CURRAMBENE AND MOONA MOONA CREEKS

FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

FINAL REPORT

MARCH 2016

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Project Currambene and Moona Moona Creeks Floodplain Risk Management Study	**Project Number** 113091
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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ALS	Airborne Laser Scanning
BOM	Bureau of Meteorology
CMA	Central Mapping Authority
DECC	Department of Environment and Climate Change
DNR	Department of Natural Resources
DRM	Digital Rainfall Method
DTM	Digital Terrain Model
GIS	Geographic Information System
GPS	Global Positioning System
IFD	Intensity, Frequency and Duration of Rainfall
mAHD	meters above Australian Height Datum
PMF	Probable Maximum Flood
SRMT	Shuttle Radar Mission Topography
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model)
WBNM	Watershed Bounded Network Model (hydrologic computer model)

TERMINOLOGY USED IN REPORT

Australian Rainfall and Runoff have produced a set of draft guidelines for appropriate terminology when referring to the probability of floods. In the past, AEP has generally been used for those events with greater than 10% probability of occurring in any one year, and ARI used for events more frequent than this. However, the ARI terminology is to be replaced with a new term, EY.

Annual Exceedance Probability (AEP) is expressed using percentage probability. It expresses the probability that an event of a certain size or larger will occur in any one year, thus a 1% AEP event has a 1% chance of being equalled or exceeded in any one year. For events smaller than the 10% AEP event however, an annualised exceedance probability can be misleading, especially where strong seasonality is experienced. Consequently, events more frequent than the 10% AEP event are expressed as X Exceedances per Year (EY). Statistically a 0.5 EY event is not the same as a 50% AEP event, and likewise an event with a 20% AEP is not the same as a 0.2 EY event. For example an event of 0.5 EY is an event which would, on average, occur every two years. A 2 EY event is equivalent to a design event with a 6 month average recurrence interval where there is no seasonality, or an event that is likely to occur twice in one year.

While AEP has long been used for larger events, the use of EY is to replace the use of ARI, which has previously been used in smaller magnitude events. The use of ARI, the Average Recurrence Interval, which indicates the long term average number of years between events, is now discouraged. It can incorrectly lead people to believe that because a 100-year ARI (1% AEP) event occurred last year it will not happen for another 99 years. For example there are several instances of 1% AEP events occurring within a short period, for example the 1949 and 1950 events at Kempsey.

Where the % AEP of an event becomes very small, for example in events greater than the 0.02 % AEP, the ARR draft terminology suggest the use of 1 in X AEP so a 0.02 % AEP event would be the same as a 1 in 5,000 AEP.

The PMF is a term also used in describing floods. This is the Probable Maximum Flood that is likely to occur. It is related to the PMP, the Probable Maximum Precipitation.

This report has adopted the approach of the ARR draft terminology guidelines and uses % AEP for all events greater than the 10% AEP and EY for all events smaller and more frequent than this.

EY	AEP (%)	AEP (1 in x)	ARI	Use
6	99.75	1.002	0.17	WSUD
4	98.17	1.02	0.25	
3	95.02	1.05	0.33	
2	86.47	1.16	0.50	
1	63.21	1.58	1.00	
0.69	50.00	2	1.44	Stormwater/pit and pipe design
0.5	39.35	2.54	2.00	
0.22	20.00	5	4.48	
0.2	18.13	5.52	5.00	
0.11	10.00	10	9.49	
0.05	5.00	20	20	Flooding
0.02	2.00	50	50	
0.01	1.00	100	100	
0.005	0.50	200	200	
0.002	0.20	500	500	
0.001	0.10	1000	1000	
0.0005	0.05	2000	2000	Limit CRC FORGE
0.0002	0.02	5000	5000	Extreme risk /Dams
PMF	**1×10^{-5} AEP - 1×10^{-7} AEP**			

A copy of the draft terminology is available at: http://www.arr.org.au/arr-guideline/draft-chapters/

FOREWORD

The NSW State Government's Flood Prone Land Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any 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 liable land remains the responsibility of local government. The State Government co-funds floodplain risk management studies, plans and measures to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through five sequential stages:

1. Data Collection
- Data requirements for an ensuing flood study are assessed. Existing data sets are assessed for usability and existing reports collected and summarised.

2. Flood Study
- Determine the nature and extent of the flood problem.

3. Floodplain Risk Management
- Evaluates management options for the floodplain in respect of both existing and proposed development.

4. Floodplain Risk Management Plan
- Involves formal adoption by Council of a plan of management for the floodplain.

5. Implementation of the Plan
- Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Currambene and Moona Moona Creeks Floodplain Risk Management Study and Plan (FRMS&P) presented herein constitutes the third and fourth stages of the NSW Floodplain Risk Management Program for these catchments. Prior to commencement of the FRMS&P, a review of the 2006 Flood Study (Reference 1) was undertaken and 2D hydraulic models of the Currambene and Moona Moona Creek catchments were established.

WMAwater has been engaged by Shoalhaven City Council to prepare this Study under the guidance of Council's Central Shoalhaven Natural Resources and Floodplain Management Committee (NRFMC).

EXECUTIVE SUMMARY

Introduction

This document comprises the Floodplain Risk Management Study and Draft Plan (FRMS&P). Provided within is a description of the flooding problem in the Currambene and Moona Moona Creek catchments as well as the assessment of a number of floodplain risk management options. This public exhibition draft final report provides an opportunity for the community and other stakeholders to submit feedback prior to the report being finalised and offered up for endorsement by Council.

Objectives of the Floodplain Risk Management Study and Plan

The objectives of this study are to:

- Develop a draft Floodplain Risk Management Plan that addresses the existing, future and continuing flood problems.
- In doing so, the objectives include:
  - Review of the Flood Study;
  - Preparation of a Floodplain Risk Management Study (FRMS) – investigating flood management options and making recommendations; and
  - Preparation of a draft Floodplain Risk Management Plan (FRMP) – developed from the FRMS detailing how flood prone land within the study area is to be managed.

Desired Outcomes

The final outcome is a document setting out the flood risk management measures to be implemented which identifies their priority, time for implementation, indicative costs, authority or body responsible for implementation and implementation strategy. This document would be adopted by Council following a period of public exhibition and then, following feedback from the community, Council can initiate the implementation of any agreed floodplain risk management measures.

Methodology

Following a thorough engagement process between Council and the Consultant (WMAwater), a detailed methodology has been tailored to achieve the best outcomes from the FRMS&P process for the Currambene and Moona Moona Creek catchments. The key steps agreed upon can be summarised as follows;

- Compilation and review of available information;
- Review of Flood Study – including revision of hydraulic modelling techniques;
  - Mapping of the design event floods for the 0.2 EY, 10% AEP, 5%, 2%, 1% and 0.5% events as well as the PMF including;
  - Peak flood levels, depths and velocities;
  - Hydraulic categorisation – floodway, flood storage or flood fringe;
  - Hydraulic hazard categorisation;
- Establish impacts of climate change on flood levels (for the 1% AEP event);

- Assess the flooding issue, including;
    - Identify key locations for flood management known as flooding hot-spots;
    - Identifying emergency response classifications;
    - Flood damages assessment to identify potential flood damages under current conditions to be compared with costs associated with potential mitigation works; and
- Review of current flood planning controls and emergency management;
- Assessment of risk management options to identify practical options for the study area through options including;
    - Flood modification;
    - Property modification; and
    - Response modification.
- Community consultation through media releases, newsletters and public workshops to obtain additional information and seek resident opinions on potential flood management measures proposed; and finally
- The preparation of the draft Floodplain Risk Management Plan.

Summary of Flooding Issues

Currambene Creek is a 160 km^2 catchment made up of a variety of different landscapes from steeper upper areas which are forested and exhibit deeply incised watercourses to the lower reaches such as Woollamia which are relatively low lying and where flood levels are subject to tidally influenced flooding mechanisms.

Moona Moona Creek is smaller at ~ 28 km^2 and there is less contrast in the landscapes. An upper area which is thickly vegetated flows to a large storage area that is defined at its downstream limit by the Elizabeth Drive Bridge. Flood liability tends to be due to residential lots that back onto this area.

The flood liability of both catchments is summarised in the tables below. Note that overall the flood liability defined by the Study, including the Average Annualised Damages estimates, tend to indicate a limited over floor flooding issue, with most severe impacts limited to rare events such as the 1% AEP.

Table A: Estimated Flood Damages for Currambene Creek Catchment

Event	Number of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected Property
PMF	145	134	$11,574,800	$ 79,800
0.5%	52	26	$ 1,588,300	$ 30,500
1%	42	16	$ 916,100	$ 21,800
2%	29	9	$ 590,000	$ 20,300
5%	2	0	$ 3,900	$ 2,000
10%	0	0	$ 0	$ 0
20%	0	0	$ 0	$ 0
Average Annual Damages (AAD)			**$ 55,700**	**$ -**

Table 1: Estimated Flood Damages for Moona Moona Creek Catchment

Event	Number of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected Property
PMF	78	55	$ 4,358,300	$ 55,900
0.5%	26	18	$ 1,174,300	$ 45,200
1%	26	10	$ 666,500	$ 25,600
2%	18	9	$ 487,000	$ 27,100
5%	1	0	$ 2,300	$ 2,300
10%	1	0	$ 300	$ 300
20%	0	0	$ 0	$ 0
Average Annual Damages (AAD)			**$ 27,500**	**$ -**

Recommendations

This FRMS and draft FRMP identifies a number of management options and strategies to be considered by Council and the FMC. Section 8 discusses the various options assessed in the process of coming up with the shortlisted recommendations presented in the Plan. The Plan itself is presented in Section 9 and this includes their priority, time for implementation and implementation strategy.

1. INTRODUCTION AND BACKGROUND

This Study has been prepared by WMAwater on behalf of the Shoalhaven City Council (Council). The Study is composed of three phases:

1. Revision of the 2006 Currambene Creek and Moona Moona Creek Flood Study (Reference 1);
2. Preparation of the Currambene and Moona Moona Creek Floodplain Risk Management Study; and
3. Preparation of the Currambene and Moona Moona Creek Floodplain Risk Management Plan.

This document details all three phases of work. The FRMS&P follows on from the Flood Study revision which defines the flood behaviour in Currambene and Moona Moona Creeks under existing conditions to determine the nature and extent of the flood problem.

1.1. Objectives

This project involves preparing a Floodplain Risk Management Study and Floodplain Risk Management Plan (FRMS&P) for Currambene and Moona Moona Creeks. The main objective of this FRMS&P is to identify potential floodplain risk, test amelioration strategies for the management of risk and to put forward priorities and approximately costed recommendations in regards to flood risk mitigation in the Study Areas. The Currambene Creek Study Area is presented in Figure 1 and the Moona Moona Creek Study Area is presented in Figure 2.

Council requires consideration of a range of management options to effectively manage existing, future and continuing flood risks in the region. The outcomes from the Flood Study revision, Floodplain Risk Management Study and Floodplain Risk Management Plan will also assist the SES in preparing a Local Flood Plan for the region.

The information and results obtained from the Flood Study revision (see Section 3.3), define existing flood behaviour and provides a firm basis for the subsequent FRMS&P which constitutes Phases 3 & 4 of the overall work (see Sections 5 to 9).

1.1.1. Flood Study Revision Objectives

The revision of the Flood Study (Reference 1) aimed to meet the objective of defining the design flood behaviour (0.2 EY, 10%, 5%, 2%, 1%, 0.5% Annual Exceedance Probability (AEP) events and the Probable Maximum Flood (PMF)) in Currambene and Moona Moona Creeks and to:

- Identify peak flood levels, depths, velocities, flows and flood extents within the Study Area;
- Prepare flood extent mapping (for all design events modelled);
- Prepare provisional flood hazard category mapping (1% and 0.5% AEP events, 2050 and 2100 sea levels);
- Prepare provisional hydraulic category mapping (1% and 0.5% AEP event, 2050 and 2100 sea levels);

- Investigate various climate change scenarios caused by potential increases to rainfall as well as sea level rise; and to
- Create a modelling system to be used in the subsequent FRMS&P to test flood mitigation works.

1.1.1.1. Flood Study Revision Preamble

The flood study revision is a de facto new flood study with data collection and review, building of new models, calibration and validation of the models and then generation of new design flows and flood levels.

During the above process it was noted that Australian Rainfall and Runoff, 1987 (ARR87) design rainfall intensities are significantly higher than ARR2013 design rainfall intensities. It was found that use of ARR2013 design rainfall in hydrologic model calibration to Flood Frequency Analysis (FFA) was able to be validated with a high degree of confidence whilst use of ARR87 rainfall could not. Accordingly, ARR2013 design rainfall has been used in the ensuing analysis.

Significant work has been undertaken to assure confidence in use of ARR2013 design rainfall. These works includes:

- Detailed FFA approach incorporating regional flood frequency covariants from the current ARR revision Project 5;
- Rigorous calibration of the hydrologic model to the FFA;
- Validation of the hydrologic model using a PhD research study for which the local stream gauge was calibrated against over 30 historic events; and
- IFD analysis of the relevant pluviograph (068072) and comparison to both ARR87 and ARR2013 rainfalls.

These works provide significant confidence in the ARR2013 design rainfall estimates for the region and provide the impetus for use of this data in the current study.

1.1.2. Floodplain Risk Management Study Objectives

The objective of the Floodplain Risk Management Study is to investigate a range of floodplain risk management mitigation works and measures that address existing and potential future flood related issues, in accordance with the NSW Government's Flood Prone Land Policy. This includes:

1. Effective community consultation to help provide information and gain community acceptance of the study and findings and the subsequent plan;
2. Identify and describe the various potential flood problems and specific future flooding issues in the Study Area;
3. To assess whether the flood provisions in Council’s existing environmental planning policies and instruments, including Council’s long term planning strategies for the study area, are consistent with each other, the Floodplain Development Manual and the findings of the flood analyses incorporating potential climate change impacts including sea level

rise;

4. To identify and assess potential management measures for existing developed areas, aimed at reducing the existing and future social, environmental and economic impacts of flooding on development and the community, over the full range of potential flood events included in the analyses incorporating potential climate change impacts including sea level rise;
5. To assess the cumulative effects of potential new development and redevelopment areas within the floodplain, and identify development limits, types, scales and controls and/or works necessary to reduce continuing flood risk in developable areas to an acceptable level, this may include consideration of rezoning existing residential areas to facilitate more flood tolerant commercial or tourist based redevelopment;
6. To assess the benefits and cost of the potential management measures and whether they (individually and cumulatively) might produce adverse effects (social, environmental, economic or flooding) in the floodplain and whether these can be reduced to an acceptable level;
7. To examine ways in which the creek and floodplain environment may be enhanced by preparing a strategy that will create a valuable corridor of vegetation without having a detrimental effect on flooding;
8. To identify modifications required to current policies in the light of investigations; and
9. To assess flood risks to or associated with existing infrastructure and opportunities to manage future infrastructure replacement so as to maximise flood tolerance and mitigation potential.

1.1.3. Floodplain Risk Management Plan Objectives

The Floodplain Risk Management Plan makes a range of recommendations relating to flood mitigation works and measures that address existing and potential future flood related issues, in accordance with the NSW Government's Flood Prone Land Policy. The recommended works and measures presented in the Plan are aimed to:

1. Describe an appropriate mix of measures that address existing and potential future flood risk in order to:
    a. reduce the danger to personal safety and flood damage to property and infrastructure in the existing community;
    b. manage the risk to critical infrastructure during and after a flood event to ensure it is available in a suitable form as and when required;
    c. ensure future development is as flood tolerant as possible, is controlled in a manner consistent with the flood hazard and risk and does not create additional flooding problems in other areas;
    d. manage the flood risk to future infrastructure to reduce potential damages; and
    e. reduce private and public losses due to flooding.
2. Protect and where possible enhance the creek and floodplain environment;
3. Be consistent with the objectives of relevant State policies, in particular, the Government’s Flood Prone Lands and State Rivers and Estuaries Policies, and to satisfy the objectives and requirements of the Environmental Planning and Assessment Act, 1979;

4. Integrate the floodplain risk management plan with the local emergency management plan (flood plan), other relevant catchment management plans, Council's existing corporate, business and strategic plans, existing and proposed environmental planning instruments and policies, and to meet Council's obligations under the Local Government Act, 1993;
5. Have the support of the local community;
6. Ensure actions arising out of the management plan are sustainable in social, environmental and economic terms, including the timely adaptation to climate change impacts as they manifest; and
7. Establish a program for implementation that will include priorities, staging, responsibilities, funding mechanism, constraints and monitoring.

1.2. The Study Area

The Study Area comprises two separate catchments, Currambene Creek (see Figure 1) to the north and Moona Moona Creek (see Figure 2) to the south. Although modelled separately, model parameters have generally remained uniform where possible and thus throughout this report details apply to both catchments unless otherwise specified.

1.2.1. Currambene Creek Catchment

The Currambene Creek catchment is part of the Clyde River and Jervis Bay Basin, on the South Coast of NSW situated between Moruya and Nowra. The headwaters of Currambene Creek (at an elevation of 100 mAHD) rise in heavily vegetated, mountainous terrain where land slopes are generally steeper than eight degrees. Small alluvial flats have developed in the downstream regions of the catchment, which become more extensive nearer the coast. The lower sections of these streams are tidal and are situated in areas of coastal swamps. The centre of the Currambene Creek catchment is located approximately 12 km south of Nowra. The Turpentine Range, which runs along the northern and western boundaries separates the catchment from that of several streams which drain northwards to the Shoalhaven River and several small creeks which drain eastwards to St Georges Basin (Reference 1).

Just upstream of the Princes Highway, Currambene Creek is joined by Parma Creek which rises to the south-west at an elevation of 300 mAHD and has a stream length of 20 km. The combined Currambene Creek catchment area at the Princes Highway is 95 km^2 with the majority (75 km^2) being composed of the Parma Creek catchment (Reference 1).

A series of small waterfalls are situated near the Princes Highway on Currambene Creek. At a location known as The Falls, immediately upstream of the Princes Highway, the stream bed drops 8 m. A smaller waterfall, located approximately 300 m downstream of the Highway, marks the tidal barrier on Currambene Creek. The stream is tidal from this point to its outlet at Jervis Bay at Huskisson. The length of this reach is approximately 16 km and has been modelled in the hydraulic model. The tidal section of Currambene Creek is fed by a sub-catchment of 64 km^2, giving a total catchment of 160 km^2 at the outlet (Reference 1).

On the northern bank, the main sub-catchment is Georges Creek which drains the Currambene State Forest and enters Currambene Creek via an extensive swampy area about 7 km downstream of the highway opposite Goodland Road (Reference 1).

Several un-named streams drain the southern part of the catchment and cross Woollamia Road before joining the right bank of Currambene Creek. The most important of these streams drains the Tomerong State Forest area and enters the main stream opposite the Georges Creek junction (Reference 1).

For the first 4 km below The Falls, the Currambene Creek waterway comprises a tree lined main channel of uniform width of around 40 m rising relatively steeply to cleared grazing land. Below this point the tidal channel gradually opens out to an estuarine area, with a typical width below mean sea level of 100 to 200 m (Reference 1).

Downstream of Willowford Road and Streamside Street, which are located on comparatively high ground on the southern side of the stream, Currambene Creek flows in a generally southerly direction for about 3 km to its outfall to Jervis Bay at Huskisson (Reference 1).

In its southward passage to Huskisson, the creek passes the townships of Woollamia on the western bank and Myola on the eastern side. The creek outlet is located at the southern extremity of Callala Beach, with Currambene Creek flowing along the rear of the frontal dune of the beach over the final kilometre of its length. The existing outlet is about 100 m wide and its invert level is currently at RL –3.5 m AHD (obtained via survey, see Section 2.2.4).

The outlet is sheltered by a reef formation, which extends into Jervis Bay. The low energy environment behind the reef has encouraged the development of the Callala Beach barrier spit. North of the reef, erosion of the beach berm and frontal dune has occurred in the past and a successful stabilisation (re-grassing) programme has been undertaken. However, should the creek break through the beach to form a new outlet, such events as storm tides and wave action may have a more pronounced effect upstream of the creek's mouth than under present day conditions (Reference 1).

1.2.2. Moona Moona Creek Catchment

The Moona Moona Creek catchment drains the area to the south of Currambene Creek and outfalls to Jervis Bay at the northern end of Collingwood Beach. The total catchment area at the outfall is 28 km². The catchment is undeveloped apart from the urbanised strip of Vincentia running along the dune adjacent to Elizabeth Drive and the portion to the south of Vincentia Road. The southern and western parts of Huskisson also drain to Moona Moona Creek (Reference 1).

Moona Moona Creek and its main tributary Duck Creek drain the foothills comprising the western portion of the catchment and cross Jervis Bay Road, before entering a low lying heavily overgrown, swampy area which occupies the middle reaches of the catchment upstream of the bridge at Elizabeth Drive. Above the tidal limit, the creek is overgrown with little evidence of a defined channel. The tidal channel commences about 3 km upstream of the outlet to Jervis Bay and progressively widens to about 80 m in width at the bridge. The overbanks are heavily overgrown with little conveyance capacity. The flood gradient in this area is low as it mainly functions as a basin for the temporary storage of runoff (Reference 1).

A minor tributary conveys runoff from the southern portion of the catchment extending to Vincentia. It runs to the east of the Sewage Treatment Plant before joining the southern bank of Moona Moona Creek about 600 m upstream of Elizabeth Drive Bridge. The bridge comprises a two span crossing about 20 m wide at spring tide level. The creek invert within the immediate vicinity of the bridge waterway has scoured to an elevation of RL –3.2 m (obtained via survey, see Section 2.2.4). Downstream of the bridge, the creek traverses a sandy lagoon area about 350 m in length and outfalls to Jervis Bay immediately south of an unnamed point at the northern end of Collingwood Beach. The width of the lagoon averages 100 – 120 m and has a sandy bed, which is likely to show considerable variation in level over time, although local opinion suggests the presence of a rock shelf beneath the sand which would limit the depth of erosion during flood periods. The highest invert elevation within the lagoon at the time of the creek survey was RL 0 m. The lagoon outlet was about 40 – 60 m wide in mid-2004 and had an invert of RL –2 m AHD (at the time of the 2006 Reference 1 study).

1.2.3. Proposed Development Areas

Major development proposals of note in the Currambene and Moona Moona Creek catchments include:

- Shaolin Temple Site: In 2014 the NSW Planning Assessment Commission approved a concept plan for a Shaolin temple and tourism complex at Comberton Grange subject to a range of conditions and requirements which the proponents would need to satisfy before the proposal could proceed.
- Vincentia Coastal Village and District Centre: The Vincentia Coastal Village and District Centre was originally approved under what was Part 3A of the Environmental Planning and Assessment Act 1979. The original approval included a 604 lot residential subdivision, residential development for adaptable housing, a commercial development and environmental protection measures on the remaining part of the site. The residential and commercial components are partly completed.

A number of areas within the Currambene and Moona Moona Creek catchments were identified for rezoning investigation in the Jervis Bay Settlement Strategy (JBSS) prepared by Council and endorsed by the State Government in 2003. An update on the status of these is provided below:

- Woollamia Farmlets Small Lot Rural Subdivision: The Jervis Bay Settlement Strategy (JBSS) prepared by Council in 2003, identified approximately 70 allotments to be investigated for their suitability to accommodate dwellings. Apart from Goodland Road (see below) and 5 lots which were separately rezoned to enable a dwelling on each, Council resolved not to proceed with this Planning Proposal (PP) in 2013.
- Goodland Road, Woollamia: A PP to create 7 dwelling entitlements subject to 11 lots being combined to create a community title subdivision. Council resolved not to proceed due to lack of landowner agreement.

- Jerberra Estate: 153 lot paper subdivision in the upper reaches of the Moona Moona Creek catchment was rezoned in 2014 allowing up to 87 dwellings to be approved. Construction of roads and associated subdivision infrastructure commenced in late 2015 and development of the lots is expected to proceed over several years. WSUD principles have been integrated into the Estate's planning controls.
- Woollamia Falls Creek Deferred Areas – The JBSS identifies approximately 350 deferred areas for consideration to allow rural residential subdivision. Following strategic planning investigations and landowner consultation, investigations have been reduced to 15 lots located along Seasongood and Woollamia Roads.

2. AVAILABLE DATA

Various items of data salient to the study have been collected and reviewed. Most datasets were sourced from Council and the Office of Environment and Heritage (OEH) and supplemented by additional survey where required. The key focus of the exercise was to collect data suitable for the model build and the calibration/validation process. This section provides a summary of the various forms of data utilised in the study.

It should be mentioned that the Reference 1 study forms the starting point of this Flood Study review and has been referred to throughout this report.

2.1. Relevant Studies

2.1.1.1. Lyall & Associates, Currambene Creek and Moona Moona Creek Flood Studies, 2006 (Reference 1)

The Lyall & Associates, Currambene Creek and Moona Moona Creek Flood Studies (Reference 1) forms the basis of the current Flood Study Revision. The Reference 1 study objective was to define flood behaviour in the creeks and their main tributaries in terms of flows, levels and flooding behaviour for floods ranging between 5 and 200 years Average Recurrence Interval (ARI), as well as for the Probable Maximum Flood (PMF).

Flood behaviour was defined using hydrologic models (RORB) of the catchments and hydraulic models (HECRAS) of the two main streams and their tributaries. The hydrologic models were based on a runoff routing approach and in the case of Currambene Creek, calibrated against recorded rainfall and stream flow data. Parameters derived from calibrating the Currambene Creek model gave guidance for the parameters selected for design flood estimation on that catchment and also on Moona Moona Creek.

Design storms were applied to the models to generate discharge hydrographs within the study area. These hydrographs constituted the upstream boundaries and tributary inflow inputs to the hydraulic models.

A flood envelope approach was adopted for defining design water surface profiles for design events. This procedure involved selection of the upper limit of expected flooding for each frequency resulting from two alternative scenarios:

- Catchment runoff derived from design storm events of the relevant frequency in conjunction with a Normal Semi-Diurnal Tide.
- Storm tide hydrographs of the relevant frequency in conjunction with a minor 5 year ARI catchment flood.

Elevated ocean levels due to storm tides and wave action controlled design flood levels in the lower reaches of both creeks, whereas catchment flooding controlled further upstream.

Where reasonable a similar methodology as described in the Reference 1 study has been employed for the current study. A comparison of the study results is presented in Section 4.3.11.3.

2.1.1.2. Quantifying uncertainty in rainfall-runoff models due to design losses using Monte Carlo Simulation: A case study in New South Wales, Australia (Reference 2)

A PHD research project is currently being undertaken for four catchments in New South Wales (NSW), one of which is the Currambene Creek catchment. The project is entitled '*Quantifying uncertainty in rainfall-runoff models due to design losses using Monte Carlo Simulation: A case study in New South Wales, Australia'* (Reference 2) and is being performed under direction of Ataur Rahman from the University of Western Sydney.

The Reference 2 study findings and results have been used to validate the current study hydrologic model calibration parameters (see Section 4.2.3). Details of the results of the Reference 2 study and how they were used to verify the current study hydrologic model findings is presented in Section 4.2.4.

An abstract of the Reference 2 study is presented below:

> ***Abstract*** *With the potentially devastating consequences of flooding, it is crucial that uncertainties in the modelling process are quantified in flood simulations. In this paper, the impact of uncertainties in design losses on peak flow estimates is investigated. Simulations were carried out using a conceptual rainfall-runoff model called RORB in four catchments along the east coast of New South Wales, Australia. Monte Carlo simulation was used to evaluate parameter uncertainty in design losses, associated with three loss models (initial loss-continuing loss, initial loss-proportional loss and soil water balance model). The results show that the uncertainty originating from each loss model differs and can be quite significant in some cases. The uncertainty in the initial loss-proportional loss model was found to be the highest, with estimates up to 2.2 times the peak flow, whilst the uncertainty in the soil water balance model was significantly less, with up to 60% variability in peak flows for an annual exceedance probability of 0.02. Through applying Monte Carlo simulation a better understanding of the predicted flows is achieved, thus providing further support for planning and managing river systems (Reference 2).*

As part of the Reference 2 study, hydrologic model (RORB) calibration/validation was undertaken for 36 events over the period of record of the Currambene stream gauge (see Section 2.4). It should be noted that the Reference 2 RORB model was only constructed for regions upstream of the Currambene Creek stream gauge and was unavailable for use in the current study. A summary of the Reference 2 study methodology is presented below:

Event selection

Storm events were selected based on rainfall bursts, rather than runoff, to avoid being biased towards wet antecedent conditions. All rainfall bursts over a 1 EY (based on BoM 2013 IFD's) were selected - for all hourly durations (from 1 to 168 hours). The start and end of each complete storm then needed to be defined using the extracted bursts. The entire storm event including antecedent and subsequent rainfall and the storm burst of interest, always ranged from 9:00am to 9:00am (in order to incorporate daily rainfall in defining the spatial distribution of rainfall) and were selected based on a 24 hour 'dry' period (i.e. less than 6mm rainfall).

Rainfall spatial pattern

Rainfall data is essentially a point measurement of a spatially variable input. For this study, the spatial pattern for each event was produced using nearby gauges (similar to the methods described in Section 2.3.1.2). These data were aggregated for each sub-catchment in order to estimate mean areal rainfall inputs. The catchment modelling for the study area was performed using the RORB model (Laurenson et al, 2007).

Baseflow separation

RORB only models surface runoff, therefore the contribution of baseflow to each event was first removed using a recursive digital filter (ARR Project 7 – Murphy et al. 2011) which was calibrated for each catchment.

Calibration

The non-linearity exponent (*m*) in RORB was held constant at 0.8 for each catchment, in line with ARR87 (ed. Pilgrim 1987). The k_c (routing) parameter and loss parameters (IL-CL model) were calibrated by matching the observed and modelled hydrographs for each storm event (based on hourly time series).

2.2. Model Build Data

Topographical and survey data provide a basis for both the hydrologic and hydraulic models in terms of catchment delineation and properties. Furthermore, in a hydraulic model this data is vital for model configuration. Structures such as bridges, levees, culverts and pipes need to be realistically represented to reproduce accurate hydraulic properties. A surveyor (AAM surveying) was commissioned to survey these structures as well as a selection of cross sections used to determine in-bank conveyance. The surveyor also surveyed a set of peak flood level marks for the June 2013 flood event to be used in hydraulic model calibration (see Section 2.2.5) as well as floor levels of selected properties to be used in a damage assessment (see Section 2.2.6). The Survey Brief is contained in Appendix B.

All topographical and survey data used to construct the Currambene and Moona Moona Creek hydrologic and hydraulic models is outlined in Section 2.2.1, 2.2.2 and 2.2.4.

2.2.1. ALS Data

Airborne Laser Scanning (ALS) data of the Study Area was obtained from Council in conjunction with LPI to define ground surface elevation. The ALS data was flown in 2012. The ALS provides ground level spot heights from which a Digital Elevation Model (DEM) can be constructed. For the purpose of this study a two metre DEM grid was constructed and this data, in conjunction with channel cross section survey, formed the foundation of the 2D hydraulic model build process.

It should be noted that the accuracy of the ground definition of the ALS data can be adversely affected by the nature and density of vegetation and/or the presence of steeply varying terrain. Both catchments in this study are heavily vegetated and the quality of the ALS and interpretation of the ground elevation is poor. This is particularly the case for the Moona Moona Creek catchment.

The ALS data for the study area is displayed in Figure 3.

2.2.2. 30 m SRTM Data

For the wider catchment, Council, through OEH, have also provided SRTM DEM-S data, which is a 30 m resolution DEM from the Shuttle Radar Topographic Mission. This data has been used in catchment delineation for Currambene and Moona Moona Creeks (See Section 4.2.2.2) and is displayed in greyscale on Figure 3. Whilst not of a comparable accuracy or resolution relative to the ALS the SRTM data is perfectly adequate for catchment delineation work.

2.2.3. Hydraulic Structure Data

27 bridges and culverts in the Currambene and Moona Moona catchments were surveyed (by AAM surveyors) so that the conveyance capacity and other details of these structures could be accurately modelled. The following features were surveyed for each bridge:

- Creek cross section survey at upstream face;
- Creek cross section survey at downstream side offset a few meters from structure;
- Pier locations and width;
- Level of deck underside at each creek side (and middle if curved bridge deck);
- Level of deck top at each creek side (and middle if curved bridge deck); and
- Level of fence/railing top at each creek side (and middle if curved bridge deck).

For each culvert the following data was requested:

- Provide internal dimensions of circular culverts (diameter) and rectangular box culverts (width, height);
- Provide upstream and downstream levels of culvert inverts; and
- Provide cross section survey of culvert topping flow path (e.g. road height).

Further details and locations of the surveyed features are displayed in the Survey Brief contained in Appendix B.

2.2.4. Channel Cross Section Survey

The DEM generated from the ALS data mentioned in Section 2.2.1 does not define the in-bank bathymetry below the water level at the time survey was flown. To determine the in-bank conveyance below the water level, a number of surveyed channel cross sections have been obtained along Currambene and Moona Moona Creeks. 23 cross sections on Currambene Creek were available from the Reference 1 study and a further 15 were available for Moona Moona Creek. These cross sections have been used in conjunction with an additional 10 cross sections obtained by AAM surveyors as part of the current study. The survey Brief and is displayed in Appendix B. The cross sections were used to generate a DEM of the River's bathymetry (within the river banks) with was then combined with the ALS data mentioned in Section 2.2.1. The locations of these cross sections are displayed in Figure 1 for the Currambene Creek Study Area and Figure 2 for the Moona Moona Study Area.

A similar process was performed for Moona Moona Creek using the cross sections obtained upstream and downstream of the Elizabeth Drive Bridge (see Section 2.2.3).

2.2.5. Peak Flood Level Survey

Peak flood levels to be used in model calibration were obtained for the June 2013 flood event. This event was selected as it was a relatively recent event in which at least nine properties were flood affected (determined from community consultation questionnaire results, see Section 3).

Questionnaire results were examined and a short list of people who had witnessed flooding was put together. WMAwater engineers met with ten local residents to obtain peak flood level marks for the June 2013 flood. Ten flood marks were identified and AAM surveying reduced the levels to mAHD to be used in model calibration. Details of the floodmarks are presented below in Table 2 and the locations are displayed in the calibration Figure 28.

Table 2 also provides an indication of the accuracy of the surveyed floodmarks and provides comments. It should be noted that the most reliable method of determining peak flood level is generally from eye witness accounts of the maximum height of flooding on a fixed manmade object such as a home, shed or fence post. Estimates of flood extent where the witness indicates how far the flood encroached on their land are generally less accurate, particularly if no fixed objects are close by. Another problem with obtaining accurate peak flood level marks is the confusion between local drainage issues and mainstream flooding. Witnesses often do not differentiate local drainage flows with creek flows leading to 'false' peak flood levels for calibration purposes. These problems with determining peak flood levels are often not able to be identified with any certainty until the floodmarks have been surveyed and comparisons to ground levels in mAHD and estimated peak flood extents have been reviewed.

Peak flood level marks with a 'Poor' accuracy rating on Table 2 have not been used in model calibration. Unfortunately, 50% of the surveyed flood level marks have been classified as poor, leaving four floodmarks available for calibration of the Currambene Creek hydraulic model and one for the Moona Moona Creek hydraulic model.

The survey Brief for these floodmarks is contained in Appendix B.

Table 2: June 2013 - Peak Flood Level Survey Marks for Calibration

Id	X	Y	Z	Accuracy*	Comment
1	287071	6120104	2.641	Good	Flood depth provided on fence post
2	286070	6123287	2.313	Poor	Peak flood extent estimate (steep terrain)
3	287696	6118196	2.354	Poor	See Section 2.2.5.2
4	287434	6119342	3.146	Poor	See Section 2.2.5.3
5	283215	6124431	2.301	Average	Peak flood extent estimate (flat terrain)
6	282793	6125368	2.697	Good	Flood depth estimate on fence post
7	282803	6125520	4.493	Poor	See Section 2.2.5.4
8	286621	6122037	1.287	Good	Flood depth estimated on boat shed
9	285056	6123715	1.966	Good	Flood depth estimate on table
10	284489	6122441	1.53	Poor	See Section 2.2.5.5

*Note: the accuracy of the peak flood level marks has been estimated from witness statements.

2.2.5.1. Floodmark 2 Comments

Floodmark 2 is an estimate of peak flood extent on steep terrain. As mentioned previously, if the recorded location of a peak flood extent is slightly incorrect in an area where terrain is steep, then the peak flood level can be significantly inaccurate. This is the case for Floodmark 2 where the modelled level is 0.3 m lower than the surveyed level, however the mark is an excellent indication of flood extent. Both the upstream and downstream surveyed peak flood levels (Floodmarks 8 and 9) are a good match to the modelled results indicating that the surveyed level of Floodmark 2 is likely inaccurate.

2.2.5.2. Floodmark 3 Comments

Floodmark 3 is a local drainage peak flood level. The witness noted that local flows were passing down the driveway of the property and ponding at the back fence. The best estimate of peak flood level for the June 2013 event is 1.3 m lower than the surveyed level of Floodmark 3. To further test the accuracy of this floodmark, sensitivity analysis was undertaken on rainfall (50% increase in rainfall intensity) and losses (zero initial and continuing losses) of the June 2013 event. By manipulating these parameters the ‘observed’ floodmark was unable to be matched with the modelled peak flood level being 0.8 m lower than Floodmark 3.

As Floodmark 3 is a local drainage peak flood level this mark has not been used to calibrate the Moona Moona Creek hydraulic model.

2.2.5.3. Floodmark 4 Comments

Floodmark 4 is a local drainage peak flood level. The witness noted significant local flows on Currambene Street which passed over the driveway of the property. The best estimate of peak flood level for the June 2013 event is 0.5 m lower than the surveyed level of Floodmark 4. To further test the accuracy of this floodmark, sensitivity analysis was undertaken on rainfall (50% increase in rainfall intensity) and losses (zero initial and continuing losses) of the June 2013 event. By manipulating these parameters the ‘observed’ floodmark was unable to be matched with the modelled peak flood level being 0.4 m lower than Floodmark 4.

As Floodmark 4 is a local drainage peak flood level this mark has not been used to calibrate the Moona Moona Creek hydraulic model.

2.2.5.4. Floodmark 7 Comments

Floodmark 7 is an estimate of peak flood extent on steep terrain. The modelled level is 1.6 m lower than the surveyed level. The good match at the nearby Floodmark 6 (a mark associated with a high degree of accuracy) situated 160 m away (and other flood marks further downstream) indicates that this floodmark is likely inaccurate and therefore has not been used in Currambene Creek hydraulic model calibration.

2.2.5.5. Floodmark 10 Comments

Floodmark 10 is an estimate of peak flood extent on the side of a farm dam (steep terrain). The witness was unsure of the maximum level that the flood achieved and this is a best estimate. The modelled level is 0.6m higher than the surveyed level. There is also a lack of agreement between the location of the surveyed mark and that determined by the engineer on the field trip. It appears that the survey mark should be 0.2 – 0.3 m higher than that determined during survey. It is considered unlikely that this mark is accurate and therefore has not been used in Currambene Creek hydraulic model calibration.

2.2.6. Floor Level Survey

Floor level survey was performed by AAM surveyors for 226 selected properties which were estimated to be within the 1% AEP flood extent. This included 210 residential properties, 10 commercial properties and 6 vacant lots. The location of these properties are presented in Appendix B in the survey Brief.

The floor levels of other properties within the PMF extent were estimated by use of ALS data (see Section 2.2.1) in combination with visual inspection of properties by WMAwater engineers.

2.3. Rainfall Data

2.3.1. Historic Rainfall Data

The rainfall data described in the following sections pertains to information that was used in calibration of the hydraulic model as well as verification of the Currambene Creek stream gauge FFA. The hydraulic model was calibrated to the June 2013 event (see Section 4.3.8) and the AEP of the five largest flood events at the Currambene Creek stream gauge were compared to the AEP of the associated rainfall event to add robustness to the FFA (see Section 4.2.1.4). Due to a lack of suitable rainfall data from any one source, a combination of data described in Sections 2.3.1.1 and 2.3.1.2 has been used to create rainfall inputs for the Currambene catchment. Dataset details are contained in Section 2.3.1.3.

In this section of the report, the AEP of all analysed historic rainfall events is based on the ARR2013 IFD data for the reasons described in Section 2.3.2.

2.3.1.1. Sub-daily Rainfall Data

Sub-daily rainfall data (high temporal resolution rainfall data) is advantageous as it contains information on both a storms temporal pattern and total rainfall depth. The Bureau of Meteorology (BoM) Nowra RAN Air Station AWS gauge (RAN gauge) records sub-daily rainfall data and is situated slightly outside of the Currambene Creek catchment to the north-west (see Figure 8 for location).

The RAN gauge has two gauge numbers; 068072 for the 6 minute data period and 068076 for the 30 minute data period. 6 minute rainfall data was available from 1964 to 1998 and for the period of 2000 to 2014, 30 min rainfall data was available. This is a total record period of 50 years. This data was used to determine temporal patterns for the Currambene catchment for the historic rainfall events.

2.3.1.2. Daily Read Rainfall Data

Daily read rainfall gauges do not adequately define the shorter duration intensities that are responsible for flooding in the region and (in isolation) are therefore not suitable for calibration of the hydraulic model or verification of the FFA. However due to spatial distribution of gauges, daily read rainfall data has been used to determine total rainfall depths and rainfall spatial distribution across the catchment.

Regional daily read gauges were investigated to determine catchment rainfall depths for the June 2013 hydraulic model calibration event as well as for the four additional storm events that were used to add robustness to the FFA. These gauges along with rainfall depths for the June 2013 and February 1971 events are presented in Table 3.

Table 3: Daily Rainfall Gauges Used in this Study

ID	Name	2013 Rainfall (mm)			1971 Rainfall (mm)		
		24th Jun	25th Jun	26th Jun	5th Feb	6th Feb	7th Feb
68085	Nerriga (Tolwong)	25	146	39.2	-	-	-
68233	Grassy Gully (Shoalhaven River)	41	120	72	-	-	-
68213	Nowra Boat Shed (Shoalhaven River)	49	99	61	-	-	-
68048	Nowra Treatment Works	33	106	62	97.8	291.8	43.9
68080	Greenwell Point Bowling Club	83	90	59	-	-	-
68083	Culburra Treatment Works	36	119	56	45.5	88.9	107.2
68245	Callala Treatment Plant	39	126	55.2	-	-	-
68251	Callala Bay (Donovan Close)	62	86.2	36	-	-	-
68072	Nowra RAN Station AWS	45	159	66	50.4	190.1	55.0
68151	Jervis Bay (Point Perpendicular AWS)	67.2	143	63.4	-	-	-
68088	Sanctuary Point (Salinas Street)	64.8	144.4	47.2	-	-	-
68204	Sussex Inlet Bowling Club	61.6	93	47	82.6	379.5	221.1
68229	Bendalong STP	73.2	73	16.6	37.3	365.8	163.8
069016	Milton (Sarah Claydon Village)	-	-	-	43.0	224.0	0
068008	Bundanoon	-	-	-	14.2	23.6	10.4

Rainfall depths for the region were created by interpolating (Kriging) between neighbouring gauges. As an example the estimated rainfall distribution of the catchment for the 2013 and 1971 events is shown in Figure 4 and Figure 5 respectively. Utilising these rainfall distribution grids, unique rainfall depths for each sub-catchment were able to be calculated for input in the hydrologic model for hydraulic model calibration to the June 2013 event (see Section 4.2.3).

The same process was also undertaken for the February 1971, March 1975, March 1974 and October 1976 rainfall events which produced the first, second, third and fourth largest flows at the Currambene gauge in recorded history (see Section 2.4.2). This was done so that the event rainfall AEP could be compared to the Currambene Creek discharge AEP to add robustness to the FFA flow estimates (see Section 4.2.1.4).

2.3.1.3. Rainfall Data Merge

Rainfall data mentioned in Sections 2.3.1.1 and 2.3.1.2 was used to create rainfall data sets with six minute (1971, 1974, 1975 and 1976 event) and 30 minute (2013 event) temporal resolution. The catchment weighted average rainfall depth was determined from the spatial rainfall patterns mentioned in Sections 2.3.1.2 and this depth was applied to the temporal patterns obtained from the RAN gauge mentioned in Sections 2.3.1.1. The results of the merged rainfall data for the above listed events are presented in Figure 6. The Figure 6 charts display the upstream Currambene Creek stream gauge catchment average rainfall for these events.

2.3.1.4. Historical Event Rainfall Analysis

Five historic rainfall events that produced the highest flows at the Currambene gauge have been analysed. The February 1971, March 1975, March 1974, October 1976 and June 2013 rainfall events were selected for analysis (see Section 2.3.1.3). Note that the 5th largest event occurred in 1990, however rainfall data was not available.

The rainfall burst intensity and frequency of these events has been examined with the results displayed in Figure 7. The coloured lines represent the intensity/duration relationship for each of the events mentioned above (Event Relationships). The black lines display the ARR2013 IFD intensity/duration relationships for design events of varying frequencies (IFD Relationships). By comparing the coloured Event Relationships with the black IFD Relationships, the AEP of each of these events for various durations can be inferred. Note that the displayed ARR2013 IFD Relationships (the black lines) have been adjusted to incorporate an Aerial Reduction Factor (ARF) for the 95 km^2 upstream Currambene gauge catchment. The ARF has been calculated using the techniques described in Section 4.2.5.3.

For each event, Figure 7 displays event burst intensities ranging from 6 minutes to 48 hours, however not all burst durations are likely to cause significant flooding in the Currambene Catchment. For example an event with a 6 minute duration 1% AEP intensity would not create a 1% AEP flow at the Currambene Creek stream gauge. An event which is most likely to have a flow AEP corresponding to the events rainfall AEP would be for a duration similar to the catchment's time of concentration (TOC). Estimates of the catchment's TOC have been calculated using the Bransby Williams method (6.3 hours, Reference 3) and the hydrologic model (8.3 hours). The estimated TOCs are displayed on Figure 7 as vertical hashed black lines.

For each previously mentioned historic event, the estimated rainfall AEP for the catchment's TOC estimated durations are displayed below in Table 4. The average of the AEP for both methods of determining the TOC has been used to estimate the event AEP.

Table 4: Historic Rainfall Events – Estimated Average Recurrance Interval (AEP)

Event	Event AEP (%)		
	Bransby Williams TOC (6.3 hour duration)	Hydrologic Model TOC (8.3 hour duration)	Average Estimated*
1971	0.25	0.5	0.33
1974	4.3	6.7	5.3
1975	4.2	7.1	5.3
1976	4.0	4.0	4.0
2013	33.3	25	28.6

*The Average Estimated Event AEP has been used to describe estimated frequency of each historic rainfall event.

Table 4 indicates that the 1971 rainfall event has an approximate 0.33% AEP (300 year ARI) which is in good agreement with the 1971 event flow AEP determined by findings from the FFA (see Section 4.2.1.4).

The 1974, 1975 and 1976 rainfall events estimated AEPs range from approximately 4.0% - 7.1% AEP (19 - 25 year ARI) using the ARR2013 IFD relationships. The rainfall AEP corresponds well with the flow AEP for each of these events (see Section 4.2.1.4).

June 2013 rainfall was considerably smaller than the other events that were analysed. The rainfall intensity of this event is estimated to have an approximate 30% AEP (3.5 year ARI). In spite of the June 2013 rainfall event being relatively minor, the magnitude of the tides that occurred at this time (see Section 2.5) and the event rainfall volume (see Figure 6), did lead to minor flooding in the region. For longer durations, such as the 48 hour duration this rainfall event did experience rainfall intensities approximating the 10% AEP.

2.3.2. Design Rainfall Data

Design rainfall data is an important input parameter into a hydrologic model to determine design flows. The design rainfall depths are used in conjunction with design rainfall temporal patterns to create design storms. In current practise, design rainfalls are based on Australian Rainfall and Runoff 1987 (ARR87) design rainfall data. However this data is in the process of being revised with new Intensity-Frequency-Duration (IFD) relationships available as part of the ARR revision (ARR2013).

A comprehensive analysis of both the ARR87 IFDs and ARR2013 IFDs has been undertaken to show that for the current study the revised IFDs should be used to determine design flows. The revised IFDs have been used in conjunction with ARR87 design rainfall temporal patterns (see Section 2.3.3) which is not ideal, however revised temporal patterns were not available at the time of this work.

2.3.2.1. Comparison of ARR87 and ARR2013 Design Rainfall Data

The ARR2013 IFD design rainfall mentioned above is based on a more extensive database than the ARR87 IFDs, with nearly 30 years' (an approximate 100% increase) additional rainfall data and data from 2300 extra rainfall stations. This equates to four times as many sub-daily rainfall gauges than were used in creation of the ARR87 IFD data. By combining contemporary statistical analyses and techniques with this expanded rainfall database, the new IFDs provide more accurate design rainfall estimates for Australia generally and in particular for the Currambene and Moona Moona catchments.

In the Currambene Creek catchment and surrounds a number of additional rainfall gauges have been used in the ARR2013 IFD revision. Figure 8 displays the available rainfall gauges that were used in creation of the ARR87 (blue points only) and ARR2013 (blue and red points) IFDs. Sub-daily gauges are presented as yellow points. An additional five rainfall gauges (2 sub-daily, 3 daily read) have been used to create the ARR2013 IFD design rainfall data in this region. Particularly of note is the sub-daily gauge at Turpentine situated near the top of the catchment which provides better rainfall estimates in the upper Currambene Creek catchment.

Both the ARR87 and ARR2013 IFDs use elevation as a covariant for IFD estimates. Without the additional rainfall gauges used in the ARR2013 IFD estimates, the ARR87 IFD estimates greatly increase with elevation at the top of the catchment. Image 1 below clearly shows the increase in rainfall intensity with increasing elevation in the Currambene catchment for the ARR87 1% AEP 9 hour duration event. Similar trends are noticed with all ARR87 durations and AEP. However ARR2013 design rainfalls better represent realistic rainfall patterns for the region and do not exhibit this strong rainfall gradient due to influences of the additional rainfall gauges mentioned above.

Image 1: Comparison of ARR87 Rainfall Intensity and Ground Level Elevation

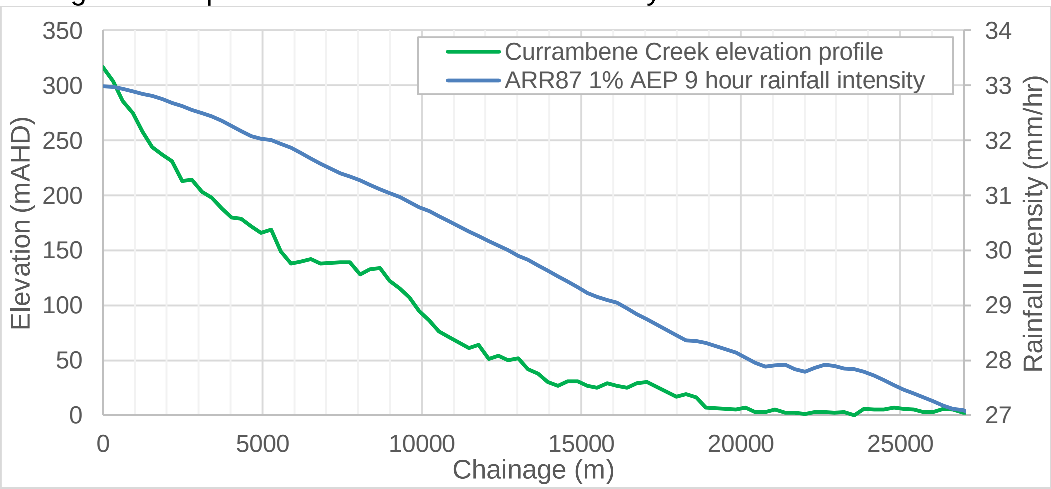


Figure 9 displays the difference in rainfall depth between the ARR87 and ARR2013 1% AEP 9 hour duration events. It can be seen that the ARR87 design rainfall estimates produce over 80 mm more rainfall than the ARR2013 design rainfall in the upper catchment. This equates to an approximate 30% decrease in rainfall depth for the revised ARR2013 design rainfall estimates.

Due to the large difference in design rainfall depths between the ARR87 and ARR2013 IFD relationships, analysis on gauged rainfall at the RAN gauge was performed. This was done to produce an IFD relationship for recorded rainfall in the region which was compared to both the ARR87 and ARR2013 IFD relationships (see Section 2.3.2.2).

In addition to this, both the ARR87 and ARR2013 design rainfalls were used as input into the hydrologic model for calibration to the Currambene Creek stream gauge FFA (see Section 4.2.3). It was found for the ARR87 design rainfall that the hydrologic model routing parameter was outside of values that are generally considered acceptable for a catchment with topographic characteristics consistent with Currambene Creek and that this parameter was unable to be verified when considering historic rainfall events (see Section 4.2.3.2). However, when using ARR2013 rainfall, the Reference 2 study (see Section 2.1) findings successfully validated the hydrologic model parameters (see Section 4.2.3.1).

2.3.2.2. Comparison of RAN gauge, ARR87 and ARR2013 IFD Relationships

IFD relationships for the RAN gauge data (RAN IFDs) were created from data for the entire period of record (see Section 2.3.1.1). This is a period of 50 years which provides reasonably accurate IFD estimates up to 2% AEP intensities. The RAN IFDs were compared to both the ARR87 and the ARR2013 IFD relationships (see Figure 10) at the location of the RAN gauge. On Figure 10 the RAN IFDs are displayed in black, the ARR87 IFDs are displayed in blue and the ARR2013 IFDs are displayed in red.

It is apparent that the ARR87 IFDs are significantly higher than both the RAN IFDs and ARR2013 IFDs. As displayed in Figure 9 the RAN gauge is situated to the north of the catchment and regions to the west of the RAN gauge are likely to experience greater differences in rainfall intensity than that displayed in Figure 10. Differences in regions in the east of the RAN gauge are significant, however they not as great as at the location of the RAN gauge.

A clear indication of the difference in magnitude of these design rainfalls is presented below in Table 5. Table 5 displays the maximum design rainfall in the Currambene Catchment for the 9 hour duration event. It can be seen that for all AEP the ARR87 maximum rainfall depths are approximately 40% higher than the ARR2013 maximum rainfall depths.

Table 5: ARR87 and ARR2013 Rainfall – Currambene Catchment Maximum 9 hour Depth

Event	Currambene Catchment – Max 9 hour Rainfall	
	ARR87 (mm)	ARR2013 (mm)
0.2 EY	159	111
10% AEP	185	134
5% AEP	218	156
2% AEP	262	187
1% AEP	297	210
0.5% AEP	332	235

Further to this, the RAN IFDs are a good match to the ARR2013 IFDs. This finding, in conjunction with the findings related to calibration of the hydrologic model to the Currambene Creek stream gauge FFA (see Section 4.2.3), leads to the conclusion that ARR2013 design rainfall is a better representation of rainfall characteristics for this region than ARR87 estimates. Accordingly, ARR2013 design rainfall has been used instead of ARR87 design rainfall for the current study.

2.3.2.3. Design Rainfall Data

ARR2013 design rainfall for the region was obtained from the Bureau of Meteorology (BoM) and spatial variation in design rainfall has been accounted for in the current study. Temporal patterns (ARR87) are for Zone I and were obtained from Australian Rainfall and Runoff (Reference 3).

ARR2013 design rainfall depths are for the Currambene and Moona Moona Creek catchment's critical durations (9 and 12 hours respectively).

Table 6: ARR2013 Design Rainfall – Currambene and Moona catchments – Critical Duration

Event	Currambene Catchment (9 hour)		Moona Moona Catchment (12 hour)	
	Average (mm)	Max (mm)	Average (mm)	Max (mm)
0.2 EY	134	159	123	124
10% AEP	158	185	148	150
5% AEP	189	218	172	175
2% AEP	231	262	205	209
1% AEP	264	297	231	235
0.5% AEP	298	332	258	263

2.3.2.4. Probable Maximum Precipitation

Currambene and Moona Moona catchments have catchment areas of less than 1,000 km^2. PMP depth calculation for these catchments is therefore calculated by the Generalised Short Duration Method (GSDM) (Reference 4).

Figure 11 displays the PMP spatial rainfall distribution and the rainfall depths allocated to each ellipsoid for Currambene Creek for the critical duration of 4 hours (see Section 4.2.6). Figure 12 displays the same for the Moona Moona Creek catchment for which the PMP critical duration is 2 hours.

2.3.3. Design Temporal Patterns

ARR87 design temporal patterns were created so that the AEP of a pattern's internal rainfall bursts would not exceed the event AEP. As part of the development of temporal patterns for ARR87, temporal patterns were filtered to ensure all internal storm bursts did not have a rarer AEP than that of the total duration of the burst. Hence, filtering was employed to reduce the most intense bursts within the pattern and to redistribute this rainfall depth to other periods within the pattern.

It was recognised that in some locations there may still be a problem but it was considered prudent to recommend further filtering of ARR87 temporal patterns for these locations rather than over filter all locations. This is the case with the Currambene and Moona Moona catchments, which for longer duration events, experience rainfall bursts with significantly rarer AEP than that of the event being examined.

ARR2013 temporal patterns were not available at the time of this study. The proposed ARR2013 temporal patterns will be based on regional data and will be far less likely to deviate from AEP neutrality. Use of the ARR2013 design rainfall depths in conjunction with ARR87 temporal patterns further compounds the embedded storm burst paradigm. This methodology creates embedded rainfall bursts in the Currambene Creek catchment that greatly exceed 1% AEP estimates, particularly for the longer duration events. This effect is especially pronounced for the 24, 36, 48 and 72 hour durations where embedded bursts exceed 0.2% AEP estimates (see Figure 13). However, for the current study the benefit of using ARR2013 design rainfall depths even with the ARR87 temporal patterns, far outweighs the negatives compared to using the ARR87 design depths (see Section 2.3.2).

ARR87 guidelines recommend that temporal pattern filtering be undertaken to remove embedded bursts when required but provide no detailed guidance on how to conduct the temporal pattern filtering procedure. Accordingly, instead of temporal pattern filtering, the current study has elected to exclude events for which embedded bursts greatly exceed the event AEP. As mentioned previously, this effect is predominately experienced by the longer duration events which are much longer than the Currambene Creek catchment’s TOC.

The Currambene Creek TOC is estimated to be approximately 6-8 hours (see Section 2.3.1.4) and it is likely that a storm event with a duration similar to the TOC would be found to be critical. A critical duration assessment undertaken using the hydrologic model (see Section 4.2.6) indicates that the critical duration at the both the Currambene Creek stream gauge and the Creek outlet is the 9 hour event when excluding the 24 - 72 hour duration events from the analysis.

2.4. Stream Gauge Data

Flood heights, rating curves, cross-sections and other details for the Currambene Creek stream gauge (No. 216004) were obtained from PINNEENA. This data was not only used to inform flow inputs into the hydraulic model for calibration (see Section 4.3.11.1) but also as a basis for FFA used to determine design flows (see Section 4.2.1).

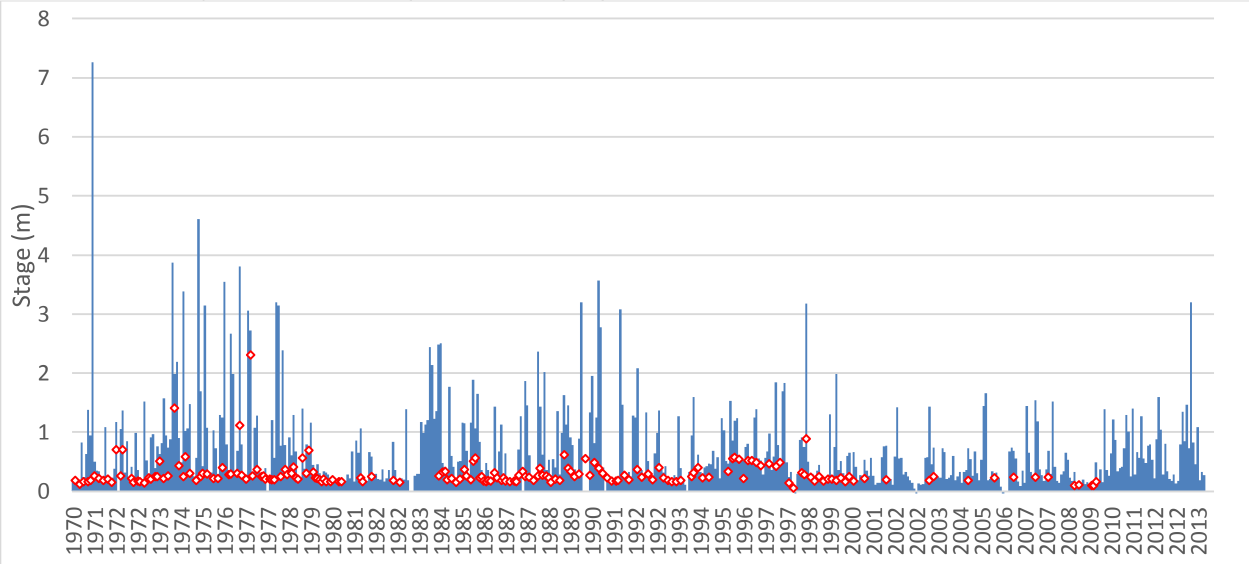
The Currambene gauge (gauge zero = 2.07 mAHD) was established on Currambene Creek in 1969 and is situated downstream of the Princes Highway. The location of the gauge is presented in Figure 1. This is an automatic gauge which provides relatively accurate flood stage hydrograph data, virtually uninterrupted, since its installation.

2.4.1. Rating Analysis

Flow gaugings have been undertaken at the Currambene gauge since its installation in 1969. These gaugings are used to develop rating curves that allow an estimate of flow based on a gauge height. Rating curves above the highest available gauging are determined via extrapolation. This means that rating curves are often less accurate above the highest level for which a flow gauging has been performed.

Chart 1 displays the maximum stage recorded each month for the gauges entire period of record along with Currambene gaugings for this period. Of note is that the maximum gauging was performed at a stage of 2.3 m on the Currambene gauge whilst the highest recorded flood (February 1971) was five meters higher at the peak stage of 7.3 m. This tends to indicate that the peak flow estimate provided in PINEENA may be less than perfect.

Chart 1: Monthly Maximum Stage and Gaugings Level

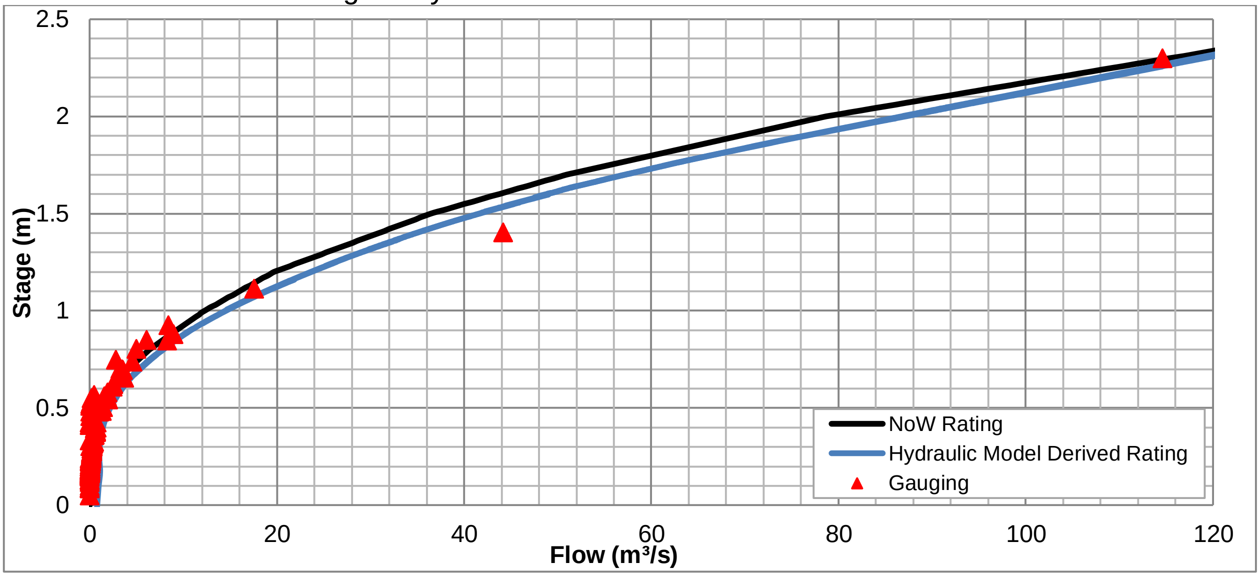


Note: gaugings post 2009 were not available for this study.

As such, in order to ensure the accuracy of the flow estimates at the Currambene Creek stream gauge, a Gauge model has been established. This model was created separate to the main hydraulic model described in Section 4.3.

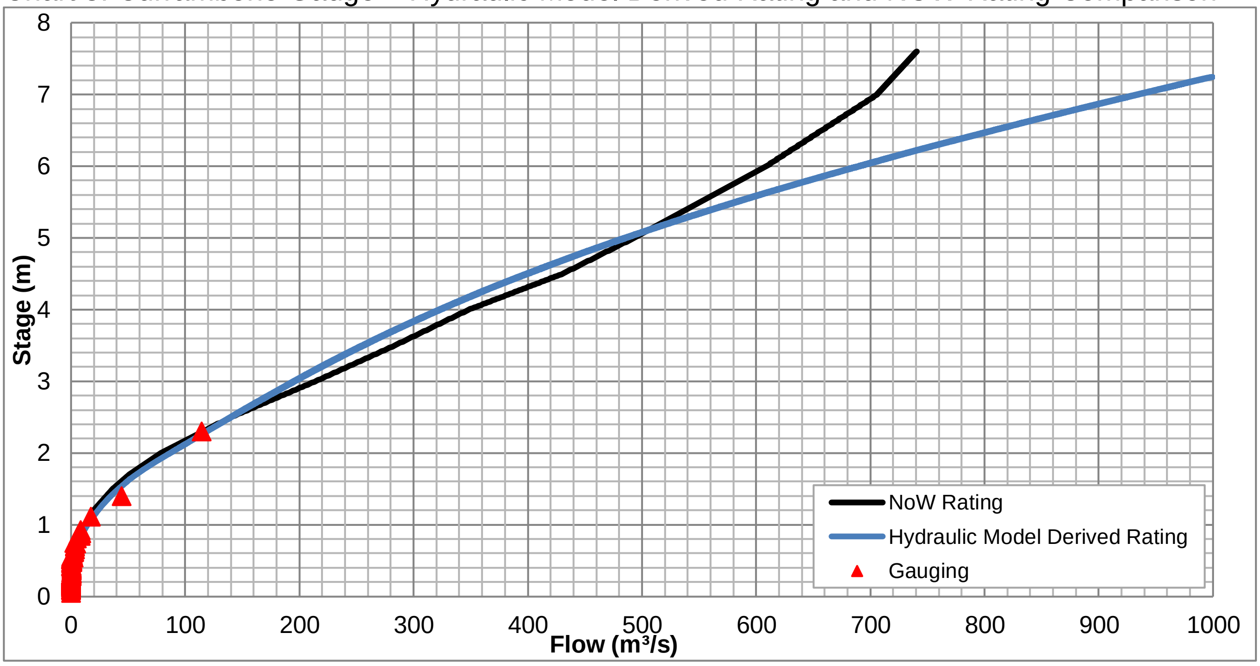
The Gauge Model was calibrated to match previous gaugings in an attempt to obtain a more accurate high flow rating (see Chart 2). Chart 3 (as zoomed out version of Chart 2) displays a comparison of the hydraulic model derived rating and the NSW Office of Water (NOW) rating. It can be seen that both ratings are similar up to approximately 2.5 m, where gaugings are available. However for larger flows, particularly flows greater than 500 m³/s, there is a significant difference in the stage/discharge relationship between the two ratings. For example the estimated peak flow of 721 m³/s for the 1971 event using the NOW rating is 290 m³/s lower than the hydraulic model rating estimated flow of 1,010 m³/s.

Chart 2: Currambene Gauge – Hydraulic Model Calibration



Note: Gauge zero = 2.07 mAHD

Chart 3: Currambene Gauge – Hydraulic Model Derived Rating and NOW Rating Comparison



Note: Gauge zero = 2.07 mAHD

Therefore the hydraulic model derived rating has been used to determine flows for both FFA (see Section 2.4.2 for annual series data and Section 4.2.1 for FFA) and for hydrologic model calibration (see Section 4.2.3).

2.4.2. Annual Series Data

The annual series data used in FFA is presented in Table 7. All flows have been determined by using the hydraulic model derived rating (see Section 2.4.1) applied to annual maximum levels obtained from PINNENA.

Table 7: Currambene Gauge Annual Maximum Flow

Year	Stage (m)	Flow (m^3/s)	Year	Stage (m)	Flow (m^3/s)	Year	Stage (m)	Flow (m^3/s)
1970	0.82	8	**1985**	1.89	75	**2000**	0.66	4
1971	7.27	1010	**1986**	1.65	53	**2001**	0.77	7
1972	1.37	33	**1987**	1.45	38	**2002**	1.42	36
1973	1.52	43	**1988**	2.36	126	**2003**	1.43	37
1974	3.87	304	**1989**	1.63	51	**2004**	0.73	6
1975	4.60	418	**1990**	3.57	266	**2005**	1.65	53
1976	3.80	297	**1991**	3.08	206	**2006**	0.74	6
1977	3.06	203	**1992**	1.28	28	**2007**	1.54	44
1978	3.19	219	**1993**	1.37	33	**2008**	1.52	43
1979	1.40	35	**1994**	1.60	49	**2009**	0.49	2
1980	0.33	1	**1995**	1.53	44	**2010**	1.39	34
1981	1.07	17	**1996**	1.37	34	**2011**	1.40	35
1982	0.84	9	**1997**	1.84	71	**2012**	1.60	49
1983	1.39	34	**1998**	3.18	217	**2013**	3.20	220
1984	2.51	141	**1999**	1.99	86			

2.5. Ocean Level Data

Flooding in tidal waterways may occur due to a combination of oceanic inundation (tailwater level) and catchment flooding derived from the same storm. The combined impact of these two sources on overall flood risk varies significantly with distance from the ocean and the degree of ocean influence, which is in turn affected by the estuary's entrance conditions.

Tailwater levels in coastal rivers are influenced by a number of different processes. Some of these are regional in character while others may be more local and dependent on the particular site characteristics. Regional influencing factors include astronomical tide, the effects of storm surge (combined effects of barometric setup and wind setup), shelf waves/ long waves, ocean current effects, effects of the El Nino/southern oscillation phenomenon as well as long term climate change/greenhouse related sea level rise. Local effects may include factors like wave setup, seiching and berm height for entrances subject to closure (berm height is primarily dependant on wave run-up which is dependent on the degree of exposure to waves and the beach grain size)

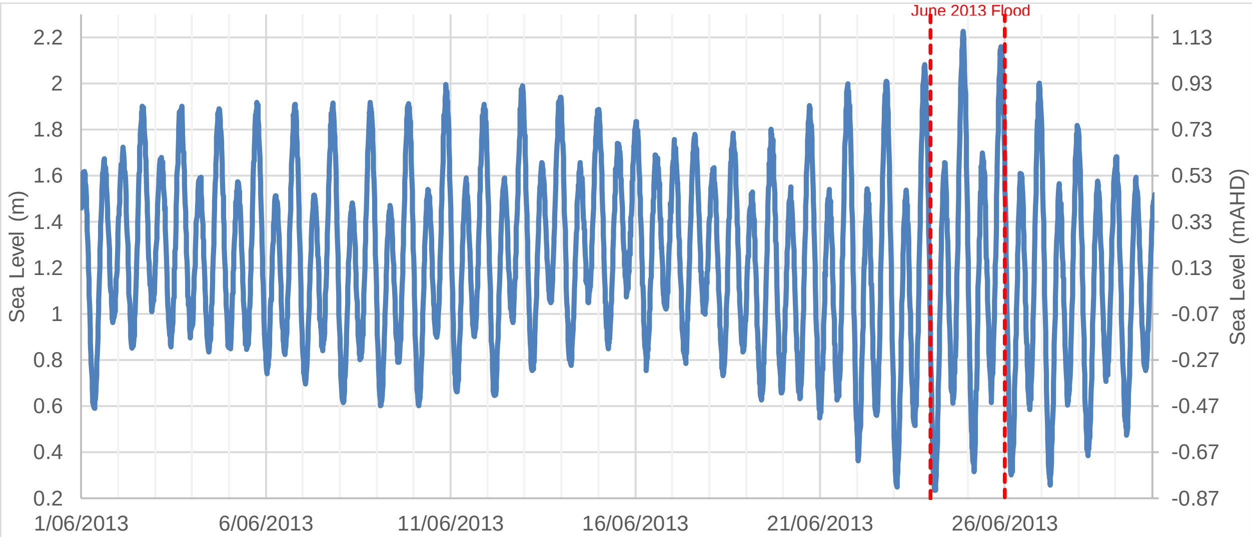
Whilst the regional effects are likely to be similar for much of the NSW coast, local effects of wave setup or entrance closure are highly variable and in most cases may be more significant than the regional processes.

2.5.1. June 2013 Calibration Ocean Level Data

The ocean level at the time of the June 2013 event was obtained for Jervis Bay to inform the downstream tailwater level of the model for calibration. Continuously recorded sea level data was obtained for the Month of June 2013 for the HMAS Creswell gauge. This data was provided by the Manly Hydraulics Laboratory (MHL) in conjunction with the OEH.

The June 2013 sea level in Jervis Bay is displayed below in Chart 4. It can be seen that the event occurred in conjunction with an elevated tailwater level (1.16 mAHD) that was slightly higher than the Highest Astronomical Tide (HAT) of 1.1 mAHD.

Chart 4: June 2013 Sea Level – HMAS Creswell



2.5.2. Design Ocean Level Data

The Reference 5 study determined design ocean levels incorporating a combination of both regional and local factors. These levels are presented in Table 8 and form the basis of design tailwater levels for Currambene and Moona Moona Creeks used in hydraulic modelling.

Table 8: Reference 5 Study – Downstream Tailwater Levels (mAHD)

	5% AEP	1% AEP
Currambene Creek	1.71	1.89
Moona Moona Creek	1.91	2.09

Note: Reference 5 Study estimates that the accuracy of these levels is ±0.2m

A full joint probability analysis to consider the interaction of these two mechanisms is beyond the scope of the present study. A joint event is an event where two flood mechanisms (independent or otherwise) interact in order to produce the flood levels, extents, flows and depths characterising the flood event. A key issue in joint modelling is independence, as in, are the two mechanisms being modelled independent or otherwise. Where events are independent coordinating them to produce peak flood behaviour can be inappropriate as the rarity of the event would be increased.

Ocean level anomalies and intense rainfall events are weakly correlated, and thus a joint probability frame work has been incorporated into the analysis using the methodology outlined in the Reference 6 study. Both entrances are classed as ICOLLS and dynamic tides of varying magnitude, dependant on event AEP, have been applied to the downstream boundary. For each design event the flow AEP and selected tailwater conditions are presented in Table 9.

A flood envelope approach was adopted for defining design flood behaviour for the 1% AEP event. The combination of catchment flows and downstream tailwater levels for this event are presented in Table 9.

Table 9: Combinations of Catchment Flooding and Oceanic Inundation Scenarios (Reference 6)

Design AEP for peak levels / velocities	Catchment Flood Scenario	Ocean Water Level Boundary Scenario
50% AEP	50% AEP	HHWS*
20%	20% AEP	HHWS
10%	10% AEP	HHWS
5%	5% AEP	HHWS
2%	2% AEP	5% AEP
1% Envelope level	5% AEP	1% AEP
1% Envelope level	1% AEP	5% AEP
1% Envelope velocity	1% AEP	Neap
0.50%	0.5% AEP	1% AEP
0.20%	0.2% AEP	1% AEP
PMF	PMF	1% AEP

* Highest High Water Spring (HHWS)

The localised design ocean levels displayed in Table 8 were used to factor down design ocean levels presented in the Reference 6 study so that the Reference 5 study levels were not exceeded, particularly at high tide. The factored downstream design tailwaters (5% AEP and 1% AEP) and the HHWS tide for both Currambene and Moona Moona used in design runs are presented in Figure 14.

Due to the dynamic nature of the downstream water level, the alignment of tailwater and catchment flow peaks can affect design flood levels. At Currambene Creek, the tide and flow peaks were timed so that they aligned at Woollamia. Woollamia was selected as it experiences the highest level of flood affectation in the Currambene Creek catchment. In Moona Moona Creek, the tide and catchment flow peaks were aligned at the Elizabeth Drive Bridge.

Reference 6 requires that for catchments with a TOC longer than 6 hours, sensitivity to the relative timing of catchment flooding and oceanic inundation be determined. Catchments with a TOC of 6 to 24 hours must vary the coincident peak timing +/- 3 hours. This sensitivity analysis has been performed on Currambene Creek which has a TOC of approximately 7 hours and the results presented in Section 4.3.12. The Moona Moona Creek catchment has a TOC of approximately 4 hours and therefore this analysis was not necessary.

2.5.3. Sea Level Rise – Climate Change

The *NSW Sea Level Rise Policy Statement* was released by the NSW Government in October 2009. This Policy Statement was accompanied by the *Derivation of the NSW Government's sea level rise planning benchmarks* (Reference 7) which provided technical details on how the sea level rise assessment was undertaken. Additional guidelines were issued by OEH, including the *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments 2010* (DECCW 2010). These guidelines have since been retracted by the NSW government. On 8 September 2012, the NSW Government announced its Stage One Coastal

Management Reforms. As part of these reforms, the NSW Government no longer recommends state-wide sea level rise benchmarks for use by local councils, with councils having the flexibility to consider local conditions when determining local future hazards.

Subsequent to the retraction of the state government benchmarks, Eurobodalla Shire Council and Shoalhaven City Council jointly commissioned a study to:

- develop regionally relevant projections for sea level rise along the coastline of these Council areas; and
- develop a risk assessment and policy framework for sea level rise impacts on strategic planning, development control and consent activities.

Following the completion of the study and based on other considerations as provided in Appendix D, Council adopted the following projections.

- by 2050, a 0.23 m increase from current (2014) sea levels; and
- by 2100, a 0.36 m increase from current (2014) sea levels.

The model results presented in this Flood Study Revision are based primarily on topographic and climate data which is representative of conditions around 1990. There has been additional sea level rise increase between 1990 and 2014 of approximately 0.05 m (Reference 8). Therefore, for this study, an additional 0.05 m was added to the above for determining the projected change in flood levels by 2050 and 2100. Therefore, for this study, the sea level rise adopted were:

- by 2050, a 0.28 m increase from 1990 levels; and
- by 2100, a 0.41 m increase from 1990 levels.

It should also be noted that climate change and the associated rise in sea levels are expected to continue beyond 2100.

The 2050 and 2100 sea level rise estimates have been modelled in the current study for each of the design flows with the results presented in Section 4.3.11.4. In addition to these results the design results' sensitivity to predicted sea level rise has been analysed. The sea level rise sensitivity analysis results are presented in Section 4.3.12.2.

At Council's request the Reference 7 guidelines' predicted ocean levels have also been modelled to further test Currambene and Moona Moona Creeks' sensitivity to sea level rise and tailwater conditions. The Reference 7 guidelines indicate a 0.9 metre sea level rise by the year 2100 and a 0.4 metre rise by the year 2050. Again, these increases in ocean level have been added to 1% AEP downstream tailwater levels presented in Section 2.5.2 and the results are displayed in Section 4.3.12.2.

2.6. Creek Entrance Characteristics

The downstream entrance conditions of an ICOLL can impact on peak flood levels during a flood event due the influence on entrance conveyance capacity. ICOLLs, such as Currambene and Moona Moona Creeks, experience significant scouring of the entrance during flood, which increases channel conveyance and decreases upstream flood levels. The degree to which an entrance is scoured during a flood event is dependent on entrance conditions such as shape, sand type and the presence of bedrock as well as the magnitude of the flood event and event tailwater conditions. The amount of scour can be estimated using morphodynamic flood modelling, however this is outside the scope of the current study and various data not currently available would also be required.

To account for the impact of entrance scour, the current study has made a number of assumptions in regards to entrance conditions for events of varying AEP. Sensitivity analysis has been used to show that these assumptions are valid. The described analysis in this study has been carried out assuming that the channel condition dimensions are maintained over the duration of the model simulation. However, for sand bed channels such as Currambene Creek and Moona Moona Creek, it is likely that some movement of the bed may take place over the duration of the flood event.

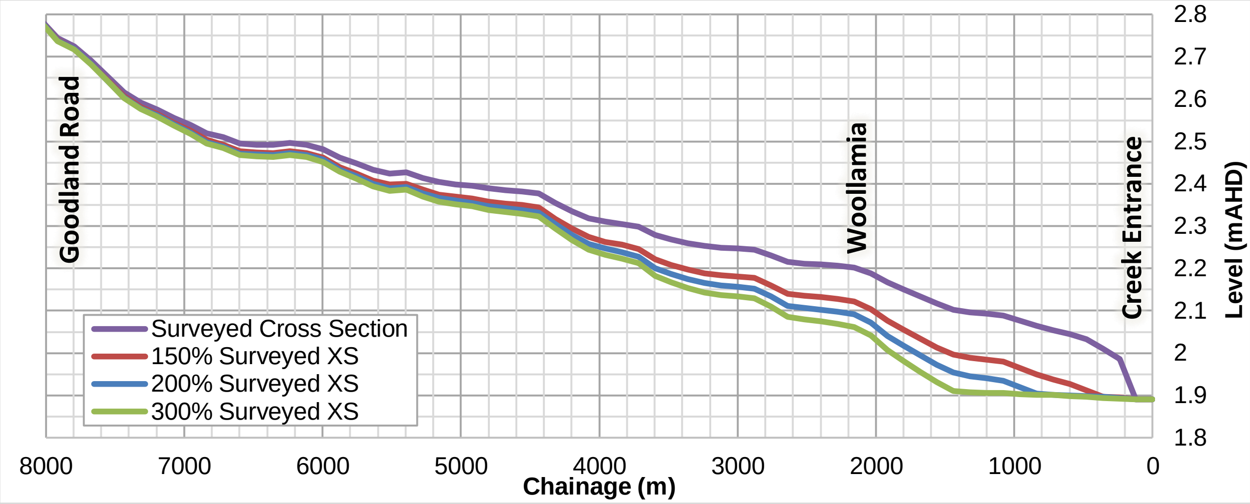
A study performed by BMT WBM for Burrill, Conjola & Tabourie Lakes (Reference 9) used a morphologic module of TUFLOW to simulate entrance scour during flood. Findings from these studies found that scour throughout the rising limb of the flood generally eroded sufficient sand to pass the event peak flow. Essentially, the degree to which an entrance is scoured at the beginning of an event only influenced the shape of the rising limb, but had negligible impact on the peak flood level. This indicates that the assumption of static entrance conditions used in the current study is a valid approach.

2.6.1. Currambene Entrance Conditions

Currambene Creek’s sensitivity to entrance scour has been investigated by running the 1% design event (peak envelope mentioned in Section 2.5.2) with various entrance scour conditions and comparing results. The surveyed entrance condition (see Section 2.2.4) conveyance capacity was increased to approximately 150%, 200% and 300% of the surveyed cross section capacity for comparison.

The results (see Chart 5) showed that a 50% increase in entrance conveyance reduces peak flood level by a maximum of approximately 0.1 m upstream of the outlet (the maximum difference occurs at approximately 1 km upstream of the outlet due to the enveloping of peak flood levels, see Section 2.5.2). However, peak flood levels exhibit far less sensitivity to further increases in conveyance capacity. For example, tripling the entrance conveyance to 300% of the surveyed cross section conveyance only further reduced peak flood levels by an additional 0.1 m at the same point. This effect is more pronounced in Woollamia where the 50% increase in conveyance reduces peak flood levels by 0.08 m, where as 300% conveyance only further reduces flood levels by 0.05 m (0.13 m total reduction).

Chart 5: Currambene Creek 1% AEP Flood Profile – Various Entrance Scour Conditions



As some scour can be assumed but the impact of scour is not overly significant in terms of peak flood levels past a certain threshold, the assumptions for entrance scour displayed in Table 10 have been used for the current study.

Table 10: Currambene Creek Design Entrance Conditions

Event	Assumed Entrance Condition
0.2 EY	Surveyed Cross Section
10% AEP	Surveyed Cross Section
5% AEP	150% Surveyed XS
2% AEP	150% Surveyed XS
1% AEP	200% Surveyed XS
0.5% AEP	200% Surveyed XS
PMF	300% Surveyed XS

The above entrance scour conditions assume that smaller events will produce less scour than larger events, however as sensitivity analysis shows, design flood levels are generally insensitive to the selected entrance conveyance capacity (scour) past a threshold. Further sensitivity analysis has been undertaken to assure that the selected event AEP specific scour presented in Table 10 is reasonable. Table 11 displays the maximum reduction in peak flood level with the increased scour for each design event.

Table 11: Currambene Creek Sensitivity to Scour - Increased Conveyance

Event	Increased Entrance Condition	Maximum Sensitivity (m)
0.2 EY	150% Surveyed XS	-0.00
10% AEP	150% Surveyed XS	-0.01
5% AEP	200% Surveyed XS	-0.01
2% AEP	200% Surveyed XS	-0.02
1% AEP	300% Surveyed XS	-0.03
0.5% AEP	300% Surveyed XS	-0.06
PMF	400% Surveyed XS	-0.27

The results presented in Table 11 indicate that further increase to the design outlet conveyance capacities due to erosion, makes little difference to design flood levels with the exception of the PMF. Further erosion of the entrance during a PMF is likely, however the current assumption of entrance scour during this event is conservative as is appropriate.

The lack of sensitivity to further outlet scour indicates that the assumed entrance conditions presented in Table 10 are reasonable and accordingly have been used in design flood modelling.

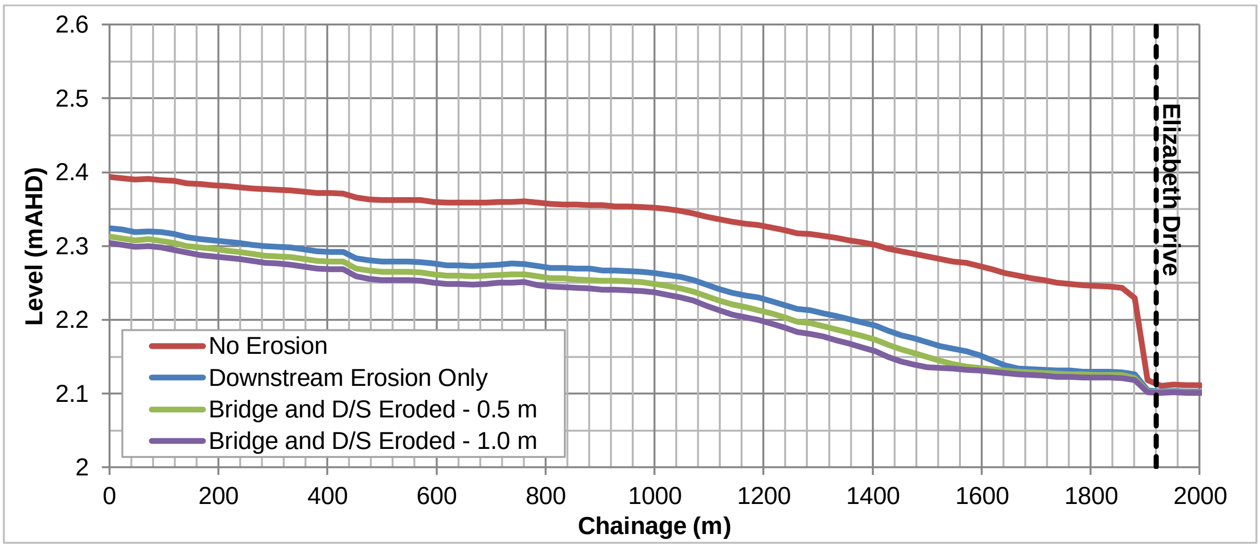
2.6.2. Moona Moona Entrance Conditions

Unlike Currambene Creek for which the hydraulic control is the creek's entrance, the hydraulic control on Moona Moona Creek is the Elizabeth Drive Bridge. Scour through this structure is inhibited by the bridge abutments which restrict scour erosion in the horizontal and only allow for scour in the vertical. Peak flood levels are shown to display only minor sensitivity to bed scour, both at the structure and downstream (see Chart 6).

Three erosion scenarios were tested (see below) and compared to the no scour scenario (displayed in red, Chart 6):

1. No scour through the structure but the channel depth at the bridge is maintained to the ocean outlet (blue);
2. An additional 0.5 m scour to the creek bed, both through the bridge and downstream to the ocean (green); and
3. An additional 1.0 m scour to the creek bed, both through the bridge and downstream to the ocean (purple).

Chart 6: Moona Moona Creek 1% AEP Flood Profile – Various Entrance Scour Conditions



It can be assumed that some scour will occur on Moona Moona Creek during a flood event. However, the impact of scour is not overly significant in terms of peak flood levels once the downstream channel has been eroded to the depth of the channel at the Bridge. Once this has occurred, peak flood levels are shown to be insensitive to further bed scour with only negligible differences in peak flood levels. Accordingly, the 'Downstream Erosion Only' scenario has been selected for use on Moona Moona Creek design runs.

3. COMMUNITY CONSULTATION

Community consultation is an important element of the floodplain risk management process ultimately facilitating community engagement and acceptance of the overall project. During the flood study review and Floodplain Risk Management Study & Plan (FRMS&P), community consultation was undertaken to assess the flood experience of the community and gather additional data.

3.1. Questionnaire Distribution

A community questionnaire survey was undertaken during March 2014. The locations of the community consultation respondents are shown in Figure 19. 811 surveys were distributed to residents near flood affected areas in the study area and a total of 140 responses were received (see Figure 20). This equates to a return rate of 17% which is relatively high although given the small number of absolute returns the views expressed by this sample may not accurately reflect that of the total population. However it is normal that responses predominately come from residents that have been affected by flooding.

The majority (83%) of respondents were from residential dwellings with 3% noted as business and 13% as ‘other’ which was generally undeveloped land or farmland (see Figure 20).

The majority of respondents have lived in the region for more than five years and would have therefore experienced the June 2013 flood events. 27% of respondents have lived in the area longer than 30 years (see Figure 21). This indicates that flood awareness of respondents (and likely the general community) should be relatively high, however community consultation results displayed in Figure 22 indicate that 43% of the respondents were ‘not aware at all’ of flooding in Currambene and Moona Moona Creeks.

Only 26% of respondents are ‘very aware’ of flooding in the region, 72% of which were aware of flooding in Currambene Creek and 28% in Moona Moona Creek. 25% of respondents reported being flood affected in their yards (with all reports of flooding relating to Currambene Creek) and one resident reported being flooded over floor (Figure 22).

A number of respondents noted that they thought that the ‘current flood zones are unnecessarily strict and were restricting development on ‘dry’ land.’

Roads and adjoining development that were notably affected by flooding include:

- Falls Creek Road;
- Duncan Street;
- Currambene Street; and
- Woollamia Road.

A copy of the distributed Community Consultation Newsletter and Questionnaire is contained in Appendix C.

3.2. Community Workshops

Three Community Workshops were held for the current study, with one workshop held during the Flood Study Revision phase, the second during the FRMS phase and a final meeting during the public exhibition period. The meetings were open to the general public and were advertised via mailed community newsletters, local newspapers and Council's website.

3.2.1. Community Workshop 1

The first Community Workshop was held in Huskisson on the 26th August 2014. Approximately 25 people attended the meeting which covered a range of topics including:

- Context of the Currambene and Moona Moona Creeks Flood Study revision;
- Summary of works completed at the time of the meeting;
- Available Data;
- Community consultation process;
- Flood mechanisms;
- Historic events and design terminology;
- Model build;
- Calibration results;
- Indicative design behaviour – current study versus 2006 Flood Study (Reference 1); and
- Discussion of potential mitigation works.

The majority of people who attended the meeting were predominately concerned about local drainage issues in Woollamia, not flooding in Currambene and Moona Moona Creeks. Accordingly, the FRMS&P component of this study investigated how to ameliorate flood affectation in Woollamia due to local flows by improving the local drainage system.

3.2.2. Community Workshop 2

The second Community Workshop was held in Huskisson on the 27th May 2014. Approximately 20 people attended with focus of workshop covering a range of topics including:

- Flood Study Revision Results (Section 4.3.11);
- Flood liability and damages (Section 6);
- Investigated mitigation works (Section 8);
    - Elizabeth Drive bridge mitigation option (Section 8.4.3.1);
    - Woollamia drainage investigation (Section 8.4.3.2);
- Emergency Response Planning (Section 8.6);
    - Emergency evacuation (Section 8.6.2);
    - Flood Access (Section 7.4);
    - Flood warning time (Section 8.6.2);
    - Community flood education and awareness (Section 8.6.4);
    - Installation of a manual gauge on Edendale Street (Section 8.6.2.5);

3.2.3. Community Workshop 3

The third Community Workshop was held in Huskisson on the 11th February 2016. The workshop was aimed to present findings from the Draft Final report and to gain community acceptance of the project. Approximately 35 people attended the Workshop. Once the presentation was complete the community put forward questions to WMAwater engineers. These questions largely pertained to drainage and other non-flood related issues. People that attended the Workshop were invited to provide feedback as a public exhibition submission. Information relating to the public exhibition period is contained in Section 3.3.

3.3. Public Exhibition of the Draft Final Report

The Currambene and Moona Moona Creeks Floodplain Risk Management Study and Plan Draft Final report was on public exhibition for a period of 7 weeks between 6th January and 26th February. Hard copies of the report were available at the Shoalhaven City Council City Administrative Centre, Bridge Road, Nowra. The report was also available online on Council's website during this period.

Three submissions were made, two from private residents living in the study area and a third submission from Shoalhaven Council's strategic planning section. Responses to the three submissions are provided below:

Public Exhibition Submission #1 – This submission focused on Woollamia local drainage issues and the impact on septic tanks leading to effluent release and the associated health hazard. The submission requested that the township of Woollamia be connected to the sewerage system. The submission is not flood related and therefore not pertinent to the current study.

