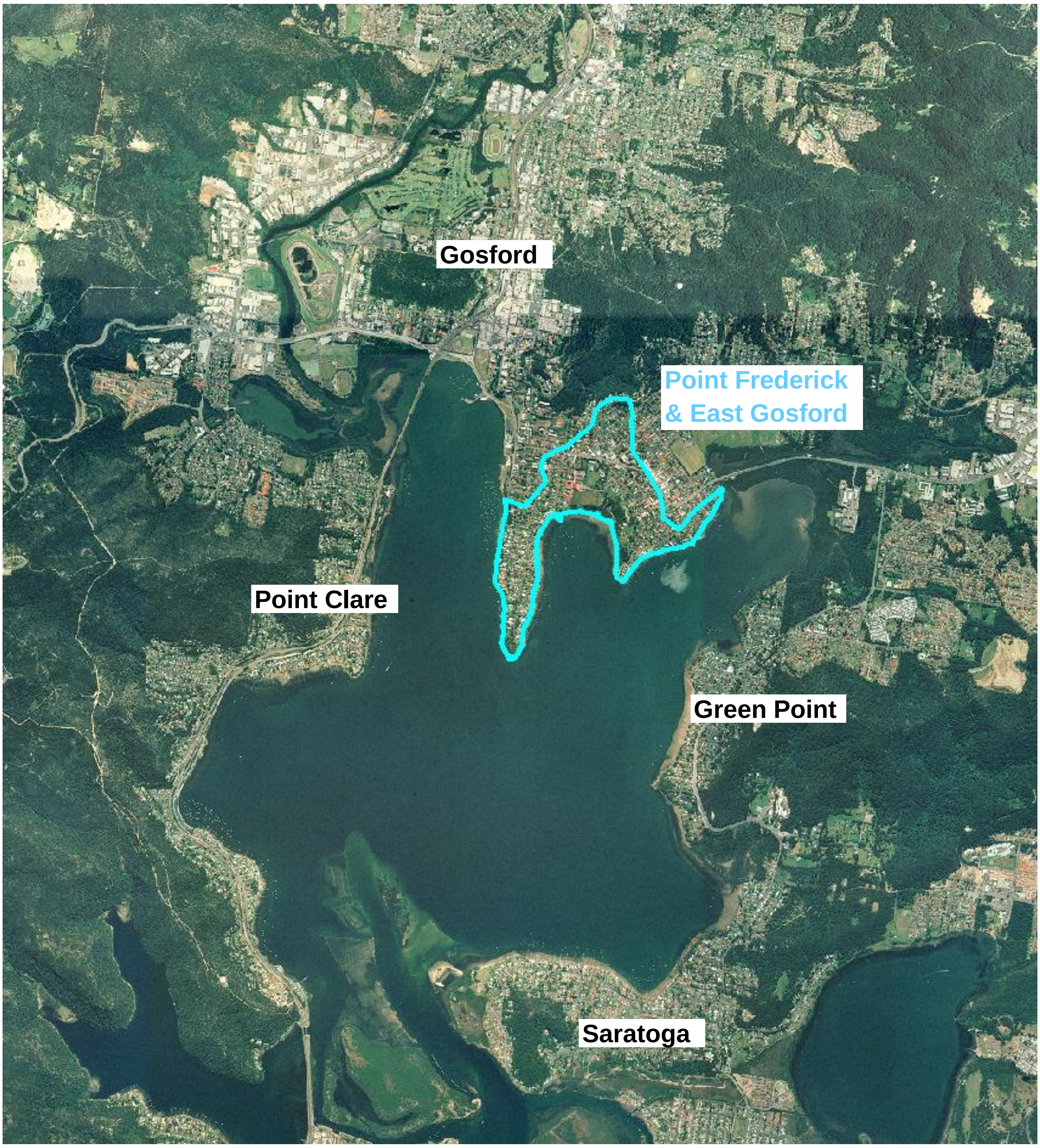


FIGURE 1.1 - SITE AREA LOCALITY

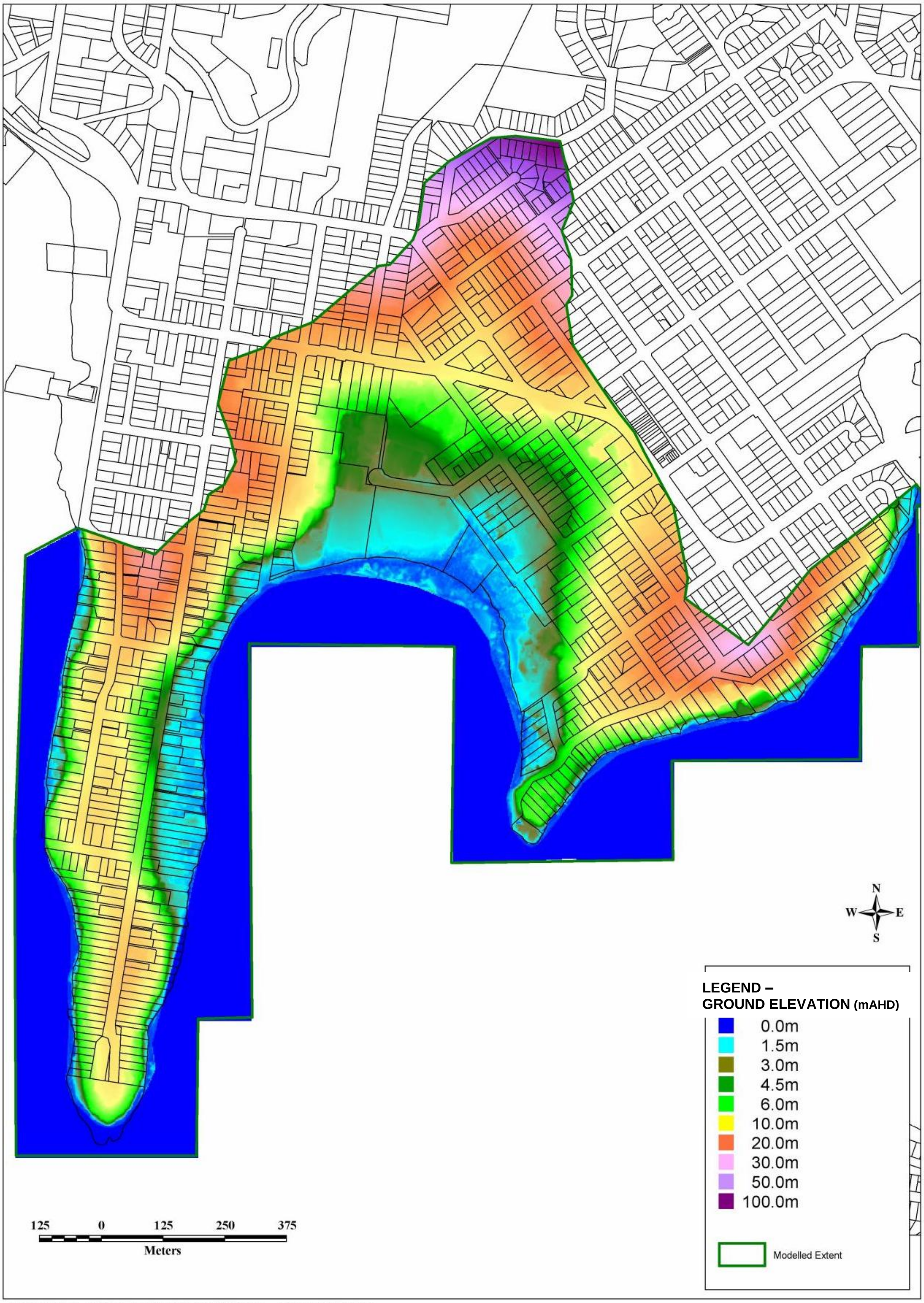


FIGURE 3.1 - GROUND ELEVATION MODEL - EAST GOSFORD

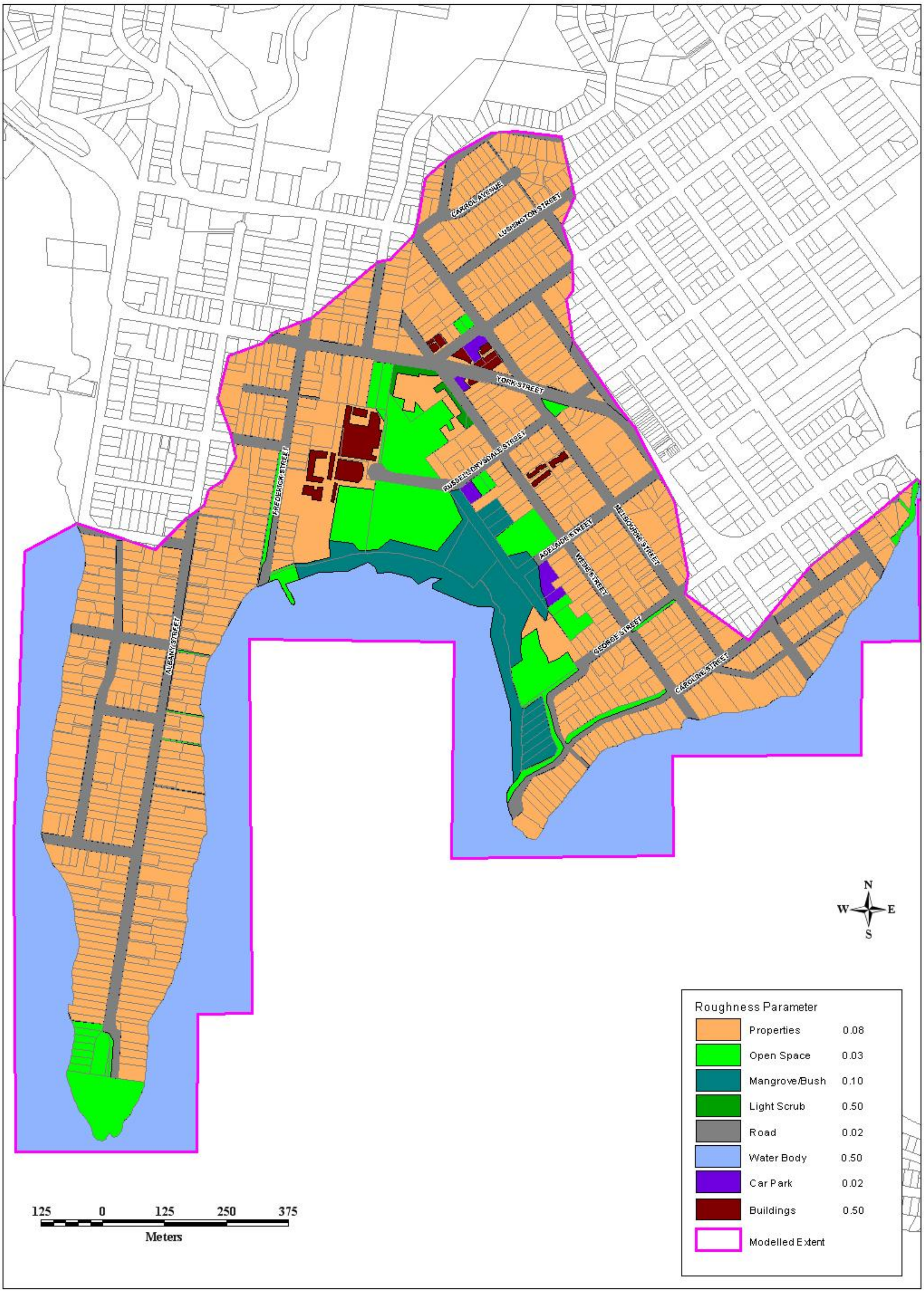


FIGURE 3.2 - SOBEK MODEL - ROUGHNESS LAYOUT

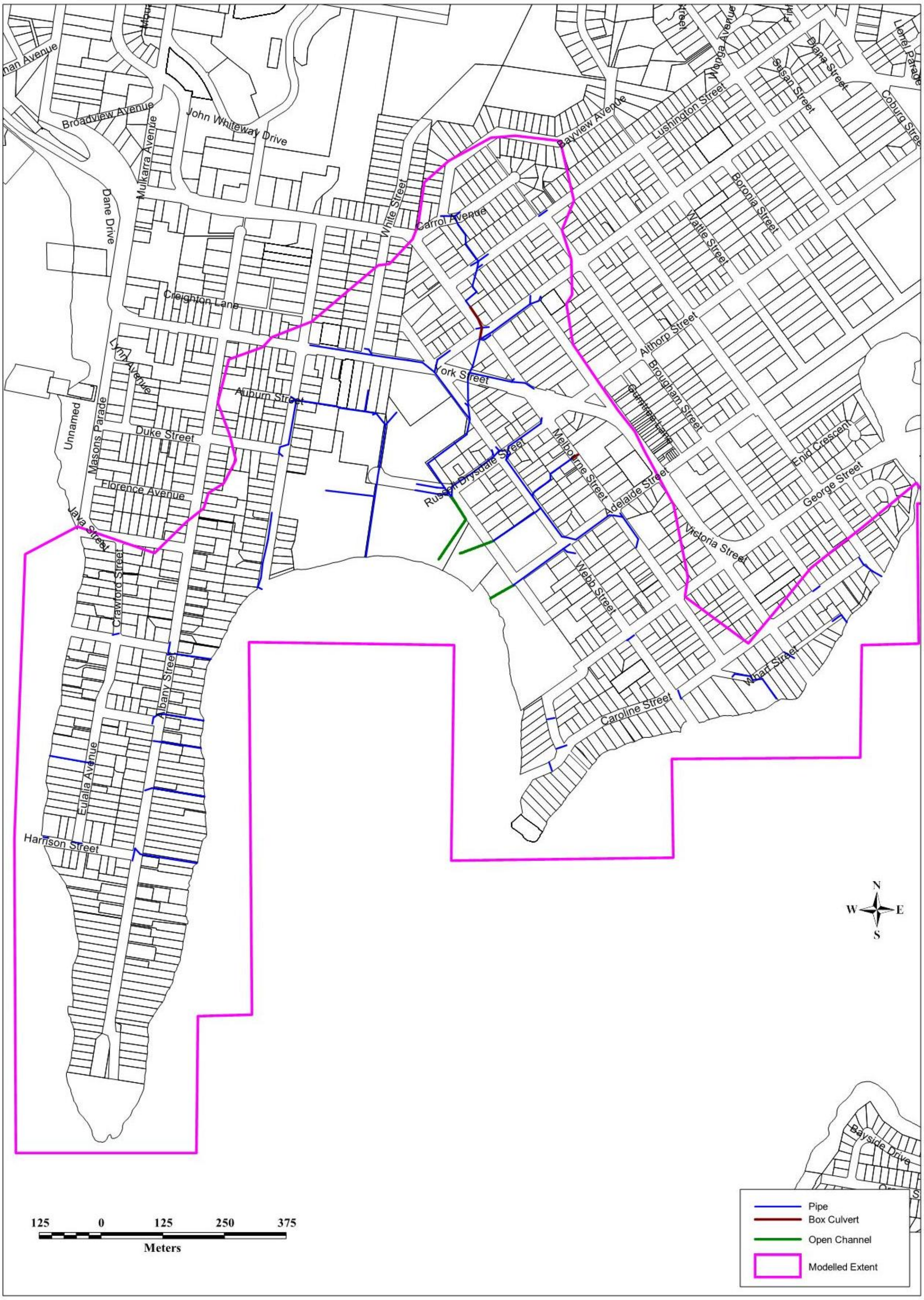


FIGURE 3.3 - SOBEK MODEL - 1D DRAINAGE SYSTEM

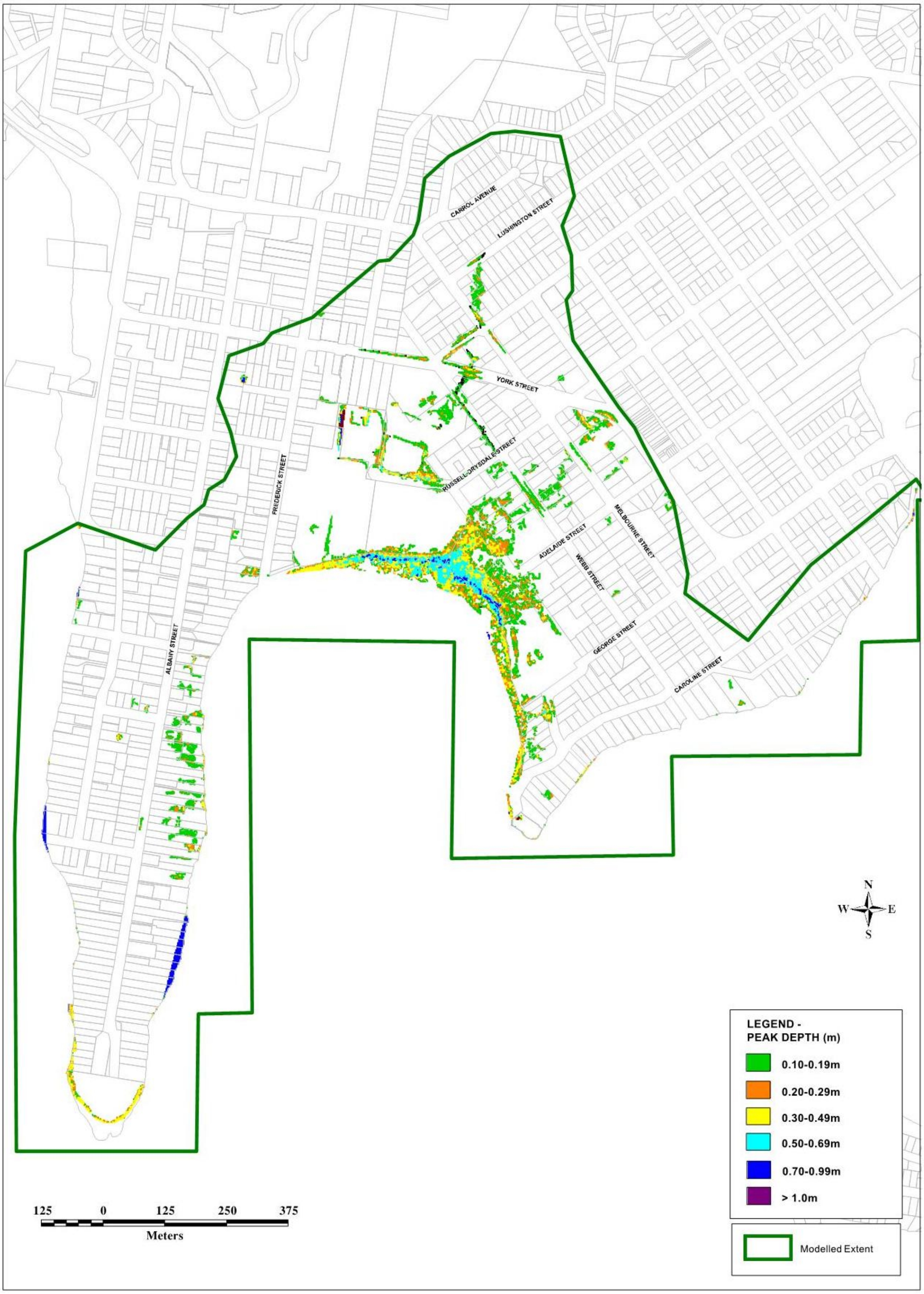


FIGURE 4.1 - PEAK FLOOD DEPTHS - EAST GOSFORD 10% AEP

