Flood Study Revision Report

Elliot Lake – Little Lake Floodplain Risk Management Study and Plan

W4917

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Executive Summary

This report provides an overview of the flood modelling work undertaken to update the previous Elliot Lake Little Lake Flood Study (Cardno Lawson Treloar, 2006). This flood study revision was undertaken as part of the overall Elliot Lake – Little Lake Floodplain Risk Management Study and Plan. The report details:

- Data compilation & review, as it relates to the flood modelling;
- Community consultation;
- Model setup;
- Model calibration & validation;
- Model setup for Design Flood Estimation; and
- Existing Scenario Design Flood Modelling Results.

It is intended that this report will eventually accompany the overall Floodplain Risk Management Study and Plan currently being prepared by Cardno.

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1 Introduction

Cardno was commissioned by Shellharbour City Council to undertake the Elliot Lake – Little Lake Floodplain Risk Management Study and Plan. The Elliot Lake – Little Lake catchment lies in the Shellharbour LGA and includes the suburbs of Barrack Heights, Shellharbour, Flinders, Blackbutt and large parts of Mt Warrigal and Warilla. A locality plan of the Elliot Lake – Little Lake catchment can be found in Figure 1-1.

This Flood Study update has been undertaken to provide a comprehensive investigation of flood behaviour, reviewing the nature and extent of flood risk in the catchment. A Flood Study for the Elliot Lake – Little Lake catchment was completed by Cardno Lawson Treloar in 2006. The Cardno Lawson Treloar Flood Study (2006) has been reviewed and updated using previously unavailable information to define mainstream flooding behaviour for a range of design events. This additional information included many observations from the large flood event that occurred in March 2011, which was valuable in calibrating the flood model. These tasks have been undertaken with the aim of ensuring community concerns are heard and addressed, as well as improving community awareness.

In accordance with its objectives, the study has determined the nature and extent of mainstream flooding through the estimation of design flood flows, levels and velocities from a calibrated model. This flood study update will then become a key input to the overall Floodplain Risk Management Study.

1.1 Study Process

The Floodplain Risk Management process is an iterative process which involves six stages:

1. Formation of a Floodplain Management Committee
2. Data Collection
3. Flood Study
4. Floodplain Risk Management Study
5. Floodplain Risk Management Plan
6. Implementation of the Floodplain Risk Management Plan.

This report addresses Stages 2 and 3.

1.2 Study Methodology

Detailed objectives of this study include:

- Review previous studies and available data (Section 3);
- Community consultation (Section 4);
- Detail the modelling methodology (Section 5);
- Define existing flood behaviour including assessment of recent historical events for calibration purposes (Sections 5, 6, and 7).

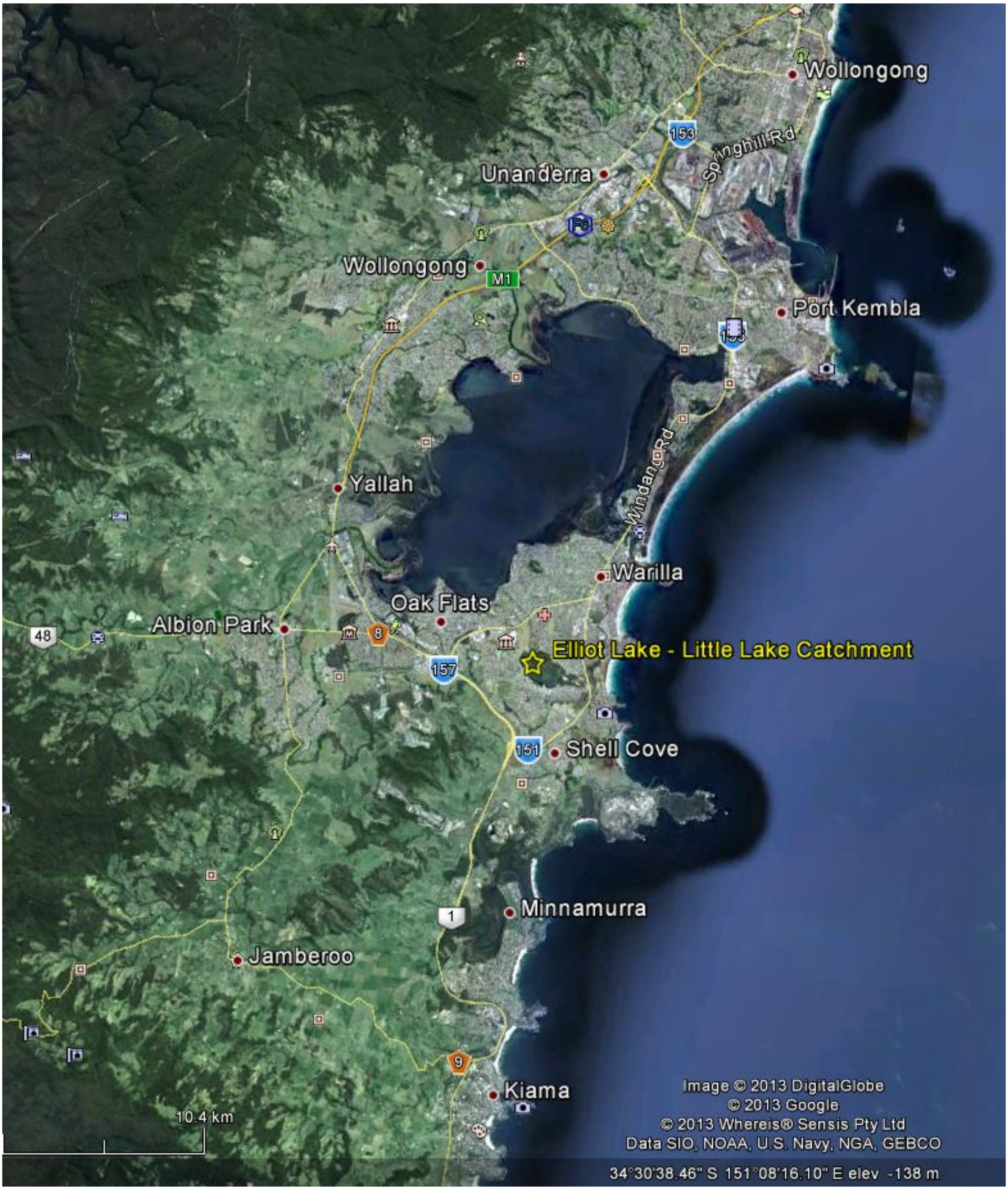

Figure 1-1 Locality Plan (courtesy Google Earth)

2 Catchment Description

The Elliot Lake – Little Lake catchment lies south of Lake Illawarra in the Shellharbour LGA and drains to the Tasman Sea via Elliot Lake – Little Lake. The catchment covers approximately 12.4 km^2 and includes the suburbs of Barrack Heights, Shellharbour, Flinders, Blackbutt and large parts of Mt Warrigal and Warilla. The majority of the catchment is urbanised with predominantly residential development and some business and light industry. Blackbutt Forest Reserve and the area upstream of the Princes Highway in the southern part of the catchment form the two main undeveloped areas.

The Study Area includes a majority of the catchment, but excludes most of the Blackbutt Forest Reserve and areas west of Fisher Rd and Brunderee Rd, as shown in Figure 2-1.

The main waterways of the catchment are Bensons Creek, Bensons Tributary and Tongarra Creek. Bensons Creek and Bensons Tributary drain the northern part of the study area, whilst Tongarra Creek drains the southern part. Both creeks drain into Elliot Lake – Little Lake which discharges to the Tasman Sea at Barrack Point. Most of these waterways are natural channels, except for:

- A piped section running from Andrew Park to Shellharbour War Memorial Park;
- A short concrete lined section in Bensons Creek just downstream of Shellharbour War Memorial Park; and
- A short concrete lined section in Bensons Tributary downstream of JN King Memorial Park.

The Elliot Lake – Little Lake catchment has experienced a number of flood events in recent years. Most notably, a significant flood event occurred in March 2011 which caused widespread property damage and a fatality.

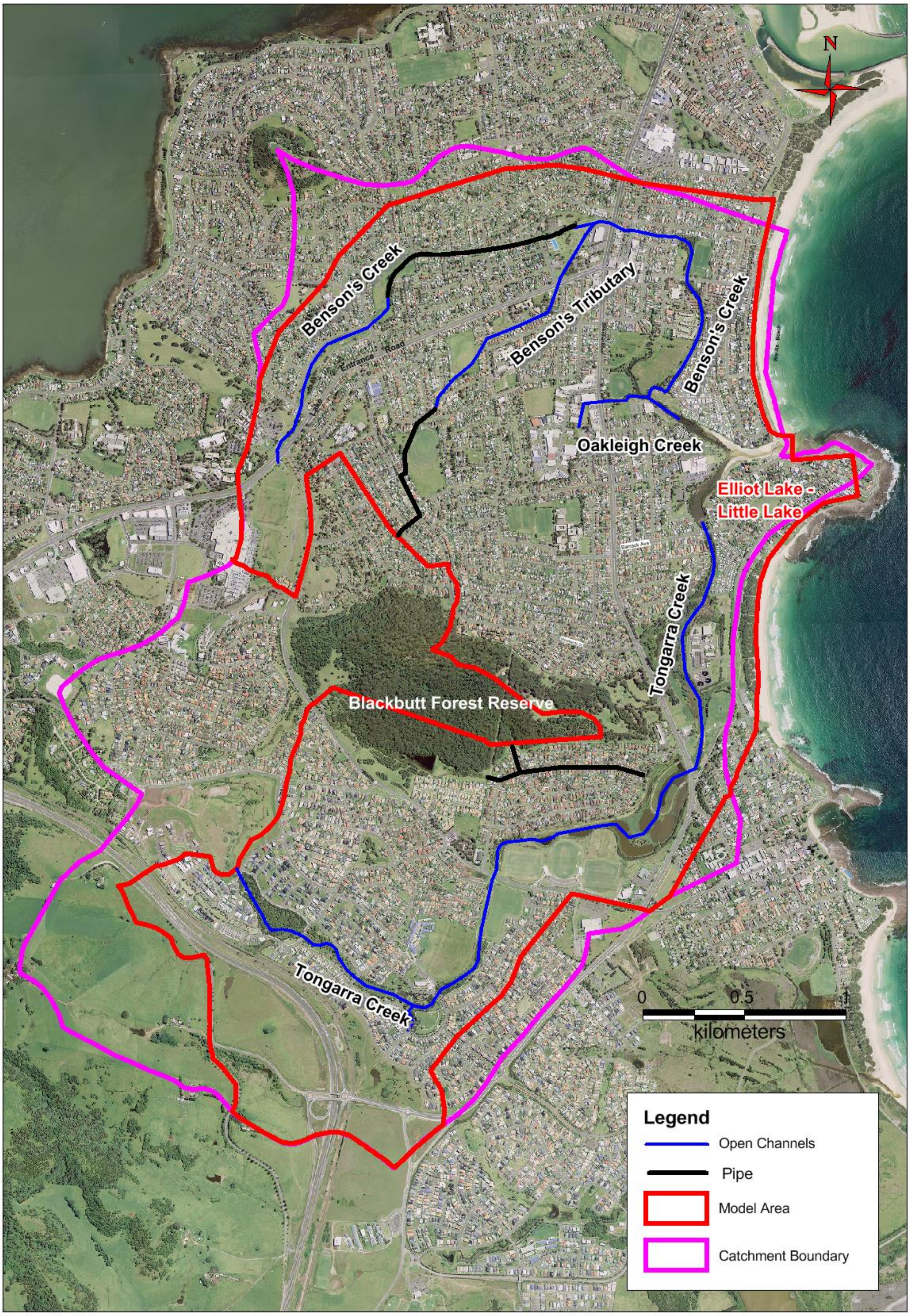

Figure 2-1 Elliot Lake – Little Lake Catchment and Study Area

3 Available Data

3.1 Previous Studies and Reports

A number of studies have been conducted concerning the Elliot Lake – Little Lake catchment and the recent flood event in March 2011. These reports were reviewed as part of this study and relevant information incorporated as required. Relevant studies are summarised in Table 3-1.

Table 3-1 Summary of Previous Studies and Reports

Study	Description
Elliot Lake – Little Lake Flood Study (Cardno Lawson Treloar, January 2006)	This study defined the flood behaviour for the catchment for a number of events including the PMF, 1% AEP, 5% AEP and the 20% AEP. Flooding behaviour was defined for two development stages of the catchment : 1) April 2001 and 2) fully developed/final catchment conditions (all urban areas fully developed along with inclusion of freshwater/saltwater wetland and sports fields along the wetland). The hydraulic model was calibrated using the May 1983 event and validated using the March 1975 event. The hydrologic and hydraulic models developed for this study have been used as the basis for flood modelling in the current study.
A Review of Rainfall & Flooding in the Shellharbour City LGA during the Storm of March 2011 (Rienco Consulting, March 2012)	This study summarised the available data (in terms of rainfall, runoff and tidal levels) for the March 2011 event. It also provided an analysis of rainfall for key locations within the LGA as well as description of antecedent conditions, tidal conditions and flood discharges. It was noted in the report that flood marks were available only for the Horsley Creek catchment and that none were available for the Elliot Lake catchment. A flood level at the Surfrider Caravan Park detailed in this report was used for model calibration.

Other studies and reports which were reviewed included:

- Dam Safety Emergency Plan for Blackbutt Dam (Van Drie, 2011);
- Elliot Lake (Little Lake) Estuary Management Study and Plan (WBM, 2003);
- Draft Shellharbour Coastal Zone Management Plan (BMT WBM, 2013);
- Seacrest Subdivision Riparian Concept Design (Storm Consulting, 2009); and
- An integrated research assessment of the physical and social aspects of the March 2011 flash flooding in Shellharbour, Kiama and Bega Valley, NSW (Risk Frontiers, 2013).
- A review of Rainfall and Flooding in the Shellharbour City LGA during the storm of March 2011. (Rienco Consulting, 2012).

3.2 Survey Information

The majority of the survey data utilised in the flood modelling for this study was taken from the Cardno Lawson Treloar Flood Study (2006). Additional ground survey was carried out by Craven, Elliston & Hayes (Dapto) Pty Ltd for areas not covered by existing survey or where it was deemed that additional detail was necessary (as shown in Figure 3-1). The final ground survey data was provided on 30th January 2013 and included:

- Additional cross - sections along the main open channels;
- Bathymetry of Elliot Lake-Little Lake;
- Historical flood levels based on observations gained from the community consultation process.

3.2.1 Additional Survey Information

Additional survey information was made available by Council on 24th September 2012:

- Bathymetry of Shadforth (Myimbarr) Wetlands;
- Bathymetry of Blackbutt Dam;
- Works as executed plans for Myimbarr Community Park and Playing Fields;
- Works as executed plans for the development at Precinct 28, Flinders; and
- Dunsters Lane to Shellharbour Rd Drainage Layout (Princes Highway).

Hydrographic Survey of Elliot Lake – Little Lake undertaken in 2002 was also downloaded from the NSW OEH Website:<http://www.environment.nsw.gov.au/estuaries/stats/ElliottLake.htm>.

3.2.2 ALS Data

Council provided Aerial Laser Scanning (ALS) levels surveyed in 2010 for the entire study area on 18th December 2012. Generally the accuracy of the ALS data is ± 0.15m to one standard deviation for the z-coordinate on hard surfaces.

3.3 GIS Data

Council provided Geographic Information System (GIS) data to update the existing Cardno Lawson Treloar (2006) flood model. The data provided included:

- Aerial Photography (1938, 1993, 2001 and 2010);
- Cadastre; and
- Pit and Pipe Data.

3.4 Site Inspections

Two site inspections of the study area were conducted. An initial site visit was carried out to determine the areas to be modelled and to undertake an initial overview of the key hydraulic features of the catchment.

A subsequent site visit was undertaken to fine tune the modelling approach, verify Mannings ‘n’ roughness values adopted, check reported flood levels from the March 2011 event and examine flooding hotspots in greater detail.

3.5 Historical Flood Information

The Shellharbour LGA experienced a storm event in March 2011 that caused significant and widespread flooding, particularly in the Elliot Lake - Little Lake catchment. This flood event was used for model calibration, due in part to the extent of flooding information available. The following were available for this event:

- Flood depths, photos and other information from the resident survey (refer Section 4);
- Flood information as detailed by Rienco Consulting (2012);
- Photos provided by Council for a number of areas within the catchment;
- Water level gauge at Elliot Lake – Little Lake (station 214466, maintained by MHL);
- Newspaper articles (mainly photos); and
- YouTube videos.
- Historical ocean levels (water level data) was obtained from the Port Kembla Tide gauge. This data was provided by the Port Kembla Ports Corporation.

A majority of the historical inundation information for this event was sourced from the community consultation process. Unlike in the case of the nearby Horsley Creek catchment, there were no surveyed flood marks available for this catchment prior to survey undertaken by Craven Elliston & Hayes (CEH Dapto). Craven Elliston & Hayes (CEH Dapto) provided historical flood levels based on observations from the community, as indicated in Section 3.2.

As reported in Cardno Lawson Treloar (2006), there were only two other historical events in recent years with a reasonable amount of observed inundation data (March 1975 and May 1983). The May 1983 event was used to validate the flood model, as there was more historical flooding information available for this event than the 1975 event.

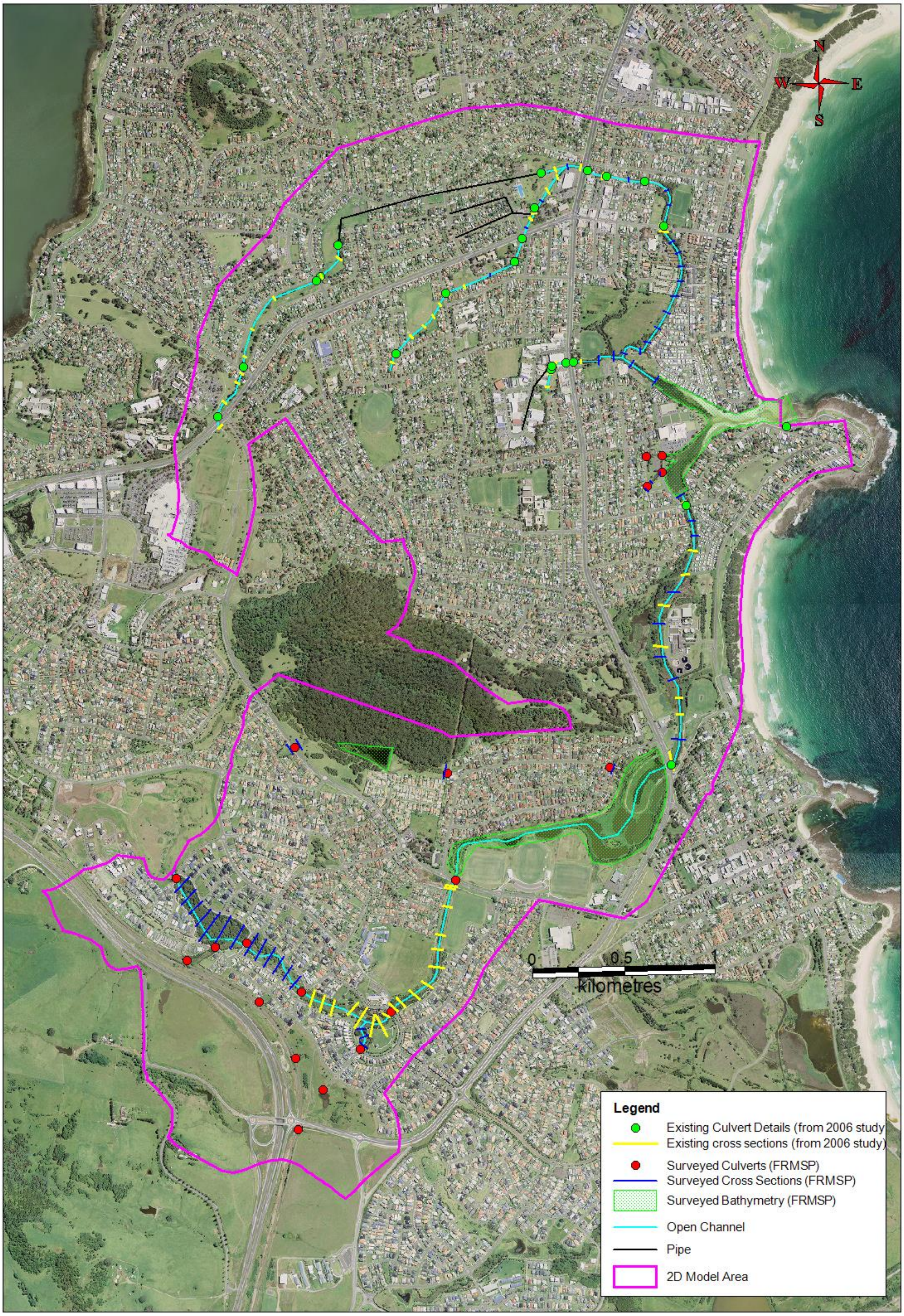

Figure 3-1 Existing survey information from 2006 Flood Study and Ground Survey undertaken by Craven Elliston &Hayes (CEH Dapto) for the FRMSP

3.6 Historical Streamflow Data

No streamflow data was available for calibration purposes, as there are no flow gauges within the catchment.

3.7 Historical Ocean Water Level Data

As noted in Section 2, the catchment drains to the Tasman Sea via Elliot Lake – Little Lake. Historical ocean levels were therefore required to define the downstream boundary condition for modelling the March 2011 historical event. Water level data from the Port Kembla Tide gauge was obtained for this purpose. This data was provided at a 10 minute time interval by the Port Kembla Ports Corporation.

3.8 Historical Rainfall Data

There are two rainfall stations within the catchment and another six located within a 10 km radius of the catchment. These are listed in Table 3-2, noting that not all of these were operational during the March 2011 event. Rainfall data from the Little Lake gauge (station 214466) was used for modelling the calibration event as it was the only gauge located within the catchment that was operational during the event. The locations of the rain gauges are shown in Figure 3-2.

Table 3-2 Rain Gauges

Station No.	Station Name	Location		Type	Source*	Operational during March 2011 event?	Gauge within Catchment?
		Lat.	Lon.				
068241	ALBION PARK (WOLLONGONG AIRPORT)	34°33'49.68"S	150°47'24.00"E	Pluvio	BOM	Yes	No
068131	PORT KEMBLA (BSL CENTRAL)	34°28'2.64"S	150°52'52.68"E	Pluvio	BOM	Yes	No
568171	ALBION PARK BOWLING CLUB	34°34'12.92"S	150°46'7.28"E	Pluvio	SWC	Yes	No
568119	SHELLHARBOUR STP	34°34'9.87"S	150°51'52.73"E	Pluvio	SWC	No	Yes
068242	KIAMA (BOMBO HEADLAND)	34°39'11.88"S	150°51'39.24"E	Pluvio	BOM	No	No
068038	KIAMA BOWLING CLUB	34°40'30.00"S	150°51'6.84"E	Pluvio	BOM	No	No
568170	BOMBO STP	34°39'8.30"S	150°51'30.06"E	Pluvio	SWC	Yes	No
214466	LITTLE LAKE	34°33'46.71"S	150°51'51.14"E	Pluvio	MHL	Yes	Yes

**BOM = Bureau of Meterology, MHL = Manly Hydraulics Laboratory, SWC = Sydney Water Corporation*

As shown in Table 3-2, only 5 of the 8 gauges were operational during the March 2011 event, with only one of these located within the catchment boundary. The recording interval for these gauges was 5 to 6 minutes, which is suitable for the purposes of modelling the historical event. These gauges provide a reasonable representation of spatial variation in rainfall in the area, although rainfall over the southern portion of the catchment is not well represented (rainfall from the Bombo STP gauge 568170 was not sourced due to its distance from the catchment). Figure 3-2 shows indicative rainfall depth isohyets for the March 2011 event (determined based on gauges 214466, 068241 and 068131 for midnight to midnight rainfall on 21 March 2011).

Figure 3-2 provides an indication of the spatial variation in rainfall for the event, with total daily rainfall for 21st March 2011 ranging from around 200mm to 250mm based on the Little Lake (214466), Albion Park (068241) and Port Kembla (068131) gauges. Both Figure 3-2 and Figure 3-3 show that the rainfall recorded at Port Kembla is significantly different in intensity and volume to the rest of the gauges. Given the distance of the gauge from the catchment, this is not likely to be representative of conditions within the catchment.

Figure 3-3 also shows that the rainfall characteristics are fairly similar between the gauges until about 1pm on 21st March 2011 (excluding Port Kembla). However, the mass curves after this time are reflective of the movement of the storm from east to west, as indicated in Rienco (2012). High intensity rainfall ceases at Little Lake at around 1pm, whereas this intense rainfall ceases about an hour later at the Albion Park gauges (towards the west of the catchment) at around 2pm – 2:30 pm. This leads to a noticeable difference in the total rainfall depth over the storm event between the eastern and western gauges. Table 3-3 shows that the total daily rainfall on 21st March at the Little Lake gauge was approximately 220 mm, whilst the Albion Park gauges, which lie further west, recorded 250 – 280 mm over the same period. The impact of this spatial variation in rainfall on modelled flood levels is detailed in Section 6.4.2.

Table 3-3 Total Daily Rainfall for 21st March 2011 (midnight to midnight) for nearby operational rain gauges

Station No.	Station Name	Data Authority	Total Rainfall on 21st March 2011 (midnight to midnight)
068241	ALBION PARK (WOLLONGONG AIRPORT)	BOM	252.2
568171	ALBION PARK BOWLING CLUB	SWC	279.5
214466	LITTLE LAKE	MHL	218.5
068131	PORT KEMBLA (BSL CENTRAL)	BOM	111.27

Table 3-4 provides an indication of the magnitude of the March 2011 event in relation to design storms. The statistics for the historical event in Table 3-4 were determined using rainfall data from the Little Lake Gauge (214466).

Table 3-4 Rainfall Depth (mm) for 21st March 2011 Event (from Station 214466) and for various Design Storms.

	Rainfall Depth (mm)			
Duration	21 March 2011 Event	1% AEP	2% AEP	5% AEP
1hr	85.5	98	87	74
2hr	123.5	128	116	96.8
3hr	148.5	150	134.1	113.1
6hr	188.5	195.6	174.6	147
9hr	202	228.6	204.3	171.9
12hr	206.5	255.6	228	192

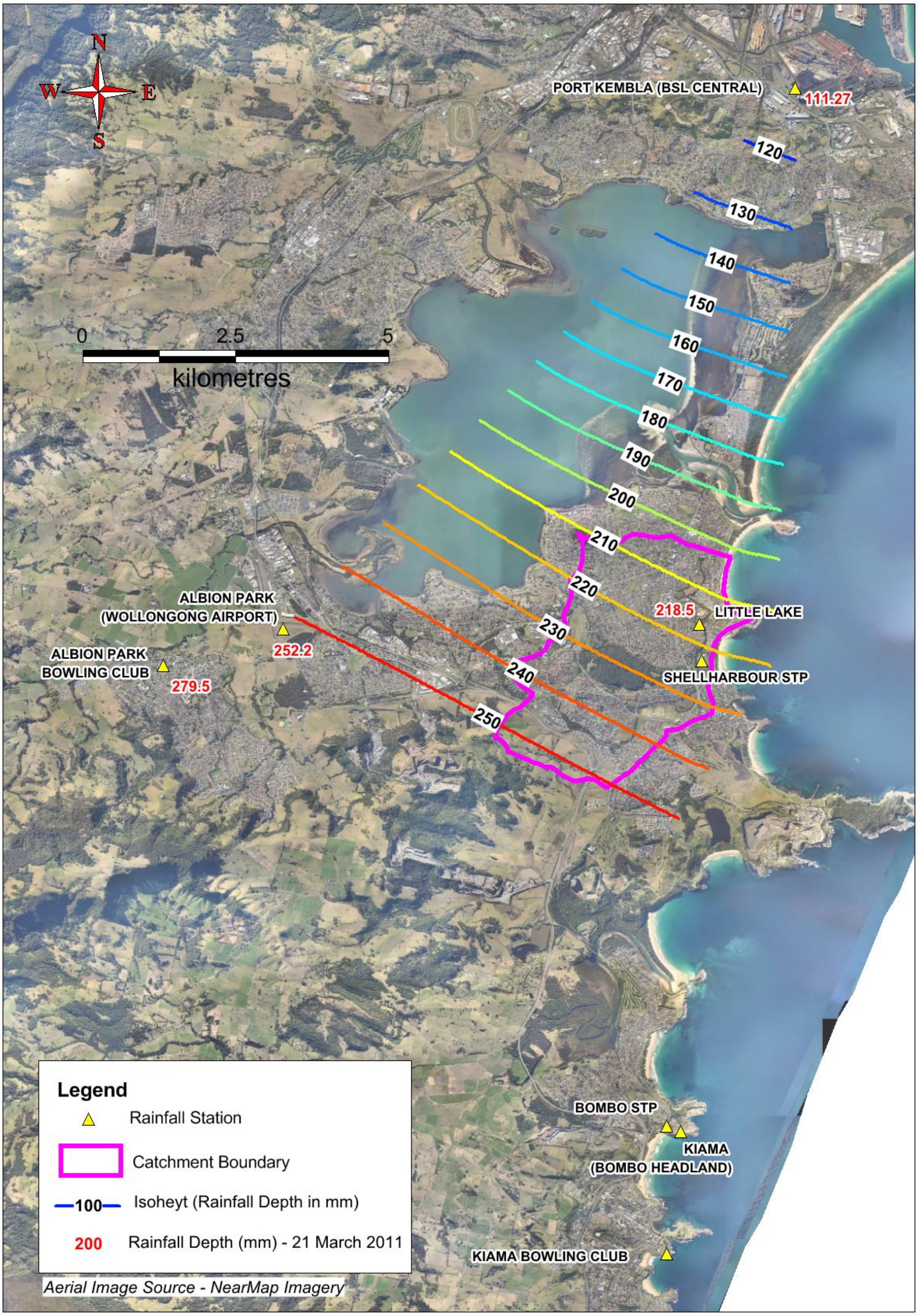

Figure 3-2 Estimated Rainfall Depth Isohyets for 21 March 2011 based on selected gauges

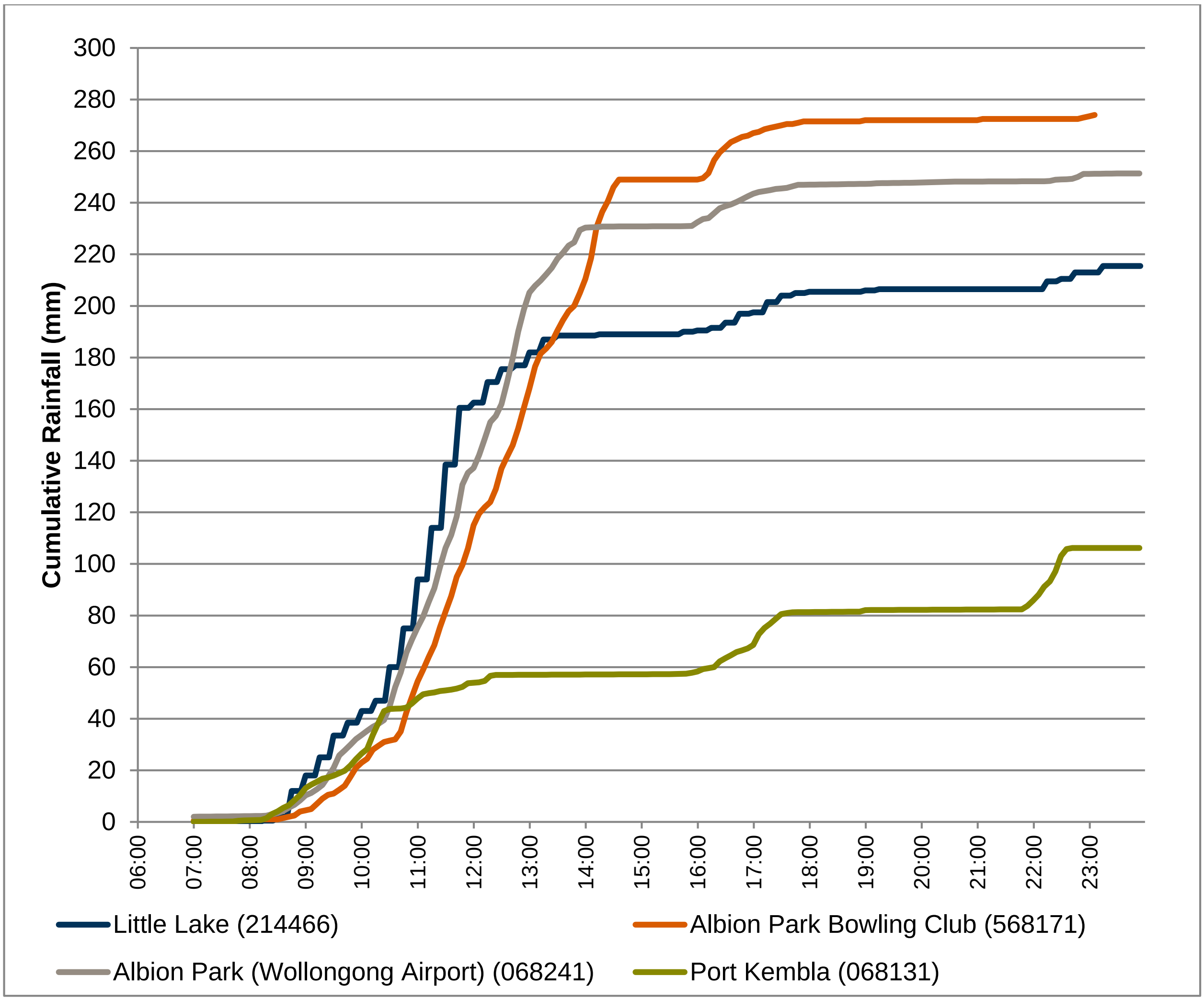

Figure 3-3 Cumulative Rainfall Curve (mass curve) for nearby operational rainfall gauges for 21st March 2011

3.9 Design Rainfall

Rainfall intensities and temporal patterns of design events calculated for the 2006 Flood Study were used in flood modelling for the FRMSP. The design rainfall intensities for the full range of storm frequencies can be found in Cardno Lawson Treloar (2006).

4 Consultation

Consultation with the community and key stakeholders is an essential component of the overall study. Consultation has been undertaken through a number of key interest groups, including:

- Community members and community groups;
- Key stakeholders, such as utilities, SES and government departments;
- The Floodplain Risk Management Committee; and
- Shellharbour City Council.

The consultation process is detailed in the *Elliot Lake – Little Lake Floodplain Risk Management Study* (Cardno, 2014)

5 Hydrological and Hydraulic Modelling

A 1D/2D SOBEK hydraulic model, along with an XP-RAFTS hydrological model were developed as part of the Cardno Lawson & Treloar Flood Study (2006). These models were used as the basis for flood modelling in this study. A detailed description of the setup of these models can be found in Cardno Lawson & Treloar (2006).The flood models were updated taking into account new information about the catchment and to also provide a better definition of overbank and floodplain flows. The modifications made to the models are discussed in further detail below.

5.1 Hydrology

The XP-RAFTS hydrological model was used to generate inflow hydrographs to the hydraulic model in the study area. In the 2006 Flood Study, two hydrologic models were developed for different catchment development stages. These were the April 2001 catchment development condition, and the fully developed or final catchment condition (see Section 5 of Cardno Lawson & Treloar, 2006).

The model developed for the April 2001 catchment condition was used as the basis for hydrologic modelling in this study, as the fully developed condition model included development that had not yet occurred. This model required only minor adjustments to account for changes in the catchment condition that have occurred in the period April 2001 to March 2011. These changes are described in further detail below. Additional adjustments made for the purposes of design event modelling are discussed in Section 8.

5.1.1 Catchment Parameters

Relatively minor updates to the subcatchment delineation were undertaken using pit and pipe data provided by Council as well as 2010 ALS data, both of which were unavailable for the 2006 Flood Study. Figure 5-1 shows the revised subcatchment delineation.

Catchment imperviousness was also updated to account for development that had occurred since 2001. Figure 5-1 shows areas that were identified as being developed after 2001, which are predominantly residential development located around and upstream of Munmorah Basin.

For consistency with the 2006 modelling approach, the same land use classification system of Urban, Forest and Grass was used, along with 50% imperviousness on urban areas. The pervious urban areas were lumped together with the Grass and Forest areas to form the total pervious area for each subcatchment. Table 5-1 shows the updated catchment area and imperviousness parameters, as compared to those adopted in the 2006 Flood Study. The differences noted in Table 5-1 are due to:

1) Changes in land use that have occurred since 2001; and
2) Changes in the subcatchment delineation (and thus the total area and percentage imperviousness).

The subcatchment slope parameters were not changed, given the relatively minimal changes to the subcatchment boundaries and the extent and nature of the development that has occurred since 2001.

5.1.2 Rainfall

Hydrologic modelling of the calibration event was undertaken by applying point rainfall from a single gauge uniformly throughout the catchment. Data from the Little Lake gauge (214466) was utilised as this was the only gauge located within the catchment. A sensitivity analysis was also undertaken using rainfall from the next closest gauge (Albion Park Bowling Club – 568171) to determine the impact of spatial variation in rainfall on flood levels.

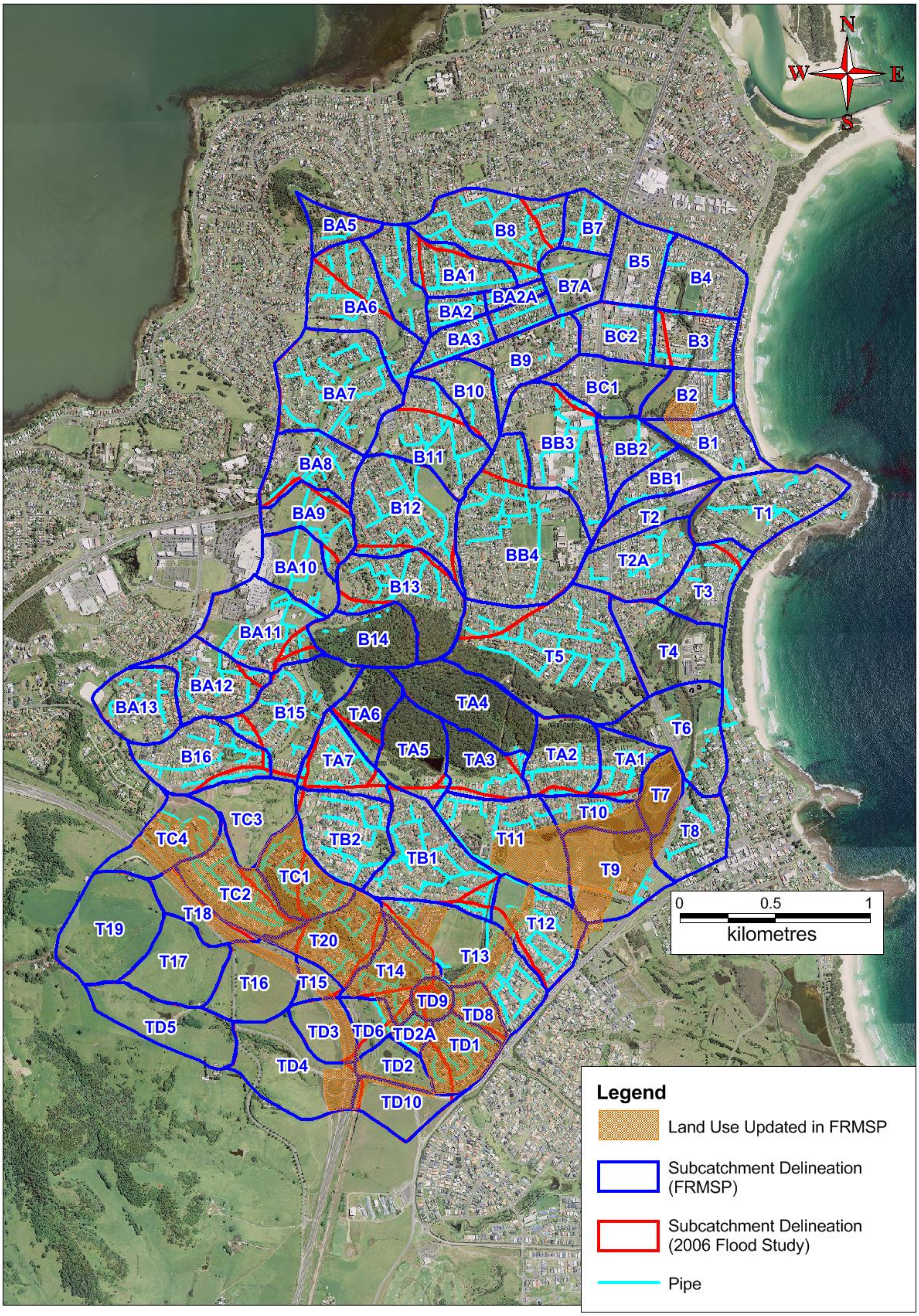

Figure 5-1 RAFTS Subcatchment Delineation

Table 5-1 Updates to XP-RAFTS Model

RAFTS Catchment ID	Total Area (ha)		Percentage Urban Impervious	
	2006 Flood Study	FRMSP	2006 Flood Study	FRMSP
BB3	29.41	25.43	47%	46%
BB4	45.25	43.92	44%	44%
B2	10.67	10.67	31%	35%
B1	12.34	12.34	44%	47%
BA8	14.68	14.44	50%	49%
BA10	13.31	12.29	16%	14%
BA11	20.12	21.83	33%	39%
BA12	14.93	16.01	45%	48%
BA9	11.4	12.65	24%	26%
BA2	7.41	4.58	50%	50%
BA1	11.25	12.35	48%	48%
BA3	11.3	6.33	50%	50%
B11	16.99	21.33	43%	45%
B10	14.48	10.16	40%	35%
B12	24.78	26.66	42%	43%
B13	22.68	23.13	35%	36%
T9	20.47	20.47	0%	15%
TD1	11.81	12.07	47%	49%
TD4	23.07	22.71	0%	7%
TD3	14.78	9.04	6%	12%
T16	17.29	15.94	0%	8%
TC3	17.98	14.98	7%	0%
TD2	25.25	6.88	15%	0%
T15	22.94	3.90	0%	36%
TC1	9.68	14.34	2%	35%
TC4	15.14	15.14	0%	30%
T18	7.79	8.27	0%	22%
TC2	15.78	16.90	0%	44%
T13	34.44	26.92	33%	35%
T12	17.12	17.30	31%	38%
T11	26.63	24.48	29%	30%
TB1	22.76	25.63	50%	49%
TB2	21.32	19.87	50%	50%
T10	10	8.42	27%	25%
T3	11.67	13.12	36%	38%

RAFTS Catchment ID	Total Area (ha)		Percentage Urban Impervious	
T1	24.23	22.77	46%	46%
T2	26.38	8.73	50%	50%
T5	44.85	50.03	30%	32%
TA1	8.33	9.14	38%	41%
TA2	13.89	14.63	32%	34%
TA4	21.12	20.27	2%	0%
TA3	11.18	12.51	19%	23%
TA5	14.34	15.32	4%	7%
TA6	8.3	10.45	0%	0%
TA7	11.39	12.36	38%	50%
B16	18.43	19.08	48%	48%
B15	23.16	22.91	37%	49%
B14	17.83	14.71	11%	0%
BC2	13.4	11.54	50%	50%
BC1	14.6	13.73	25%	24%
B3	10.41	12.26	50%	50%
BA4	19.98	11.03	45%	41%
BA6	15.14	22.47	39%	43%
B7	11.77	7.98	50%	50%
B8	20.36	24.67	50%	50%
TD10	-	10.08	-	0%
TD6	-	5.54	-	0%
TD9	-	4.00	-	0%
TD8	-	5.14	-	50%
T2A	-	17.65	-	50%
BA2A	-	2.83	-	50%
BA3A	-	4.94	-	50%
T20	-	15.67	-	40%
TD2A	-	2.93	-	48%
T14	12.98	12.58	20%	40%

5.1.3 Rainfall Losses

An initial loss-constant continuing loss model was used in the RAFTS model to determine rainfall excess. The design rainfall losses adopted in the 2006 Flood Study (as shown in Table 5-2) were utilised as a starting point for modelling the calibration event. Due to the lack of flow gauge data within the catchment, direct calibration of the hydrologic model (by varying the loss parameters, and routing parameters) was not possible. Therefore, a sensitivity analysis of the loss parameters was undertaken to determine the impact on flood levels and extents. This is discussed in further detail in Section 6.2.

Table 5-2 Initial Loss –Continuing Loss parameters used in the 2006 Flood Study hydrologic model

Catchment Type	Initial Loss (mm)	Continuing Loss (mm/hr)
Forest	30	3.0
Rural – Grass	20	1.5
Urban Pervious (Backyards)	10	1.0
Urban Impervious	1.0	0

5.1.4 Lag Times and Storage Parameters

The hydrologic routing parameters used in the 2006 Flood Study model (as shown in Table 5-3) were also adopted in this study. Due to the relatively minor changes to the catchment condition that have occurred since 2001, the lag time and storage parameters were not modified. Although there were no changes to the Mannings ‘n’ roughness for the three land-use types, the overall roughness for some subcatchments was indirectly adjusted due to the changes described in Section 5.1.1.

Table 5-3 Routing parameters used in the 2006 Flood Study hydrologic model

RAFTS parameter	Forest	Pervious (grass and backyard)	Urban Impervious Area
Mannings ‘n’ for subcatchments	0.04	0.02	0.01
Storage delay parameter, B	1.0	1.0	1.0
Hydrograph Routing Lag	Based on a flow velocity of 1 and 2 m/s in the upper reaches of the catchment (upstream of the Princes Highway), and 0.5m/s for the rest.		

5.2 Hydraulic Modelling

A 1D/2D hydraulic model, SOBEK, was established for the study area. The 1D component of the model generally represents channels, culverts and pipes, while the 2D component represents the overbank flows in the model. The focus of the study is on mainstream flooding. Many of the secondary overland flowpaths that discharge into the creeks and channels have only been represented in the hydrological component of the model and are not modelled explicitly in the hydraulic model.

