EUROBODALLA SHIRE COUNCIL

WAGONGA INLET, KIANGA AND DALMENY FLOOD STUDY

FINAL DRAFT REPORT

FEBRUARY 2016

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Project WAGONGA INLET, KIANGA AND DALMENY FLOOD STUDY	**Project Number** 112034
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1	Draft Flood Study – Public Exhibition	ESC, OEH	September 2013

**WAGONGA INLET, KIANGA AND DALMENY
FLOOD STUDY**

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LIST OF ABBREVIATIONS

1D	One (1) Dimensional
2D	Two (2) Dimensional
ALS	Airborne Laser Scanning
DEM	Digital Elevation Model
ICOLL	Intermittently Closed and Open Lake or Lagoon
IFD	Intensity-Frequency-Duration
LiDAR	Airborne Light Detection and Ranging Survey
NPWS	National Parks and Wildlife Services
TIN	Triangular Irregular Network
UTC	Coordinated Universal Time

FOREWORD

The NSW Government's Flood Prone Land Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The NSW Government provides technical and financial assistance to Councils in the discharge of their floodplain management responsibilities.

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

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

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

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

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

This document forms the first stage of the floodplain risk management process, i.e. the Flood Study. The Flood Study is based upon data relevant at the date of commencement (2012). At the commencement of subsequent stages of the floodplain risk management process, the data is updated to include changes that have occurred within the catchments over the interim period.

EXECUTIVE SUMMARY

BACKGROUND

The Flood Study includes four catchments; the Wagonga Inlet, Kianga Lake, “Duck Pond” and Mummuga Lake Catchments. Wagonga Inlet is a trained entrance estuary with the township of Narooma located within the catchment. The Kianga Lake, “Duck Pond” and Mummuga Lake Catchments are Intermittently Closed and Open Lakes and Lagoons (ICOLL’s). The township of Kianga is within Kianga Lake Catchment and the township of Dalmeny is within the Mummuga Lake and “Duck Pond” Catchments.

OBJECTIVES

The purpose of this Flood Study is to define the flood behaviour under existing catchment conditions (at the commencement of the study), through the development of a suite of hydrologic and hydraulic models that can also be used as the basis for a future Floodplain Risk Management Study and Plan for the study area, and to assist Eurobodalla Shire Council (ESC) when undertaking flood-related planning decisions for existing and future developments.

The primary objectives of the study are:

- to determine the flood behaviour including design flood levels and velocities over a range of flooding events, from storm runoff in the catchment and from tidal influences;
- to determine provisional residential flood planning areas and flood planning levels;
- to undertake provisional flood emergency response planning classification of communities;
- to provide a model that can establish the effects of flood behaviour of future development; and
- to assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities and sea level rise.

FLOODING HISTORY

There have been a number of flood events known to have occurred within the catchments. Data suggests that the 2010 event was the largest rainfall event to have occurred in recent times, with a 100 year ARI estimate at Narooma. An event in 1999 had an estimate of between a 20 year and a 50 year ARI event at Narooma. The 2007 event had an estimate of between a 10 year and a 20 year ARI event at Narooma. And the 2014 event had an estimate less than or equal to a 1 year ARI event.

Photographs of flooding were available for the 2010 and 2014 events and survey data of flood levels were available for the 1999 and 2010 events. Water levels recorded within Barlows Bay were available for all the events investigated.

HYDROLOGIC AND HYDRAULIC MODELLING PROCESS

The hydrologic modelling was undertaken using WBNM and the hydraulic model was established using TUFLOW.

The design rainfall events that were modelled were the 20%, 10%, 5%, 1% and 0.5% AEP design events and the Probable Maximum Precipitation (PMP). The temporal patterns for the design events were sourced from Australian Rainfall and Runoff (AR&R) (Pilgrim, 1987) and the Intensity-Frequency-Duration (IFD) data was obtained from the Bureau of Meteorology's (BoM). The PMP estimates were derived according to the BoM guidelines, the *Generalised Short Duration Method* (BoM, 2003).

OUTCOMES

The flood study report details the results and findings of the investigations. The key elements include:

- a summary of available flood related data;
- establishment and validation of the hydrologic and hydraulic models;
- sensitivity analysis of the model results to variation of input parameters;
- the estimation of design flood behaviour for existing catchment conditions;
- preliminary hydraulic categories and provisional hazard mapping;
- preliminary residential flood planning areas and flood planning levels;
- flood emergency response classification of communities; and
- potential implications of climate change projections.

1. INTRODUCTION

1.1. Background

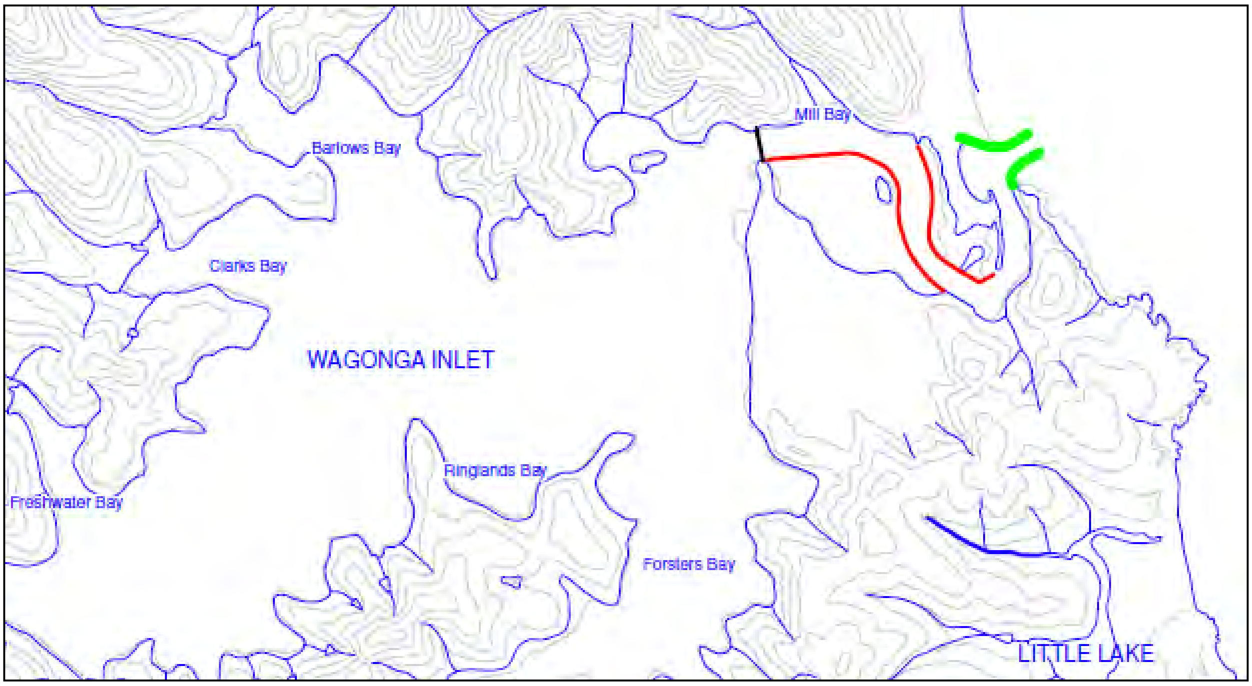
This flood study has been prepared on behalf of Eurobodalla Shire Council (ESC), on the South Coast of New South Wales. It includes four catchments; the Wagonga Inlet, Kianga Lake, "Duck Pond" and Mummuga Lake Catchments, shown in Figure 1. Within this report, the latter two catchments are identified as the Dalmeny Catchments.

The Wagonga Inlet catchment has an approximate catchment area of 100 square kilometres, the majority of which are within the Eurobodalla National Park. The catchment has three main tributaries discharging into the inlet, namely the Bilba Bilba Creek, the Burrimbidgee Creek and the Punkally Creek. The commercial areas of the township of Narooma are located within this catchment on low lying land that is locally known as "The Flat" with an average elevation of 2 m AHD or less.

The estuary area itself has been reported as being 6.9 square kilometres (Reference 20) and is a wave dominated estuary (Reference 22). It includes two breakwaters and twin training walls within the estuary channel. These are shown in Diagram 1, with green representing the breakwaters and red representing the training walls.

The Inlet itself is within the Batemans Marine Park, with varying classification zones. The Habitat Protection Zone includes Wagonga Inlet and Black Bream Point (near Clarks Bay). The Sanctuary Zone includes Forsters Bay, Punkalla Creek and Clarks Bay. The Special Purpose Zones are located at Forsters Bay and Mill Bay.

Diagram 1: Wagonga Inlet Entrance Conditions



The Kianga Lake and Dalmeny catchments are intermittently closed and open lakes and lagoons (ICOLL's). The Kianga Lake catchment is located north of the Wagonga Inlet catchment and south of the Dalmeny catchments. The management of these ICOLL's (and the policies that govern artificial opening of the entrances) differ between the catchments. The Kianga Lake entrance is managed by ESC and the Mummuga Lake entrance is managed by the National Parks and Wildlife Services. The Duck Pond entrance is under the management of ESC, however no formal policy exists for the artificial opening of this entrance and as discussed below, the ICOLL entrance at Duck Pond does not form the predominant hydraulic control for this catchment.

The Kianga Lake catchment has an area of approximately 8 square kilometres. Within this area, Eurobodalla National Park accounts for the majority of the area. The main creek that discharges into Kianga Lake is Kianga Creek. The lake itself is within the Batemans Marine Park and is classified as a Sanctuary Zone. The urban area of this catchment, namely the township of Kianga, is located on the southern shoreline.

The Dalmeny catchments (Duck Pond and Mummuga Lake) include the township of Dalmeny.

The Duck Pond entrance is not identified on the OEH online estuary summary that details physical characteristics (such as ICOLL status) due to its relatively small size, however the features of the entrance indicate that it is an ICOLL, as discussed in Section 7.4. The catchment has an area of approximately 0.5 square kilometres. The majority of this area is highly urbanised including part of the township of Dalmeny. Dalmeny Drive crosses the downstream area of this catchment, located upstream of the sand berm and downstream of the lake. The Dalmeny Drive roadway and culvert are man-made structures which act as a hydraulic control structure. Flow that exceeds the capacity of the culvert accumulates upstream of the roadway and flood levels rise until the flood level exceeds the height of the roadway, between approximately 3.5 and 4 m AHD.

The Mummuga Lake catchment has an area of approximately 28 square kilometres. Of this, the majority of the catchment area is within the Eurobodalla National Park. The catchment contains two main creeks that discharge into Mummuga Lake, namely Lawlers Creek and Spring Creek. The lake itself is within the Batemans Marine Park and is classified as a Habitat Protection Zone. Only a relatively small portion of the catchment is urbanised. This is located on the southern shoreline and includes part of the township of Dalmeny.

The study areas are shown on Figure 1.

1.2. Objectives

The purpose of this Flood Study is to define the flood behaviour under existing catchment conditions (at the commencement of the study), through the development of a suite of hydrologic and hydraulic models that can also be used as the basis for a future Floodplain Risk Management Study and Plan for the study area, and to assist Eurobodalla Shire Council (ESC) when undertaking flood-related planning decisions for existing and future developments.

The study includes the assessment of the 20%, 10%, 2%, 1% and 0.5% AEP design events and the Probable Maximum Flood (PMF). The primary objectives of the study are:

- to determine the flood behaviour including design flood levels and velocities over a range of flooding events, from storm runoff in the catchment and from tidal influences;
- to determine provisional residential flood planning areas and flood planning levels;
- to undertake provisional flood emergency response planning classification of communities;
- to provide a model that can establish the effects of flood behaviour of future development; and
- to assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities and sea level rise.

The flood study report will detail the results and findings of the Flood Study investigations. The key elements include:

- a summary of available flood related data;
- establishment and validation of the hydrologic and hydraulic models;
- sensitivity analysis of the model results to variation of input parameters;
- the estimation of design flood behaviour for existing catchment conditions;
- preliminary hydraulic categories and provisional hazard mapping;
- preliminary residential flood planning areas and flood planning levels;
- flood emergency response classification of communities; and
- potential implications of climate change projections.

A glossary of flood related terms is provided in Appendix A.

2. AVAILABLE DATA

The data utilised in this study has been sourced from a variety of organisations or references. The table in Appendix B lists the data supplied to the study and the date this data was received or made available.

2.1. Topographic Data

The catchment topography was defined by Airborne Light Detection and Ranging (LiDAR) survey, bathymetric survey and topographic contours. From the combined LiDAR and bathymetric survey, a Triangular Irregular Network (TIN) was generated. This TIN was sampled at a regular spacing of 5 m by 5 m to create a Digital Elevation Model (DEM), discussed in Section 6.3, which formed the basis of the two-dimensional hydraulic modelling for the study (shown in Figure 3). Topographic data extents are shown on Figure 2.

2.1.1. LiDAR Survey

LiDAR survey of the catchment and its immediate surroundings was provided for the study by Eurobodalla Shire Council. The LiDAR collected in 2005 was undertaken by AAM Hatch. Subsequent to the commencement of this study, additional LiDAR survey became available, having been collected by the NSW Department of Lands in 2012.

LiDAR data typically have accuracy in the order of:

- +/- 0.15m in the vertical direction (to one standard deviation); and
- +/- 0.25m in the horizontal direction (to one standard deviation).

The accuracy of the LiDAR data can be influenced by the presence of open water or vegetation (tree or shrub canopy) at the time of the survey. Within the areas of open water (in this case Wagonga Inlet, Kianga Lake and Mummuga Lake) the bathymetric survey was utilised, refer to Section 2.1.2.

2.1.2. Bathymetric Survey

The bathymetric survey for the Wagonga Inlet was obtained from the Office of Environment and Heritage (OEH) website. The website indicated that the data was collected in May 1997. The data extended from approximately 400 m offshore of the breakwater walls at Wagonga Head up to Burrimbidgee Creek. It included Forsters Bay, Ringlands Bay, Clarks Bay and Barlows Bay.

The bathymetric survey for Kianga Lake was obtained from Eurobodalla Shire Council. The accompanying documents indicated that the data was collected in August 2002. The data extended from the shoreline up to the sewage treatment plant located on Lakeside Drive.

The bathymetric survey for Mummuga Lake was collected by OEH in April 2013. It extended from approximately 5 km offshore up into the basin of the lake.

2.1.3. Topographic Contours

Contours of ground level were provided for the study by Eurobodalla Shire Council. East of Clarks Bay, these contours were at 2 m elevation intervals. The remaining area consisted of contours at 10 m elevation intervals.

In areas where LiDAR data was not available, these contours were used to inform the hydrologic sub-catchment delineation. This data was not used to generate the DEM employed in the hydraulic model, as the LiDAR data covered the model domain.

2.2. Pit and Pipe Data

Eurobodalla Shire Council provided an asset database that included pit and pipe data for the stormwater network, the sewage network and the potable water network. The stormwater network was included in the hydraulic modelling process.

The stormwater pipe data detailed the dimensions of the ESC-owned structures across the study areas. The ground level and invert level of the upstream and downstream end of the pipes were also provided within the Wagonga Inlet catchment. For the most part, this correlated with the pit invert levels supplied within the stormwater pit data, with the stormwater pit inverts given precedence. Within the Dalmeny and Kianga catchments, the stormwater pit inverts were assumed to be the pipe diameter plus 0.5 m below the LiDAR, as details did not exist in the Council database.

2.3. Spot Water Level Data

Eurobodalla Shire Council undertook a spot water level survey of Duck Pond in June 2012. Although the survey was not for the purpose of this Flood Study, the data was provided for additional use in the study.

The water level recorded within Duck Pond at 11:00 am on the 27th June 2012 was 2.14 m AHD.

2.4. Historic Water Level Data (Continuous)

There are two water level recorders within Wagonga Inlet that were active during events known to have resulted in flooding within the catchment. These are operated by Manly Hydraulics Laboratory (MHL) and are located at Barlows Bay and Narooma Public Wharf, the latter of which has since been decommissioned. These water level stations are summarised in Table 1 and shown in Figure 4.

Table 1: Water Level Stations Operated by MHL within the Wagonga Inlet Catchment

Station Number	Station Name	Operating Authority	Date Opened	Date Closed
218415	Barlows Bay	MHL	30/08/1996	-
218420	Narooma Public Wharf	MHL	30/08/1996	20/08/2008

The water level data supplied was reported as having an accuracy range in the order of +/- 0.02 m. The data provided by these water level stations was correlated with the pluviometer data, discussed in Section 2.7.2 and shown in Figure E 6, Figure E 11 and Figure E 16.

As part of the Wagonga Estuary Tidal Behaviour Study Report MHL499, four water level stations were established for a short duration. The dates of operation of these stations did not coincide with any known flood event. The details of these stations are summarised in Table 2.

Table 2: Water Level Stations Operated by MHL for the Wagonga Estuary Tidal Behaviour Study

Station Number	Station Name	Operating Authority	Date Opened	Date Closed
N/A	Narooma Apex Park Boat Ramp	MHL	26/11/1986	06/01/1987
N/A	Narooma M.S.B. Jetty	MHL	12/11/1986	06/01/1987
N/A	Narooma Old Municipal Wharf	MHL	12/11/1986	25/03/1987
N/A	Narooma Princes Highway Bridge	MHL	13/01/1987	05/03/1987

There are no other publicly available water level records for the Kianga and Dalmeny catchments.

2.5. Historic Ocean Tide Data (Continuous)

Ocean tide levels were obtained from the National Tidal Centre (NTC), operating within the Bureau of Meteorology, and from the Manly Hydraulics Laboratory (MHL). The tide stations closest to the study area from each of the databases are provided in Table 3.

Table 3: Ocean Tide Level Stations

Station Number	Station Name	Operating Authority	Distance from Wagonga Breakwaters (km)	Date Opened	Date Closed
219470	Bermagui	MHL	22.5	29/07/1987	-
216471	Ulladulla Harbour	MHL	91.9	6/12/2007	-
	Port Kembla	NTC	190.3	01/07/1991	-

The NTC operate sea level monitoring stations across Australia, with only one on the NSW coastline (i.e. the Port Kembla station). This data was provided in hourly increments in Coordinated Universal Time (UTC). The vertical datum of the data was Lowest Astronomical Tide (LAT), which the metadata advised as being 0.872 m below Australian Height Datum (AHD).

MHL operates the Bermagui and Ulladulla Harbour stations and data was provided in 15 minute increments in Australian Eastern Standard Time (AEST). The vertical datum of the Ulladulla Harbour data was AHD and the Bermagui data was in Bermagui Local Hydro Datum (BLHD). Advice obtained from MHL indicated that the BLHD is 0.714 m below AHD.

The Port Kembla and Ulladulla Harbour ocean level stations are located north of the catchment and Bermagui is located to the south. It was found that there was a marginal difference in peak ocean levels recorded, generally in the order of 0.1 m. The typical trend was that the further north the station was located, the higher the peak ocean level. This is shown in Diagram 2 for the 2008 no-rainfall period used for calibration discussed in Section 8.

During periods where rainfall was known to have occurred, the Bermagui station appears to be influenced by freshwater inflows as well as ocean levels. This is shown in Diagram 3 for the 2010 storm event used for calibration, whereby the increased Bermagui levels coincided with the elevated water levels recorded at Barlows Bay.

Due to the short period of record at the Ulladulla Harbour station and the freshwater influence on the Bermagui station, neither could be used as the downstream boundary condition for the calibration and validation events. The Port Kembla tide station was applied, as discussed in Section 8.4.