Public Exhibition Submission #2 – This submission makes two main points relating to a specific lot within the study area. The first issue was that that the bottom of the lot in question is mapped as flood affected and a request was made to have the mapping results altered to remove flood affectation of the lot. This request is denied due to the significance of the flow path in the lower areas of the lot in question. The upstream catchment area at lot is in the order of 30 ha and is determined to have a 1% AEP flow of 4 m^3/s which has the potential to cause significant flood affectation. The submission makes comment that the majority of the lot is not flood affected which is noted.

The second point made by Submission #2 is that the residence in question has direct access to the Princes Highway which affects the Emergency Response Planning Classification (ERP) (see Section 7.5) of the lot. The ERP map (Figure 83) has been adjusted accordingly such that the residence in question is classified as 'Not Flood Affected'.

Shoalhaven Council Strategic Planning Section Submission #3 – This submission makes various recommendations for changes to the planning sections of the report. All recommended changes have been incorporated into the Final Report. The affected sections of the report are limited to Sections 1.2.3, 7.5.1, 8.5.1 and 8.6.3.

4. FLOOD STUDY REVIEW

The November 2006, Lyall and Associates ‘Currambene Creek and Moona Moona Creek Flood Studies’ (Reference 1) was reviewed as part of the current study. That revision is documented herein. It was found that both the hydrologic and hydraulic models required revision (see Section 4.1 for modelling approach).

4.1. Modelling Approach

In order to accurately model the Currambene and Moona Moona Creeks, the development of hydrologic and hydraulic models was required. The overall modelling approach was to establish a hydrologic model in conjunction with a 1D/2D hydraulic model (see Diagram 1). The hydrologic model is used to generate flow hydrographs for input to the hydraulic model. The 1D/2D hydraulic model then utilises flows from the hydrologic model to calculate flood levels and velocities in the region. The hydrologic model used was the Watershed Bounded Network Model (WBNM) and the hydraulic model used was TUFLOW, a 1D/2D fully dynamic fixed grid based model.

The WBNM hydrologic model was calibrated to the Currambene Creek Stream Gauge Flood Frequency Analysis (FFA) (see Section 4.2.3) and verified against findings from the Reference 2 Study (see Section 4.2.4). The Currambene Creek Stream Gauge FFA was examined by comparing the AEP of the five largest flood events at the Currambene Creek stream gauge to the associated rainfall event AEP to add robustness to the FFA (see Section 4.2.1.4). Flows from the WBNM model were then input into the TUFLOW hydraulic model which was calibrated to the June 2013 event (see Section 4.3.8)

It is important to note that the calibration/verification process has been performed on Currambene Creek as significant gauge (both stream and rainfall) data is available. The data is not available for Moona Moona Creek, however the same hydrologic and hydraulic model parameters have been used for both catchments as it is assumed that hydrologic/hydraulic parameters are similar for the region. Sensitivity analysis (see Section 4.3.10) indicates that these assumptions don’t not significantly impact on study results and findings.

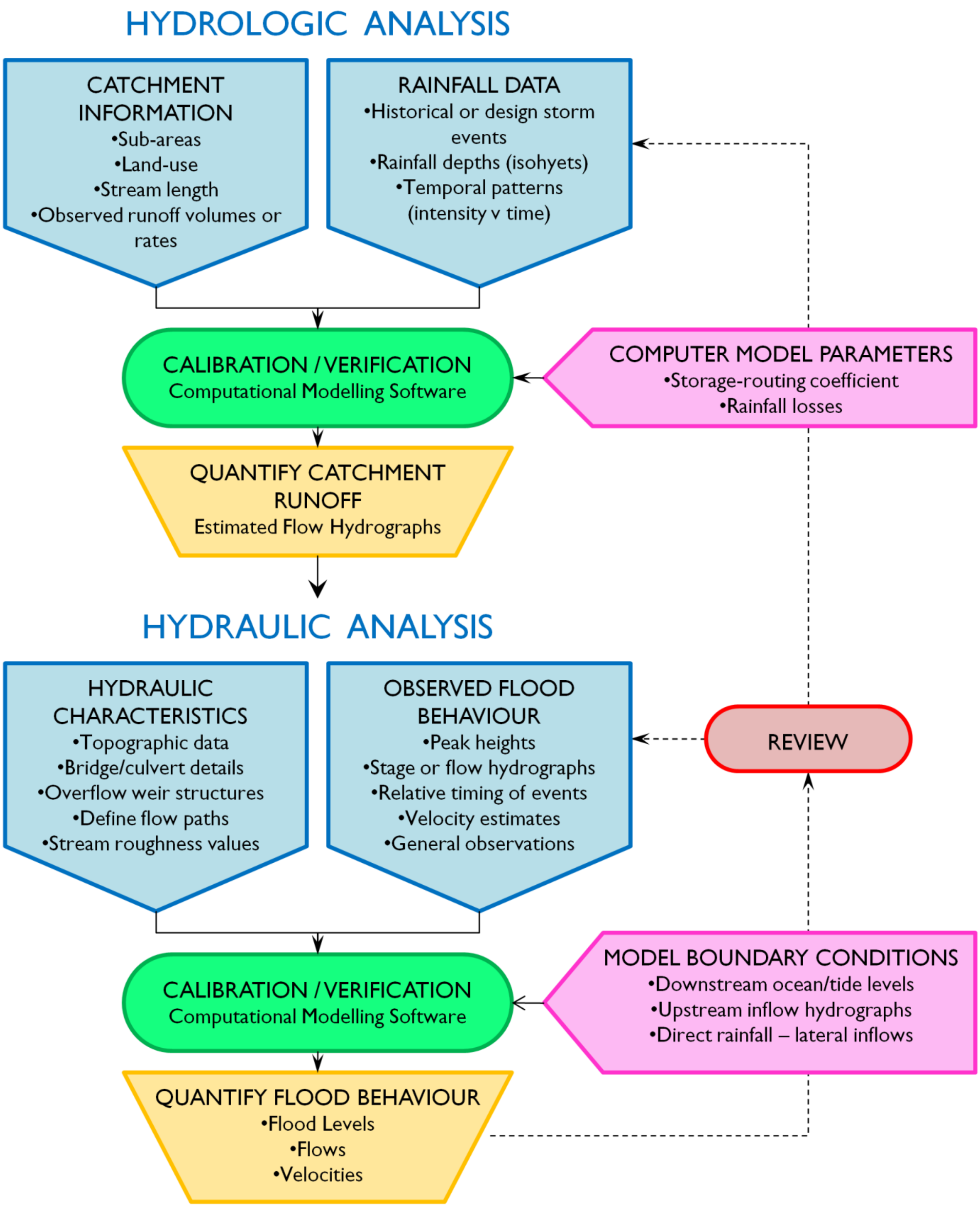


Diagram 1: Flood Study Process

4.2. Hydrology

There are two basic approaches to undertaking design flood analysis:

- The rainfall runoff routing approach (hydrologic modelling); and
- Flood frequency analysis (FFA).

FFA is generally preferred over the rainfall/runoff routing approach where the length and quality of the observed record and accuracy of the rating curve are considered adequate. In addition, large complex upstream catchments will lead to less reliable design flow estimates when using rainfall/runoff routing methods.

The Currambene Creek catchment does have some stream gauge data, however the length (see Section 2.4.2) and quality of the rating (rectified in Section 2.4.1) are insufficient to obtain quality 1% AEP flow estimates via FFA. To improve design flow estimates, the Australia Rainfall and Runoff Revision, Project 5, Regional Flood Methods (P5) (Reference 10) covariants have been incorporated in the Currambene Creek FFA. The P5 covariants have been developed for regional flood frequency estimation (RFFE) which provides design flow estimates for catchments up to 1,000 km^2. The covariants include regional estimates of statistical flow parameters such as mean, standard deviation and skew which when incorporated with the Currambene Creek stream gauge FFA provides higher quality design flow estimates.

A hydrologic model (see Section 4.2.2), calibrated to FFA results (see Section 4.2.1) to increase the robustness of the design flow estimates, has been used to determine flows for input into the hydraulic model. Using a straight FFA approach (i.e. applying a flow hydrograph at the location of the gauge) would not have enabled the inclusion of flows from sub-catchments downstream of the gauge such as Georges Creek which contributed a significant portion of flow and influence flood behaviour.

These analyses constitute the hydrological analysis component of the study and aim to describe the probability of a given discharge occurring in both Currambene and Moona Moona Creeks. Calculated design flows (as time varying hydrographs) are then input into the hydraulic model so that design flood levels, extents and hazard can be determined.

4.2.1. Flood Frequency Analysis

FFA uses the record of past flooding at a site to determine design event discharge. By fitting a probability distribution to a series of historical floods, the AEP of a given discharge can be determined. The two principles underlying the analysis are that previous floods will re-occur with the same frequency in the future and that the flood record is an accurate representation of the general flooding behaviour, i.e. of adequate sample size. For the case of Currambene Creek the record period is not of sufficient length to determine design flows with any confidence for the rarer events such as those from the 2% AEP and larger (see Section 2.4.2). However, incorporation of P5 covariants into the FFA using the FLIKE software (Reference 11) improved design flow estimates for these rarer events.

The FFA undertaken as part of this study uses the data sets described in Section 2.4.2 and follows methods prescribed by Australian Rainfall & Runoff (ARR87). 44 years of data for the period of 1969 – 2013 has been used in this analysis.

The analysis was made up of two stages: constructing a time series of flood events at the Currambene Creek stream gauge and applying a probability distribution to this time series. The first stage involved determining what data was available for analysis and what is the appropriate data for the FFA (this is covered in Sections 2.4.2 and 4.2.1.1) and the second stage involves fitting a probability distribution and P5 covariants to the data set to determine design flows (see Section 4.2.1.2).

4.2.1.1. Adopted Data Set

FFA has been performed on the highest recorded value of discharge for each year of record at the Currambene gauge (see Section 2.4.2). Using a series of annual maximums lowers the risk of two successive peaks being dependent, and is recommended by ARR (2012).

The regional P5 Log-Pearson III covariants that were input into the FLIKE software are presented in Table 12.

Table 12: Project 5 Regional Log-Pearson III Covariants – Currambene Creek Catchment

Parameter	Mean	Standard Deviation	Correlation	
Mean of Log Flow	4.129	0.579	1.00	-
Standard Deviation of Log Flow	1.220	0.183	-0.21	1.00
Skew of Log Flow	-0.471	0.134	-0.04	-0.41

4.2.1.2. Probability Distribution

A Bayesian maximum likelihood approach was used to fit a specified probability distribution to the annual maximum series. Two probability distributions were used; the Log-Pearson III (LP3), which is commonly used in FFA, and the Generalized Extreme Value (GEV) distribution, which is a more recently developed family of probability distributions that combine the Gumbel, Frechet and Weibull families of distributions. These distributions were used in combination with P5 covariant data. It was found that the LP3 distribution fitted the data better than the GEV distribution and as such was used in preference. Flike (file version 5) was used to apply the Bayesian maximum likelihood approach.

4.2.1.3. FFA Flow Results

The update to the FFA has been carried out as follows:

- WMAwater rating table flows (see Section 2.4.1 and 2.4.2) have been utilised for FFA; and
- P5 covariants have been incorporated into the Currambene Creek stream gauge FFA to provide higher quality design flow estimates.

The frequency plot at the Currambene gauge is displayed in Figure 15 with design flows tabulated in Table 13. For comparison, the probability distribution of the Currambene Creek stream gauge annual series without incorporation of P5 covariant information, is also displayed in Figure 15 as a blue line. Note that the two parameter fits are similar for the 50% - 10% AEP events however begin to diverge as event magnitude increases. The presence of the 1971 flood event has skewed results for the annual series distribution without P5 covariant information and significantly increases the 1% AEP estimate (1,010 m³/s). By comparing the AEP of the largest flood events with the AEP of the associated rainfall event the P5 series distribution has been determined to be closer to the gauges true underlying distribution (see Section 4.2.1.4).

Table 13: Currambene Creek Stream Gauge – FFA Design Flow Estimates

Event	Peak Flow (m³/s)	90% Confidence Limits	
		Lower Limiting Flow (m³/s)	Upper Limiting Flow (m³/s)
0.2 EY	150	110	210
10%	250	190	360
5%	370	270	540
2%	560	390	840
1%	720	500	1,110
0.5%	900	600	1,430

4.2.1.4. Discussion of FFA Flow Results

The six largest flood events at the Currambene Creek stream gauge were compared to the AEP of the associated rainfall event to add robustness to the FFA. The magnitude of these historic events and their approximate exceedance probabilities are presented in Table 14 along with the estimated rainfall AEP for each event (determined via methods described in Section 2.3.1.4).

Table 14: Calibration/Validation Event AEP

Event	1971	1975	1974	1976	1990	2013
Flow (m³/s)	1,010	418	303	297	266	220
Flow AEP (%)	0.33	4.0	7.7	7.7	9.1	14.3
Rainfall AEP* (%)	0.33	5.2	5.2	25	No data	28.1

*Rainfall AEP determined based ARR2013 IFD information (see Section 2.3.1.4).

Rainfall AEP and the FFA flow AEP (P5 series distribution) correspond well giving confidence to the FFA results. Accordingly the FFA results be used to calibrate the hydrologic model (see Section 4.2.3). Note for less rare events it can be expected that the probability of the event rainfall and event flow may diverge as antecedent conditions have a relatively larger impact.

4.2.2. Hydrologic Modelling Introduction

For the current study, design hydrologic modelling was undertaken using WBNM. WBNM is a widely used hydrologic model which has been substantially tested on Australian catchments. The default runoff routing and linearity parameters are based on data from 54 catchments in Queensland, NSW, Victoria and South Australia and have been used for modelling the current study.

WBNM has numerous variables that impact on the calculated catchment discharge. This includes input rainfall, rainfall losses (initial and continuing), the WBNM routing parameter 'C' and the non-linearity parameter 'm'. For the current study, input rainfalls and losses are described in Sections 4.2.5.1 and 4.2.5.2. The non-linearity parameter 'm' has been set as default (0.77) which is in agreement with ARR guidelines (Reference 3). The routing parameter 'C' has been varied during model calibration to match the Currambene Creek stream gauge FFA. Further details of the WBNM routing parameter are contained in Section 4.2.2.1.

Creeks and major overland flow paths in the region were modelled in the hydrologic model which covers the entire Currambene and Moona Moona Creek catchments downstream to their outlets to Jervis Bay.

The hydrologic model has been calibrated to the Currambene Creek stream gauge FFA in order to ensure that the adopted WBNM routing parameter 'C' is representative of this catchment (see Section 4.2.3) with the assumption being made that the adjacent Moona Moona Creek catchment shares similar hydrologic properties and has thus been calibrated by default. All hydrologic model results are contained in Section 4.2.5.4.

4.2.2.1. WBNM Routing Parameter 'C'

WBNM uses a routing parameter (also referred to as the 'C' parameter) to calculate the catchment response time for intra-catchment runoff and channel flow. The WBNM routing parameter is important in determining the timing of runoff from a catchment which influences the shape of the hydrograph as well as the catchments channel routing properties that affect routing speed and attenuation. The general relationship is that a decrease in the lag parameter will result in an increase in flood peak discharge (Reference 12) and as such a smaller 'C' value will typically produce shorter lag times and less attenuation. This follows the philosophy of the Reference 1 study.

In catchments for which reliable gauge data is available, the WBNM model should be calibrated against recorded flood data in order to ensure that the adopted routing parameter is representative of the catchment being modelled. For ungauged catchments Reference 12 recommends a routing parameter value of 1.6. This was determined in studies undertaken on ten catchments in eastern NSW, and an additional 54 catchments across Queensland, NSW, Victoria and South Australia. This is based on the average calculated C parameter from numerous storm events on each of these calibrated catchments. However, variance in the C parameter across these catchments is relatively large with the sample having a standard deviation of 0.5 and a minimum C value of 0.7 (maximum of 2.8).

WBNM routing parameter is a function of the catchments channel and floodplain. Typically, steeper catchments with narrow floodplains, such as the Currambene Creek catchment upstream of the stream gauge, have lower 'C' values. As mentioned previously, a lower 'C' parameter will lead to faster flood travel times and less attenuation. West of the Great Divide, local topography tends to lend itself to flatter catchments with larger floodplains. This leads to more attenuation and slower flood travel times, which a higher 'C' value achieves.

4.2.2.2. Hydrologic Catchment Delineation

Hydrologic model delineation was determined by interpretation of aerial imagery, ALS and 30 m SRTM data provided by Council (see Sections 2.2.1 and 2.2.2).

The hydrologic model layout for Currambene and Moona Moona Creeks is presented in Figure 18 and summary of the hydrologic catchment properties is displayed in Table 15 and Table 16 respectively.

Table 15: Currambene Creek Hydrology Catchment Properties

Catchment	Number of Catchments	Total Area (km²)	Average Area (km²)	Minimum Area (ha)	Maximum Area (km²)
Currambene Creek	96	160	2.5	5	17

Table 16: Moona Moona Creek Hydrology Catchment Properties

Catchment	Number of Catchments	Total Area (km²)	Average Area (km²)	Minimum Area (km²)	Maximum Area (km²)
Moona Moona Creek	77	23	1.4	0.2	2.8

4.2.2.3. Percentage Imperviousness

The model percentage imperviousness was based on inspection of aerial photography for each sub-catchment. The majority of the catchments have a percentage impervious of zero as they are predominately natural/rural in nature. The maximum assigned percentage impervious was 10% and an average percentage impervious for all sub-catchments is approximately equal to 1%.

4.2.3. Hydrologic Model Calibration

Hydrologic model calibration has been undertaken such that design flows are intended to have the same AEP as the AEP of the selected design rainfall. To achieve this, the WBNM hydrologic model has been calibrated to the FFA distribution presented in Section 4.2.1.3. Model flows were matched at the gauge location for the 0.2 EY – 1% AEP design events. The calibration was undertaken using ARR2013 design rainfall depths (Section 4.2.5.1), ARR87 temporal patterns for the 9 hour critical duration (Sections 2.3.3 and 4.2.6), ARR2013 design losses (Section 4.2.5.2) and ARR2013 Aerial Reduction Factors (ARF) for a 95 km² catchment (Section 4.2.5.3).

Details of the calibration are presented in the following section. The model was also 'calibrated' to ARR87 design rainfall depths so that the WBNM routing parameters could be compared and add further confidence to the hydrology methodology.

4.2.3.1. ARR2013 Design Rainfall Hydrologic Model Calibration

A WBNM routing parameter 'C' of 1.25 was found to accurately match the Currambene Creek stream gauge FFA for all design events. A coefficient of determination (R^2) of 0.998 shows that the modelled flows accurately match the FFA distribution. The hydrologic model design flows are presented along with the FFA distribution in Figure 16.

The robustness of the 'C' parameter has been validated by the Reference 2 study (see Section 4.2.4) via actual event analysis and is considered a very good match indicating a high level of confidence in hydrologic model calibration/validation.

4.2.3.2. ARR87 Design Rainfall Hydrologic Model Calibration

The hydrologic model was calibrated using the ARR87 design rainfall depths using the same techniques as above. It was found that the hydrologic model flows could be accurately matched to the FFA design flow distribution with an R^2 of 0.997, with the exception of the 0.2 EY event. For this event the hydrologic model flow was 20% greater than the flow determined via FFA.

However to achieve a hydrologic model / FFA flow match using ARR87 design rainfall, a WBNM routing parameter 'C' equal to 2.1 was required. A 'C' value of 2.1 is outside of the range of expected values determined in the Reference 2 study (see Section 4.2.4) via analysis of actual events. Higher 'C' values (generally greater than 1.6) are typical in creeks and streams west of the Great Dividing Range. The topography in this region is generally flatter and with larger floodplains which leads to more attenuation, which a higher 'C' value achieves. In the Currambene Creek catchment, topography is steep and the floodplains are constrained which tends to indicate that the catchment 'C' parameter should be lower.

These findings indicate that use of the ARR2013 rainfall data instead of ARR87 rainfall data is appropriate for the current study. This is in line with findings presented in Sections 2.3.2

4.2.4. Hydrologic Model Validation

Findings from the Reference 2 study (see Section 2.1) were used to validate the current study hydrologic model calibration parameters. The Reference 2 study RORB routing parameter (k_c) was converted to the WBNM routing parameter 'C' so that comparison could be made to the current study. The RORB to WBNM routing parameter conversion was done using the following formula (Reference 13):

$$C = \frac{k_c}{d_{av}}$$

where d_{av} is the average reach length.

In the current study, discussion of the Reference 2 study RORB routing parameter will be in terms of the converted WBNM routing parameter 'C' for ease of comparison.

Reference 2 study RORB routing parameters varied greatly between events as displayed in Table 17. The calculated routing parameters ranged from 0.8 to 3.3 with an average of 1.5 (standard deviation of 0.6).

Table 17: Reference 2 study RORB parameters – all events

	Initial Loss (mm)	Continuing Loss (mm/hr)	Routing Parameter
Mean	39.6	6.1	1.5
Min	5.0	0.0	0.8
Max	129.7	19.9	3.3

However, for events experiencing a flow equal to or greater than the 0.2 EY flow the routing parameters ranged from 0.8 to 1.8 with an average of 1.2 and a standard deviation of 0.3 (see Table 18).

Table 18: Reference 2 study RORB parameters – events greater than the 0.2 EY event

	Initial Loss (mm)	Continuing Loss (mm/hr)	Routing Parameter
Mean	28.8	3.2	1.2
Min	5.0	1.3	0.8
Max	70.0	6.5	1.8

The Reference 2 study routing parameters are in good agreement with the routing parameter determined during hydrologic model calibration using ARR2013 design rainfall (see Section 4.2.3.1). This is particularly true if compared to the larger events (greater than 0.2 EY) as the calculated WBNM ‘C’ parameter of 1.25 matches the Reference 2 study determined average routing parameter value of 1.2.

4.2.5. Design Flow Hydrologic Modelling

4.2.5.1. Design Rainfall

Hydrologic modelling has been undertaken with ARR2013 rainfall. Details of why the ARR2013 rainfall has been used instead of ARR87 rainfall, along with details of the applied design rainfall is presented in Section 2.3.2. ARR87 temporal patterns have been used as ARR revised temporal patterns are not yet available (see Section 2.3.3).

4.2.5.2. Design Loss Parameters

Reference 3 suggests the following losses for ungauged NSW catchments (Table 19).

Table 19: Suggested losses for ungauged NSW catchments (Reference 3)

Location	Initial Loss (IL)	Continuing Loss (CL)
East of Western Slopes	10-35 mm	2.5 mm/h

Taking into account the losses displayed in Table 19, a continuing loss of 2.5 mm/hour has been adopted for both catchments. For impervious regions a 0 mm/h continuing loss has been applied.

An initial loss model proposed by Walsh (Reference 14) in which initial losses vary dependant on event AEP has been used instead of the losses recommended in Reference 3. The approach derived design initial losses on a probabilistic basis using streamflow data from gauged catchments in conjunction with design rainfall data. The recommended Reference 14 losses have been used in the current study and are presented in Table 20. For impervious regions of the catchments, an initial loss of 1.5 mm has been assigned to account for ponding.

Table 20: Currambene and Moona Moona Creeks Initial Loss Model - Reference 14

ARI (years)	5	10	20	50	100
Initial Loss (mm)	55	60	50	40	30

PMP rainfall losses are based on Reference 15 and are shown in Table 21. Note losses shown in Table 21 are valid for PMP burst hydrology.

Table 21: Adopted PMP Losses

Initial Loss (mm)	Continuous Loss (mm/h)
0	1

The above continuing losses are comparable to those adopted in the nearby Lake Woolumboola Flood Study (Reference 15) and the initial loss model is the same as that adopted in the Reference 1 Study.

4.2.5.3. Aerial Reduction Factors

The aerial reduction factors (ARF) published in ARR87 (Reference 3) are based on American data and have now been superseded by application of the CRC-Forge method developed with Australian data (Reference 16 and 17). The following equations have been utilised in the current study along with applicable regional parameters from Table 22 to determine the ARF for Currambene and Moona Moona design hydrology.

Equation 1: Short duration aerial reduction factor equation (less than 18 hours)

$$ARF = min\{1, [1 + a(Area^{b} + c) + d(Area^{e})(f - log_{10}Duration)]\}$$

Equation 2: Long duration aerial reduction factor equation (18 to 120 hours)

$$ARF = \min\{1, \left[1 + \mathrm{a}\left(\mathrm{Area}^{\mathrm{b}} + \mathrm{c}\log_{10}\mathrm{Duration}\right)\mathrm{Duration}^{\mathrm{d}} + \mathrm{e}\mathrm{Area}^{\mathrm{f}}\mathrm{Duration}^{\mathrm{g}}(0.3 + \log_{10}\mathrm{AEP})\right]\}$$

Where:

$Duration\ =\ storm\ duration\ (h)$

$Area = area\ of\ interest\ (sq.km)$

$AEP\ =\ Annual\ exceedance\ probablity\ as\ a\ fraction\ between\ 0.5\ and\ 0.0005$

Table 22: Parameters for ARF equations

Region	Duration	a	b	c	d	e	f	g
NSW (GSAM)	<18h	-0.0439	0.23	-0.923	-0.0255	0.309	1.17	NA

The ARFs determined for the Currambene Creek critical duration of 9 hours (see Section 4.2.6) at both the Currambene Creek stream gauge (95 km² catchment) and at the outlet (160 km² catchment) are presented in Table 23. The ARF for the 12 hour critical duration for Moona Moona Creek (28 km² catchment) is also displayed in Table 23.

Table 23: Catchment Aerial Reduction Factors

Catchment	Currambene Creek (gauge location*) – 9h	Currambene Creek (outlet**) – 9h	Moona Moona Creek – 12h
ARF	0.89	0.87	0.94

*95 km² catchment area at the Currambene Creek stream gauge location

** 160 km² catchment area at the Currambene Creek stream gauge location

It should be noted that an ARF for a 95 km² catchment (upstream Currambene Creek stream gauge area) has been used in calibration of the hydrologic model. However, for hydraulic model input design flows, an ARF for a 160 km² catchment (Currambene Creek catchment size at the outlet) has been used.

4.2.5.4. Hydrologic Model Design Flow Results

Hydraulic model input design flow results for the critical duration of 9 hours at the Currambene stream gauge are displayed in Table 24. These flows have been determined using an ARF consistent with a 160 km² catchment area.

Table 24: Currambene Creek Design Flow Results at the Currambene Creek Stream Gauge

Event (AEP)	0.2 EY	10%	5%	2%	1%	0.5%	PMF
Design Flow (m³/s)	144	223	365	536	690	805	2,639

The Moona Moona Creek design flows at the Elizabeth Drive Bridge for the catchments critical duration of 12 hours are presented in Table 25.

Table 25: Moona Moona Creek Design Flow Results at the Elizabeth Drive Bridge

Event (AEP)	0.2 EY	10%	5%	2%	1%	0.5%	PMF
Design Flow (m³/s)	82	109	139	187	236	274	1,279

4.2.5.5. Comparison of Design Flow Results with the Reference 1 Study

A comparison between the current study design flows and Reference 1 study flows at the Currambene Creek stream gauge are presented in Table 26.

Table 26: Currambene Creek Gauge – Current Study Design Flow / Reference 1 Comparison

Event (AEP)	0.2 EY	10%	5%	2%	1%	0.5%	PMF
Current Study Flow (m³/s)	144	223	365	536	690	805	2,639
Reference 1 Flow (m³/s)	198	339	403	522	606	721	1,860*
Difference (m³/s / %)	54 / 38%	116 / 52%	38 / 10%	-14 / -3%	-84 / -12%	-84 / -10%	-779 / -30%

*Reference 1 flow for non-linear model with losses.

The Reference 1 Currambene Creek flows are higher for events less than the 5% AEP and for the PMF. Numerous differences between the methods used in determining design flows between the two studies are responsible. It is interesting to note that in spite of the current study flows being higher for the 1% AEP event than the Reference 1 study, peak flood levels have generally decreased (see Section 4.3.11.3).

A comparison between the current study design flows and Reference 1 study flows at the

Elizabeth Drive Bridge on Moona Moona Creek is presented in Table 27.

Table 27: Moona Moona Creek, Elizabeth Drive Bridge – Flow Comparison

Event (AEP)	0.2 EY	10%	5%	2%	1%	0.5%	PMF
ARR2013 Rainfall Flow (m³/s)	82	109	139	187	236	274	1,279
Reference 1 Flow (m³/s)	117	148	185	235	278	328	786*
Difference (m³/s / %)	35 / 43%	39 / 36%	46 / 33%	48 / 26%	42 / 18%	54 / 19%	-493 / -39%

*Reference 1 flow for non-linear model with losses.

The Reference 1 flows are higher than the current study flows due to the low RORB k_c parameter that has been used. A k_c value of 5.4 was utilised for the Moona Moona Creek catchment in the Reference 1 study which equates to a WBNM C parameter of 0.63 which is significantly lower than the current study C parameter value of 1.25.

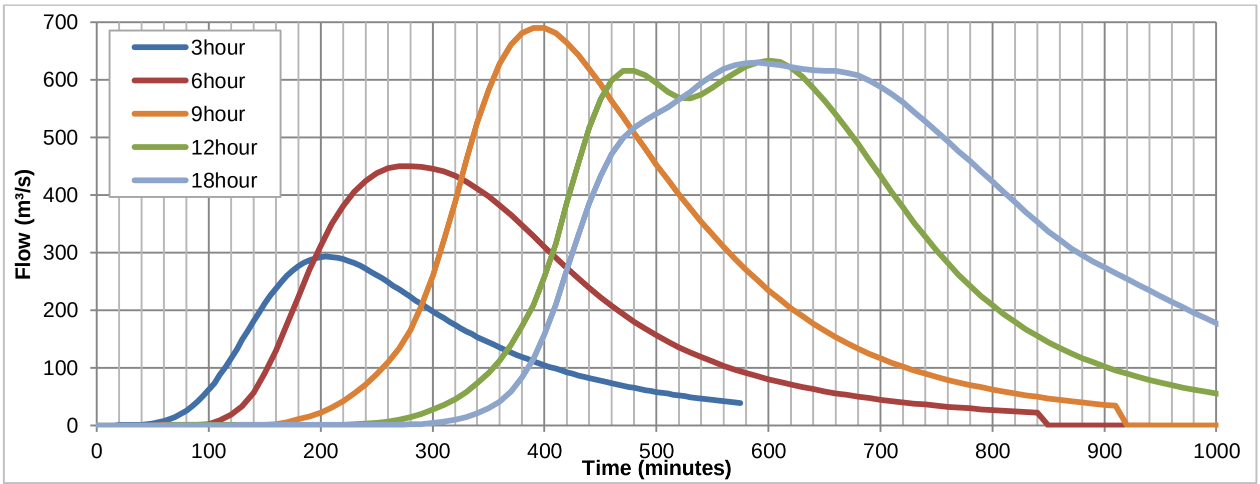
The difference in flow between the two studies has not significantly affected design flood levels (see Section 4.3.11.3).

4.2.6. Currambene Creek Critical Duration Assessment

A critical duration assessment was undertaken to determine which storm duration is responsible for generating the largest flow in Currambene Creek.

Currambene Creek 1% AEP design events were used to determine the Currambene Creek critical duration with the assumption that the critical duration remains constant for events of all AEP (with the exception of the PMF). The flow hydrographs for the 1% AEP events of varying durations at the Currambene Creek stream gauge are presented in Chart 7. The 9 hour duration event was found to be critical at the Currambene Creek stream gauge and all other regions in the study area including the Creek outlet.

Chart 7: Currambene Creek Stream Gauge - Critical Duration – 1% AEP Flow Hydrographs



However as mentioned in Section 2.3.3, durations longer than the 18 hour event have not been investigated as part of this critical duration analysis due to embedded storm bursts that greatly exceed the event AEP. It is expected that with the implementation of the revised ARR2013 temporal patterns which have not yet been released, the Currambene Creek critical duration will be closer to the catchment's time of concentration of approximate 7 hours (see Section 2.3.1.4). Accordingly, it is recommended that a critical duration of 9 hours be implemented for the ARR2013 rainfall as it is likely that the flows derived from this duration will be closer to the flows calculated for the critical duration determined when use of the ARR2013 temporal patterns are utilised.

A critical duration assessment using the same process was undertaken for the PMP with the critical duration of the PMF for Currambene Creek found to be 4 hours.

The critical duration of Moona Moona Creek was determined using the hydraulic model (see Section 4.3.9).

4.2.7. Hydrologic Sensitivity Analysis

Sensitivity analysis was carried out in order to assess the effect that adjusting hydrologic model parameters has on model results. Comparisons were carried out in the hydraulic models to determine impacts on peak flood levels for the 1% AEP design flood event.

The following hydrologic parameters were tested:

- An increase in rainfall losses of 20% (both initial and continuing losses);
- A decrease in rainfall losses of 20% (both initial and continuing losses);
- An increase in routing parameter 'C' of 20%;
- A decrease in routing parameter 'C' of 20%;
- Increases in rainfall of 10%, 20% and 30%.

All hydrologic model sensitivity analysis results are presented in Section 4.3.12 with the exception of increases to rainfall which is covered in the section on climate change (Section 4.3.12.2).

4.3. HYDRAULIC MODELLING

4.3.1. Introduction

The hydraulic model converts applied flow (discharge hydrographs generated by a hydrological model) into flood levels and velocities. The hydrodynamic modelling program TUFLOW (Reference 18) has been used in this study. TUFLOW is a finite difference grid based 1D/2D hydrodynamic model which uses the St Venant equations in order to route flow according to gravity, momentum and roughness.

TUFLOW is ideally suited to this study because it facilitates the identification of the potential overland flow paths and flood problem areas as well as inherently representing the available floodplain storage within the 2D model geometry. In addition to this, TUFLOW allows for the utilisation of breaklines at differing resolution to the main grid. Breaklines are used to ensure the correct representation of features which may affect flooding (features such as roads, embankments, etc.) which is especially important in an urban environment.

The incorporation of 1D elements into the 2D domain is another beneficial factor of TUFLOW. This allows such elements as culverts represented in 1D to function dynamically within the 2D grid. This suits the study as it facilitates the inclusion of channel flow within the context of a medium resolution 2D approach as well as facilitating the inclusion of the pit and pipe network.

Importantly, TUFLOW models can clearly define spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped in detail across the model extent. This information can then be easily integrated into a GIS based environment enabling outcomes to be efficiently incorporated into Council's planning activities (in for example waterRIDE or Mapinfo).

4.3.2. Model Build Process

Model construction begins with the DEM (constructed from the ALS mentioned in Section 2.2.1) which defines at high resolution a catchment's topographical characteristics. Finer features (drainage channel and levees) that have significant impacts on flows may then be incorporated via additional spatial layers of information. Also, via the inclusion of dynamically linked 1D elements, drainage pits and pipes are also incorporated. Numerous spatial layers are applied to the model with the aim of closely replicating the catchment's true hydraulic conditions.

4.3.3. Model Domain and Grid Size

The Currambene Creek hydraulic model extent covers an area of 63 km² and is displayed in Figure 23. The Moona Moona Creek hydraulic model extent covers an area of 29 km² and is displayed in Figure 25. Ground elevations in the model were informed by the DEM described in Section 2.2.1.

The selection of grid size for use in a hydraulic model is based on ensuring hydraulic features are adequately defined whilst not creating excessively long model run times. An important feature of a hydraulic model (depending on site characteristics and applicable flood mechanism) is the capacity to model channel in-bank conveyance accurately. Emulation of in-bank capacity is key to correctly modelling the study area and as such the conveyance characteristics of the in-bank, based on the model, have been compared to cross-sections achieved by survey (see Section 4.3.3). This conveyance comparison can be seen in Figure 27 which displays that a 10 m grid adequately defines the in-bank conveyance for Currambene and Moona Moona Creek. The locations of the examined cross sections are displayed on Figure 3, with the corresponding cross section numbers displayed.

Accordingly, a 10 m finite difference grid was utilised for both the Currambene and Moona Moona Creek catchments. The selected grid size allowed for reasonable run times whilst adequately defining in-bank conveyance in 2D.

4.3.4. Breaklines

Flow paths, open drains, levee banks, farm dams, railway lines and road embankments are hydraulic features that have a significant impact on flood behaviour, especially in a relatively flat area such as the areas on the Currambene and Moona Moona Creek floodplains. Such features have been represented in the model by breaklines with crest and invert heights determined by analysis of the 1m DEM information (the 1 m DEM was derived from ALS data). The locations of these various hydraulic features are displayed in Figure 23 for the Currambene Creek model and Figure 25 for the Moona Moona Creek model.

4.3.5. Roughness Values

As mentioned in the previous section various hydraulic characteristics are combined with the model grid in order to inform the final hydraulic model properties. This is equally true for cell roughness estimates. The Manning's 'n' values for each grid cell were estimated based on established references and previous studies and were then confirmed by calibration of the hydraulic model. Values were applied to the 2D overland area based on land use information as shown in Table 28 below.

Sensitivity testing of the applied roughness values has been carried out. See Section 4.3.10 for the results of this analysis.

Table 28: Mannings 'n' values

Land Use	Manning's 'n'
Open Areas (grazing, cropping etc.)	0.045
Roads	0.02
Urban Residential Lots	0.05
Creek in-bank	0.03
Low Density Vegetation	0.06
Medium Density Vegetation	0.08
Dense Bush	0.11

It should be noted that these roughness values are similar to those recommended by Chow (1959) and Henderson (1966).

4.3.6. Bridges and Culverts

27 bridges and culverts in the Currambene and Moona Moona study areas are present in the hydraulic models. Bridge and culvert information was sourced from survey commissioned as part of this study (see Section 2.2.3). These details were input into the model as 1D and 2D elements where appropriate with the locations of these structures displayed in Figure 23 and Figure 25 for the Currambene and Moona Moona Creek catchments respectively. Further information on these structures is contained in Appendix B.

4.3.6.1. Blockage

Structure blockage can significantly affect peak flood levels both upstream and downstream of a structure. Blockage of hydraulic structures can occur with the transportation of materials by flood waters, which in the Currambene and Moona Moona Creek catchments is most likely vegetation such as logs and fallen trees.

Due to a lack of available information in relation to structure blockage during the June 2013 event, structure blockage was not incorporated into model calibration (structure blockage assigned as zero). This is not considered problematic as a conservative structure blockage of 25% has been incorporated into flood modelling of all design events for all culverts. Bridges have not been blocked for design runs as their diagonal spans exceed 6 m and are therefore not likely to block during a flood event (as per the guidelines proposed by the AR&R Revision Project 11).

4.3.7. Boundary Conditions

4.3.7.1. Inflows

A calibrated/validated hydrologic model (see Section 4.2.2) produced design flows for the 0.2 EY, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and the PMF events. These design flows were used as inflows for the hydraulic model at the upstream boundaries and for internal sub-catchments, to define design flood behaviour such as peak flood levels and velocities.

4.3.7.2. Tailwater

Tailwater levels were applied at the ocean for both Currambene and Moona Moona Creeks. Dyanmic tailwater levels was applied for the June 2013 calibration event as per Section 2.5.1 and for the various design runs as per Section 2.5.2.

4.3.8. Hydraulic Model Calibration

Hydraulic model calibration was undertaken using available rainfall data (Section 2.3.1), stream gauge data (see Section 2.4), ocean level data (see Section 2.5.1) and peak flood level information (see Section 2.2.5).

Calibration of the hydraulic models generally consisted of matching surveyed peak flood levels (see Section 2.6.2) and Currambene Creek stage hydrograph levels to the modelled levels. Calibration was performed on the June 2013 flood event for both the Currambene and Moona Moona Creek catchments with calibration results contained in Section 4.3.11.1.

4.3.9. Moona Moona Creek Critical Duration

A critical duration assessment was undertaken to determine which storm duration is responsible for generating the highest peak flood levels in Moona Moona Creek. The catchments critical durations for the design events is presented in Table 29.

Moona Moona Creek 1% AEP design events were used to determine the catchment's critical duration with the assumption that the critical duration remains constant for events of all AEP (with the exception of the PMF). Peak flood levels for 1% AEP events of varying durations were compared with the results presented in Figure 30. The 12 hour duration event was found to be critical for the majority of the catchment with only minor regions where other durations were found to be critical. For these regions, peak flood levels of these other durations were less than 0.1 m higher than the 12 hour event. Accordingly, the 12 hour duration events is considered critical for Moona Moona Creek.

The Moona Moona Creek catchment is typically a flat swamp which retards water and leads to volume sensitivity and a longer critical duration when compared to Currambene Creek which has an open, free flowing flow path. This is compounded by the impact of the Elizabeth Drive Bridge, which causes higher flood levels due to backwatering as the conveyance at the Bridge cannot be scoured significantly to allow excess flow to escape (see Section 2.6.2). As mentioned in Section 2.6, scour throughout the rising limb of the flood generally erodes sufficient sand to pass the event peak flow. This leads to Currambene Creek being more sensitive to peak flow rather than volume.

A similar process was undertaken for the PMF with various PMP durations (1 to 6 hours) modelled so that peak flood levels and associated rainfall durations could be identified. The 2 hour duration PMP was determined to be the critical duration for Moona Moona Creek.

Table 29: Catchment Critical Durations

Catchment	Moona Moona Creek
Design Events	12 hours
PMF	2 hours

4.3.10. Hydraulic Sensitivity Analysis

Sensitivity analysis was carried out in order to assess the effect that adjusting hydraulic model parameters has on model results. Sensitivity was determine by investigating impacts on peak flood levels for the 1% AEP design flood event.

The following hydraulic model parameters were tested:

- An increase in Manning's n roughness of 20%;
- A decrease in Manning's n roughness of 20%;
- Pipe/culvert blockage at 50%;
- Sensitivity to entrance scour; and
- Grid size reduced.

The sensitivity to entrance scour for both Creeks has been investigated in Section 2.6. All other sensitivity analysis results are presented in Section 4.3.12.

4.3.11. Hydraulic Model Results

A summary of the hydraulic model results is contained in the following sections. Hydraulic model results provide peak flood surface levels, depths and extents for the model calibration (see

Section 4.3.11.1) as well as design floods (see Section 4.3.11.2). Calibration peak flood levels have been compared to surveyed flood levels and gauged data where available (see Section 2.2.5). All design results are displayed for the critical durations determined in Section 4.2.6.

A summary all of model runs for both Currambene Creek and Moona Moona Creek are presented in Table 30.

Table 30: Modelled Events and Scenarios

Event	0.2EY	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
June 2013 Event							
Design Flood Events	x	x	x	x	x	x	x
Council adopted 2050 Sea Level (+0.28 m)	x	x	x	x	x	x	x
Council adopted 2100 Sea Level (+0.41 m)	x	x	x	x	x	x	x
2009 NSW (Reference 7) 2050 Sea Level (+0.4 m)			x		x		
2009 NSW (Reference 7) 2100 Sea Level (+0.9 m)			x		x		
Climate Changed Increased Rainfall (+10%)					x		
Climate Changed Increased Rainfall (+20%)					x		
Climate Changed Increased Rainfall (+30%)					x		
Entrance Scour zero (100% capacity)					x		
Entrance Scour 150%					x		
Entrance Scour 200%					x		
Entrance Scour 300%					x		
Critical Duration x 7 (1, 2, 3, 6, 9, 12, 18 hours)					x x x x x x x		
Increased Rainfall Losses (+20%)					x		
Decreased Rainfall Losses (-20%)					x		
Increased routing Parameter 'C' (+20%)					x		
Decreased routing Parameter 'C' (-20%)					x		
Increased Manning's 'n' (+20%)					x		
Decreased Manning's 'n' (-20%)					x		
Grid size reduced (3 m)					x		
Tidal timing (+3 hours)					x		
Tidal timing (-3 hours)					x		
Structure Blockage (50%)					x		

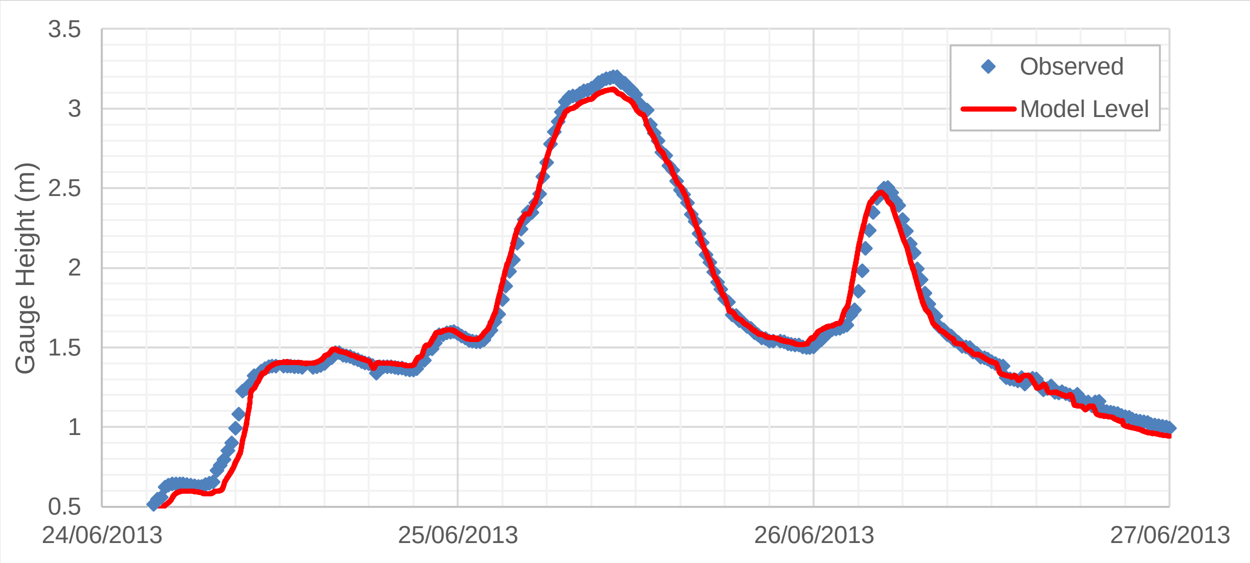
4.3.11.1. Calibration

Currambene Creek Results

Figure 28 shows the modelled June 2013 flood event depths and extent (raster) as well as a comparison of observed peak flood levels to modelled levels (displayed as red points) over the model domain. The maximum difference in peak flood level is an over estimate of 0.2 m (i.e. the modelled level is 0.2 m higher than that observed), however a mean absolute error of approximately 0.1 m was achieved. This calibration is based on comparison of modelled and surveyed peak flood levels at 4 locations throughout the domain. An additional four peak flood level marks were removed from this analysis as they are considered unreliable for calibration purposes for the reasons presented in Section 2.2.5.

The observed stage hydrograph at the Currambene gauge (see Section 2.4) was compared to modelled flood levels (see Chart 8). The modelled flood level and timing was found to accurately represent observed conditions with a difference of 0.1 m at the peak[1].

Chart 8: June 2013 Event – Currambene Gauge Stage Hydrograph – Model and Observed*



* The 'Model Level' stage hydrograph was produced in the 10 m model for comparison to the observed hydrograph.

Moona Moona Creek Results

Only one peak flood level mark was able to be used for calibration of the Moona Moona Creek model with two flood marks being excluded from this analysis (see Section 2.2.5). Figure 29 shows the modelled June 2013 flood event depths and extent (raster) as well as a comparison of the observed peak flood level to modelled level (displayed as a red point). The model achieved a perfect match at this location, however as only one point is available this cannot be called a rigorous calibration. Confidence in the hydraulic model is improved as the same model parameters as the Currambene Creek have been used and it is assumed that these parameters have some regional validity.

4.3.11.2. Design

A number of maps have been produced to display the flood affected regions for the various design events. It should be noted that inundation patterns and/or peak flood levels shown for design events are based on best available estimates of flood behaviour within the catchment. Inundation from creek and particularly local overland flow may vary depending on the actual rainfall event, relative timing of flows and local influences (parked cars, change in topography, road works etc.). Please note however that results produced herein are relatively conservative in that local flow and creek systems are assumed to flood simultaneously.

[1] Note: Chart 8 shows the comparison between the observed peak flood level and the 10 m model levels. The 2 m Gauge Model mentioned in Section 2.4.1 achieves a near perfect match to that observed.

A summary of the provided results are displayed below with further details in the following sections:

- Peak flood depths and levels for the design flood events (PMF, 0.2 EY, 10%, 5%, 2%, 1% and 0.5% AEP) (all depths < 200 mm clipped);
- Flood profiles along Currambene Creek for each design flood event modelled;

Peak flood depths and extents for the Currambene Creek catchment are presented in Figure 31 to Figure 37. For the Moona Moona Creek catchment results are presented in Figure 39 to Figure 45. The Currambene and Moona Moona Creeks design flood profiles are presented in Figure 38 and Figure 46 respectively.

4.3.11.3. Result comparison to the Reference 1 Study

Figure 47 displays the Currambene Creek peak flood profiles for the current study and the Reference 1 study for the 1% AEP and 10% AEP events. The current study 1% AEP flood levels are significantly lower than the Reference 1 study levels (in excess of 1 m in some regions) for the region upstream of Goodland Road. Downstream of this point backwatering at the entrance increases current study flood levels in relation to the Reference 1 study so that in the vicinity of Woollamia both studies have similar levels.

10% AEP levels are again lower in the current study particularly upstream of Goodland Road. Near Woollamia, 10% AEP flood levels are estimated to be approximately 0.5 m lower in the current study than the Reference 1 study.

Figure 48 displays a comparison of the current study and Reference 1 study peak flood profiles on Moona Moona Creek. The 1% AEP peak flood levels are slightly higher (generally less than 0.3 m) in the current study that the Reference 1 study, whereas the 10% AEP flood is generally lower (up to 0.5 m) particularly near Elizabeth Road Bridge.

4.3.11.4. Sea Level Rise Results

A number of maps have been produced to display the flood affected regions for the various design events taking into account predicted sea level rise under 2050 and 2010 climate change scenarios. These results have the same disclaimer as the design results (see Section 4.3.11.2).

Peak flood depths and extents for the Currambene Creek catchment various design scenarios with:

- 2050 sea level rise are presented in Figure 49 to Figure 55 with the flood profiles for these events presented in Figure 56; and
- 2100 sea level rise are presented in Figure 57 to Figure 63 with the flood profiles for these events presented in Figure 64.

Peak flood depths and extents for the Moona Moona Creek catchment various design scenarios with:

- 2050 sea level rise are presented in Figure 65 to Figure 71 with the flood profiles for these events presented in Figure 72; and

- 2100 sea level rise are presented in Figure 73 to Figure 79 with the flood profiles for these events presented in Figure 80.

4.3.12. Sensitivity Analysis Results

Sensitivity analysis was carried out in order to assess the effect that adjusting model parameters has on model results. Comparisons were carried out using enveloped peak flood levels (see Section 2.5.2) for the 1% AEP design flood event.

The results were examined at numerous locations throughout both catchments with a summary of the sensitivity analysis point details presented in Table 31 and Table 32 for Currambene and Moona Moona Creeks respectively. The locations of these points are also presented in Figure 1 and Figure 2.

Table 31: Currambene Creek Sensitivity Analysis Point Details

ID	Chainage	Easting	Northing	Location
C1	30	287522	6120536	Currambene Creek Outlet
C2	2260*	286499	6122464	Intersection of Woollamia Road and Edendale Street
C4	5680	286493	6123269	End of Streamside Street, Woollamia
C5	7640	285205	6123680	End of Goodland Road, Woollamia
C3	2830	287481	6122161	Myola
C6	8750*	284385	6122931	Woollamia Road between Pritchard Road and Seasongood Road
C7	10790	283207	6124414	261B Woollamia Rd, Woollamia
C8	12480	282912	6125556	775D Falls Rd, Falls Creek, at Creek
C9	14980	281500	6127113	120 Falls Road, Falls Creek
C10	16470	280859	6127602	Currambene Creek, Gauge location

* Sensitivity analysis point is situated on Currambene Creek tributary (i.e. not on the main channel)

Table 32: Moona Moona Creek Sensitivity Analysis Point Details

ID	Chainage	Easting	Northing	Location
M1	0	287921	6118805	Moona Moona Creek Bridge
M2	330	287803	6118508	End of Duncan Street, Vincentia
M3	1140*	287514	6117929	Berry Street between Wally Court and McNamara Court, Vincentia
M4	1340*	287415	6119280	Currambene Street between Moona and Keppel Street, Husskisson
M5	1920*	287279	6119826	End of Beecroft Street
M6	870	287299	6118548	Chainage 870 m from Creek outlet on mainstream channel
M7	1700	286471	6118614	Chainage 1700 m from Creek outlet on mainstream channel
M8	2560	285619	6118713	Chainage 2560 m from Creek outlet on mainstream channel
M9	3720*	284787	6119166	Northern upstream tributary
M10	4330	284023	6118235	Jervis Bay Road near Evelyn Road, Huskisson
M11	4910	283446	6118293	Upstream of Moona Moona Creek

* Sensitivity analysis point is situated on Moona Moona Creek tributary (i.e. not on the main channel)

4.3.12.1. Model Parameter Sensitivity

The following scenarios were modelled in the Currambene and Moona Moona Creek hydraulic models to test model sensitivity:

- An increase in Manning's n roughness of 20%;
- A decrease in Manning's n roughness of 20%;

- An increase in rainfall losses of 20% (both initial and continuing losses);
- A decrease in rainfall losses of 20% (both initial and continuing losses);
- An increase in WBNM routing parameter ‘C’ of 20%;
- A decrease in WBNM routing parameter ‘C’ of 20%;
- Timing of tide shifted 3 hours forward (Currambene only, see Section 2.5.2);
- Timing of tide shifted 3 hours back (Currambene only, see Section 2.5.2)
- Pipe/culvert blockage at 50%; and
- Reduced grid size (7.5 m for Currambene and 5 m for Moona Moona).

The Currambene Creek sensitivity results are presented in Table 33 and the Moona Moona Creek results are presented in Table 34 for the locations described in Section 4.3.12.

Table 33: Currambene Creek Model Parameter Sensitivity

Location ID	WBNM ‘C’ Parameter		Losses (IL & CL)		Mannings		Timing of Tide		Structure Blockage (50%)	7.5 m Grid
	-20%	20%	-20%	20%	-20%	20%	+ 3 hours	- 3 hours		
C1	0.00	0.00	0.01	-0.01	0.00	0.00	-0.01	-0.01	0.00	0.00
C2	0.05	-0.05	0.08	-0.09	-0.03	0.03	-0.10	-0.01	0.00	0.00
C4	0.05	-0.04	0.07	-0.07	-0.07	0.05	-0.04	0.03	0.00	0.00
C5	0.07	-0.07	0.09	-0.10	-0.09	0.07	0.01	0.05	0.00	0.00
C3	0.04	-0.04	0.06	-0.07	-0.04	0.03	-0.11	-0.02	0.00	0.00
C6	0.10	-0.09	0.10	-0.11	-0.09	0.08	0.02	0.04	0.00	-0.01
C7	0.11	-0.11	0.09	-0.11	-0.15	0.12	0.02	0.01	0.00	-0.03
C8	0.12	-0.10	0.07	-0.08	-0.14	0.12	0.01	0.00	0.00	-0.01
C9	0.25	-0.20	0.09	-0.12	-0.23	0.22	0.00	0.00	0.00	-0.05
C10	0.40	-0.33	0.14	-0.16	-0.28	0.28	0.00	0.00	0.00	-0.04
Average	0.12	-0.10	0.08	-0.09	-0.11	0.10	-0.02	0.01	0.00	-0.01

The Currambene Creek model was found to be generally insensitive to the tested model parameters. The model was most sensitive in the upper reaches of the study area where the floodplain is narrow which leads to greater variability in peak flood levels. The more densely populated areas closer to the outlet, such as Woollamia, were far less sensitive to changes to tested model parameters than the upper reaches. In Woollamia (see point C2) the maximum sensitivity experienced was 0.1 m indicating that model results are robust.

Table 34: Moona Moona Creek Model Parameter Sensitivity

Location ID	WBNM 'C' Parameter		Losses (IL & CL)		Mannings		Structure Blockage (50%)	5 m Grid
	-20%	20%	-20%	20%	-20%	20%		
M1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
M2	0.00	-0.01	0.03	-0.03	-0.01	0.01	0.00	-0.01
M3	0.00	-0.01	0.03	-0.03	-0.03	0.02	0.00	0.00
M4	0.00	0.00	0.01	-0.01	-0.02	0.02	0.00	0.00
M5	0.00	0.00	0.01	-0.01	-0.03	0.03	0.00	0.00
M6	0.09	-0.08	0.03	-0.03	-0.12	0.11	0.00	-0.10
M7	0.00	-0.01	0.03	-0.03	-0.03	0.02	0.00	-0.01
M8	0.01	-0.01	0.03	-0.03	-0.04	0.04	0.00	0.00
M9	0.01	-0.01	0.02	-0.02	-0.07	0.06	0.00	0.00
M10	0.06	-0.01	0.04	-0.02	-0.08	0.08	0.00	0.00
M11	0.11	-0.15	0.02	-0.02	-0.19	0.11	0.00	0.00
Average	0.03	-0.03	0.02	-0.02	-0.06	0.05	0.00	-0.01

The Moona Moona Creek model is insensitive to model parameter changes. Peak flood levels were on average less than 0.1 m different to the base case regardless of the tested input parameter. It should be noted that due to the span size of the Elizabeth Street Bridge, blockage of this structure is considered unlikely (see Section 4.3.6.1) and has therefore not been tested.

4.3.12.2. Climate Change Sensitivity

Sensitivity to potential changes in rainfall intensities due to climate change and sea level rise have been analysed. As per Section 2.5.3, four increases to mean sea level have been investigated along with a 10%, 20% and 30% increase in rainfall intensity. The Currambene Creek sensitivity results are presented in Table 35 and the Moona Moona Creek results are presented in Table 36 for the locations described in Section 4.3.12.

Table 35: Currambene Creek Climate Change Sensitivity

Location ID	Sea Level Rise (Council Policy)		Sea Level Rise (Previous Policy)		Increased Rainfall		
	2050	2100	2050	2100	+10%	+20%	+30%
C1	0.27	0.40	0.39	0.87	0.01	0.04	0.11
C2	0.22	0.32	0.24	0.69	0.15	0.30	0.43
C4	0.12	0.19	0.12	0.48	0.13	0.25	0.37
C5	0.09	0.14	0.03	0.28	0.17	0.33	0.48
C3	0.19	0.28	0.21	0.67	0.12	0.24	0.37
C6	0.08	0.12	0.00	0.17	0.19	0.36	0.53
C7	0.03	0.05	0.00	0.02	0.18	0.35	0.51
C8	0.02	0.03	0.00	0.01	0.16	0.31	0.46
C9	0.00	0.00	0.00	0.00	0.25	0.46	0.67
C10	0.00	0.00	0.00	0.00	0.37	0.74	1.06
Average	0.10	0.15	0.10	0.32	0.17	0.34	0.50

Table 36: Moona Moona Creek Climate Change Sensitivity

Location ID	Sea Level Rise (Council Policy)		Sea Level Rise (Previous Policy)		Increased Rainfall		
	2050	2100	2050	2100	+10%	+20%	+30%
M1	0.27	0.40	0.39	0.89	0.01	0.02	0.02
M2	0.19	0.31	0.31	0.77	0.07	0.15	0.23
M3	0.14	0.23	0.19	0.70	0.08	0.15	0.24
M4	0.00	0.00	0.14	0.37	0.02	0.04	0.06
M5	0.00	0.00	0.27	0.25	0.03	0.05	0.07
M6	0.15	0.25	0.12	0.01	0.10	0.18	0.28
M7	0.11	0.18	0.06	0.71	0.08	0.16	0.25
M8	0.05	0.09	0.03	0.63	0.08	0.16	0.24
M9	0.00	0.01	0.00	0.44	0.07	0.14	0.21
M10	0.00	0.00	0.00	0.12	0.09	0.17	0.24
M11	0.00	0.00	0.15	0.00	0.09	0.18	0.26
Average	0.08	0.13	0.15	0.44	0.06	0.13	0.19

Both models are particularly sensitive to sea level rise, particularly in the lower reaches of the catchments. The opposite is true for increases in rainfall intensity, with higher levels experienced in the upper catchments due to the confined nature of the floodplain. Both catchments are similarly affected by sea level rise, however increases to rainfall intensity tend to have a greater effect on the Currambene catchment as the upstream catchment area is larger.

5. POLICIES AND PLANNING

5.1. Legislative and Planning Context

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any 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 liable land remains the responsibility of local government. Furthermore, Section 117(2) of the 1979 Environmental Planning and Assessment Act Direction 15 states that Council must ensure development is appropriate in regard to flood risk and that furthermore it does not cause impacts on adjoining property.

Councils have a number of planning tools available to them in order to fulfil this role, including the Local Environment Plan (LEP) and Development Control Plans (DCPs). Detail of the specific planning documents relevant to Currambene Creek and Moona Moona Creek are provided below.

5.1.1. NSW Flood Prone Land Policy

The primary objective of the NSW Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property and reduce public and private losses resulting from floods whilst utilising ecologically positive methods wherever possible.

The NSW Floodplain Development Manual (Reference 15) relates to the development of flood liable land for the purposes of Section 733 of the Local Government Act 1993 and incorporates the NSW Flood Prone Land Policy.

The Manual outlines a merits based approach to floodplain management. At the strategic level this allows for the consideration of social, economic, cultural, ecological and flooding issues to determine strategies for the management of flood risk. The Manual recognises differences between urban and rural floodplain issues. Although it maintains that the same overall floodplain management approach should apply to both, it recognises that a different emphasis is required for each type of floodplain.

5.1.2. Existing Council Policy

Updated and relevant planning controls are important in flood risk management. Appropriate planning restrictions, ensuring that development is compatible with flood risk, can significantly reduce flood damages. They can also be used to develop appropriate evacuation and disaster management plans to better reduce flood risks to the existing population. Councils use Local Environmental Plans (LEPs) and Development Control Plans (DCPs) to govern control on development with regards to flooding. Existing Council Policy is discussed below.

5.1.2.1. Shoalhaven Local Environmental Plan (2014)

The Shoalhaven LEP 2014 came into force in April 2014. It covers the whole Shoalhaven area including Currambene and Moona Moona Creek catchments. Two clauses are relevant to this study.

Clause *7.3 Flood planning* applies to land falling within the "Flood Planning Area" (mapped as the 100y ARI design event + 0.5m flood extent, see Section 8.5.3), as well as other land at or below the flood planning level (defined as the 100y ARI design flood level plus 0.5m freeboard, see Section 8.5.2). The clause seeks to "*minimise the flood risk to life and property"* as well as *"allow development on land that is compatible with the land's flood hazard, taking into account projected changes as a result of climate change"* and, *"avoid significant adverse impacts on flood behaviour and the environment."* It does this through six general considerations which must be accommodated in any proposed development, paraphrased below being:

a) ensuring development is compatible with the flood hazard,
b) that it does not significantly adversely affect flood behaviour resulting in detrimental impacts elsewhere,
c) that it manages risk to life from flooding,
d) does not significantly adversely affect the environment,
e) does not result in unsustainable social and economic costs to the community,
f) does not affect safe occupation or evacuation of the land.

Clause *7.4 Coastal risk planning* follows a similar format to clause 7.3 but applies to land identified as *"Coastal Risk Planning Area"* as delineated on the Coastal Risk Planning Map. It also specifies that development must have regard to the impacts of sea level rise.

5.1.2.2. Shoalhaven Development Control Plan 2014

A Development Control Plan (DCP) is a written document that supports the Local Environmental Plan (LEP) and expands its principal development standards. All of Shoalhaven's current DCPs and some Planning Policies were consolidated into a single DCP covering the Shoalhaven Local Government Area (LGA) in October 2014. There are three relevant chapters to this study *G2 Sustainable Stormwater Management and Erosion Sediment Control*, *G9 Development on Flood Prone Land*, *G10 Caravan Parks in Flood Prone Areas – Flood Emergency Plan*.

Chapter G2, amongst other objectives, seeks to *"manage stormwater flowpaths and systems to ensure the safety of people and property"* through a number of performance criteria.

Chapter G9 applies development controls to land that falls within the Flood Planning Area, but also stipulates that additional controls apply to buildings and activities requiring special evacuation considerations up to the Probable Maximum Flood (PMF). It considers fill and excavation, new development and subdivisions, and also quantifies the effects of climate change to be considered in a development application.

Chapter G10 specifically applies to caravan parks in flood prone land and as well as applying development controls, requires the preparation of a Flood Emergency Plan.

There are also chapters relating to specific areas in the LGA. Chapter N19 relates to the Huskisson Mixed Use Zone and recognises the flood risk to the southern part of the precinct, referring back to chapter G9 for specific development controls.

6. IMPACTS OF FLOODING

6.1. Flood Damages

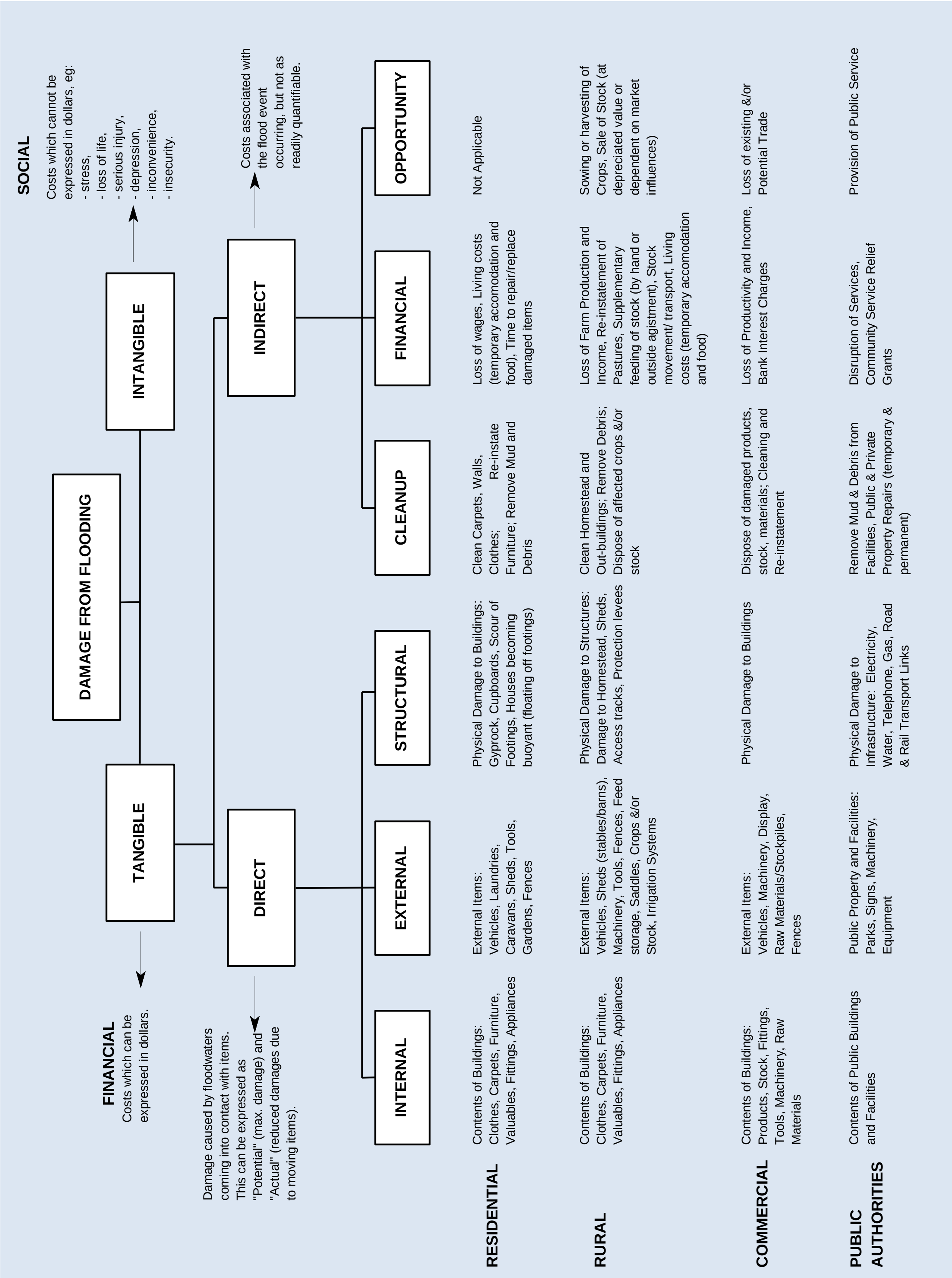
6.1.1. Economic Impact of Flooding

The impact of flooding can be quantified through the calculation of flood damages. Flood damage calculations do not include all impacts associated with flooding such as stress, inconvenience, injury, etc. They do, however, provide a basis for assessing the economic loss of flooding and also a non-subjective means of assessing the merit of flood mitigation works such as retarding basins, levees, drainage enhancement etc. The quantification of flood damages is an important part of the floodplain risk management process. By quantifying flood damage for a range of design events, appropriate cost effective management measures can be analysed in terms of their benefits (reduction in damages) versus the cost of implementation. The cost of damage and the degree of disruption to the community caused by flooding depends upon many factors including:

- The magnitude (depth, velocity and duration) of the flood;
- Land use and susceptibility to damages;
- Awareness of the community to flooding;
- Effective warning time;
- The availability of an evacuation plan or damage minimisation program;
- Physical factors such as failure of services (sewerage), flood borne debris, sedimentation; and
- The types of asset and infrastructure affected.

The estimation of flood damages tends to focus on the physical impact of damages on the human environment but there is also a need to consider the ecological cost and benefits associated with flooding. Flood damages can be defined as being tangible or intangible. Tangible damages are those for which a monetary value can be easily assigned, while intangible damages are those to which a monetary value cannot easily be attributed. Types of flood damages are shown in Image 2.

Image 2: Flood Damages Categories (including damage and losses from permanent inundation)



6.1.2. Tangible Flood Damages

Tangible flood damages are comprised of two basic categories; direct and indirect damages (refer Image 2). Direct damages are caused by floodwaters wetting goods and possessions thereby damaging them and resulting in either costs to replace or repair, or in a reduction to their value. Direct damages are further classified as either internal (damage to the contents of a building including carpets, furniture), structural (referring to the structural fabric of a building such as foundations, walls, floors, windows) or external (damage to all items outside the building such as cars, garages). Indirect damages are the additional financial losses caused by the flood for example the cost of temporary accommodation, loss of wages by employees etc.

Given the variability of flooding and property and content values, the total likely damages figure in any given flood event is useful to get a feel for the magnitude of the flood problem, however it is of little value for absolute economic evaluation. Flood damages estimates are also useful when studying the economic effectiveness of proposed mitigation options. Understanding the total damages prevented over the life of the option in relation to current damages, or to an alternative option, can assist in the decision making process.

The standard way of expressing flood damages is in terms of average annual damages (AAD). AAD represents the equivalent average damages that would be experienced by the community on an annual basis, by taking into account the probability of a flood occurrence. This means the smaller floods, which occur more frequently, are given a greater weighting than the rare catastrophic floods.

Floor level survey (refer Section 2.2.6) in conjunction with modelled flood level information was used to quantify the damages caused by inundation for existing development. Damage calculations were carried out for all properties within the PMF flood extent for which survey was available, in accordance with current OEH guidelines (Reference 19) and the Floodplain Development Manual (Reference 15). The damages were calculated using a number of height-damage curves which relate the depth of water above the floor with tangible damages. Each component of tangible damages is allocated a maximum value and a maximum depth at which this value occurs. Any flood depths greater than this allocated value do not incur additional damages as it is assumed that, by this level, all potential damages have already occurred. The results for each catchment are provided in Table 37 and Table 38.

Table 37: Estimated Flood Damages for Currambene Creek Catchment

Event	Number of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected Property
PMF	145	134	$11,574,800	$ 79,800
0.5%	52	26	$ 1,588,300	$ 30,500
1%	42	16	$ 916,100	$ 21,800
2%	29	9	$ 590,000	$ 20,300
5%	2	0	$ 3,900	$ 2,000
10%	0	0	$ 0	$ 0
20%	0	0	$ 0	$ 0
		Average Annual Damages (AAD)	**$ 55,700**	**$ -**

Table 38: Estimated Flood Damages for Moona Moona Creek Catchment

Event	Number of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected Property
PMF	78	55	$ 4,358,300	$ 55,900
0.5%	26	18	$ 1,174,300	$ 45,200
1%	26	10	$ 666,500	$ 25,600
2%	18	9	$ 487,000	$ 27,100
5%	1	0	$ 2,300	$ 2,300
10%	1	0	$ 300	$ 300
20%	0	0	$ 0	$ 0
		Average Annual Damages (AAD)	**$ 27,500**	**$ -**

For residential properties, external damages (damages caused by flooding below the floor level) were scaled up to a maximum of $10,000 at 0.75 m depth. For additional accommodation costs or loss of rent, a value of $220 per week was allowed assuming that the property would have to be unoccupied for up to three weeks. Internal (contents) damages were allocated a minimum value of $24,750 ($17,300 for high set) ranging to a maximum value of $67,500 occurring at a depth of 2.0 m above the building floor level. Structural damages vary on flood depth and whether the property is slab (max $54,000), low set (max $78,000) or high set (max $62,000). For the purpose of this study, any property with a floor level of 0.5 m or more above ground level was assumed to be high set. For two storey properties, damages (apart from external damages) are reduced by a factor of 70% where only the ground floor is flooded as it is assumed some contents will be on the upper floor and unaffected and that structural damage costs will be less. In some instances external damage may occur even where the property is not inundated above floor level and therefore tangible damages include external damages which may occur with or without house floor inundation.

The AAD for both catchments is relatively low due to the limited number of properties with above-floor affectation, even in the PMF. This means that intervention will be hard to justify on economic grounds as the costs are likely to exceed benefits in most instances. However, what is not reflected in the AAD are the intangible risks – such as risk to life, inconvenience, loss of amenity, etc., as discussed in the following section.

6.1.3. Intangible Flood Damages

The intangible damages associated with flooding, by their nature, are inherently more difficult to estimate in monetary terms. In addition to the tangible damages discussed previously, additional costs/damages are incurred by residents affected by flooding, such as stress, risk/loss to life, injury, loss of sentimental items etc. It is not possible to put a monetary value on the intangible damages as they are likely to vary dramatically between each flood (from a negligible amount to several hundred times greater than the tangible damages) and depend on a range of factors such as the size of flood, the individuals affected, and community preparedness. However, it is still important that the consideration of intangible damages is included when considering the impacts of flooding on a community.

Post flood damages surveys have linked flooding to stress, ill-health and trauma for the residents. For example the loss of memorabilia, pets, insurance papers and other items without fixed costs and of sentimental value may cause stress and subsequent ill-health. In addition flooding may affect personal relationships and lead to stress in domestic and work situations. As well as stress caused during an event (from concern over property damage, risk to life for the individuals or their family, clean up etc.) many residents who have experienced a major flood are fearful of the occurrence of another flood event and the associated damage. The extent of the stress depends on the individual and although the majority of flood victims recover, these effects can lead to a reduction in quality of life for the flood victims. With regards to the Currambene catchment, and in particular at Woollamia, other intangible damages include long periods of ponding/saturated ground which affects land useability, reduces amenity value and has also resulted in a change in the local flora and fauna.

During any flood event there is the potential for injury as well as loss of life caused by drowning, floating debris or illness from polluted water. This is discussed further in Sections 7.4 - 7.7.

6.2. Public Infrastructure and Other Land Uses

Public sector (non-building) damages include; recreational/tourist facilities; water and sewerage supply; gas supply; telephone supply; electricity supply including transmission poles/lines, sub-stations and underground cables; rail; roads and bridges including traffic lights/signs; and costs to employ emergency services and assist in cleaning up. Public sector damages can contribute a significant proportion to total flood costs but are difficult to accurately calculate or predict.

Costs to Councils from flooding typically comprise;

- Clean-up costs;
- Erosion and siltation;
- Drain cleanout and maintenance;
- Removing fallen trees;
- Inundation of Council buildings;
- Direct damage to roads, bridges and culverts;
- Removing vehicles washed away;
- Assistance to ratepayers;

- Increases in insurance premiums;
- Closures of streets;
- Loss of working life of road pavements; and
- Operational costs in the lead up to and during flood events.

4.6.3.1. Electricity

No Electrical Sub-stations are situated on the Currambene or Moona Moona Creek floodplains.

4.6.3.2. Sewerage

The regions sewerage treatment plant is situated on the southern bank of the Moona Moona Creek floodplain and is accessible by Moona Creek Road. The sewerage treatment plant is partially flooded in the PMF which would lead to significant biohazard due to effluent in the Moona Moona Creek catchment. The Plant is not flood affected in the 0.5% AEP event.

In addition, numerous waste water pumping stations for which the study areas sewerage system relies are situated on the floodplain of both Currambene and Moona Moona Creeks. These pumping stations are above the 1% AEP flood level, however many of them are flooded in the PMF event which could potentially affect the workings of the sewerage system during this event.

4.6.3.3. Schools

A number of schools are situated in both the Currambene and Moona Moona Creek catchments. These schools include:

- Huskisson Public School, situated on the corner of Sydney and Watt Streets in Huskisson;
- The Central Shoalhaven Mobile Pre-school, situated in the Huskisson Community Centre on Dent Street;
- Jervis Bay Christian Community School, situated on the corner of The Wool Road and St George Avenue, Vincentia;
- Vincentia Public School, situated on George Caley Place, Vincentia; and
- Vincentia High School, situated at 142 The Wool Road, Vincentia.

All of these schools and their grounds are above the level of the Currambene and Moona Moona Creeks PMF.

Risk due to flooding could occur if a heavy local storm occurs as the school day is ending, and parents and children should be educated about the danger of entering floodwaters (see Section 8.6.4).

4.6.3.4. Hospital

No hospitals are situated in the study areas with the nearest hospitals and emergency services situated in Nowra. As mentioned in Section 8.6.3, flooding can restrict access to Nowra which could have significant consequences if a medical emergency occurs during a flood event. See Section 8.6.3 for potential road closures.

4.6.3.5. SES Operations Centres

No NSW SES Operations Centres are located in the study areas. The nearest SES unit is situated in St Georges Basin approximately 10 km to the south east of Huskisson/Vincentia. It is important to note that this SES unit may have restricted access to Huskisson and further north (Woollamia) due to the Moona Moona Creek PMF event which cuts the Elizabeth Drive Bridge. However, this bridge is unlikely to be cut in events up to and including the 0.5% AEP event.

The Nowra SES Unit is situated approximate 20 km north of the study areas, and again has the potential to have access restricted due to flooding from larger events (see Section 8.6.3 for potential road closures).

4.6.3.6. Evacuation Centres

The *Shoalhaven Local Flood Plan* (Reference 25), Clause 3.18.43 lists locations that may be suitable for use as evacuation centres including:

- Senior Citizens Centre, Huskisson Road, Huskisson (servicing Woollamia);
- Lady Denman Complex, Dent Street, Huskisson (servicing Woollamia);
- Community Hall, Callala Beach (servicing Myola).

The second of these (aka the Jervis Bay Maritime Museum) is revealed by the latest flood modelling to be surrounded by floodwater in the PMF and so may not be suitable as an evacuation centre.

Further details on recommendations for Evacuation Centres are discussed in Section 8.6.3.

7. CATCHMENT CHARACTERISTICS

7.1. Existing Flood Risk

The flood risk in both catchments is influenced by tides and the entrance conditions, as discussed in Sections 2.5 and 2.6, however in large events it is the conveyance capacity of the main watercourse which has the greatest influence on flooding mechanism.

In the Currambene Creek catchment, floodwaters break out of banks in all events greater than the 0.2 EY, however it is not until the 5% AEP that properties begin to be affected, and the 2% AEP for above floor inundation to begin to occur. Table 39 provides an overview of properties affected in the Currambene Creek catchment with the locations of these properties displayed in Figure 81 and Figure 82 for yard and over floor flood affectation respectively.

Table 39: Currambene Creek Catchment Property Affectation

Location*	Properties Affected	Number of Properties Inundated per Event	Number of Properties Inundated Over Floor per Event
Myola	33	2% AEP - (2 properties) PMF - (33 properties)	2% AEP - (1 property) PMF - (33 properties)
Woollamia (township)	73	5% AEP - (2 properties) 2% AEP - (24 properties) 1% AEP - (37 properties) PMF - (79 properties)	2% AEP - (7 properties) 1% AEP - (13 properties) PMF - (79 properties)
Woollamia (rural)	12	2% AEP - (2 properties) PMF - (12 properties)	2% AEP - (1 property) 1% AEP - (2 property) PMF - (12 properties)
Falls Creek	3	PMF - (3 properties)	PMF - (3 properties)

* See Figure 1 for locations

In the Moona Moona Creek catchment, floodwaters break out of banks in all events greater than the 0.2 EY. There are fewer properties affected by flooding in this catchment compared to Currambene. Although one property is affected by floodwaters in the 10% AEP event, for most it does not occur until the 2% AEP event or greater. Table 40 provides an overview of properties affected in the Moona Moona Creek catchment with the locations of these properties displayed in Figure 84 and Figure 85 for yard and over floor flood affectation respectively.

Table 40: Moona Moona Creek Catchment Property Affectation

Location	Properties Affected	Event Ground First Inundated	Event Above-Floor Inundation First Occurs
Vincentia	63	2% AEP - (17 properties) 1% AEP - (25 properties) 0.2% AEP - (29 properties) PMF - (63 properties)	2% AEP - (9 properties) 1% AEP - (10 property) 0.2% AEP - (21 properties) PMF - (49 properties)
Huskisson	15	10% AEP - (1 property) PMF - (15 properties)	PMF - (6 properties)

* See Figure 2 for locations

7.1.1. Woollamia

Woollamia is somewhat unique in the study area in that it is also affected by overland flows originating in the west and flowing through the populated area, towards the river near the corner of Woollamia Road and Edendale Street. This is the dominant flooding mechanism in events up to 5% AEP, after which flooding from the river becomes the greater source of risk.

Within the overall study area, Woollamia suffers the highest degree of flood affectation. This is compounded by limited evacuation as flood levels rise (refer Section 7.4). However, the main issue raised by Woollamia residents during community consultation (see Section 3) was flooding due to local flows for properties upstream of Woollamia Road. Community members represented a view that in light of “environmental” controls, the drain was no longer able to be maintained by residents. This had overall led to a decline in drainage such that property previously usable had become “boggy” or susceptible to vegetation changes which made it less suitable for a variety of uses.

Drainage issues such as this are typically beyond the scope of a Floodplain Risk Management Study, which focuses on the larger, more extreme events (i.e. 1% AEP river flooding), however due to the communities concerns this issue has also been considered in the management options (see Section 8.4.3.2).

7.2. Land Use

The land use zones as identified in Council’s LEP (2014) are shown in Figure 86 and Figure 87 for Currambene Creek and Moona Moona Creek catchments respectively. The land usage within Currambene largely comprises *Rural Landscape (RU2)* as well as large areas of *National Parks & Reserves (E1)* and *Environmental Conservation (E2).* In the upper catchment there are areas of *Large Lot Residential (R5)* associated with the township of Woollamia, as well as one small area designated *Public Recreation (RE1)*. In the lower catchment, within the townships of Myola and Huskisson, are areas of *General Industrial (IN1)*, *Public Recreation (RE1)*, *Mixed Use (B4)*, *Low Density Residential (R2)* and *Infrastructure (SP2).*

The Moona Moona Creek catchment predominantly comprises *National Parks & Reserves (E1)*, *Rural Landscape (RU1)* and some *Environmental Conservation (E2)* areas. The lower catchment, within the towns of Vincentia and Huskisson, comprises a mixture of *Low Density Residential (R2)*, *General Residential (R1)* and *Medium Density Residential (R3)*, as well as small sections of *Environmental Living (E4), Infrastructure (SP4), Public Recreation (RE1),* and *Local Centre (B2)*

7.3. Social Characteristics

Understanding the social characteristics of the area can help in ensuring that the floodplain risk management practices adopted are aligned with the communities at risk. For example, ‘stable’ communities (characterised by a high proportion of homeownership and low frequency of residents moving into or out-of the area) are more like to have a better understanding of the flood risks within the area.

Social characteristic data were obtained from the 2011 census (http://www.abs.gov.au/) for the study area. The study area contains a number of towns including Huskisson, Vincentia, Woollamia and Myola with a combined population of approximately 7,400. Table 41 summarises some of the key characteristics relevant to this study.

Table 41: 2011 Census data by location

	NSW Average	Huskisson	Vincentia	Woollamia	Myola
Population Age:					
0 – 14 years	19.2%	10.3%	15.5%	14.4%	7.7%
15 - 64 years	66.1%	64.2%	56.8%	67.9%	58.3%
> 65 years	14.7%	25.7%	27.7%	17.6%	32.1%
Average people per dwelling	2.6	1.8	2.2	2.6	2
Rent property	30.1%	44.1%	24.8%	5.2%	18.8%
Own/mortgage property	66.6%	52.6%	75.2%	94.8%	81.2%
No cars at dwelling	10.9%	10.4%	4.5%	0%	13.3%
Speak English only	72.5%	94.1%	82.1%	89.5%	99.2%

The average number of people per dwelling did not vary greatly from the state average which means no extra consideration need to be given in evacuation planning for large households (whereas, for example, a high number of single person households could create an extra burden on emergency rescue personnel). There is a greater portion of over 65 year olds in the study area than seen nationally, and this will need to be considered when determining appropriate evacuation routes.

There is a high proportion of home ownership in the study area, except in Huskisson where more than 40% of residents are renting their property. Generally, home ownership correlates with longer residence times, which in turn helps to maintain a higher level of flood awareness as people are more likely to have witnessed a flood event themselves. However, in the case of the study area, many of the properties are holiday homes which leads to a more transient population. This combined with the last major flood occurring in 1971 would suggest that community flood awareness is low.

The languages spoken by the population are also useful to consider as this can have implications with regards to the provision of flood information to the public. Within the study area, all residents were able to communicate in English to some degree and only 6% of the population in the study area spoke a language other than English at home. As such, language is unlikely to be a barrier during flood evacuation and in communicating flood risk and raising flood awareness.

7.4. Flood Access

Having safe access and egress during a flood event is an important consideration in emergency planning. Access and egress routes for each of the residential properties surveyed (for floor level) in the study area were identified. Only 74 of the 320 properties had entirely flood free access. Table 42 and Figure 88 shows the event from which access is first compromised. Note, for the purposes of this exercise it was assumed that floodwaters less than 300 mm could still be traversed safely by motor vehicles (Reference 22), and although traversing flood waters is not recommended, routes were not considered flooded until depths exceeded this.

Table 42: Access and Egress

Event which first cuts flood access route	No. of properties – Currambene	No. of Properties – Moona Moona
5% AEP	82	8
2% AEP	3	24
1% AEP	10	-
0.5% AEP	92	27
Flood free	24	50

In the Currambene catchment, 187 residential properties, predominantly in Woollamia, are subject to evacuation restrictions due to road flooding. In the 2% AEP event, there are 7 properties which will experience above-floor inundation who also do not have flood-free access. In the 1% AEP event this increases to 13 properties which are both flooded above-floor and without a flood-free route. In the PMF, 159 properties will experience above-floor inundation (74 of which experience depths greater than 1 m) and do not have a flood-free route. As such it is considered that there is a serious potential risk to life in the Currambene catchment from events larger than the 5% AEP.

In the Moona Moona Creek catchment, 109 residential properties are subject to evacuation restrictions due to road flooding. In the 2% AEP event, there are 9 properties which will experience above-floor inundation who also do not have flood-free access. In the 1% AEP event this increases to 10 properties which are both flooded above-floor and without a flood-free route. In the PMF, 44 properties will experience above floor-inundation (27 of which experience depths greater than 1 m) and do not have a flood-free route. As such it is considered that there is a serious potential risk to life in the Moona Moona Creek catchment from events larger than the 2% AEP.

7.5. Flood Emergency Response Planning

To assist in the planning and implementation of response strategies, the SES in conjunction with OEH has developed guidelines to classify communities according to the impact that flooding has upon them. These Emergency Response Planning (ERP) classifications (Reference 20) consider flood affected communities as those in which the normal functioning of services is altered, either directly or indirectly, because a flood results in the need for external assistance. This impact relates directly to the operational issues of evacuation, resupply and rescue. Based on the guidelines, communities are classified as either; Flood Islands; Road Access Areas; Overland Escape Routes; Trapped Perimeter Areas or Indirectly Affected. The ERP classification can identify the type and scale of information needed by the SES to assist in emergency response planning (refer to Table 43).

Table 43: Emergency Response Planning Classifications of Communities

Classification	Response Required		
	Resupply	Rescue/Medivac	Evacuation
High flood island	Yes	Possibly	Possibly
Low flood island	No	Yes	Yes
Area with rising road access	No	Possibly	Yes
Area with overland escape routes	No	Possibly	Yes
Low trapped perimeter	No	Yes	Yes
High trapped perimeter	Yes	Possibly	Possibly
Indirectly affected areas	Possibly	Possibly	Possibly

Key considerations for flood emergency response planning in these areas include:

- Cutting of external access isolating an area;
- Key internal roads being cut;
- Transport infrastructure being shut down or unable to operate at maximum efficiency;
- Flooding of any key response infrastructure such as hospitals, evacuation centres, emergency services sites;
- Risk of flooding to key public utilities such as gas, power, sewerage; and
- The extent of the area flooded.

Flood liable areas within the Currambene Creek catchment study area have been classified according to the ERP classification. In the Moona Moona Creek catchment, all populated areas above the PMF are 'Not Flood Affected', and all those below are classed as having 'Rising Road Access'.

Figure 83 shows the ERP classifications for Currambene Creek. This figure shows that over half the flood affected catchment is classed 'Area with Overland Escape Route'. Falls Creek is classified as 'High Trapped Perimeter Area', whilst Myola is 'Rising Road Access'. Woollamia comprises areas of 'High Flood Islands', 'Low Flood Island' and 'High Trapped Perimeter Area'.

7.5.1. ERP Classification Definitions

High Flood Island - The flood island includes enough land higher than the limit of flooding (i.e. above the PMF) to cope with the number of people in the area. During a flood event the area is surrounded by floodwater and property may be inundated. However, there is an opportunity for people to retreat to higher ground above the PMF within the island and therefore the direct risk to life is limited. The area will require resupply by boat or air if not evacuated before the road is cut. If it will not be possible to provide adequate support during the period of isolation, evacuation will have to take place before isolation occurs.

Low Flood Island - The flood island is lower than the limit of flooding (i.e. below the PMF) or does not have enough land above the limit of flooding to cope with the number of people in the area. During a flood event the area is isolated by floodwater and property will be inundated. If floodwater continues to rise after it is isolated, the island will eventually be completely covered. People left stranded on the island may drown and property will be inundated.

High Trapped Perimeter Area - The inhabited or potentially inhabited area includes enough land to cope with the number of people in the area that is higher than the limit of flooding (i.e. above the PMF). During a flood event the area is isolated by floodwater and property and may be inundated. However, there is an opportunity for people to retreat to higher ground above the PMF within the area and therefore the direct risk to life is limited. The area will require resupply by boat or air if not evacuated before the road is cut. If it will not be possible to provide adequate support during the period of isolation, evacuation will have to take place before isolation occurs.

Low Trapped Perimeter Area - The inhabited or potentially inhabited area is lower than the limit of flooding (i.e. below the PMF) or does not have enough land above the limit of flooding to cope with the number of people in the area. During a flood event the area is isolated by floodwater and property may be inundated. If floodwater continues to rise after it is isolated, the area will eventually be completely covered. People trapped on the island may drown.

Areas with Overland Escape Route - are those areas where access roads to flood free land cross lower lying flood prone land. Evacuation can take place by road only until access roads are closed by floodwater. Escape from rising floodwater is possible but by walking overland to higher ground. Anyone not able to walk out must be reached by using boats and aircraft. If people cannot get out before inundation, rescue will most likely be from rooftops.

Areas with Rising Road Access - are those areas where access roads rising steadily uphill and away from the rising floodwaters. The community cannot be completely isolated before inundation reaches its maximum extent, even in the PMF. Evacuation can take place by vehicle or on foot along the road as floodwater advances. People should not be trapped unless they delay their evacuation from their homes. For example people living in two storey homes may initially decide to stay but reconsider after water surrounds them.

Indirectly Affected Areas - are areas which are outside the limit of flooding and therefore will not be inundated nor will they lose road access. However, they may be indirectly affected as a result of flood damaged infrastructure or due to the loss of transport links, electricity supply, water supply, sewage or telecommunications services and they may therefore require resupply or in the worst case, evacuation

Overland Refuge Areas - are areas that other areas of the floodplain may be evacuated to, at least temporarily, but which are isolated from the edge of the floodplain by floodwaters and are therefore effectively flood islands or trapped perimeter areas. They should be categorised accordingly and these categories used to determine their vulnerability.

7.6. Hydraulic Categories

The 2005 NSW Government's Floodplain Development Manual (Reference 15) defines three hydraulic categories which can be applied to different areas of the floodplain; namely floodway, flood storage or flood fringe. Floodway describes areas of significant discharge during floods, which, if partially blocked, would cause a significant redistribution of flood flow. Flood storage areas are used for temporary storage of floodwaters during a flood, while flood fringe is all other flood prone land.

There is no single definition of these three categories or a prescribed method to delineate the flood prone land into them. Rather, their categorisation is based on knowledge of the study area, hydraulic modelling and previous experiences.