The SOBEK model from the 2006 Flood Study served as a backbone for the development of the current 1D/2D hydraulic model. However, significant updates were undertaken with additional data that was available. The extent and nature of the updates to the 2006 Flood Study model are discussed in detail below.

5.2.1 1D Network

The 1D component of the model consists primarily of the main drainage channels in the study area, namely Bensons Creek, Bensons Tributary and Tongarra Creek. A number of culverts and major stormwater pipes were also included. Figure 5-3 shows the layout of the pit, pipe and channel systems incorporated into the model.

The configuration of the 1D network from the hydraulic model was altered primarily to incorporate key hydraulic controls such as culverts and major pipes not previously modelled. Additional channel cross sections were also incorporated into the 1D network to provide improved definition of channel variations. The 1D section of Tongarra Creek upstream of Jindabyne Road was also replaced with representation in the 2D grid. This was because the channel is sufficiently wide for representation with the adopted grid resolution (3m), and the presence of Munmorah basin where there are complex two dimensional flows.

It is noted that the pedestrian/cycleway bridge at Elliot Lake – Little Lake (which was near completion at March 2011, see Figure 5-2) was not modelled as preliminary review indicated it may not have significant impact on the flow behaviour. The schematisation of the bridge for modelling of design events is discussed in Section 8.2.

Figure 5-2 Pedestrian/Cycleway Bridge at Elliot Lake – Little Lake (construction completed in June 2011)

5.2.2 2D Model Area

The 2D model area of the SOBEK model was extended to allow for better definition of overbank and floodplain flows throughout the study area, using the 2010 ALS data that was not available for the 2006 Flood Study. Figure 5-3 shows the model area adopted in this study, which was developed to:

- Model key storages in the catchment not modelled in the hydraulic part of the 2006 Flood Study model such as Blackbutt Dam, Myimbarr Wetlands and the sportsfields adjacent to Shellharbour Council Chambers.
- Provide improved definition of mainstream flooding from Tongarra Creek (particularly at the Surfrider Caravan Park and upstream of Munmorah Basin), Bensons Creek upstream of Memorial Park and also Benson's Tributary.
- Mode important flowpaths such as:
  - Parklands Drive (downstream of Blackbutt Dam)
  - Lake Entrance Road near Madigan Boulevard
  - Sunset Avenue

5.2.3 2D Grid

A detailed terrain grid was generated to represent surface elevations, primarily using ALS data (2010) supplied by Council (see Section 3.2.2). ALS data is not capable of providing levels below a water level surface.

Detailed bathymetric survey was therefore utilised in generating the terrain grid for Elliot Lake – Little Lake, the Myimbarr Wetlands and Blackbutt Dam (as detailed in Section 3.2).

A 3m grid was developed for the extended 2D study area as shown inFigure 5-3. The size of the model area is approximately 9.0 km^2, represented by approximately 1,003,750 grid cells.

5.2.4 Hydraulic Roughness (Mannings 'n')

The hydraulic roughness (Mannings 'n') for the 1D cross sections and 2D grid were determined initially using the land-use zones as described in the Council LEP, aerial photography supplied by Council and site inspections carried out during the study. Values were assigned to various land uses, taking into consideration recommendations in Australian Rainfall & Runoff Revision Project 15 – *Two Dimensional Modelling in Urban and Rural Floodplains of the Australian Rainfall and Runoff* (see Table 5-4).

Table 5-5 shows the roughness parameters that were adopted as a starting point for the calibration. These values were subsequently refined during the calibration process. Details of the calibration methodology and final calibration parameters are provided in Section 6.3.

Table 5-4 Valid Mannings 'n' Ranges for Different Land Use Types (ARR Revision – Project 15, 2012)

Land Use Type	Manning's 'n'
Residential areas – high density	0.2 – 0.5
Residential areas – low density	0.1 – 0.2
Industrial/commercial	0.2 – 0.5
Open pervious areas, minimal vegetation (grassed)	0.03 – 0.05
Open pervious areas, moderate vegetation (shrubs)	0.05 – 0.07
Open pervious areas, thick vegetation (trees)	0.07 – 0.12
Waterways/channels – minimal vegetation	0.02 - 0.04
Waterways/channels – vegetated	0.04 – 0.1
Concrete lined channels	0.015 – 0.02
Paved roads/car park/driveways	0.02 – 0.03
Lakes (no emergent vegetation)	0.015 – 0.35
Wetlands (emergent vegetation)	0.05 – 0.08
Estuaries/Oceans	0.02 – 0.04

Table 5-5 Initial Hydraulic Roughness Parameters for the 2D areas and 1D elements

	Land Use Classification	Mannings 'n'
2D Grid	Grass	0.03
	Roads	0.02
	Residential	0.10
	Caravan Parks	0.05
	Forest/Bushland	0.06
	Creeks/Waterways	0.03
	Open Bushlands/Shrubs	0.03
1D network	Pipe	0.02
	Culvert	0.02
	Grassed Open Channel	0.03
	Concrete Lined Open Channel	0.02

5.2.5 Buildings

Large industrial and commercial buildings within the extent of mainstream flooding were modelled as completely blocking flow by raising the extent of their footprint in the terrain grid. Figure 5-3 shows the extent of the raised buildings. The impact of residential buildings was modelled by applying a higher roughness (0.1) to areas with a residential land use zoning. This is consistent with the approach taken in the 2006 Flood Study, as well as recommendations from the Australian Rainfall & Runoff Revision Project 15 – *Two Dimensional Modelling in Urban and Rural Floodplains of the Australian Rainfall and Runoff* (see Table 5-4).

5.2.6 Boundary Conditions

The upstream boundaries were defined as discharge boundaries using hydrographs from the xp-RAFTS model. These were predominantly applied directly to the 1D branches of the model as point inflows, except where modelling of specific flowpaths required these to be applied onto the 2D grid. The use of point inflows to the 1D branches was deemed sufficient due to the extent of the drainage network discharging to the main channels.

The downstream boundary was defined at the ocean near the Elliot Lake – Little Lake entrance. A historical tidal series (as detailed in Section 7) was used for modelling the March 2011 event.

The entrance conditions were defined as per the hydrographic survey undertaken in late 2012 (see Section 3.2). This is likely to be a reasonably close representation of the lake bathymetry and entrance condition at March 2011, as it is understood from observations that it has not changed significantly over the years. The presence of the rock training walls as well as the sheltering of the entrance from waves due to Barrack Point have led to reduced sediment build-up inside the lake mouth (WBM, 2003). Previous investiagtions found that full closure of the entrance is highly unlikely to occur. It was found by WBM (2003) that "groyne construction combined with loss of sand from Warilla Beach generally prevented the mouth of the estuary from closing off completely".

A detailed description of the downstream boundary conditions adopted for design event modelling is provided in Section 8.2.1.

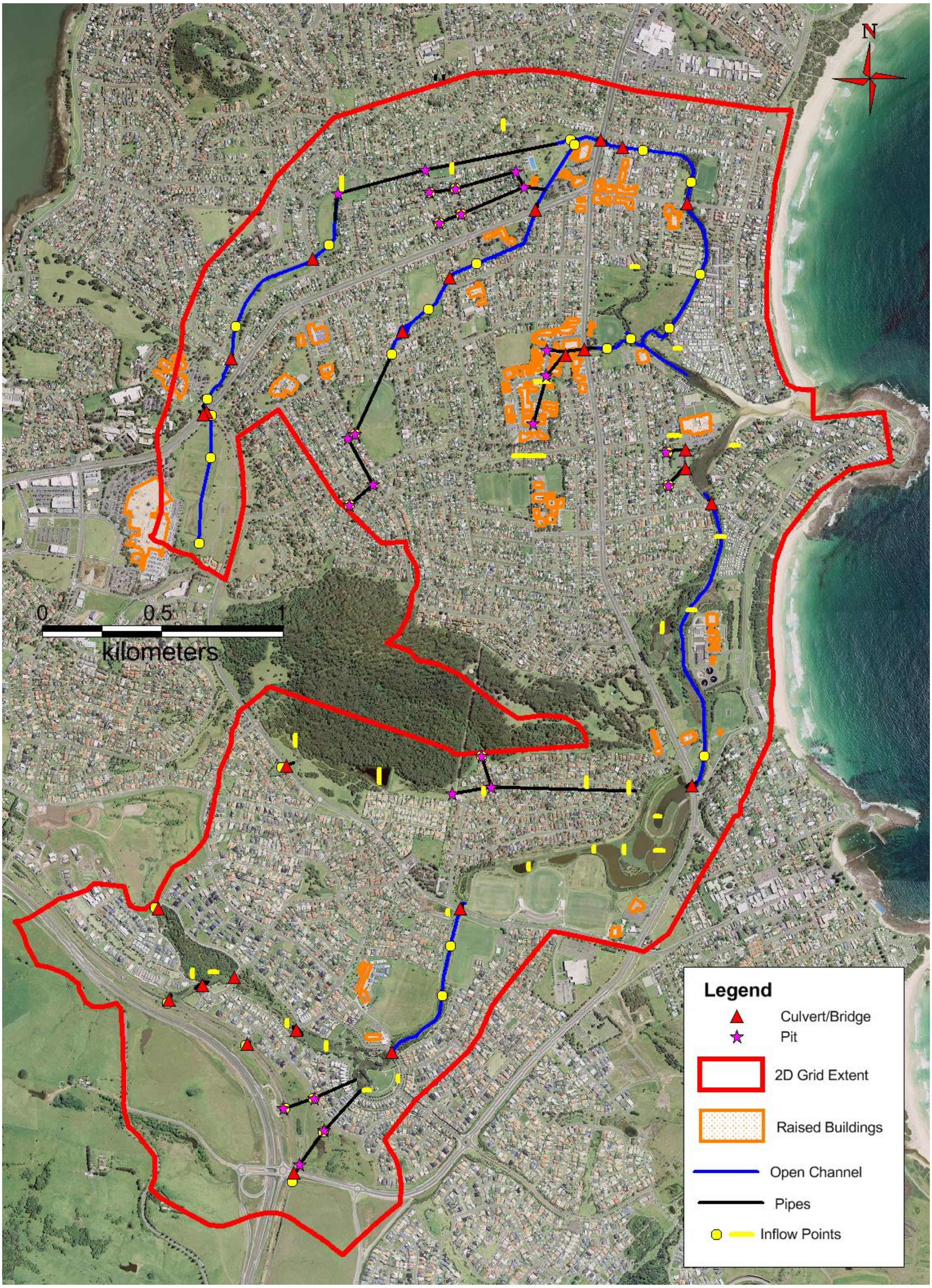

Figure 5-3 SOBEK Model layout

6 Model Calibration

As noted in Section 3.5, the Elliot Lake – Little Lake catchment recently experienced a significant rain event on 21st March 2011. This event was in the order of a 1 in 100 year ARI event (Rienco, 2012) making it preferable for calibration, particularly when the model is to be used for the purposes of modelling rare design events. Therefore this event was used for calibration of the flood model.

Section 5 discussed updates that were made to the hydrological and hydraulic models developed for the 2006 Flood Study. These updates were made primarily to reflect catchment conditions at March 2011. Further refinements made as part of the model calibration process are discussed in detail below.

6.1 Initial Conditions

There had been significant rainfall over the catchment prior to the 21st March 2011. It was therefore assumed that all major storages within the catchment (namely Blackbutt Dam, Myimbarr Wetlands and Munmorah basin) would be full (up to the crest level of the outlet) at the start of the historical event. This assumption gave a reasonable match to observed water levels at Munmorah Basin and near Blackbutt Dam (See TC11 and BB2 in Table 6-2). However, preliminary sensitivity testing with the initial water levels in Munmorah Basin and Blackbutt Dam resulted in minimal variation to peak flood levels.

6.2 Hydrologic Parameters

The hydrological model could not be calibrated directly due to the lack of streamflow data. Therefore a combined hydrology/hydraulics approach was taken where the hydraulic model was calibrated with input from the hydrology model, thus indirectly validating the results of the hydrology model.

A sensitivity analysis was undertaken to determine the impact of changing the hydrologic parameters on the modelled flood levels. This was done for:

- **Hydrologic Losses** (Initial Loss – Continuing Loss). The losses outlined in Section 5.1.3 are indicative of a high initial loss, low continuing loss regime. For comparison, a low initial loss, higher continuing loss regime was investigated (see Table 6-1). The results showed minimal differences in peak flood depths, generally less than 5 cm throughout the catchment (see Figure B-1 in Appendix B).
- **Rainfall** – Section 3.8 noted spatial variation in rainfall for the historical event. Modelling was therefore undertaken using the Little Lake Gauge (214466) and also with the Albion Park Bowling Club Gauge (568171) as these were located closest to the catchment. The results from this analysis are discussed in Section 6.4.2.

Table 6-1 Initial Loss – Continuing Loss Parameters used in Sensitivity Analysis.

Catchment Type	Initial Loss (mm)	Continuing Loss (mm/hr)
Forest	10	2
Rural – Grass	10	2
Urban Pervious (Backyards)	10	2
Urban Impervious	5	1

6.3 Hydraulic Parameters

The main parameters that were adjusted during the calibration process were roughness (both in-channel and overland), culvert/pipe blockage and culvert entrance and exit loss coefficients. These were adjusted until a reasonable match was obtained between recorded and modelled levels, whilst ensuring that the parameters chosen were physically realistic (through judgement and verification on site where possible). Modifications to the DTM were also made where appropriate. The following conditions gave the closest match to recorded levels:

- 50% blockage of the pipe under Parklands Drive in Shellharbour. This was based on anecdotal information from Council that the inlet to this pipe was blocked during the storm event. It should be noted that all other pipes were assumed unblocked.
- Increased in-channel roughness from the initial values detailed in Section 5.2.4 (up to 0.06). It was found during the calibration process that increases in the in-channel roughness were necessary in order to obtain a better match with recorded flood levels. This was subsequently verified with observations from the site inspection where heavily vegetated channels (particularly at Memorial Park and at Bensons Creek near King Mickey Park) were noted. Figure 6-2 shows the final Mannings 'n' parameters adopted for the calibration.
- Modification of losses for culverts and bridges. This generally was for in-line culverts and bridges, such as the Barrack Avenue bridge, where the bridge or culvert represents little impact to flow because the peak water level in the calibration event is below the obvert.

6.4 Calibration Results

The results of the calibration along with the sources of historical flood data are summarised in Table 6-2 and Figure 6-1. Longitudinal profiles for the main channels can also be found in Appendix C. Modelled peak depths have been provided as an indicative range for areas where the precise location of the historical observation was not known. Generally, there is a reasonable match between the modelled and historical depths throughout the catchment. There are several factors which can contribute to differences between the observed and modelled flood levels. These are discussed in further detail below.

6.4.1 Reliability of Calibration Data

A majority of the historical data was sourced from resident's survey. The reliability of resident's estimates is not guaranteed and inconsistencies between reports are expected. For example, a resident indicated that the peak water level in the Surfrider Caravan Park was approximately 4m AHD, which is inconsistent with two other reported levels (2.8m AHD as indicated in Rienco (2012)) and 3.0m AHD from photo provided by Surfrider Caravan Park). Similar examples can be seen at Joan Avenue, Warilla where good agreement with the historical depth is obtained at one location but not at another nearby location (see BC2 and BC3 in Table 6-2).

Whilst photos are a fairly reliable form of historical flood data, in this case the time at which the photo was taken was often not known. As a result, it is uncertain whether the peak water levels were captured in the photo. This may explain the differences in levels at location ID TC6, TC3 and TC9 (see Table 6-2).

6.4.2 Spatial Variation in Rainfall

The hydrologic modelling was undertaken by applying point rainfall from a single gauge uniformly throughout the catchment. Section 3.8 noted the variation in rainfall in terms of total depth, intensity and temporal pattern between the different gauges. Modelling was undertaken using rainfall data from the Little Lake Gauge (214466) and then the Albion Park Bowling Club Gauge (568171) in order to estimate the impact of this variability on flood levels.

Peak flood level results from the model with rainfall from the Little Lake Gauge (214466) generally gave a better match to the observations than when rainfall from the Albion Park Bowling Club gauge was used (see Table 6-2) where the shading highlights which scenario gave a better match to the observed data). Differences in modelled peak water level of up to approximately 0.2m result when using rainfall inputs from the two different gauges (refer Appendix B).

6.4.3 Uncertainty in Catchment Conditions

The bathymetry of the lake at the time of the event was unknown. The bathymetry applied to the model is representative of late 2012 conditions. Potential differences between the bathymetry at the time of flooding and 2012 conditions may explain the discrepancy between the modelled level at Elliot Lake – Little Lake and the recorded level (see entry LL in Table 6-2). It was noted that the recorded water level at Elliot Lake reached levels as lows as -0.01m AHD, whilst the hydrographic survey indicated bottom levels of about 0.1 – 0.3m AHD in the vicinity of the gauge.

According to BMT WBM (2013), the lake remains permanently open due to the 80m rock groyne on the northern side of the entrance and the natural bedrock along the southern bank and headland. Despite this, sediment transport processes give rise to dynamic lake bed levels. WBM (2003) note that training of the lake entrance promotes the ingress of marine sand well into the entrance channel and the northern and southern arms of the lake, which are only scoured out during flooding events with outflows of sufficient velocity. Available data shows that in 2002, lake bed levels were up to 1 m higher than in 2012 near the confluence of the northern and southern arms. Scouring during the large flood event in March 2011 may have contributed to the lower lake bed levels in 2012 when compared to the 2002 condition.

6.4.4 Mainstream Flooding

The focus of the study was on mainstream flooding. Much of the historical data provided by residents was likely due mostly to flooding from overland flows and so was not considered as part of this study, though may still be important to Council. For instance, photos provided by Council as well as resident responses indicated that most of Munmorah Circuit was inundated, although the modelling does not indicate this (see Figure 6-1). On the contrary, the modelled levels within the Munmorah Basin are fairly close to the historical level. This indicates that it is likely that the overland flows from Jindabyne Road, Haddin Road and Lakewood Boulevard would have contributed to flooding on Munmorah Circuit. Similar reasoning could be applied to the levels at location TC1 and at BC7.

Table 6-2 Calibration Results for the March 2011 Event

ID	Historical Flood Level Location	Branch^	Historical Flood Level Source	Peak Historical Flood Depth (m)	Scenario with Rainfall from Gauge 214466		Scenario with Rainfall from Gauge 568171
					Peak Modelled Flood Depth (m)	Depth Difference (m) (Mod. - Obs.)	Peak Modelled Flood Depth (m)
BC1	22 Spofforth Street Barrack Heights	BC	Resident	Approx. 0.4	0.30 - 0.44	(-0.10, 0.04)	0.18 – 0.41
BC2	Intersection of Joan Ave and George Street	BC	Resident	Approx. 0.3	0.66 - 0.80	(0.36, 0.50)	0.50 – 0.70
BC3	8 Joan Ave, Warilla	BC	Resident	Approx. 0.4	0.40 - 0.45	(0.00, 0.05)	0.28 – 0.42
BC4	20 Stephanie Ave, Warilla	BC	Resident	Approx. 0.2	0.15 - 0.22	(-0.05, 0.02)	0.10 – 0.22
BC6	18 Terry Ave, Warilla	BC	Resident	Approx. 0.2	0.19 - 0.25	(-0.01, 0.05)	0.11 – 0.21
BC7	7 Terry Ave, Warilla	BC	Resident	Approx. 0.4	0.25 - 0.35	(-0.15, -0.05)	0.10 – 0.26
BC8	108 Raymond Street, Warilla	BC	Resident	Approx. 0.3	0.22 - 0.28	(-0.08, -0.02)	0.15
BC9	120 Osborne Pde, Warilla	BC	Resident	Approx. 0.1	0.05 - 0.15	(-0.05, 0.05)	0.01 – 0.05
BC10	Shellharbour Rd near Memorial Park crossing	BC	Youtube	0.05 – 0.1	0.05 - 0.15	(0.00, 0.05)	Not Flooded
BC11	Shellharbour Rd in front of McDonalds	BC	Youtube	Approx. 0.20	0.25 - 0.44	(0.05, 0.24)	0.22 – 0.42
BC12	32 Woodford Avenue, Warilla	BC	Resident	Approx. 0.2	0.21 - 0.25	(0.01, 0.05)	0.08 – 0.15
BC13	Shellharbour Rd north of Bensons Creek, Warilla	BC	Resident	Approx. 0.3	0.25 - 0.34	(-0.05, 0.04)	0.05 – 0.15
SA1	232 Shellharbour Road Warilla	SAF	Photo from Illawarra Mercury	Approx 0.3	0.26 - 0.43	(-0.04, 0.13)	0.32 – 0.45
BT1	Intersection of Lake Entrance Rd and Leawarra Ave	BT	Resident	Approx. 0.3	0.33 - 0.45	(0.03, 0.15)	0.18 – 0.24
BT3	Intersection of Lake Entrance Rd, George St & Shellharbour Rd, Warilla	BT	Photo in Risk Frontiers (2013)	Approx. 0.1-0.2	0.15 - 0.22	(0.02, 0.05)	0.10 – 0.30
BT4	Intersection of O'Connell St and Lindesay St Barrack Heights	BT	Photos from resident	Approx. 0.6	0.55 - 0.62	(-0.05, 0.02)	0.23 – 0.36
TC1	271 Grand Pacific Drive Shellharbour	TC	Resident	Approx. 0.4	Not Flooded	-0.4	Not Flooded

ID	Historical Flood Level Location	Branch^	Historical Flood Level Source	Peak Historical Flood Depth (m)	Scenario with Rainfall from Gauge 214466		Scenario with Rainfall from Gauge 568171
					Peak Modelled Flood Depth (m)	Depth Difference (m) (Mod. - Obs.)	Peak Modelled Flood Depth (m)
TC2	92 Junction Road, Barrack Point	TC	Resident	Approx. 0.3	0.20 - 0.28	(-0.10, -0.02)	0.28 – 0.37
TC3	Shellharbour Rd just d/s of Myimbarr Wetlands	TC	Photo from Council	0.45	0.57	0.12	0.62
TC5	17 Munmorah Circuit, Flinders	TC	Resident	Approx. 0.3	0.20 - 0.30	(-0.10, 0.00)	0.20 – 0.30
TC6	Munmorah Circuit, Flinders	TC	Resident	Approx. 0.3	0.15 - 0.29	(-0.15, -0.01)	0.15 – 0.30
TC7	74 Jason Ave Barrack Heights	TC	Resident	Approx. 0.4	0.24	-0.16	0.32
TC8	54 Bass Street Barrack Heights	TC	Resident	Approx. 0.17	0.13 - 0.17	(-0.04, 0.00)	0.24 – 0.28
TC9	44 Bass Street Barrack Heights	TC	Photos from Resident	Approx. 0.05	Not Flooded	-0.05	0.23
TC10	94 Pelican Place, SurfriderCaravan Park	TC	Photo from Surfrider Submission	1.25	1.2	-0.05	1.32
N/A	Surfrider Caravan Park*	TC	Rienco Report	2.8m AHD	2.79 - 2.86 m AHD	(-0.01, 0.06)	3.08 m AHD
TC11	Munmorah Basin	TC	Photo from Council	2.4	2.39	-0.01	2.31
BB1	Intersection of Corella Close & Parklands Drive, Blackbutt	BDF	Resident	0.58	0.45 - 0.57	(-0.13, -0.01)	0.42 – 0.46
BB2	2 Parklands Drive,Shellharbour	BDF	Resident	Approx. 0.1	0.13 - 0.19	(0.03, 0.09)	0.10 – 0.13
BB3	Intersection of Dryandra Way and Parklands Drive, Shellharbour	BDF	Youtube	Approx. 0.3	0.30 - 0.36	(0.00, 0.06)	0.24 – 0.25
LL	Elliot Lake – Little Lake d/s of Barrack Ave Bridge	LL	MHL	1.4 m AHD	2.06 m AHD	0.6	2.0 m AHD

Shading indicates this that this scenario gave a better match to the peak water levels than the other.

^BC = Benson's Creek, BT = Benson's Tributary, SAF = Sunset Ave Flowpath, TC = Tongarra Creek, BDF = Blackbutt Dam Flowpath, LL = Little Lake.
**Exact Location within the Caravan Park unknown.*

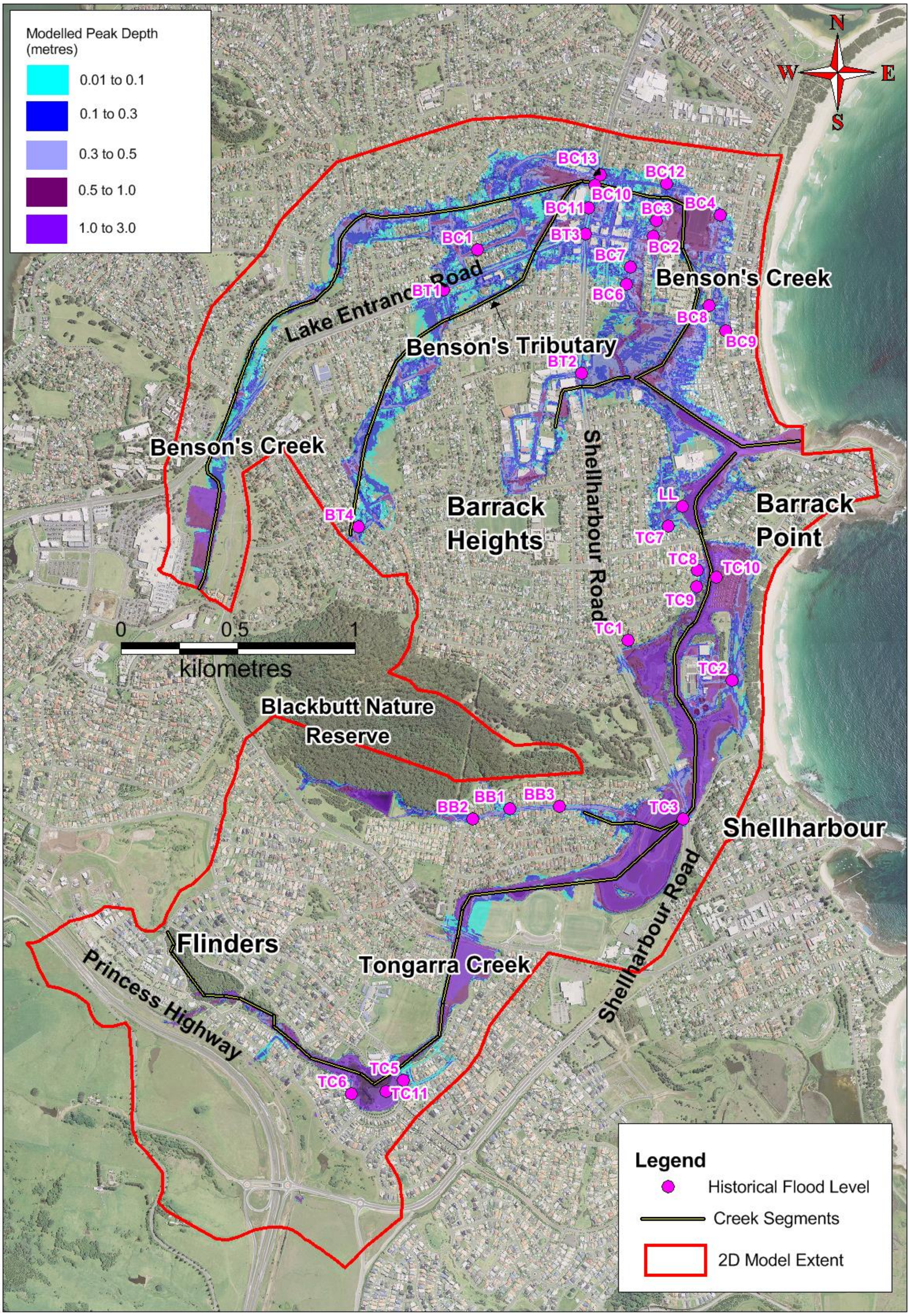

Figure 6-1 Location of Calibration Data for the March 2011 Event

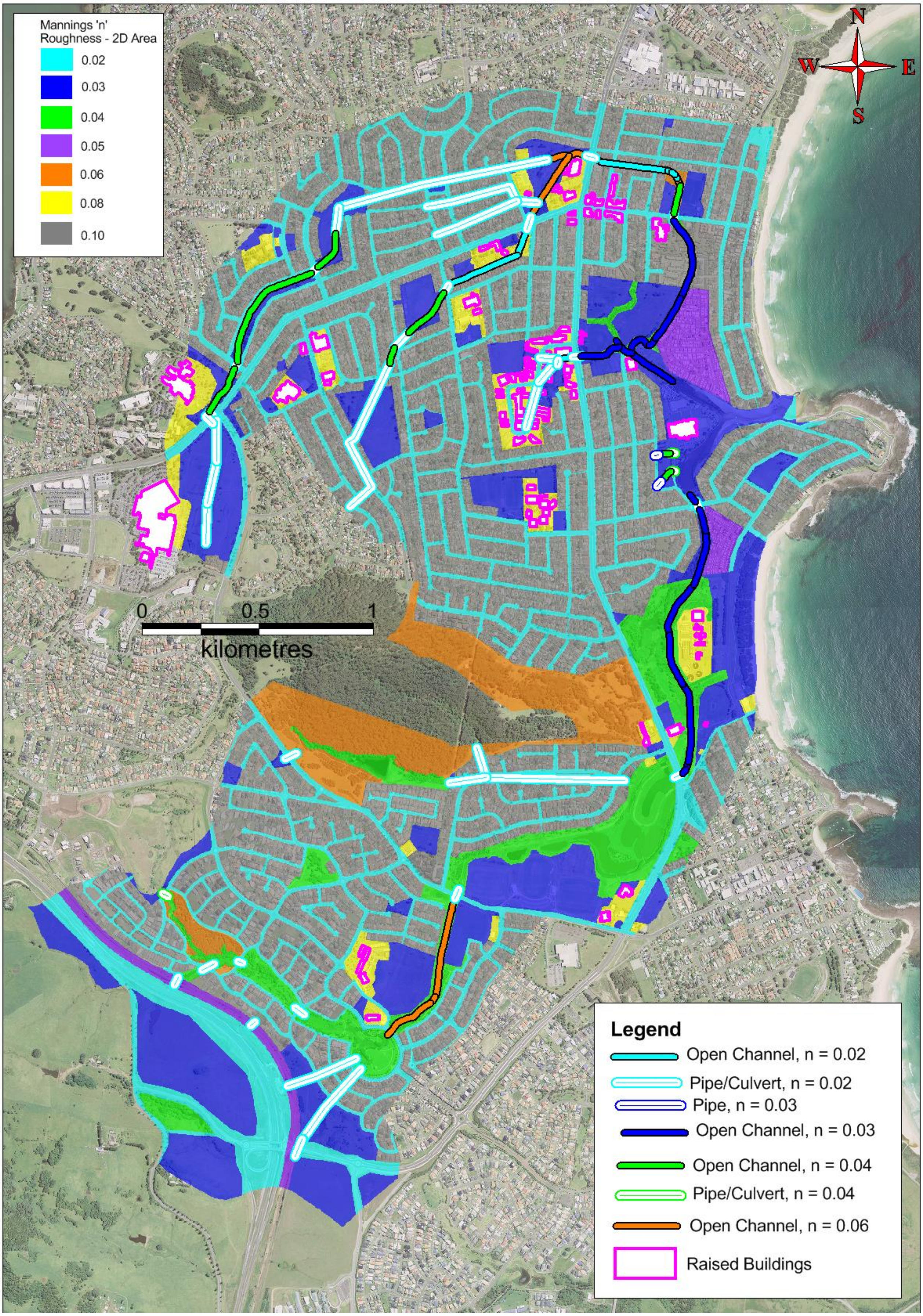

Figure 6-2 Final Mannings 'n' Roughness Parameters for the March 2011 Calibration Event

7 Model Validation

7.1 Historical Event Validation

There have been no significant storm events occurring in the last 20 years in the Elliot Lake - Little Lake catchment with sufficient flood data, with the exception of the March 2011 event. Cardno Lawson Treloar (2006) identified a number of historical events which had occurred prior to 1990. The May 1983 event was the only event identified which had in excess of six recorded flood levels (22 levels in total). This event was used for calibration of the flood model in the 2006 Flood Study.

The May 1983 event was used to validate the flood model due to the availability of flooding information. However, it is noted that there have been significant changes to the catchment since 1983, including (but not limited to):

- Construction of Myimbarr Wetlands and Myimbarr Playing Fields;
- Construction of Munmorah Basin;
- Extensive residential development, particularly in the southern portion of the catchment;
- Construction of Princes Highway and the culverts under the intersection of Lindsays Lane and Princes Highway.

Figure 7-1 and Figure 7-2 show some of these changes in land use that have occurred since the early 1990s (refer to yellow outline).

The calibrated flood model was therefore adjusted to a limited extent to represent 1983 catchment conditions. The changes were focused primarily on the xp-RAFTS hydrology model, specifically:

- Adjustments to Initial Losses as per 2006 Flood Study. The initial loss is known to vary between events because of its dependence on antecedent rainfall; and
- Reduction in percentage imperviousness of selected subcatchments south of Blackbutt Forest Reserve to reflect pre-developed conditions.

Table 7-1 summarises the peak water level results from the FRMSP flood model and the 2006 Flood Study model for the recorded flood levels from the May 1983 Event. The recorded flood levels have been extracted from Cardno Lawson Treloar (2006), and are shown in Figure 7-3. Generally, the FRMSP flood model shows a good match to the observed levels, with absolute differences less than 0.2m at most locations. In some cases, the reliability of the recorded data is questionable, for instance at 56 Bass Street, Barrack Heights where the recorded peak water level is about 0.7m less than the level in nearby Tongarra Creek. Table 7-1 also shows that the FRMSP flood model gives an equivalent or better match to the recorded levels than the 2006 Flood Study model in approximately 70% of cases.

The Water Board (now Sydney Water Corporation) surveyed the flood level profile at Tongarra Creek during the May 1983 event. Figure 7-4 shows a comparison of this data with the results from the FRMSP flood model and 2006 Flood Study Model. It demonstrates that the FRMSP flood model provides a good representation of the observed peak water level profile at Tongarra Creek. The modelled flood profile is also a better representation than that from the 2006 Flood Study Model, particularly near the Surfrider Caravan Park.

Figure 7-1 Elliot Lake – Little Lake Catchment – 1993 catchment condition (Source: NSW OEH)

Figure 7-2 Elliot Lake Little Lake Catchment – 2012 Condition (Source: Google Earth)Table 7-1 Validation Results for the May 1983 Event

Table 7-1 Model Validation Results for the May 1983 Event

Historical Flood Level Location	Branch	Peak Historical Flood Level (m AHD)	FRMSP Modelled Peak Flood Level (m AHD)	FRMSP Flood Level Difference (m)*	2006 FS Peak Modelled Flood Level (m AHD)	2006 FS Flood Level Difference (m)#
38 Woodford Ave, Warilla	Bensons	2.70	2.75	-0.05	2.58	0.12
40 Woodford Ave, Warilla	Bensons	2.77	2.75	0.02	2.57	0.20
16 Joan Ave, Warilla	Bensons	2.95	2.50	0.45	2.54	0.41
6 Joan Ave, Warilla	Bensons	2.53	2.40	0.13	2.52	0.01
33 George St, Warilla	Bensons	2.63	2.40	0.23	2.52	0.11
11 Stephanie Ave (Rear), Warilla	Bensons	2.67	2.54	0.13	2.54	0.13
11 Stephanie Ave (Front), Warilla	Bensons	2.55	2.54	0.01	2.54	0.01
9 Stephanie Ave, Warilla	Bensons	2.41	2.54	-0.13	2.54	-0.13
19 Terry Ave, Warilla	Bensons	2.21	2.03	0.18	2.08	0.13
106 Osborne Pde, Warilla	Bensons	2.20	Not Flooded	N/A	2.12	0.08
4 Raymond Street, Warilla	Bensons	2.16	Not Flooded	N/A	2.13	0.03
10 Raymond Street, Warilla	Bensons	2.20	Not Flooded	N/A	2.14	0.06
25 Headland Pde, Barrack Point	Lake	1.55	1.61	-0.06	1.77	-0.22
29 Headland Pde, Barrack Point	Lake	1.50	1.57	-0.07	1.75	-0.25
50 Jason Ave, Barrack Heights	Tongarra	1.73	1.94	-0.21	Not flooded 1.78[1]	-0.05
54 Jason Ave, Barrack Heights	Tongarra	1.98	1.94	0.04	Not flooded 1.78[1]	0.20
72 Jason Ave, Barrack Heights	Tongarra	2.11	1.93	0.18	Not flooded 1.78[1]	0.33
74 Jason Ave, Barrack Heights	Tongarra	2.06	1.93	0.13	Not flooded 1.78[1]	0.28
56 Bass St, Barrack Heights	Tongarra	1.30[2]	Not Flooded	1.30	2.50	-1.20
Surfrider Caravan Park	Tongarra	2.30	2.15	0.15	2.50	-0.20
Surfrider Caravan Park - Junction Rd	Tongarra	2.25	2.16	0.09	2.50	-0.25
Lake Windemere Caravan Park	Bensons	2.00	1.95	0.05	2.12	-0.12

Shading indicates this that this scenario gave a better match to the peak water levels than the other.

**FRMSP Peak Flood Level Difference = Historical Peak Flood Level – FRMSP Peak Flood Level*

 # 2006 Flood Study (FS) Peak Flood Level Difference = Historical Peak Flood Level – 2006 Flood Study Peak Flood Level

[1]Nearest peak flood level in Lake

[2]Peak Flood Level in Tongarra Creek near this location is > 2.0m AHD according to Water Board data (refer Figure 7-4).

Figure 7-3 Location of Recorded Flood Levels for the May 1983 Validation Event

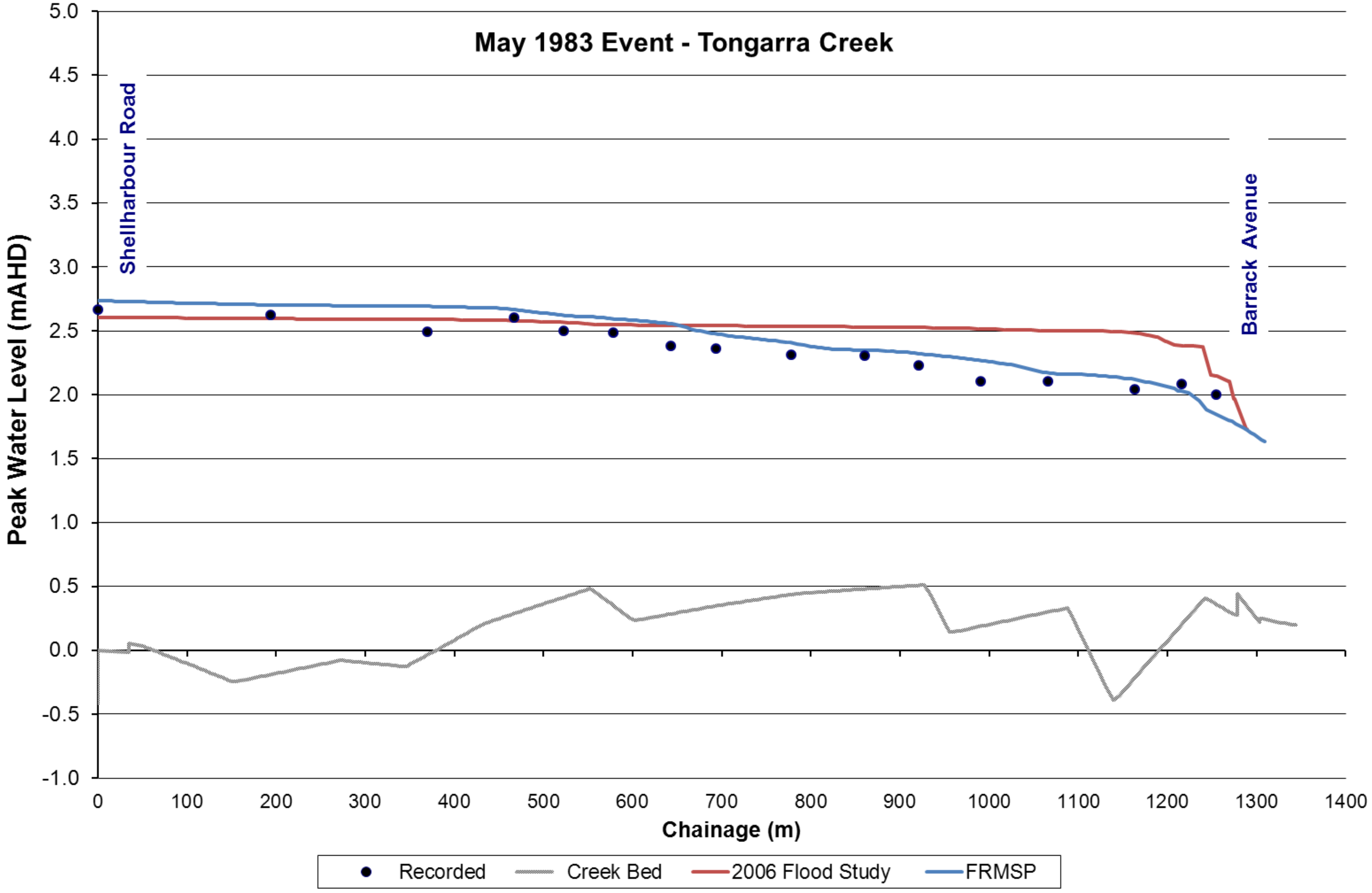

Figure 7-4 Peak Water Level Profile in Tongarra Creek for the May 1983 Validation Event

7.2 Rational Method

The rational method formula as defined in Australian Rainfall and Runoff (ARR98) (Institution of Engineers Australia, 1998) is shown in Equation 1. It provides an estimate of peak discharges for various design events and is applicable only for catchments less than 250 km^2 in area.

$$Q_Y = C_Y I_{t_{c,Y}} A \qquad (1)$$

Where A = Catchment Area

t_c = Time of concentration

$I_{t_{c,Y}}$ = Intensity for storm with duration equal to t_c and an ARI of Y years.

C_Y = Runoff Coefficient for storm with ARI of Y years.

For the rational method to be used appropriately, the following assumptions and limitations must be true:

- The time of concentration is less than the duration of peak rainfall intensity;
- Runoff is directly proportional to rainfall intensity;
- Rainfall intensity is uniform throughout the duration of the storm;
- Rainfall is distributed uniformly over the drainage area; and,
- The rational method does not account for storage in the drainage area. Available storage is assumed to be filled.

A rational method calculation to estimate the peak 1% AEP discharge was undertaken using Equation 1 and the procedures outlined in ARR98. Peak flow estimates were calculated at Andrew Park (Benson's Arm), as this was a more suitable location to apply the rational method than the catchment outlet. This is because the flow behaviour at the lake (catchment outlet) is influenced by the presence of storages within the catchment, as well as the coincidence of flows from two independent sub-catchments (Benson's and Tongarra Arms).

Table 7-2 summarises the peak discharges obtained from the rational method and the xp-RAFTS model for the 1% AEP 1 hour event (the time of concentration (t_c) for the area upstream of Andrew Park was found to be 1 hour).

Table 7-2 Summary of Peak Discharges

Method used to estimate Peak Flow at Andrew Park	Peak Discharge (m^3/s)
Rational Method	55
RAFTS model (1% AEP 1 hour event)	48

7.3 March 2011 Event with 1983 Catchment Conditions

During the consultation process, members of the community indicated that the extent of flooding, particularly around the Surfrider Caravan Park, during the March 2011 event could have been due in part to recent development in Flinders. Some community members expressed concern that the upstream development resulted in a high, faster flood peak during the March 2011 event.

In order to test this suggestion, the March 2011 calibration hydrological model was revised to incorporate 1983 catchment conditions. The model was then used to determine peak flow rates and flow timings in the study area. The regions revised are shown in **Figure 5-1**.

The analysis showed that there was no change to peak flows along Bensons Creek, Bensons Creek Tributary or the Blackbutt Dam flowpath. This result is consistent with the minimal catchment changes in these regions between 1983 and 2011.

Only minor differences were observed along Tongarra Creek. Shown below in **Figure 7-5** is the flow hydrograph for subcatchment T6 (refer **Figure 5-1**) which is located immediately downstream of the large redevelopment regions that have been constructed since 1983 and upstream of the STP.

It can be seen that in the early period of the storm (hour 2 to hour 4) the 2011 event responding slightly faster, with the curve rising approximately 15mins in advance for the 1983 conditions model. However, by hour 4, approximately 1.5 hours before the peak, the hydrographs are generally similar.

The peak of the 2011 model was 63 cumecs. The 1983 conditions model was 62.7 cumecs; approximately 1% lower than the 2011 model.

After the flood peak, the hydrograph was largely identical for both models, due to the outlet controls being the same in both cases.

Given the similarity of the hydrographs, it is unlikely that the upstream development would have had an influence over flood behaviour in the March 2011 event.