Diagram 2: Ocean Tide Station Comparison – 2008 (no-rainfall)

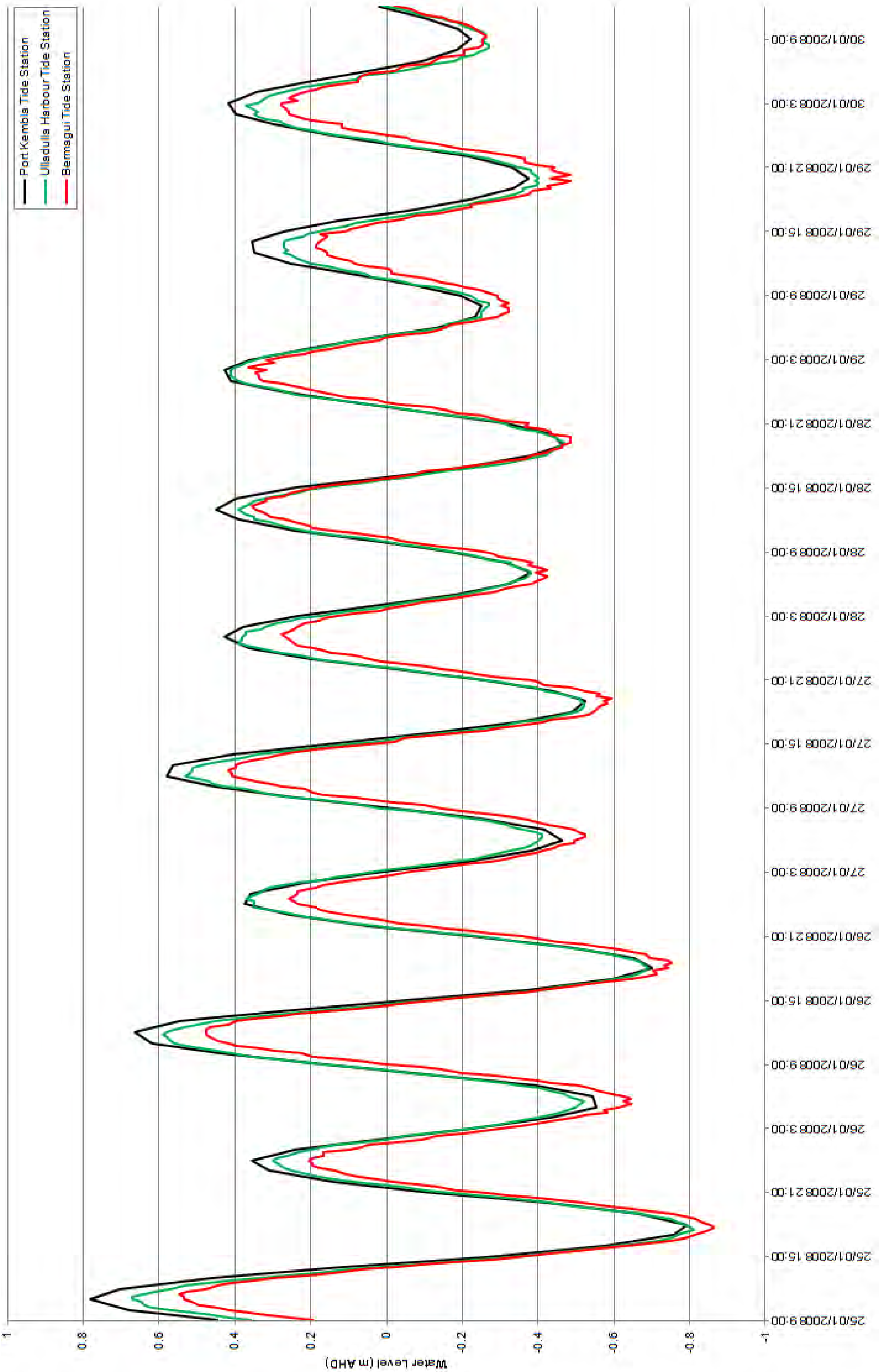
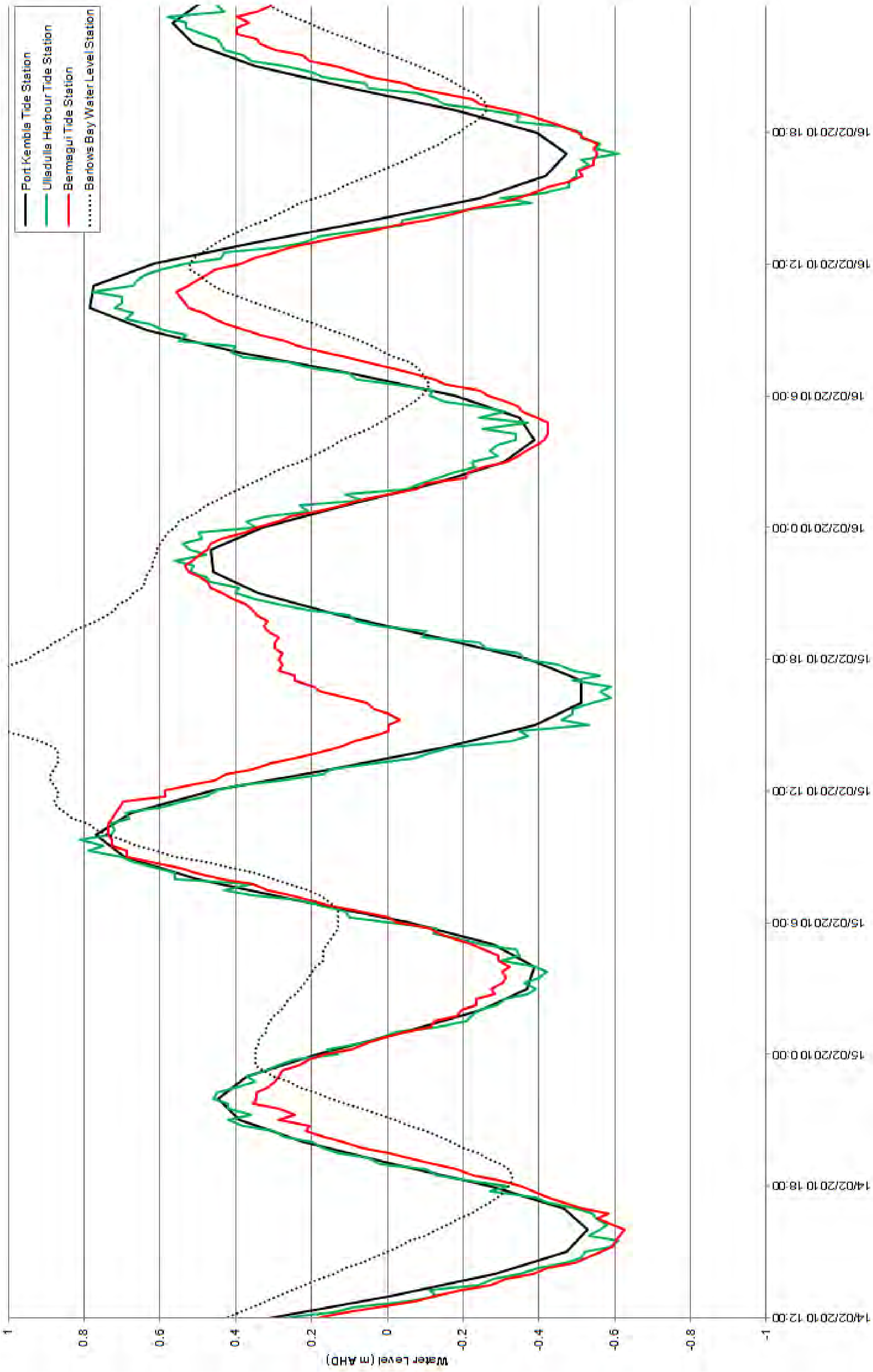


Diagram 3: Ocean Tide Station Comparison – 2010 storm event



2.6. NSW Tidal Planes Analysis

Manly Hydraulics Laboratory prepared the *NSW Tidal Planes Analysis: 1990-2010 Harmonic Analysis* report on behalf of the NSW Office of Environment and Heritage. It was released in October 2012 and was based on data from 188 tidal monitoring stations from the 1st July 1990 to the 30th June 2010. Data from the relevant stations are shown in Table 4.

Table 4: Tidal Planes Analysis Results (MHL, 2012)

Tidal Planes	Annual Average Amplitude (m AHD)			
	Ocean Tide Gauge – Ulladulla Harbour (216471)	Ocean Tide Gauge – Bermagui (219470)	Station Locations Wagonga Inlet – Narooma Wharf (218420)	Station Locations Wagonga Inlet – Barlows Bay (218415)
High High Water Solstices Springs (HHWSS)	0.960	0.865	0.667	0.640
Mean High Water Springs (MHWS)	0.617	0.528	0.399	0.376
Mean High Water (MHW)	0.510	0.425	0.325	0.324
Mean High Water Neaps (MHWN)	0.403	0.322	0.251	0.272
Mean Sea Level (MSL)	0.040	-0.027	-0.026	0.040
Mean Low Water Neaps (MLWN)	-0.325	-0.376	-0.304	-0.192
Mean Low Water (MLW)	-0.431	-0.479	-0.378	-0.245
Mean Low Water Springs (MLWS)	-0.538	-0.581	-0.452	-0.297
Indian Spring Low Water (ISLW)	-0.783	-0.822	-0.643	-0.485

2.7. Historic Rainfall Data

There are a number of rainfall stations within a 50km radius of the study area. This includes daily read stations, continuous pluviometer stations, operational stations and synoptic stations.

The daily read stations record total rainfall for the 24 hours to 9am of the day being recorded. Hence the rainfall received for the period between 9:00am 28th January to 9:00am 29th January 1999 would be recorded on the 29th January 1999.

The continuous pluviometer stations record rainfall in sub-daily increments. These records are typically used to create the rainfall temporal distribution used to model the historical events, against which the hydrologic and hydraulic models are calibrated.

The operational stations can be continuous or a combination of daily read with sub-daily records during flooding events. These stations are used for flood warning services.

The synoptic stations record rainfall at particular synoptic hours. Primary synoptic hours occur every six hours, beginning at 00:00 UNC. Additionally, synoptic stations also record rainfall at 9am. As such, synoptic stations typically record rainfall at 6am, 9am, 12pm, and 3pm.

Table 5 presents a summary of the official rainfall gauges located close to or within the catchment. These gauges are operated either by the Bureau of Meteorology (BOM), the Department of Natural Resources (DNR) (abolished in 2007; information now held by the Office of Environment and Heritage), the Manly Hydraulics Laboratory (MHL) and Eurobodalla Shire Council (ESC). Figure 4 shows the locations of these stations.

Table 5: Rainfall Stations within 50km of the centre of Wagonga Inlet Catchment

Station Number	Station Name	Operating Authority	Distance from centre of catchment (km)	Elevation (m AHD)	Date Opened	Date Closed	Type
218415	BarlowsBay	MHL	5.0	*	14/08/1999	-	Continuous
69149	Central Tilba (Braeside)	BOM (AUS)	6.2	85	23/04/2003	-	Daily
*	Narooma	ESC	7.1	*	26/12/1998	-	Continuous
69022	Narooma Rvcp	BOM (AUS)	8.0	25	1/01/1910	-	Daily
69022	Narooma Rvcp	BOM (AUS)	8.0	25	1/01/1910	-	Synoptic
69007	Bodalla State Forest	BOM (AUS)	9.0	12.2	29/06/1936	29/12/1961	Daily
69076	Dignams Ck	BOM (AUS)	9.1	*	30/01/1912	29/12/1929	Daily
69028	Tilba Tilba	BOM (AUS)	9.1	15.2	30/03/1901	29/12/1962	Daily
69131	Dalmeny (Mummuga Way)	BOM (AUS)	9.2	35	1/01/1983	18/09/2009	Daily
69039	Mountain Valley	BOM (AUS)	10.8	25	30/03/1955	12/04/2003	Daily
218008	Tuross R at Eurobodalla	DNR (NSW)	11.3	*	13/10/1998	-	Continuous
69103	Tyrone	BOM (AUS)	12.1	91.4	29/04/1970	29/12/1974	Daily
69034	Tilba Tilba 2	BOM (AUS)	13.8	*	1/01/1952	1/01/1955	Daily
69036	Bodalla Post Office	BOM (AUS)	14.2	42	01/01/1876	-	Daily
69036	Bodalla Post Office	BOM (AUS)	14.2	42	01/01/1876	-	Synoptic
69036	Bodalla Post Office	BOMNS (NSW)	14.2	42	29/06/1995	-	Operational
69044	Wattlegrove	BOM (AUS)	16.0	*	30/07/1961	29/12/1962	Daily
69017	Montague Island Lighthouse	BOM (AUS)	17.2	52	1/01/1949	5/04/1998	Daily
69017	Montague Island Lighthouse	BOM (AUS)	17.2	52	1/01/1949	-	Synoptic
69067	Tuross Head (Nelson Pde)	BOM (AUS)	18.0	20	29/10/2001	-	Daily
*	Tuross	ESC	18.5	*	30/01/1994	-	Continuous
69059	Nerrigundah	BOM (AUS)	19.3	*	29/04/1900	29/12/1966	Daily
69005	Bermagui South (Young Street)	BOM (AUS)	19.9	15	30/10/1924	-	Daily
69087	Coolagolite (Lyrebird Ridge Rd)	BOM (AUS)	21.1	25	1/01/2001	-	Daily
69050	Cobargo (Wandella)	BOM (AUS)	22.4	135	30/03/1965	-	Daily
69014	Cobargo Post Office	BOM (AUS)	23.1	85	30/10/1887	-	Daily
69064	Wee-Bah	BOM (AUS)	28.4	137.2	29/04/1962	29/12/1970	Daily
218005	Tuross R D/S Wadbilliga R Junction	DNR (NSW)	29.7	*	1/01/1988	30/07/1998	Continuous
69111	Quaama (Merrydale)	BOM (AUS)	29.8	160	29/09/1971	-	Daily

69142	Moruya (Kiora)	BOM (AUS)	30.6	20	1/01/1993	-	Daily
69038	Moruya Bowling Club	BOM (AUS)	31.3	6.1	30/10/1886	29/12/1966	Daily
*	Moruya	ESC	31.7	*	*	-	Continuous
69145	Moruya (Plumwood)	BOMNS (NSW)	31.9	930	11/11/1999	-	Operational
69112	Verona (Cobbobra)	BOM (AUS)	33.4	223	28/02/1972	-	Daily
69018	Moruya Heads Pilot Stn	BOM (AUS)	33.4	17	30/05/1875	-	Daily
69018	Moruya Heads Pilot Stn	BOM (AUS)	33.4	17	30/05/1875	-	Synoptic
69075	Yowrie	BOM (AUS)	33.5	210	30/10/1903	28/09/1988	Daily
69075	Yowrie	BOM (AUS)	33.5	210	30/08/1973	28/09/1988	Continuous
69148	Moruya Airport AWS	BOM (AUS)	34.0	4	27/09/1999	-	Continuous
69148	Moruya Airport AWS	BOM (AUS)	34.0	4	27/09/1999	-	Synoptic
69033	Moruya (Burra Ck)	BOMNS (NSW)	34.2	20	2/04/2001	-	Operational
69037	Belowra Stn	BOM (AUS)	34.7	113	1/01/1938	-	Daily
569035	Belowra (Alert)	BOMNS (NSW)	35.2	150	15/12/2004	-	Operational
69051	Upper Brogo (Upper Brogo Rd)	BOM (AUS)	37.1	150	29/06/1962	-	Daily
69082	Verona	BOM (AUS)	37.3	*	30/01/1906	29/12/1928	Daily
69032	Wapengo Lake Rd	BOM (AUS)	37.7	15	29/11/1926	-	Daily
69068	Wapengo (Hunters Rd)	BOM (AUS)	37.9	20	25/04/2002	-	Daily
219007	Brogo R at Brogo	DNR (NSW)	38.7	*	31/05/1974	31/07/1992	Continuous
69114	Brogo Bridge House	BOM (AUS)	38.8	61	30/05/1974	-	Daily
69086	Tanja	BOM (AUS)	38.9	*	29/09/1903	29/12/1916	Daily
569020	Bendethera	BOMNS (NSW)	40.3	300	5/08/1999	-	Operational
69043	Deua R Farm	BOM (AUS)	40.3	76.2	30/01/1971	29/12/1976	Daily
219027	Brogo R at Brogo Dam (Storage)	DNR (NSW)	40.6	*	30/06/1970	-	Continuous
69140	Brogo Dam	BOM (AUS)	41.1	115	28/02/1992	-	Daily
69063	Wadbilliga	BOM (AUS)	41.5	250	29/04/1962	29/12/1995	Daily
219025	Brogo R at Angledale	DNR (NSW)	42.8	*	4/08/1999	-	Continuous
69104	Stockridge	BOM (AUS)	43.3	183	29/06/1970	29/12/1978	Daily
69098	Bevian Park	BOM (AUS)	44.3	15.2	1/01/1968	1/01/1973	Daily
69053	Burrewarra North	BOM (AUS)	44.3	*	30/05/1962	29/12/1967	Daily
69065	Brogo (Hawks Head Rd)	BOM (AUS)	45.6	265	29/04/1962	-	Daily
*	Deep Creek	ESC	48.7	*	*	-	Continuous
*	Batemans Bay	ESC	52.0	*	*	-	Continuous
69054	Tuross	BOM (AUS)	55.1	970	27/02/1946	-	Daily

* Data Not Available

2.7.1. Analysis of Daily Read Data

An analysis of the daily records for the nearest daily rainfall stations was undertaken to identify and provide some context for past storm events. One daily rainfall gauge is located within the Wagonga Inlet catchment and two are located within the Dalmeny catchment. No rainfall gauges have been established in the Kianga catchment.

Table 6: Highest 20 Daily Rainfalls at (A) Narooma – Marine Rescue and (B) Dalmeny – Mummuga Way

Narooma (Marine Rescue) (69022)			
Jan 1910 – to date			
Rank	Date	Rainfall (mm)	Period over which rainfall was measured (days)
1	26/09/1992	362	1
2	29/01/1999	242	1
3	14/06/1966	215	2
4	8/01/1934	205	1
5	6/12/1992	203	1
6	10/03/1993	195	1
7	9/09/1978	187	2
8	14/01/1911	168	1
9	16/02/2010	162	1
10	6/02/1971	157	1
11	5/05/1953	153	1
12	15/02/2010	152	1
13	5/11/1973	150	1
14	30/10/1959	149	1
15	7/02/1971	147	1
16	30/01/1958	145	1
17	16/03/1979	142	3
18	11/02/2007	139	1
19	26/01/1911	138	1
20	15/10/1976	134	2

Dalmeny (Mummuga Way) (69131)			
Jan 1983 – August 2009			
Rank	Date	Rainfall (mm)	Period over which rainfall was measured (days)
1	29/01/1999	276	1
2	12/03/1993	210	4
3	11/02/2007	178	1
4	26/09/1992	171	2
5	13/06/1991	161	2
6	1/04/1989	140	1
7	24/05/2006	133	1
8	21/03/1983	129	1
9	11/02/1992	127	1
10	11/12/1992	126	6
11	28/06/1997	119	1
12	25/10/1999	116	1
13	20/06/1984	103	2
14	29/04/1988	101	1
15	8/11/1989	98	8
16	26/04/1990	98	7
17	1/09/1996	96	1
18	20/03/1989	95	7
19	8/08/1998	93	1
20	24/03/1984	92	1

The Narooma Marine Rescue (69022) gauge is the only daily read station that is within the Wagonga Inlet catchment. It has been in operation since 1910. The highest daily totals recorded at this gauge are shown in Table 6(A). The January 1999 event (ranked second) and February 2010 (ranked ninth and twelfth) correlate with storms that were known to have caused flooding in the catchment areas. The February 2007 event was ranked eighteenth and third and the October 2014 event had a ranking lower than 20 with a rainfall depth of 127 mm at the Narooma (69022) gauge.

Within the Dalmeny catchment, two gauges have been shown to be present; the Dalmeny (69131) gauge and the Bodalla State Forest (69007) gauge. The Bodalla State Forest gauge was decommissioned in 1961 and so could not provide data relevant to known flood events, the earliest of which was recorded in 1974 (discussed in Section 2.9.1.2). The Dalmeny station was established in 1983; however was decommissioned in 2009 thereby omitting the February 2010 and October 2014 events. For the available period of record at the Dalmeny station, the January 1999 event ranked first. The highest daily totals recorded at the Dalmeny gauge are shown in Table 6(B).

Within the surrounding area are gauges at Central Tilba (69149), Dignams Creek (69076) and Tilba Tilba (69028). The Dignams Creek and Tilba Tilba stations were not analysed because they were decommissioned in 1929 and 1962, respectively. The Central Tilba (69149) gauge is closest to the Wagonga Inlet catchment centre; however it is outside the catchment area and possibly subject to orographic rainfall as a result of Mt Dromedary. The Central Tilba station was established in 2003, thereby omitting the January 1999 event. For the duration of record at the Central Tilba station, the February 2010 event ranked first and second for daily totals, the February 2007 event was ranked fifth and the October 2014 event was ranked seventh and is shown in Table 7.