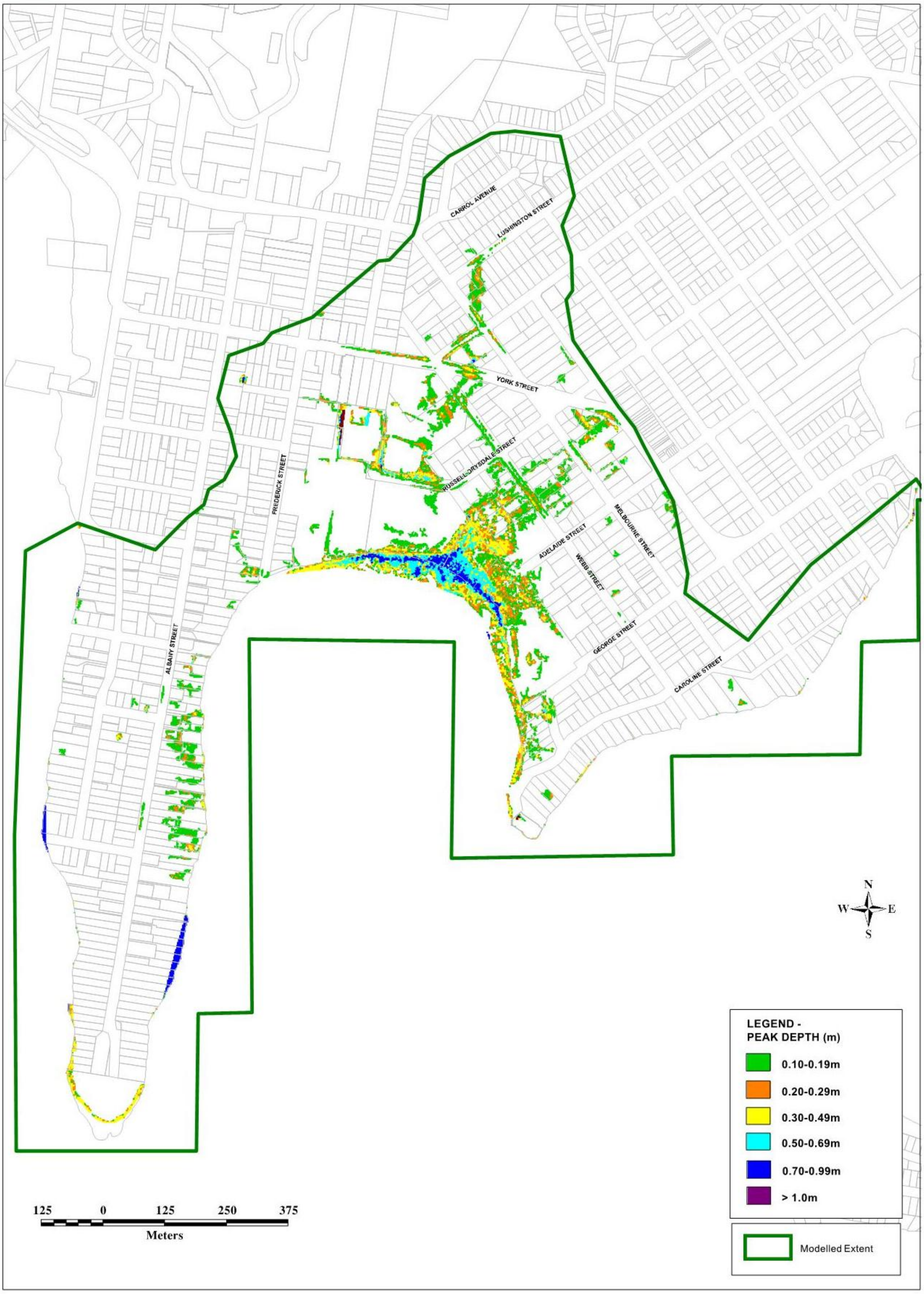


FIGURE 4.2 - PEAK FLOOD DEPTHS - EAST GOSFORD 1% AEP

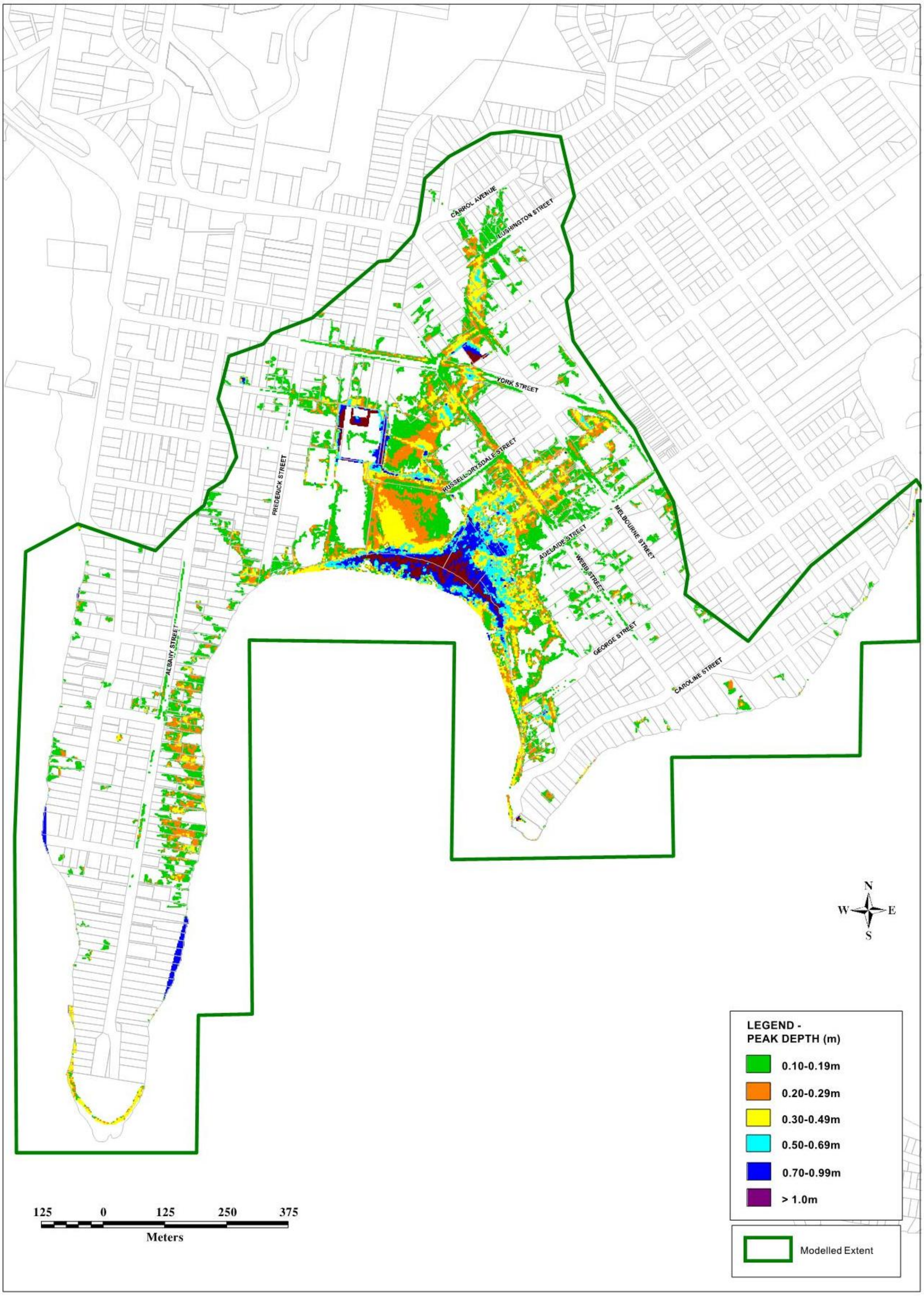


FIGURE 4.3 - PEAK FLOOD DEPTHS - EAST GOSFORD PMF

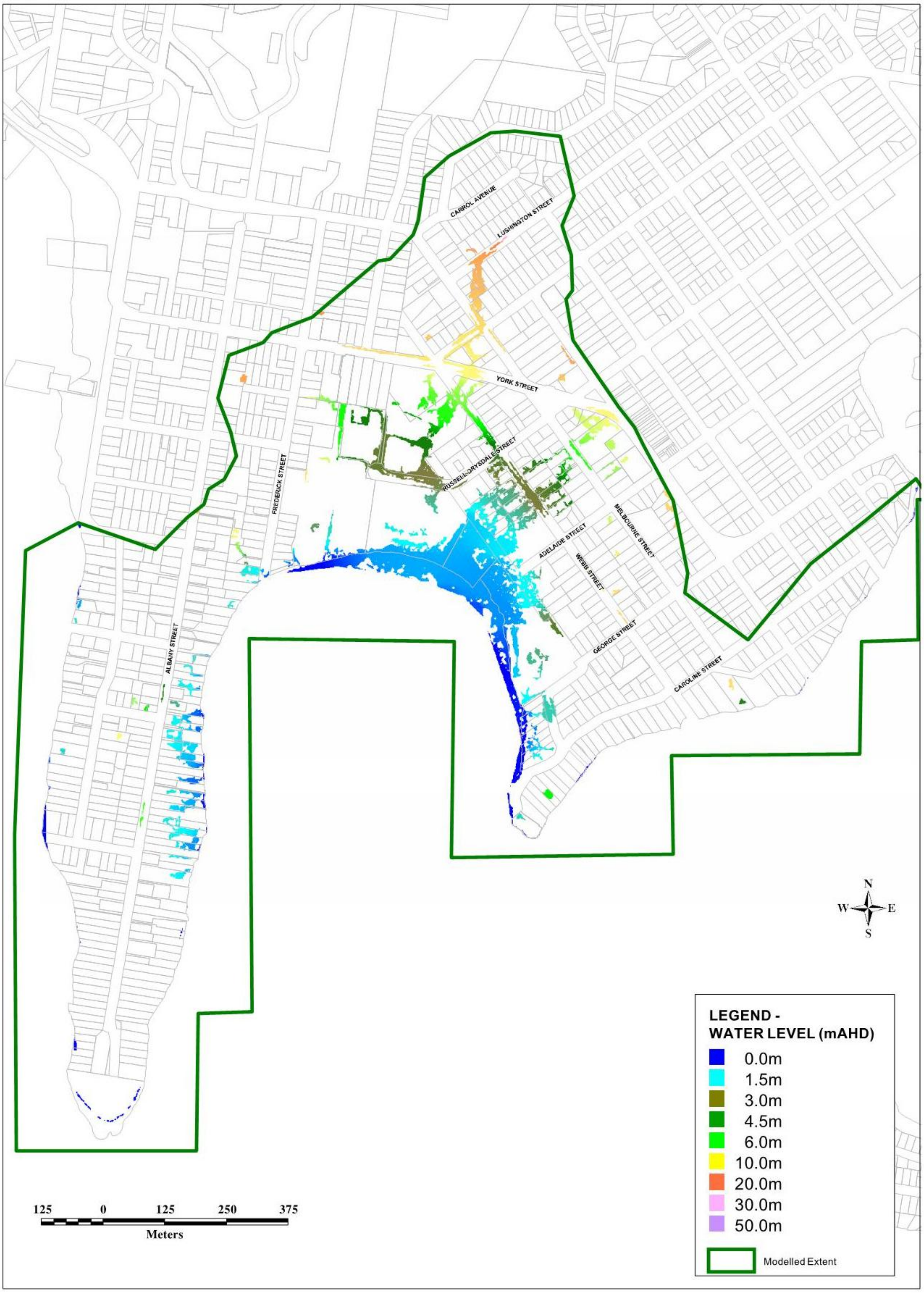


FIGURE 4.4 - PEAK WATER LEVEL - EAST GOSFORD 1% AEP

FIGURE 4.5 - WATER LEVEL REFERENCE LOCATIONS

FIGURE 4.6 - RESULTS REFERENCE LOCATIONS - PEAK FLOWS

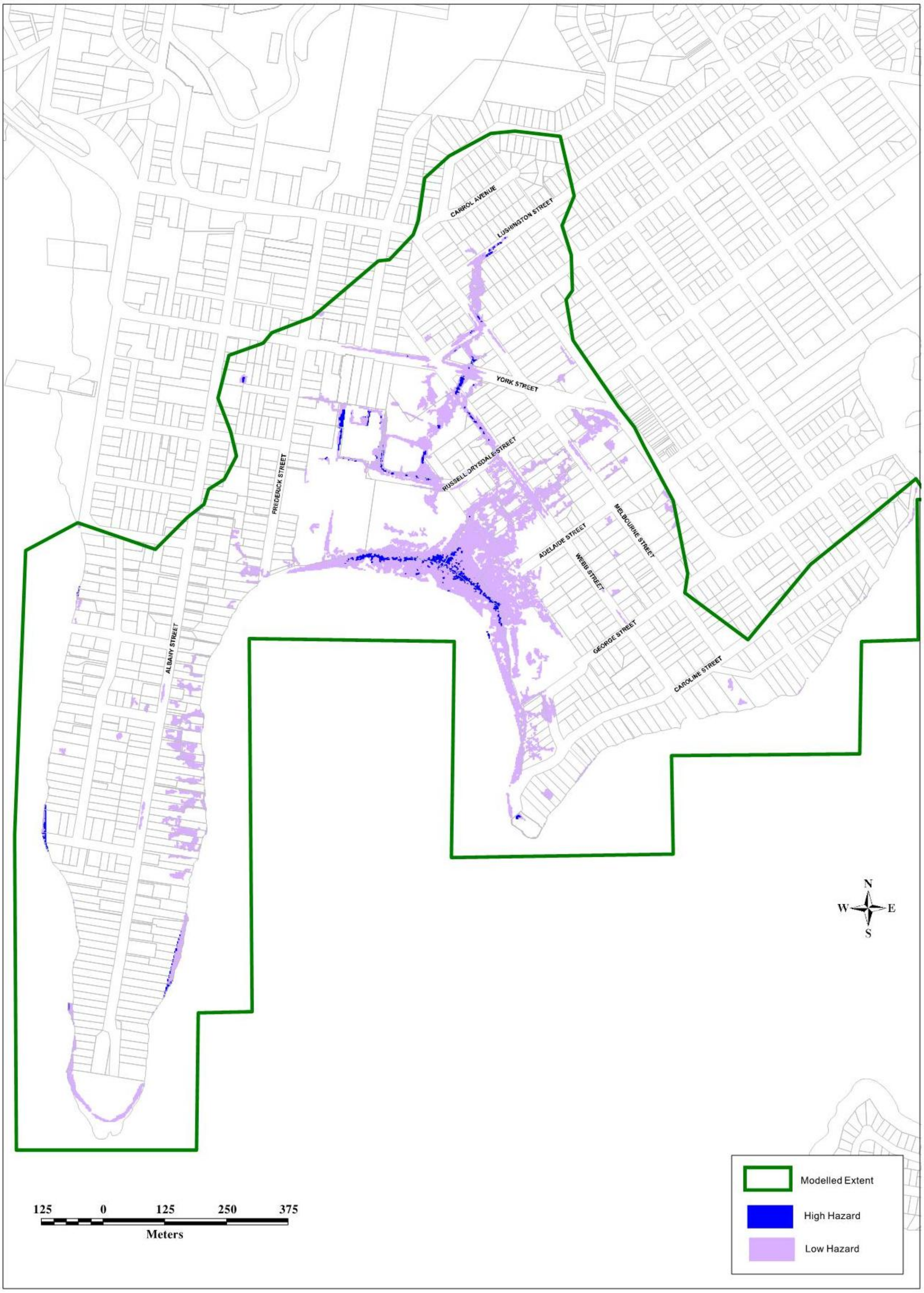