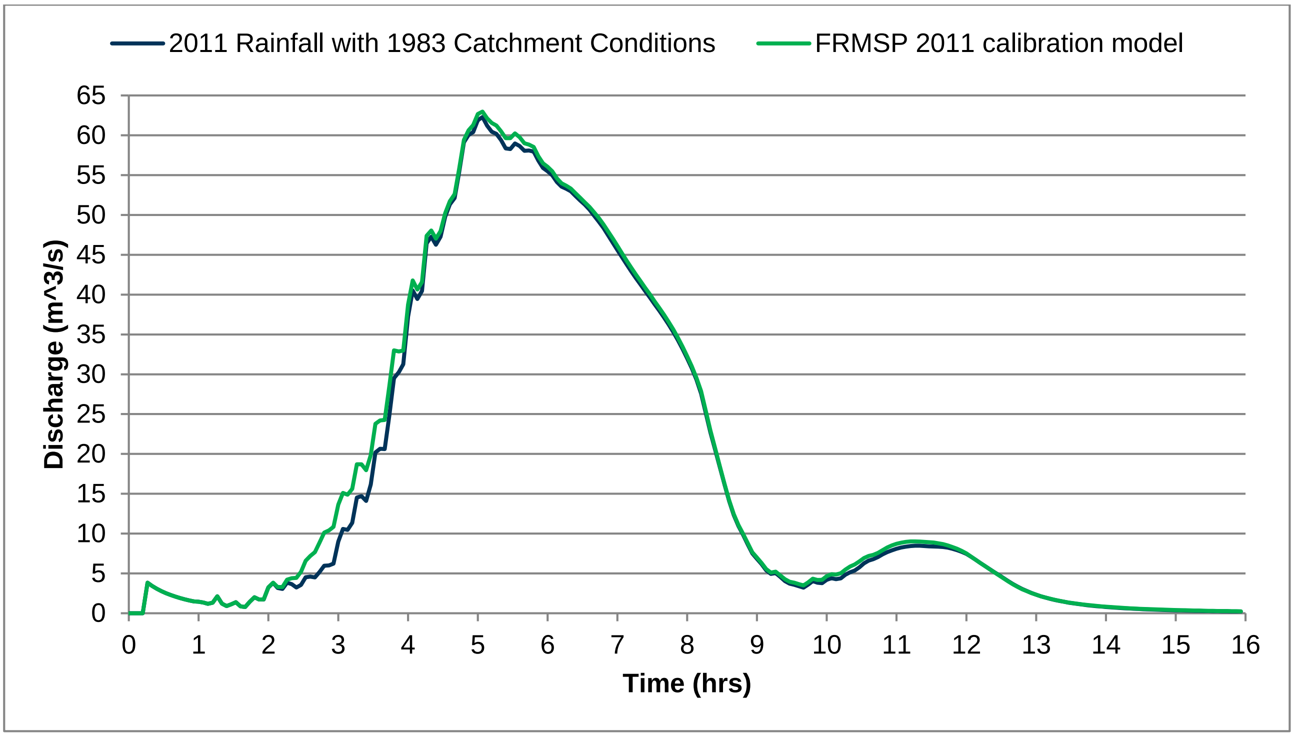

Figure 7-5 Flow Hydrograph Comparison between 2011 and 1983 Conditions

8 Design Event Modelling

The calibrated flood model required only minor adjustments for design event modelling. It was assumed that the condition of the catchment has not changed significantly since March 2011, except for a few isolated areas where residential development has occurred. Furthermore, the calibration event was roughly in the order of a 1% AEP event, making the parameter values suitable for modelling the rarer design events. Generally, the calibrated model parameters are suitable for design event modelling, with the exception of some relatively minor changes which are discussed in further detail below.

8.1 Hydrologic Parameters

The changes to the XP-RAFTS model for modelling the design events were primarily to account for changes in land use. The percentage imperviousness was adjusted to account for residential development that occurred after March 2011 (some of which is currently still in progress). These areas are highlighted in Figure 8-5. Full details of the hydrologic parameters for design event modelling can be found in Appendix D.

8.2 Hydraulic Model

The changes to the SOBEK hydraulic model for modelling the design events are outlined below:

1) Adjustments to the hydraulic roughness in the 2D grid for residential development that has occurred after March 2011 (some of which is currently still in progress). These areas are highlighted in Figure 8-5. All other roughness parameters in the hydraulic model remain the same (as per Figure 6-2);

2) Inclusion of the pedestrian/cycleway bridge at Elliot Lake – Little Lake;

3) Blockage of selected culverts, as discussed in Section 8.2.3; and

4) All major storages within the catchment assumed full prior to the event (ie. Munmorah Basin, Myimbarr Wetlands, and Blackbutt Dam). This approach was adopted in modelling the March 2011 event.

Downstream boundary conditions for the design events are discussed below.

8.2.1 Downstream Boundary Conditions

As discussed in Section 5.2.6, the downstream boundary for the flood model was defined at the ocean near the Elliot Lake- Little Lake Entrance. The design ocean water levels were determined based on recommendations in the Flood Risk Management Guide (FRM) (DECCW, 2010).

An envelope approach to estimating peak flood levels and velocities as described in the FRM (DECCW, 2010) was adopted. This considers scenarios involving the coincidence of a more (less) frequent ocean flooding event with a less (more) frequent catchment flooding event. This approach can be particularly relevant where the low-lying downstream areas can be impacted by coastal inundation. Specifically, the 1% AEP flood peaks would be defined as the envelope of:

- Estimated 1% AEP ocean flooding with 5% AEP catchment flooding with coincident peaks;
- Estimated 5% AEP ocean flooding with 1% AEP catchment flooding with coincident peaks.

This approach was adopted for other design events less frequent than the 5% AEP (in the above, replace 1% AEP with other design events). For design events more frequent than the 5% AEP, the peak flood characteristics were defined from the following scenario:

- Estimated x% AEP catchment flooding with 1% Probability of Exceedance (POE) ocean flooding with coincident peaks. The 1% POE is the water level which is exceeded only 1% of the time.

The FRM guide (DECCW, 2010) outlines a three tiered approach for adopting ocean water level conditions, but does not provide strict guidance for determining the most suitable approach. The three approaches are:

1) Static Boundary of 2.6 m AHD (non-site specific 1% AEP ocean level, which includes tidal anomalies and wave setup) for a catchment that drains directly into the ocean (ie. not into an ICOLL or tidal waterway);
2) Default Dynamic Boundary (given for the 1% AEP and 5% AEP events), which includes tidal anomalies and wave setup; and
3) Site specific analysis to determine ocean water levels.

It is noted in the FRM guideline that methods 1 and 2 can be considered conservative in some situations, particularly where the entrance conditions can reduce or negate tidal anomalies and wave setup incorporated into the 1% AEP ocean level estimates provided. Therefore, site specific peak design ocean water levels were determined using estimates of wave-setup from the surf zone model from Cardno Lawson Treloar (2006). The peak ocean water levels for each AEP event were calculated based on the design still water level and the estimated wave set up for each AEP event. These levels, along with details of the calculations, are provided in Table 8-1.

Table 8-1 Derivation of Proposed Peak Ocean Water Levels for Design Event Modelling

	Proposed Peak Ocean Level = Design Still Water Level + Estimated Wave Setup			Peak Ocean Water Level (m AHD)
Annual Exceedance Probability (AEP)	Design Still Water Level^ (m AHD)	Estimated Wave Setup* (m)	Proposed Peak Ocean Water Level (m AHD)	FRM Guidelines (DECCW, 2010)
PMF	1.61	0.9	2.5	N/A
0.5%	1.46#	0.8%	2.3	N/A
1%	1.44	0.8	2.2	2.6
2%	1.42	0.6	2.0	N/A
5%	1.38	0.4	1.8	2.3
POE	1.0	0.1	1.1	N/A

**from Cardno Lawson Treloar (2006)*
^Sydney Harbour design still water level which includes effects of tides and meteorological processes (incl. storm surge), from CSIRO (2012).
% Wave Setup not analysed for the 0.5% AEP event in Cardno Lawson Treloar (2006).
 # Sydney Harbour design still water level(Watson and Lord, 2008).

The peak ocean levels detailed in Table 8-1 can be used either as a fixed level or incorporated into a tidally varying downstream boundary. A fixed or static ocean water level was used for design event modelling. This was determined following sensitivity testing of static and dynamic downstream boundary conditions for the 1% AEP 36 hour event, which showed only minor differences in terms of peak water levels, generally less than 0.05 to 0.06m (refer Figure B-3 in Appendix B). It is also noted that use of a static water level equal to the peak ocean level is more conservative than a tidally varying condition. Further details of the sensitivity testing undertaken are provided in Section 8.2.1.1.

8.2.1.1 Sensitivity Testing of Downstream Boundary Conditions

The impact of a static ocean level compared to a tidally varying ocean level on inundation characteristics was examined for the 1% AEP 36 hour event. The 36 hour duration event was selected for testing purposes because:

1) The critical duration upstream of Barrack Ave Bridge near the Surfrider Caravan Park was 36 hours for the 1% AEP event, according to the 2006 Flood Study; and

2) Longer duration events have greater potential to give varying inundation characteristics when a static level is used compared with a dynamic level.

The following downstream boundary conditions were examined for the 1% AEP 36 hour event:

1) Static ocean level of 1.8m AHD (equal to the 5% AEP ocean level in); and

2) Dynamic ocean level based on the default tidal boundary provided in the FRM guide (DECCW, 2010). The water level time series was scaled so that a peak of 1.8m AHD was achieved, and also shifted so that the peak occurred at the time of peak catchment flooding (refer Figure 8-1). Note that the time of peak catchment flooding varies for the northern part of the catchment (which drains into Benson's Creek) and for the southern part of the catchment (which drains into Tongarra Creek) by approximately 1 hour, although the variation in ocean levels within this time is only about 0.1m.

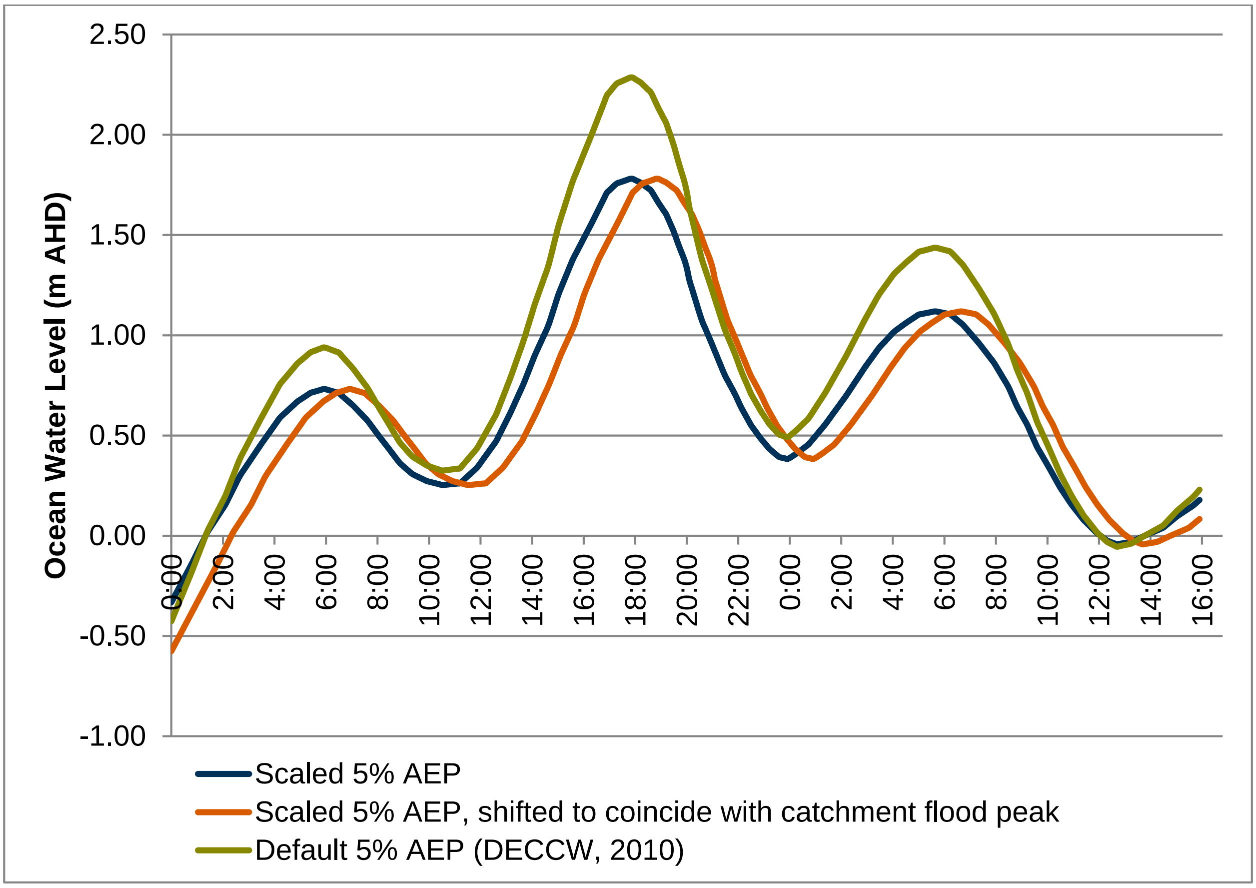

Figure 8-1 Dynamic Downstream Boundary Condition – 5% AEP

Testing of the 1% AEP 36 hour event with a static and dynamic boundary, as described above, was undertaken. Results of this sensitivity testing showed only minor differences in terms of peak water levels, generally less than 0.05 to 0.06m (refer Figure B-3 in Appendix B). A static downstream boundary condition was therefore adopted for design event modelling. It is also noted that use of a static water level equal to the peak ocean level is more conservative than a tidally varying condition.

8.2.2 Lake Entrance Conditions

As noted in Section 2, Elliot Lake – Little Lake is an estuary through which catchment flows discharge to the Pacific Ocean. The condition of the estuary, specifically, the extent of entrance closure as well as the lake bathymetry, have the potential to impact on the behaviour of catchment outflows and coastal inundation.

This section examines the Elliot Lake estuary to determine the most suitable conditions to adopt for modelling design events.

According to BMT WBM (2013), the lake remains permanently open due to the 80m rock groyne on the northern side of the entrance and the natural bedrock along the southern bank and headland. Despite this, sediment transport processes give rise to dynamic lake bed levels. WBM (2003) note that training of the lake entrance promotes the ingress of marine sand well into the entrance channel and the northern and southern arms of the lake, which are only scoured out during flooding events with outflows of sufficient velocity. Differences in lake bed levels with time are evident in Figure 8-3, which shows that in 2002, lake bed levels were up to 1 m higher than in 2012 near the confluence of the northern and southern arms. Scouring during the large flood event in March 2011 may have contributed to the lower lake bed levels in 2012 when compared to the 2002 condition.

Sensitivity testing was therefore undertaken to determine the impact of lake conditions on catchment flood levels. In lieu of morphodynamic modelling to provide an indication of the range of possible entrance conditions, sensitivity testing was undertaken using a fixed bed approach and available survey data. The various scenarios examined were:

- Scenario 1: Lake bathymetry as per the 2002 hydrographic survey;
- Scenario 2: Lake bathymetry as per the 2012 hydrographic survey; and
- Scenario 3: Lake bathymetry as per the 2012 hydrographic survey with 50% of the entrance fully blocked (refer Figure 8-2).

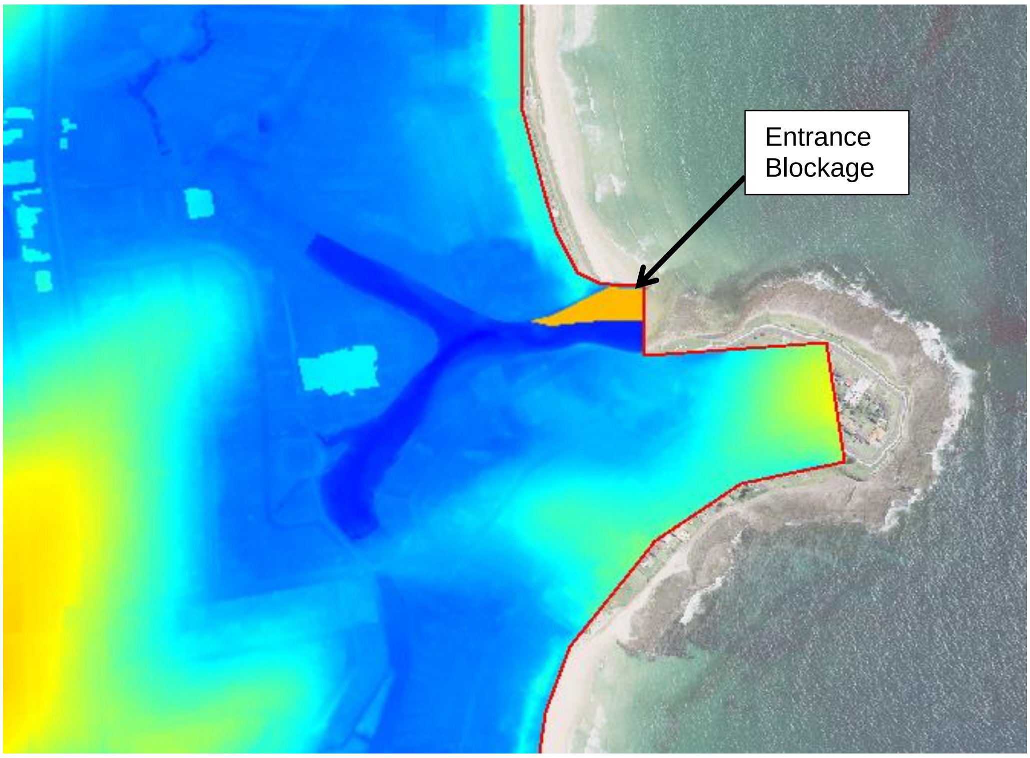

Figure 8-2 Digital Terrain Model showing the extent of entrance blockage for Scenario 3 (2012 bathymetry, 50% blocked)

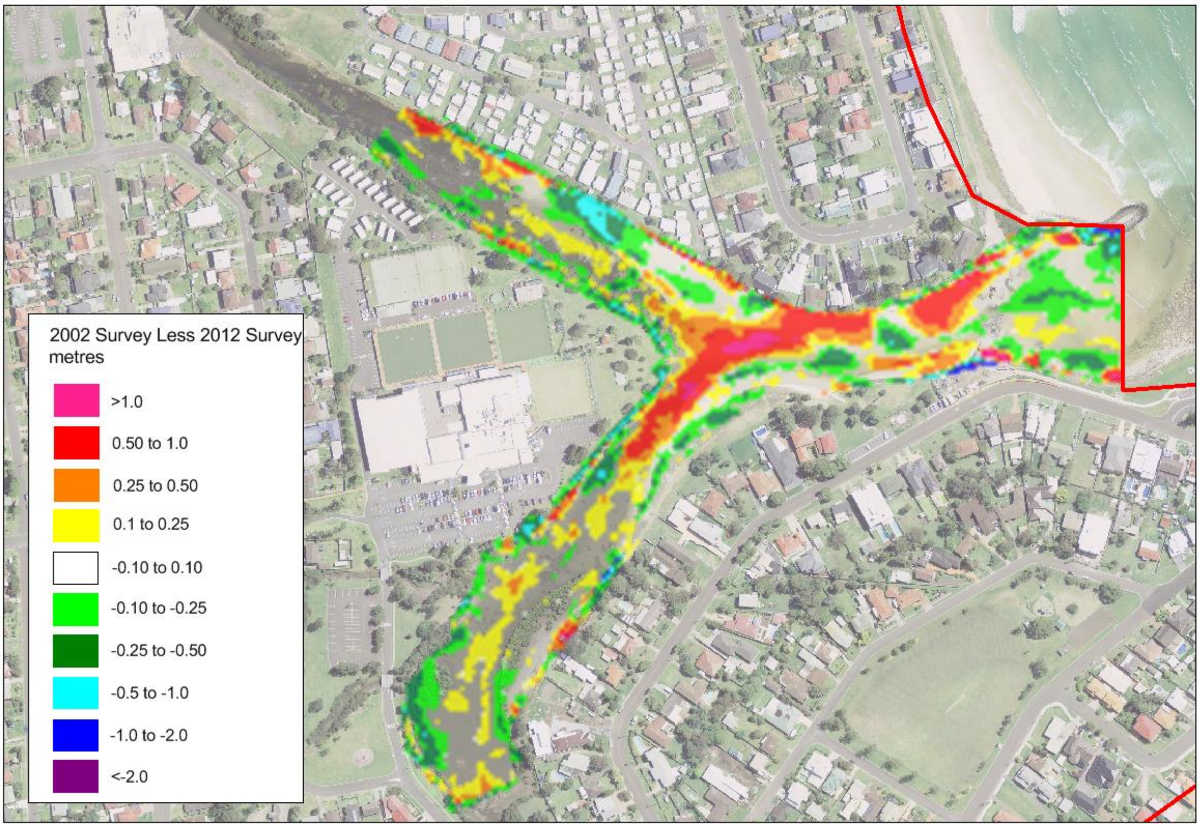

Figure 8-3 Difference in Lake Bathymetry (2002 Survey Less 2012 Survey)

Testing was undertaken for both the 1% AEP 36 hour event and the 1% AEP 2 hour event as these were found to be the critical durations in and around the lake (Cardno Lawson Treloar, 2006). A static downstream boundary condition equal to the peak 5% AEP ocean level (refer Table 8-1) was used. Figures B-4 to B-7 in Appendix B show the differences in terms of peak water levels for the different scenarios.

Changes to the entrance conditions generally lead to differences in and around the lake, up to Oakleigh Park and down to the Surfrider Caravan Park. Scenario 1 (2002 bathymetry) gives peak water levels which are around 0.06 to 0.1 m higher in these areas than in Scenario 2 (2012 bathymetry). This is slightly higher for Scenario 3 (2012 bathymetry, 50% blocked) at around 0.1 to 0.2m.

The 2002 hydrographic survey (ie. Scenario 1) was used to define the lake bathymetry for design event modelling, based on the outcomes of the sensitivity testing. This scenario represents a more conservative condition than Scenario 2 (2012 bathymetry), but is a more realistic representation than Scenario 3 (2012 bathymetry, 50% blocked) which is unlikely to occur based on the analysis of entrance morphology in WBM (2003). It is proposed to utilise the approach in Scenario 3 (2012 bathymetry, 50% blocked) for the Sensitivity Analysis phase of design event modelling.

8.2.3 Blockage

An analysis of likely culvert blockage was undertaken to determine suitable blockage conditions for design event modelling. The analysis was based on the recently released report for the Australian Rainfall and Runoff Revision Project 11: Blockage of Hydraulic Structures (Engineers Australia, February 2013). It provides guidance on accounting for blockage in the design and modelling of hydraulic structures which are applicable Australia wide.

The report details two blockage assessment approaches which are best suited for culverts, namely:

- Scheme A: qualitative assessment with adjustments for ARIs; and
- Scheme B: more quantitative assessment based on scoring system with no adjustments for ARIs.

An assessment of culvert blockage for the Elliot Lake – Little Lake catchment was undertaken according to Scheme A, using the procedures outlined in Engineers Australia (February, 2013). Figure 8-4 outlines the structures to be blocked for the design runs, with the extent of blockage indicated in Table 8-2. It is conservatively assumed that blockage will occur for the entire duration of the event. Refer to Appendix E for further details of the assessment.

Table 8-2 Blockage of Hydraulic Structures for Design Event Modelling

ID	Location	Type of structure	Blockage for Various Design Events		
			< 20yr ARI	20 yr <= ARI <= 200yr	> 200 yr ARI
1	Fischer Rd	Culvert	Unblocked	Unblocked	Unblocked
2	Railway near Bush St	Culvert	Unblocked	Unblocked	Unblocked
3	Whittaker St	Culvert	Unblocked	Unblocked	Unblocked
4	Baragoot Rd	Culvert	Unblocked	Unblocked	10%
5	Railway near Meryla Way	Culvert	Unblocked	Unblocked	Unblocked
6	Seymour Dr	Culvert	Unblocked	Unblocked	10%
7	Shellharbour Rd near Dunmore Rd	Culvert	Unblocked	Unblocked	Unblocked
8	Haddin Rd	Pit Inlet (multiple)	Unblocked	Unblocked	Unblocked
9	Munmorah Circuit	Culvert	Unblocked	Unblocked	10%
10	Wattle Rd	Culvert	25%	50%	100%
11	Shellharbour Rd d/s of Wetlands	Culvert	Unblocked	Unblocked	Unblocked
12	Lavender Grove	Grated Inlet	25%	50%	100%
13	Downstream of the Blackbutt Dam Spillway	Pipe Inlet	25%	50%	100%
14	Gallen Reserve	Pit Inlet (multiple)	Unblocked	Unblocked	Unblocked
15	Barrack Ave	Culvert	Unblocked	10%	20%
16	Jason Ave North	Culvert	Unblocked	10%	20%
17	Jason Ave South	Culvert	Unblocked	10%	20%
18	Sunset Ave	Grated Kerbside Inlet (multiple)	25%	25%	50%
19	Shellharbour Rd at Oakleigh Ck	Culvert	25%	50%	100%
20	Oakleigh Creek U/S	Culvert	Unblocked	Unblocked	Unblocked
21	George St	Culvert	Unblocked	10%	20%
22	Beverly Ave	Culvert	Unblocked	Unblocked	10%
23	Shellharbour Rd d/s Memorial Park	Culvert	25%	50%	100%
24	Lake Entrance Rd u/s Memorial Park	Culvert	25%	50%	100%
25	Leawarra Ave	Culvert	Unblocked	Unblocked	Unblocked
26	The Kingsway	Culvert	Unblocked	Unblocked	10%
27	Captain Cook Dr	Grated Pit Inlet (multiple)	25%	25%	50%
28	Lake Entrance Rd near Wattle Rd	Grated Pipe Inlet	25%	25%	50%
29	Cycleway under Lake Entrance Rd	Informal Culvert	Unblocked	Unblocked	Unblocked
30	Madigan Blvd	Culvert	25%	50%	100%
31	Landy Dr	Culvert	25%	25%	50%
32	Andrew Reserve	Culvert	25%	25%	50%
33	Grimmett St & Spofforth St	Grated Kerbside	25%	25%	50%

ID	Location	Type of structure	Blockage for Various Design Events		
		Inlet (multiple)			

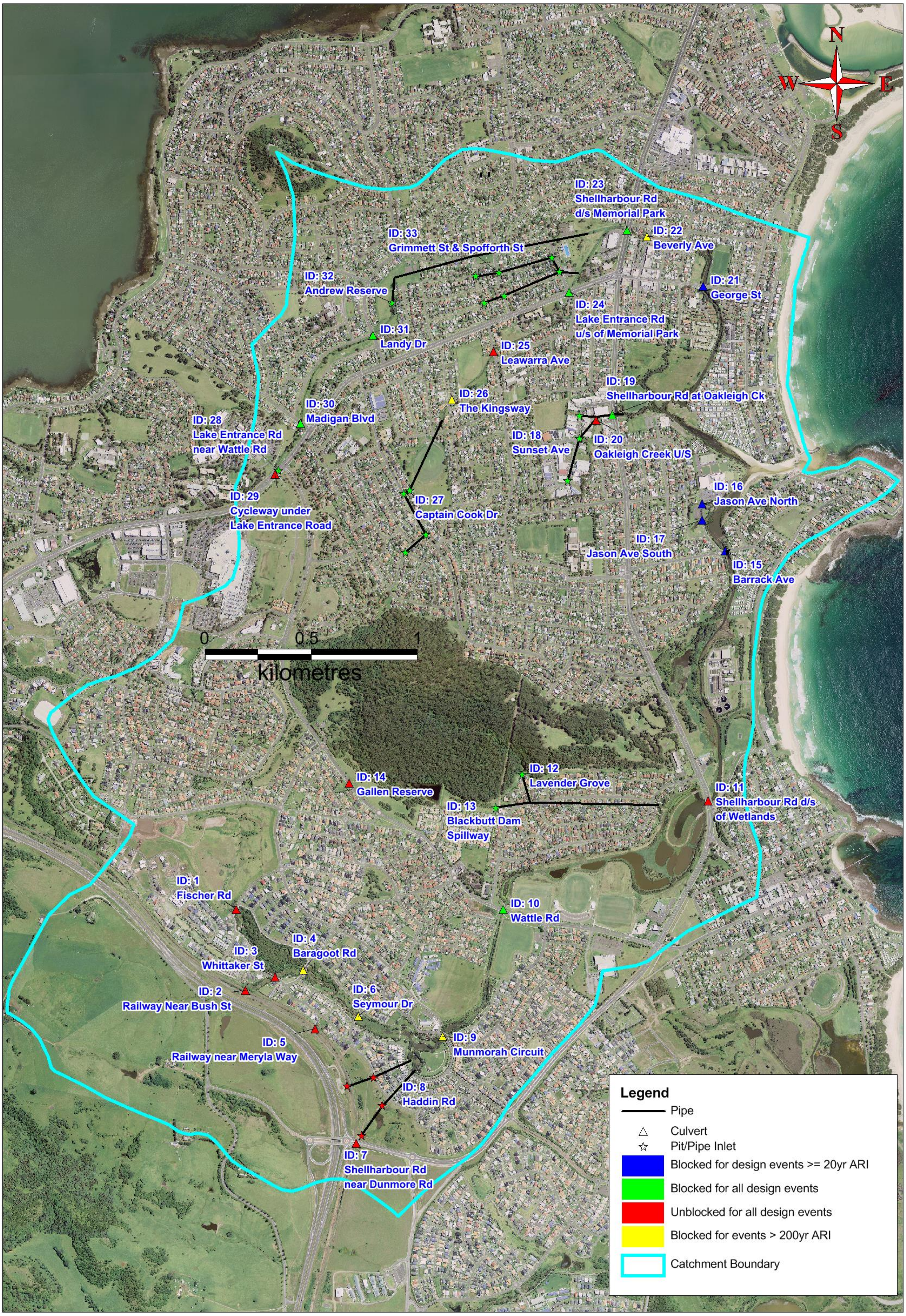

Figure 8-4 Hydraulic Structures to be blocked for design event modelling

8.3 Comparison with 2006 Flood Study Design Events

A preliminary model run was undertaken for the 1% AEP design event, to provide a comparison with the results from the 2006 Flood Study. This was undertaken for the 2 hour duration event only due to the model run time required to simulate all durations. Cardno Lawson Treloar (2006) found that the critical duration in most parts of the catchment for the 1% AEP event was 2 hours.

The proposed adjustments to the calibrated flood model outlined in Section 8.1 and 8.2 were made prior to modelling the 1% AEP design event. Note that for the sake of comparison, the same ocean water levels used in the 2006 Flood Study were adopted for this run (ie. a static water level equal to 2 m AHD), and all pipes were assumed unblocked.

Long profiles showing peak water levels in the main channels are provided in Appendix C. In general, the results are similar between the two models, with differences at key locations due largely to the extensive changes to the model structure that have been made in the FRMSP model, namely:

- Representation of the entire model domain in 2D to better define overbank flows, with 1D elements used only for in-channel flows and pipe flows. The 2006 Flood Study model is predominantly defined using 1D elements with only small areas at Shellharbour War Memorial Park and Warilla represented as 2D components.
- Altered schematisation of key hydraulic structures, such as Barrack Ave Bridge. Section 7.1 demonstrated that the FRMSP model gave a better representation of the flood profile near Barrack Avenue Bridge for the May 1983 validation event.

Figure 8-5 Proposed Areas To Be Updated For Modelling Design Events

9 Existing Scenario Flood Modelling Results

Design event modelling was undertaken using the calibrated flood model and the modifications for design event modelling outlined in Section 8. This section details the results from design event modelling for existing conditions.

9.1 Extents and Flood Depths

Flood modelling of the design storms was undertaken for the 1 EY (1yr ARI), 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and PMF events. Flood extents for these design storms are shown in Appendix F (refer Figures F-1 to F-8).

The peak flood depths for these design storms are shown in Appendix F (refer Figures F-9 to F-16).

9.2 Critical Duration

For the 1% AEP event, critical durations range from 90 minutes and 120 minutes in the upper catchment areas, where peak depths are driven by rainfall intensity, to 6 hours and 9 hours in the lakes where flood levels are driven by rainfall volume. A map showing the critical duration throughout the catchment for the 1% AEP event can be found in Appendix F (refer Figure F-17). Similar critical durations were observed for the other design events.

9.3 Flood Hazard

9.3.1 Provisional Flood Hazard

Provisional flood hazard is determined through a relationship developed between the depth and velocity of floodwaters and is based strictly on hydraulic considerations (NSW Government, 2005). The Floodplain Development Manual (NSW Government, 2005) defines two categories for provisional hazard – high and low.

The model results were processed using an in-house developed program, which utilises the model results of flood depth and velocity to determine hazard. Provisional hazard was prepared for all design events.

Hazard is calculated for each grid cell at each time step based on velocity, depth and velocity x depth, with the highest value giving the hazard rating for the cell.

The provisional hazard is shown in Appendix F (refer Figures F-18 to F-25).

9.3.2 True Flood Hazard

Provisional flood hazard categorisation based around the hydraulic parameters described above in Section 9.3.1, does not consider a range of other factors that influence the “true” flood hazard. In addition to water depth and velocity, other factors contributing to the true flood hazard include the:

- Size of the flood;
- Effective warning time;
- Flood readiness;
- Rate of rise of floodwaters;
- Duration of flooding;
- Ease of evacuation;
- Effective flood access; and
- Type of development in the floodplain.

True flood hazard will be assessed as part of the Floodplain Risk Management Study and Plan.

9.3.3 Hydraulic Categories

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

- Floodway - Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- Flood Storage - Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.
- Flood Fringe - Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

Floodways were determined for the 1% AEP event by considering those model branches that conveyed a significant portion of the total flow. These branches, if blocked or removed, would cause a significant redistribution of the flow. The criteria used to define the floodways are described below (based on Howells et al, 2004).

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

- Velocity x Depth product must be greater than 0.25 m2/s and velocity must be greater than 0.25 m/s; OR
- Velocity is greater than 1 m/s.

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

Previous analysis of flood storage in 1D cross sections assumed that if the cross-sectional area is reduced such that 10% of the conveyance is lost, the criteria for flood storage would be satisfied To determine the limits of 10% conveyance in a cross-section, the depth was determined at which 10% of the flow was conveyed. This depth, averaged over several cross-sections, was found to be 0.2 m (Howells et al, 2004). Thus the criteria used to determine the flood storage is:

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

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

The hydraulic categories for the 1% AEP event can be found in Appendix F (refer Figure F-26).

Combined hazard and hydraulic categories for the 1% AEP event can be found in Appendix F (refer Figure F-27).

10 Discussion on Existing Flooding

10.1 Major Flowpaths

10.1.1 Benson's Creek

Benson's Creek is the main channel which drains the northern portion of the catchment. Starting from the Council basins near Shellharbour Council Chambers, the open channel runs through to Andrew Park where it becomes piped drainage. It then reconnects with the open channel at Shellharbour War Memorial Park which continues on to Elliot Lake – Little Lake.

The majority of the creek length is a low hazard flow path in the 1% AEP event, with isolated portions of the creek classed as high hazard. Specifically, King Mickey Park and Shellharbour War Memorial Park are both high hazard flow paths.

Inundation occurs in events as small as the 20% AEP in the area between Andrew Park and Shellharbour War Memorial Park due to surcharging of the drainage network. Properties surrounding King Mickey Park are impacted in events less frequent or equivalent to the 20% AEP due to limited culvert capacity under George Street constricting flood flows and the fairly flat low lying park acting as an informal detention.

10.1.2 Benson's Tributary

Benson's Tributary enters Benson's creek at Shellharbour War Memorial Park. It begins as piped drainage at the Northern end of Blackbutt Forest Reserve, passing through Jock Brown Oval, before it turns into an open channel. It drains parts of Barrack heights and Warilla.

Upstream of the concrete lined portion as well as within Shellharbour War Memorial Park, it is mainly characterised as a high hazard flow path.

In events as small as the 20% AEP, surcharging causes inundation of Lindesay Street, Captain Cook Drive, The Kingsway and Ulster Avenue. Limited culvert capacity under Leawarra Avenue result in water flowing down Leawarra Avenue and onto Lake Entrance Road. Benson's tributary breaks its banks at Shellharbour War Memorial Park in events above the 20% AEP.

10.1.3 Tongarra Creek

Tongarra Creek is the main channel which drains the southern portion of the catchment, covering parts of or all of the suburbs of Flinders, Barrack Point, Barrack Heights, Shellharbour and Blackbutt. It is an open channel for its entire length, starting from Fischer Road at Blackbutt, until Barrack Avenue Bridge at Barrack Point. It passes through a series of storages, including Munmorah Basin at Flinders and the Myimbarr Wetlands at Shellharbour. Before draining to Elliot Lake – Little Lake, it passes alongside both the Surfrider Caravan Park and Shellharbour Sewage Treatment Plant.

Tongarra Creek is a high hazard flow path for its entire length in the 1% AEP event.

Flood flows are generally contained within the main channel upstream of Munmorah Basin for the events up to and including the 0.5% AEP. However, downstream of Shellharbour Road, it breaks its banks in the 1 EY due to the relatively large volume of water from the upstream contributing catchment. The low lying Surfrider Caravan Park experiences inundation to depths of up to around 0.5m in the 20% AEP. This occurs due to a combination of the Barrack Avenue Bridge constricting outflow into the lake and Tongarra creek breaking over its eastern bank just upstream of the caravan park. In addition to flooding from Tongarra Creek, the Surfrider Caravan Park is also impacted by ocean flooding events which increase the water levels within Elliot Lake and Little Lake. Shellharbour Road and Wattle Road are overtopped in events greater than the 10% AEP to depths in excess of 0.2m (for further details, refer Section 10.2).

10.1.4 Oakleigh Creek

Oakleigh Creek is a relatively short drainage canal which passes through Oakleigh Park before entering the northern arm of Elliot Lake – Little Lake. Stormwater flows from the industrial area near Sunset Avenue drain to Oakleigh Creek through the concrete lined open channel upstream of Shellharbour Road.

Oakleigh Creek downstream of Shellharbour Road is predominately a low hazard flow path in the 1% AEP event. However, the concrete lined channel upstream of Shellharbour Road, along with the eastern side of Sunset Avenue, are both high hazard flow paths in the 1% AEP.

10.2 Main Road Overtopping

There are a number of main roads throughout the study area that are inundated in various design events. These overtopping locations are shown in Figure 10-1. Overtopping depths in the 10%, 2%, and 1% AEP events for these locations are summarised in Table 10-1.

The table shows that a number of locations are flooded by depths greater than 0.2m, which is considered the safe limit for vehicle access.

The implications of this loss of vehicular access will be examined as part of the subsequent Floodplain Risk Management Study.

Table 10-1 Main Road Overtopping Depths

ID	Location	10% AEP Depth (m)	2% AEP Depth (m)	1% AEP Depth (m)
A	Lake Entrance Road & Wattle Road Intersection	0.05	0.16	0.20
B	Landy Drive & Garrard Avenue Intersection	0.02	0.15	0.21
C	Lake Entrance Road & Leawarra Avenue Intersection	0.22	0.38	0.45
D	Leawarra Avenue &William Avenue Intersection	0.18	0.31	0.36
E	Shellharbour Road at Bensons Creek Crossing	0.11	0.31	0.40
F	Shellharbour Road & Lake Entrance Road intersection	0.18	0.25	0.28
G	George Street at Bensons Creek Crossing	-	0.09	0.17
H	Shellharbour Road and Sunset Avenue Intersection	0.22	0.29	0.35
I	Woodlands Drive and Shellharbour Road Intersection	-	0.02	0.10
J	Shellharbour Road and Beach Road Intersection	-	0.14	0.22
K	Wattle Road at Tongarra Creek Crossing	0.20	0.28	0.30
L	Munorah Circuit at Tongarra Creek Crossing	-	-	0.02

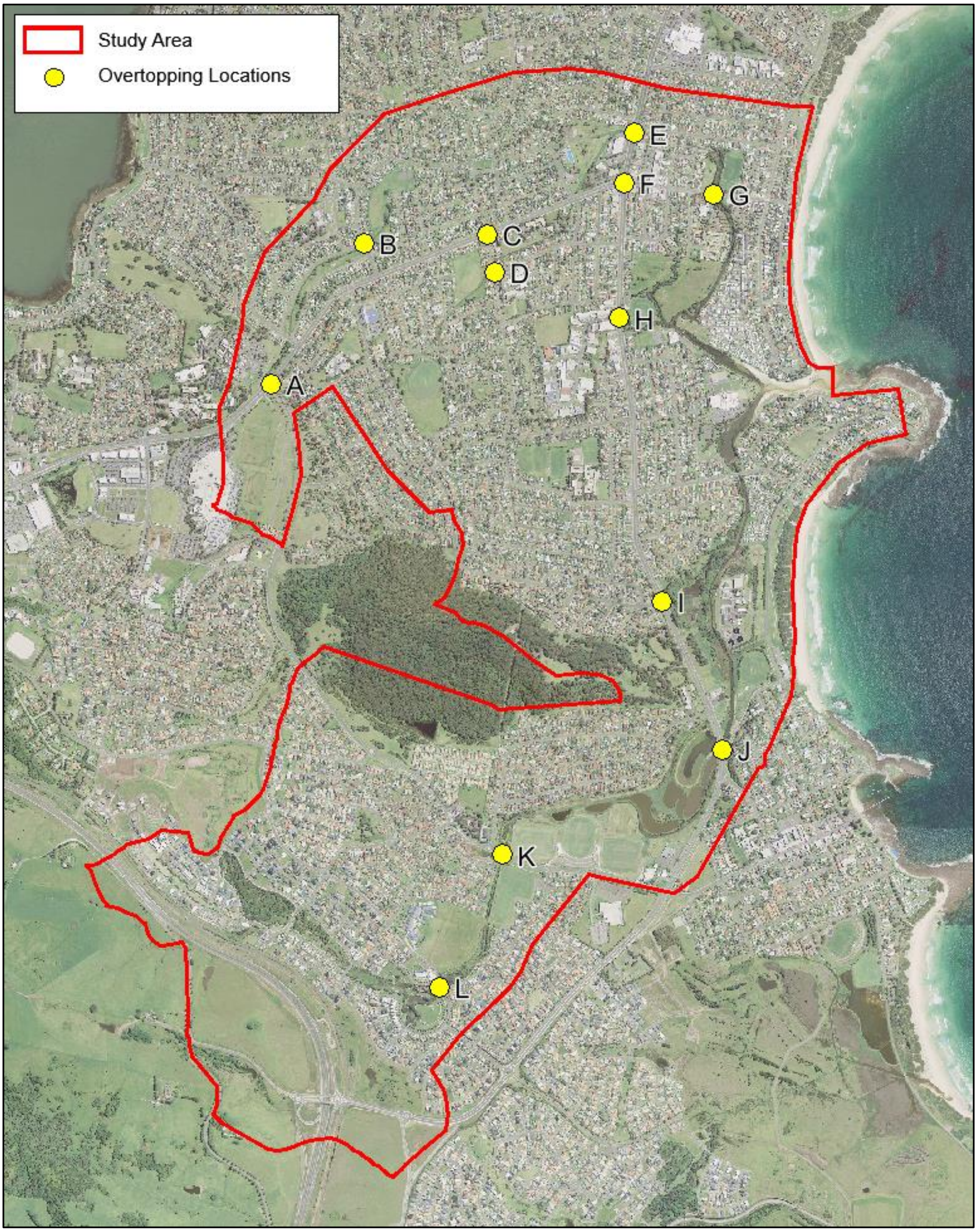

Figure 10-1 Main Road Overtopping Locations

11 Conclusion

Flood modelling has been undertaken for the Elliot Lake – Little Lake catchment in order to describe the existing flood behaviour, as part of the NSW Floodplain Management Process.

Hydrologic and hydraulic modelling undertaken for the 2006 Elliot Lake Little Lake Flood Study (Cardno Lawson Treloar, 2006) was updated using previously unavailable information. The flood models were calibrated and validated against two historical events, and adjusted for the purposes of design event modelling. The design events assessed were the 1 EY (1 year ARI), 20% AEP, 10% AEP, 5% AEP, 2% AEP events and the PMF event.

Peak water levels depths as well as provisional flood hazards and hydraulic categories were determined for each AEP event. These results represent the flooding behaviour for "existing" conditions. The outcomes of this investigation will form the basis for the subsequent Floodplain Risk Management Study and Plan.

12 Qualifications

This report has been prepared by Cardno for Shellharbour City Council and as such should not be used by a third party without proper reference.

The investigation and modelling procedures adopted for this study follow industry standards and considerable care has been applied to the preparation of the results. However, model set-up and calibration depends on the quality of data available. The flow regime and the flow control structures are complicated and can only be represented by schematised model layouts.

Hence there will be a level of uncertainty in the results and this should be borne in mind in their application.

The report relies on the accuracy of the survey data and pit and pipe date provided.

Study results should not be used for purposes other than those for which they were prepared.

13 References

BMT WBM (2013), Draft Shellharbour Coastal Zone Management Study, Prepared for Shellharbour City Council, February 2013.

Cardno Lawson & Treloar (2006).“Elliot Lake Little Lake Flood Study.”Prepared for Shellharbour City Council.

DECCW, 2010. Coastal Risk Management Guide: Incorporating sea level rise benchmarks in coastal risk assessments. Sydney, Department of Energy, Climate Change and Water NSW.

Howells, McLuckie, Collings, Lawson, 2004. Defining the floodway – Can one size fit all? FMA NSW Annual Conference, Coffs Harbour, February 2004.

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Rienco Consulting (2012).“A review of Rainfall and Flooding in the Shellharbour City LGA during the storm of March 2011.”Prepared for Shellharbour City Council.

SMEC (2010). Shellharbour Coastal Hazard Study, Prepared for Shellharbour City Council, August 2010.

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Watson and Lord, 2008. Sea Level Rise Vulnerability Study. Sydney, DECC.

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Elliot Lake – Little Lake Floodplain Risk Management Study and Plan

APPENDIX A

RESIDENT BROCHURE AND QUESTIONNAIRE

Floodplain Risk Management Options

The following list of Floodplain Risk Management options presents some preliminary strategies that could be considered to minimise the risk and reduce the impact of flooding throughout the Elliot Lake - Little Lake floodplain. These options will be considered in further detail during the preparation of the Management Study and Plan.

Examples of Flood Management Options	Description
Flood Modification Options	• Construction of levees where properties are most at risk • Upgrading of drainage systems i.e. construction of detention/retarding basins • Stabilisation works of eroding foreshore areas and along drainage channels
Property Modification and Planning Control Options	• Building and development controls • Voluntary house raising program (for selected properties) • Voluntary house rebuilding subsidy scheme (for selected properties) • Voluntary property purchase program (for selected properties).
Emergency Response Modification Options	• Revision of the Local Disaster Plan (DISPLAN) • Public awareness and education—locality based flooding information for residents • Public awareness and education—flooding information for schools • Flood depth markers at major (flood affected) road crossings • Continuation of existing public awareness and education campaigns • Data collection strategies for future floods

Consultation

During the Floodplain Risk Management Study and Plan process, consultation will be undertaken with the community in order to establish a comprehensive list of management options.

