Central Coast Council

TUGGERAH LAKES SOUTHERN CATCHMENTS FLOOD STUDY

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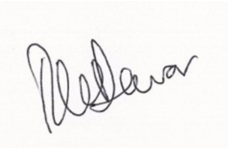
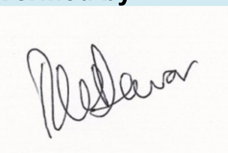
Authors Zac Richards Beth Marson Richard Dewar	**Prepared by** 
Date 9 February 2018	**Verified by** 

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AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff
ARR87	1987 edition of Australian Rainfall and Runoff
ARR2016	2016 edition of Australian Rainfall and Runoff
ALS	Airborne Laser Scanning
BoM	Bureau of Meteorology
DECC	Department of Environment and Climate Change
DEM	Digital Elevation Model
GIS	Geographic Information System
GPS	Global Positioning System
HEC-2	one-dimensional (1D) steady state hydraulic computer model
HEC-RAS	update to HEC-2
IFD	Intensity, Frequency and Duration of Rainfall
LPI	Land and Property Information
mAHD	meters above Australian Height Datum
MHL	Manly Hydraulics Laboratory
MIKE-11	one-dimensional (1D) unsteady flow hydraulic computer model
OEH	Office of Environment and Heritage
PMF	Probable Maximum Flood
RAFTS	Hydrologic runoff routing computer model
RSWM	Regional Stormwater Drainage Model
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)

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 Study***
   - 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 Tuggerah Lakes Southern Catchments Flood Study (the Study) presented herein constitutes the first and second stages of the NSW Floodplain Risk Management Program for the Wyong Shire Council. The Study takes into account overland flow and mainstream flooding in the suburbs of Glenning Valley, Berkeley Vale, Tumbi Umbi, Bateau Bay, Shelly Beach, Toowoon Bay, Blue Bay and The Entrance.

WMAwater has been engaged by the Central Coast Council to prepare this Study under the guidance of the Council's Floodplain Management Committee.

Central Coast Council has prepared this document with financial assistance from the NSW Government through its Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Office of Environment and Heritage.

TERMINOLOGY USED IN REPORT

Australian Rainfall and Runoff (ARR) has produced a set of 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 terminology guidelines and uses % AEP for all events greater than the 0.2 EY and EY for all events smaller and more frequent than this. The image below provides the relationship between the various terminologies.

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

1. INTRODUCTION AND BACKGROUND

This Study has been prepared by WMAwater on behalf of the Central Coast Council (Council). The main objective of this study is to define mainstream and overland flood affectation for the areas within the Tuggerah Lakes Southern Catchments. The Study has examined past flood events in addition to undertaking a flood assessment for a range of design storms under existing conditions. The findings in this report provide material to inform Council with regards to managing existing and future flood risk due to mainstream and overland flow flooding in the suburbs of Glenning Valley, Berkeley Vale, Tumbi Umbi, Bateau Bay, Shelly Beach, Toowoon Bay, Blue Bay and The Entrance.

The Study investigates flooding due to both mainstream and overland flow in this area, however flooding due to elevated water levels in Tuggerah Lakes is not under investigation.

1.1. Objectives

The information and results obtained from this study define existing flood behaviour for the Tuggerah Lakes Southern Catchments and provide a firm basis for the development of a subsequent Floodplain Risk Management Study and Plan (FRMS&P).

Primarily, the study was developed in order to meet the objective of defining design flood behaviour (0.2EY, 5%, 1% AEP events and the Probable Maximum Flood (PMF)) for mainstream and overland flow flooding and to produce:

- Flood levels, extents, velocities and flows for the full range of modelled design events;
- Provisional hazard and preliminary hydraulic category figures for the 1% AEP and PMF events;
- Flood emergency response classification of communities;
- Preliminary flood planning levels and areas;
- Analysis on the sensitivity of flood behaviour to changes in flood producing rainfall events due to climate change; and
- A modelling system to be used in the subsequent FRMS&P to test proposed flood risk management strategies.

1.2. The Study Area

The Tuggerah Lakes Southern Catchments are located on the Central Coast of NSW approximately 90 km north of Sydney in the Central Coast (formerly Wyong Shire) Council Local Government Area (LGA). The study area (shown in Figure 1) can be considered as three individual sub-areas:

- Glenning Valley catchment;
- Tumbi Umbi Creek catchment; and
- The Wyong Eastern Coastal catchments.

These catchments have a combined population of approximately 34,000 (2011 census) with further details presented in the following sections.

1.2.1. The Glenning Valley Catchment

The Glenning Valley catchment has an area of approximately 7.4 km² at its outlet to Tuggerah Lakes with the main flow path running in a northerly direction through the suburbs of Glenning Valley and Berkeley Vale. The Glenning Valley catchment extends approximately 4 km upstream (south) of Wyong Road with Tuggerah Lake situated approximately 1 km downstream. In the upper reaches of the catchment, the land use is predominately composed of *'E3 Environmental Management'* and *'E4 Environmental Living'*. Closer to Tuggerah Lake on the downstream (east) of Wyong Road, land use is predominantly *'R2 Low Density Residential'*.

1.2.2. Tumbi Umbi Creek Catchment

Tumbi Umbi Creek is the largest flow path in the study area with a catchment area of approximately 16.2 km² at its outlet to Tuggerah Lakes. In addition to Tumbi Umbi Creek, the catchment contains numerous tributaries and overland flow paths which typically flow in a northerly direction through the suburbs of Tumbi Umbi and Berkeley Vale. Tumbi Umbi Creek extends approximately 6 km upstream of Wyong Road with Tuggerah Lake situated approximately 1.5 km downstream. Upstream of Wyong Road, the land use is predominately composed of *E3* and *E4* with some areas of *R2*. At Wyong Road and downstream, land use is primarily *R2* with the notable inclusions of the Mingara Recreation Club *'RE2 Private Recreation'* and the Tumbi Umbi Industrial Estate *'IN2 Light Industrial'*.

1.2.3. Wyong Eastern Coastal Catchments

The Wyong Eastern Coastal Catchments cover an area of 2.5 km² and include the suburbs of Bateau Bay, Shelly Beach, Toowoon Bay, Blue Bay and The Entrance. The area is composed of a series of smaller catchments with areas typically less than 25 ha which flow into the ocean via a number of coastal coves and beaches. Land use in these catchments is a range of predominately residential land uses including *'R1 General Residential', R2* and *'R3 Medium Density Residential'* as well as *'E1 National Parks and Nature Reserves'.*

1.3. Flood History

Flooding in the region has been known to occur due to both mainstream and overland flows as well as elevated water levels in Tuggerah Lakes. Flood events have been experienced in January 1978, February 1981, May 1988, January, February and April 1990, February 1992, April 1999 and October 2004. More recently, flood events have also occurred during June 2007 and April 2015.

A summary of the reported information on flooding within the study area is provided in the following sections. Details of the questionnaire survey to obtain information on flooding undertaken as part of this study is provided in Section 3. A key issue with the information provided on the flood history summary below is that it is not extensive and undoubtedly significant parts are missing. Flooding has occurred many times in the past in the study area but generally it is only the recent flood events that are remembered and these are not the largest floods that have occurred. Also, many residents who experienced flooding in past events will have moved and thus will not have been contacted to obtain their flood history. In summary whilst the flood history below is informative, it should be viewed in light of the above comments.

1.3.1. Glenning Valley Catchment Flood History

Examination of previous reports (see Section 2.1) indicates that the 1978 and 1981 storm events caused extensive flooding in the Glenning Valley catchment.

The 1981 Berkeley Vale Valley Regional Flood Study (Reference 1) noted that 230 mm of rain was recorded over a seven hour period on the 29th January 1978. The resulting flood event was the flood of record for the catchment and was reported to have led to widespread property flood depths exceeding 0.5 m. Flood behaviour was described as “rapids of water” running through properties and over floor flood depths of up to 0.4 m were recorded.

In addition to property flood affectation, roads were also significantly flood affected. Most notably, Bundilla Parade was overtopped by an average depth of 0.1 m for a 200 m stretch of road. Additionally, Windsor, Blenheim, St James and Kingsford Smith roads were also flood affected.

The flood event on 6 February 1981 recorded approximately 150 mm of rainfall over a six hour period. Significant flooding was again experienced, however not to the extent of the 1978 event.

Widespread flooding was experienced in June 2007 with the Community Consultation process (Section 3) reporting that at least six properties were flooded above floor level in the main residence. Slightly fewer properties were flooded during the April 2015 event, with three properties flooded above floor level. It must be noted that these numbers are based on questionnaire responses (12% return rate) and could potentially be higher than the numbers presented above.

1.3.2. Tumbi Umbi Creek Catchment Flood History

Table 1 presents the recorded flood levels at Wyong Road and Tumbi Road, collated as a part of the 2014 Tumbi Umbi Creek Floodplain Risk Management Study and Plan (Reference 2).

It is interesting to note that the January 1978 event is again the flood of record followed by the February 1981 flood. Anecdotal information relating to property inundation is not available for the Tumbi Umbi Creek catchment for these events.

Table 1: Recorded Floods – Tumbi Umbi Creek (Reference 2)

Rank	Flood	Peak Flood Level (mAHD)	
		Wyong Road	Tumbi Road
1	January 1978	4.6	9.5
2	February 1981	3.6	9.5
3	April 1990	3.58	N/A
4	February 1990	3.26	9.43
5	May 1988	3.26	9.4
6	January 1990	N/A	9.17
7	April 1999	2.25	N/A
8	October 2004	2.13	N/A
9	June 2007	2.12	N/A
10	February 1992	2.05	9.08
11	April 2015	1.81	N/A

In recent years, flooding was experienced in June 2007 (rank #9 in Table 1) with the Community Consultation process (Section 3) reporting that eight properties were flooded above floor level in the main residence. During the April 2015 event (rank #11 in Table 1), nine properties were reported as flooded above floor level. It must be noted that these numbers are based on questionnaire responses (12% return rate) and could potentially be higher than the numbers presented above.

1.3.3. The Wyong Eastern Coastal Catchments Flood History

The 1981 Berkeley Vale Valley Regional Flood Study (Reference 1) study notes that the February 1981 storm was particularly intense over the Bateau Bay catchment, with 205 mm of rainfall recorded over a six hour period, and 180 mm recorded during a two hour period. Anecdotal information relating to flood behaviour and affectation for historic events in these catchments is not available.

The Community Consultation questionnaire indicates that the flooding in the Wyong Eastern Coastal Catchments is not as significant as the Glenning Valley and Tumbi Umbi catchments with only four properties reporting property flooding and no instances of over floor flooding reported.

2. AVAILABLE DATA

Various items of data salient to the study have been collected and reviewed. Most datasets were sourced from Council, Manly Hydraulic Laboratory (MHL), the Bureau of Meteorology (BoM), and the Office of Environment and Heritage (OEH) and supplemented by additional survey where required. The community consultation process also provided data based on the resident's knowledge of the local area (see Section 3). 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.

2.1. Relevant Studies

2.1.1. Berkeley Vale Valley Regional Flood Study, Interim Report, Willing & Partners 1981 – Reference 1

Willing & Partners completed a Flood Study for the Berkeley Vale Valley catchment in 1981. The study utilised a Regional Stormwater Drainage Model (RSWM) of the catchment which was calibrated to historical flood flow estimates, and then used to determine design flows in the catchment. The 1981 Flood Study design flows are presented in Table 2.

Table 2: 1981 Flood Study Design Flows (m^3/s) – RSWM (Reference 1)

	Event (AEP)			Historical Storms	
Location	5%	2%	1%	1978	1981
Heather Avenue at Wyong Road	26.9	35.2	41.7	49.5	30.2
Bundeena Road at Wyong Road	13.1	17.5	21.1	24.7	14.1
Lakedge Avenue	38.7	49.9	58.7	77.2	47.1

The flows presented in Table 2 indicate that the Reference 1 study determined that the 1978 flood event in the Berkeley Vale Valley was larger than the 100 year ARI event and that the 1981 event was between a 20 and 50 year ARI event. It should be noted that these flows were superseded as part of the 1988 Berkeley Vale Floodplain Management Study (Reference 3).

A peak flood profile for the 100 year ARI was derived from the Manning's formula and the flood extent for these events inferred from available topographic data. The report notes that the most at-risk areas are at the downstream end of the catchment.

2.1.2. Berkeley Vale Floodplain Management Study, Willing & Partners 1988 – Reference 3

The 1988 Berkeley Vale Floodplain Management Study was completed by Willing & Partners on behalf of Wyong Shire Council and supersede results from the 1981 Berkeley Vale Valley Regional Flood Study (Reference 1). Hydrologic modelling was carried out using a rainfall-runoff model (RAFTS) to determine historic event and design flows in the catchment. The model was run for the historical floods of January 1978, February 1981 and November 1984.

Table 3 presents historic and design flows calculated in the 1988 Berkeley Vale Floodplain Management Study (Reference 3) study.

Table 3: 1988 Floodplain Management Study Design Flows (m^3/s) – RAFTS (Reference 3)

Location	1% AEP Event	Historical Storms	
		1978	1981
Heather Avenue at Wyong Road	51.5	47.3	46.4
Bundeena Road at Wyong Road	27.0	22.5	22.2
Lakedge Avenue	49.3	43.5	39.1

The flows presented in Table 3 indicate that the Reference 3 study determined that both the 1978 and 1981 flood events were smaller than the 100 year ARI event.

Hydraulic modelling was undertaken with HEC-2 and the floodplain topography was defined using a series of cross-sections across the channel and floodplain. This model was calibrated against observed levels from the 1978 and 1984 flood events.

The Reference 3 study investigated a number of mitigation options, recommending four retarding basins located at Berkeley Road, Corona Lane, Bundilla Parade and Bundeena Road. The study also suggests limiting urbanisation to prevent exacerbating the flood problem in the Berkeley Vale catchment.

2.1.3. Tumbi Umbi Creek Flood Study Review, Paterson Consultants 1994 – Reference 4

Paterson Consultants completed a Flood Study Review in 1994 for Wyong Shire Council where previous flood studies (from 1983 and 1991) were reviewed and new hydrologic and hydraulic models were established using WBNM and MIKE-11 respectively. Historic flood events occurring in 1978, 1981, 1990 and 1992 were used to calibrate and verify these models using the data presented in Table 4.

Table 4: Reference 4 (Table 6) Flood Ranking

Rank	Event	Flood Level (mAHD)		Rainfall
		Wyong Road	Tumbi Road	
1	January 1978	4.6*	9.5*	280
2	February 1981	3.6*	9.5*	240
3	April 1990	3.58	-	-
4	February 1990	3.26	9.43	180
5	May 1988	3.26#	9.4	-
6	February 1992	2.05	9.08	100
7	January 1984	1.8	9.04	-

* Levels deduced from recorded peak levels.

Public Works Department advise level is debris mark.

The Reference 4 design flows extracted from the hydraulic model are presented in Table 5.

Table 5: 1994 Tumbi Umbi Creek Peak Flow Estimates (m³/s) – MIKE-11 Model (Reference 4)

Location	0.2EY	5% AEP	1% AEP	1978	1981
Tumbi Umbi at Tumbi Road	14.9	28.3	41.3	47.1	50.9
Tumbi Umbi at Wyong Road	38.2	51.1	103.9	99.4	115.7
Killarney Vale at Wyong Road basin	7.0	7.2	7.9	10.0	15.7

The flows presented in Table 5 indicate that the Reference 4 study determined that both the 1978 and 1981 flood events in Tumbi Umbi Creek were larger than the 100 year ARI event for the majority of the catchment.

2.1.4. Hydraulic Investigation of the Wyong Road Detention Basin, Worley Parsons 2010 – Reference 5

Worley Parsons completed a hydraulic/hydrologic assessment in 2010 to determine the possibility of reducing existing flood levels through a section of the Corona stormwater channel by amending an existing detention basin, located at the intersection of Wyong Road and Bundeena Road, Berkley Vale. The study used RAFTS and HEC-RAS models produced as part of the Wombat Street Stream Rehabilitation study (Worley Parsons 2009, Reference 6) to assess whether raising the Wyong Road spillway and/or constricting the outlet structure would reduce flooding to properties adjacent to the channel. It was concluded that there were no solutions whereby current discharges along the channel could be significantly reduced.

Survey data from this study was used when collating hydraulic structure data (see Section 2.2.3).

2.1.5. Wyong Road Detention Basin, Dam Safety Emergency Plan, Hunter Water Australia 2011 – Reference 7

In 2011 Hunter Water Australia conducted a Dam Safety Emergency Plan for the Wyong Road Detention Basin. The basin is located off Wyong Road in Killarney Vale, opposite the Killarney Court Aged Care Facility and adjacent to Killarney Vale Public School. The study estimates that in the event of a dam failure at the spillway, up to 23 properties could be inundated immediately downstream of the basin with the aged care facility most at risk. The report outlines the emergency procedures to be adopted for flooding or seismic events.

Survey data from this study was used when collating hydraulic structure data (see Section 2.2.3).

2.1.6. Tuggerah Lakes Floodplain Risk Management Study & Plan, WMAwater 2014 – Reference 8

The Tuggerah Lakes Floodplain Risk Management Study and Plan was prepared by WMAwater in 2014 for Wyong Shire Council. The study was prepared to examine a range of measures that could potentially be implemented to reduce the impact of flooding across the floodplains of the Tuggerah Lakes system. The study focused on flooding due to elevated lake levels and did not consider flooding in tributaries such as those examined in the current study.

The Reference 8 study does provide useful information relating to design flood levels in Tuggerah Lake which have been used as a basis to determine design flood levels at the downstream model boundary (see Section 4.3.8). Design Tuggerah Lake levels as presented in the Reference 8 study are presented in Table 6.

Table 6: Tuggerah Lakes Design Levels (Reference 8)

Event	Flood Level (mAHD)
0.5 EY (50% AEP)	0.91
0.2EY (20% AEP)	1.36
5% AEP	1.80
1% AEP	2.23
PMF	2.70

2.1.7. Tumbi Umbi Creek Floodplain Risk Management Review & Plan, Paterson Consultants 2014 – Reference 2

Paterson Consultants conducted the Tumbi Umbi Creek Floodplain Risk Management Review and Plan for Wyong Shire Council in 2014. The study updated the hydrologic (WBNM) and hydraulic (MIKE-11) models established as a part of the Tumbi Umbi Creek Flood Study (1994). Table 7 presents the peak flood levels adopted in the study at various locations in the catchment.

Table 7: Design Flood Levels Adopted in Reference 2

Tributary	Killarney Vale			Tumbi Umbi				
Location	D/S Playford Road Basin	U/S Killarney Vale Basin	D/S Wyong Road	Creek Entrance	D/S Wyong Road	U/S Wyong Road	U/S Tumbi Road	D/S Pat Morley Oval
	Flood Level (mAHD)							
0.2EY	8.20	2.65	1.82	1.29	1.98	3.14	9.52	18.76
5% AEP	8.41	3.00	1.90	1.40	2.28	3.61	9.70	18.84
1% AEP	8.50	3.44	2.04	1.56	2.72	4.40	9.85	18.95
0.01% AEP	9.10	4.56	3.18	2.32	5.05	6.02	10.38	19.40

The Floodplain Risk Management Plan recommended the following measures in response to flooding from Tumbi Umbi Creek:

- Increased public information and education by including flood risk notation on Section 149 Certificate and updating flood mapping;
- Inspecting and maintaining existing waterways particularly the Killarney Vale tributary;
- Developing Flood Knowledge through reviewing flood hazard downstream of the Playford Road detention basin and conducting a Flood Study.

2.2. Model Build and Calibration 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 and culverts need to be realistically represented to reproduce accurate hydraulic properties. This information has been obtained from a variety of sources including Council, OEH and survey where information was not available.

Additional information used to ensure the models' accuracy through calibration/validation was also obtained from a variety of sources including Council, OEH, MHL and BoM. Information such as historic rainfall (see Section 2.3), stream gauge (see Section 2.5) and community observations of flooding (see Section 3.2) data have been used to calibrate/validate the hydrologic/hydraulic model system through a joint calibration process (see Section 4.1).

The topographical and survey data used to construct and calibrate both the hydrologic and hydraulic models is outlined in Sections 2.2.1 to 2.2.3.

2.2.1. ALS Data

Airborne Laser Scanning (ALS) data of the study area was provided by Land and Property Information (LPI) (via Council) and was used to define ground surface elevation. ALS provides ground level spot heights from which a Digital Elevation Model (DEM) has been constructed. The DEM data was composed of the following two data sets:

- The Wyong DEM, flown in 2014, encompasses the Glenning Valley catchment and the northern areas of the Wyong Eastern Coastal Catchments; and
- The Hawkesbury North DEM which was flown in 2011. This area covers the Tumbi Umbi Creek catchment and the southern areas of the Wyong Eastern Coastal Catchments.

For the purpose of this study these data sets were merged to form a one metre DEM grid and this data, in combination with channel cross section survey (see Section 2.2.2), formed the foundation of the 2D hydraulic model build process (see Section 4.3.2). The DEM for the study area is presented in Figure 2.

Analysis of the two data sets found a significant discontinuity at the interface of the two DEMs. The accuracy of the data sets was investigated by comparing them to ground survey provided by Council. Survey data distributed throughout the study area were used for this comparison. It was found that the difference between available ground survey and the Wyong DEM was on average 0.0 m indicating that this data set is accurate. However, the average difference between ground survey and the Hawkesbury North DEM was -0.25 m, indicating that there is potentially an issue with the datum of this data set. Accordingly, the Hawkesbury North DEM was raised by 0.25 m to remove this anomaly and improve the discontinuity at the interface of the two DEMs.

2.2.2. River Bathymetry 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. This is an issue in creeks such as Tumbi Umbi Creek where the depth of water is significant at the time of survey. To determine the in-bank conveyance below the water level, bathymetry survey was carried out. Bathymetry survey was undertaken by a registered surveying firm (Barry Hunt Associates) which included the survey of approximately 15 cross sections on Tumbi Umbi Creek (displayed in Figure 2).

The cross sections were used to generate a DEM of the Tumbi Umbi Creek bathymetry (within the creek banks). The bathymetry was then combined with the ALS data (see Section 2.2.1) to create a DEM of the combined in-bank and floodplain. This combined DEM was used for modelling purposes.

2.2.3. Hydraulic Structure Data

Structures such as local drainage networks, bridges, weirs and road/rail crossings can impact on flood behaviour. In the study area various structures were identified as having the potential to impact significantly on flood behaviour. These structures are described below and have been incorporated into the hydraulic model as described in Section 4.3.6. The locations of these structures are presented in Figure 1 and are numbered to match the numbering system below.

Design plans for the structures listed below were obtained from previous studies:

1. Details of the Berkeley Vale Detention Basin on the corner of Wyong Road and Bundeena Road (Reference 6), including crest level, culvert details and downstream channel dimensions; and
2. Details of the Killarney Vale Detention Basin on Wyong Road at Cornish Avenue (Reference 7).

Additionally, Council provided WMAwater with pit and pipe data which was implemented in the hydraulic model to incorporate Council's local drainage network. The pit and pipe database was incomplete in parts and gaps were infilled as follows:

- missing pipe sizes were assumed as the size of the upstream pipe;
- pit invert levels were assumed as the diameter / width of the culvert plus an assumed cover (typically 0.5m);
- the level of the pit grate (mAHD) was obtained from a review of the surrounding ALS ground survey points;
- an inspection of each street was not undertaken to locate missing pits in the database.

Where design plans were not available a hydraulic structure survey was conducted. These structures are listed below with their locations (numbered accordingly) displayed in Figure 1:

1. Lakedge Avenue culvert next to Wombat Street – Berkeley Vale
2. Lakedge Avenue culvert next to Kingsford Smith Drive – Berkeley Vale
3. Kingsford Smith Drive culvert next to Windsor Road – Berkeley Vale
4. Lorraine Avenue culvert next to Grevillea Crescent – Berkeley Vale
5. Bundilla Parade Bridge next to Lorraine Avenue – Berkeley Vale
6. Berkeley Road culvert – Berkeley Vale
7. Heather Avenue culvert next to Berkeley Road – Berkeley Vale

8. Wyong Road culvert next to Greenwood Avenue – Berkeley Vale
9. Lakedge Avenue culvert next to Loxley Close – Tumbi Umbi
10. Adelaide Street culvert next to Warratta Road – Tumbi Umbi
11. Wyong Road bridge next to Cornish Avenue – Tumbi Umbi
12. Tumbi Road bridge – Tumbi Umbi
13. Playford Road culvert next to Mawson Drive – Tumbi Umbi
14. Cresthaven Avenue culvert next to Ireland Drive – Tumbi Umbi
15. Cresthaven Avenue culvert next to Dunning Avenue – Tumbi Umbi
16. The Entrance Road culvert – Tumbi Umbi
17. Adelaide Street culvert next to Hinemoa Avenue – Tumbi Umbi
18. Hansen Road culvert next to Mingara Drive – Tumbi Umbi
19. Bundeena Road next to Wyong Road – Berkeley Vale

Survey for each structure was undertaken by Barry Hunt Associates so that the conveyance capacity and other details of these structures could be accurately modelled.

The following features were requested as part of the survey Brief for each bridge structure:

- Creek cross section survey at upstream face;
- Creek cross section survey at downstream side offset a few meters from the 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 culvert type structures, the following details were 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).

Whilst it is impossible to accurately account for each and every hydraulic feature of waterway crossings in a numerical model, those that could be reasonably represented, such as the levels of railings or fences across the structures, were implicitly included in the hydraulic model. Where they could not be included there were assumed to be accounted for by hydraulic losses linked to the structure.