FIGURE 4.7 - PROVISIONAL HAZARD - EAST GOSFORD 1% AEP

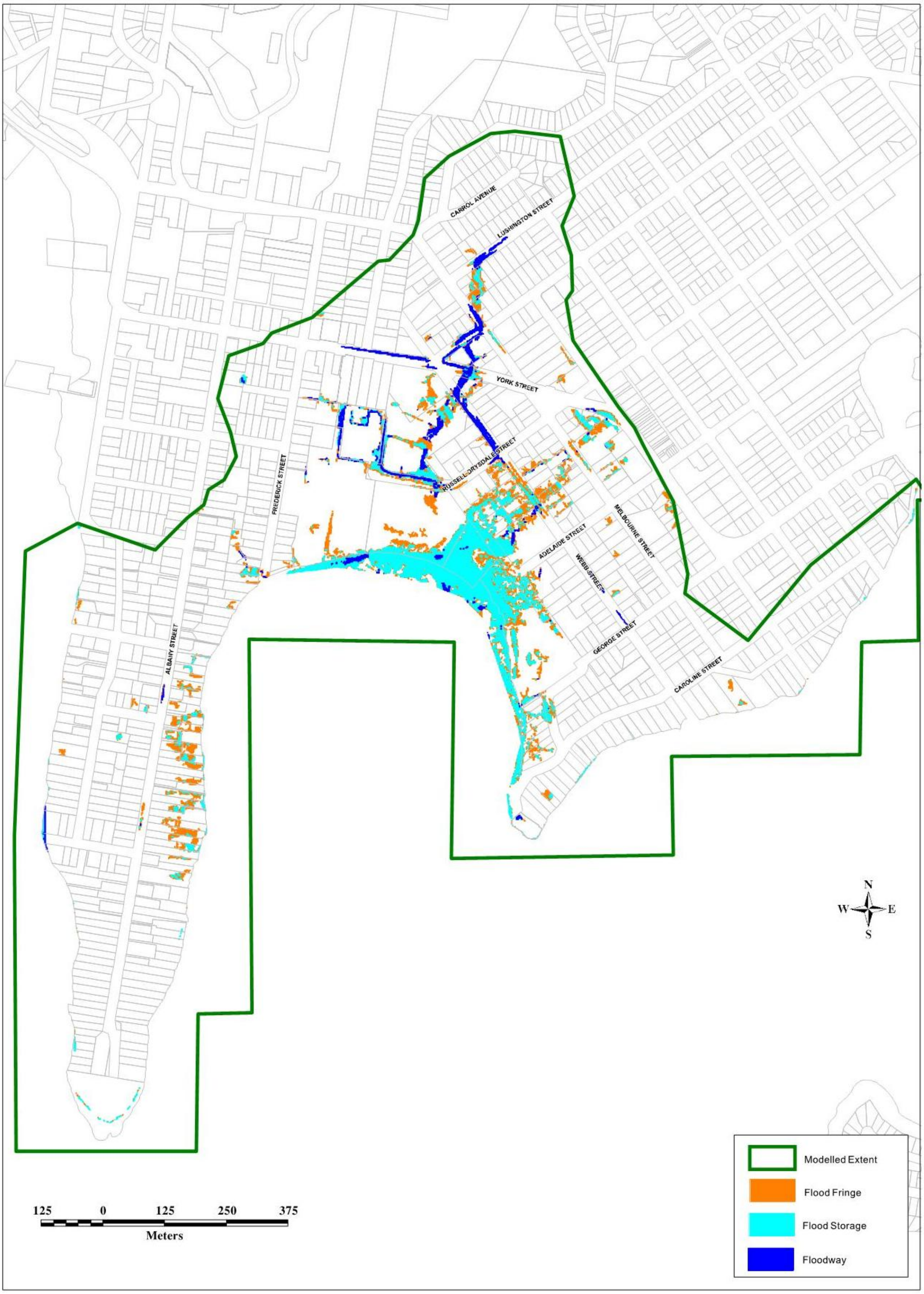


FIGURE 4.8 - HYDRAULIC CATEGORIES - EAST GOSFORD 1% AEP

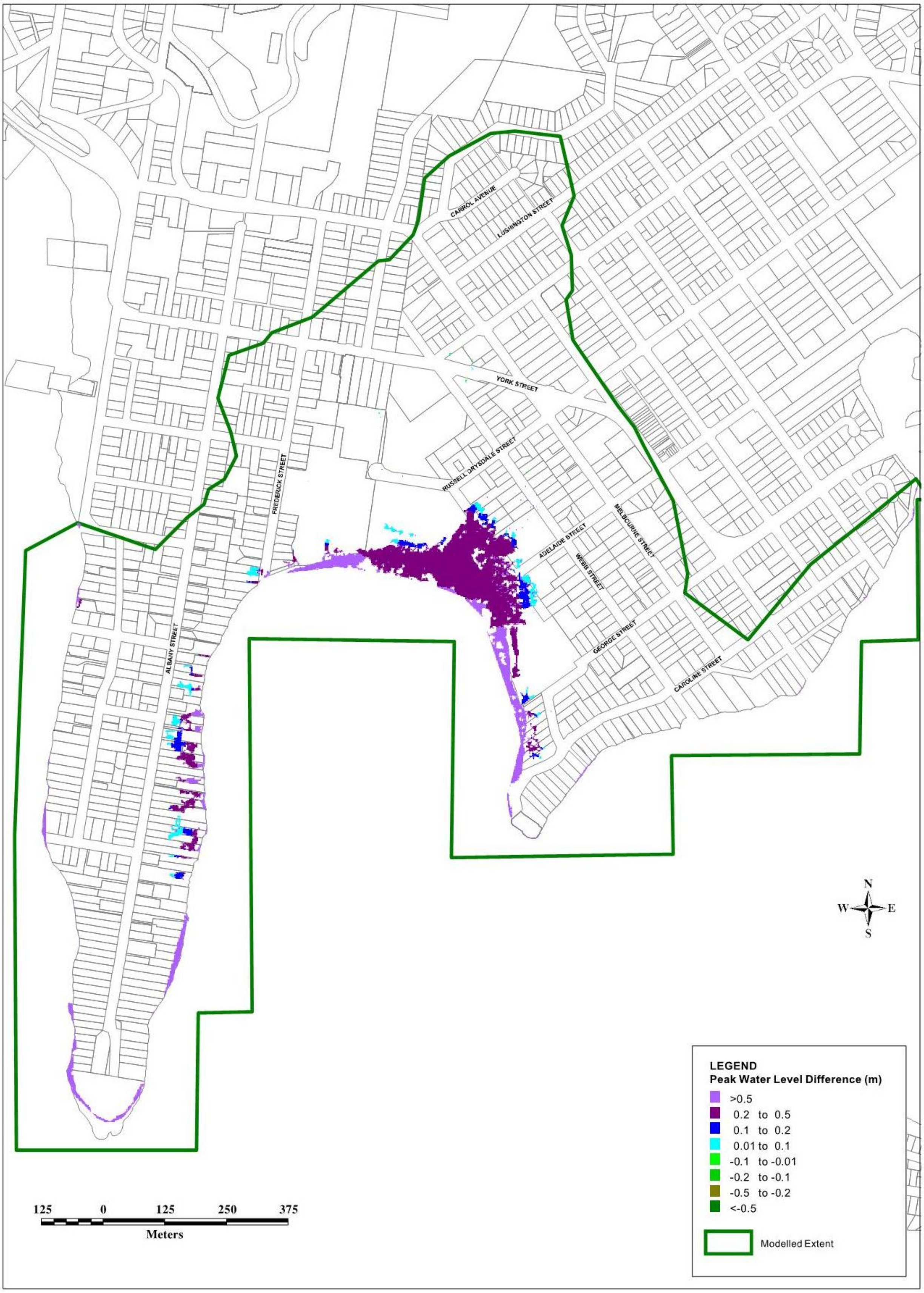


FIGURE 4.9 - CLIMATE CHANGE PEAK LEVEL COMPARISON - EAST GOSFORD 1% AEP 0.9m SEA LEVEL RISE

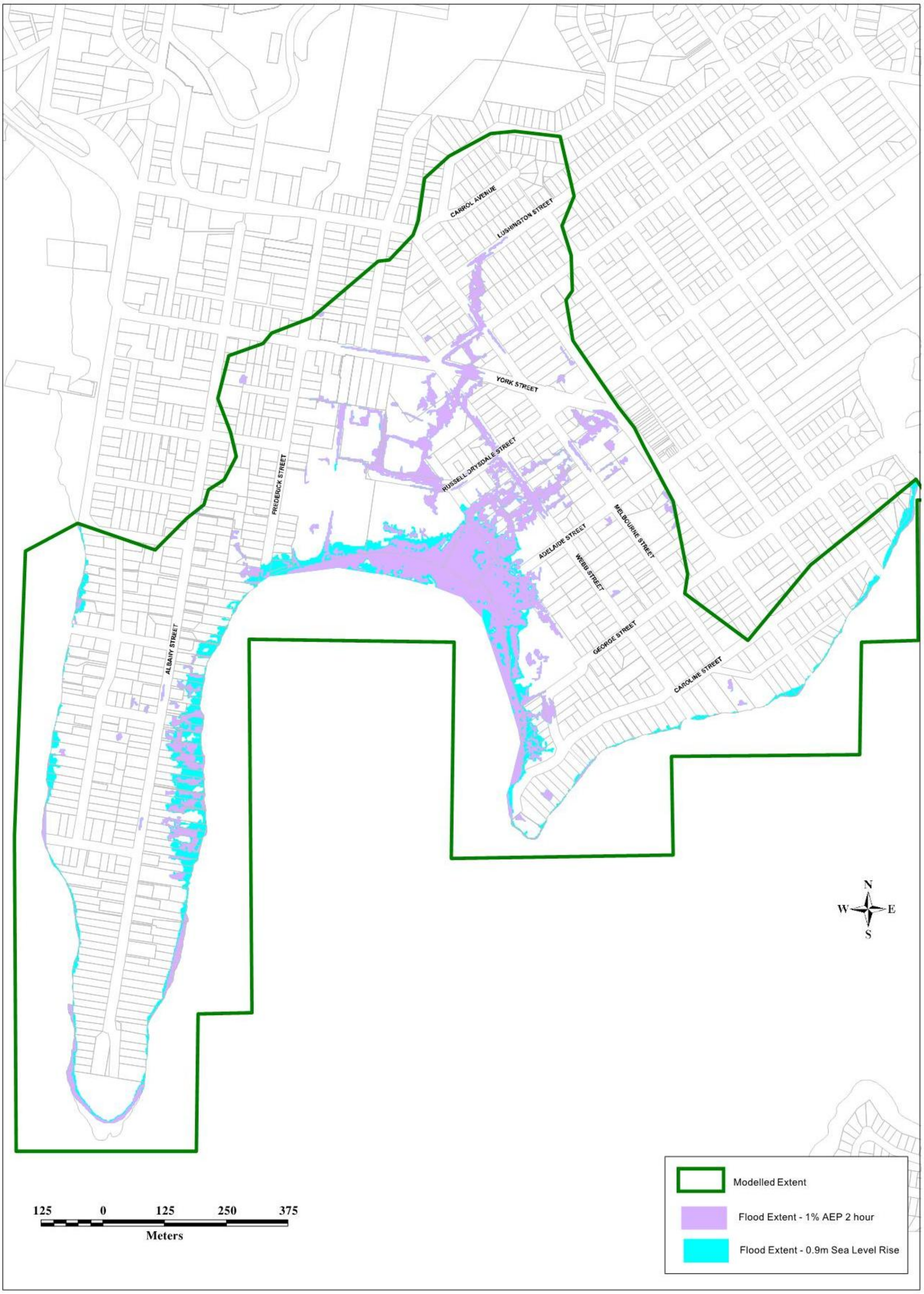


FIGURE 4.10 - CLIMATE CHANGE EXTENT COMPARISON - EAST GOSFORD 1% AEP 2 HOUR - 0.9m SEA LEVEL RISE

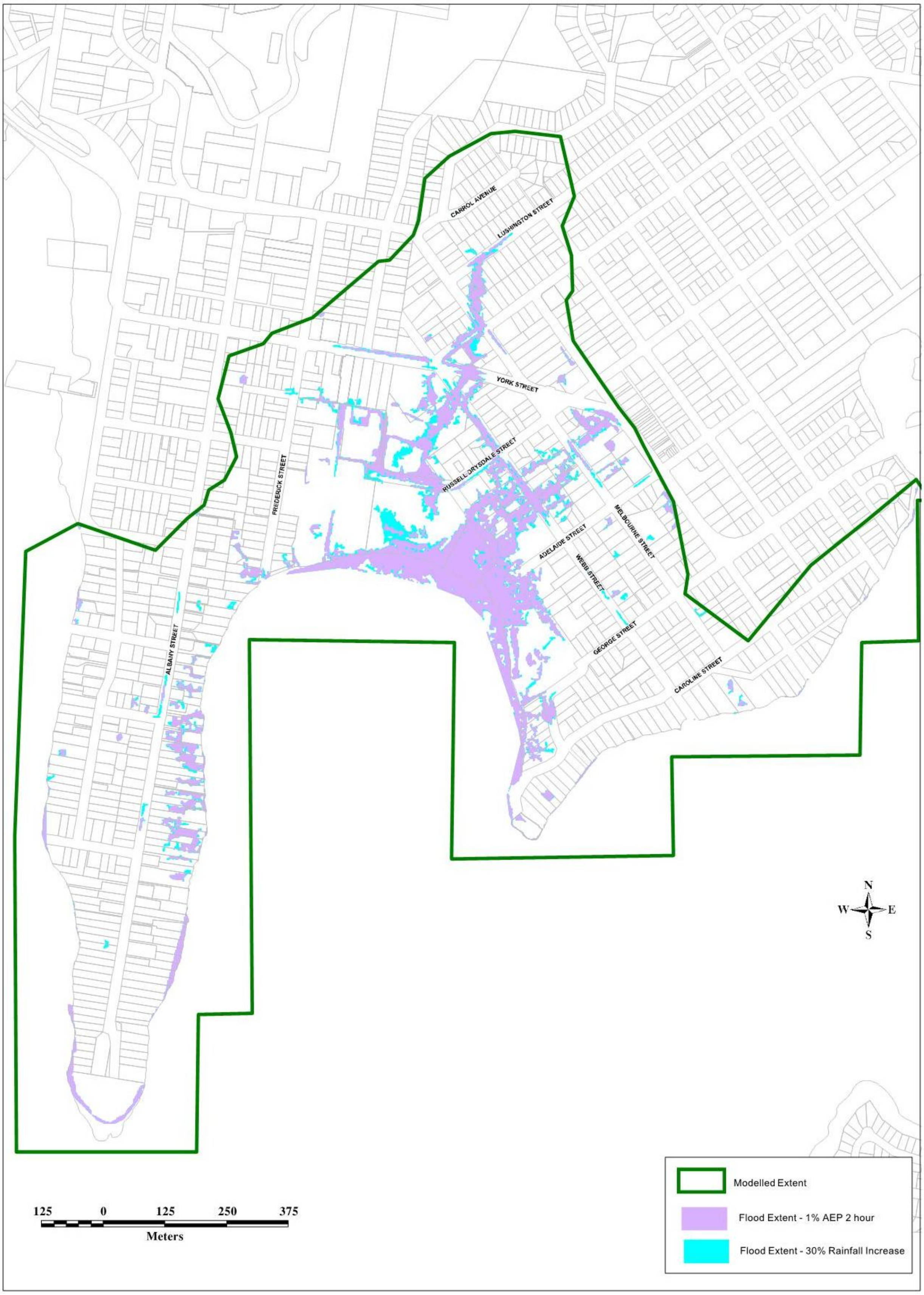