In addition to the accompanying Survey, which can also be found on Council's website, you will have further opportunities to comment on the direction of the project during the public exhibition periods of the Draft Risk Management Study and Plan. Any comments received during these periods will be taken into account before finalisation.

For further information regarding this project, please contact Shellharbour City Council or Cardno via the details below.

Contact Us

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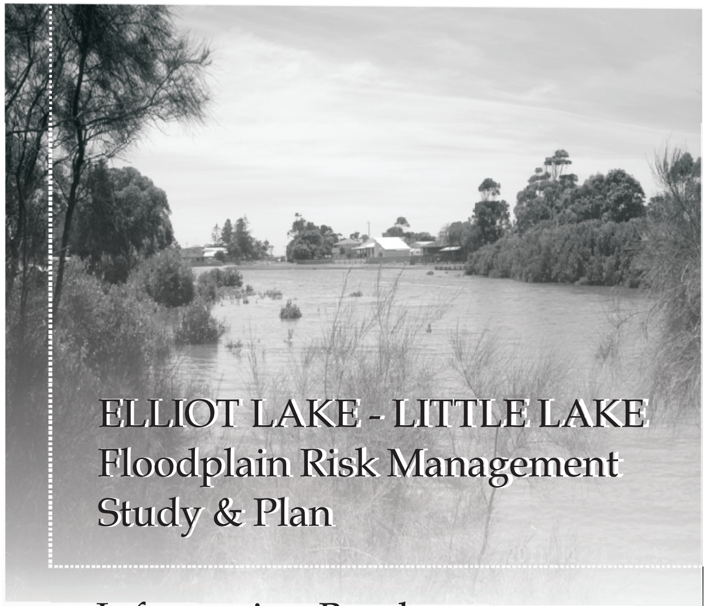
E: sahani.pathiraja@cardno.com.au



ELLIOT LAKE - LITTLE LAKE Floodplain Risk Management Study & Plan

Information Brochure

Shellharbour City Council has engaged Cardno to assist with the preparation of the Elliot Lake - Little Lake Floodplain Risk Management Study and Plan.

The Floodplain Risk Management Study and Plan follows from the Flood Study, completed in 2006 by Cardno, which identified the existing flood behaviour in the Elliot Lake - Little Lake floodplain. The purpose of this Risk Management Study and Plan is to identify and recommend appropriate actions to manage flood risks in the Elliot Lake - Little Lake floodplain.

This brochure provides an introduction to the Floodplain Risk Management Study and Plan and informs you of its objectives.

prepared for Shellharbour City Council | prepared by Cardno Shaping the Future

Formation of a Committee | Data Collection | Flood Study | Floodplain Risk Management Study | Floodplain Risk Management Plan | Implementation of Plan

Study Area

The study area is the Elliot Lake - Little Lake catchment. The area comprises mainly residential areas with some business and light industry. Blackbutt Nature Reserve lies at the heart of the study area.

The main waterways of the catchment are Bensons Creek, Benson Tributary and Tongarra Creek. Bensons Creek drains the northern portion of the study area while Tongarra Creek drains the southern portion. Both creeks drain into Elliot Lake which discharges into the ocean at Barrack Point.

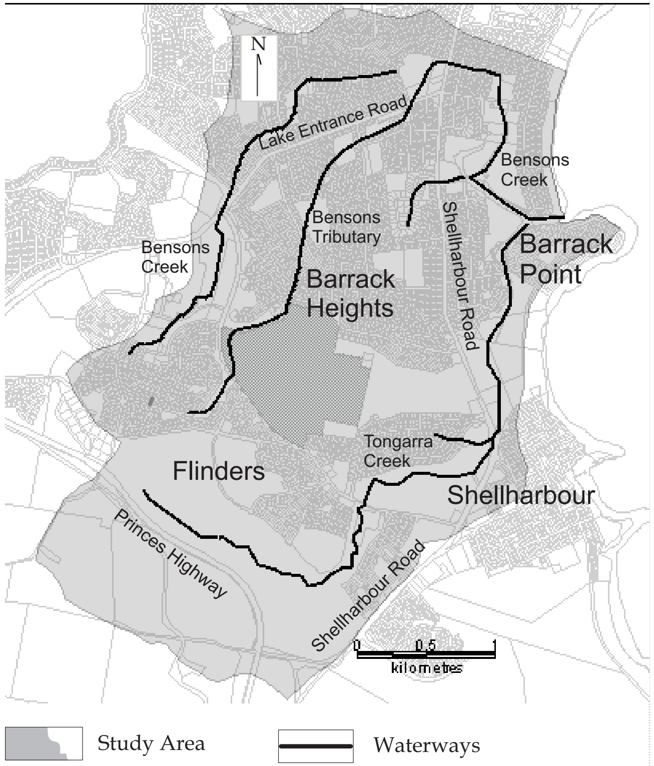
Flooding in Elliot Lake - Little Lake Catchment

Elliot Lake – Little Lake Flood Study, undertaken by Cardno in 2006, identified that flooding in the catchment area is predominately caused by runoff from Bensons Creek in the north and Tongarra Creek in the south. This can result in wide spread flooding due to the limited capacity of the pipe drainage systems and flow paths in the area.

Flooding has occurred in the catchment on a number of occasions, with the most recent serious event being March 2011.

Elliott Lake - Little Lake Catchment

The Elliot Lake - Little Lake Catchment is located south of Lake Illawarra and includes the suburbs of Barrack Heights, Shellharbour, Flinders, Blackbutt and parts of Mt Warrigal and Warilla.



Floodplain Management Process

Council's Floodplain Management Committee (the Committee) oversees the Floodplain Management process and is part of the NSW Government process for Floodplain Management. The Committee meets regularly and includes representatives from Council, Office of Environment and Heritage, Roads and Maritime Services, State Emergency Service (SES), Landcare, NSW Fisheries and representatives of the local community.

Floodplain Risk Management Study and Plan Objectives

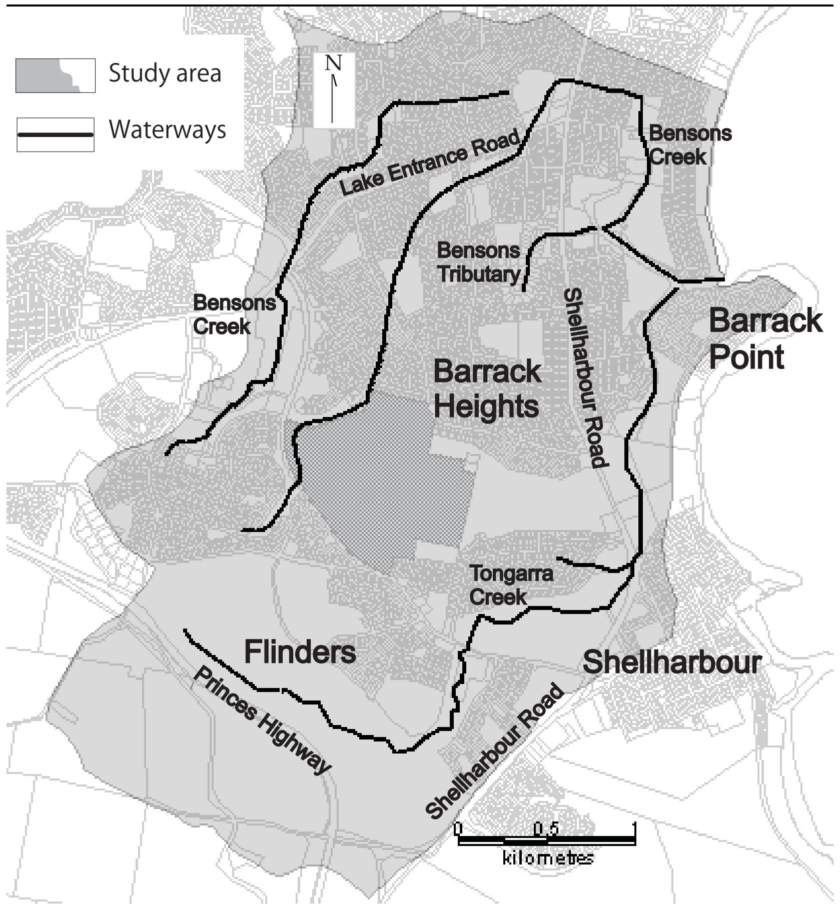
The objectives of the study and plan are:

Floodplain Risk Management Study

Find an appropriate mix of management measures and strategies to effectively manage the full range of flood risk in accordance with the NSW Government Floodplain Development Manual (2005) through an effective public participation and community consultation program. The information from this study will enable Council to formulate a Floodplain Risk Management Plan for the study area.

Floodplain Risk Management Plan:

Formulate a cost effective plan for the study area based on the findings of the Floodplain Risk Management Study and provide a priority program for implementation of the recommended works and measures in accordance with the Manual. The plan will detail how the existing and future flood risk within the study area will be managed.



Glossary

Culvert – a drain or covered channel that passes under a road or railroad.

Levee Banks – An embankment usually constructed from earth or concrete built along the banks of a river to help prevent overflow of its waters.

Retarding/Detention Basin - A naturally occurring or constructed depression in the land surface that detains stormwater runoff by allowing it to slowly drain out of the basin into the adjoining natural drainage line or creek.

Stormwater Harvesting - the collection, storage, treatment and use of stormwater runoff from urban areas.

If you have any further comments that relate to the Elliot Lake - Little Lake Floodplain Risk Management Study and Plan, please express them in the space below. Please feel free to attach additional pages if necessary.

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YOUR PERSONAL INFORMATION WILL REMAIN CONFIDENTIAL

If you have any queries, please contact:

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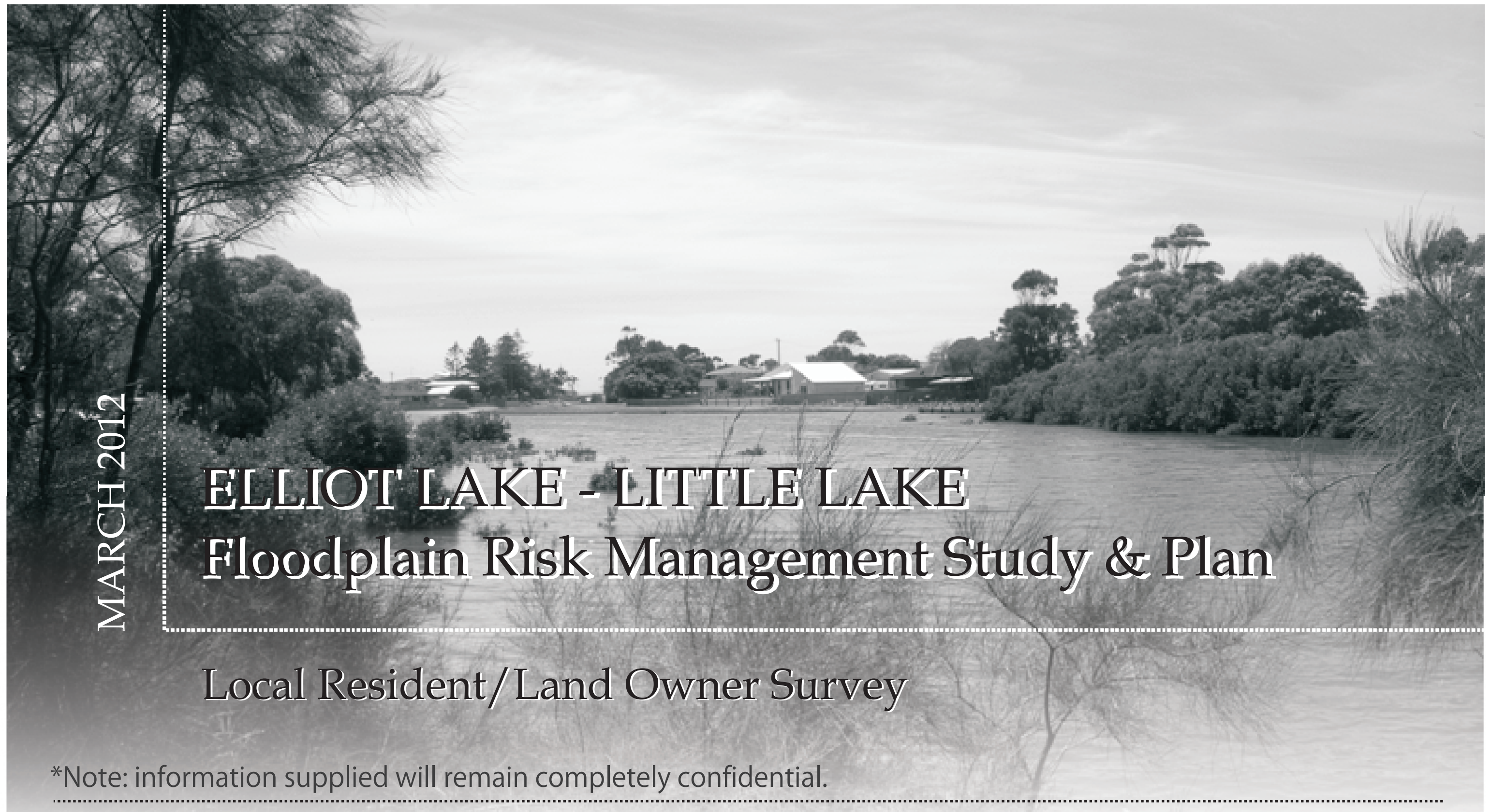
Thank you for providing the above information. Please remember to put the pages back in the reply paid envelope by 6th April 2012. A representative from Cardno may contact you in the near future to discuss your response.



MARCH 2012

ELLIOT LAKE - LITTLE LAKE
Floodplain Risk Management Study & Plan

Local Resident/Land Owner Survey

*Note: information supplied will remain completely confidential.

Q1. Could you please provide us with the following details? We may wish to contact you to discuss some of the information you have provided us.

Name: ....

Address: ....

....

Daytime Ph: ....

Email: ....

Q2. Is your property (please tick)

☐ Owner occupied ☐ Occupied by a tenant

☐ Business ☐ Other

Q3. What type of structure is your property/business? (please tick)

☐ Freestanding house ☐ Apartment/ dual occupancy

☐ Caravan/mobile home ☐ Other (Please Specify)

....

Q4. How long have you lived, worked and/or owned your property?

.... Years .... Months

Q5. How long have you lived in the Shellharbour City Local Government Area?

.... Years .... Months

Q6. How many people live/work at your property?

....

Q 7. Number of permanent residents at this address aged:

☐ 0 - 4 years ☐ 5 - 24 years

☐ 25 - 64 years ☐ 65+ years

prepared for SHELLHARBOUR CITY COUNCIL prepared by Cardno Shaping the Future

Our team appreciates the diverse effects of flooding – from its dynamic shaping of the environment through to its potential negative social and economic impact. With this knowledge we analyse and develop comprehensive plans.

Q 8. Have you ever experienced flooding since living/working in Shellharbour? (please tick relevant boxes)

- ☐ Yes, floodwaters entered my house/business
- ☐ Yes, floodwaters entered my yard
- ☐ Yes, the road was flooded and I couldn't drive my car
- ☐ Yes, the creek broke its banks
- ☐ Yes, other parts of my neighbourhood were flooded
- ☐ No, I haven't experienced a flood (go to Q.11)

Q 9. If you have experienced a flood, how did the flooding affect you and your family/business? (please tick relevant boxes)

- ☐ Parts of my house/business building were damaged
- ☐ The contents of my house/business were damaged
- ☐ My garden, yard, and/or surrounding property were damaged
- ☐ My car(s) were damaged
- ☐ Other property was damaged (specify) ....
- ☐ I couldn't leave the house/business
- ☐ Family members/work mates couldn't leave/return to the house/business
- ☐ The flood disrupted my daily routine
- ☐ The flood affected me in other ways (specify) ....
- ☐ The flood didn't affect me

Q 10. Do you have any materials or photos you can provide to evidence the flooding you experienced? If yes, when did the flooding occur?

☐ Yes ☐ No

The flooding occurred on ....

Q 11. Do you think your property would be flooded sometime in the future? (please tick relevant boxes)

- ☐ No
- ☐ Yes, but only a small part of my yard
- ☐ Yes, most of my yard/outdoor areas of business could be flooded
- ☐ Yes, my house/office/business could flood over the floor

Q12. Where have you looked for information about flooding on your property? (please tick relevant boxes)

- ☐ Council's customer service centre
- ☐ Other information from Council (specify)..
- ☐ Viewed a Property Planning (Section 149) Certificate
- ☐ Information from a real estate agent
- ☐ Information from relatives, friends, neighbours, or the previous owner
- ☐ Other information (specify)...
- ☐ No information has been sought
- ☐ I do not believe my property is affected by flooding

If you answered yes to having looked for information on Council's website:

- ☐ What information have you looked for? (Please specify) ....
- ☐ Where were you able to find information? (Please specify) ....

Q13. As a local resident who may have witnessed flooding/drainage problems, you may have your own ideas on how to reduce flood risks. Which of the following management options would you prefer for the Elliot Lake - Little Lake catchment (1=least preferred, 5=most preferred)? Please also provide comments as to the location where you think the option might be suitable.

Proposed Option	Preference (please circle)	Location/Other Comments?
Stormwater harvesting, such as rainwater tanks	1 2 3 4 5	
Retarding or detention basins; these temporarily hold water and reduce peak flood flows	1 2 3 4 5	
Improved flood flow paths	1 2 3 4 5	
Culvert/ bridge/pipe enlarging	1 2 3 4 5	
Levee banks (note Glossary on next page)	1 2 3 4 5	
Diversion of creeks and channels	1 2 3 4 5	
Environmental channel improvements, including removal of weeds & bank stabilisation	1 2 3 4 5	
Planning and flood-related development controls	1 2 3 4 5	
Education of community, providing greater awareness of potential hazards	1 2 3 4 5	
Flood forecasting, flood warning, evacuation planning and emergency response	1 2 3 4 5	
Other (please specify any options you believe are suitable). Please attach extra pages for other suggestions	1 2 3 4 5	

Q14. What do you think are the best ways to get input and feedback from the local community about this project? (please tick relevant boxes)

- ☐ Council's website
- ☐ Emails from Council
- ☐ Council's Floodplain Management Committee
- ☐ Formal Council meetings
- ☐ Council's information page in the local paper
- ☐ Other articles in the local paper
- ☐ Information days in the local area
- ☐ Community meetings
- ☐ Mail outs to all residents/business owners in the study area

Q15. What is the main language spoken at home?

- ☐ English
- ☐ Other (specify)..

Elliot Lake – Little Lake Floodplain Risk Management Study and Plan

APPENDIX B

SENSITIVITY ANALYSIS FIGURES

Cardno
Shaping the Future

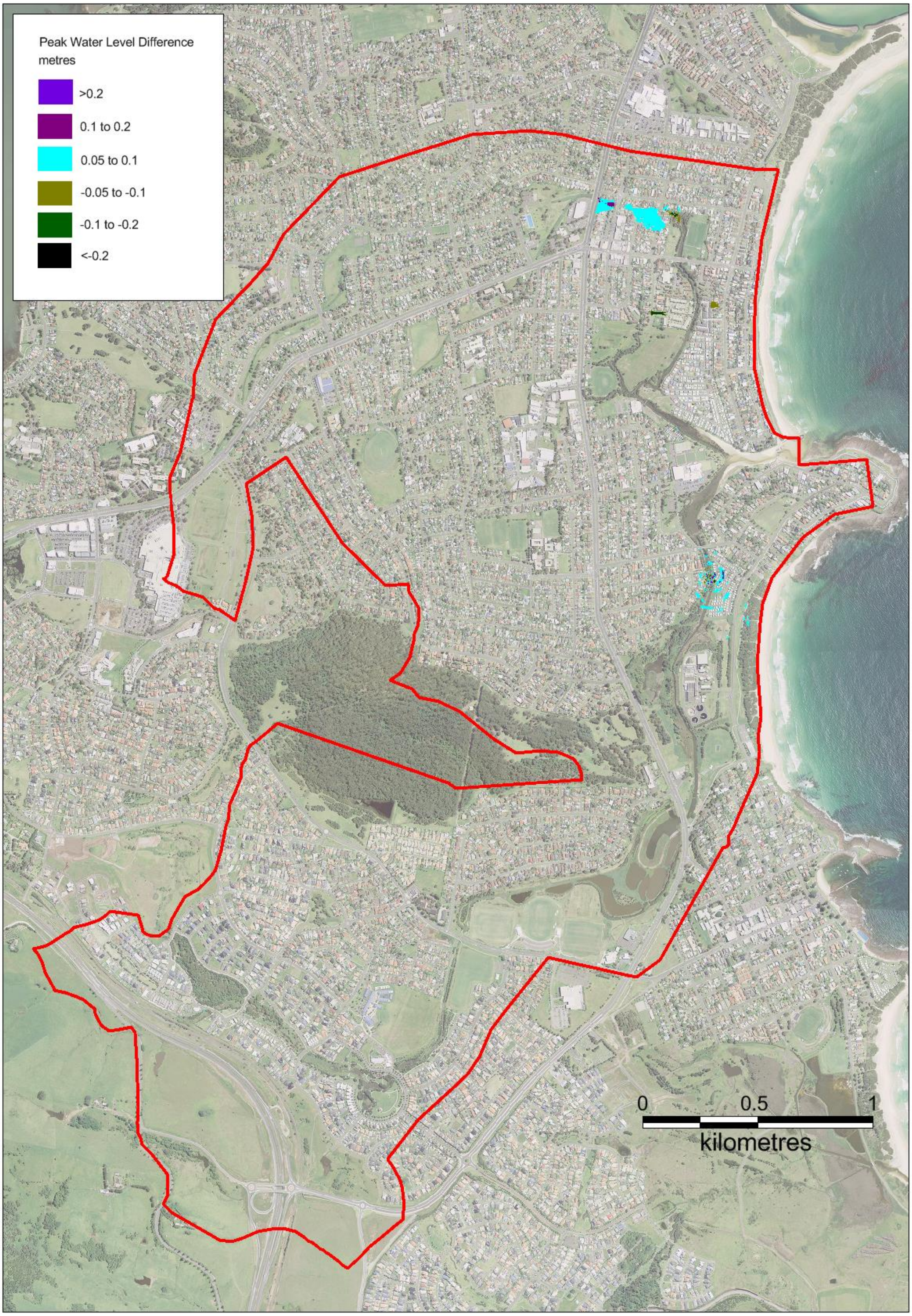


Figure B-1 Difference in Peak Water Level between Scenarios with two different hydrologic losses

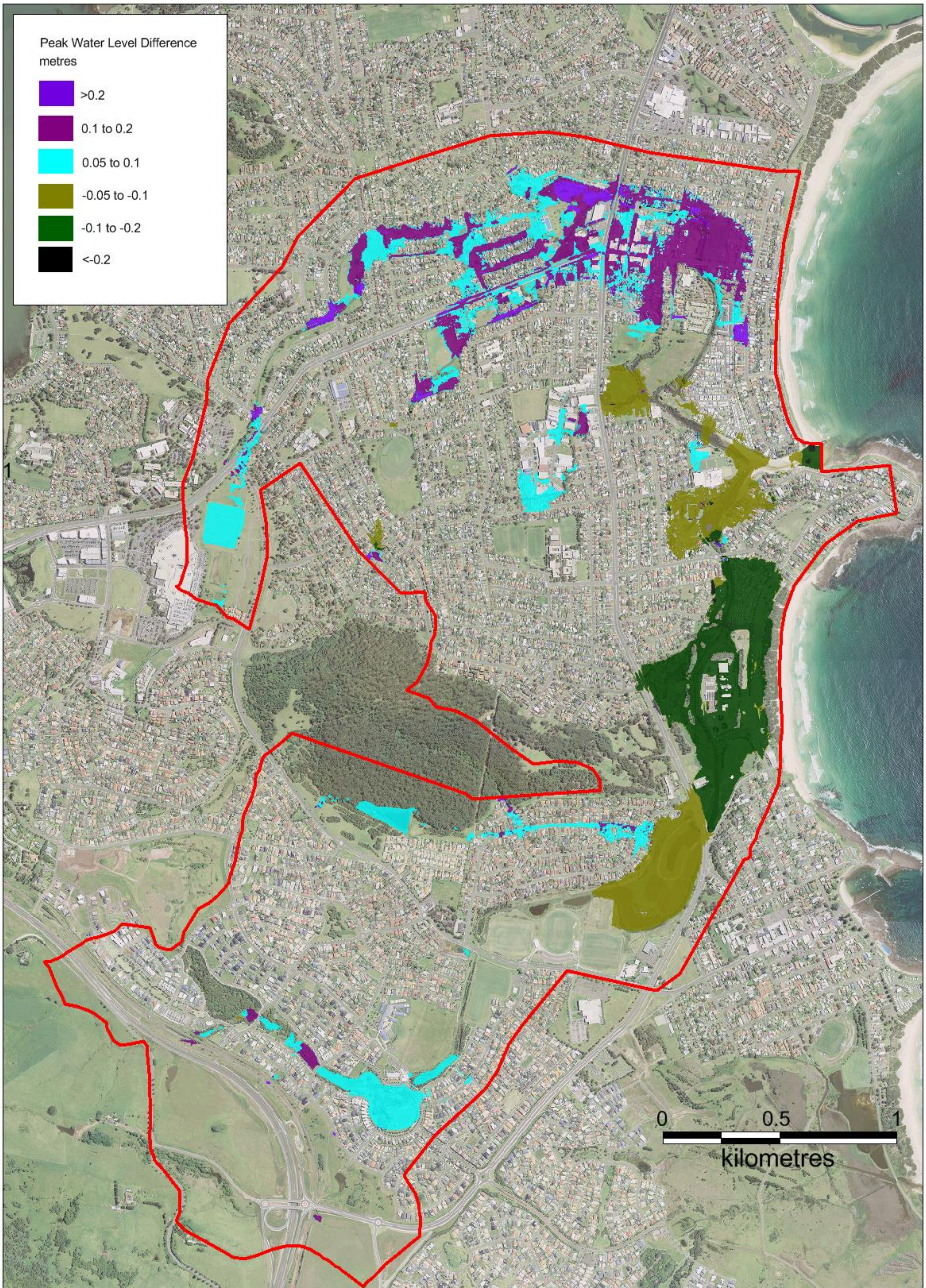


Figure B-2 Difference in Peak Water Level between Scenarios with Rainfall sourced from within the catchment area (Little Lake Gauge, 214466) and the next closest gauge (Albion Park Bowling Club, 568171) (refer Table 3-2)

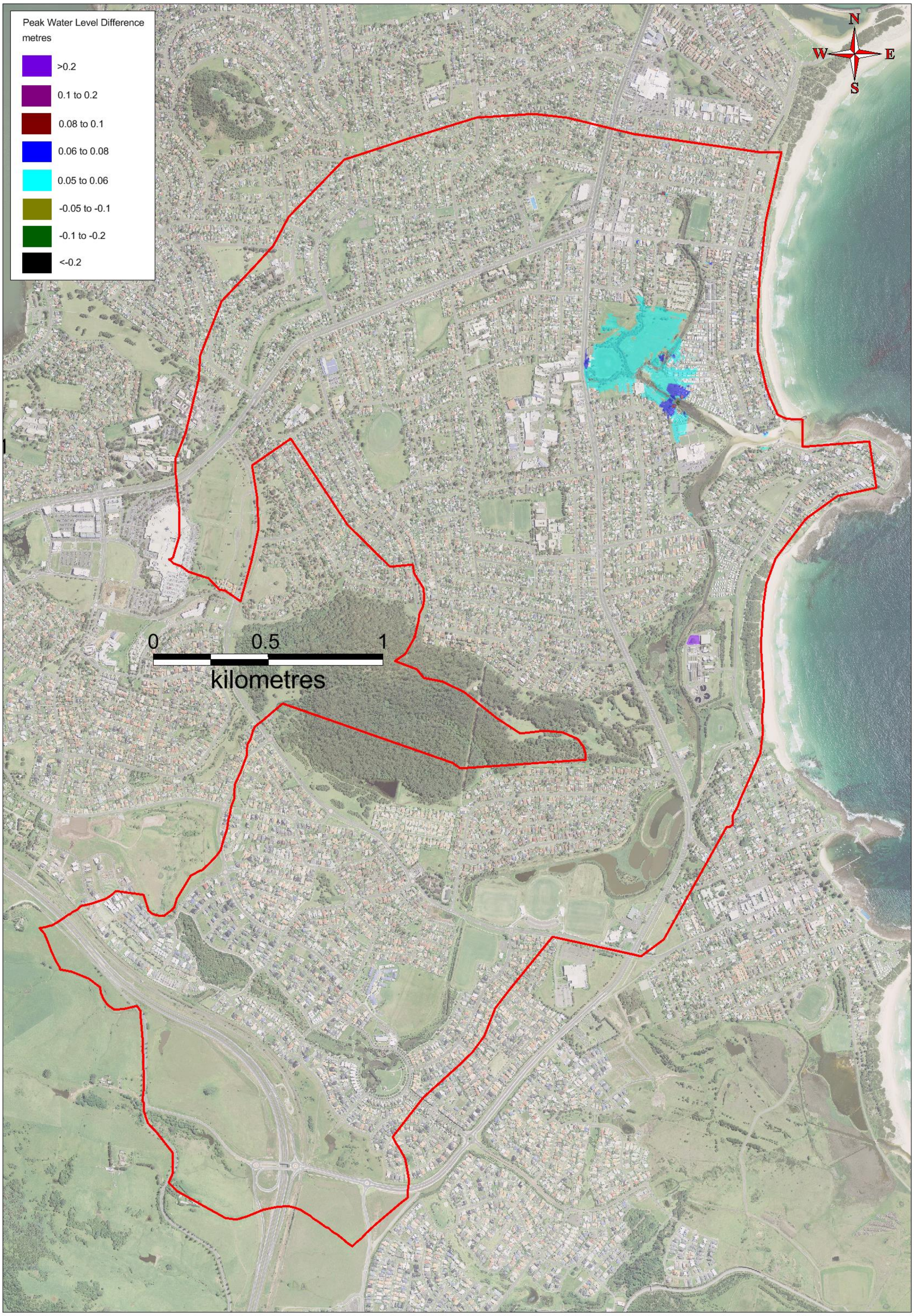


Figure B-3 Difference in Peak Water Level for the 1% AEP 36 hour – Static Downstream Boundary Less Dynamic Downstream Boundary

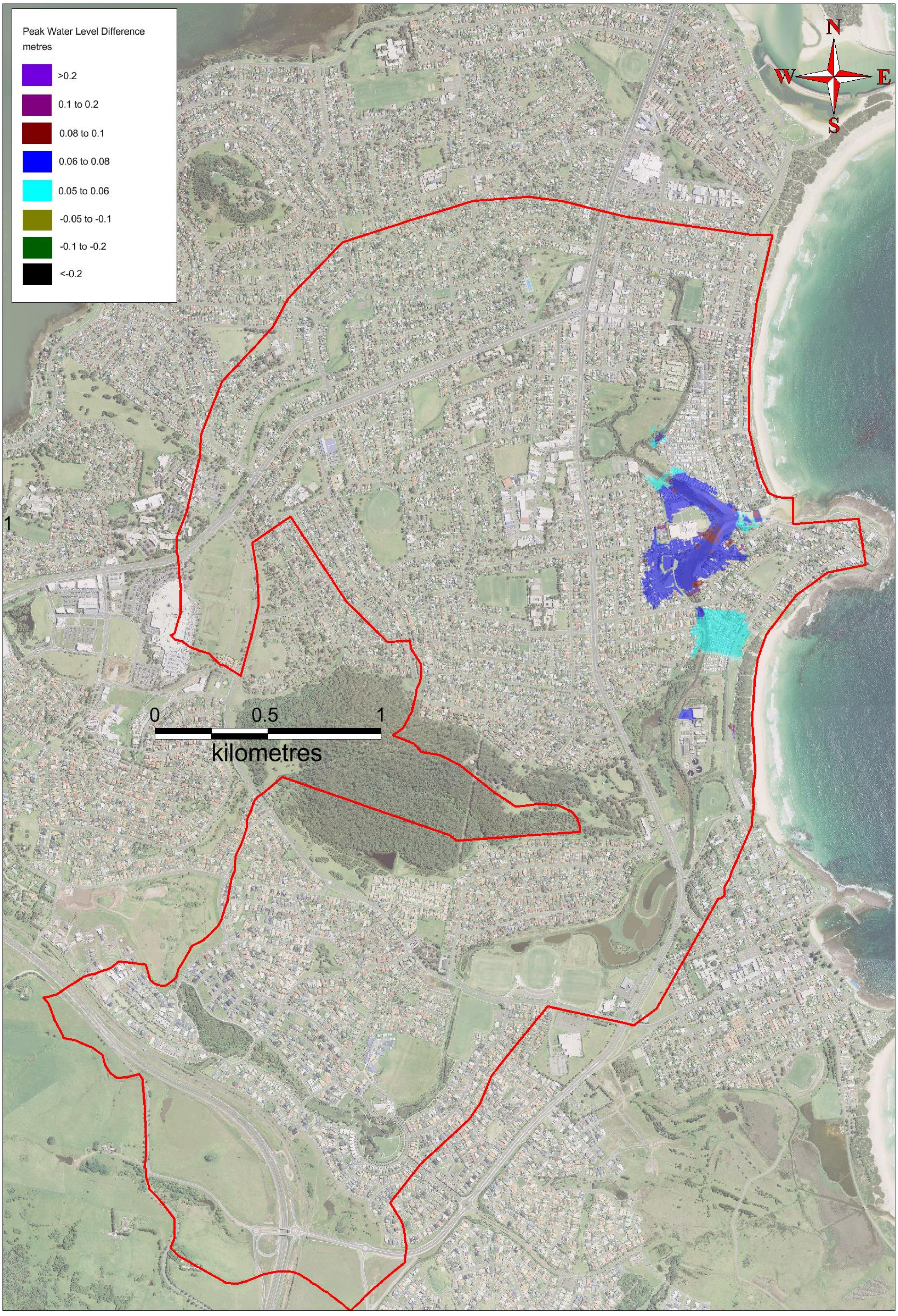


Figure B-4 Entrance Condition Testing - Difference in Peak Water Level for the 1% AEP 36 hour – Scenario 1 (2002 Bathymetry) less Scenario 2 (2012 Bathymetry)

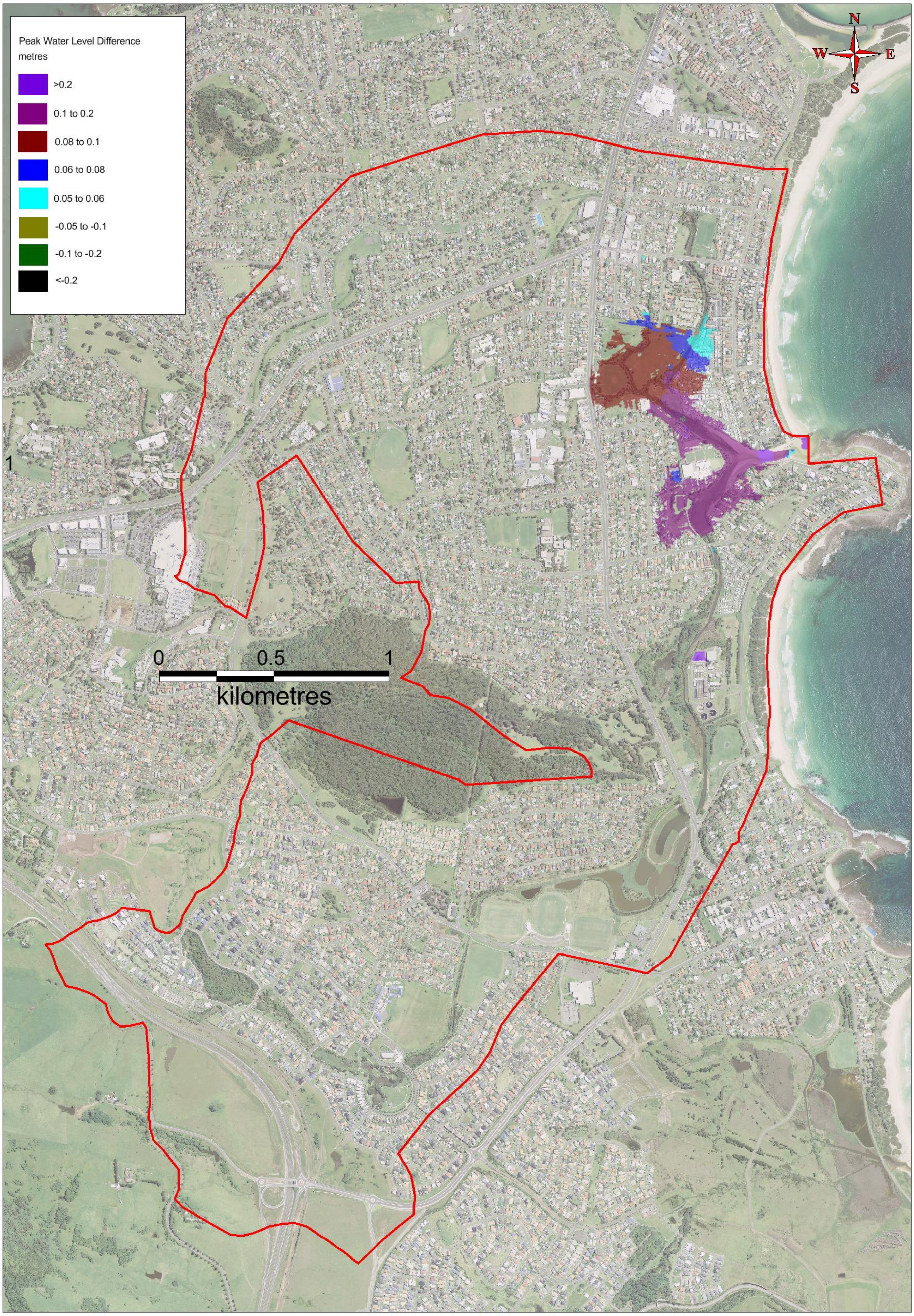


Figure B-5 Entrance Condition Testing - Difference in Peak Water Level for the 1% AEP 36 hour – Scenario 3 (2012 Bathymetry, 50% blocked) less Scenario 2 (2012 Bathymetry)

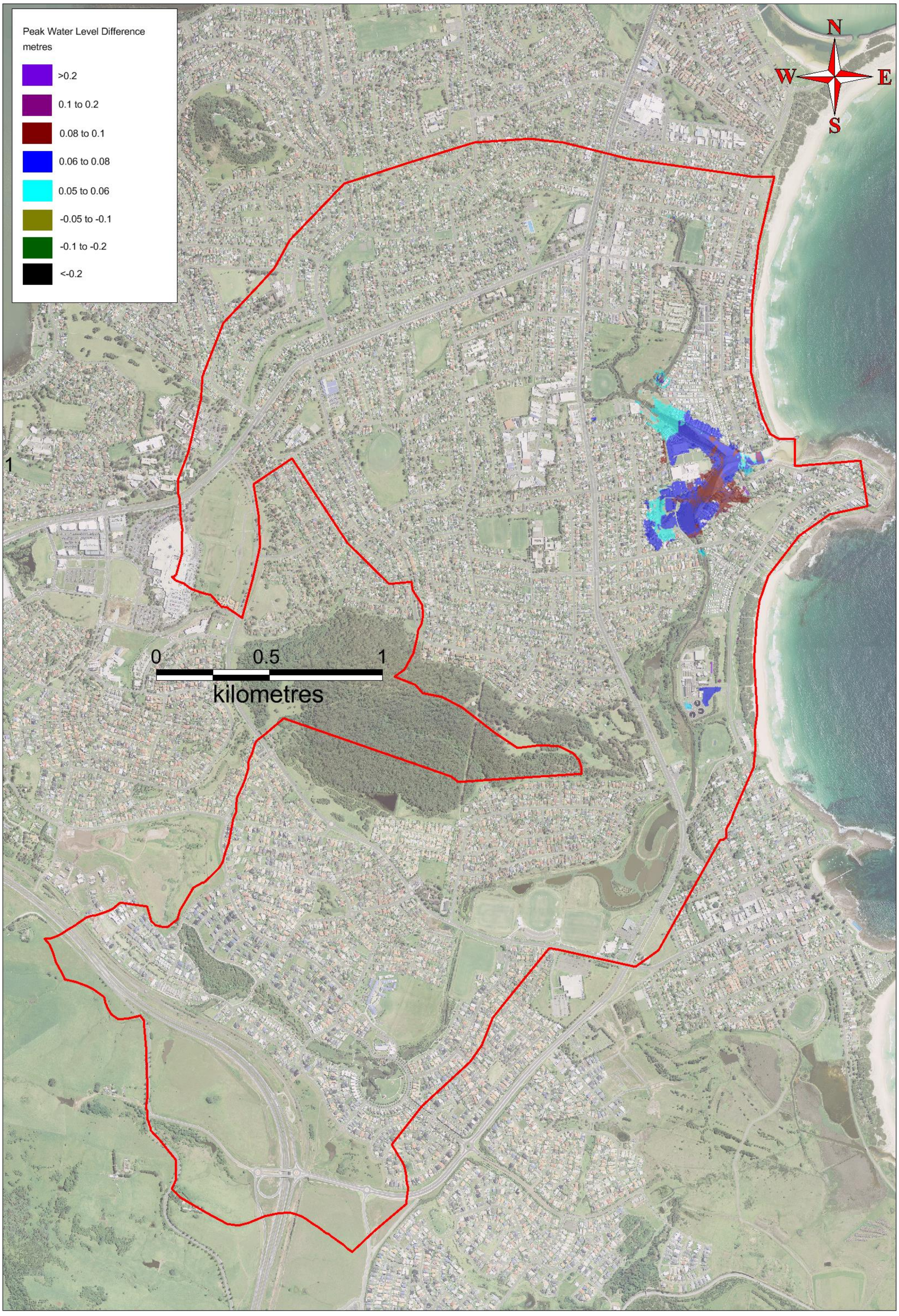


Figure B-6 Entrance Condition Testing - Difference in Peak Water Level for the 1% AEP 2 hour – Scenario 1 (2002 Bathymetry) less Scenario 2 (2012 Bathymetry)