All identified detention / retarding basins were included in the model (refer Table 8). The data for these structures was obtained from detailed survey information (as noted above), prior reports, ALS survey and site inspection / outlet measurement.

Table 8: Detention / Retarding Basins included in TUFLOW

Catchment	Letter on Figure 1	Location	Downstream Structure	Outlet Pipe	Outlet Overflow
Glenning Valley	A	The basin is heavy vegetated and not readily accessible. It is 600 m long and 200m wide with an upstream rural catchment.	Wyong Road	Twin RCBC 3m by 2m invert 4.2 mAHD	6.9 mAHD
Tumbi Umbi	B	The basin is a sports field with a small capacity and small upstream urban catchment.	Weir type structure	Twin RCP 0.9 m Dia RCP with invert at 2 mAHD	3.5 mAHD
Tumbi Umbi	C	Pond made in the 2000's. Full most of the time.	Weir type structure	No pipe	5.9 mAHD
Tumbi Umbi	D	Pond with 2 weirs drains a small urban upstream catchment.	Hansens Road	0.45 m Dia RCP drains the pond before the weir is overtopped invert at 4.5 mAHD. Triple 0.9 m Dia RCP under the road invert at 3.6 mAHD	6 mAHD
Tumbi Umbi	E	Heavy vegetated basin upstream of Wyong Road.	Weir type structure	Twin 1.05 m Dia RCP with invert at 1.3 mAHD	4.6 mAHD
Tumbi Umbi	F	Sports field surrounded by elevated bank, drains small upstream catchment.	Weir type structure	0.675 m Dia RCP invert at 9.5 mAHD	12.5 mAHD
Tumbi Umbi	G	Small vegetated basin. Small upstream catchment.	Weir type structure	Twin 0.45 m Dia RCP with invert at 10.8 mAHD	12.5 mAHD

2.3. Historic Rainfall Data

The rainfall data described in the following sections pertains to information that was used in calibration/validation process. Calibration/validation events were selected based on available pluviometer rainfall data (Section 2.3.1), daily read rainfall data (Section 2.3.2), water level recorded data (Section 2.5) and community observations of flooding (Section 3.2). Selected events had all data requirements from these data sets. A joint calibration process (see Section 4.1) was undertaken using the April 2015 storm event followed by model validation using the June 2007 event. Model calibration/validation results are presented in Section 5.2.

Due to a lack of suitable rainfall data from any one source, a combination of pluviometer rainfall data (Section 2.3.1) and daily read rainfall data (Section 2.3.2) has been used to create rainfall inputs for the study area. Section 2.3.3 outlines the process of merging these data sets for use in the hydrologic model.

2.3.1. Pluviometer Rainfall Data

Pluviometer rainfall data (high temporal resolution rainfall data) is advantageous as it contains information on both a storm's temporal pattern and total rainfall depth. Two pluviometer rainfall gauges were identified within the catchment and have been used in the current study. A summary of the pluviometer rainfall gauge details is presented below in Table 9.

Table 9: Available Pluviometers Proximate to the Study Area

Name	Number	Distance to Catchment Centroid Glenning Valley / Tumbi Umbi / Eastern Coastal	Available Record Period		Owner of Pluviometer
			Start	End	
Bateau Bay	561069	5 km / 2 km / 1 km	17/06/1987	Ongoing	MHL
Berkeley Vale	561134	1 km / 4 km / 7 km	24/11/1988	Ongoing	MHL

Only the Glenning Valley catchment contains a pluviometer rainfall gauge, with the Tumbi Umbi and Eastern Coastal catchments relying on extrapolated temporal patterns provided by the above listed gauges.

2.3.2. Daily Read Rainfall Data

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

Regional daily read gauges were investigated to determine catchment rainfall depths for the two calibration/validation events. Table 10 presents the daily read rainfall gauges used, catchment location and distance to the catchment centroid. Table 11 displays the rainfall depths obtained at each of these gauges for the 2015 and 2007 storm events. The locations of the daily read gauges are displayed in Figure 3.

Rainfall depths for the region were created by interpolating (Nearest Neighbour) between neighbouring gauges. The estimated rainfall distribution for the 2015 and 2007 storm events are presented in Figure 3 and Figure 4. Utilising these rainfall distribution grids, unique rainfall depths for each sub-catchment within the study area were able to be calculated for the hydrologic model calibration/validation events. This allowed for modelling of the spatial variation in rainfall across the catchment.

Table 10: Daily Rainfall Gauges Used in this Study

ID	Name	Distance (km)*	Closest Catchment
61294	Avoca Beach	11	Tumbi Umbi
61383	Gears (Wyong River)	17	Glenning Valley
61387	Gorokan	13	Glenning Valley
61425	Gosford AWS	9	Tumbi Umbi
61319	Gosford North	8	Tumbi Umbi
61380	Jilliby Creek	10	Glenning Valley
61380	Mangrove Mountain	23	Glenning Valley
61381	Mount Elliot	4	Tumbi Umbi
61366	Norah Head	12	Eastern Coastal
61093	Ourimbah	11	Glenning Valley
61384	Ourimbah Creek	8	Glenning Valley
61351	Peats Ridge	17	Glenning Valley
61074	The Entrance	3	Eastern Coastal
61369	Wamberal	6	Eastern Coastal
61386	Wyong River	20	Glenning Valley
61220	Yarramalong	20	Glenning Valley

* Distance has been determined as the shortest distance from the study area centroid to each gauge.

It should be noted that none of the three catchment areas the study area is composed of contain daily read rainfall gauges. The gauges presented in Table 10 are only used to interpolate an estimate of the rainfall depths experienced within the catchment. Accordingly, the rainfall spatial pattern within the study area used in model calibration/validation is a best estimate only and not based on real recorded at site rainfall data.

Table 11: Recorded Daily Rainfall

ID	Name	Event Rainfall (mm)						
		April 2015			June 2007			
		20th	21st	22nd	6th	7th	8th	9th
061294	Avoca Beach	35	100	115	18	86.4	50	97
061383	Gears (Wyong River)	11	94	100	0	21	84	246
061387	Gorokan	15.2	66.4	81.6	0	15.2	57.6	215.4
061425	Gosford AWS	22.2	120.8	113.6	-	-	-	-
061319	Gosford North	18	140	140	0	72.2	95.6	153
061380	Jilliby Creek	15	75	87	0	25	89	238
061381	Mount Elliot	20	108	131	-	-	-	-
061366	Norah Head	23.6	61.4	76.2	0	29.2	56.8	235.4
061093	Ourimbah	-	-	-	0	24.4	135	263
061384	Ourimbah Creek	16	112	152	0	37	74	218
061351	Peats Ridge	23.6	146.2	63.8	0	48.8	89.6	276.6
061074	The Entrance	-	-	-	6	18	72	106
061369	Wamberal	-	-	-	26	26	37	218
061386	Wyong River	-	-	-	-	-	-	-
061220	Yarramalong	13.4	104	100	0	20	74	119
561069	Bateau Bay*	62	84.5	93	0	15	59.5	115.5
561134	Berkeley Vale*	18.5	80.5	103.5	0	24.5	79.5	174

* These values have been calculated as the cumulative 24 hour rainfall totals from 9 am for the pluviometer rainfall gauges described in Section 2.3.1.

2.3.3. Rainfall Data Merge

Rainfall data mentioned in Sections 2.3.1 and 2.3.2 was used to create rainfall data sets with 5 minute temporal resolution for input into the hydrologic model. The catchment weighted average rainfall depth was determined from the spatial rainfall patterns mentioned in Sections 2.3.2 and this depth was applied to the temporal patterns obtained from the pluviometer rainfall gauges described in Sections 2.3.1. Figure 5 presents rainfall hyetographs for the April 2015 and June 2007 historic events using the average rainfall depth and average temporal patterns across the study area. The Figure 5 hyetographs are for display purposes only and in the hydrologic model, each sub-catchment has been assigned its own unique rainfall depth and associated hyetograph depending on the rainfall depth at that sub-catchment. This allows for the spatial variation of rainfall across the catchment.

2.4. 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.

2.4.1. Design Rainfall Data

ARR87 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 ARR87 (Reference 9).

Table 12 presents the ARR87 Intensity Frequency Duration (IFD) relationship at the study area centroid. It should be noted that the IFD relationship varies spatially throughout the study area and that the rainfall intensities presented in Table 12 are for the centroid of the study area. Spatial variation in design rainfall has been accounted for in the current study.

Table 12: ARR1987 Design Rainfall – Study Area Centroid

	Average Recurrence Interval						
Duration	1 YEAR	2 YEARS	5 YEARS	10 YEARS	20 YEARS	50 YEARS	100 YEARS
5Mins	102	130	163	181	206	237	261
6Mins	95.9	122	153	170	193	223	246
10Mins	78.5	100	126	141	160	186	205
20Mins	57.6	73.8	93.9	105	121	141	156
30Mins	46.9	60.3	77.2	86.9	99.9	117	129
1Hr	31.8	40.9	52.9	59.9	69.0	81.0	90.1
2Hrs	20.6	26.6	34.6	39.2	45.3	53.4	59.5
3Hrs	15.8	20.4	26.6	30.2	34.9	41.1	45.8
6Hrs	10.0	12.9	16.8	19.1	22.2	26.1	29.2
12Hrs	6.38	8.27	10.8	12.3	14.3	16.9	18.9
24Hrs	4.16	5.41	7.14	8.18	9.53	11.3	12.7
48Hrs	2.69	3.51	4.69	5.42	6.34	7.56	8.51
72Hrs	2.01	2.63	3.53	4.10	4.80	5.75	6.49

(Raw data: 41.25, 8.24, 2.63, 81.99, 16.83, 5.76, skew=0.00, F2=4.3, F50=15.91)

2.4.2. Probable Maximum Precipitation

Catchments within the study area 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 10). Individual PMP rainfall depths were calculated for each of the three catchments within the study area. The PMP rainfall was applied uniformly across each catchment rather than using the GSDM ellipsoids which would lead to an underestimate of PMF flows in the upper regions of the catchments. Figure 6 presents the PMP rainfall depths allocated to each catchment in the study area for the critical duration of 1 hour (see Section 5.3).

2.5. Water Level Gauge Data

Table 13 details the relevant water level gauges for the study area with the locations of these gauges presented in Figure 1. These gauges only record water level and do not provide flow estimates based on velocity gaugings. Recorded water levels for these gauges were obtained from MHL.

The Long Jetty gauge records water levels in Tuggerah Lakes which are useful for defining the downstream boundary of the hydraulic model for the model calibration/validation. The Tumbi Umbi gauge provides stage hydrographs for Tumbi Umbi Creek downstream of Wyong Road.

Further details on the gauges used in model calibration/validation are presented in Table 13.

Table 13: Water Level Recorder Gauges

Site Number	Name	Available Record Period			Gauge Owner
		Start	End	Years	
211418	Long Jetty	12/09/1991	Ongoing	26	MHL
211419	Tumbi Umbi	05/04/1994	Ongoing	23	MHL

2.5.1. Annual Series Data

Of interest to the current study are the recorded annual maximum water levels at the Tumbi Umbi gauge. The annual maximum series is presented in Table 14.

Table 14: Tumbi Umbi Gauge Annual Maximum Level (mAHD)

Year	Level	Year	Level	Year	Level	Year	Level
1994	0.53	**2000**	0.80	**2006**	0.62	**2012**	1.77
1995	0.63	**2001**	1.59	**2007**	2.12	**2013**	1.17
1996	1.16	**2002**	1.28	**2008**	1.67	**2014**	0.71
1997	0.92	**2003**	1.13	**2009**	0.51	**2015**	1.81
1998	1.17	**2004**	2.13	**2010**	0.80		
1999	2.26	**2005**	1.09	**2011**	1.67		

Table 14 indicates that the 1999 event is the largest to have occurred since the gauge was installed in 1994. However, Reference 4 identified peak flood levels for a number of major flood events preceding the official gauge record. These peak flood levels are presented in Table 5. It must be noted however, that the Reference 4 peak flood levels may not have been determined at the precise location to the Tumbi Umbi gauge and may therefore not be comparable.

The historic flood record is useful for comparing to the design results to add confidence in the current study. This was undertaken once the design flood events had been modelled at a later stage of the project.

3. COMMUNITY CONSULTATION

Community consultation is an important element of this study ultimately facilitating community engagement and acceptance of the overall project. Consultation work 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 April 2016. 4,050 surveys were distributed to residents within the study area and a total of 500 responses were received (see Figure 7). This equates to a return rate of 12% which is similar to questionnaire return rates of other flood studies in the area. A summary of the questionnaire results is presented in Figure 8a–c.

The large majority (97%) of respondents were from residential dwellings with 1% reported as business and another 2% of respondents noted as ‘other’ which was generally undeveloped land or farmland (see Figure 8a).

The majority (32%) of respondents have lived in the region for more than ten years and would have therefore experienced both the 2015 and 2007 storm events, however a significant portion (20%) have lived in the region for less than five years indicating that their experience of flooding in the region may be limited (see Figure 8b).

38% of respondents were ‘very aware’ of flooding in the area, with 21% of respondents having ‘some awareness’ (see Figure 8b). 41% of respondents were ‘not aware’ of flooding in the study area.

29 (6%) respondents noted that they had been flooded above floor level in the past and 193 (39%) respondents reported to have experienced flooding in their yard (see Figure 8c). It must be noted that upon further analysis of the returned questionnaires, many of the respondents that indicated they had experienced yard flooding would not be classified as ‘true’ flooding in the context of the current study. Many of the reported instances of ‘flooding’ related to minor drainage issues, problems with individual property downpipes and guttering, elevated groundwater levels and localised ponding due to ineffective local drainage. These issues are not considered in the current study and are typically the responsibility of the land owner to address.

126 (29%) respondents reported that they had information relating to observed flood behaviour, and in particular flood depths and levels that are useful for model calibration (see Figure 8c). This information has been refined and further details are presented in Section 3.2.

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

3.2. Community Observations of Flood Behaviour

Community observations of flood behaviour are vital for the success of any flood study. Flood observations can be used to ensure the accuracy of the computer models used to determine design flood behaviour. By ensuring that the computer models can accurately reproduce historic flood behaviour through the calibration/validation process, confidence can be had in the design flood results. The model calibration/validation using the obtained community consultation information is described in Section 5.2.

Of the 500 returned community consultation questionnaires, 126 respondents reported that they had information relating to observed flood behaviour and 193 people claimed to have experienced flooding at their property. The questionnaires that reported observations of flooding have been examined in detail to better understand flood behaviour in the study area. When required, questionnaire respondents have been contacted directly to clarify or provide additional information relating to observed flood behaviour.

A review process was undertaken for questionnaires that reported flooding, with a number of observations determined to not be suitable for the calibration/validation process. Community observations of flooding that were deemed unsuitable for model calibration/validation have been excluded from the calibration process. A summary of the reasons why these marks were removed is contained below:

- Reported flooding is not within the study area;
- Reported flooding is due to flood event other than April 2015 or June 2007 events;
- Reported flooding was due to minor drainage issues, problems with individual property downpipes and guttering, flooding due to water leakage through the roof, rising damp or localised ponding due to ineffective local drainage;
- Reported flooding is due to elevated groundwater levels not allowing effective drainage;
- Described flooding is within a defined flow path, channel or creek watercourse; or
- Described flooding is minor in nature and relates to shallow ponding on the road or in the kerb/gutter.

In total approximately 100 observations of flooding, which could be used for comparison to model results, were available for the 2015 event and 80 observations were available for the 2007 event. The majority of these were situated in the Glenning Valley and Tumbi Umbi catchments and were due to elevated water levels in Tuggerah Lakes.

4. MODELLING METHODOLOGY

4.1. Modelling Approach

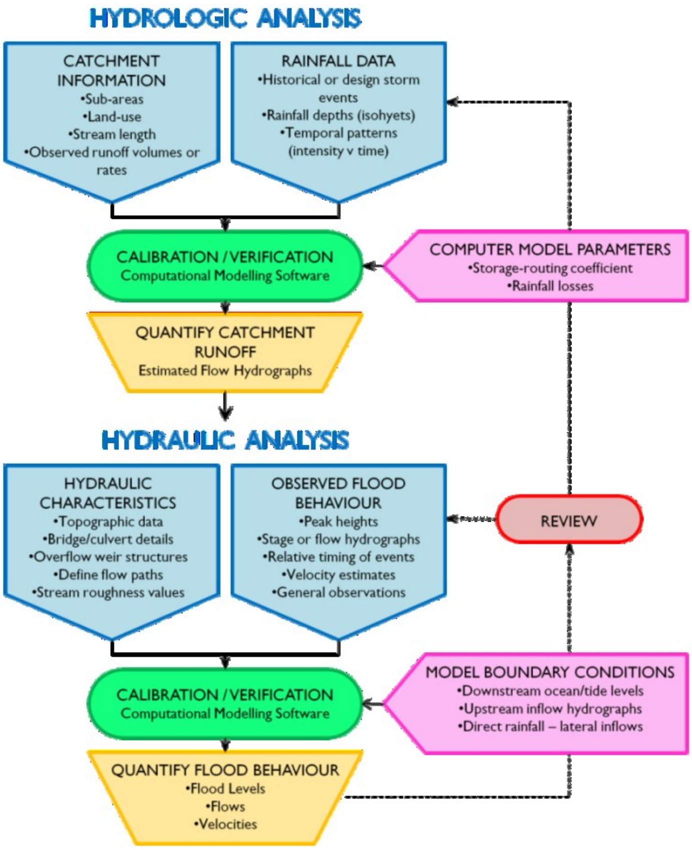
In order to accurately model flood behaviour in the study area, the development of hydrologic and hydraulic models was required. The overall modelling approach was to establish a hydrologic model in conjunction with a 1D/2D hydraulic model. The hydrologic model is used to generate flow hydrographs for 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. Both models are discussed in greater detail in Section 4.2 and Section 4.3.

Generally, the adopted approach used to determine design flood levels largely depends upon the objectives of the study and the quantity and quality of the data (survey, flood, rainfall, flow etc.). Given the absence of rated stream gauges (see Section 2.5) a joint calibration approach was utilised for the current study in which the suitability of the hydrologic flow estimates are determined via the water levels they subsequently achieve in the hydraulic model.

Therefore model calibration results are purely based on the performance of the hydraulic model and calibration results should be interpreted from these findings. The hydraulic model calibration has been undertaken using observations of flood behaviour identified by the community consultation process (see Section 3.2) and stage hydrographs recorded by the Tumbi Umbi gauge (see Section 2.5). A representation of the flood study process is presented in Diagram 1.

Diagram 1: Flood Study Process



4.2. Hydrology

4.2.1. Background

The key purpose of this study is to define design flood behaviour for the Study Area described in Section 1.2 (see Figure 1). To achieve this goal the development of flows (described in the ensuing sections) for input into a 1D/2D hydraulic model (see Section 4.3) was required.

There are two basic approaches to undertaking design flood analysis:

- The rainfall runoff routing approach (hydrologic modelling); and
- The flood frequency approach (also called FFA).

Both approaches have advantages and disadvantages however for the current study the balance was very much in favour of using the rainfall/runoff routing approach for the study area. For a FFA approach, a nearby stream gauge must have an adequate length and quality of observed record and an accurate rating curve to determine event flows (see Section 2.5.1). As described in Section 2.5, flow gaugings have not been undertaken on Tumbi Umbi Creek and accordingly, flow estimates for historic events are not available.

Instead of FFA, a hydrologic model (see Section 4.2.2) has been used to determine flows for input into the hydraulic model. Again, due to the absence of a rated stream gauge, a joint calibration approach was utilised in which the accuracy of the hydrologic model flow estimates are assessed via the water levels they subsequently achieve in the hydraulic model. The models were calibrated to the April 2015 storm event and validated to the June 2007 event. The calibration/validation results are presented in Section 5.2.

These analyses constitute the hydrological analysis component of the study and aim to describe the probability of a given discharge occurring in the Study Area. Calculated design flows (as time varying hydrographs) are then input into the hydraulic model (see Section 4.3) so that design flood levels, extents and hazard can be determined.

4.2.2. Hydrologic Model

Hydrologic modelling of the study area was undertaken using WBNM which consisted of over 1,000 subcatchments. WBNM is a widely used hydrologic model which has been substantially tested on Australian catchments.

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 rainfall data for historic events and design rainfalls are described in Sections 2.3 and 2.4 respectively and model losses are described in Section 4.2.6. The non-linearity parameter 'm' has been set as default (0.77) which is in agreement with ARR guidelines (Reference 9). The selected routing parameter 'C' (see Section 4.2.3) has been confirmed by the joint calibration process. All selected parameters have been validated using the 2007 event.

4.2.3. 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 11) and as such a smaller 'C' value will typically produce shorter lag times and less attenuation.

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. However as previously mentioned, no gaugings have been performed within the catchment and accordingly there is no rated stream gauge available. For ungauged catchments Reference 11 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 minimum C value of 0.7 and maximum of 2.8 (standard deviation of 0.5).

The recommended WBNM 'C' parameter for ungauged catchments of 1.6 was determined to be suitable for modelling of the study area's rainfall/runoff characteristics. The selected 'C' parameter has been confirmed via joint calibration with the hydraulic model (see Section 4.3.9).

4.2.4. Hydrologic Catchment Delineation

Hydrologic model delineation was determined by interpretation of aerial imagery and DEM data (see Section 2.2).

The hydrologic model layout for the study area is presented in Figure 2 and a summary of the hydrologic catchment properties is displayed in Table 15.

Table 15: Study Area Hydrology - Catchment Properties

Catchment	Number of Catchments	Total Area (ha)	Average Area (ha)	Minimum Area (ha)	Maximum Area (ha)
Glenning Valley	210	740	3.2	0.2	23.6
Tumbi Umbi	655	1,620	2.5	0.1	29.9
Eastern Coastal	160	250	1.6	0.2	16.0
TOTAL	1,025	2,610	2.4	0.2	23.2

4.2.5. Percentage Imperviousness

The model's sub-catchment percentage imperviousness was based on aerial inspection of a sample region within the study area (see Image 1 and Figure 1b). The average percentage imperviousness of residential regions was calculated to be 55%. Significant variability does occur between individual sub-catchments and this has been incorporated in the hydrologic modelling by visual inspection estimates. For example, residential areas were assigned a higher percentage imperviousness and natural/non-developed regions percent imperviousness was assigned as zero.

Image 1: Percentage Impervious Sample Region

4.2.6. Hydrologic Model Losses

During the joint calibration process, initial and continuing losses for pervious regions were varied to obtain a good fit to observed flood data. It was found that by applying the losses presented in Table 16 a reasonable calibration/validation could be achieved for both the 2015 and 2007 events.

Table 16: Calibration/Validation Losses

Event	Initial Loss (mm)	Continuous Loss (mm/h)
April 2015	20	4
June 2007	20	4

The Australia Rainfall and Runoff 2016 revision (ARR2016 - Reference 12) indicates that the expected continuing loss rate for the pervious regions of the study area is 4 mm/h. Additionally, a continuing loss rate of 4 mm/h is consistent with losses identified for the neighbouring Ourimbah Creek catchment as determined in the Ourimbah Creek Catchment Flood Study (Reference 13). This confirms the continuing losses presented in Table 16 which have been adopted in the calibration/validation process. As such, a continuing loss rate of 4 mm/h has also been used for the pervious regions of the study areas for design flood modelling.

ARR2016 recommends an initial loss of 20 mm, which is again consistent with initial losses used in the model calibration process. Accordingly, an initial loss of 20 mm has been used for the pervious regions of the study areas for design flood modelling.

For the impervious regions a 0 mm/h continuing loss has been applied and an initial loss of 1.5 mm has been assigned to account for ponding on impervious surfaces.

PMP rainfall losses are shown in Table 17.

Table 17: Adopted PMP Losses

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

4.2.7. Input Rainfall

For the calibration/validation process, the historic event rainfall data described in Section 2.3 were input into the hydrologic model. The design event modelling was undertaken with ARR87 (Reference 9) design rainfall and ARR87 temporal patterns (see Section 2.4) for the 0.2EY, 5% AEP and 1% AEP events. The PMP rainfall discussed in Section 2.4.2 has been used to derive the PMF flows.

A critical duration assessment was undertaken in the hydraulic model (see Section 4.3.10).

4.3. Hydraulic Modelling

4.3.1. Introduction

The hydraulic model uses flow inputs (discharge hydrographs generated by a hydrologic model) to calculate flood levels, depths and velocities. The hydrodynamic modelling program TUFLOW

(Reference 14) 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 potential 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.

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 combined with channel cross section survey described in Section 2.2.2) 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. Numerous spatial layers are applied to the model with the aim of closely replicating the catchment's hydraulic conditions. However it should always be noted that it is a model and thus represents an approximation of the complex topographic and hydraulic characteristics that exist.

Building footprints were identified from aerial photography and were assumed as physical barriers to flow which do not contain any temporary floodplain storage. This is a conservative assumption as it is possible that some flow will pass beneath timber houses on piers or possibly flow through houses with inundated floor levels. Site inspections indicated that the amount of flow that could pass through/beneath buildings in typical suburbs would be small and it is reasonable to assume there is no flow.

Fences on property boundaries can also be a significant impediment to overland flow. The amount of impediment would depend on the type of fence (paling, colorbond, concrete, brushwood), the likelihood of its failure and the quantity of flow that would be affected. However there are issues in identifying the type of fencing, quantifying the type of failure and establishing the amount of "leakage" through a fence as this requires entry into each property and a detailed inspection. Fences are also frequently replaced and do not necessarily require Council approval. Thus a front fence might be removed or replaced with a completely different type. In addition there are modelling issues with including individual fences in a 2m by 2m grid model. For these and other reasons this makes it impractical for a catchment wide study to individually include each fence surrounding a property. There is no definitive guidance on this issue but it is assumed that the assumed Manning's "n" value plus blocking out the building footprint provides a reasonable estimate of the flow characteristics across a property.