For this study, hydraulic categories were defined by the following criteria, which correspond in part with the criteria proposed by Howells et. al. (2003):

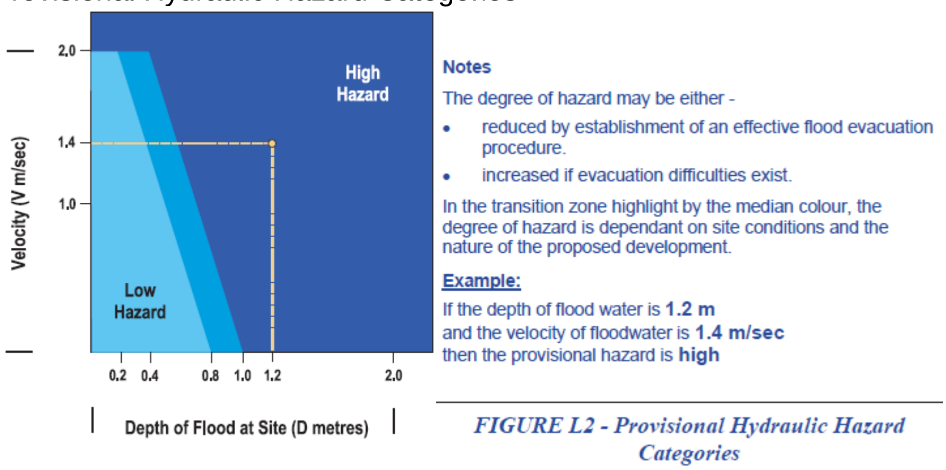
Floodway:		**Velocity x Depth > 0.25 m^2/s AND Velocity > 0.25m/s**
	OR	**Velocity > 1m/s AND Depth > 0.15m**
Flood Storage:		Land outside the floodway where Depth > 0.5m
Flood Fringe		Land outside the floodway where Depth < 0.5m

The hydraulic categories for the 1% AEP, PMF and FPA are shown in combination with the flood hazard (see Section 7.7) in the Council requested format. Further details are presented in Section 7.8.

7.7. Flood Hazard Classification

Flood hazard is a measure of the overall adverse effects of flooding and the risks they pose. The 2005 NSW Government's Floodplain Development Manual (Reference 15) describes two *provisional flood hazard* categories; High and Low, based on the product of the depth and velocity of floodwaters (see Diagram 1). These hazard categories do not consider other factors which may influence the flood hazard; hence they are a provisional estimates only with "true" hazard to be defined through the process of the current study. The boundary of the provisional High and Low hazard classification will change according to the magnitude of the flood in question.

Diagram 1: Provisional Hydraulic Hazard Categories



Extracted from The Floodplain Development Manual (Reference 15)

Provisional hazard was established based on the Floodplain Development Manual criteria (Appendix L of the Floodplain Development Manual). The majority of the flood affected areas in the Currambene Creek catchment are classed as High Hazard due to depths exceeding 1 m. The Moona Moona Creek catchment typically has shallower depths in the 1% AEP flood than the Currambene catchment and accordingly high hazard flow is confined to the channel where velocities are high.

To assess the true flood hazard, all adverse effects of flooding have to be considered. This includes the provisional (hydraulic) hazard, threat to life, danger and difficulty in evacuating people and possessions and the potential for damage, social disruption and loss of production including those detailed in Table 44. The classification is a qualitative assessment, which results in two categorisations:

High Hazard - *an area or situation where there is possible danger to personal safety, evacuation by trucks is difficult and able-bodied adults would have difficulty in wading to safety. There could also be potential for significant structural damage to buildings.*

Low Hazard - *people and possessions can still be evacuated by trucks if necessary and able-bodied adults would have little difficulty wading to safety.*

Table 44: Hazard Classification

Criteria	Weight (1)	Comment
Size of the Flood	Low	Relatively low flood hazard is associated with more frequent minor floods while the less frequent major floods are more likely to present a high hazard situation. Neither the Currambene nor Moona Moona Creek catchments scale significantly with increases in event magnitude with the exception of the PMF event. Typically both catchments do not experience high hazard flooding in residential areas until the PMF.
Depth & Velocity of Floodwaters	Low	The provisional hazard is the product of depths and velocity of flood waters. In this study no houses are located within the floodway and only a small number of properties have the floodway crossing within their boundary.
Rate of Rise of Floodwaters	Medium	Rate of rise of floodwaters is relative to catchment size, soil type, slope and land use cover and downstream boundary conditions. In the study area the rate of rise is moderate dependant on the prevailing tidal conditions.
Duration of Flooding	Low	The greater the duration of flooding the more disruption to the community and potential flood damages, however flooding in both catchments is relatively short and not a significant issue in this case
Flood Awareness and Readiness of the Community	High	General community awareness tends to reduce as the time between flood events lengthens and people become less prepared for the next flood event. The level of awareness of larger, more extreme flooding is currently very low with the community focusing on nuisance drainage issues.
Effective Warning & Evacuation Time	Medium	This is dependent on rate at which waters rise, an effective flood warning system and the awareness and readiness of the community to act. In both catchments the effective warning time is limited.
Effective Flood Access	High	Access is affected by the depths and velocities of flood waters, the distance to higher ground, the number of people using and the capacity of evacuation routes and good communication. There are a large number of properties within the study area that do not have flood-free access for all events.
Evacuation	Low	The number of people to be evacuated and limited resources of the SES and

Problems		other rescue services can make evacuation difficult, however besides access which is considered above, there are no other known evacuation difficulties.
Provision of Services	Low	In a large flood it is likely that services will be cut (sewer and possibly others). There is also the likelihood that the storm may affect power and telephones. However, the low number of properties affected do not make this a significant issue in the study area
Additional Concerns	Low	Floating debris, vehicles or other items can increase hazard.

(1) Relative weighting in assessing the hazard for the study area

The flood hazard for the study area varies by location based on the relative depths, velocities and effective flood access. Flood hazard will vary depending on the magnitude of the event, and therefore its AEP.

Consideration was given to upgrading 1% AEP design event's low provisional hydraulic hazard mapped at the Woollamia Township due to the low community flood awareness, the potential for rapid rise with limited warning time as well as difficulty of access to flood free areas in Huskisson. However, to upgrade such a large area to high hazard was considered overly risk averse due to the lack of scaling for the majority of design events and the low velocities in this region. Furthermore, all other scenarios (see Section 7.8) experience high flood hazard in this region and therefore do not require adjustment.

Elsewhere, only minor amendments (increased hazard classification of low hazard areas totally surrounded by high hazard areas) to the provisional flood hazard have been made. There may be some localised areas subject to higher hazard where flood velocities are high, such as near obstructions to flow or culverts and drains that would not be identified at the current scale of the result mapping.

The true flood hazard for the 1% AEP, PMF and FPA are shown in combination with the hydraulic categories (see Section 7.6) in the Council requested format. Further details are presented in Section 7.8.

7.8. Hydraulic and Hazard Category Mapping

Combined hydraulic and hazard mapping has been produced for the Currambene and Moona Moona Creek study areas for the 1% AEP, FPA (see Section 8.5.3) and PMF events in conjunction with existing, 2050 and 2100 sea level scenarios. For each of the 18 mapped scenarios the associated figure number is presented in Table 45 and Table 46 for the Currambene and Moona Moona Creeks respectively.

Table 45: Currambene Hydraulic and Hazard Category Mapping Scenario and Figure Numbers

Event	Sea Level Condition		
	Current	2050	2100
1% AEP	Figure 89	Figure 90	Figure 91
FPA (1% AEP + 0.5 m)	Figure 92	Figure 93	Figure 94
PMF	Figure 95	Figure 96	Figure 97

Table 46: Moona Moona Hydraulic and Hazard Category Mapping Scenario and Figure Numbers

Event	Sea Level Condition		
	Current	2050	2100
1% AEP	Figure 98	Figure 99	Figure 100
FPA (1% AEP + 0.5 m)	Figure 101	Figure 102	Figure 103
PMF	Figure 104	Figure 105	Figure 106

Results show that there are no houses located within the floodway in either catchment for the 1% AEP and FPA scenarios regardless of the selected sea level scenario. However, there are numerous houses located in regions classified as flood storage, particularly in Woollamia. The Currambene Creek catchment PMF has a large number of homes within the floodway, again with the Woollamia township worst affected. The Moona Moona Creek catchment does not have any homes located in the floodway however numerous homes are situated in flood storage areas.

Due to significant flood depths, the Currambene Creek catchment is predominately high flood hazard for all scenarios with the exception of the 1% AEP design event with current sea level conditions. However the Moona Moona Creek catchment predominately experiences low flood hazard for the 1% AEP and FPA scenarios for all regions outside of the main channel. The Moona Moona Creek catchment PMF is entirely high flood hazard for all sea level rise scenarios.

8. FLOODPLAIN RISK MANAGEMENT MEASURES

8.1. General

The NSW Government's Floodplain Development Manual (2005) separates floodplain management measures into three broad categories:

Flood modification measures modify the flood's physical behaviour (depth, velocity) and include flood mitigation dams, retarding basins and levees.

Property modification measures modify land use including development controls. This is generally accomplished through such means as flood proofing (house raising or sealing entrances), planning and building regulations (zoning) or voluntary purchase.

Response modification measures modify the community's response to flood hazard by educating flood affected property owners about the nature of flooding so that they can make informed decisions. Examples of such measures include provision of flood warning and emergency services, improved information, awareness and education of the community and provision of flood insurance.

A number of methods are available for judging the relative merits of competing measures. The benefit/cost (B/C) approach has long been used to quantify the economic worth of each option enabling the ranking against similar projects in other areas. The B/C is the ratio of the net present worth of the reduction in flood damages (benefit) compared to the cost of the works. Generally, the ratio only expresses the reduction in tangible damages as it is difficult to accurately include intangibles (such as anxiety, risk to life, ill health, etc.).

The potential environmental or social impacts of any proposed flood mitigation measure are of great concern to society and these cannot be evaluated using the classic B/C approach. For this reason, a matrix type assessment has been used which enables a value (including non-economic worth) to be assigned to each measure. The public consultation program has ensured that identifiable social and environmental factors were considered in the decision making process.

8.2. Overview

Under the NSW Floodplain Risk Management Program priorities are risk to life and the minimisation of flood damages for existing and future development. The three types of management approaches described above can be classed as one of three forms of response:

- **Works** for abatement of current risk and damages, such as construction of a levee or flood proofing a house;
- **Response** which intrinsically involves SES and for abatement of current risk, such as evacuation planning and raising community awareness; and
- **Planning** for abatement of future risk and damages for example through setting minimum floor levels.

Works can be further broken down as being communal and property specific, for example of levee versus house raising. For a works measure to be considered viable it would first need to be shown that it is economically justified, that is, the benefits outweigh the costs. The flood damages assessment undertaken as part of this study has shown that the AAD experienced in the study area are relatively low, which makes the justification of works difficult on economic grounds.

However, there are a relatively high number of residents who do not have a safe access/egress route during a flood event, many of whom will also experience above floor-inundation in larger events. As such response and planning measures will need to be utilised to manage this potential risk to life, and are the focus of the analysis in the following sections.

A further issue, which is one of the main concerns for the effected community, is local drainage in Woollamia. As such, this issue has also been considered in the development of management options despite being beyond the scope of a typical floodplain risk management study.

8.3. Measures Not Considered Further

During the early phase of this study a review of all possible floodplain management measures and their application for Currambene Creek or Moona Moona Creek catchments was undertaken. The measures not taken forward for further consideration, and the reasons for their exclusion, are summarised in the following sections.

8.3.1. Floodways

Floodways or bypass channels redirect some of the floodwaters away from the main channel, reducing the flood levels between the bypass offtake and inflows. However, they may also exacerbate flood problems in the area of the bypass channel as well as downstream, once the channels have re-joined. The opportunities for their implementation are limited by topography, availability of land, and ecological considerations.

Recommendation
Bypass floodways are not considered further due to the low AAD (i.e. lack of economic justification), high environmental impacts, issues with land ownership, lack of suitable sites and high costs of land purchase. Accordingly, the economic, social and environmental impacts of this option have not been investigated.

8.3.2. Channel Dredging

Option D1 for both Currambene and Moona Moona Creek catchments was undertaken to simulate dredging of the Creek channels in the lower reaches of the study area. This was mentioned as a potential mitigation measure by community members during the Community Consultation process (see Section 3). To simulate dredging of the channel both creek inverts were modelled as 1 m lower than their current state. The simulated dredging of Currambene Creek was modelled from the Creek entrance to a distance 4 km upstream of Woollamia. Moona

Moona Creek was dredged from its entrance to a distance 1 km upstream of the Elizabeth Drive Bridge. It was assessed whether increasing the creek conveyance through dredging of the creek channel would reduce peak flood levels in the study areas.

Results indicated that dredging of Currambene Creek does not produce any reduction in peak flood levels. Dredging of the Moona Moona creek channel provides less than a 0.05 m decrease in peak flood levels.

Recommendation

Option D1 is not recommended for further investigation in either catchment due to the relatively small impact on flood levels for the 1% AEP event, its high cost and associated environmental impacts. Accordingly, the economic, social and environmental impacts of this option have not been investigated.

8.4. Flood modification Measures

8.4.1. Dams and retarding basins

Flood mitigation dams and their smaller urban counterparts termed retarding basins have frequently been used in NSW to reduce peak flows downstream.

Dams are rarely used as a flood mitigation measure for existing development on account of the:

- High cost of construction,
- High cost of land purchase,
- Risk of failure of the dam wall,
- Likely low benefit/cost ratio,
- Lack of suitable sites as a considerable volume of water needs to be impounded by the dam in order to provide a significant reduction in flood level downstream.

Options Considered

At the request of Council, an inflatable rubber weir has been modelled at the outlet of the overland flow path at Woollamia that crosses Woollamia Road and Edendale Street (see Section 7.1.1). A rubber weir was selected for investigation as they are typically less invasive to the local environment than traditional weirs and can be deflated when not in use. The weir was modelled in an attempt to increase the time that Woollamia Road and Edendale Street are trafficable during flood.

8.4.1.1. Option W1 - Woollamia Inflatable Rubber Weir

The inflatable rubber weir was modelled with a crest level of 1.5 mAHD and a maximum height of approximately 2 m above the channel invert. The weir was situated immediately upstream of the Currambene Creek Ox-bow lake at Woollamia on the Woollamia overland flow path (see Section 7.1.1). The inflatable weir was modelled for the 1% and 10% AEP events.

It was found that construction of an inflatable rubber weir on this flow path increases the flood's rate of rise due to local rainfall in the catchment to the west of Woollamia as overland flow flood waters cannot escape into Currambene Creek. This leads to roads being overtopped more rapidly, thus reducing evacuation time. The weir offers minor protection from elevated Currambene Creek levels up until it is overtopped at 1.5 mAHD, however the Woollamia Road and Edendale Street crest levels are at 1.4 mAHD and thus the rubber weir will provide little additional protection in terms of increasing available evacuation time. Additionally, elevated Currambene Creek levels are extremely unlike to occur without rainfall in the local catchment to the west of Woollamia as Currambene Creek flooding, elevated ocean levels and local catchment rainfall are typically all caused by the same mechanism.

Accordingly, there is no probable scenario where implementation of a rubber weir will benefit Woollamia residents and thus the economic, social and environmental impacts of this option have not been investigated.

Recommendation

Option W1 is not recommended for further investigation as in the majority of cases this option will increase flood affectation and reduce evacuation route trafficability. In the unlikely scenario of elevated Currambene Creek levels occurring without local catchment runoff, Option W1 provides only minor benefits.

8.4.2. Levees, floodgates and pumps

Overview

Levees are built to exclude previously inundated areas of the floodplain from a waterbody up to a certain design event, and are commonly used on large river systems (e.g. Hunter and Macleay Rivers), but can also be found on small creek systems and urban areas.

Flood gates allow local waters to be drained from the leveed area when the external level is low, but when the river is elevated, the gates prevent floodwaters from entering.

Pumps are often associated with levee designs. They are installed to remove local floodwaters from behind levees when flood gates are closed or there are no flood gates.

Options Considered

Woollamia Township and Vincentia were identified as potential locations for levees in the study area.

Woollamia was selected due to the relatively high concentration of flood-affected properties. However, no viable locations for a levee system were identified, predominantly due to the dual flooding mechanism in this area (that is, a levee that may assist in alleviating overland flow flooding would not prevent river flooding, and vice-versa).

A levee surrounding flood affected properties in Vincentia was also considered a theoretical possibility. However, it was not taken forward for more detailed consideration due to the sandy soils (which would make construction problematic and/or very expensive), the need for a long levee so as to ensure no other properties were adversely affected by a levee design (which would increase construction and maintenance costs disproportionately to benefits) and the relatively few properties at risk. For these reasons, it was not considered economically viable.

Recommendation

Levee systems are not considered a viable option for flood management in the study area. Accordingly, the economic, social and environmental impacts of this option have not been investigated.

8.4.3. Channel modifications

Overview

Channel modifications are undertaken to improve the conveyance and/or capacity of a river/drainage system. This includes a range of measures from straightening, concrete lining, removal/augmentation of structures, dredging and vegetation clearing. Channel modifications may reduce flood levels at the location of the works but need careful planning to ensure that the flood risk is not exacerbated downstream.

Options Considered

Two areas were identified for potential channel modification measures – the Elizabeth Drive Bridge between Huskisson and Vincentia and the main drain in Woollamia Township.

8.4.3.1. Elizabeth Drive Bridge

The existing Elizabeth Drive Bridge has length of 21 m, and restricts downstream flows in large (greater than 5% AEP) events, causing flood levels upstream of the crossing to be elevated. This affects parts of Huskisson and Vincentia which are located either side of the bridge. An option to double the span of the bridge was considered and modelled in the existing TUFLOW model. The impact on 1% AEP design flood levels is shown in Figure 107. Although this option did provide some benefit, the maximum reduction in flood level proximate to residential properties is approximately 0.1 m. Any monetary benefits associated with these works would be relatively minor compared to the high construction costs. As such, the B/C ratio would be substantially less than one, and the option not economically viable.

Accordingly, adjustments to Elizabeth Drive Bridge are not recommended from a flood risk management perspective and thus the economic, social and environmental impacts of this option have not been investigated.

However, the option to increase the opening widths of the bridge span should be considered when the bridge is modified/upgraded for future maintenance reasons as there may be an opportunity to provide some reduction in flood levels with little additional cost.

8.4.3.2. Woollamia Township

As discussed in Section 7.1.1, the main concern perceived by residents in Woollamia is the duration of inundation and ponding due to local runoff (not river overbank flooding). A perception that exists is that as landholders are no longer permitted to “clean out” drains with heavy machinery, flooding issues, predominately long duration ponding, have increased. To attempt to address this concern WMAwater constructed a separate detailed model of the Woollamia area on a 2 m grid and have focussed mitigation results on not just peak water level, but also the duration of flooding.

In carrying out this work it was noted that flooding in overbank areas might be decreased by installation of formalised lateral drains. As such these works were also modelled on a conceptual basis with impact on the duration of flooding being the main metric for assessment.

Model Setup

The detailed model used in this analysis is effectively the same as the 10 m hydraulic model discussed in Section 4.3 however the model grid size has been reduced to 2 m and the model extent has been reduced so that the focus is on the Woollamia Township. The detailed model results were compared to the main model design results (see Section 4.3.11.2) for the 1% AEP event and differences in peak flood levels were shown to be insignificant.

Mitigation Scenarios

With the aim of mitigating flooding and decreasing drainage inundation time, three scenarios were tested:

- Reduced channel Mannings to simulate channel clearing;
- Drainage channel conveyance and culverts under Woollamia Road doubled in capacity; and
- Addition of lateral drainage channels at approximately 60 m intervals with 1 m depth.

Results

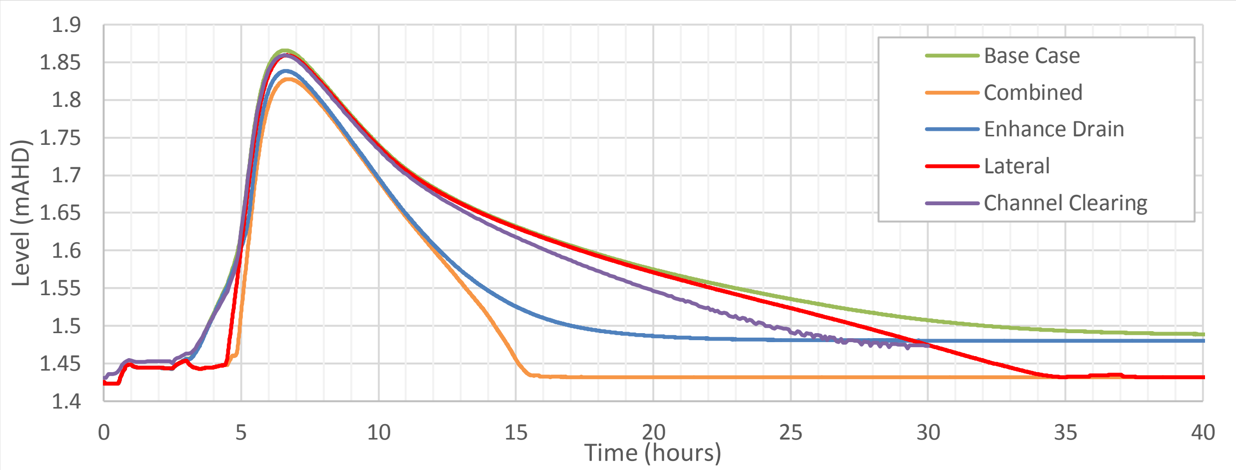
Results indicate that from a flooding perspective the above listed works provide no significant benefits (less than 0.1 m) in the reduction of peak flood levels. However, some reduction in the duration of inundation was noted.

Chart 9 presents stage hydrographs for the above listed mitigation scenarios at a flood affected lot in the Woollamia Township upstream of Woollamia Road.

Results indicate that increasing the drainage channel and culverts capacity (blue line) does aid in removing flood waters from the region, however will not reduce shallow ponding. Lateral drainage channels (red line) do aid in removing shallow water that cannot drain otherwise. Combining the increased channel and culvert conveyance with the lateral drainage channels (orange line) allows floodwaters including shallow ponding to disburse more rapidly than the base case.

To simulate clearing of the drainage channel as suggested by the community, the models Mannings roughness was reduced (purple line). It was found that water disbursed only slightly more rapidly than the base case, however did not impact on shallow ponding.

Chart 9: Woollamia Drainage – 10% AEP Stage Hydrograph – Mitigation Options Comparison



Discussion

Flood levels due to local flows in the Woollamia area do not scale significantly. This is due to the expansive overbank area and the relatively limited nature of the upstream catchment. This lack of range limits flood risk due to local flooding but also limits the efficacy of works that aim to reduce flood levels.

It was considered based on the community consultation process that the real concern to residents was the frequency of ponding and the duration of the same. As such, works aimed at reducing inundation time were trialled. This included creek clearing, increased culvert and drainage capacity and the installation of lateral drains.

Of the tested mitigation options, increasing the culvert and drainage capacity had the greatest impact on disbursing the flood peak, however the lateral drains assisted in removing shallow ponding.

Recommendation

Channel modification measures were shown to have minimal impact on flood levels in the options tested, and therefore could not be justified on economic grounds. As such, these options were not considered further and accordingly the associated economic, social and environmental impacts of implementation have not been investigated.

Implementation of lateral drainage channels could however alleviate ponding and this may be a result of interest to local residents. However, these works are not recommended from a flood risk management perspective, and accordingly the economic, social and environmental impact of implementation of lateral drainage channels have not been investigated.

8.5. Property Modification Measures

8.5.1. Land use planning

Appropriate zoning of flood liable land ensures development only occurs in suitable locations compatible with flood risk and hazard. As recognised in the Floodplain Development Manual

(Reference 15) land use planning cannot be undertaken effectively without a good understanding of the flood risks and the associated consequences. Council's set out land use zones within their LEP.

Within the Currambene catchment there are a number of proposed development areas. Unless planned for and carefully managed, any large developments (e.g. Shaolin Temple and tourism complex) will increase the impervious area which in turn will potentially increase catchment runoff and localised flooding.

Any changes to the land use should consider the flood risk, as presented in this study, and ensure that future development does not adversely affect that risk. This can be achieved through measures such as controlling runoff (through WSUD / on-site detention), ensuring development is located outside the floodplain (either through elevated floor levels or physically locating buildings beyond the flood extent) and that safe access and egress can be achieved in all events up to the PMF.

Recommendation
Any new development proposed in the study should be compatible with the flood risk as well as ensuring it does not adversely affect the flood risk elsewhere in the catchment. To do this, consideration should be given to the flood planning levels (Section 8.5.2), controlling on-site runoff and ensuring safe access and egress routes are available so as not to increase the burden on emergency services.

The DCP does provide sufficient controls to achieve the above stated objectives. Verification of this was established by review of specifically proposed developments, as outlined in Section 1.2.3, against flooding behaviour (1% AEP plus climate change, PMF and hazard/hydraulic categories) and extant DCP controls. So for example proposed developments #1 and #3, as per Section 1.2.3, are well serviced by Chapter G9, Sections 5.1, 5.2 and 5.3 of Council's DCP.

8.5.2. Flood Planning Levels

Flood Planning Levels (FPLs) are an important tool in floodplain risk management. Appendix K of the Floodplain Development Manual, 2005 (Reference 15) provides a comprehensive guide to the purpose and determination of FPLs. The FPL provides a development control measure for managing future flood risk and is derived from a combination of a flood event and a freeboard. It defines the minimum level at which habitable floor levels should be constructed.

The Floodplain Development Manual (Reference 15) states that in general the FPL for a standard residential development would be the 1% AEP event plus a freeboard, typically 0.5 m. According to the Floodplain Development Manual (Reference 15) the purpose of the freeboard is to provide reasonable certainty that the reduced flood risk exposure provided by selection of a particular flood as the basis of a FPL is actually provided given the following factors;

- Uncertainties in estimates of flood levels;
- Differences in water level because of local factors;
- Increases due to wave action; and

- The cumulative effect of subsequent infill development on existing zoned land.

In determining a suitable FPL, Council must balance the cost to the community by restricting development in flood prone areas with the benefits of the reduction in damage, frequency and danger to life caused by flooding. Generally Councils apply the 1% AEP event flood level plus 0.5 m freeboard criteria in determining the FPL as per standard DPE clause in the LEP. Depending on the nature of the development and the level of flood risk, individual FPLs can be adopted for a local area within a greater floodplain area. In some instances, the FPL can be varied depending on the use, and the vulnerability of the building/development to flooding although this is not common practice.

The FPL is defined in Shoalhaven's LEP (2014) as the 100y ARI design event (2100 1% AEP) plus 0.5 m. The LEP does not differentiate between different types / vulnerabilities of development. However, Chapter G9 of the Shoalhaven Development Control Plan (2014), defines the FPL for new development as the 2050 1% AEP flood event plus 0.5 m. For new subdivisions, the 2100 1% AEP flood event plus 0.5 m defines the FPL.

Recommendation
For new development a FPL defined as the 2050 1% AEP flood event plus 0.5 m, as per Chapter G9 of the Shoalhaven DCP (2014), is considered appropriate and therefore no changes to Council's existing policy is required. The determination of the final FPL is based on the revised flood levels provided as part of this study.

8.5.3. Flood Planning Area

The LEP Standard Instrument for NSW does not include a specific land use zone classification for flood prone land, rather it permits a Flood Planning Area (FPA) map to be included as a layer imposed across all land zones.

The FPA is used to define an area to which flood related development and planning controls are applied and Councils are required to include a FPA map in their LEP. Like the FPL, it is usually taken as the extent of the 1% AEP flood level plus 0.5 m. Therefore planning controls may be applied to development which is not necessarily within the 1% AEP flood extent but is within the FPA. It is important to base the FPA on suitable criteria appropriate to the nature of flooding so as not to over or understate the need to control development impacted by floods in some areas.

The purpose of adding a freeboard and extending the FPA past the 1% AEP flood extents is to allow for any future increases in flood extents due to climate change as well as an allowance for differences between flood behaviour during events and local small scale behaviour which cannot be replicated in hydraulic modelling.

The 1% AEP event with current sea level conditions plus 0.5 m freeboard, is presented in Figure 108 and Figure 111 for Currambene and Moona Moona Creeks respectively. Maps have also been derived for the 1% AEP event plus 0.5 m freeboard with 2050 and 2100 sea level rise scenarios. The 2050 FPA maps for Currambene and Moona Moona Creeks are presented Figure

109 and Figure 112 and the 2100 FPA maps are presented in Figure 110 and Figure 113.

Recommendation

Council currently have a FPA map in their LEP (see Section 5.1.2.1). This study has updated the hydraulic modelling for the study area and it is therefore recommended that the current LEP FPA map be updated with the revised FPA map. Due to predicted sea level rise associated with climate change (see Section 2.5.3), the 1% AEP event with 2050 ocean levels plus 0.5 m freeboard is recommended for use as Councils nominated FPA.

FRMP RECOMMENDATIONS

The following measure is recommended:

► Update the Flood Planning Area map in Councils LEP to which flood planning controls apply.

8.5.4. Voluntary House Purchase

Voluntary purchase involves the acquisition of flood affected residential properties (particularly those frequently inundated in high hazard areas) and demolition of the residence to remove it from the floodplain. Generally the land is returned to open space, however there may be an opportunity for a new house to be built at a higher floor level, either on fill or on a higher part of the property,

Voluntary purchase is mainly implemented in high hazard areas over a long period as a means of removing isolated or remaining buildings and thus freeing both residents and potential rescuers from the danger and cost of future floods. It also helps to restore hydraulic capacity of the floodplain (storage volume and waterway area). Voluntary purchase is an effective strategy where it is impractical or uneconomic to mitigate high flood hazard to an existing property and it is more appropriate to cease occupation to meet the above objectives and is often a measure that is used as part of a wider management strategy than on its own. Government funding for voluntary purchase schemes can be made available through the Floodplain Management Program as long as a number of complying criteria are met

Voluntary purchase has no environmental impacts although the economic cost and social impacts can be high. Many residents do not accept voluntary purchase because it would have significant impact on their community and way of life. Among these are concerns are:

- It can be difficult to establish a market value that is acceptable to both the State Valuation Office and the resident;
- In many cases residents may not wish to move for a reasonable purchase price;
- Progressive removal of properties may impose stress on the social fabric of an area; and,
- It may be difficult to find alternative equivalent priced housing in the nearby area with similar aesthetic value or features.

In the study area, no houses are located in the 1% AEP high hazard floodway and therefore voluntary purchase is not considered appropriate for the area.

Recommendation
There are no eligible properties in the study area and therefore voluntary purchase is not recommended.

8.5.5. Voluntary House Raising

House raising has been widely used throughout NSW to reduce over floor flood liability. However it has limited application as it is not suitable for all building types. House raising is suitable for most non-brick, single storey buildings on piers and is particularly relevant to those houses situated in low hazard areas of the floodplain. The benefit of house raising is that it eliminates inundation to the height of the floor, and consequently reduces the flood damages. House raising also provides a safe refuge during a flood, assuming that the building is suitably designed for the water and debris loading. However the potential risk to life is still present if residents choose to enter floodwaters or are unable to leave the house during a medical emergency or larger floods than the design flood occurs particularly in high hazard areas. Furthermore, unless the house is raised beyond the PMF level, flood damages will not be completely eliminated.

For new development, floor level requirements will negate the need for future raising of properties.

A review of at-risk properties in the study area failed to identify any specific houses for house raising. This due to a combination of factors, being:

- Construction material of properties incompatible with house raising;
- Most properties do not suffer from above floor inundation until very large events (most at the PMF, though some floors are at risk from the 2% AEP and greater events) which means the benefits of house raising in terms of reduction in AAD would be marginal;
- Large difference between 1% AEP and PMF design flood levels means that properties raised to above the 1% AEP level will still incur damages in larger floods, thereby reducing the benefits of the option. Raising properties to above the PMF level is not considered practical.
- Raising properties comes with an associated increased risk with people staying in their houses during a flood event.

House raising is not considered to be a cost effective option for the catchment and no specific houses have been identified for raising.

Recommendation
Voluntary house raising is not recommended for the study area.

8.5.6. Flood Proofing

Flood proofing requires sealing of doors (new frame, seal and door); sealing and re-routing of ventilation gaps in brickwork, sealing of underfloor entrances and checking of brickwork to ensure that there are no gaps or weaknesses in the mortar. It is only suitable for brick buildings with concrete floors and can prevent ingress for outside depths of approximately one metre. Greater depths may cause collapse of the structure unless water is allowed to enter. It will not reduce the flood hazard, and in fact may increase the true hazard if residents stay in their houses and a large flood eventually inundates the building.

An existing house could be sealed for approximately $20,000 while the cost to flood proof a new house or an extension would be much less if included as part of construction. Although generally, this measure is most suited to commercial premises where there are only one or two entrances, and maintenance and operation procedures can be better enforced. They are more likely to be effective for the more frequently flooded properties as infrequency of use will lead to the system being poorly maintained leading to a greater chance of failure during a flood event. Temporary flood proofing techniques may be deployed for commercial properties, although a lack of warning time may limit their efficiency. This is a good technique to use where stock, machinery or other goods cannot be moved before the onset of flooding and also suitable where flood depths may be shallow but have potential to cause significant damages.

The opportunities for flood proofing existing properties is limited in the study area due to issues with retrofitting existing residential properties. Chapter D9 in Council's DCP provides details on how flood resilient/resistant design should be considered for new developments.

Recommendation
Council's existing approach is considered appropriate and no further changes are required.

8.6. Response Modification Measures

Response modification measures aim to reduce risk to life and property in the event of flooding through enhancements to flood prediction and warning, through improvements to emergency management capabilities and planning, and through better flood-educated communities.

8.6.1. Risk Assessment

Response modification measures are considered once other floodplain management measures (i.e. flood and property modification measures, see Section 8.1) have been investigated and exhausted. Response modification measures examine the residual risk to life from flooding. Flood risk within the study areas is generally low, with the exception of Woollamia and accordingly, focus in this FRMS has been maintained on the Woollamia Township. This assessment also examines the feasibility of various emergency response approaches including:

- evacuation to Huskisson;
- evacuating to neighbouring properties; and
- sheltering-in-place within dwellings.

Generally, the flood risk has be investigated by considering:

- Patterns of above floor inundation (see Figure 82) and preliminary assessment of the hazard when floors are inundated; but also considering the distribution of houses not flooded above floor and the distribution of two-storey houses;

- Flood emergency response classification (Figure 83);
- Isolation (Figure 88); and
- Caravan parks and other ‘sensitive’ land uses.

Table 47 summarises the findings for various Currambene Creek risk sectors arranged from upstream to downstream. The risk to life classification is broadly based upon a qualitative risk matrix presented in the *National Emergency Risk Assessment Guidelines* (Reference 21).

Four sectors are considered to be high risk. These are:

1. Campsite in Jervis Bay Cabins and Camping in Goodland Road which are frequently flooded;
2. Paperbark Camp ‘glamping’ resort which is flooded over ground and isolated in a 10% AEP event;
3. a house at the eastern end of Streamside Street which is cut off in a 10% AEP event (see Figure 32) and flooded over floor in a 2% AEP event (see Figure 82); and
4. 24 houses in the Edendale Street sector which are cut off in a 2% AEP event with houses progressively flooded as the water continues to rise (i.e. a dangerous low flood island setting).

Medium risk sectors identified in Table 47 include:

5. A large number of houses located along Woollamia Road between Willowford Road and James Farmer Grove. In this sector there is generally rising road access either northwest to a high trapped perimeter or south to Huskisson from a low-point near the Edendale Street intersection (see Figure 83). Nevertheless, properties near Edendale Street could still be inundated to serious depths even in a 2% AEP event (see Figure 82), compromising egress if people attempt to evacuate late;
6. Jervis Bay Caravan Park located at 785 Woollamia Road is partly within the 1% AEP flood extent but has rising road access to Huskisson; and
7. Properties in Coulon Street could be cut off in a 2% AEP event and would be flooded in a PMF.

Other areas in both the Currambene and Moona Moona study areas are considered to be in low risk sectors.

Table 47: Risk assessment and emergency management strategies for Currambene Creek sectors

#	Location	Inundation	FERP (Figure 83)	Risk to life	EM strategy
1	Woollamia Rd b/n Falls Rd + Knoll Pde, Woollamia	• 3 houses AFF in PMF (max 0.5 m depth)	Low trapped perimeter	Low	1. Evacuate early to Huskisson 2. Shelter on properties
2	Goodland Rd, Woollamia	• 1 house AFF in PMF (0.1m depth) • Caravan park (27 sites) (camp sites flooded in 0.2 EY; cabins flooded only in PMF)	Rising road access to high flood island	Low except for campsites in caravan park which are **High**	1. Evacuate early to Huskisson 2. Evacuate to high flood island (some houses not flooded) [1]
3	Woollamia Rd b/n Goodland + Willowford Rds, Woollamia	• Paperbark Camp resort flooded in 10% AEP (12 luxury tents on platforms + restaurant with raised floor)	**Low flood island** in 10% AEP	**>High**	1. Evacuate **early** to Huskisson 2. Shelter in restaurant
4	Willowford Rd/ Allora Cl/ Streamside St, Woollamia	• 6 houses AFF in PMF (1 two-storey) (max 1.0m depth)	Rising road access to high trapped perimeter	Low	1. Evacuate early to Huskisson 2. Evacuate to high trapped perimeter (many houses not flooded) [2]
5	Eastern end Streamside St, Woollamia	• 1 house AFF in 2% AEP (two-storey brick) (2.5m depth in PMF)	**Low flood island** in 10% AEP	**High**	1. Evacuate **early** to Huskisson 2. Shelter in house
6	Woollamia Rd b/n Willowford + Edendale Rds, Woollamia	• 1 house AFF in 2% AEP • 4 houses AFF in 1% AEP (1 two-storey) • 7 houses AFF in PMF (1 two-storey) (max 2.4m depth)	Rising road access to high trapped perimeter (northwest)	Medium	1. Evacuate early to Huskisson 2. Evacuate to high trapped perimeter (many houses not flooded) 3. Evacuate/shelter in 2-storey or high-set neighbours' houses
7	Edendale St/ Sunnyside Ave/	• 4 houses AFF in 2% AEP (2 two-storey) • 6 houses AFF in 1% AEP (4 two-storey)	**Low flood island** in 2% AEP	**High**	1. Evacuate **early** to Huskisson 2. Evacuate/shelter in 2-storey

#	Location	Inundation	FERP (Figure 83)	Risk to life	EM strategy
	Edendale St East, Woollamia	• 24 houses AFF in PMF (15 two-story) (max 2.6m depth)			neighbours' houses
8	Woollamia Rd b/n Edendale St + James Farmer Gr, Woollamia	• 2 houses AFF in 2% AEP (1 two-storey) • 2 houses AFF in 1% AEP (1 two-storey) • ~39 houses AFF in PMF (6 two-storey) (max 2.7m depth) • Caravan park (70 sites) (~30 flooded in 1% AEP; all flooded in PMF)	Generally rising road access south to Huskisson	Medium	1. Evacuate early to Huskisson 2. Evacuate to high flood island at western end James Farmer Grove (some houses not flooded) 3. Evacuate/shelter in 2-storey or high-set neighbours' houses
9	Frank Lewis Way/ Coulon St, Woollamia	• 1 house AFF in 1% AEP • 9 houses AFF in PMF (4 two-storey) (max 2.2m depth) • Woollamia boat ramp carpark flooded in 2% AEP (max 0.5m depth)	Frank Lewis Way has rising road access south to Huskisson; Coulon St may be cut in 2% AEP flood and flooded in PMF so is **low flood island**	Medium-High	1. Evacuate **early** to Huskisson 2. Evacuate/shelter in 2-storey neighbours' houses
10	Dent St/ Wood Ln, Huskisson	• 1 house AFF in 1% AEP (two-storey) • 7 houses AFF in PMF (3 two-storey) (max 1.8m depth) • Jervis Bay Maritime Museum surrounded in PMF	Rising road access	Low	1. Evacuate to Huskisson 2. Evacuate/shelter in 2-storey neighbours' houses
11	Myola	• 1 house AFF in 2% AEP (two-storey) • 34 houses AFF in PMF (16 two-storey))max 2.7m depth)	Generally rising road access	Low	1. Evacuate to Callala Beach 2. Evacuate/shelter in 2-storey neighbours' houses

Notes:
AFF = above floor flooding
FERP = Flood Emergency Response Classification in PMF unless otherwise stated
[1] An alternative evacuation route might possibly be available southwards via Pritchard Ave, tracks through Woollamia Nature Reserve and Huskisson Rd, but may not be weather-proof.
[2] An alternative evacuation route might possibly be available southwards via Willowford Rd, tracks through Woollamia Nature Reserve and Huskisson Rd, but may not be weather-proof.

8.6.2. Flood Warning and Emergency Response Strategies

8.6.2.1. General considerations

Early evacuation is the NSW SES's preferred emergency response for flooding. This reflects the understanding that the safest place to be in a flood is well away from the affected area (Reference 22). Evacuation should be the primary strategy where the available warning time and resources permit (Reference 22). The alternative to evacuating is to shelter in a building within the floodplain. But the SES contends that sheltering in a building that could be flooded is not low risk, presenting a number of concerns:

- Floodwater reaching the place of shelter (unless the shelter is above the PMF level);
- Structural collapse of the building that is providing the place of shelter (unless the building has been designed to withstand the forces of floodwater, buoyancy and debris in a PMF);
- Isolation, with possible loss of power, water and sewerage;
- People's unpredictable behaviour (e.g. drowning if they change their mind and attempt to evacuate through flooded roads);
- People's mobility (not being able to reach the highest part of the building);
- People's safety (fire and accident); and
- People's health (pre-existing condition or sudden onset e.g. heart attack).

8.6.2.2. Evacuation feasibility assessment - Available warning time

The feasibility of evacuation from the Currambene Creek floodplain has been evaluated. The first consideration is available warning times.

Currambene Creek catchment is relatively small (160 km^2) so floods tend to rise relatively quickly following the onset of flood-producing rainfall. The critical duration (the duration of the storm that produces the largest flows and highest flood levels in the hydraulic model) is 9 hours for all design events except the PMF, for which the critical duration is 4 hours (Section 4.2.6). The TOC for Currambene Creek catchment is about 7 hours (Section 2.3.1.4). This catchment is not serviced with official flood warnings.

Peak flood level stage hydrographs at a key location are presented in Chart 10. This shows that the 1% AEP catchment-generated flood peaks at the low point near the junction of Woollamia Road and Edendale Street approximately 11 – 12 hours after the storm commences. The peak is slightly later for the 1% AEP ocean-generated flood. The roads are expected to be cut about at about the 8 hour mark (assuming they are trafficable until depths of ~0.3 m). In the PMF, the flood peaks 4.3 hours after the commencement of rain and the roads are cut from 1.7 – 1.8 hours. These times do not represent warning times because there would be insufficient basis to trigger evacuations based on the commencement of rain in a storm.

Chart 10: 1% AEP Stage Hydrograph – Corner of Woollamia Road and Edendale Street

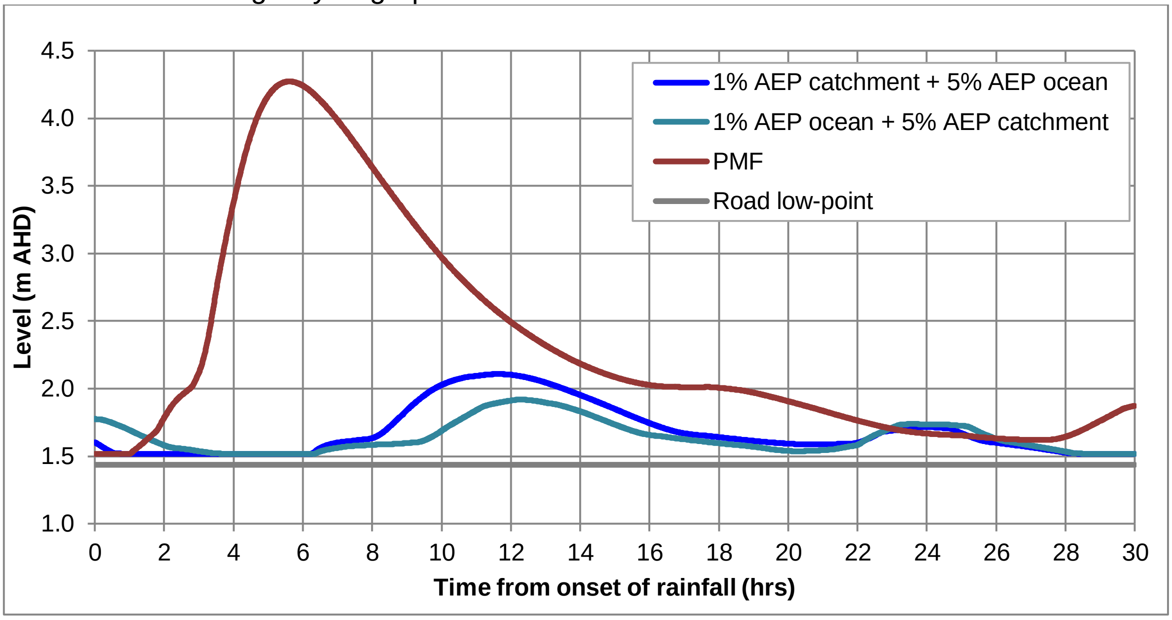


Table 48 presents flood peak travel times from the Currambene Creek gauge below the Princes Highway to three locations downstream. The locations described as '2.5 km downstream of gauge' and '6.5 km downstream of gauge' are for illustrative purposes only, to show the time gradient down through the catchment. Clearly, travel times are not linear throughout the study area. In the upper reaches, where the floodplain is constrained, floodwaters travel much faster than in the lower reaches, where the floodplain widens. But even in the lower reaches (i.e. Woollamia), the travel times are rather short, and increasingly so as the intensity of rain increases with less frequent storms: the flood peak travel time for the 1% AEP flood is just over 5 hours, and for the PMF just over 2 hours. Further, as seen above, the evacuation routes are cut well before peak, so the *effective* warning times provided using the Currambene Creek gauge would be significantly less than the overall travel times.

Table 48: Flood peak travel time from Currambene Creek at Falls Creek gauge

Event	Warning time at location (hh:mm)		
	2.5 km downstream of gauge	6.5 km downstream of gauge	Woollamia
20% AEP	0:14	1:37	9:27
10% AEP	0:58	2:53	9:19
5% AEP	0:36	2:34	7:19
2% AEP	0:23	1:44	6:13
1% AEP	0:21	1:17	5:24
0.5% AEP	0:16	1:07	5:22
PMF	0:11	0:37	2:23

It should be noted that the times reported from Chart 10 and Table 48 are indicative only. They are based on design conditions, which in most cases assume elevated tailwater levels. Should the tailwater during an actual event be different to that assumed, then the travel times would also be different (e.g. lower tailwater would lead to faster travel times/steeper time gradient through the catchment). Similarly, entrance scour would have an effect on travel times due to the presence, or not, of tailwater. These are additional reasons why flood levels and times observed at the Currambene Creek gauge may not be a reliable basis for predicting downstream flood levels and times.

Another factor why effective warning times at Woollamia could be constrained is the presence of local overland flows prior to flooding from Currambene Creek. However, the 1% AEP overland flow over Woollamia Road is less than 0.3 m deep, of low velocity (~0.2 m/s) and of short duration, which is not expected to affect evacuation significantly.

It is difficult, then, to provide a definitive available or effective warning time because this depends on the particular trigger used (which can be lowered to provide more time at the cost of greater uncertainty) and will vary from flood to flood with variable tailwater. We can assume a *maximum* of five hours for most events.

8.6.2.3. Evacuation feasibility assessment - Required warning time

For evacuation to be feasible, the available warning time must exceed the required warning time (see Section 8.6.2.2). The required warning time may be assessed by protocols set out in Reference 23 and since formalised in a *Guide for Using the SES Timeline Evacuation Model Standard Tool*. Calculations for this assessment are set out in Table 49 and Table 50. We assess the time required for two areas: the Edendale Street low flood island (#3 in Table 47, 24 houses flooded in a PMF) and Woollamia as a whole (90 houses flooded in a PMF) (see Table 47).

Table 49: Calculations to assess required time to evacuate, Edendale Street sector

Phase	Time (hrs)	Explanation
Warning Delivery (WD)	2.0	24 houses flooded in PMF at 5 minutes per house per doorknocking team with 1 team
Warning Acceptance Factor (WAF)	1	SES recommended value, allowing for people to accept the need to evacuate
Warning Lag Factor (WLF)	1	SES recommended value, allowing for people to prepare to evacuate
Travel Time (TT)	0.1	50 vehicles (based on average vehicle ownership in Woollamia at 2011 Census) at 600 vehicles/hr; note that according to the Census, every dwelling in Woollamia has at least one vehicle
Traffic safety factor (TSF)	1	SES recommended value, allowing for possibility of accidents or tree/power line falls slowing progress
Total	**4.1**	WD + WLF + TT + TSF (note that Reference 23). advise against adding WAF because this occurs concurrently with WD and WLF and sufficient momentum should have developed by the end of the warning delivery)

Table 50: Calculations to assess required time to evacuate, Woollamia

Phase	Time (hrs)	Explanation
Warning Delivery (WD)	7.5	90 houses flooded in PMF at 5 minutes per house per doorknocking team with 1 team
Warning Acceptance Factor (WAF)	1	SES recommended value, allowing for people to accept the need to evacuate
Warning Lag Factor (WLF)	1	SES recommended value, allowing for people to prepare to evacuate
Travel Time (TT)	0.3	185 vehicles (based on average vehicle ownership in Woollamia at 2011 Census) at 600 vehicles/hr; note that according to the Census, every dwelling in Woollamia has at least one vehicle
Traffic safety factor (TSF)	1	SES recommended value, allowing for possibility of accidents or tree/power line falls slowing progress
Total	**9.8**	WD + WLF + TT + TSF (note that Reference 23 advise against adding WAF because this occurs concurrently with WD and WLF and sufficient momentum should have developed by the end of the warning delivery)

A number of assumptions need to be made, and the result is very sensitive to the number of doorknocking teams available. The area is serviced by the St Georges Basin SES Unit. If flooding is threatening at Woollamia, it might well be threatening at St Georges Basin and Sussex Inlet, and it is unclear how many volunteers would be available for doorknocking along Currambene Creek. We have conservatively assumed only one team. A method of rapid dissemination (e.g. SMS alerts when water reaches a pre-determined level) could avoid the need for doorknocking, but experience indicates that personal engagement through doorknocking is a more effective means of persuading people to act and is an appropriate basis for assessing warning delivery time (Reference 23). The SES recommends allowances of one hour for people to accept a warning, another hour for people to prepare to evacuate and another hour (depending on the number of vehicles) for traffic safety. Applying these factors results in required times of 4.1 hours to evacuate the Edendale Street sector and 9.8 hours to evacuate potentially flooded houses in Woollamia as a whole. Even these required times are arguably optimistic because:

- It does not include time for the SES to make a decision for evacuation and to mobilise resources for doorknocking;
- We have not included the sensitive risk exposures in the Currambene Creek floodplain which ideally will self-manage evacuations from their facilities; these uses include caravan parks in Goodland Road and Woollamia Road and Paperbark Camp ‘glamping’ resort accessed via Woollamia Road;
- It is doubtful that owners of houses with a low risk of inundation – predicted to be flooded over floor only in events much rarer than a 0.5% AEP flood – will evacuate; historically it is understood that people in Woollamia tend to ‘sit out’ floods, and this behaviour is expected to continue; if residents did agree to evacuate, and a significant flood did not eventuate, it is likely that their confidence in future Evacuation Warnings or Evacuation Orders would be eroded resulting in increasing non-compliance; hence, any time allowance for warning acceptance may be inadequate or irrelevant.

8.6.2.4. Evacuation feasibility assessment – Conclusion

Given available warning times of five hours *at most*, and required warning times of *at least* four hours for one low flood island sector, it is far from certain that safe evacuation from Woollamia can be achieved. If faster rising, more extreme floods are experienced, or a larger area needs to be evacuated, there will be inadequate time for safe evacuation.

8.6.2.5. Opportunities to increase available warning time

Opportunities to increase available warning time can be considered. The SES have indicated that there would be value in having a pluviometer in the catchment to provide an early indication of the threat of flooding. The Currambene Creek stream gauge (see Section 2.4), situated below the Princes Highway (AWRC No. 216004), reports near real-time water levels on the Bureau of Meteorology website (http://www.bom.gov.au/nsw/flood/southcoast.shtml). A pluviometer could be installed at this site at a low cost (approximately $1,000 with no additional gauge maintenance on top of existing costs), taking advantage of existing communications infrastructure. Rainfall and water level data from this site may help the SES make an earlier decision to deploy resources to Woollamia. Figure 47 of this study presents flood profiles from the gauge to Woollamia for the 10% AEP and 1% AEP events, which could assist the SES to approximately estimate the magnitude of flooding downstream. However, as described earlier, given the variable relationship between the gauge and Woollamia due to tailwater variation, water levels at the gauge would not provide a strong basis for triggering evacuations. There would be even greater uncertainty attached to the effects of rainfall.

Another option is to install a local automatic water level recorder at Woollamia at the cost of approximately $10,000 for installation and $2,000 per annum for maintenance. Possible locations are near the boat ramp off Frank Lewis Way or at Jervis Bay Caravan Park. Both these sites are relatively accessible in the event of instrument failure during a flood, though the second may be preferable for security. In order to best inform responses, a gauge would ideally be located near the primary risk exposure, which in this case is the Edendale Street low flood island. A possible site here is the Crown Land reserve at the southern end of Sunnyside Street.

A trigger level could be selected sufficiently above the highest astronomical tide of 1.1m AHD so as not to trigger overly frequent alarms, but sufficiently below the level of 1.7 mAHD at which egress from the sector is cut when Edendale Street (and Woollamia Road nearby) are flooded to depths of 0.3 m. A 1% AEP model run with a zero tide was inspected to better understand potential rates of rise within this range of the stage hydrograph. Adopting a trigger of 1.2 mAHD would provide 3.6 hours until 1.7 mAHD was reached; adopting 1.3 mAHD would provide 3.3 hours; and adopting 1.4 m would provide 2.8 hours. Again, it is noted that these results are based on one design run, and in a real flood, with variable tailwater levels and entrance conditions, differences are expected.

It is possible to configure a water level recorder to issue multiple alerts with different actions connected to each. For example, at 1.2 mAHD an initial alert could be issued via SMS to the NSW SES and to local resident wardens to advise of a rising flood and to commence evacuating any identified vulnerable persons. Then at 1.3 mAHD, a more general evacuation of any low-lying houses could commence. (Edendale Street begins to be flooded from about 1.4 mAHD).

8.6.2.6. Opportunities to reduce required warning time

Opportunities to reduce the required warning time can also be considered. The SES could in the first instance target the 14 houses in Woollamia assessed as flooded over floor in the 1% AEP event, which would reduce doorknocking time to 70 minutes for one team, and reduce the overall required time to just over 3 hours. And/or, the SES could pre-arrange for other emergency services teams such as Huskisson Police (or local resident wardens) to be available for Woollamia to increase the number of doorknocking teams. Even having two doorknocking teams available would reduce the doorknocking time for Woollamia as a whole to 3.8 hours and the overall required time to 6.1 hours. Active and ongoing education and engagement of local communities would also be advantageous in speeding their acceptance and response to warnings (see Section 8.6.4).

8.6.2.7. Shelter-in-place feasibility assessment

As noted above, historically residents of Woollamia have tended to ‘sit out’ floods in their houses rather than evacuate. But as noted in Section 8.6.2.1, the SES has a number of concerns about this approach. Consideration, in broad terms, of the safety of sheltering in place in the Currambene Creek floodplain, especially at Woollamia is investigated in this section.

One issue is whether floor levels are sufficiently high to be above the PMF. This is shown in Figure 82 and in Table 47. From Table 47, the few houses flooded in the PMF in sectors #1, #2 and #4 are inundated to depths above floor that should be survivable. If the residents in the house in sector #5 failed to evacuate prior to egress being lost, they should still be able to evacuate to the top level of their two-storey, brick house. For many houses in sectors #6 to #10 including in Edendale Street, Woollamia Road and Coulon Street, people cannot safely shelter in their houses during an extreme flood. However, Table 47 indicates that there are a number of two-storey dwellings scattered through these sectors, where the top level would be above the floodwater, as well as a few high-set houses that are not flooded, to which people from other dwellings could potentially evacuate provided they did not delay the evacuation until the water was too deep.

For example, the Edendale Street sector (#7) has 15 two-storey dwellings servicing an area of 24 dwellings that could be flooded in a PMF. Woollamia Road between Edendale Street and James Farmer Grove (sector # 8) is less well serviced, with only six two-storey dwellings and another raised dwelling servicing some 39 dwellings. Early evacuation to Huskisson would be much preferred, but in the event of people failing to evacuate early, there are local refuges provided the owners are willing to make their houses available in these extreme events, that evacuees know where to go and leave before their evacuation route is cut.

Another issue is whether houses are able to survive the forces of floodwater, buoyancy and debris in an extreme flood. It is beyond the scope of this study to assess this on a house by house basis. In general, it is noted that hydraulic hazard is driven by water depths rather than velocities, which are typically moderate at worst. Light-framed fibreboard or timber dwellings sitting on stumps could nevertheless be at greater risk of floating off their foundations. Brick, two-storey dwellings would generally be preferred as local refuges. Of these, there are adequate numbers in the Edendale Street sector, but few in Woollamia Road and Coulon Street sectors.

Isolation is a further consideration. The tolerability of isolation relates to its duration. In the modelled 1% AEP rainfall-generated flood, residents in the Edendale Street sector could be isolated for about 8 hours. This is not ideal and may be uncomfortable and present other risks. Again, early evacuation to Huskisson is the preferred strategy, especially for anyone with pre-existing medical conditions or tourists who may find isolation particularly frustrating. However, if people fail to evacuate, such a period of isolation is considered tolerable.

8.6.2.8. Evacuation summary and recommendations

In the final column in Table 47, provisional hierarchy of recommended emergency management strategies for each sector is presented. Early evacuation away from the floodplain is the preferred strategy but as noted above, there may be insufficient time in some floods (even with efforts to increase the available warning time and to reduce the required time), and the culture of 'sitting it out' described for Woollamia may be difficult to reverse. This is why secondary strategies are also listed, particularly to shelter in the raised or two-storey (preferably brick) dwellings scattered through the area. One way forward is for the NSW SES to commence a Community Led Planning process (see Reference 24) for Woollamia, so that residents have a good appreciation for the flood hazard and are co-opted as partners in confirming strategies for their community. This process could result in a local residents' warden system and confirm Currambene Creek evacuation triggers and local flood refuges.

Recommendations

FRMP RECOMMENDATIONS

The following measures are recommended to increase available warning time:

► Install pluviometer at existing Currambene Creek gauge and report real-time information on Bureau website and Enviromon (Council/NSW Office of Water).

► Install water level recorder at suitable location in Woollamia, preferably near Edendale Street sector, report real-time data on Bureau website and Enviromon, and alarm recorder so that SMS alerts are issued to SES personnel and local wardens when pre-determined triggers are exceeded (Council/MHL).

The following measure is recommended to reduce required warning time:

► Develop inter-agency cooperation and a local resident warden system to speed the delivery of flood warnings (NSW SES).

The following measure is recommended to gain community concurrence and ownership of flood warning and emergency response strategy:

► Commence and continue a Community Led Planning process with the community of Woollamia to confirm evacuation triggers and local flood refuges (NSW SES).

8.6.3. Flood Planning Documentation

The *Shoalhaven Local Flood Plan* (Reference 25) sets out responsibilities and arrangements for managing flood emergencies. Clause 3.18.43 lists locations that may be suitable for use as evacuation centres including:

- Senior Citizens Centre, Huskisson Road, Huskisson (servicing Woollamia);
- Lady Denman Complex, Dent Street, Huskisson (servicing Woollamia);
- Community Hall, Callala Beach (servicing Myola).

The second of these (aka the Jervis Bay Maritime Museum) is revealed by the latest flood modelling to be surrounded by floodwater in the PMF and so may not be suitable as an evacuation centre.

Volume 2 of the Local Flood Plan details the nature of flooding and the effects of flooding in different communities. It has not been updated since 2004. The focus of the current Plan is on Shoalhaven River flooding with very little information about Currambene or Moona Moona Creeks. Annex B can be updated using the information derived from the study including:

- Distribution of houses flooded over ground/floor levels (Figures 81, 82, 84, 85);
- Flood emergency response classifications (Figure 83);
- Flooding of access routes (Figure 88);
- Property database in a spreadsheet setting out design flood levels, depths, velocities, hydraulic hazard and evacuation routes, as well as addresses, number of stories and building material, for every house in the floodplain

The information on road closures can be updated using the information in Table 51.

Volume 3 of the Local Flood Plan lists gauges monitored by the SES, which will need to be amended should the proposed Woollamia gauge be installed. It also lists evacuation arrangements, which will need to be updated in accordance with the recommendations in Table 47 and following confirmation of local evacuation triggers and the broader strategy as accepted by the community through the proposed Community Led Planning process.

Should the proposed Woollamia gauge be installed, a flood intelligence card should initially be constructed using design flood information, and could be maintained following significant floods.

Flood emergency plans were prepared for Jervis Bay Cabins and Camping and Jervis Bay Caravan Park in Woollamia as part of the Shoalhaven *Caravan Parks Flood Safety Study* in 2008 (Reference 26). After local evacuation triggers are confirmed, these should be updated to take advantage of the information provided by the recent Flood Study. Similarly, Paperbark Camp resort should be encouraged to prepare or update a flood emergency plan. All these tourist facilities would benefit from ongoing outreach by the SES to help them understand the flood risk and the need for early evacuation. Waiting for a gauge-triggered alert might not allow sufficient time for evacuation from these sensitive risk exposures, particularly Paperbark Camp which can get flooded and cut off in frequent events. Consideration will need to be given to closing this facility upon issuance of a Flood Watch or Severe Weather Warning for the region.

Table 51: Key road closures

Location	AEP at which flooded	AEP at which flood depth > 0.3 m	Effects of road inundation	Duration of inundation > 0.3 m in 1% AEP Event*
Woollamia Rd 160m west of Pritchard Ave	<20% AEP	10% AEP	Isolates main route from Princes Hwy	~13 hours
Woollamia Rd between Willowford and Goodland Rd	1% AEP	0.5% AEP	High Trapped Perimeter Area on Woollamia Rd	Not inundated in 1% AEP
Streamside St 480m east of Willowford Rd	20% AEP	10% AEP	Low Flood Island – 1 house	~20 hours
Edendale St 80m east of Woollamia Rd	5% AEP	5% AEP	Low Flood Island – 25 houses	~7 hours
Woollamia Rd 20m sth of Edendale St	5% AEP	5% AEP	Isolates large part of Woollamia from Huskisson	~7 hours
Falls Rd 700 m east of Princes Hwy	2% AEP	1% AEP	High Trapped Perimeter Area on Falls Rd – 4 house	~2 hours
Falls Rd 120 m north of Woollamia Rd	5% AEP	5% AEP	High Trapped Perimeter Area on Falls Rd – 4 house	~10 hours
Jervis Bay Road north of Fairfax Rd	0.5% AEP	>0.5% AEP	High Trapped Perimeter Area on Falls Rd – +100 house	~3 hours (PMF)
Jervis Bay Road 350 m south of Seasongood Rd	0.5% AEP	>0.5% AEP	High Trapped Perimeter Area on Falls Rd – +100 house	~3 hours (PMF)
Jervis Bay Road 1.7 km north of Tomerong Rd	0.5% AEP	>0.5% AEP	High Trapped Perimeter Area on Falls Rd – +100 house	~3 hours (PMF)
Jervis Bay Road 900 m north of Tomerong Rd	0.5% AEP	>0.5% AEP	High Trapped Perimeter Area on Falls Rd – +100 house	~3 hours (PMF)

*Whilst it is not recommended to drive in flood waters it has been assumed that roads are trafficable for depths less than ~0.3 m. The provided duration is for the 1% AEP design flood event for a critical duration of 9 hours. It should be noted that the duration of inundation can vary greatly (± 100%) for individual storm events dependant on storm magnitude, duration and ocean and entrance conditions. The provided duration of inundation should be used as indicative only.

Recommendations

FRMP RECOMMENDATIONS

The following measures are recommended to improve flood planning:

► Reassess the suitability of Lady Denman Complex in Dent Street Huskisson as an evacuation centre (NSW SES).

► Update Shoalhaven Local Flood Plan to include Currambene Creek and Moona Moona Creek flood intelligence and evacuation arrangements (NSW SES).

► Develop and maintain flood intelligence card for proposed new Woollamia gauge (NSW SES).

► Encourage and assist key floodplain exposures (Jervis Bay Cabins and Camping; Jervis Bay Caravan Park; Paperbark Camp resort) to develop and update flood emergency plans (Council and NSW SES).

8.6.4. Flood Education

Actual flood damages can be reduced, and safety increased, where communities are flood-ready:

> *'People who understand the environmental threats they face and have considered how they will manage them when they arise will cope better than people who lack such comprehension… Many people who live and work in flood liable areas have little idea of what flooding could mean to them – especially in the case of large floods of severities well beyond their experience or if a long period has elapsed since flooding last occurred. It falls to the combat agency, with assistance from councils and other agencies, to raise the level of flood consciousness and to ensure that people are made ready for flooding. In other words, flood-ready communities must be purposefully created. Once created, their flood-readiness must be purposefully maintained and enhanced.'* (Reference 27)

Based on learnings from recent disasters, the focus of community disaster education has shifted from a concentration on raising awareness and preparedness to building community resilience through learning. Simply disseminating information to the community does not necessarily trigger changed attitudes and behaviours. Flood education programs are most effective when they:

- Are participatory i.e. not consisting only of top-down provision of information but where the community has input to the development, implementation and evaluation of education activities;
- Involve a range of learning styles including experiential learning (e.g. field trips, flood commemorations), information provision (e.g. via pamphlets, DVDs, the media), collaborative group learning (e.g. scenario role plays with community groups) and community discourse (e.g. forums, post-event de-briefs); and
- Are ongoing programs rather than one-off, unintegrated 'campaigns', with activities varied for the learner.

It is difficult to accurately assess the benefits of a community flood education program but the consensus is that the benefits far outweigh the costs. Nevertheless, sponsors must appreciate that ongoing funding is required to sustain gains that have been made.

Levels of flood awareness and preparedness in the study area are judged to be low given the last major flood occurred in 1971. This is amplified by the prevalence of holiday homes and tourist sites. Furthermore, most residents who indicated an awareness of flooding were referring only to minor, overland flow events that affect Woollamia Township, rather than larger, rarer, mainstream events.

Risky behaviours that flood educators will need to give thought to for the Currambene Creek study area include:

- Delaying evacuation during a rising flood; and
- Driving through flooded roads.

Delaying evacuation is unsurprising given most houses in the floodplain have floors that are above the 1% AEP level. However, it is of concern given that about 131 houses in the Currambene Creek floodplain would be flooded over floor in a PMF (including Woollamia, Huskisson and Myola), a number to serious depths. It is difficult for people to give credence to low probability but high consequence events. The example of the 2015 Dungog flood may be a persuasive illustration of the need to give at least some thought to how such events could be survived. As recommended in Section 8.6.2, a Community Led Planning process would be a useful forum for helping the community to develop and own solutions to manage this residual risk. The risk varies from house to house depending on floor level, structural stability and vulnerability of the residents (e.g. those whose health requires guaranteed power supply). A meeting staffed by Council officers and NSW SES personnel would be an appropriate forum for disseminating available risk information such as floor levels and flood levels and helping residents to devise their own emergency plans (and advising the SES of anyone who may require assistance in evacuating).

The second behaviour is also unsurprising given people's desire to avoid being isolated as a flood is rising and threatening loss of egress, and given people's mounting frustration if isolated for an extended period. This behaviour could be combatted through frequent broadcasting of the key NSW SES message never to drive, ride or walk through floodwater. It could also be underscored at the proposed Community Led Planning forums showing how easily a vehicle can become buoyant. There would also be benefit in installing additional signage at key road low-points at an estimated cost of $2,000 per sign. One of the most frequently cut roads is Woollamia Road west of Pritchard Avenue (Table 51), which already has depth indicators but where explicit messaging along the lines of "If it's flooded, forget it" would be a worthy addition. There is also a need for depth indicators at the low-points in Edendale Street and Woollamia Road near Edendale Street, since these are critical points on the evacuation route and would be a useful guide for evacuating motorists or the emergency services.

Once the proposed Woollamia water level recorder is installed and evacuation triggers are confirmed, a FloodSafe guide for Woollamia could be developed to incorporate key aspects of flood behaviour and key actions residents should undertake.

Shoalhaven City Council could also issue flood certificates to properties within the PMF floodplain, once a year, together with a FloodSafe guide. The intention of flood certificates is to inform individual property owners of the flood situation (flood levels, floor levels, etc) at their particular property. It is the site-specific nature of this advice that offers a chance of overcoming the scepticism typical of a community that has not experienced serious flooding for some years. Only after floodplain occupants accept that they could be flooded are they ready to take on board ideas about addressing the problem.

Recommendations

FRMP RECOMMENDATIONS

The following measures are recommended to improve flood education:

► Use Community Led Planning process to help the community understand the residual risk and to develop their own flood emergency plans (NSW SES).

► Continue to develop media for disseminating messages about the dangers of driving through floodwater (NSW SES).

► Install signage advising motorists to avoid driving through floodwater at the Woollamia Road low-point west of Pritchard Avenue (Council).

► Install depth indicators adjacent to low points in Edendale Street and Woollamia Road near the intersection (Council).

► Install signage advising of the flood risk at the boat ramp carpark in Frank Lewis Way (Council).

► Develop a FloodSafe guide for Woollamia (NSW SES).

► Regularly Issue flood certificates to residents within the PMF floodplain (Council).

9. FLOODPLAIN RISK MANAGEMENT PLAN

This section comprises the Floodplain Management Plan and forms a framework identifying aims, objectives and a guide to the list of strategies by which the plan will be implemented. Any recommendations in terms of policy should be reviewed and approved by Councils planners.

9.1. Aims and Objectives

The primary objective of the Floodplain Management Plan is to recommend a range of property, response and flood modifications that address the existing and future flood problems, in accordance with the Floodplain Development Manual (Reference 15). The recommended works and measures presented in the Plan will:

- Reduce the flood hazard and risk to people and property in the existing community and to ensure future development is controlled in a manner consistent with the flood hazard and risk;
- Reduce private and public losses due to flooding;
- Protect and, where possible, enhance the river and floodplain environment;
- Be consistent with the objectives of relevant State policies, in particular, the Government's Flood Prone Lands and State Rivers and Estuaries Policies and satisfy the objectives and requirements of the Environmental Planning and Assessment Act, 1979;
- Ensure that the floodplain risk management plan is fully integrated with Council's existing corporate, business and strategic plans, existing and proposed planning proposals, meets Council's obligations under the Local Government Act, 1993 and has the support of the local community;
- Ensure actions arising out of the management plan are sustainable in social, environmental, ecological and economic terms;
- Ensure that the floodplain risk management plan is fully integrated with the local emergency management plan (Local Flood Plan) and other relevant catchment management plans; and
- Establish a program for implementation and a mechanism for the funding of the plan and should include priorities, staging, funding, responsibilities, constraints, and monitoring.

9.2. Identification of Actions Suitable For Implementation

The following matrix (Table 52) identifies the practical options which have been identified to Councils Central Shoalhaven Natural Resources and Floodplain Management Committee (NRFMC) for further approval. Those options or strategies approved by the Committee will be further investigated.

Table 52: Measures Recommended for Implementation – Risk Management Options Matrix

Measure	Description	Priority	Benefits	Concerns	Implementation, Costs and Funding
			FLOOD MODIFICATION MEASURES		
Increasing the length of Elizabeth Drive Bridge (Section 8.4.3.1)	The length of the Elizabeth Drive Bridge could be increased to reduce upstream flood levels during flood. This option should only be considered when the bridge is modified/upgraded as benefits are minimal.	Only to be investigated if bridge is to be upgraded.	A slight reduction in peak flood levels upstream of the bridge. However, this option provides a maximum decrease in flood level for upstream properties of 0.1 m.	Replacing the Elizabeth Drive Bridge would be expensive and provides only minor decreases in peak flood level and minimal benefits to upstream residents.	Council would be responsible for construction and maintenance.
			PROPERTY MODIFICATION MEASURES		
Redefine the Flood Planning Area and incorporate into Council's LEP (Section 8.5.3)	A requirement of the Floodplain Development Manual. The FPA is required to identify all properties to which flood related development controls will apply.	High	Provides a clear method of identifying properties subject to flood related development controls.	There is a need to include properties impacted by both mainstream and overland flow. Also good communication with residents about process is key.	The revised FPA map should be included in Councils LEP. Costs are minimal.
			RESPONSE MODIFICATION MEASURES		
Install Pluviometer rainfall gauge at Currambene Creek stream gauge (Section 8.6.2.5)	The SES have indicated that there would be value in having a pluviometer in the catchment to provide an early indication of the threat of flooding. The Currambene Creek stream gauge (see Section 2.4) reports near real-time water levels on the Bureau of Meteorology website. A pluviometer could be installed at this site at a low cost, taking advantage of existing communications infrastructure. Rainfall and water level data from this site may help the SES make an earlier decision to deploy resources to Woollamia.	High	Provide increased warning time for potential flood events.	Use of rainfall data to predict floods can be difficult and unreliable.	Council in conjunction with NOW would responsible for implementation and maintaining the gauge. Estimated cost of installation is $1,000 with no additional maintenance cost on top of existing gauge costs.
Install a water level recorder in Woollamia (Section 8.6.2.5)	The water level recorder could be configured to issue multiple alerts with different actions connected to each. For example, at a certain level an initial alert could be issued via SMS to the NSW SES and to local resident wardens to advise of a rising flood and to commence evacuating any identified vulnerable persons. Then at a higher level, a more general evacuation of any low-lying houses could commence.	High	Notify the NSW SES and local residents of flooding and provide various evacuation triggers.	Potentially costly to install and maintain.	Council in conjunction with MHL would responsible for implementation and maintaining the gauge. Estimated cost of installation is $10,000 with the cost of maintenance estimated to be $2,000 per annum.

Measure	Description	Priority	Benefits	Concerns	Implementation, Costs and Funding
Develop inter-agency cooperation and flood warden system (Section 8.6.2.6)	Ensure that all emergency operations agencies, such as NSW SES and police etc. and the local community, liaise and coordinate effectively during a flood event.	Medium	Better coordinated emergency response with more personnel available to assist.	None.	NSW SES are the responsible for organisation.
Commence Community Led Planning process to confirm evacuation triggers (Section 8.6.2.5)	Commence and continue a community based planning process at Woollamia and surrounds to confirm evacuation triggers and confidence in the warning system.	On going	Will provide a more reliable flood warning system that the community understands and supports.	None.	NSW SES are the responsible for organisation.
Reassess the suitability of Lady Denman Complex as an evacuation centre (Section 8.6.3)	The Lady Denman Complex on Dent Street Huskisson is flooded in the PMF and potentially unsuitable for use as an evacuation centre.	High	Relocation of this evacuation centre will remove flood risk for people using the centre.	It may be difficult to find another suitable location.	NSW SES are the responsible for organisation.
Update the Shoalhaven Local Flood Plan and Flood Intelligence Cards (Section 8.6.3)	Local Flood Plan sets out measures to take before and during flooding. This document should be updated to include Currambene and Moona Moona Creeks flood intelligence.	High	Provide more information such that informed decision can be made during a flood and allow from flood preparedness. Latest information from the Flood Study revision and the FRMS&P can be included.	Need for strong communication with communities of concern.	SES are responsible for maintaining the Local Flood Plan.
Prepare a Flood Intelligence Card for the proposed Woollamia gauge (Section 8.6.3)	FIC's provide usable flood intelligence that can be used to inform emergency procedure.	High	Emergency procedure is supplied for flooding at Woollamia which would lead to increased efficiency and reduced flood risk.	Need for strong communication with communities of concern.	SES are responsible for maintaining the FIC.
Encourage floodplain exposures to develop flood emergency plans (Section 8.6.2.8)	Key floodplain exposures such as Jervis Bay Cabins and Camping, Jervis Bay Caravan Park and Paperbark Camp resort etc. are at risk of flooding due to their locations on the floodplain and should prepare for potential flooding by preparing flood emergency plans.	Medium	Reduce flood risk for locations situated in the highest risk areas.	None.	Council and the NSW SES have shared responsibility.
Community Consultation Program (Section 8.6.4)	Undertaken by Council and the SES. Community consultation to inform the community of flood risk. The Program should include: • Help the community understand the residual flood risk and develop their own emergency plans. • Develop media to promote the dangers of driving through floodwaters	On going	Continuing awareness of the community leads to better preparedness and therefore fewer damages during a flood event.	People begin to ignore advice and information if too much is given, particularly if they believe there is little risk of flooding.	Council and NSW SES. Can be variable depending on the methods used. Can be incorporated with other Council information provision to reduce costs.
Install road signs with flood warnings (Section 8.6.4**)**	Roads signs that indicate flood depths and the risks of driving through flood waters should be installed where roads are cut by flooding.	High	Reduced flood risk for drivers.	None.	Council would be responsible for implementation and maintaining road signs. Estimated cost of approximately $2,000 per sign.

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Figures

Appendix A

APPENDIX A: GLOSSARY of TERMS

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
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.
consent authority	The Council, Government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (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. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.
disaster plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of

	connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (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).
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at

	State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the Aflood liable land@ concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL=s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the Astandard flood event@ in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a 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 hazard categories are provided in the Manual.

hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or • water depths generally in excess of 0.3 m (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 flow paths through developed areas outside of defined drainage reserves; and/or • the potential to affect a number of buildings along the major flow path.
mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State=s rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. **major flooding:** appreciable urban areas are flooded and/or extensive rural areas

	are flooded. Properties, villages and towns can be isolated.
modification measures	Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to Awater level@. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Appendix B

CURRAMBENE AND MOONA MOONA CREEKS FLOOD STUDY SURVEY BRIEF

1. BACKGROUND

WMAwater are preparing a Floodplain Risk Management Study and Plan for Currambene and Moona Moona Creeks on behalf of Shoalhaven City Council. Part of this work involves obtaining survey. We require:

1. Creek in-bank and floodplain cross section survey perpendicular to flow direction at 10 locations (see Section 2);
2. floor levels of all potential flood liable buildings (habitable or commercial buildings but not sheds or garages) within the study area (see Section 3). The number of properties floor levels to be surveyed is 226 in the Huskisson/Woollamia region; and
3. Survey of 27 hydraulic structures (see Section 4).

You are invited to provide an email with an attached letter quote, by Thursday 17th April 2014, detailing your proposal and timeframe for completion to undertake the works as described above.

We have provided the following information to assist with your quotation:

Cross Section Survey

- Images of cross section locations (Images 1 – 3); and
- Coordinates of the start and finish of each cross sections (Table 1).

Floor Level Survey

- Figures 1 to 9 showing the properties to be surveyed (properties displayed as pink dots);
- Table 2 which displays the property ID number (for reference to Figures 2 – 9), the XY coordinates in MGA56, the street address and the map on which each point is displayed; and
- Spreadsheet for results format of floor level information (Table 3).

Structure Survey

- Coordinates of structures which require survey (Table 4); and
- Survey requirements of each structure type (i.e bridges and culverts).

Note that if required, GIS layers of the cadaster and property/structure points can be made available.

Should you require further clarification please do not hesitate to contact the undersigned.

Zac Richards – Engineer
WMAwater, Level 2, 160 Clarence Street, SYDNEY NSW 2000
Telephone: (02) 9299 2855
Email: richards@wmater.com.au

Note that the surveyor is to follow all OEH/Council protocols for entering private property and the relevant Occupational Health and Safety requirements for working in traffic.

2. CROSS SECTION SURVEY

Cross section survey of Currambene Creek (in-bank and overbank) is required at 10 locations. The locations of the seven upstream cross sections are displayed in Image 1 and Image 2, a region located 300 m downstream (east) of the Princess Highway. Survey of three additional cross section are required near the Currambene Creek outlet at Huskisson (Image 3).

The coordinates of each end of the 10 cross sections is presented in Table 1. These should be used to determine the cross sections locations and a straight line should be surveyed between these two points.

Table 1: Cross sections start and end locations

	Start Point		End Point	
Cross Section	X	Y	X	Y
1	280824.3	6127546	280845.2	6127667
2	280826.3	6127541	280902.3	6127641
3	280828.8	6127537	280942.5	6127590
4	280826.3	6127535	280946	6127486
5	280815.4	6127506	280936.6	6127438
6	280772.1	6127385	280895.3	6127347
7	280746.8	6127116	280898.3	6127116
8	287328.5	6120728	287612.6	6120654
9	287396	6120481	287587.8	6120493
10	287592.7	6120385	287630.5	6120285

The purpose of survey is for hydraulic (flood) modelling. Data can be provided as x,y,z points. The required horizontal and vertical accuracy for these cross sections is different to that of the floor level survey. We require ± 0.15 m accuracy in the vertical (1st confidence interval) and ± 1.0 m in the horizontal.

Image 1: Upstream estimated cross section locations presented with DEM

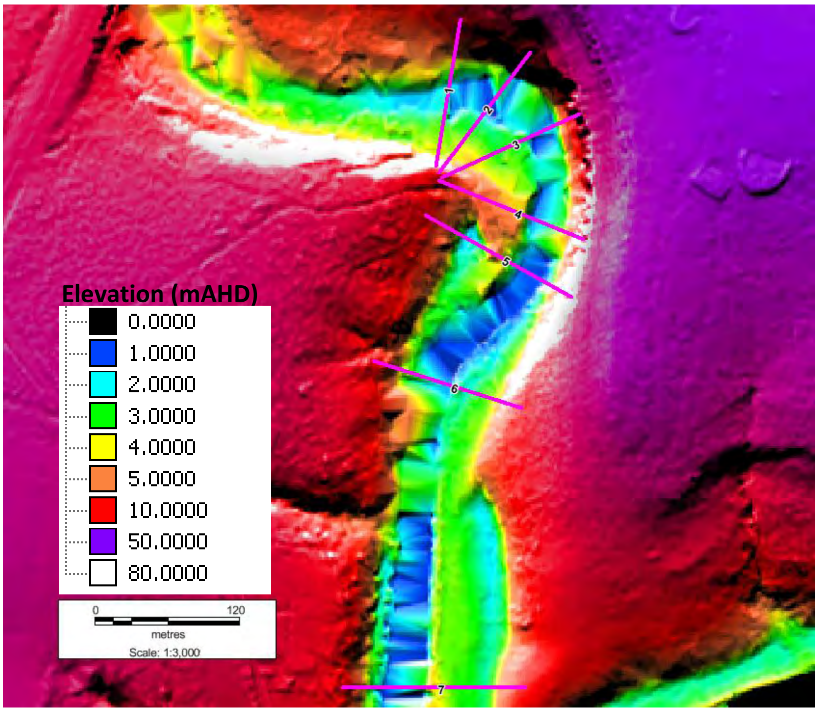

Figure 2: Upstream estimated cross section locations presented with aerial imagery

Image 3: Downstream cross section at Currambene Creek outlet

The furthest upstream cross section (Cross Section 1) is located at the minor waterfall (likely dry, see Images 4 and 5). Images 4 and 5 below show the side view (Image 4) and view from downstream (Image 5) at Cross Section 1. The survey should describe the most confined cross section possible at this location (i.e. the top of the water fall).

Image 4

Image 5

Cross section survey is required within the in-bank, which at some locations may be several metres under water. Survey on the overbank is required at ground level in regions which are likely to be heavily vegetated.

At each cross section, 4 suitably labelled photographs are to be provided:

1. Photograph looking upstream from the cross section;
2. Photograph looking downstream from the cross section;
3. Photograph of the right bank (when looking downstream); and
4. Photograph of the left bank (when looking downstream);

3. FLOOR LEVEL SURVEY

We require floor level information for all buildings listed in Table 2. Further details of the locations of the required properties are presented in Figures 1 – 9. Survey details are to be provided as per the format displayed in Table 3 (a digital version of Table 3 will be provided). At each location a digital photograph (suggested max size of photo 500kb) of each building is required with the file name of the photograph provided in Table 3.

The following deliverables are required for each surveyed residence.

- Completed Table 3 in a spreadsheet to include;
    - property tag ID (as per Table 2);
    - Photograph of each building;
    - Number of buildings on property (small sheds / garages do not need to be included);
    - Property name, number and street address;
    - True XY co-ordinate of survey point in MGA56 (i.e. not provided estimate XY);
    - Indicative ground level of property (taken at front door / same location as floor level) in mAHD;
    - Lowest floor level (lowest habitable level if residential) in mAHD;
    - If residential;
        - Habitable floor level;

    - Number of storeys;
    - Comment if habitable uses on ground floor;
    - House size (estimate);
    - Floor and Wall construction.
  - If non-residential;
    - Type of use, Commercial, Industrial, Public etc;
    - Name / nature of business or use;
    - Lowest floor level;
    - Approximate floor area;
    - Floor and Wall construction.
- Set of photographs – appropriately named and referenced to the properties (can be digital format).

For residential blocks where one floor level applied to the block, the number of ground floor properties needs to be noted. Likewise for commercial office blocks, the number of ground floor companies needs to be noted.

We require ± 0.1 m accuracy in the vertical for floor level survey (1st confidence interval) and ± 1.0 m in the horizontal.

4. STRUCTURE SURVEY

The approximate coordinates of 27 structures that require survey is displayed in Table 4 with the locations presented in Figure 10.

Table 4: Structure Locations

Structure ID	X	Y
1	286581.78	6122463.09
2	286434.27	6122663.76
3	285299.32	6122910.29
4	284509.91	6122865.1
5	282495.18	6121871.03
6	282755.66	6121687.63
7	282846.04	6121621.18
8	282955.01	6121536.13
9	281636.67	6122761.44
10	282572.27	6122830.55
11	283598.23	6123186.71
12	282997.54	6123925.62
13	282694.54	6124382.79
14	283163.78	6123197.23
15	281472.23	6123804.12
16	280792.16	6123674.99
17	281304.36	6124613.31
18	282651.58	6124548.75
19	282083.43	6126060.6
20	280753.42	6126938.66
21	287922.08	6118805.87
22	287519.63	6117929.96
23	286516.76	6116808.71
24	283026.04	6118037.56
25	284020.32	6118248.47
26	283783.58	6119049.06
27	283483.04	6121172.43

Please note the survey requirements for each structure type below.

BRIDGE:

Please provide scaled diagrammatic representation of available flow area under and over bridge including:

- Creek cross section survey at upstream face;
- Creek cross section survey at downstream side offset a few meters from structure;
- Pier locations and width;
- Level of deck underside at each creek side (and middle if curved bridge deck);
- Level of deck top at each creek side (and middle if curved bridge deck); and
- Level of fence/railing top at each creek side (and middle if curved bridge deck).

Additional to diagrammatic representation please provide ASCII (X, Y, Z) electronic format of all survey points. Examples of these requirements are contained in Figures 11 and 12.

CULVERT:

Please provide scaled diagrammatic representation of available flow area through structure and via over flow path (i.e. road topping) including:

- Provide internal dimensions of circular culverts (diameter) and rectangular box culverts (width, height);
- Provide upstream and downstream levels of culvert inverts; and
- Provide cross section survey of culvert topping flow path (eg road height).

Additional to diagrammatic representation please provide ASCII (X, Y, Z) electronic format of all survey points.

ADDITIONAL REQUIREMENTS:

For all structure types please note:

- Sections should show the distance relative to a zero point on the left bank looking downstream.
- Provide labelled photographs of all structures surveyed.

Vertical accuracy should be ± 25 mm and Horizontal accuracy ± 1 m.

5. Projection and Datum

All data is required in the Map Grid of Australia (MGA) Zone 56 projected Cartesian coordinate system, based on the Geocentric Datum of Australia (GDA) 1994 geocentric coordinate system. An easting and northing is required for each survey point. All survey levels will be in metres reduced to Australian Height Datum (m AHD).

6. Tender Requirements

Please provide a fixed price quotation to undertake the above work together with a timetable for completion via email to **richards@wmawater.com.au by Thursday 17th April**. Please contact the undersigned if you require any further clarification.