FIGURE 4.11 - CLIMATE CHANGE EXTENT COMPARISON - EAST GOSFORD 1% AEP 2 HOUR - 30% RAINFALL INCREASE

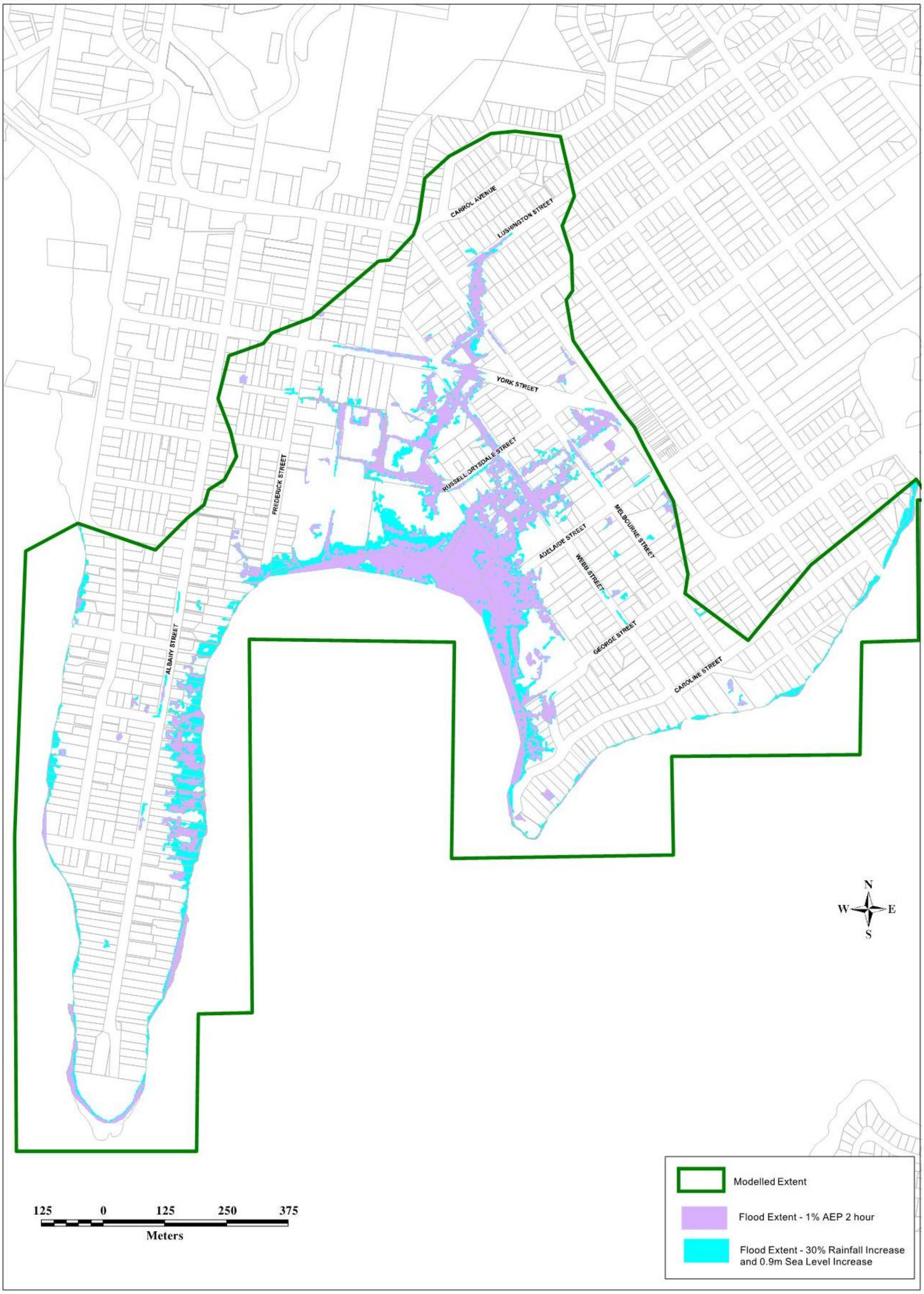


FIGURE 4.12 - CLIMATE CHANGE EXTENT COMPARISON - EAST GOSFORD 1% AEP 2 HOUR - 30% RAINFALL INCREASE + 0.9m SEA LEVEL INCREASE

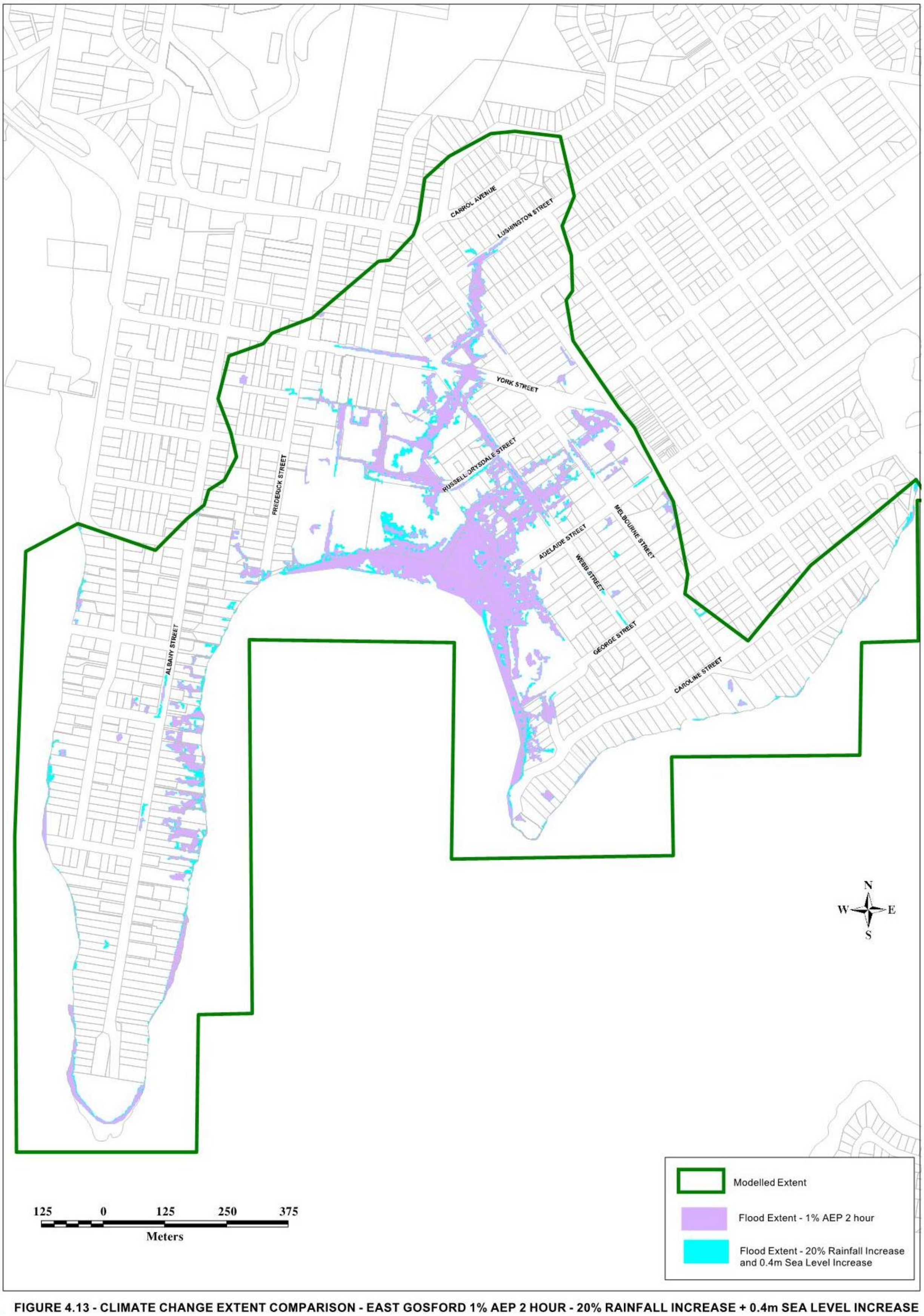


FIGURE 4.13 - CLIMATE CHANGE EXTENT COMPARISON - EAST GOSFORD 1% AEP 2 HOUR - 20% RAINFALL INCREASE + 0.4m SEA LEVEL INCREASE