Table 7: Daily Rainfalls greater than 70mm at Central Tilba

Central Tilba (69149)		
Jan 2003 – to date		
Rank	**Date**	**Rainfall (mm)**
1	16/02/2010	276
2	15/02/2010	265
3	5/02/2010	143
4	20/04/2013	132
5	11/02/2007	127
6	26/03/2014	121
7	14/10/2014	118
8	6/02/2010	111
9	12/11/2013	108
10	26/08/2015	107
11	24/05/2006	98
12	7/12/2014	94
13	26/05/2010	93
14	31/10/2005	92
15	27/03/2014	86
16	12/10/2012	84
17	8/12/2004	84

However, high daily rainfall totals will not necessarily result in flooding of a catchment, particularly if the rainfall is fairly evenly distributed throughout the day with no particularly intense burst. An example is the March 2014 event for which no reports of flooding were received, having recorded a higher daily rainfall total than the October 2014 event for which flooding was reported.

2.7.2. Analysis of Pluviometer Data

Continuous pluviometer stations provide a more detailed description of temporal variations in rainfall. Within the Wagonga Inlet catchment area, there are two pluviometers; at Narooma and Barlows Bay. The Narooma pluviometer is operated by Eurobodalla Shire Council and was established in December 1998. The Barlows Bay pluviometer is operated by MHL and was established in August 1999. To the north of the study areas, there are two pluviometers within the Tuross region. One is operated by Eurobodalla Shire Council and the other by DNR (as discussed previously, this information now held by the Office of Environment and Heritage). The Council operated pluviometer at Tuross was established in January 1994. The DNR established pluviometer has been in operation since October 1998. For the four storm events that were known to have caused flooding, these four gauges have been compared in Table 8.

Table 8: Maximum Recorded Storm Depths at Pluviometers (in mm)

	Duration	Barlows Bay (218415) (MHL)	Narooma (ESC)	Tuross (218008) (DNR)	Tuross (ESC)
28th January 1999	30 minute	Not In Operation	28	14	0
	1 hour		40	23	0
	2 hour		68	40	0
	3 hour		88	43	0
	6 hour		114	79	0
	12 hour		131	91	0
10th - 11th February 2007	30 minute	26	47	18	19
	1 hour	36	50	24	27
	2 hour	41	52	32	38
	3 hour	49	54	38	43
	6 hour	88	68	68	81
	12 hour	88	82	68	86
14th -15th February 2010	30 minute	39	46	35	59
	1 hour	57	61	67	93
	2 hour	111	92	97	173
	3 hour	124	116	127	233
	6 hour	145	142	148	260
	12 hour	167	158	182	329
14th October 2014	30 minute	22	15	5	25
	1 hour	39	25	9	42
	2 hour	66	25	14	78
	3 hour	97	25	17	67
	6 hour	103	30	23	131
	12 hour	189	55	38	144

2.8. Design Rainfall Data

The design rainfall intensity-frequency-duration (IFD) data, for events up to and including the 1% AEP event, were obtained from the Bureau of Meteorology's online design rainfall tool. The input parameters for these calculations were sourced from AR&R (1987)

Table 9: Rainfall IFD Data at the Narooma rainfall gauge

DURATION	Design Rainfall Intensity (mm/hr)						
	1 yr ARI	2 yr ARI	5 yr ARI	10 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI
5 minutes	91.6	119	156	178	207	246	276
6 minutes	85.8	111	146	167	194	231	260
10 minutes	70.3	91.5	121	139	162	193	218
20 minutes	51.6	67.6	90.5	105	123	148	168
30 minutes	42.1	55.3	74.6	86.7	102	124	140
1 hour	28.5	37.6	51.2	59.9	71	86.1	98.1
2 hours	18.6	24.6	33.5	39.2	46.5	56.5	64.4
3 hours	14.4	18.9	25.8	30.1	35.6	43.3	49.3
6 hours	9.15	12	16.3	19	22.5	27.2	30.9
12 hours	5.87	7.72	10.4	12.1	14.3	17.3	19.7
24 hours	3.79	4.99	6.8	7.93	9.41	11.4	13
48 hours	2.39	3.17	4.38	5.14	6.14	7.5	8.58
72 hours	1.77	2.35	3.26	3.84	4.59	5.63	6.44

2.9. Previous Reports

2.9.1. Wagonga Inlet

There have been a number of previous reports related to Wagonga Inlet. These have been summarised in Table 10.

Table 10: Previous Reports

Document	Date
Wagonga Inlet Data Compilation Study	November 1997
Wagonga Inlet Flooding Investigation	April 2002
Wagonga Inlet Estuary Processes Study	April 2001
Wagonga Inlet Estuary Processes Study and Plan	November 2001

2.9.1.1. Wagonga Inlet Data Compilation Study (Webb, McKeown and Associates, 1997)

This report was prepared by Webb, McKeown and Associates on behalf of Eurobodalla Shire Council. The purpose of this study was to compile the data and reports that were existing at the time and based upon this prepare an issue assessment. The data from this report was referenced in the Estuary Processes Study and Estuary Management Study and Plan, discussed in Section 2.9.1.3 and Section 2.9.1.4, respectively.

2.9.1.2. Wagonga Inlet Flooding Investigation (Gary Blumberg and Associates, 2002)

This study was undertaken by Gary Blumberg and Associates on behalf of Eurobodalla Shire Council. The final document was released in April 2002, although a draft document was available from October 1999 (with the 1999 version referenced in the Estuary Processes Study and Estuary Management Study and Plan, discussed in Section 2.9.1.3 and Section 2.9.1.4).

The objective of this study was "not to develop a detailed hydrodynamic flood model for Wagonga Inlet, but rather to use desk-top methods, experience and sound engineering judgement ... to review Council's existing flood planning levels" (Gary Blumberg and Associates, 2002). For this, RAFTS was used for the hydrologic modelling.

The flooding analysis was separated into two models; Wagonga Inlet flooding, and stormwater flooding. The Wagonga Inlet hydrologic model covered the total catchment area of approximately 102 km^2. The hydrologic model developed for stormwater flooding was limited to the area known as Narooma Flat.

The study investigated the 25-28 May 1974 and the 28th January 1999 events. For the May 1974 event, a daily rainfall station at Narooma and a pluviometer called “The Badga” were the only available data. The pluviometer station was owned by the Bureau of Meteorology, who advised against utilising that pluviometer due to the 50 km distance from the catchment. It was concluded that the 1974 event should not be employed for calibration. For the January 1999 event, a Council operated pluviometer station at Narooma provided the appropriate data. From this it was estimated that the 1999 event was in the range of a 15 to 20 year ARI event. Flood data for the 1999 event was also available and collected. This consisted of surveyed flood marks based upon local observed flood levels (relevant for calibration of the Narooma Flat model), and water level stations within Wagonga Inlet (relevant for calibration of the Wagonga Inlet model).

The data for the Narooma Flat model is shown in Table 11 and the location of these flood levels is shown in Figure E 7. This information is useful for the calibration and validation of the models established as part of the current study.

Table 11: Survey of Flood Marks from Event of 28th January 1999 (Gary Blumberg and Associates, 2002)

ID Number	Street Address	Reduced Level (m AHD)
01	46 McMillan Road	1.28
02	19 Hyland Avenue	1.27
03	10 Lynch Street	1.26
04	12 Brice Street	1.26
05	14 Lynch Street	1.26
06	10 Brice Street	1.24
07	8 Nichelsen Street	1.28
08	7 Nichelsen Street	1.28
09	grass verge west side of Riverside Drive	1.3
10	intersection of Riverside Drive and McMillan Road	1.41
11	54 McMillan Road	1.29
12	"Hibiscus Court" Hyland Avenue	1.66
13	5 Hyland Avenue	1.63
14	4 Hyland Avenue	1.58
15	7 Hyland Avenue	1.67
16	9 Hyland Avenue	1.63
17	9 Hyland Avenue	1.57
18	13 Hyland Avenue	1.5
19	"Magnolia Park" McMillan Road	1.67
20	House under construction McMillan Road	1.68
21	32 McMillan Road	1.53
22	38 McMillan	1.5
23	"Milford Lodge" cnr McMillan Rd and Brice St	1.44
24	"Apollo Flats" McMillan Road	1.79
25	14 McMillan Road	1.89
26	12 McMillan Road	1.75
27	6 McMillan Road	1.79
28	"Olympic Lodge" Princes Highway	1.77
29	Caravan Park Princes Highway	1.82

There were two MHL operated water level stations used for calibration of the Wagonga Inlet model. One station is located at Narooma Public Wharf (218420) and another station is located in Barlows Bay (218415). The five highest water levels recorded at these stations are presented in Table 12.

Table 12: Highest Water Levels from DPWS Water Level Recorders in Wagonga Inlet (Gary Blumberg and Associates, 2002)

Recorder Location	Peak Water Level (m AHD)	Date	Time	Recurrence (years)
Narooma Public Wharf (218420)	1.03	26/06/1998	20:45	2.9
	0.97	24/06/1998	21:45	1.5
	0.86	07/08/1998	21:00	1.0
	0.86	15/05/1998	22:30	0.7
	0.83	25/06/1998	22:30	0.6
Barlows Bay (218415)	1.03	23/06/1998	21:00	2.9
	0.99	24/06/1998	22:15	1.5
	0.88	15/05/1999	22:00	1.0
	0.84	16/05/1999	22:45	0.7
	0.83	25/06/1998	22:45	0.6

The Flood Planning Levels (FPL) applicable at the time of this study were reported as 2.7 mAHD for residential development and 2.2 mAHD for commercial developments on Narooma Flat.

2.9.1.3. Wagonga Inlet Estuary Processes Study (MHL, 2001)

This study was carried out by MHL in 2001 and was jointly funded by Eurobodalla Shire Council and the Department of Land and Water Conservation. The report discussed the climate conditions, geology and geomorphology, soils, land and waterway usage and zoning, flora and fauna, hydrology and hydrodynamics, water and sediment quality, and sediment dynamics.

Within the hydrology and hydrodynamics section, catchment hydrology, water level variability, ocean entrance conditions, tidal flow model, and circulation and mixing within the Inlet is discussed. With the exception of extreme events, the January 1999 event given as an example, the freshwater inflows resulting from rainfall runoff was reported as being "...relatively small and hence have only a minor influence on the water levels in the inlet." (MHL, 2001)

Additionally, this report detailed the history of the entrance development. This is summarised in Table 13.

Table 13: History of Development at the Entrance (MHL, 2001)

Year	Action
1919 to 1920	Construction of two short training walls
1921 to 1922	Rock blanketing at outer end of eastern wall
1932 to 1933	Extension of eastern wall Raising and repair subsidence Extension of western wall upstream
1938 to 1939	Repairs to eastern wall
1939 to 1940	Construction of the salmon drive by opening eastern wall
1977	Construction of breakwaters

2.9.1.4. Wagonga Inlet Estuary Management Study and Plan (Nelson Consulting, 2001)

This report was prepared by Nelson Consulting for Eurobodalla Shire Council. It included discussion on issues and options, as well as an action plan. The issues and options discussed encompassed the entrance bar, shoaling, erosion and sedimentation, water quality, flooding, waterway facilities, and mangroves and seagrasses.

Of flooding within the catchment, it was reported that:

> *"Flooding of the flat area [of Narooma] is due to a combination of oceanic influences (eg tide levels, elevated ocean water levels due to coastal storms) and freshwater influences (i.e. intensity of rainfall in the catchment), rather than factors associated with the capacity or maintenance of the stormwater drainage system." (Nelson Consulting, 2001)*

2.9.2. Kianga Lake

2.9.2.1. Review of Environmental Factors for Entrance Management of Coila, Tuross, Kianga, Little, Bullengella and Nangudga Lakes (BMT WBM, 2010)

This report was prepared by BMT WBM in 2010 on behalf of Eurobodalla Shire Council. The objective of this study was to assess the entrance management policy of artificially opening ICOLL's within Council's jurisdiction. Of the six lakes reported on, Kianga Lake was the only one relevant to the present study.

The report listed the policy outline, constraints to water levels, and description of the existing lake environment, including hydrology and entrance behaviour.

The policy outline included the current initial trigger water level for when an artificial breakout of the entrance sand berm would be undertaken. It also proposed a long term trigger target to incorporate the projected 2100 sea level. For Kianga Lake the current initial trigger water level was specified as water levels exceeding 2 m AHD for any period of time or if water levels exceed 1.8 m AHD for a period of 14 days. The long term trigger target was suggested to be 2.8 to 3 m AHD. This is summarised in Table 14.

Table 14: Policy Outline for Kianga Lake (BMT WBM, 2010)

Initial Trigger	Water Level > RL 2.0 m AHD Water Level > RL 1.8 m AHD for 14 days
Long Term Trigger Target (ideal 2100 level)	No artificial opening of entrance preferable. RL 2.8 to 3 m AHD

Constraints detailed water levels at which certain locations or structures would be overtopped. For Kianga Lake these constraints are described below.

Table 15: Constraints for Kianga Lake (BMT WBM, 2010)

Water Level	Consequences
RL 1.8 m AHD	Water enters private properties on the northern side of Lakeside Drive – the lowest area is towards the western end of this road.
RL 2.0 m AHD	Water overtops the access road to Kianga Sewage Treatment Plant (STP).
RL 2.2 m AHD	Water overtops the sewage pumping station located on Council land between the lake and the lakeside properties.
RL 2.6 m AHD	Water overtops the Kianga – Dalmeny coastal road on the northern approach to the bridge over Kianga Lake.

Of the existing lake environment at Kianga Lake, the sand berm was described as being closed the majority of the time. Information from local residents indicated that this could be due to backfill material from an excavation in the 1980's being removed over time and enabling the lake to release water into the ocean via the rock shelf. If this were the case, it would in turn inhibit water levels in the lake from rising to an appropriate level to produce a natural entrance breakout.

2.9.3. Dalmeny

2.9.3.1. Review of Environmental Factors for Artificial Opening of Lakes Corunna, Brou, Mummuga (Dalmeny), 'Potato Point' and Congo Creek within Eurobodalla National Park (National Parks and Wildlife Services, 2007)

This report was prepared by the National Parks and Wildlife Services (NPWS) in 2007. The objective of this study was to assess the entrance management policy of artificially opening ICOLL's that are located within the NPWS jurisdiction in Eurobodalla National Park. Of the five lakes and creeks reported on, Mummuga Lake was the only one relevant to the present study.

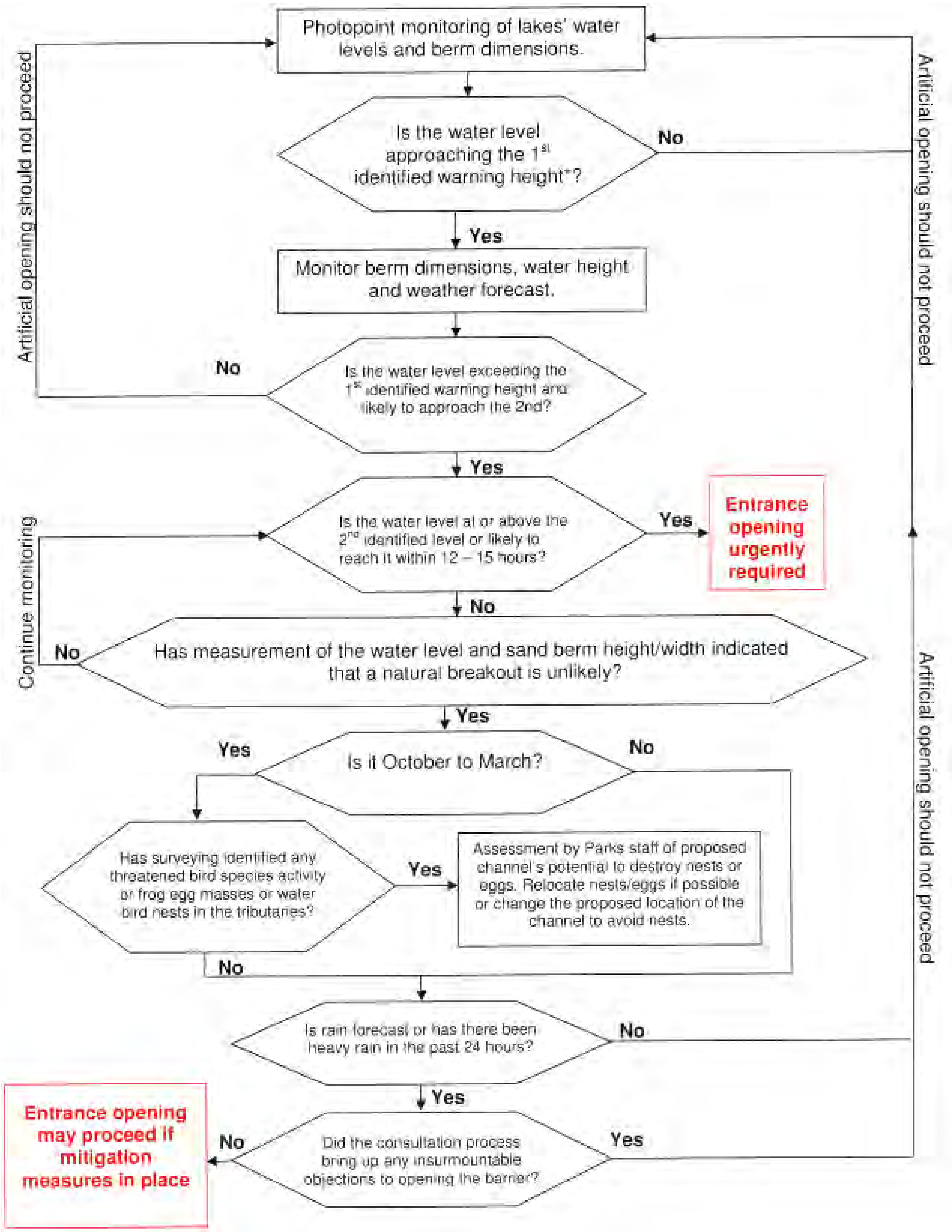
The report included the indicators necessary to initiate an artificial opening of the entrances and some history of when the ICOLL's have been open previously, both naturally and artificially.

The indicators necessary to initiate an artificial breakout of the entrance sand berm were categorised as a primary and a secondary indicator level. The primary indicator level was established based on assessment of when damage is possible. This instigates monitoring of the environmental situation including the berm dimensions, water levels and predicted weather reports. The secondary indicator level was based upon when damage was determined to be inevitable. Dependent on a number of other conditions, the secondary indictor level may result in the artificial opening of the ICOLL. This decision-making process is detailed in Diagram 4 and the indicators specific to Mummuga Lake are described in Table 16.

Table 16: Indicator Levels for the Mummuga Lake ICOLL (NPWS, 2007)

Primary Indicator Level (1st)	Water level in the Lake beginning to inundate properties located at 27-33 Mort Avenue, Dalmeny
Secondary Indicator Level (2nd)	Water level in the Lake has reached the identified 1.175 m AHD level marked on Dalmeny footbridge and directly threatens the infrastructure of properties in Mort Avenue, Dalmeny

Diagram 4: Decision flowchart for entrance management (NPWS, 2007)



Generally, excavation of an entrance sand berm was reported as being in the range of 2 to 4 hours, depending on the size of the sand berm.

The history of openings within this report was sourced from the NPWS records (in the case of artificial openings), and anecdotal reports from local residents and Eurobodalla Shire Council staff. The history specific to Mummuga Lake is detailed below in Table 17.

Table 17: History of openings of Mummuga Lake (NPWS, 2007)

Date Opened	Date Closed	Duration of Opening	Artificial or Natural	Details
8th August 1998	No Data	Known to be greater than 5 months	Natural	Opened following heavy rainfall. Further rain of approximately 280mm on 28th January 1999 established a better opening.
28th August 2001	No Data	No Data	Natural	Opened after approximately 170mm of rain.
12th July 2005	No Data	Lake remained open for only a short period	Artificial	Heavy rainfall resulted in the flooding of private property in Mort Avenue, Dalmeny.
12th February 2007			Artificial	Local flooding under houses in Mort Avenue following approximately 200mm of rain.
The entrance was open as at 19 February 2007 (when the assessment was made for this report)				

3. COMMUNITY CONSULTATION

3.1. Media Release

A media release titled 'Flood stories wanted for Narooma catchment study' was publicised by Eurobodalla Shire Council on the 12th September 2012. It was requesting community involvement in the flood study being undertaken in the Wagonga Inlet, Kianga and Dalmeny catchments. It provided details about the community information sheet and questionnaire to be distributed, as well as the upcoming drop-in session.