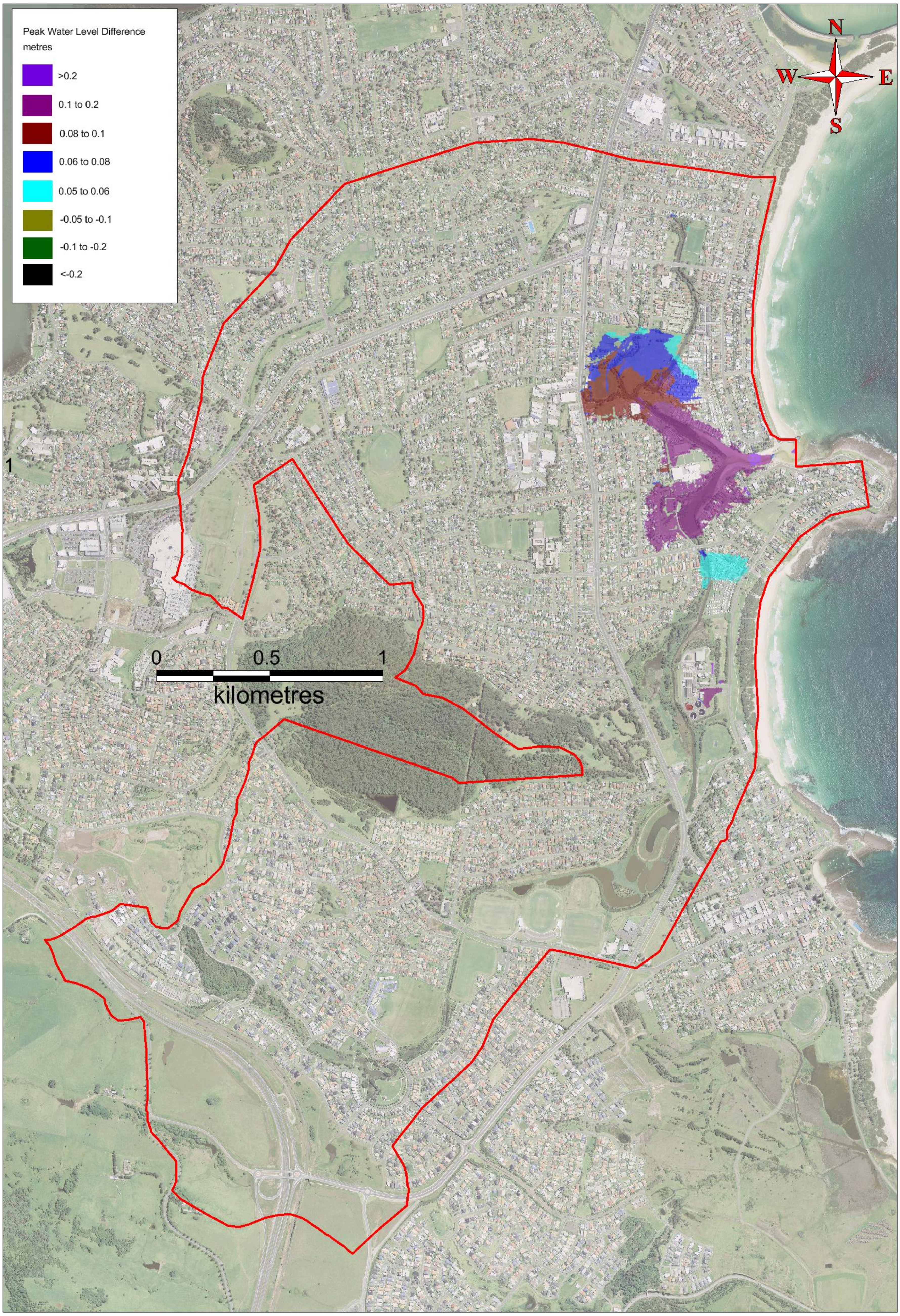
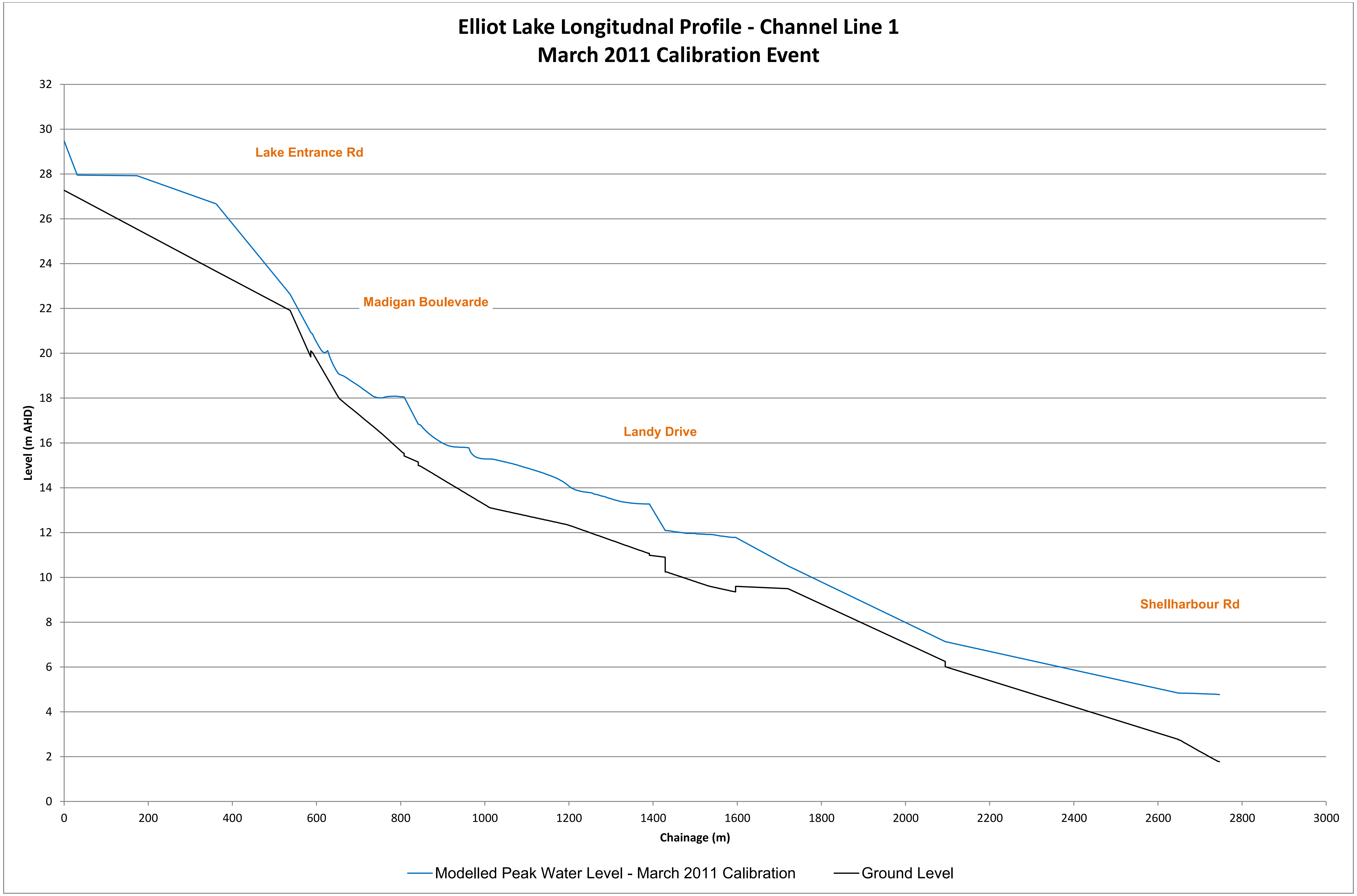
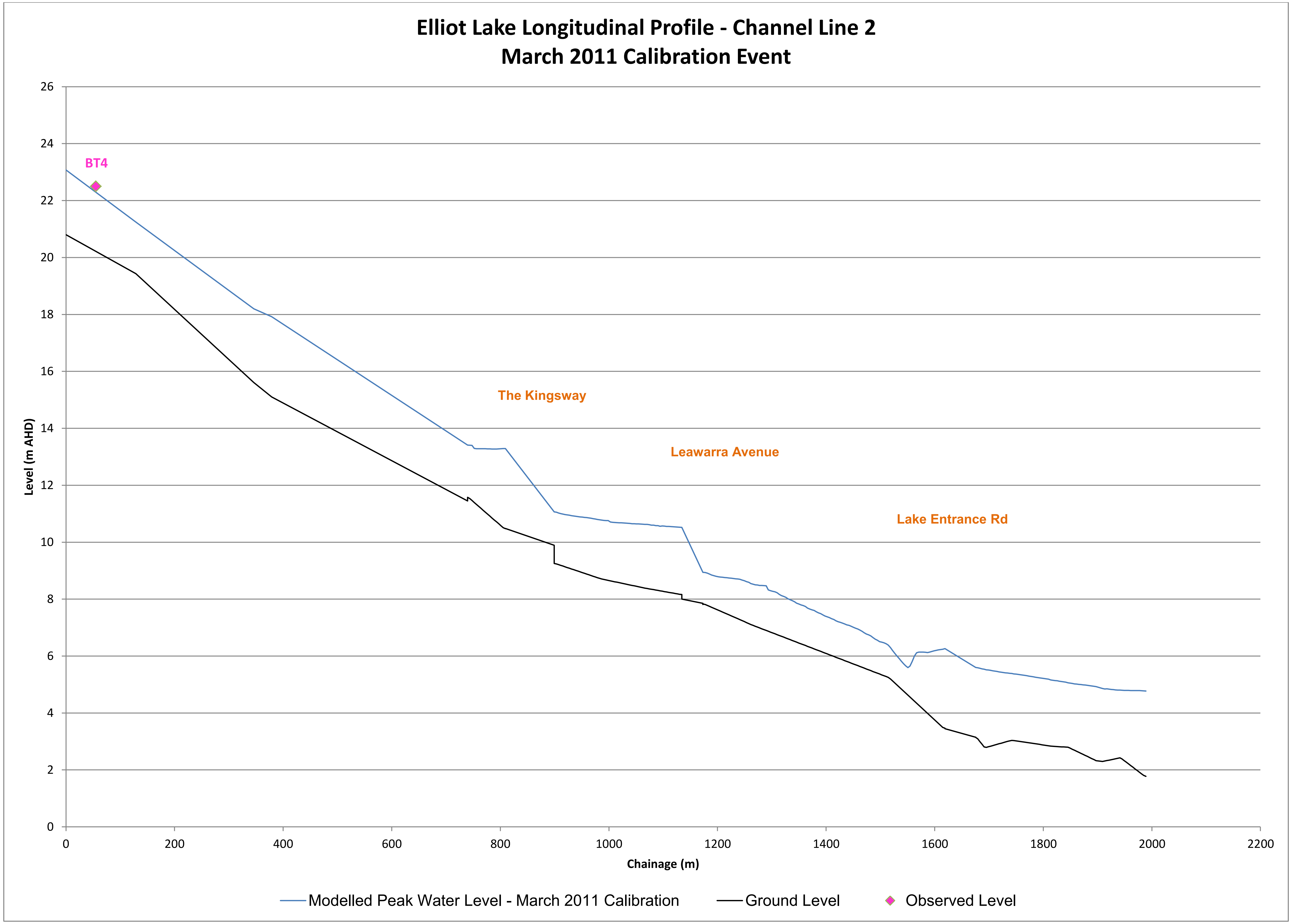


Figure B-7 Entrance Condition Testing - Difference in Peak Water Level for the 1% AEP 2 hour – Scenario 3 (2012 Bathymetry, 50% blocked) less Scenario 2 (2012 Bathymetry)

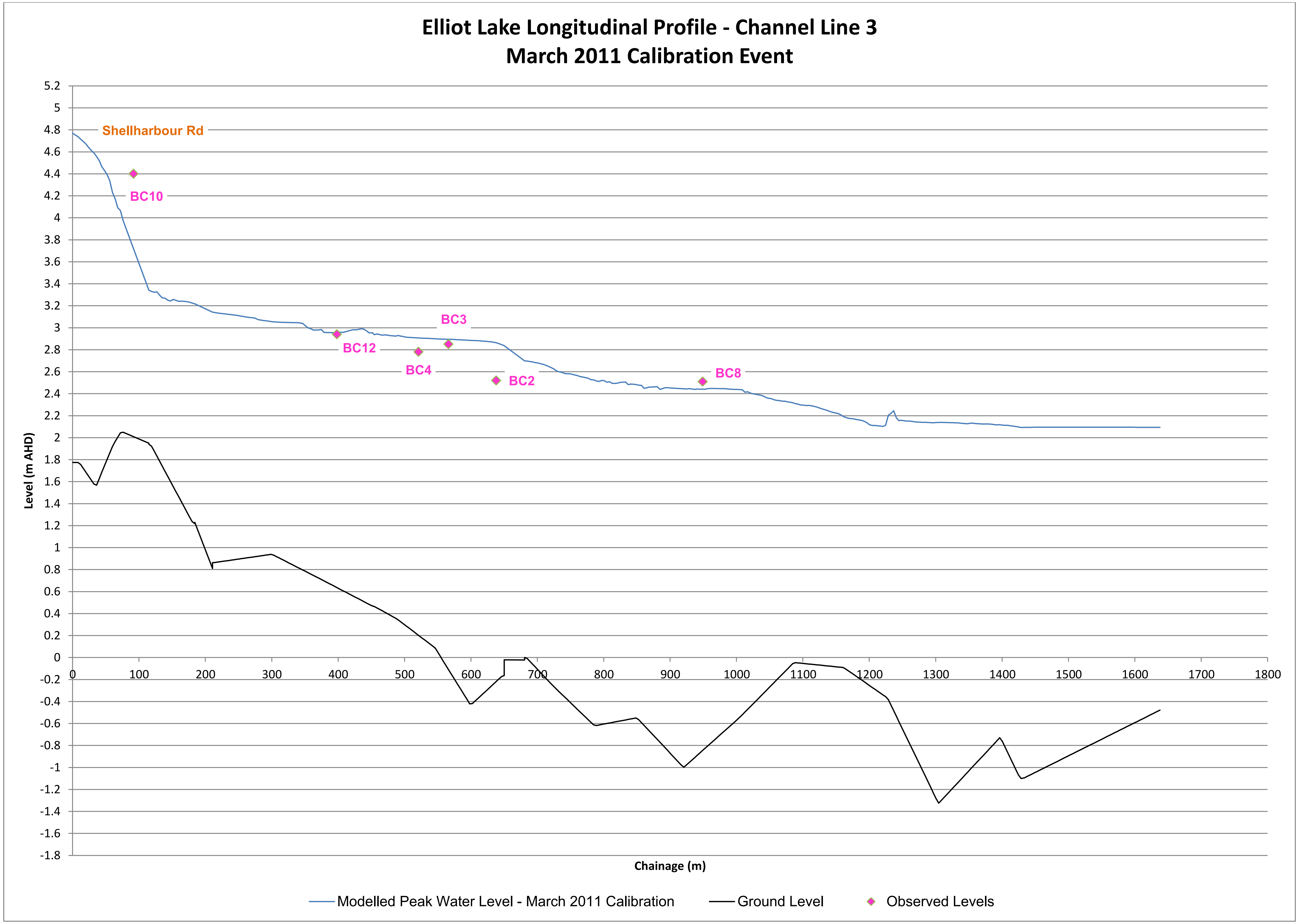
Elliot Lake – Little Lake Floodplain
Risk Management Study and Plan

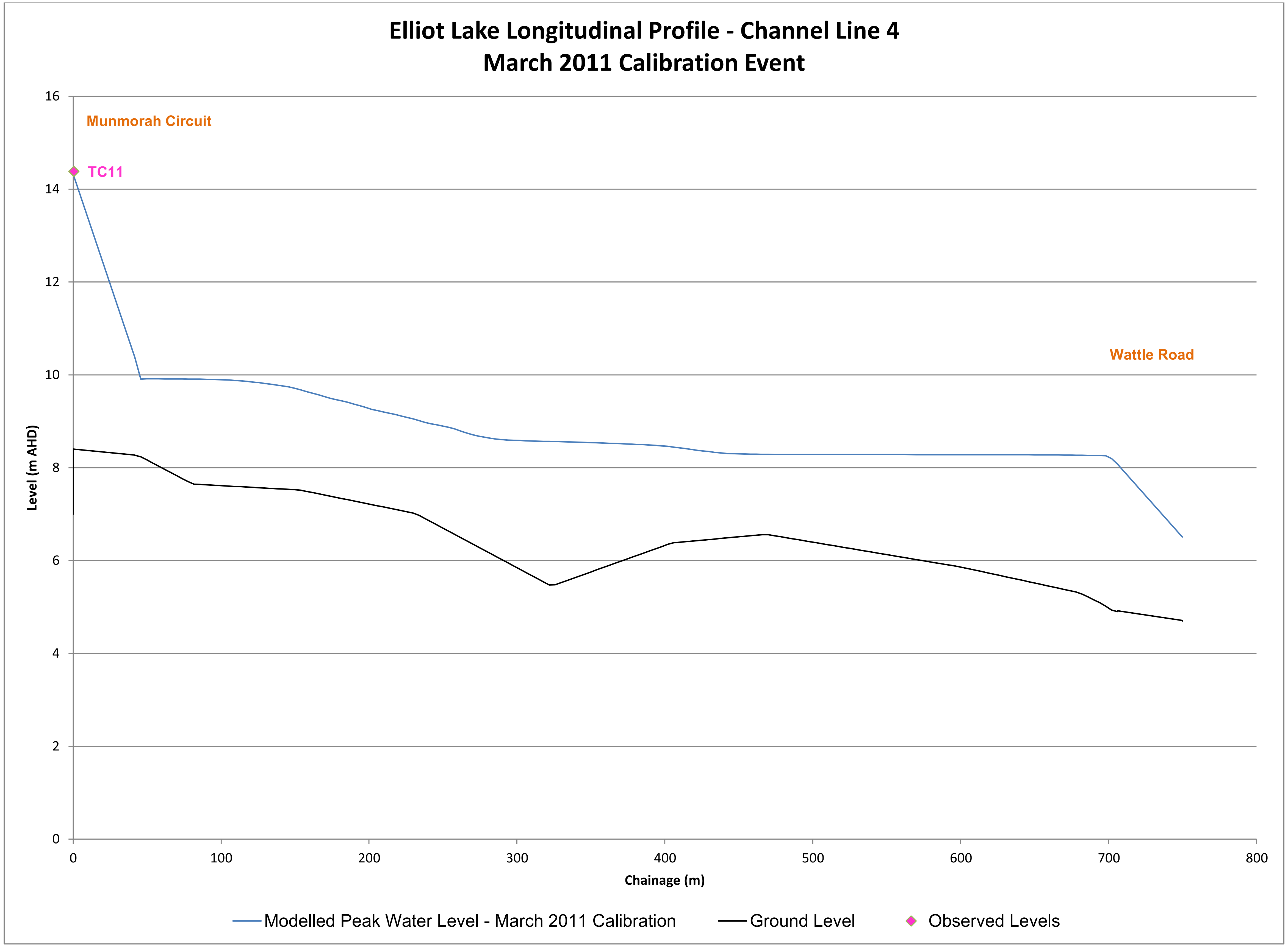
APPENDIX C
LONGITUDINAL PROFILES


Elliot Lake Longitudnal Profile - Channel Line 1
March 2011 Calibration Event
Lake Entrance Rd
Madigan Boulevarde
Landy Drive
Shellharbour Rd
Level (m AHD)
Chainage (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
Modelled Peak Water Level - March 2011 Calibration
Ground Level

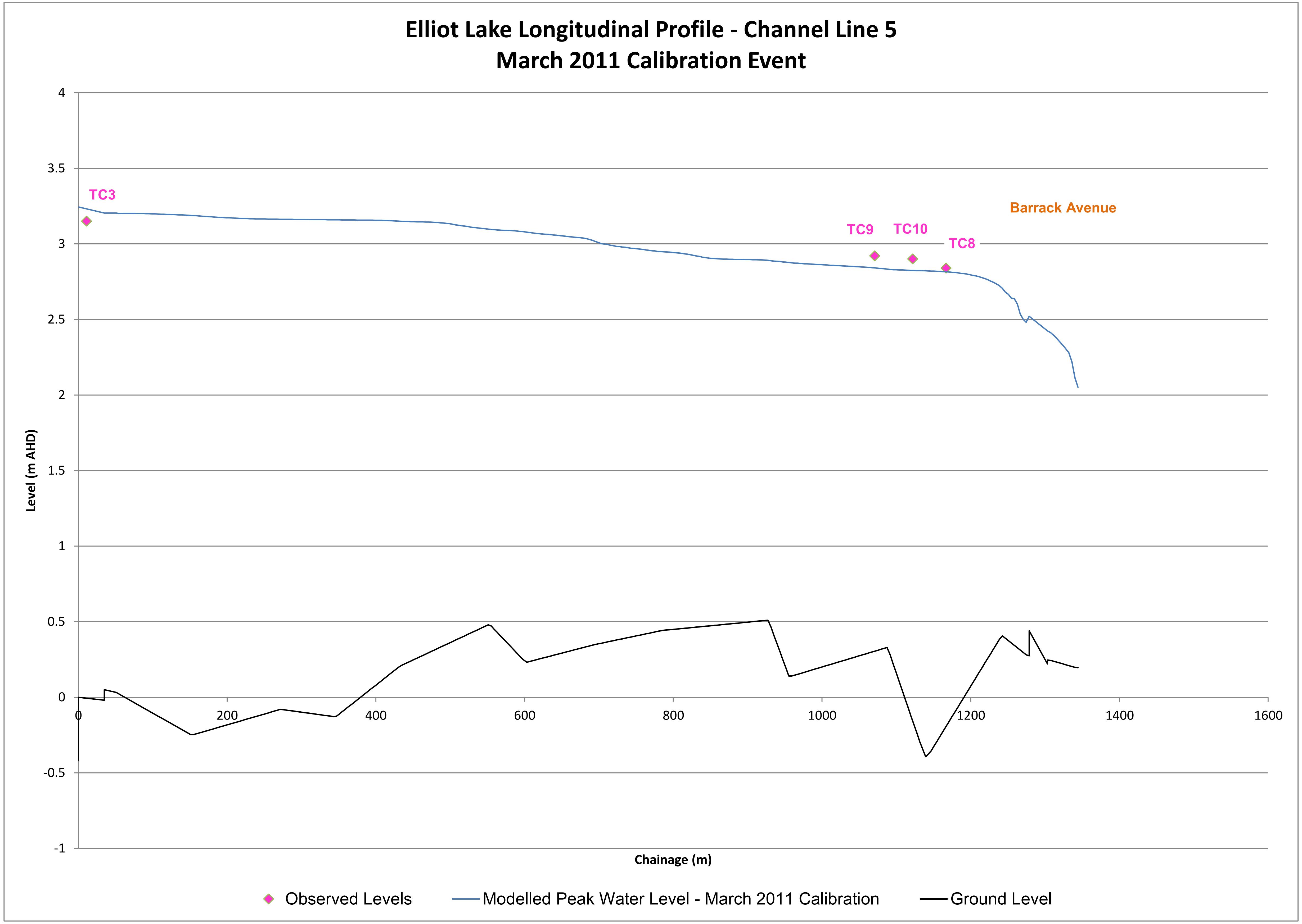


Elliot Lake Longitudinal Profile - Channel Line 2
March 2011 Calibration Event
Level (m AHD)
Chainage (m)
BT4
The Kingsway
Leawarra Avenue
Lake Entrance Rd
Modelled Peak Water Level - March 2011 Calibration
Ground Level
Observed Level

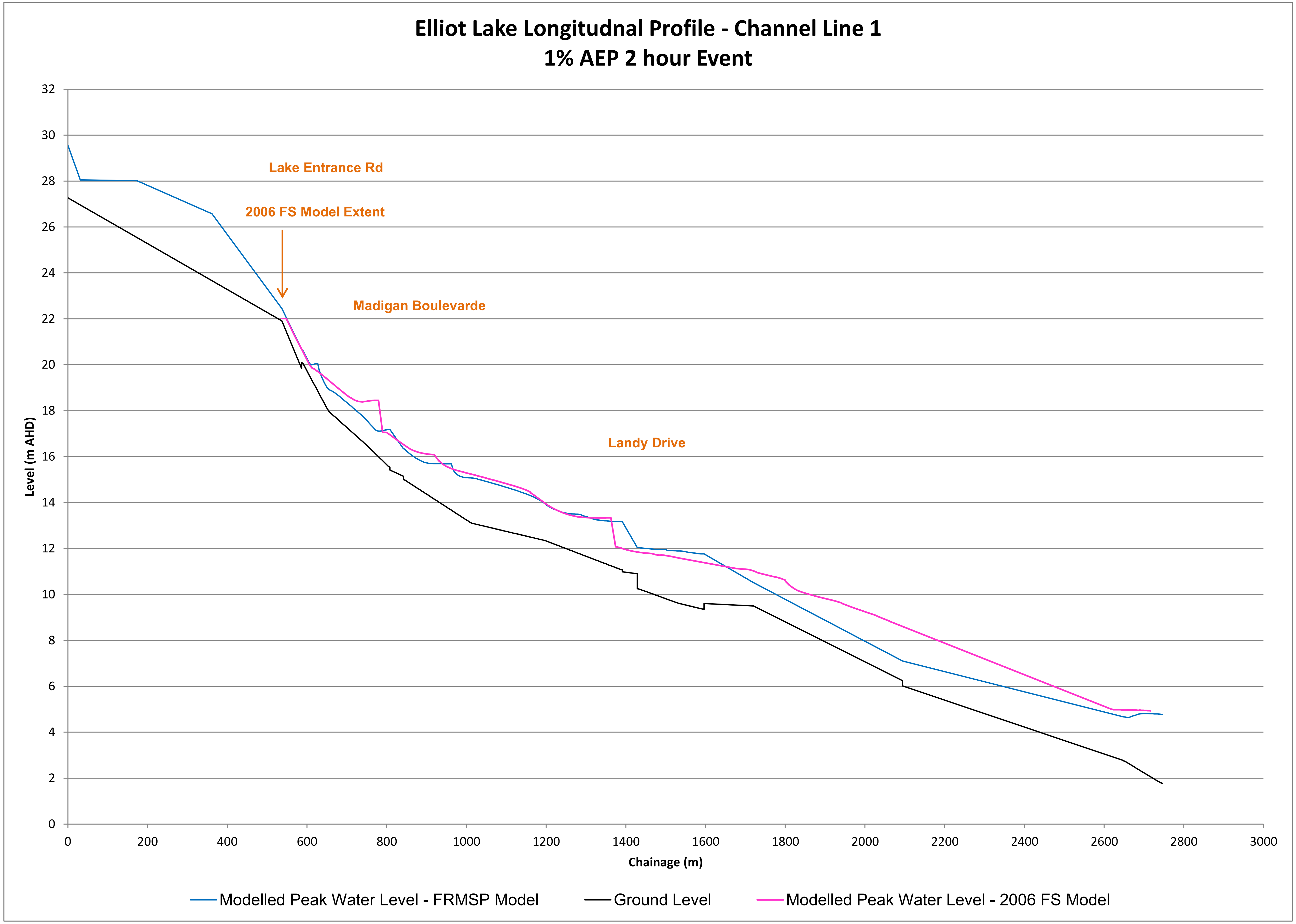

Elliot Lake Longitudinal Profile - Channel Line 3
March 2011 Calibration Event
Level (m AHD)
Chainage (m)
Shellharbour Rd
BC10
BC3
BC12
BC4
BC2
BC8
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Modelled Peak Water Level - March 2011 Calibration
Ground Level
Observed Levels



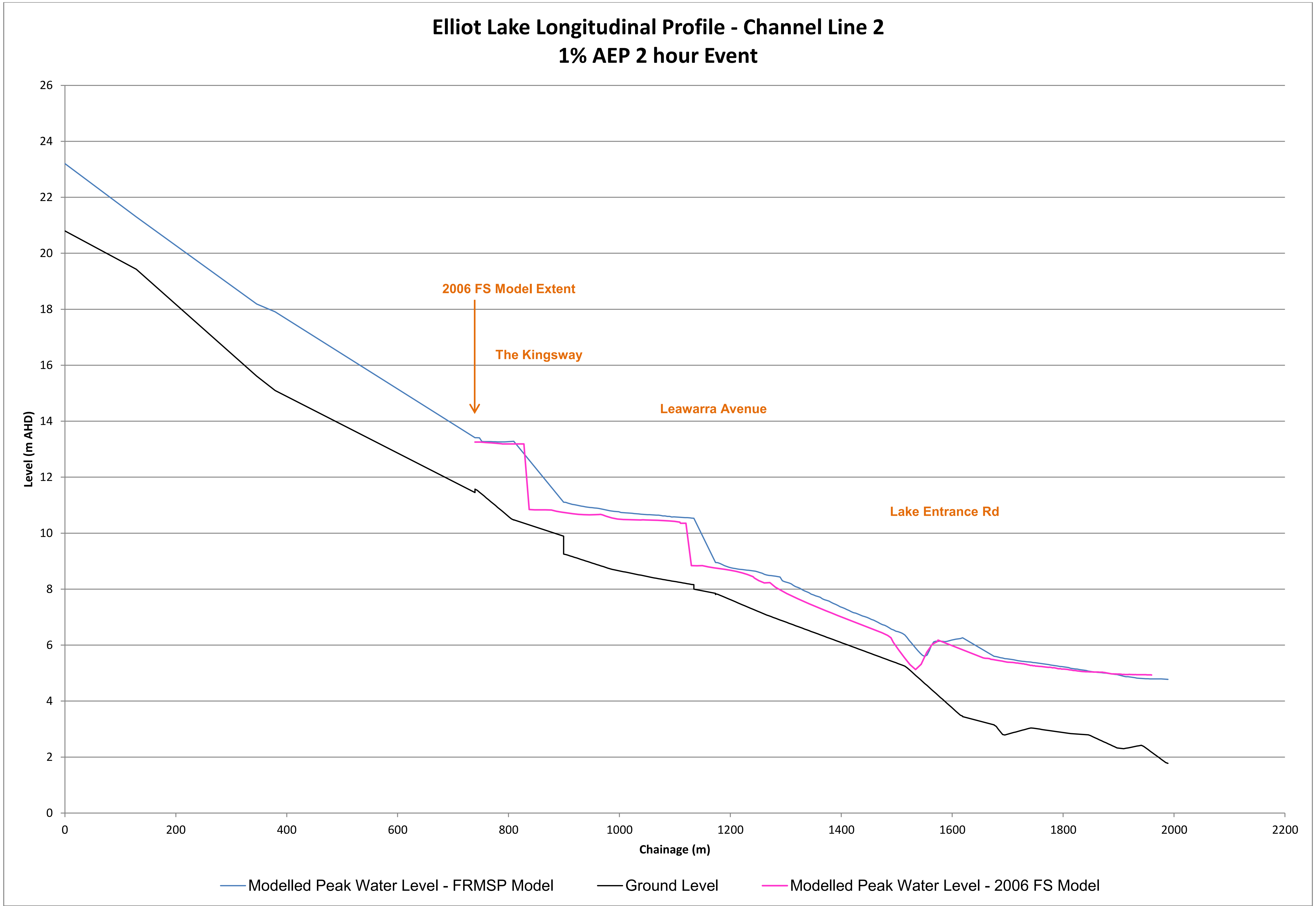
Elliot Lake Longitudinal Profile - Channel Line 4
March 2011 Calibration Event
Munmorah Circuit
TC11
Wattle Road
Level (m AHD)
16
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
Chainage (m)
Modelled Peak Water Level - March 2011 Calibration
Ground Level
Observed Levels



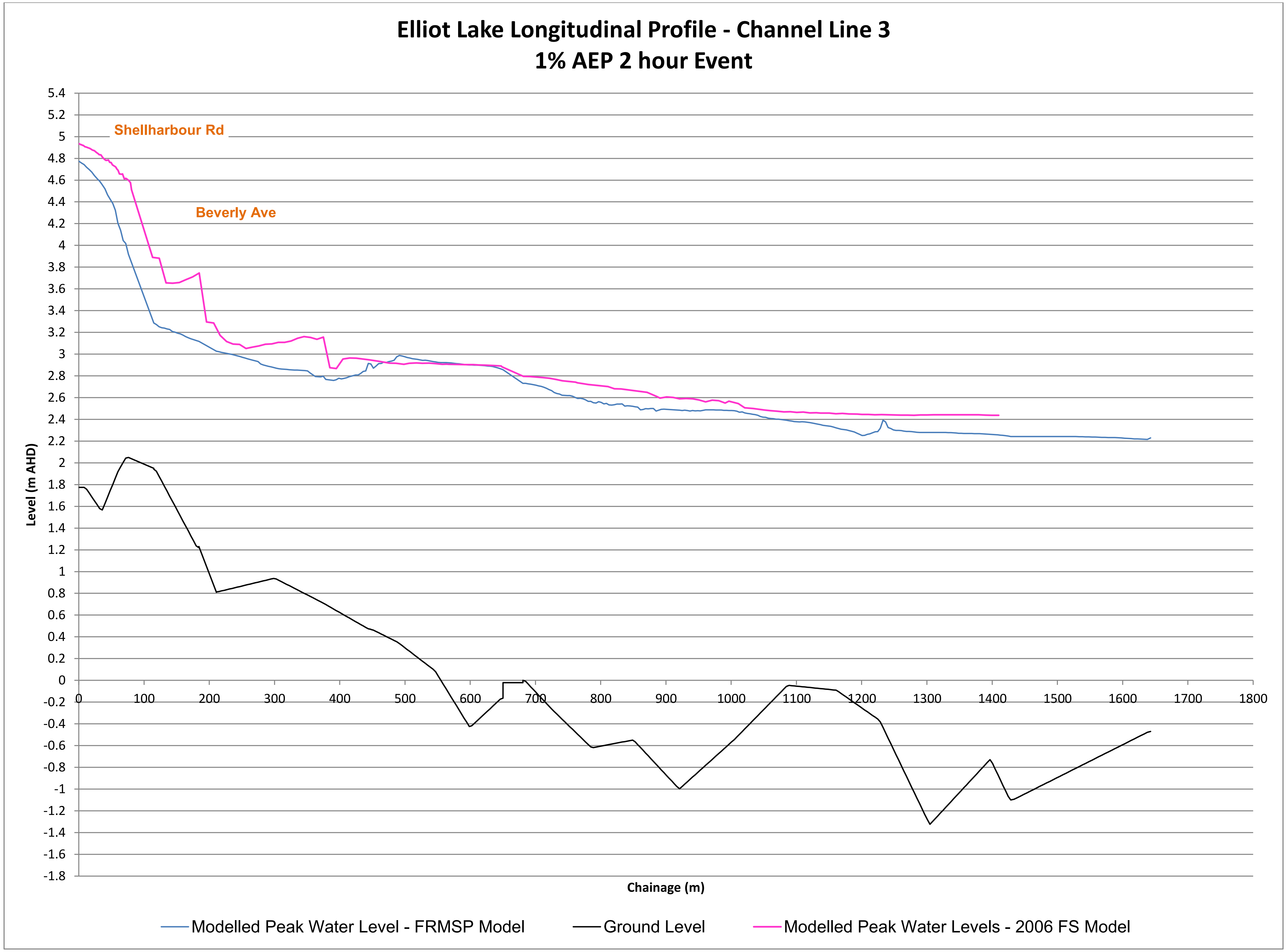
Elliot Lake Longitudinal Profile - Channel Line 5
March 2011 Calibration Event
Level (m AHD)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
TC3
TC9
TC10
TC8
Barrack Avenue
0
200
400
600
800
1000
1200
1400
1600
Chainage (m)
Observed Levels
Modelled Peak Water Level - March 2011 Calibration
Ground Level



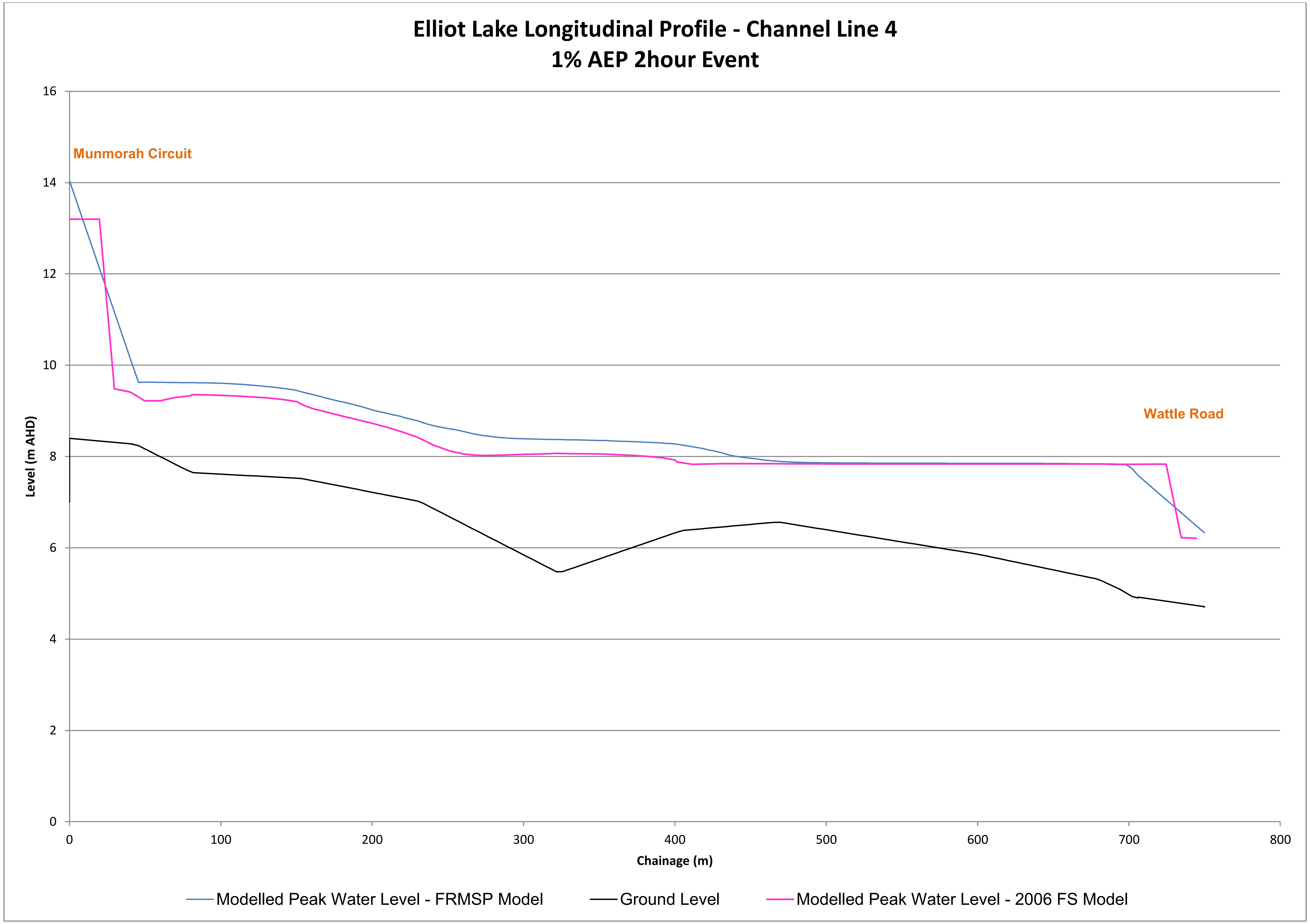
Elliot Lake Longitudnal Profile - Channel Line 1
1% AEP 2 hour Event
Lake Entrance Rd
2006 FS Model Extent
Madigan Boulevarde
Landy Drive
Level (m AHD)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
Chainage (m)
Modelled Peak Water Level - FRMSP Model
Ground Level
Modelled Peak Water Level - 2006 FS Model



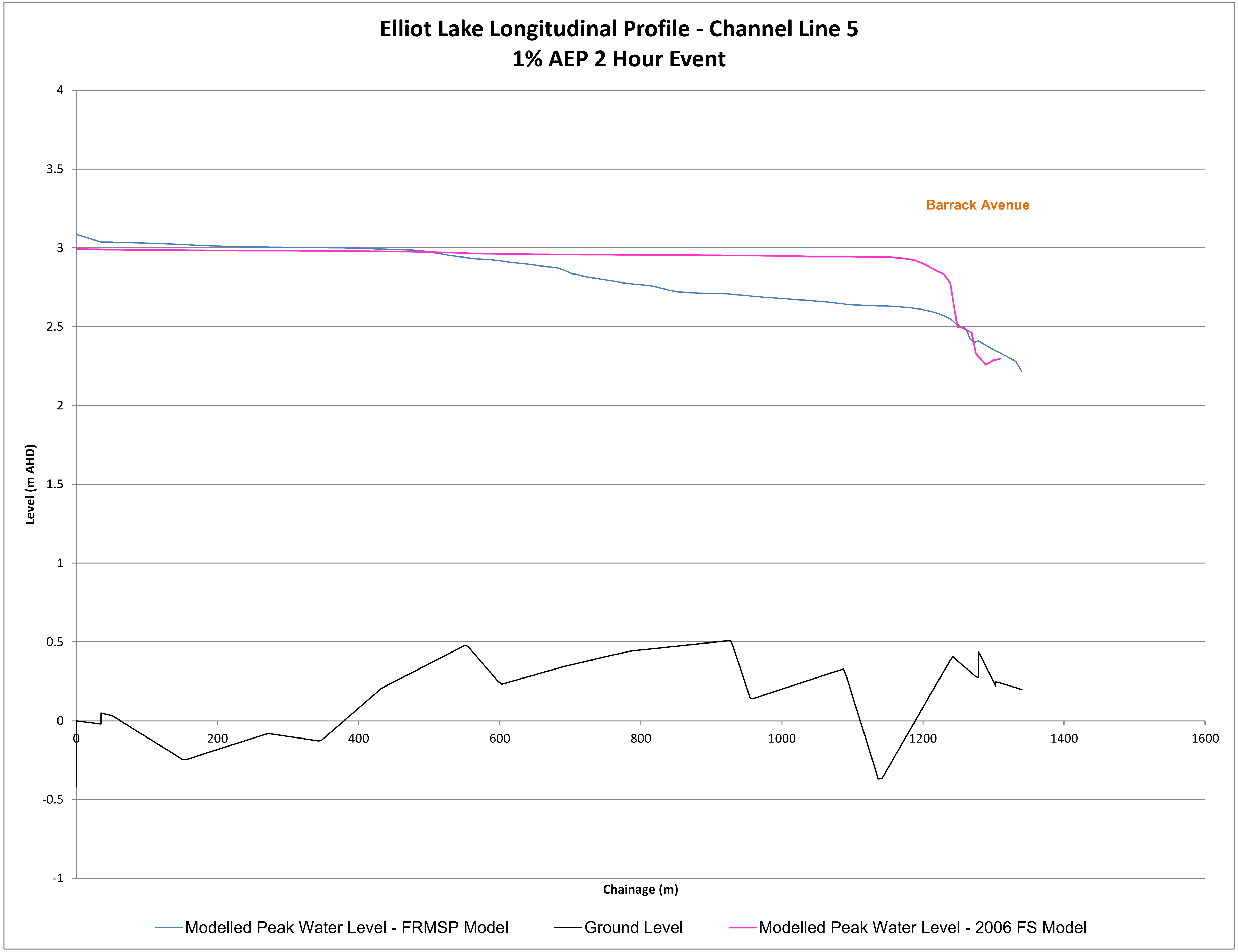
Elliot Lake Longitudinal Profile - Channel Line 2
1% AEP 2 hour Event
Level (m AHD)
Chainage (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2006 FS Model Extent
The Kingsway
Leawarra Avenue
Lake Entrance Rd
Modelled Peak Water Level - FRMSP Model
Ground Level
Modelled Peak Water Level - 2006 FS Model

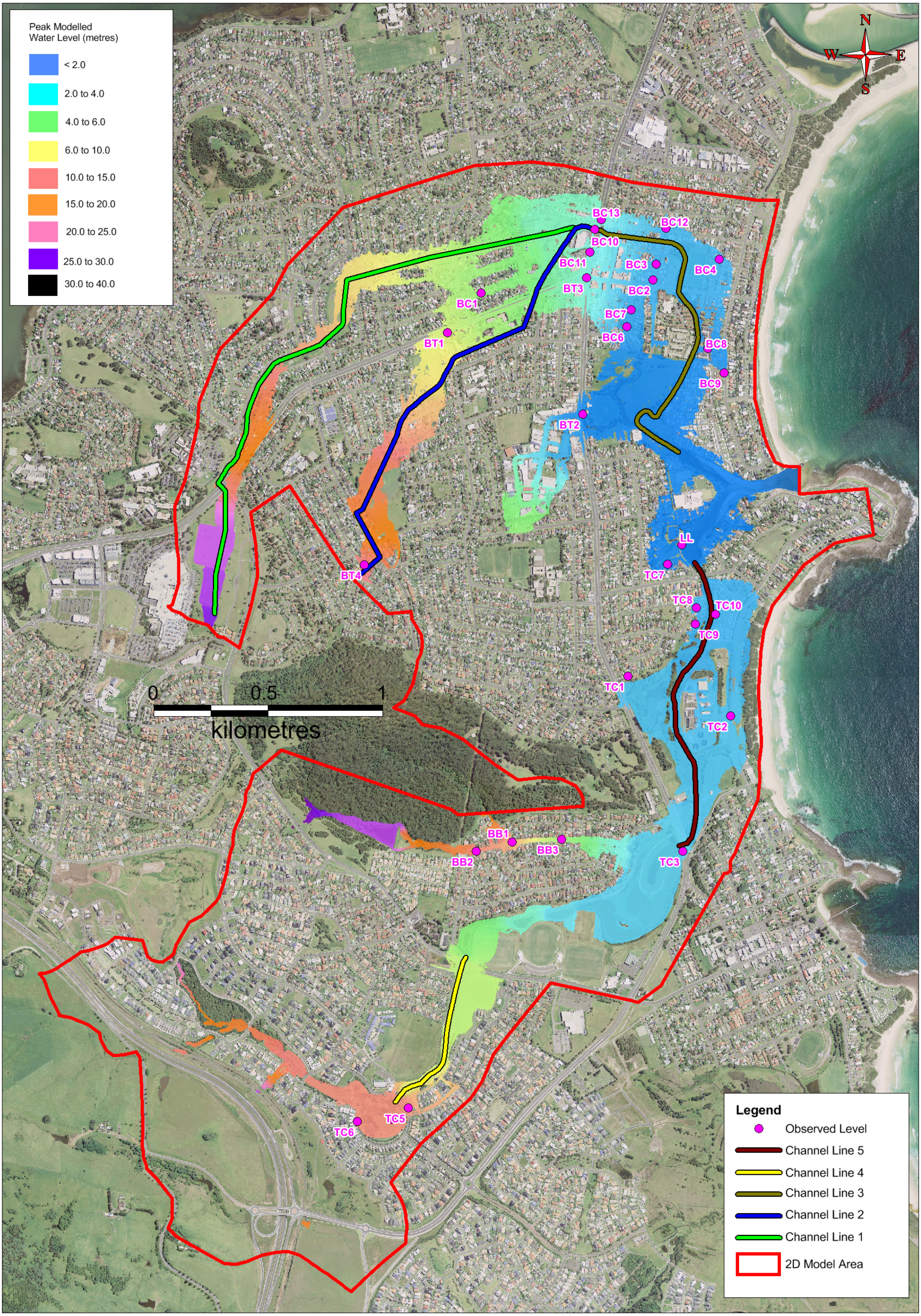


Elliot Lake Longitudinal Profile - Channel Line 3
1% AEP 2 hour Event
Shellharbour Rd
Beverly Ave
Level (m AHD)
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Chainage (m)
Modelled Peak Water Level - FRMSP Model
Ground Level
Modelled Peak Water Levels - 2006 FS Model



Elliot Lake Longitudinal Profile - Channel Line 4
1% AEP 2hour Event
Munmorah Circuit
Wattle Road
Level (m AHD)
16
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
Chainage (m)
Modelled Peak Water Level - FRMSP Model
Ground Level
Modelled Peak Water Level - 2006 FS Model


Elliot Lake Longitudinal Profile - Channel Line 5
1% AEP 2 Hour Event
Barrack Avenue
Level (m AHD)
Chainage (m)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200
1400
1600
Modelled Peak Water Level - FRMSP Model
Ground Level
Modelled Peak Water Level - 2006 FS Model



Peak Modelled Water Level (metres)
< 2.0
2.0 to 4.0
4.0 to 6.0
6.0 to 10.0
10.0 to 15.0
15.0 to 20.0
20.0 to 25.0
25.0 to 30.0
30.0 to 40.0
N
W
E
S
BC13
BC12
BC10
BC11
BC3
BC4
BT3
BC2
BC1
BC7
BC6
BT1
BC8
BC9
BT2
LL
BT4
TC7
TC8
TC10
TC9
TC1
TC2
0
0.5
1
kilometres
BB1
BB2
BB3
TC3
TC5
TC6
Legend
Observed Level
Channel Line 5
Channel Line 4
Channel Line 3
Channel Line 2
Channel Line 1
2D Model Area