Yours Sincerely,
WMAwater

Zac Richards
Project Engineer

Table 2: Property Floor Level Survey

ID	X	Y	ADDRESS	Map No.
1	286282	6123288	29 Streamside St	Figure2
2	286261	6123294	27 Streamside St	Figure2
3	286241	6123280	25 Streamside St	Figure2
4	286220	6123285	23 Streamside St	Figure2
5	286200	6123282	21 Streamside St	Figure2
6	286180	6123276	19 Streamside St	Figure2
7	286160	6123273	17 Streamside St	Figure2
8	286140	6123272	15 Streamside St	Figure2
9	286121	6123269	13 Streamside St	Figure2
10	286101	6123267	11 Streamside St	Figure2
11	286081	6123264	9 Streamside St	Figure2
12	286060	6123264	7 Streamside St	Figure2
13	286039	6123258	5 Streamside St	Figure2
14	286300	6123290	31 Streamside St	Figure2
15	286318	6123321	33 Streamside St	Figure2
16	286341	6123321	35 Streamside St	Figure2
17	286360	6123330	37 Streamside St	Figure2
18	286376	6123331	39 Streamside St	Figure2
19	286401	6123303	41 Streamside St	Figure2
20	285901	6123129	12 Willowford Rd	Figure2
21	286462	6122509	720 Woollamia Rd	Figure8
22	286467	6122491	722 Woollamia Rd	Figure8
23	286464	6122474	724 Woollamia Rd	Figure8
24	286473	6122440	728 Woollamia Rd	Figure8
25	286458	6122237	752 Woollamia Rd	Figure8
26	286460	6122252	750 Woollamia Rd	Figure8
27	286463	6122289	746 Woollamia Rd	Figure8
28	286457	6122308	Woollamia Rd	Figure8
29	286457	6122323	742 Woollamia Rd	Figure8
30	286453	6122340	740 Woollamia Rd	Figure8
31	286467	6122357	738 Woollamia Rd	Figure8
32	286472	6122373	736 Woollamia Rd	Figure8
33	286470	6122390	734 Woollamia Rd	Figure8
34	286468	6122408	732 Woollamia Rd	Figure8
35	286558	6122416	1 Edendale St	Figure8
36	286538	6122339	737 Woollamia Rd	Figure8
37	286516	6122256	749 Woollamia Rd	Figure8
38	286522	6122235	751 Woollamia Rd	Figure8
39	286523	6122212	753 Woollamia Rd	Figure8
40	286531	6122180	755 Woollamia Rd	Figure8
41	286543	6122127	759 Woollamia Rd	Figure8
42	286474	6122121	760 Woollamia Rd	Figure8
43	286478	6122100	762 Woollamia Rd	Figure8
44	286484	6122082	764 Woollamia Rd	Figure8
45	286491	6122062	766 Woollamia Rd	Figure8
46	286496	6122047	768 Woollamia Rd	Figure8
47	286531	6121980	774 Woollamia Rd	Figure8
48	286537	6121962	776 Woollamia Rd	Figure8
49	286536	6121941	778 Woollamia Rd	Figure8
50	286534	6121923	780 Woollamia Rd	Figure8
51	286545	6121909	782 Woollamia Rd	Figure8
52	286546	6121891	784 Woollamia Rd	Figure8
53	286621	6121988	779 Woollamia Rd	Figure8
54	286966	6121604	49 Frank Lewis Way	Figure4
55	286920	6121632	10B Coulon St	Figure4
56	286961	6121677	8 Coulon St	Figure4
57	286944	6121688	10 Coulon St	Figure4
58	287465	6122100	7 Cartwright St	Figure9
59	287485	6122105	9 Cartwright St	Figure9
60	287501	6122105	11 Cartwright St	Figure9
61	287515	6122105	13 Cartwright St	Figure9
62	287592	6122175	61 Catherine St	Figure9
63	287569	6122159	59 Catherine St	Figure9
64	287565	6122140	57 Catherine St	Figure9
65	287567	6122114	55 Catherine St	Figure9
66	287565	6122096	53 Catherine St	Figure9
67	287563	6122044	49 Catherine St	Figure9
68	287559	6122030	47 Catherine St	Figure9
69	287576	6122000	43 Catherine St	Figure9
70	287561	6121968	39 Catherine St	Figure9
71	287546	6121922	35 Catherine St	Figure9
72	287626	6121984	28 Catherine St	Figure9
73	287628	6122000	30 Catherine St	Figure9
74	287503	6121997	1 Cartwright St	Figure9
75	287566	6121910	33 Catherine St	Figure9
76	287569	6121880	29 Catherine St	Figure9
77	287594	6121822	21 Catherine St	Figure9

ID	X	Y	ADDRESS	Map No.
78	287571	6121866	27 Catherine St	Figure9
79	287575	6121850	25 Catherine St	Figure9
80	287579	6121836	23 Catherine St	Figure9
81	287618	6121638	1 Catherine St	Figure9
82	287604	6121659	3 Catherine St	Figure9
83	287622	6121690	5 Catherine St	Figure9
84	287606	6121703	7 Catherine St	Figure9
85	287589	6121714	9 Catherine St	Figure9
86	287613	6121742	11 Catherine St	Figure9
87	287588	6121758	13 Catherine St	Figure9
88	287595	6121777	15 Catherine St	Figure9
89	287593	6121791	17 Catherine St	Figure9
90	287599	6121808	19 Catherine St	Figure9
91	287630	6122019	32 Catherine St	Figure9
92	287632	6122037	34 Catherine St	Figure9
93	287632	6122054	36 Catherine St	Figure9
94	287637	6122094	38 Catherine St	Figure9
95	287635	6122111	40 Catherine St	Figure9
96	287499	6122041	3 Cartwright St	Figure9
97	287641	6122128	42 Catherine St	Figure9
98	287650	6122146	44 Catherine St	Figure9
99	287646	6122166	46 Catherine St	Figure9
100	287648	6122183	48 Catherine St	Figure9
101	287651	6122202	50 Catherine St	Figure9
102	287645	6122221	52 Catherine St	Figure9
103	287649	6122239	54 Catherine St	Figure9
104	287650	6122258	56 Catherine St	Figure9
105	287652	6122275	58 Catherine St	Figure9
106	287659	6122295	60 Catherine St	Figure9
107	287668	6122312	62 Catherine St	Figure9
108	286039	6123193	2 Streamside St	Figure2
109	286382	6123217	36 Streamside St	Figure2
110	286337	6123152	34 Streamside St	Figure2
111	286205	6123068	661B Woollamia Rd	Figure2
112	286170	6123064	661A Woollamia Rd	Figure2
113	286122	6123051	4 Allora Cl	Figure2
114	286089	6122981	3 Allora Cl	Figure2
115	286049	6122905	655B Woollamia Rd	Figure2
116	286248	6122856	685 Woollamia Rd	Figure2
117	286005	6122819	660 Woollamia Rd	Figure2
118	286369	6122583	712 Woollamia Rd	Figure8
119	286407	6121944	14 James Farmer Gr	Figure8
120	286433	6121840	17 James Farmer Gr	Figure8
121	286374	6122206	754 Woollamia Rd	Figure8
122	285555	6123078	609 Woollamia Rd	Figure2
123	285610	6123064	613 Woollamia Rd	Figure2
124	285679	6123060	621 Woollamia Rd	Figure2
125	286635	6122421	13 Edendale St	Figure8
126	286655	6122410	15 Edendale St	Figure8
127	286674	6122425	17 Edendale St	Figure8
128	286692	6122425	19 Edendale St	Figure8
129	286708	6122425	21 Edendale St	Figure8
130	286722	6122423	23 Edendale St	Figure8
131	286739	6122422	25 Edendale St	Figure8
132	286758	6122421	27 Edendale St	Figure8
133	286775	6122420	29 Edendale St	Figure8
134	286796	6122419	31 Edendale St	Figure8
135	286814	6122394	1 Sunnyside Ave	Figure8
136	286816	6122428	33 Edendale St	Figure8
137	286840	6122425	35 Edendale St	Figure8
138	286930	6122448	10 Sunnyside Ave	Figure8
139	286936	6122463	12 Sunnyside Ave	Figure8
140	286949	6122478	14 Sunnyside Ave	Figure8
141	286965	6122491	16 Sunnyside Ave	Figure8
142	286972	6122505	18 Sunnyside Ave	Figure8
143	286985	6122520	20 Sunnyside Ave	Figure8
144	286857	6122373	39 Edendale St East	Figure8
145	286873	6122368	41 Edendale St East	Figure8
146	286887	6122366	43 Edendale St East	Figure8
147	286903	6122364	45 Edendale St East	Figure8
148	286918	6122359	47 Edendale St East	Figure8
149	286935	6122365	49 Edendale St East	Figure8
150	287410	6120306	14 Sydney St	Figure 6
151	287422	6120292	3 Field St	Figure 6
152	287430	6120285	5 Field St	Figure 6
153	287439	6120280	7 Field St	Figure 6
154	287445	6120266	9 Field St	Figure 6

ID	X	Y	ADDRESS	Map No.
155	287468	6120262	13 Field St	Figure 6
156	287389	6120337	10 Sydney St	Figure 6
157	287413	6120354	6 Sydney St	Figure 6
158	287394	6120375	4 Sydney St	Figure 6
159	287390	6120400	2 Sydney St	Figure 6
160	287379	6120438	12 Admiralty Cres	Figure 6
161	287380	6120457	10 Admiralty Cres	Figure 6
162	287377	6120474	8 Admiralty Cres	Figure 6
163	287377	6120491	6 Admiralty Cres	Figure 6
164	287375	6120507	4 Admiralty Cres	Figure 6
165	287361	6120523	2 Admiralty Cres	Figure 6
166	287323	6120545	15 Wood Cres	Figure 6
167	287328	6120618	4 Wood Cres	Figure 6
168	287315	6120635	4 Dent St	Figure 6
169	287309	6120599	6 Wood Cres	Figure 6
170	287341	6120669	1 Wood Cres	Figure 6
171	287346	6120652	3 Wood Cres	Figure 6
172	287359	6120647	5 Wood Cres	Figure 6
173	287369	6120634	7 Wood Cres	Figure 6
174	287381	6120624	9 Wood Cres	Figure 6
175	287216	6120735	11 Dent St	Figure6
176	286842	6121750	20 Coulon St	Figure4
177	286859	6121741	18 Coulon St	Figure4
178	286907	6121708	12 Coulon St	Figure4
179	286974	6121664	6 Coulon St	Figure4
180	286989	6121654	4 Coulon St	Figure4
181	287001	6121644	2 Coulon St	Figure4
182	285236	6123508	50 Goodland Rd	Figure3
183	285148	6123639	55 Goodland Rd	Figure3
184	285109	6123613	53 Goodland Rd	Figure3
185	285021	6123249	13 Goodland Rd	Figure3
186	285104	6123514	Goodland Rd	Figure3
187	286587	6121362	2 Duranbah Dr	Figure5
188	286640	6121276	1 Bolten Rd	Figure5
189	286706	6121208	2 Erina Rd	Figure5
190	286776	6121133	1 Erina Rd	Figure5
191	286563	6122347	Woollamia Rd	Figure8
192	286521	6122275	747 Woollamia Rd	Figure8
193	286617	6122014	777 Woollamia Rd	Figure8
194	281476	6127048	120 Falls Rd	Figure7
195	282067	6126483	120 Falls Rd	Figure7
196	281864	6127071	140 Comberton Grange Rd	Figure7
197	282656	6125599	775B Falls Rd	Figure7
198	282759	6125606	775C Falls Rd	Figure7
199	282788	6125545	775D Falls Rd	Figure7
200	282619	6125183	805 Falls Rd	Figure7
201	282512	6124584	206A Woollamia Rd	Figure7
202	282560	6124461	216A Woollamia Rd	Figure7
203	282597	6124426	216B Woollamia Rd	Figure7
204	283484	6123683	335 Woollamia Rd	Figure3
205	283603	6123440	355 Woollamia Rd	Figure3
206	284644	6122739	444B Woollamia Rd	Figure3
207	284596	6122539	8 Pritchard Ave	Figure3
208	284570	6122457	10 Pritchard Ave	Figure3
209	284501	6122368	12 Pritchard Ave	Figure3
210	284516	6122199	14 Pritchard Ave	Figure3
211	284762	6123100	521 Woollamia Rd	Figure3
212	285148	6122845	560 Woollamia Rd	Figure3
213	285466	6122864	598 Woollamia Rd	Figure2
214	286574	6123201	52 Streamside St	Figure2
215	286241	6123217	26 Streamside St	Figure2
216	287497	6120243	57 Owen St	Figure 6
217	283603	6122966	37 Seasongood Rd	Figure3
218	283130	6122853	27 Seasongood Rd	Figure3
219	283040	6122815	25 Seasongood Rd	Figure3
220	282907	6122832	23 Seasongood Rd	Figure3
221	282657	6122650	19 Seasongood Rd	Figure3
222	282763	6122533	21 Seasongood Rd	Figure3
223	282173	6125607	726 Falls Rd	Figure7
224	282268	6125588	740 Falls Rd	Figure7
225	282006	6125204	111 Woollamia Rd	Figure7
226	281916	6125199	101 Woollamia Rd	Figure7

Table 3 - Format for Provision of Floor Level Data

											RESIDENTIAL BUILDINGS						NON RESIDENTIAL BUILDINGS						
WMA ID	Parcel Tag as on Council cadastre (LIC_TAG)	Photograph name	Total number of buildings	Comment	Street Number	Street Name	Sub-Area	Easting	Northing	Indicative Ground Level (m AHD)	Lowest Habitable Floor Level (m AHD)	Number of Storeys	Do people live on the Ground Floor (Y or N)	**House Size** - Small (S), Medium (M), Large (L)	**Floor Construction** Pier (P) or Slab (S) Other - describe	**Wall Construction** Brick stone or rendered (B), Clad (C) , Mixed (M)	Type (commercial = C, industrial = I, public = P)	Name and Nature of Use/Business eg. Bob's Nursery, toilet block	Lowest Floor Level (m AHD)	Approximate Floor Area (m^2)	**Floor Construction** Pier (P) or Slab (S) Other - describe	**Wall Construction** Brick stone or rendered (B), Clad (C) , Mixed (M)	
WMA1	013/2//182986	31SmithSt	1		31	Smith Street		349719.030	6298859.741	2.53	2.81	1	Y	L	S	B							
WMA2	013/2//231730	36SmithSt	1		36	Smith Street		349719.030	6298859.741	6.35	4.19	1	Y	L	S	B							
WMA3	013/2//129559	38SmithSt	2	building 1	38a	Smith Street		349719.030	6298859.741	2.86	3.25	2	Y	L	S	M							
		AS ABOVE		building 2	38b	Smith Street		349719.030	6298859.741	2.83	3.45	2	Y	L	S	M							
WMA4	013/1//310952	67JonesRd	2		67	Jones Road		349719.030	6298859.741	2.50							C	BOB'S ELECTRICAL	4.47	225	S	M	second building is shed
WMA5	013/3//310952	11JonesRd	1		11	Jones Road		349719.030	6298859.741	2.50							C	CENTRAL COAST STAIRS	2.84	1000	S	M	
WMA6	013/A//410107	15JonesRd	1		15	Jones Road		349719.030	6298859.741	2.08							I	CUSTOM STAINLESS DESIGN	2.30	800	S	B	
WMA7	013/E//321030	2ANewcastleSt	1		2A	Newcastle Street		349719.030	6298859.741	12.40	12.91	1	Y	L	P	C							
		2BNewcastleSt	1		2B	Newcastle Street		349719.030	6298859.741	12.35	12.96	1	Y	L	P	C							
WMA8	013/PT3//1104617	31NewcastleSt	1		31	Newcastle Street		349719.030	6298859.741	2.19	2.79	2	Y	S	P	B							
WMA9	013/OT//112/1459	BobApts	1	flats - 5 units on ground floor	1	Bob Street		349719.030	6298859.741	3.26	3.98	56	Y	S	S	C							All units on ground floor have same floor level

FIGURE B1
FLOOR LEVEL SURVEY

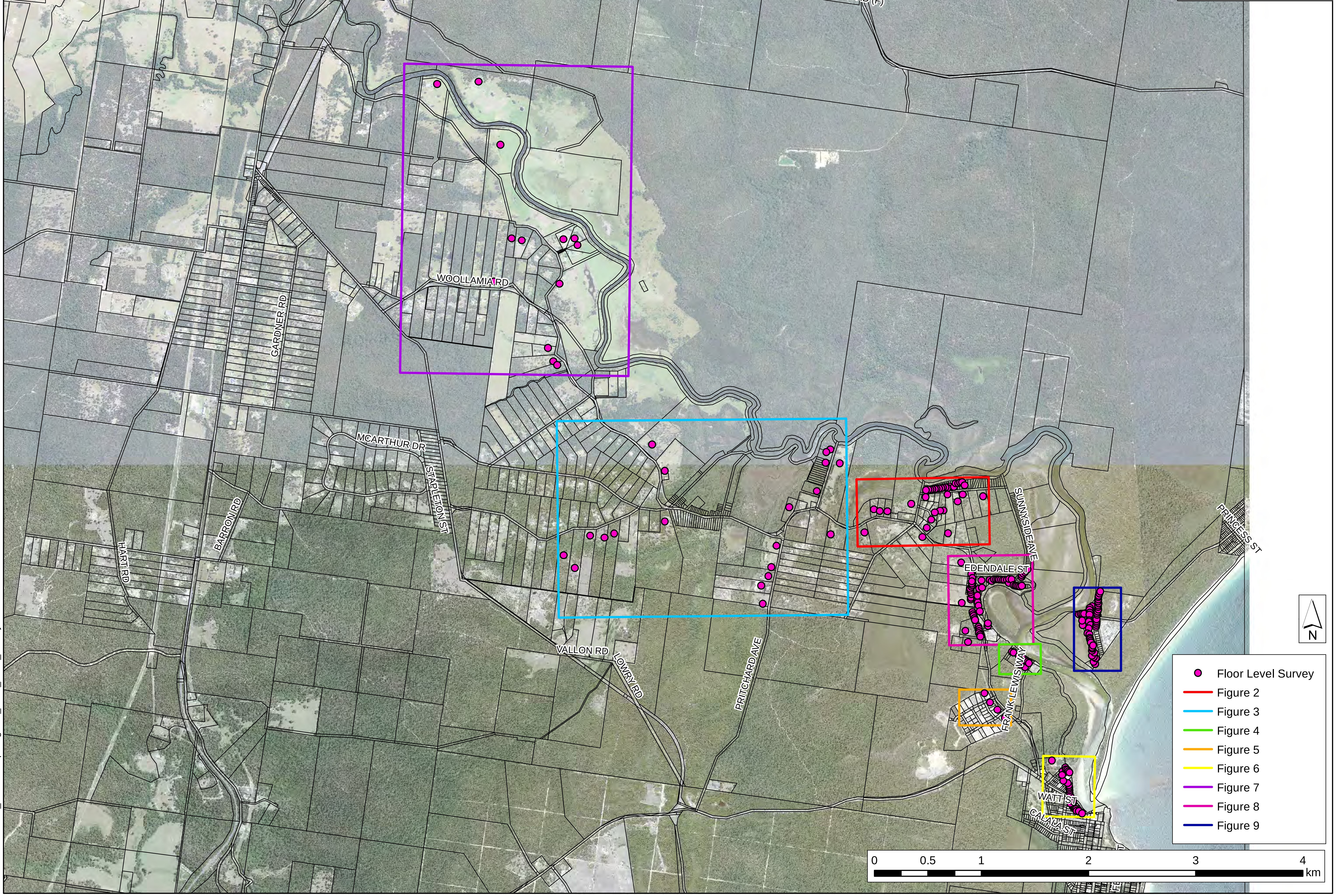

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FIGURE B2
FLOOR LEVEL SURVEY

J:\Jobs\113091\ARC_GIS\ArcMaps\Figure2_Floor_Level_Survey_woollamia and sunnysideave.mxd

FIGURE B3
FLOOR LEVEL SURVEY

J:\Jobs\113091\ARC_GIS\ArcMaps\Figure3_Floor_Level_Survey_pritchard_ave.mxd

FIGURE B4
FLOOR LEVEL SURVEY

J:\Jobs\113091\ARC_GIS\ArcMaps\Floor_Level_Survey_FranklewisWay.mxd

J:\Jobs\113091\ARC_GIS\ArcMaps\Floor_Level_Survey_Woollamia_FranklewisWay_cnr.mxd

FIGURE B6
FLOOR LEVEL SURVEY
WOOLLAMIA RD
WATT ST
FIELD ST
175
170
171
172
173
174
168
167
169
166
165
164
163
162
161
160
159
158
157
156
150
151
152
153
154
155
216
ID Survey ID
Floor Level Survey
0
100
200
m
N
J:\Jobs\113091\ARC_GIS\ArcMaps\Floor_Level_Survey_Wattst_FieldStreet.mxd

FIGURE B7
FLOOR LEVEL SURVEY
194
196
195
197
198
199
223
224
226
225
200
201
202
203
WOOLLAMIA RD
ID Survey ID
Floor Level Survey
0
0.5
1
km
N
J:\Jobs\113091\ARC_GIS\ArcMaps\Floor_Level_Survey_woollamia_road.mxd

FIGURE B8
FLOOR LEVEL SURVEY
EDENDALE ST
SUNNYSIDE AVE
EDENDALE ST EAST
WOOLLAMIA RD
JAMES FARMER GR
118
21
22
23
24
34
33
32
31
30
29
28
27
26
25
121
35
36
191
192
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
193
119
120
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
ID Survey ID
Floor Level Survey
0
125
250
m
N
J:\Jobs\113091\ARC_GIS\ArcMaps\Floor_Level_Survey_edendalestreet.mxd

FIGURE B9
FLOOR LEVEL SURVEY

J:\Jobs\113091\ARC_GIS\ArcMaps\Floor_Level_Survey_coastal.mxd

FIGURE B10
HYDRAULIC STRUCTURE SURVEY

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FIGURE B11
EXAMPLE SECTION

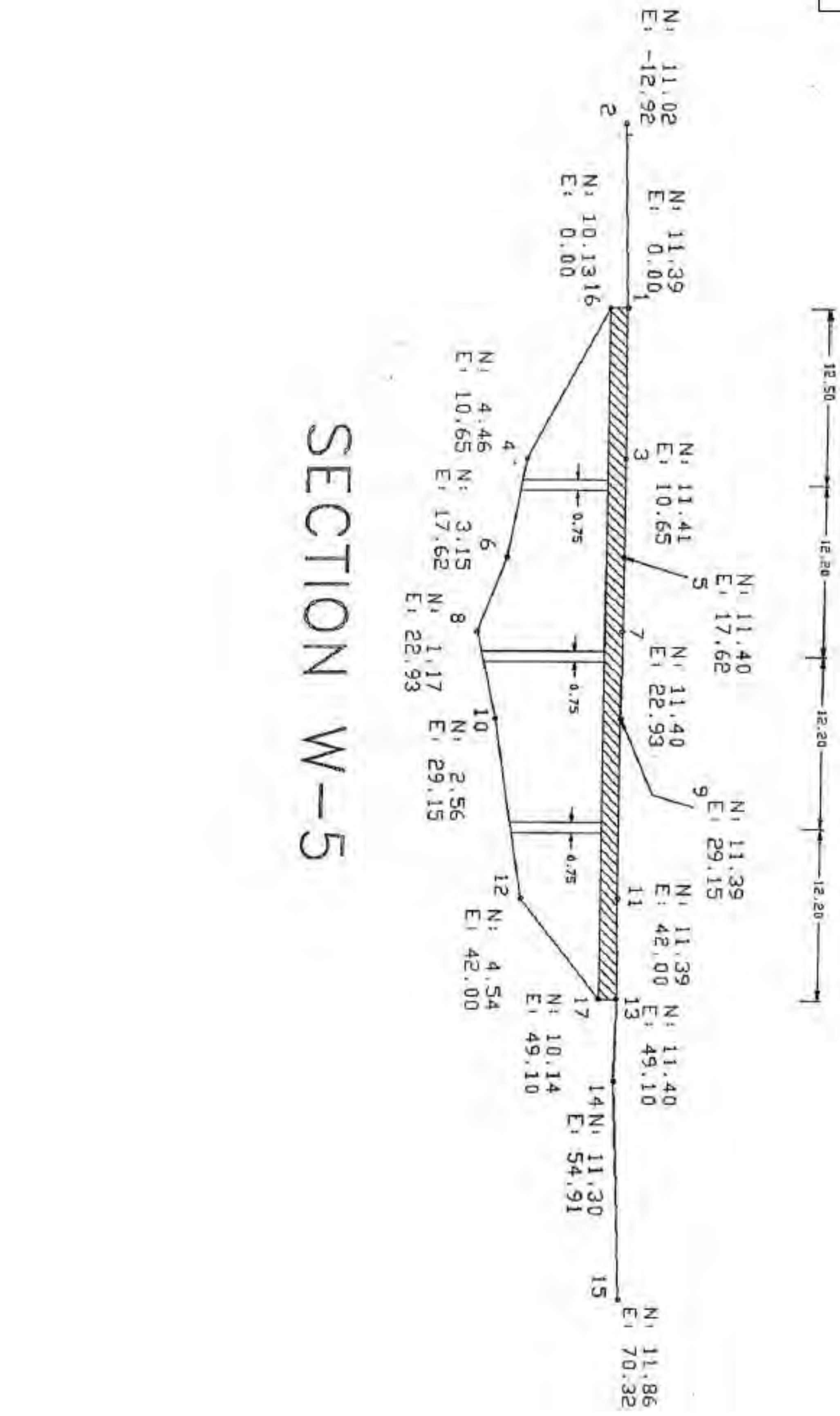


FIGURE B12
EXAMPLE OUTPUT

FORMAT OF ASCII DATA LISTING OF SECTIONS

Note that the order of points should define the cross-section as if viewed from left to right looking downstream

```
SECTION_NAME
Easting,Northing,Elevation
Easting,Northing,Elevation,
.,.,.
.,.,.
Easting,Northing,Elevations
NEXT_SECTION_NAME
Easting,Northing,Elevation
Easting,Northing,Elevation,
.,.,.
.,.,.
Easting,Northing,Elevation
```

EXAMPLE LISTING

```
UPPER CREEK Xs50
323777.500,1265590.895,56.965
323777.528,1265590.794,56.881
323777.566,1265590.657,56.880
323777.694,1265590.192,55.389
323777.696,1265590.185,55.380
323778.137,1265588.585,55.108
323778.146,1265588.551,55.108
323778.469,1265587.379,55.181
323778.469,1265587.377,55.181
323778.469,1265587.375,55.181
323778.468,1265587.374,55.181
323778.323,1265586.285,56.978
323778.065,1265584.352,57.393
323778.229,1265582.479,57.845
323778.375,1265580.838,58.241
323778.375,1265580.837,58.241
UPPER CREEK Xs60
323799.969,1265589.013,56.186
323799.968,1265589.011,56.186
323799.569,1265587.583,55.025
323799.094,1265585.883,55.074
323799.094,1265585.883,55.074
323799.094,1265585.883,55.074
```

Appendix C

MEDIA RELEASE

CURRAMBENE AND MOONA MOONA CREEKS FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

Shoalhaven City Council is seeking input from local residents for the Currambene and Moona Moona Creeks Floodplain Risk Management Study and Plan (The Study).

Council have engaged flooding consultants WMAwater to carry out The Study. An important feature of The Study is community consultation which aims at discussing options and informing the public on the progress of the project. Consultation allows the community to provide information on previous personal flooding experiences. Of particular interest are records of previous flooding and rainfall. This information will be used in computer modelling of flood behaviour in the Currambene and Moona Moona catchments. This modelling will also consider the effects of ocean levels and entrance behaviour.

Residents living near these Creeks in parts of Husskinson, Vincentia, Woollamia and Myola will soon be sent a newsletter containing details about the study along with a questionnaire seeking information about any flooding they have observed.

At the latter stages of the process, there will also be opportunity for the community to comment through further newsletters and community workshops.

For more information on the work proposed or to discuss any issues in regards to the Currambene and Moona Moona Creek Floodplain Risk Management Study, community members are encouraged to contact WMAwater or Council on:

- Zac Richards, Engineer, WMAwater
  (02) 9299 2855
  curramoona_ck@wmawater.com.au

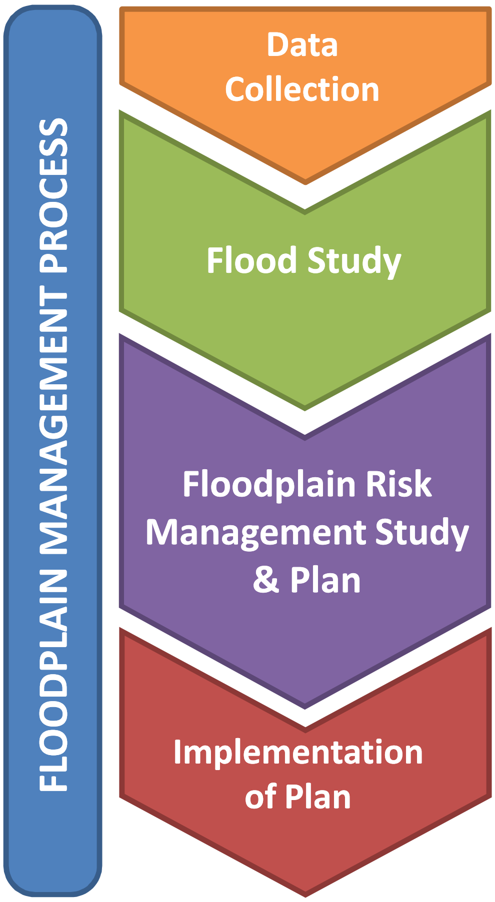
- Matthew Apolo, Senior Floodplain Engineer,
  Shoalhaven City Council
  (02) 4429 3354
  council@shoalhaven.nsw.gov.au

The study is aimed at meeting the objectives of the NSW State Government Flood Prone Land Policy. Under State Policy, NSW Local Governments are responsible for identifying and managing the risk to life and property from flooding. Funding is provided by the State Government's Flood Risk Management Program and Shoalhaven City Council.

Monday, 24 February 2014

Currambene and Moona Moona Creeks
Floodplain Risk Management Study and Plan

A Floodplain Risk Management Study and Plan (the Risk Study) is currently being prepared for Currambene and Moona Moona Creeks. Shoalhaven City Council has appointed WMAwater to undertake this Study.



The Floodplain Management Process

The State Government's Flood Policy aims to reduce the impacts of flooding and flood liability on individual owners and occupiers, and to reduce private and public losses resulting from flooding. Under the Policy, local government is responsible for managing flood liable land.

The Policy encourages the development of:

- solutions to existing flood problems in developed areas, and
- strategies for ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in existing developed areas.

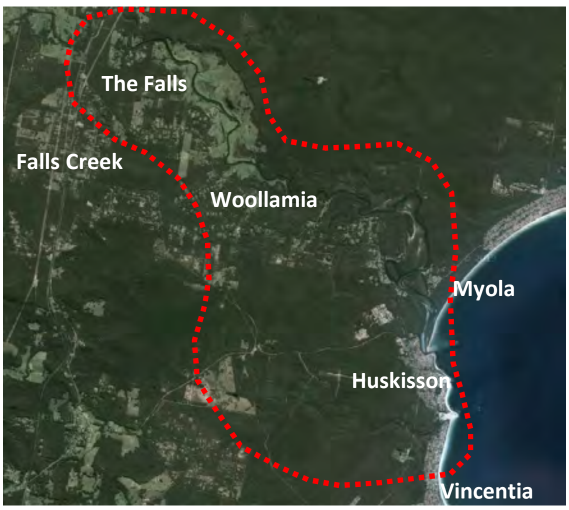
The State Government's Flood Policy provides technical and financial support for a number of floodplain management activities. Funding for this Study was provided from the State Government's Flood Risk Management Program and Shoalhaven City Council.

What's Happening Now?

This Risk Study aims to understand and determine the nature and extent of potential flooding from Currambene and Moona Moona Creeks. The first stage of the Risk Study will be to collect, compile and review all available information, including valuable community knowledge and experiences. This information will then be used to update the previous 2006 Flood Study.

Computer models will be established to determine the extent and nature of flooding along Currambene and Moona Moona Creeks and the collected historical data such as observations and photos of flooding behaviour and records of rainfall leading to flooding will be used to ensure their accuracy. In particular, information on observed peak flood levels is most important. This is where we need your help.

The Study Area



Currambene and Moona Moona Creeks flow into Jervis Bay to the north and to the south of Huskisson. The Currambene Creek catchment has an area of 160 km², while the Moona Moona Creek catchment has an area of 28 km².

Flooding from these creeks has the potential to inundate properties and areas in the vicinity of the Huskisson, Vincentia, Myola and Woollamia townships. To account for this the study area will reach as far upstream as the Princes Highway on Currambene Creek, down to the ocean.

Both the Currambene and Moona Moona Creeks are estuarial in their lower reaches with Currambene Creek being tidal to as far upstream as "The Falls" situated near the Princes Highway.

Currambene and Moona Moona Creeks
Floodplain Risk Management Study

Community involvement in this Floodplain Risk Management Study is important. The Central Shoalhaven Natural Resources and Floodplain Management Committee will oversee this Study. The committee is made up of members from Council, Office of Environment and Heritage, the State Emergency Services and local residents. A questionnaire is included with this newsletter so that your views can also be included. At a later date you will be invited to attend community workshops where we will discuss and present results of the Floodplain Risk Management Study in more detail.

How can I have my say?

A questionnaire is enclosed with this newsletter. Please complete this and return to the FREEPOST address in the envelope provided. If you prefer, questionnaires can also be completed online at: https://www.surveymonkey.com/s/currambene

Please make sure that all surveys are returned before 10th April 2014 or they may not be counted.

If you have additional information you would like to make available for this Study, or further comments, please attach these to your questionnaire response or alternatively email your comments to the contacts below.

This newsletter and questionnaire forms part of our community consultation, which aims to collect information about previous floods. The local knowledge and personal experiences of residents and business operators are an important source of information. We are specifically interested in historical records of flooding such as photographs, flood marks or observations that residents may have.

Feedback from the community will be analysed and used to establish an accurate flood model of the study area.

After data collection, the preliminary results will be produced and a draft study will be placed on public exhibition. You will be invited to view and comment on the Study and public forums will be held to present and discuss the results of the Study.

Contacts

If you would like to know more, or if you have any information on flooding which would assist in this Study, please complete the relevant sections on the questionnaire and return. Additional information and comment can be attached to the questionnaire when you return it or provided to the contacts below.

Matthew Apolo
Senior Floodplain Engineer
council@shoalhaven.nsw.gov.au

Shoalhaven City Council
PO Box 42, Nowra, NSW 2541

Tel: 02 4429 3354

Zac Richards
Project Engineer
Curramoona_ck@wmawater.com.au

WMAwater
Level 2, 160 Clarence Street
Sydney, NSW 2000

Tel: 02 9299 2855

Currambene and Moona Moona Creeks - QUESTIONNAIRE
Floodplain Risk Management Study

Please complete this questionnaire and return to the FREEPOST address in the envelope provided. If you prefer, questionnaires can also be completed online at: www.surveymonkey.com/s/currambene
Please make sure that all surveys are returned before 10th April 2014 or they may not be counted.

1. Your Details
(Please note your contact details are optional , will be held confidential and will only be used to contact you for more information regarding this study)

Name:

Address: (please enter South Coast address only)

Telephone:

Email:

Can we contact you directly for more information? ☐ Yes ☐ No

2. Is this property a residence, business, other?

☐ Residence ☐ Business ☐ Other

If business or other please provide details – e.g. Joe's Fish Shop:

3. How long have you lived/owned/worked at this address?

☐ Years ☐ Months

4. How long have you lived/owned in this area? (Huskisson, Vincentia, Woollamia etc.)

☐ Years ☐ Months

5. Are you aware of any flooding in Currambene or Moona Moona Creeks?

☐ Very Aware ☐ Some awareness ☐ Not aware at all

If "Aware" or "Some awareness" do you have any information we could use such as photographs of flooding or flood damages, recorded observations of flood depths or other information? Please provide details below or attach information. Please include dates when known.

6. Has your property ever been affected by flooding?

☐ No ☐ Yes, but only the yard ☐ Yes, above the floor level

If Yes, please provide details below (additional information can be attached to this questionnaire if necessary or emailed to curramoona_ck@wmawater.com.au).

7. Please use this section to provide any additional information or comments if you have them

Appendix D

MINUTES OF THE POLICY & RESOURCES COMMITTEE MEETING HELD ON TUESDAY, 10 FEBRUARY, 2015 IN THE COUNCIL CHAMBERS, CITY ADMINISTRATIVE CENTRE, BRIDGE ROAD, NOWRA COMMENCING AT 4.11 PM.

1. South Coast Regional Sea Level Rise Planning and Policy Response Framework
File 30596E

Note: George Kruk addressed the meeting earlier in relation to this item.

Note: That the General Manager advised that Attachment D Item 12 was withdrawn to allow the document to be peer reviewed prior to presentation to Council.

Note: Clr Findley asked that Clr Watson be requested to withdraw his comment that Clr Findley provided a 'rant' in debate. Clr Watson withdrew his comment.

MOTION: Moved: Watson / Second: Gash

RESOLVED that, in accordance with Committee's delegated authority from Council, that Council reaffirm its decision in respect of sea level projections as follows:

a) Establish a sea level rise benchmarks for planning purposes based on a 2030 horizon 100 mm, a 2050 horizon of 230 mm and 360 mm horizon for 2100 as indicated in the Whitehead & associates Report.

b) Review the projection based on real data every 7 years with tidal gauges at HMAS Creswell and Ulladulla being included in the calculations along with other NSW gauges, modelled or corrected altimeter data be excluded unless new Satellites overcome the present measurement error.

c) Apply the adopted sea level rise projections for the preparation and review of flood studies, flood risk management studies and plans, coastal hazard studies and asset management plans;

d) As part of a future amendment to Shoalhaven Development Control Plan 2014, review Chapter G6: Areas of Coastal Management and other relevant chapters to ensure provisions are consistent with the adopted Sea Level Rise Policy and

e) Continue to monitor State and Federal Government advice including Stage 2 Coastal Reform and future Intergovernmental Panel on Climate Change (IPCC) reports and review its sea level rise projections in accordance with part b.

f) Adopt the explanatory Notes and Guidelines as follows:-

   i) This resolution takes into account the following papers and Presentation, and Complementary Review of the Whitehead Report and is adopted on the basis of 7 year reviews primarily using real long term data from the Fort Denison Tidal Gauge as well as the consideration of trends from local tidal stations.

   The seven year reviews means Council's plans can quickly respond to any significant change in the rate of sea level increase or decrease and on this basis Council believes it is reasonable to use the above methodology to determine the planning levels.

It is also noted that the CZMP's are plans which are assented to by the Minister.

Whitehead and Associates Report Eurobodalla and Shoalhaven Councils.
Whitehead & Lord

The presentation by George Kruk Chartered Civil Engineer 10th Feb 2015

Commentary and Analysis on the
Whitehead & Associates 2014 NSW Sea-Level Report
Carter R.M., de Lange W., Hansen, J.M., Humlum O., Idso C.,
Kear, D., Legates, D., Mörner, N.A., Ollier C., Singer F. & Soon W.

NSW Ocean Water Levels
B Modra1, S Hesse
Manly Hydraulics Laboratory, Sydney, NSW

FOR: White, Tribe, Kearney, Gash, Baptist, Guile, Wells Watson, McCrudden and Kitchener.

AGAINST: Findley and Russ Pigg.

FIGURE 1
CURRAMBENE CREEK CATCHMENT STUDY AREA

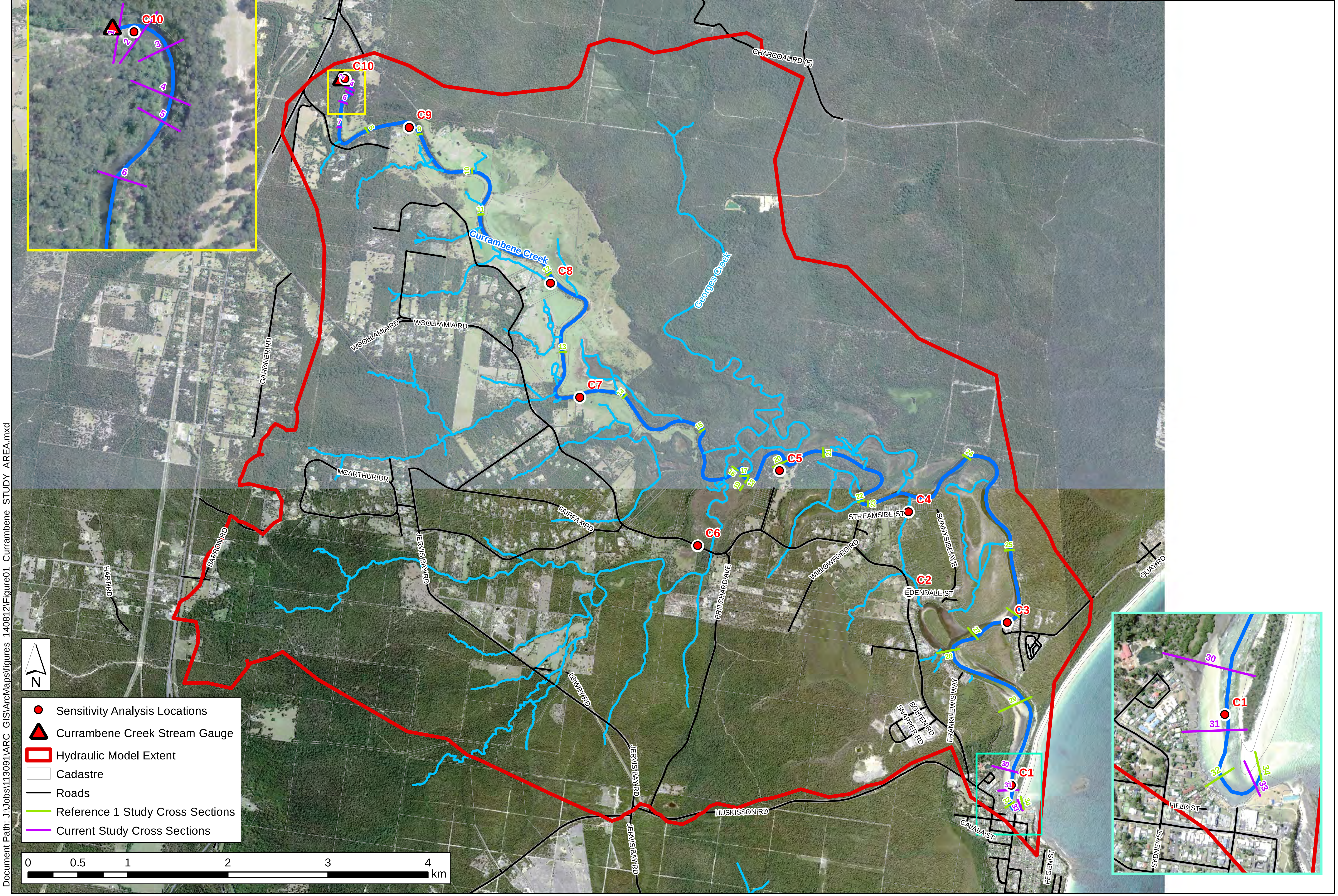


FIGURE 2
MOONA MOONA CREEK CATCHMENT STUDY AREA

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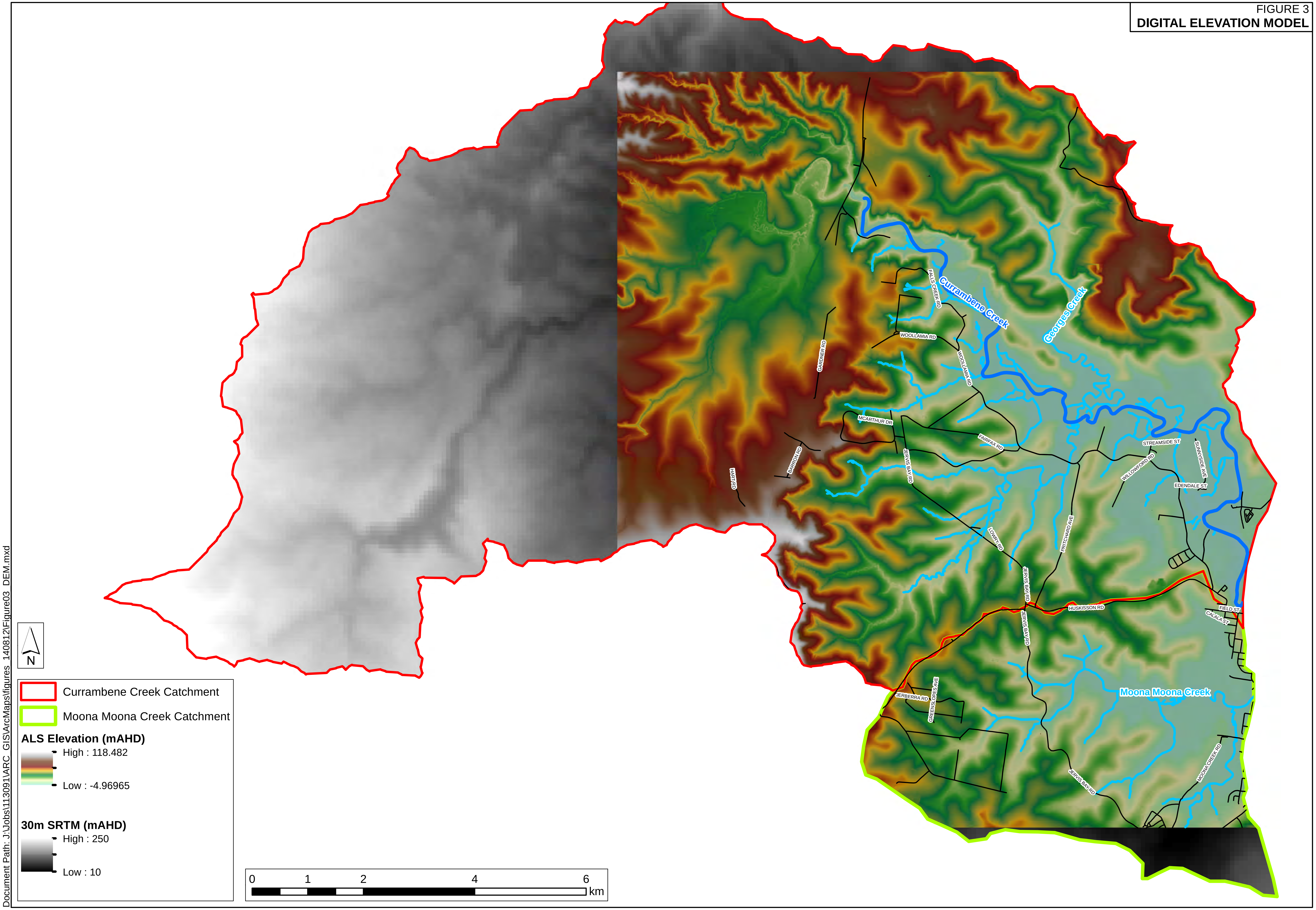

FIGURE 3
DIGITAL ELEVATION MODEL

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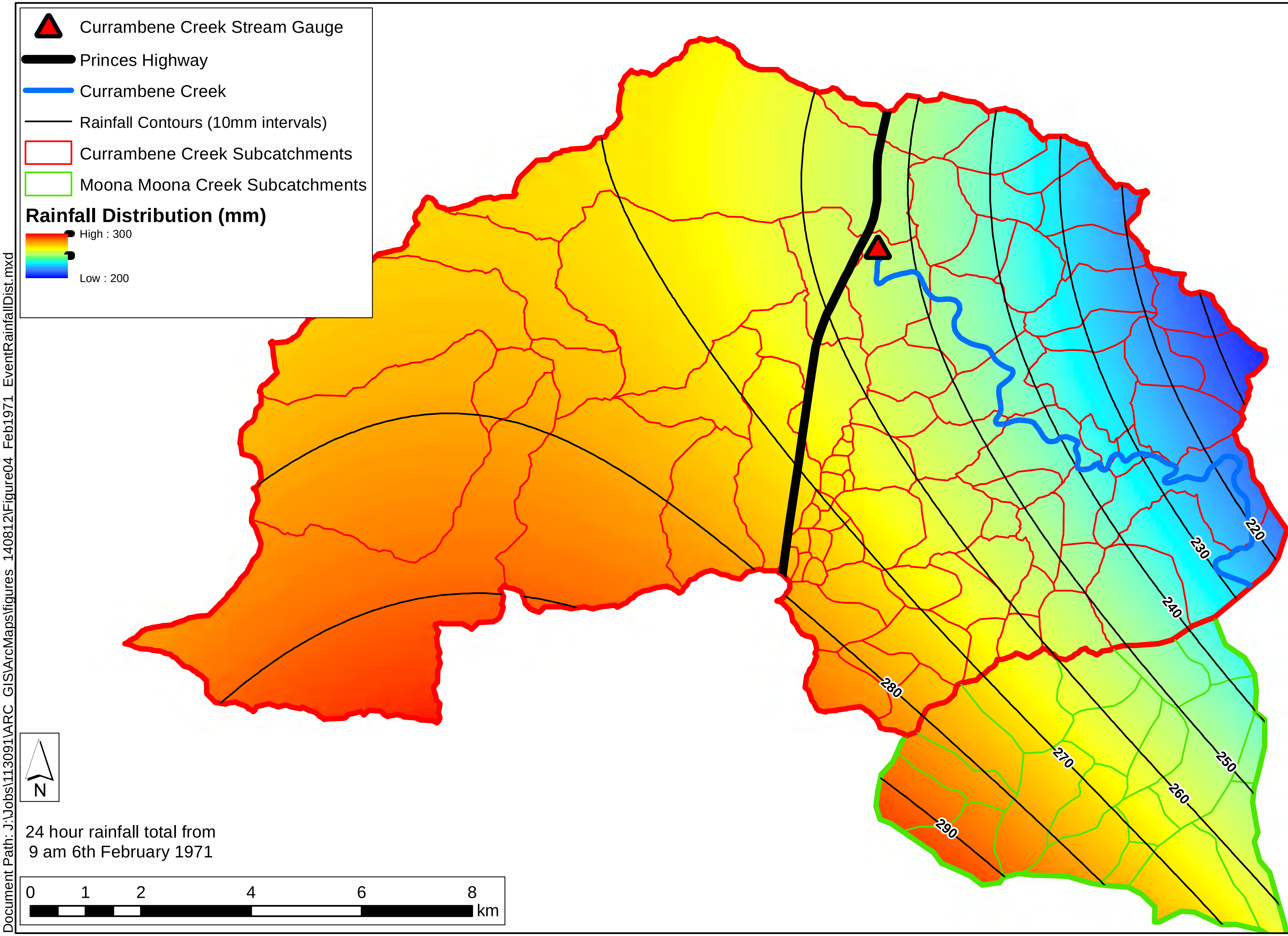


FIGURE 4
RAINFALL DISTRIBUTION
FEBRUARY 1971 EVENT

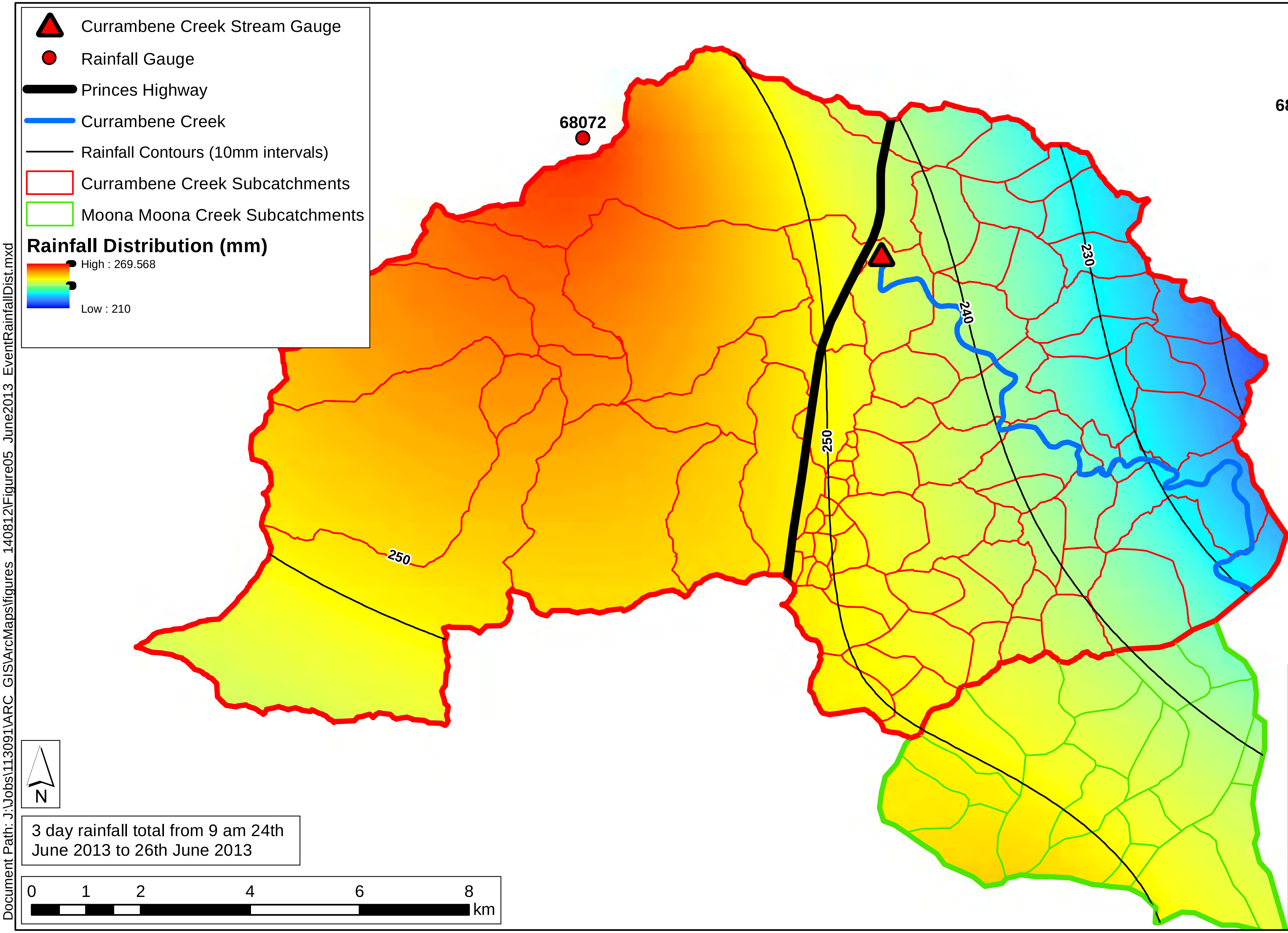
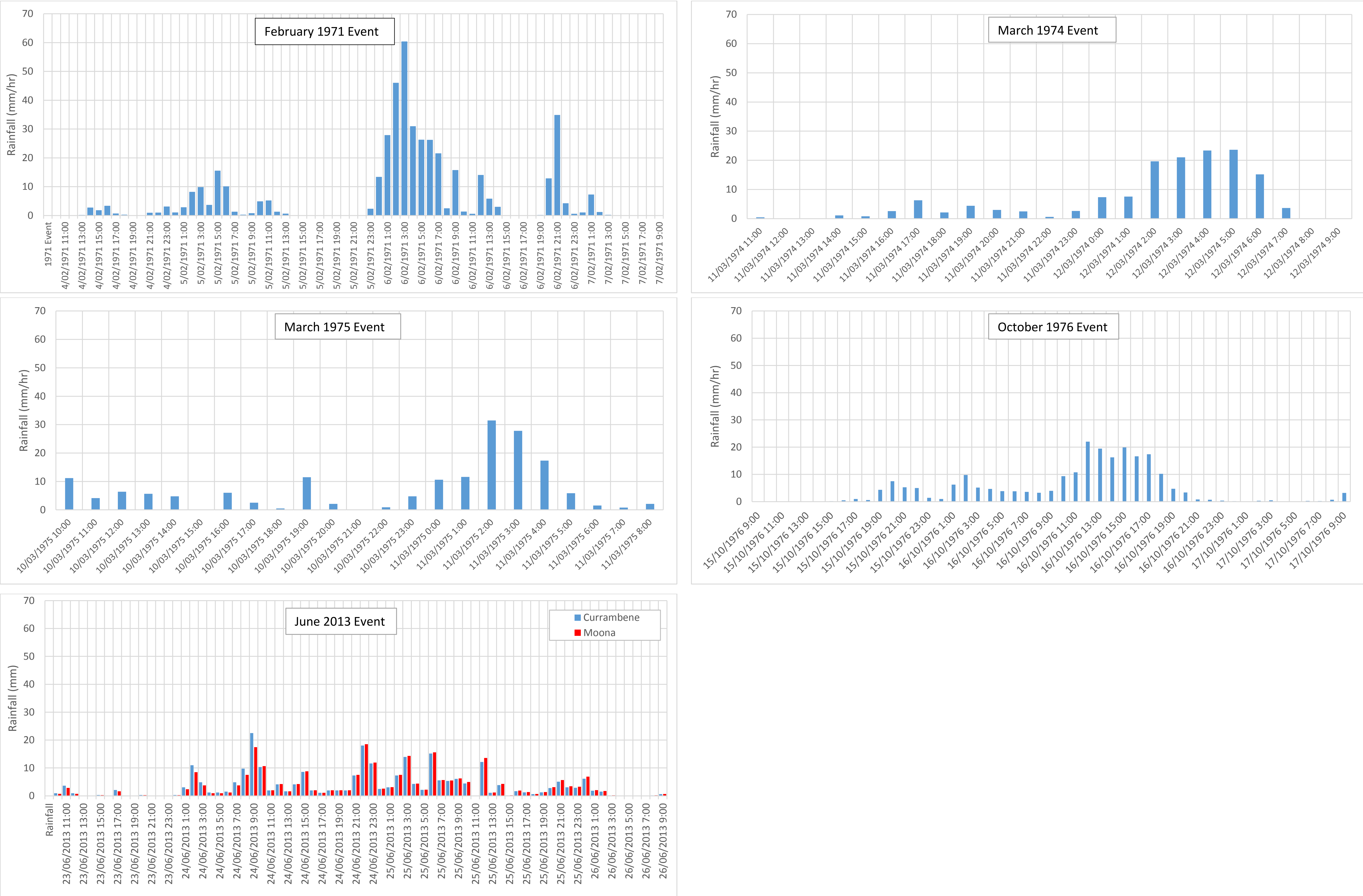


FIGURE 5
RAINFALL DISTRIBUTION
JUNE 2013 EVENT

Document Path: J:\Jobs\113091\ARC GIS\ArcMaps\figures 140812\Figure05 June2013 EventRainfallDist.mxd

FIGURE 6
HISTORIC EVENTS HYETOGRAPHS



J:\Jobs\113091\Hydrology\Historic_Event_Rainfall\Currambene_IFD_Bursts.xlsm

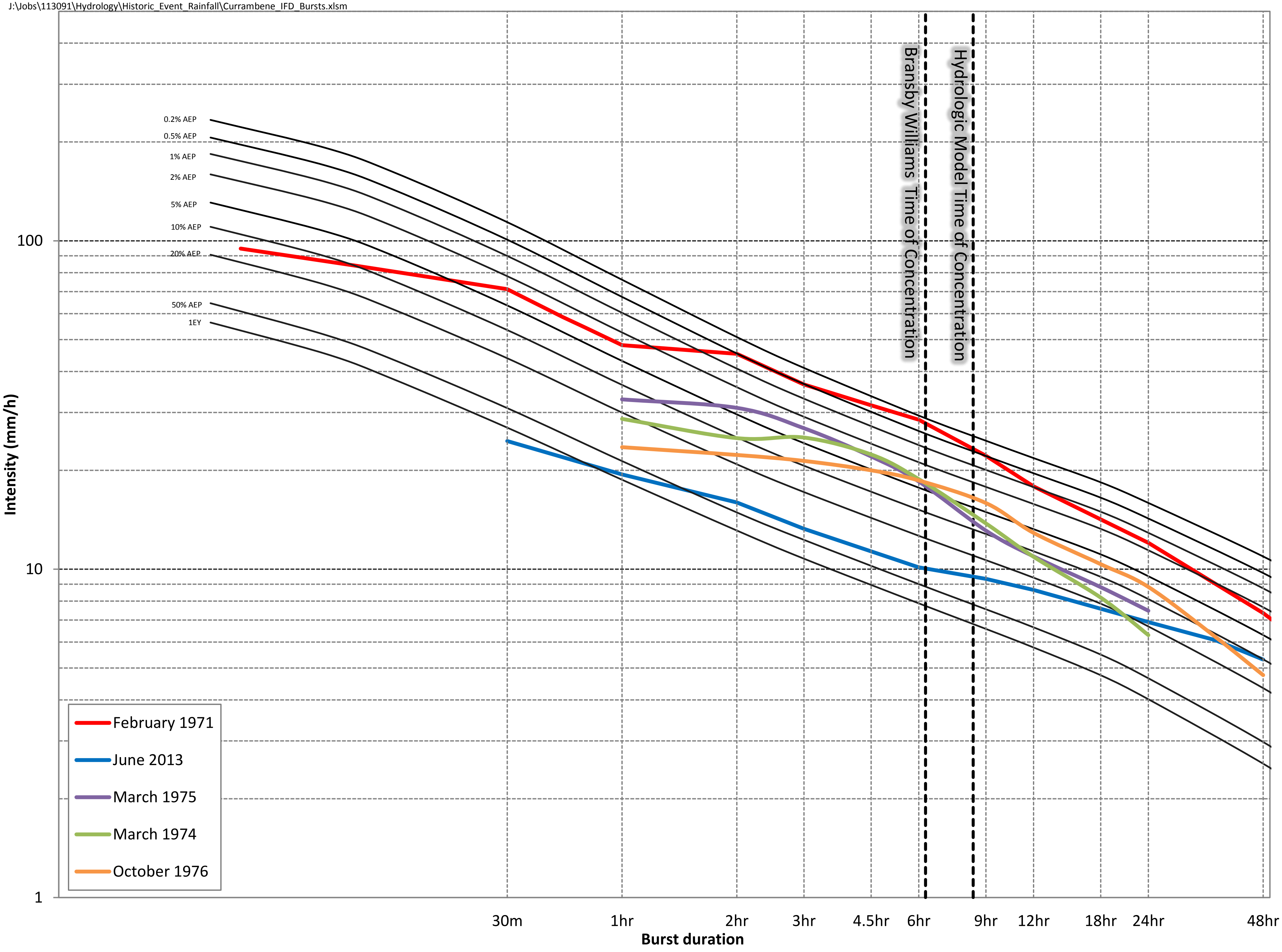
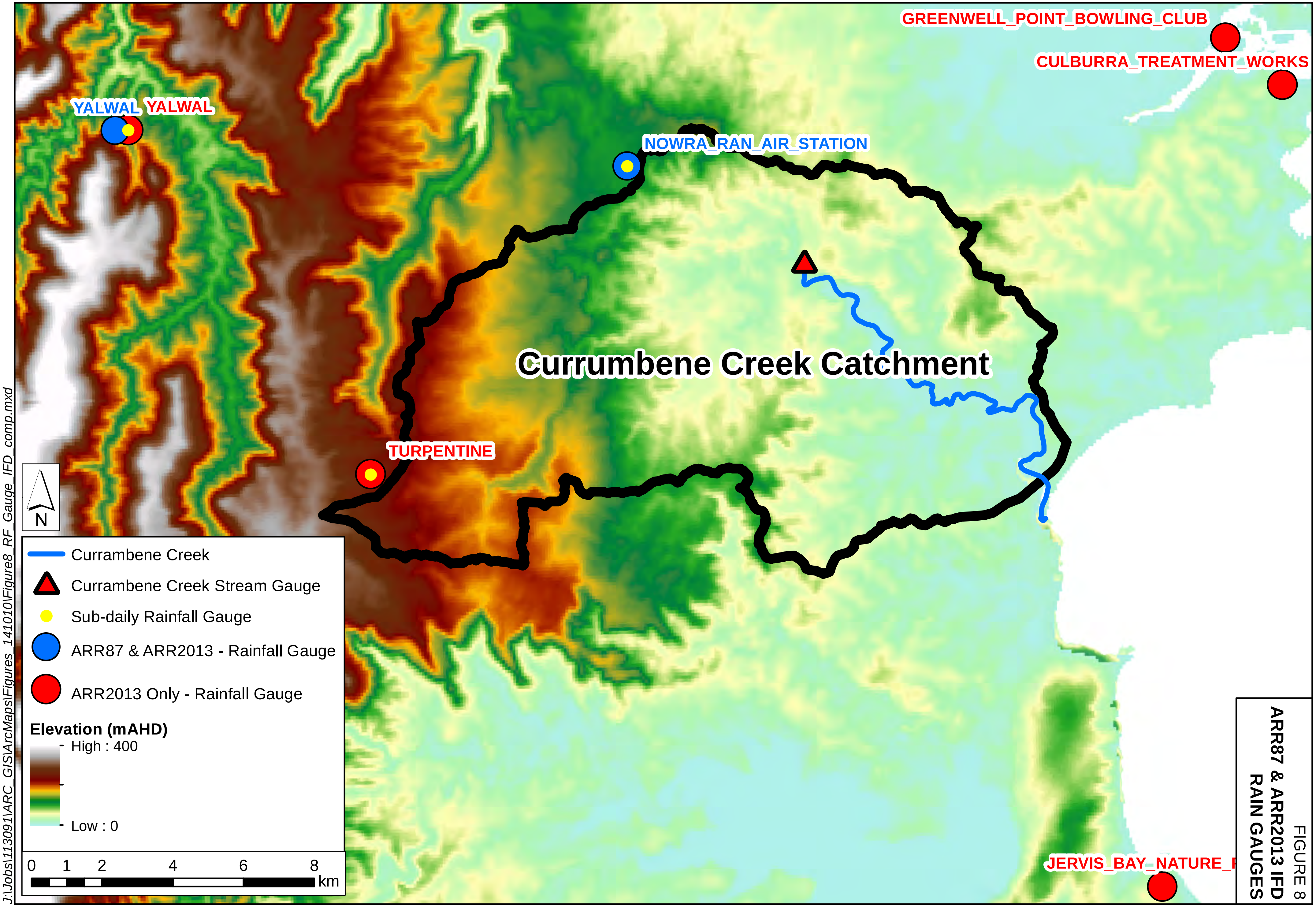


FIGURE 7
HISTORIC EVENTS
BURST INTENSITIES AND FREQUENCIES
ARR2013 IFD



GREENWELL_POINT_BOWLING_CLUB
CULBURRA_TREATMENT_WORKS
YALWAL
YALWAL
NOWRA_RAN_AIR_STATION
Currumbene Creek Catchment
TURPENTINE
JERVIS_BAY_NATURE_F
N
Currambene Creek
Currambene Creek Stream Gauge
Sub-daily Rainfall Gauge
ARR87 & ARR2013 - Rainfall Gauge
ARR2013 Only - Rainfall Gauge
Elevation (mAHD)
High : 400
Low : 0
0 1 2 4 6 8 km
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FIGURE 8
ARR87 & ARR2013 IFD RAIN GAUGES

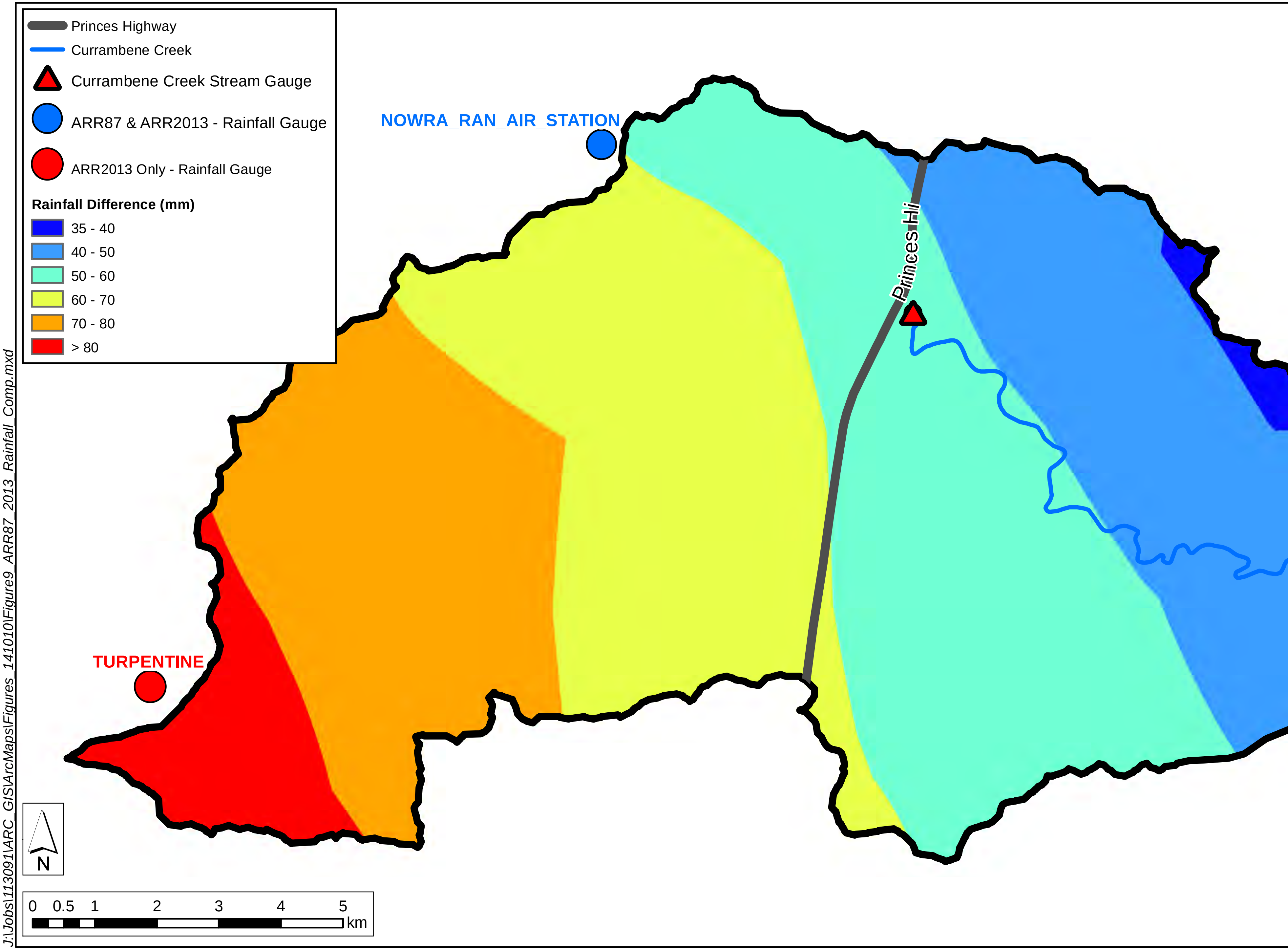

FIGURE 9

ARR87 AND ARR2013 IFD
DESIGN RAINFALL DEPTH COMPARISON
1% AEP, 9 HOUR DURATION EVENT

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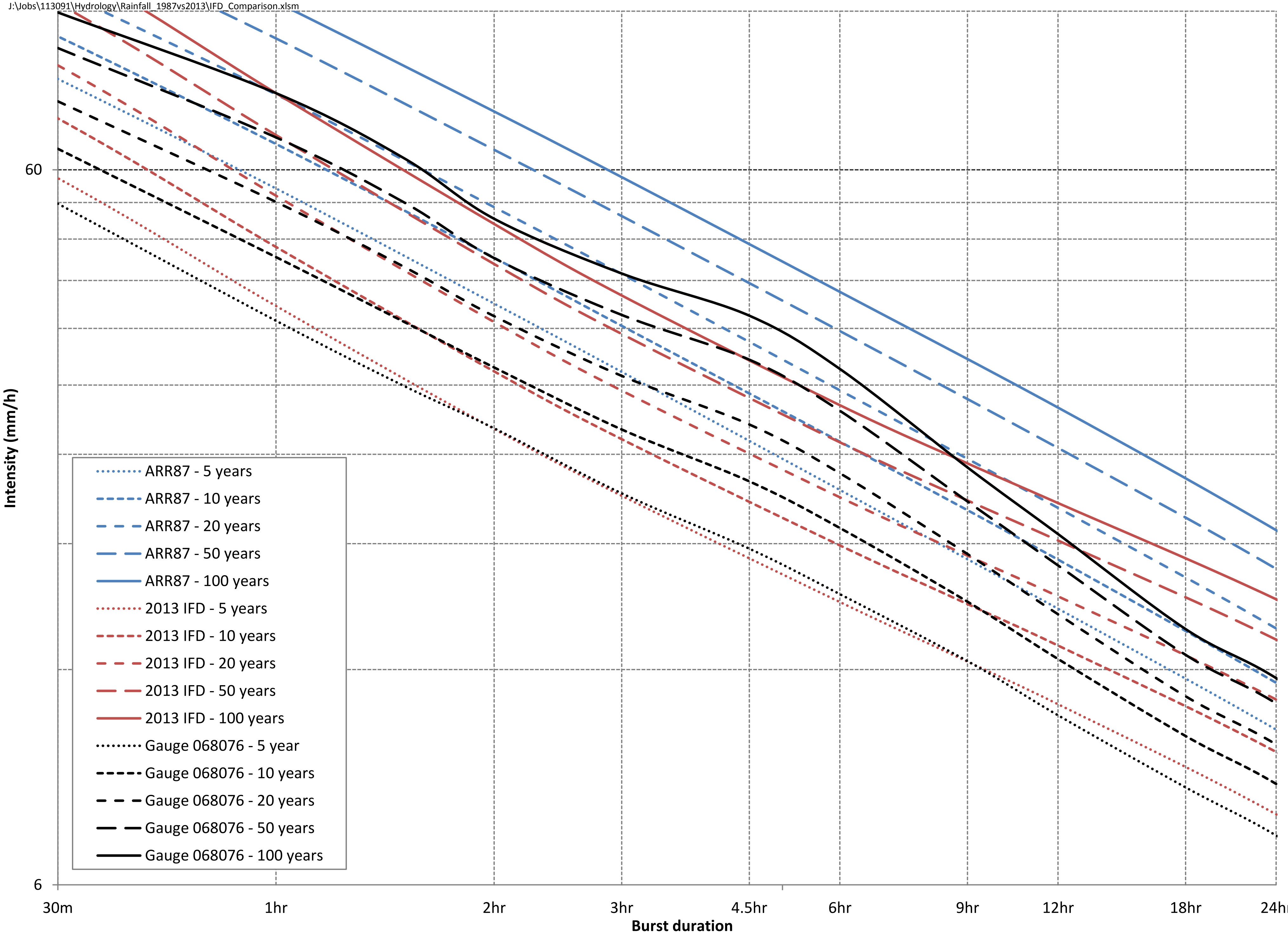

FIGURE 10

ARR87, 2013 IFD AND GAUGE IFD COMPARISON BURST INTENSITIES AND FREQUENCIES

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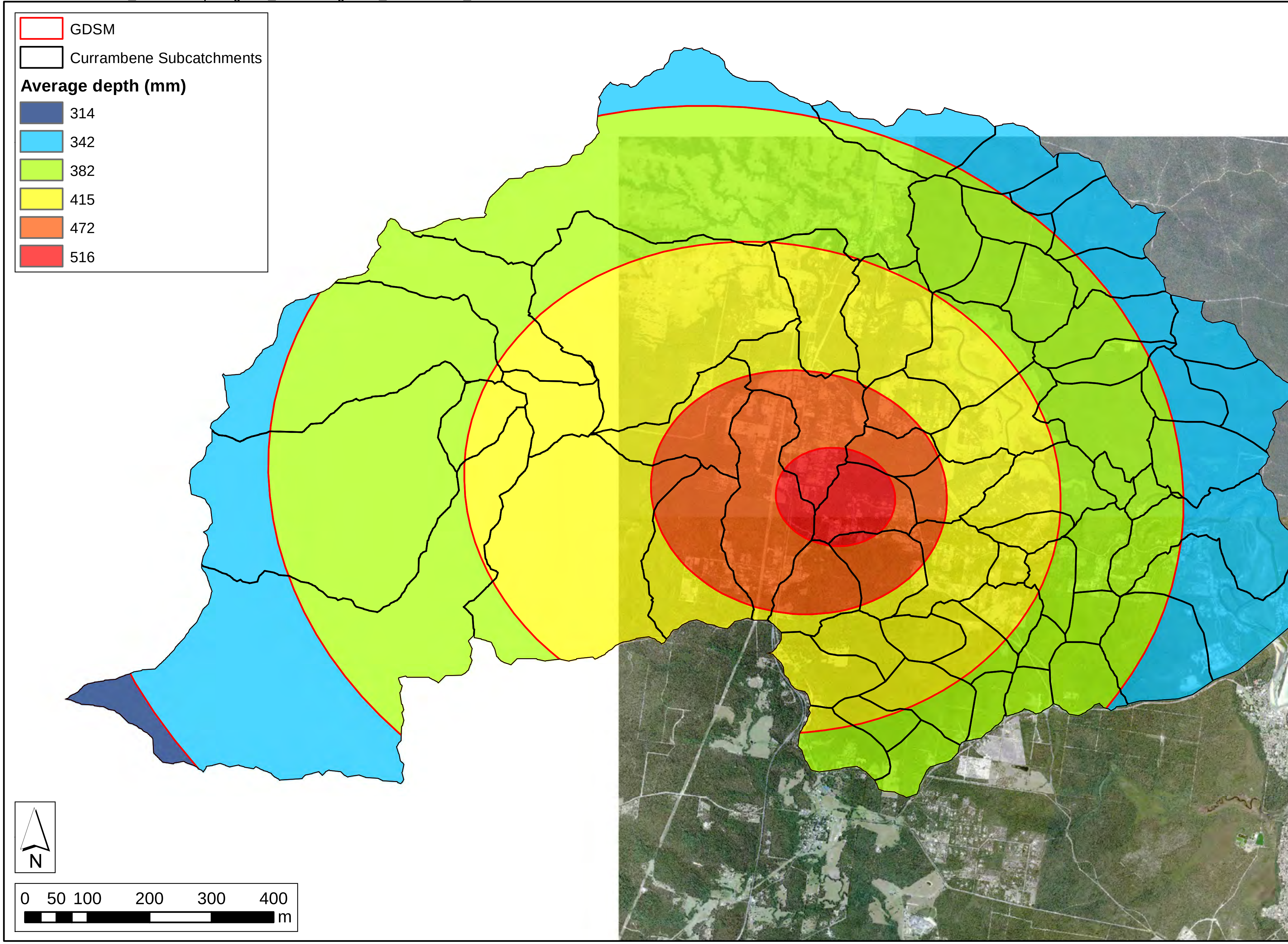

FIGURE 11
CURRAMBENE CREEK PMP
GSDM 4 HR CRITICAL DURATION

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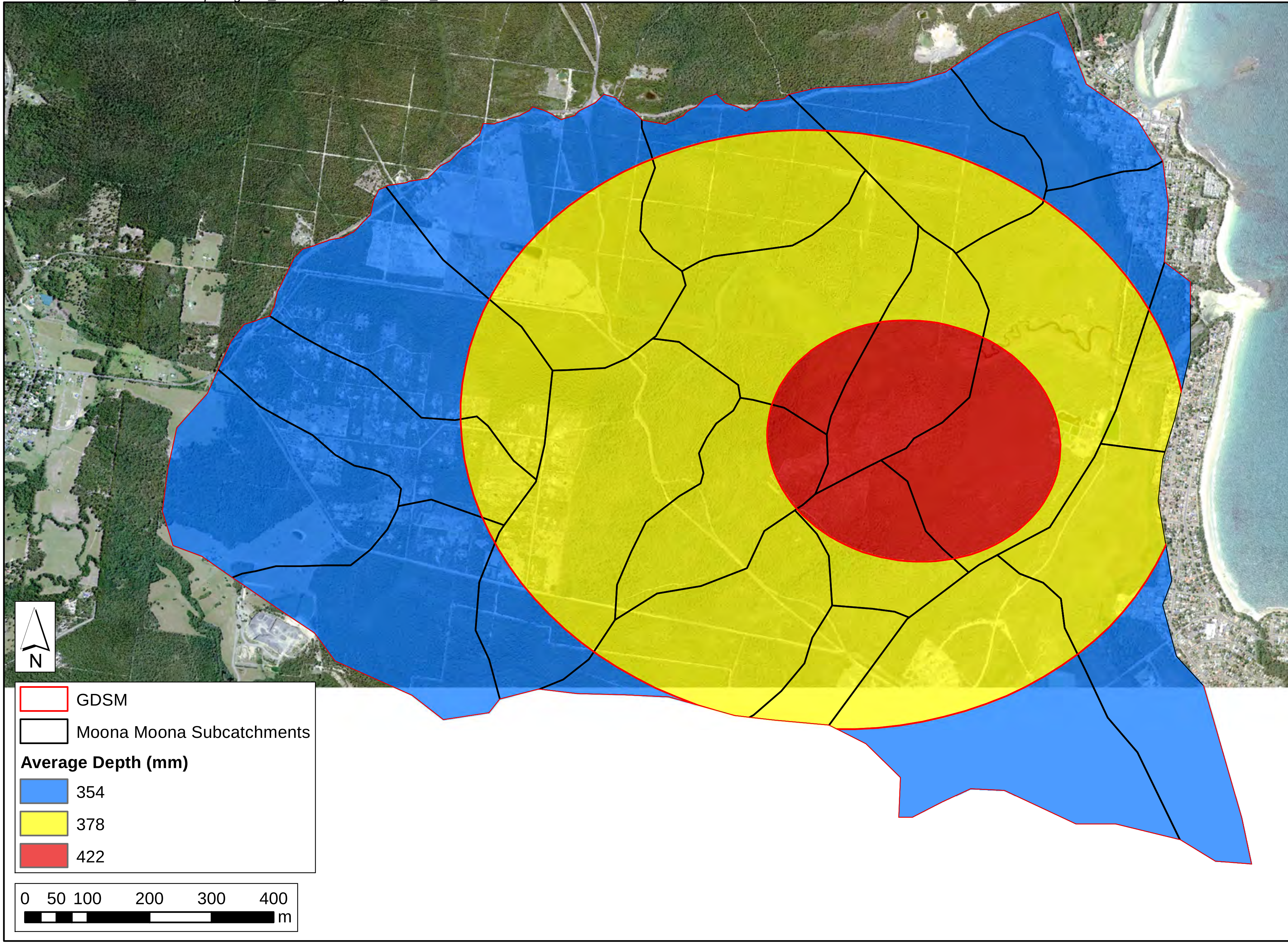


FIGURE 12
MOONA MOONA CREEK PMP
GSDM 2 HR CRITICAL DURATION

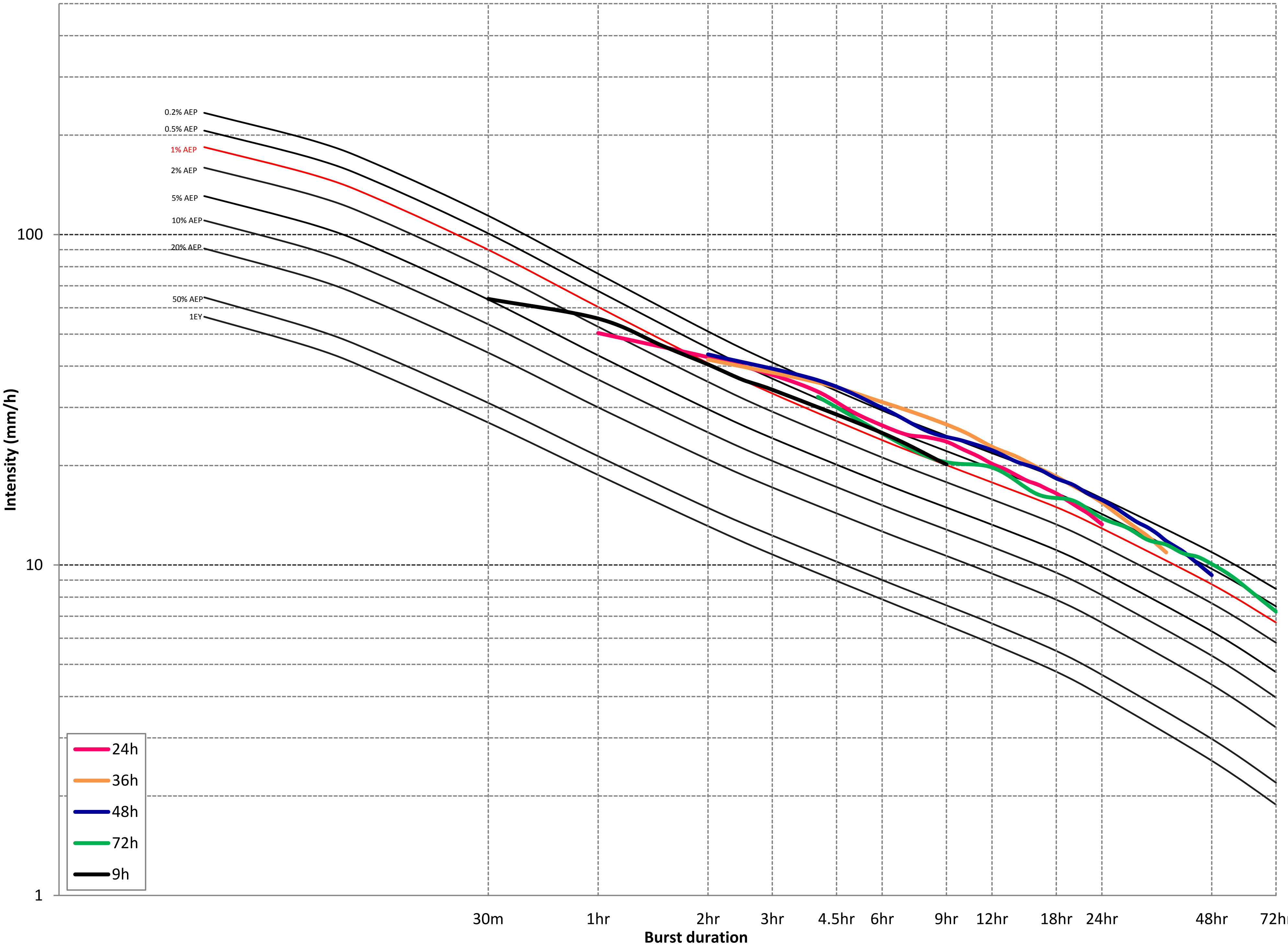
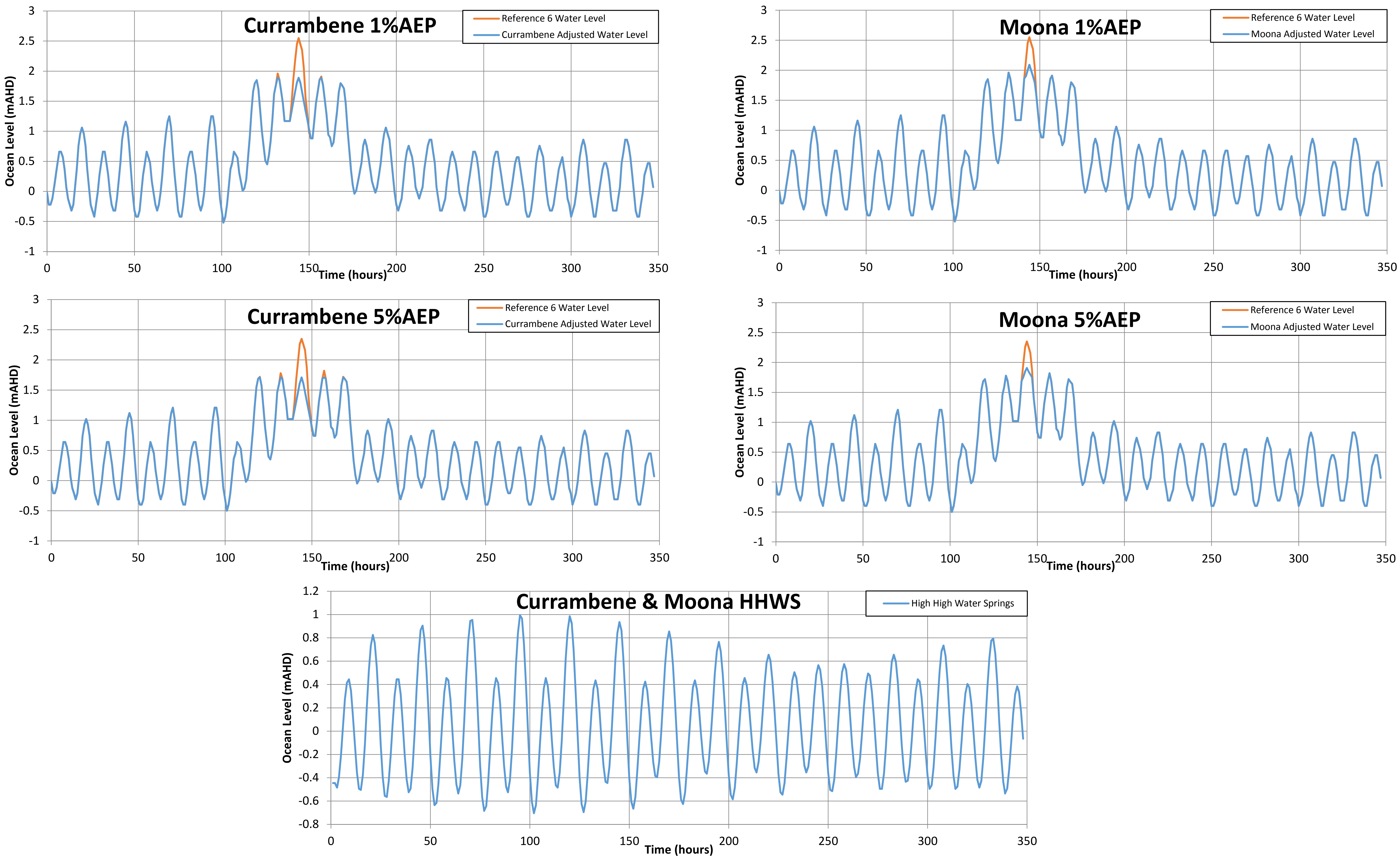


FIGURE 13
DESIGN EVENTS
BURST INTENSITIES AND FREQUENCIES
ARR2013 IFD

FIGURE 14
CURRAMBENE CREEK AND MOONA MOONA CREEK
DYNAMIC TAILWATER CONDITIONS



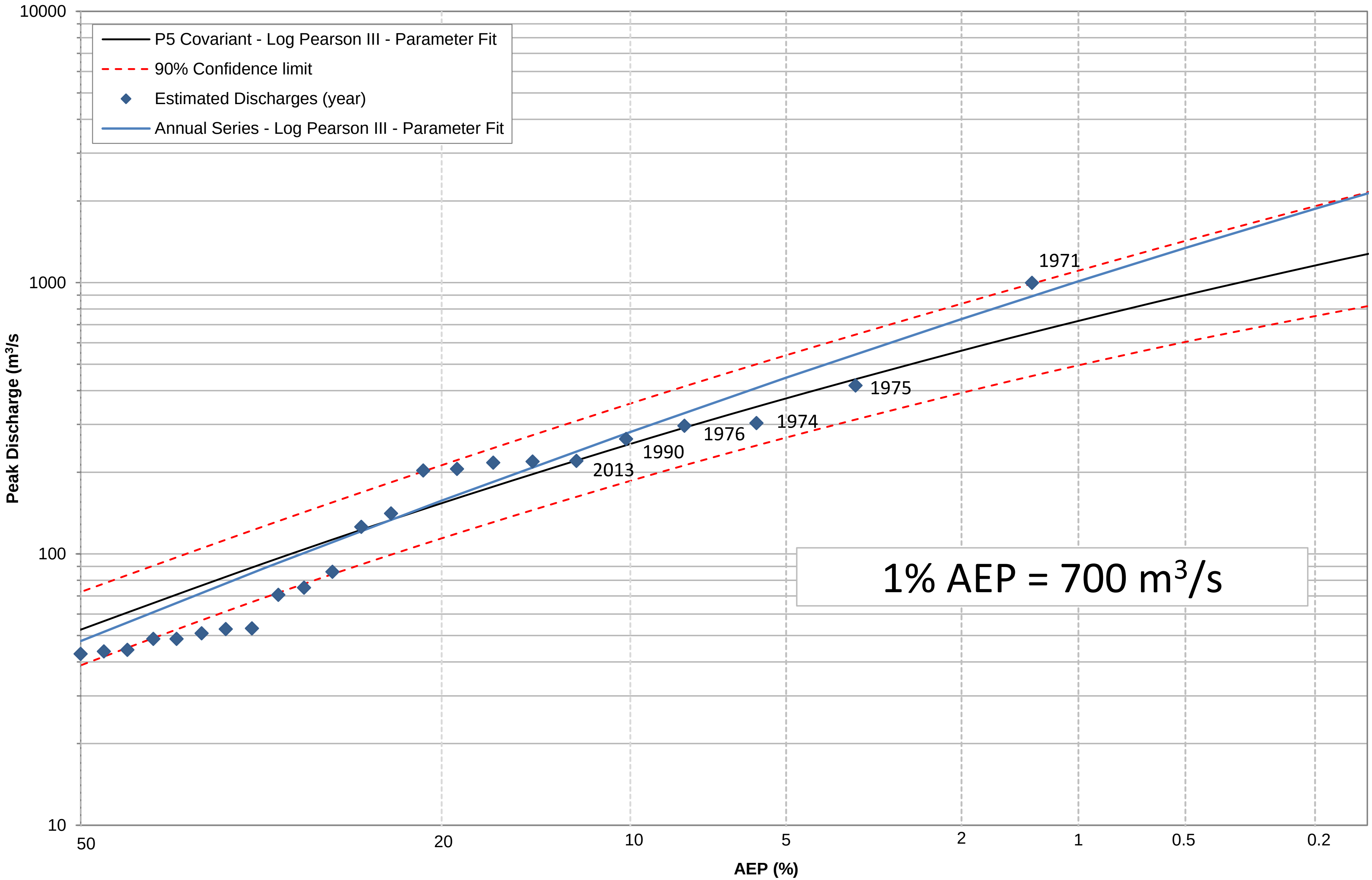


FIGURE 15
CURRAMBENE CREEK
FLOOD FREQUENCY ANALYSIS AND HYDROLOGIC MODEL FLOWS
LOG PERSON III

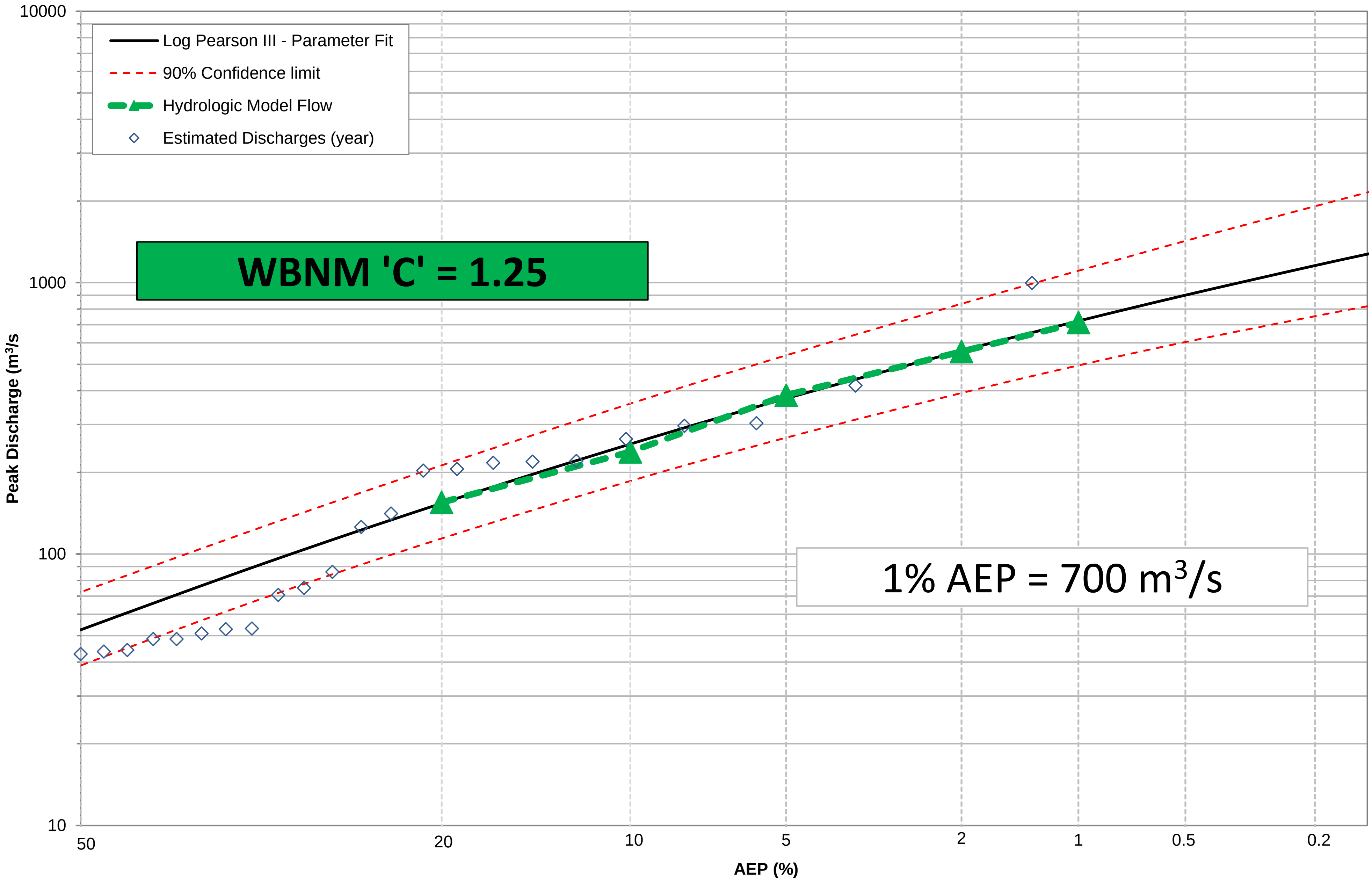


FIGURE 16
CURRAMBENE CREEK
FLOOD FREQUENCY ANALYSIS AND HYDROLOGIC MODEL FLOWS
LOG PERSON III

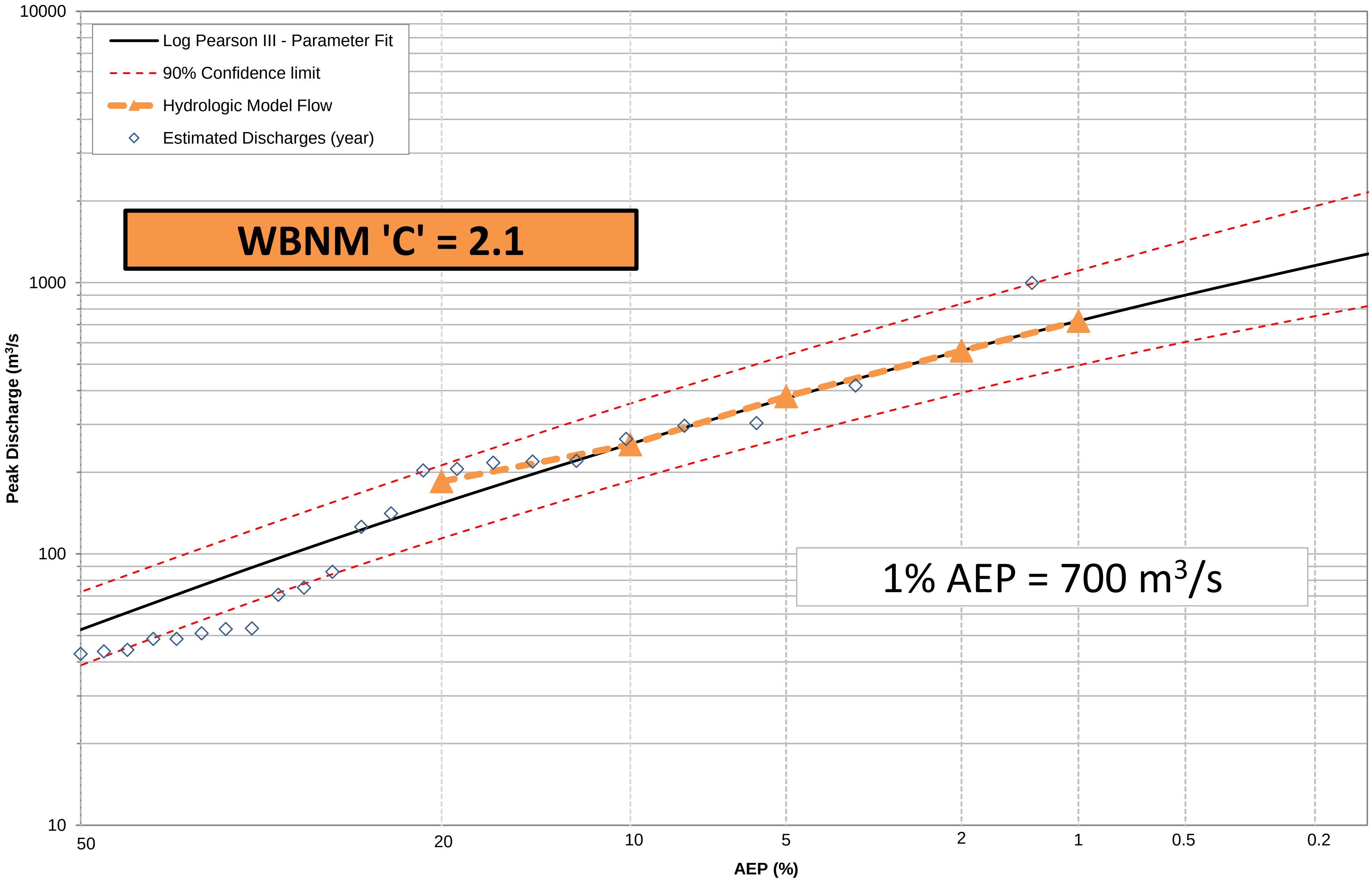


FIGURE 17
CURRAMBENE CREEK
FLOOD FREQUENCY ANALYSIS AND HYDROLOGIC MODEL FLOWS
LOG PERSON III

FIGURE 18
HYDROLOGIC MODEL LAYOUT

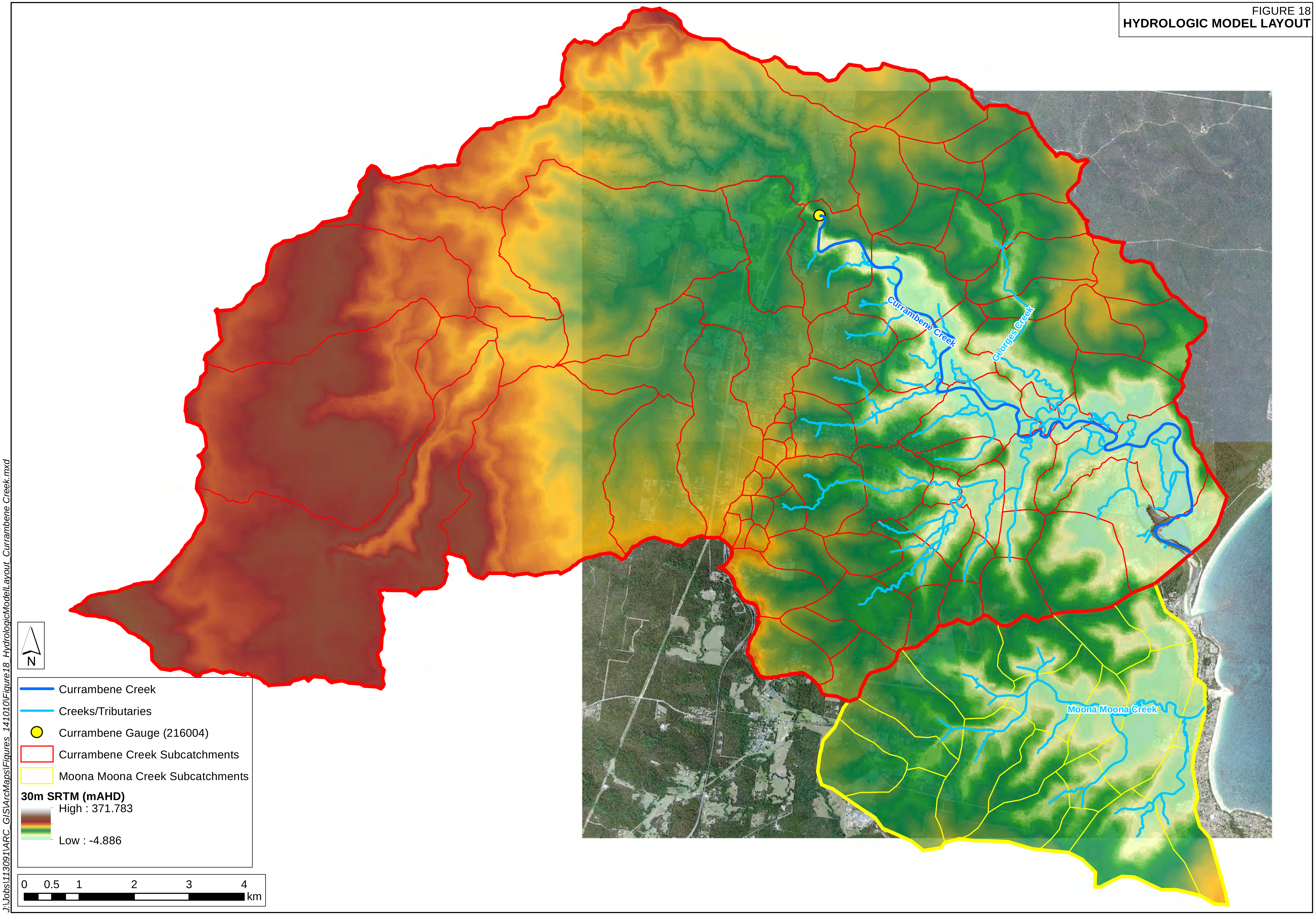


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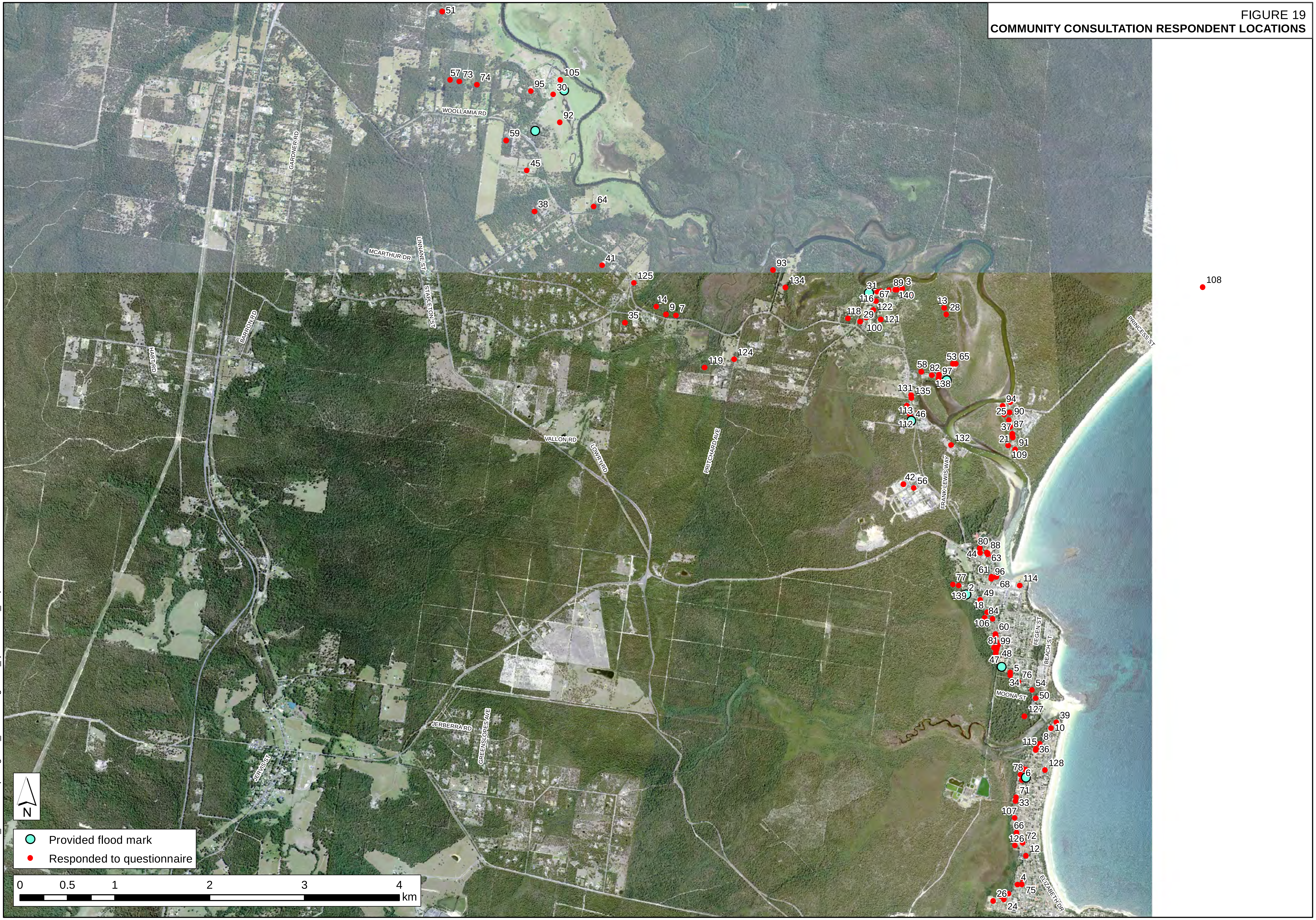
FIGURE 19
COMMUNITY CONSULTATION RESPONDENT LOCATIONS