The media release is found in Appendix C and was previously available on the following link:
http://www.esc.nsw.gov.au/publications/mediacentre/mediareleases/2012/september/flood-stories-and-photos-wanted-for-narooma-catchment-study/

3.2. Community Questionnaire and Information Sheet

In collaboration with Eurobodalla Shire Council, a questionnaire and information sheet were distributed to residents and business owners within the study areas. The information sheet described the Floodplain Risk Management Process and provided information on the current flood study. The questionnaire requested information on flooding that residents and business operators may hold. This could be based upon photographs or observations of previous floods. Both the questionnaire and the information sheet directed the community to an online questionnaire (on the Survey Monkey platform), should they wish to complete the questionnaire via an alternative method. The information sheet also informed the community of a drop-in session held on the 17th September 2012 (see Section 3.3).

The community questionnaire and information sheet that was distributed by Eurobodalla Shire Council can be found in Appendix C.

3.3. Drop-in Session

Eurobodalla Shire Council and WMAwater organised a drop-in session that was held in Narooma Library on the 17th September 2012, between 4:00pm and 7:00pm. Present were representatives from both Eurobodalla Shire Council and WMAwater. The community was informed of this meeting via the community information sheet and media release.

The community could attend on an individual basis at any time that was convenient for them during the hours that representatives were present. The objective of this being that attendance would not be unreasonably hindered by restrictive hours that would have been the case in a collective meeting rather than individualised ("drop-in") meetings.

3.4. Community Responses

From both the community questionnaires and the drop-in session, it was found that the community were generally aware of flooding within the catchment. Of the respondents, just over 10% had performed flood mitigation or emergency work on their property due to flooding, and a quarter had been isolated due to flood waters in the past. There were also a higher number of respondents who had experienced the 2010 flood event in comparison to the 1999 flood event.

The analysis of the community response is provided in Figure C 1. Information that was employed in the model calibration phase of this study (discussed in Section 8) can be found in Appendix C.

3.5. Consultation on Draft Report

Eurobodalla Shire Council carried out the public exhibition of the Wagonga Inlet, Kianga and Dalmeny Draft Flood Study Report in June-July 2015. Residents were informed of the public exhibition via:

- Council website notice published on the 12th June 2015;
- Media release within Narooma News published on the 10th June 2015;
- Newsletter mailout to residents identified as affected by the 1% AEP event on the 15th June 2015;
- Media release within Eurobodalla News published on the 3rd July 2015;
- Council website notice “what’s on”; and
- Additional media release within Narooma News published on the 8th July 2015.

During the public exhibition period, the report was available online at www.esc.nsw.gov.au and hard copies were available from Narooma, Moruya and Batemans Bay Libraries and Eurobodalla Shire Council Offices. Two public information sessions were conducted with Council staff and WMAwater present on Wednesday 8th July 2015 from 4:00pm to 7:00pm and Thursday 9th July 2015 from 10:00am to 1:00pm. An additional business information session was also conducted on Wednesday 8th July 2015.

During the information sessions, additional historical flood information was provided by the community for the Dalmeny catchment area. This additional information allowed for the further calibration of the 2010 event and the addition of the 2014 event discussed in Section 8, the latter of which occurred after calibration had been completed for the study.

Seven written submissions were received from the public exhibition process. Of these, four identified typographical errors or requested clarification of technical information provided in the report. Three submissions provided additional photographs and descriptions of historic flood events. Three submissions also suggested or requested flood mitigation works to be investigated in the next stage of the floodplain risk management process (i.e. the Floodplain Risk Management Study and Plan). A summary of the issues raised in the submissions as well as responses are included in Appendix C.

4. STUDY METHODOLOGY

The estimation of flood behaviour in a catchment is often conducted as a two-stage process, consisting of:

1. hydrologic modelling to convert rainfall estimates to overland flow and stream runoff; and
2. hydraulic modelling to estimate flow distributions, flood levels and velocities.

When historical flood data are available they can be used to allow calibration of the models, and increase confidence in the estimates. The calibration process is undertaken by altering model input parameters to improve the reproduction of observed catchment flooding. Recorded rainfall and stream-flow data are required for calibration of the hydrologic model, while historic records of flood levels, velocities and inundation extents can be used for the calibration of hydraulic model parameters.

Following model calibration the design rainfall is modelled. The approach adopted in flood studies to determine design flood levels largely depends upon the objectives of the study and the quantity and quality of the data (survey, flood, rainfall, flow etc.).

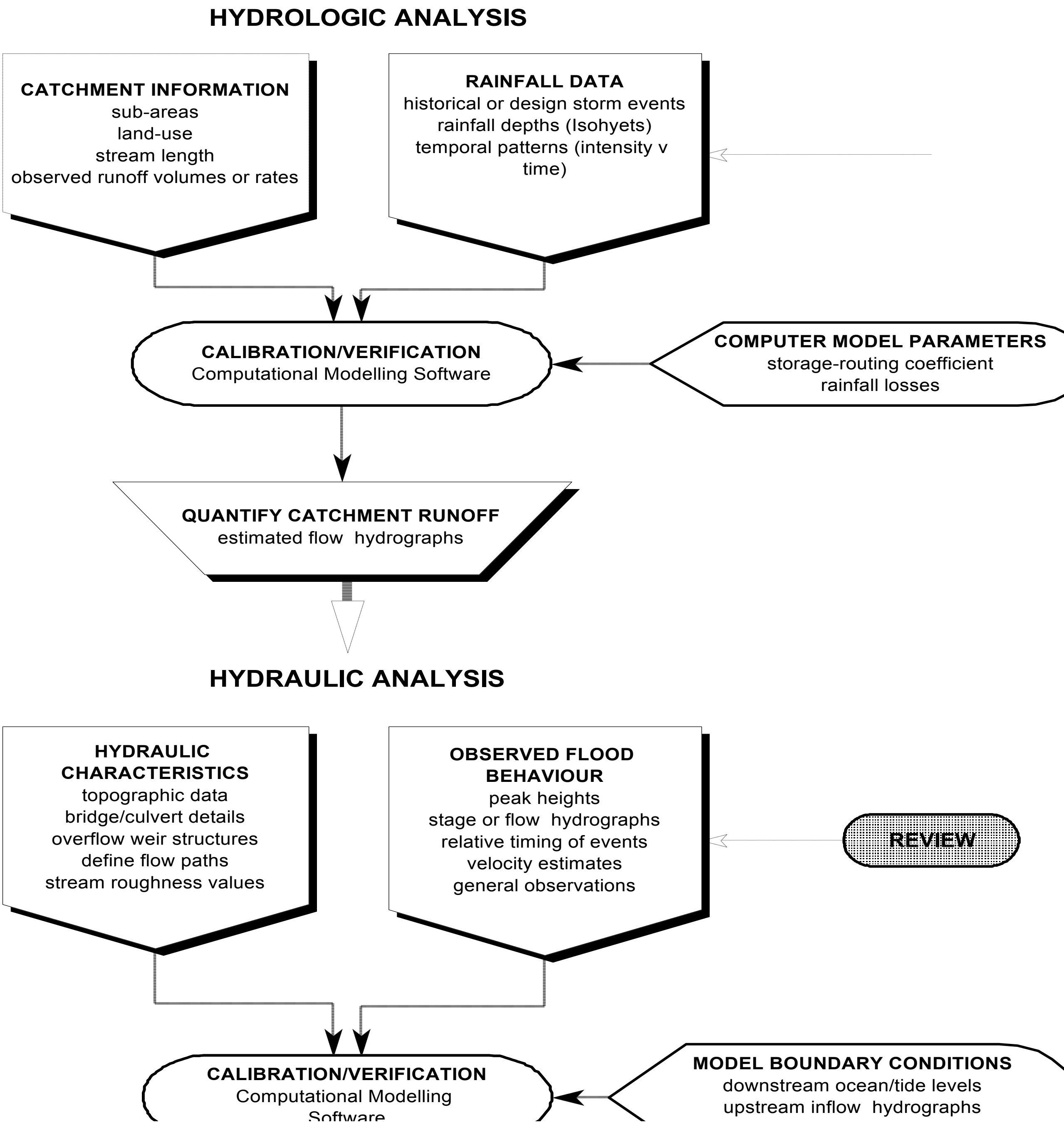
Flood estimation in urban catchments generally presents challenges for the integration of the hydrologic and hydraulic modelling approaches, which have been treated as two distinct tasks as part of traditional flood modelling methodologies. As the main output of a hydrologic model is the flow at the outlet of a catchment or sub-catchment, it is generally used to estimate inflows from catchment areas upstream of an area of interest. The hydrological model can also be useful to conceptually model hydrologic processes within the study area (such as runoff from roof and gutter systems, and On-site Stormwater Detention (OSD) systems). The aim of identifying the full extent of flood inundation can therefore be complicated by the separation of hydrologic and hydraulic processes into separate models, and these processes are increasingly being combined in a joint modelling approach.

The broad approach adopted for this study was to use a widely utilised and well-regarded hydrologic model to conceptually model the rainfall concentration phase, and for steep catchment areas upstream of the hydraulic model study area. The runoff hydrographs from the hydrologic model were then used in a hydraulic model to estimate flood depths, velocities and hazard in the study area. This joint modelling approach was calibrated against observed historical flood levels.

This approach reflects current engineering practice and is consistent with the quality and quantity of available data.

A diagrammatic representation of the Flood Study process is shown in Diagram 5.

Diagram 5: Flood Study Process



5. HYDROLOGIC MODEL DEVELOPMENT

5.1. Introduction

AR&R (1987) describes various techniques suitable for design flood estimation in rural and urban catchments. These techniques range from simple procedures to estimate peak flows (such as the Probabilistic Rational Method), to flood frequency analysis and more complex rainfall-runoff routing models that estimate complete flow hydrographs. Determination of which technique to employ is often based on the availability of data. For the present study, the rainfall and runoff routing approach was adopted. In current Australian engineering practice, examples of the more commonly used runoff routing models include RORB, RAFTS and WBNM. These models allow the rainfall depth to vary both spatially and temporally over the catchment, and have parameters governing runoff volume/shape that can be calibrated against recorded data.

For the present study, the Watershed Bounded Network Model (WBNM) was used. The WBNM model is an event-based, lumped-catchment conceptual model that is based on an extensive empirical dataset of rainfall-runoff relationships for Australian catchments. The model requires very few parameters to describe the physical aspects of the catchment, and is therefore less sensitive than other models to assumptions about catchment characteristics such as shape, steepness, and ground cover. WBNM was therefore considered a suitable tool for this study. WBNM has been widely adopted in Australia for use in similar studies.

5.2. Sub-catchment Delineation

The catchment boundary was determined by the ridges that create the natural drainage division. Precipitation falling on the other side of these boundaries would flow into other catchments and so was not modelled within these study areas.

The ridge bounding the Mummuga Lake catchment coincides with Brou Lake Road and Mitchells Ridge Road to the north and Tobacco Pinch Road, Box Cutting Road, Kianga Forest Road and Bell Ridge Road to the south. Part of the south boundary of this catchment forms the north boundary of the adjacent Kianga Lake catchment. Upon the ridge that bounds the Kianga Lake catchment is Bell Ridge Road and Kianga Forest Road to the north, Kianga Forest Road to the west and Appleby Road to the south. The ridge that defines the Wagonga Inlet catchment coincides with the south boundary of the Mummuga Lake and Kianga Lake catchments, along Applyby Road, Box Cutting Road and Tobacco Pinch Road. The ridge that defines the Wagonga Inlet catchment to the west coincides with Morts Folly Road. These boundaries are shown on Figure 1.

Within these catchments, smaller sub-catchment areas were delineated based on ALS survey and contours where ALS survey was not available. The sub-catchment layout ensures that where hydraulic controls exist that these are accounted for and able to be appropriately incorporated into hydraulic routing. The catchment layout for the hydrologic model is shown on Figure 6.

5.3. Model Parameters

The WBNM hydrologic runoff-routing model was used to determine hydraulic model inflows, both from catchment areas upstream of the hydraulic model extent, and for the local sub-catchments within the hydraulic model domain of the study.

The model input parameters for each sub-catchment are:

- a lag factor (termed C), which can be used to accelerate or delay the runoff response to rainfall;
- a stream-flow routing factor, which can speed up or slow down concentrated flows occurring through each catchment;
- rainfall initial and continuing losses to represent infiltration and filling of depression storage; and
- the percentage of catchment area with a pervious/impervious surface.

5.3.1. Lag Parameter

Lag times for runoff depend on several physical catchment characteristics, including area, shape and steepness (among others) for natural catchments. Experimental data for natural catchments in Australia has demonstrated that the dominant factor affecting lag is catchment area, with other characteristics showing strong correlation with area such that there is a strong case for catchment lag to be determined on area alone.

Experimental derivation of the Lag Parameter for 129 storms on 10 catchments in eastern NSW found that a value of 1.68 gave a good fit to all the data. A value of 1.7 was adopted for historical and design flood modelling in this study, in agreement with the NSW data.

5.3.2. Stream-flow Routing Parameter

WBNM provides the option to route upstream flows to the bottom of a sub-catchment via nonlinear routing, time-delay routing and Muskingum routing. This routing is required to estimate the attenuation and timing of flows from sub-catchments in the steep upper catchment areas that are not included in the hydraulic model extent. The nonlinear method was adopted for this study. For this method, Boyd et. al. (2007) recommends values of 1.0 for natural channels and 0.67 for gravel beds. Therefore, for this study, a value of 1.0 was adopted.

Where the hydrologic sub-catchment area coincided with the hydraulic sub-catchment area, these were applied as local inflows with no routing of upstream flows.

5.3.3. Rainfall Losses

Methods for modelling the proportion of rainfall that is "lost" to infiltration are outlined in AR&R (1987). The methods are of varying complexity, with the more complex options only suitable if sufficient data are available (such as detailed soil properties). The method most typically used for design flood estimation is to apply an initial and continuing loss to the rainfall. The initial loss represents the wetting of the catchment prior to runoff starting to occur, and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

Initial and continuing losses are often used as the primary parameters for calibrating hydrologic models when observational data are available. For this study, typical values were adopted based on available data in similar catchments. Table 6.2 of AR&R (1987) recommends that for catchments east of the dividing range in New South Wales, an initial loss of 10 mm to 35 mm is appropriate, with a continuing loss of 2.5 mm/hr.

For this study, the initial loss of 10 mm was adopted, which is at the lower end of values recommended in AR&R.

5.3.4. Impervious Areas

Runoff from connected impervious surfaces such as roads, gutters, roofs or concrete surfaces occur significantly faster than from vegetated surfaces. This results in a faster concentration of flow within the downstream area of the catchment, and increased peak flow in some situations. It is therefore necessary to estimate the proportion of the catchment area that is covered by such surfaces.

The impervious surfaces within the study areas were determined through digitisation of the road surfaces (used in the hydraulic model to specify Manning's 'n' roughness coefficients, see Section 6.4) and building footprints (used in the hydraulic model to simulate impermeable obstructions to the flood flow, see Section 6.3) through visual inspection of aerial photography. The proportion of these impervious surfaces within the sub-catchment area was adopted as the impervious percentage of the sub-catchment area.

5.3.5. Summary of Model Parameters

The key modelling parameters adopted for the historic and design hydrologic modelling are summarised as follows:

- Lag Parameter (C) – 1.7
- Pervious Area Initial Rainfall Loss – 10 mm
- Pervious Area Continuing Rainfall Loss – 2.5 mm/hour
- Impervious Area Initial Rainfall Loss – 1 mm
- Impervious Area Continuing Rainfall Loss – 0 mm/hour

6. HYDRAULIC MODEL DEVELOPMENT

6.1. Introduction

The availability of high quality ALS data means that the study area is suitable for two-dimensional (2D) hydraulic modelling of major flowpaths and lake areas. Various 2D software packages are available, such as SOBEK, TUFLOW and Mike FLOOD, among others. The TUFLOW package was adopted for this study as it is widely used in Australia and WMAwater have extensive experience in the use of the TUFLOW model.

The TUFLOW modelling software is produced by BMT WBM. The modelling package includes a finite difference numerical model for the solution of the depth averaged shallow water flow equations in two dimensions. The 2D model is capable of dynamically simulating complex overland flow regimes and interactions with sub-surface drainage systems.

For the hydraulic analysis of complex overland flow paths an integrated 1D/2D model such as TUFLOW provides several key advantages when compared to a 1D only model. For example, a 2D approach can:

- provide localised detail of any topographic and /or structural features that may influence flood behaviour,
- better facilitate the identification of the potential overland flow paths and flood problem areas,
- dynamically model the interaction between hydraulic structures such as culverts and complex overland flowpaths, and
- inherently represent the available flood storage within the 2D model geometry.

Importantly, a 2D hydraulic model can better define the spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped across the model extent. This information can then be easily integrated into a GIS based environment enabling the outcomes to be readily incorporated into Council’s planning activities. The model developed for the present study provides a flexible modelling platform to properly assess the impacts of any management strategies within the floodplain (as part of the ongoing floodplain management process).

In TUFLOW the ground topography is represented as a uniformly-spaced grid with a ground elevation and a Manning’s “n” roughness value assigned to each grid cell. The grid cell size is determined as a balance between the model definition required and the computer run time (which is largely determined by the total number of grid cells).

6.2. Model Extent

The hydraulic model extent for the Kianga and Duck Pond catchments coincided with the catchment boundaries in the hydrologic model extent. The upper reaches to the west of the Mummuga Lake and Wagonga Inlet catchment (along Cowdroy Creek, Billa Bilba Creek, Burrimbidgee Creek and Punkally Creek) were solely modelled within the hydrologic model, which provided inflows at the hydraulic model boundary for the catchment. The hydraulic model extents are shown on Figure 5.

6.3. Digital Elevation Model

The model uses a regularly spaced computational grid. The Wagonga Inlet catchment was simulated in two distinct hydraulic models. The Inlet model had a grid cell size of 12 m by 12 m and the Narooma Flat model had a grid cell size of 3 m by 3 m. The Mummuga Lake catchment was simulated in two hydraulic models, with a grid cell size of 6 m by 6 m in the Lake model and a grid cell size of 3 m by 3 m in the Dalmeny Township model. The Kianga Lake catchment had a grid cell size of 6 m by 6 m and the Duck Pond catchment had a grid cell size of 3 m by 3 m. This resolution was adopted as it provides an appropriate balance between providing sufficient detail for roads and overland flow paths, while still resulting in workable computational run-times.

The model grid was established by sampling from a 1 m by 1 m DEM. This DEM was generated from a triangulation of filtered ground points from the 2012 LiDAR dataset and 2002 bathymetric survey, discussed in Section 2.1 and shown on Figure 3. Locations where the topography differed from this were in the vicinity of the ICOLL sand berms, discussed in Section 7.1.2.

Permanent buildings and other significant structures likely to act as significant flow obstructions were incorporated into the terrain model. These features were identified from the available aerial photography and modelled as impermeable obstructions to the flood flow.

6.4. Roughness Coefficient

The TUFLOW model used for this study utilises the Manning’s formulation to determine the energy loss from friction and other sources. The roughness coefficient, ‘*n*’, is an empirically derived parameter which represents the retarding force applied to flowing water by the channel bed or ground surface. In practice, in computational modelling of real systems, this parameter often also incorporates other sources of energy loss such as turbulence and flow expansion/contraction from non-uniform cross sections.

The value of '*n'* represents the resistance to flow in a given channel which depends on a number of factors such as:

- surface roughness;
- vegetation;
- channel irregularity and alignment;
- obstructions;
- silting and scouring;
- the size and shape of the channel; and
- the stage and discharge.

Inspection of the aerial photography was used to classify various land-uses categories, such as urban areas and vegetated areas. From this, spatially varying roughness values were applied to the model, based upon these differing categories. The roughness values adopted for the hydraulic model are shown in Table 18 and Figure 8.