Elliot Lake – Little Lake Floodplain Risk Management Study and Plan

APPENDIX D

DESIGN EVENT MODEL PARAMETERS

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Shaping the Future

Table D-1 Proposed XP-RAFTS Model Parameters for Design Event Modelling

			Subcatchment Division 1				Subcatchment Division 2			
Sub-catchment	Total area (ha)	Slope (%)	Area (ha)	Mannings 'n'	Perc. Imperv. (%)	Init/Cont. Rainfall Loss	Area (ha)	Mannings 'n'	Perc. Imperv. (%)	Init/Cont. Rainfall Loss
BA13	14.45	9.540	7.22	0.02	5	Yards	7.22	0.01	100	Urban
BA12	16.01	8.250	8.31	0.02	5	Yards	7.70	0.01	100	Urban
BA11	21.83	5.620	13.39	0.02	5	Rural	8.44	0.01	100	Urban
BA10	12.30	8.190	10.61	0.02	5	Rural	1.69	0.01	100	Urban
BA9	12.64	4.920	9.34	0.02	5	Rural	3.30	0.01	100	Urban
BA8	14.44	4.640	7.31	0.02	5	Yards	7.13	0.01	100	Urban
BA7	31.40	3.330	17.57	0.02	5	Yards	13.83	0.01	100	Urban
BA6	22.46	3.840	12.80	0.02	5	Yards	9.66	0.01	100	Urban
BA4	11.04	5.820	6.52	0.02	5	Yards	4.52	0.01	100	Urban
BA1	12.35	3.490	6.37	0.02	5	Yards	5.98	0.01	100	Urban
BA5	6.16	12.870	4.42	0.04	5	Rural	1.74	0.01	100	Urban
B7A	9.79	0.001	7.88	0.02	5	Rural	1.91	0.01	100	Urban
B7	7.98	3.800	3.99	0.02	5	Yards	3.99	0.01	100	Urban
B5	12.67	1.620	6.34	0.02	5	Yards	6.34	0.01	100	Urban
B4	15.22	1.660	9.13	0.02	5	Yards	6.09	0.01	100	Urban
B3	12.26	1.870	6.13	0.02	5	Yards	6.13	0.01	100	Urban
B2	10.67	0.830	6.92	0.02	5	Rural	3.75	0.01	100	Urban
BC1	13.73	2.510	10.50	0.02	5	Rural	3.23	0.01	100	Urban
BC2	11.54	1.910	5.77	0.02	5	Yards	5.77	0.01	100	Urban
BB4	43.92	4.760	24.51	0.02	5	Yards	19.41	0.01	100	Urban
BB3	25.43	2.820	13.62	0.02	5	Yards	11.81	0.01	100	Urban
BB2	10.37	2.110	6.24	0.02	5	Yards	4.13	0.01	100	Urban
B1	12.35	0.790	6.55	0.02	5	Yards	5.80	0.01	100	Urban
T1	22.77	2.130	12.27	0.02	5	Yards	10.50	0.01	100	Urban
T3	13.12	1.690	8.17	0.02	5	Yards	4.95	0.01	100	Urban
T2	8.73	1.880	4.36	0.02	5	Yards	4.36	0.01	100	Urban
T4	20.00	1.560	15.08	0.02	5	Rural	4.92	0.01	100	Urban
T6	20.66	4.060	17.11	0.02	5	Rural	3.55	0.01	100	Urban
T7	6.99	0.010	6.99	0.02	5	Rural	0.00	N/A	N/A	N/A
TA1	9.14	8.670	5.42	0.02	5	Rural	3.72	0.01	100	Urban
T9	20.47	3.720	17.40	0.02	5	Rural	3.07	0.01	100	Urban
TA2	14.63	7.790	9.62	0.04	5	Forest	5.01	0.01	100	Urban
T11	24.48	4.260	17.06	0.02	5	Rural	7.42	0.01	100	Urban
TA3	12.51	6.850	9.64	0.04	5	Forest	2.87	0.01	100	Urban
TA4	20.27	5.780	20.27	0.04	5	Forest	0.00	N/A	N/A	N/A
TA5	15.32	7.950	14.32	0.04	5	Forest	1.00	0.01	5	Urban
TA6	10.45	11.530	10.45	0.04	5	Forest	0.00	N/A	N/A	N/A
TA7	12.36	9.280	6.18	0.02	5	Yards	6.18	0.01	100	Urban

			Subcatchment Division 1				Subcatchment Division 2			
Sub-catchment	Total area (ha)	Slope (%)	Area (ha)	Mannings 'n'	Perc. Imperv. (%)	Init/Cont. Rainfall Loss	Area (ha)	Mannings 'n'	Perc. Imperv. (%)	Init/Cont. Rainfall Loss
B15	22.92	4.690	11.58	0.02	5	Rural	11.34	0.01	100	Urban
B14	14.71	10.050	14.71	0.04	5	Forest	0.00	N/A	N/A	N/A
B16	19.07	5.310	9.85	0.02	5	Yards	9.22	0.01	100	Urban
TC3	14.98	7.610	7.49	0.02	5	Yards	7.49	0.01	100	Urban
TC4	15.14	10.120	10.66	0.02	5	Rural	4.48	0.01	100	Urban
TB2	19.87	9.080	9.93	0.02	5	Yards	9.93	0.01	100	Urban
TB1	25.64	5.120	13.07	0.02	5	Yards	12.57	0.01	100	Urban
T12	17.30	4.380	10.80	0.02	5	Rural	6.50	0.01	100	Urban
T13	26.93	4.890	17.58	0.02	5	Rural	9.35	0.01	100	Urban
T14	12.58	6.100	7.55	0.02	5	Yards	5.03	0.01	100	Urban
TD2	6.88	2.300	3.44	0.02	5	Yards	3.44	0.01	100	Urban
TD3	9.03	12.500	7.98	0.02	5	Rural	1.05	0.01	100	Urban
TD1	12.06	6.520	6.13	0.02	5	Yards	5.93	0.01	100	Urban
T20	15.67	7.900	9.38	0.02	5	Yards	6.29	0.01	100	Urban
T16	15.94	6.600	14.59	0.02	5	Rural	1.35	0.01	100	Urban
TC2	16.90	6.430	9.52	0.02	5	Yards	7.38	0.01	100	Urban
TC1	14.34	11.200	9.36	0.02	5	Rural	4.98	0.01	100	Urban
T19	24.07	16.160	24.07	0.02	5	Rural	0.00	N/A	N/A	N/A
T17	16.32	11.440	16.32	0.02	5	Rural	0.00	N/A	N/A	N/A
T18	8.27	6.820	6.49	0.02	5	Rural	1.78	0.01	100	Urban
TD5	17.80	9.410	17.80	0.02	5	Rural	0.00	N/A	N/A	N/A
TD4	22.70	6.540	21.09	0.02	5	Rural	1.61	0.01	100	Urban
T5	50.04	6.110	34.17	0.04	5	Forest	15.87	0.01	100	Urban
B13	23.13	5.800	14.72	0.04	5	Forest	8.41	0.01	100	Urban
B12	26.66	4.990	15.32	0.02	5	Yards	11.34	0.01	100	Urban
B11	21.33	4.300	11.71	0.02	5	Yards	9.62	0.01	100	Urban
B10	10.17	3.340	6.57	0.02	5	Yards	3.60	0.01	100	Urban
B9	14.90	1.810	7.74	0.02	5	Yards	7.16	0.01	100	Urban
BA3A	4.94	2.270	2.47	0.02	5	Yards	2.47	0.01	100	Urban
BA2A	2.83	1.260	1.42	0.02	5	Yards	1.42	0.01	100	Urban
T10	8.42	2.720	6.30	0.02	5	Rural	2.12	0.01	100	Urban
T8	13.99	3.870	7.63	0.02	5	Yards	6.36	0.01	100	Urban
BB1	9.01	1.860	4.51	0.02	5	Yards	4.51	0.01	100	Urban
B8	24.67	3.590	12.33	0.02	5	Yards	12.33	0.01	100	Urban
TD10	10.09	8.000	10.09	0.02	5	Rural	0.00	N/A	N/A	N/A
TD6	5.54	3.560	2.77	0.02	5	Yards	2.77	0.01	100	Urban
TD8	5.14	6.900	2.57	0.02	5	Yards	2.57	0.01	100	Urban
T15	3.90	12.700	2.47	0.02	5	Rural	1.43	0.01	100	Urban

			Subcatchment Division 1				Subcatchment Division 2			
Sub-catchment	Total area (ha)	Slope (%)	Area (ha)	Mannings 'n'	Perc. Imperv. (%)	Init/Cont. Rainfall Loss	Area (ha)	Mannings 'n'	Perc. Imperv. (%)	Init/Cont. Rainfall Loss
BA3	6.33	2.270	3.16	0.02	5	Yards	3.16	0.01	100	Urban
BA2	4.58	1.260	2.29	0.02	5	Yards	2.29	0.01	100	Urban
TD2A	2.93	2.300	1.52	0.02	5	Yards	1.41	0.01	100	Urban
T2A	17.64	1.880	8.90	0.02	5	Yards	8.74	0.01	100	Urban
TD9	4.00	0.500	4.00	0.01	100	BasinLoss	0.00	N/A	N/A	N/A

Table D-1 Proposed XP-RAFTS Model Parameters for Design Event Modelling – Rainfall Losses

Catchment Type	Initial Loss (mm)	Continuing Loss (mm/hr)
Forest	30	3.0
Rural (Grass)	20	1.5
Yards (Urban Pervious – eg. Backyards)	10	1.0
Urban (Urban Impervious Areas)	1.0	0

Elliot Lake – Little Lake Floodplain
Risk Management Study and Plan

APPENDIX E
BLOCKAGE ASSESSMENT

ID	Location	Type of structure	Detailed Blockage Assessment Reqrd?*	Width (W) in metres	L10 (metres)	L10 Justification	Debris Availability (H,M,L)	Justification for Debris Availability	Debris Mobility (H,M,L)	Justification for Debris Mobility	Debris Transportability (H,M,L)	Justification for Debris Transportability	Base At Site Debris Potential	Event Based At Site Debris Potential			Most Likely Blockage Level		
														< 20yr ARI	20 yr <= ARI <= 200yr	> 200 yr ARI	< 20yr ARI	20 yr <= ARI <= 200yr	> 200 yr ARI
1	Fischer Rd	Culvert	No														0%	0%	0%
2	Railway near Bush St	Culvert	No														0%	0%	0%
3	Whittaker St	Culvert	No														0%	0%	0%
4	Baragoot Rd	Culvert	Yes	12	3	Based on heavy vegetation cover in upstream areas of creek, limited urban debris potential	H	upstream section of creek is densely vegetated, urban residential areas located close to watercourse, considerable fallen tree limbs and leaves (based on site visit)	M	moderate catchment slope (5% - 15%), moderate rainfall intensities	L	Flat bed slopes (< 1%), regular rainfall distribution, banks not prone to scour	M	L	M	H	0%	0%	10%
5	Railway near Meryla Way	Culvert	No														0%	0%	0%
6	Seymour Dr	Culvert	Yes	3.2	2	Based on moderate vegetation cover in upstream areas of creek, limited urban debris potential, limited input due to Baragoot Rd culvert	M	moderate tree cover in upstream section of creek, urban residential areas located close to watercourse, limited input due to Baragoot Rd culvert	M	similar to ID 4	L	similar to ID 4	L	L	L	M	0%	0%	10%
7	Shellharbour Rd near Dunmore Rd	Culvert	No														0%	0%	0%
8	Haddin Rd	Pit Inlet (multiple)	No														0%	0%	0%
9	Munmorah Circuit	Culvert	Yes	2.4	2	Based on moderate vegetation cover in upstream areas of creek, limited urban debris potential, limited input due to Seymour Dr culvert	M	moderate tree cover in upstream section of creek, urban residential areas located close to watercourse, limited input due to Seymour Dr culvert	M	similar to ID 4	L	similar to ID 4	L	L	L	M	0%	0%	10%
10	Wattle Rd	Culvert	Yes	1.8	2	Based on in-channel vegetation cover, limited urban debris potential	M	moderate tree cover in upstream section of creek, some urban areas close to water course	M	similar to ID 4	M	stream size comparable to expected debris load dimensions, moderate bed slopes (1-3%)	M	L	M	H	25%	50%	100%
11	Shellharbour Rd d/s of Wetlands	Culvert	No														0%	0%	0%
12	Lavender Grove	Grated Inlet	Yes	0.05	2	Based on heavy vegetation cover in Blackbutt Reserve, limited urban debris potential.	H	dense forest at Blackbutt Reserve	M	similar to ID 4	M	flat bed slopes, stream size comparable to expected debris load dimensions.	M	L	M	H	25%	50%	100%
13	Blackbutt Dam Spillway	Pipe Inlet	Yes	1.8	2	Based on heavy vegetation cover in Blackbutt Reserve, limited urban debris potential.	H	dense forest at Blackbutt Reserve	M	similar to ID 4	L	flat bed slopes, banks not prone to scour	M	L	M	H	25%	50%	100%
14	Gallen Reserve	Pit Inlet (multiple)	No														0%	0%	0%
15	Barrack Ave	Culvert	Yes	8	3	Based on moderate vegetation in upstream sections of creek, fairly dense urbanised areas close by - greater potential for larger urban debris	H	urban areas close to water course, relatively thick vegetation along water course, loose vegetation and exposed soils	M	Flat catchments, moderate rainfall intensities.	M	moderate bed slope, stream size comparable to debris dimension	M	L	M	H	0%	10%	20%

ID	Location	Type of structure	Detailed Blockage Assessment Reqrd?*	Width (W) in metres	L10 (metres)	L10 Justification	Debris Availability (H,M,L)	Justification for Debris Availability	Debris Mobility (H,M,L)	Justification for Debris Mobility	Debris Transportability (H,M,L)	Justification for Debris Transportability	Base At Site Debris Potential	Event Based At Site Debris Potential			Most Likely Blockage Level		
														< 20yr ARI	20 yr <= ARI <= 200yr	> 200 yr ARI	< 20yr ARI	20 yr <= ARI <= 200yr	> 200 yr ARI
16	Jason Ave North	Culvert	Yes	9	4	fairly dense urbanised areas close by along with nearby car park - greater potential for larger urban debris such as cars	H	urban areas close to water course, loose vegetation and exposed soils	M	similar to ID 15	L	narrow stream relative to debris loading, large flat source areas	M	L	M	H	0%	10%	20%
17	Jason Ave South	Culvert	Yes	8	4	similar to ID 16	H	similar to ID 16	M	similar to ID 15	L	similar to ID 16	M	L	M	H	0%	10%	20%
18	Sunset Ave	Grated Kerbside Inlet (multiple)	Yes	0.05	0.3	Likely debris at kerbside pit inlets mostly tree branches.	M	Commercial and industrial areas as well as residential source areas	M	similar to ID 15	L	relatively flat overland slopes	L	L	L	M	25%	25%	50%
19	Shellharbour Rd at Oakleigh Ck	Culvert	Yes	1.2	4	industrial areas close to water course, potential for large urban debris	H	urban areas close to water course - industrial areas with sources of large urban debris such as cars	M	similar to ID 15	M	moderate bed slope, stream size comparable to debris dimension	M	L	M	H	25%	50%	100%
20	Oakleigh Creek U/S	Culvert	No														0%	0%	0%
21	George St	Culvert	Yes	3	2	Mainly from heavy vegetation cover in riparian zone, limited urban debris potential (such as cars)	M	some areas of dense vegetation upstream (near King Mickey Park), inputs limited by upstream culverts.	M	similar to ID 15	M	stream size larger than debris, flat bed slopes	M	L	M	H	0%	10%	20%
22	Beverly Ave	Culvert	Yes	11	4	Based on potential for large urban debris due to nearby commercial areas and car park	M	urban areas close to water course with commercial properties and nearby carpark. However nearby upstream culvert (ID 21) will limit debris availability	M	similar to ID 15	L	flat bed slopes, stream size greater than debris load, banks not prone to scour as concrete lined	L	L	L	M	0%	0%	10%
23	Shellharbour Rd d/s Memorial Park	Culvert	Yes	3.2	4	Based on potential for large urban debris due to nearby commercial areas.	M	some urbanised areas close to water course, but also mown parklands	M	similar to ID 15	M	flat bed slopes, wide streams relative to expected debris load dimensions	M	L	M	H	25%	50%	100%
24	Lake Entrance Rd u/s of Memorial Park	Culvert	Yes	3	4	Based on potential for large urban debris due to nearby car park	H	urban areas close to water course, potential for cars from nearby car park to be washed in	M	similar to ID 15	M	streams size comparable to expected debris load dimensions, flat bed slopes	M	L	M	H	25%	50%	100%
25	Leawarra Ave	Culvert	No														0%	0%	0%
26	The Kingsway	Culvert	Yes	1.2	1	some urban residential areas close by, minimal vegetation in upstream areas	L	small area of urbanised areas, all fenced off, minimal vegetation in upstream areas	M	similar to ID 15	M	flat bed slopes, wide streams relative to expected debris load dimensions	L	L	L	M	0%	0%	10%
27	Captain Cook Dr	Grated Pit Inlet (multiple)	Yes	0.05	0.3	Likely debris at kerbside pit inlets mostly tree branches.	M	urban residential areas close by, dense forested areas (Blackbutt Reserve) in upstream contributing catchment	M	similar to ID 15	L	relatively flat overland slopes	L	L	L	M	25%	25%	50%
28	Lake Entrance Rd near Wattle Rd	Grated Pipe Inlet	Yes	0.2	1	upstream area predominantly parkland with minimal vegetation cover, limited potential for urban debris as urban areas located some distance from structure	L	upstream area predominantly parkland with minimal vegetation cover, urban areas located some distance from structure.	M	similar to ID 15	M	flat bed slopes, wide streams relative to expected debris load dimensions	L	L	L	M	25%	25%	50%
29	Cycleway under Lake Entrance Rd	Informal Culvert	Yes	5	1	similar to ID 28	L	similar to ID 28	M	similar to ID 28	M	similar to ID 28	L	L	L	M	0%	0%	0%
30	Madigan Blvd	Culvert	Yes	1.25	4	urbanised areas close by,unfenced car park upstream, some vegetation	H	urban areas close by, some cars, material not limited by upstream culverts as most water gets diverted to Lake Entrance Rd	M	similar to ID 4	M	moderate bed slopes, stream size comparable to debris load dimension	M	L	M	H	25%	50%	100%

ID	Location	Type of structure	Detailed Blockage Assessment Reqrd?*	Width (W) in metres	L10 (metres)	L10 Justification	Debris Availability (H,M,L)	Justification for Debris Availability	Debris Mobility (H,M,L)	Justification for Debris Mobility	Debris Transportability (H,M,L)	Justification for Debris Transportability	Base At Site Debris Potential	Event Based At Site Debris Potential			Most Likely Blockage Level		
														< 20yr ARI	20 yr <= ARI <= 200yr	> 200 yr ARI	< 20yr ARI	20 yr <= ARI <= 200yr	> 200 yr ARI
31	Landy Dr	Culvert	Yes	1.22	2	residential urban areas close by, debris availability limited by upstream culvert, sparse vegetation	L	residential urban areas close, debris availability limited by upstream culvert, sparse vegetation	M	similar to ID 4	M	flat bed slopes, wide streams relative to expected debris load dimensions	L	L	L	M	25%	25%	50%
32	Andrew Reserve	Culvert	Yes	1.35	2	residential areas close by, limited potential for cars, surrounded by parkland, limited by upstream culvert at Landy Dr	L	residential areas close by, limited potential for cars, surrounded by parkland, limited by upstream culvert at Landy Dr	M	similar to ID 4	M	flat bed slopes, wide streams relative to expected debris load dimensions	L	L	L	M	25%	25%	50%
33	Grimmett St & Spofforth St	Grated Kerbside Inlet (multiple)	Yes	0.05	0.3	Likely debris at kerbside pit inlets mostly tree branches.	M	urban residential areas close by	M	similar to ID 15	L	relatively flat overland slopes	L	L	L	M	25%	25%	50%

**Structures located away from urbanised areas and/or with minimum debris potential where not considered for the detailed assessment and will be assumed unblocked for the design events.*

Elliot Lake – Little Lake Floodplain Risk Management Study and Plan

APPENDIX F

DESIGN FLOOD FIGURES

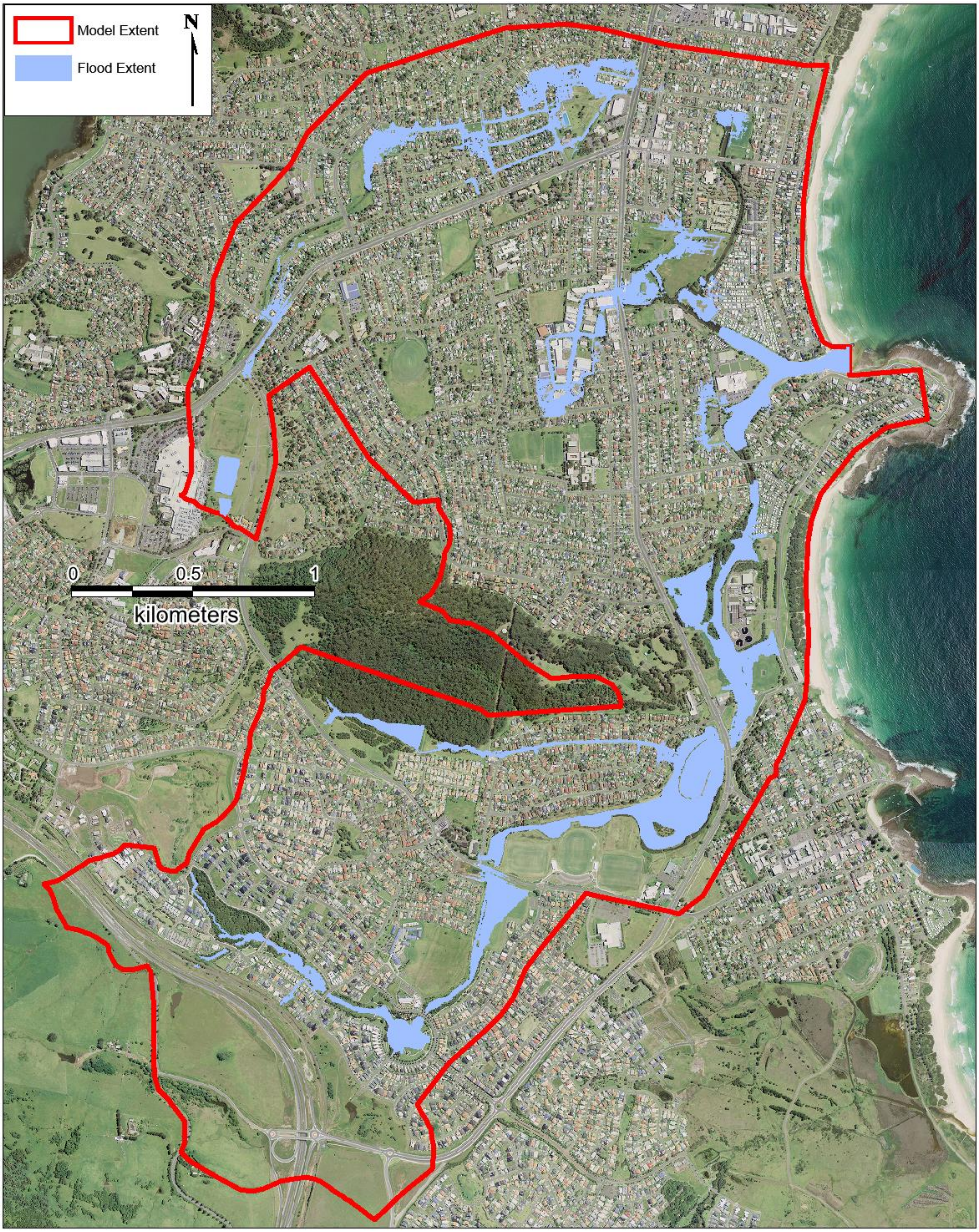

Figure F-1 Design Flood Extent for Existing Conditions – 1 EY (1 yr ARI)

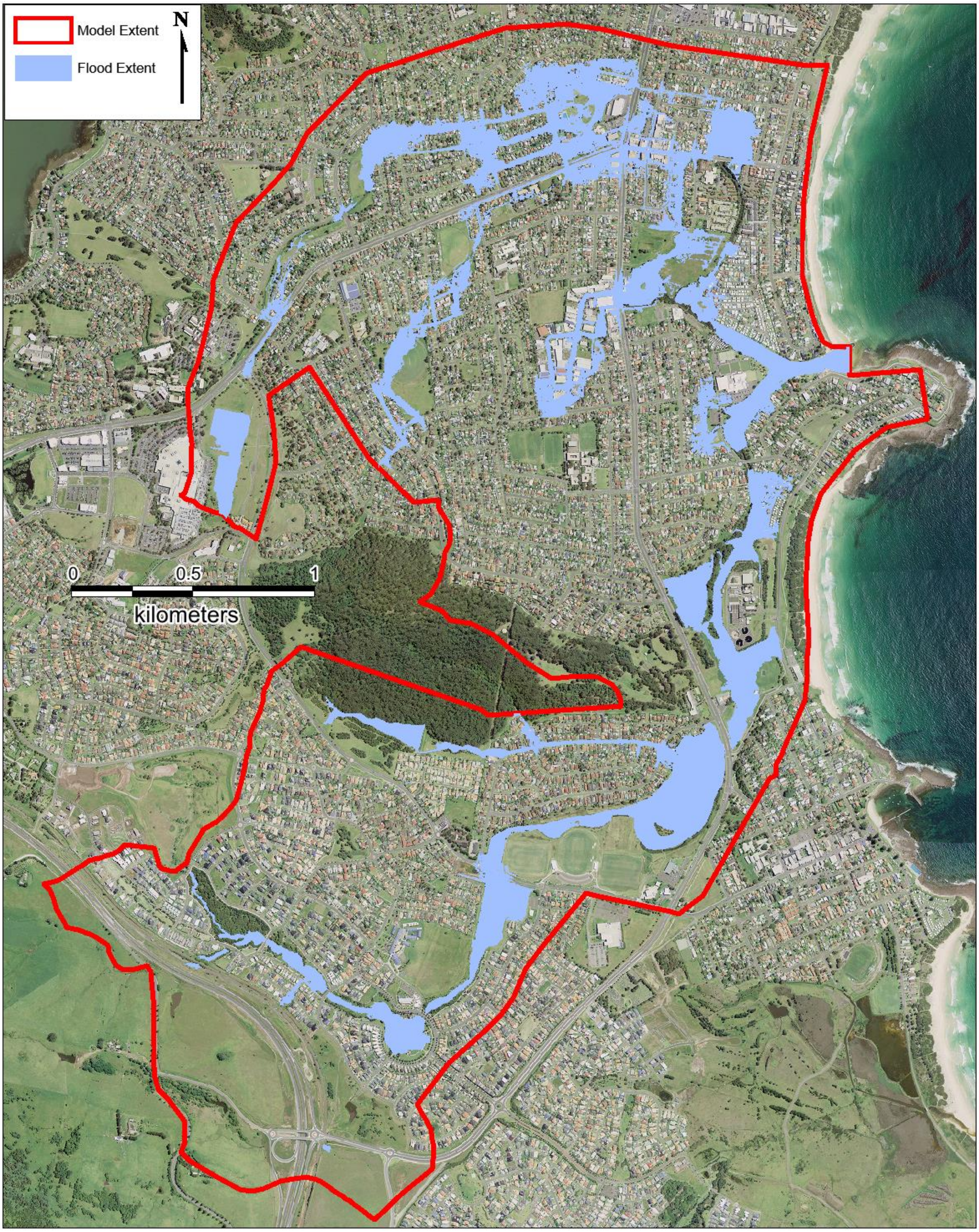

Figure F-2 Design Flood Extent for Existing Conditions – 20% AEP

Figure F-3 Design Flood Extent for Existing Conditions – 10% AEP

Figure F-4 Design Flood Extent for Existing Conditions – 5% AEP

Figure F-5 Design Flood Extent for Existing Conditions – 2% AEP

Figure F-6 Design Flood Extent for Existing Conditions – 1% AEP

Figure F-7 Design Flood Extent for Existing Conditions – 0.5% AEP

Figure F-8 Design Flood Extent for Existing Conditions – PMF

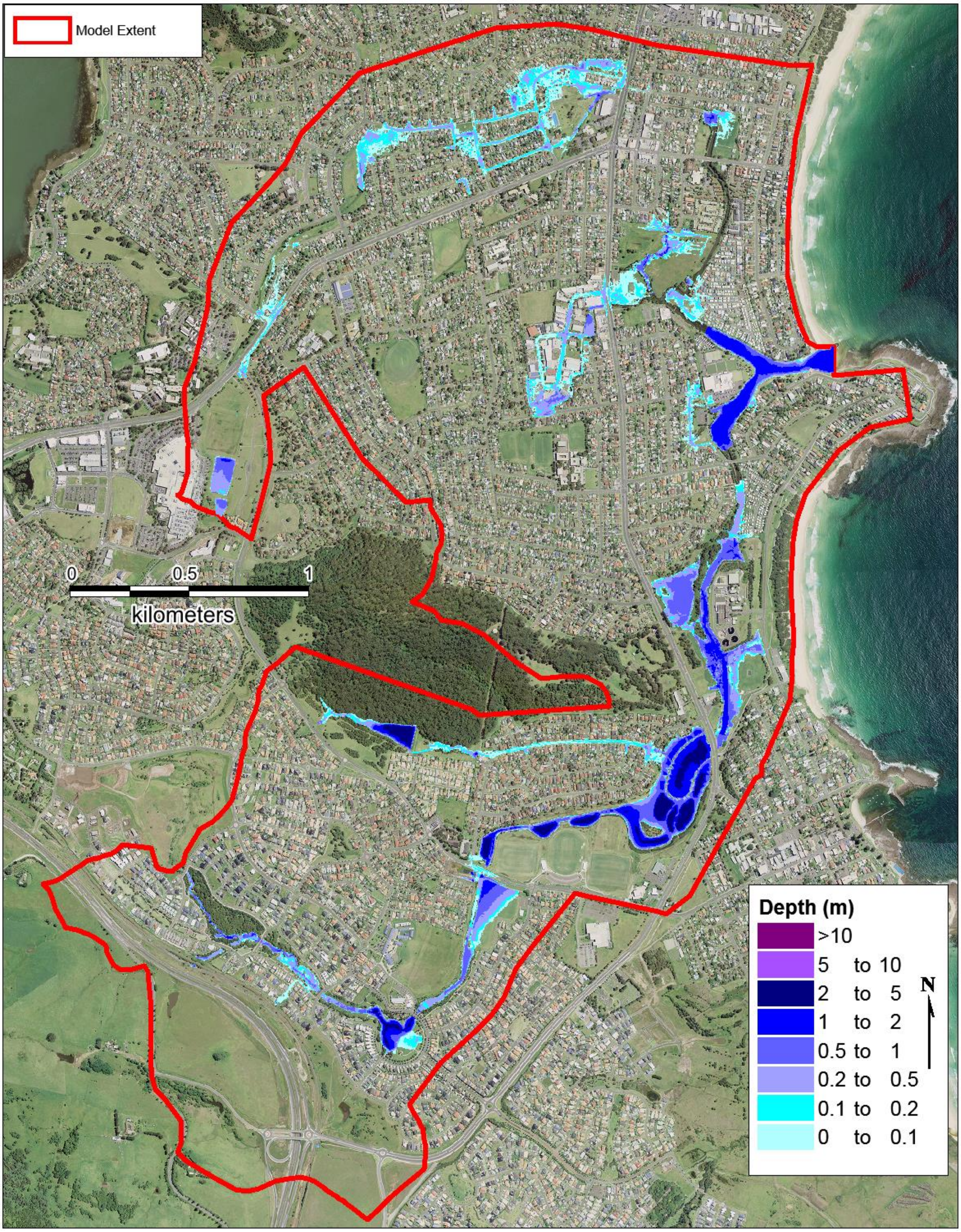

Figure F-9 Peak Flood Depth for Existing Conditions – 1EY (1 yr ARI)