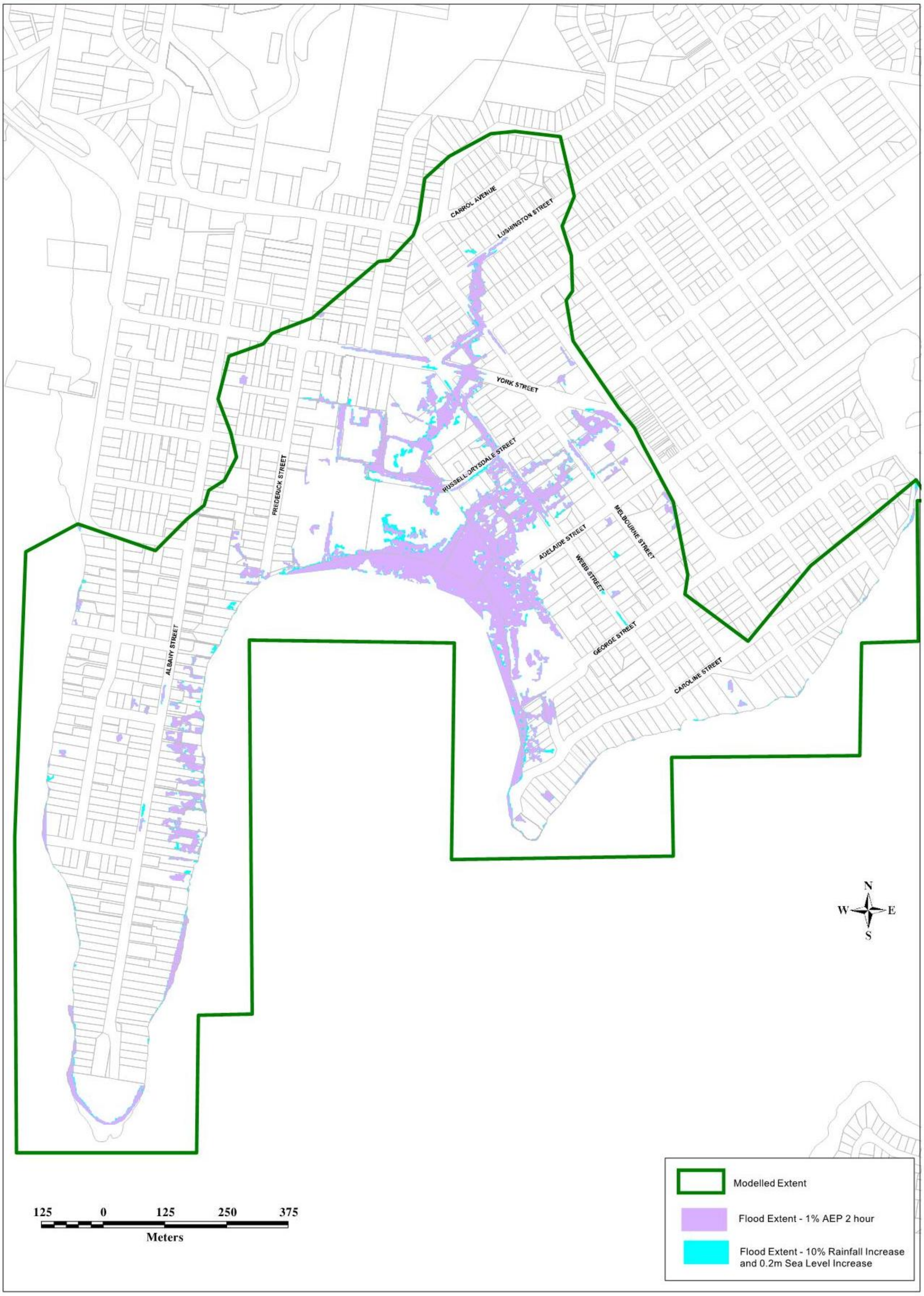


FIGURE 4.14 - CLIMATE CHANGE EXTENT COMPARISON - EAST GOSFORD 1% AEP 2 HOUR - 10% RAINFALL INCREASE + 0.2m SEA LEVEL INCREASE

Appendix A

Data Sharing Agreement

DATA SHARING AGREEMENT

This deed is made the 16th day of November 2011

BETWEEN

1. THE COUNCIL OF THE CITY OF GOSFORD ("COUNCIL")

AND

2. Cardno Lawson Treloar PTY LTD. ("RECIPIENT")

THE PARTIES AGREE AS FOLLOWS:

1. DEFINITIONS

Currency means current as at the date an inquiry is made (clause 16(i)).

Update schedule is a schedule showing data types to be updated according to a defined term.

2. DURATION OF THIS AGREEMENT

i. This agreement begins from the date shown above and shall end on the 30th November 2012.

ii. This agreement may be renewed by consent before 30th November 2012.

3. PURPOSE OF THE DATA SHARING

To undertake stage 2 of the Gosford CBD Overland Flow Study on behalf of Gosford City Council.

NOTE: The data may not be used for any other project apart from that stated above.

4. DATA DESCRIPTION

The following spatial datasets will be provided:

- Cadastre (with property address details and Lot/Plan No's)
- Current LEP Zones
- Contour data
- Road Centrelines
- Geo referenced aerial photographs
- ALS (ground and non ground points in X,Y,Z format, 1m grided ground points and 0.5m ground contours);
- Vegetation
- Creeks
- Waterways

- 100 year flood extent
- Drainage pipes and pits, box culverts
- Suburbs
- Drainage Sub Catchments
- Building Footprints
- Wetlands SEPP 14
- Raster DEM

Data will be provided as ESRI Shape files in GDA94 MGA Zone 56. The Aerial Photography and Raster DEM may be accessed through a Web Mapping Service (WMS). Details will be provided.

.

AUTHORITY TO SHARE DATA

i. The data provided under this agreement is for the exclusive use of the Recipient. It may not be copied, lent, sold, altered, decompiled, disassembled, transferred or adopted, in whole or in part, to any other party without the express written permission of Council, or

ii. Where the data is subject to a reciprocal data sharing agreement, all intellectual property rights, including copyright, for all shared datasets shall remain the property of the custodian of the relevant dataset, and data shall not be provided to a third party without consent of the custodian.

5. PERSONAL INFORMATION TO BE SHARED

Any personal information provided under this agreement is subject to the protection principles of the Privacy and Personal information Act 1998 and the Freedom of Information Act 1989.

6. USE OF PERSONAL INFORMATION

i. Personal information shall not be shared with any other party.

ii. If any personal information is provided in error the Recipient is to return that information immediately to Council in whole without copying or duplicating in any form.

iii. If personal information is provided and either distributed to or accessed by any unauthorised third parties, the Recipient indemnifies Council for any liability, loss, damage, suffering and any other cause of action arising from that distribution.

7. NOTICE REQUIREMENT

If personal information provided is for a further stated purpose **notice to individuals to whom the personal information relates** shall be provided by the collecting party in accordance with the protection principles of the Privacy and Personal Information Protection Act 1998.

8. METHOD OF SHARING DATA

i. Where an update schedule is required it shall be provided by the party requesting the data, and

ii. Data will <u>only</u> be updated where an update schedule is part of this agreement.

9. SECURITY OF SHARED DATA

i. Where one party receives data, that party shall use adequate security measures to protect the data from unauthorised use, reproduction, distribution or publication, or

ii. Where data sharing exists between both parties then both parties shall use adequate security measures to protect the data from unauthorised use, reproduction, distribution or publication.

10. PROVISION AND RETENTION OF DATA

i. The provision of data under this agreement will commence on the date of this agreement and continue for the term shown at clause 2.

ii. Upon expiry or termination of this agreement the Recipient shall cease using the data, erase the data from all forms of digital storage and return the data to Council.

11. TERMINATION

This agreement may be terminated by either party if there is a breach by the other party. At least 28 bays notice in writing must be given.

12. SUSPENSION

Council may suspend the Recipient's access to data if it knows of or reasonably suspects unauthorized use or supply of data

13. CHANGES THAT AFFECT AGREEMENT

Where any of the following changes occur, this agreement shall be amended, re-negotiated or terminated, depending on the effect of the change on the data shared under the agreement, subject to the termination notice requirements at clause 12:

i. legislation or common law affects the nature of the agreement;
ii. Council policy materially affects the data shared under the agreement;

14. LIABILITY

The information provided by Council is to Council's knowledge correct however it may include inaccuracies or errors. Gosford City Council makes no warranties or representations regarding the currency, quality, accuracy, merchantability or fitness for the purpose that the recipient intended to use the information, or that it is free from any virus or other defect. The recipient should make their own assessment.

Gosford City Council will not be liable to the recipient for any loss or damage (including without limitation, consequential loss or damage) however caused and whether arising directly or indirectly from the recipients use of the information.

Gosford City Council shall not accept liability, claim or damage of any kind arising out of, resulting from or relating to the use or the inability to use the information.

15. DISCLAIMER

i. The Recipient acknowledges that Council does not guarantee the currency, accuracy, completeness or fitness for purpose of the data provided.

ii. Any reliance upon the information is at the recipients own risk.

16. COSTS OF DATA PROVISION

i. No cost of data provision for this project.

17. DISPUTE RESOLUTION

i. The parties' employee or agent will use all reasonable efforts in good faith to resolve any dispute relating to this agreement or its termination.

ii. Where the parties' employee or agent cannot resolve a dispute within a reasonable time, the dispute will be referred to the Chief Executives of the parties for determination.

iii. If the dispute is not resolved by the Chief Executives within a reasonable time, either party may refer the matter to an arbitrator for determination which shall be binding.

Iv The arbitrator will be a person agreed to by the Chief Executive and if no agreement a person nominated by the Chief Executive Officer of LEADR. Each party is responsible for half the fees of the arbitrator unless the arbitrator decides a different amount.

V Except on a question of law there is no appeal from the arbitrator's decision.

18. ASSIGNMENT

The Recipient may not assign, sub contract or otherwise transfer any or all of its rights or obligations under this Agreement.

IN WITNESS WHEREOF the parties have set their hands and seals on the date above

EXECUTED BY

Gosford City Council

Signature: Melanie Bosshard

Name: Melanie Bosshard

Date: 16/11/2011

EXECUTED BY

Cardno (NSW/ACT) Pty Ltd
...