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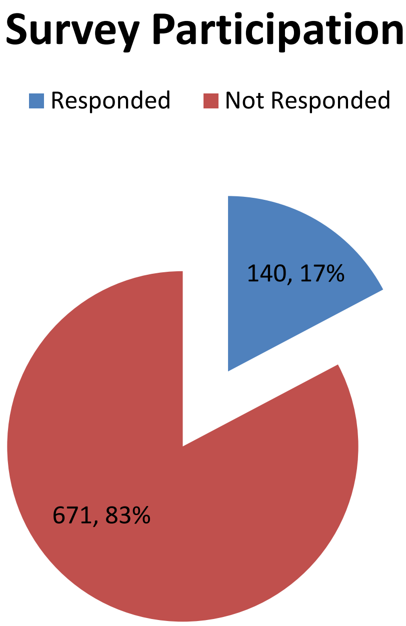
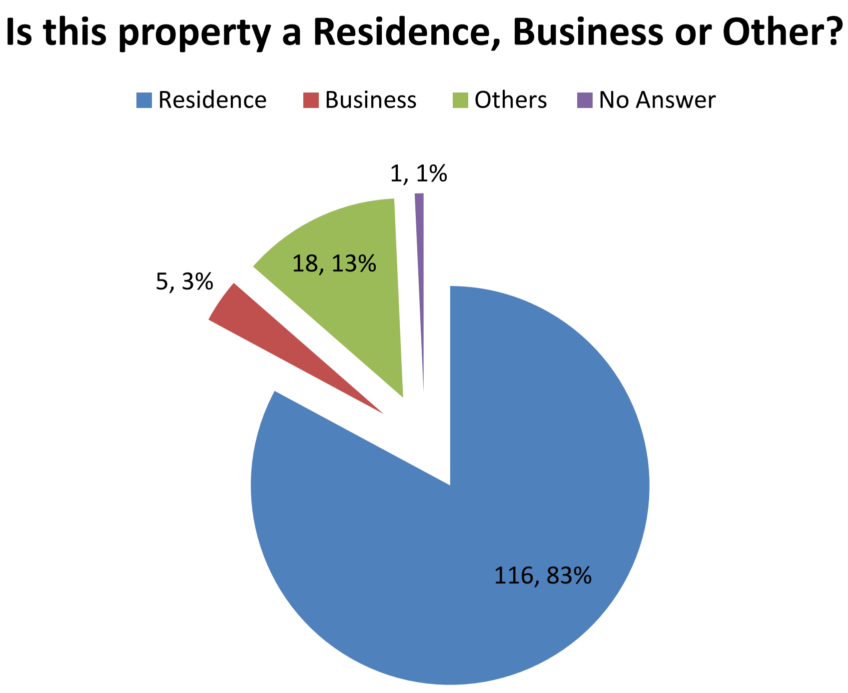
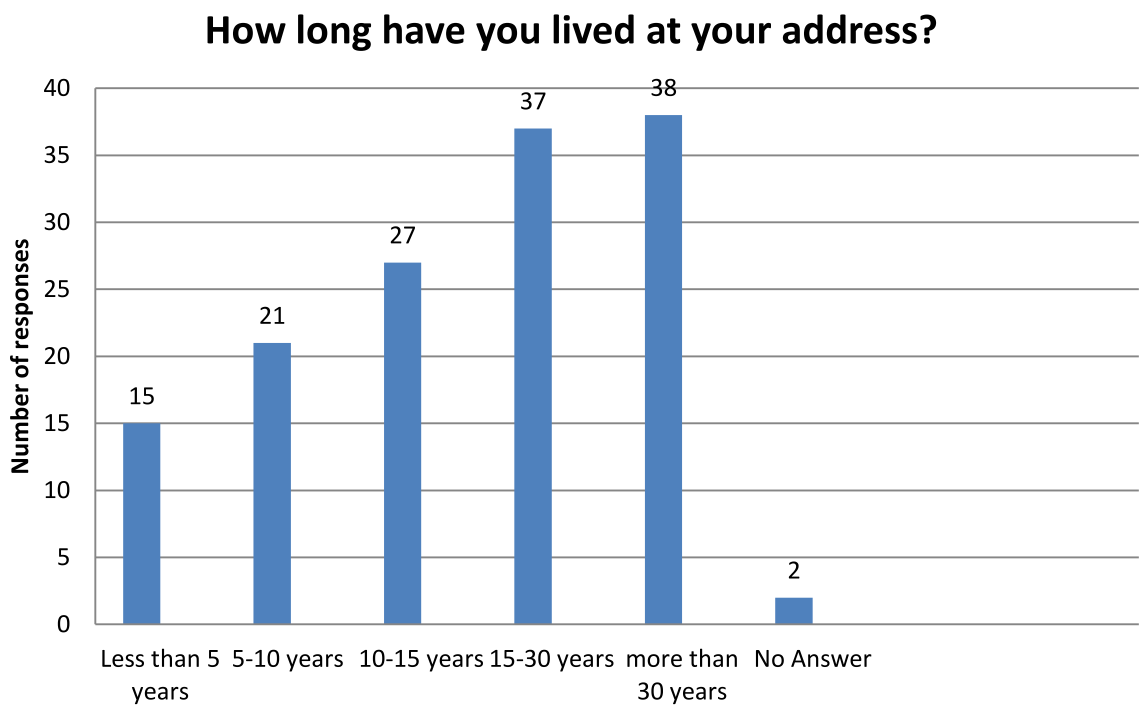
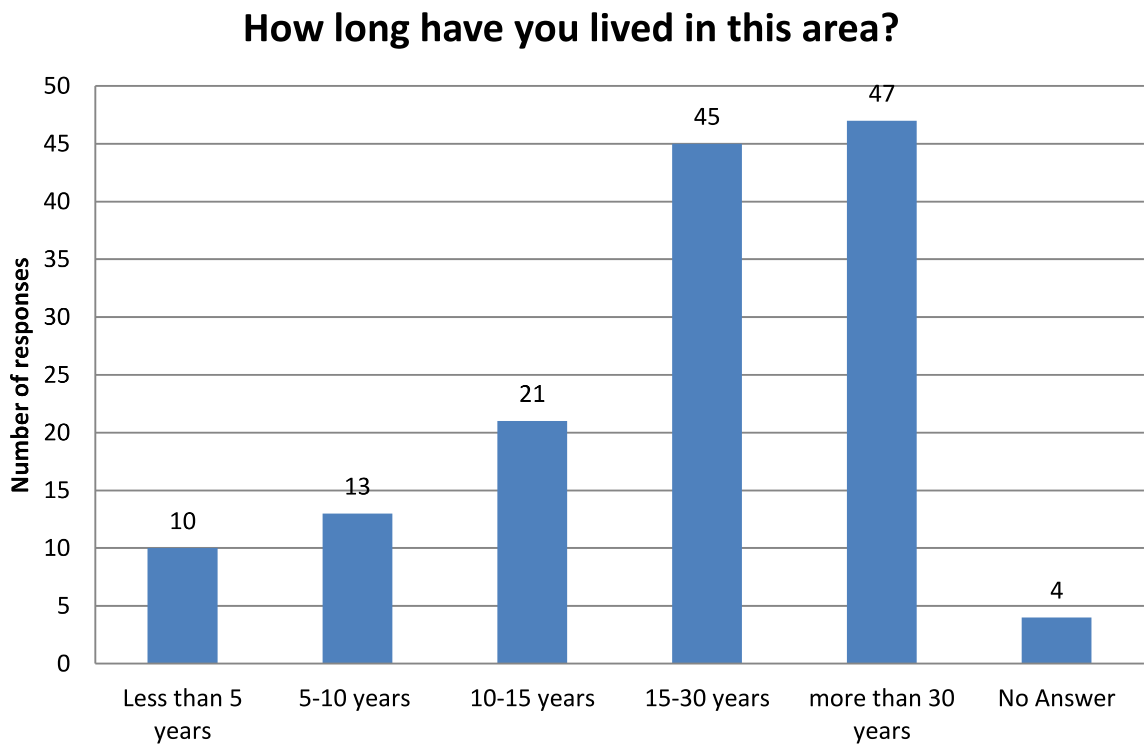


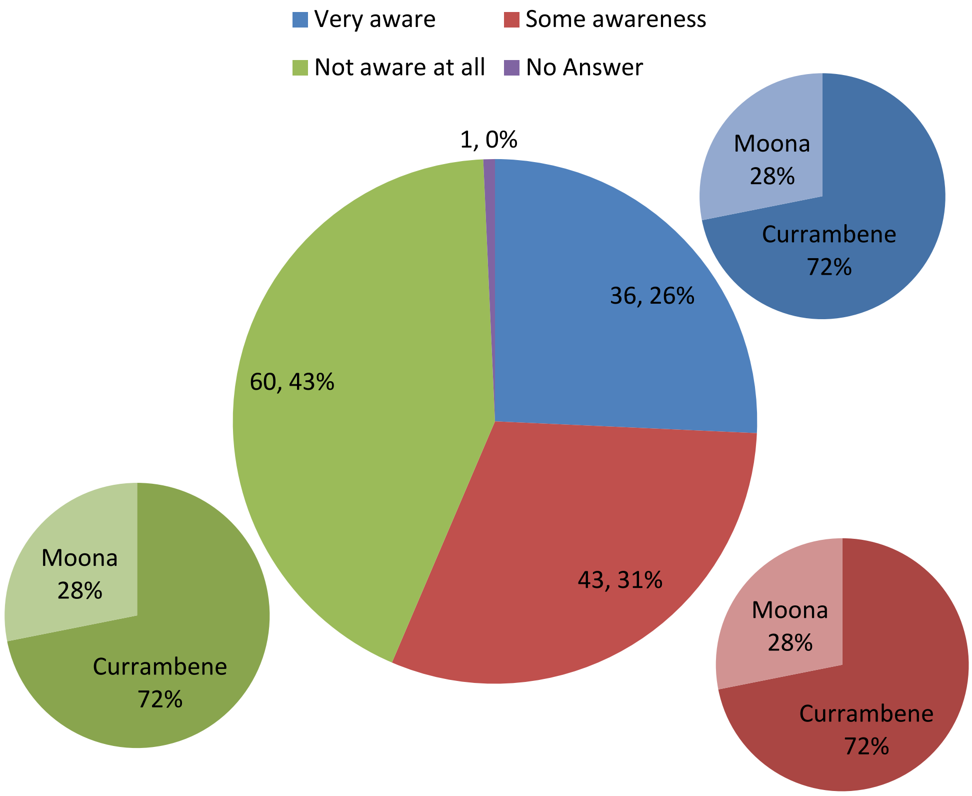


Many people that checked 'other' stated that the property was either farmland or an undeveloped block.


How long have you lived at your address?
Number of responses
0
5
10
15
20
25
30
35
40
15
21
27
37
38
2
Less than 5 years
5-10 years
10-15 years
15-30 years
more than 30 years
No Answer


How long have you lived in this area?
Number of responses
0
5
10
15
20
25
30
35
40
45
50
10
13
21
45
47
4
Less than 5 years
5-10 years
10-15 years
15-30 years
more than 30 years
No Answer

Are You aware of Flooding in Currambene or Moona Moona Creeks?

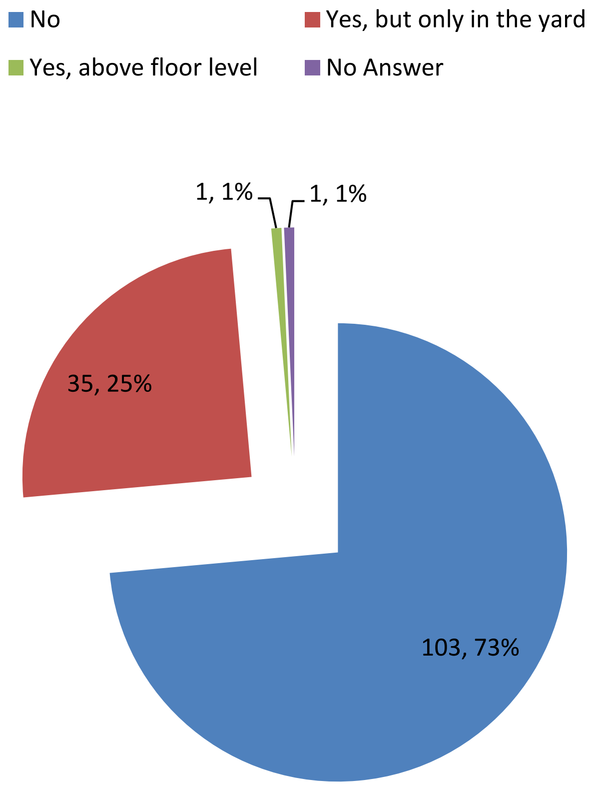


If aware, please provide details

9 properties were affected by flooding in June 2013.

Most residents were not able to pin point a year that flooding occurred. However many recalled floods in the early 1970's and 1950's

Has your property ever been affected by flooding?



If yes, please provide details

Many people commented they believe the current flood zones unnecessarily strict and were restricting development on 'dry' land.

Many also thought flooding was due to poor drainage and /or high tides.

The main streets that were affected seemed to be

- Falls Creek Road
- Duncan Street
- Currambene Street
- Woollamia Rd
- A number of other roads were mentioned.

FIGURE 23
HYDRAULIC MODEL LAYOUT
CURRAMBENE

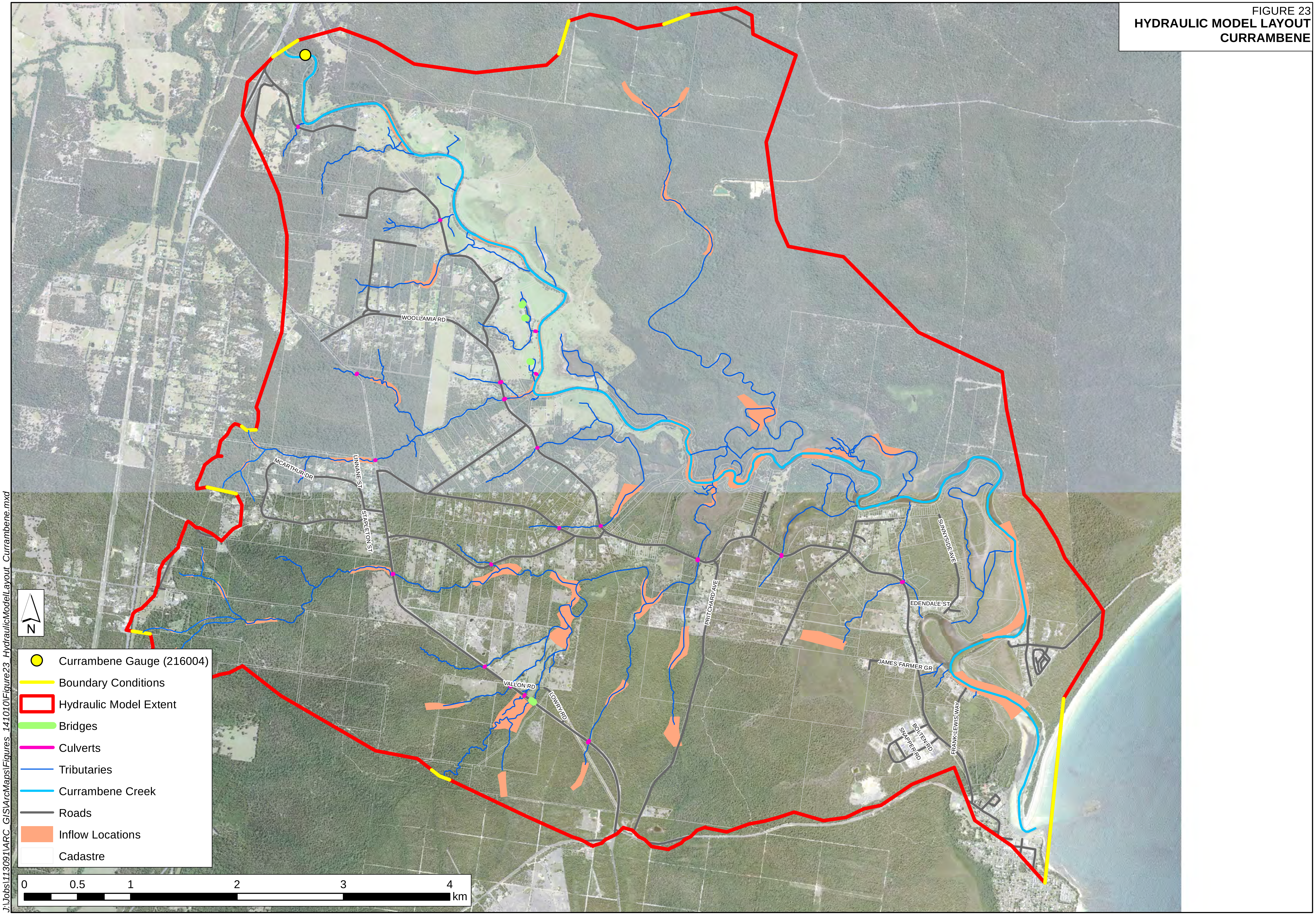
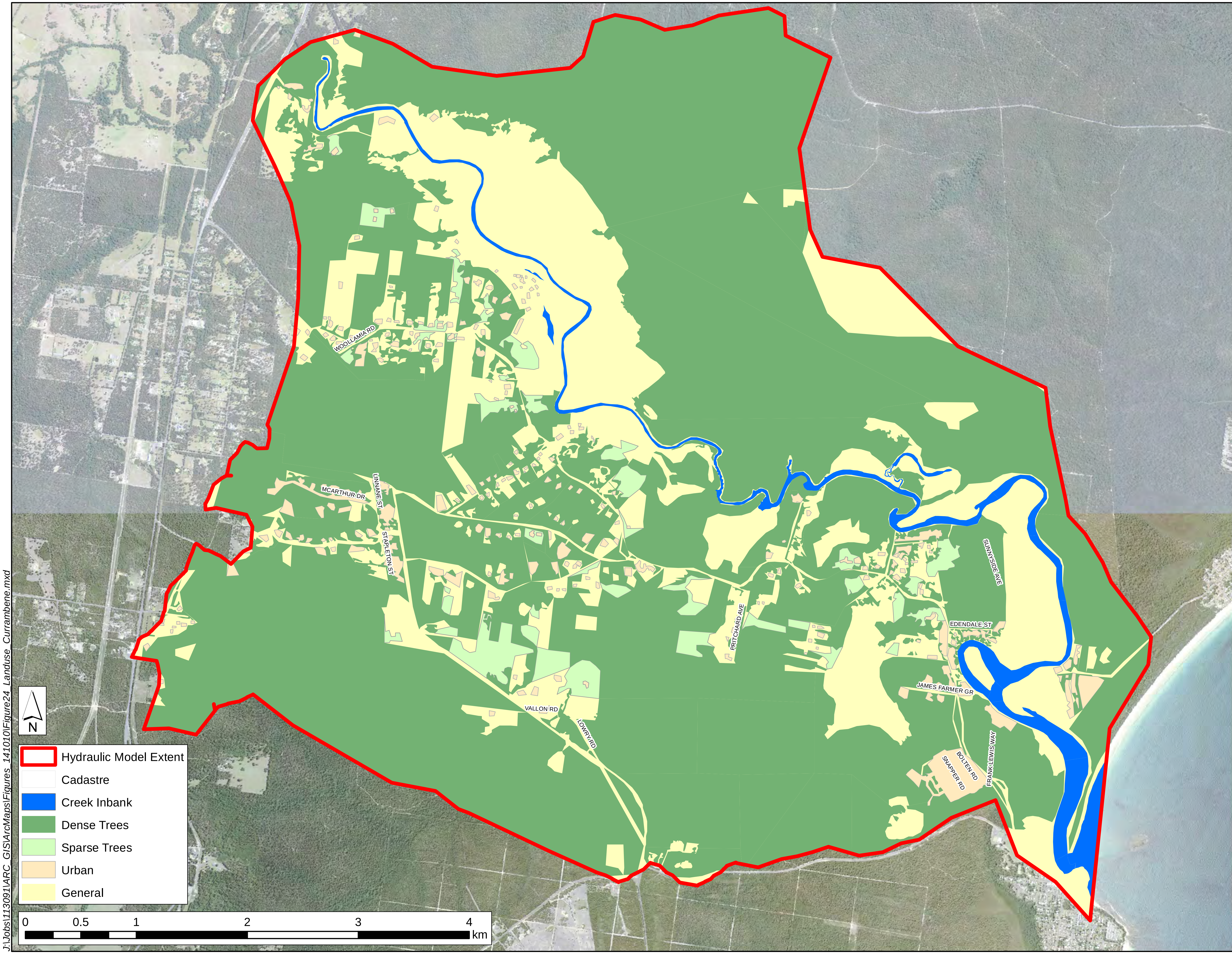


FIGURE 24
LAND USE ZONES
CURRAMBENE



J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure24_Landuse_Currambene.mxd

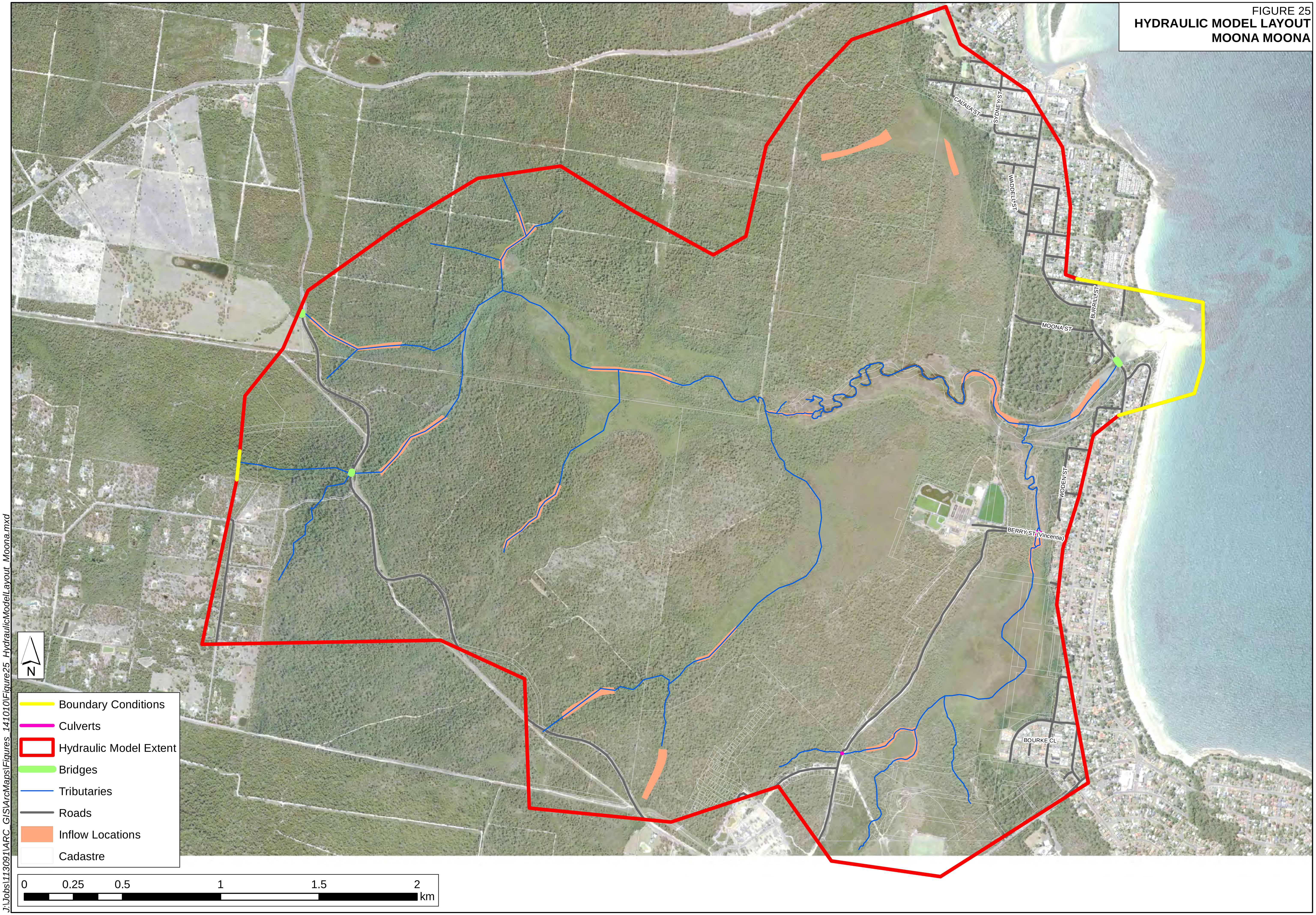


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FIGURE 26
LAND USE ZONES
MOONA MOONA

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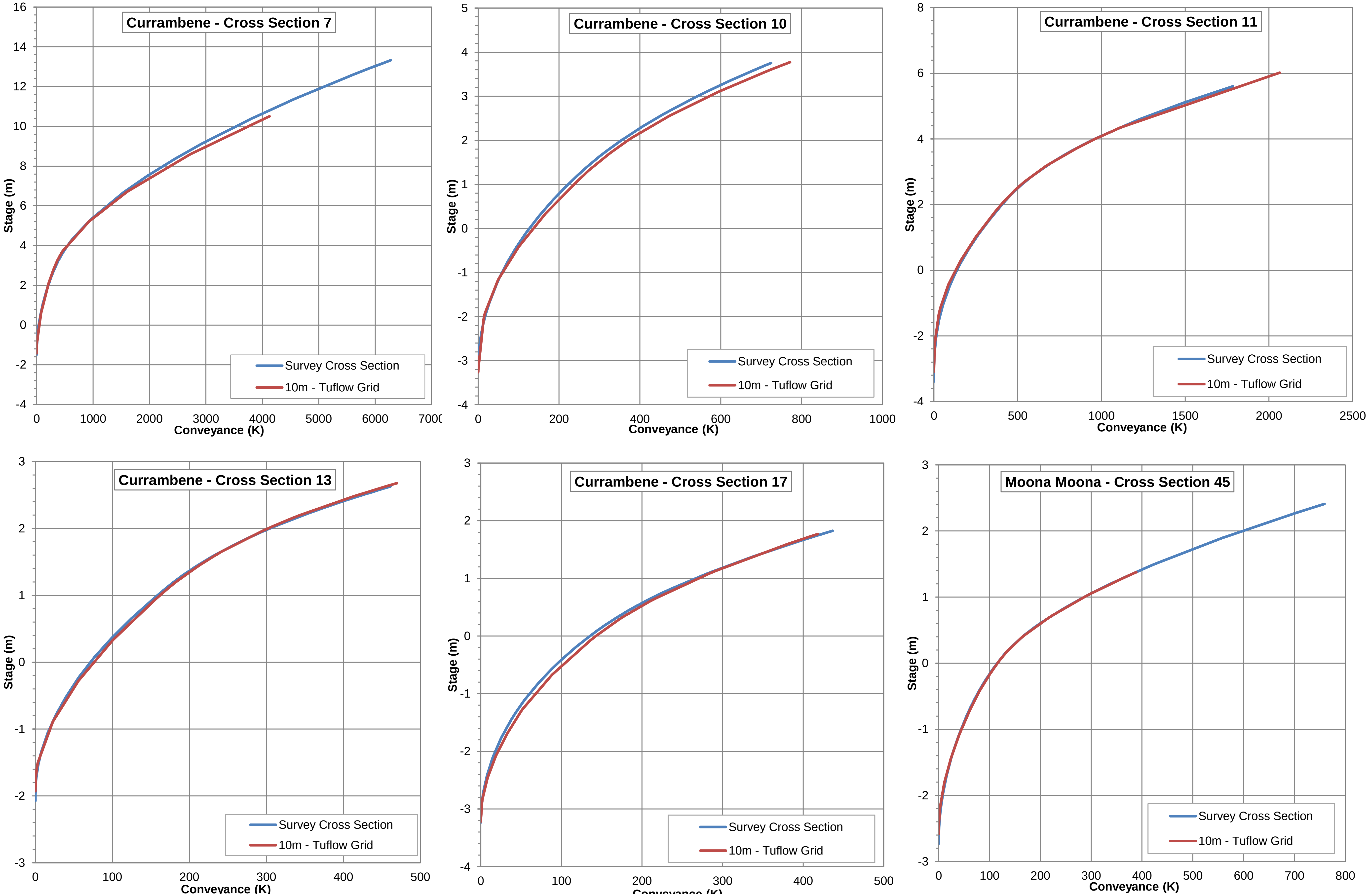
FIGURE 27

10 m TUFLOW MODEL GRID RESOLUTION vs. SURVEY CONVEYANCE COMPARISON



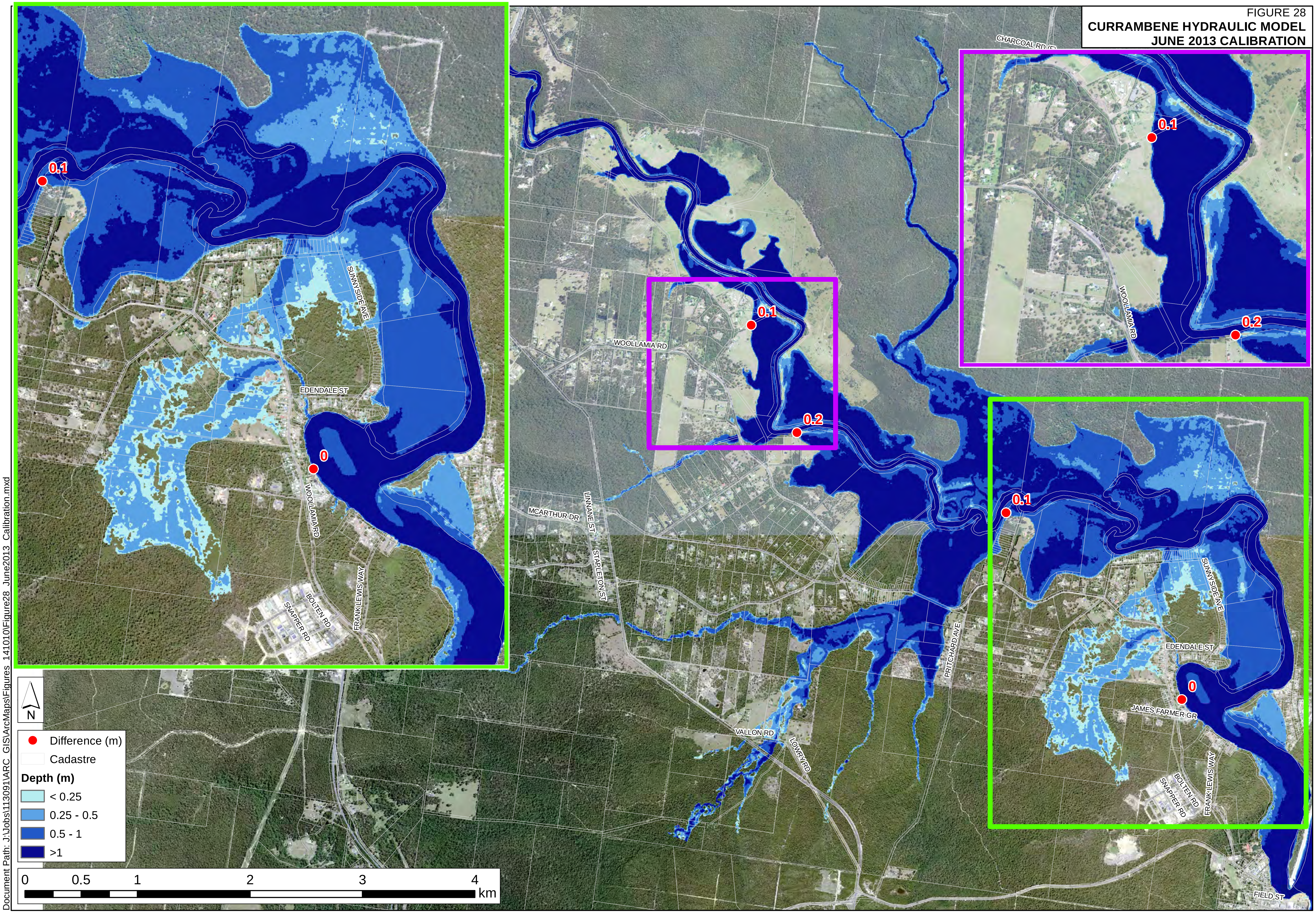
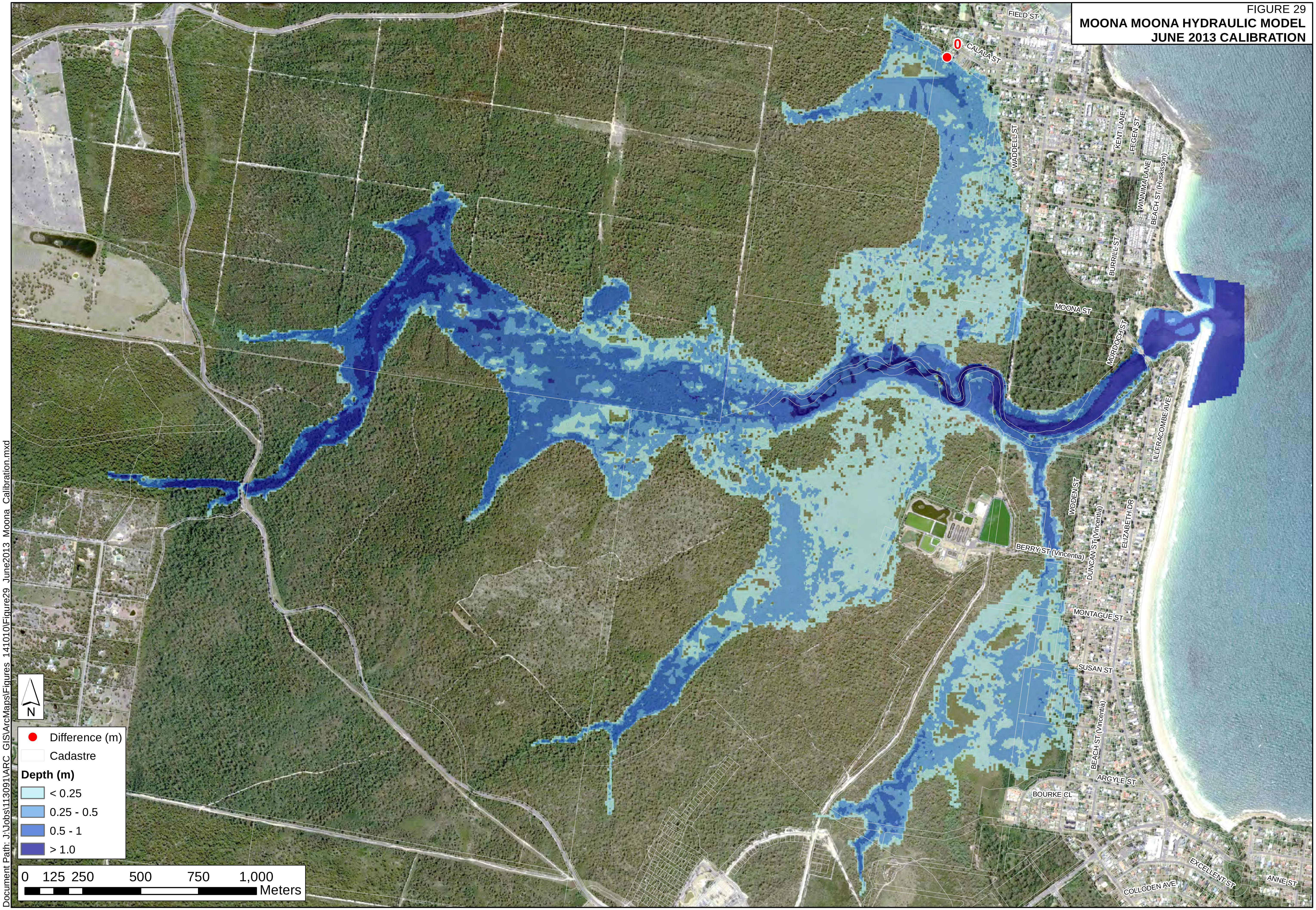


FIGURE 28
CURRAMBENE HYDRAULIC MODEL
JUNE 2013 CALIBRATION

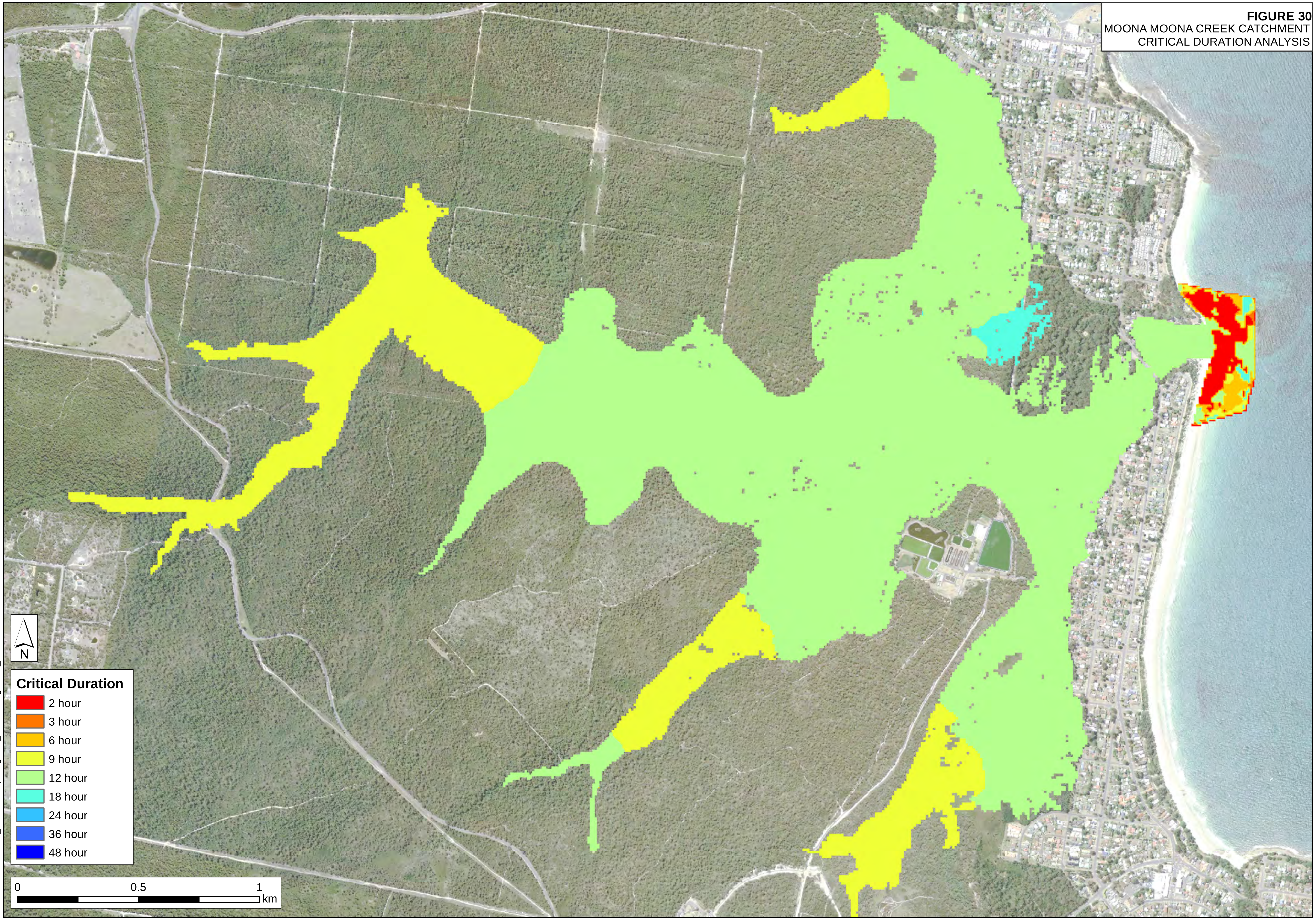
Document Path: J:\Jobs\113091\ARC GIS\ArcMaps\Figures 141010\Figure28 June2013 Calibration.mxd

MOONA MOONA HYDRAULIC MODEL
JUNE 2013 CALIBRATION



Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure29_June2013_Moona_Calibration.mxd

FIGURE 30
MOONA MOONA CREEK CATCHMENT
CRITICAL DURATION ANALYSIS



J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure30_CriticalDuration.mxd

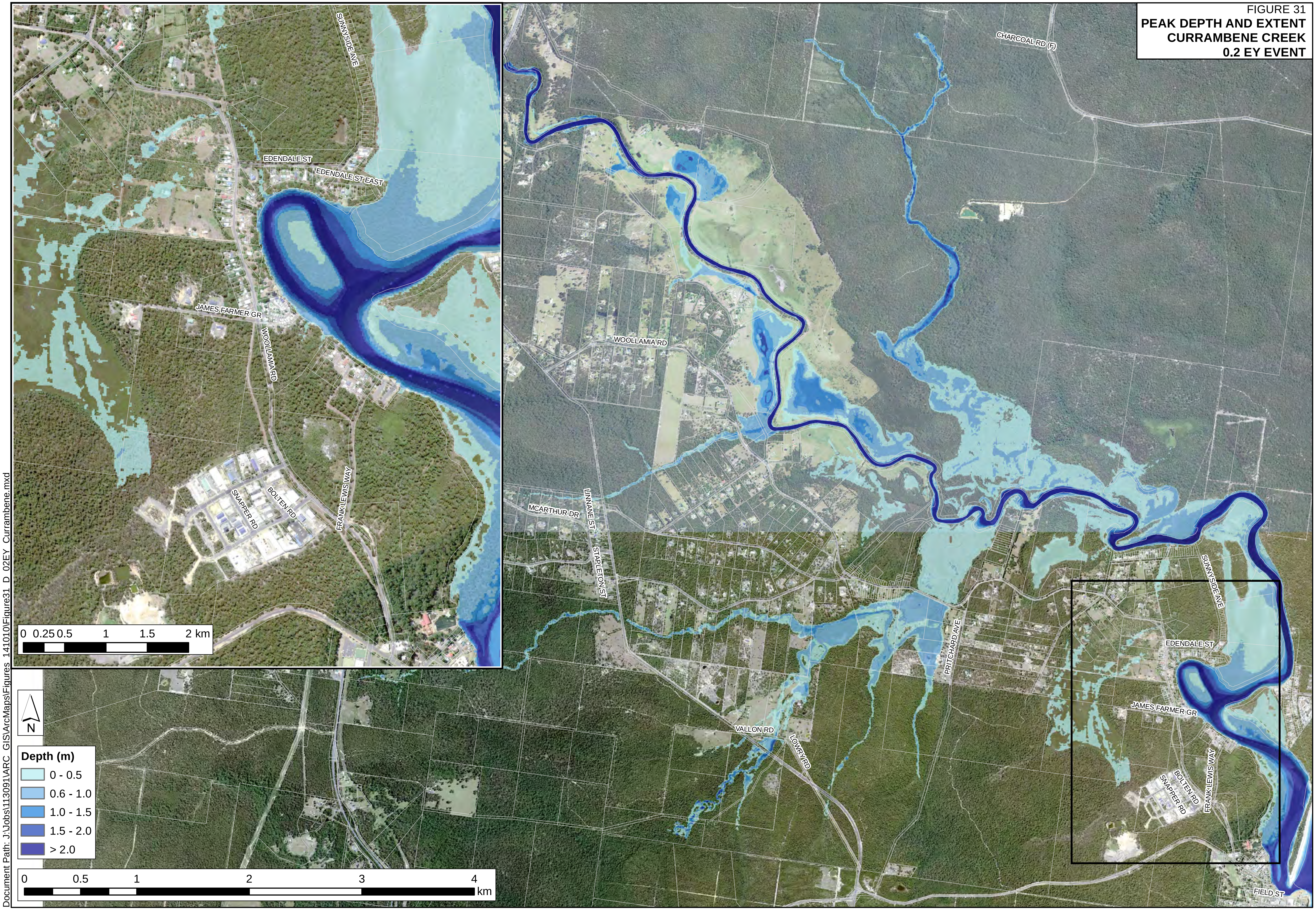
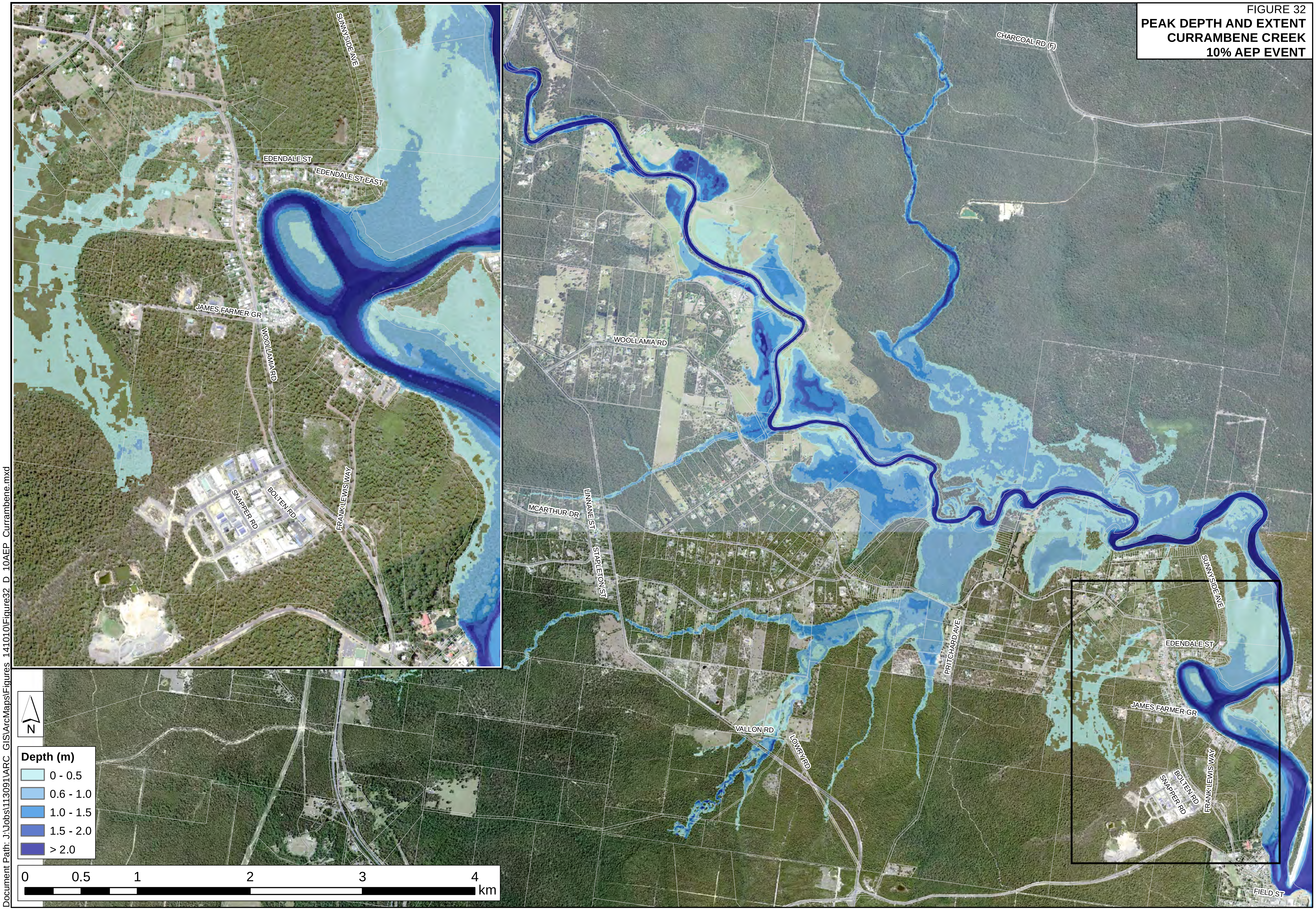


FIGURE 31
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
0.2 EY EVENT
CHARCOAL RD (F)
WOOLLAMIA RD
MCARTHUR DR
LINNAKE ST
STAPLETON ST
PRITCHARD AVE
SUNNYSIDE AVE
EDENDALE ST
EDENDALE ST EAST
JAMES FARMER GR
WOOLLAMIA RD
SNAPPER RD
BOLTEN RD
FRANK LEWIS WAY
VALLON RD
LOWRY RD
FIELD ST
0 0.25 0.5 1 1.5 2 km
N
Depth (m)
0 - 0.5
0.6 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
0 0.5 1 2 3 4 km
Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure31_D_02EY_Currambene.mxd

FIGURE 32
PEAK DEPTH AND EXTENT CURRAMBENE CREEK 10% AEP EVENT



Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure32_D_10AEP_Currambene.mxd

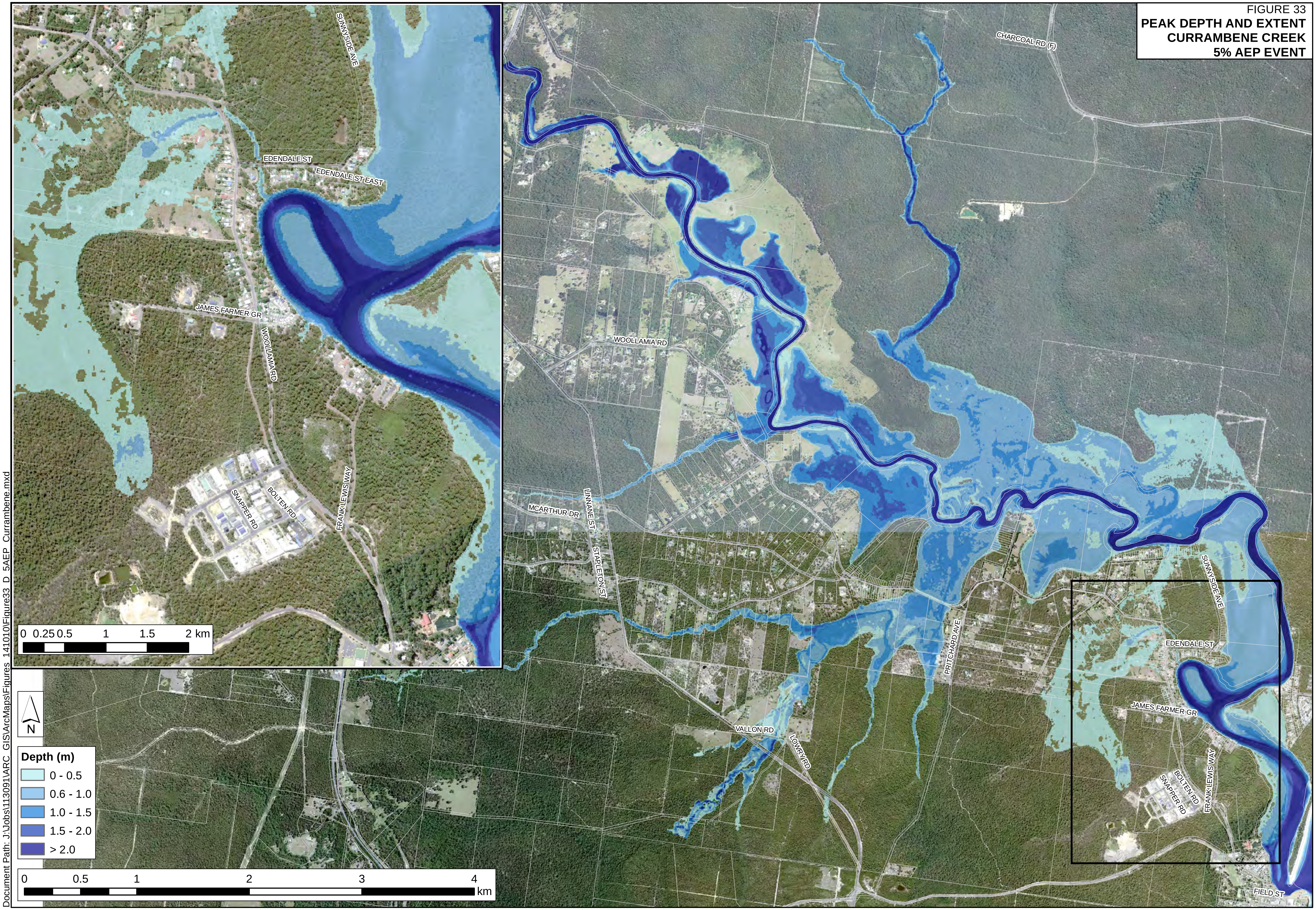


FIGURE 33
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
5% AEP EVENT

Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure33_D_5AEP_Currambene.mxd

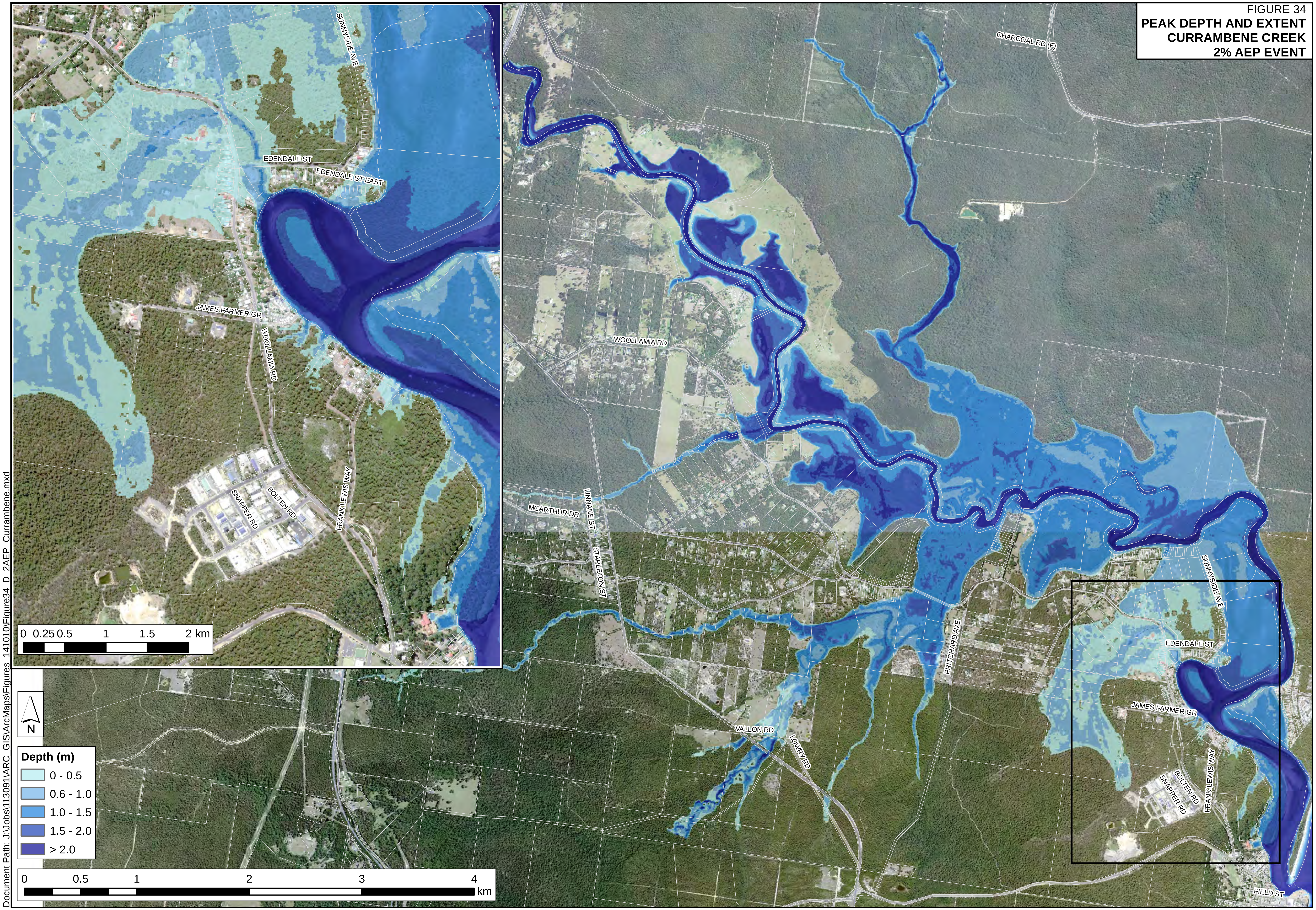


FIGURE 34
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
2% AEP EVENT

Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure34_D_2AEP_Currambene.mxd

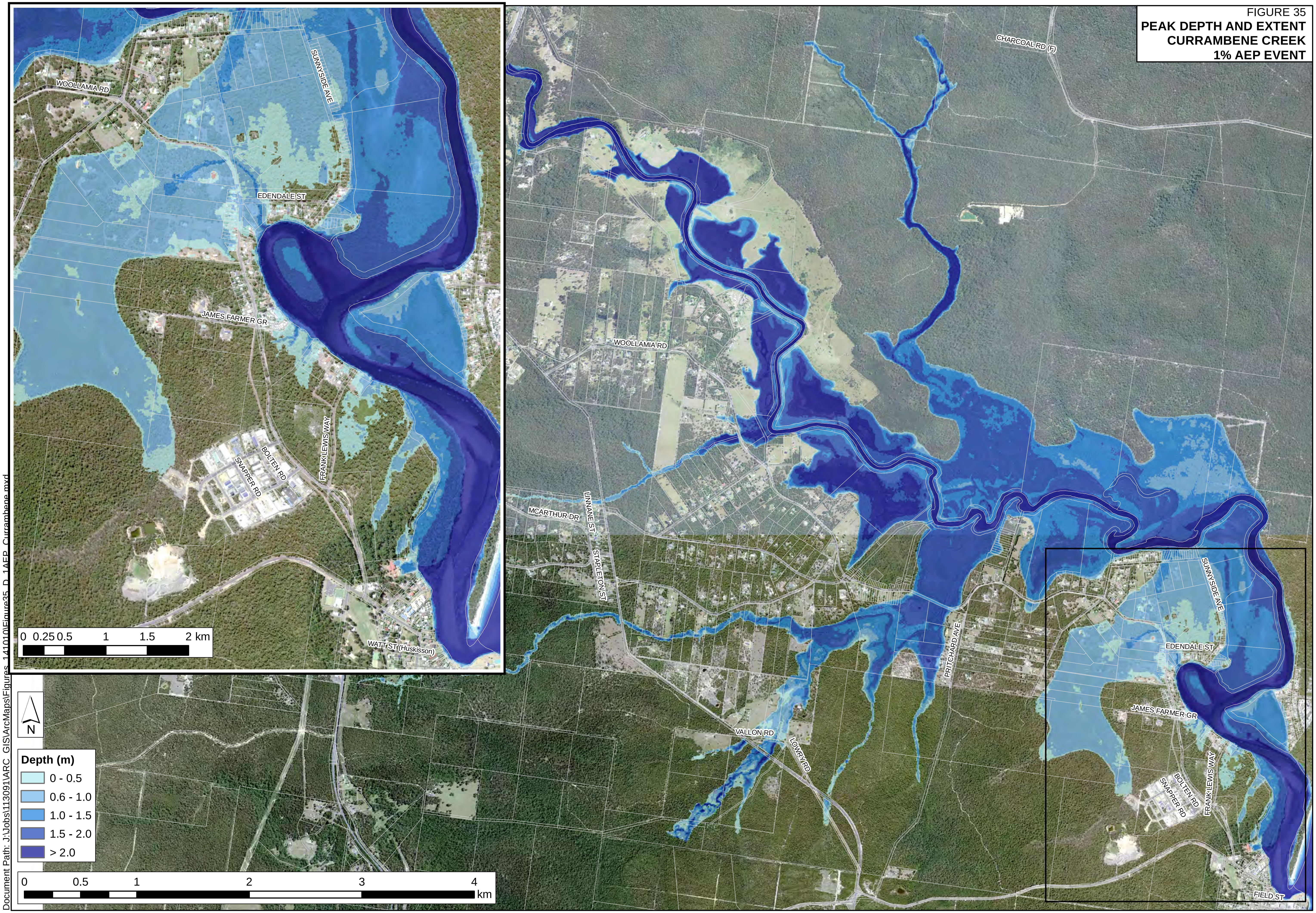


FIGURE 35
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
1% AEP EVENT
CHARCOAL RD (F)
WOOLLAMIA RD
MCARTHUR DR
LINNANE ST
STAPLETON ST
PRITCHARD AVE
VALLON RD
LOWRY RD
SUNNYSIDE AVE
EDENDALE ST
JAMES FARMER GR
BOLTEN RD
SNAPPER RD
FRANK LEWIS WAY
FIELD ST
WATT ST (Huskisson)
0 0.25 0.5 1 1.5 2 km
N
Depth (m)
0 - 0.5
0.6 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
0 0.5 1 2 3 4 km
Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure35_D_1AEP_Curranbene.mxd

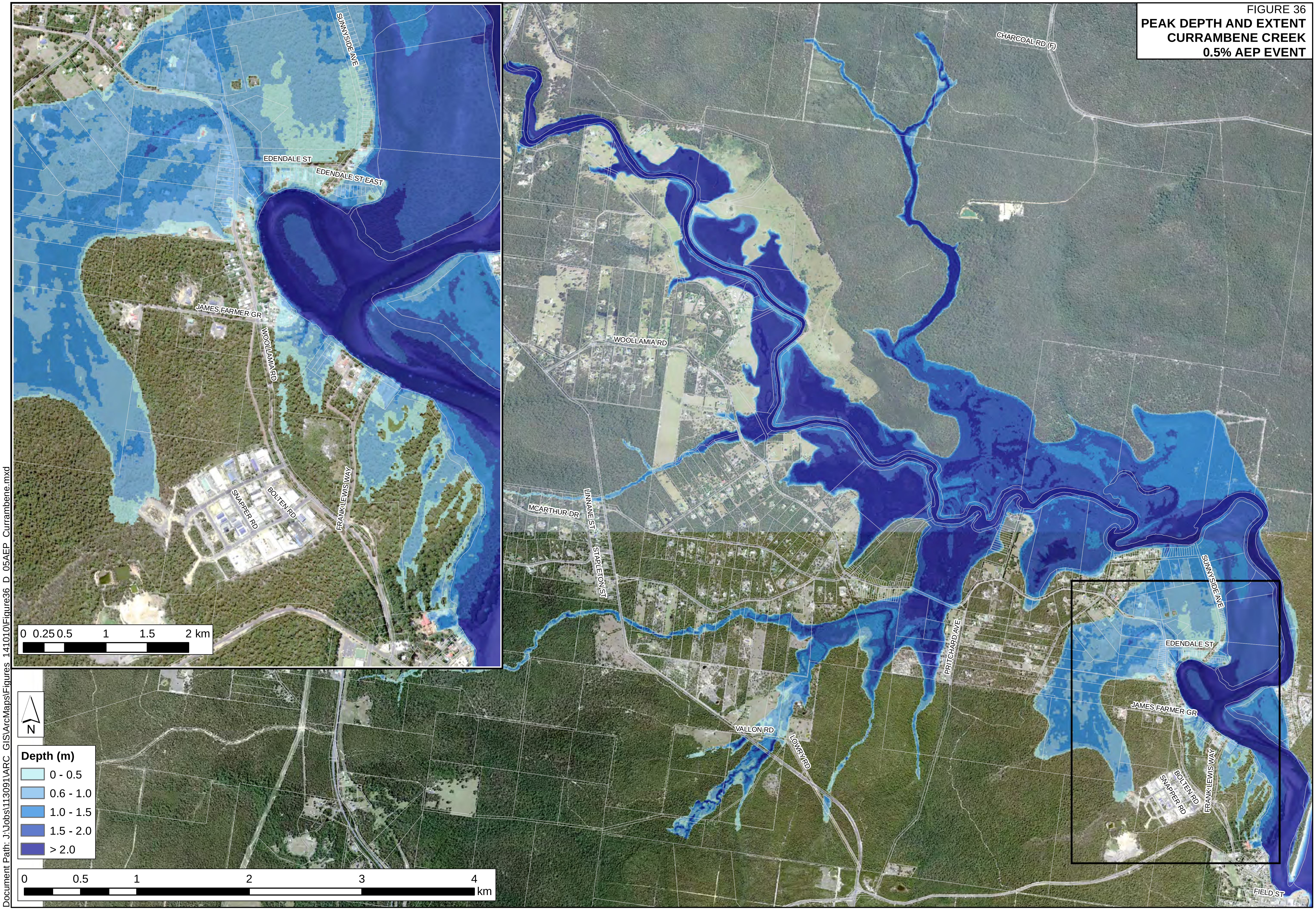
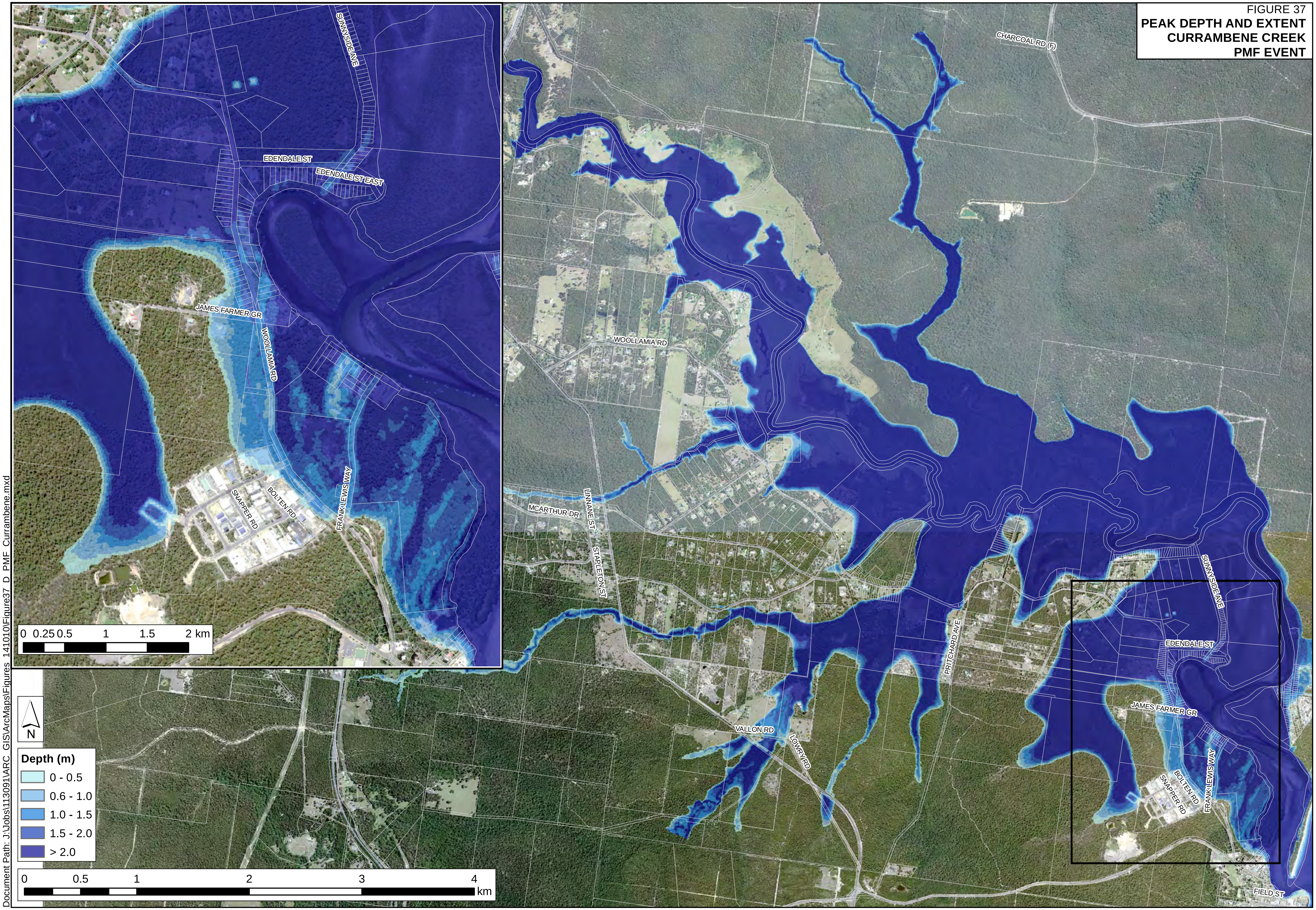


FIGURE 36
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
0.5% AEP EVENT
CHARCOAL RD (F)
WOOLLAMIA RD
MCARTHUR DR
LINNANE ST
STAPLETON ST
PRITCHARD AVE
VALLON RD
LOWRY RD
SUNNYSIDE AVE
EDENDALE ST
EDENDALE ST EAST
JAMES FARMER GR
BOLTEN RD
SNAPPER RD
FRANK LEWIS WAY
FIELD ST
N
Depth (m)
0 - 0.5
0.6 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
0 0.25 0.5 1 1.5 2 km
0 0.5 1 2 3 4 km
Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure36_D_05AEP_Currambene.mxd

FIGURE 37
PEAK DEPTH AND EXTENT CURRAMBENE CREEK PMF EVENT



Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure37_D_PMF_Currambene.mxd

FIGURE 38
CURRAMBENE CREEK
DESIGN FLOOD PROFILES

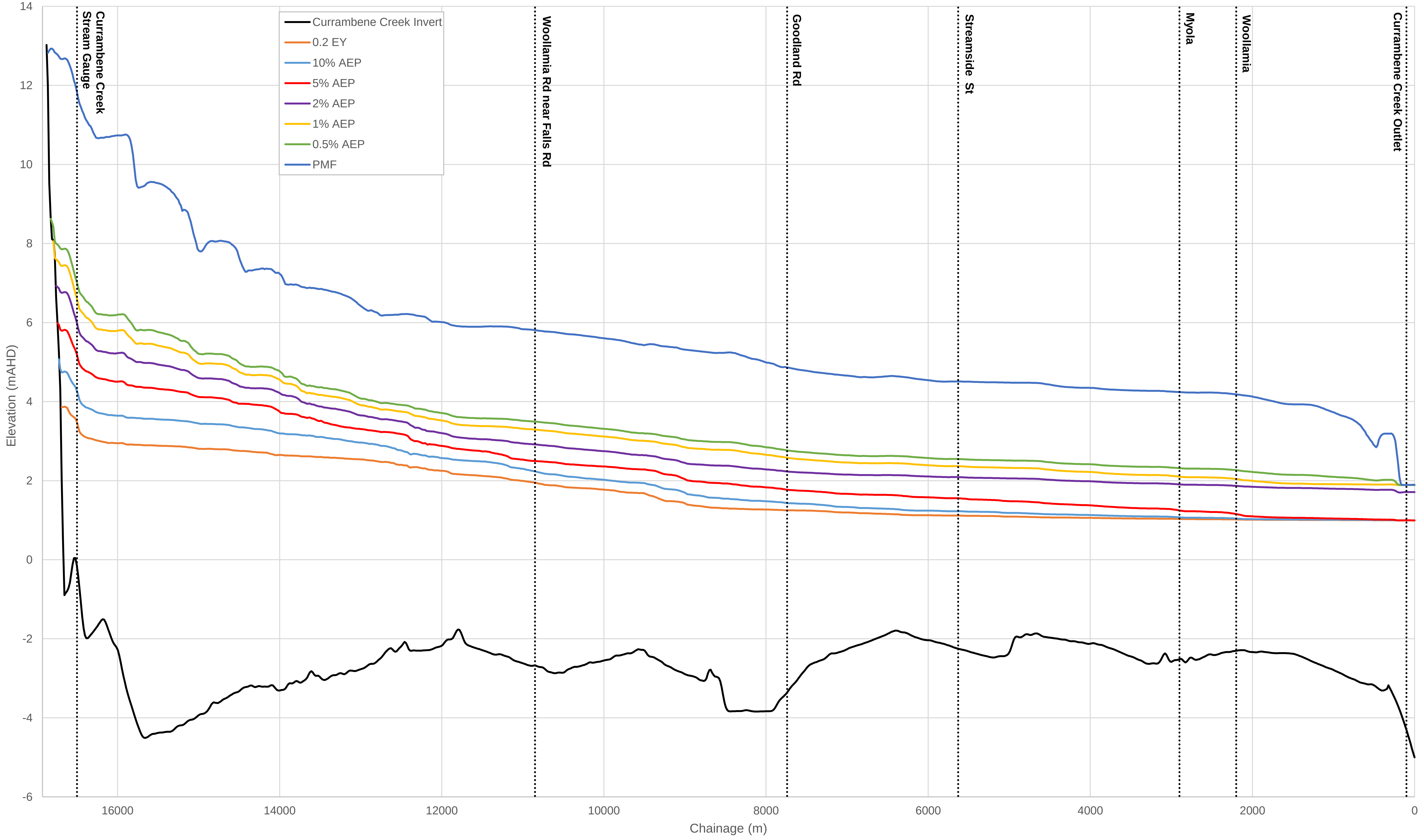
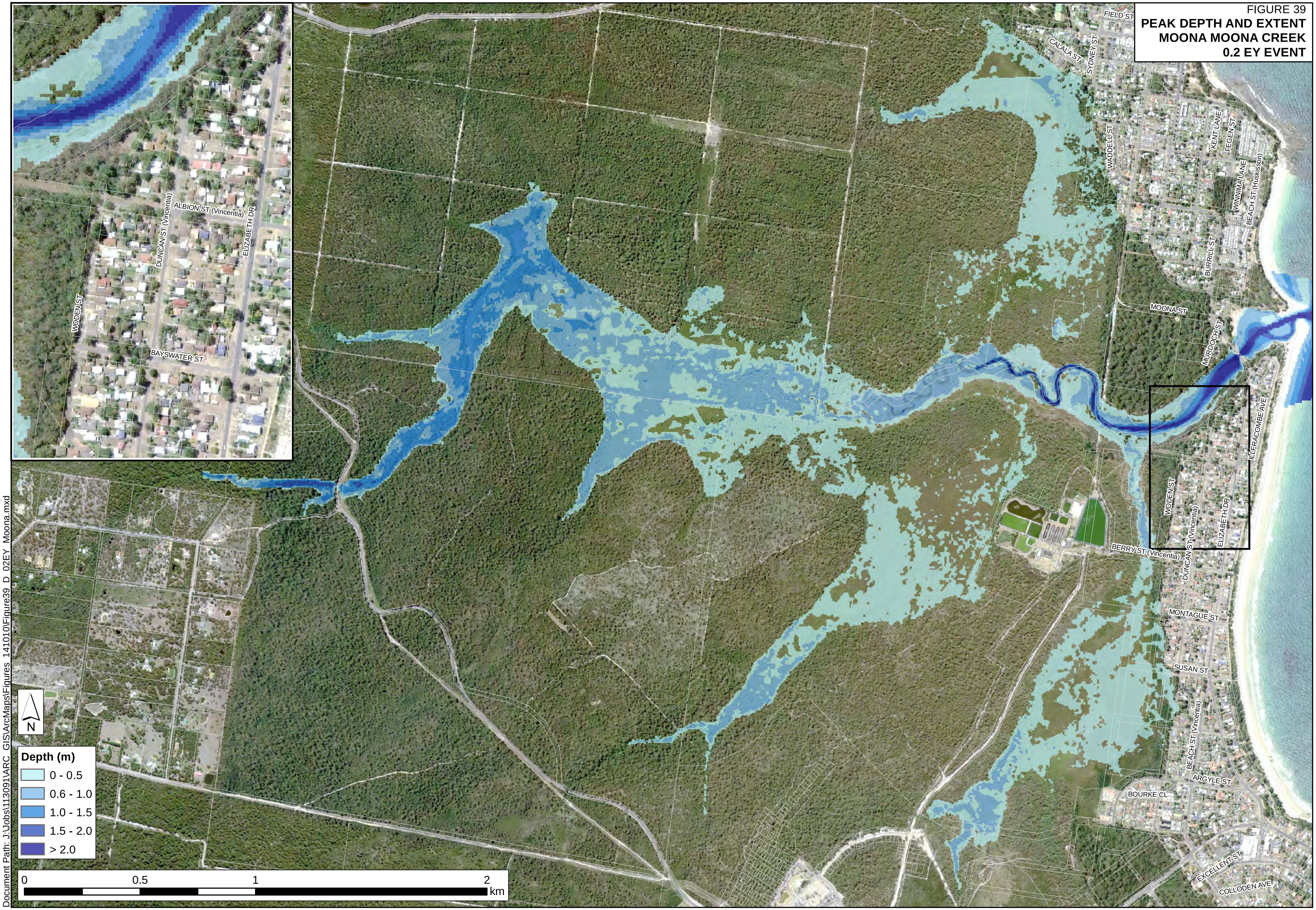
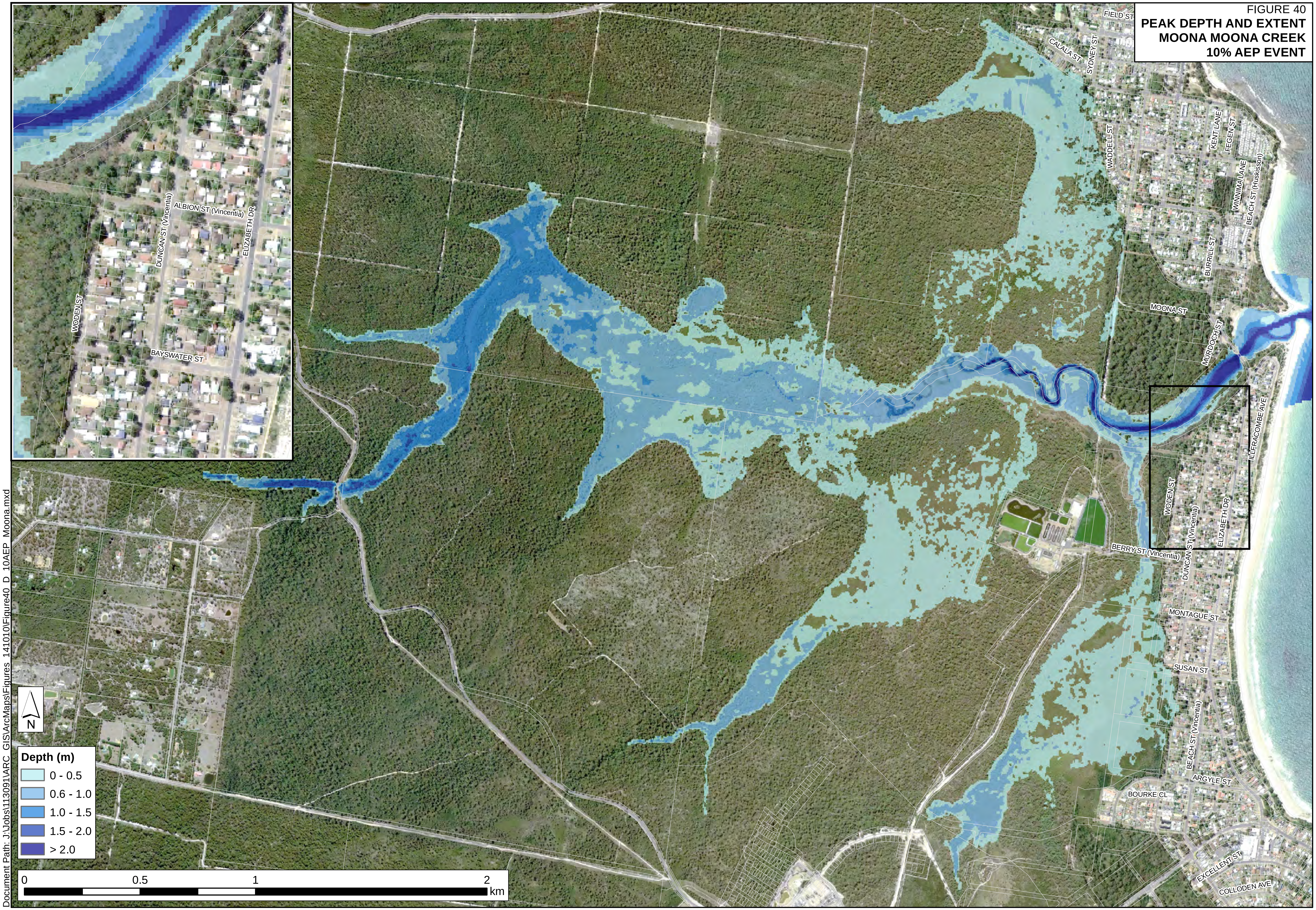


FIGURE 39
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
0.2 EY EVENT



Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure39_D_02EY_Moona.mxd

FIGURE 40
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
10% AEP EVENT



Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure40_D_10AEP_Moona.mxd

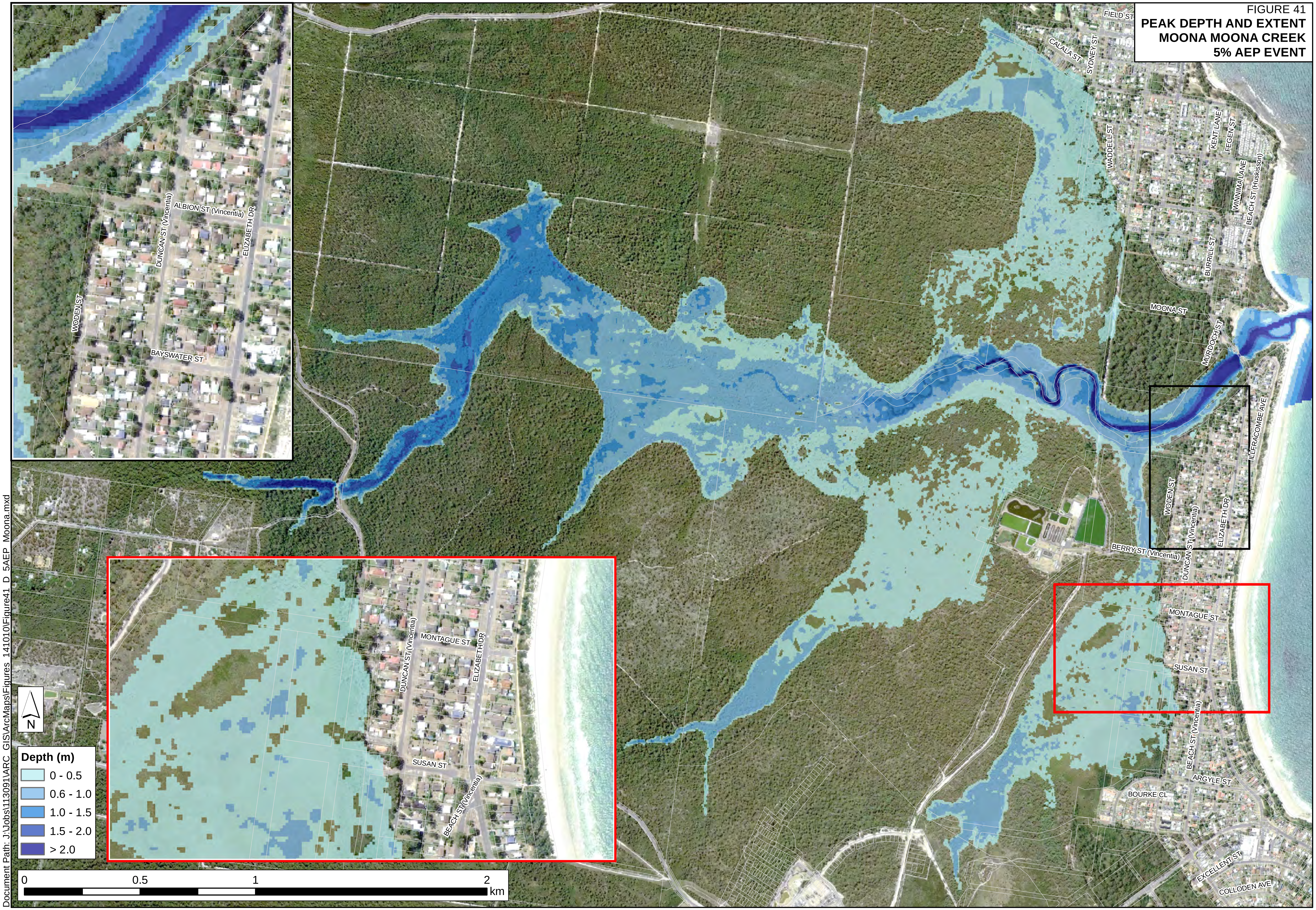


FIGURE 41
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
5% AEP EVENT
FIELD ST
CALALA ST
SYDNEY ST
WADDELL ST
KENT LANE
FEGEN ST
WINNIMA LANE
BEACH ST (Huskisson)
BURRILL ST
MOONA ST
MURDOCH ST
ILLFRACOMBE AVE
WODEN ST
DUNCAN ST (Vincentia)
ELIZABETH DR
ALBION ST (Vincentia)
BAYSWATER ST
BERRY ST (Vincentia)
MONTAGUE ST
SUSAN ST
BEACH ST (Vincentia)
ARGYLE ST
BOURKE CL
EXCELLENT ST
COLLODEN AVE
N
Depth (m)
0 - 0.5
0.6 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
0
0.5
1
2
km
Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure41_D_5AEP_Moona.mxd