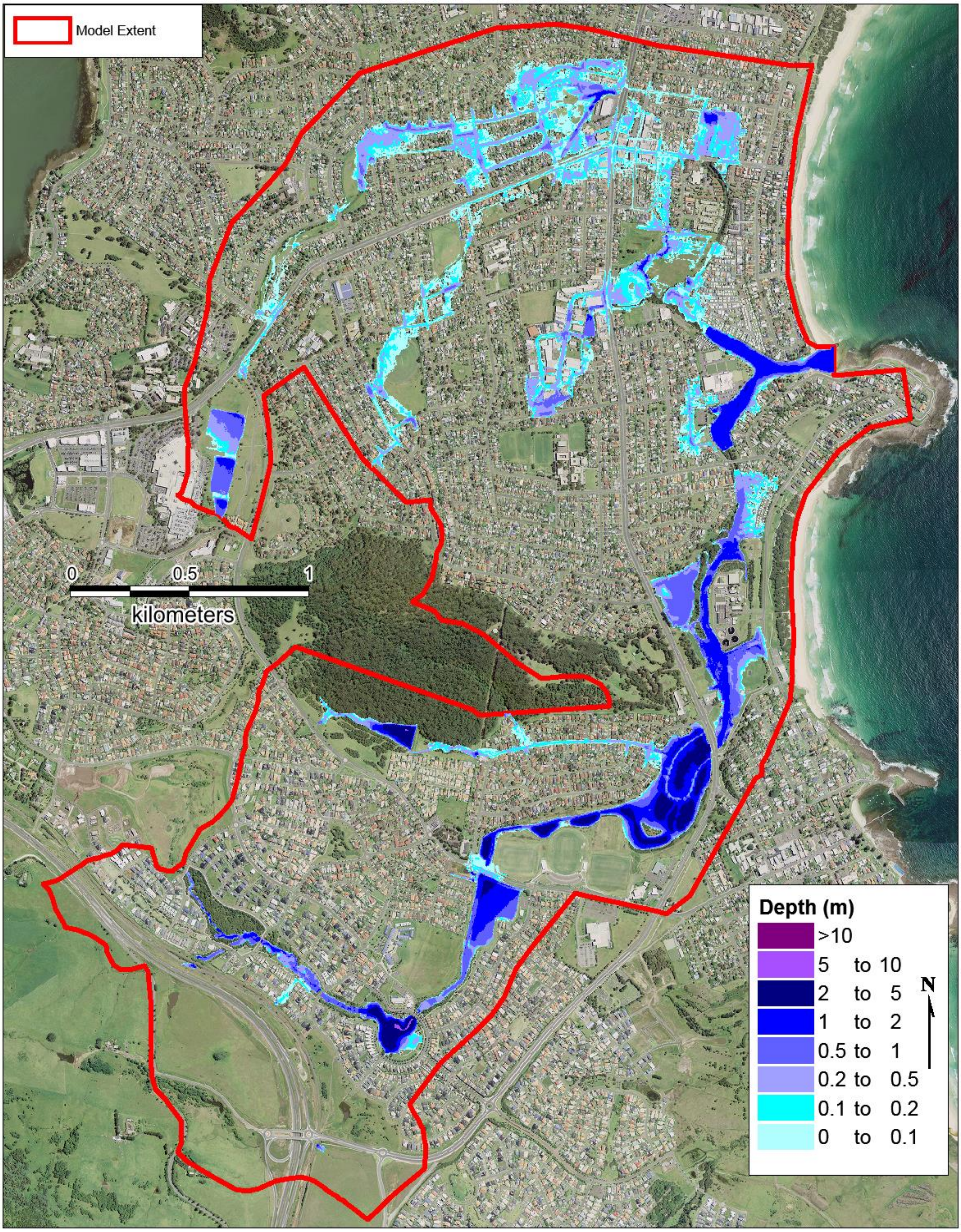

Figure F-10 Peak Flood Depth for Existing Conditions – 20% AEP

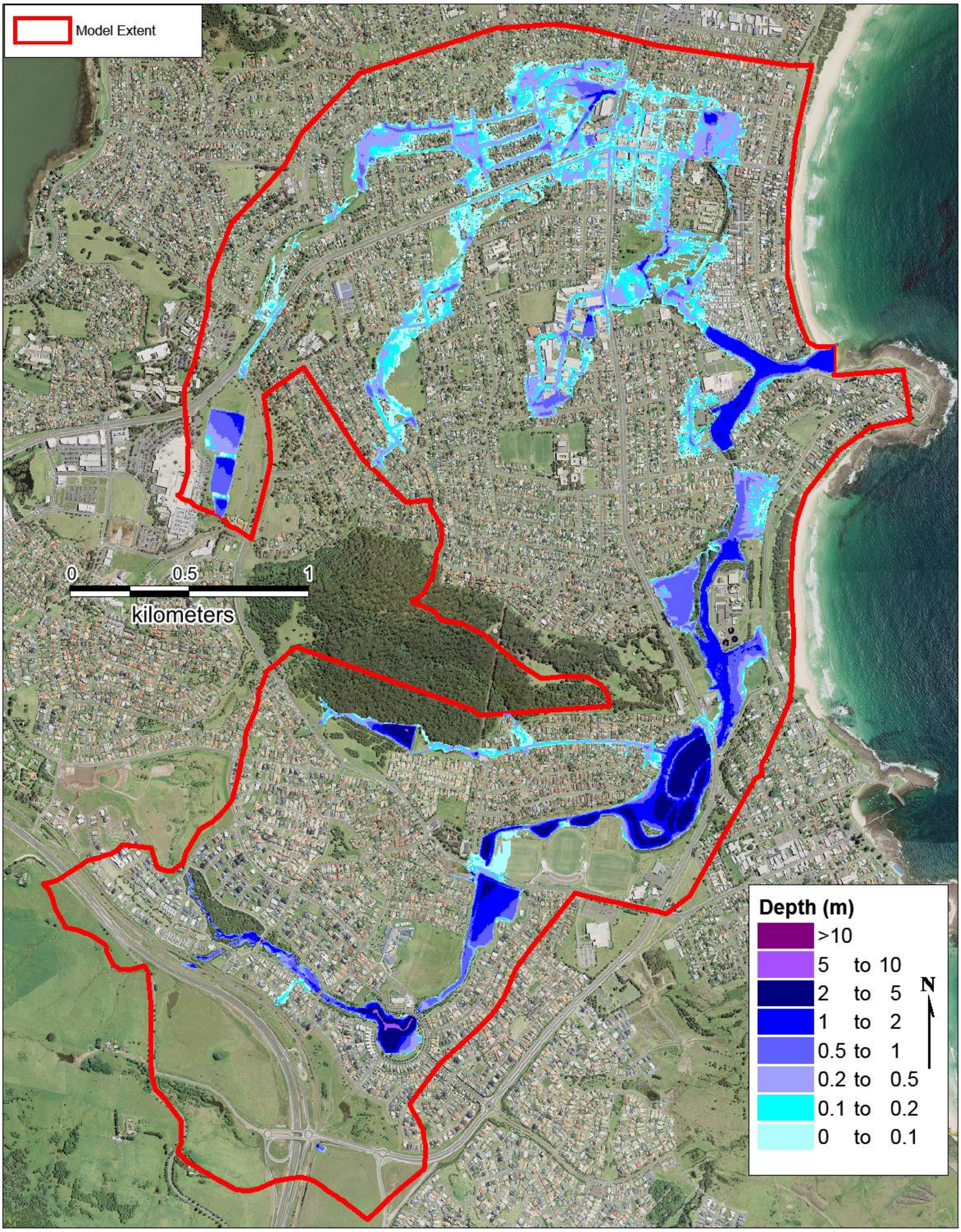

Figure F-11 Peak Flood Depth for Existing Conditions – 10% AEP

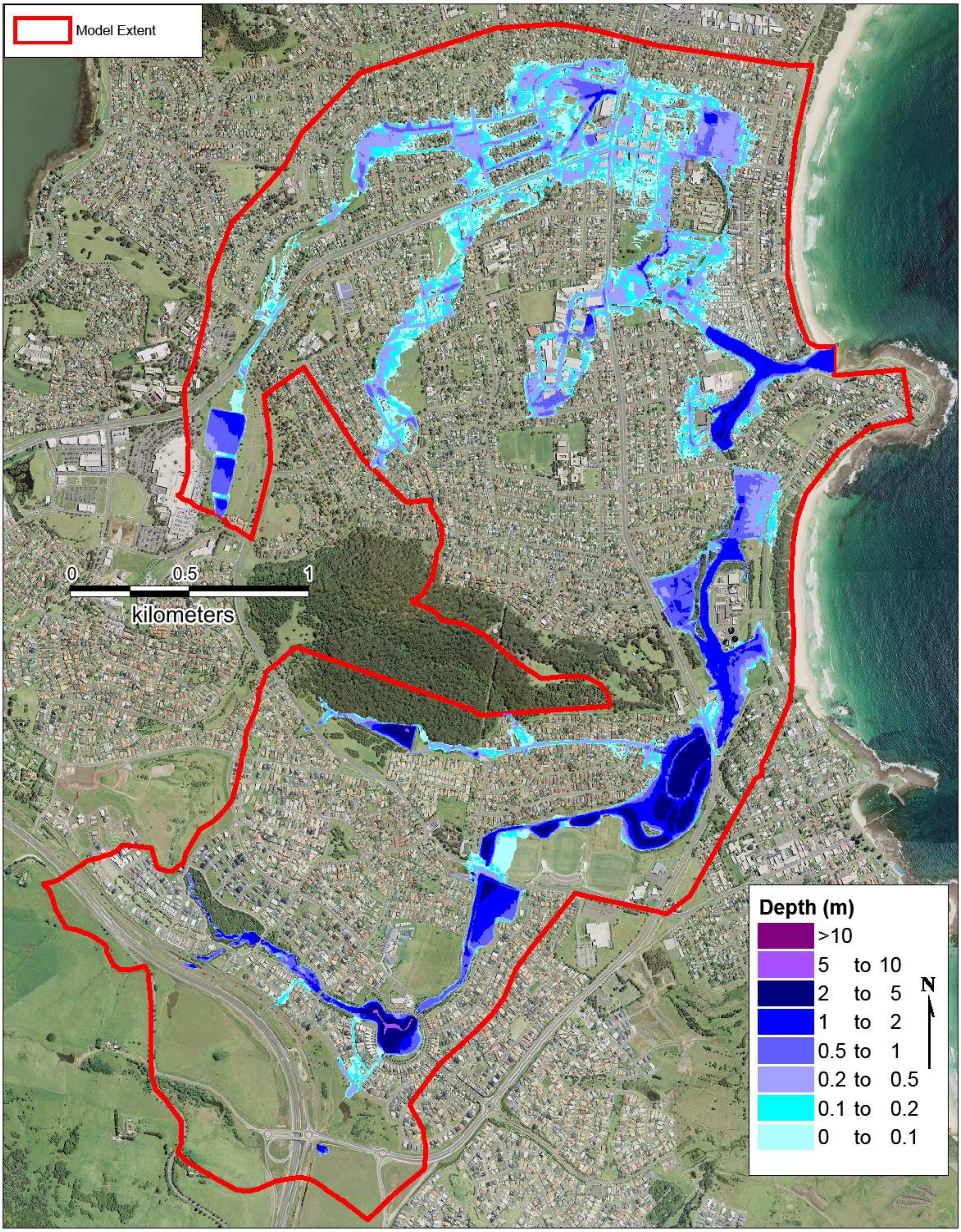

Figure F-12 Peak Flood Depth for Existing Conditions – 5% AEP

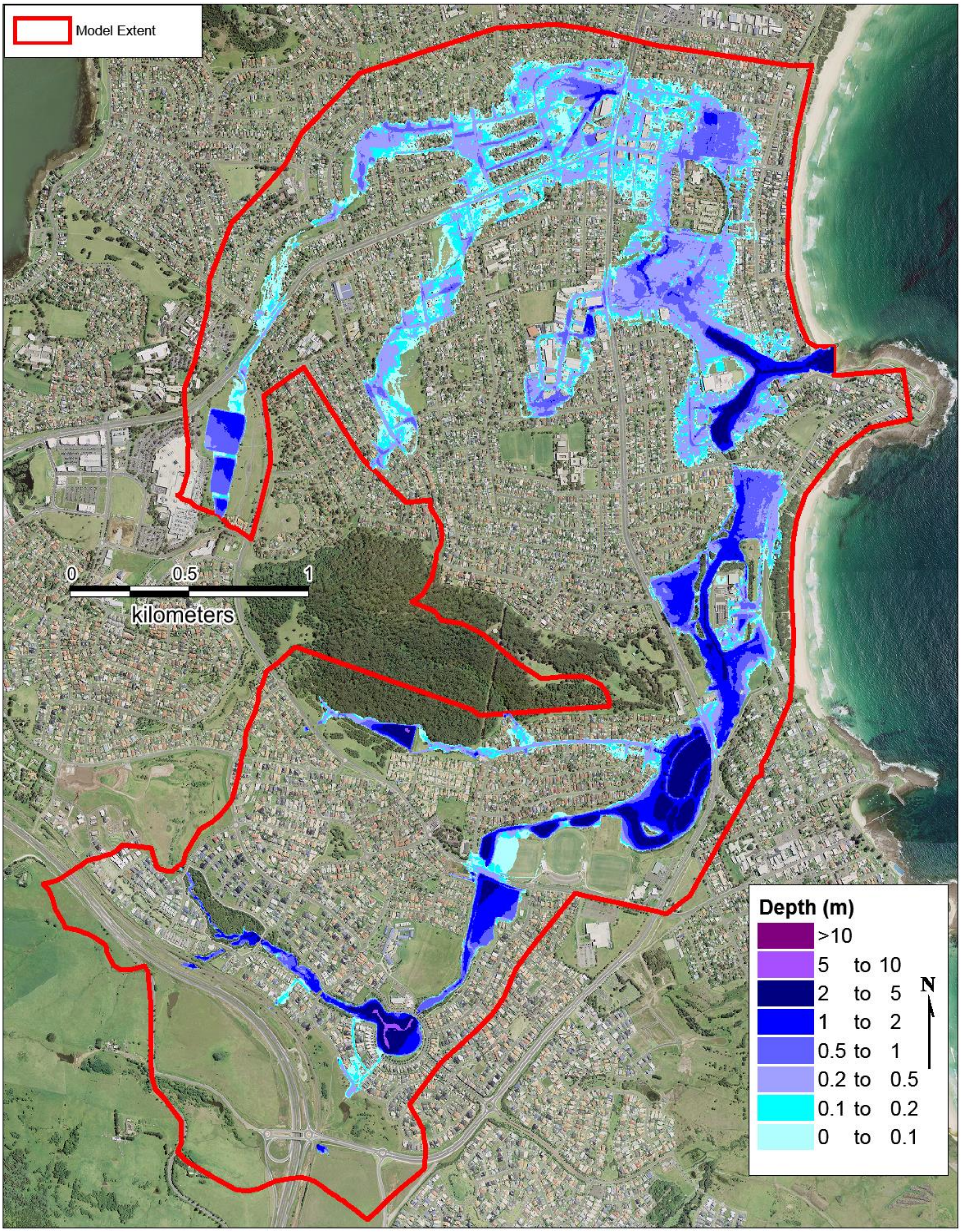

Figure F-13 Peak Flood Depth for Existing Conditions – 2% AEP

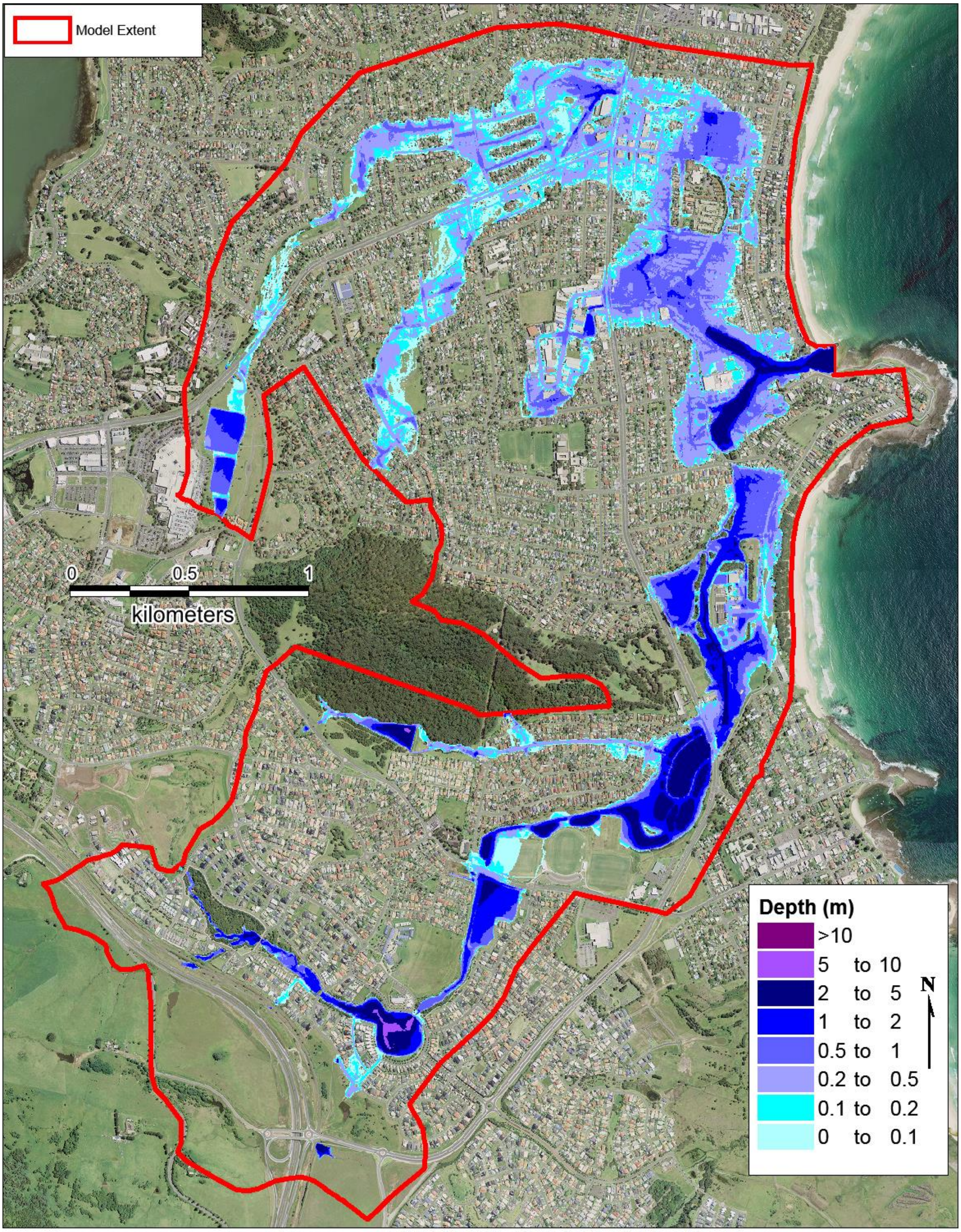

Figure F-14 Peak Flood Depth for Existing Conditions – 1% AEP

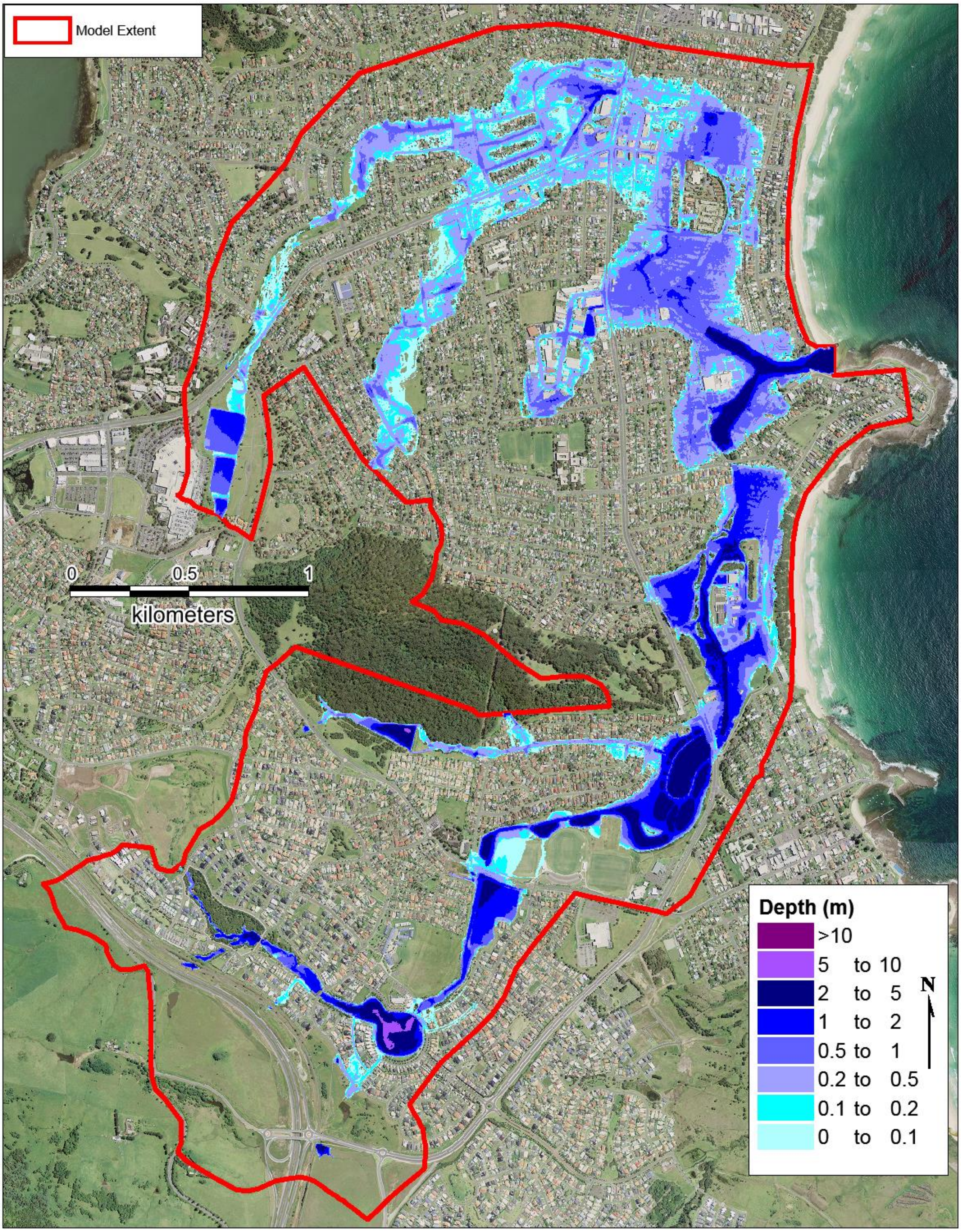

Figure F-15 Peak Flood Depth for Existing Conditions – 0.5% AEP

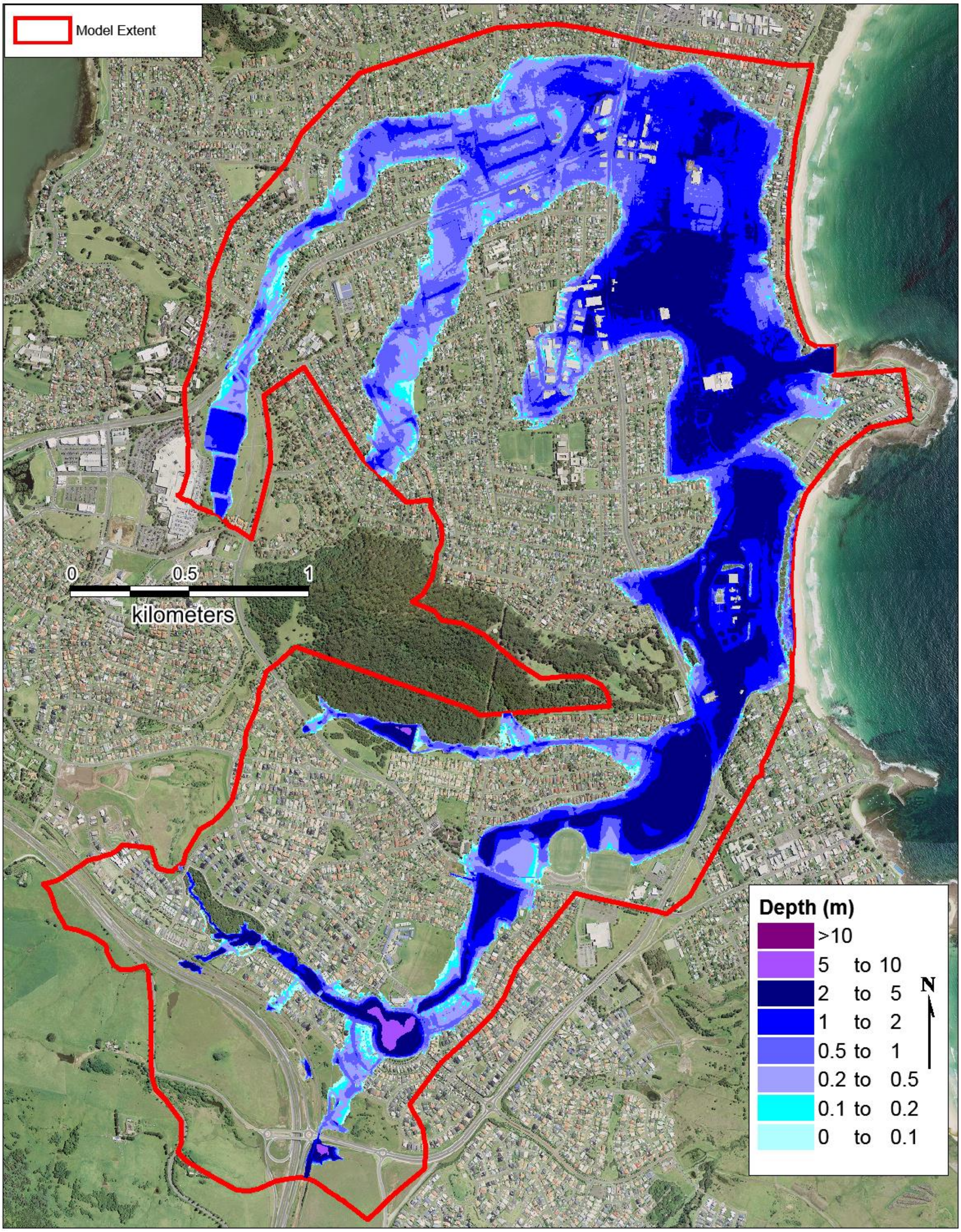

Figure F-16 Peak Flood Depth for Existing Conditions – PMF

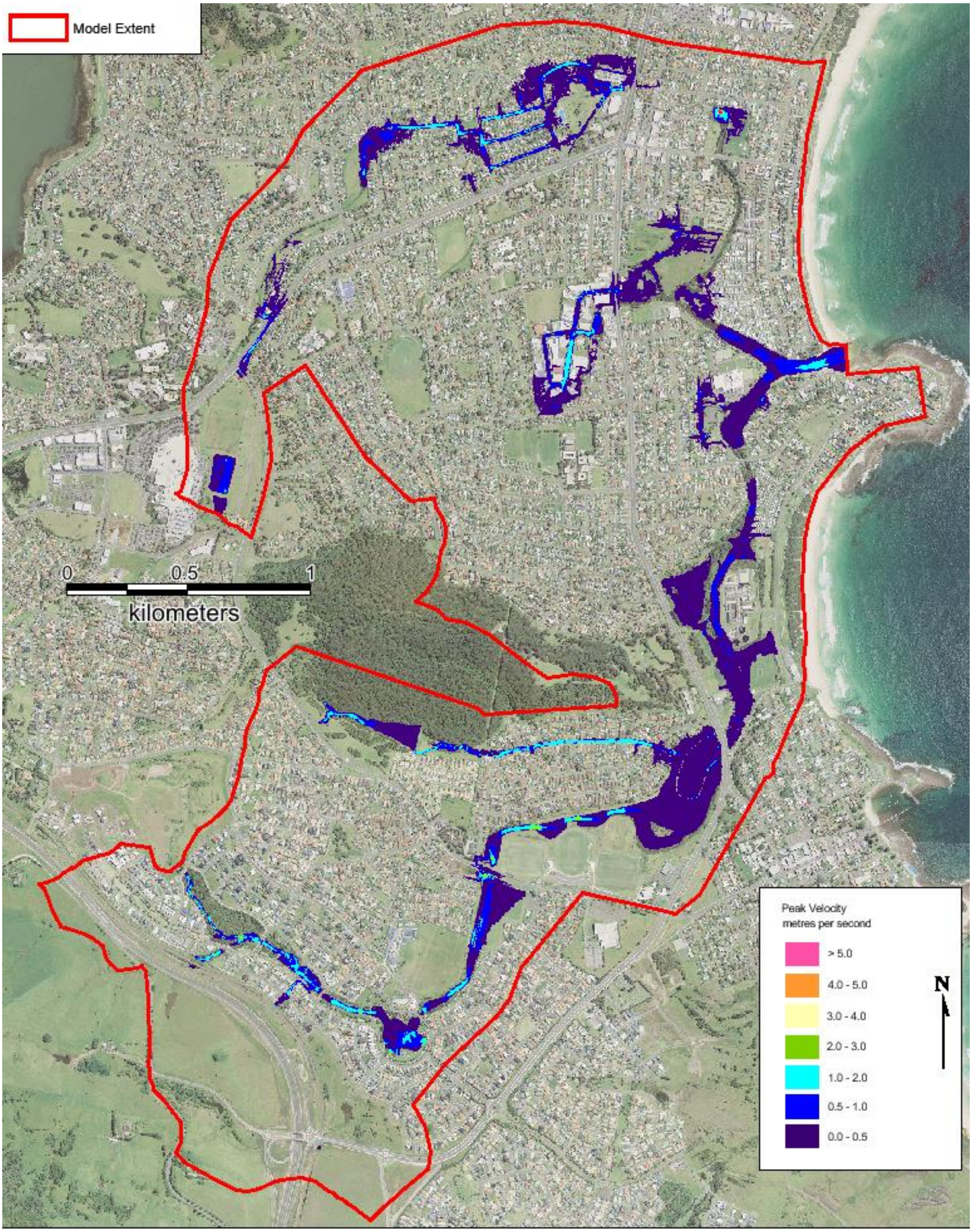

Figure F-17 Peak Flood Velocity for Existing Conditions – 1EY (1 year ARI)

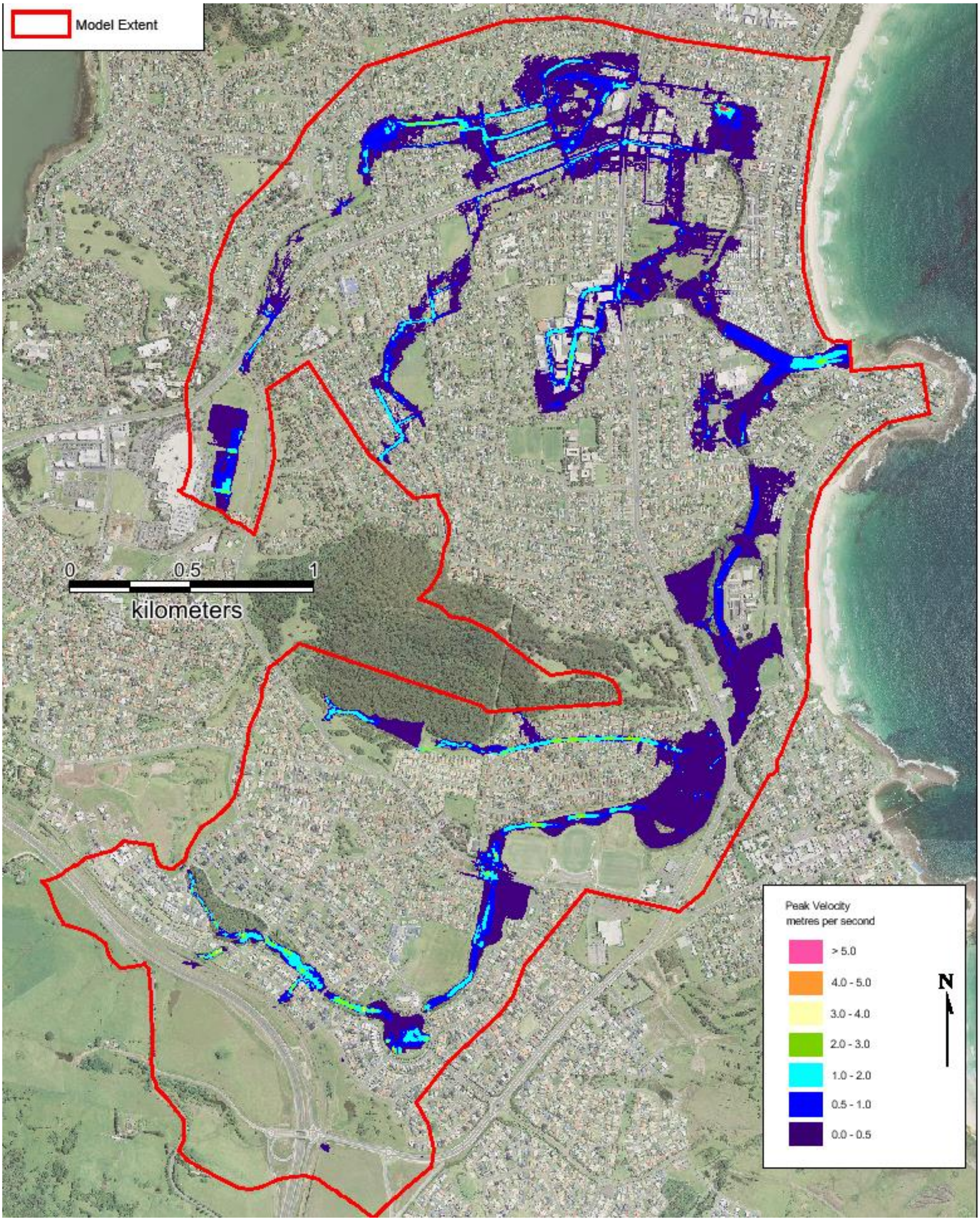

Figure F-18 Peak Flood Velocity for Existing Conditions – 20% AEP

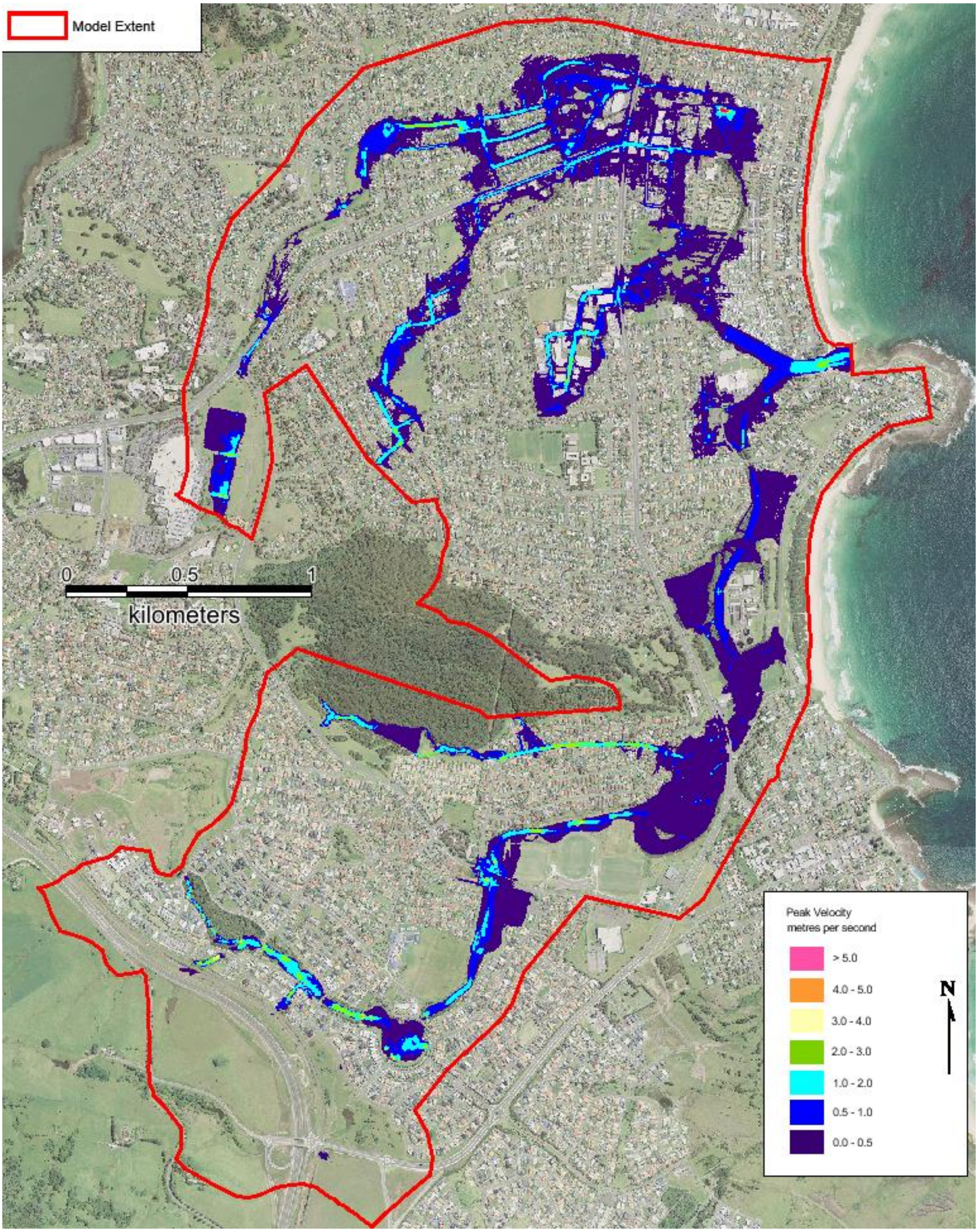

Figure F-19 Peak Flood Velocity for Existing Conditions – 10% AEP

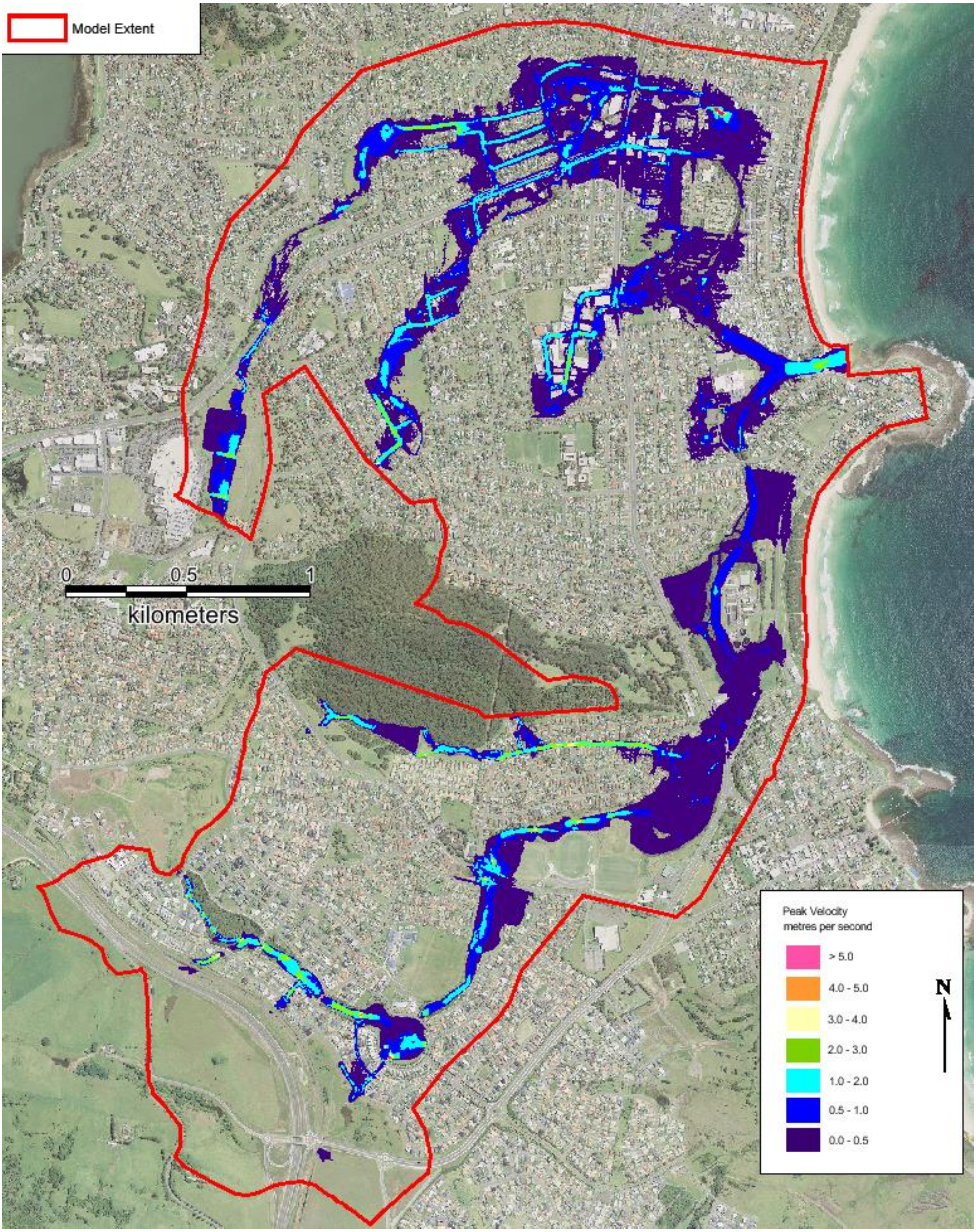

Figure F-20 Peak Flood Velocity for Existing Conditions – 5% AEP

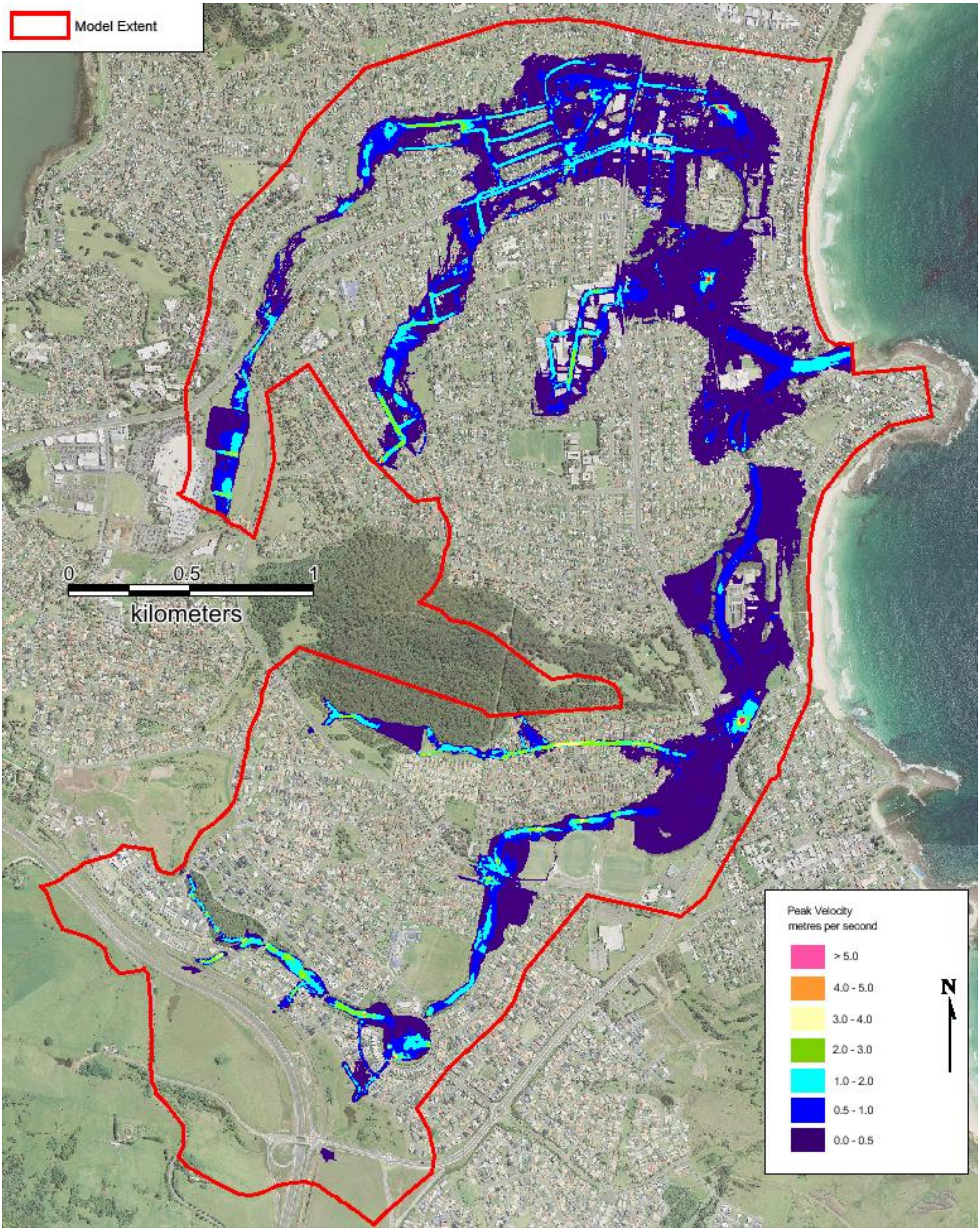

Figure F-21 Peak Flood Velocity for Existing Conditions – 2% AEP

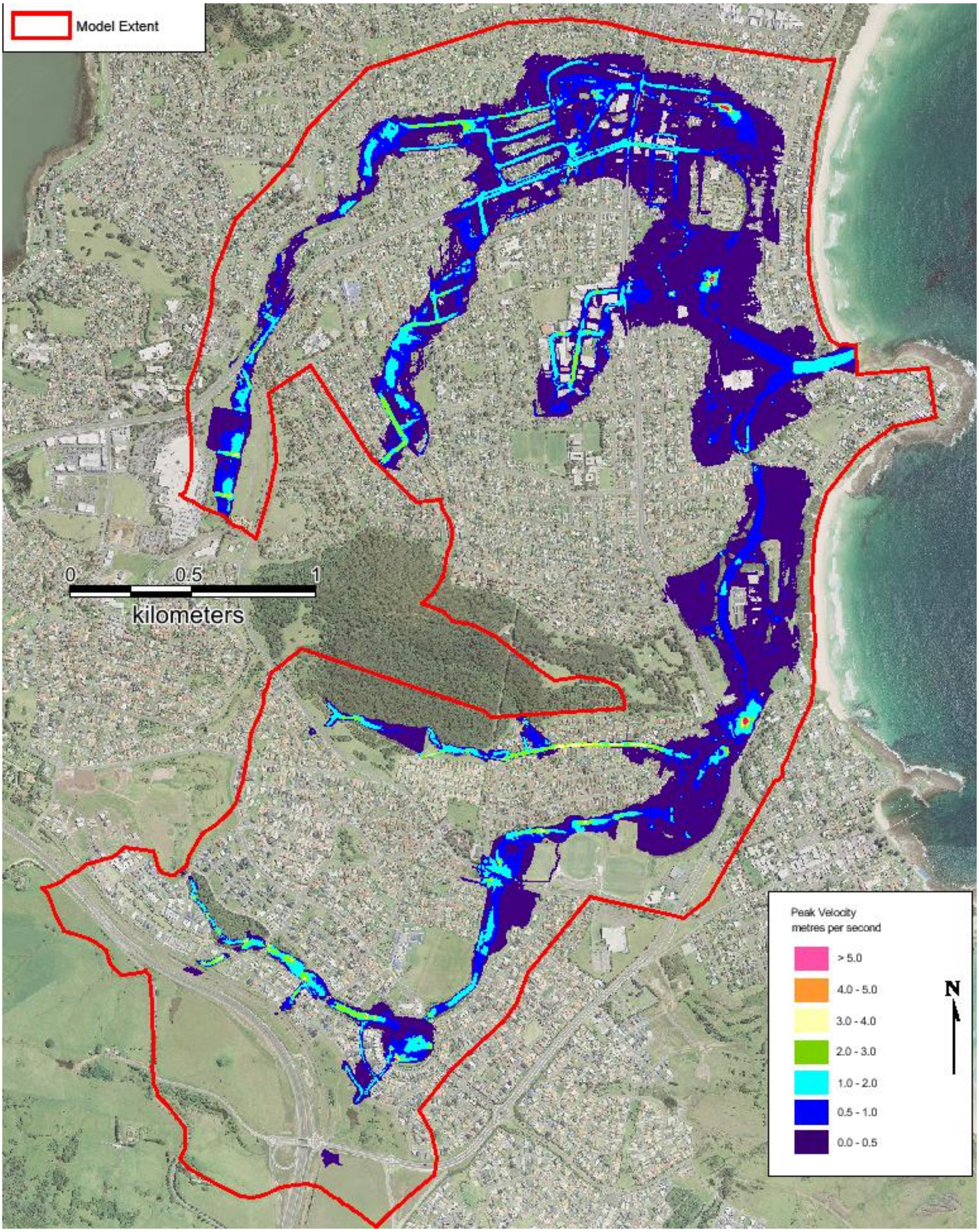

Figure F-22 Peak Flood Velocity for Existing Conditions – 1% AEP

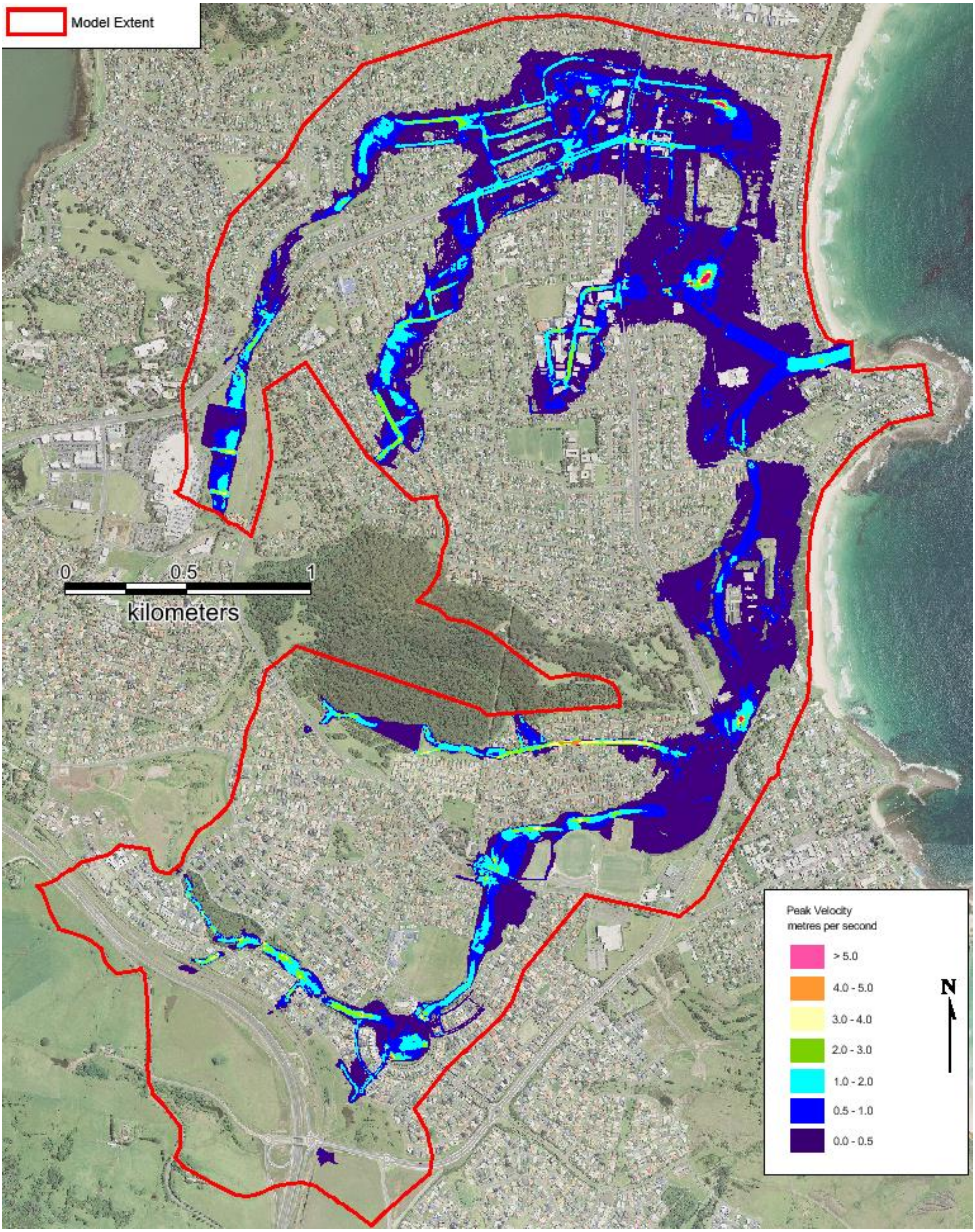

Figure F-23 Peak Flood Velocity for Existing Conditions – 0.5% AEP

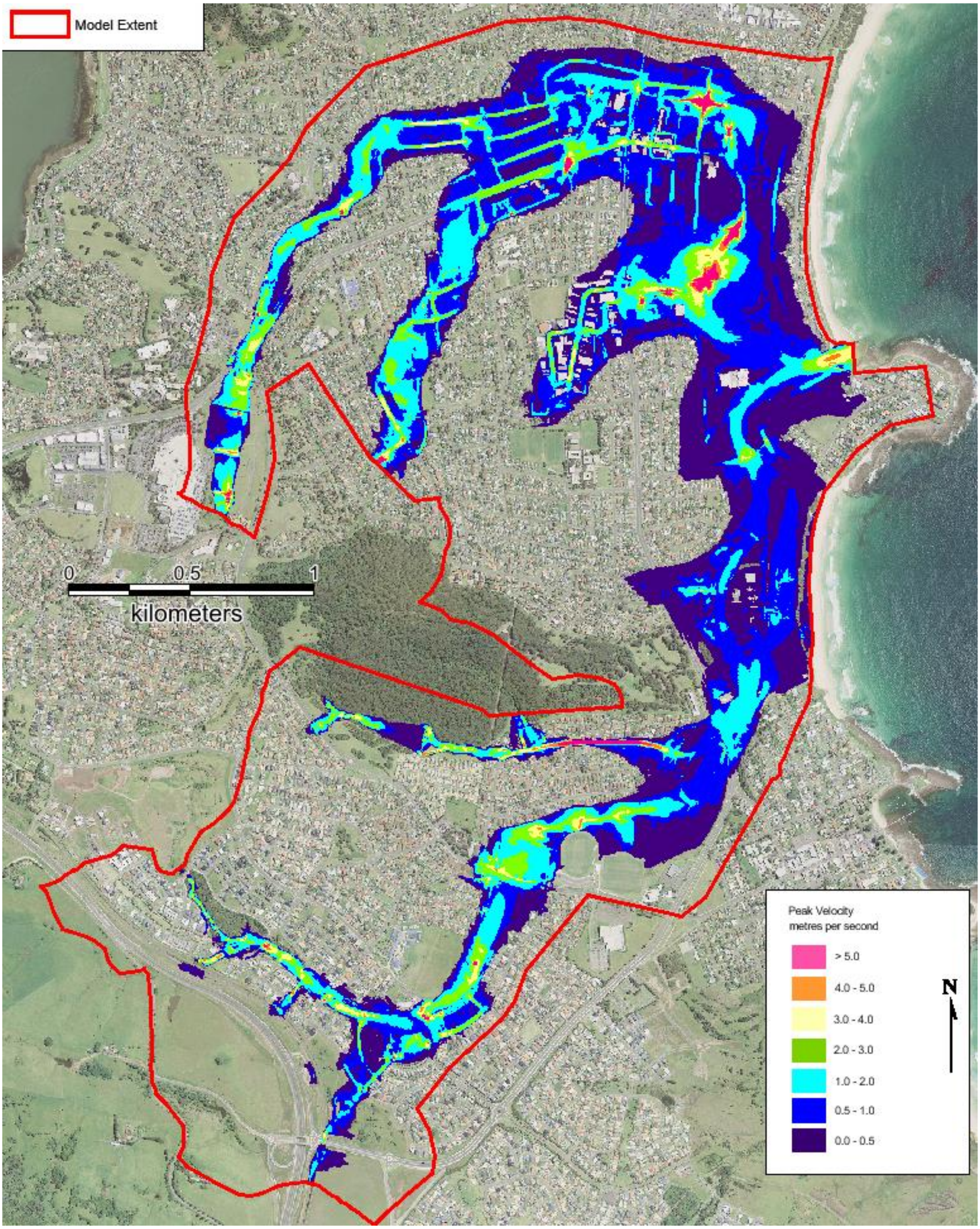

Figure F-24 Peak Flood Velocity for Existing Conditions – PMF

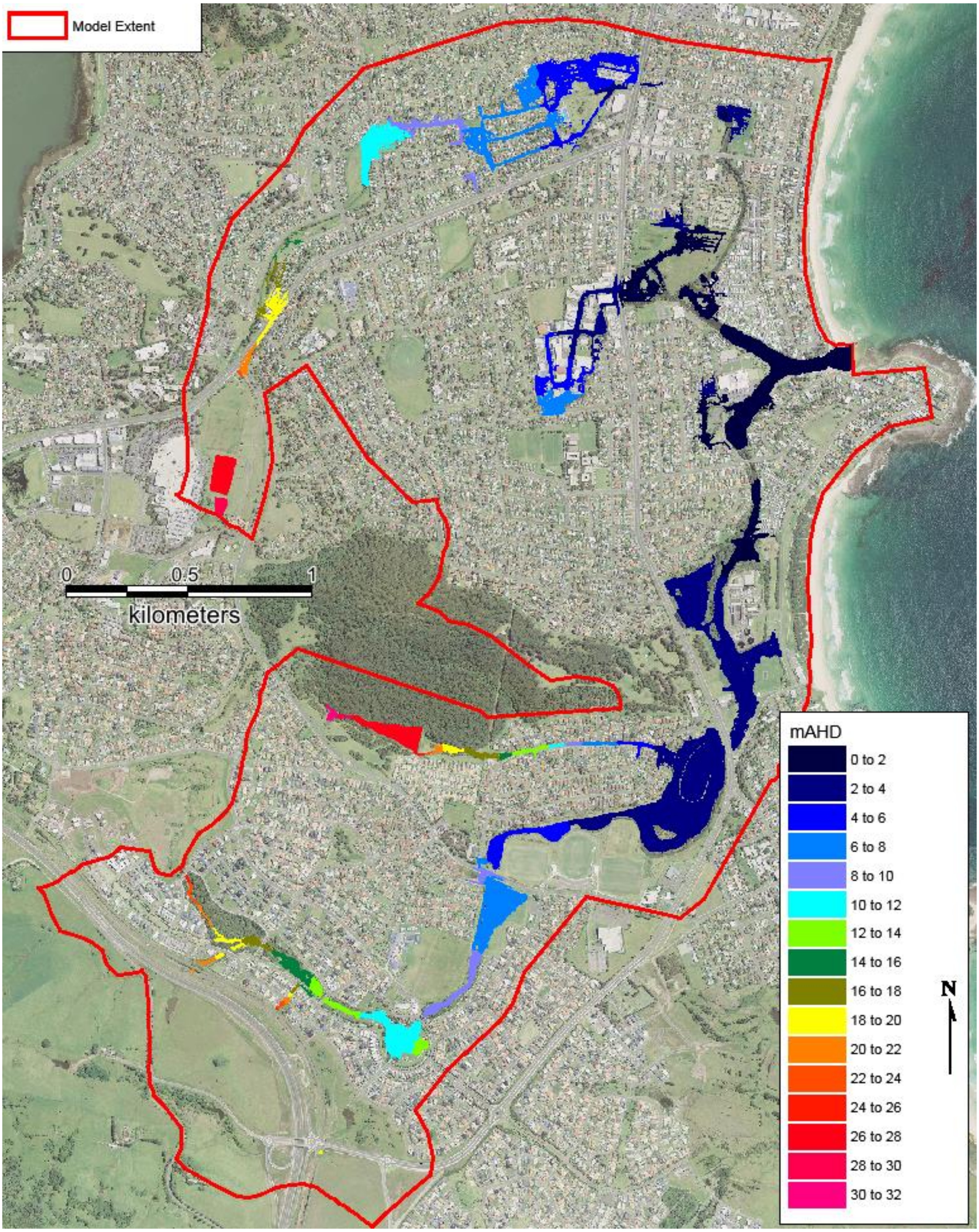

Figure F-25 Peak Flood Water Surface Elevation for Existing Conditions – 1EY (1 year ARI)