The values are consistent with typical values in the literature (Chow, 1959 and Henderson, 1966), industry guidelines (*AR&R Revision Project 15: Two Dimensional Modelling in Urban and Rural Floodplains Report*, Engineers Australia, 2012) and previous experience with modelling similar catchment conditions. The sensitivity of model results to changes in the roughness values is discussed in Section 14.

Table 18: Manning's 'n' Values

Surface Type	Manning's 'n' Value
Concrete-lined pipes	0.015
Roads and paved surfaces	0.025
Urban areas – general overland areas, gardens, roadside verges, low density residential lots etc	0.05
Light density vegetation (very short grass or sparse vegetation)	0.04
Medium density vegetation	0.07
Heavy density vegetation	0.10
Waterways, such as Lakes, Estuaries and Ocean areas	0.03
Default	0.05

6.5. Hydraulic Structures

The behaviour of hydraulic structures like culverts, fences, channels and bridges can have a significant influence on flood behaviour. When culverts are flowing near capacity or become blocked, backwater upstream of the culvert can flood properties or cause the road to be overtopped. The piers and deck of bridges over creeks can present an obstruction to flow, resulting in afflux (increased water level) upstream of the structure. It is therefore important to pay particular attention to the modelling of these features.

Key hydraulic structures were included in the hydraulic model, as shown on Figure 9. Culverts were generally modelled as 1D features embedded in the 2D model, since the majority of the culverts of interest have dimensions smaller than the grid resolution. For the bridges, where the main flow width exceeds the grid resolution, modelling was undertaken in the 2D domain using a TUFLOW software feature specifically designed for this purpose, whereby the energy losses and blockage caused by the piers, deck and above deck structure can be applied directly to the grid cells.

The modelling parameter values for the culverts and bridges were based on the geometrical properties of the structures, which were obtained from records of structures held by the authorities responsible for them, photographs taken during site inspections, and previous experience modelling similar structures. The Roads and Maritime Services provided data on the dimensions of structures underneath the Princes Highway. This included the bridge over Wagonga Inlet, the bridge over Kianga Creek and the bridge over Lawler's Creek (within the Mummuga Lake catchment). Eurobodalla Shire Council provided data on the dimensions of other structures within their jurisdiction. Sensitivity analysis of the effect of the hydraulic structure parameters is presented in Section 14.

Smaller localised obstructions within private property, such as fences, were not explicitly represented within the hydraulic model, due to the difficulty of identifying and characterising these structures from aerial photographs, and the relative impermanence of these features. The cumulative effects of fences on flow behaviour were assumed to be partially addressed via the roughness adopted for residential areas.

6.6. Blockage Assumptions

Blockage of hydraulic structures can occur with the transportation of a number of materials by flood waters. This includes vegetation, garbage bins, building materials and cars, the latter of which has been seen post-flood in Newcastle. However, the disparity in materials that may be mobilised within a catchment can vary greatly.

Debris availability and mobility can be influenced by factors such as channel shear stress, height of floodwaters, severity of winds, storm duration and seasonal factors relating to vegetation. The channel shear stress and height of floodwaters that influence the initial dislodgment of blockage materials are also related to the average exceedance probability (AEP) of the event. Storm duration is another influencing factor, with the mobilisation of blockage materials generally increasing with increasing storm duration (Barthelmess and Rigby 2009, cited in Engineers Australia 2013).

The potential effects of blockage include:

- decreased conveyance of flood waters through the blocked hydraulic structure or drainage system;
- variation in peak flood levels;
- variation in flood extent due to flows diverting into adjoining flow paths; and
- overtopping of hydraulic structures.

Existing practices and guidance on the application of blockage can be found in:

- the Queensland Urban Drainage Manual (Department of Natural Resources and Water, 2008);
- AR&R Revision Project 11 Blockage of Hydraulic Structures (Engineers Australia, 2013); and
- the policies of various local authorities and infrastructure agencies.

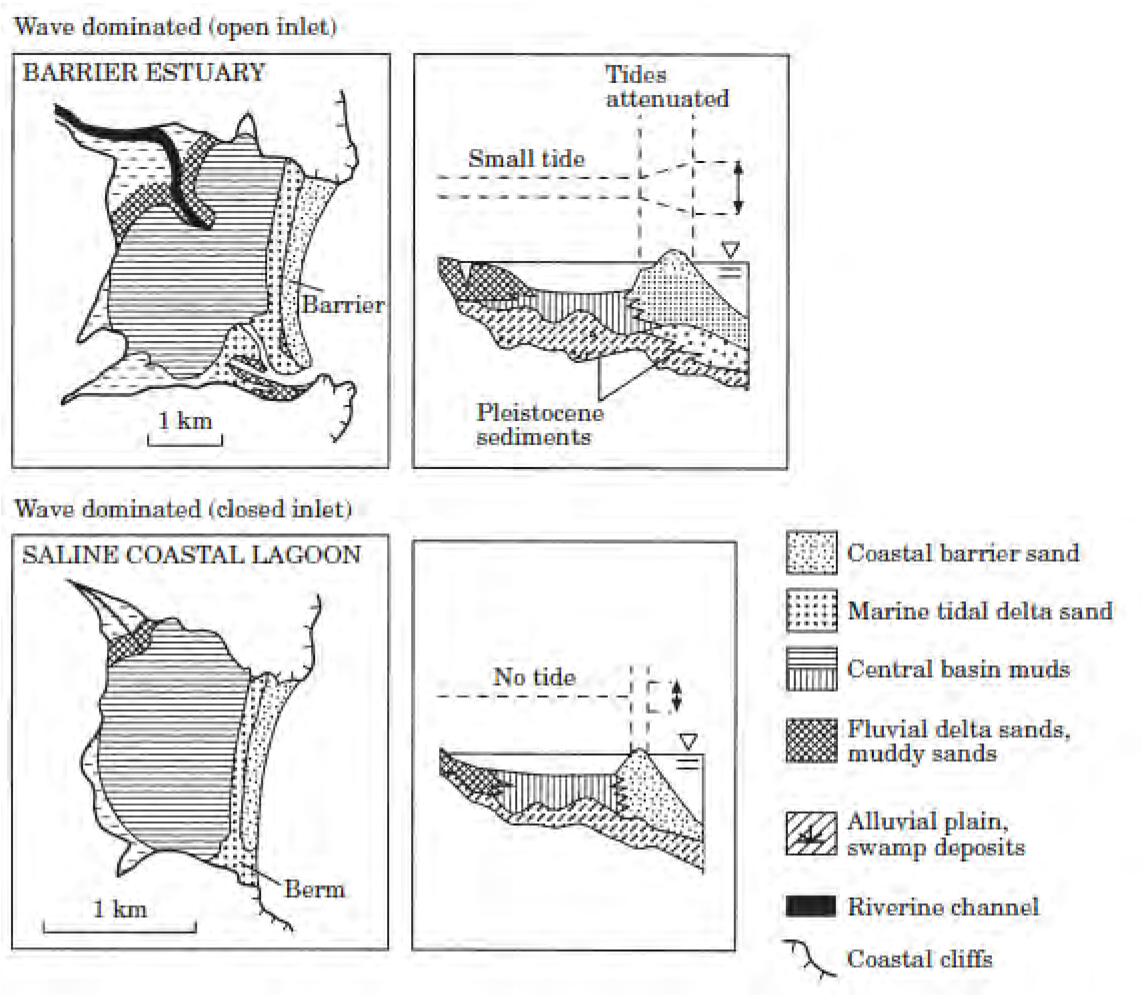
Current modelling has been undertaken assuming no blockage of pipes, culverts and bridges greater than 450 mm in diameter. Pipes less than 450 mm in diameter were conservatively assumed to be completely blocked. The sensitivity of peak flood levels to blockage will be considered in design sensitivity.

7. ENTRANCE CONDITIONS

7.1. Introduction

The entrance conditions of the catchments are separated by type into two categories; barrier estuary and ICOLL's (shown in Diagram 6). The Wagonga Inlet catchment is classified as a barrier estuary. The Dalmeny (consisting of both the Mummuga Lake and Duck Pond) catchments and the Kianga Lake catchments are categorised as ICOLL's.

Diagram 6: Estuary Types Extracted from Roy et. al. (2001)



General information regarding the entrance conditions, the use of software features in the hydraulic model to broadly represent these types of entrance conditions, and the catchment specific application, is provided below.

7.1.1. Barrier Estuary

Barrier estuaries are open inlets with a constricted entrance. The river discharges from barrier estuaries "tend to counteract the flux of wave-transported beach sand in the estuary mouths" (Roy et. al., 2001).

The tides between the ocean outlet and the estuary basin are subject to attenuation in barrier estuaries. This attenuation results in a spatially varying water level within the Wagonga Inlet basin, as characterised by the difference in water level hydrographs recorded at Narooma Public Wharf (located in the entrance channel) and Barlows Bay (located upstream of Narooma Public Wharf within the estuary basin) in Figure E 2. Also, given that the Barlows Bay station is a greater distance from the ocean outlet than the Narooma Public Wharf station, it also shows that the low tide does not propagate as great a distance into the Inlet as the high tide does.

7.1.2. ICOLL's

The modelled conditions of ICOLL entrances can considerably affect the flooding behaviour in the lower reaches of the catchments, in both the historic flood modelling and design flood modelling. Closed entrance conditions would likely produce higher flood levels during events with rainfall-derived inflows and lower flood levels during events with ocean-derived inflows. Open entrances conditions would likely produce the converse of this.

There are a number of approaches to simulating the entrance conditions of ICOLL's in the hydraulic model, including:

- A constant closed entrance: The sand berm would be elevated. When the level required to initiate an artificial opening of the ICOLL is reached, flow would occur over the sand berm, with no change in sand berm topography;
- A constant open entrance: This approach considers the entrance to be open prior to the event occurring, with no change in entrance topography during the simulation;
- A variable entrance: The sand berm would be elevated prior to the commencement of the event. During the simulation, the sand berm dimensions would gradually lower until the open entrance topography was achieved based upon specified initiation criteria. After the entrance reached open conditions, no further topographic changes would occur.

The constant closed or constant open entrance condition can be simulated in the 2D domain of the TUFLOW hydraulic model using the DEM. The variable entrance condition requires the schematisation of a variable shape element to be incorporated into the hydraulic model using a 2D feature provided in the TUFLOW software package. This feature is a simplified representation of the more complex processes that occur.

In the variable entrance scenario, the initial closed entrance dimensions are simulated in the DEM. The variable shape specifies the dimensions of the final open entrance conditions. Between the initial dimensions and final dimensions, the TUFLOW software adjusts the dimensions incrementally based upon the duration of change specified. The software provides various options for the initialisation of the varying topography including: at a specified time, when the water level reaches a stipulated height at a specified (trigger) location, or the water level difference between two specified locations exceeds a stipulated amount.

The approach adopted in this Flood Study for the simulation of the ICOLL entrance conditions, varies according to the different scenarios, such as the historic flood modelling, the design flood modelling and the sensitivity flood modelling. For each of the ICOLL catchments, the topographic dimensions (closed entrance and open entrance conditions) used in the three approaches discussed above is specified in the following.

7.2. Wagonga Inlet

In the case of Wagonga Inlet, the open entrance is characterised by twin training walls within the estuary channel and two breakwaters at the ocean outlet. The breakwaters are located at Wagonga Head. The twin training walls extend from Narooma Public Wharves on Bluewater Drive to the Princes Highway Bridge. The Wagonga Inlet is a wave dominated estuary (Roy et. al., 2001). The tidal prism of the Wagonga Inlet is provided in Table 19.

Table 19: 380m from the entrance on 3 December 1986 (OEH, 2012)

Tide State	Wagonga Inlet Flow (10^6 m^3)	Wagonga Inlet Tidal Range (m)	Sydney Harbour Tidal Range (m)
Ebb Flow	6.34	1.49	1.89
Flood Flow	6.64	1.24	1.57

The two breakwaters at Wagonga Heads were defined in the hydraulic model's DEM. The height and width of the structures enabled this schematisation, as it was of a sufficient width as to be greater than the computational grid cell size used in the 2D domain (discussed in Section 6.3).

The parallel training walls were of a width less than the computational grid cell size, and so the structure was not consistently identified within the DEM. The training walls were schematised in the hydraulic model using a 2D feature provided in the TUFLOW software package. The variables that may be specified in the feature include average height of the structure and percentage impervious through the structure. The unprocessed ALS data contained greater resolution than the DEM and was used to define the average height of the training walls. The percentage impervious parameter was used to represent the ratio of the area that was impervious (due to the rocks that the training walls are constructed from) and pervious (due to the gaps between the rocks facilitating marginal flow from one side of the training wall to the other). It was assumed that 10% of the lateral area may be considered pervious.

To simulate the varying water levels and flow velocities within Wagonga Inlet that is probable to have occurred just prior to the various events, the hydraulic model simulation was started 3 hours prior to the commencement of the applied rainfall. During this part of the simulation the initial water level applied to the inlet is singularly the subject of the ocean tide. As such, the inlet condition at the commencement of the rainfall is the product of the relationship between the varying inlet water level and the ocean tide level. The values applied as the initial water levels within the inlet in the hydraulic model were dependent upon the event being modelled. This is discussed in Section 8 for the calibration events, Section 10 for the design events and Section 14 for the sensitivity analysis events.

7.3. Kianga

The location of the sand berm at the Kianga Lake entrance is shown in the 2010 aerial images (provided in Diagram 7) and the LiDAR survey that was obtained in 2005 and 2012 (provided in Diagram 8 and Diagram 9).

Both of the LiDAR sets defined the sand berm as having an elevation of approximately 2 m AHD. This elevation corresponds with that required to initiate an artificial entrance opening. The DEM produced from the 2012 LiDAR survey was adopted as the closed entrance topography.

However, no survey was available to define the open entrance topography. As such, the open entrance topography was assumed to be an interpolation of elevations from downstream of the sand berm to the channel inverts located upstream of the sand berm. These elevations were obtained from the bathymetric survey undertaken in 2002.

Diagram 7: Kianga Lake ICOLL Entrance – 2010 Aerial Images

Diagram 8: Kianga Lake ICOLL Entrance – DEM of 2005 LiDAR and 2002 bathymetric survey

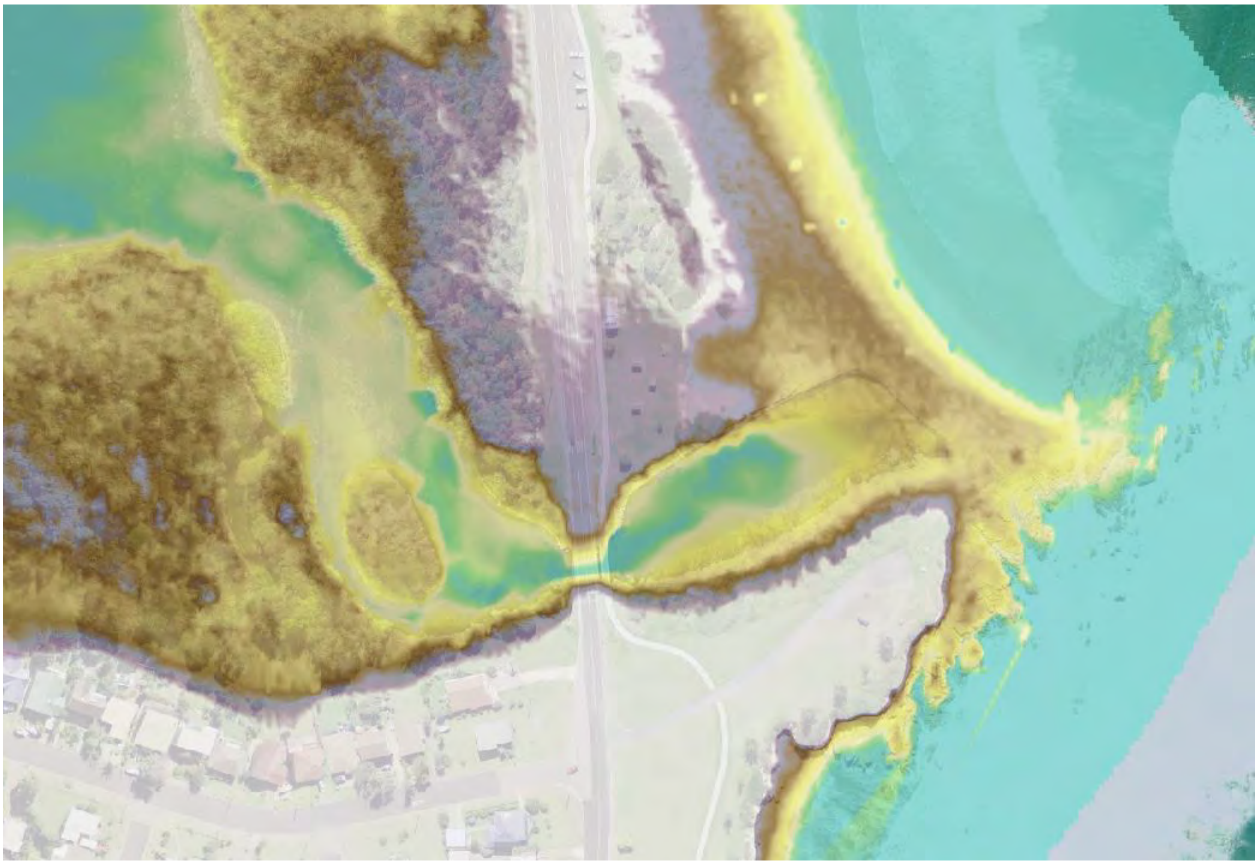
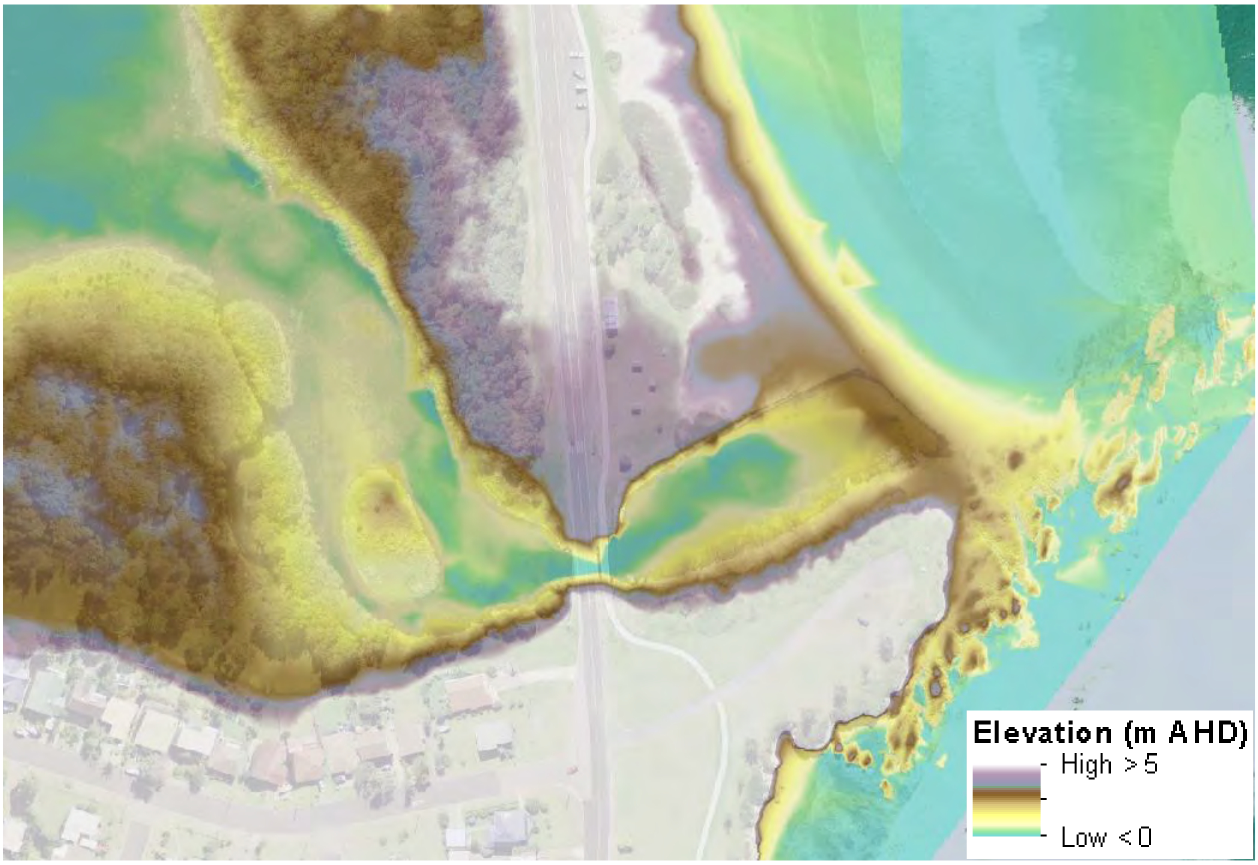


Diagram 9: Kianga Lake ICOLL Entrance – DEM of 2012 LiDAR and 2002 bathymetric survey



7.4. Dalmeny

The location of the sand berm at the Mummuga Lake entrance is shown in the LiDAR survey that was obtained in 2005 (provided in Diagram 11). At the time of the survey, the sand berm was found to have an elevation of approximately 1.4 m AHD at its peak. This is higher in elevation than the water level height required at the footbridge to initiate an artificial entrance breakout (specified as 1.175 m AHD). As such, the closed entrance topography was defined by the 2005 LiDAR survey.