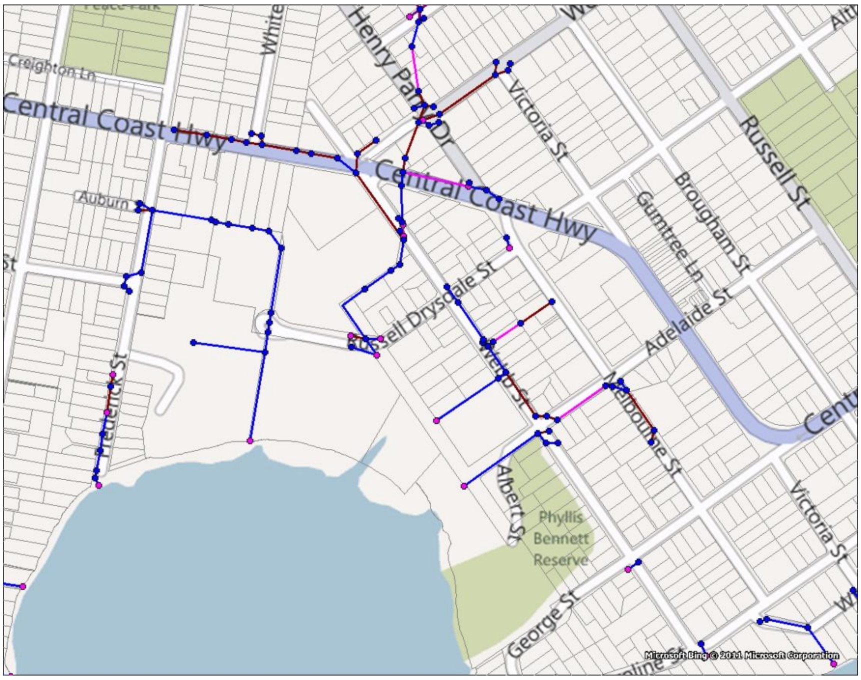
Signature AReid

Name: Andrew Reid

Date: 16/11/11

Appendix B

Additional Survey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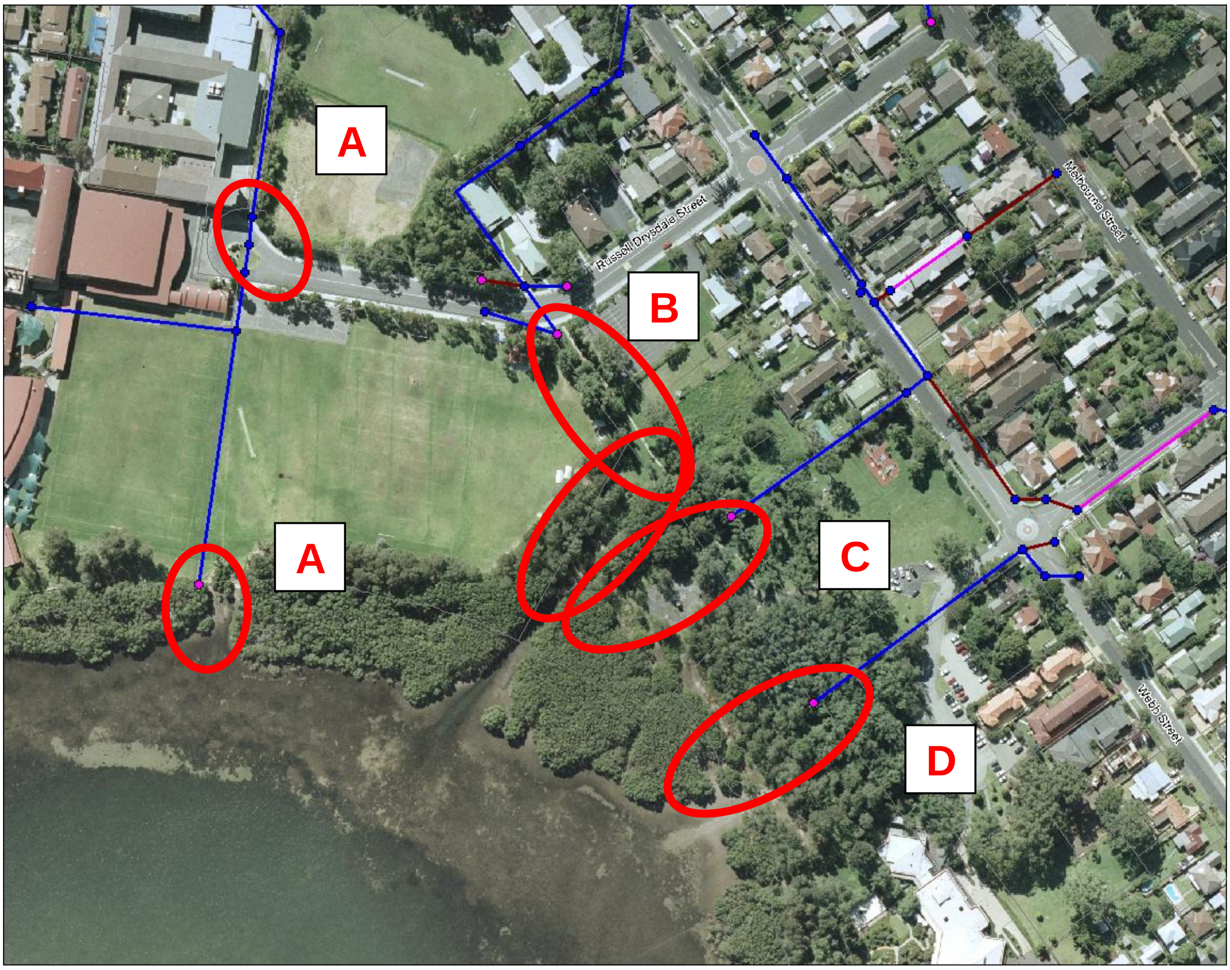
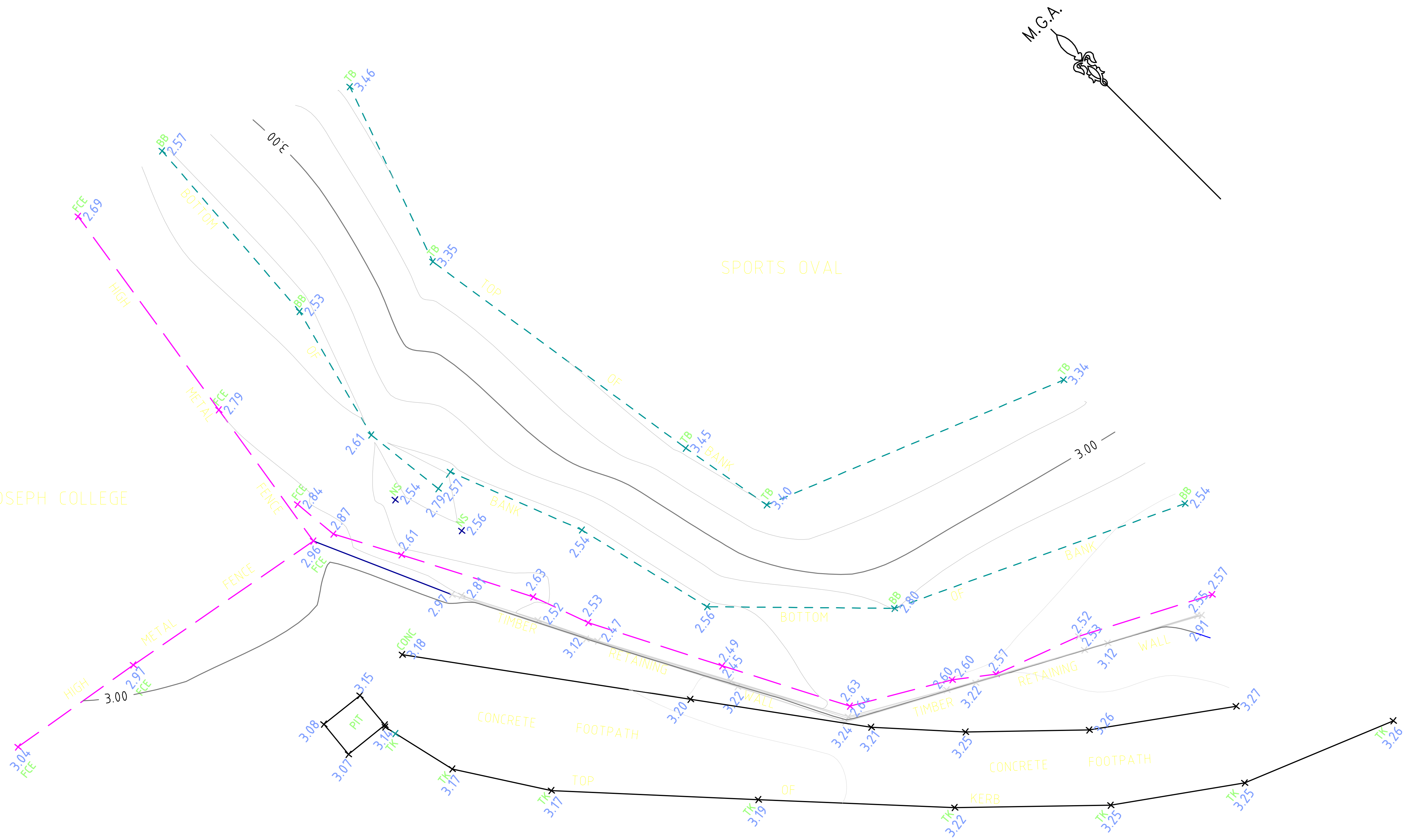
Creighton Ln
Auburn
White
Henry Parry Dr
Victoria St
Russell St
Brougham St
Gumtree Ln
Adelaide St
Russell Drysdale St
Melbourne St
Albert St
Phyllis Bennett Reserve
George St
Victoria St


A
B
A
C
D



Rev	DATE	REVISIONS	Drn	Chk

DRAWN: G.MURRAY
CHECKED: T. BARTLETT
DATUM: AHD
ORIGIN OF LEVELS: PM 19192 RL=3.497
CONTOUR INTERVAL: 0.2 METRES
SCALE: 1:100

A3

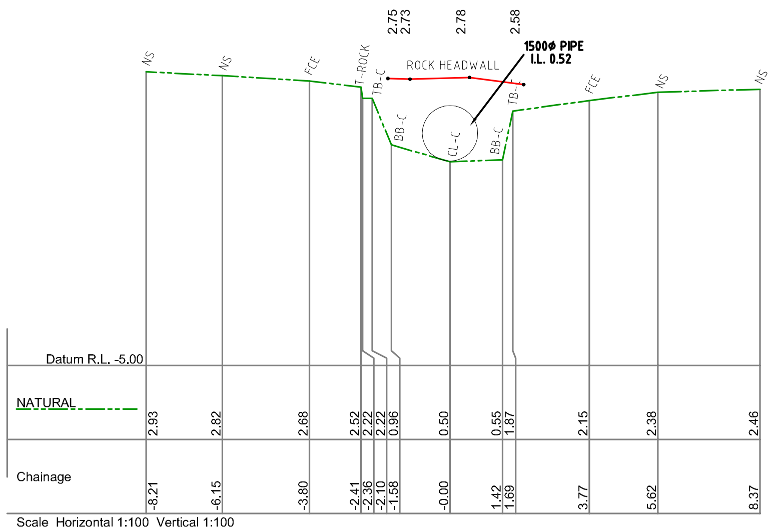
Cardno
Cardno (NSW / ACT) Pty Ltd
ABN: 95 001 145 035
Level 3, 910 Pacific Hwy,
Gordon NSW 2072 Australia
Phone (+61 2) 9496 7700
Fax (+61 2) 9499 3902
Email: sydney@cardno.com.au

GOSFORD CITY COUNCIL

DETAIL SURVEY

SURVEY FOR DRAINAGE STUDY
ST. JOSEPH COLLEGE, EAST GOSFORD
L.G.A. GOSFORD

DATE: 15-12-2011
DRAWING No: W4816-CD-01
A



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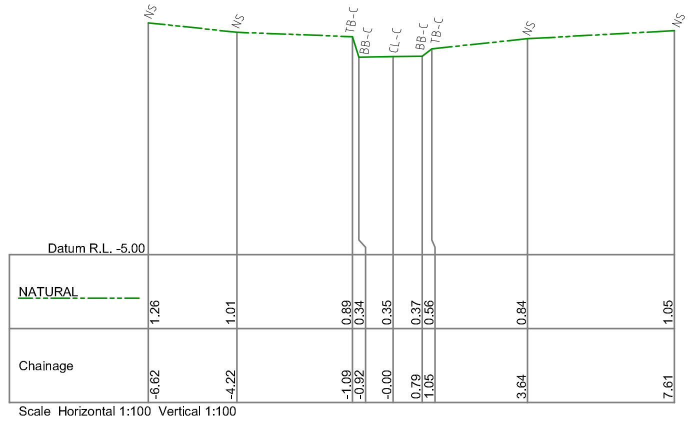

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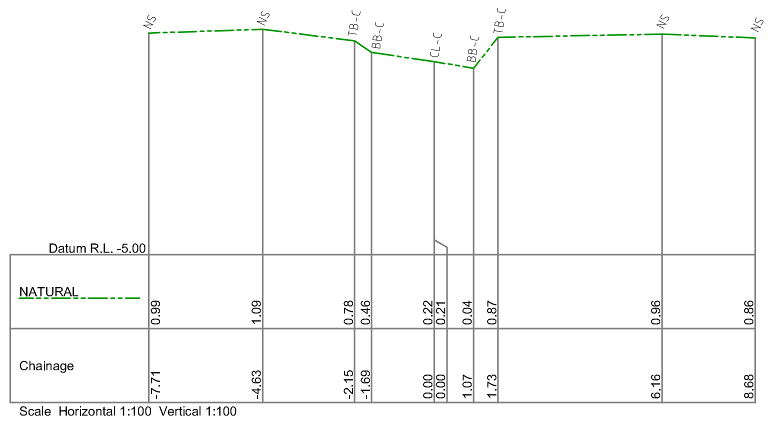

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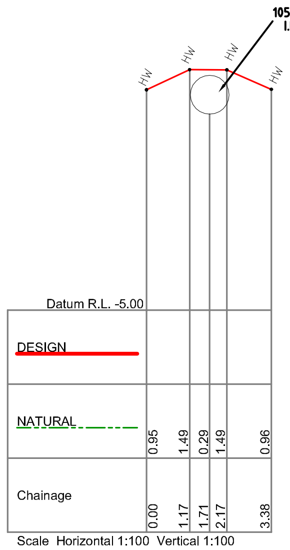
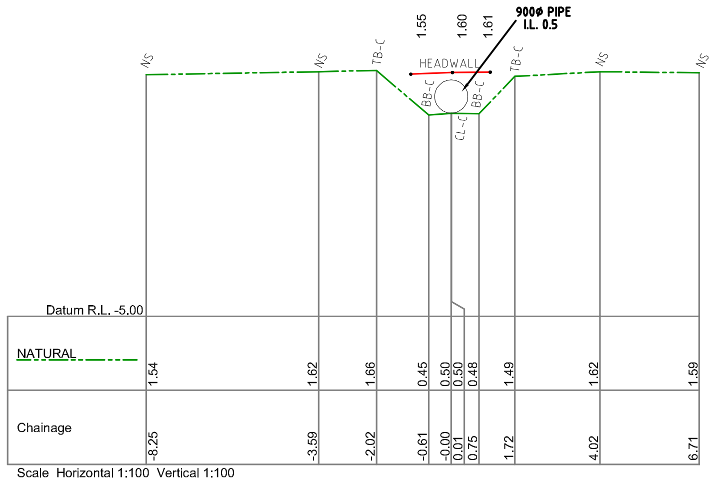


HEADWALL-A



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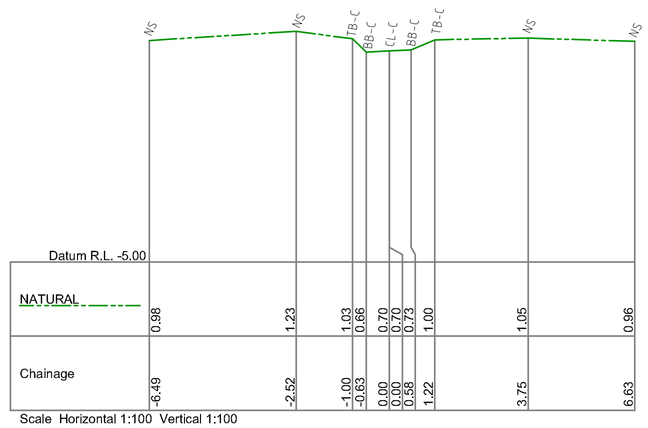

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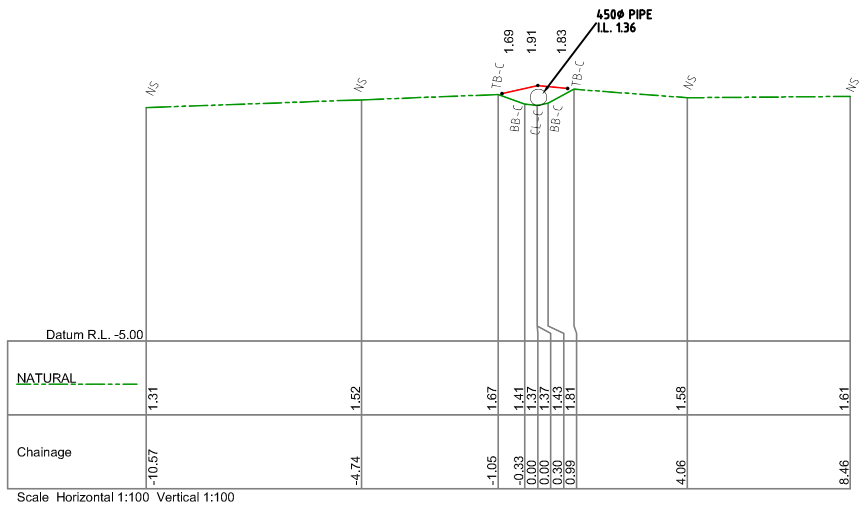

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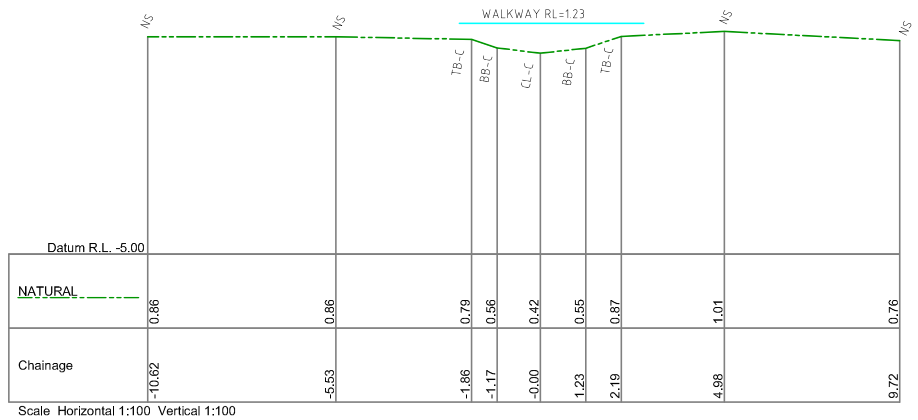

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Rev	DATE	REVISIONS	Drn	Chk

DRAWN:	G.MURRAY
CHECKED:	T.BARTLETT
DATUM:	A.H.D.
ORIGIN OF LEVELS:	PM 19193 RL=3.973
CONTOUR INTERVAL:	N/A
SCALE:	1:100

A1

Cardno (NSW / ACT) Pty Ltd
ABN: 95 001 145 035
Level 3, 910 Pacific Highway,
Gordon NSW 2072 Australia
Phone (+61 2) 9496 7700
Fax (+61 2) 9499 3902
Email: sydney@cardno.com.au