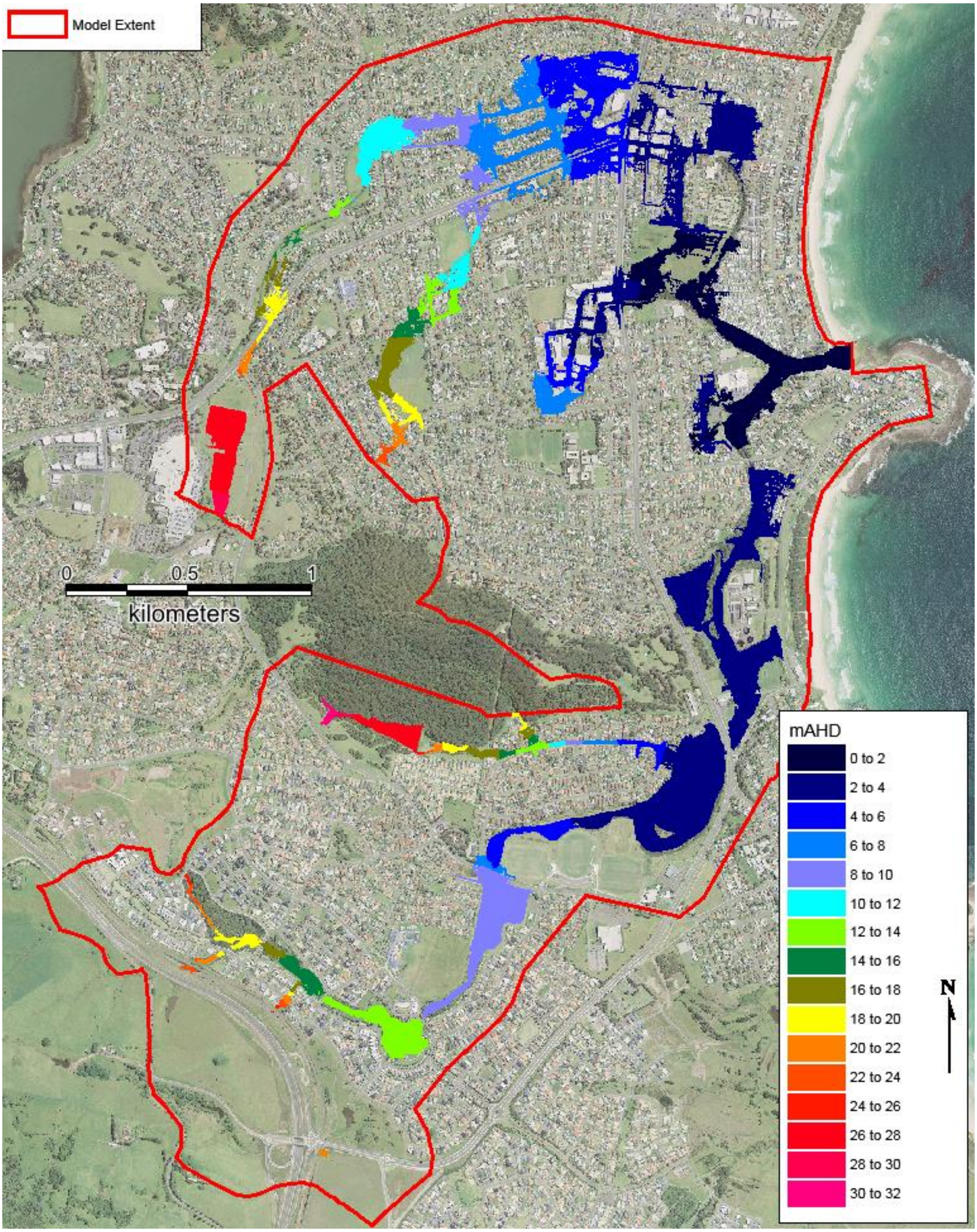

Figure F-26 Peak Flood Water Surface Elevation for Existing Conditions – 20% AEP

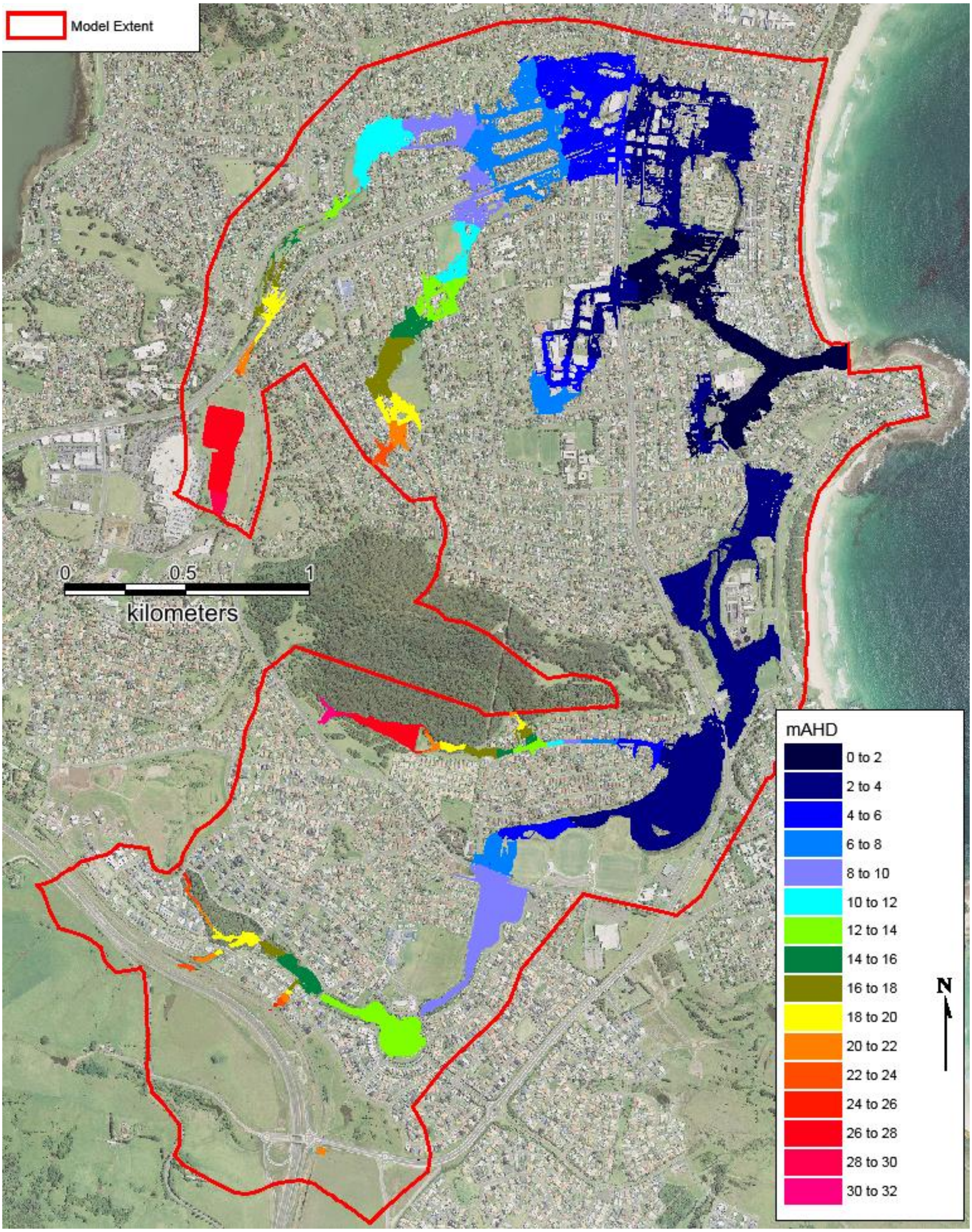

Figure F-27 Peak Flood Water Surface Elevation for Existing Conditions – 10% AEP

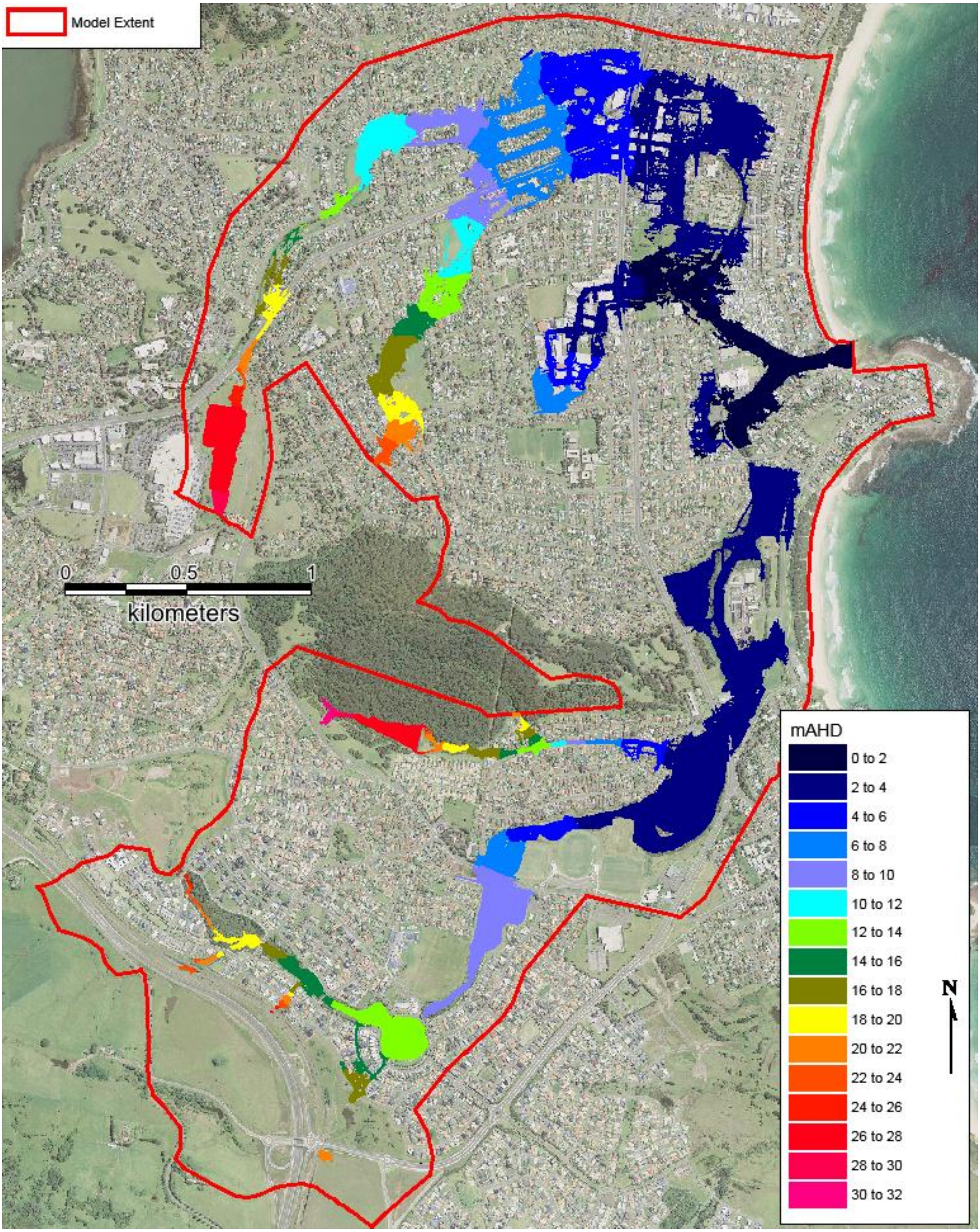

Figure F-28 Peak Flood Water Surface Elevation for Existing Conditions – 5% AEP

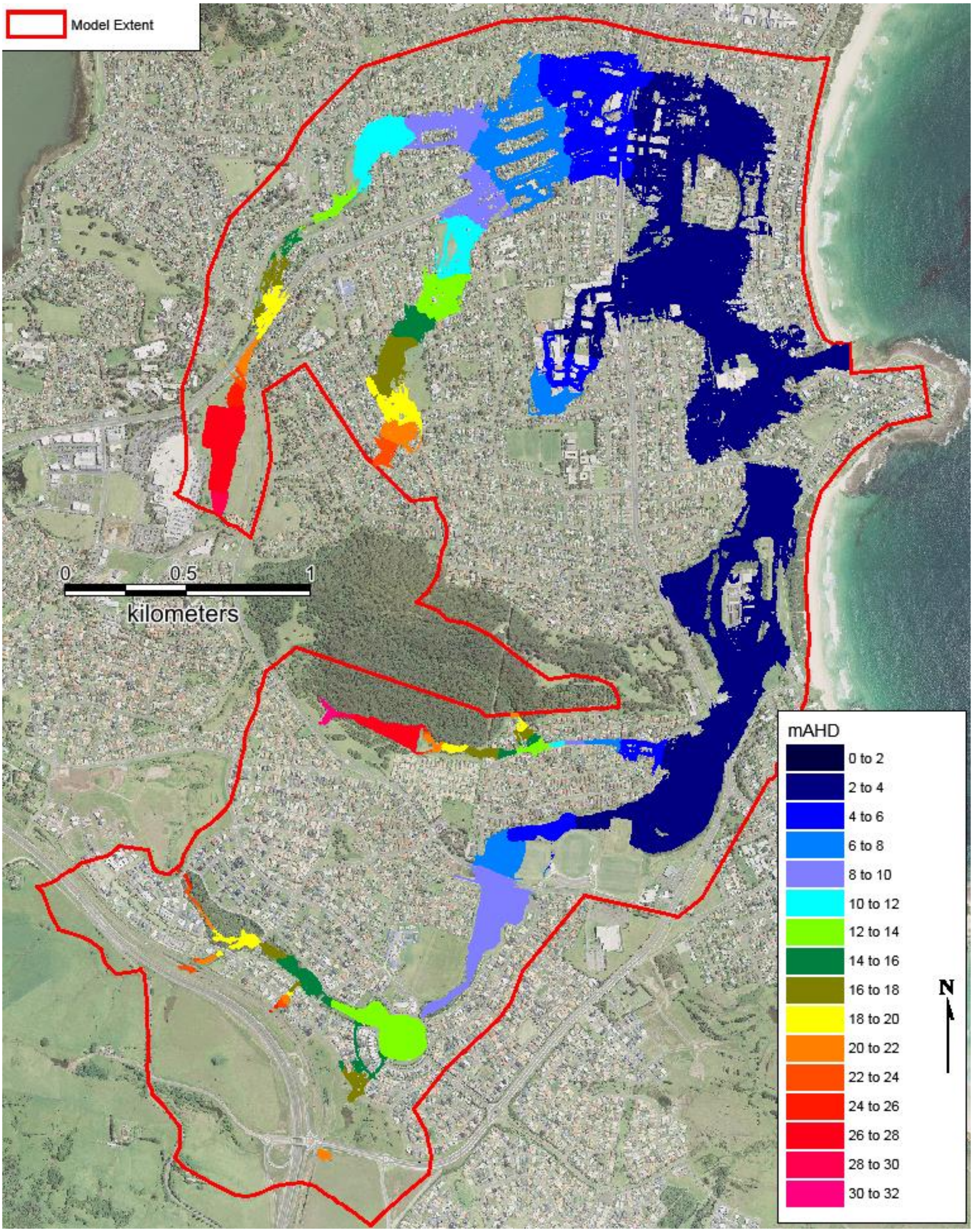

Figure F-29 Peak Flood Water Surface Elevation for Existing Conditions – 2% AEP

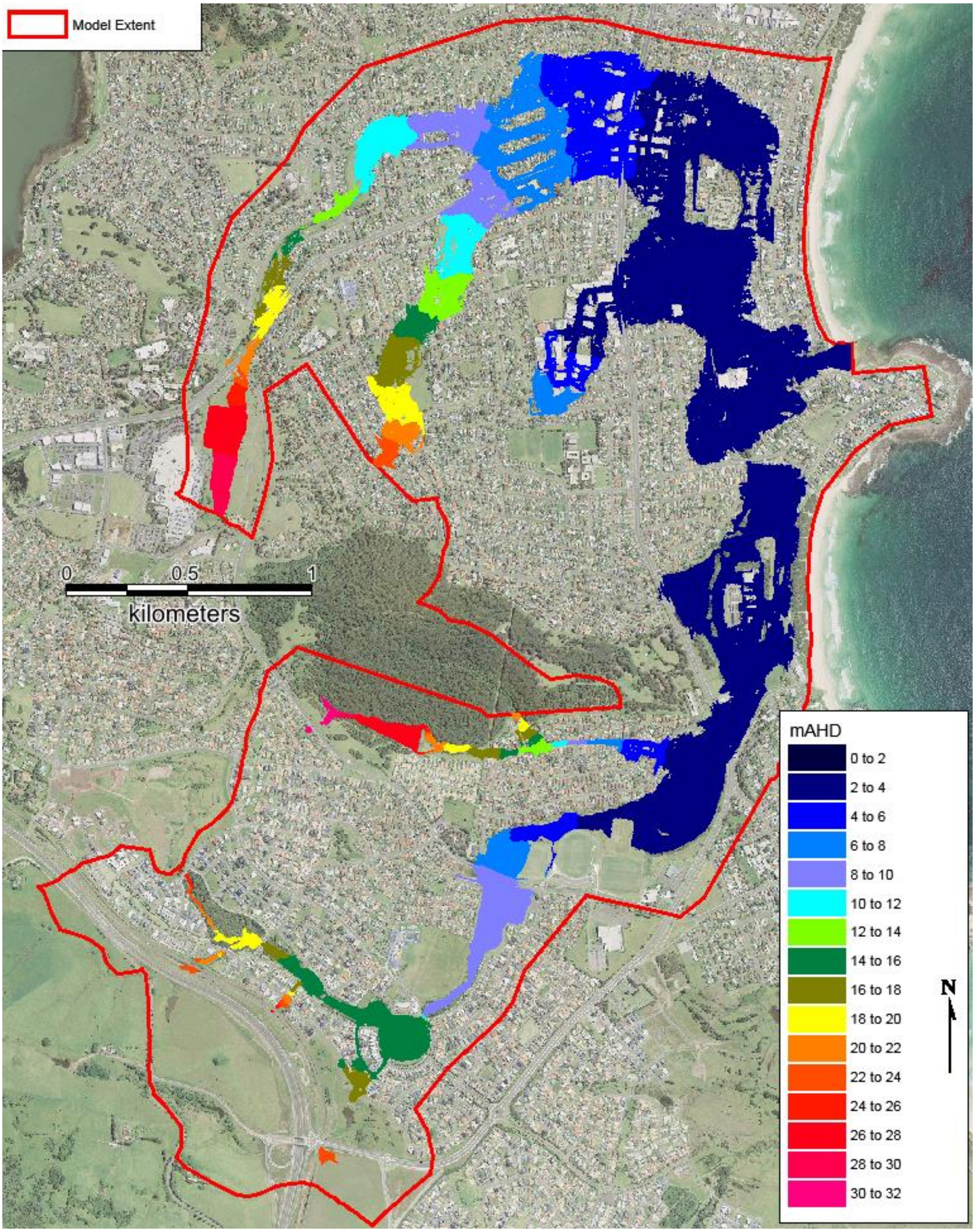

Figure F-30 Peak Flood Water Surface Elevation for Existing Conditions – 1% AEP

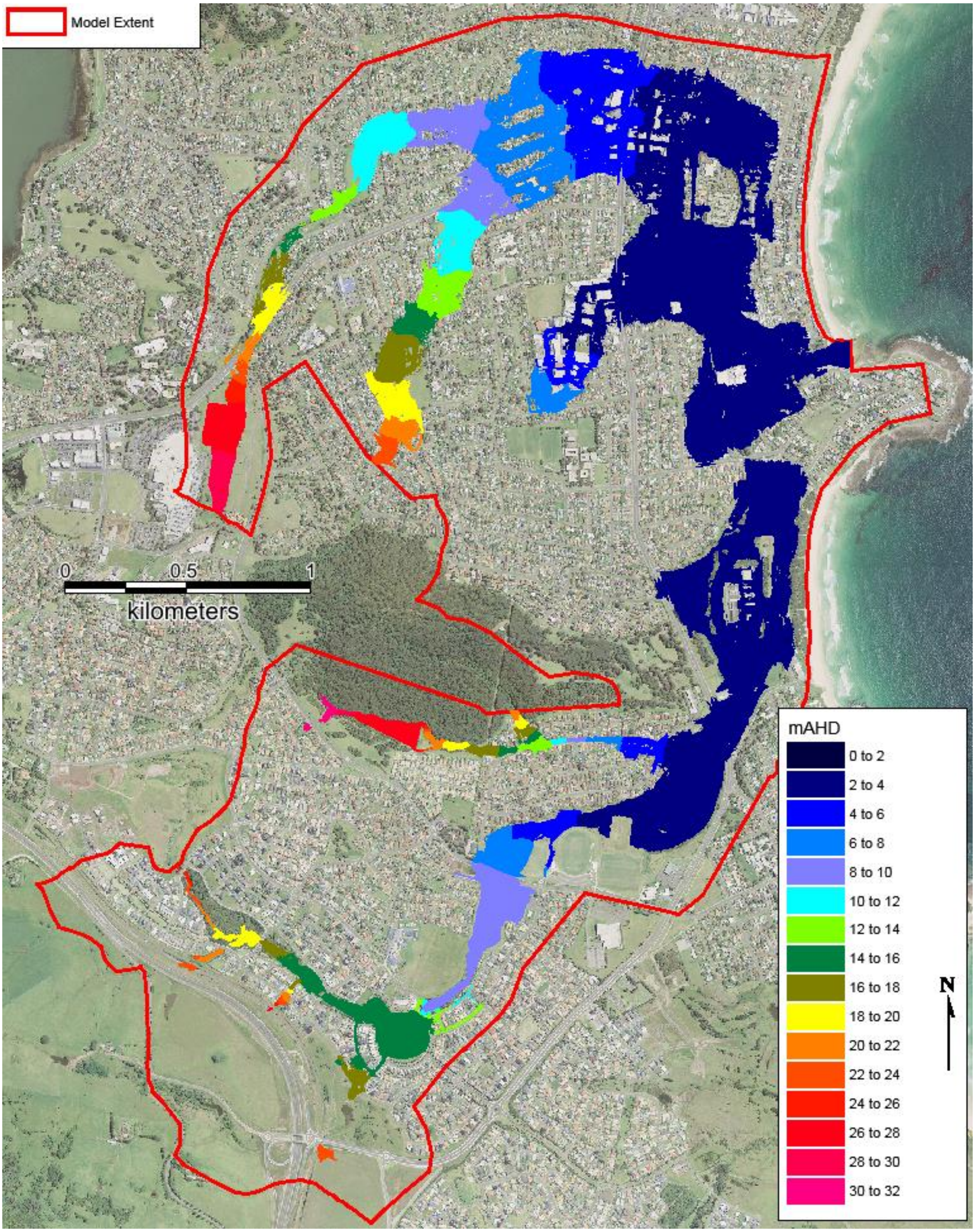

Figure F-31 Peak Flood Water Surface Elevation for Existing Conditions – 0.5% AEP

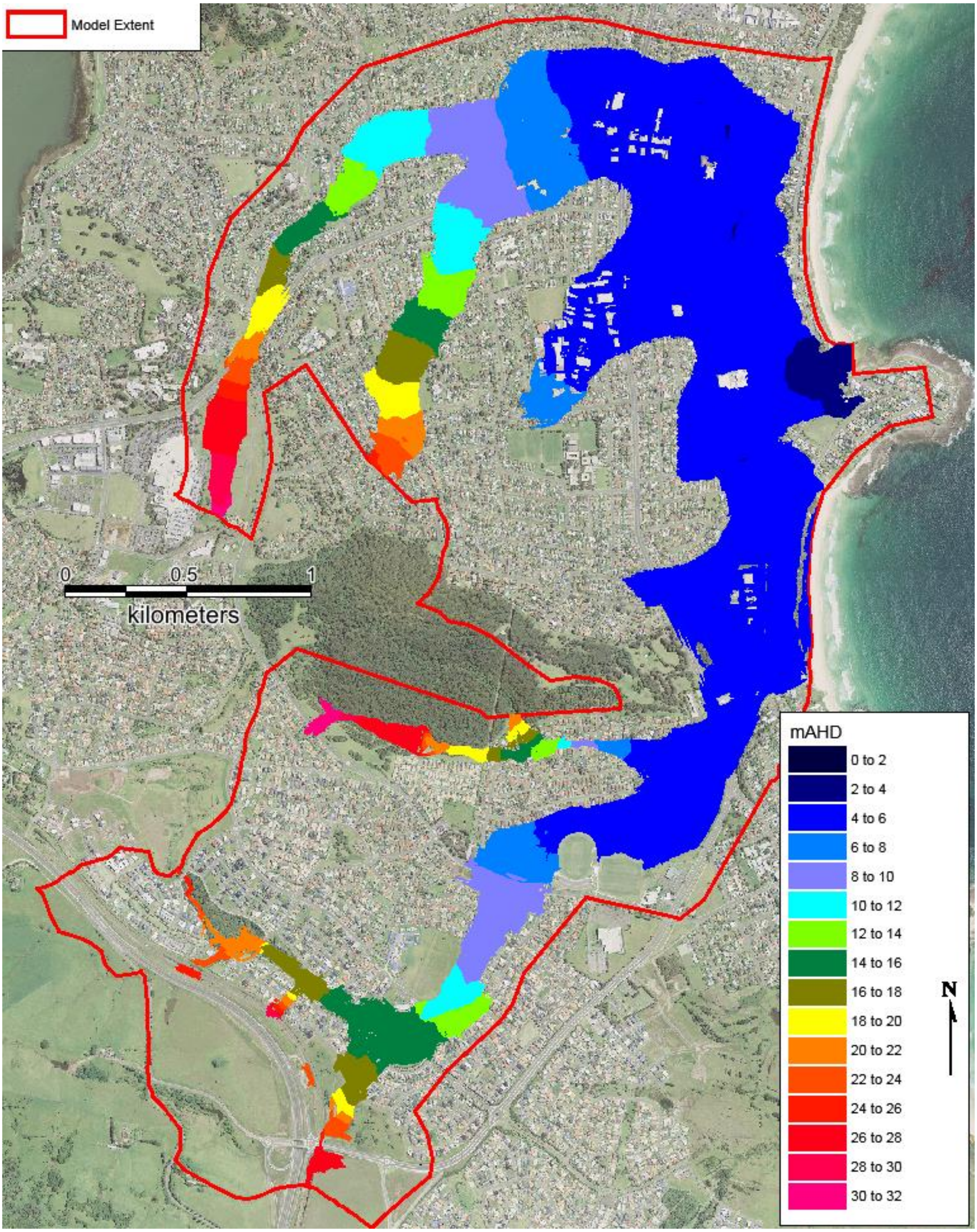

Figure F-32 Peak Flood Water Surface Elevation for Existing Conditions – PMF

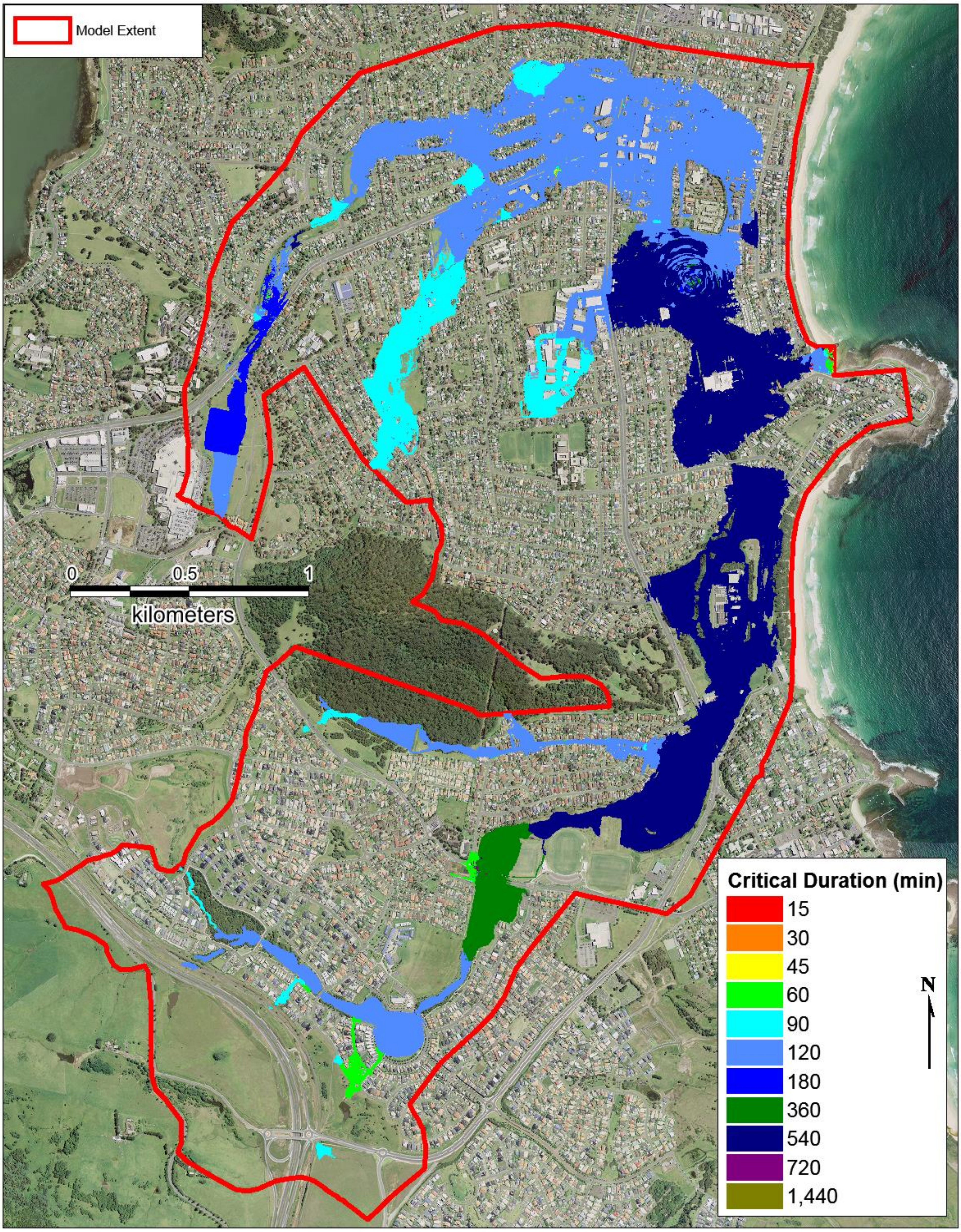

Figure F-33 Critical Duration for the 1% AEP Event for Existing Conditions -

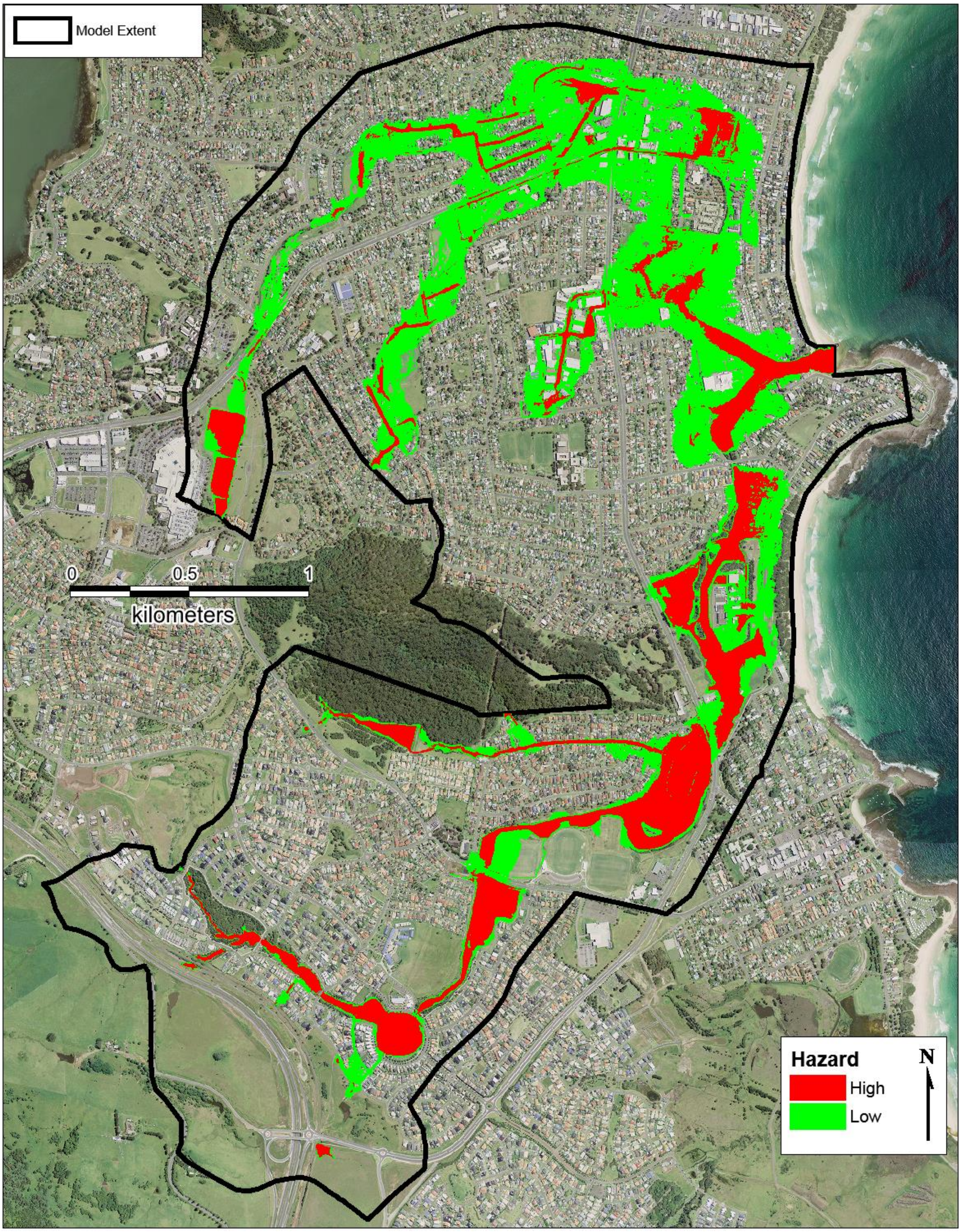

Figure F-34 Provisional Hazard for Existing Conditions – 1% AEP

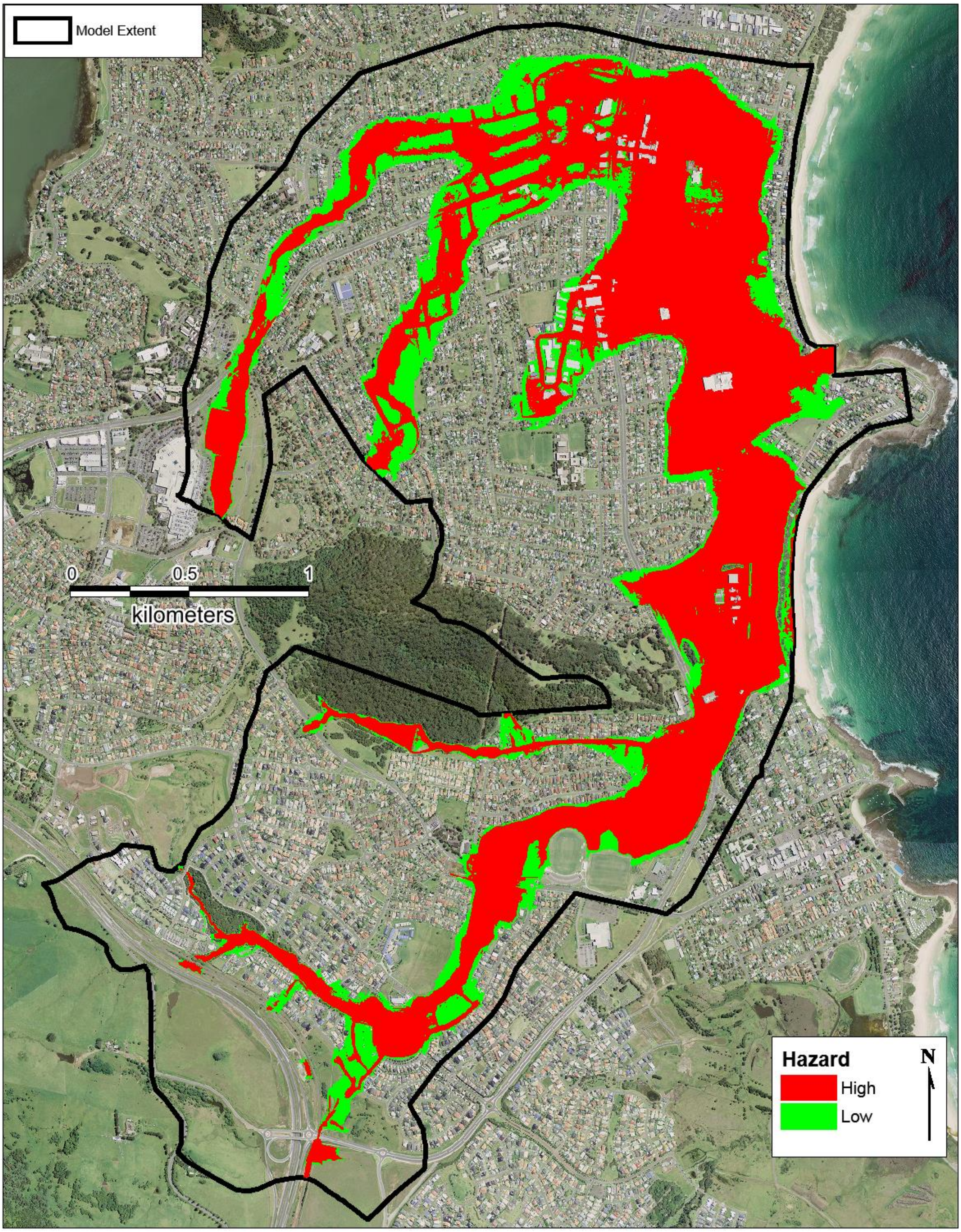

Figure F-35 Provisional Hazard for Existing Conditions – PMF

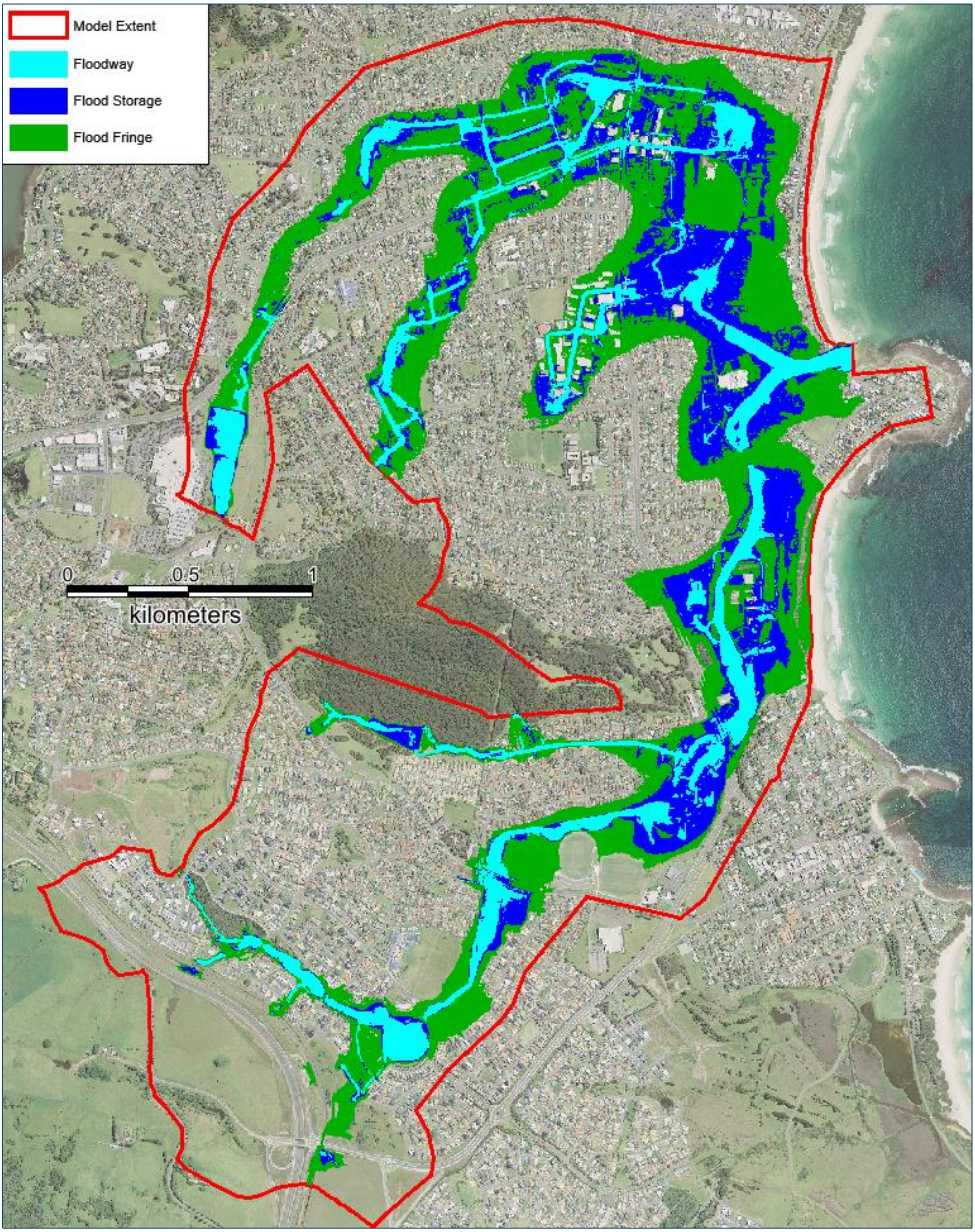

Figure F-36 Hydraulic Categories for Existing Conditions

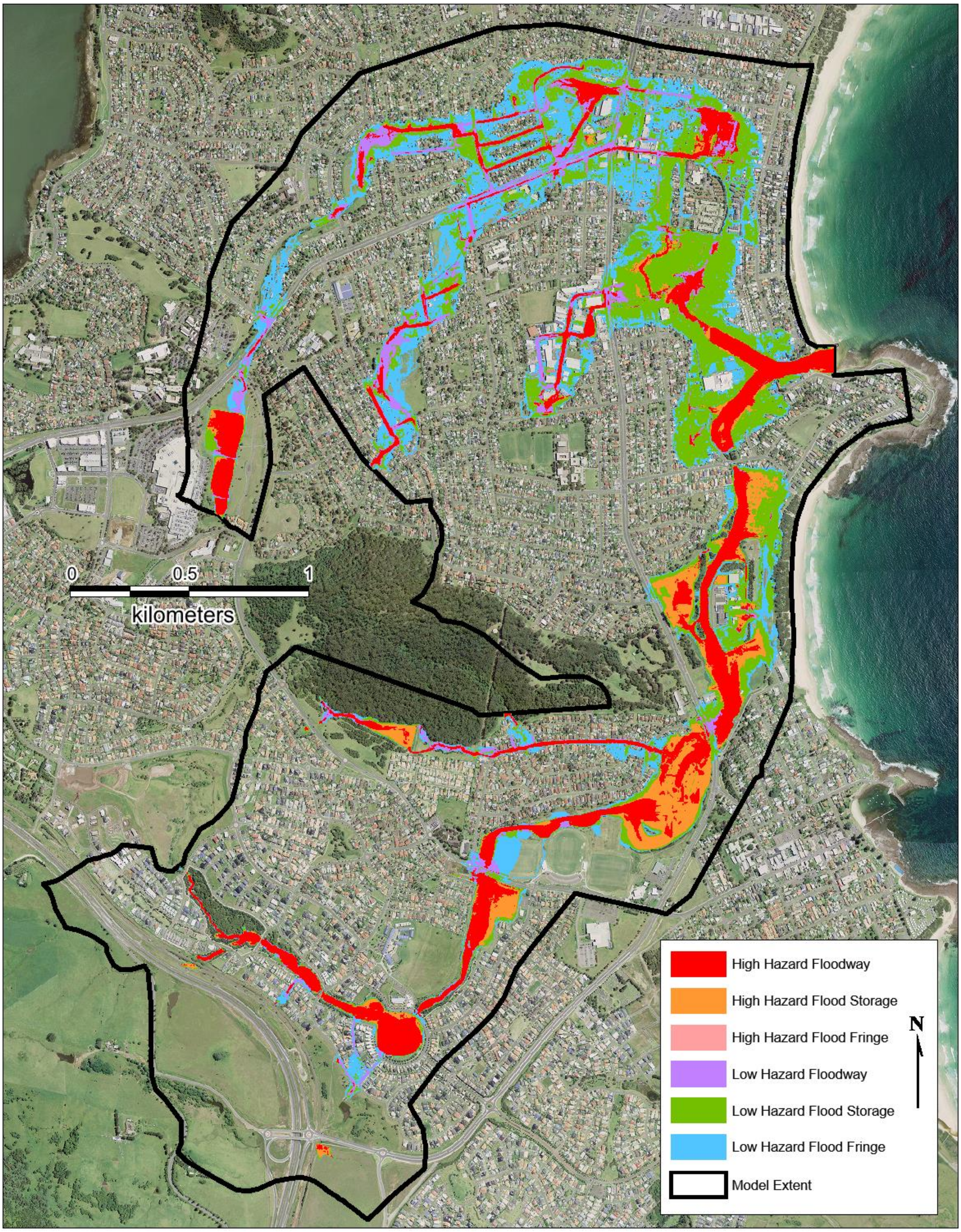

Figure F-37 Combined Provisional Hazard and Hydraulic Categories for Existing Conditions