The open entrance conditions at the Mummuga Lake entrance is shown in the 2010 aerial images (provided in Diagram 10) and the LiDAR survey that was obtained in 2012 (provided in Diagram 12). The combination of the 2012 LiDAR survey and the 2013 bathymetric survey was adopted as the open entrance topography.

Diagram 10: Mummuga Lake ICOLL Entrance – 2010 Aerial Images

Diagram 11: Mummuga Lake ICOLL Entrance – DEM of 2005 LiDAR

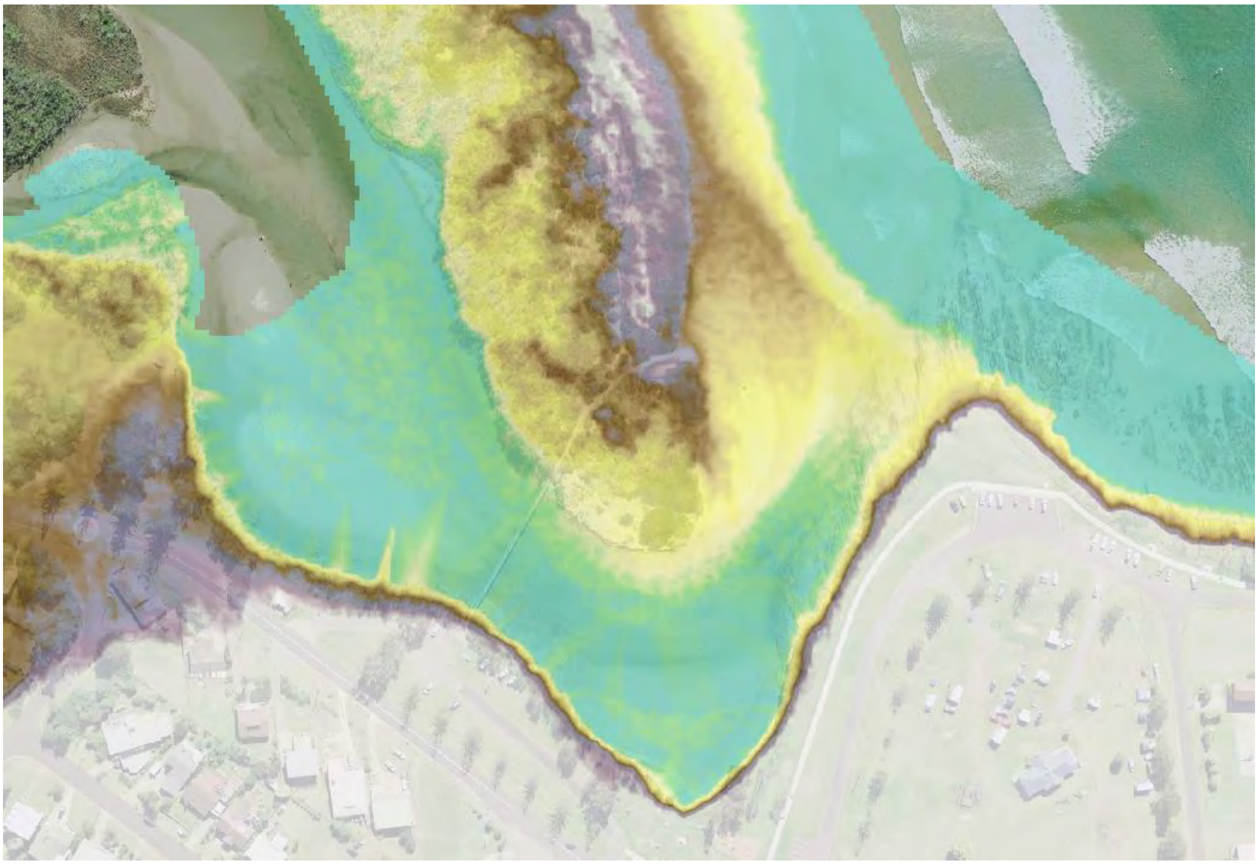
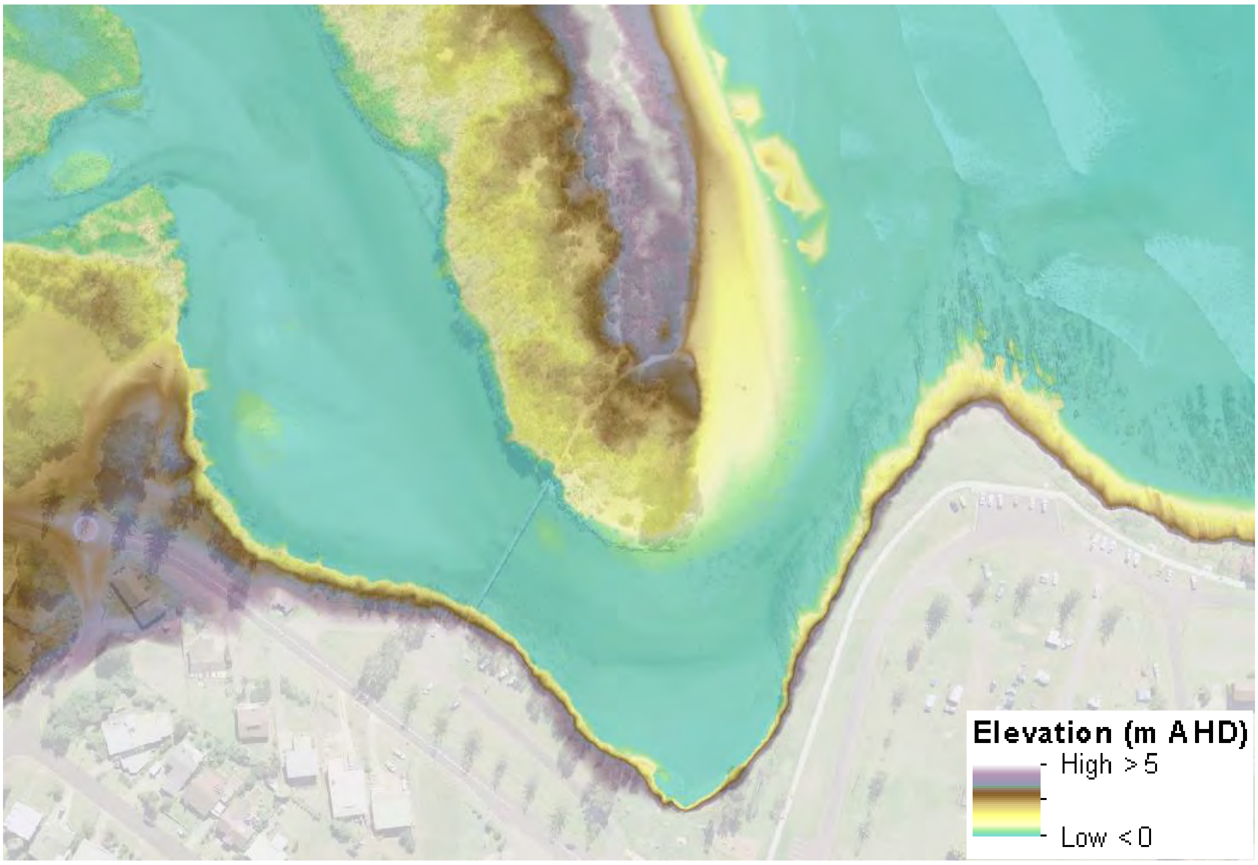


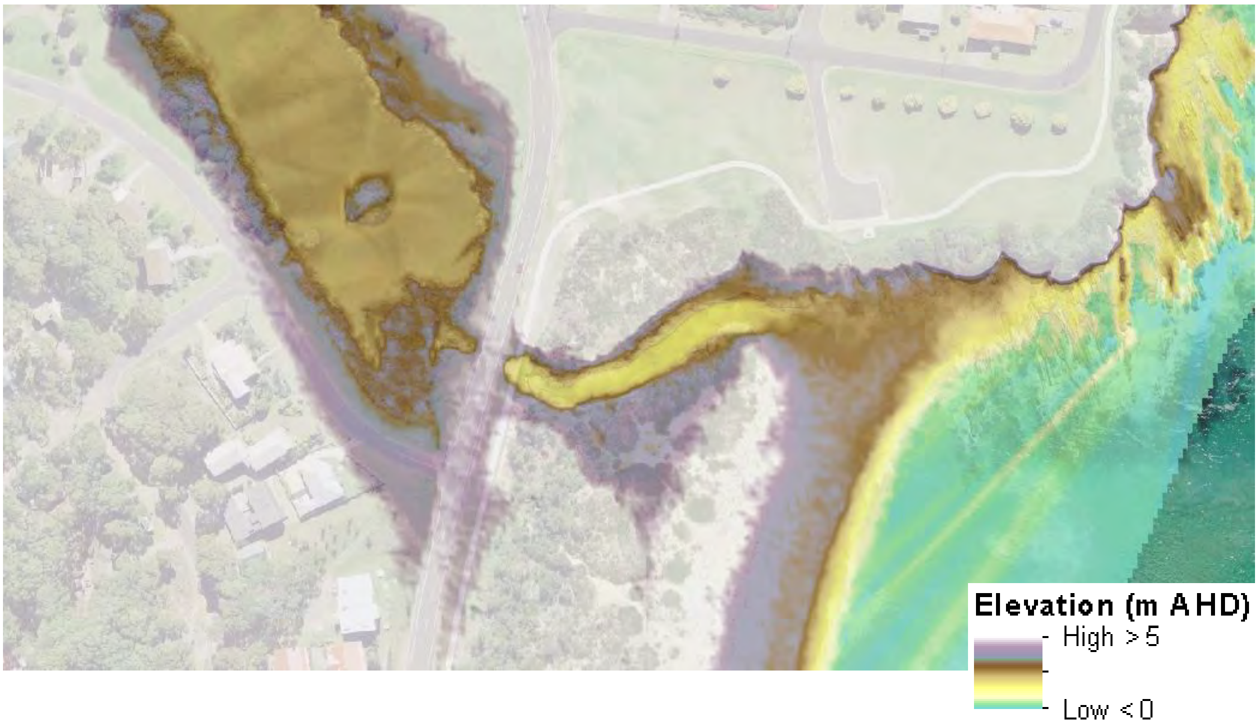
Diagram 12: Mummuga Lake ICOLL Entrance – DEM of 2012 LiDAR and 2013 bathymetric survey



The Duck Pond entrance is not identified on the OEH online estuary summary that details physical characteristics (such as ICOLL status) due to its relatively small size, however the features of the entrance indicate that it is an ICOLL. The location of the sand berm at the Duck Pond entrance is shown in the 2010 aerial images (provided in Diagram 13) and the LiDAR survey that was obtained in 2005 (shown in Diagram 14). However, as very little data is available concerning this ICOLL (including entrance breakout criteria or conditions), no variation in topography was adopted for this ICOLL to represent variations in open or closed entrance conditions.

Diagram 13: Duck Pond ICOLL Entrance – 2010 Aerial Images

Diagram 14: Duck Pond ICOLL Entrance – DEM of 2005 LiDAR



8. HISTORIC FLOOD MODELLING

8.1. Introduction

Modelling of known historic flood events is carried out to calibrate and validate the hydrologic and hydraulic models. This process is important to ensure that the models are sufficiently representing flood behaviour within acceptable limits. Calibration involves modifying (within an acceptable range) the model parameter values to replicate observed flood behaviour or levels. Validation is undertaken to ensure that the model parameter values determined in the calibration phase are acceptable in other flood events with no need for additional alteration of values.

The model parameters that are typically adjusted include (as detailed within the *AR&R Revision Project 15: Two Dimensional Modelling in Urban and Rural Floodplains Report*, 2012):

- Hydraulic roughness parameters;
- Energy losses at structures/bends;
- Inflow hydrographs (parameters involved include temporal rainfall patterns and spatial rainfall distribution);
- Downstream boundary location and assumptions, particularly stage-discharge boundaries; and
- Blockage of inlets and hydraulic structures.

Selection of calibration and validation events is based upon data availability and magnitude of the storm or flood event. Ideally, the rainfall calibration events span a range of magnitudes with a preference for the more significant events, such as those near the 1% AEP event.

It is ideal to have historical rainfall (daily and pluviographic) and historical streamflow (daily and instantaneous) data to calibrate the hydrologic model, independent of the hydraulic model. As streamflow data is not available within the study areas, the hydrologic model has been calibrated in tandem with the hydraulic model in this flood study. This is in accordance with guidelines produced by Engineers Australia (within the *AR&R Revision Project 15: Two Dimensional Modelling in Urban and Rural Floodplains Report*, 2012) that recommends that the two models be jointly calibrated.

To calibrate the hydrologic and hydraulic models it is necessary to have data on historical rainfall, historical boundary conditions and historical flood records or observations.

The historic rainfall conditions can be determined from daily and pluviometer gauging stations. The pluviometer data provides information on the temporal pattern of the rainfall (as in, the variation in the rainfall amount across a period of time). The combination of the daily and pluviometer data provides information on the possible spatial distribution of the rainfall (as in, the variation in the rainfall depth across the catchment area). The rainfall conditions applied to the catchments within this study are discussed in Section 8.3.

Generally, historic boundary conditions may be a stage-discharge relationship or tidal data for catchments discharging into ocean-influenced waterways. For this study, the tidal data is relevant and available. Additionally, the entrance condition of the ICOLL's sand berm is also relevant to the downstream conditions of the Dalmeny and Kianga catchments. The ocean levels applied to the catchments are discussed in Section 8.4 and the entrance conditions for each of the catchments are discussed in Section 8.5.

Historic records or observations that can be used to define historical flood behaviour, and thereby calibrate the model against, include:

- *Continuous Water Level Recorders*: gauges that record the complete hydrograph enable calibration of not just the peak flood level but also the timing of the rise and fall of the flood;
- *Maximum Height Gauges*: gauges that record the peak flood level reached during a specific event;
- *Peak Level Records*: markers placed (usually by government agencies) after the event to indicate the peak flood level or maximum flood extent reached;
- *Debris Marks*: where floating debris remains on an object from the receding flood waters, resulting in a line indicating the flood level reached;
- *Watermarks on Structures*: residual watermarks on structures can indicate the flood level reached; and
- *Anecdotal Information*: descriptions of flood levels or behaviour, as well as photographs or videos.

For this flood study, a number of these records are available including continuous water level recorders (located within the Wagonga Inlet catchment at Barlows Bay and Narooma Public Wharf, as discussed in Section 2.4), peak flood level records (that were surveyed as part of the previous study and discussed in Section 2.9.1.2), and anecdotal information including photographs obtained from various sources.

In addition to rainfall-derived calibration events, it is recommended that tidal calibration be undertaken in catchments where the interaction between the tidal inundation and the rainfall runoff is important, as is the case in the catchments investigated in this flood study. Tidal calibration ensures that the model can reproduce tidal amplification and isolate the mechanisms that may be responsible for variations in the modelled and recorded hydrographs.

Tidal calibration is undertaken by modelling a period with no recorded precipitation and comparing the hydraulic model hydrograph against the recorded hydrograph produced by continuous water level gauges. It is necessary to have sufficient tidal records to apply as a hydraulic model boundary condition, and continuous water level records to compare against.

The data availability enables tidal calibration of the Wagonga Inlet catchment. Although additionally, due to the tidal attenuation and spatially varying water level gradient that occurs within Wagonga Inlet (as discussed in Section 7.1.1), it is preferable to have more than one water level recorder to calibrate against, which the current study does.

8.2. Event Selection

The calibration and validation events selected were the following:

- 25th-29th January 2008 – Calibration Event (Tidal Conditions);
- 28th January 1999 – Calibration Event (Rainfall Generated);
- 11th February 2007 – Calibration Event (Rainfall Generated);
- 15th February 2010 – Calibration Event (Rainfall Generated); and
- 14th October 2014 – Calibration Event (Rainfall Generated).

The January 2008 period was employed to calibrate the hydraulic model of the Wagonga Inlet catchment to solely ocean conditions. During this period, no rainfall was recorded at Narooma (daily rainfall station 69022, located within the catchment) that would influence the water levels recorded within the Inlet. The dates also coincided with the period in which both the Barlows Bay and Narooma Public Wharf water level stations were simultaneously operating.

The 15th February 2010 event was chosen due the magnitude of the rainfall event, the availability of recorded flood levels and the relatively recent occurrence of this event. The flood levels available for this event include the water level record at Barlows Bay as well as photographs of flooding provided by the community, Eurobodalla Shire Council and Narooma Newspaper. As such, both the mainstream flow and the local overland flow had data to calibrate against.

The 28th January 1999 was chosen as a validation event due to the availability of flood level data to compare the model against. This included the water level stations at Barlows Bay and Narooma Public Wharf, as well as surveyed flood levels sourced from the Gary Blumberg and Associates (2002) flood study.

The 11th February 2007 was modelled due to the availability of water level stations at Barlows Bay and Narooma Public Wharf that facilitated validation of the mainstream flow. The 14th October 2014 event was chosen based upon community concerns.

8.3. Rainfall

Storm behaviour often varies across different storm events, as well as varying temporally and spatially across the one storm event.

The spatial variation is indicated in the rainfall distribution shown on Figure E 4, Figure E 9, Figure E 14 and Figure E 19, for each of the storm events. The temporal variation of the historical storms is demonstrated in the hyetographs shown in Figure E 5, Figure E 10, Figure E 15 and Figure E 20.

28th January 1999

The pluviometer data for this storm event shows the storm took place over a 14 hour period. The rainfall distribution indicates that the peak rainfall intensity was experienced on the coast, inclined towards the north-east of the Mummuga Lake catchment area. The rainfall intensity decreases towards the south-west in an almost linear progression.

11th February 2007

The rainfall distribution for the 2007 storm event indicates two storm cells were active, with large rainfall depths recorded inland to the south-west of Wagonga Inlet and on the coast within the eastern quadrant of the Mummuga Lake catchment. The precise divide between these two storm cells is unknown as rainfall data is scarce adjacent to the western border of the Wagonga Inlet catchment. Of the three storm events investigated, the 2007 event had the shortest burst duration of approximately 12 hours.

15th February 2010

To estimate the storm behaviour for the 2010 event, the pluviometer data, the rainfall distribution derived from rainfall gauges within the area, and radar data originating from the Canberra (Captains Flat) radar station were analysed.

The 2010 storm event was considered to have occurred over a 24 hour period; straddling two days of daily read rainfall data (hence the rainfall distribution is derived from the 48 hour period prior to 9am on the 16th February 2010). The rainfall distribution indicated two storm cells were present; located to the north of Mummuga Lake and to the south-east of Wagonga Inlet (centred over the Central Tilba (69149) daily read rainfall gauge).

However, steep increases in elevation are present to the west of the Central Tilba gauge as a result of Mt Dromedary. Such topographic features can result in orographic rainfall where higher rainfall can occur on the coastal side of the elevated topography. This was found to be the case in the 2010 event.