There are several retarding basins within the three catchments and they have all been included in the hydraulic model (refer Table 8).

4.3.3. Model Domain and Grid Size

The study area has been divided into three hydraulic models for each of the catchments described in Section 1.2. The total model extent covers an area of 26 km² and the hydraulic model layout for each of the three models are displayed in Figure 9 a - c. Ground elevations in the model were informed by the DEM described in Section 2.2.1 and displayed in Figure 2. Modelling was undertaken using a 2 m by 2m grid as defined in the Brief and provides a compromise between the level of detail required, the model run time and the availability of data (the ALS data is at approximately 1m spacings).

4.3.4. Breaklines

Flow paths, channels, embankments and roads are hydraulic features that can have a significant impact on flood behaviour. Such features have been represented in the model by breaklines with crest and invert heights determined by analysis of the ALS data (see Section 2.2.1). The locations of these various hydraulic features are displayed in Figure 9 a - c.

4.3.5. Roughness Values

As mentioned, 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 18 below.

Table 18: Mannings 'n' values

Land Use	Manning's 'n'
Urban Land	0.045
Low Density Vegetation	0.06
Medium Density Vegetation	0.08
High Density Vegetation	0.10
Creek Channels	0.045
Concrete Channels	0.015
Roads	0.02

Sensitivity testing of the applied roughness values has been carried out (Section 5.5.1).

It should be noted that these roughness values are within the range of those recommended by Chow (1959) and Henderson (1966) as well as the revised ARR guidelines (Project 15: Two Dimensional Modelling in Urban and Rural Floodplains). They are also comparable to the roughness values used in the Ourimbah Creek Catchment Flood Study (Reference 13).

4.3.6. Hydraulic Structures

Numerous hydraulic structures such as bridges and culverts have been identified in the study area. Structure information was sourced from Council as well as survey commissioned as part of this study or measured by WMAwater engineers during a site visit (see Section 2.2.3). Details of these structures were input into the model as 1D and 2D elements with the locations of these structures displayed in Figure 9 a - c. Further information on these hydraulic structures is provided in Section 2.2.3.

4.3.7. Structure 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 study area could range from vegetation such as logs and fallen trees, to urban debris such as wheelie bins or shopping trolleys.

No specific information related to blockage of hydraulic structures in past flood events is available and accordingly, the hydraulic model calibration/validation blockage has been assumed to be zero. However, anecdotal evidence indicates that significant blockage of structures does occur, particularly in the lower reaches of the study area. It should be noted that in general blockage raises flood levels upstream, thus a model calibration that assumes no blockage and matches the recorded levels is a "conservative" approach as the inclusion of blockage would require other model inputs and/or parameters to be altered to produce lower flood levels.

For design flood analysis an assessment of blockage is required and the process is outlined below. There is no definitive outcome from an assessment of blockage and for this reason the approach adopted was agreed upon with Council before proceeding.

Identification of Key Structures

The sensitivity of hydraulic structures to blockage throughout the model domain was examined by comparing peak flood levels between blocked and unblocked scenarios for the 1% AEP event. Three blockage scenarios have been examined:

- 1% AEP event with all structures defined as 0% blocked;
- 1% AEP event with all structures defined as 50% blocked; and
- 1% AEP event with all structures defined as 100% blocked.

The differences in peak flood level between the 0% blocked run and the 50% and 100% blocked runs were analysed to determine the key structures that are sensitive to blockage. Structures were classified as “Key Structures” if the following criteria are met:

1. The impact on peak flood level either upstream or downstream of the structure was increased or decreased by more than 0.1 m in the 50% blocked scenario; and/or
2. During the 100% blocked scenario, the flood behaviour was noted to have been significantly altered leading to the formation of new major flow paths or the development

of other major flood impacts.

Additionally, structures which cause impacts greater than 0.1 m but only impact on road and/or drainage easements or on undeveloped land have not been classified as Key Structures.

Table 19 presents the identified 19 Key Structures which meet the above mentioned criteria.

Table 19: Key Structures

ID	Location	Catchment	Dimensions	Reason
1	Wyong Road-Bundeena Road	Glenning Valley	2 x 3.0m x 2.0 m	Increase in flood level of 0.41 m in 50% blocked scenario
2	Bundilla Parade	Glenning Valley	3 x 1.5m x 1.2 m	Increase in flood level of 0.39 m in 50% blocked scenario
3	Wyong Road-Palm Springs Ave	Glenning Valley	2 x 3.4m x 1.15 m	Increase in flood level of 0.62 m in 50% blocked scenario
4	Lorraine Avenue	Glenning Valley	3 x 2.1m x 1.2 m	Increase in flood level of 0.16 m in 50% blocked scenario
5	KingsFord Smith Ave	Glenning Valley	3 x 1.2m x 1.2 m	Increase in flood level of 0.24 m in 50% blocked scenario
6	Lakedge Ave-KingsFord Smith Ave	Glenning Valley	3 x 1.5m x 0.9 m	Significant increase in impacts with 100% blocked scenario
7	Berkeley Road	Glenning Valley	2 x 2.7m x 1.2 m	Significant flow diversion with 100% blocked scenario
8	Palm Springs Ave	Glenning Valley	2 x 1.6m x 0.9 m	Significant increase in impacts with 100% blocked scenario
9	Heather Ave	Glenning Valley	3 x 1.35m Ø	Increase in flood level of 0.11 m in 50% blocked scenario
10	Berkeley Road-Wyong Road	Glenning Valley	4 x 3.8m x1.5 m	Significant increase in impacts with 100% blocked scenario
11	Tumbi Umbi Creek Rd–Culwulla St	Tumbi Umbi	2 x 1.8m x 1.2m	Increase in flood level of 0.29 m in 50% blocked scenario
12	Mingara Drive	Tumbi Umbi	4 x 2.4 m x 1.2 m	Increase in flood level of 0.17 m in 50% blocked scenario
13	Wyong Road at Peach Ave	Tumbi Umbi	4 x 3 m x 3.6 m	Increase in flood level of 0.22 m in 50% blocked scenario
14	Warrata Road Adelaide St	Tumbi Umbi	3 x 3.6m x 1.2m	Increase in flood level of 0.11 m in 50% blocked scenario
15	Wyong Road at Cornish Ave	Tumbi Umbi	2x 1.05m Ø	Increase in flood level of 0.30 m in 50% blocked scenario
16	Tumbi Road	Tumbi Umbi	4 x 3.0 m x1.2m	Significant increase in impacts with 100% blocked scenario
17	Cresthaven Avenue	Tumbi Umbi	3 x 2.4m x 0.6m	Increase in flood level of 0.30 m in 50% blocked scenario
18	Nirvana Street	East Catchments	1 x 1.05 m Ø	Increase in flood level of 0.15 m in 50% blocked scenario
19	Koonah Avenue	East Catchments	1 x 0.45 m Ø	Increase in flood level of 0.26 m in 50% blocked scenario

Blockage of Key Structures

Blockage of Key Structures has been addressed using the approach outlined in the ARR Blockage Guidelines (Reference 15). Use of the ARR Blockage Guidelines is recommended for flood modelling of all design events for the Key Structures in the study area. The design blockage is the blockage condition that is most likely to occur during a given design storm and needs to be an “average” of all potential blockage conditions to ensure that the calculated design flood levels reflect the defined probability.

The ARR methodology considers blockage due to various sources and takes into account the:

- Debris dimensions;
- Debris type (i.e. floating, non-floating or urban debris);
- Debris availability – the volume of debris available in the source area;
- Debris mobility – the ease with which available debris can be moved into the stream;
- Debris transportability – the ease with which the mobilised debris is transported once it enters the stream; and
- Structure interaction – the resulting interaction between the transported debris and the bridge or culvert structure.

The ARR methodology was applied to each Key Structure taking into account the variables listed above. An example for culverts with mixed upstream land uses (i.e. a mixture of rural and urban land uses) is presented in Appendix C. Whilst these culverts were assessed individually, the Blockage Assessment Form in Appendix C (obtained from Reference 15) provides a good indication of the expected blockage that was applied to the structures for the various design events. The average structure blockages for the Key Structures are shown in Table 20.

Table 20: Catchments with Mix Land Uses – Average Design Blockage Factor

Event AEP	Non-floating	Urban Blockage	Floating Debris	Design Blockage*
AEP > 5% (frequent)	Varying dependent on velocity	25%	25%	25%
AEP 5% - AEP 0.5%	Varying dependent on velocity	50%	50%	50%
AEP < 0.5% (rare)	Varying dependent on velocity	100%	100%	100%

* Assuming that non-floating blockage is not greater than Urban of Floating Blockage. Assessed individually for each key structure.

<u>Blockage of all Other Structures</u>

For structures that were not determined to be key structures, the average blockage for all key structures was determined and the Design Blockage factor shown in Table 20 was assigned. As mentioned previously, the assigned blockage for the majority of structures has little impact on flood behaviour and peak flood levels. Accordingly, detailed analysis of the +8,000 hydraulic structures in the study area was not warranted.

4.3.8. Boundary Conditions

<u>Inflows</u>

The hydrologic model (see Section 4.2) was used to produce design flows for the 0.2 EY, 5% AEP, 1% 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.

<u>Downstream Boundary</u>

For the calibration/validation events, the downstream boundary of the 2D model is Tuggerah

Lake which has been modelled as a time-varying 2D stage hydrograph to represent changing levels in the lake. These hydrographs are based on the Long Jetty gauge (see Section 2.5).

A constant water level of 0.6 mAHD was used as the downstream boundary in Tuggerah Lake for the design events. This water level was adopted to maintain consistency with the 2015 Northern Lakes Flood Study (Reference 16).

The same level was adopted for the catchments draining to the ocean as this level represents a modest high tide. Plus modelling showed that changing the tailwater on these catchments made little difference due to the relatively steep grade on the land upstream.

A sensitivity analysis of the downstream boundary is presented in Section 5.5.2.

4.3.9. Hydraulic Model Calibration

Hydraulic model calibration/validation was undertaken for the April 2015 and June 2007 events via a joint calibration process. Available recorded water levels at the Tumbi Umbi gauge (see Section 2.5) and observed flood behaviour from the community consultation (see Section 3.2) process was compared to model results. Calibration/validation results are presented in Section 5.2.

4.3.10. Critical Duration Assessment

A critical duration assessment was undertaken to determine the storm duration that is responsible for generating the highest peak flood levels in the study area. Various duration 1% AEP design events were used to determine the critical duration in the study area with the assumption that the critical duration remains constant for events of all AEP (with the exception of the PMF).

A similar process was undertaken for the PMF with various PMP durations (0.25 to 6 hours) modelled so that peak flood levels and associated rainfall durations could be identified.

The results of the critical duration assessment are presented in Section 5.3.

5. RESULTS AND ANALYSIS

5.1. Hydraulic Model Results Overview

A summary of the hydraulic model results is contained in the following sections. Hydraulic model results provide peak flood levels, depths and extents for the calibration/validation historic events (see Section 5.2) and design floods (see Section 5.4). For historic events, calibration/validation involved matching modelled flood levels to recorded flood levels at the Tumbi Umbi gauge, and flood behaviour to information obtained from the Community Consultation process (Section 3).

5.2. Hydraulic Model Calibration/Validation Results

5.2.1. Review of Historical Data and Process

Observations of flood behaviour obtained as part of the Community Consultation process were not surveyed due to the shallow flood depths associated with overland flow flooding at the majority of locations. Additionally, flood depths reported by the community are considered inappropriate for precise comparison to model results due to the potential for large difference in flood depths experienced within a single lot as the exact location of the flood depth is unknown. For the calibration/validation process, it was considered a positive calibration where community observations of flooding coincide with model flood depths greater than 0.1 m.

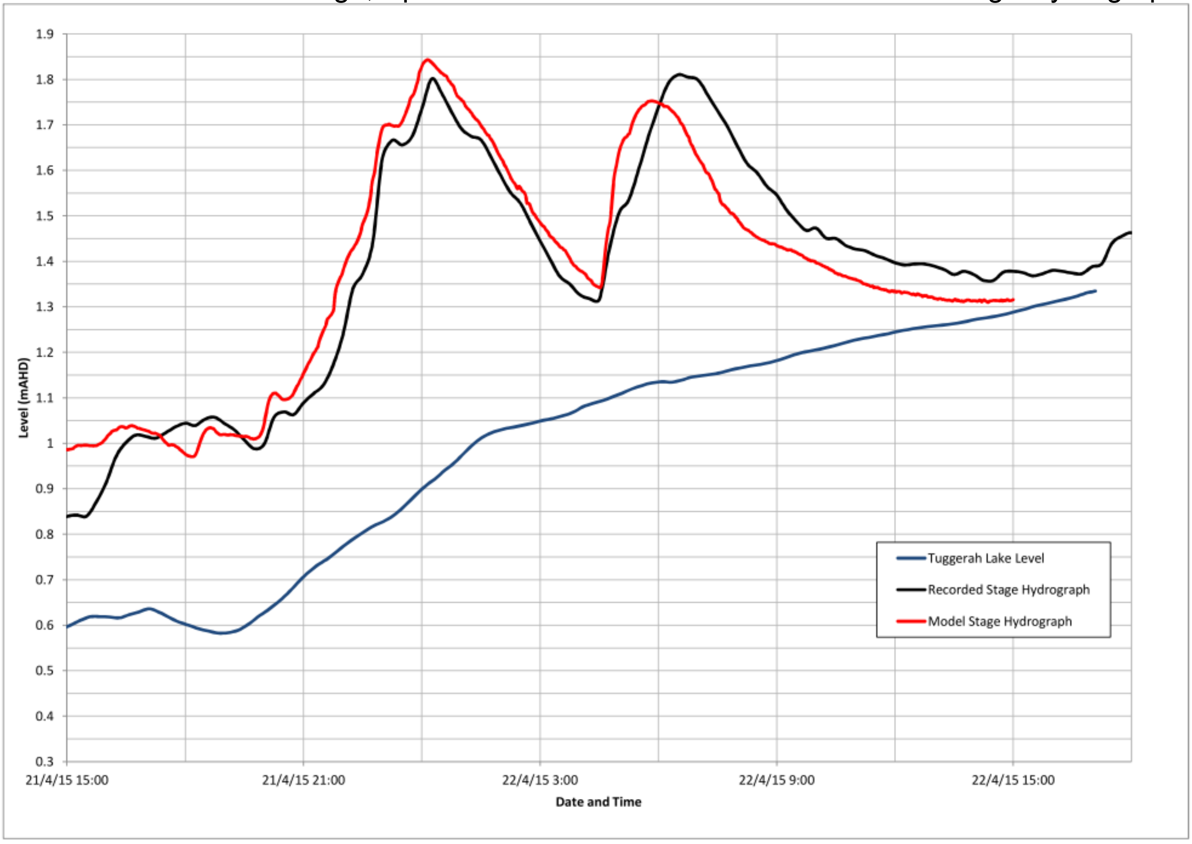
The calibration process involves matching the modelled peak levels to those that were observed or recorded by adjustment of model parameters within acceptable bounds. The model verification process is the comparison of observed versus peak levels for a different flood event but using the same model parameters as for calibration.

5.2.2. Hydraulic Model Calibration

The April 2015 event was simulated in the hydraulic model using flows determined from the hydrologic model (see Section 4.2.2). Figure 10a - c presents the modelled April 2015 flood event depths and extent (raster) as well as the locations of observed flood behaviour (displayed as yellow points) obtained from the community (see Section 3.2). A comparison of the modelled flood extent and the observations of flooding indicate that there is typically a good match between the modelled flood behaviour and that which was observed by the community. The detailed review of the community questionnaires described in Section 3.2 indicates that flood behaviour is largely as described by the community.

The April 2015 event was also calibrated to the observed stage hydrograph recorded by the Tumbi Umbi water level gauge (see Section 2.5). A comparison of the model stage hydrograph (red) and recorded stage hydrograph (black) is presented in Chart 1. The modelled peak flood level and the general shape of the modelled stage hydrograph is a good match to that observed and the data indicates that both peaks reached similar levels. Worth mentioning is that the model slightly underestimated (0.05 m) the second peak of the April 2015 event but slightly over estimated the first peak by a similar amount. This is likely due to the relatively poor availability of rainfall data within the Tumbi Umbi catchment described in Section 2.3.2.

Chart 1: Tumbi Umbi Gauge, April 2015 Event - Modelled and Observed Stage Hydrographs

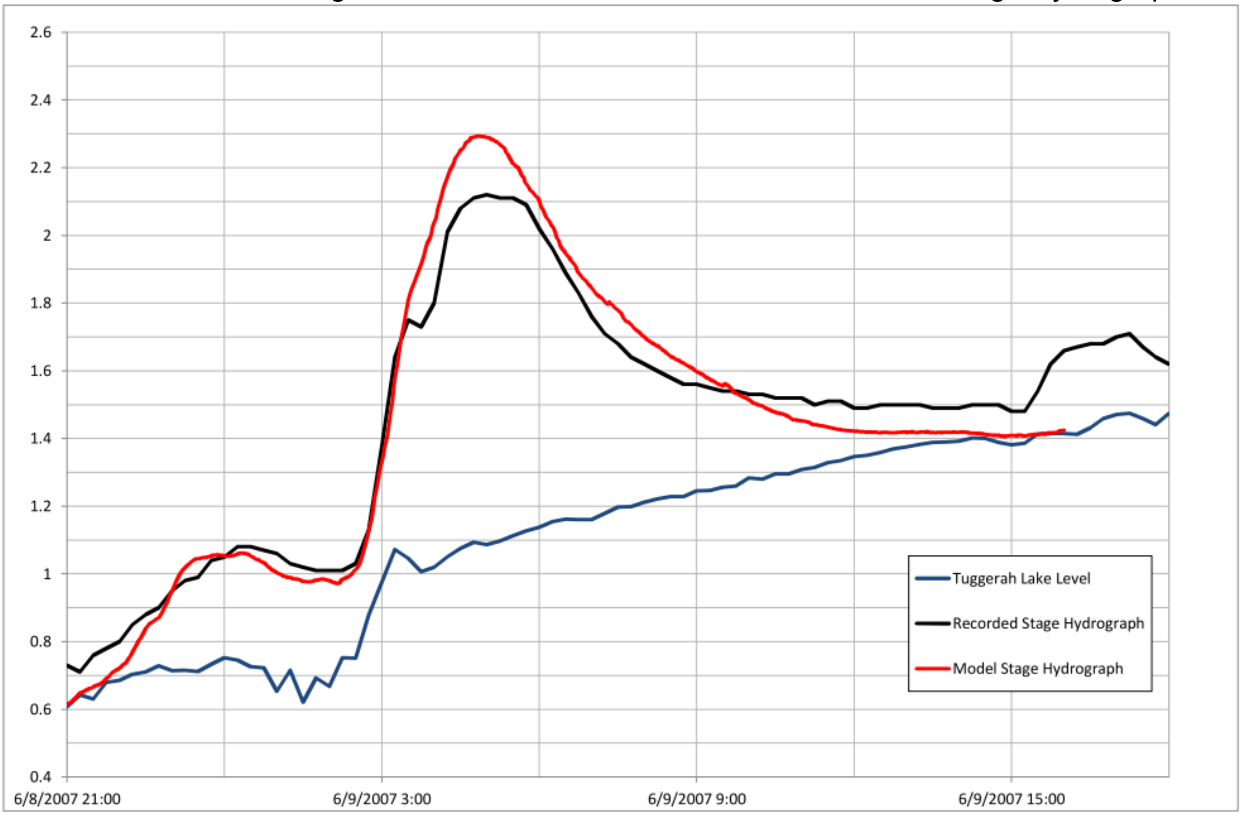


5.2.3. Hydraulic Model Validation

The June 2007 event was modelled in the hydraulic model using flows determined from the hydrologic model (see Section 4.2.2). Figure 11a - c presents the modelled June 2007 flood event depths and extent (raster) as well as the locations of observed flood behaviour obtained from the community (displayed as yellow points). A comparison of the modelled flood extent and the observations of flooding again indicate that there is typically a good match between the modelled flood behaviour and that which was observed by the community. The detailed review of the community questionnaires described in Section 3.2 indicates that flood behaviour is largely as described by the community.

The June 2007 event was also compared to the observed stage hydrograph recorded by the Tumbi Umbi water level gauge (see Section 2.5). A comparison of the model stage hydrograph (red) and recorded stage hydrograph (black) is presented in Chart 2. The modelled peak flood level was slightly higher than that observed (0.2 m), however the general shape of the modelled stage hydrograph is a good match to that observed. The slight overestimation of the peak flood level is likely due to the relatively poor availability of rainfall data within the catchment described in Section 2.3.2.

Chart 2: Tumbi Umbi Gauge, June 2007 Event - Modelled and Observed Stage Hydrographs



5.2.4. Discussion of Calibration/Validation Results

The results of the April 2015 and June 2007 calibration/validation are considered to be good, with the large majority of flood observations matching flood behaviour produced by the model. Additionally, the timings and shapes of the modelled stage hydrographs at the Tumbi Umbi gauge are a reasonable match to that observed for both events. The results indicate that a high degree of confidence can be had in the models and subsequent design flood results. However it should be noted that the recorded levels at the Tumbi Umbi gauge for the April 2015 and June 2007 events are smaller than a 0.2EY event (refer Table 25).

5.3. Critical Duration Assessment Results

A critical duration assessment was undertaken to determine which design storm duration is responsible for generating the highest peak flood levels in the study area. The 1% AEP design event was modelled for various durations to determine the critical duration in the study area with the assumption that the critical duration remains constant for events of all AEP events (with the exception of the PMF). The critical duration for the study area was determined to be the 2 hour and 9 hour durations.

Figure 12a – c display the spatial distribution of storm duration which produce the highest peak flood levels in various regions of the study area. It was found that the smaller upper reaches of the study area typically have a critical duration of 2 hours whereas the main flow paths and storage areas tended to have a critical duration of 9 hours. Whilst Figure 12a – c predominantly display the 2 hour and 9 hour durations as critical, there are areas where other durations were found to produce higher flood levels. The critical duration analysis determined that there were only minor differences (less than 0.05 m) in peak flood level between these durations and the adopted 9 hour and 2 hour envelope. Accordingly, it was considered reasonable to only use the 2 hour and 9 hour durations to produce the peak flood envelope.

A critical duration assessment using the same process was undertaken for the PMF event. The critical duration was found to be the 1 hour or 2 hour durations dependant on location. The PMF envelope was produced using these two events.

5.4. Hydraulic Model Design Results

Design results are the peak flood envelope of the 2 hour and 9 hour critical duration events (see Section 5.3) and blocked/unblocked structure scenarios (see Section 4.3.7).

A number of figures (Figure 13 to Figure 24) have been produced to display flood affected regions for the 0.2 EY, 5%, 1% AEP and PMF design events. These figures are:

- Figure 13a-e: 0.2 EY Design Flood Depths and Levels – Glenning Valley;
- Figure 14a-j: 0.2 EY Design Flood Depths and Levels – Tumbi Umbi;
- Figure 15a-c: 0.2 EY Design Flood Depths and Levels – Eastern Coastal Catchments;
- Figure 16a-e: 5% AEP Design Flood Depths and Levels – Glenning Valley;
- Figure 17a-j: 5% AEP Design Flood Depths and Levels – Tumbi Umbi;
- Figure 18a-c: 5% AEP Design Flood Depths and Levels – Eastern Coastal Catchments;
- Figure 19a-e: 1% AEP Design Flood Depths and Levels – Glenning Valley;
- Figure 20a-j: 1% AEP Design Flood Depths and Levels – Tumbi Umbi;
- Figure 21a-c: 1% AEP Design Flood Depths and Levels – Eastern Coastal Catchments;
- Figure 22a-e: PMF Design Flood Depths and Levels – Glenning Valley;
- Figure 23a-j: PMF Design Flood Depths and Levels – Tumbi Umbi;
- Figure 24a-c: PMF Design Flood Depths and Levels – Eastern Coastal Catchments.

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 the creeks, overland flow paths and the lake may vary depending on the actual rainfall event, local tributary flows, the relative timing of flows and local influences such as blockage (see Section 4.3.7), changes in topography and road works etc.

The flood extents shown have not been trimmed to eliminate shallow depths of inundation. Thus at the perimeter of the flood extent the flood depths will approach zero.

The figures display peak flood depths and levels for the design flood events described above based on the full extent determined in the model (i.e no filtering to eliminate shallow depths). The flood depths are displayed in various shades of blue with lighter shades of blue indicating shallower flood depths and the darker blues indicating deeper flood depths. The depth of flooding is indicated on the colour palette on each of these figures. Additionally, peak flood levels in Australian Height Datum (m) are presented as flood level contours at 0.5 m increments. The design peak flood level is displayed as contours throughout the study area, with flood levels typically ranging between 70 mAHD to 1 mAHD for the 1% AEP event. It should be noted that Council will be provided with digital data that describe flood behaviour and site specific information pertaining to flooding should be requested from Council.

Table 21 and Table 22 display the peak flood heights and flows at the Tumbi Umbi gauge (see Section 2.5) and at the Bundeena Road basin outlet, respectively, for the range of design flood events. Table 23 provides details on the design overtopping events at the retarding basins within the catchments (assuming nil freeboard).