GOSFORD CITY COUNCIL

CREEK SECTIONS
OVERLAND FLOW STUDY
POINT FREDERICK & EAST GOSFORD
L.G.A. GOSFORD

DATE: 15-12-2011
DRAWING No: W4816-CD-02
Rev A

Appendix C

Reference Results Tables

Table C.1: Peak Water Level (m AHD)

Location	Grid Elevation	10% AEP	5% AEP	2% AEP	1% AEP	PMF
EG-1	1.10	N/A	N/A	N/A	1.21	1.32
EG-2	0.72	1.13	1.18	1.22	1.25	1.63
EG-3	1.89	2.04	2.05	2.06	2.07	2.23
EG-4	1.14	1.39	1.41	1.42	1.43	1.59
EG-5	2.63	2.76	2.77	2.78	2.83	2.99
EG-6	3.01	3.14	3.24	3.29	3.33	3.73
EG-7	11.58	N/A	N/A	N/A	N/A	11.73
EG-8	3.72	3.81	3.82	3.83	3.83	3.86
EG-9	2.91	3.02	3.04	3.06	3.08	3.25
EG-10	6.49	6.59	6.60	6.61	6.62	6.70
EG-11	8.12	8.21	8.23	8.24	8.24	8.44
EG-12	10.30	10.41	10.43	10.45	10.47	10.69
EG-13	12.64	12.72	12.73	12.73	12.74	12.86
EG-14	16.82	16.99	16.99	17.00	17.02	17.22

* Refer to Figure 4.5 for reference locations

Table C.2: Blockage Sensitivity Scenario - Peak Water Level (m AHD)

Location	Base Case 1% AEP 2h	Pipe Blockage	Difference (m)
EG-1	1.21	1.21	0.00
EG-2	1.25	1.26	0.02
EG-3	2.07	2.07	0.00
EG-4	1.43	1.43	0.00
EG-5	2.79	3.01	0.22
EG-6	3.33	3.42	0.10
EG-7	N/A	11.64	N/A
EG-8	3.83	3.84	0.01
EG-9	3.08	3.12	0.04
EG-10	6.62	6.62	0.00
EG-11	8.24	8.28	0.03
EG-12	10.47	10.55	0.08
EG-13	12.74	12.76	0.02
EG-14	17.01	17.03	0.02

* Refer to Figure 4.5 for reference locations

Table C.3: Climate Change Scenario (Sea Level Rise) - Peak Water Level (m AHD)

Location	Base Case 1% AEP 2h	Level Plus 0.9m	Difference (m)
EG-1	1.21	1.62	0.41
EG-2	1.25	1.63	0.38
EG-3	2.07	2.07	0.00
EG-4	1.43	1.63	0.20
EG-5	2.79	2.79	0.00
EG-6	3.33	3.33	0.00
EG-7	N/A	N/A	0.00
EG-8	3.83	3.83	0.00
EG-9	3.08	3.08	0.00
EG-10	6.62	6.62	0.00
EG-11	8.24	8.24	0.00
EG-12	10.47	10.47	0.00
EG-13	12.74	12.74	0.00
EG-14	17.01	17.01	0.00

* Refer to Figure 4.5 for reference locations

Table C.4: Climate Change Scenario (Rainfall Increase) - Peak Water Level (m AHD)

Location	Base Case 1% AEP 2h	Rainfall Plus 30%	Difference (m)
EG-1	1.21	1.22	0.01
EG-2	1.25	1.33	0.08
EG-3	2.07	2.09	0.02
EG-4	1.43	1.46	0.03
EG-5	2.79	2.82	0.03
EG-6	3.33	3.40	0.08
EG-7	N/A	N/A	0.00
EG-8	3.83	3.84	0.01
EG-9	3.08	3.11	0.04
EG-10	6.62	6.63	0.02
EG-11	8.24	8.27	0.02
EG-12	10.47	10.51	0.04
EG-13	12.74	12.76	0.02
EG-14	17.01	17.05	0.03

* Refer to Figure 4.5 for reference locations

Table C.5: Climate Change Scenarios (Rainfall & Sea Level Increase) - Peak Water Level (m AHD)

Location	Base Case 1% AEP 2h	Rainfall Plus 10% & Level Plus 0.2m	Difference (m)	Rainfall Plus 20% & Level Plus 0.4m	Difference (m)	Rainfall Plus 30% & Level Plus 0.9m	Difference (m)
EG-1	1.21	1.21	0.01	1.22	0.01	1.62	0.41
EG-2	1.25	1.28	0.03	1.33	0.08	1.64	0.39
EG-3	2.07	2.08	0.01	2.09	0.02	2.09	0.02
EG-4	1.43	1.44	0.01	1.45	0.02	1.64	0.21
EG-5	2.79	2.80	0.01	2.81	0.02	2.82	0.03
EG-6	3.33	3.35	0.03	3.38	0.05	3.40	0.08
EG-7	N/A	N/A	0.00	N/A	0.00	N/A	0.00
EG-8	3.83	3.84	0.00	3.84	0.01	3.84	0.01
EG-9	3.08	3.09	0.01	3.10	0.02	3.12	0.04
EG-10	6.62	6.62	0.01	6.63	0.01	6.63	0.02
EG-11	8.24	8.25	0.01	8.26	0.02	8.27	0.02
EG-12	10.47	10.48	0.01	10.50	0.03	10.51	0.04
EG-13	12.74	12.75	0.01	12.75	0.01	12.76	0.02
EG-14	17.01	17.03	0.01	17.04	0.02	17.05	0.03

* Refer to Figure 4.5 for reference locations

Appendix D

Exhibition Documents

City of Gosford

Public Notice

PUBLIC EXHIBITION – DRAFT EAST GOSFORD LOCAL OVERLAND FLOW FLOOD STUDY

Gosford City Council has received a grant offer from the Federal and State Governments under the Natural Disaster Mitigation Programme to undertake an overland flow study within the Council area. A study has been prepared for areas in East Gosford and Point Frederick draining to The Broadwater and Caroline Bay and a draft report for the Study has been prepared by Council's consultant, Cardno.

The draft East Gosford Local Overland Flow Flood Study identifies flow behaviour in the overland flow paths in the study area for several event frequencies, including the 100-year Average Recurrence Interval and Probable Maximum Flood and will be on exhibition from 11 May to 8 June 2012 at the Ground Floor Counter of Council's Administration Building, 49 Mann Street, Gosford, at the Gosford and Erina libraries and on Council's website at **http://www.gosford.nsw.gov.au/exhibition/**

The input of the community into this study is highly valued and Council now invites comment from the public.

Written submissions should be forwarded to Cardno (NSW/ ACT) Pty Ltd, Attention: Mr Andrew Reid, PO Box 19, St Leonards NSW 1590, Fax: (02) 9439 5170, Email: andrew.reid@cardno.com.au

Please quote 'Draft East Gosford Local Overland Flow Flood Study' in subject reference. Submissions must be received by Friday, 22 June 2012.

All submissions will be publicly available and may be read and copied. To ensure your submission is duly considered please include your name and contact details.

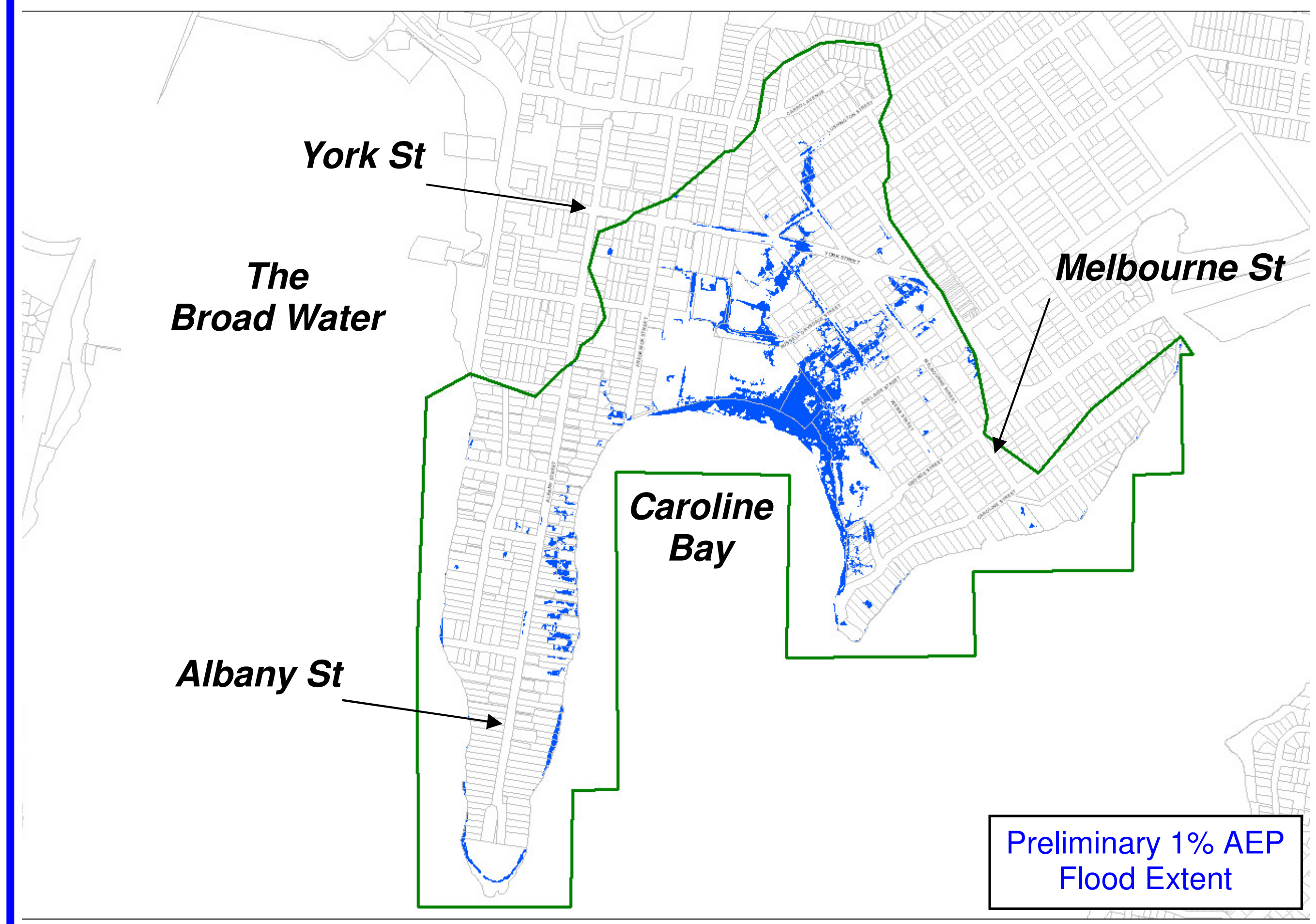
Requests for additional information, or questions regarding the draft study should be directed to Council's Senior Flooding & Drainage Planning Engineer, Robert Baker on 4304 7087 or by email to robert.baker@gosford.nsw.gov.au

Peter Wilson *General Manager*

www.gosford.nsw.gov.au

East Gosford

Local Overland Flow Flood Study



Gosford City Council has received a grant offer from the Federal and State Governments under the Natural Disaster Mitigation Programme to undertake an overland flow study within the Council area. In 2011, an overland flow flood study was completed for the Gosford CBD and West Gosford areas. Currently a study has been prepared for areas in East Gosford and Point Frederick draining to The Broadwater and Caroline Bay.

The objective of the study is to define the behaviour of local overland flows and flooding to properties in the study area.

A draft report for the Study has been prepared by Council's consultant, Cardno. The draft report identifies flow behaviour in the overland flowpaths in the study area for several event frequencies, including the 100 year Average Recurrence Interval and Probable Maximum Flood. The Flood Study will complement previous flood studies and form the basis for future master planning, development assessment and flood investigations in the catchment.

Invitation to Comment

The input of the community into this study is highly valued by Council. Exhibition of the draft East Gosford Local Overland Flow Flood Study will be from the 11th May to 8th June 2012 at the following locations:

- Council's Administration Centre, on 49 Mann Street, Gosford between 8:30am and 5:00pm Monday to Friday.
- Gosford Library, at 118 Donnison Street, Gosford
- Erina Library, at The Hive, Erina Fair
- On Council's website at www.gosford.nsw.gov.au with link to "Items on Exhibition".

Written submissions on the draft Study should be forwarded to:

Cardno Pty Ltd, Attention: Andrew Reid
PO Box 19
St Leonards, New South Wales, 1590

Please quote "Draft Gosford CBD Local Overland Flow Flood Study" in subject reference. Submissions must be received by Friday 22nd June 2012

This project is funded by the Federal and State Governments under the Natural Disaster Mitigation Program

Prepared by Cardno Shaping the Future

May 2012
Summary Report

East Gosford Overland Flow Study

Gosford City Council has received a grant offer from the Federal and State Governments under the Natural Disaster Mitigation Programme to undertake an overland flow study within the Council area. In 2011, an overland flow flood study was completed for the Gosford CBD and West Gosford areas. Currently a study has been prepared for areas in East Gosford and Point Frederick draining to The Broadwater and Caroline Bay.

A draft report for the Study has been prepared by Council's consultant, Cardno. The draft report identifies flow behaviour in the overland flowpaths in the study area for several event frequencies, including the 100 year Average Recurrence Interval and Probable Maximum Flood. The Flood Study will complement previous flood studies and form the basis for future master planning, development assessment and flood investigations in the catchment.

Floodplain Risk Management Process in NSW

The NSW Government's Flood Prone Land Policy provides for the development of sustainable strategies for managing the occupation and use of floodplains from a risk management perspective. The Policy provides for technical and financial support by the State Government through the following sequential stages:

Flood Study to determine the nature and extent of the flood problem.

Floodplain Risk Management Study which evaluates management options for the floodplain with respect to both existing and future development.

Floodplain Risk Management Plan which is adopted by Council for management for the floodplain.

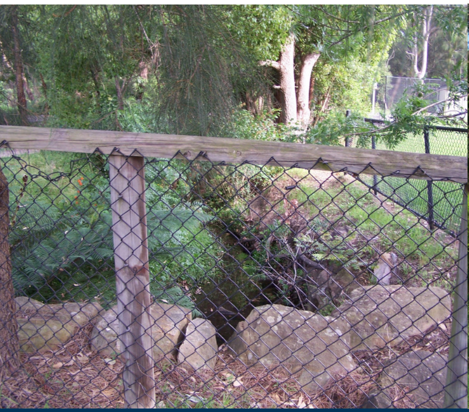
Plan Implementation which involves construction of flood mitigation works, where viable, to protect existing development and uses.

East Gosford Catchment

The study area incorporates the area of Point Frederick, Gosford East and the surrounding region comprising an area of about 1.1 km^2. It includes parts of the suburbs Point Frederick and Gosford East bounded by The Gosford Broad Water and Caroline Bay.