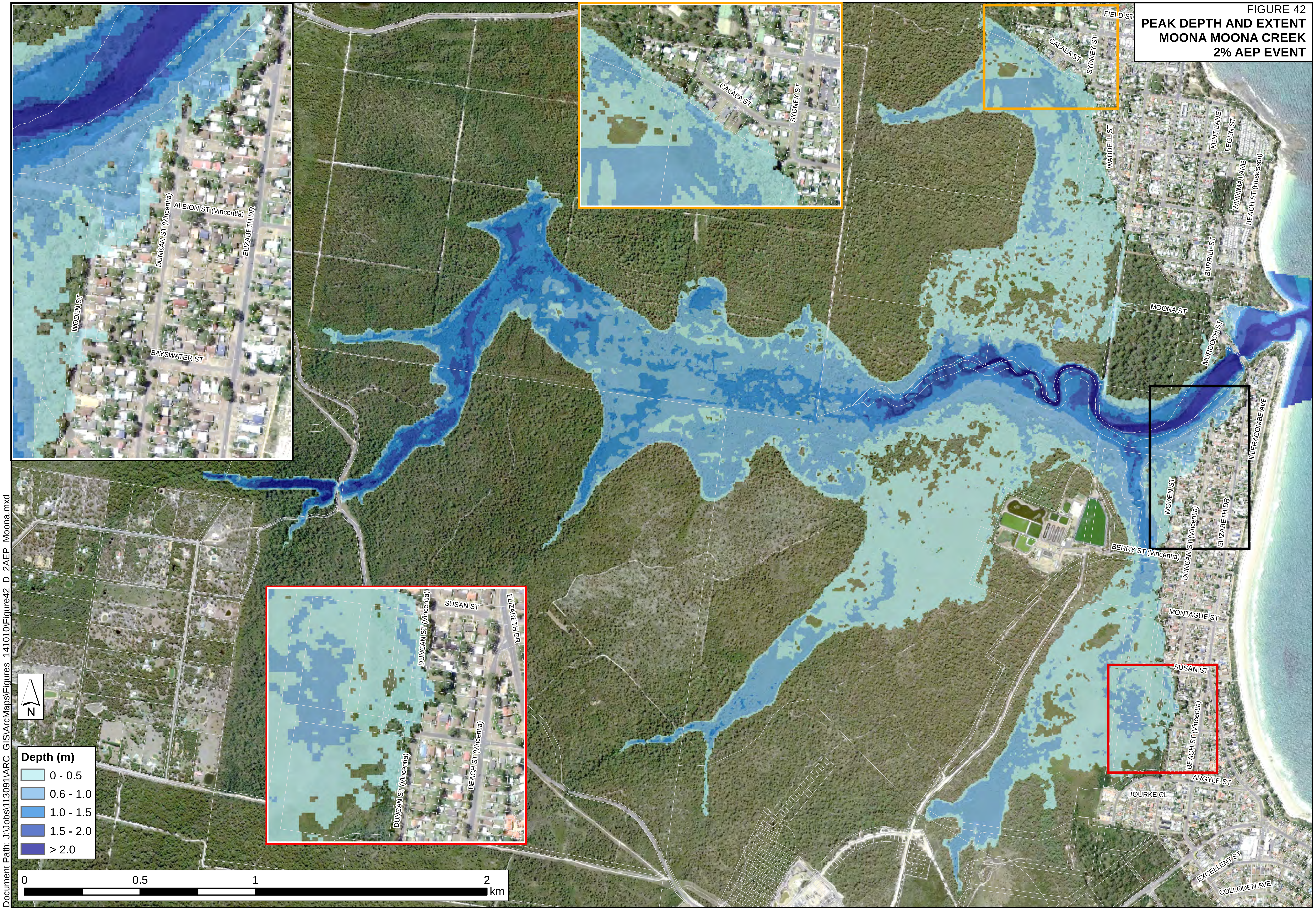
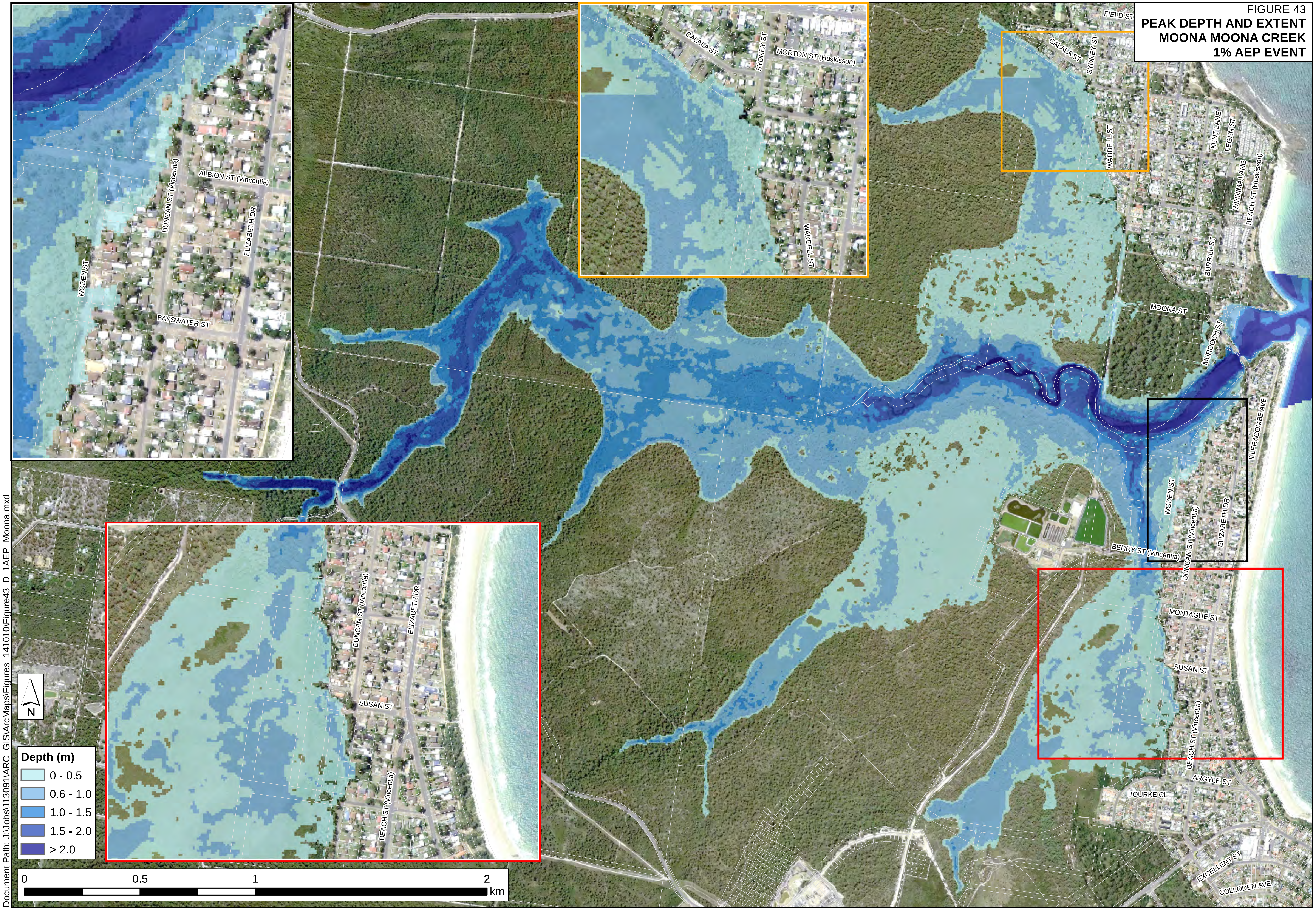


FIGURE 42
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
2% AEP EVENT

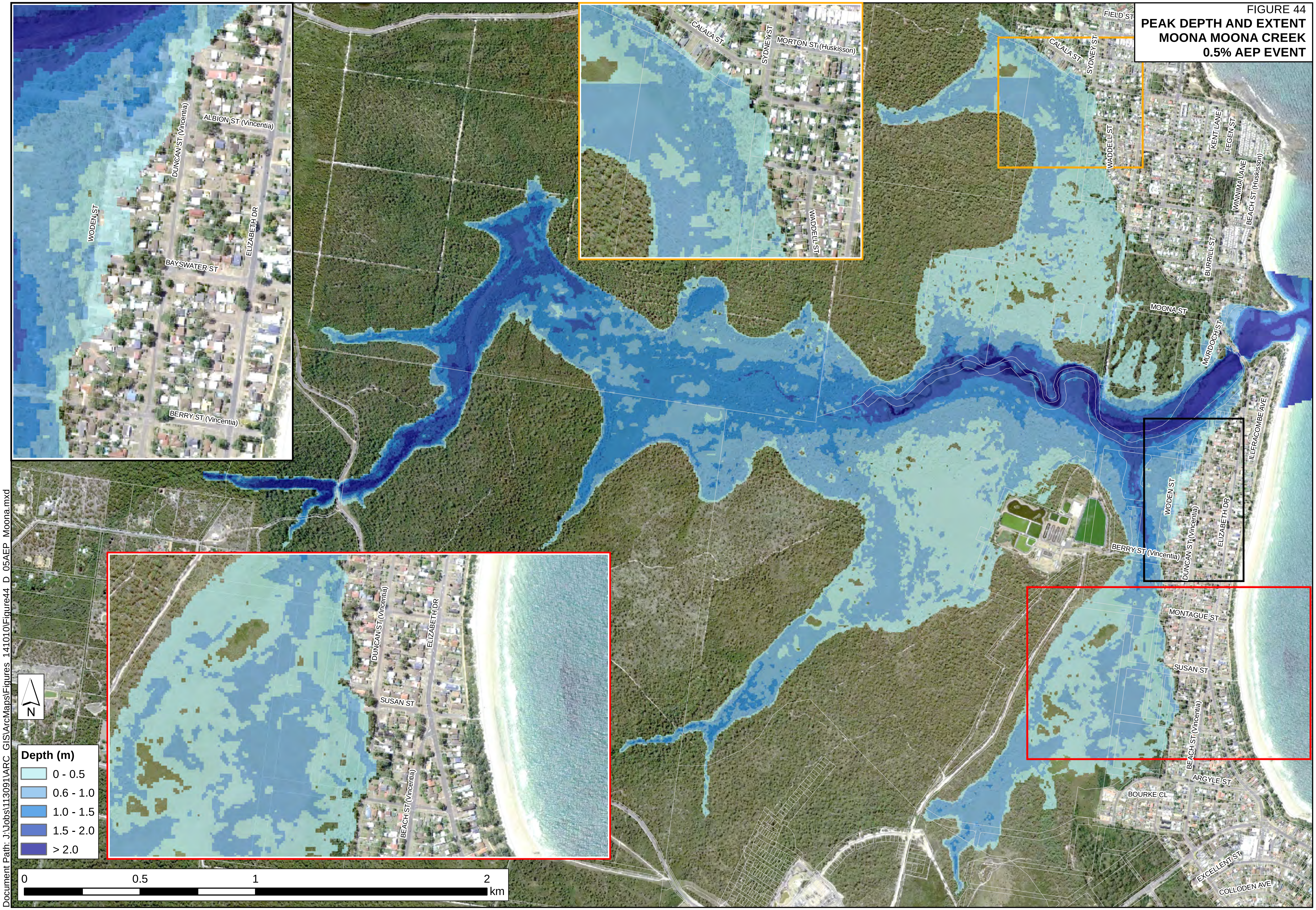
Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure42_D_2AEP_Moona.mxd

FIGURE 43
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
1% AEP EVENT



Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure43_D_1AEP_Moona.mxd

FIGURE 44
PEAK DEPTH AND EXTENT MOONA MOONA CREEK 0.5% AEP EVENT



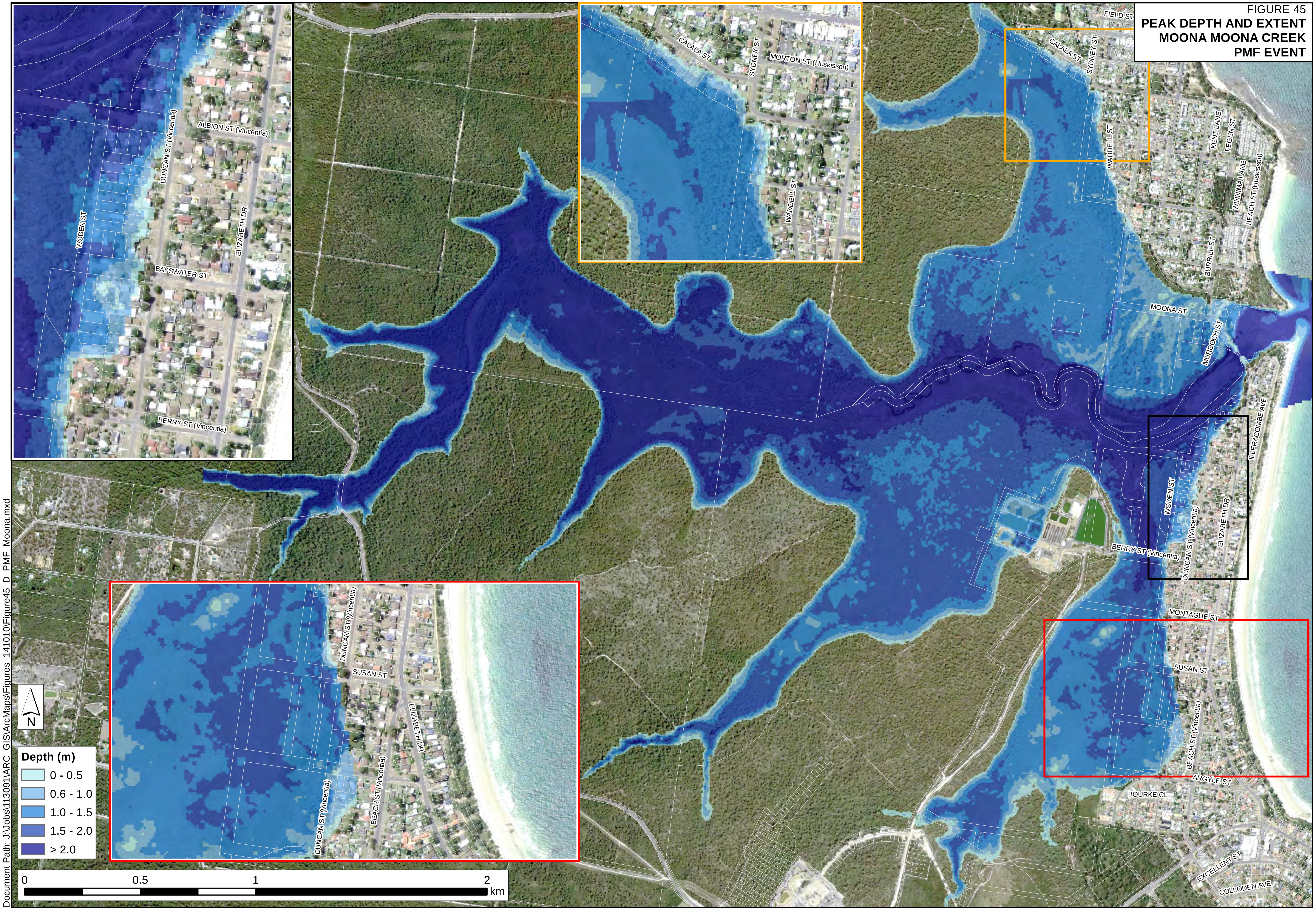


FIGURE 45
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
PMF EVENT
Depth (m)
0 - 0.5
0.6 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
0
0.5
1
2
km
N
FIELD ST
CALALA ST
SYDNEY ST
MORTON ST (Huskisson)
WADDELL ST
KENT LANE
FEGEN ST
WINNIMA LANE
BEACH ST (Huskisson)
BURRILL ST
MOONA ST
MURDOCH ST
ILFRACOMBE AVE
WODEN ST
DUNCAN ST (Vincentia)
ELIZABETH DR
BERRY ST (Vincentia)
MONTAGUE ST
SUSAN ST
BEACH ST (Vincentia)
ARGYLE ST
BOURKE CL
EXCELLENT ST
COLLODEN AVE
ALBION ST (Vincentia)
BAYSWATER ST
Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_141010\Figure45_D_PMF_Moona.mxd

FIGURE 46
MOONA MOONA CREEK
DESIGN FLOOD PROFILES

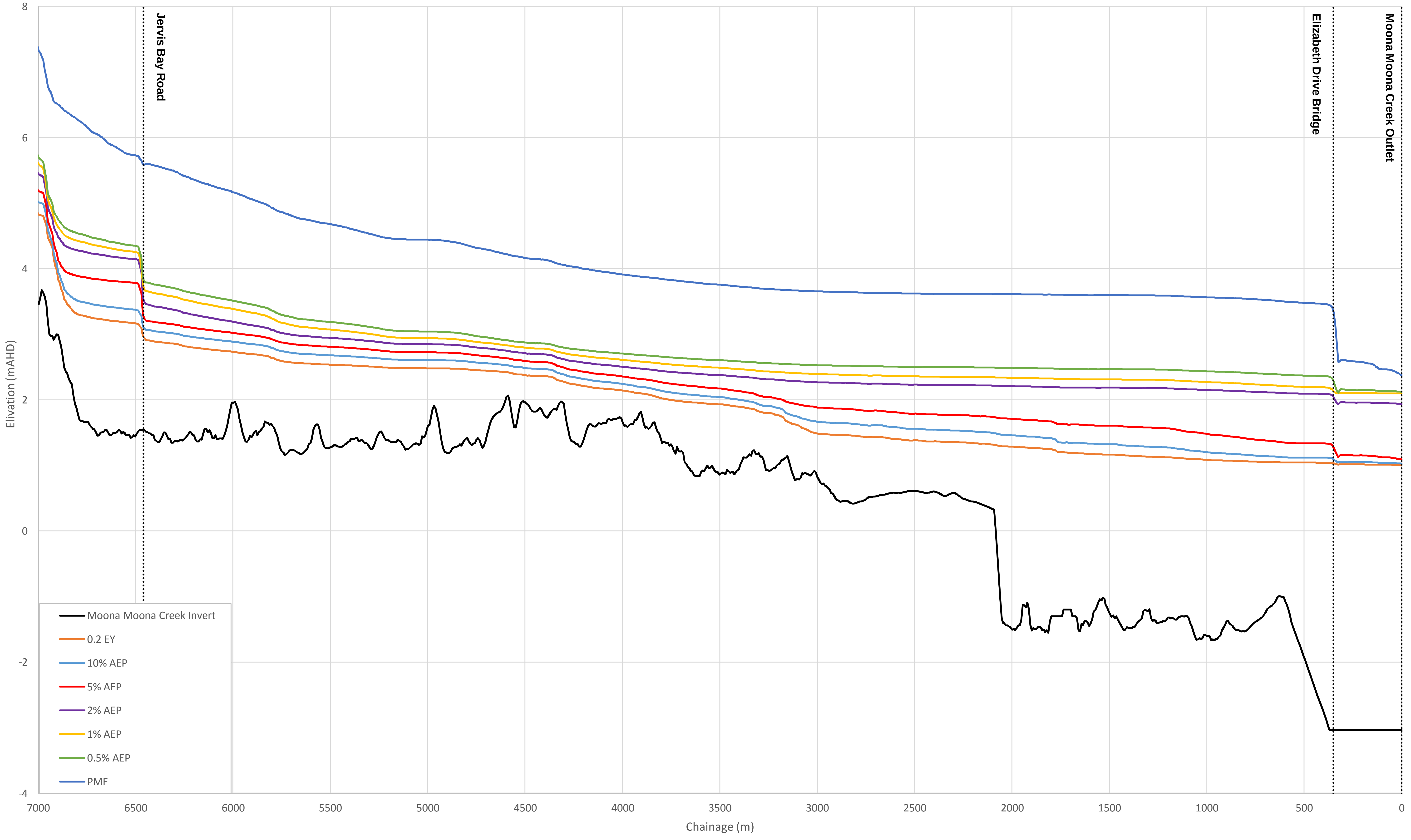


FIGURE 47
CURRAMBENE CREEK
REFERENCE 1 / CURRENT STUDY FLOOD PROFILE COMPARISON

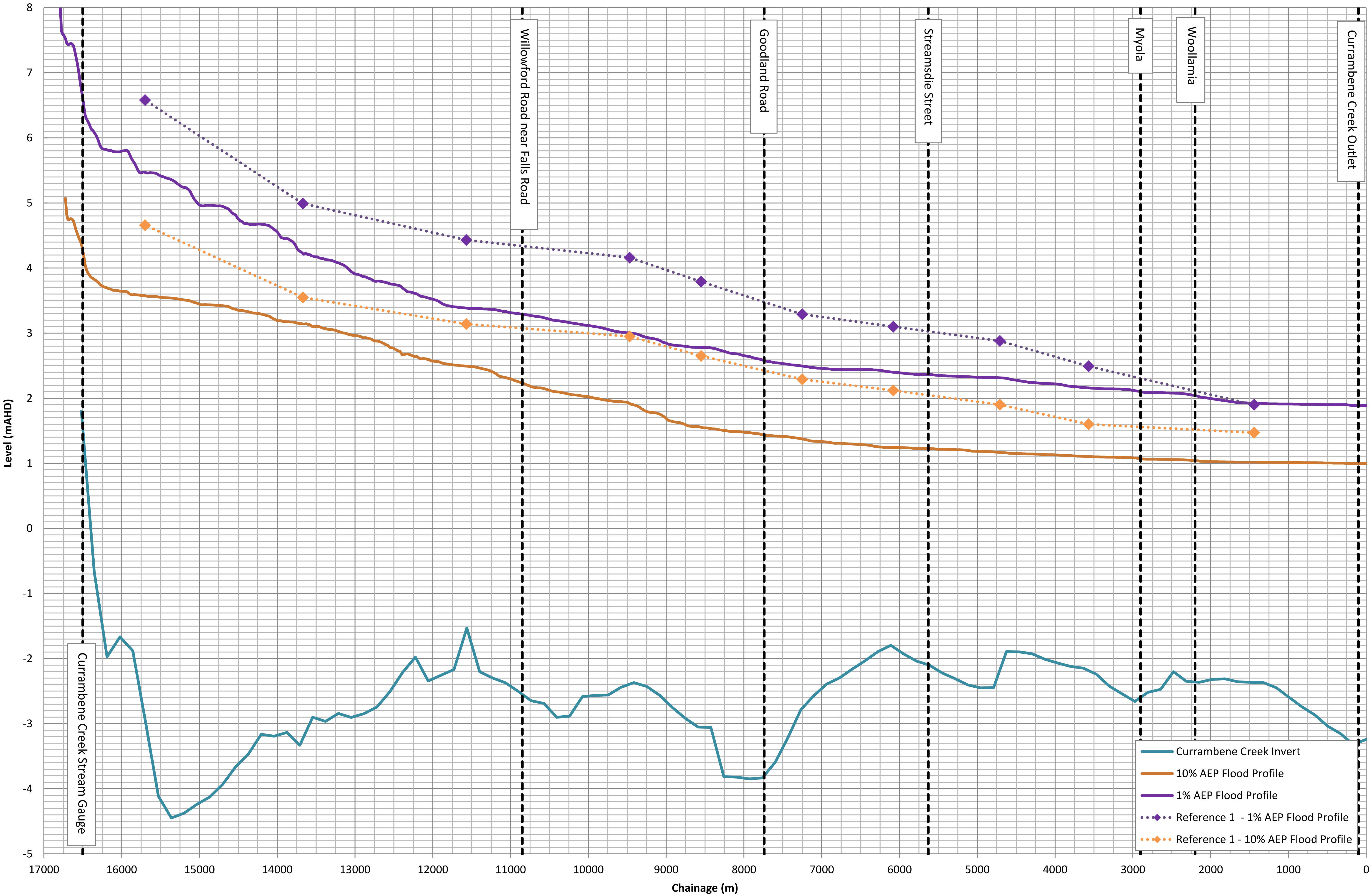


FIGURE 48

MOONA MOONA CREEK

REFERENCE 1 / CURRENT STUDY FLOOD PROFILE COMPARISON

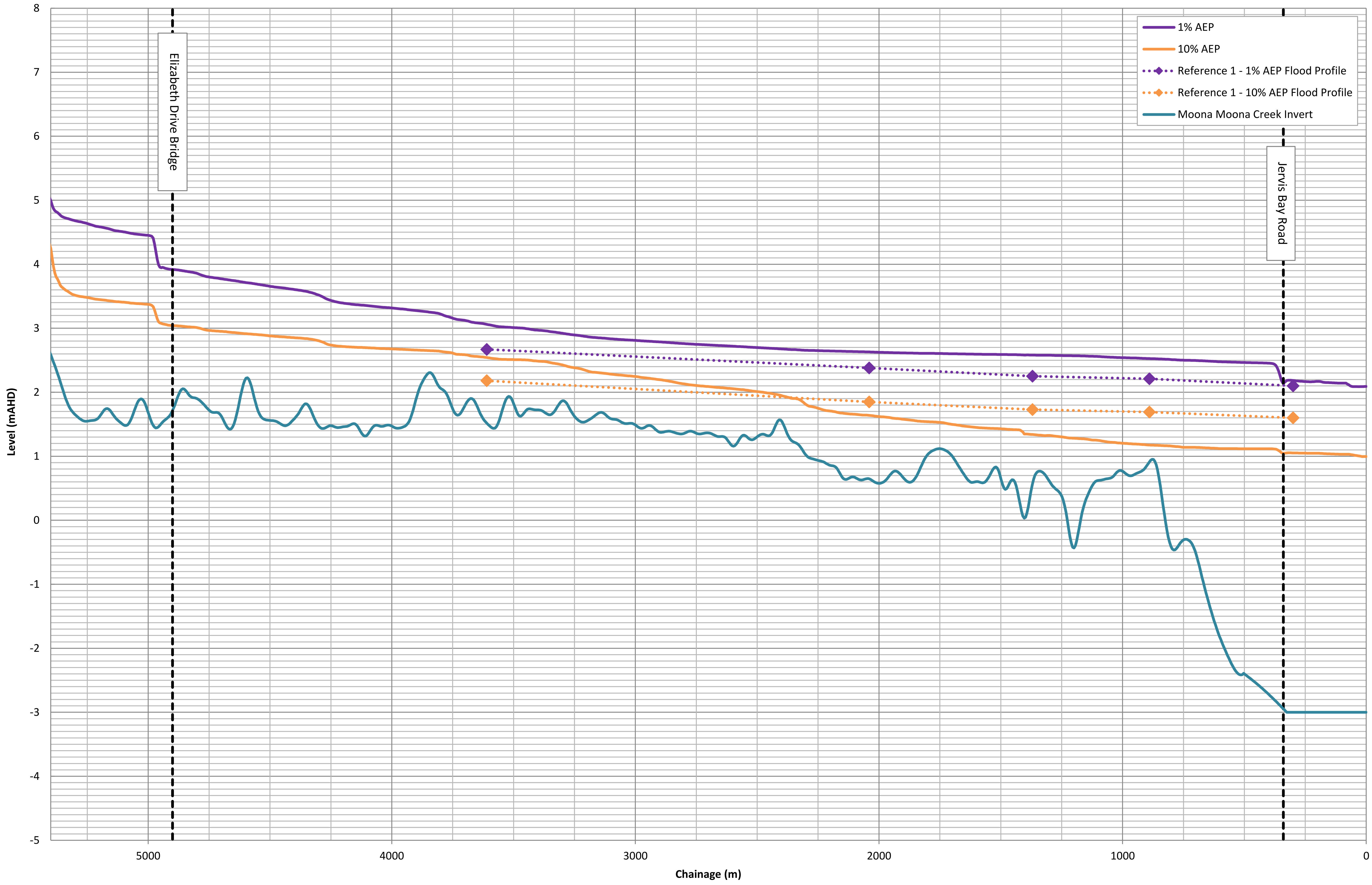
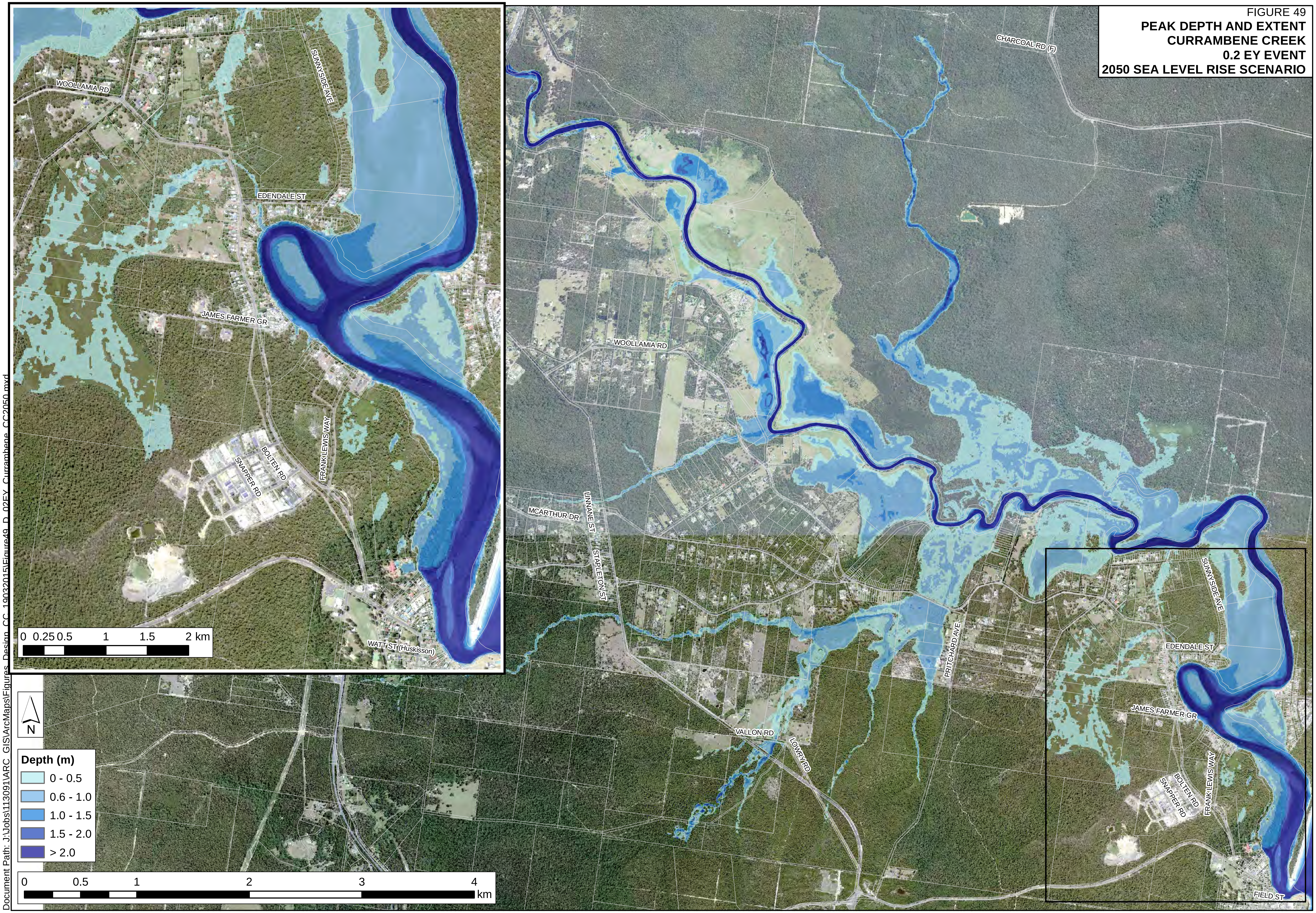
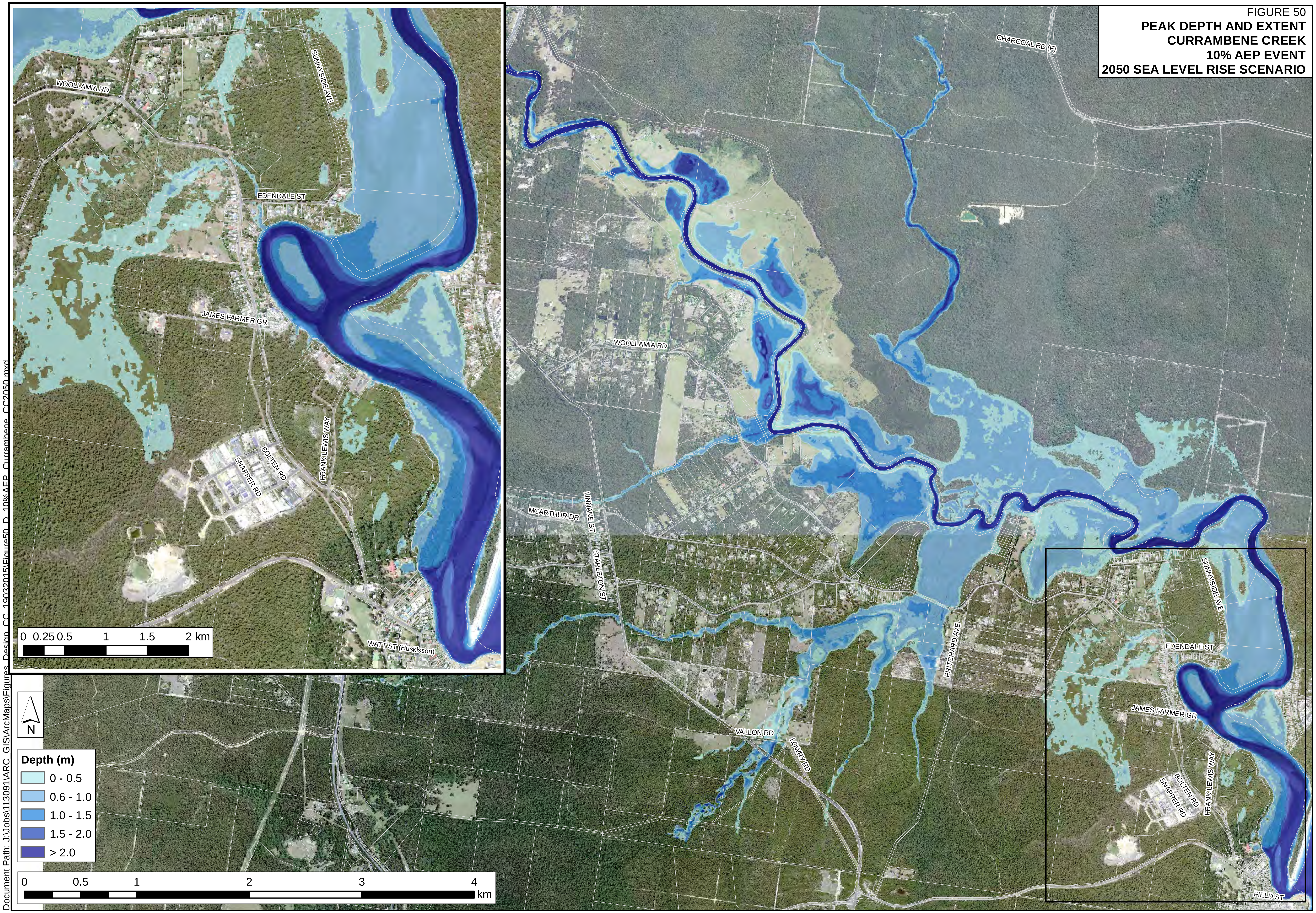


FIGURE 49
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
0.2 EY EVENT
2050 SEA LEVEL RISE SCENARIO



Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure49_D_02EY_Currambene_CC2050.mxd

FIGURE 50
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
10% AEP EVENT
2050 SEA LEVEL RISE SCENARIO



Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure50_D_10%AEP_Currambene_CC2050.mxd

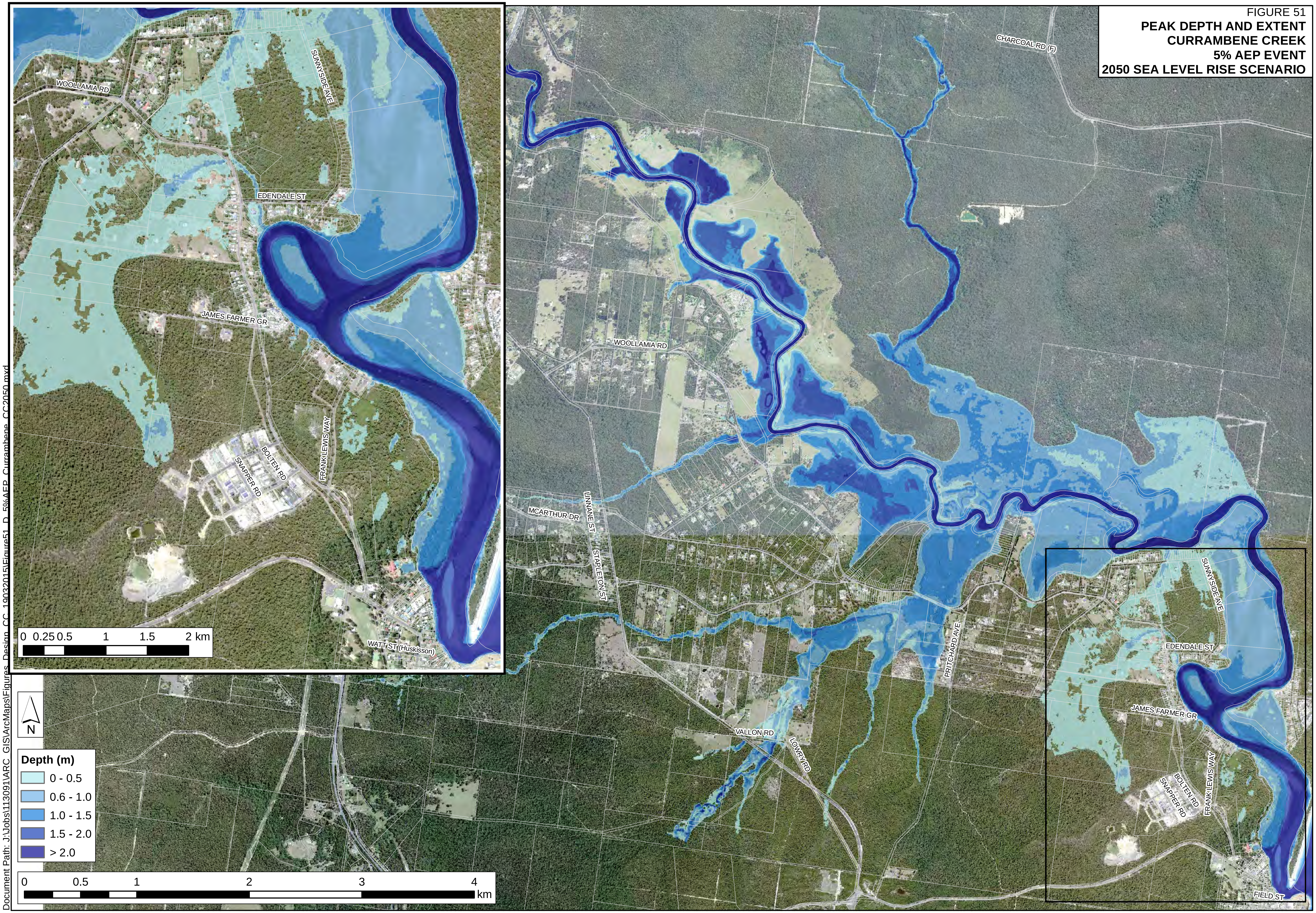


FIGURE 51
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
5% AEP EVENT
2050 SEA LEVEL RISE SCENARIO

Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure51_D_5%AEP_Currambene_CC2050.mxd

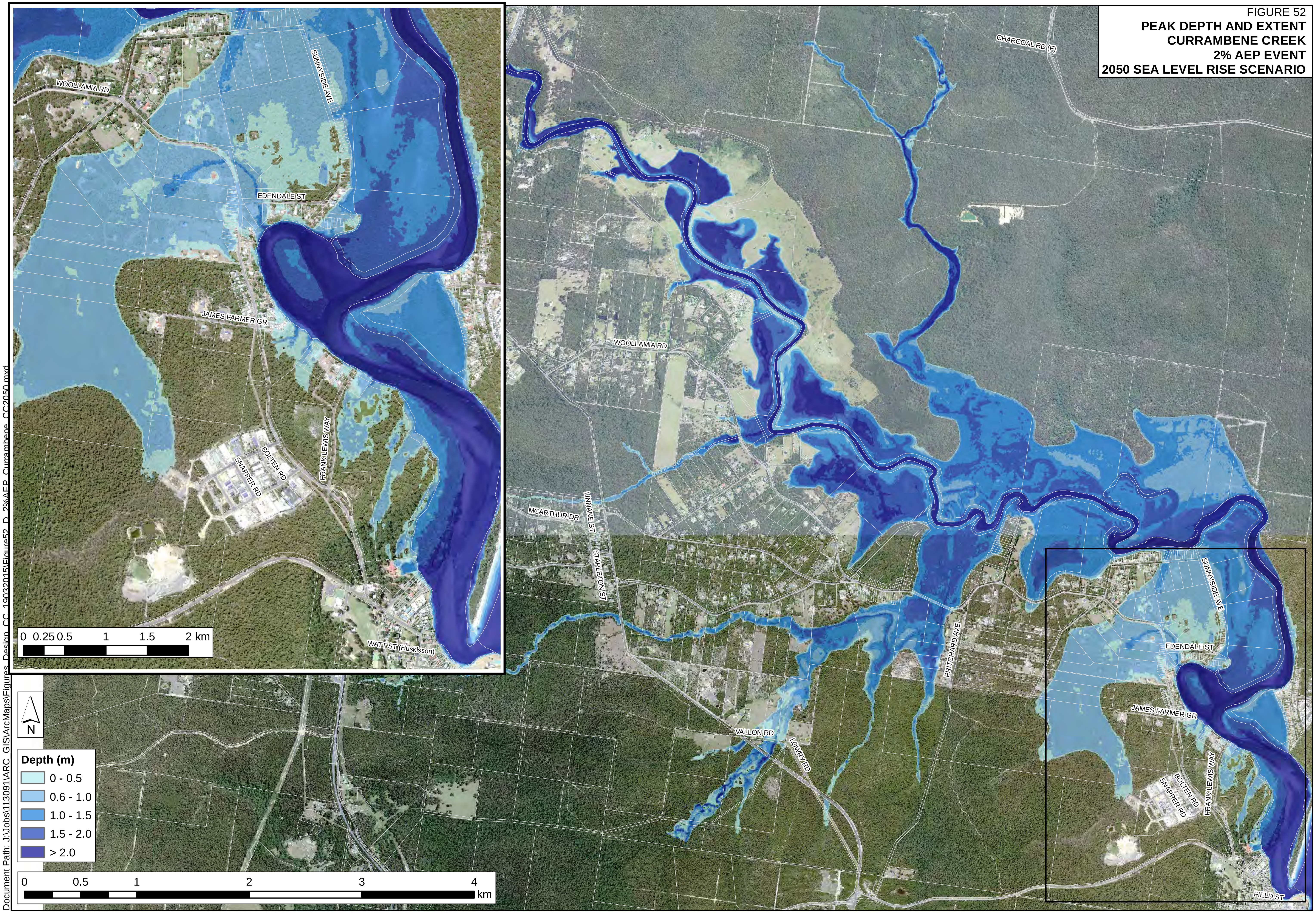


FIGURE 52
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
2% AEP EVENT
2050 SEA LEVEL RISE SCENARIO
CHARCOAL RD (F)
WOOLLAMIA RD
MCARTHUR DR
LINNANE ST
STAPLETON ST
PRITCHARD AVE
VALLON RD
LOWRY RD
SUNNYSIDE AVE
EDENDALE ST
JAMES FARMER GR
FRANK LEWIS WAY
BOLTEN RD
SNAPPER RD
FIELD ST
WATT ST (Huskisson)
0 0.25 0.5 1 1.5 2 km
N
Depth (m)
0 - 0.5
0.6 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
0 0.5 1 2 3 4 km
Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure52_D_2%AEP_Currambene_CC2050.mxd

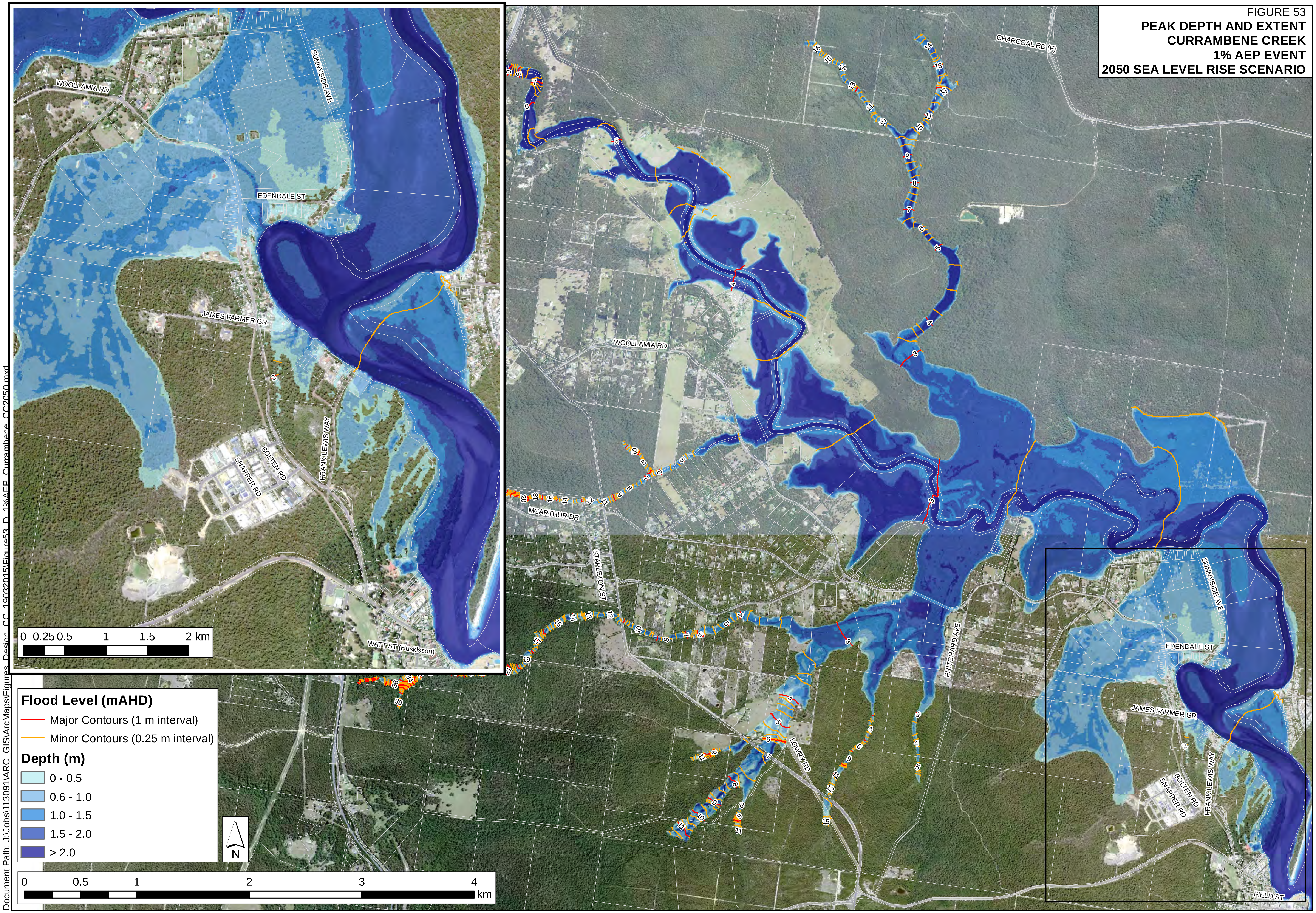


FIGURE 53
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
1% AEP EVENT
2050 SEA LEVEL RISE SCENARIO
CHARCOAL RD (F)
WOOLLAMIA RD
MCARTHUR DR
STAPLETON ST
PRITCHARD AVE
LOWRY RD
SUNNYSIDE AVE
EDENDALE ST
JAMES FARMER GR
BOLTEN RD
SNAPPER RD
FRANK LEWIS WAY
FIELD ST
WATT ST (Huskisson)
0 0.25 0.5 1 1.5 2 km
Flood Level (mAHD)
Major Contours (1 m interval)
Minor Contours (0.25 m interval)
Depth (m)
0 - 0.5
0.6 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
N
0 0.5 1 2 3 4 km
Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure53_D_1%AEP_Currambene_CC2050.mxd

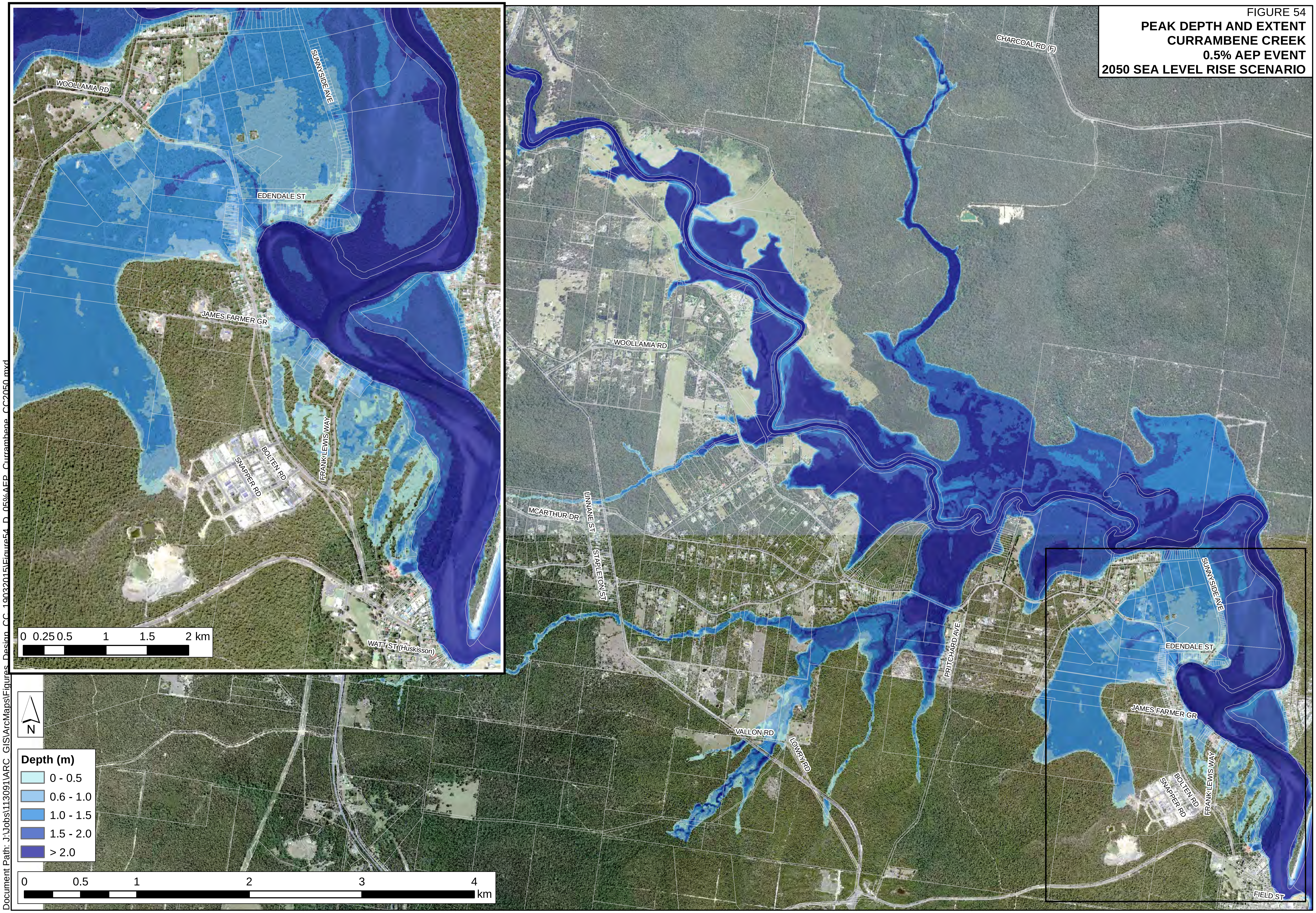
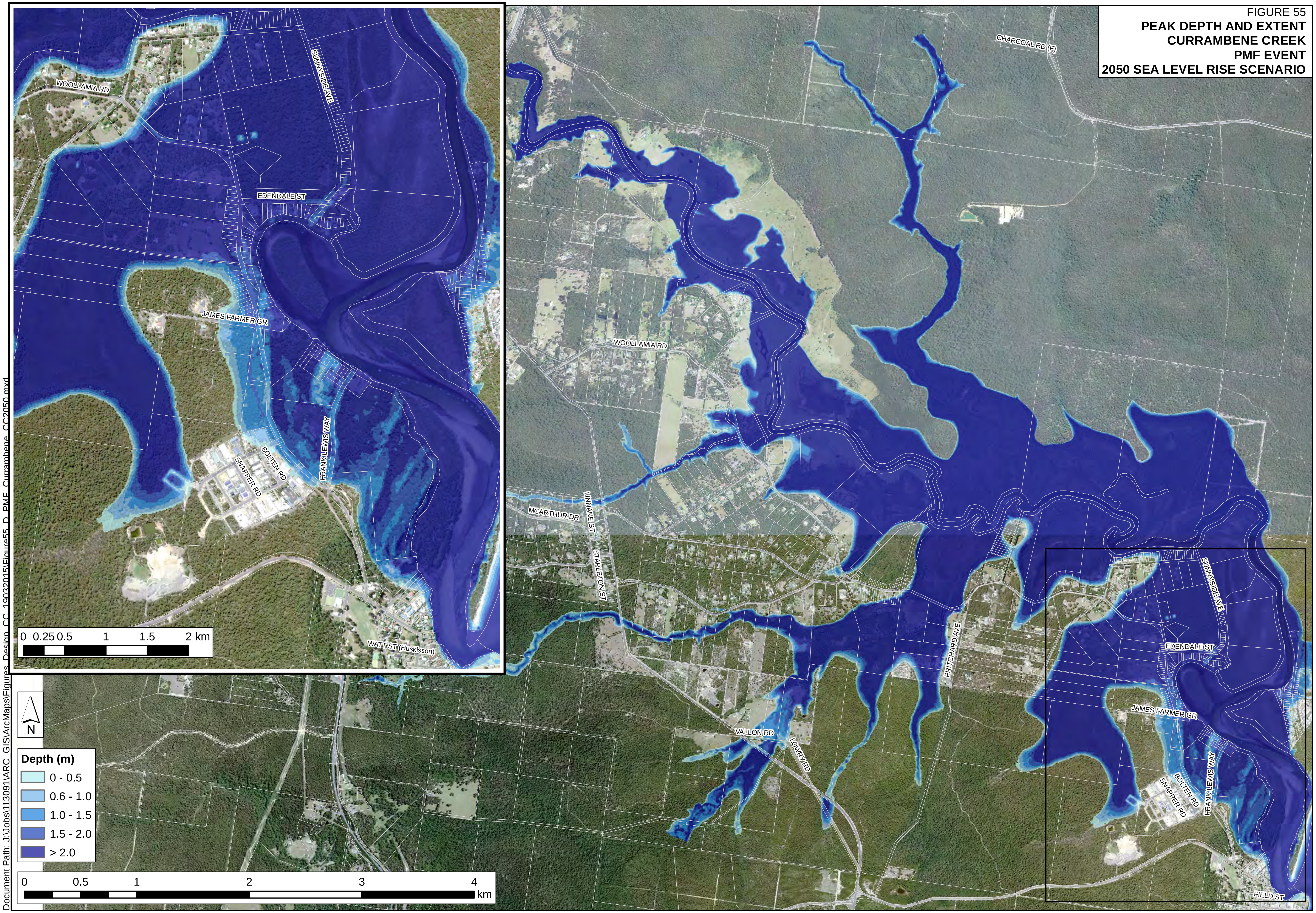


FIGURE 54
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
0.5% AEP EVENT
2050 SEA LEVEL RISE SCENARIO



Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure55_D_PMF_Currambene_CC2050.mxd

FIGURE 56

CURRAMBENE CREEK

2050 SEA LEVEL RISE FLOOD PROFILES

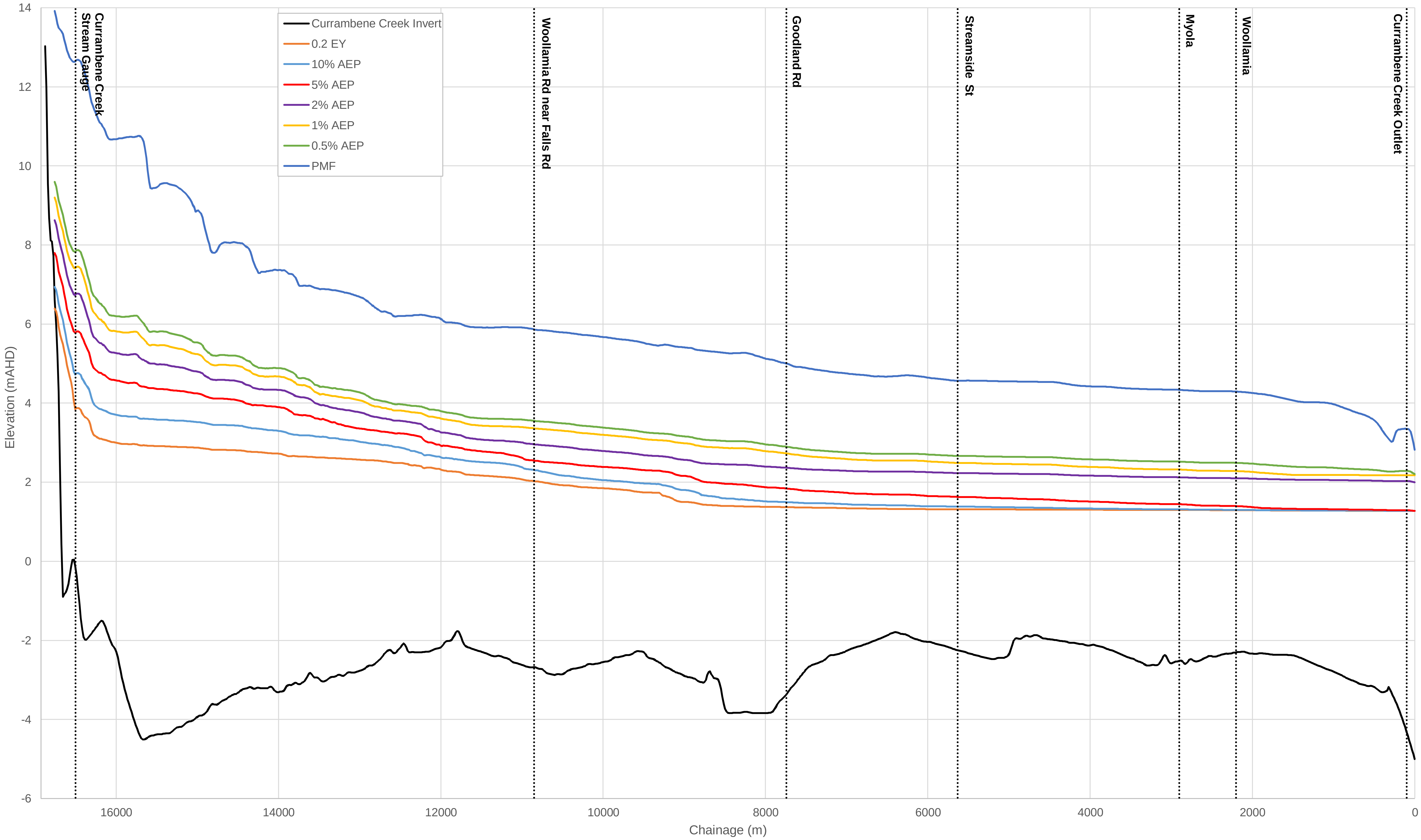
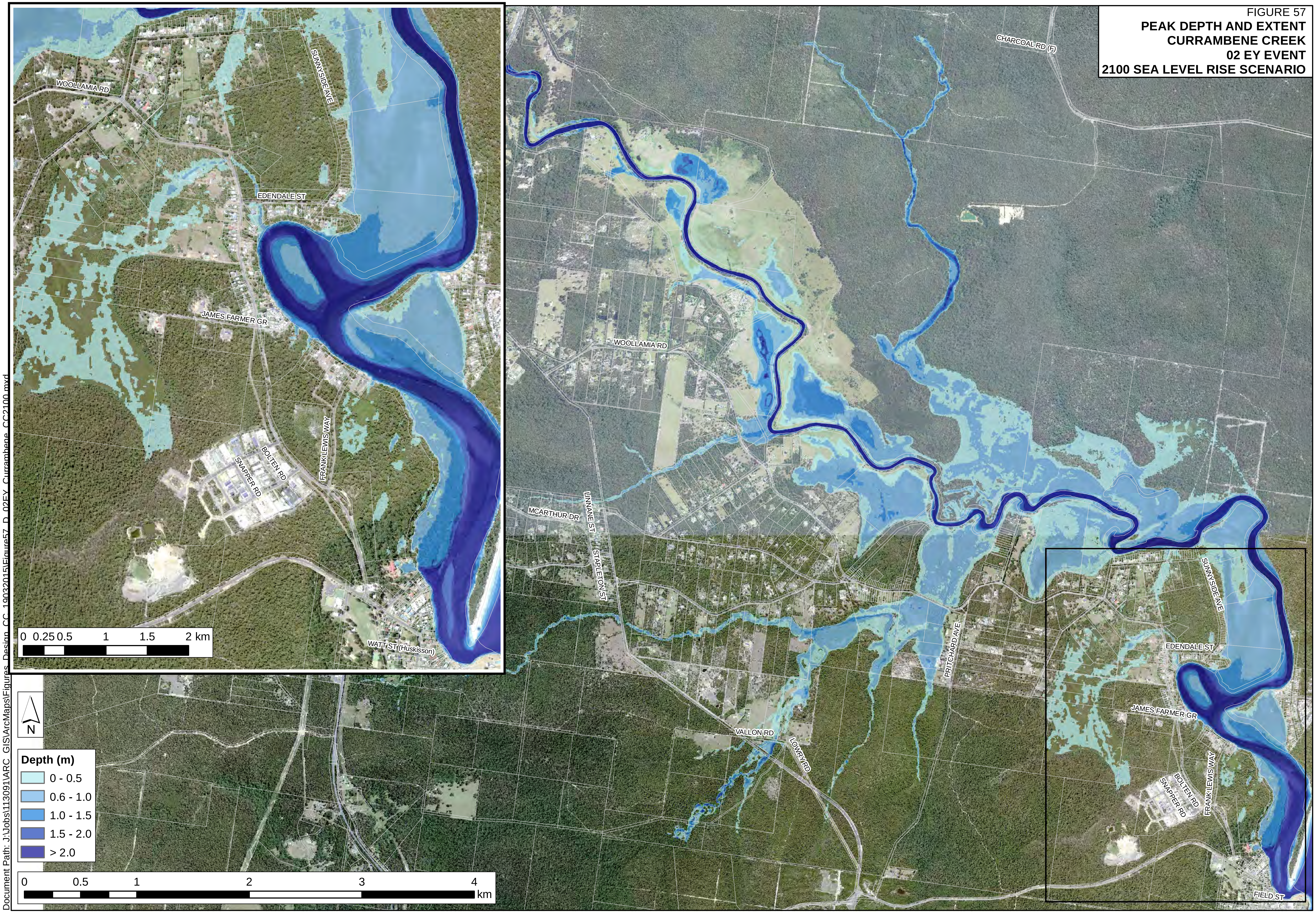


FIGURE 57
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
02 EY EVENT
2100 SEA LEVEL RISE SCENARIO



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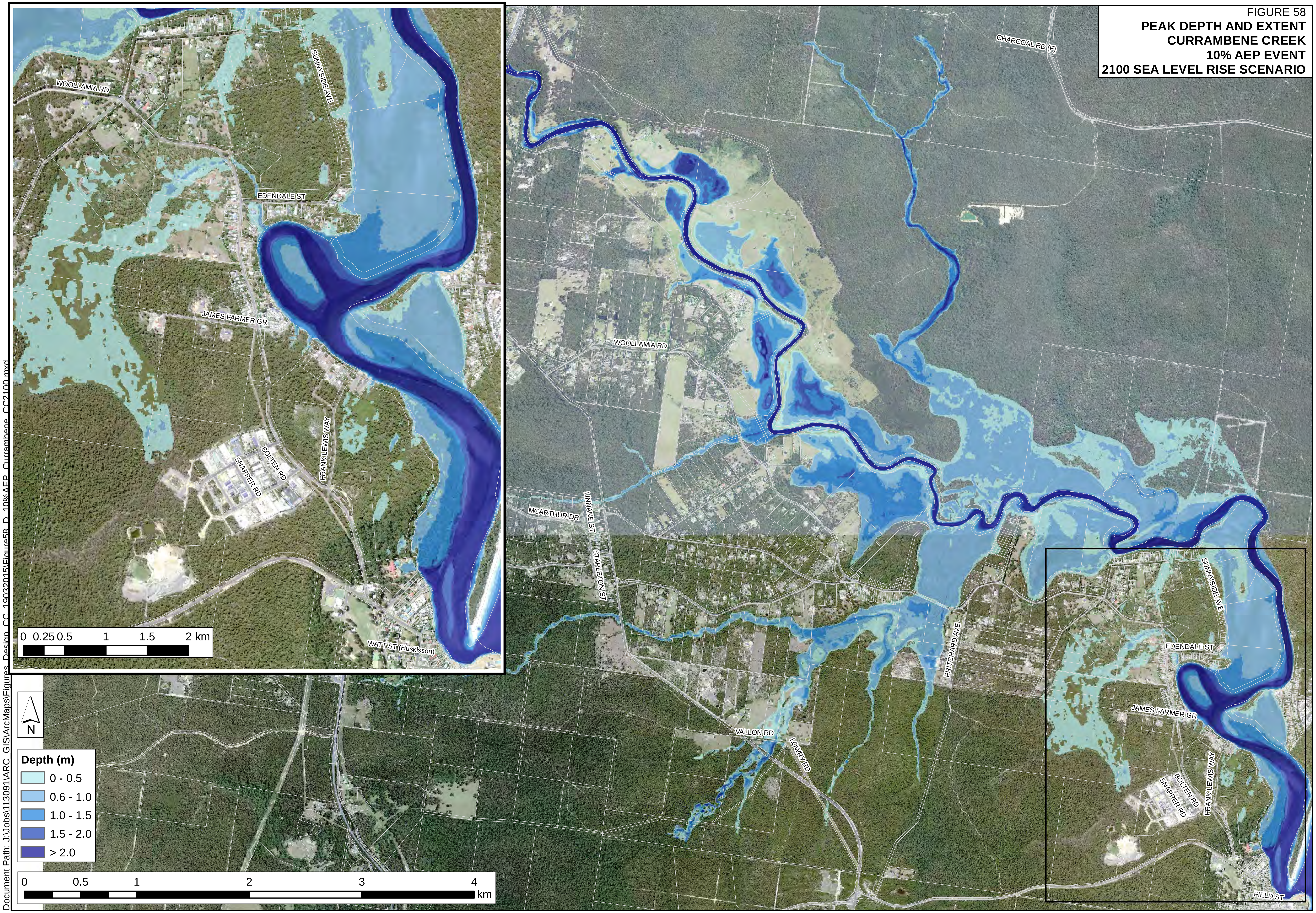

FIGURE 58
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
10% AEP EVENT
2100 SEA LEVEL RISE SCENARIO
CHARCOAL RD (F)
WOOLLAMIA RD
MCARTHUR DR
LINNANE ST
STAPLETON ST
PRITCHARD AVE
VALLON RD
LOWRY RD
SUNNYSIDE AVE
EDENDALE ST
JAMES FARMER GR
FRANK LEWIS WAY
BOLTEN RD
SNAPPER RD
FIELD ST
WATT ST (Huskisson)
0 0.25 0.5 1 1.5 2 km
N
Depth (m)
0 - 0.5
0.6 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
0 0.5 1 2 3 4 km
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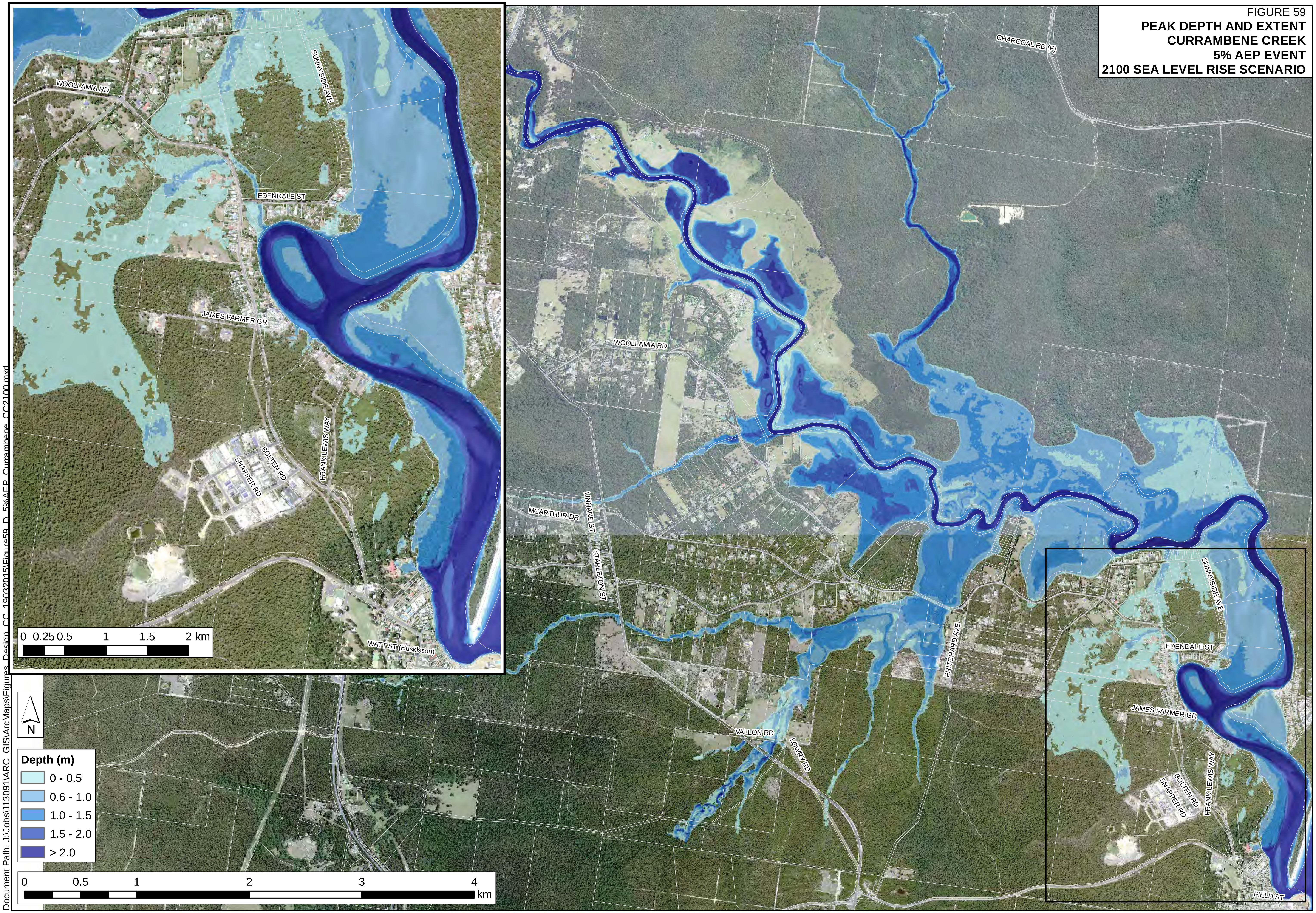

FIGURE 59
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
5% AEP EVENT
2100 SEA LEVEL RISE SCENARIO

Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure59_D_5%AEP_Currambene_CC2100.mxd

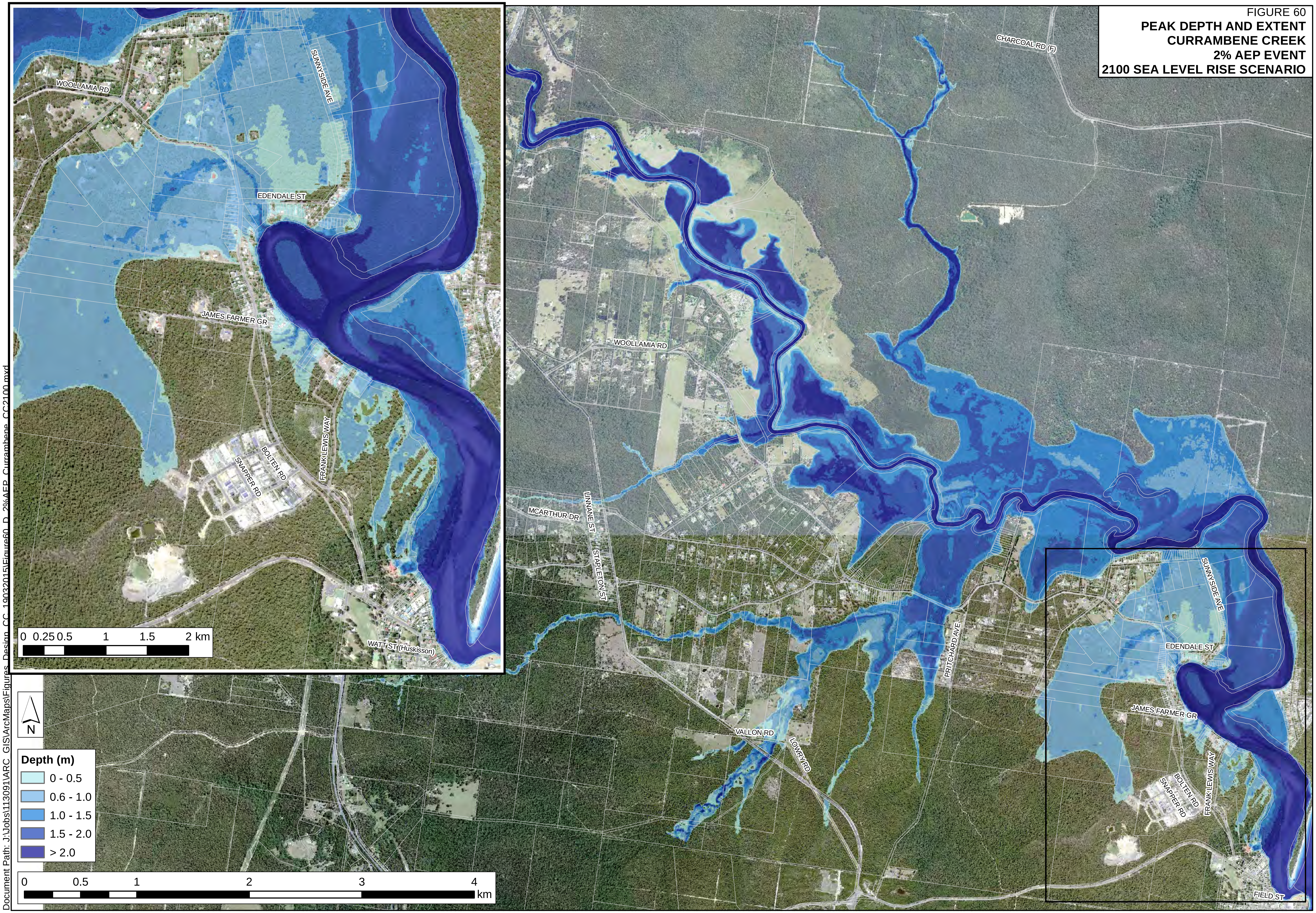

FIGURE 60
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
2% AEP EVENT
2100 SEA LEVEL RISE SCENARIO

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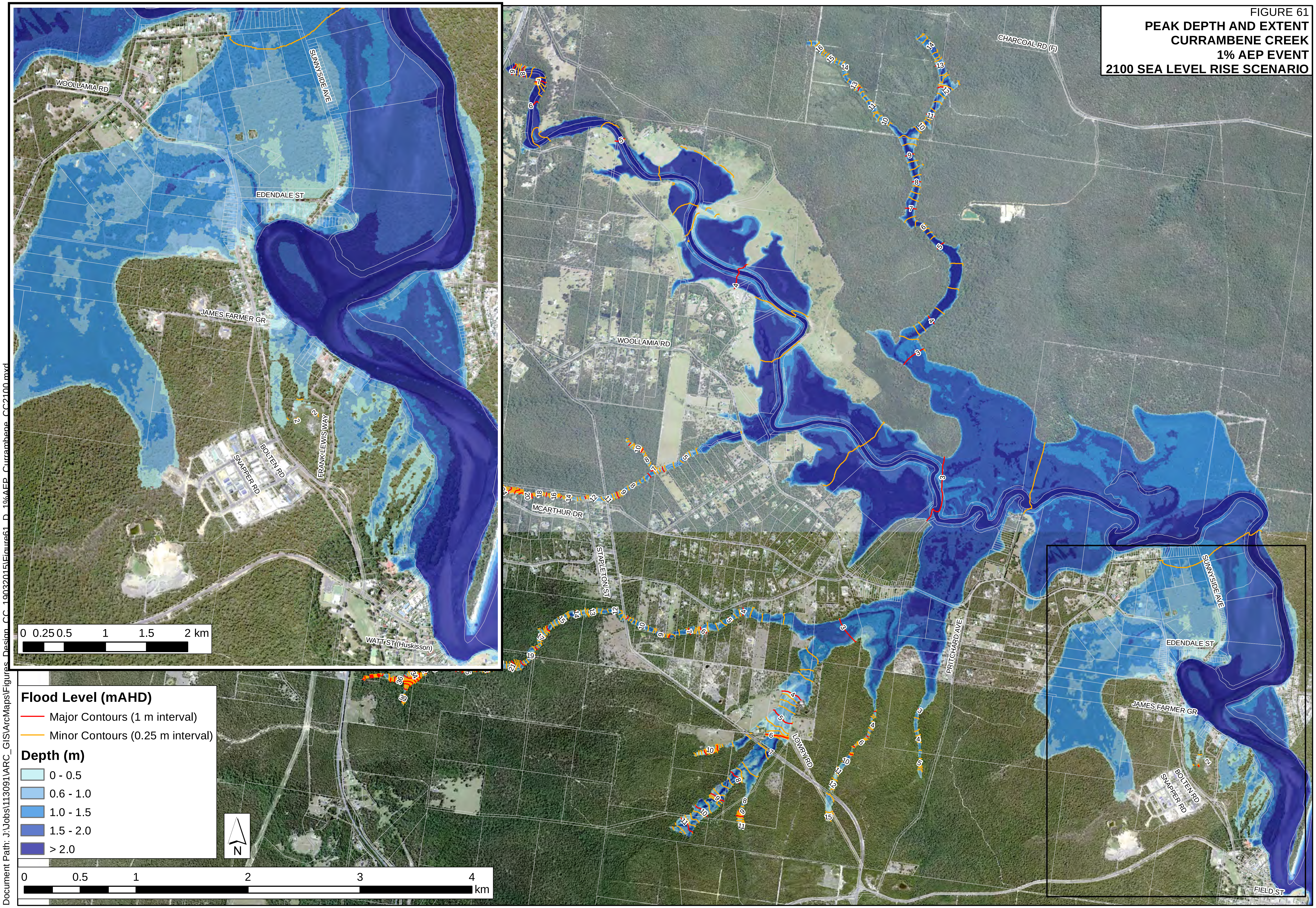
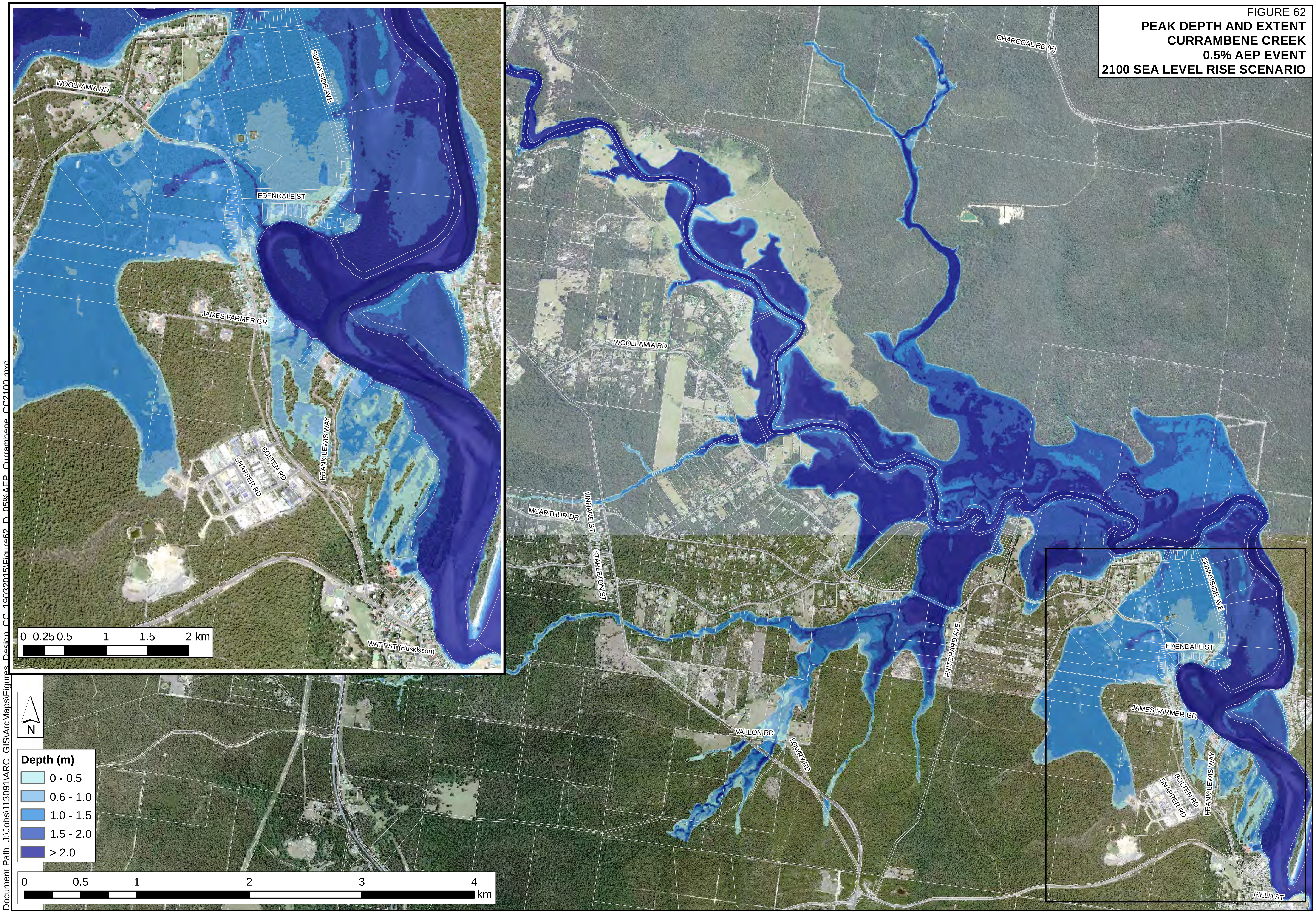
FIGURE 61

PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
1% AEP EVENT
2100 SEA LEVEL RISE SCENARIO



Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure61_D_1%AEP_Currambene_CC2100.mxd



Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure62_D_05%AEP_Currambene_CC2100.mxd

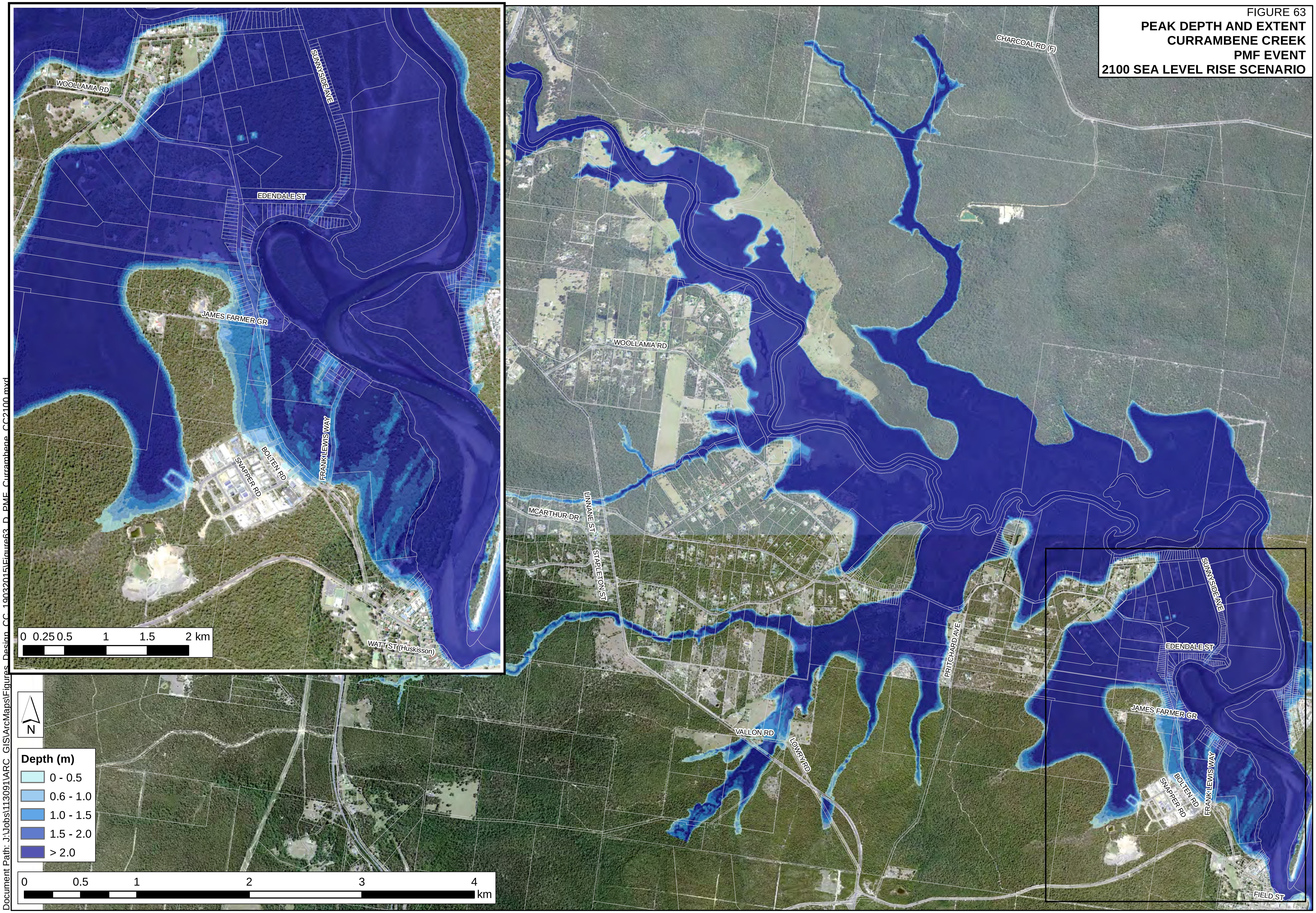
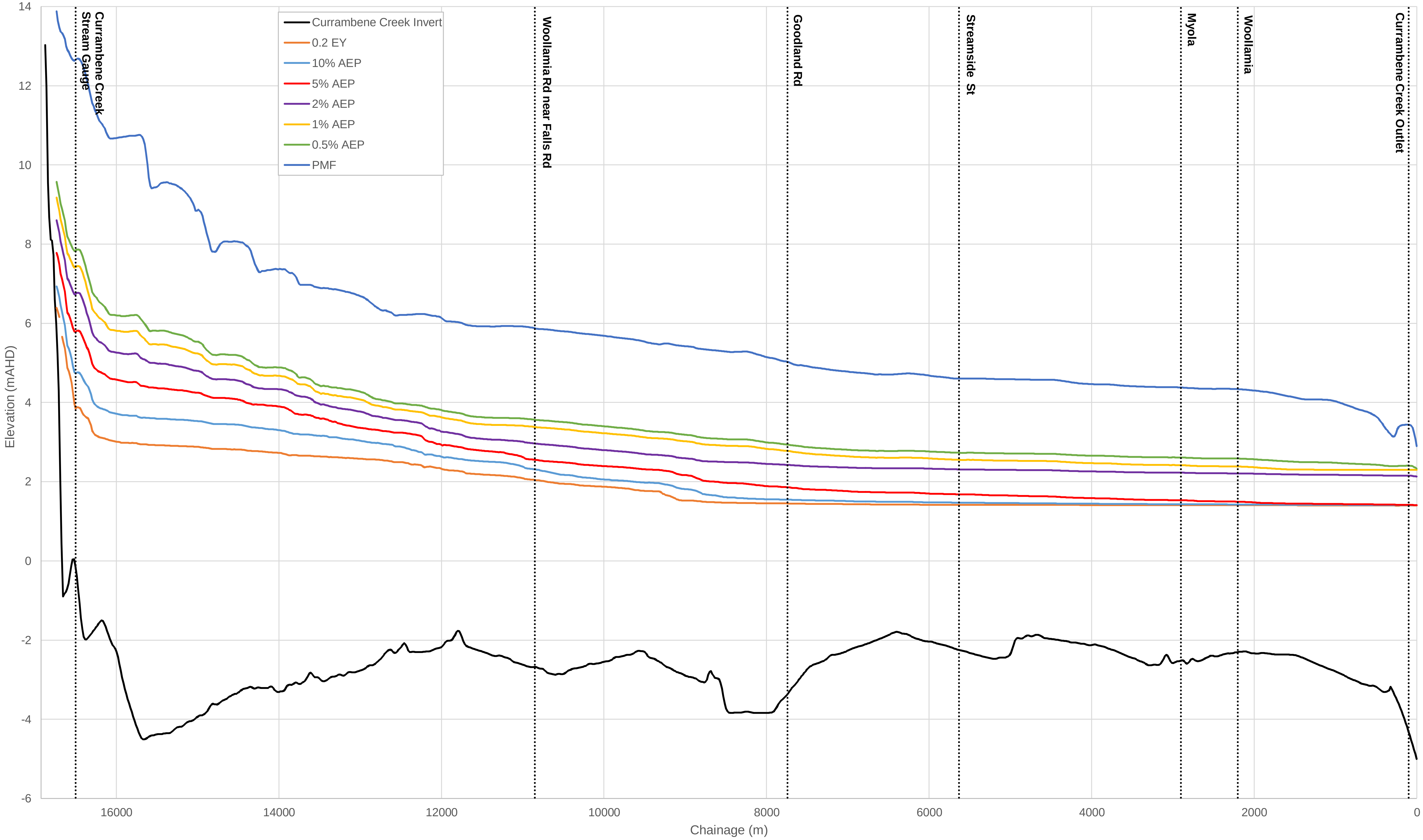


FIGURE 63
PEAK DEPTH AND EXTENT
CURRAMBENE CREEK
PMF EVENT
2100 SEA LEVEL RISE SCENARIO

Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure63_D_PMF_Currambene_CC2100.mxd

FIGURE 64
CURRAMBENE CREEK
2100 SEA LEVEL RISE FLOOD PROFILES



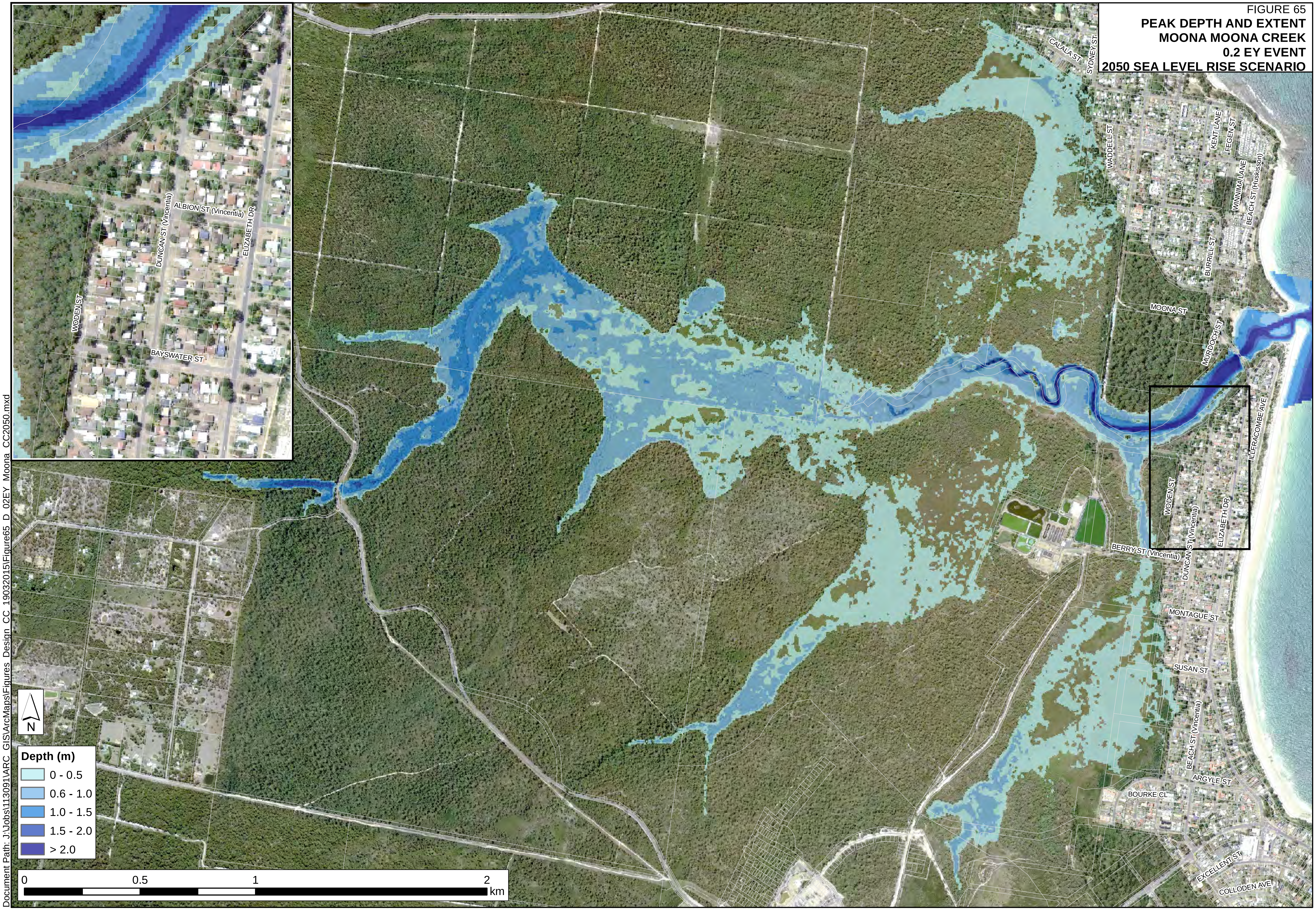


FIGURE 65

PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
0.2 EY EVENT
2050 SEA LEVEL RISE SCENARIO

Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure65_D_02EY_Moona_CC2050.mxd

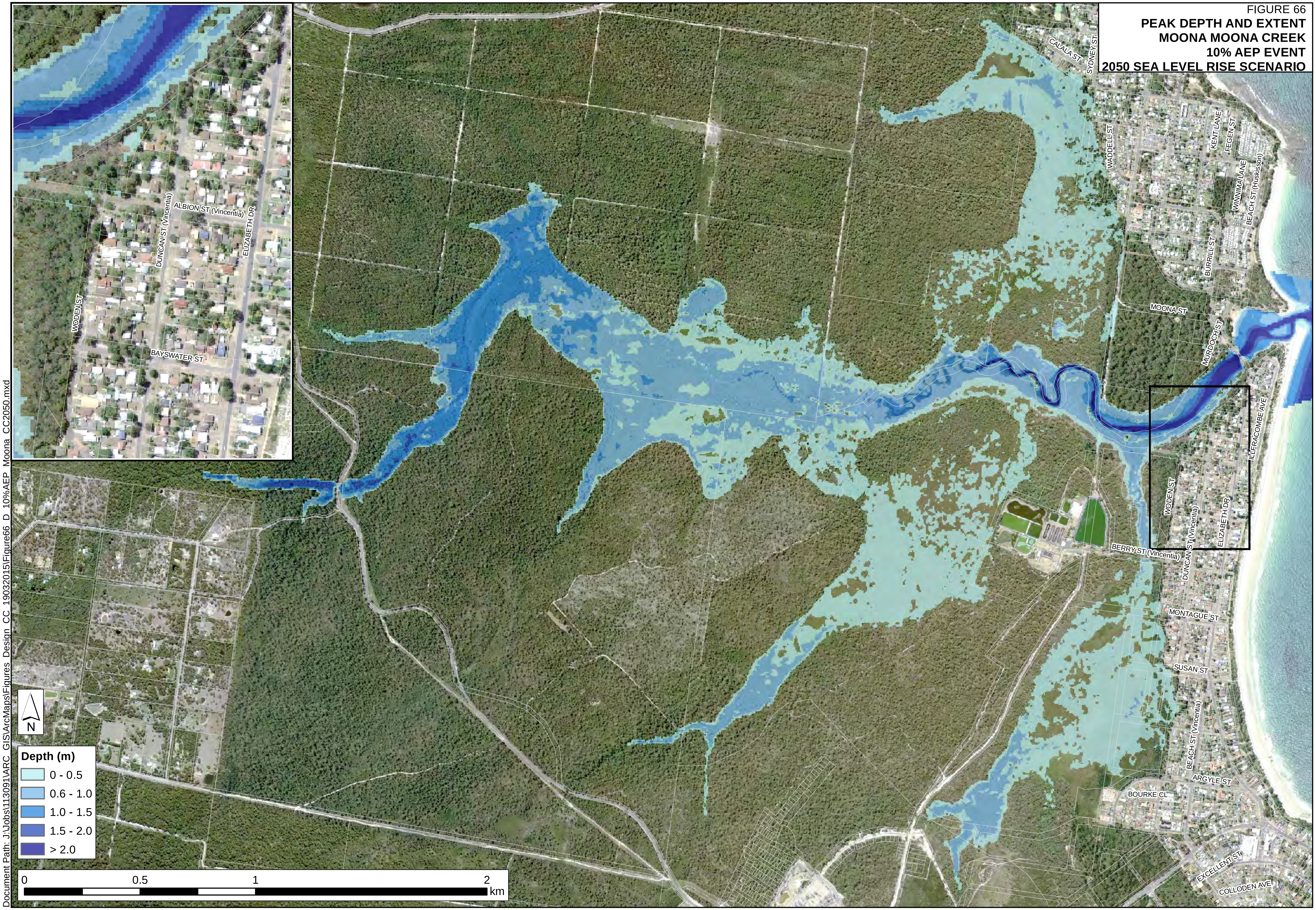


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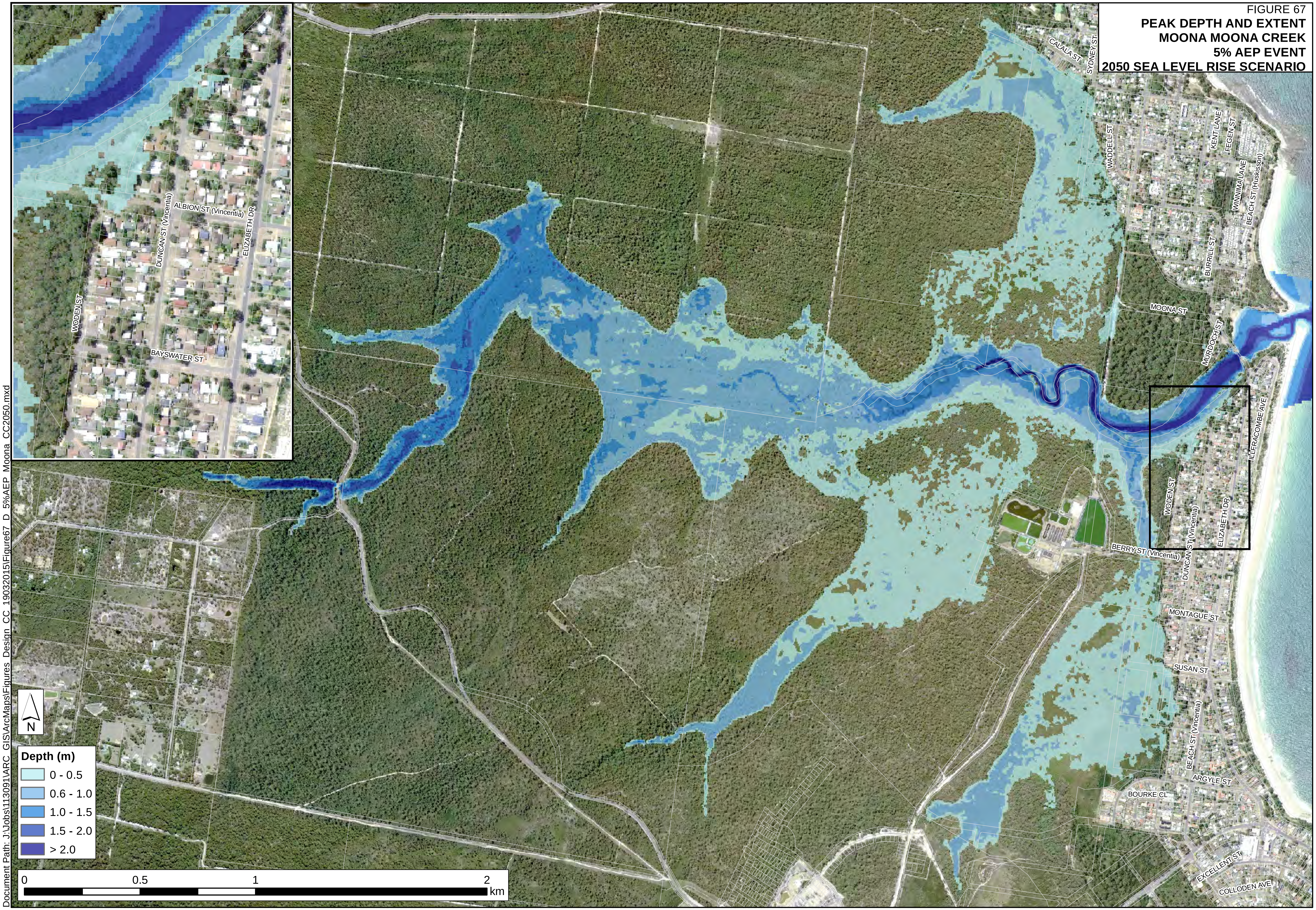
FIGURE 67
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
5% AEP EVENT
2050 SEA LEVEL RISE SCENARIO



Document Path: J:\Jobs\113091\ARC GIS\ArcMaps\Figures Design CC 19032015\Figure67 D 5%AEP Moona CC2050.mxd

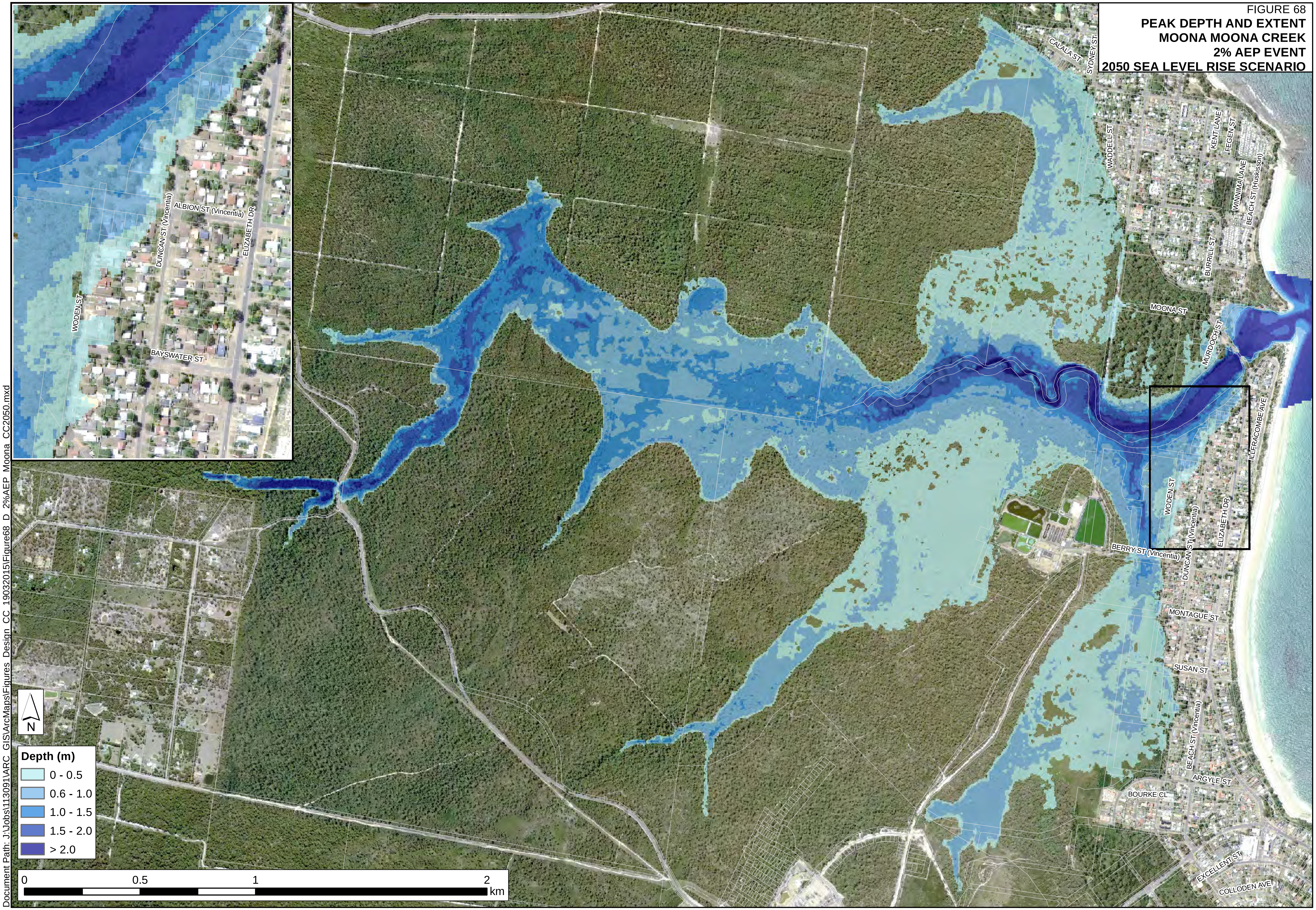


FIGURE 68
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
2% AEP EVENT
2050 SEA LEVEL RISE SCENARIO

Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure68_D_2%AEP_Moona_CC2050.mxd

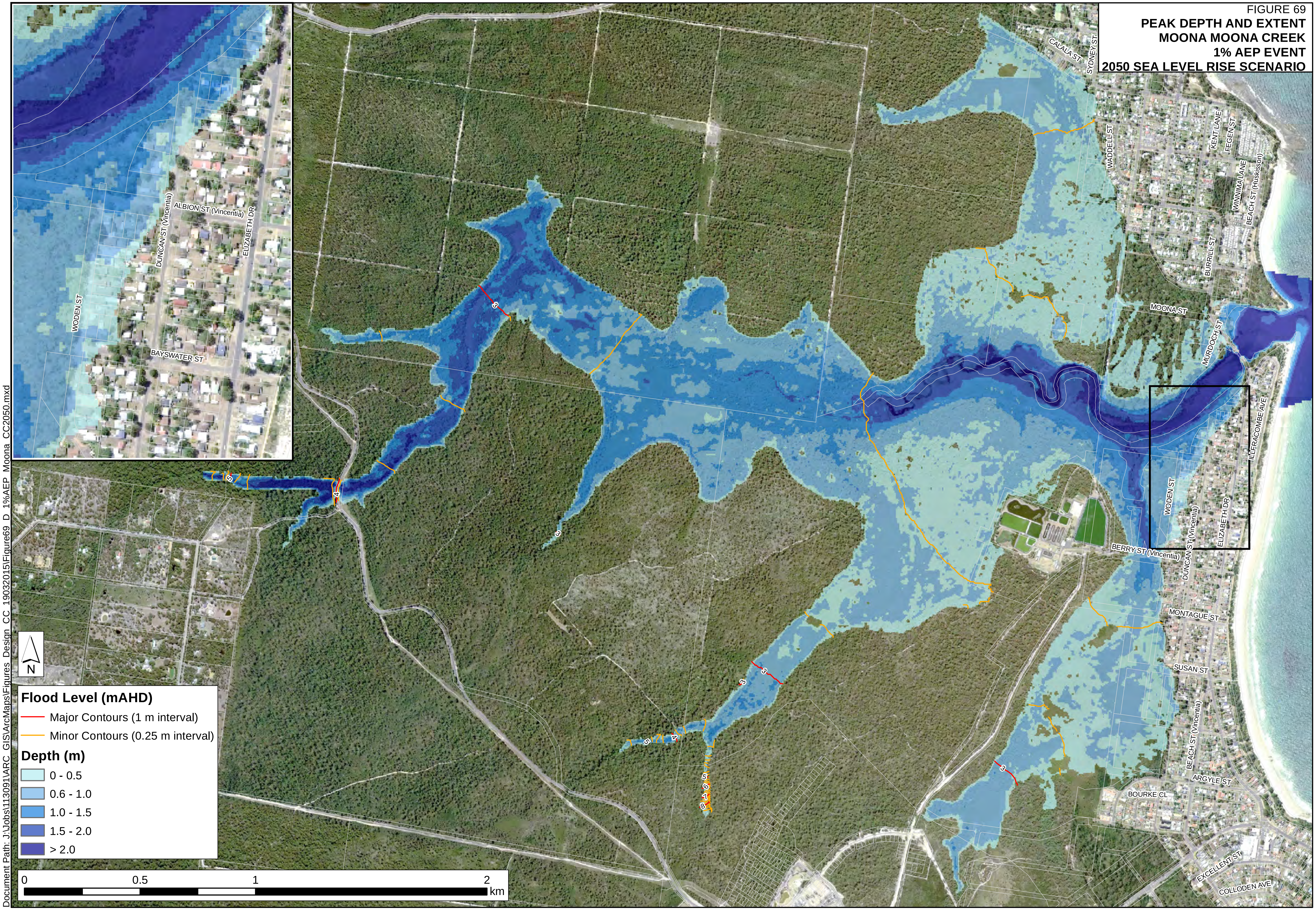


FIGURE 69
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
1% AEP EVENT
2050 SEA LEVEL RISE SCENARIO

Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure69_D_1%AEP_Moona_CC2050.mxd

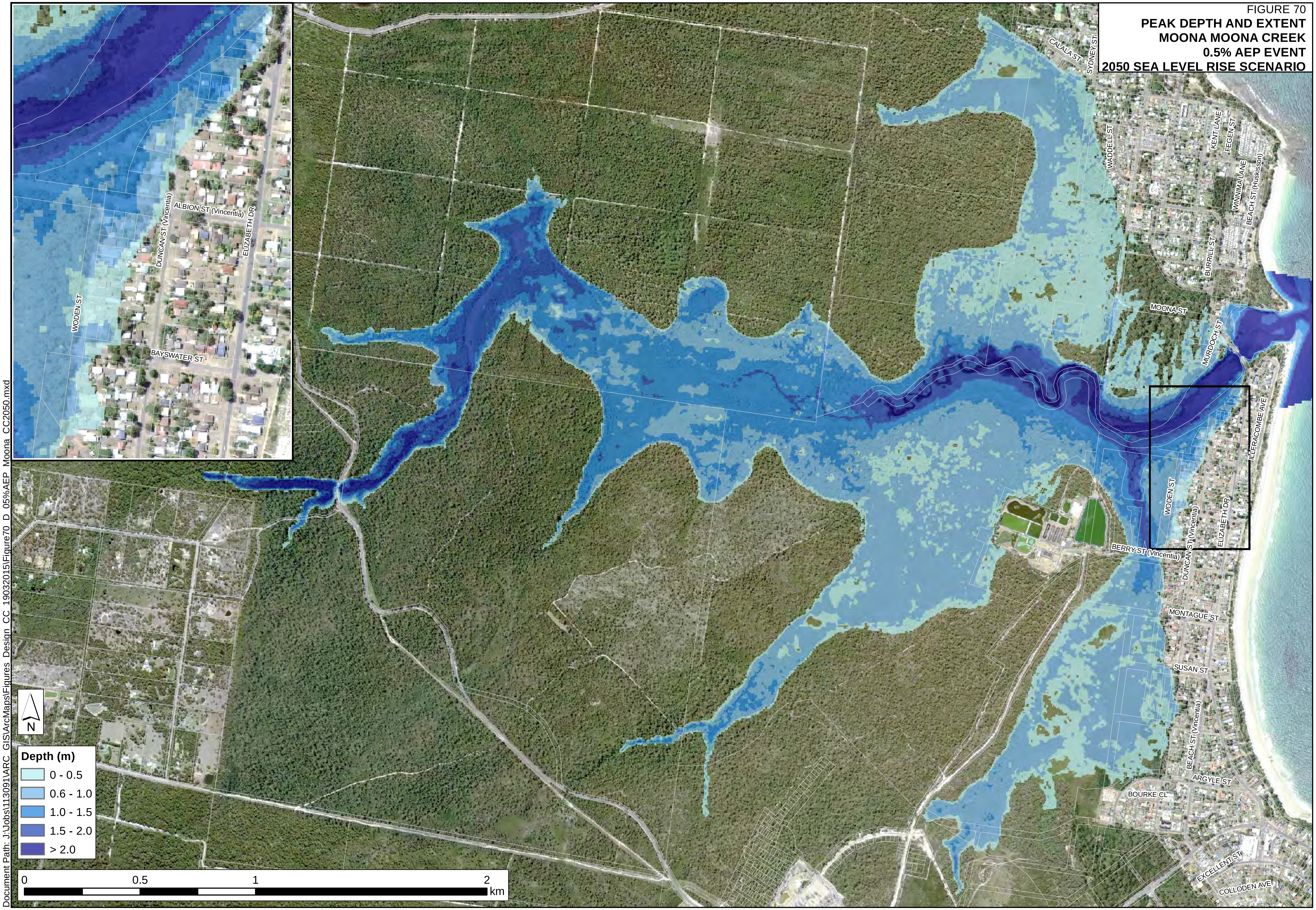
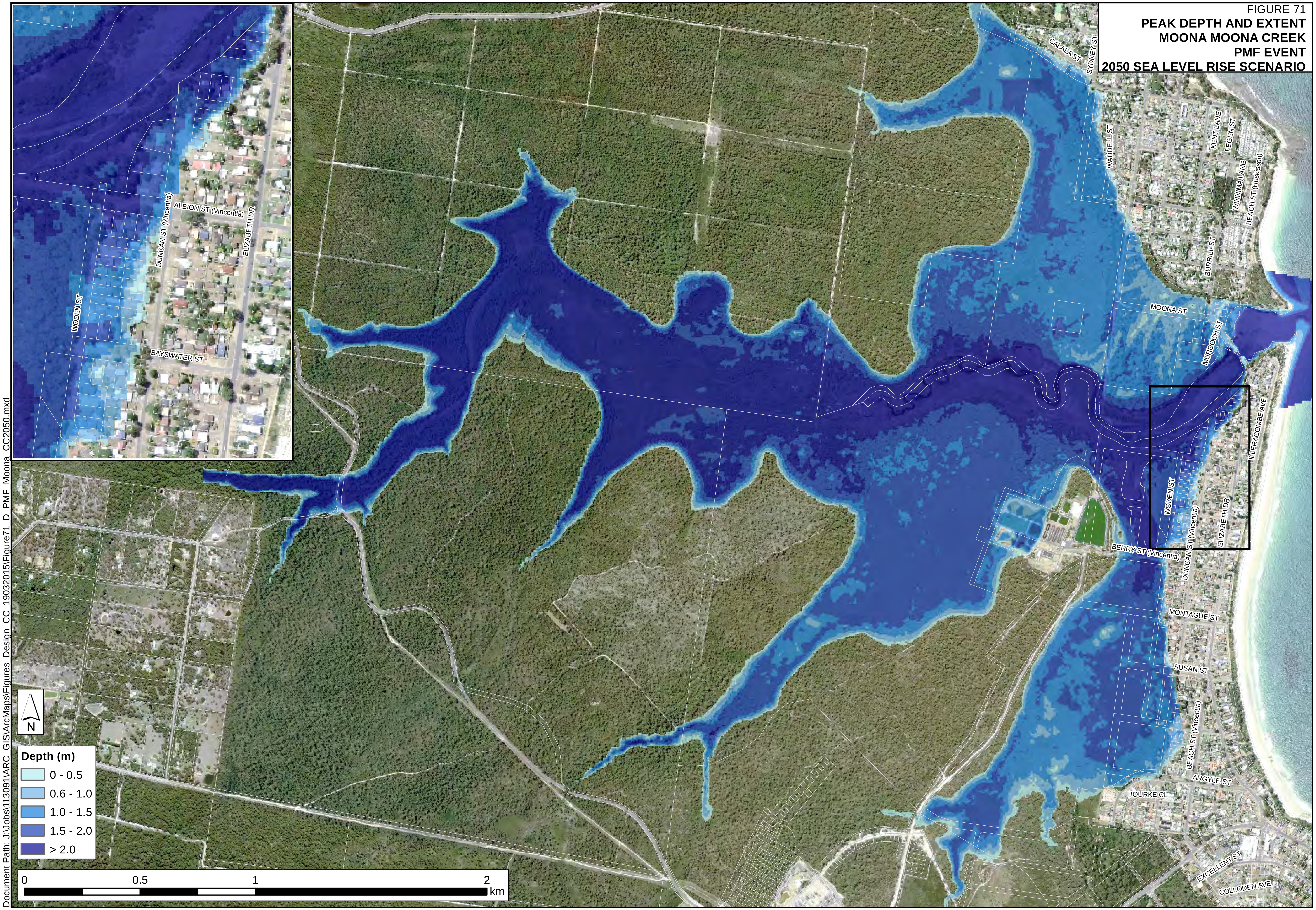


FIGURE 70
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
0.5% AEP EVENT
2050 SEA LEVEL RISE SCENARIO

FIGURE 71
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
PMF EVENT
2050 SEA LEVEL RISE SCENARIO



Document Path: J:\Jobs\113091\ARC GIS\ArcMaps\Figures Design CC 19032015\Figure71 D PMF Moona CC2050.mxd

FIGURE 72
MOONA MOONA CREEK
2050 SEA LEVEL RISE FLOOD PROFILES

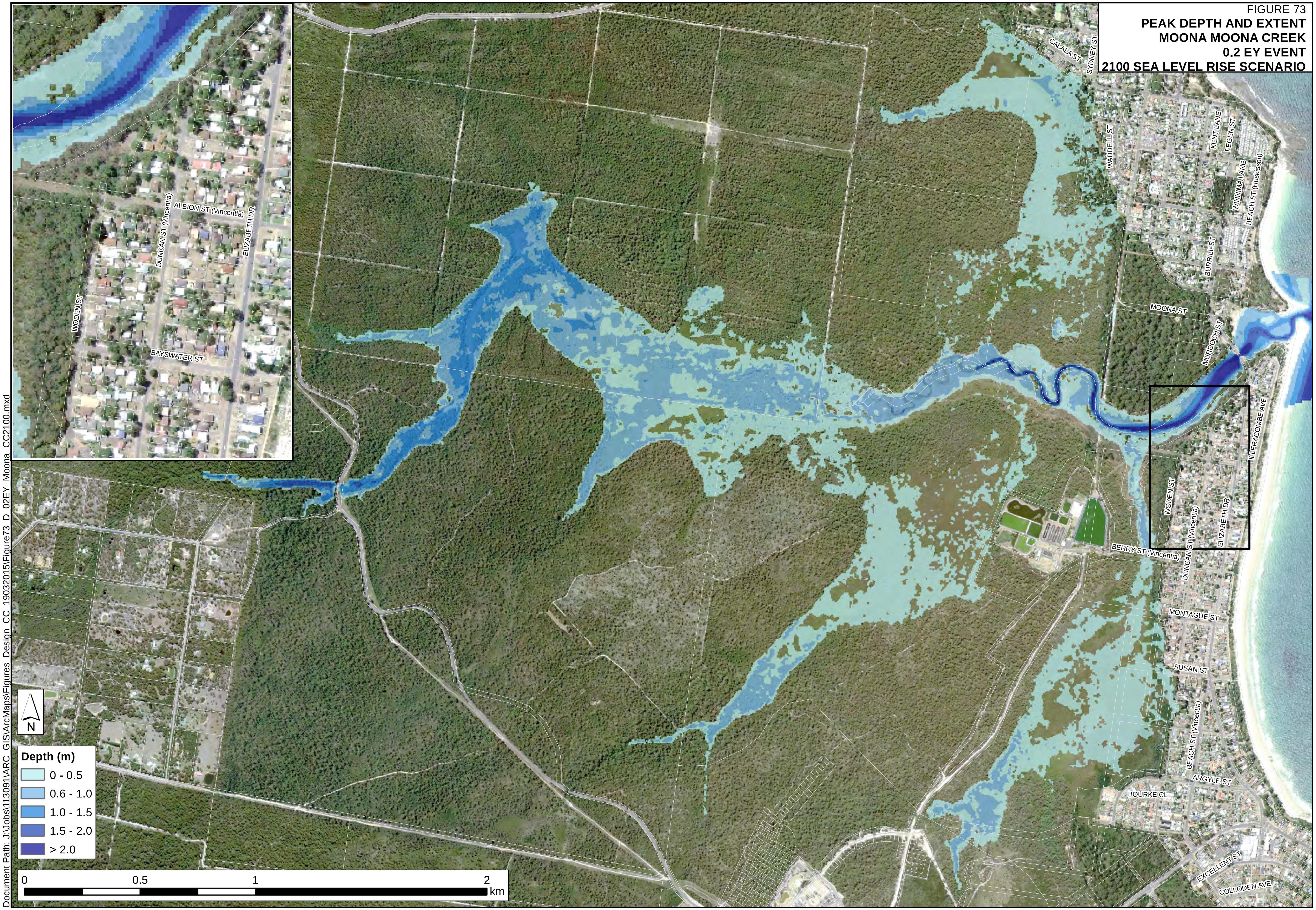
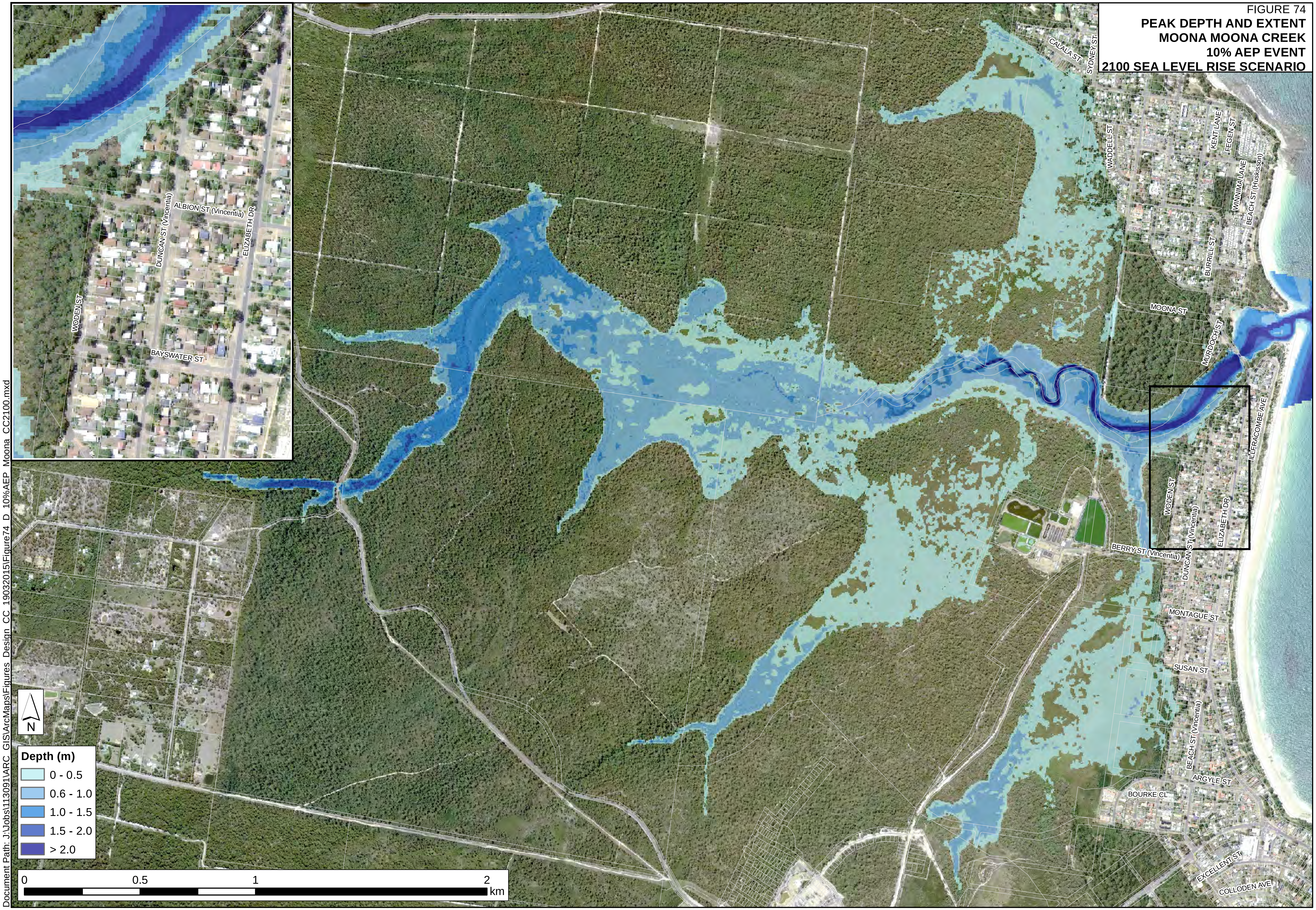


FIGURE 73
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
0.2 EY EVENT
2100 SEA LEVEL RISE SCENARIO

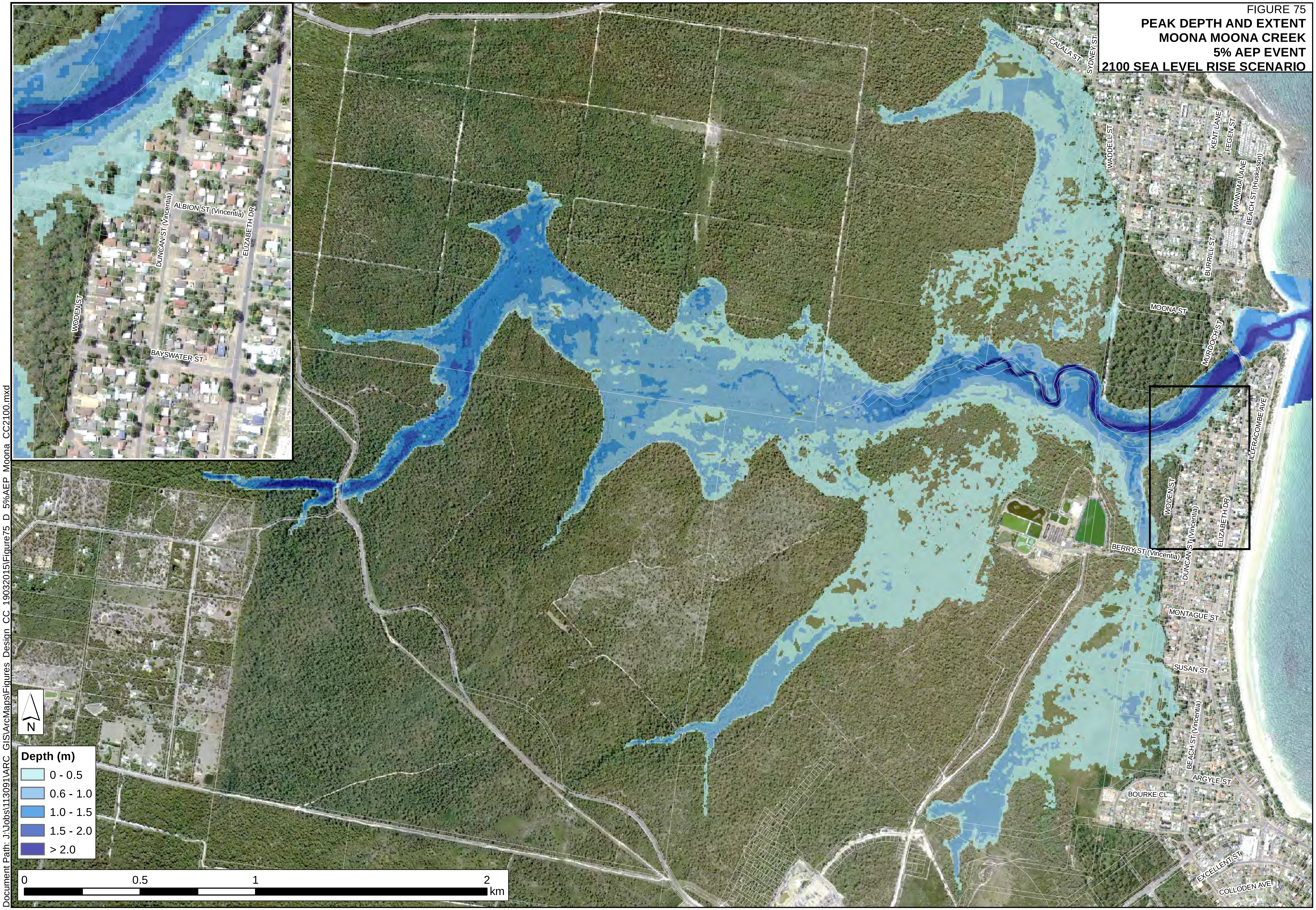
Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure73_D_02EY_Moona_CC2100.mxd

FIGURE 74
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
10% AEP EVENT
2100 SEA LEVEL RISE SCENARIO



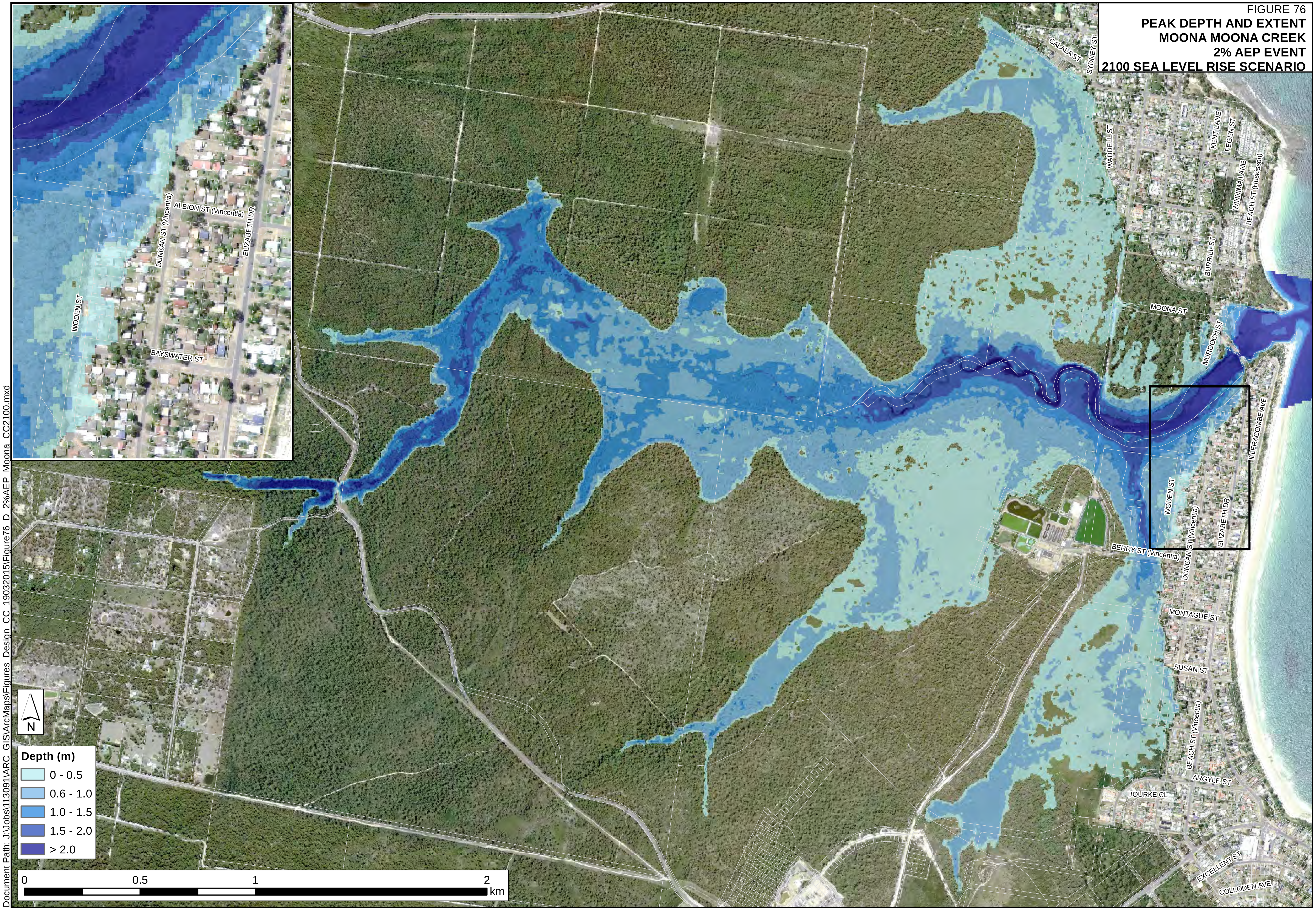
Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure74_D_10%AEP_Moona_CC2100.mxd

FIGURE 75
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
5% AEP EVENT
2100 SEA LEVEL RISE SCENARIO



Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure75_D_5%AEP_Moona_CC2100.mxd

FIGURE 76
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
2% AEP EVENT
2100 SEA LEVEL RISE SCENARIO



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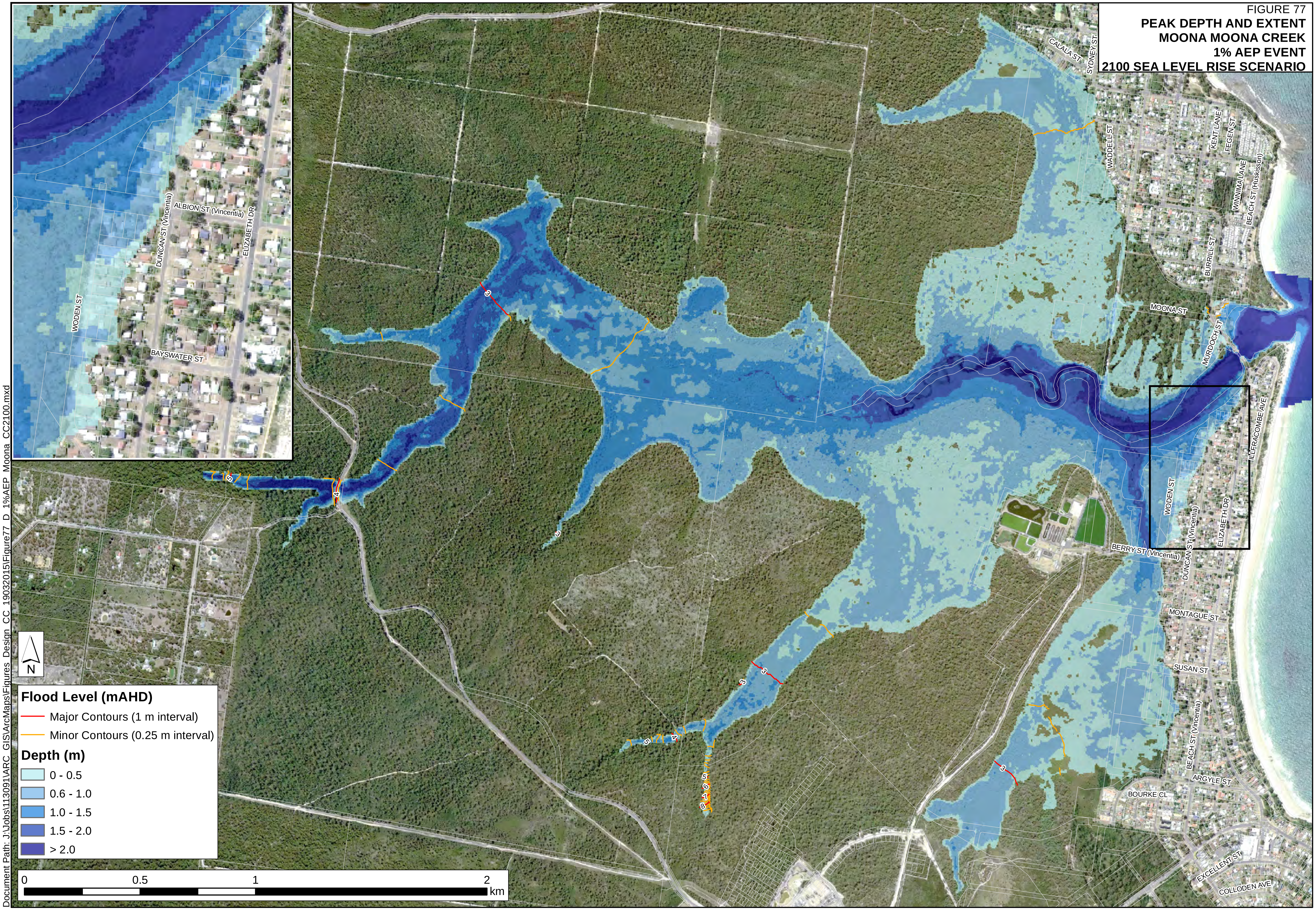

FIGURE 77
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
1% AEP EVENT
2100 SEA LEVEL RISE SCENARIO

Document Path: J:\Jobs\113091\ARC GIS\ArcMaps\Figures Design CC 19032015\Figure77_D_1%AEP_Moona_CC2100.mxd

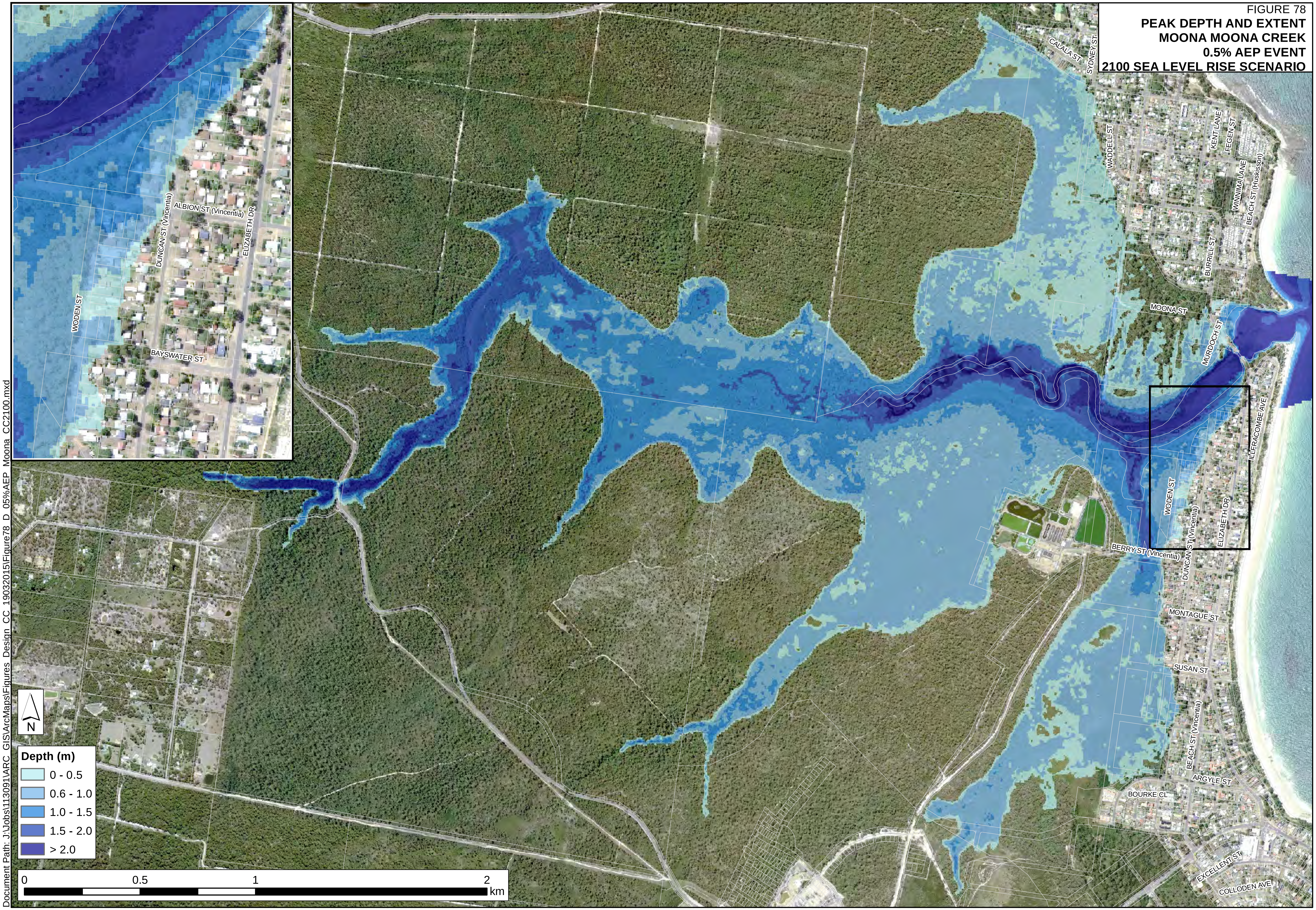

FIGURE 78
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
0.5% AEP EVENT
2100 SEA LEVEL RISE SCENARIO

Document Path: J:\Jobs\113091\ARC_GIS\ArcMaps\Figures_Design_CC_19032015\Figure78_D_05%AEP_Moona_CC2100.mxd

FIGURE 79
PEAK DEPTH AND EXTENT
MOONA MOONA CREEK
PMF EVENT
2100 SEA LEVEL RISE SCENARIO

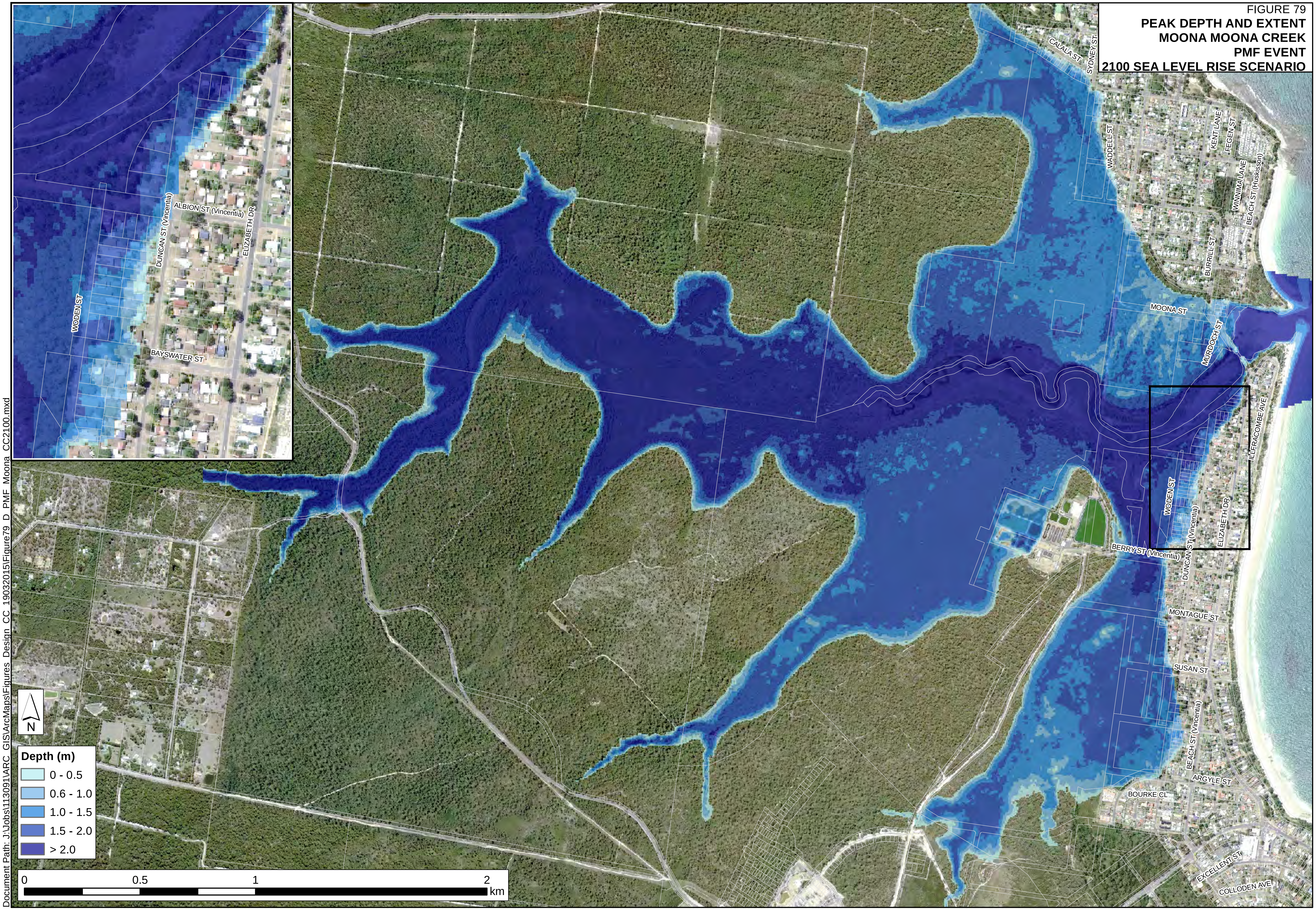

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FIGURE 80
MOONA MOONA CREEK
2100 SEA LEVEL RISE FLOOD PROFILES

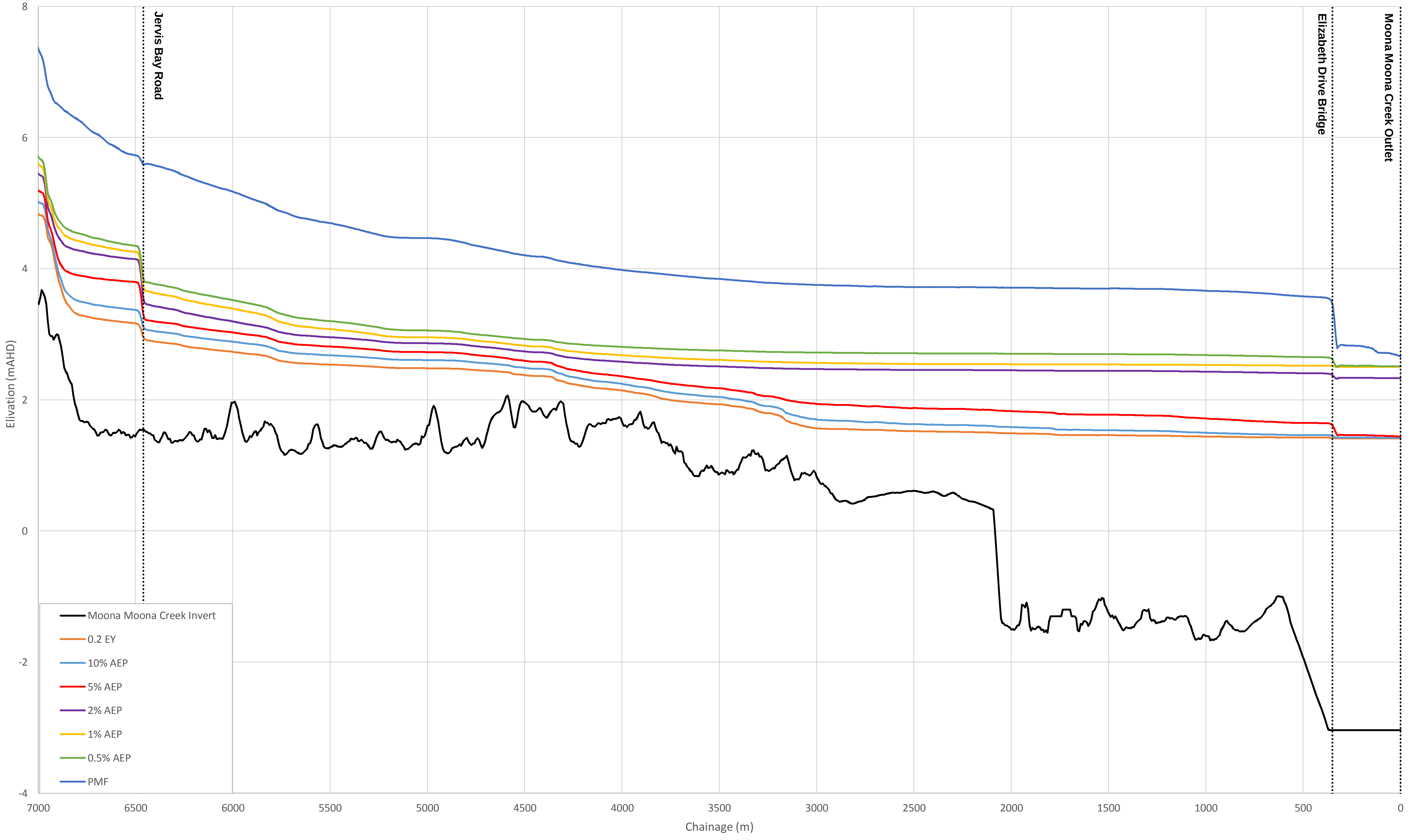

FIGURE 81
PROPERTIES FIRST FLOODED OVER GROUND
CURRAMBENE CREEK

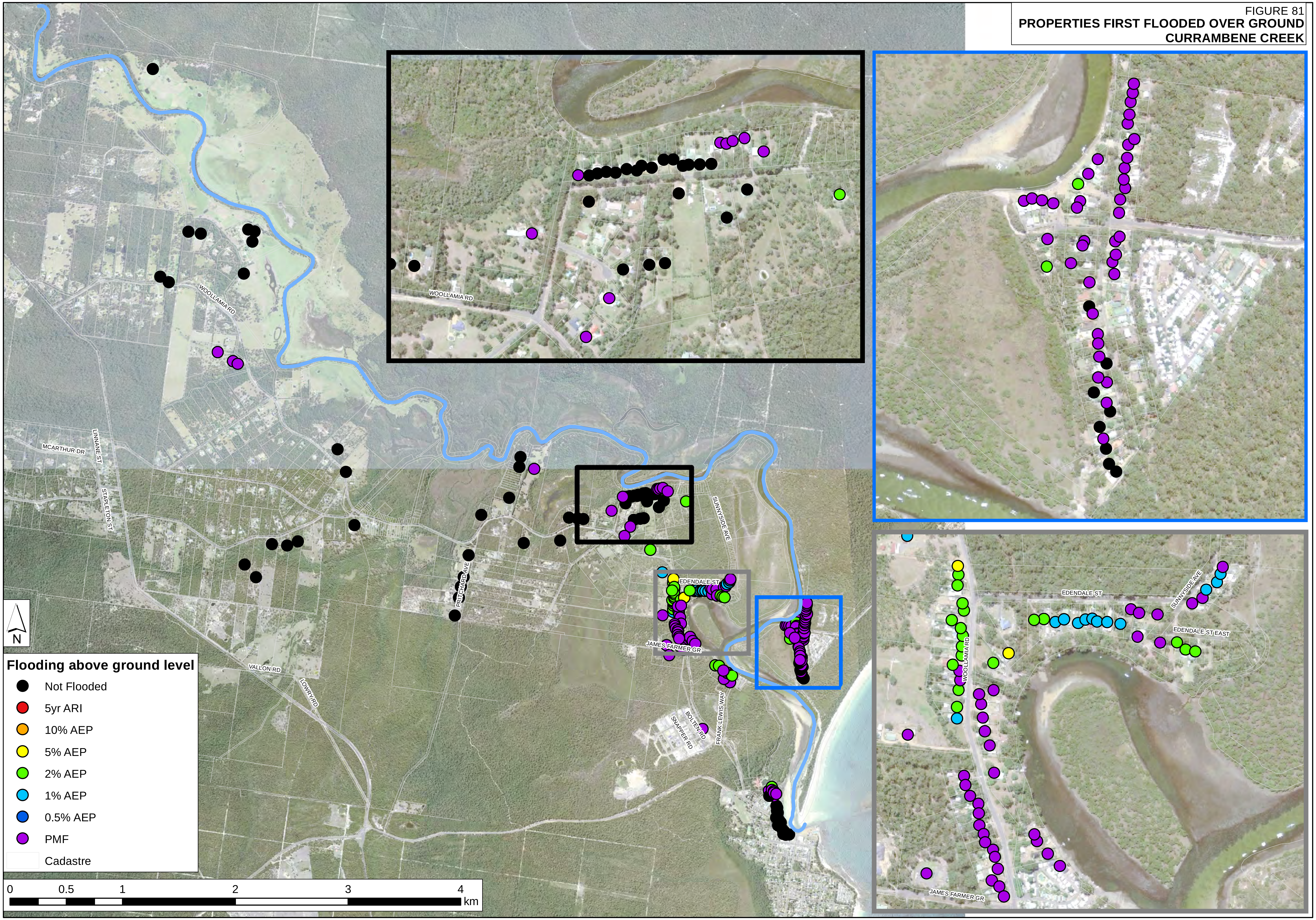

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FIGURE 82
PROPERTIES FIRST FLOODED OVER FLOOR
CURRAMBENE CREEK

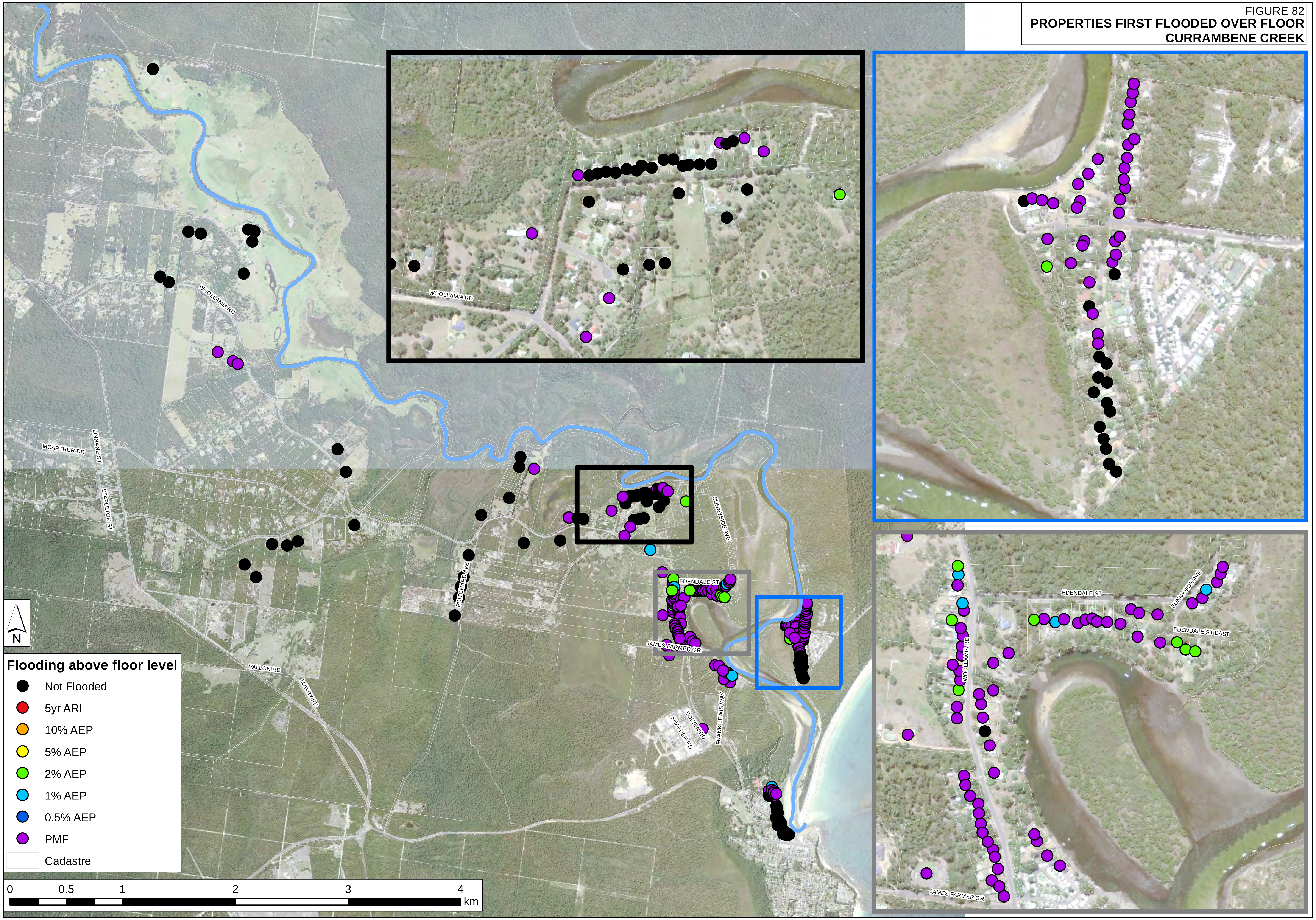

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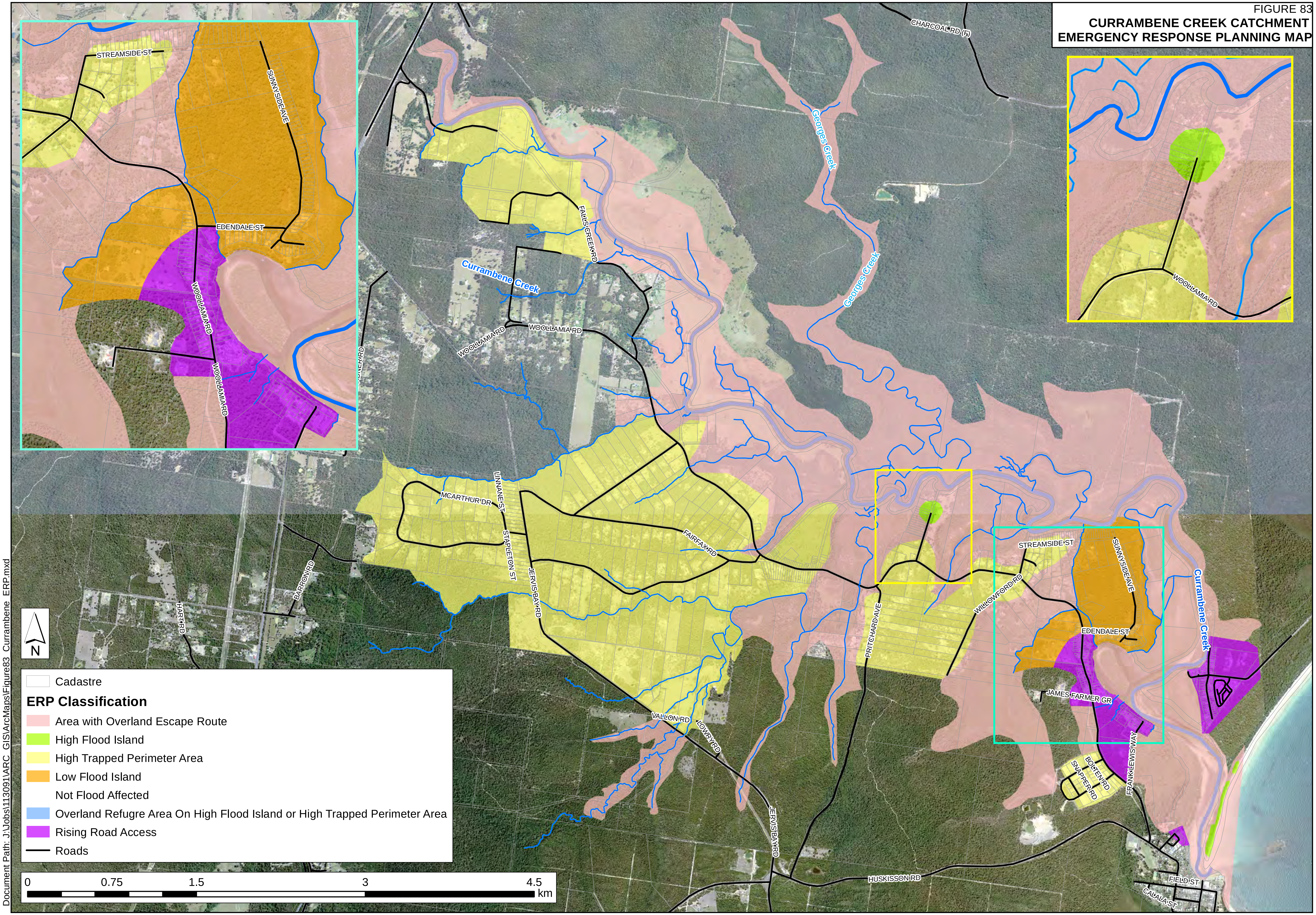
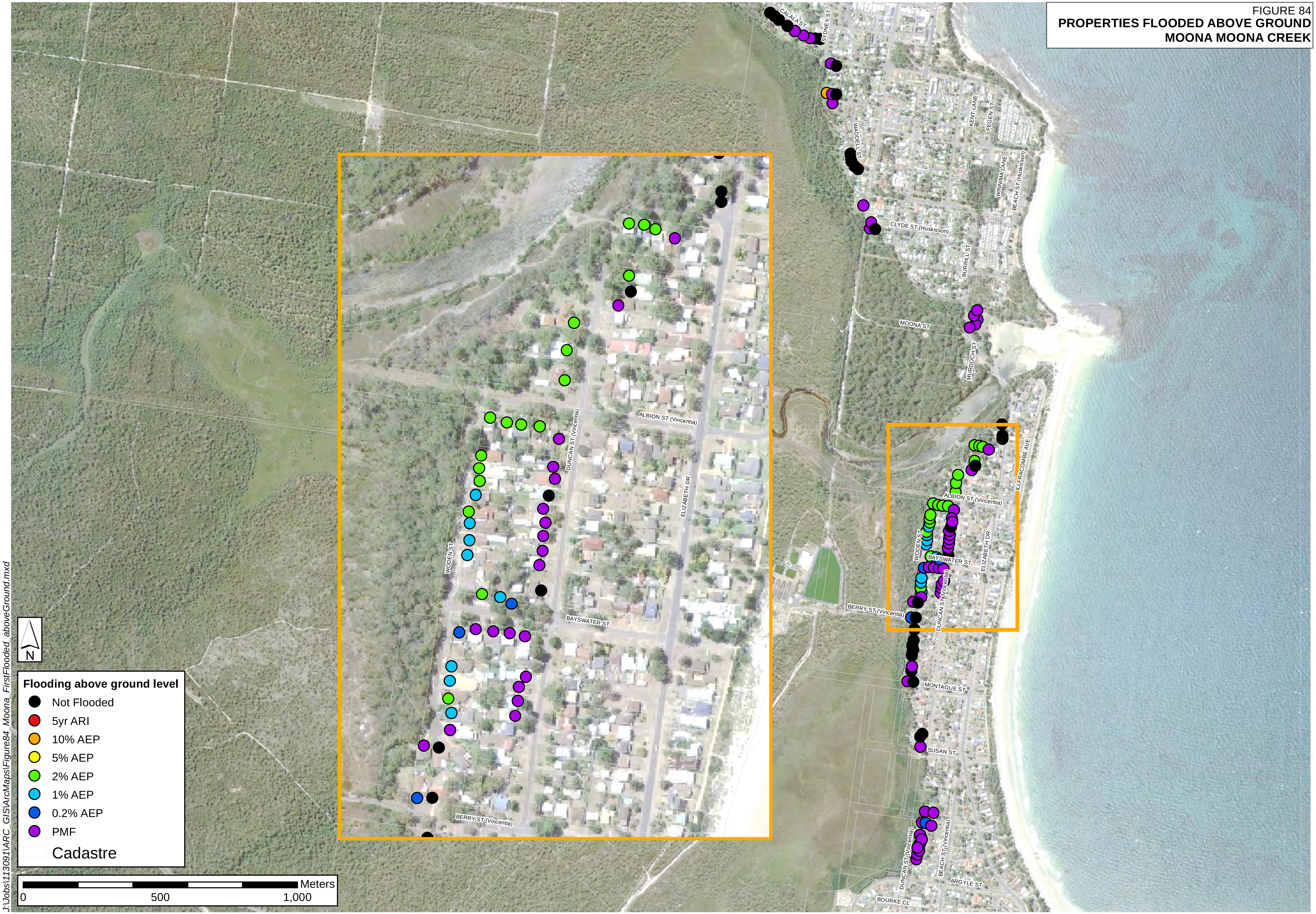
FIGURE 83
CURRAMBENE CREEK CATCHMENT EMERGENCY RESPONSE PLANNING MAP



Document Path: J:\Jobs\113091\ARC GIS\ArcMaps\Figure83 Currambene ERP.mxd

FIGURE 84
PROPERTIES FLOODED ABOVE GROUND
MOONA MOONA CREEK



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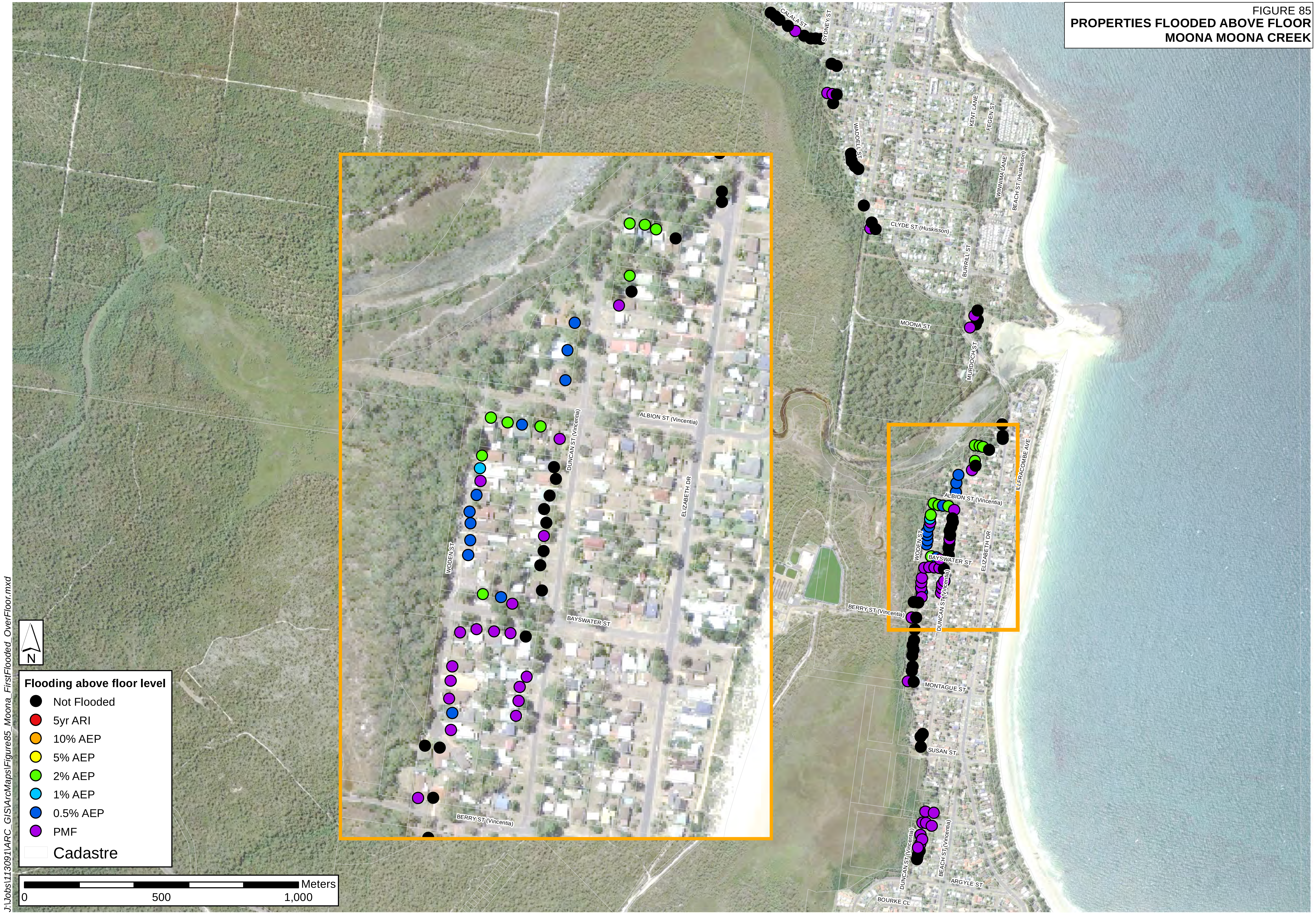


FIGURE 85
PROPERTIES FLOODED ABOVE FLOOR
MOONA MOONA CREEK
Flooding above floor level
Not Flooded
5yr ARI
10% AEP
5% AEP
2% AEP
1% AEP
0.5% AEP
PMF
Cadastre
Meters
0
500
1,000
N
J:\Jobs\113091\ARC_GIS\ArcMaps\Figure85_Moona_FirstFlooded_OverFloor.mxd
CALALA ST
SYDNEY ST
WADDELL ST
KENT LANE
FEGEN ST
WINNIMA LANE
BEACH ST (Huskisson)
CLYDE ST (Huskisson)
BURRILL ST
MOONA ST
MURDOCH ST
ILFRACOMBE AVE
ALBION ST (Vincentia)
WODEN ST
ELIZABETH DR
DUNCAN ST (Vincentia)
BAYSWATER ST
BERRY ST (Vincentia)
MONTAGUE ST
SUSAN ST
BEACH ST (Vincentia)
ARGYLE ST
BOURKE CL

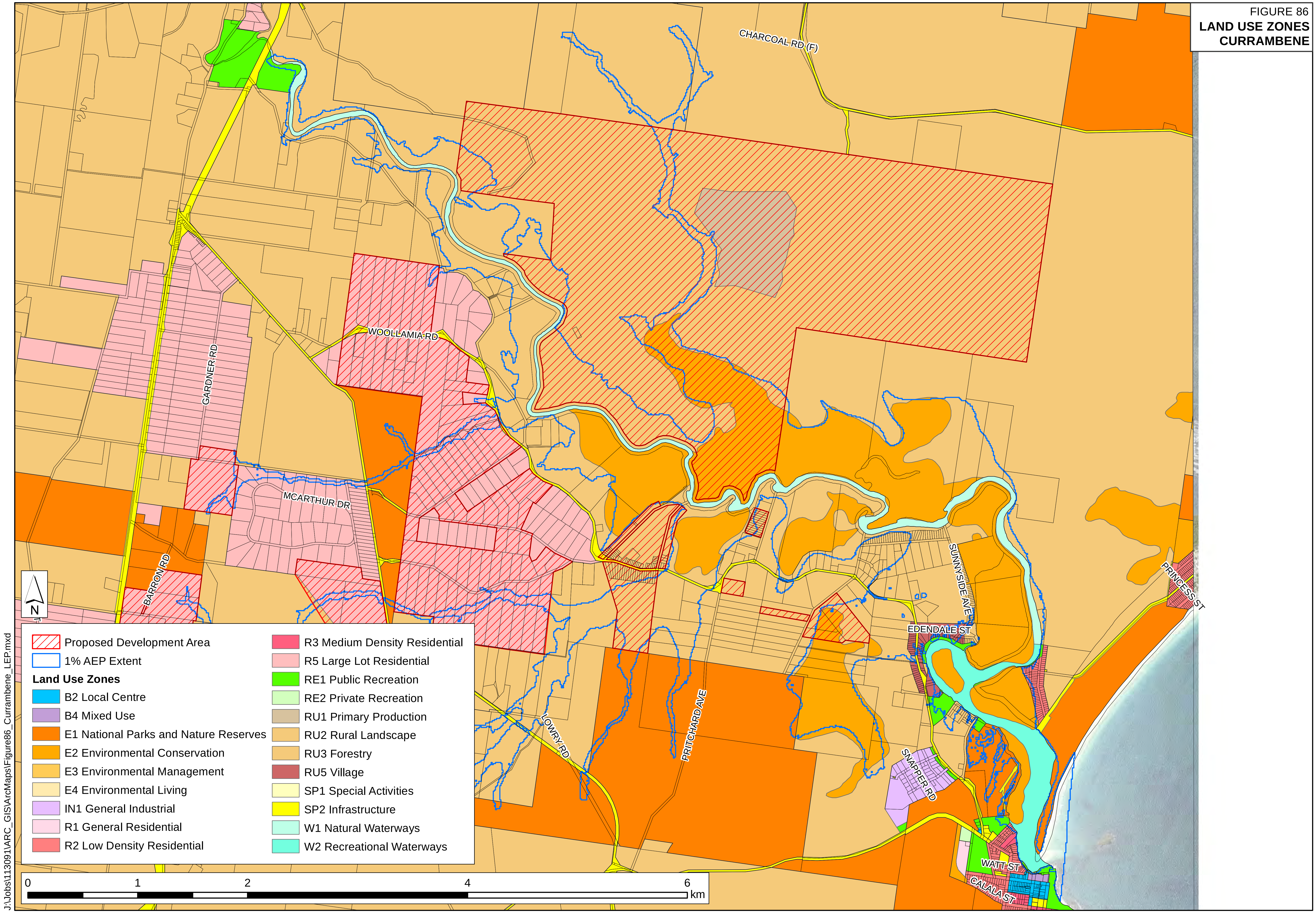
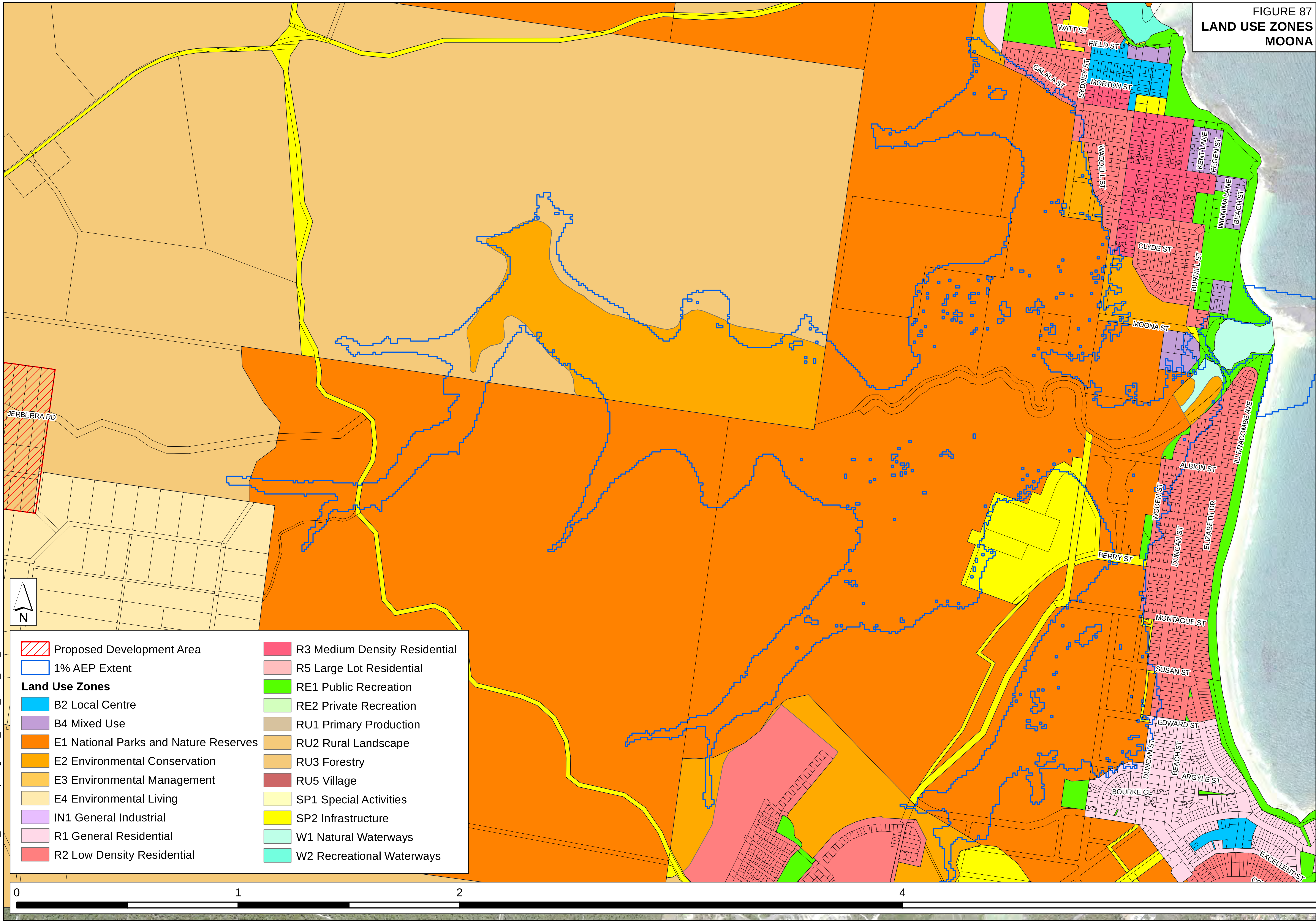


FIGURE 86
LAND USE ZONES
CURRAMBENE
CHARCOAL RD (F)
WOOLLAMIA RD
GARDNER RD
MCARTHUR DR
BARRON RD
LOWRY RD
PRITCHARD AVE
SUNNYSIDE AVE
EDENDALE ST
PRINCESS ST
SNAPPER RD
WATT ST
CALALA ST
N
Proposed Development Area
1% AEP Extent
Land Use Zones
B2 Local Centre
B4 Mixed Use
E1 National Parks and Nature Reserves
E2 Environmental Conservation
E3 Environmental Management
E4 Environmental Living
IN1 General Industrial
R1 General Residential
R2 Low Density Residential
R3 Medium Density Residential
R5 Large Lot Residential
RE1 Public Recreation
RE2 Private Recreation
RU1 Primary Production
RU2 Rural Landscape
RU3 Forestry
RU5 Village
SP1 Special Activities
SP2 Infrastructure
W1 Natural Waterways
W2 Recreational Waterways
0 1 2 4 6 km
J:\Jobs\113091\ARC_GIS\ArcMaps\Figure86_Currambene_LEP.mxd



J:\Jobs\113091\ARC_GIS\ArcMaps\Figure87_Moona_Land_Use_Zones.mxd

FIGURE 88
EVENT FIRST INUNDATING ACCESS ROUTE CURRAMBENE CREEK

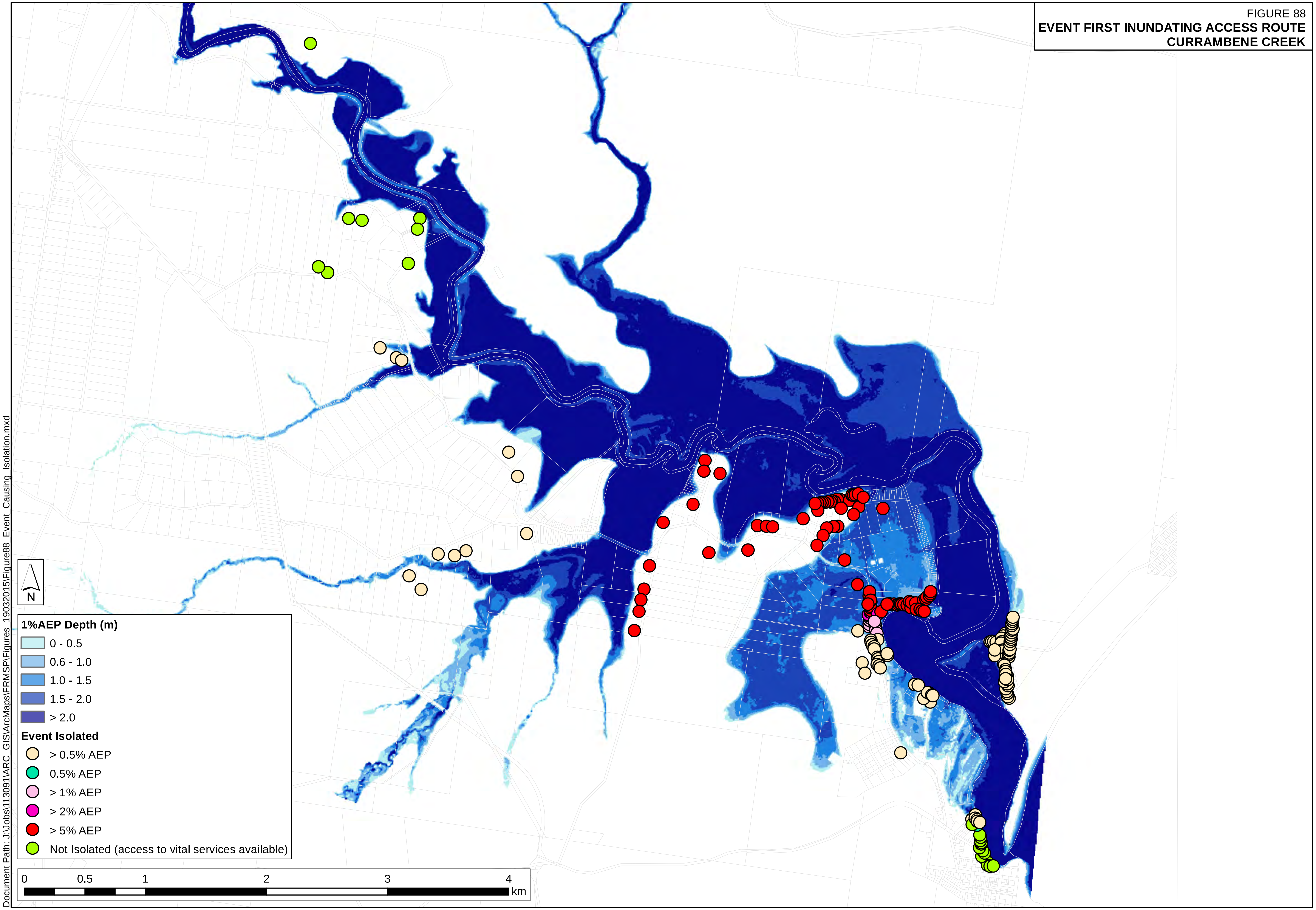


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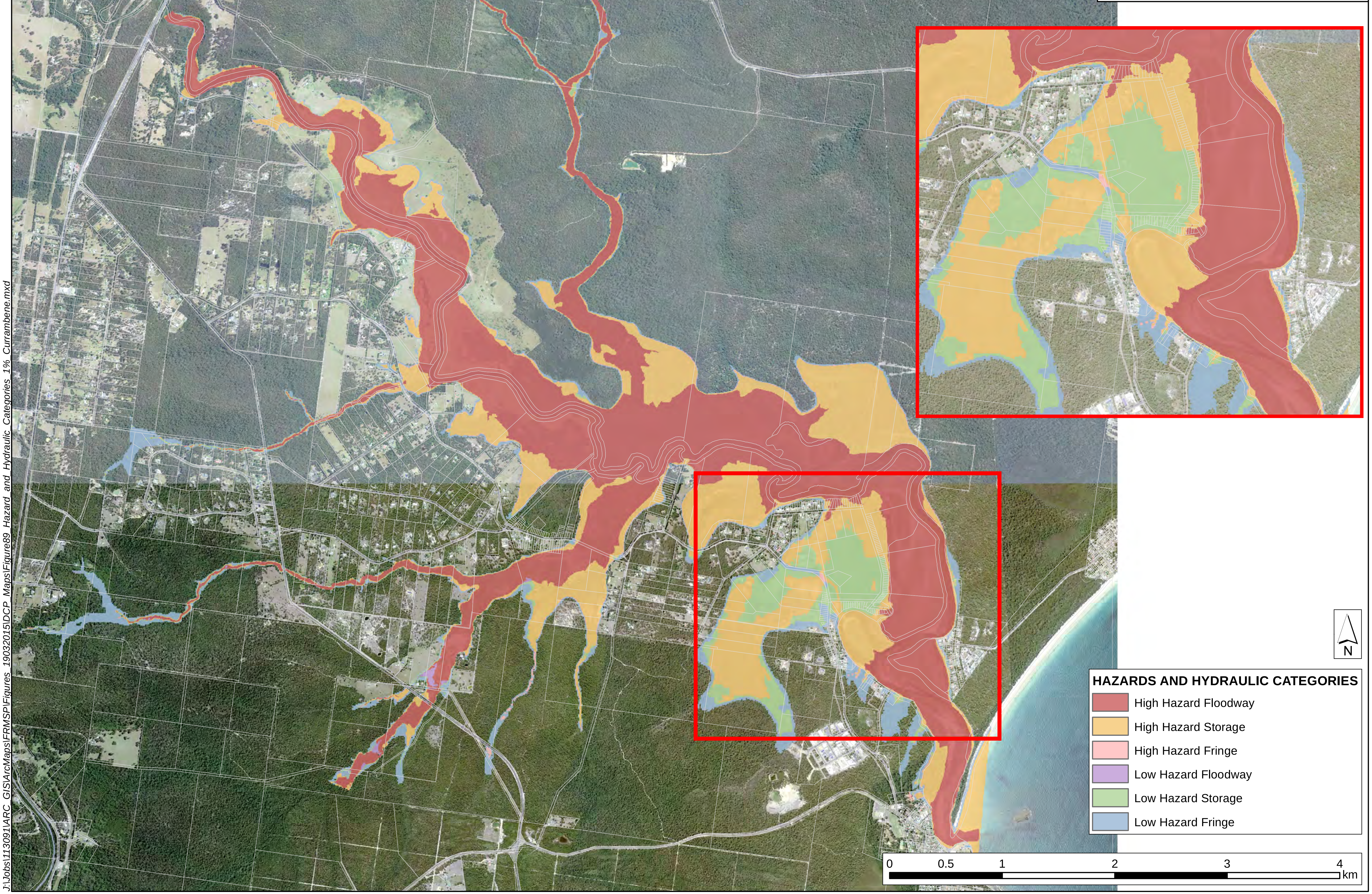
FIGURE 89
HYDRAULIC AND HAZARD CATEGORIES
1% AEP EVENT
CURRAMBENE CREEK