Table 21: Tumbi Umbi gauge – Design Peak Flood Heights and Flows

Event*	0.2 EY	5% AEP	1% AEP	PMF
Peak Gauge Height (mAHD)	3.0	3.4	3.8	6.1
Peak Flow (m^3/s)	54	71	87	306

*Event probability is displayed as AEP. Refer to the Terminology Section at the beginning of this report for conversion to ARI.

Table 22: Bundeena Road basin outlet – Design Peak Flood Heights and Flows

Event	0.2 EY	5% AEP	1% AEP	PMF
Peak Flood Level (m)	6.5	7.2	7.4	8.5
Peak Flow Through Culvert beneath Wyong Road (m^3/s)	18	25	36	*
Peak Flow across Road (m^3/s)	3	9	22	305

* Culvert was modelled with 100% blockage in the PMF event (see Section 4.3.7)

Table 23: Design Overtopping Events at Retarding Basins

Catchment	Letter on Figure 1	Location	Overtopping Event	Basin Crest Height	Peak Basin Level (mAHD)			
					0.2EY	5%AEP	1%AEP	PMF
Glenning Valley	A	Bundeena Road and Wyong Road	5% AEP	6.9 mAHD	6.6	7.3	7.4	8.6
Tumbi Umbi	B	Kuraba Oval	0.2EY	3.5 mAHD	3.6	3.7	3.7	3.9
Tumbi Umbi	C	Sandpiper Way	0.2EY	5.9 mAHD	6.3	6.4	6.5	7.4
Tumbi Umbi	D	Hansens Road	5% AEP	6.0 mAHD	6.0	6.2	6.3	7.1
Tumbi Umbi	E	Wyong Road	PMF	4.6 mAHD	3.9	4.2	4.6	5.2
Tumbi Umbi	F	Eastern Road Oval	1% AEP	12.5 mAHD	12.0	12.5	12.6	12.9
Tumbi Umbi	G	Rotherham Street	1% AEP	12.5 mAHD	12.3	12.3	12.6	12.8

A tabulation of the number of properties affected in each event is shown on Table 24.

Table 24: Properties Affected in Design Events

Land Use	5% AEP	1% AEP	PMF
Business	18	19	25
Environmental Protection	288	297	319
Residential	3391	3713	4948
Industrial	25	28	30
Recreation	55	55	59
Special Purpose (Infrastructure)	2	2	2
Unspecified	19	19	20
Mixed Lot	306	321	350
TOTAL	**3798**	**4133**	**5403**

Notes:
1. Mixed lots are where a property includes more than one land use zone.
2. All residential properties do not always have a house on them.
3. Houses may be situated in non residential land use zones.

Peak velocities for the 1% AEP and PMF events are shown on the following figures:

- Figure 49a-e: Design Flood Velocities– 1% AEP – Glenning Valley;
- Figure 50a-j: Design Flood Velocities – 1% AEP – Tumbi Umbi;
- Figure 51a-c: Design Flood Velocities – 1% AEP – Eastern Coastal Catchments;
- Figure 52a-e: Design Flood Velocities – PMF – Glenning Valley;
- Figure 53a-j: Design Flood Velocities – PMF – Tumbi Umbi;
- Figure 54a-c: Design Flood Velocities – PMF – Eastern Coastal Catchments.

5.4.1. Design Results Comparison to Historic Events

Table 25 presents the peak flood levels for historic and design events at the Tumbi Umbi Creek gauge. Design results were obtained from the hydraulic model and the historic events were obtained from Reference 4.

Table 25: Historic and Design Flood Levels (mAHD) near the Tumbi Umbi Creek Gauge

Event Date/AEP	Tumbi Umbi Creek Gauge
January 1984	1.8
April 2015*	1.8
February 1992	2.05
June 2007*	2.1
0.2 EY	**3.0**
May 1988	3.26
February 1990	3.26
5% AEP	**3.4**
April 1990	3.58
February 1981	3.6
1% AEP	**3.8**
January 1978	4.6
PMF	**6.1**

* Observed Stage Hydrograph at Tumbi Umbi Creek Gauge

The results indicate that the most recent events in 2015 and 2007 are relatively insignificant in the context of the design flood levels presented in Table 25. It is noted that the April 1990 and February 1981 events had a magnitude greater than the 5% AEP and the January 1978 event exceeded a 1% AEP event.

The January 1978 achieved a peak flood level significantly higher than the 1% AEP event. This makes sense in the context of the 1978 event rainfall which was noted by the 1981 Berkeley Vale Valley Regional Flood Study (Reference 1) to have been 230 mm of rainfall over a six hour period. Analysis of design rainfall for the region indicates that the 1% AEP rainfall for the region is significantly less with only 175 mm for the six hour duration.

5.4.2. Design Results Comparison to Previous Studies - Glenning Valley

A hydraulic investigation of the Wyong Road Detention Basin (Reference 5) determined a 1% AEP flood level of 7.3 mAHD in the basin at Bundeena Road (refer Table 8 for description of basin outlets and invert levels). In the hydraulic model developed for the current study a level of 7.4 mAHD was found at the same location. This is a difference in peak flood level of 0.1 m indicating the two studies are comparable. The design estimates from the current study supersede the Reference 5 study.

5.4.3. Design Results Comparison to Previous Studies - Tumbi Umbi

The 1% AEP flood levels determined in the Tumbi Umbi Creek Floodplain Risk Management Review and Plan (Reference 2) were compared to the design flood levels achieved in the current hydraulic model. Table 26 presents the 1% AEP design flood level results from both studies and the difference in peak flood level. Generally, flood levels between the two studies are similar.

Table 26: Comparison of Current Study and Reference 2 1% AEP Flood Levels – Tumbi Umbi

Location	Current Study (mAHD)	Reference 2 * (mAHD)	Difference (m)
Tumbi Umbi Creek			
Tumbi Umbi Creek Entrance	1.2	1.6	-0.4
Downstream Wyong Road near Peach Avenue	3.9	4.0*	-0.1
Upstream Wyong Road	5.7	4.4	1.3
Upstream Tumbi Road	10.4	9.9	0.5
Downstream Pat Morley Oval	19	19	0
Killarney Vale Tributary			
Tumbi Umbi Creek Entrance	1.2	1.6	-0.4
Downstream Wyong Road next to Warratta Road	2.3	2.9*	-0.3
Upstream Killarney Vale Basin	4.7	4.6*	0.1
Downstream Playford Road Basin	8.4	8.5	-0.1
		Absolute Average	0.4

* Level determined from flood contours from Reference 2

Notable differences in flood level between the two studies (as presented in Table 26) are:

- Tumbi Umbi Creek Entrance (-0.4 m) – Reference 2 adopted a higher level in Tuggerah Lake than the current study which is reflected in the flood level at this location.
- Upstream Wyong Road (1.3 m) – Upstream of Wyong Road the current study flood level is 1.3 m higher than the Reference 2. This is due to the assumed structure blockage applied to the Wyong Road culverts as per that discussed in Section 4.3.7.
- Upstream Tumbi Road (0.5 m) – Upstream of Tumbi Road the current study flood level is 0.5 m higher than the Reference 2. This is again due to the assumed structure blockage applied to culverts under Tumbi Road.

5.5. Sensitivity Analysis Results

Sensitivity analysis was carried out in order to assess the effect that adjusting model parameters (Manning's 'n', blockage, lake level, rainfall) has on design model results. Comparisons were carried out using peak flood levels for the 1% AEP design event. The location of the 'Sensitivity Analysis Points' are presented in the 1% AEP Figures (Figure 19 to Figure 21) and Figure 1a.

Section 5.5.1 investigates the model's parameter sensitivity, Section 5.5.2 investigates the impact that Tuggerah Lake levels have on peak flood levels and Section 5.5.3 investigates the impact that potential changes to rainfall intensity associated with climate change will have on design flood levels. The results are provided below with figures shown in Appendix D.

5.5.1. Model Parameter Sensitivity

To investigate the model's sensitivity to selected parameters the following runs have been examined:

- An increase in Manning's n roughness of 20%;
- A decrease in Manning's n roughness of 20%;
- 100% structure blockage; and
- 0% structure blockage.

Details of the analysis for each of the three catchments are presented below.

Glenning Valley Catchment

The Glenning Valley sensitivity results are presented in Table 27. The analysis indicates that the Glenning Valley catchment is particularly sensitive to structure blockage, however is insensitive to selected Manning's roughness.

Table 27: Model Parameter Sensitivity Analysis Results – Glenning Valley

ID	Location (refer Figure 1a)	Blockage		Manning's 'n'	
		0%	100%	-20%	+20%
GV 01	Downstream Bundeena Road Basin	-0.30	0.20	0.01	-0.01
GV 02	Wombat Street Channel near Marlborough Place	0.00	-1.93	-0.06	0.09
GV 03	Wombat Street Channel at Lakedge Avenue	0.00	-0.09	-0.01	0.01
GV 04	Seawind Terrace near Wombat Street	0.00	-0.12	-0.01	0.01
GV 05	Corner of Kingsford Smith Drive and Lakedge Avenue	-0.08	0.09	0.00	0.00
GV 06	Kingsford Smith Drive at Windsor Road	-0.26	0.20	0.04	-0.02
GV 07	Flow path upstream of Lorraine Avenue	-0.05	0.06	-0.01	0.01
GV 08	Bundilla Parade at Jeannie Crescent	-0.19	0.07	0.00	0.00
GV 09	Berkeley Creek at Berkeley Road	-0.07	0.10	-0.01	0.01
GV 10	Greenacres Branch at Berkeley Road	-0.10	1.60	0.02	-0.01
GV 11	Quondong Gully at Palm Springs Avenue	0.00	0.16	-0.02	0.02
GV 12	Quondong Gully at Wyong Road	-0.70	0.51	0.02	-0.02
GV 13	Greenacres Branch at Heather Avenue	-0.07	0.07	0.00	-0.01
GV 14	Wyong Road at Kingsford Smith Drive	-1.14	0.26	0.03	-0.03
GV 15	Bundeena Road Basin	-0.11	0.19	-0.02	0.01
	Absolute Average	**0.20**	**0.38**	**0.02**	**0.02**

The 0% blockage scenario flood levels were decreased by 0.2 m on average at the points examined. Upstream of the intersection of Wyong Road and Kingsford Smith Drive (Sensitivity Point GV14), flood levels are decreased by up to 1.14 m. The increased conveyance through the structure associated with the 0% blocked scenario leads to less backwatering and lower flood levels upstream. Similar flood behaviour is apparent at a number of locations in the Glenning Valley catchment including sensitivity points GV01, GV06, GV08 and GV12. The impact of 0% blockage downstream of structures is typically presented as zero in Table 27 as the peak flood envelope has included both blocked and unblocked scenarios.

In the 100% blockage scenario, peak flood level increases (of up to 1.6 m, GV10) and decreases (of up to -1.93 m, GV03) were experienced in the Glenning Valley catchment. As expected, sensitivity points located directly upstream of major structures experienced peak flood level increases, whilst those downstream experienced decreases in flood level associated with the reduction in flow.

An increase in roughness led to a maximum increase in peak flood level of 0.09 m across the sensitivity analysis locations (shown in Table 27) although on average the increase in peak flood level was 0.02 m. This indicates that the model results are not overly sensitive to the selected roughness values.

Tumbi Umbi Catchment

The Tumbi Umbi catchment sensitivity results are presented in Table 28. The analysis indicates that the Tumbi Umbi catchment is generally insensitive to selected roughness and blockage parameters, particularly in the contexts of a 0.5m freeboard adopted for residential floors above the 1% AEP flood level.

Table 28: Model Parameter Sensitivity Analysis Results – Tumbi Umbi

ID	Location (refer Figure 1a)	Blockage		Manning's 'n'	
		0%	100%	-20%	+20%
TB 01	Tumbi Umbi Creek at Tuggerah Lake	0	0.03	-0.03	0.01
TB 02	Tumbi Umbi Creek downstream of Wyong Road Bridge	0	0.07	-0.05	0.05
TB 03	Tumbi Umbi Creek upstream of Wyong Road Bridge	-0.21	0.2	0.03	-0.01
TB 04	Upstream of Mingara Drive bridge	-0.16	0.15	0.02	-0.01
TB 05	Downstream of Mingara Drive Wetland	-0.01	-0.01	-0.08	0.06
TB 06	Killarney Creek upstream of Wyong Road	-0.23	0.09	0.01	-0.14
TB 07	Killarney Creek downstream of Wyong Road	-0.02	0.26	-0.03	0.02
TB 08	Killarney Creek upstream of Adelaide Street	-0.06	0.3	-0.02	0.01
TB 09	Tumbi Umbi Creek at Killarney Creek confluence	0	0.03	-0.04	0.02
TB 10	Killarney Creek at Bligh Close	0	-0.03	-0.05	0.04
TB 11	Killarney Creek downstream of Mawson Drive	0	-0.24	-0.01	0.01
TB 12	Eastern Road Oval, Killarney Vale	-0.13	0.03	0	-0.04
TB 13	Tumbi Umbi Creek upstream of The Entrance Road	-0.17	0.06	0	0
TB 14	Tumbi Umbi Creek near Charlotte Close	0	-0.02	-0.03	0.01
TB 15	Tumbi Umbi Creek upstream of Tumbi Road Bridge	-0.09	0.06	0.01	-0.05
TB 16	Tumbi Umbi Creek near Rotherham Street	-0.05	0.05	-0.01	-0.06
TB 17	Tumbi Umbi Creek near Lancaster Parade	0	0.01	-0.03	0.02
TB 18	Tumbi Umbi Creek near Aurora Place	0	-0.06	-0.05	0.04
TB 19	Flowpath near corner of Cresthaven Avenue & Dunning Avenue	-0.23	0.12	0	0
TB 20	Flowpath near Cresthaven Avenue & Finch Place	0	0.03	-0.04	0.05
	Absolute Average	**0.07**	**0.07**	**0.02**	**0.02**

Eastern Coastal Catchments

The Eastern Coastal catchments were found to be typically insensitive to adopted blockage and the roughness values. The results of the sensitivity analysis are shown in Table 29. In general, the steep topography of these catchments prevents the attenuation of flood waters and as such these catchments are insensitive to these factors.

Some sensitivity to the 0% and 100% blockage scenarios were found at Pacific Street (EC04) and the corner of Kenney Close and Koonah Avenue (EC05). The sensitivity point at Pacific Street is located upstream of a major culvert which flows toward Elsiemer Street. As a result, flood levels are decreased by 0.19 m when the culvert is 0% blocked and flood waters are able to flow through the culvert. When the culvert is 100% blocked peak flood levels are increased (by 0.19 m) at this location as flood waters are unable to enter the culvert. Similar flood behaviour is apparent at the corner of Kenney Close and Koonah Avenue (EC05), located upstream of a culvert inlet which flows toward Bay Road.

Table 29: Model Parameter Sensitivity Analysis Results – Eastern Coastal Catchments

ID	Location (refer Figure 1a)	Blockage		Manning's 'n'	
		0%	100%	-20%	+20%
EC 01	Corner of Yulong Street & Reserve Drive	0.00	0.00	0.00	0.00
EC 02	Point Street between Bateau Bay Road & Reserve Drive	-0.01	0.01	-0.01	0.01
EC 03	Corner of Koongara Street & Swadling Street	-0.06	0.07	0.00	0.00
EC 04	Pacific Street between Nirvana St & Eloora Road	-0.19	0.19	0.00	0.00
EC 05	Corner of Kenney Close & Koonah Avenue	-0.29	0.08	0.00	0.02
EC 06	Bay Road near Yamba Street	-0.01	0.01	-0.01	0.01
EC 07	Corner of Boondilla Road & Ocean Parade	-0.01	0.01	0.00	0.00
EC 08	Bay Road between Boondilla Road & Ocean Parade	0.00	0.04	-0.01	0.01
EC 09	Corner of Toowoon Parade & Weerina Parade	0.00	0.00	-0.01	0.01
EC 10	Karrooah Avenue between Eloora Road & Bay Road	0.00	0.00	0.00	0.00
	Absolute Average	**0.06**	**0.04**	**0.00**	**0.01**

5.5.2. Downstream Boundary Sensitivity

The model's sensitivity to the tailwater level in Tuggerah Lake was examined by assessing the impact that various design lake levels have on 1% AEP flood levels. The lake levels used for this analysis were prescribed in the Brief and are presented in Table 30.

Table 30: Tuggerah Lake Design Levels

Event	Lake Level (mAHD)
Normal	0.23
50% AEP	0.91
20% AEP	1.36
1% AEP	2.20
PMF	2.70

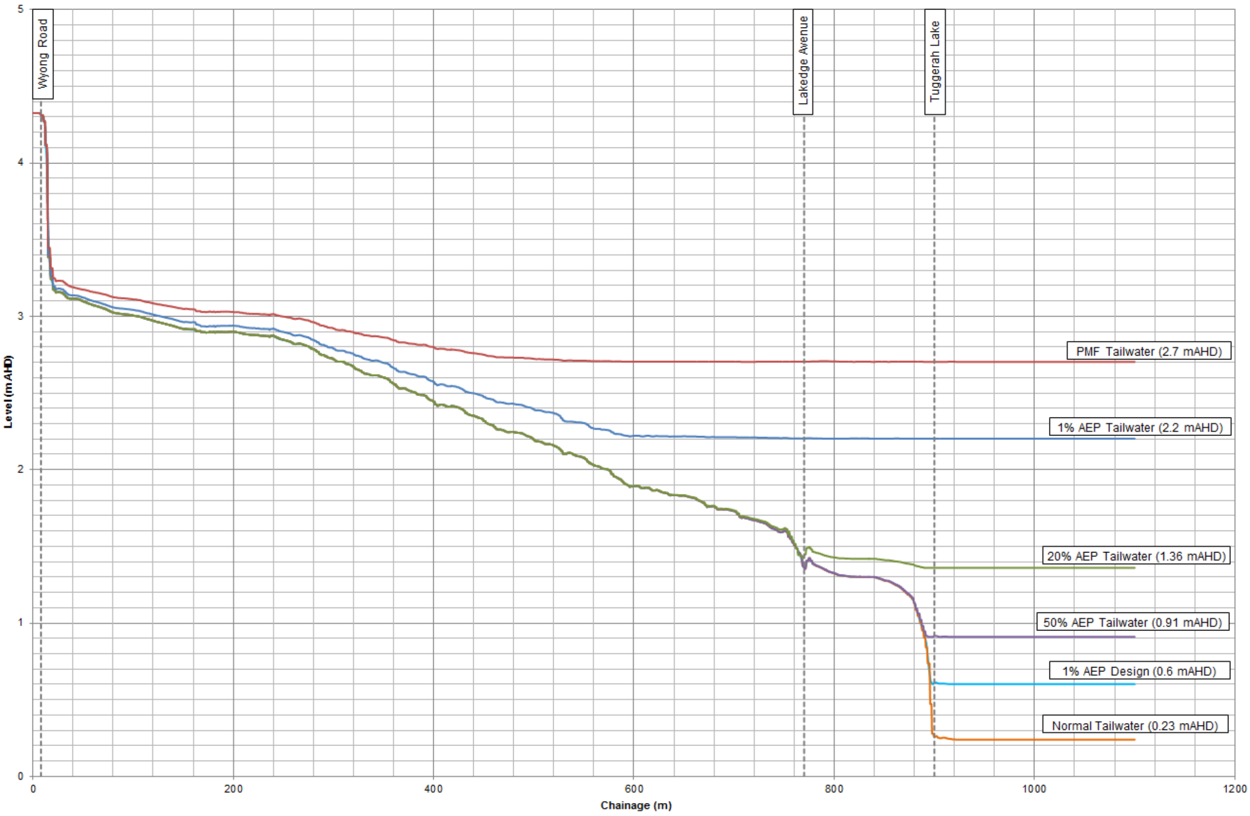
This investigation was conducted for the Glenning Valley and Tumbi Umbi catchments. The Eastern Coastal catchments do not flow into Tuggerah Lake and not been considered in this assessment. Sea level rise associated with climate change will not impact on design flood levels for this catchment due to the steep topography in the region.

Glenning Valley Catchment

The Glenning Valley catchment was found to be typically insensitive to elevated lake levels for lake scenarios up to and including the 20% AEP event. When the 1% AEP and PMF Tuggerah Lake levels were applied to the model, some sensitivity was exhibited with increased peak flood levels in the downstream catchment areas particularly along Lakedge Avenue, however this is predominately due to direct flooding from the lake rather than backwatering of local catchment flows.

The backwatering effects of the lake have the most impact on formalised flow paths such as the Wombat Street channel. The impact on peak flood levels associated with elevated lake levels in the Wombat Street channel are presented in Diagram 1. It is apparent in Diagram 1 that the flood profile for the 50% AEP and Normal Tailwater (0.23 m) scenarios are typically insensitive to the lake levels with no variation to 1% AEP design profile outside of the Tuggerah Lake extent.

Diagram 1: Glenning Valley Peak Flood Profile of the Wombat Street Channel



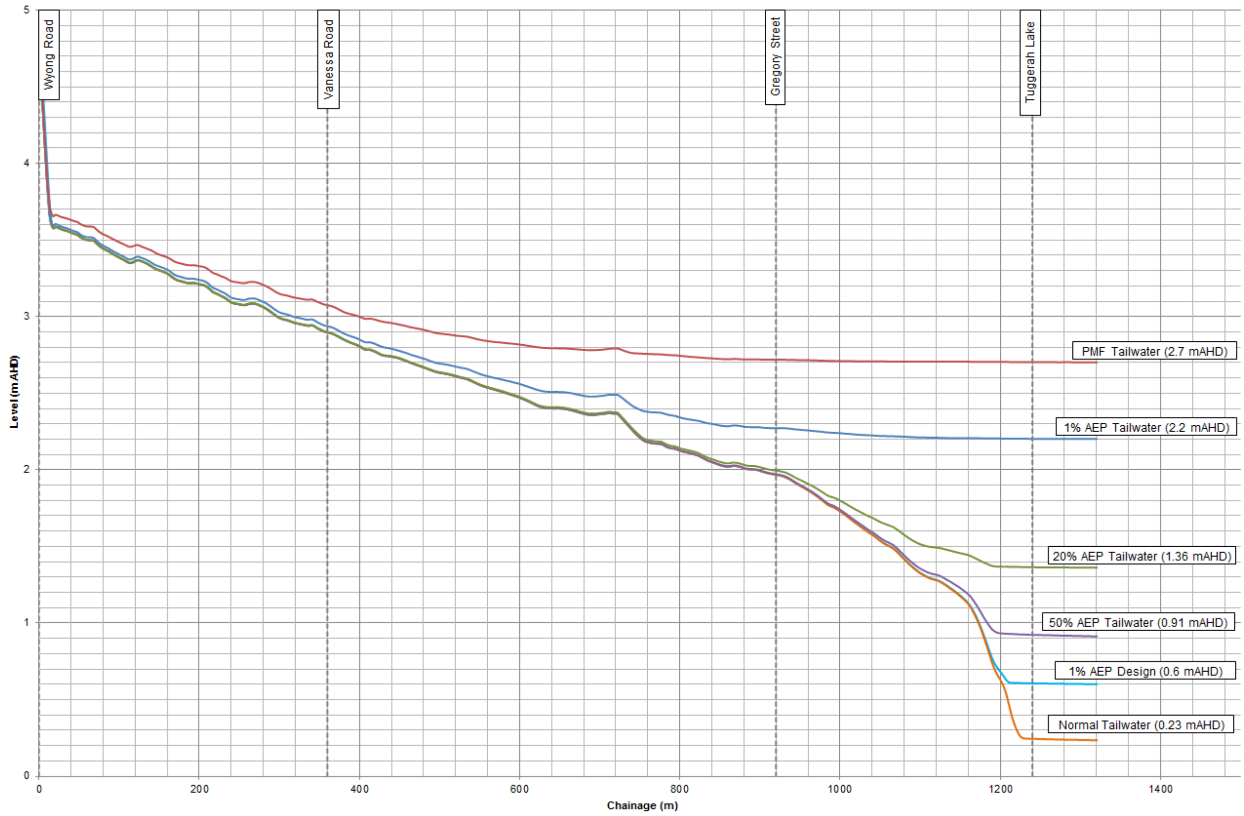
The 20% AEP lake level does lead to small increases in flood level (0.1 m) in areas downstream of Lakedge Avenue, whilst the 1% AEP and PMF lake levels impact on flood levels to as far upstream as Wyong Road. However, as mentioned previously, flood level sensitivity to lake levels outside of the main channels is relatively minor with increases typically less than 0.1 m once outside of the Tuggerah Lake flood extent.

Tumbi Umbi Catchment

In the Tumbi Umbi catchment, minor peak flood level increases were also found in the downstream catchment areas for tailwater scenarios greater than and including the 20% AEP. The model was insensitive to the Tuggerah Lake level in the areas upstream of Wyong Road and in scenarios less than the 20% AEP lake level. Diagram 2 presents a peak flood profile from Wyong Road to the Tumbi Umbi Creek entrance for each lake level scenario. Again it should be noted that formalised channels and main flows paths show significantly more sensitivity than the urban areas of the catchment. This diagram shows that the 50% AEP and Normal Tailwater (0.23 mAHD) levels generally match the 1% AEP design profile indicating that there is no sensitivity to these assigned tailwater levels.

The 20% AEP lake level does lead to small increases in flood level (0.1 m) in areas downstream of Gregory Street, whilst the 1% AEP and PMF lake levels impact on flood levels to as far upstream as Wyong Road. However, as mentioned previously, flood level sensitively to lake levels outside of the main channels is relatively minor with increases typically less than 0.1 m once outside of the Tuggerah Lake flood extent.