The study area comprises a variety of land uses such as residential, commercial, and open space areas. It includes Gosford City Arts Centre, large parklands, areas of dense vegetation and mangroves as well as several high schools.

The study area rises from the foreshore to a ridgeline in the north with highest elevation about 100m AHD. The area drains down to Caroline Bay and The Gosford Broad Water.



Hydrology and Hydraulics

Hydrologic and hydraulic computer modelling was completed to assess overland flow behaviour within the catchment. The SOBEK 1D/2D model from WL|Delft Hydraulics Laboratory was used to model the catchment and to hydraulically route overland flows and street flow.

A terrain grid representing the topography of catchment generated from the airborne laser scanning (ALS) and ground survey was input to the SOBEK model. Also input to the model was rainfall data, soil loss-rates, drainage pipes and culverts, and parameters for hydraulic roughness to account for the varying land-uses.

Estuary Level

A 1% probability of exceedance estuary level (which is exceeded 3-4 times each year) was adopted as the boundary condition at the foreshore areas. This is equal to a level of 0.72m AHD at The Broad Water determined in the Brisbane Water Foreshore Flood Study. This analysis thus determines the **flood behaviour due to runoff from the local catchment only**.

The 2009 Brisbane Water Foreshore Flood Study assesses flood impacts onto land due to raised storm event levels in the estuary.

Flood Levels, Extents and Hazard

Overland flow behaviour was modelled in SOBEK for a series of Annual Exceedance Probabilities (AEP). The events modelled were 1%, 2%, 5%, and 10% AEP and Probable Maximum Flood (PMF). A storm event of 2 hours duration was determined to be the critical duration for overland flow in both sub-catchments.

Peak flood depths for the 1% AEP event are shown in Figure 4.2 attached. Flood depths in excess of 0.2m are estimated to occur on some roads and properties in the Study Area in a 1% AEP event.

Flood hazard can be defined as the risk to life and damage caused by a flood. Provisional flood hazard (low and high hazard) was also assessed for the flows within the catchment. High hazard flows are estimated to occur at several locations in the Study Area.

Inundated Properties

The number of properties in the catchment which have a peak depth of flooding greater than 0.3m in the 1% AEP event is 104.

Invitation to Comment

The input of the community into this study is highly valued by Council. Exhibition of the draft East Gosford Local Overland Flow Flood Study will be from 11th May to 8th June 2012 at the following locations:

- Council's Administration Centre, on 49 Mann Street, Gosford between 8:30am and 5:00pm Monday to Friday.
- Gosford Library, at 118 Donnison Street, Gosford
- Erina Library, at The Hive, Erina Fair
- On Council's website at www.gosford.nsw.gov.au with link to "Items on Exhibition".

Written submissions on the draft Study should be forwarded to:

Cardno Pty Ltd

Attention: Andrew Reid

PO Box 19

St Leonards, New South Wales, 1590

Please quote "Draft East Gosford Local Overland Flow Flood Study" in subject reference. Submissions must be received by Friday 22nd June 2012.

D R A F T

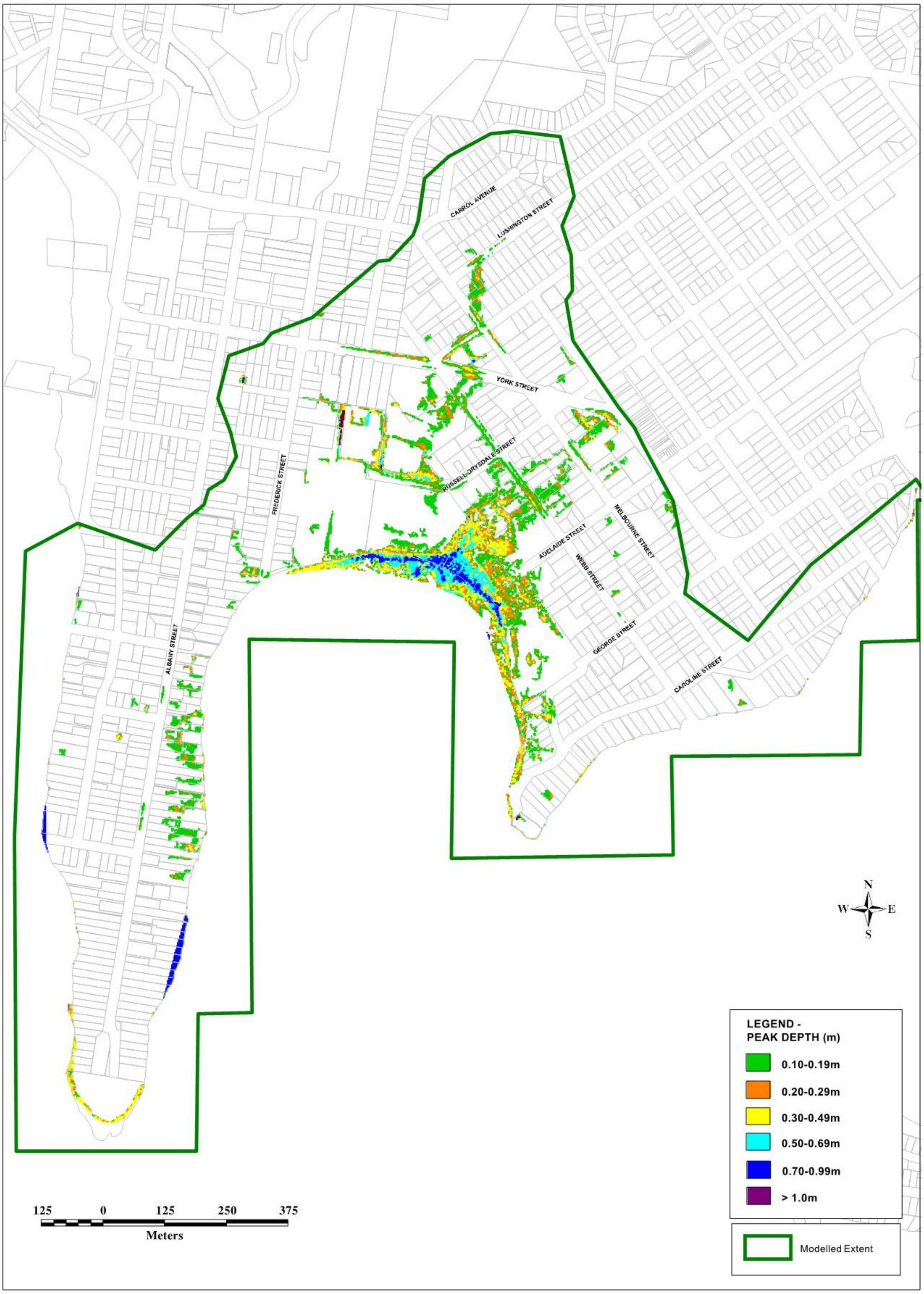


FIGURE 4.2 - PEAK FLOOD DEPTHS - EAST GOSFORD 1% AEP

Appendix E

Exhibition Submissions

4/28 Melbourne St,
E. Gosford. 2250.
3-6-12.

Andrew Reid,
Cardno Pty. Ltd.,
St. Leonards.

Dear Andrew,

On behalf of the Owners' Corporation, Strata Plan 3287, at the above address, we wish to be included in any public discussions on the flow of storm water in this area.

Having been an owner here since 1980, I have noticed several Council decisions that have had a direct effect on the flow of storm water in this area. Actually, a couple of elderly fishermen told me that they used to launch their boats in the area behind the Cultural Centre & it was all a white sandy beach in those days. This was at the end of the 2nd World War. Gosford Council was tardy in forming concrete drains beside the ~~sea~~ streets surrounding Caroline Bay. There were grassed waterways that disappeared as development in the area back to the Springfield hills gathered pace. These waterways became mini-creeks after heavy rain as torrents of water plus the topsoil hurtled down to Caroline Bay. The sandy beach became a muddy mangrove area.

Sometime in the eighties, Council rezoned the whole area medium density housing. Our peaceful suburb became a concrete & brick jungle with storm water channelled to the street. The volume of water hurtling down our street following good rain has increased in volume & intensity. This has increased social problems with neighbours blaming their immediate neighbours for the excess water flooding through their properties after rain.

Actually, the area where the Cultural Centre was built, was known as "Frog Hollow" by the old timers. Storm water flowed naturally to that area. Council built a roundabout on the corner of Webb & Adelaide Streets, raising the street level to be the same height as the top of the brick fence of the house on the corner of Webb & Adelaide, thus directing the flow of water away from the Cultural Centre. And so these band-aid measures have continued.

Our property is well drained but we are interested in the conclusion Cardno reaches as a result of the information you gather & no doubt feed into your computer.

Yours faithfully,

(Mrs.) June R. Jones.

From: Danielle Dickson <DDickson@ryde.nsw.gov.au>
Sent: Tuesday, 12 June 2012 8:46 PM
To: Andrew Reid (Sydney)
Cc: Andrew Dickson
Subject: “Draft East Gosford Local Overland Flow Flood Study”

Hi Andrew

Having viewed the exhibition documents and the weather over the weekend Andrew and I (33 Bay view avenue East Gosford) would like to submit the following comments:

- some overland flow in the nominated catchment of the study comes from the road and hard surfaces in Bay view Avenue
- much of this water is currently uncontrolled and due to the steep slope travels into the lower properties (Carol Ave & Lushington) quickly where the intake drains appear in adequate.

- the current lack of street drainage west of our property (we are at the crest of the hill) doesn't assist in retarding the flow at peak times

Andrew, our only contribution is that the control of storm water at the top of the catchment may assist in reducing the impact that your study details on the lower lying properties

Regards

Danielle Dickson

COASTAL RESIDENTS

INCORPORATED ASSOCIATION INC9894844

22 June 2012

Cardno Pty Ltd
St Leonards,
New South Wales
Attention Andrew Reid
Email: Andrew.Reid@cardno.com.au

Len Gibbons
President, Coastal Residents
C/- 148 Steyne Road
Saratoga NSW 2251
Email : gosfordsearise@bigpond.com

Submission

Gosford CBD Local Overland Flow Flood Study Addendum – Point Frederick & East Gosford

Coastal Residents Incorporated (Coastal Residents) is an association representing families in Gosford whose homes have been identified as potentially affected by forecasts of sea level rise.

The association is not an environmentalist group or an anti-climate change group. The primary concern of Coastal Residents is to promote and defend the livelihood & wellbeing of those residents whose homes have been prematurely identified as affected by forecast sea level rise.

Comments

There does not appear to have been any direct contact with the owners and residents of the 138 properties affected by the findings of this study. Taking into account the complexity of the combined impact of SLR projections up to 0.9 metre with projected overland flooding that is investigated by the Study, there should have been an attempt to provide these owners and residents with an opportunity to be more involved in the development and conduct of the Study.

The decision by Gosford Council on the 1st December 2009 to encode property planning certificates, indicating that properties may be affected by sea level rise, likewise was not made with any due process or consultation.

Following that decision, in May 2010 Gosford Council gave notice to 9000 property owners that S149(5) Planning certificates would be encoded with Sea Level Rise (SLR) information indicating that their properties were potentially affected by SLR forecast that their property would be affected by a 0.9 metre rise in sea levels by 2100.

That notice also included the following statement:

> *"At this stage, the sea level rise 'Section 149(5)' planning certificate encoding does not restrict development with respect to sea level rise. Management options to reduce the impacts of sea level rise, such as development controls and structural protection measures, will be investigated through relevant strategic processes such as floodplain, coastal and estuary risk management*

> *studies.* ***The management studies will be undertaken on a prioritised basis as resources are made available.***
>
> ***Community participation is essential to the success of the studies mentioned above.*** *Local residents are encouraged to become involved with these studies via community consultation forums such as public meetings, workshops, community surveys and other initiatives. The community consultation forums will be advertised in the local papers and on Council's website.* ***These forums will provide residents with the opportunity to 'have their say'*** *and help shape the management options to reduce the impact of sea level rise."*

Being presented with another opportunity to fulfill this obligation, Gosford Council has decided again to simply advertise the exhibition period for the Gosford CBD Local Overland Flow Flood Study– Point Frederick & East Gosford (the Study) and wait for submissions.

Gosford Council has received a grant of $68 000 to undertake the Study and has other additional resources that would allow individual property owners to be contacted and offered an opportunity to attend a public information and questions forum.

As has been the case for a number of studies/plans in development or studies/plans that have been completed since May 2010, Gosford Council continues to provide a minimum of consultation to the extent that New South Wales Government requirements and guidelines for consultation are ignored and on one occasion legislative requirements have in the opinion of Coastal Residents Incorporated, been breached.

Summary of Issues

- The Study does not detail or demonstrate any process of consultation that has allowed residents affected by the findings of this study to develop an understanding of how such findings may impact on their wellbeing and livelihood
- The study develops data and findings based on projections that rainfall will increase in intensity by up to 30% and sea levels will increase by up to 0.9 metre as a consequence of Climate Change. This was not explained in the advertising for the exhibition of the study. Consequently residents affected by the findings of this study have not been properly advised of the very good reason why they should participate in the process of consultation offered by Gosford Council.
- Complex technical content developed over at least 12 months requires greater explanation than is afforded by simply advertising the availability of the Study during an exhibition period lasting 6 weeks.
- The Study identifies 138 affected properties. Some of these homes are already affected by SLR information placed on Section 149(5) Planning Certificates and it was imperative that the owners and residents of these properties should have been advised of the possibility of further Climate Change related information being added to Section 149(5) or Section 149(2) Planning Certificates.
- In the section of the Study titled as Study Objectives, there is no reference to how the Study findings may be used to facilitate development planning. It is noted that in the Gosford Council

Report **ENV.53 Gosford Catchment Overland Flow Studies (ir 7647582**), the following statement in reference to the Study is found:

> *"The challenges now are to analysis the results and determine a methodology that will be enable development controls to be placed on individual properties that is a true representative of the hazards*."

Concluding Remarks

Coastal Residents Incorporated strongly objects to the finalisation of the Gosford CBD Local Overland Flow Flood Study– Point Frederick & East Gosford and any recommendation for adoption by Council until such time as:

- The Study is re-advertised and re-exhibited for a further 6 weeks
- Through advertising and promotion of the Study, that the findings of the Study are summarised indicating the projection of the combined risks of SLR and increased overland flooding and how this may result in development controls being placed on affected properties
- Owners and residents of the 138 affected properties identified in the Study are contacted directly and advised that it is their best interest to participate in the process of consultation for the Study now offered by Gosford City Council
- At least one public forum has been promoted, advertised and provided that attempts to explain in full, the findings of the study and the potential impact of these findings on the livelihood and wellbeing of the owners and residents of the 138 properties identified in the Study and any other properties that are identified as adversely affected by the findings of the Study

Len Gibbons

President - Coastal Residents