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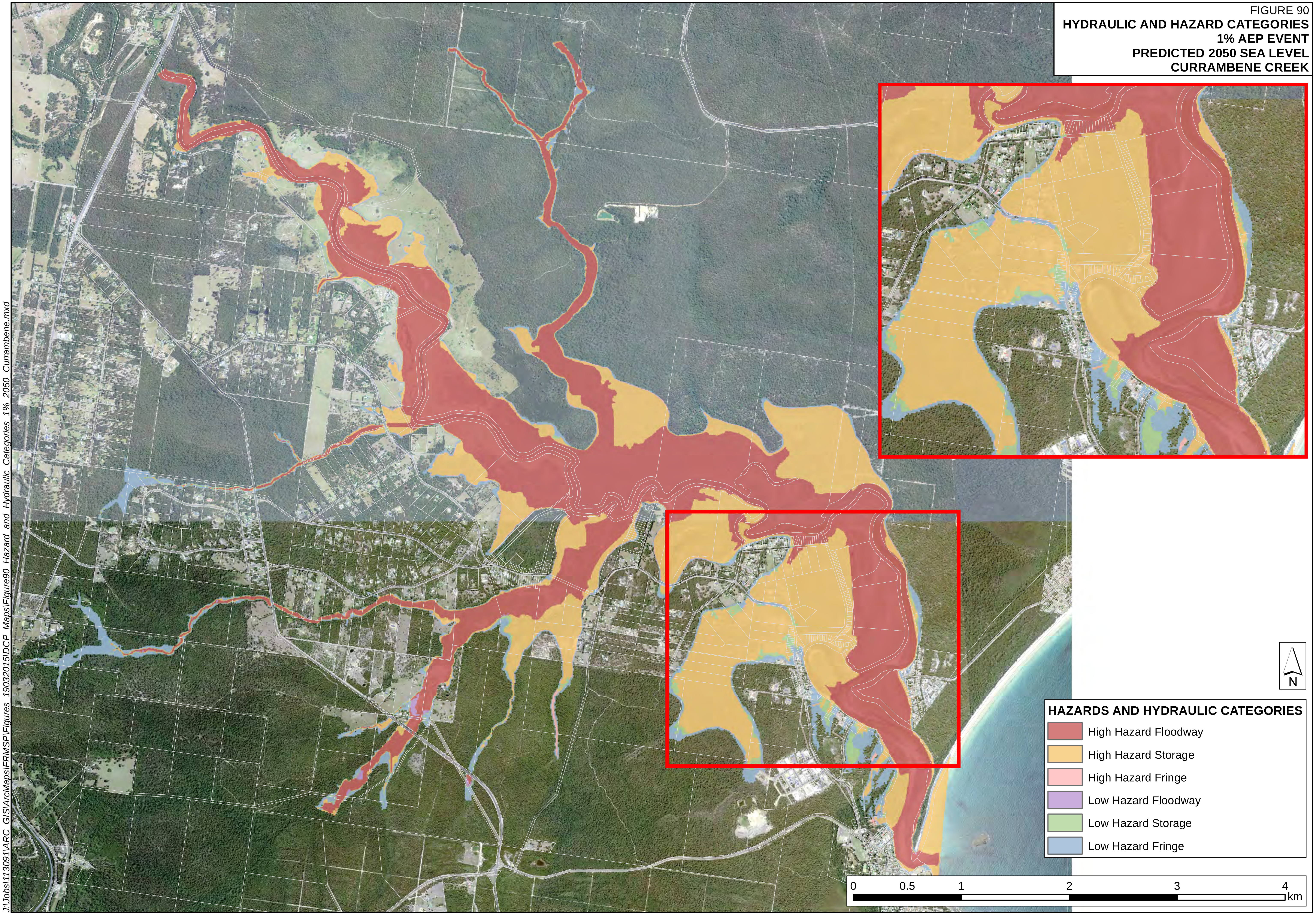

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FIGURE 91

HYDRAULIC AND HAZARD CATEGORIES
1% AEP EVENT
PREDICTED 2100 SEA LEVEL
CURRAMBENE CREEK

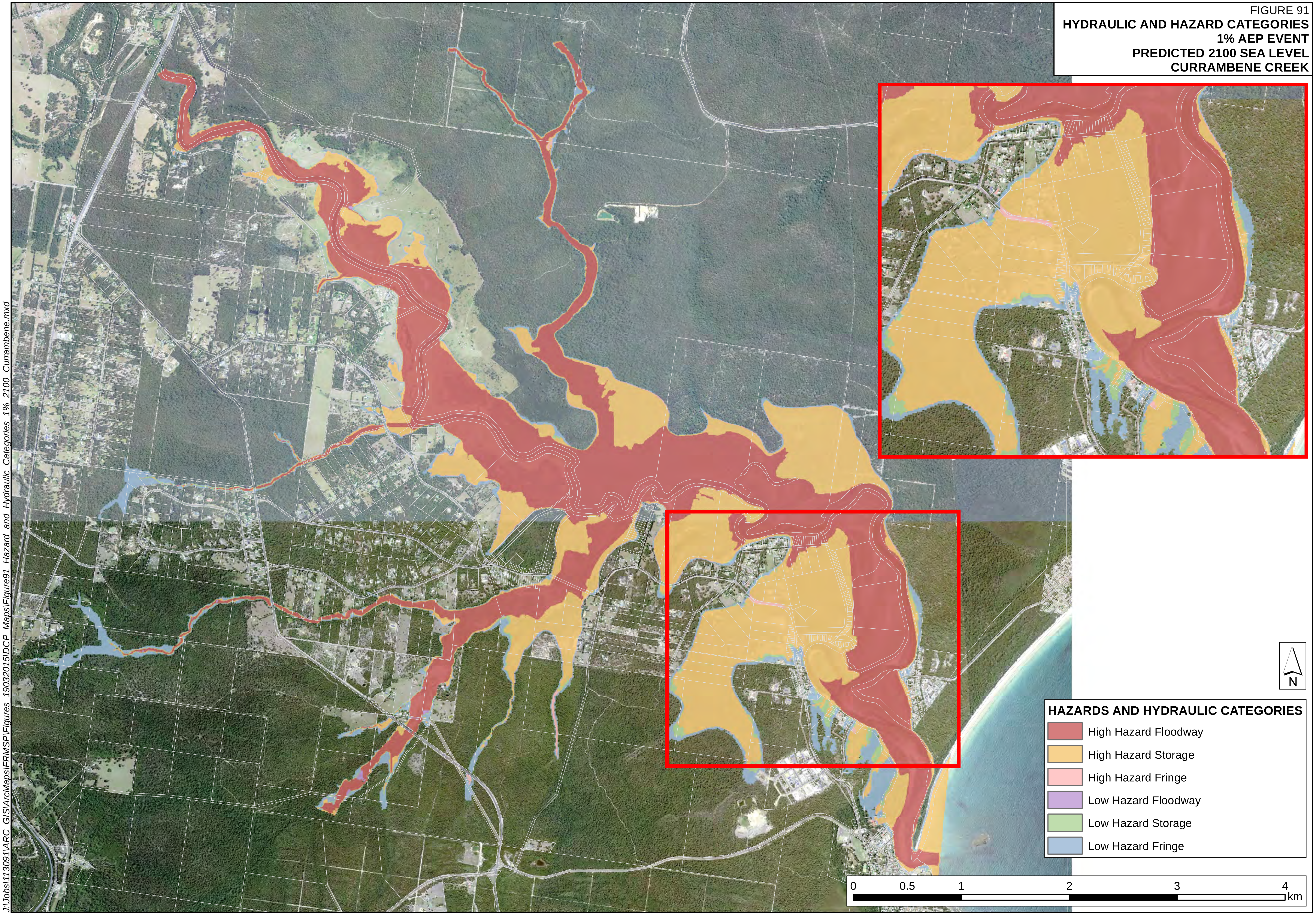

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FIGURE 92
HYDRAULIC AND HAZARD CATEGORIES
FLOOD PLANNING AREA
1% AEP + FREEBOARD
CURRAMBENE CREEK

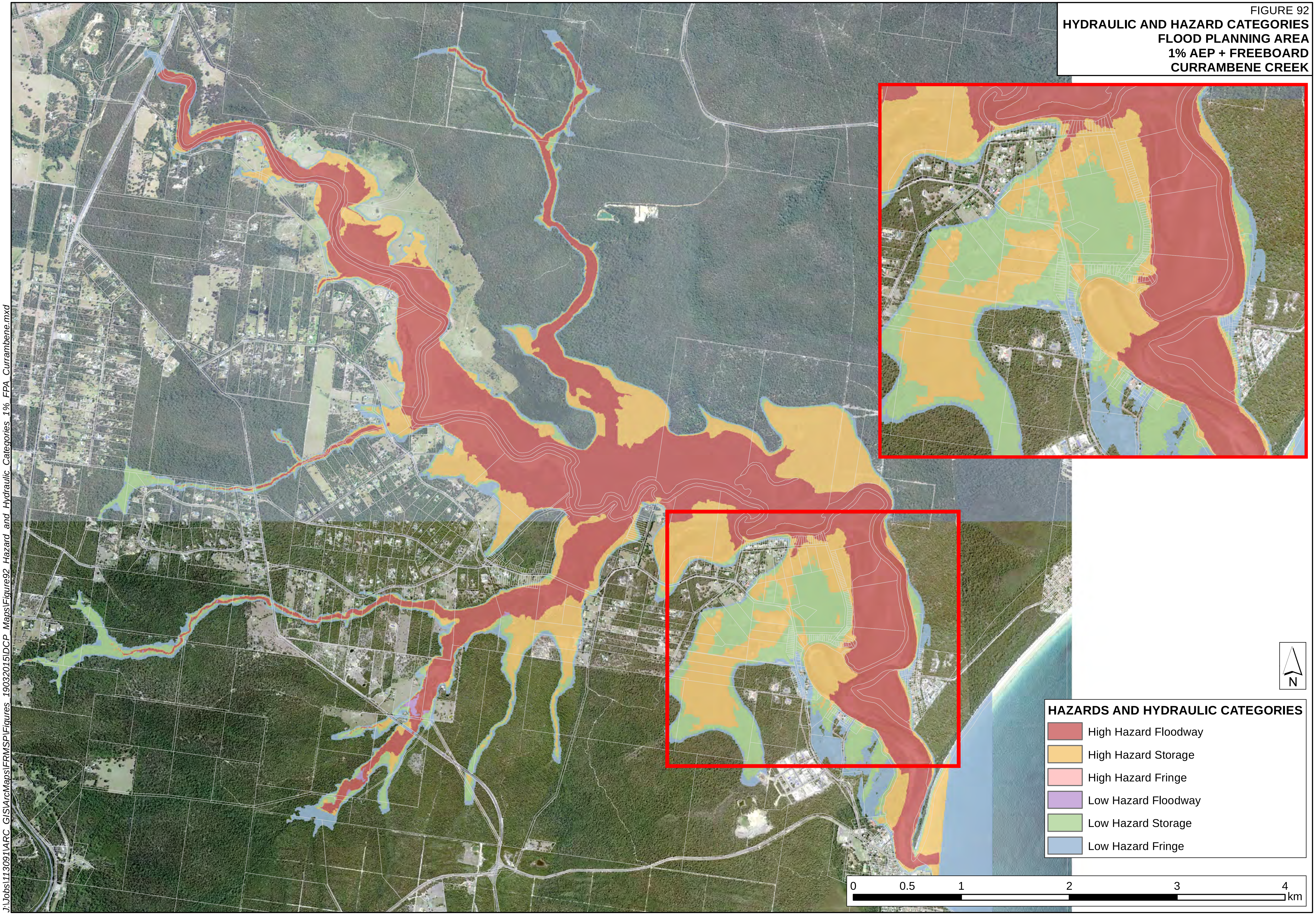

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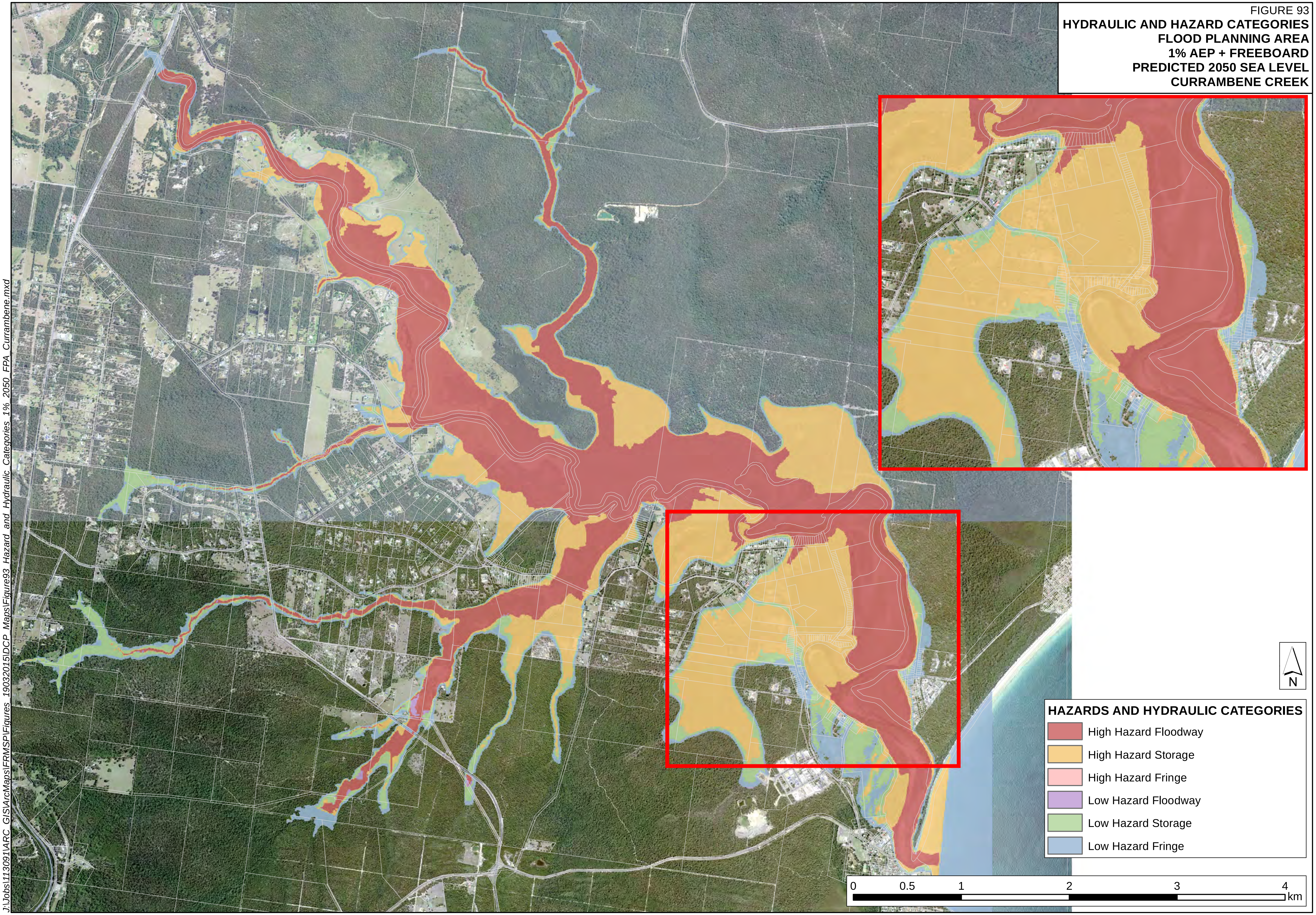
FIGURE 93
HYDRAULIC AND HAZARD CATEGORIES
FLOOD PLANNING AREA
1% AEP + FREEBOARD
PREDICTED 2050 SEA LEVEL
CURRAMBENE CREEK



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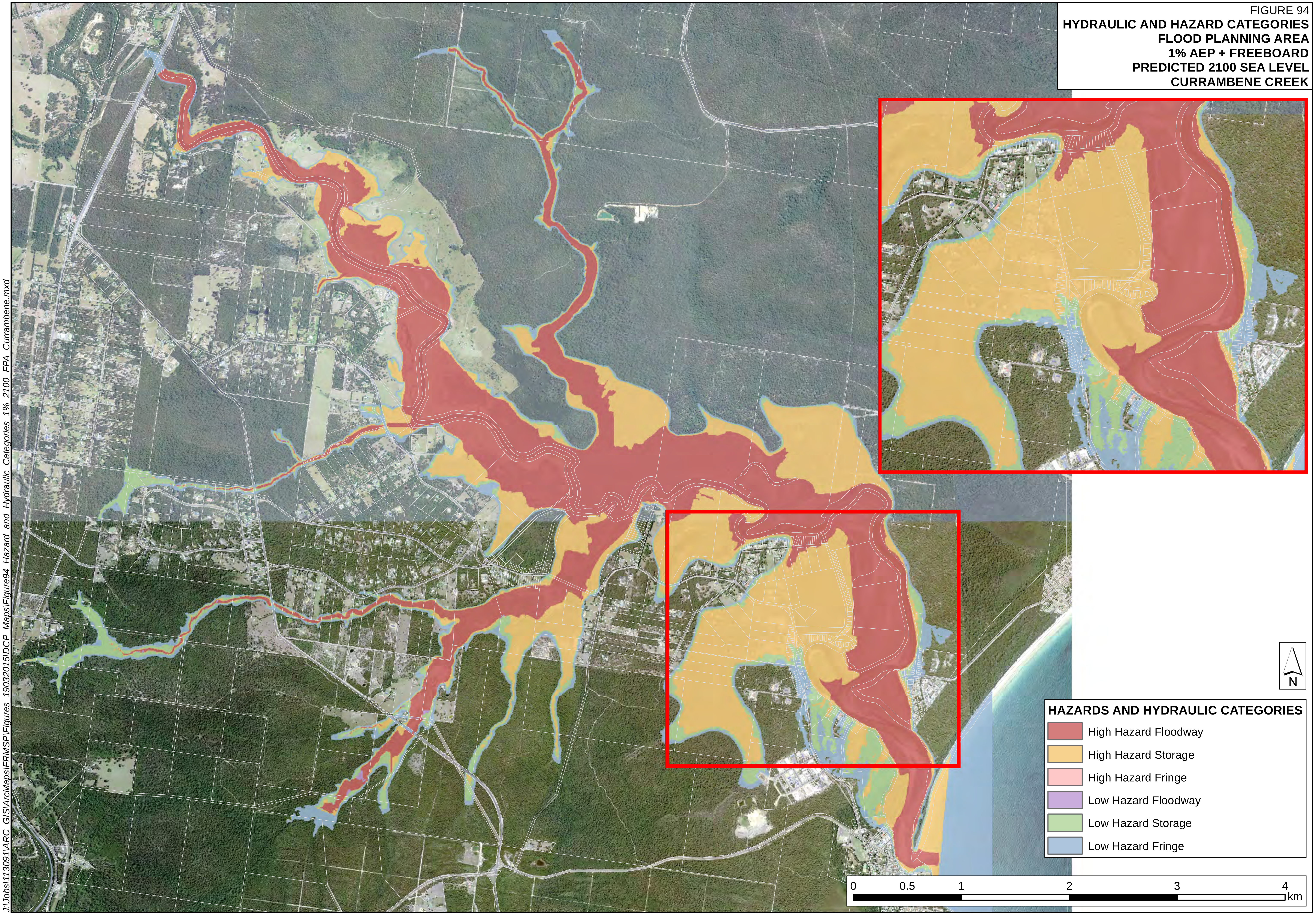
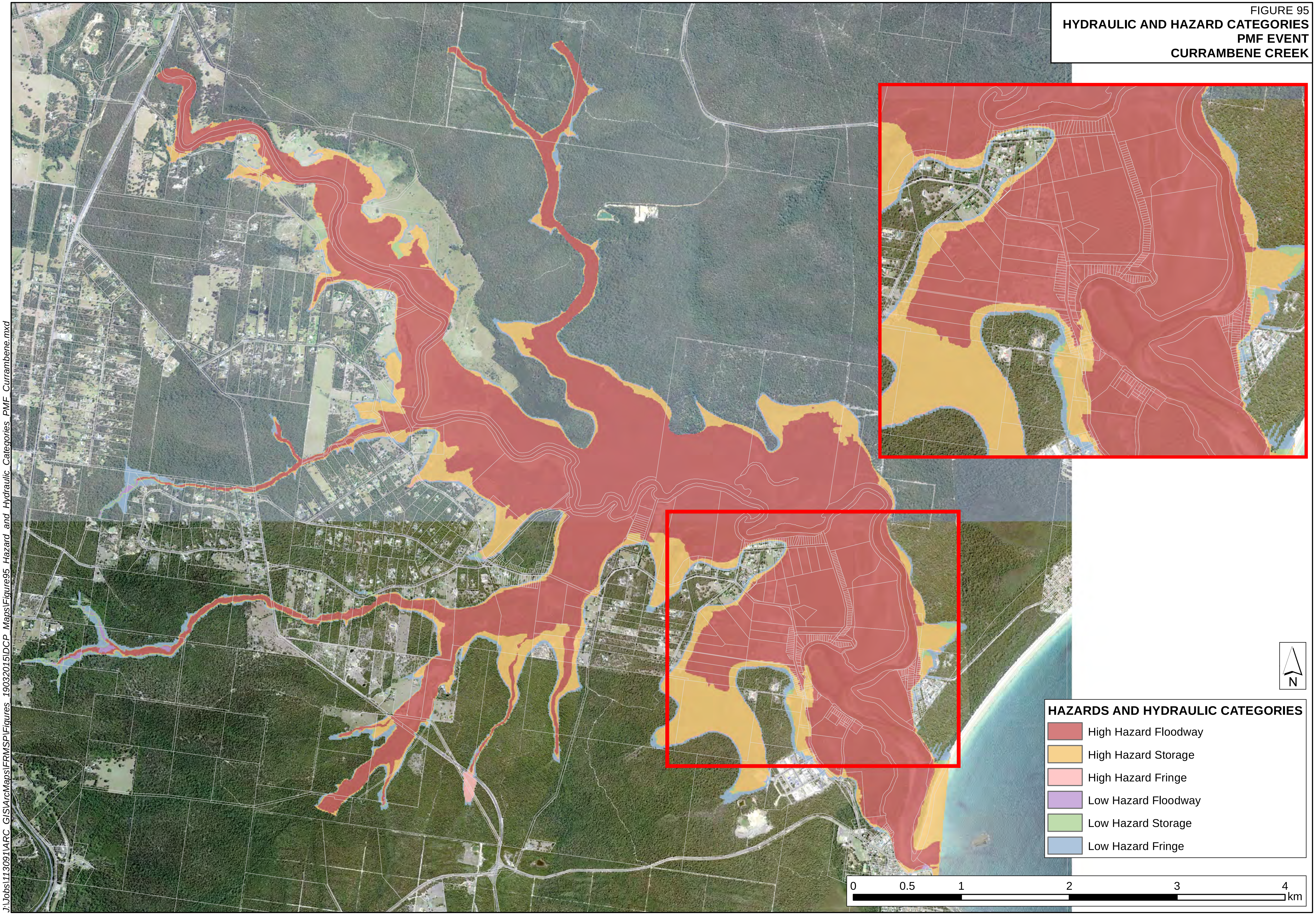


J:\Jobs\113091\ARC GIS\ArcMaps\FRMSP\Figures 19032015\DCP Maps\Figure94 Hazard and Hydraulic Categories 1% 2100 FPA Currambene.mxd

FIGURE 95
HYDRAULIC AND HAZARD CATEGORIES
PMF EVENT
CURRAMBENE CREEK



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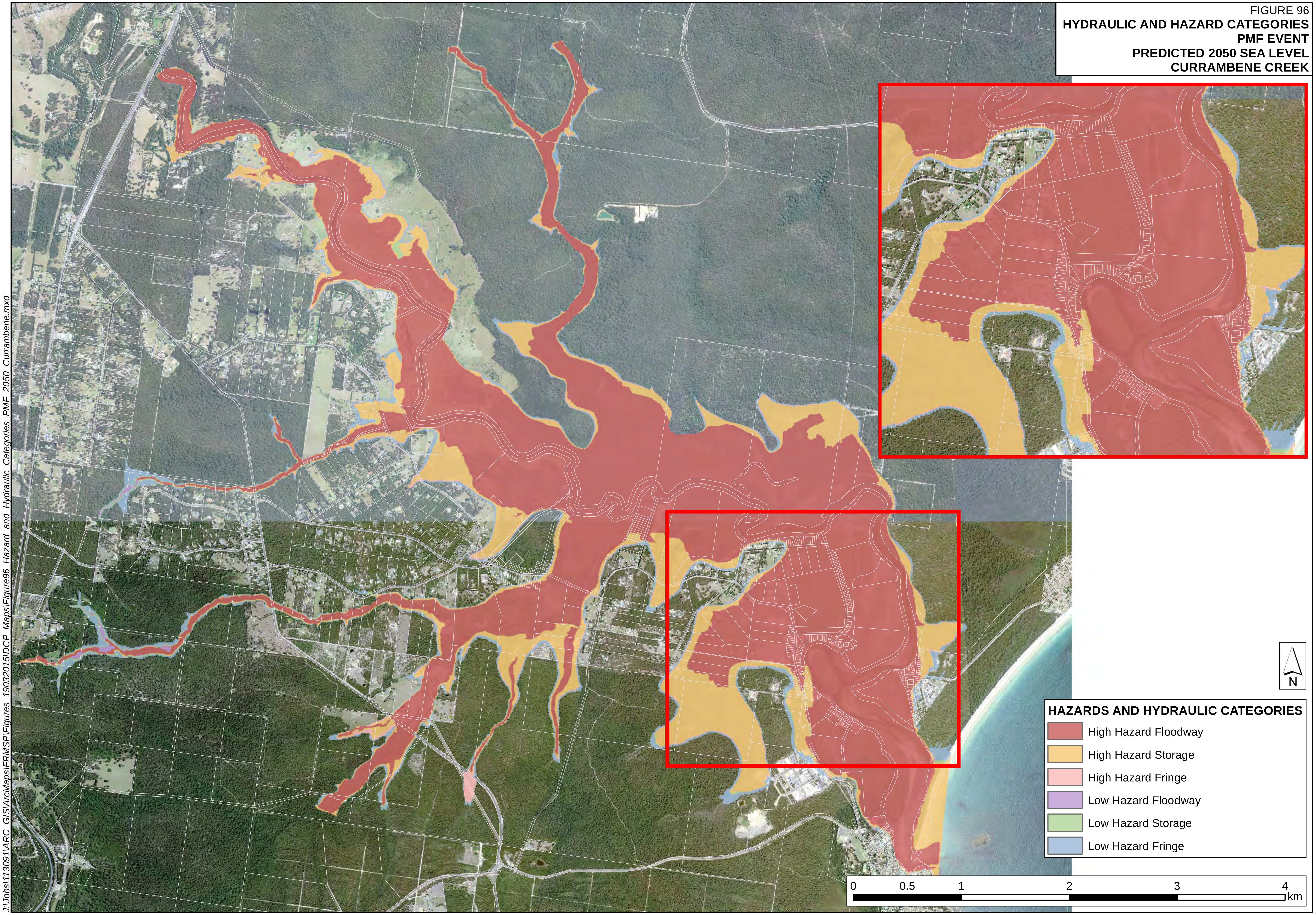

FIGURE 96
HYDRAULIC AND HAZARD CATEGORIES
PMF EVENT
PREDICTED 2050 SEA LEVEL
CURRAMBENE CREEK
HAZARDS AND HYDRAULIC CATEGORIES
High Hazard Floodway
High Hazard Storage
High Hazard Fringe
Low Hazard Floodway
Low Hazard Storage
Low Hazard Fringe
N
0
0.5
1
2
3
4
km
J:\Jobs\113091\ARC_GIS\ArcMaps\FRMSP\Figures_19032015\DCP_Maps\Figure96_Hazard_and_Hydraulic_Categories_PMF_2050_Currambene.mxd

FIGURE 97

HYDRAULIC AND HAZARD CATEGORIES
PMF EVENT
PREDICTED 2100 SEA LEVEL
CURRAMBENE CREEK

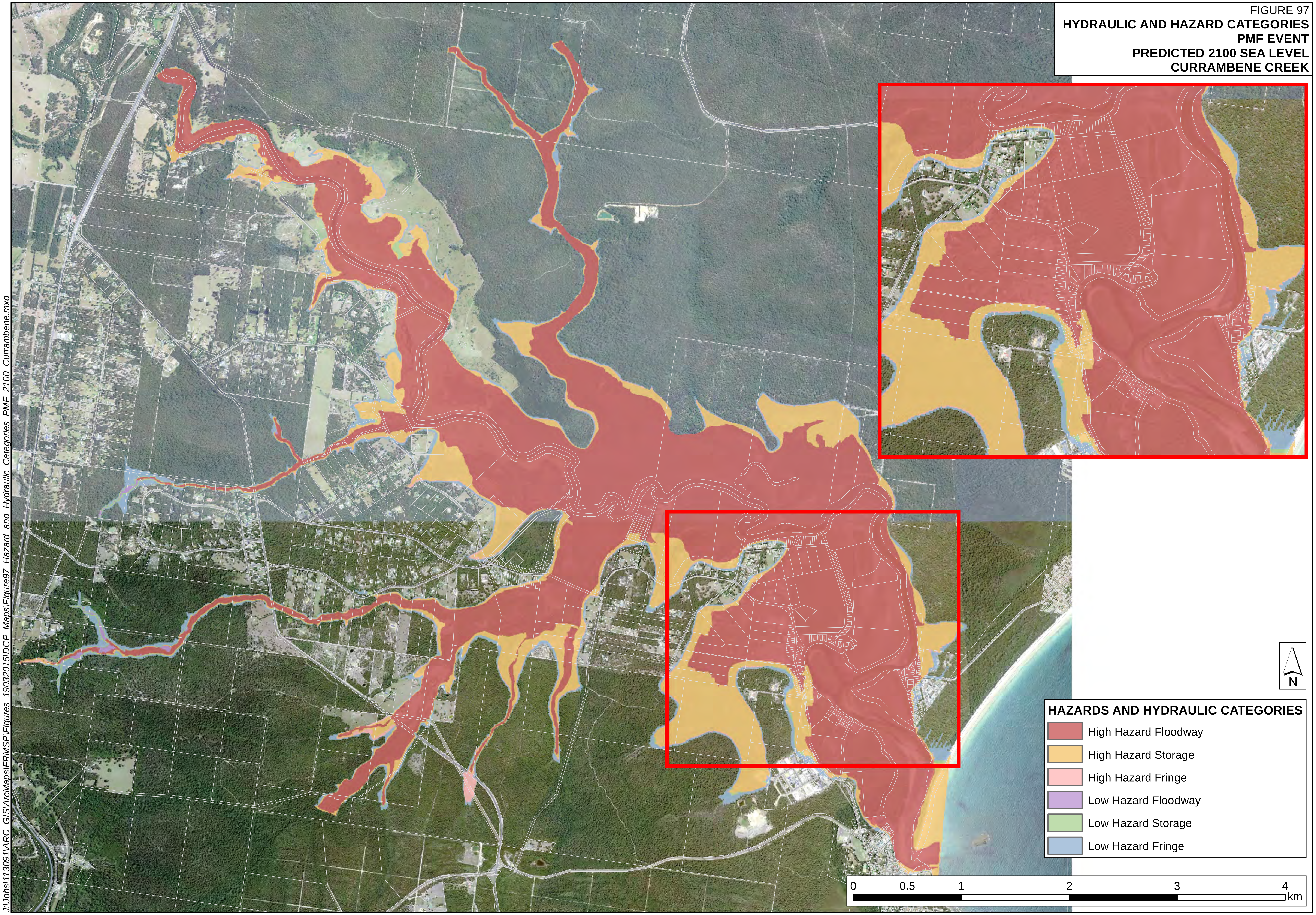

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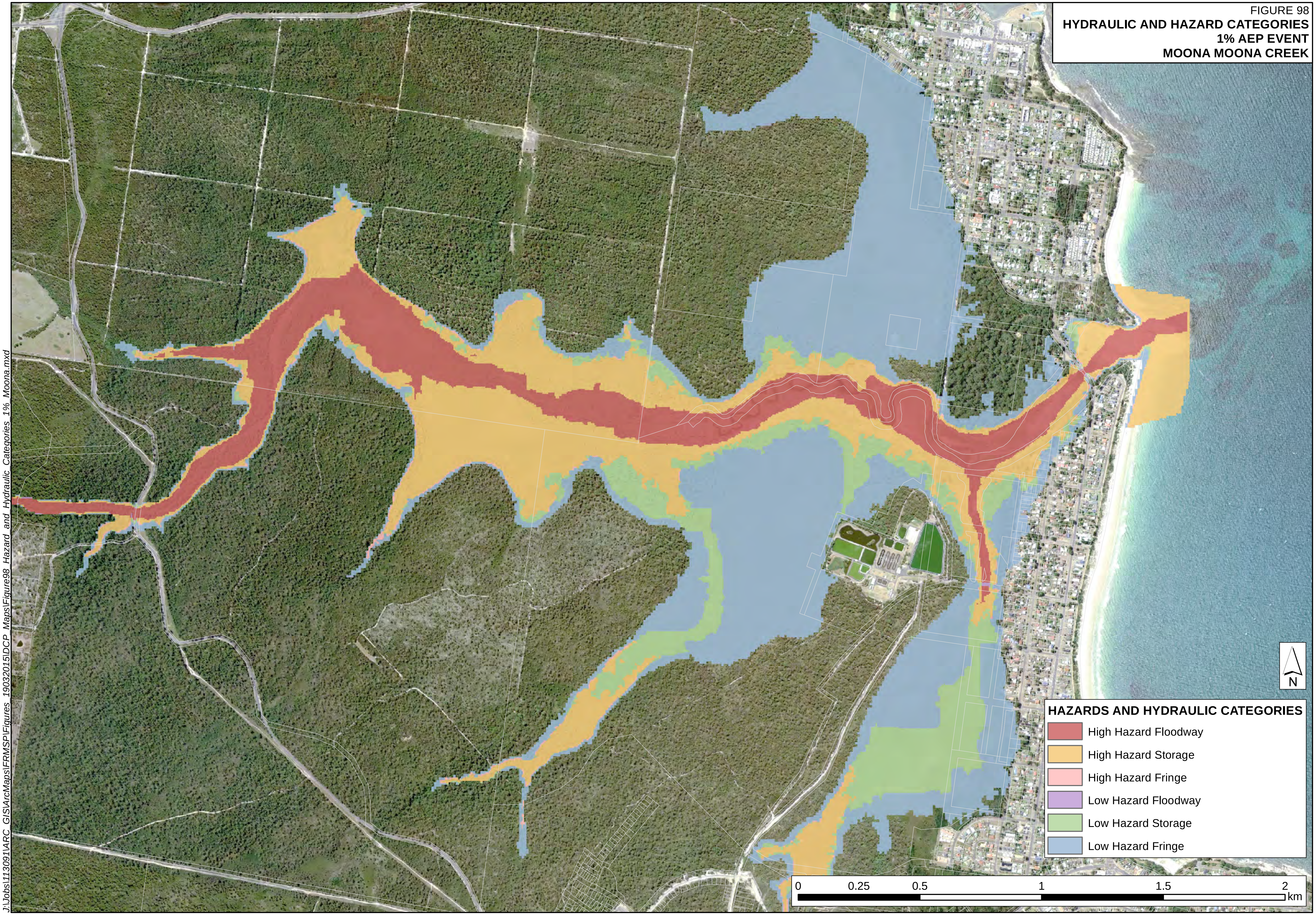
FIGURE 98
HYDRAULIC AND HAZARD CATEGORIES
1% AEP EVENT
MOONA MOONA CREEK



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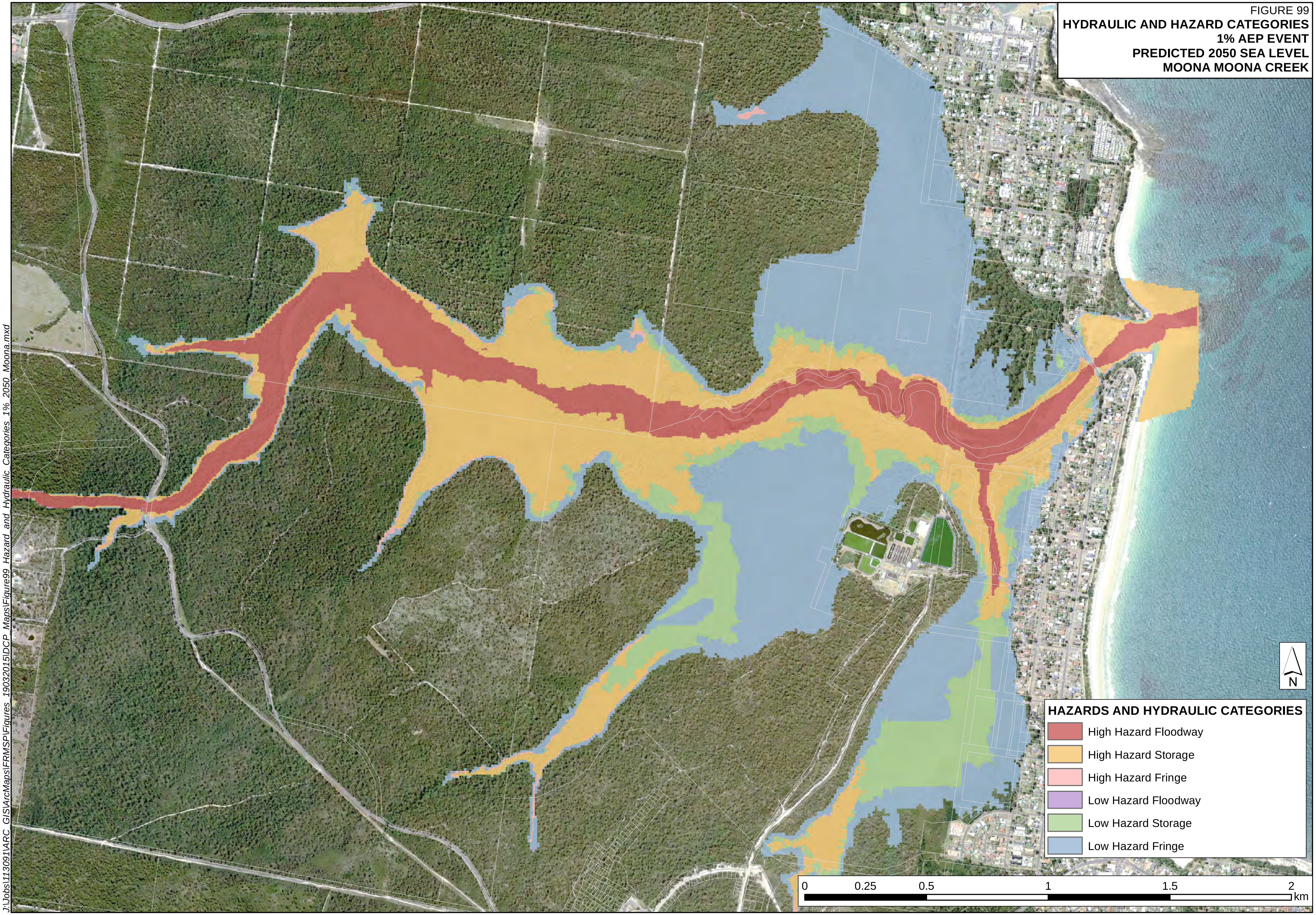

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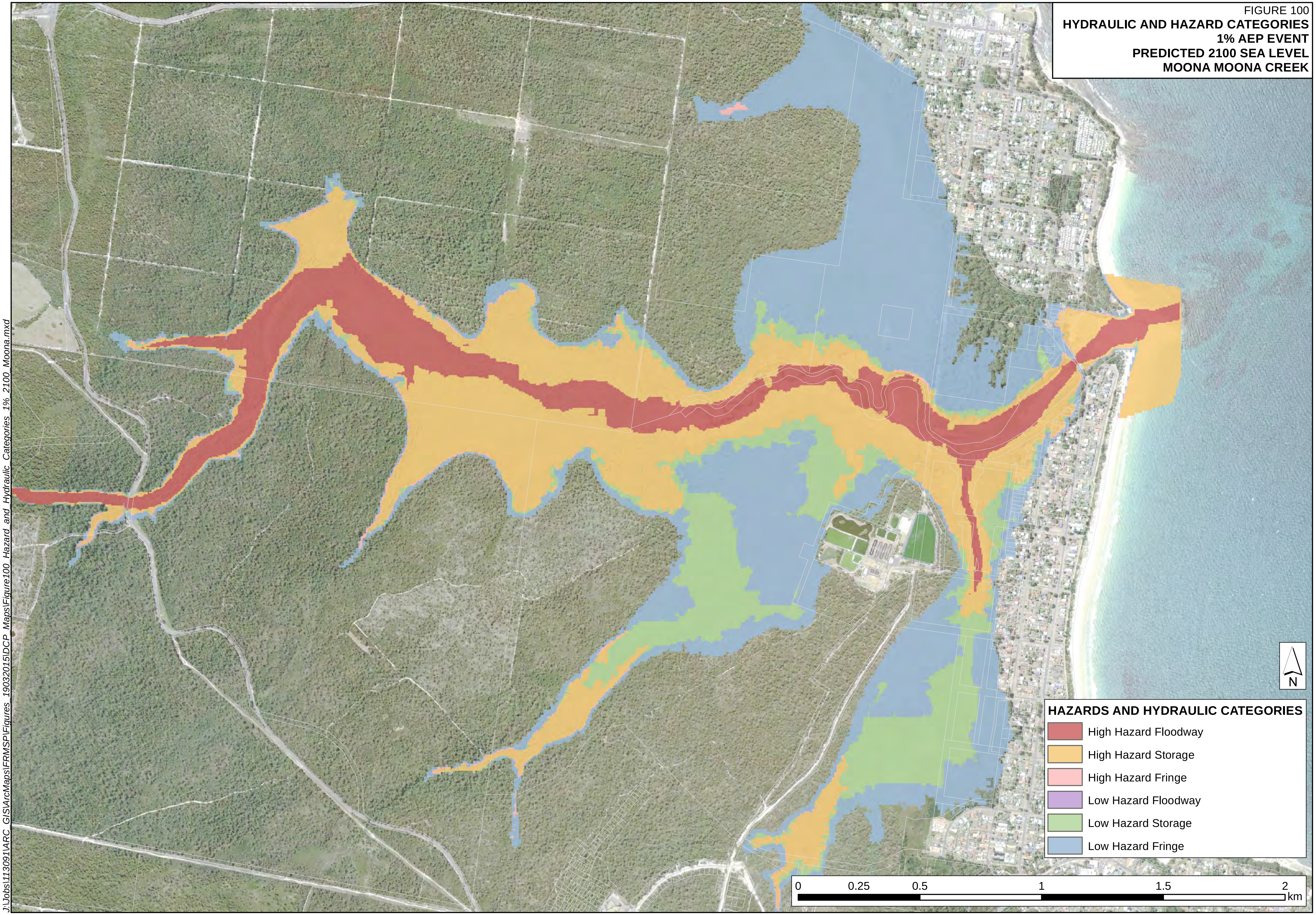
FIGURE 100
HYDRAULIC AND HAZARD CATEGORIES
1% AEP EVENT
PREDICTED 2100 SEA LEVEL
MOONA MOONA CREEK



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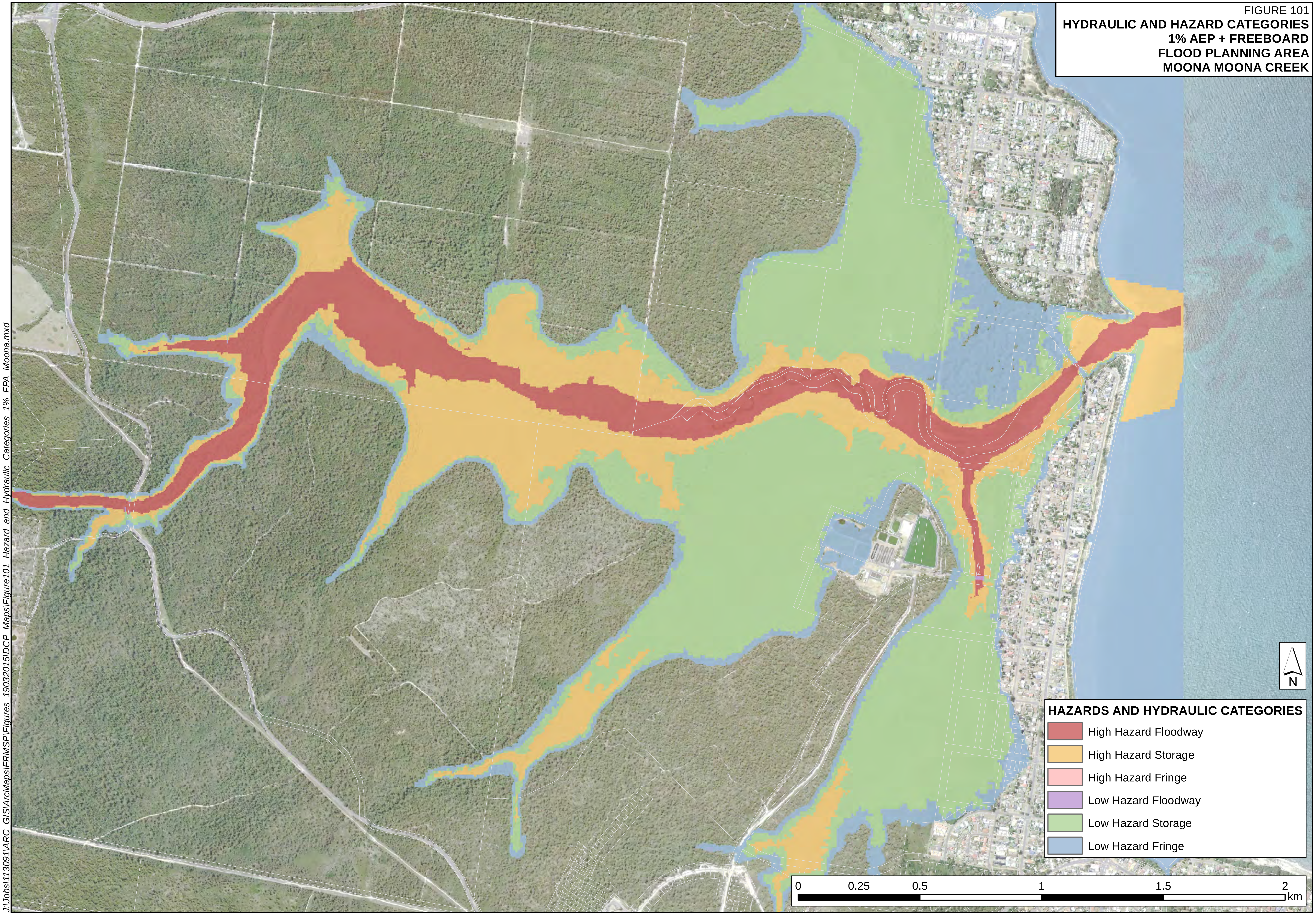


FIGURE 101
HYDRAULIC AND HAZARD CATEGORIES
1% AEP + FREEBOARD
FLOOD PLANNING AREA
MOONA MOONA CREEK
HAZARDS AND HYDRAULIC CATEGORIES
High Hazard Floodway
High Hazard Storage
High Hazard Fringe
Low Hazard Floodway
Low Hazard Storage
Low Hazard Fringe
N
0
0.25
0.5
1
1.5
2
km
J:\Jobs\113091\ARC_GIS\ArcMaps\FRMSP\Figures_19032015\DCP_Maps\Figure101_Hazard_and_Hydraulic_Categories_1%_FPA_Moona.mxd

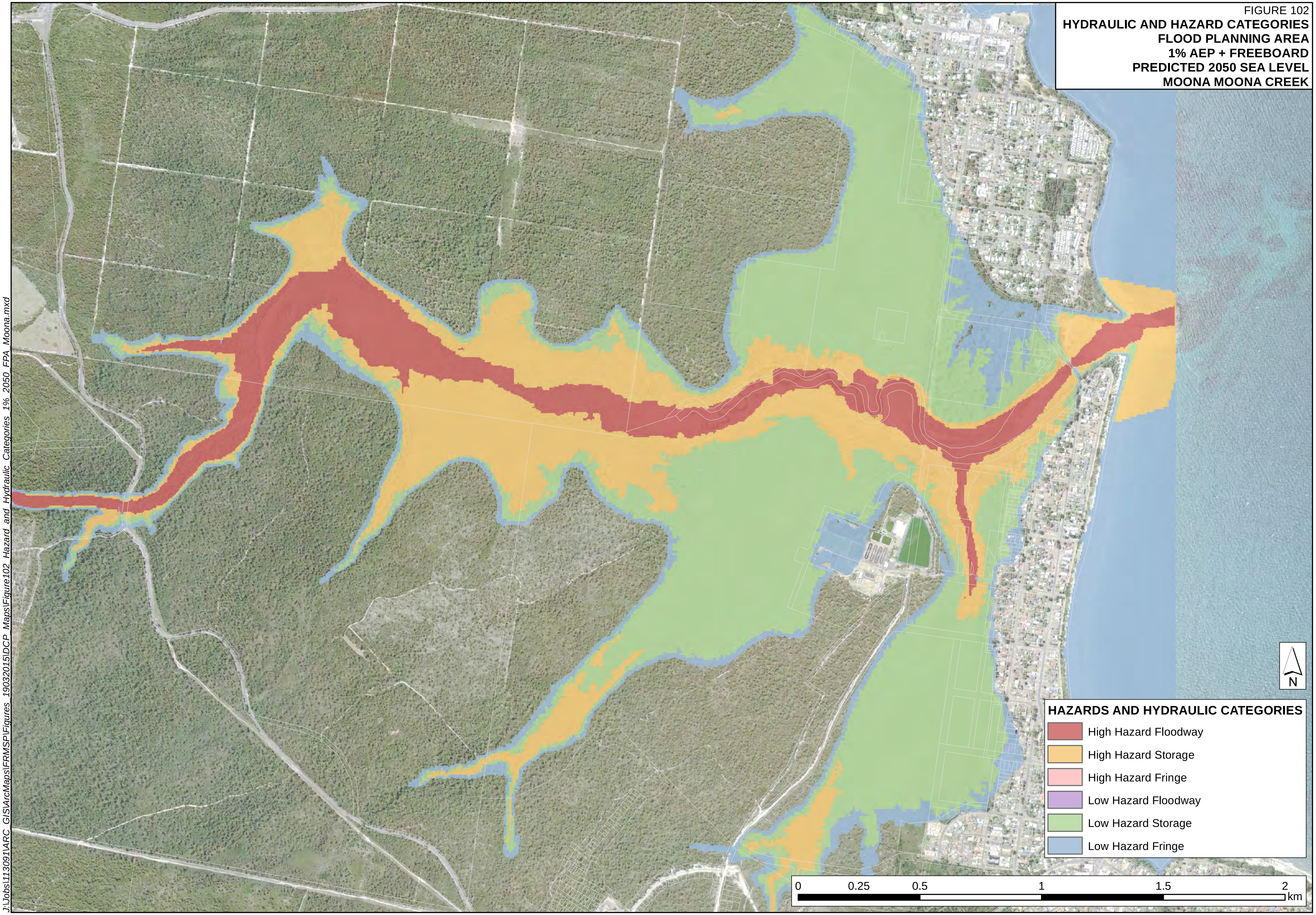
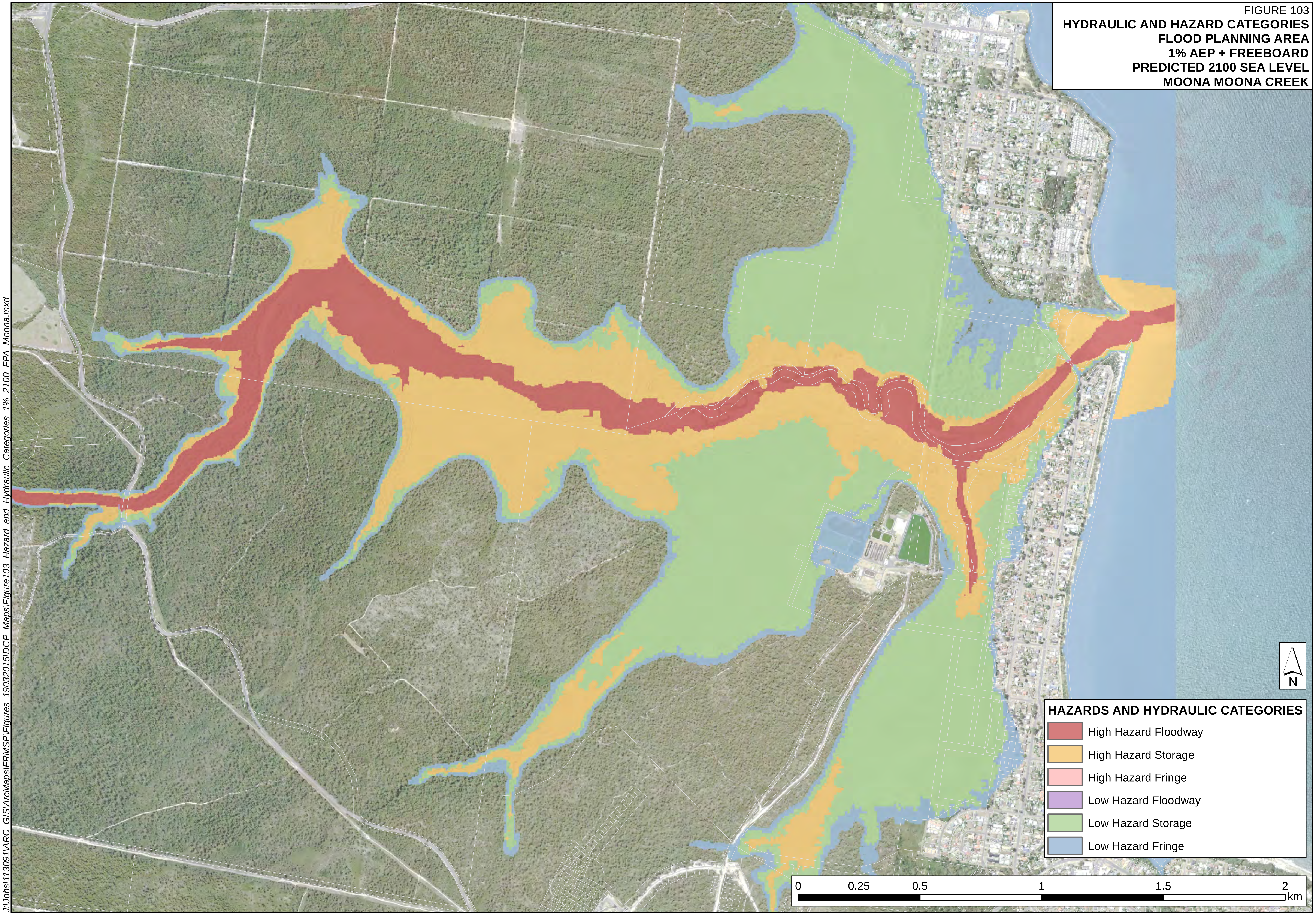


FIGURE 102
HYDRAULIC AND HAZARD CATEGORIES
FLOOD PLANNING AREA
1% AEP + FREEBOARD
PREDICTED 2050 SEA LEVEL
MOONA MOONA CREEK
HAZARDS AND HYDRAULIC CATEGORIES
High Hazard Floodway
High Hazard Storage
High Hazard Fringe
Low Hazard Floodway
Low Hazard Storage
Low Hazard Fringe
N
0
0.25
0.5
1
1.5
2
km
J:\Jobs\113091\ARC_GIS\ArcMaps\FRMSP\Figures_19032015\DCP_Maps\Figure102_Hazard_and_Hydraulic_Categories_1%_2050_FPA_Moona.mxd



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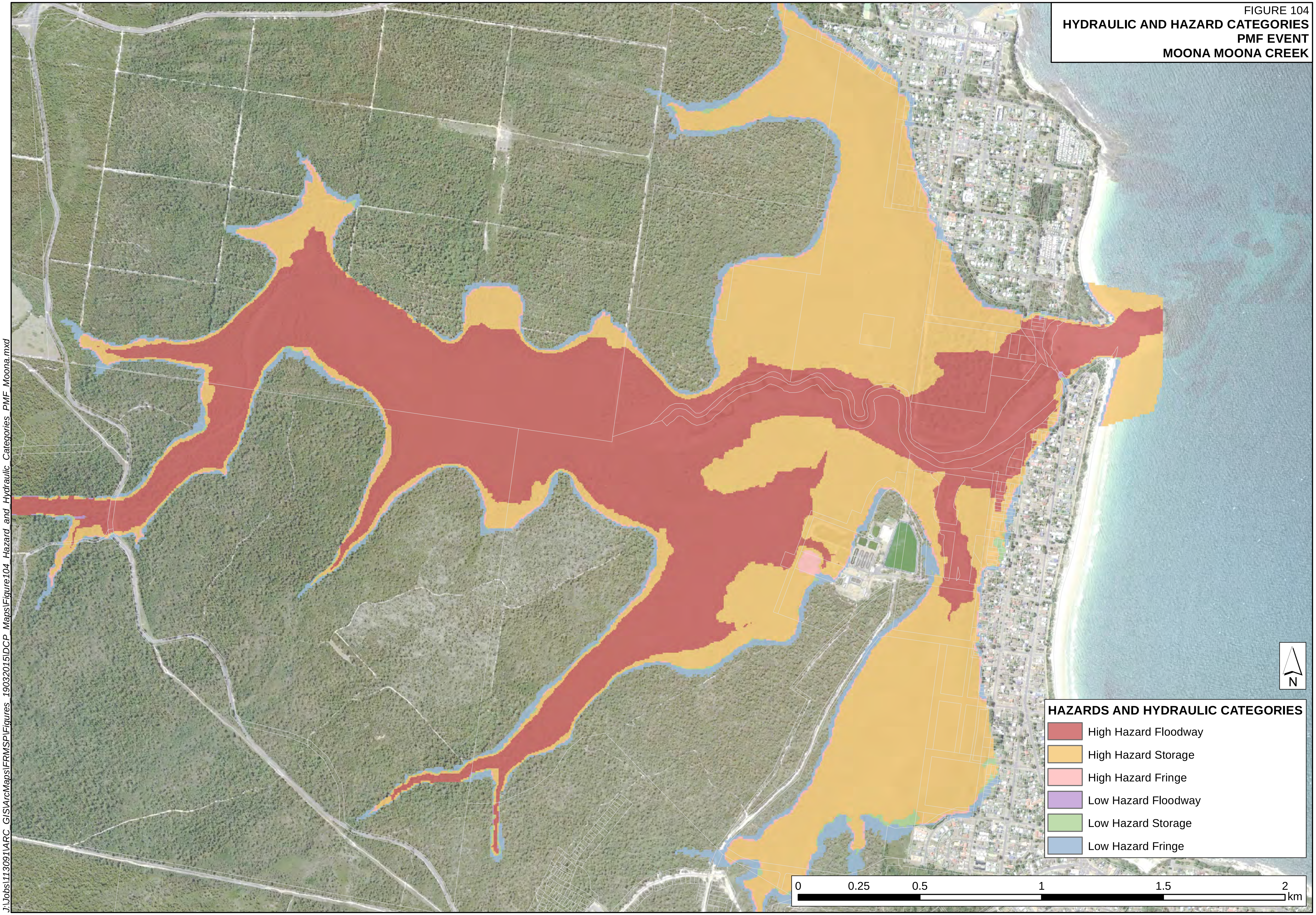

FIGURE 104
HYDRAULIC AND HAZARD CATEGORIES
PMF EVENT
MOONA MOONA CREEK
N
HAZARDS AND HYDRAULIC CATEGORIES
High Hazard Floodway
High Hazard Storage
High Hazard Fringe
Low Hazard Floodway
Low Hazard Storage
Low Hazard Fringe
0
0.25
0.5
1
1.5
2
km
J:\Jobs\113091\ARC_GIS\ArcMaps\FRMSP\Figures_19032015\DCP_Maps\Figure104_Hazard_and_Hydraulic_Categories_PMF_Moona.mxd

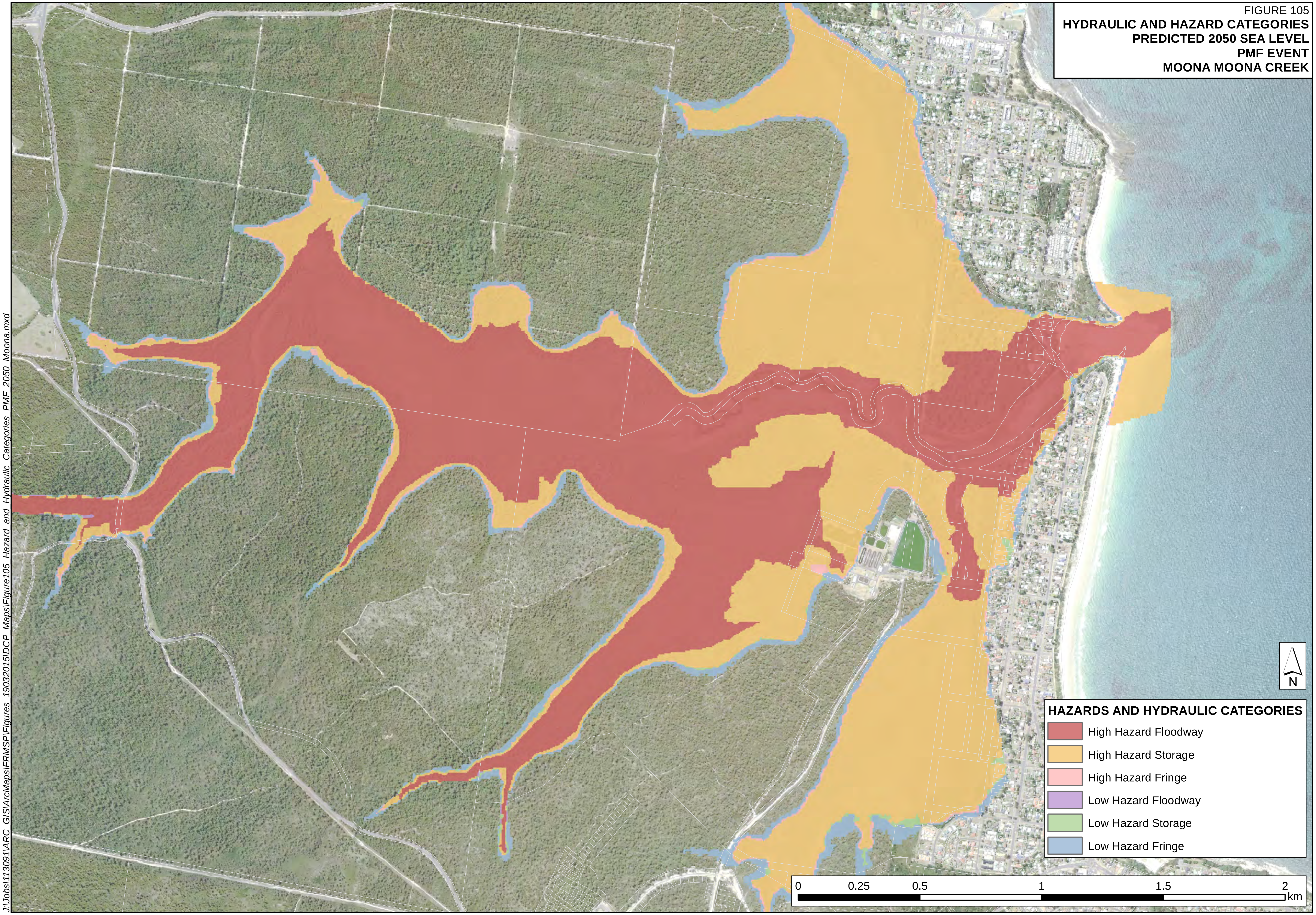

FIGURE 105
HYDRAULIC AND HAZARD CATEGORIES
PREDICTED 2050 SEA LEVEL
PMF EVENT
MOONA MOONA CREEK
HAZARDS AND HYDRAULIC CATEGORIES
High Hazard Floodway
High Hazard Storage
High Hazard Fringe
Low Hazard Floodway
Low Hazard Storage
Low Hazard Fringe
N
0
0.25
0.5
1
1.5
2
km
J:\Jobs\113091\ARC_GIS\ArcMaps\FRMSP\Figures_19032015\DCP_Maps\Figure105_Hazard_and_Hydraulic_Categories_PMF_2050_Moona.mxd

FIGURE 106

HYDRAULIC AND HAZARD CATEGORIES
PREDICTED 2100 SEA LEVEL
PMF EVENT
MOONA MOONA CREEK

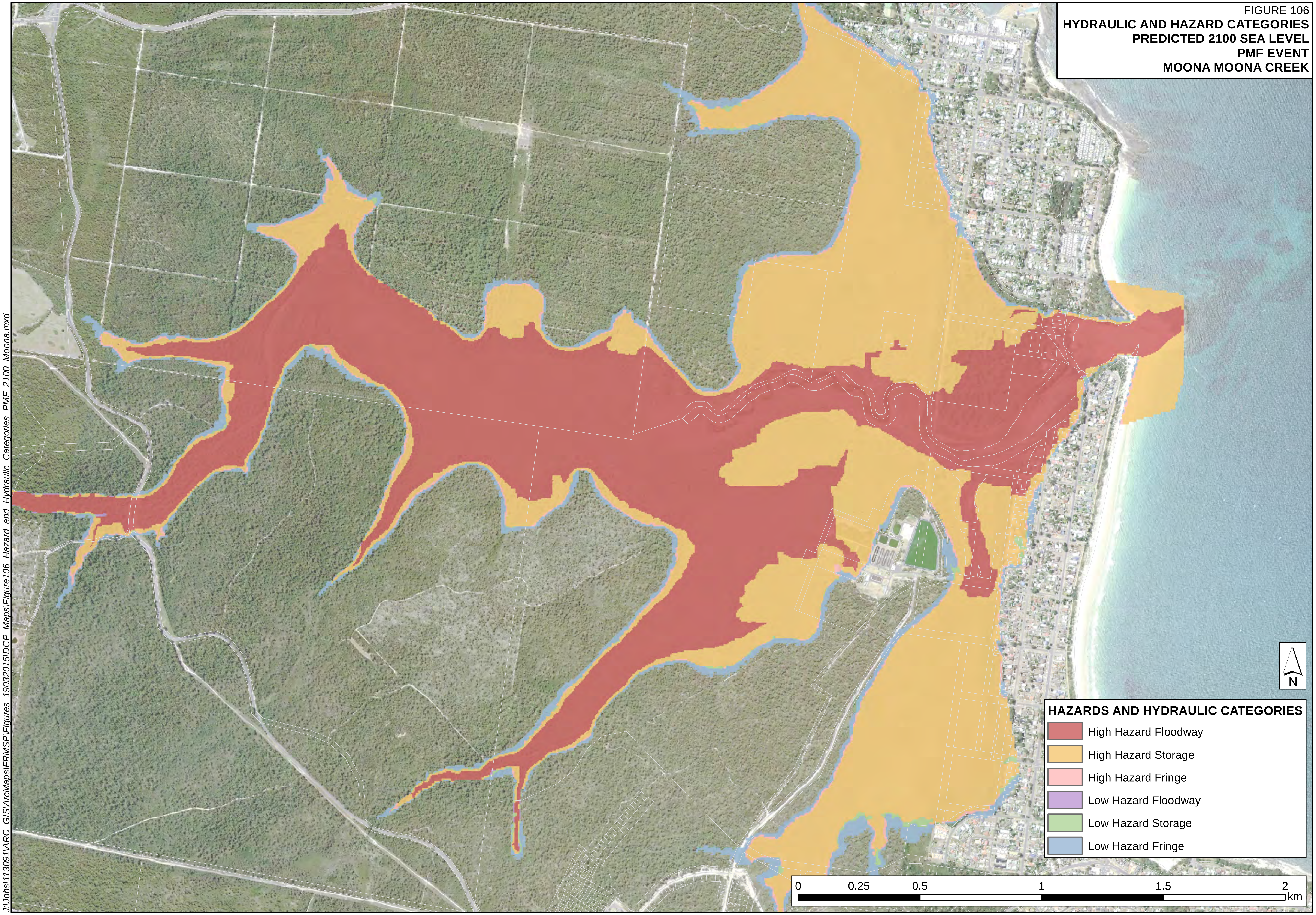

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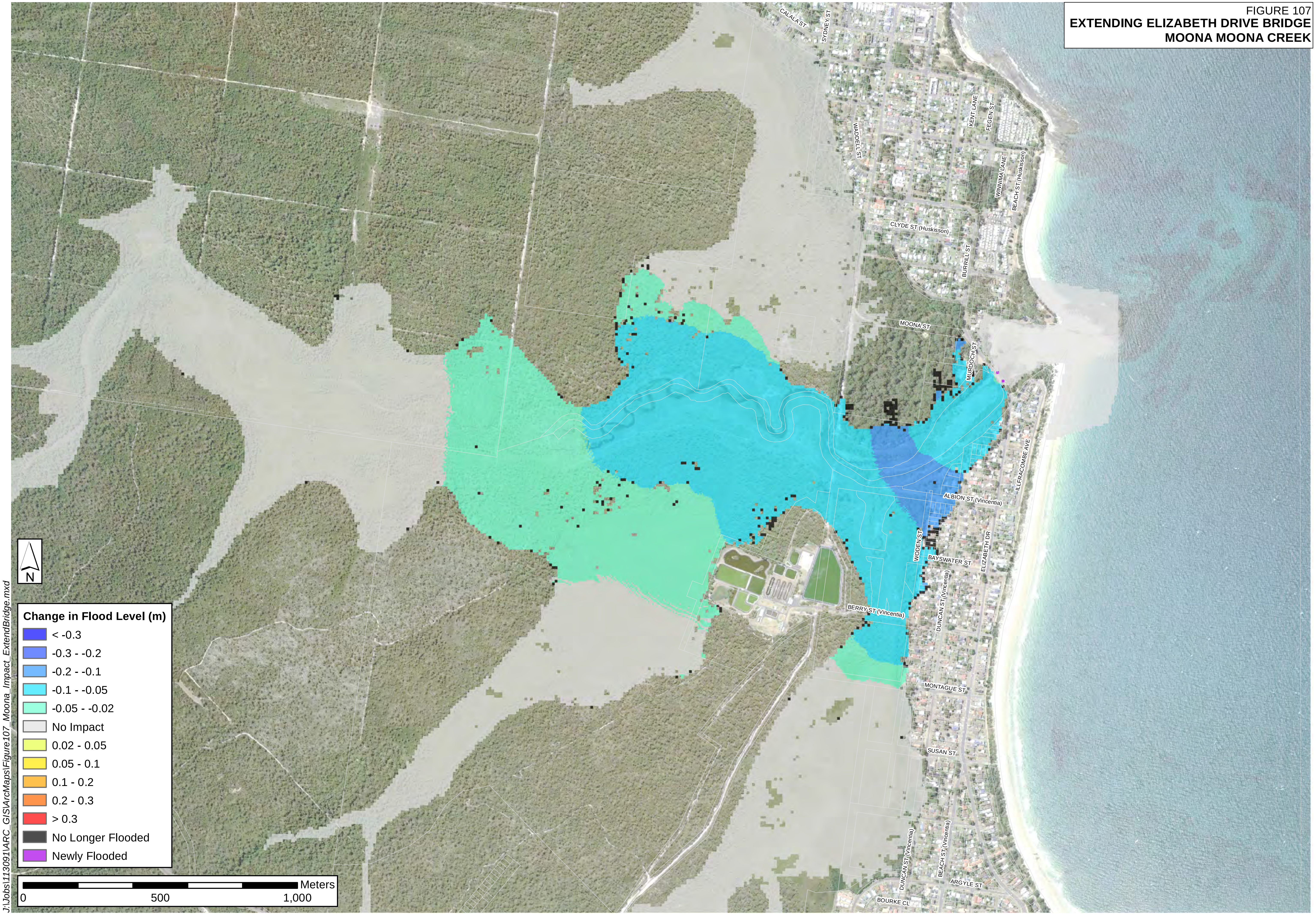
FIGURE 107
EXTENDING ELIZABETH DRIVE BRIDGE
MOONA MOONA CREEK



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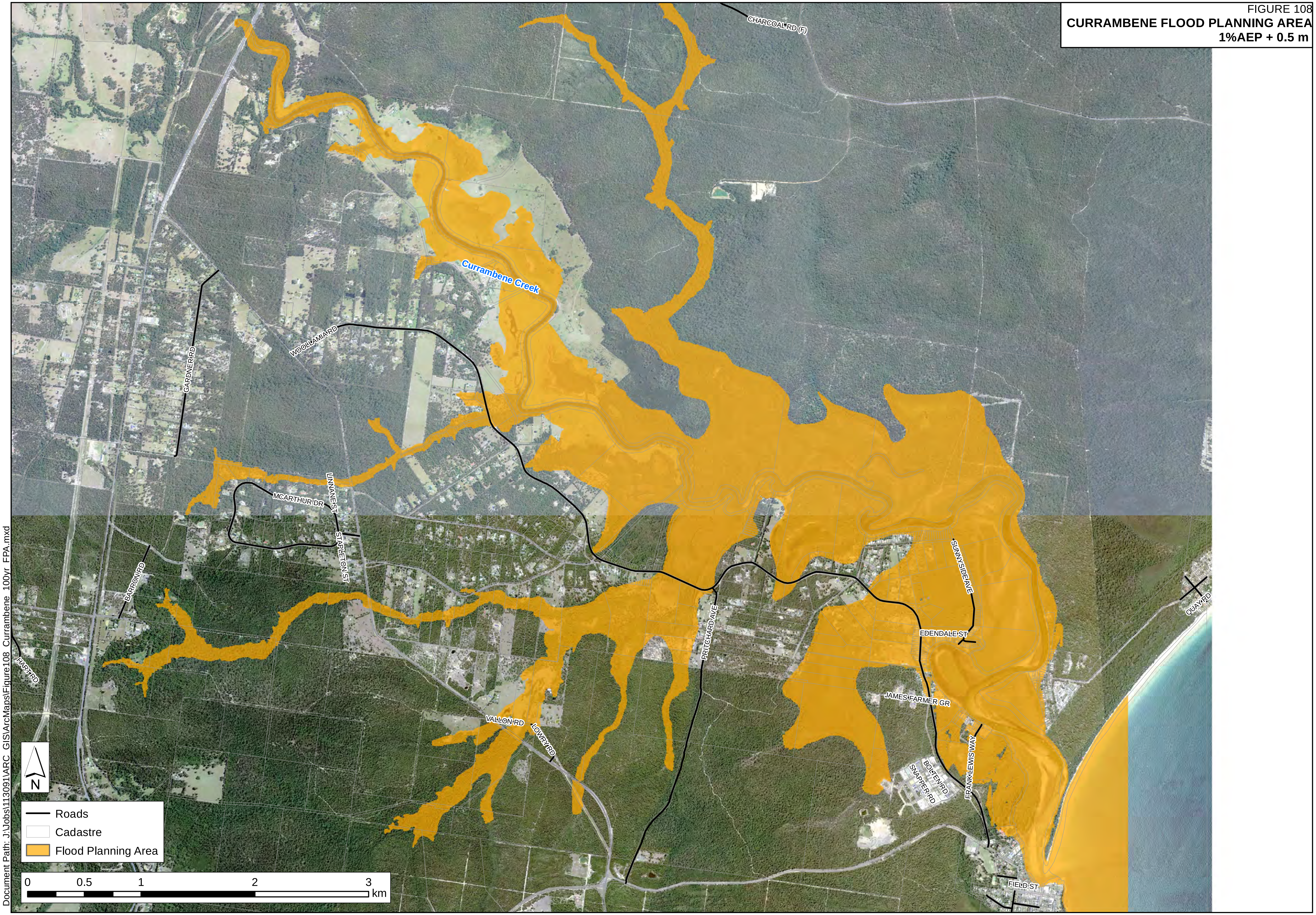

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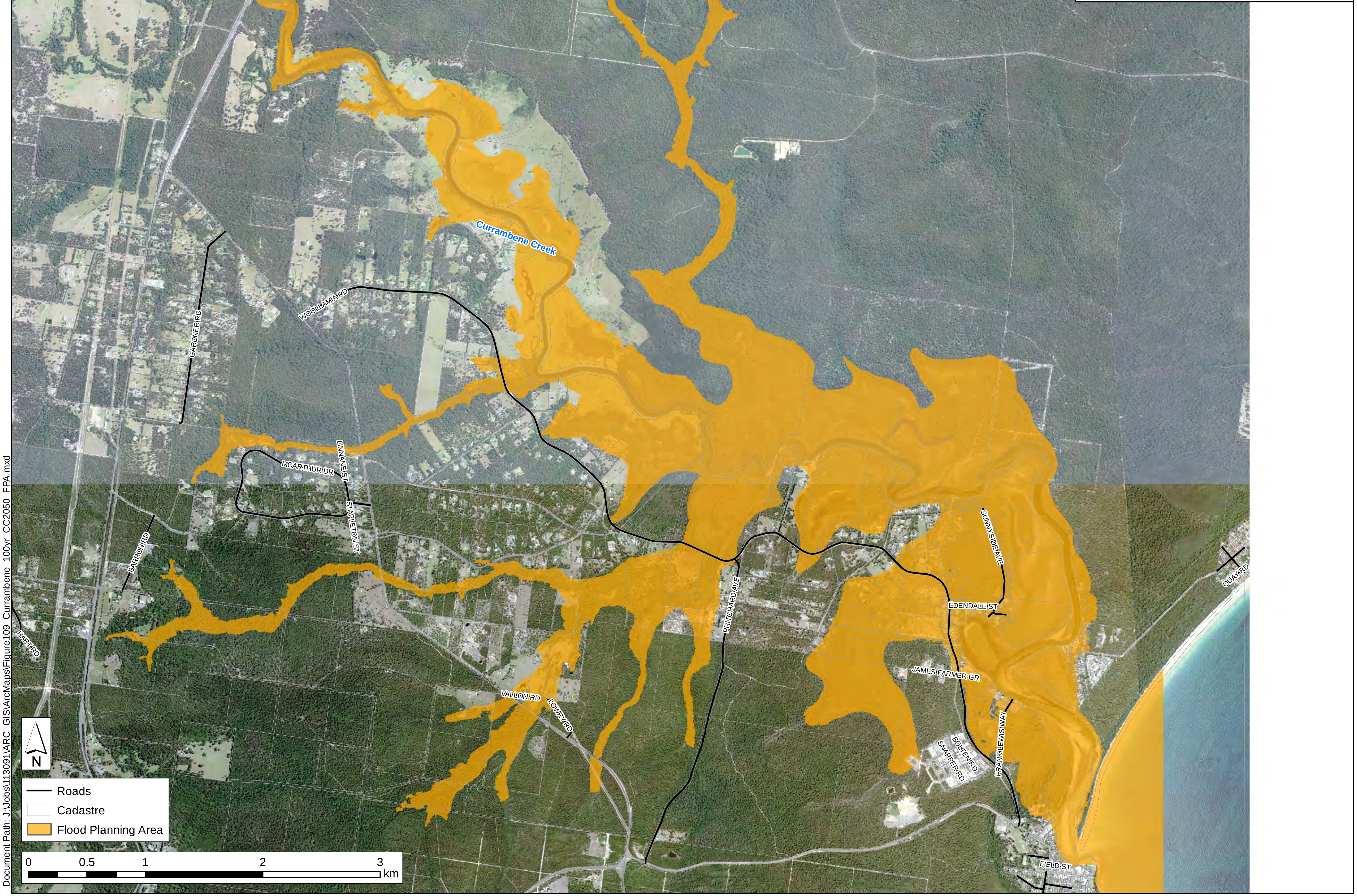
FIGURE 109

CURRAMBENE FLOOD PLANNING AREA
1%AEP + 0.5 m and 2050 SEA LEVEL



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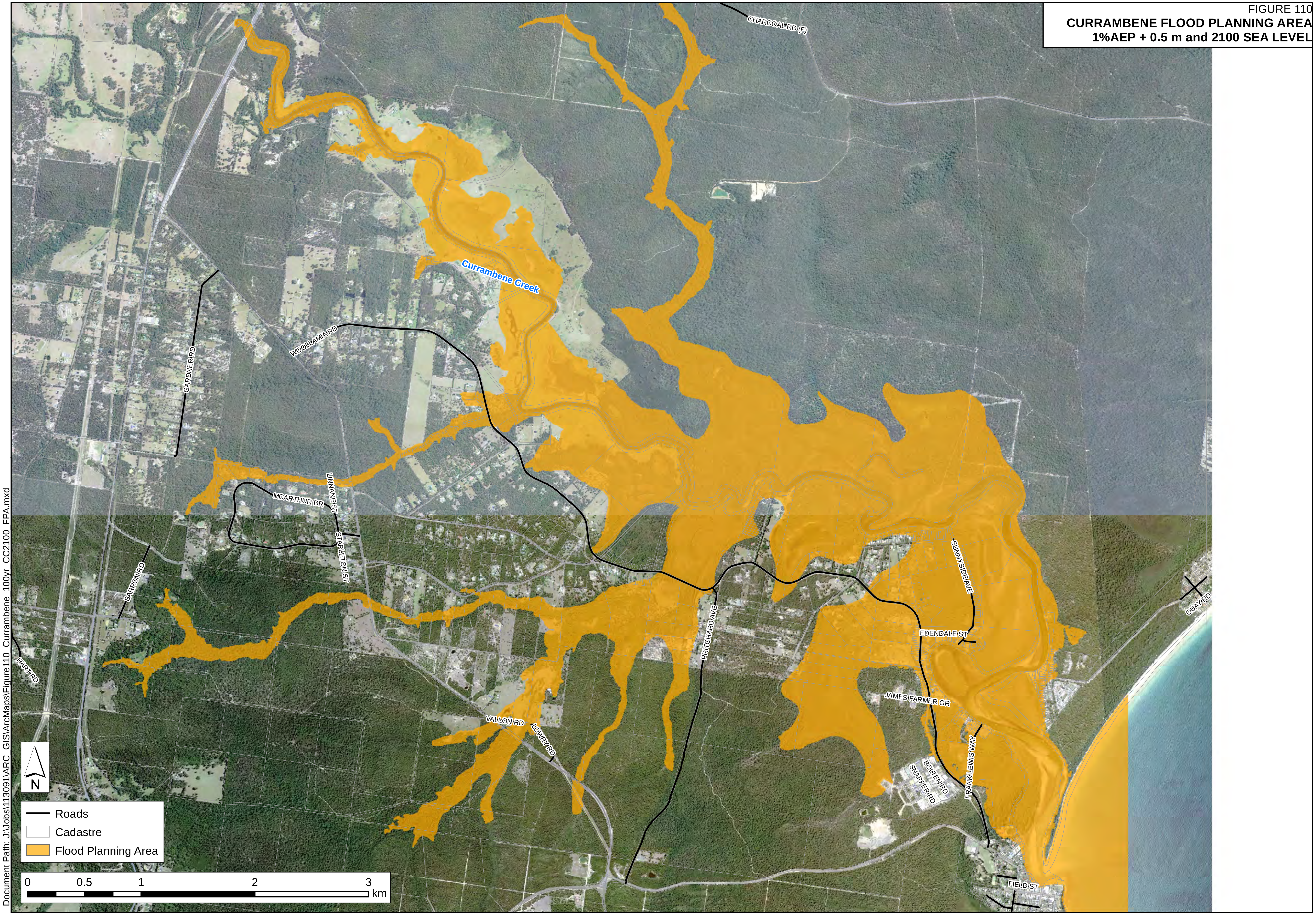

FIGURE 110
CURRAMBENE FLOOD PLANNING AREA
1%AEP + 0.5 m and 2100 SEA LEVEL

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FIGURE 111
MOONA MOONA CREEK FLOOD PLANNING AREA
1% AEP + 0.5 m

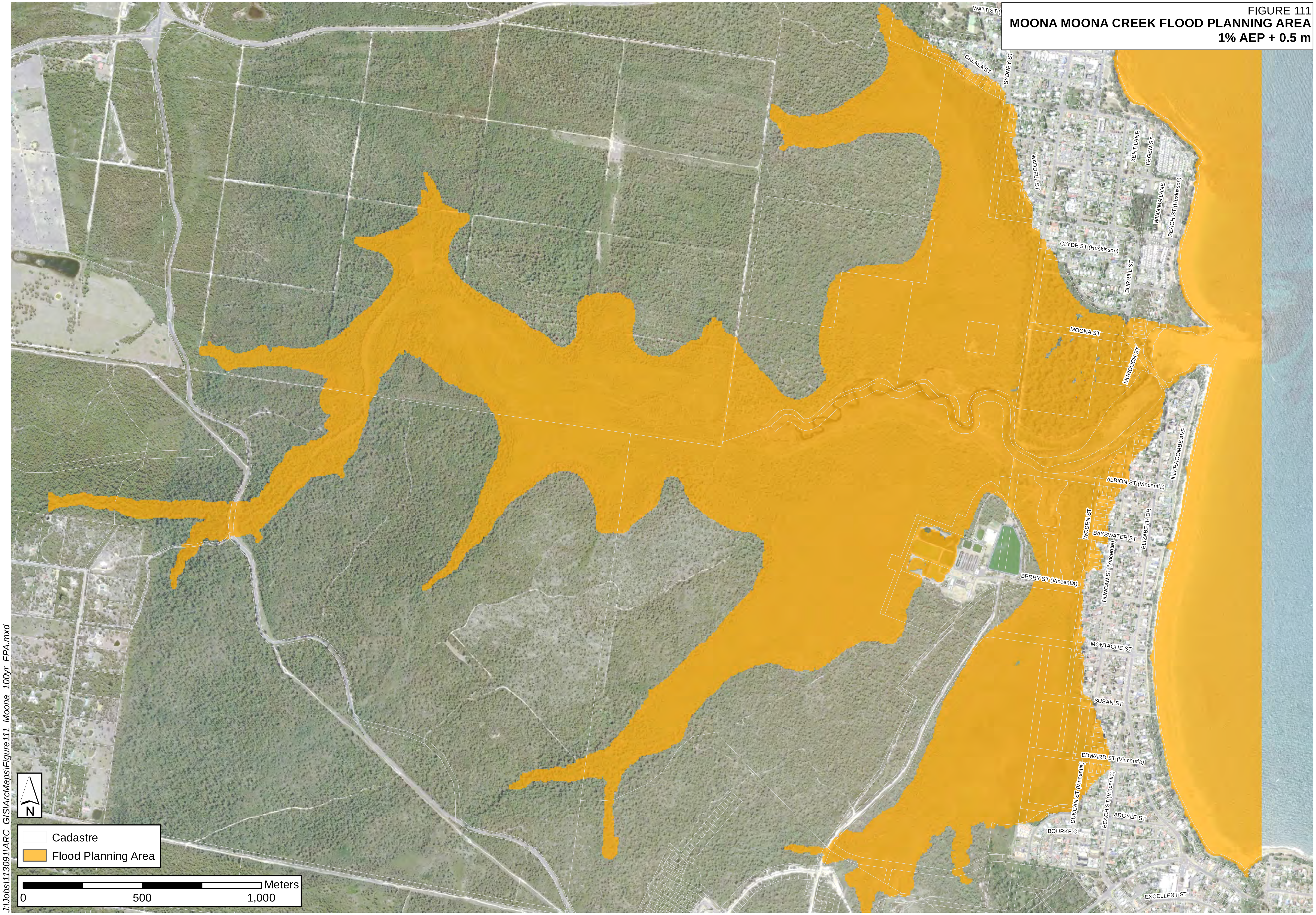

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FIGURE 112
MOONA MOONA CREEK FLOOD PLANNING AREA
1% AEP + 0.5 m and 2050 SEA LEVEL

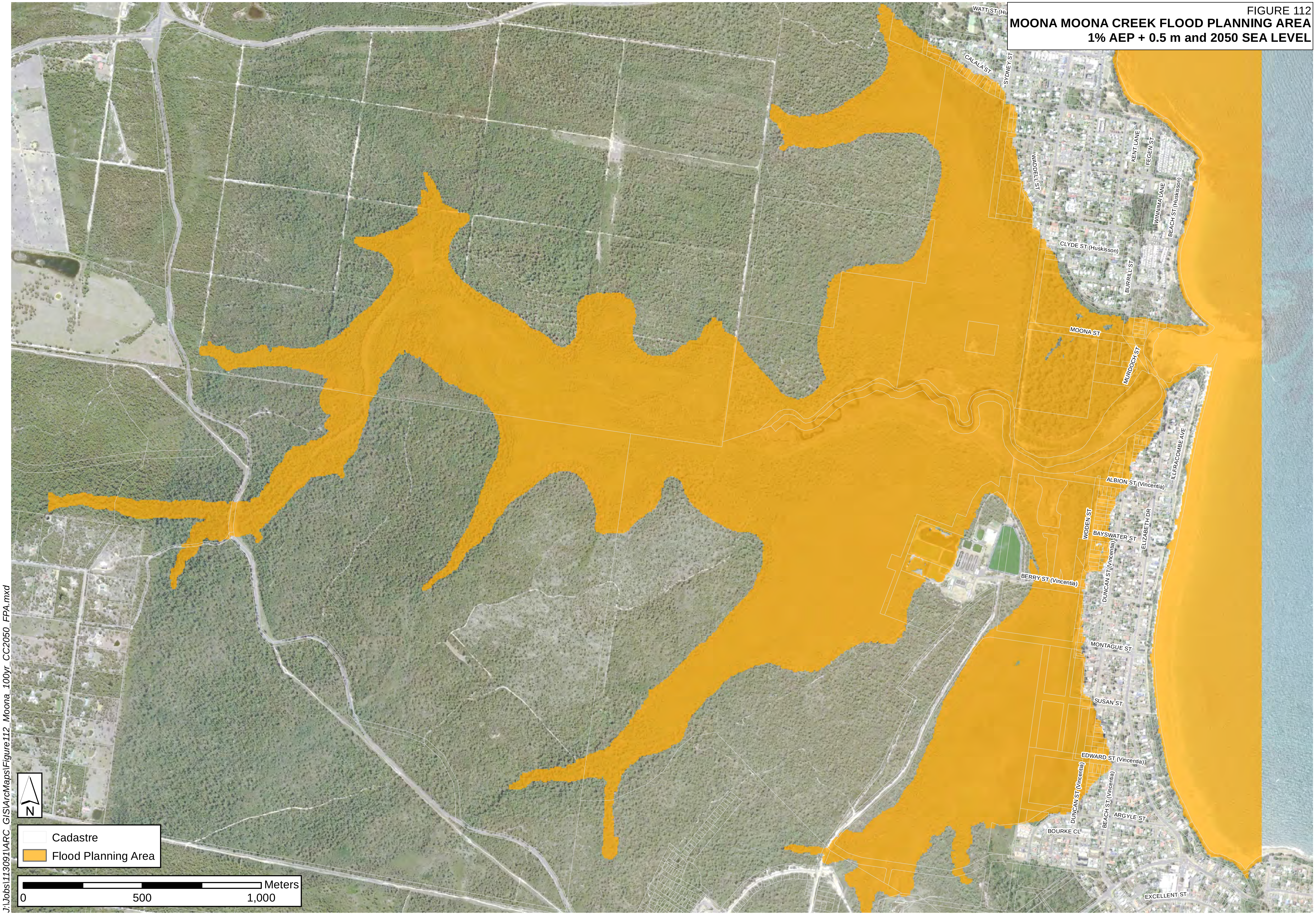

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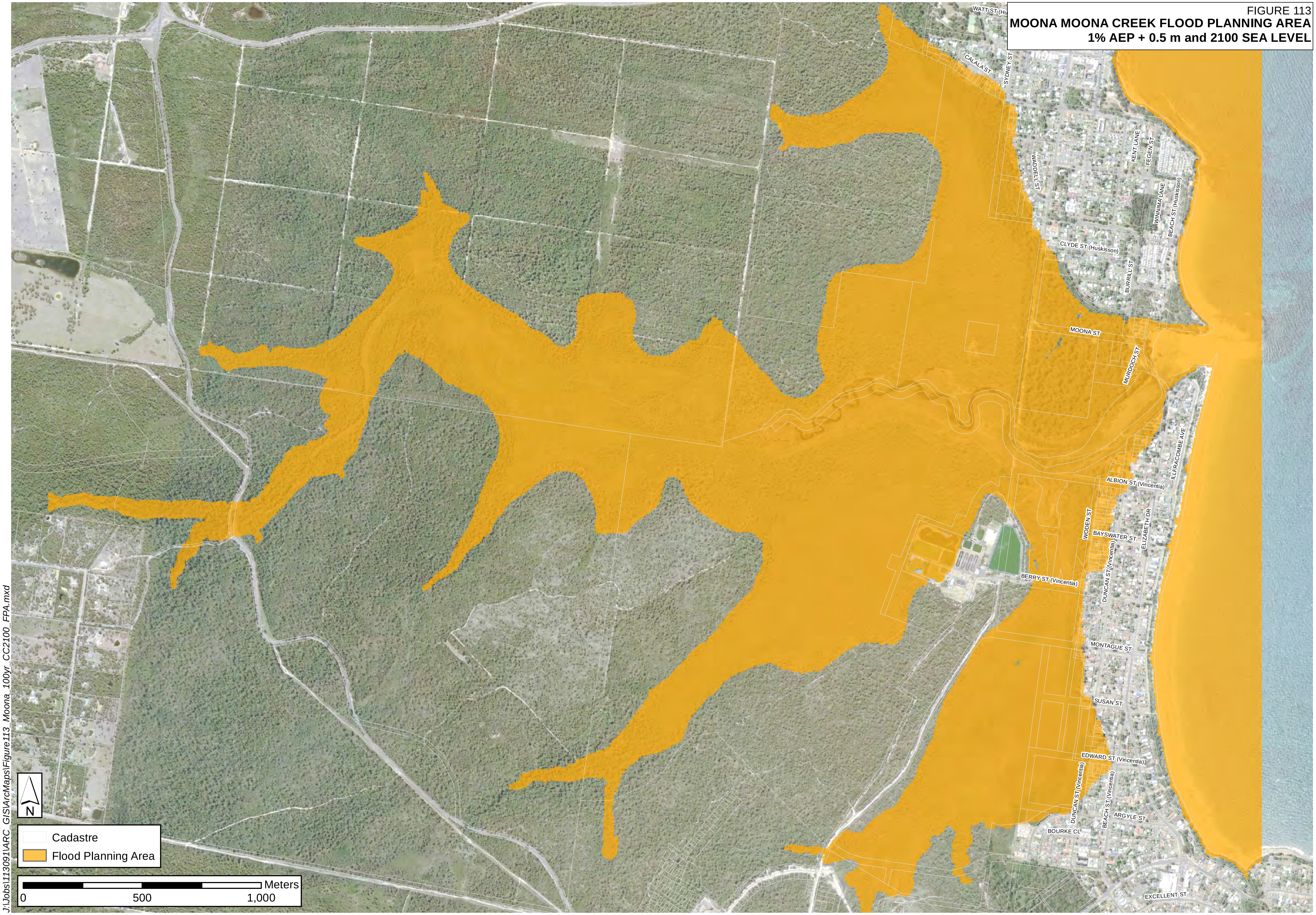
FIGURE 113
MOONA MOONA CREEK FLOOD PLANNING AREA
1% AEP + 0.5 m and 2100 SEA LEVEL



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