Diagram 2: Peak flood profile from Wyong Road to Tuggerah Lake



5.5.3. Climate Change Sensitivity

Intensive scientific investigation is ongoing to understand the impact that human activity has and will continue to have on the climate. Since the 1950s, unprecedented warming has occurred to the atmosphere and oceans, with global snow and ice diminishing, sea level rising and concentrations of greenhouse gases increasing (IPCC Fifth Assessment Synthesis Report 2014). One direct impact of a changing climate with relevance to this flood study is the potential for heavier rainfall, leading to increased flood levels in the catchments.

Rainfall intensity increases have the potential to increase flood levels in the Glenning Valley, Tumbi Umbi and Eastern Coastal catchments, the New South Wales Government recommends investigating vulnerabilities of such increases through sensitivity analysis. The results of +15% and + 30% rainfall sensitivity modelling for the 1% AEP design rainfall event are presented in Table 31, Table 32 and Table 33. Results show that the study area is sensitive to increases in rainfall intensity.

In the Glenning Valley Catchment, for the 15% and 30% increases in rainfall, peak flood levels are expected to increase on average by 0.15 m and 0.36 m (see Table 31) respectively. Particularly large increases in peak flood levels were found at points located directly upstream of major structures and road embankments. Rainfall increases result in greater peak flows as well as total volume which can lead to increased flood levels, particularly upstream of structures.

Table 31: Model Parameter Sensitivity Analysis Results – Glenning Valley

ID	Location (refer Figure 1a)	Rainfall Increase	
		15%	30%
GV 01	Downstream Bundeena Road Basin	0.18	0.42
GV 02	Wombat Street Channel near Marlborough Place	0.05	0.13
GV 03	Wombat Street Channel at Lakedge Avenue	0.09	0.26
GV 04	Seawind Terrace near Wombat Street	0.04	0.09
GV 05	Corner of Kingsford Smith Drive and Lakedge Avenue	0.09	0.25
GV 06	Kingsford Smith Drive at Windsor Road	0.15	0.32
GV 07	Flow path upstream of Lorraine Avenue	0.07	0.36
GV 08	Bundilla Parade at Jeannie Crescent	0.06	0.14
GV 09	Berkeley Creek at Berkeley Road	0.08	0.21
GV 10	Greenacres Branch at Berkeley Road	0.45	1.14
GV 11	Quondong Gully at Palm Springs Avenue	0.10	0.29
GV 12	Quondong Gully at Wyong Road	0.26	0.55
GV 13	Greenacres Branch at Heather Avenue	0.08	0.20
GV 14	Wyong Road at Kingsford Smith Drive	0.28	0.55
GV 15	Bundeena Road Basin	0.21	0.53
	Average	**0.15**	**0.36**

In the Tumbi Umbi catchment, peak flood levels are expected to increase by an average of 0.10 m and 0.19 m (see Table 32) for 15% and 30% increases in rainfall intensity. As in Glenning Valley, similar flood behaviour was observed in Tumbi Umbi. The larger peak flood level increases occurred in areas located directly upstream of major structures and road embankments.

Table 32: Model Parameter Sensitivity Analysis Results – Tumbi Umbi

ID	Location (refer Figure 1a)	Rainfall Increase	
		15%	30%
TB 01	Tumbi Umbi Creek at Tuggerah Lake	0.08	0.14
TB 02	Tumbi Umbi Creek downstream of Wyong Road Bridge	0.25	0.48
TB 03	Tumbi Umbi Creek upstream of Wyong Road Bridge	0.12	0.23
TB 04	Upstream of Mingara Drive bridge	0.1	0.19
TB 05	Downstream of Mingara Drive Wetland	0.16	0.3
TB 06	Killarney Creek upstream of Wyong Road	0.22	0.41
TB 07	Killarney Creek downstream of Wyong Road	0.09	0.16
TB 08	Killarney Creek upstream of Adelaide Street	0.1	0.16
TB 09	Tumbi Umbi Creek at Killarney Creek confluence	0.09	0.16
TB 10	Killarney Creek at Bligh Close	0.07	0.12
TB 11	Killarney Creek downstream of Mawson Drive	0.03	0.06
TB 12	Eastern Road Oval, Killarney Vale	0.07	0.1
TB 13	Tumbi Umbi Creek upstream of The Entrance Road	0.1	0.17
TB 14	Tumbi Umbi Creek near Charlotte Close	0.08	0.14
TB 15	Tumbi Umbi Creek upstream of Tumbi Road Bridge	0.06	0.11
TB 16	Tumbi Umbi Creek near Rotherham Street	0.1	0.18
TB 17	Tumbi Umbi Creek near Lancaster Parade	0.05	0.08
TB 18	Tumbi Umbi Creek near Aurora Place	0.1	0.19
TB 19	Flowpath near corner of Cresthaven Avenue & Dunning Avenue	0.06	0.11
TB 20	Flowpath near Cresthaven Avenue & Finch Place	0.06	0.11
	Average	**0.10**	**0.19**

The Eastern Coastal catchments were found to be less sensitive to rainfall increases with expected peak flood level increases of 0.05 m and 0.10 m (see Table 33) on average for the 15% and 30% increases in rainfall intensity.

Table 33: Model Parameter Sensitivity Analysis Results – Eastern Coastal Catchments

ID	Location (refer Figure 1a)	Rainfall Increase	
		15%	30%
EC 01	Corner of Yulong Street & Reserve Drive	0.01	0.02
EC 02	Point Street between Bateau Bay Road & Reserve Drive	0.04	0.06
EC 03	Corner of Koongara Street & Swadling Street	0.06	0.10
EC 04	Pacific Street between Nirvana Street & Eloora Road	0.14	0.22
EC 05	Corner of Kenney Close & Koonah Avenue	0.09	0.19
EC 06	Bay Road near Yamba Street	0.02	0.03
EC 07	Corner of Boondilla Road & Ocean Parade	0.01	0.01
EC 08	Bay Road between Boondilla Road & Ocean Parade	0.15	0.28
EC 09	Corner of Toowoon Parade & Weerina Parade	0.01	0.03
EC 10	Karrooah Avenue between Eloora Road & Bay Road	0.01	0.02
	Average	**0.05**	**0.10**

Table 34 indicates the additional properties inundated in the 1% AEP event with a 15% and 30% rainfall increase.

Table 34: Additional Properties Affected in the 1% AEP Event with Rainfall Increase

Land Use	1% AEP + 15% Rainfall Increase	1% AEP + 30% Rainfall Increase
Business	2	3
Environmental Protection	4	8
Residential	243	425
Industrial	2	2
Recreation	0	0
Special Purpose (Infrastructure)	0	0
Unspecified	0	0
Mixed Lot	9	21
TOTAL	**251**	**438**

NOTE: While other events are an envelope of duration and blockage scenarios, the 15% and 30% climate change increase are based on the 2 hour duration and 20year blockage scenario. As such they have been compared to this same 1% AEP scenario.

5.6. Preliminary Hazard Classification

The risk to life and potential damages to buildings during floods varies both in time and place across the floodplain. In order to provide an understanding of the effects of a proposed development on flood behaviour and the effects of flooding on development and people, the floodplain can be sub-divided into hydraulic and hazard categories.

Hazard classification plays an important role in informing floodplain risk management in an area. Previously, hazard classifications were binary – either Low or High Hazard as described in the Floodplain Development Manual (Reference 17). However, in recent years there has been a number of developments in the classification of hazard. *Managing the floodplain: a guide to best practice in flood risk management in Australia* (Reference 18) provides revised hazard classifications which add clarity to the hazard categories and what they mean in practice. The classification is divided into 6 categories, listed in Table 35, which indicate the restrictions on people, buildings and vehicles. The velocity/depth relationship for each of these categories is depicted in Diagram 3.

Table 35: Hazard Categories

Category	Constraint to people/vehicles	Building Constraints
H1	Generally safe	*No constraints*
H2	Unsafe for small vehicles	*No constraints*
H3	Unsafe for all vehicles, children and the elderly	*No constraints*
H4	Unsafe for all people and all vehicles	*No constraints*
H5	Unsafe for all people and all vehicles	Buildings require special engineering design and construction
H6	Unsafe for people and vehicles	All building types considered vulnerable to failure

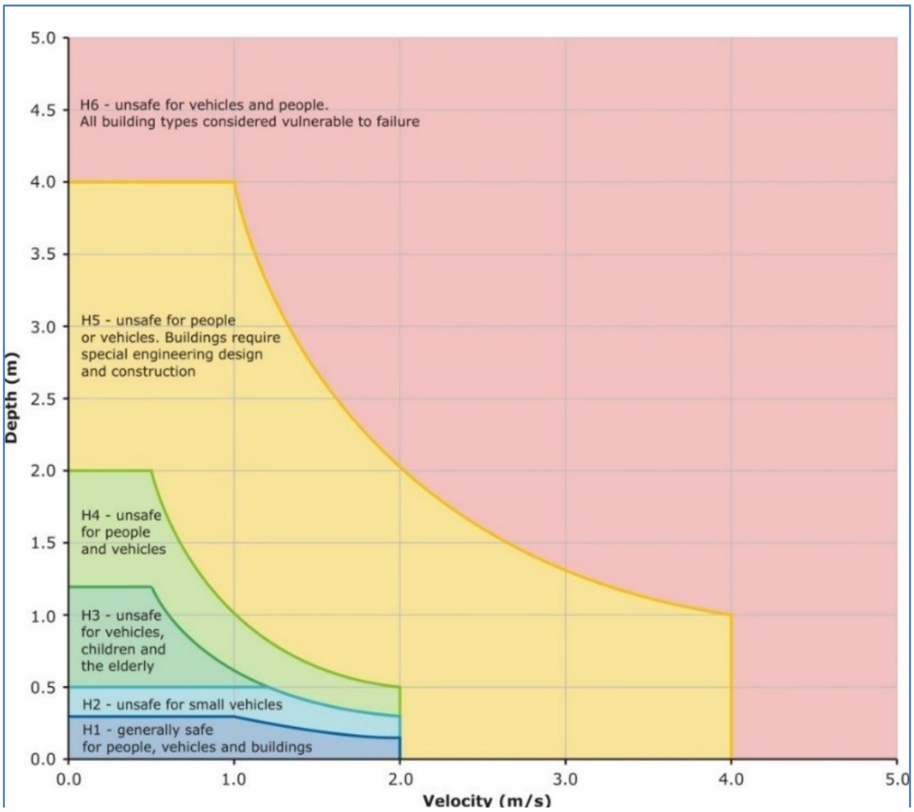


Diagram 3: Hazard Classifications

A number of figures (Figure 25 to Figure 30) have been produced that present hazard classifications based on the H1 - H6 delineations for the 1% AEP and PMF events. These figures are:

- Figure 25a-e: 1% AEP Preliminary Hydraulic Hazard – Glenning Valley;
- Figure 26a-j: 1% AEP Preliminary Hydraulic Hazard – Tumbi Umbi;
- Figure 27a-c: 1% AEP Preliminary Hydraulic Hazard – Eastern Coastal Catchments;
- Figure 28a-e: PMF Preliminary Hydraulic Hazard – Glenning Valley;
- Figure 29a-j: PMF Preliminary Hydraulic Hazard – Tumbi Umbi; and
- Figure 30a-c: PMF Preliminary Hydraulic Hazard – Eastern Coastal Catchments.

During a 1% AEP event under this classification system, much of the study area is classified as H1 due to the shallow distributed nature of the flow which is considered safe for people, vehicles and all building types. More hazardous classifications on the floodplain are generally contained in non-habitable areas including parks, reserves and golf courses which are located adjacent to formalised flow paths such as drains, channels and creeks.

The above hazard classification is preliminary and subject to review in the subsequent Floodplain Risk Management Study of this study area.

5.7. Preliminary Hydraulic Categorisation

The 2005 NSW Government's Floodplain Development Manual (Reference 17) 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 adopted by WMAwater and other consultants:

Floodway:	***OR***	**Velocity x Depth > 0.25 m^2/s AND Velocity > 0.25m/s** **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

A number of figures (Figure 31 to Figure 36) have been produced that present hydraulic categories for the 1% AEP and PMF events. These figures are:

- Figure 31a-e: 1% AEP Hydraulic Categories – Glenning Valley;
- Figure 32a-j: 1% AEP Hydraulic Categories – Tumbi Umbi;
- Figure 33a-c: 1% AEP Hydraulic Categories – Eastern Coastal Catchments;
- Figure 34a-e: PMF Hydraulic Categories – Glenning Valley;
- Figure 35a-j: PMF Hydraulic Categories – Tumbi Umbi; and
- Figure 36a-c: PMF Hydraulic Categories – Eastern Coastal Catchments.

The above hydraulic category classification is preliminary and subject to review in the subsequent Floodplain Risk Management Study of this study area.

5.8. Preliminary Flood Planning Area

The Flood Planning Area (FPA) is an area to which flood planning controls are applied and an interim FPA map has been produced as part of this study. It is important to define the boundaries of the FPA to ensure flood related planning controls are applied where necessary and not to those lots unaffected by flood risk. Typically, and as per the Floodplain Development Manual (Reference 17), the FPA for mainstream flooding will be based on the flood extent formed by the 1% AEP mainstream flooding event plus freeboard. The Central Coast Council has currently adopted a freeboard of 0.5 m (as recommended in Reference 17).

The purpose of extending the FPA past the 1% AEP flood extent is to account for modelling uncertainties as well as an allowance for differences between flood behaviour during events. The Local Environment Plan Standard Instrument for NSW does not include a specific land use zone classification for flood prone land; rather it permits a Flood Planning Area map to be included as a layer imposed across all land zones.

The FPA as defined by the Floodplain Development Manual (1% AEP + freeboard) is often only suitable for mainstream flooding, and within the study area would only be suitable for Tumbi Umbi Creek. Other areas of the study area were found to be unsuitable for applying the Floodplain Development Manual FPA method. Flooding in the study area outside of Tumbi Umbi Creek can typically be classified as overland flow which is more distributed in nature and typically does not reach the depths that occur from mainstream flooding. Additionally, flood depths do not tend to increase significantly for rarer events. Applying the Floodplain Development Manual FPA method to areas affected by overland flow will generally lead to an overly conservative FPA extent and inclusion of properties not flooded in the PMF.

Since there are no industry standards Council has been researching ways to better define the extent of the FPA in overland flow areas (i.e where either there is no open channel or it is has minimal capacity) without unnecessarily penalising properties with a flood planning level control.

One of these ways has been to use the results of the sensitivity analysis for increased rainfall of 15% and 30%, due to climate change, and which has been undertaken already as part of a sensitivity analysis in this flood study (Section 5.5.3).

The sensitivity analysis for 30% rainfall increase in the 1% AEP provided a projected design flood level that was similar in extent to the standard way of defining the FPA for mainstream flooding. It also provided a projected design flood level extent that was more realistic for use as the FPA for overland flooding. It should be noted that the idea of using projected design floods with increases in rainfall may not be suitable for all types of catchments. As such, each separate floodplain should be individually investigated to evaluate the most appropriate method in defining the FPA.

In the absence of industry standards and for this flood study the use of the 30% increase in rainfall in the 1% AEP has been used for defining the extent of the preliminary FPA across the whole floodplain, however limited in extent to the PMF.

When hydraulic modelling is undertaken using what is commonly called *direct rainfall* or *rainfall on the grid* the FPA is typically truncated to eliminate shallow depths of flow (this is necessary as with this approach the entire catchment is shown as inundated). As this method of modelling was not used in this study the FPA was not truncated.

Preliminary FPA figures are presented in Figure 37 to Figure 39. These figures are:

- Figure 37a-e: Preliminary Flood Planning Area – Glenning Valley;
- Figure 38a-j: Preliminary Flood Planning Area – Tumbi Umbi;
- Figure 39a-c: Preliminary Flood Planning Area – Eastern Coastal Catchments.

5.9. 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 19) 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 36).

Table 36: Emergency Response Planning Classifications of Communities

Classification (refer description below)	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.

The key for emergency services to enact action prior to a flood event (rescues, sand bagging, door knocking) is adequate time to respond. On major river systems such at the Hunter River at

Maitland, the Hawkesbury River at Windsor or the Shoalhaven River at Nowra there is generally several hours of warning of such an event. However, this is only possible because these catchments are very large (several thousand km^2). The catchments under consideration are only a few km^2 and flooding can start within less than an hour from the start of the rainfall. The problem is further exacerbated as at the start of the rainfall there is no warning that the rainfall will develop into a major flood, it may start very intense and then stop abruptly or continue into a flood.

On large catchments rainfall and/or water level recorders capture the event and from this the BoM can make predictions which enable action by emergency services. The very short response time means that this is not possible in the study area catchments. Even if the emergency services had advance warning (i.e from when the rain starts to flooding downstream) they would need time to mobilise and travel to the area. Thus it is unrealistic to expect that emergency services can respond in small urban catchments prior to the commencement of flooding. It is also likely that emergency services will be occupied in other roles in nearby areas (car crash, fallen power poles, fallen trees, roofs blown away, people trapped).

Whilst the critical duration storms for the 1% AEP has been determined as the 2 and 9 hour events this does not mean that the 1 hour event cannot produce peak levels very close to the 9 hour event. It would not therefore be prudent to provide detailed elapsed times from the start of the design rainfall until a road is cut as this is meaningless in small catchments as each flood is different. By providing such information this is indicating that there will be available warning time whereupon in reality this will most likely not be the case.

In the February 1990 event the rainfall occurred over a period on 5 days with several peaks and residents would have been aware of possible flooding after the first day. However in many other floods in NSW (Dungog - April 2015, Newcastle 2007, North Wollongong 1998) the very short response time means that residents are caught unaware. The same would apply with the duration of inundation. In general roads in the catchment will only be overtopped for less than 1 hour, however in a longer duration event with a smaller peak the extent of overtopping may reach 2 to 3 hours.

In conclusion it is not possible to provide exact figures for the time taken for roads to be cut or the duration of overtopping of structures as each flood is different.

A number of figures (Figure 40 to Figure 48) have been produced that present emergency response planning classifications for the 5%, 1% AEP and PMF events. These figures are:

- Figure 40a-e: Emergency Response Planning Classifications – 5% AEP– Glenning Valley;
- Figure 41a-j: Emergency Response Planning Classifications – 5% AEP – Tumbi Umbi;
- Figure 42a-c: Emergency Response Planning Classifications – 5% AEP – Eastern Coastal Catchments;
- Figure 43a-e: Emergency Response Planning Classifications – 1% AEP – Glenning Valley;
- Figure 44a-j: Emergency Response Planning Classifications – 1% AEP – Tumbi Umbi;

- Figure 45a-c: Emergency Response Planning Classifications – 1% AEP – Eastern Coastal Catchments;
- Figure 46a-e: Emergency Response Planning Classifications – PMF – Glenning Valley;
- Figure 47a-j: Emergency Response Planning Classifications – PMF – Tumbi Umbi; and
- Figure 48a-c: Emergency Response Planning Classifications – PMF – Eastern Coastal Catchments.

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.

6. CONCLUSIONS

The Tuggerah Lakes Southern Catchments Flood Study presented herein has been prepared by WMAwater on behalf of the Central Coast Council (Council) and constitutes the first and second stages of the NSW Floodplain Risk Management Program. The Study considered flooding in the Tuggerah Lakes Southern Catchments from mainstream and major overland flow inundation.

As part of this study hydrologic and hydraulic models were developed and calibrated/validated to historic flood information. The calibrated/validated models have been used to define design flood behaviour.

The information and results obtained from this study define design flood behaviour at the Tuggerah Lakes Southern Catchments and provide a firm basis for the development of a subsequent Floodplain Risk Management Study and Plan (FRMS&P).

7. ACKNOWLEDGEMENTS

WMAwater would like to acknowledge the assistance of the Central Coast Council staff in carrying out this work as well as The Office of Environment and Heritage and local residents.

The Central Coast Council has prepared this document with financial assistance from the NSW Government through its Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Office of Environment and Heritage.

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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

Tuggerah Lakes Southern Catchments
Flood Study

A flood study is currently being prepared for the southern catchments of Tuggerah Lake. The Study Area includes the suburbs of Glenning Valley, Tumbi Umbi, Berkeley Vale, Bateau Bay Blue Bay, Toowoon Bay and Shelly Beach. Wyong Shire Council have appointed WMAwater specialist engineering consultants to undertake this Study.

The Floodplain Management Process

Wyong Shire Council is carrying out a Flood Study under the NSW Government's Flood Prone Land Policy. The primary objective of the Policy is to reduce the impact of flooding and flood liability on owners and occupants of flood prone land and to reduce losses from flooding. The Policy provides for technical and financial support by the NSW State Government through four sequential stages:

1. **Flood Study**
   Determine the nature and extent of the flood problem

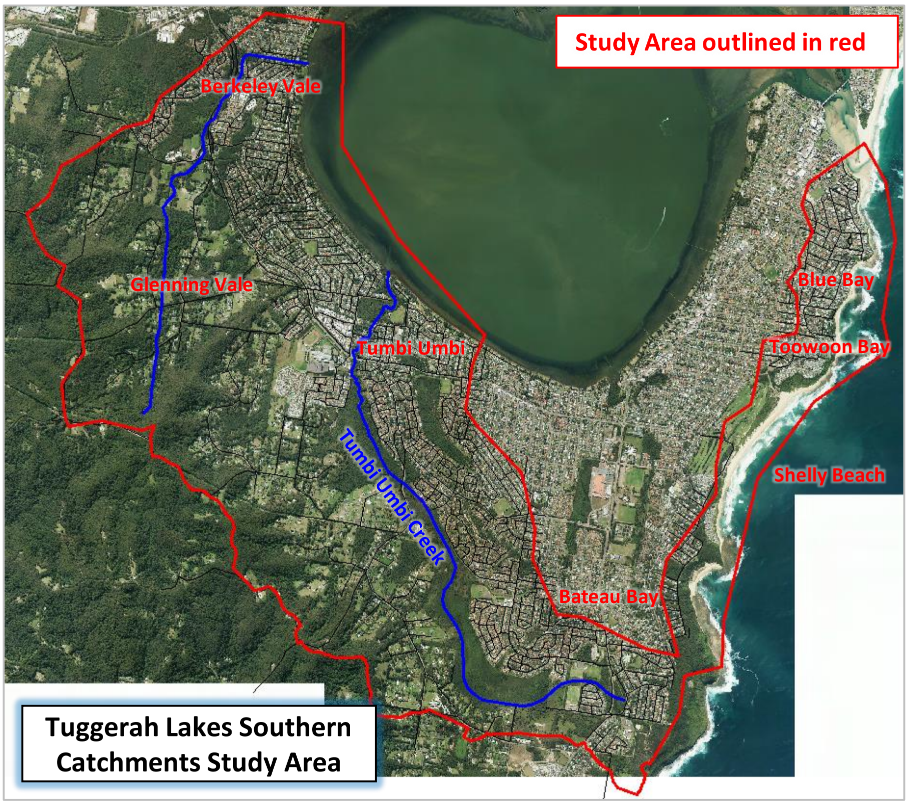
2. **Floodplain Risk Management Study**
   Evaluates management options for the floodplain in respect of existing and proposed development.

3. **Floodplain Risk Management Plan**
   Formal adoption by Council of a plan of management for the floodplain

4. **Implementation of the Plan**
   Construction of flood mitigation works to protect existing development and use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Flood Study is phase one of the four step process listed above. The Study will define flood behaviour over a range of floods of varying magnitudes.

The Study Area



The Study Area covers a number of catchments to the south of Tuggerah Lakes and includes the suburbs of Glenning Valley, Tumbi Umbi, Berkeley Vale, Bateau Bay, Blue Bay, Toowoon Bay and Shelly Beach. This area is primarily composed of urban development north of Wyong Road and semi rural development to the south.

The Study Area has a number of waterways and overland flow paths that discharge into Tuggerah Lake which have the potential to cause property inundation. The area has a history of both mainstream and overland flooding with the most recent floods occurring in April 2015 and June 2007. Other significant flood events occurred in 1999 and 1982.

The largest waterway in the Study Area is Tumbi Umbi Creek which flows in a northerly direction before discharging into Tuggerah Lake.

Tuggerah Lakes Southern Catchments Flood Study

Wyong Shire Council

Community involvement in this Study is important. The Tuggerah Lakes Estuary, Coastal and Floodplain Management Committee includes members from Council, the Office of Environment and Heritage, and the community whom will oversee this Study. A questionnaire is included with this newsletter so your views and ideas can be included in this Study.

What's happening now?

This Flood Study aims to understand and determine the nature and extent of potential flooding in this area due to creeks and overland flow paths. The first stage of the Flood Study will be to collect, compile and review all available information, including valuable community knowledge and experiences.

A computer model will determine the extent and nature of flooding in the Study Area. Historical data, such as photos and observations of flooding behaviour, will be collected and used to ensure model accuracy. In particular, information on observed peak flood levels is most important.

How can I have my say?

Please complete the enclosed questionnaire and return to the FREEPOST address in the envelope provided before 31 May 2016.

If you have additional information or further comments, please attach these to your questionnaire response or email to the contacts below.

For more information on the study, you can contact either Council or WMAwater on the details below.

This newsletter and questionnaire forms part of our community consultation to collect information about previous floods and flood behaviour. 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 you 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.

Contacts

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NSW Government — Office of Environment & Heritage

This project was supported by the NSW Government's Floodplain Management Program

Tuggerah Lakes Southern Catchments Flood Study

Wyong Shire Council

Please complete this questionnaire and return to the FREEPOST address in the envelope provided. Please make sure all surveys are returned before 31st May 2016 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:
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 in this area?