The radar station located at Canberra (Captains Flat) provided additional data for the 2010 event. The first storm cell to move through the catchments was shown to be localised around Narooma and Central Tilba before moving south-east, accounting for the first burst in the temporal pattern at Narooma and Barlows Bay. The second storm cell originated to the north-west, moving south-easterly through Tuross before proceeding on to Barlows Bay and Central Tilba. This second storm cell accounted for the single burst at Tuross having the same ascending and descending shape as second storm burst recorded at Barlows Bay (with a temporal offset). The recorded radar patterns replicated well the variability between locations across the catchment.

14th October 2014

The pluviometer data for this storm event shows the storm took place over an 18 hour period, with greater than half the rainfall occurring over a 5 hour period between 4am and 9am. The rainfall distribution indicates that the peak rainfall intensity occurred over Narooma, with rainfall decreasing to the north and west of Narooma.

Hydrologic Application

The spatial variation of the historical storms was simulated by weighting each of the individual sub-catchments based upon the average rainfall depths derived from the rainfall distribution.

The application of the recorded temporal patterns varied according to the storm, topographic features and relative spatial locations.

The Kianga Lake and Duck Pond catchments adopted the temporal rainfall pattern recorded at the Narooma pluviometer for the 1999 event and the Barlows Bay (218415) pluviometer for the 2007, 2010 and 2014 events.

The Mummuga Lake catchment adopted two temporal rainfall patterns. The sub-catchments located to the west used the temporal rainfall pattern recorded at Tuross R at Eurobodalla (218008) pluviometer. The eastern sub-catchments adopted the same temporal rainfall pattern as was applied to Kianga Lake and Duck Pond catchments.

Additional hydrologic consideration was given to the 2010 event in the Mummuga Lake catchment, given the scarcity of rainfall data in the upstream area and information provided by the community during the public exhibition process. As such, the rainfall volume applied to the west of the Princes Highway within the Mummuga Lake catchment was reduced to 60% of the 2010 rainfall shown on Figure E 14.

The catchment size and topography of Wagonga Inlet differs greatly from the other catchments in this study, such that various temporal rainfall patterns and spatial rainfall distributions were not considered wholly representative of the storm behaviour over the total catchment area.

For the 1999 event, two temporal rainfall patterns were applied. The sub-catchments to the west of the Inlet basin (including Billa Bilba Creek, Burrimbidgee Creek and Punkally Creek) adopted the pattern recorded at the Tuross (218008) pluviometer. The sub-catchments to the east adopted the pattern recorded at the Narooma pluviometer. The 2007 and 2014 event applied the rainfall pattern recorded at Barlows Bay (218415) in place of the Narooma pluviometer.

The 2010 event adopted three temporal rainfall patterns applied over different sub-catchments than the other events. The rainfall pattern recorded at the Tuross (218008) pluviometer was adopted for sub-catchments on the Billa Bilba Creek. The rainfall pattern derived from the Canberra radar data was applied to sub-catchments on the Punkally Creek. The remainder of the Wagonga Inlet catchment, including Burrimbidgee Creek, adopted the rainfall pattern recorded at the Barlows Bay (218415) pluviometer. The distribution is shown on Figure E 14.

8.4. Ocean Levels

Applied as a downstream boundary condition in the hydraulic model, the ocean levels for the calibration and validation events were variable tidal levels. These were obtained from the Port Kembla ocean level station and were adjusted to account for marginal regional differences, discussed in Section 2.5. The adjustment (lowering the ocean level by 0.1 m) was based upon the peak ocean levels recorded at the Bermagui station during the period of no-rainfall. This ocean level station was considered representative of the area due to it's proximity to the catchments. However the ocean levels recorded at the Bermagui station during periods of rainfall appeared to be influenced by freshwater inflows and so could not be adopted as a direct boundary in these circumstances. The correlation of the ocean level and the rainfall is shown in Figure E 6, Figure E 11, Figure E 16 and Figure E 21.

8.5. Inlet and Entrance Conditions

8.5.1. Wagonga Inlet

The initial water level within Wagonga Inlet, east of the Princes Highway Bridge, was based upon the water level recorded at Barlows Bay at the corresponding date and time (supplied in Australian Eastern Standard Time and adjusted for Daylight Savings Time). The initial water level between the Princes Highway Bridge and the breakwaters at Wagonga Head was based upon the water level recorded at Narooma Public Wharf during events in which it was in operation. For events which occurred when Narooma Public Wharf was not in operation, the initial water level applied was the average between the inlet water level at Barlows Bay and the ocean tide level. This was consistent with the difference in water level that was generally observed during periods of gauge operation. The correlation between the inlet water levels and ocean tide levels are shown in Table 20 for the various storm events.

Table 20: Calibration Data – Wagonga Inlet Water Level

Date	Daylight Savings Time	Inlet Water Level (m AHD) at Barlows Bay	Inlet Water Level (m AHD) at Narooma Wharf	Ocean Tide Level (m AHD) at the ocean outlet
28/01/1999	04:00 am	+ 0.03	+ 0.23	0.454
10/02/2007	03:00 pm	+ 0.06	+ 0.04	+ 0.107
25/01/2008	09:00 am	- 0.18	+ 0.07	+ 0.346
14/02/2010	05:00 pm	- 0.24	- 0.08 (Assumed)	- 0.565
13/10/2014	08:00 am	- 0.255	- 0.251 (Assumed)	- 0.246

8.5.2. Kianga

The initial lake levels, initial entrance conditions and continuing entrance conditions for the historical events modelled are discussed below.

28th January 1999
No information was available for this event. As such, the conditions applied to the 2010 storm event were adopted for this event.

11th February 2007
No information was available for this event. As such, the conditions applied to the 2010 storm event were adopted for this event.

15th February 2010
The Kianga Lake entrance was represented as a closed entrance at the commencement of this event, which is consistent with reports from ESC and residents.

No detailed information was available on the lake levels and sand berm height prior to the commencement of this event. As such, the initial sand berm height was assumed to be 2 m AHD and the initial water level within the lake was assumed to be 0.6 m AHD. The sand berm height was adopted as it corresponds with the trigger level discussed in Section 2.7.2. The initial lake level was adopted as it corresponds to the peak neap tide level.

The entrance was known to have opened during the course of this event on the 15th February 2010; however the timing of the entrance opening is unknown.

14th October 2014
No information was available for this event. As such, the conditions applied to the 2010 storm event were adopted for this event.

8.5.3. Dalmeny

The initial lake levels, initial entrance conditions and continuing entrance conditions for the Duck Pond catchment were uniform across the historical events modelled. The initial lake level adopted was 0.6 m AHD and the initial entrance conditions were those obtained from the 2005 LiDAR survey (discussed in Section 2.1.1). The continuing entrance conditions were not altered from the initial entrance topography adopted.

The initial lake levels, initial entrance conditions and continuing entrance conditions for the Mummuga Lake catchment varied according to the historical event modelled and are discussed below.

28th January 1999

The Mummuga Lake entrance was represented as a closed entrance at the commencement of this event. This is a conservative assumption, with reports from the NPWS (discussed in Section 2.9.3.1) that the entrance was considered open from the 8th August 1998 up to this storm event, whereby the opening was better established. This indicated that the entrance was somewhere between partially open and partially closed at the commencement of this event.

No detailed information is available on the lake levels and sand berm height prior to the commencement of this event. As such, the initial sand berm height was assumed to be 1.175 m AHD and the initial water level within the lake was assumed to be 0.6 m AHD. The sand berm height was adopted as it corresponds with the trigger level discussed in Section 2.9.3.1. The initial lake level was adopted as it corresponds to the peak neap tide level.

11th February 2007

The Mummuga Lake entrance was represented as a closed entrance at the commencement of this event, which is consistent with reports from ESC and residents.

No detailed information is available on the lake levels and sand berm height prior to the commencement of this event. As such, the initial sand berm height was assumed to be 1.175 m AHD and the initial water level within the lake was assumed to be 0.6 m AHD.

The entrance was known to have opened during the course of this event on the 12th February 2007; however the timing of the entrance opening is unknown.

15th February 2010

The Mummuga Lake entrance was represented as a closed entrance at the commencement of this event, which is consistent with reports from ESC and residents.

No detailed information is available on the lake levels and sand berm height prior to the commencement of this event. As such, the initial sand berm height was assumed to be 1.175 m AHD and the initial water level within the lake was assumed to be 0.6 m AHD.

The entrance was known to have opened naturally during the course of this event; occurring overnight between the 14th and 15th February 2010.

14th October 2014

The Mummuga Lake entrance was represented as an open entrance at the commencement of this event, which is consistent with reports from ESC and residents. As such, the initial water level within the lake was assumed to be equal to the ocean level at the commencement of this event.

8.6. Results

25th-29th January 2008 – Tidal Conditions Event

The stage hydrographs comparing the recorded water levels against the modelled water levels within Wagonga Inlet are shown on Figure E 2. The modelled stage hydrographs were found to correlate well with the recorded stage hydrographs in terms of peak, shape and timing. The average variation in water level was 0.04 m at both Barlows Bay and Narooma Public Wharf, across the duration of the simulation.

Generally, at Barlows Bay the difference between the modelled and the recorded water levels were consistent for both high and low tide. At Narooma Public Wharf, the modelled results correlated better to the recorded water levels for the high tides. In contrast, the modelled results were consistently lower at the low tides, by a maximum of 0.08 m.

It was investigated whether adjusting the hydraulic roughness parameter within the waterway (consisting of the Inlet, channel and ocean area) would provide a closer correlation on the low tide levels at the Narooma Public Wharf location. From this, the Narooma Public Wharf hydrograph was found to be relatively insensitive to variations in this parameter, with little to no change in the modelled hydrograph. The Barlows Bay hydrograph displayed a greater sensitivity to this variation than the Narooma Public Wharf hydrograph. Adjustment of the hydraulic roughness parameter decreased the maximum and increased the minimum water levels modelled at the Barlows Bay hydrograph.

With no substantial change to the Narooma hydrograph and a greater disparity in the Barlows Bay hydrograph, changes to the hydraulic roughness parameter were determined to be inappropriate. The model reproduces the high tide and timing at both water level records and is considered to provide a good reproduction of tidal conditions within the Wagonga Inlet catchment.

28th January 1999 – Rainfall Generated Event

The stage hydrographs comparing the recorded water levels against the modelled water levels within Wagonga Inlet are shown in Figure E 6. During the storm event, the modelled hydrographs displayed a strong correlation with the recorded hydrographs at Barlows Bay and Narooma Public Wharf. Subsequent to the storm event, the model produces lower levels at the low tide, corresponding with the model behaviour in the calibration of the ocean conditions independent of rainfall (25th-30th January 2008 event). The maximum variation in water level was 0.16 m at both Barlows Bay and Narooma Public Wharf, across the duration of the simulation. The model generally reproduced the shape and time of the event.

No specific information was available for the Kianga Lake entrance and the Mummuga Lake entrance during the course of this event, and as such the timing of the ICOLL entrance opening could not be validated for this event.

For calibration of the local overland flow, the comparison between surveyed flood levels and modelled flood levels are shown in Table 21. The model generally reproduced surveyed flood levels within ± 0.1 m.

It was found that two localised areas on Hyland Avenue and McMillian Road resulted in higher modelled water levels than were recorded. However, it should be noted that for Location ID 14 and 28, the modelled ground level was equal to the surveyed flood level. There are a number of possible reasons for this, such as localised landscaping changes resulting in slight ground elevation changes that could not be quantified and represented in the hydraulic model. As the survey did not provided details on depth of flood water or ground levels corresponding to surveyed flood levels, it is unclear the number of locations that may be influenced by such slight ground elevation changes. It is probable that the adjacent areas on Hyland Avenue (Location ID 12, 13 and 14) and McMillian Road (Location ID 26, 27 and 28) were subject to similar changes over time.

The intersection of Riverside Drive and McMillan Road (Location ID 10) was found to result in lower modelled water levels than was recorded. This could be attributed to wave action induced by boats or vehicles travelling through flood waters in the vicinity of this location that can not accounted for in the hydraulic model.

The peak flood depth for the 28th January 1999 event is provided on Figure E 7.

Table 21: Calibration Results – 28th January 1999

Location ID	Location Address	Surveyed Flood Level (m AHD)	Modelled Peak Flood Level (m AHD)	Difference (m)
1	46 McMillan Road	1.28	1.28	0.00
2	19 Hyland Avenue	1.27	1.36	0.09
3	10 Lynch Street	1.26	1.28	0.02
4	12 Brice Street	1.26	1.29	0.03
5	14 Lynch Street	1.26	1.35	0.09
6	10 Brice Street	1.24	1.27	0.03
7	8 Nichelsen Street	1.28	1.24	-0.04
8	7 Nichelsen Street	1.28	1.25	-0.03
9	grass verge west side of Riverside Drive	1.30	1.23	-0.07
10	intersection of Riverside Drive and McMillan Road	1.41	1.23	-0.18
11	54 McMillan Road	1.29	1.24	-0.05
12	"Hibiscus Court" Hyland Avenue	1.66	1.81	0.15
13	5 Hyland Avenue	1.63	1.79	0.16
14	4 Hyland Avenue	1.58	1.71	0.13
15	7 Hyland Avenue	1.67	1.72	0.05
16	9 Hyland Avenue	1.63	1.70	0.07
17	9 Hyland Avenue	1.57	1.63	0.06
18	13 Hyland Avenue	1.50	1.50	0.00
19	"Magnolia Park" McMillan Road	1.67	1.63	-0.04
20	House under construction McMillan Road	1.68	1.78	0.10
21	32 McMillan Road	1.53	1.55	0.02
22	38 McMillan	1.50	1.49	-0.01
23	"Milford Lodge" cnr McMillan Rd and Brice St	1.44	1.40	-0.04
24	"Apollo Flats" McMillan Road	1.79	1.87	0.08
25	14 McMillan Road	1.89	1.91	0.02
26	12 McMillan Road	1.75	1.94	0.19
27	6 McMillan Road	1.79	1.96	0.17
28	"Olympic Lodge" Princes Highway	1.77	1.90	0.13
29	Caravan Park Princes Highway	1.82	1.87	0.05

11th February 2007 – Rainfall Generated Event

The stage hydrographs comparing the recorded water levels against the modelled water levels within Wagonga Inlet are shown in Figure E 11. During the period where the low tide corresponded to the storm event, the hydrographs modelled displayed a strong correlation with the recorded hydrographs. During the latter part of the storm event, corresponding with the high tide, the modelled hydrograph was shown to overestimate the peak water level.

The modelled hydrograph over-estimated the water elevation by 0.13 m at Barlows Bay and 0.08 m at Narooma Public Wharf at the peak. Whereas during the receding portion of the storm, the modelled water level was consistently lower in elevation although the general shape and timing of the event is reproduced by the model. The disparity between the modelled hydrograph and the recorded hydrograph at Barlows Bay and Narooma Public Wharf was attributed to the spatial and temporal variation in rainfall across the south-western portion of the Wagonga Inlet catchment. There was not sufficient recorded rainfall data to fully estimate the movement of the storm event across the catchment.

No specific information was available for the Kianga Lake entrance and the Mummuga Lake entrance during the course of this event, and as such the timing of the ICOLL entrance opening could not be validated for this event. The peak flood depth for the 11th February 2007 event is provided in Figure E 12.

15th February 2010 – Rainfall Generated Event

The stage hydrographs comparing the recorded water levels against the modelled water levels within Wagonga Inlet are shown in Figure E 16. The modelled results compared to the recorded results during the main peak corresponded well and the overall timing is reproduced by the model. The slight plateau recorded in the water levels both before and after this peak was generally not reproduced. Similar to the 2007 event, this was attributed to the rainfall representation within the south-west portion of the Wagonga Inlet catchment being based upon scarce data in this localised area.

During the storm event, Mummuga Lake was shown to have an open entrance at approximately 10:30am on the 15th February, 2010 (according to photographs located and reproduced in Figure E 1), and anecdotal information from the community indicated that the berm was overtopping around 7am on the 15th February. Comparison was made to the modelled breakout to validate the initial water level within the lake and the entrance conditions over time. The hydraulic model resulted in a breakout during this time frame, which is consistent with the aforementioned reports.

For calibration of the local overland flow, the results of comparisons between approximated flood levels and modelled flood levels are shown in Table 22. Generally it was found that the modelled flood levels were within 0.07 m of the flood levels approximated from photographs. This was attributed to the photographs not capturing the peak flood level, but rather the lead up to the peak or after the peak when the flood water was receding. The peak flood depth for the February 2010 event is provided in Figure E 17.

Table 22: Approximate Calibration Results – 15th February 2010

Location ID	Location Address	Approximate Observed Flood Depth (m)	Approximate Observed Flood Level (m AHD)	Modelled Peak Flood Level (m AHD)	Difference (m)
30	Narooma – Bluewater Dr near Bay St	0.2	1.9	1.9	-0.03
31	Narooma – Bowling Greens	0.1	1.5	1.6	0.06
32	Narooma – McMillian Rd	0.4	1.4	1.4	-0.02
33	Narooma – Hyland Ave	0.1	1.1	1.3	0.17
34	Narooma – Junction of Hyland Ave and Brice St	0.2	2.1	2.0	-0.07
35	Narooma – Junction of Lynch St and Nichelsen St	0.3	1.5	1.6	0.06
36	Narooma – Junction of Graham St and Burrawang St	0.2	3.2	3.2	0.04
37	Narooma – Riverside Dr	0.2	1.3	1.3	-0.03
38	Kianga – Junction of Princes Hwy and Kianga Rd	0.5	8.0	8.1	0.17
39	Kianga – Kianga Ck downstream of Princes Hwy	0.8 m (below roadway)	6.4	6.5	0.05
40	Kianga – Junction of Dalmeny Dr and Centenary Dr	0.3	6.2	6.3	0.11
41	Dalmeny – Junction of Dalmeny Dr and Eucalyptus Dr	0.3 m (at ~3pm)	3.1	3.7	0.57
43	Dalmeny – Junction of Mort Ave and Binalong St	0.5	3.2	3.1	-0.11
44	Dalmeny – Acacia Cl	0.2	8.0	8.0	-0.02

Table 23: Surveyed Calibration Results – 15th February 2010

Location ID	Location Address	Surveyed Observed Flood Level (m AHD)	Modelled Peak Flood Level (m AHD)	Difference (m)
45	Dalmeny – Pedestrian bridge	Below 2.21 (top of timber board)	1.85	Correlated
42	Dalmeny – Mort Ave Fire Station	2.08	2.17	+ 0.09
46	Tatiara Street	2.11	2.17	+ 0.06
47	Mort Avenue*	2.14	2.16	+0.02
48	Myuna Street	Below 2.38	2.18	Correlated
49	Myuna Street	Above 2.01	2.18	Correlated
50	Old Jetty Handrail	Above 1.90	2.18	Correlated

14th October 2014 – Rainfall Generated Event

The stage hydrographs comparing the recorded water levels against the modelled water levels within Wagonga Inlet are shown in Figure E 21. The modelled results compared well to the recorded results during the main peak that occurred around 2pm on the 14th October 2014.

For calibration of the local overland flow, photographs obtained from Narooma News were compared to the peak modelled flood extent. Although the time stamp for the photographs is unknown (i.e. the photographs may not have been taken at the peak), the resultant model extents compared well to photographs taken during the flood event, shown in Diagram 15, Diagram 16 and Diagram 17 below.