☐ Years ☐ Months

4. Are you aware of flooding in your area?

☐ Very aware ☐ Some awareness ☐ Not aware at all

If "Very aware" or "Some awareness" do you have any information we could use such as photographs of flooding, recorded observations of flood depths or other information? Please provide details below or attach information. If possible, please include a location and a description of flood behaviour and dates when known.

5. Can you indicate the level or depth of flooding from previous flood events?

☐ Yes ☐ No

If "yes", please include a specific location, the date of flooding and relevant other information when available.

6. Has your property ever been affected by flooding?

☐ No ☐ Yes, but only the yard ☐ Yes, but only the shed/garage ☐ Yes, house

If yes, please provide details below.

7. Do you have recorded rainfall data?

☐ Yes *(if yes please attach)* ☐ No

Please attach any additional information or comments to this questionnaire or email: tuggerah_south@wmawater.com.au

Appendix C

BLOCKAGE ASSESMENT FORM AR&R PROJECT 11 GUIDELINES SEPTEMBER 2016

STRUCTURE : **Tuggerah Mixed Local Catchment Structures** **OPENING WIDTH:** **Various**

DEBRIS TYPE/MATERIAL/L_{10}/SOURCE AREA – *There may be more than one material type to consider!*

Debris Type/Material	L_{10}	Source Area	How Assessed
Floating	**5 m**	**Largely grassed with few scattered trees.**	**Google earth and street view and site visit**
Urban (floating)	**3 m**	**Well maintained urban area surrounding channel**	**Google earth and street view and site visit**
Non-floating	**Sand***	**Well maintained grassed rural and urban**	**Google earth and street view and site visit**

*** Soil type in the Study Area is predominately mix of coastal and alluvial sands (CSIRO 2014). Site inspection indicates that particle size was predominantly < 2 mm. Mean Sediment Size has been selected as 'Sand' rather than 'Clay/Silt' as a conservative assumption.**

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DEBRIS AVAILABILITY (HML) – *for the selected debris type/size and its source area*

Availability	Typical Source Area Characteristics	Notes
High	• *Dense forest, thick vegetation, extensive canopy, difficult to walk through with considerable fallen limbs, leaves and high levels of floor litter.* • *Streams with boulder/cobble beds and steep bed slopes and banks showing signs of substantial past bed/bank movements.* • *Arid areas, where loose vegetation and exposed loose soils occur and vegetation is sparse.* • *Urban areas that are not well maintained and/or old paling fences, sheds, cars and/or stored loose material etc., are present on the floodplain close to the water course.*	High. Largely dense, thick vegetation, and swamp lands.
Medium	• *State forest areas with clear understory, grazing land with stands of trees* • *Source areas generally falling between the High and Low categories.*	Medium. Medium density urban areas that reasonably maintained.
Low	• *Well maintained rural lands and paddocks, with minimal outbuildings* • *Streams with moderate to flat slopes and stable beds and banks.* • *Arid areas where vegetation is deep rooted and soils resistant to scour* • *Urban areas that are well maintained with limited debris present in the source area.*	

DEBRIS MOBILITY (HML) - *for the selected debris type/size and its source area*

Mobility	Typical Source Area Characteristics	Notes
High	• Steep source area with fast response times and high annual rainfall and/or storm intensities and/or source areas subject to high rainfall intensities with sparse vegetation cover. • Receiving streams that frequently overtop their banks. • Main debris source areas close to streams	
Medium	• Source areas generally falling between the High and Low categories.	Medium. Medium intensity rainfall characteristics with debris close to stream. Source areas tend to be in relatively flat locations. Medium. Medium intensity rainfall characteristics with debris close to stream. Source areas tend to be in relatively flat locations.
Low	• Low rainfall intensities and large, flat source areas. • Receiving streams that Infrequently overtop their banks. • Main source areas well away from streams	

DEBRIS TRANSPORTABILITY (HML) - *for the selected debris type/size and stream characteristics*

Transportability	Typical Transporting Stream Characteristics	Notes
High	• Steep bed slopes (> 3%).and/or high stream velocity (V>2.5m/sec) • Deep stream relative to vertical debris dimension ($D>0.5L_{10}$) • Wide streams relative to horizontal debris dimension. ($W>L_{10}$) • Streams relatively straight and free of constrictions/snag points. • High temporal variability in maximum stream flows	
Medium	• Streams generally falling between High and Low categories	Medium. Medium bed slopes, velocities and channel dimensions. Medium. Medium bed slopes, velocities and channel dimensions.
Low	• Flat bed slopes (< 1%).and/or low stream velocity (V<1m/sec) • Shallow stream relative to vertical debris dimension ($D<0.5L_{10}$) • Narrow streams relative to horizontal debris dimension.($W<L_{10}$) • Streams meander with frequent constrictions/snag points. • Low temporal variability in maximum stream flows	

SITE BASED DEBRIS POTENTIAL 1%AEP (HML) - *for the selected debris type/size arriving at the site*

Debris Potential	Combinations of the Above (any order)	Notes
High	HHH or HHM	
Medium	MMM or HML or HMM or HLL	HMM (Floating) MMM (Urban floating)
Low (non-floating)	LLL or MML or MLL	

AEP ADJUSTED SITE DEBRIS POTENTIAL (HML) - *for the selected debris type/size*

Event AEP	At Site 1% AEP Debris Potential			AEP Adjusted At Site Debris potential	
	High	Medium	Low		
AEP > 5% *(frequent)*	Medium	Low	Low	**Low**	**Low**
AEP 5% - AEP 0.5%	High	Medium	Low	**Medium**	**Medium**
AEP < 0.5% *(rare)*	High	High	Medium	**High**	**High**

MOST LIKELY DESIGN INLET BLOCKAGE LEVEL (B_{DES}%) *for the selected debris type/size*

Control Dimension Inlet Width W (m)	At-Site Debris Potential (Generally)		
	High	Medium	Low
$W < L_{10}$	100%	50%	25%
$W \geq L_{10} \leq 3*L_{10}$	20%	10%	0%
$W > 3*L_{10}$	10%	0%	0%

***Note: for all culverts in the Tuggerah area $W < L_{10}$**

Event AEP	BDes% FLOAT	BDes% FLOAT
AEP > 5% *(frequent)*	25%	25%
AEP 5% - AEP 0.5%	50%	50%
AEP < 0.5% *(rare)*	100%	100%

Barrel Blockage

LIKELIHOOD OF SEDIMENT BEING DEPOSITED IN THE BARREL OR WATERWAY (HML)

Peak Velocity Through Structure (m/s)	Mean Sediment Size Present				
	Clay/Silt 0.001 to 0.04 mm	Sand 0.04 to 2 mm	Gravel 2 to 63 mm	Cobbles 63 to 200 mm	Boulders > 200mm
> 5	L	L	L	M	H
3 - 5	L	L	M	H	H
1 - < 3	L	M	H	H	H
0.5 - < 1	M	H	H	H	H
< 0.5	H	H	H	H	H

*** Soil type in the Study Area is predominately mix of coastal and alluvial sands (CSIRO 2014). Site inspection indicates that particle size was predominantly < 2 mm. Mean Sediment Size has been selected as 'Sand' rather than 'Clay/Silt' as a conservative assumption.**

Examination of culverts in the TUFLOW model indicates that velocities at the time of peak vary. Accordingly the likelihood of sediment being deposited varies for each structure and has been determined independently.

MOST LIKELY DEPOSITION BLOCKAGE LEVELS

LIKELIHOOD THAT DEPOSITION WILL OCCUR (above table)	AEP Adjusted Non Floating Debris Potential (Sediment) at Structure		
	HIGH	MEDIUM	LOW
High	100%	60%	25%
MEDIUM	60%	40%	15%
LOW	25%	15%	0%

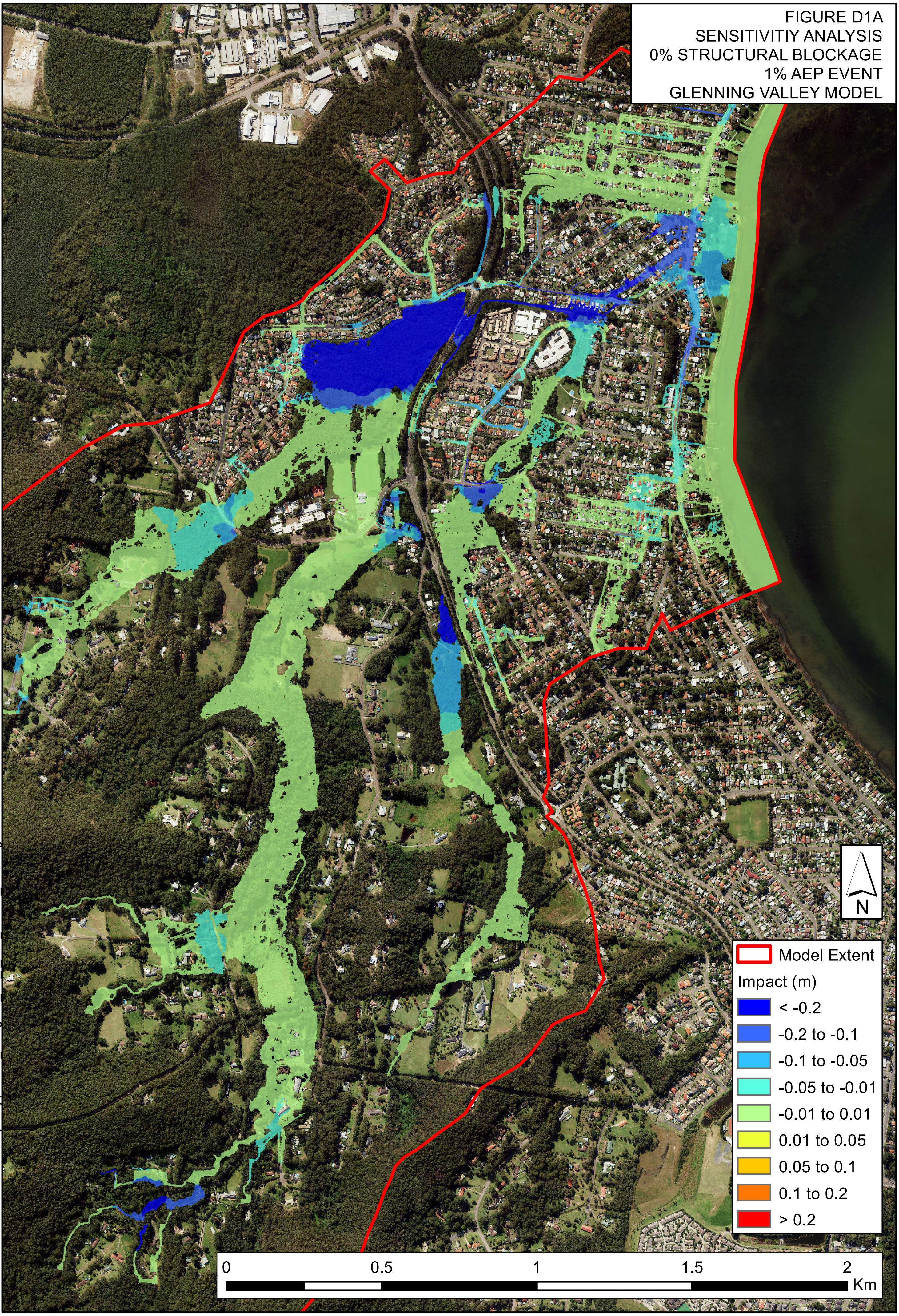
MOST LIKELY DESIGN INLET BLOCKAGE LEVEL (B_{DES}% Non-float)

Event AEP	BDes% NON-FLOAT*
AEP > 5% *(frequent)*	Varying dependent on velocity
AEP 5% - AEP 0.5%	Varying dependent on velocity
AEP < 0.5% *(rare)*	Varying dependent on velocity

*****Varying dependant on culvert flow velocity

Therefore $B_{DES\%}$ is > for Floating debris.

Appendix D



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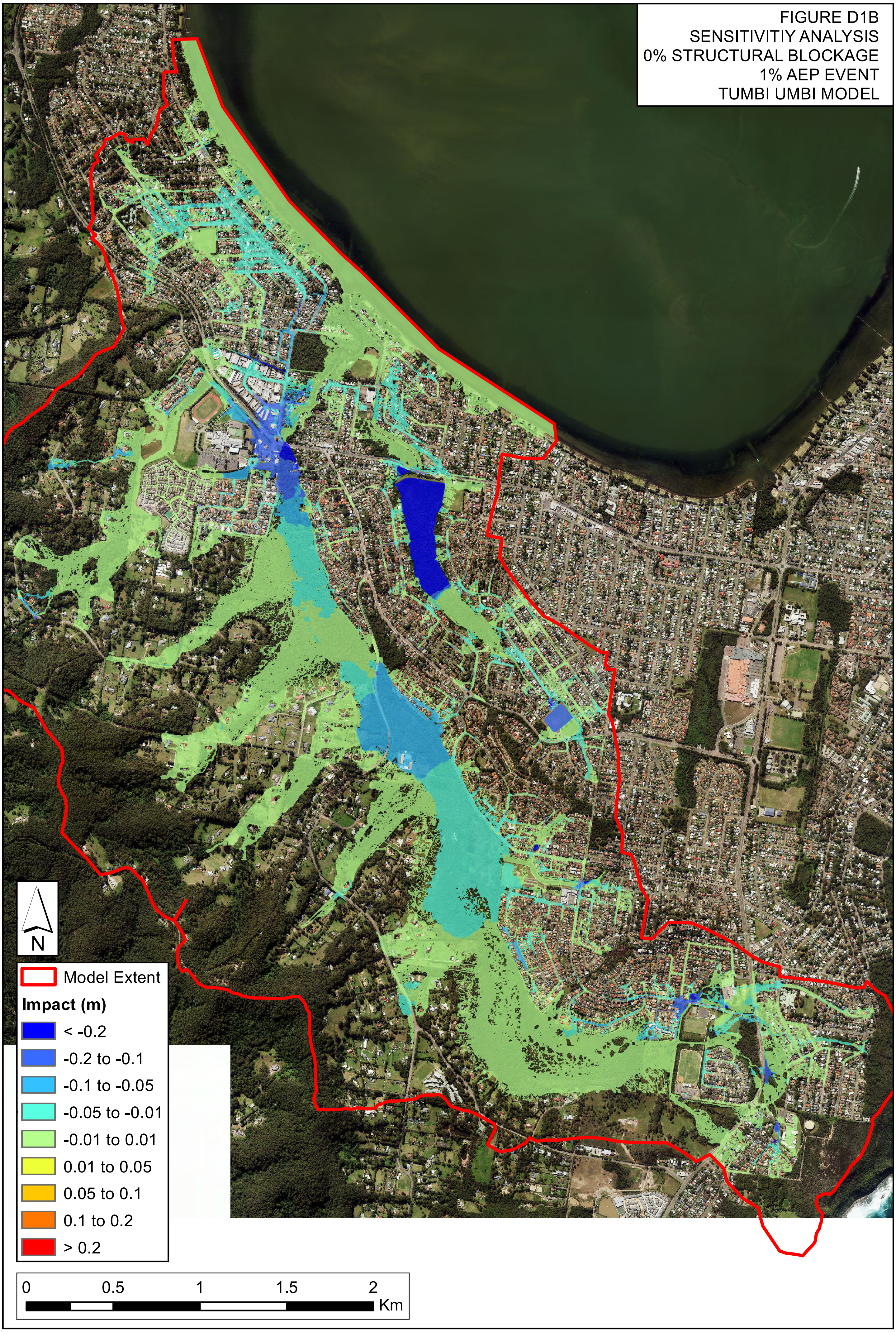

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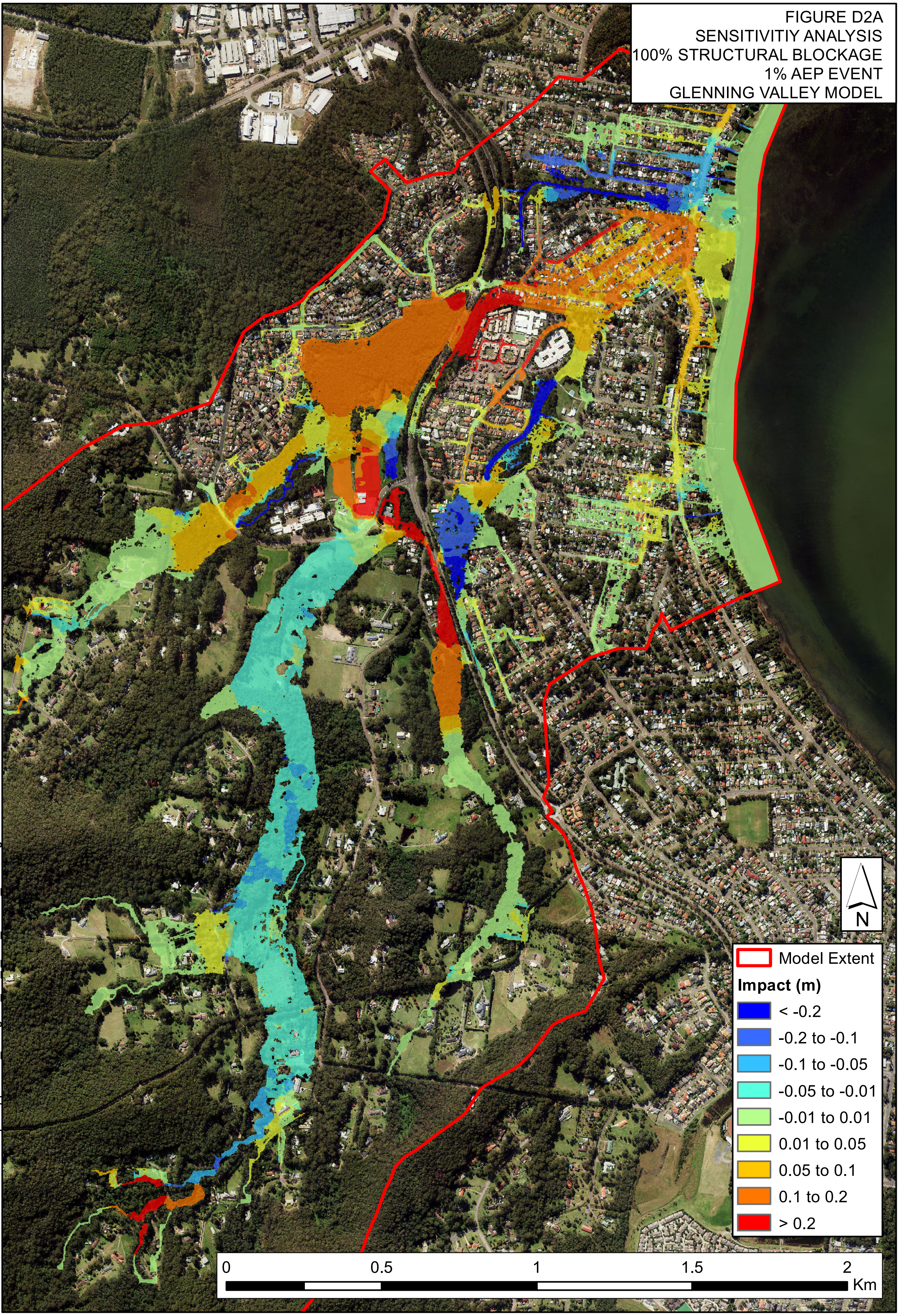

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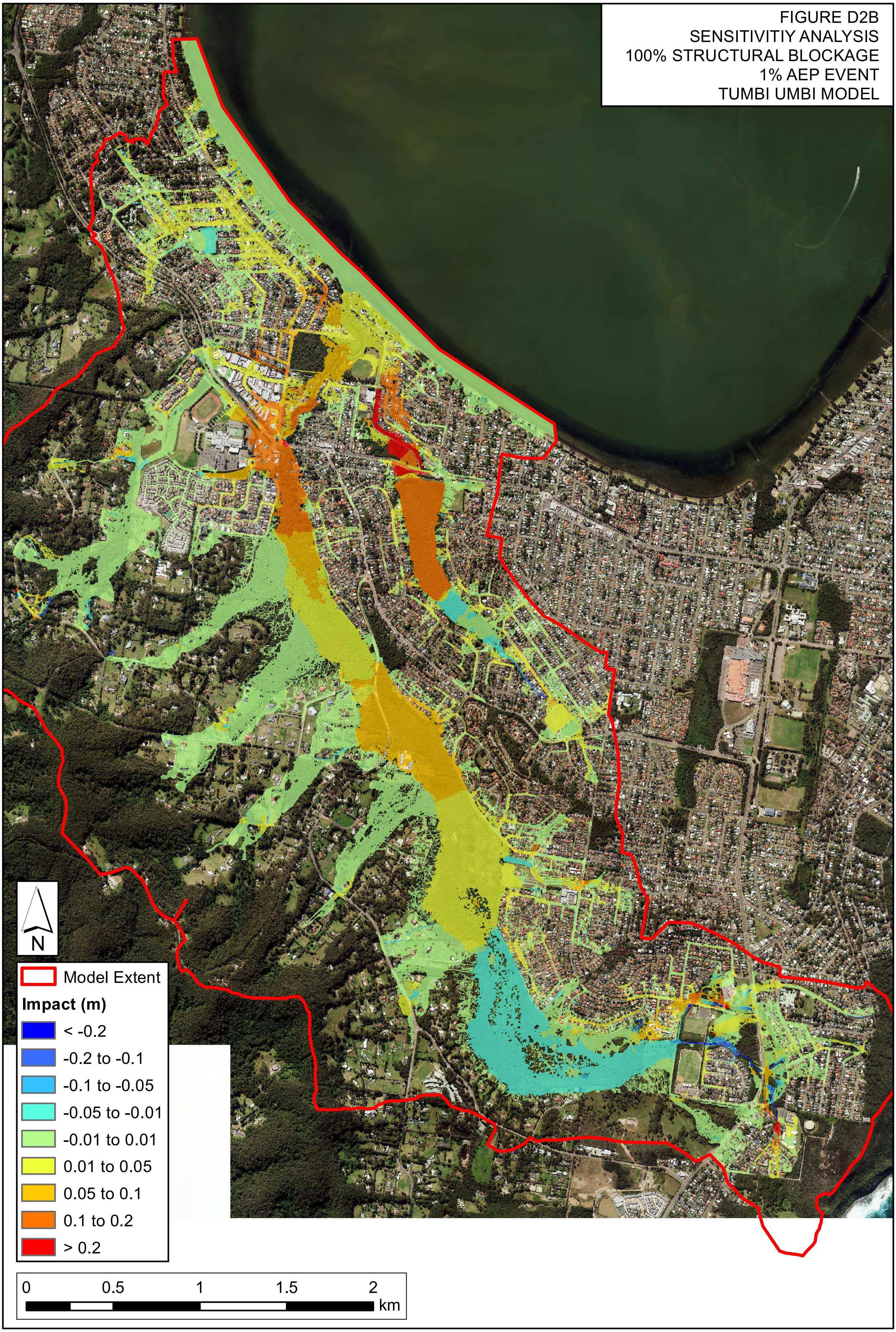

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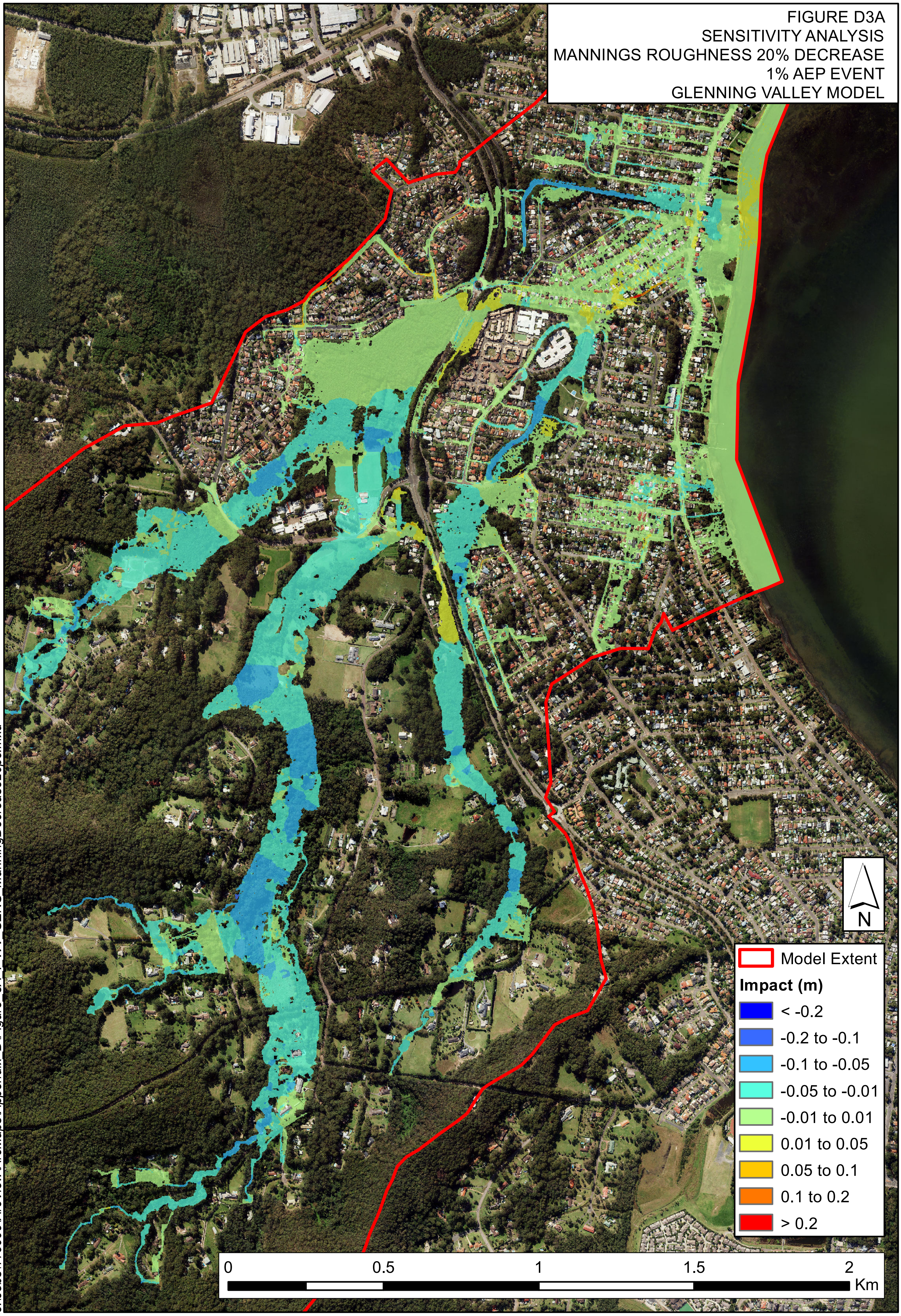
FIGURE D3A
SENSITIVITY ANALYSIS
MANNINGS ROUGHNESS 20% DECREASE
1% AEP EVENT
GLENNING VALLEY MODEL
N
Model Extent
Impact (m)
< -0.2
-0.2 to -0.1
-0.1 to -0.05
-0.05 to -0.01
-0.01 to 0.01
0.01 to 0.05
0.05 to 0.1
0.1 to 0.2
> 0.2
0
0.5
1
1.5
2
Km
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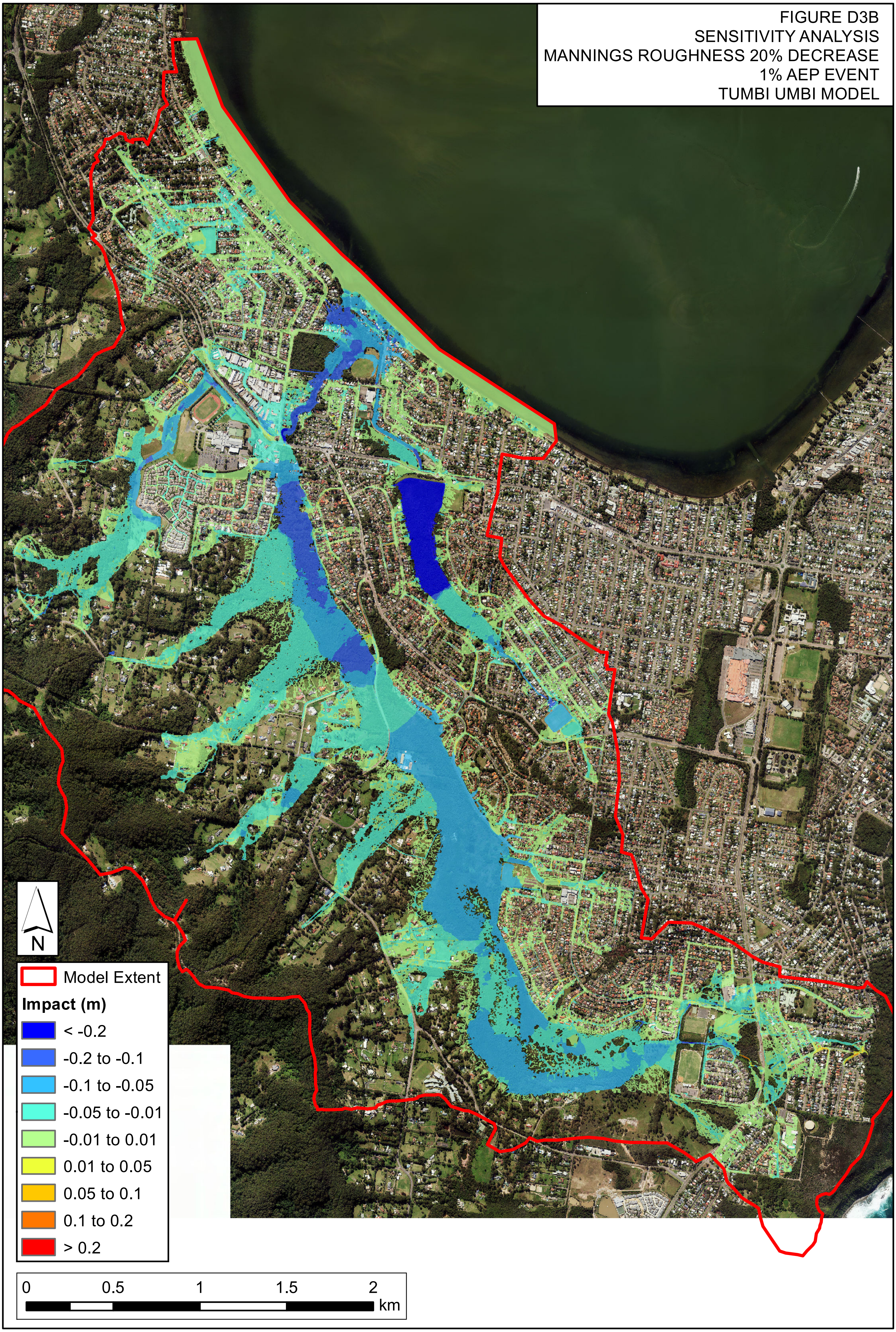

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FIGURE D3C
SENSITIVITY ANALYSIS
MANNINGS ROUGHNESS 20% DECREASE
1% AEP EVENT
EASTERN COASTAL MODEL
N
Model Extent
Impact (m)
< -0.2
-0.2 to -0.1
-0.1 to -0.05
-0.05 to -0.01
-0.01 to 0.01
0.01 to 0.05
0.05 to 0.1
0.1 to 0.2
> 0.2
0
0.5
1
1.5
2
Km
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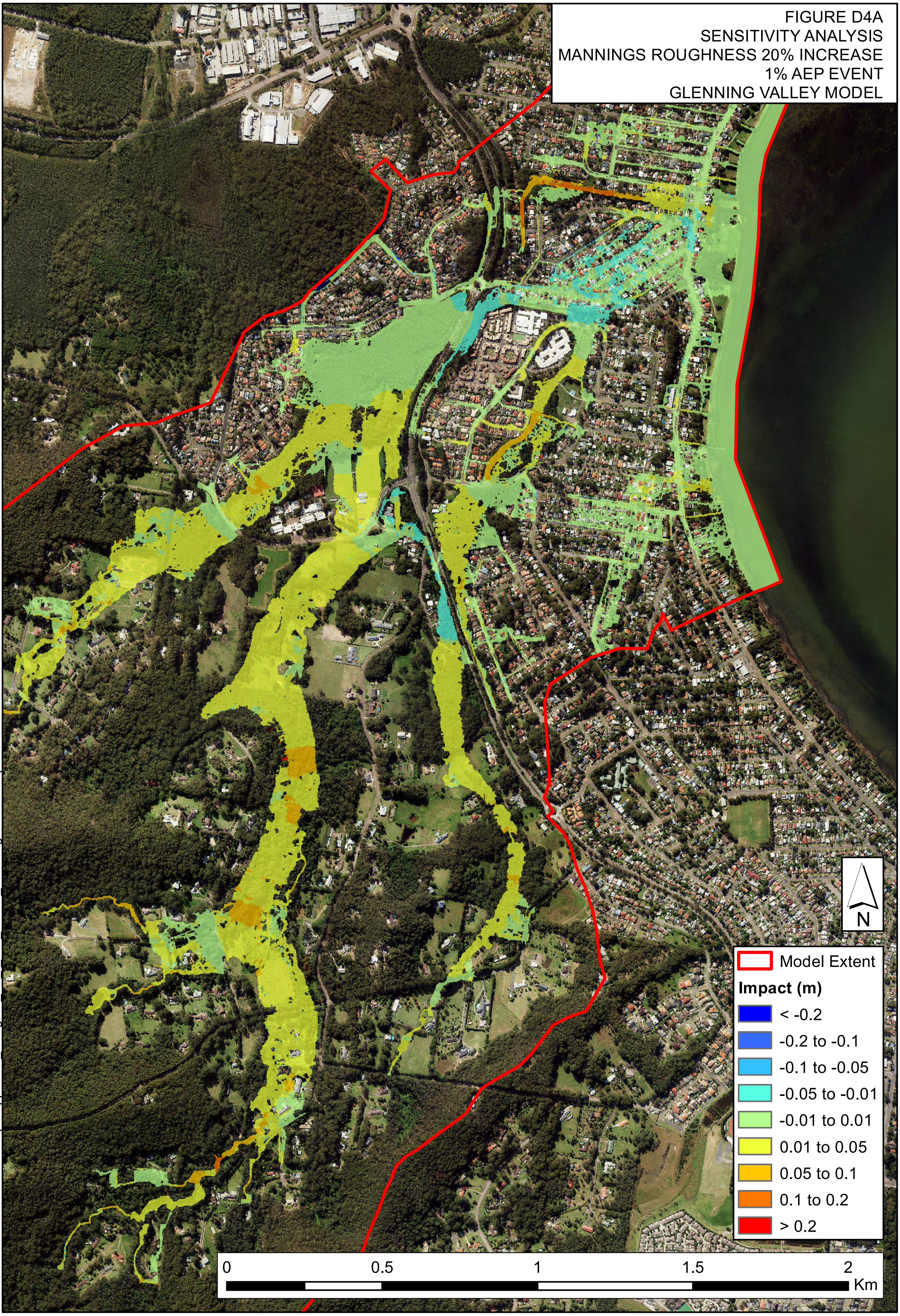

FIGURE D4A
SENSITIVITY ANALYSIS
MANNINGS ROUGHNESS 20% INCREASE
1% AEP EVENT
GLENNING VALLEY MODEL
N
Model Extent
Impact (m)
< -0.2
-0.2 to -0.1
-0.1 to -0.05
-0.05 to -0.01
-0.01 to 0.01
0.01 to 0.05
0.05 to 0.1
0.1 to 0.2
> 0.2
0
0.5
1
1.5
2
Km
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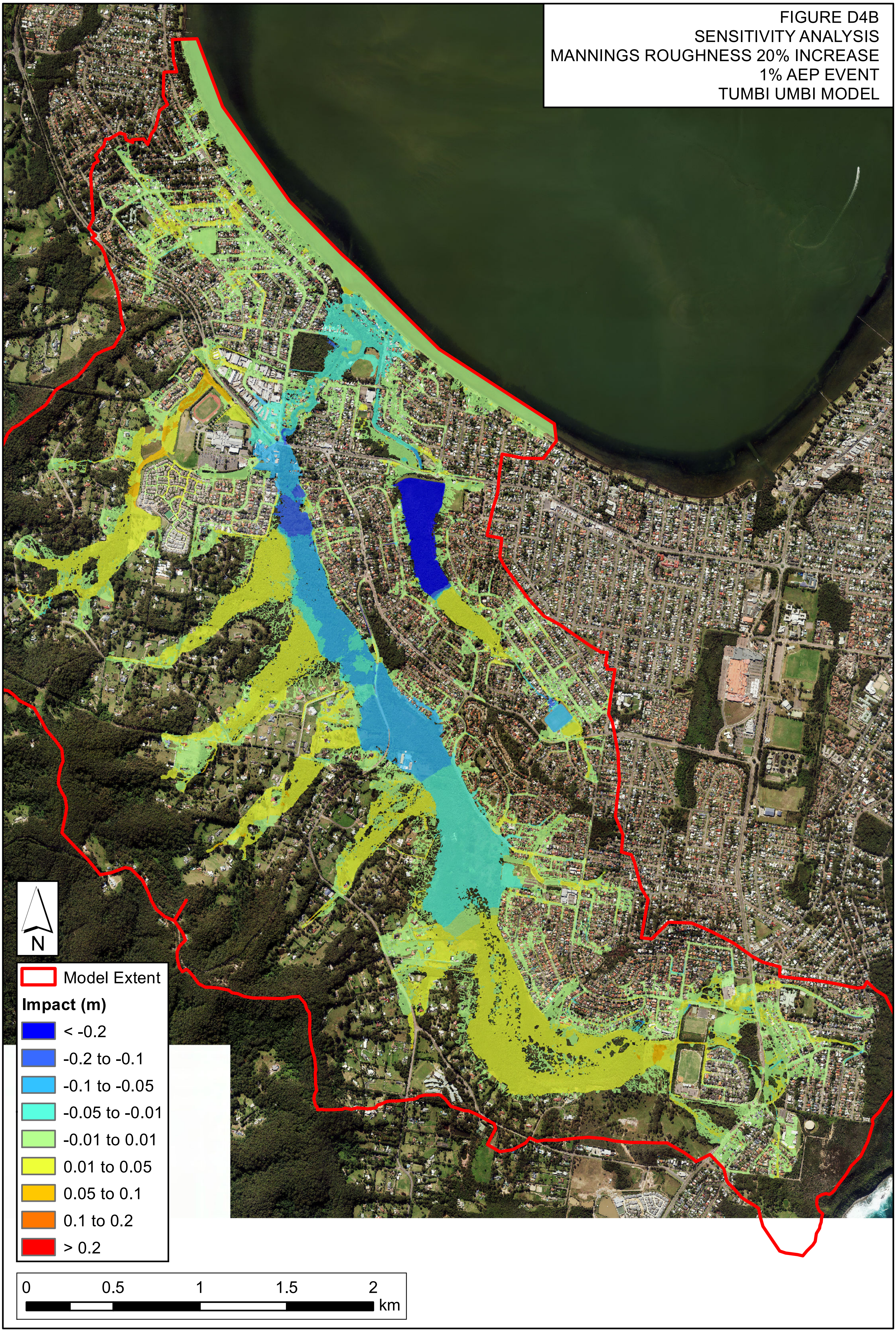

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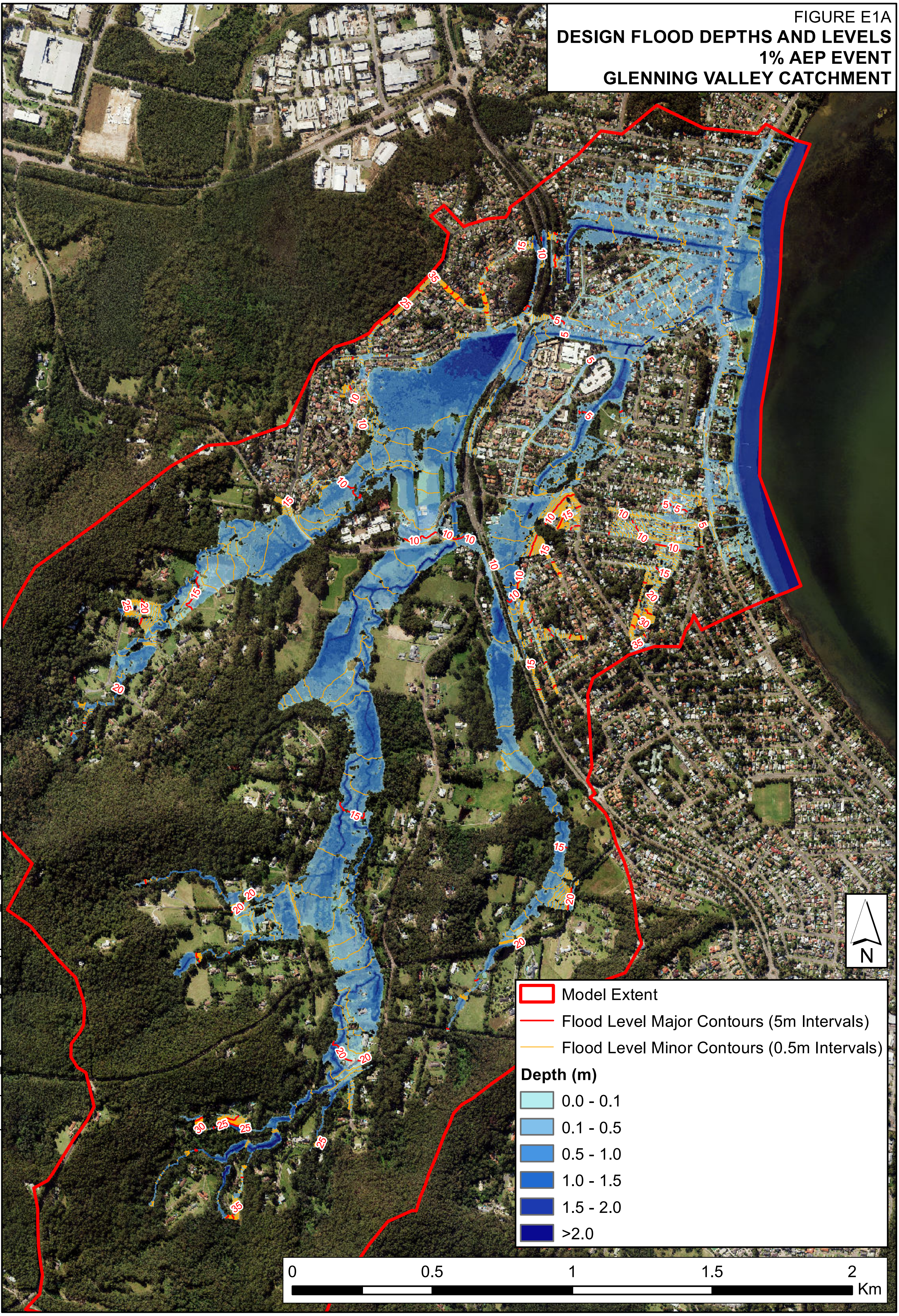
J:\Jobs\116009\ArcView\ArcMaps\Appendix D\Figure 4C I EB SENS ManningIncrease20pc.mxd

Appendix E



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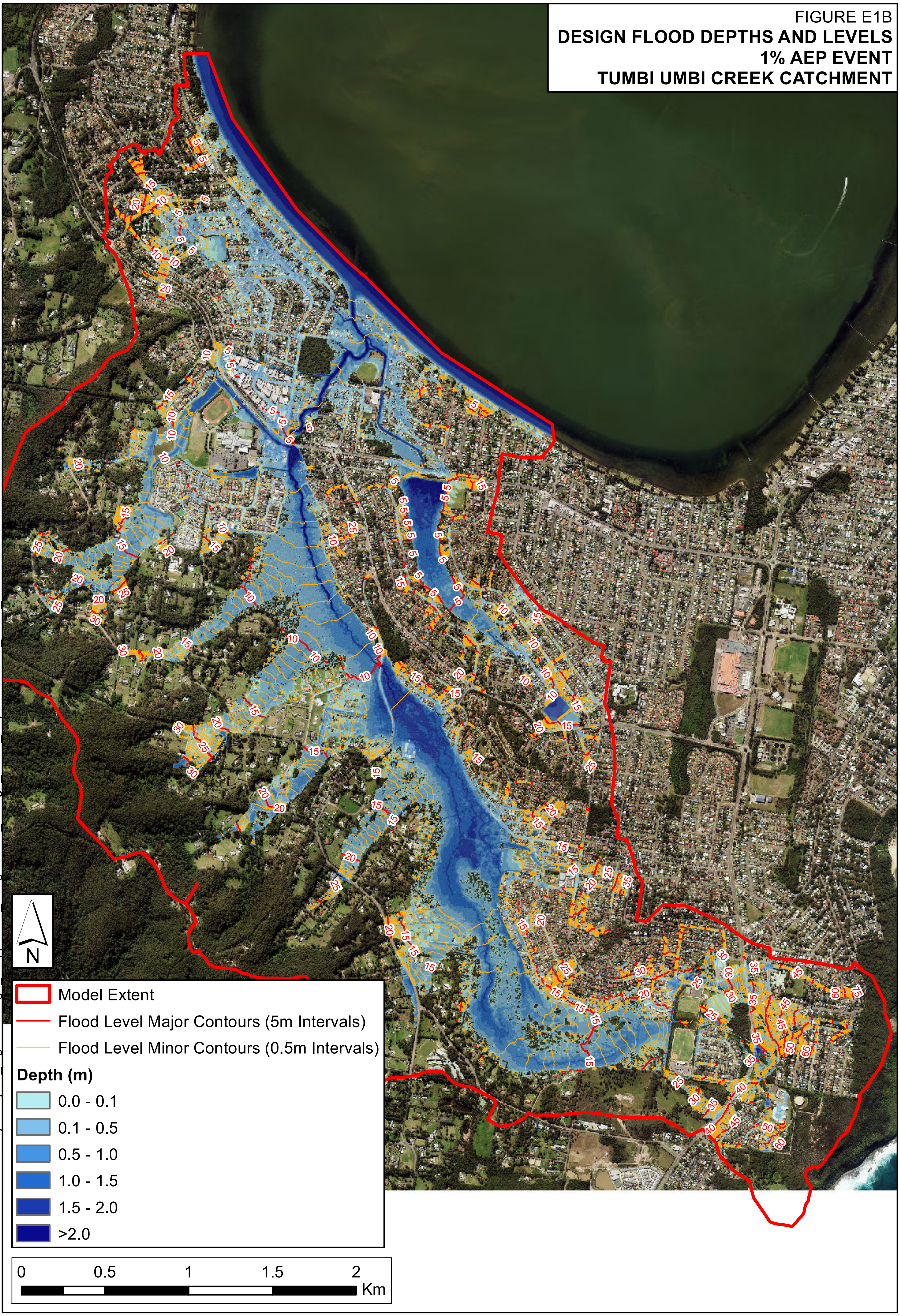

FIGURE E1B

DESIGN FLOOD DEPTHS AND LEVELS
1% AEP EVENT
TUMBI UMBI CREEK CATCHMENT

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FIGURE E1C
DESIGN FLOOD DEPTHS AND LEVELS
1% AEP EVENT
EASTERN COASTAL CATCHMENT
N
Model Extent
Flood Level Major Contours (5m Intervals)
Flood Level Minor Contours (0.5m Intervals)
Depth (m)
0.0 - 0.1
0.1 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
>2.0
0
0.5
1
1.5
2
Km
J:\Jobs\116009\ArcView\ArcMaps\Report_Figures\Stage_3\Appendix_E\FigureE1c_Design_Flood_Depths&Levels_100Y_FORMAT.mxd

FIGURE E2A

DESIGN FLOOD DEPTHS AND LEVELS PMF EVENT GLENNING VALLEY CATCHMENT

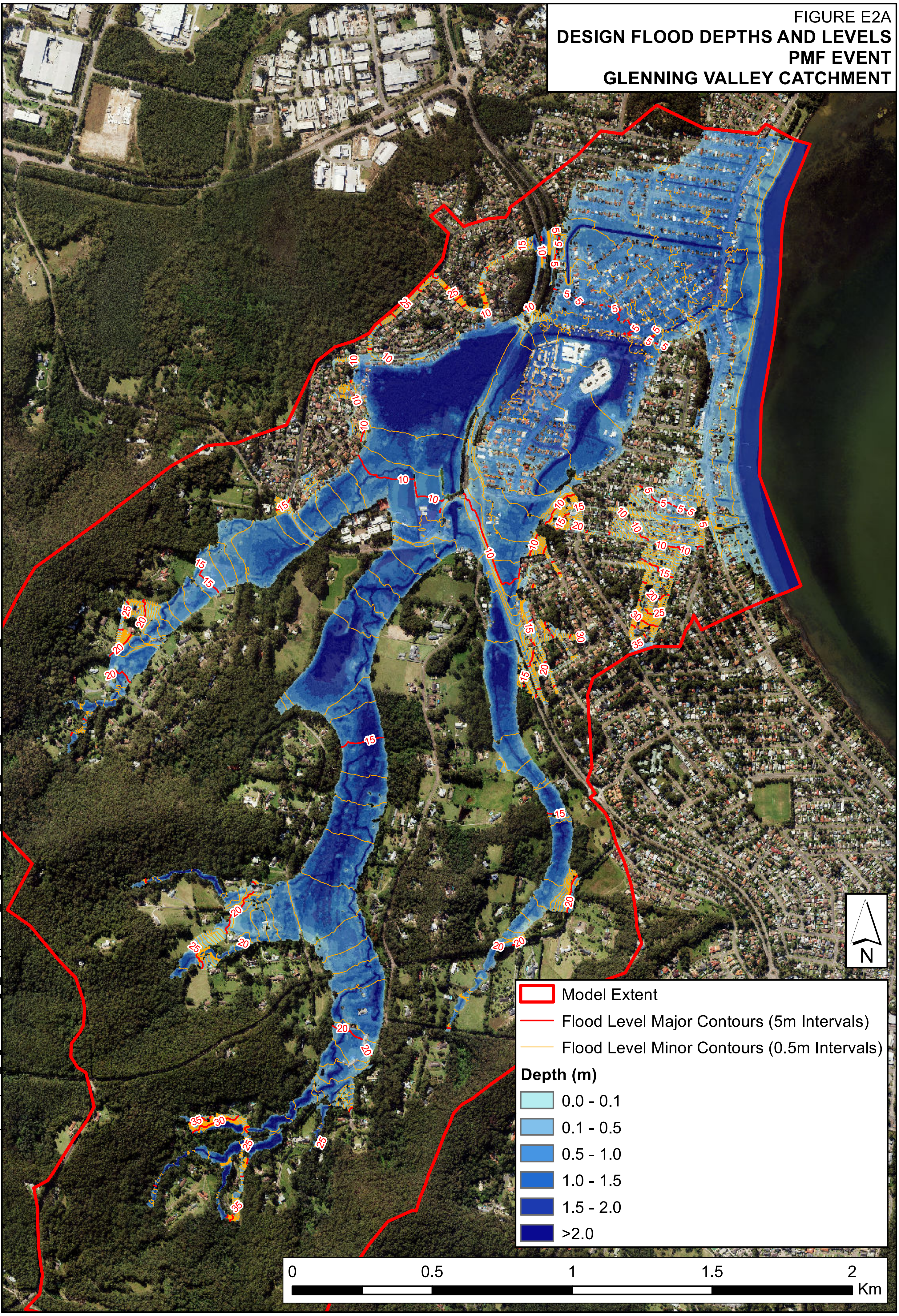

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FIGURE E2B
DESIGN FLOOD DEPTHS AND LEVELS
PMF EVENT
TUMBI UMBI CREEK CATCHMENT

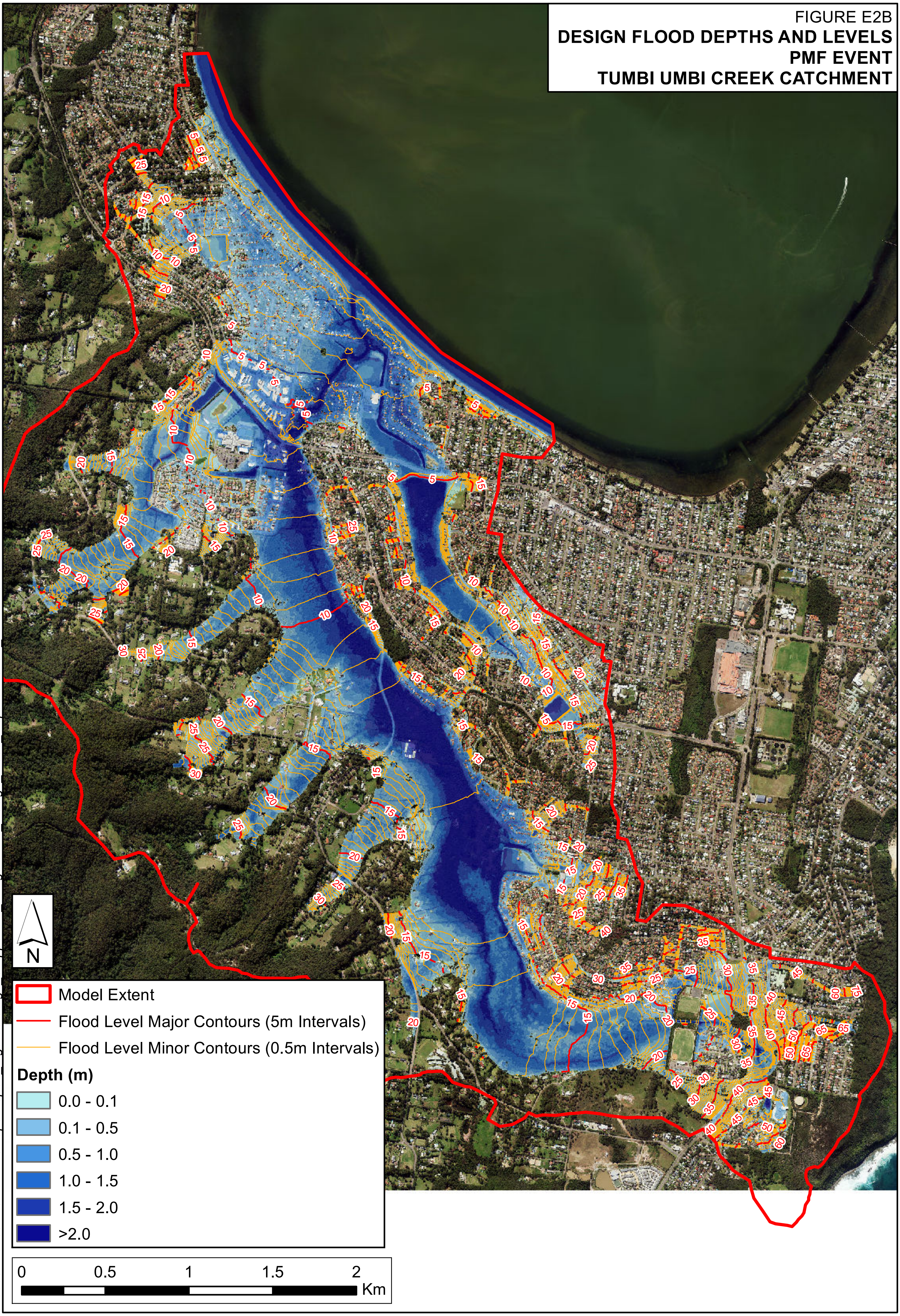

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FIGURE E2C

DESIGN FLOOD DEPTHS AND LEVELS
PMF EVENT
EASTERN COASTAL CATCHMENT

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FIGURE E3A
PRELIMINARY HYDRAULIC HAZARD
1% AEP EVENT
GLENNING VALLEY CATCHMENT

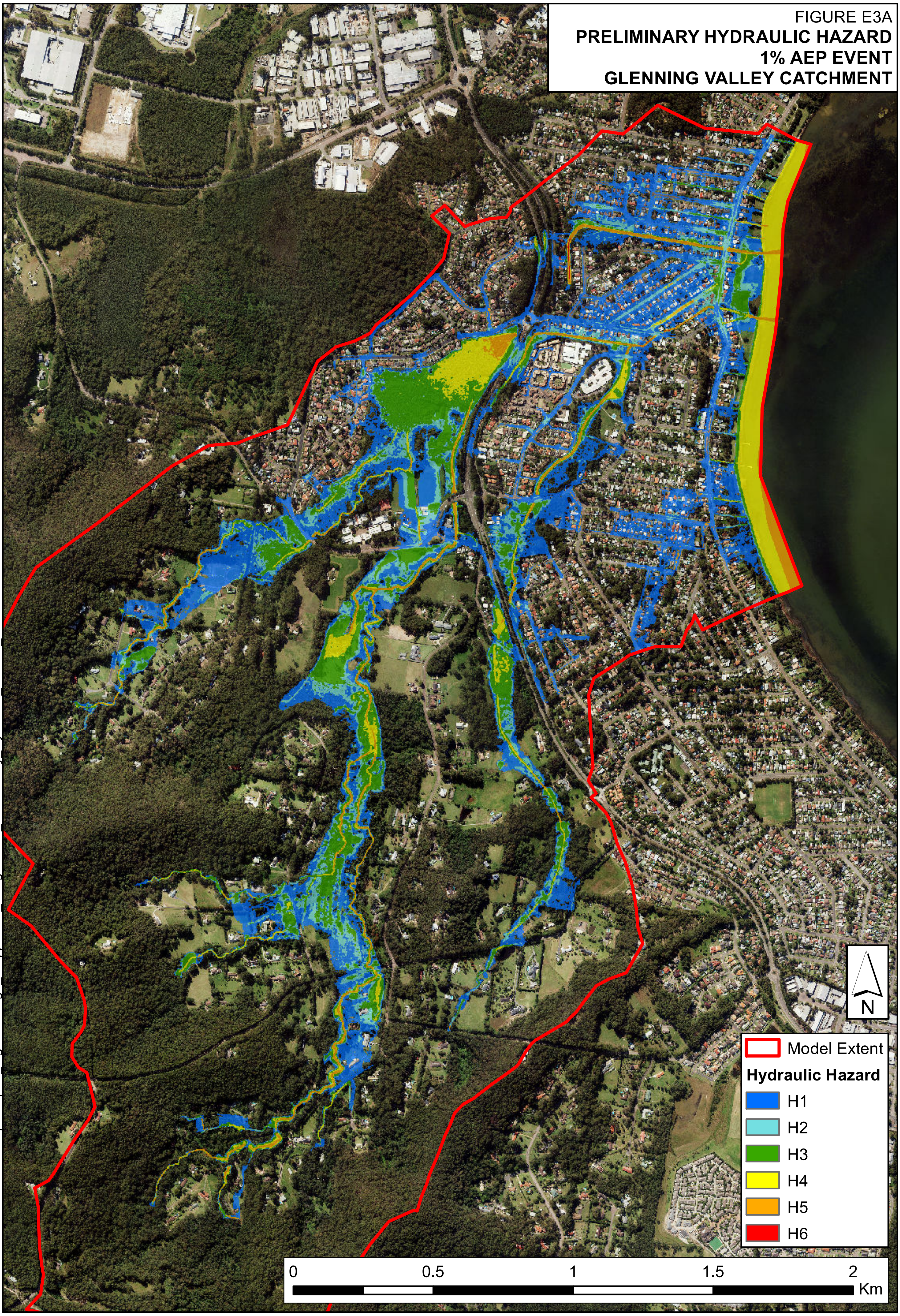

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FIGURE E3B
PRELIMINARY HYDRAULIC HAZARD
1% AEP EVENT
TUMBI UMBI CREEK CATCHMENT

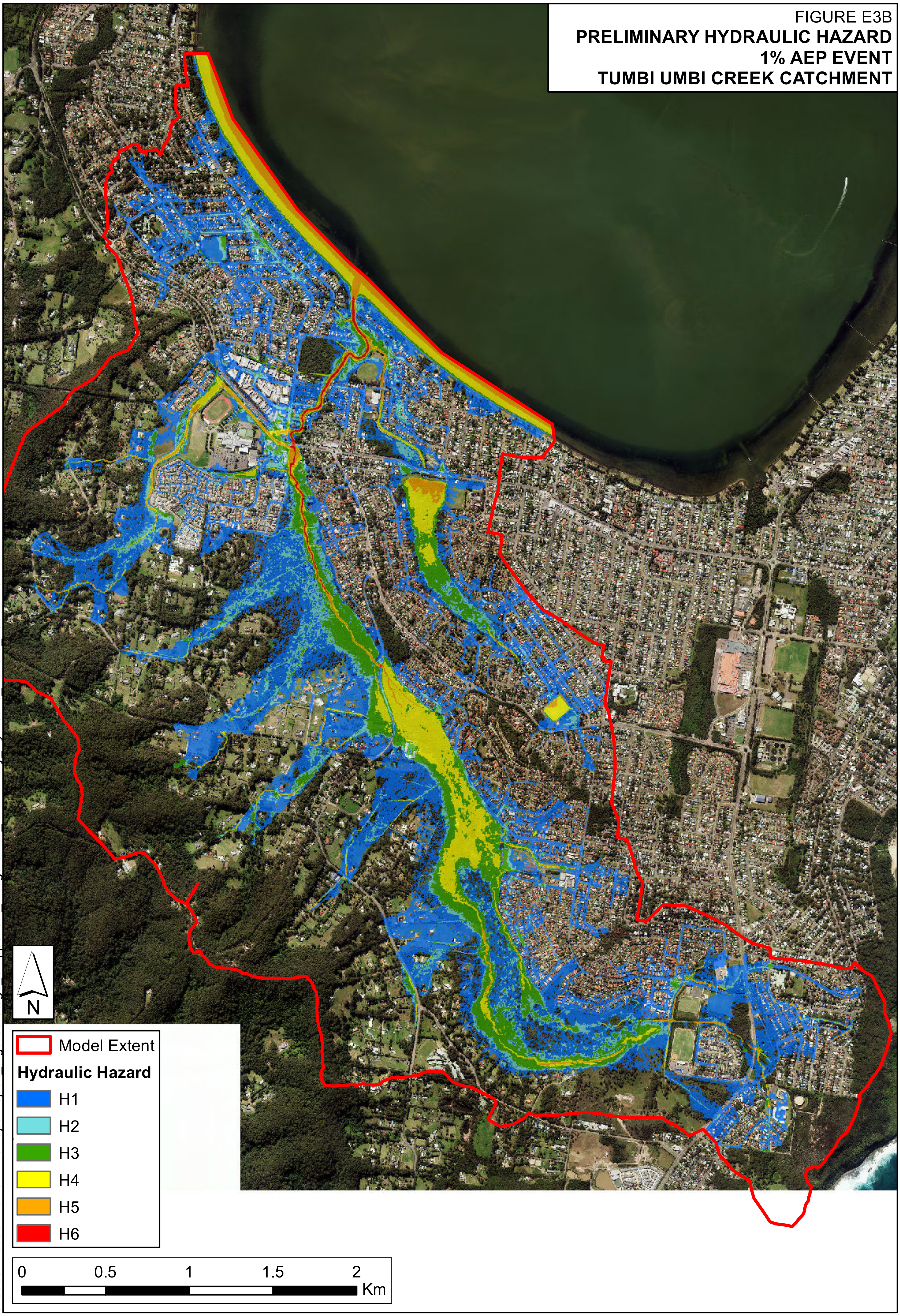

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FIGURE E3C
PRELIMINARY HYDRAULIC HAZARD
1% AEP EVENT
EASTERN COASTAL CATCHMENT
N
Model Extent
Hydraulic Hazard
H1
H2
H3
H4
H5
H6
0
0.5
1
1.5
2
Km
J:\Jobs\116009\ArcView\ArcMaps\Report_Figures\Stage_3\Appendix_E\FigureE3c_Preliminary_Hydraulic_Hazard_100Y.mxd

FIGURE E4A

PRELIMINARY HYDRAULIC HAZARD
PMF EVENT
GLENNING VALLEY CATCHMENT

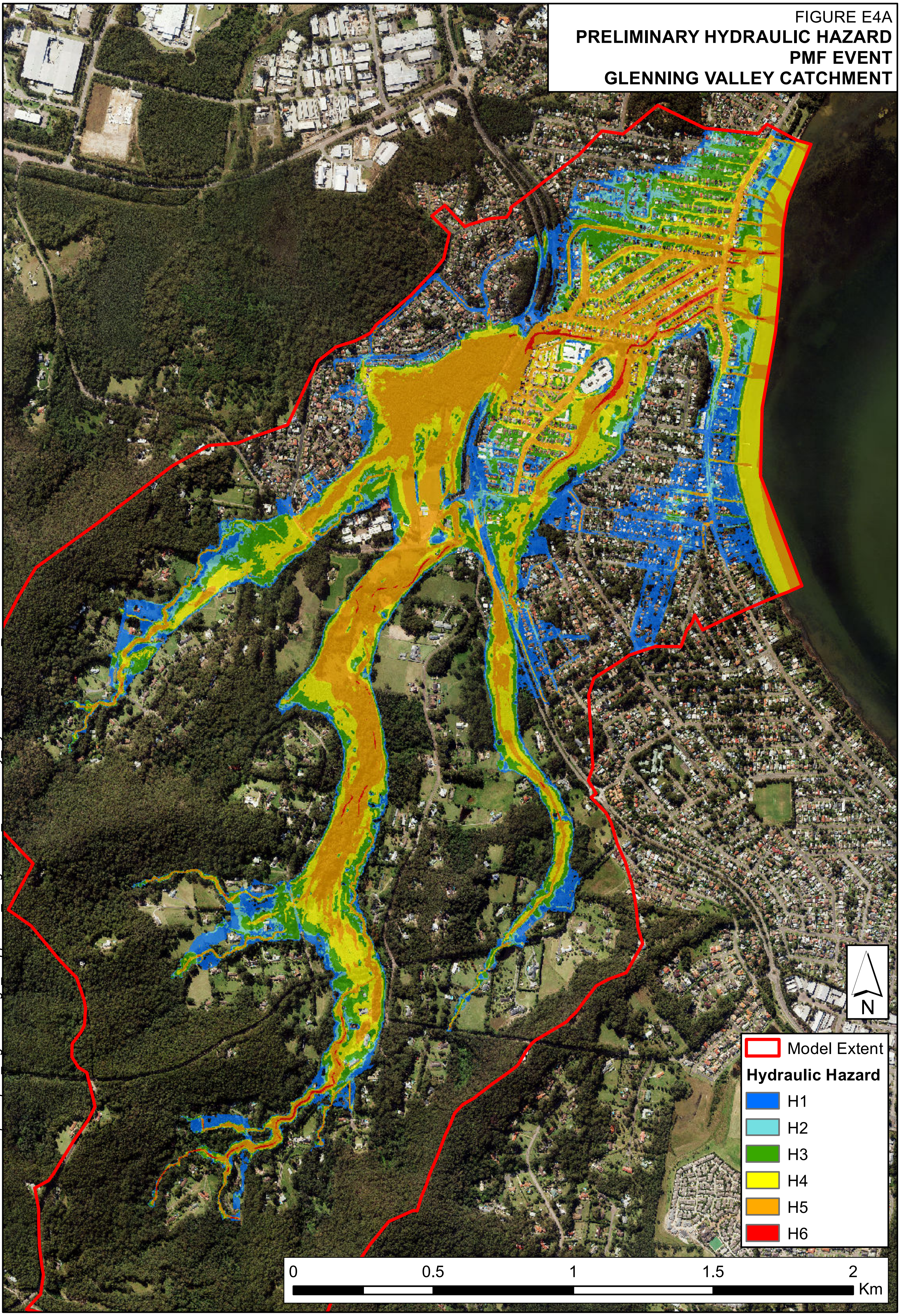

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FIGURE E4B
PRELIMINARY HYDRAULIC HAZARD
PMF EVENT
TUMBI UMBI CREEK CATCHMENT

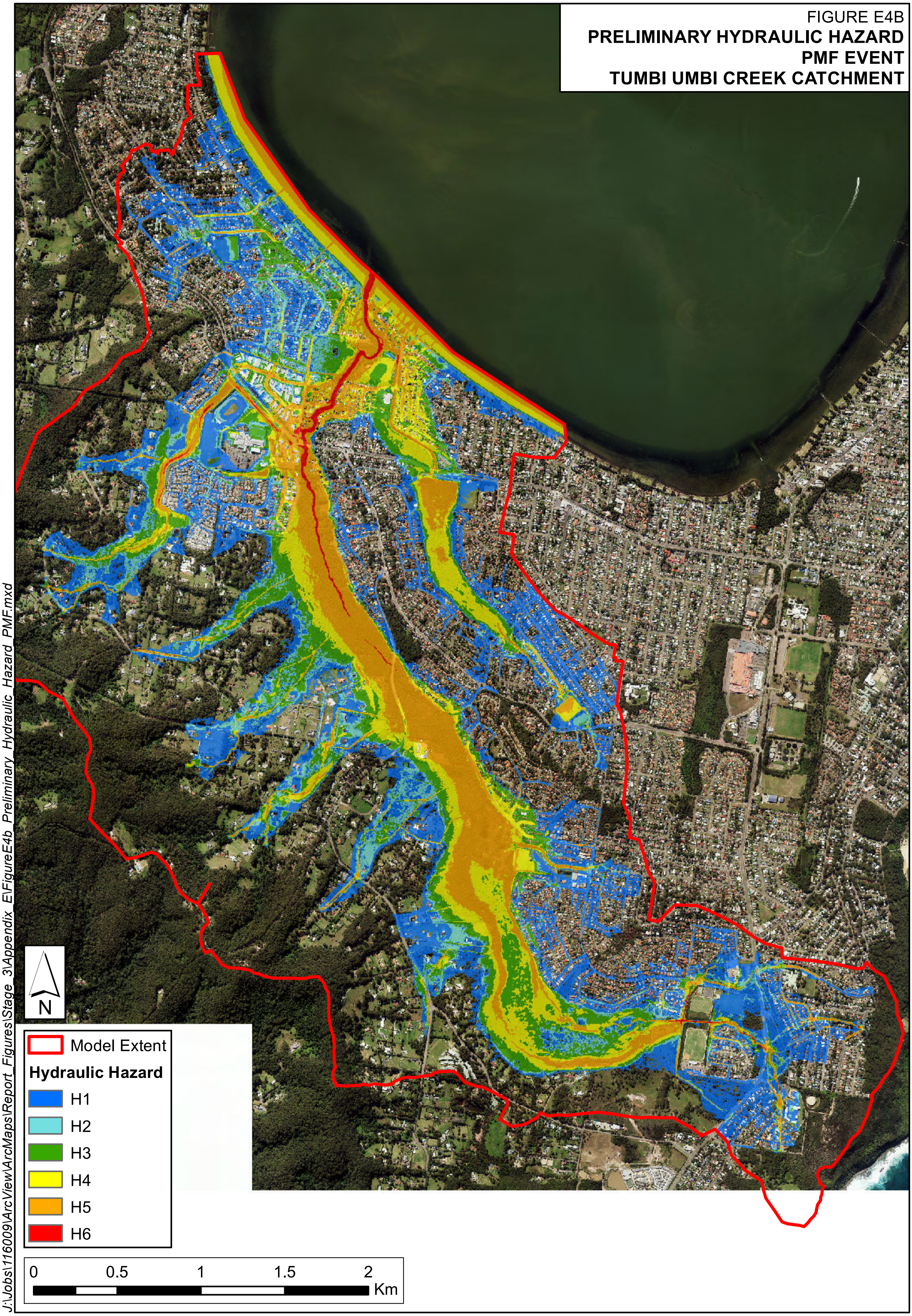

FIGURE E4C
PRELIMINARY HYDRAULIC HAZARD
PMF EVENT
EASTERN COASTAL CATCHMENT

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FIGURE E5A
INTERIM FLOOD PLANNING AREA
GLENNING VALLEY CATCHMENT

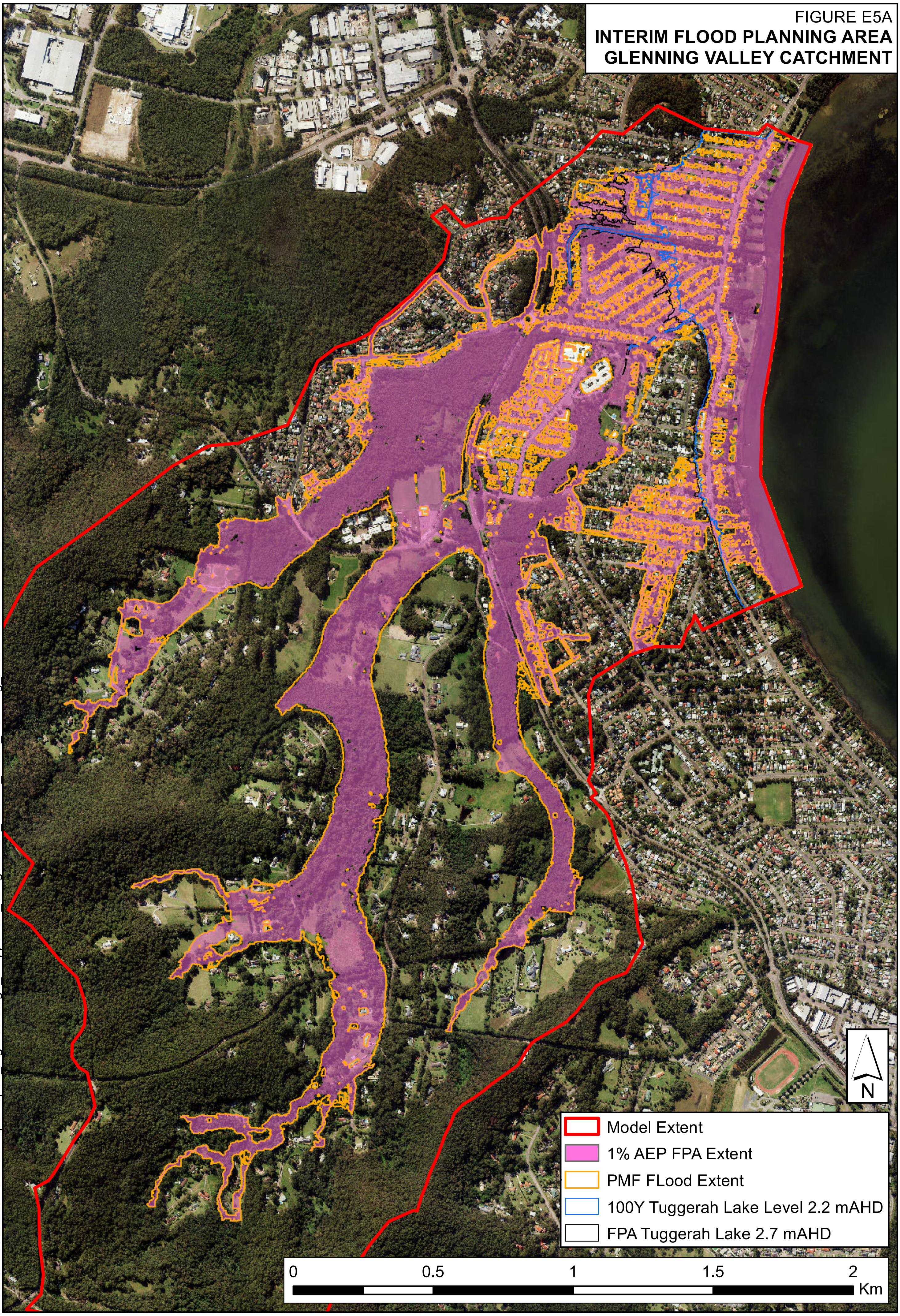

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FIGURE E5B
INTERIM FLOOD PLANNING AREA
TUMBI UMBI CREEK CATCHMENT
N
Model Extent
1% AEP FPA Extent
PMF Flood Extent
100Y Tuggerah Lake Level 2.2 mAHD
FPA Tuggerah Lake 2.7 mAHD
0
0.5
1
1.5
2
Km
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FIGURE E5C
INTERIM FLOOD PLANNING AREA
EASTERN COASTAL CATCHMENT
Model Extent
1% AEP FPA Extent
PMF Flood Extent
100Y Tuggerah Lake Level 2.2 mAHD
FPA Tuggerah Lake 2.7 mAHD
N
0
0.5
1
1.5
2
Km
J:\Jobs\116009\ArcView\ArcMaps\Report_Figures\Stage_3\Appendix_E\FigureE5c_Interim_Flood_Planning_Area.mxd