Diagram 15: Mummuga Lake – 2014 modelled extent compared to photograph extent

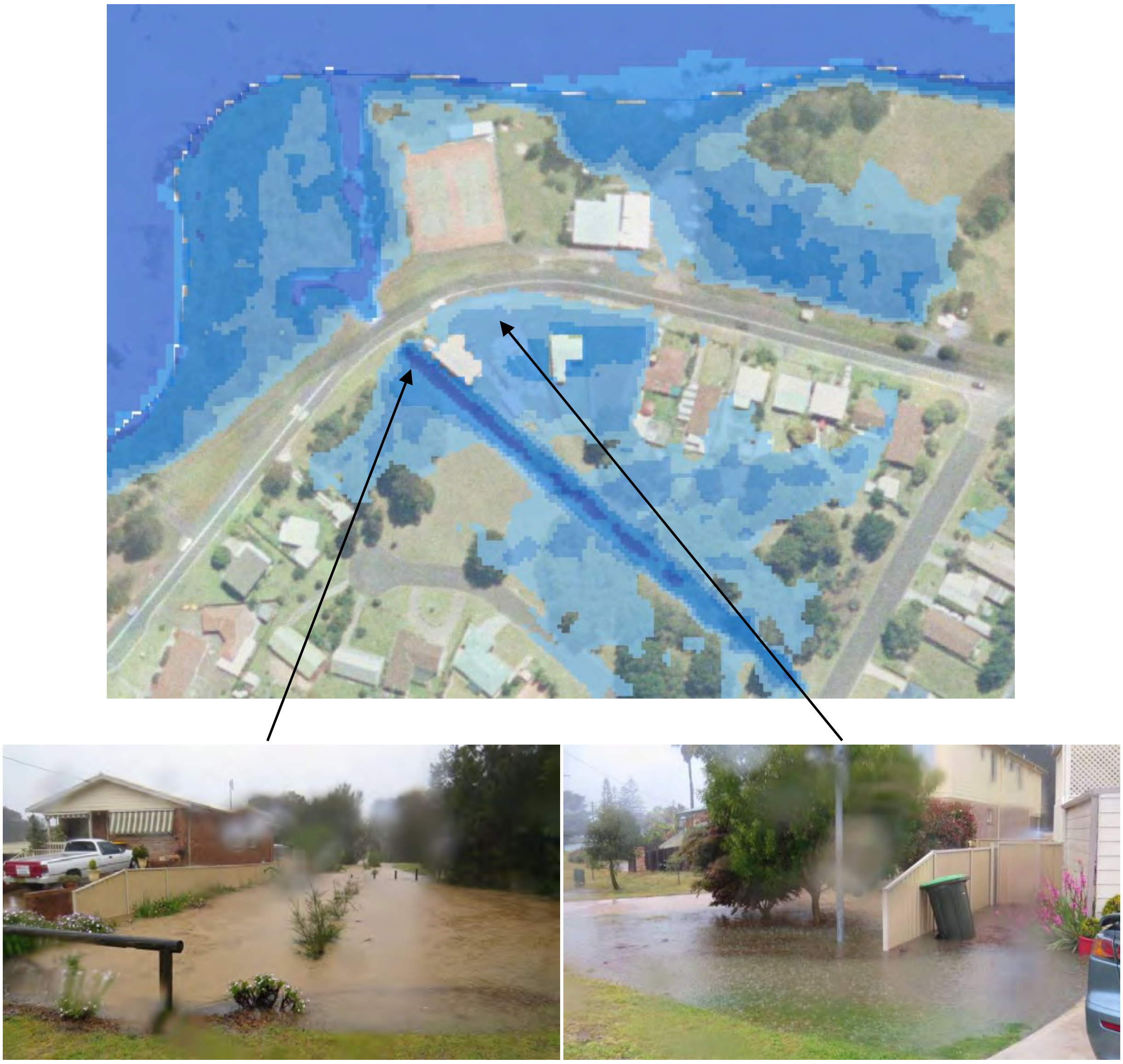


Diagram 16: Wagonga Inlet – 2014 modelled extent compared to photograph extent

Diagram 17: Wagonga Inlet – 2014 modelled extent compared to photograph extent

8.7. Discussion

According to Engineers Australia, calibration events would preferably "span the magnitude range of intended design events with a preference for the more important design floods (eg. 1% AEP event)". As such, a range of historical rainfall events have been modelled including the:

- 2010 event – Greater than or equal to a 100 year ARI event;
- 1999 event – Between a 20 year and a 50 year ARI event;
- 2007 event – Between a 10 year and a 20 year ARI event; and
- 2014 event – Less than or equal to a 1 year ARI event.

(Note: the aforementioned ARI estimates are from the pluviometer at Narooma operated by ESC, as shown in Figure E 3, Figure E 8, Figure E 13 and Figure E 18).

Given the large distance covered by the various catchments, a large rainfall event in one catchment may not correspond to a large rainfall event in the other catchments. For this reason, the rainfall distribution of the historical events was taken into consideration and shown in Figure E 4, Figure E 9, Figure E 14 and Figure E 19. From these figures, the townships have been ranked from largest to smallest rainfall depth for each of the events, as such:

- 1999 event – Dalmeny, Kianga, Narooma
- 2007 event – Dalmeny, Kianga, Narooma
- 2010 event – Dalmeny, Kianga, Narooma (Note: this ranking is based upon the township area not the whole catchment area. Outside of the Dalmeny township area, within the Mummuga Lake catchment, west of the Princes Highway the rainfall was reduced by 60%, as discussed in 8.3)
- 2014 event – Narooma, Kianga, Dalmeny

Furthermore, a range of flooding mechanisms influences the catchments; such as mainstream and overland flow. The design rainfall events are an envelope of 1% AEP storm durations that resulted in the mainstream peak and the overland peak (as discussed in Section 11), whereas the historical events may be equivalent to a 1% AEP event in the overland but not the mainstream, and vice versa.

With the variety of historical storm events investigated, across a range of magnitudes, spatial distributions and flooding mechanisms, the hydrologic and hydraulic models have been calibrated to a degree of certainty.

9. HISTORIC FLOOD MODELLING – SENSITIVITY ANALYSIS

The sensitivity of the hydraulic model to assumed entrance conditions during historic events was assessed simultaneously to calibration and validation being undertaken based upon these events.

A summary of the model scenarios is found in Appendix D.

9.1. Wagonga Inlet

9.1.1. Model Scenarios

The following sensitivity analysis were undertaken to establish the variation in historic flood levels that may occur for:

- Training Wall Gaps – The percentage of the lateral area of the training wall assumed to be pervious due to the gaps between the rocks was assessed for:
    - 100% impervious; and
    - 50% impervious.
- Tide level (without 0.1m decrease)

The sensitivity analysis was undertaken on the 2008 calibration event for tidal conditions.

9.1.2. Results

The water levels at Barlows Bay and Narooma Public wharf were found to be insensitive to variations in the impervious percentage of the training walls in the hydraulic model. Increasing the impervious percentage to 100% resulted in an average difference of less than 0.01 m at both locations, when compared to an impervious percentage of 90%. Decreasing the impervious percentage to 50% likewise resulted in an average difference of less than 0.01 m at both locations.

Varying the tide level (to remove the 0.1 m decrease), consistently resulted in higher water levels modelled at Barlows Bay and Narooma Public Wharf compared to the hydraulic model results presented in Section 8. When compared to the recorded water level, the modelled water level was consistently higher, by an average of 0.05 m at both locations. At Barlows Bay, this resulted in increases to both the high and the low tide level. However, at Narooma Public Wharf the increase in water level predominantly occurred on the high tide whilst coinciding with the low tide recorded.

9.1.3. Discussion

From the sensitivity analysis it was concluded that the assumed impervious percentage of the training wall was immaterial to the water level modelled within Wagonga Inlet.

The tide level was found to result in a relative difference, however coinciding the modelled results with the recorded level at high tide (as is the case in the base case, presented in Section 8) was prioritised instead of coinciding the low tide.

9.2. Kianga

9.2.1. Model Scenarios

The following sensitivity analysis were undertaken to establish the variation in historic flood levels that may occur for

- Initial Water Level (IWL) – Sensitivity to the assumed initial water level within Kianga Lake was assessed for:
  - *IWL = 2.0 m AHD*, which corresponds with the trigger level required to initiate an artificial entrance breakout, as discussed in Section 2.9.2.1;
  - *IWL = 1.0 m AHD;*
- ICOLL Entrance Constant – Sensitivity to the:
  - *Entrance Open* for the duration of the event;
  - *Entrance Closed* for the duration of the event;
- ICOLL Entrance Breakout Duration
  - 2 hours;
  - 6 hours;
  - 12 hours.

The sensitivity analysis was undertaken on the 2010 calibration event.

9.2.2. Results

The calibration locations listed in Table 22 were found to be insensitivity to all the scenarios investigated. The impacts of the scenarios investigated were found to occur elsewhere in the catchment, as discussed in the following.

9.2.2.1. IWL

The hydraulic model was relatively insensitive to initial water levels within the lake. No variation in peak flood levels was observed upstream of Dalmeny Drive. Downstream of Dalmeny Drive, the variation in peak flood level was minimal, less than ± 0.05 m.

Table 24: Kianga Lake – 2010 Calibration Sensitivity – Initial Water Level

Location	Base Case	Initial Water Level 1.0 m AHD	Initial Water Level 2.0 m AHD
Channel between Dalmeny Drive and sand berm			
Peak Flood Height (m AHD)	2.05	2.05	2.01
Impact vs Base Case (m)	N/A	0.01	-0.04
Upstream of Dalmeny Drive			
Peak Flood Height (m AHD)	2.84	2.84	2.84
Impact vs Base Case (m)	N/A	0.00	0.00

9.2.2.2. ICOLL Entrance Constant

Sensitivity to open verse closed entrance conditions was limited to the area downstream of the Kianga Sewage Treatment Plant (STP). Generally, the greatest impact was observed in the channel between Dalmeny Drive and the sand berm. Upstream of Dalmeny Drive the impact was found to be less due, to the bridge acting as more of an hydraulic control structure than the sand berm in larger events. The variation in extent between the two scenarios was minimal. For the closed entrance scenario, flooding extended further to the north and south of the channel between Dalmeny Drive and the sand berm.

Table 25: Kianga Lake – 2010 Calibration Sensitivity – ICOLL Entrance Constant

Location	Base Case	Entrance Open	Entrance Closed
Channel between Dalmeny Drive and sand berm			
Peak Flood Height (m AHD)	2.05	1.33	2.70
Impact vs Base Case (m)	N/A	-0.72	0.65
Upstream of Dalmeny Drive			
Peak Flood Height (m AHD)	2.84	2.84	3.21
Impact vs Base Case (m)	N/A	0.00	0.37

9.2.2.3. ICOLL Entrance Variable

The hydraulic model was relatively insensitive to entrance breakout duration. No variation in peak flood levels was observed upstream of Dalmeny Drive. Downstream of Dalmeny Drive, the variation in peak flood level was minimal, less than ± 0.1 m.

Table 26: Kianga Lake – 2010 Calibration Sensitivity – ICOLL Entrance Variable

Location	Base Case	Breakout Duration 2 hr	Breakout Duration 6 hr	Breakout Duration 12 hr
Channel between Dalmeny Drive and sand berm				
Peak Flood Height (m AHD)	2.05	2.02	2.07	2.10
Impact vs Base Case (m)	N/A	-0.03	0.02	0.06
Upstream of Dalmeny Drive				
Peak Flood Height (m AHD)	2.84	2.84	2.84	2.84
Impact vs Base Case (m)	N/A	0.00	0.00	0.00

9.2.3. Discussion

From the sensitivity analysis it was concluded that the assumed initial water level and entrance breakout duration was immaterial to the peak flood level modelled within the Kianga Lake catchment for the 2010 storm event.

9.3. Dalmeny

9.3.1. Model Scenarios

The following sensitivity analysis were undertaken to establish the variation in historic flood levels that may occur for

- Initial Water Level (IWL) – Sensitivity to the assumed initial water level within Mummuga Lake was assessed for:
    - *IWL = 1.175 m AHD*, which corresponds with the trigger level required to initiate an artificial entrance breakout, as discussed in Section 2.9.3.1;
- ICOLL Entrance Constant – Sensitivity to the:
    - *Entrance Open* for the duration of the event;
    - *Entrance Closed* for the duration of the event;
- ICOLL Entrance Breakout Duration:
    - 2 hours;
    - 6 hours;
    - 12 hours.

The sensitivity analysis was undertaken on the 2010 calibration event prior to the 60% reduction in rainfall volume.

9.3.2. Results

The calibration locations at Acacia Close and the junction of Mort Ave – Binalong St were found to be insensitive to all the scenarios investigated. Due to the proximity to the entrance sand berm, the calibration locations at Mort Avenue Fire Station and the Pedestrian Footbridge were subject to varying levels of sensitivity, as discussed below.

9.3.2.1. IWL

The hydraulic model was relatively insensitive to initial water levels within the lake, with variations less than ± 0.02 m.

Table 27: Mummuga Lake – 2010 Calibration Sensitivity – Initial Water Level

Location	Base Case	Initial Water Level – 1.175 m AHD
Dalmeny – Mort Ave Fire Station (ID 42)		
Peak Flood Height (m AHD)	2.46	2.44
Impact vs Base Case (m)	N/A	-0.02
Dalmeny – Pedestrian bridge (ID 45)		
Peak Flood Height (m AHD)	2.20	2.18
Impact vs Base Case (m)	N/A	-0.01

9.3.2.2. ICOLL Entrance Constant

Sensitivity to open verse closed entrance conditions was limited to the lake area downstream of the Princes Highway. Generally, the hydraulic model was more sensitive to the entrance closed than the entrance open for the duration of the simulation. The open entrance produced lower peak flood levels and the closed entrance produced higher peak flood levels comparative to the base case.

Comparing the approximated observed flood levels (listed in Table 22) against the entrance open scenario at the locations listed in Table 28, the hydraulic model resulted in higher peak flood levels than observed. As discussed previously, this was attributed to the photographs not capturing the peak flood level.

The variation in levels was relatively constant across the lake area, although the peak flood extent did not vary significantly.

Table 28: Mummuga Lake – 2010 Calibration Sensitivity – ICOLL Entrance Constant

Location	Base Case	Entrance Open	Entrance Closed
Dalmeny – Mort Ave Fire Station (ID 42)			
Peak Flood Height (m AHD)	2.46	2.33	2.99
Impact vs Base Case (m)	N/A	-0.13	0.53
Dalmeny – Pedestrian bridge (ID 45)			
Peak Flood Height (m AHD)	2.20	2.10	2.87
Impact vs Base Case (m)	N/A	-0.10	0.68

9.3.2.3. ICOLL Entrance Variable

The calibration locations were relatively insensitive to variations in entrance breakout duration by ± 2 hours from the base case (that conservatively adopted the 4 hour breakout duration, with the breakout duration reported in Reference 12 given as 2 to 4 hours). The 12 hour breakout duration was investigated as a 'worse-case' scenario, which produced variations in peak flood levels less than 0.10 m.

Table 29: Mummuga Lake – 2010 Calibration Sensitivity – ICOLL Entrance Variable

Location	Base Case	Breakout Duration 2 hr	Breakout Duration 6 hr	Breakout Duration 12 hr
Dalmeny – Mort Ave Fire Station (ID 42)				
Peak Flood Height (m AHD)	2.46	2.44	2.47	2.56
Impact vs Base Case (m)	N/A	-0.01	0.02	0.10
Dalmeny – Pedestrian bridge (ID 45)				
Peak Flood Height (m AHD)	2.20	2.18	2.21	2.28
Impact vs Base Case (m)	N/A	-0.01	0.01	0.09

9.3.3. Discussion

From the sensitivity analysis it was concluded that the assumed initial water level and entrance breakout duration was immaterial to the peak flood level modelled within the Mummuga Lake catchment for the 2010 storm event. In smaller rainfall events, peak flood levels may be sensitive to initial water level and entrance conditions assumptions. However in large rainfall events, the volume of rainfall is a more significant factor influencing peak flood levels.

10. DESIGN FLOOD MODELLING – OCEANIC COINCIDENCE

10.1. Background

Flooding in tidal waterways may occur due to a combination of oceanic inundation and catchment flooding derived from the same storm cell. The combined impact of these two sources on overall flood risk varies significantly with distance from the ocean and the degree of ocean influence, which is in turn affected by the estuary's entrance conditions. The *Development of Practical Guidance for Coincidence of Catchment Flooding and Oceanic Inundation*, hereon in referred to as the guide, presents a multivariate approach to translating the real-world environment for hydraulic modelling purposes. A sequential road-map is provided quantifying a number of parameters likely to affect flood mechanisms particularly in the context of peak flood levels and velocities. Parameters include the waterway entrance type, degree of accuracy required in the results and geographical location. The approach facilitates an optimum solution between the conflicting constraints of maintaining consistency in the modelling methodology while avoiding over-conservativeness in results.

The specific analysis for each catchment is provided in Appendix D.

10.2. Modelling Approach

The guide recognises the differing requirements of studies. Consequently, it accommodates three approaches to deriving ocean boundary conditions and design flood levels for flood modelling investigations in coastal waterways. A simplistic approach, a general approach and a detailed approach are proposed. The simplistic approach is considered suitable for analysis of small scale site specific developments where a cost effective but conservative method is warranted. The guide recommends either the general or detailed approaches for strategic studies undertaken for local government or with state government funding unless agreed to in writing by the local council and the funding provider, if state government.

For general or detailed approaches, the combination of catchment flooding and ocean inundation scenarios is shown in Table 30.

Table 30: Combinations of Catchment Flooding and Oceanic Inundation Scenarios (Table 8.1 within *Modelling the interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways – OEH Draft 2014)*

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

10.3. Geographic Location

Report No. MHL 1881 (*NSW Ocean Water Levels – Manly Hydraulics Laboratory, 2011*) documents a consistent tidal water level increase from south to north along the NSW coastline. Consequently, the guide splits the coastline into two regions based on whether the study area is north or south of Crowdy Head. Design ocean still water levels are obtained from the Fort Denison gauge in Sydney Harbour. This provides peak elevated ocean levels for design purposes (rounded up to nearest 0.05 m) and these levels are adjusted with an additional 0.1 m for regions situated north of Crowdy head. The site of this study is located to the south of Crowdy head.

10.4. Waterway Entrance Type

The guide provides a framework within which the interaction of catchment flooding and oceanic inundation for the various classes of estuary waterways found in NSW (as well as associated ocean boundary conditions) can be assessed. The degree of influence of coastal processes on flooding within a waterway depends on the connectivity of the waterway to the ocean. This in turn depends on the type of estuary linked to the coastal waterway, the morphology and training of the waterway entrance and any management intervention. The guide classifies waterways into five Groups which are in turn simplified in three types, namely: Type A, Type B and Type C. Type A includes open oceanic embayments, tide dominated estuaries and trained entrances draining directly to the ocean or to bays. Type B includes fully trained wave dominated entrances and Type C includes ICOLLS and estuaries with untrained entrances. The categorisation is catchment specific and can be guided by the NSW Government 'Estuaries of NSW' website (http://www.environment.nsw.gov.au/estuaries/list.htm), which provided classifications based on Roy *et al* (2001) (Reference 22); in the case of Wagonga Inlet Type B was selected, and in the case of Kianga Lake, Mummuga Lake and Duck Pond Type C was selected. Kianga Lake and Mummuga Lake are classified as Group 4 – ICOLL at 'Estuaries of NSW', however Wagonga Inlet is classified as Group 3 – Wave Dominated Estuaries and could possibly fall into either Type A or Type B. The guide calls for a conservative approach when deciding on the waterway entrance type and therefore Type B was adopted.

11. DESIGN FLOOD MODELLING – RAINFALL CRITICAL DURATION

11.1. Introduction

To determine the critical storm duration for various parts of the catchments and inform the adopted design flood modelling, modelling of the 1% AEP rainfall event with a constant 0.6 m AHD ocean level was undertaken for a range of design storm durations from 25 minutes to 72 hours, using temporal patterns from AR&R (1987). An envelope of the model results was created, and the storm duration producing the maximum flood depth was determined for each grid point within the study areas.

Additionally, the critical storm duration was determined for the PMF event for a range of storm durations, ranging from 30 minutes to 6 hours using the GSDM method and from 24 hours to 96 hours using the GSAM method. Similarly, an envelope of the model results was created, and the storm duration producing the maximum flood depth was determined for each grid point within the study areas.

11.2. Wagonga

The results of the assessment described in Section 11.1 showed that either the 9 hour or the 36 hour design storm durations were critical across the whole Wagonga catchment for the 1% AEP event. The 36 hour design storm duration was mostly critical within the volume dominated Inlet basin area while the 9 hour design storm duration was critical along the tributaries discharging into the Inlet that intersect Wagonga Scenic Drive and Narooma Flat. The peak flood level difference at a number location, between the two durations was ± 0.20 m, a significant enough variation to warrant the assessment of both duration events. Therefore it was determined appropriate to adopt an embedded design storm for the entire catchment, using the 9 hour design storm burst within the 36 hour design storm, adjusted to maintain the correct 36 hour total rainfall depth. This method is described in References 25, 26 and 27.

For the PMF it was found that either the 2 hour or the 6 hour design storm durations were critical across the whole catchment. The 6 hour design storm duration was mostly critical within the Inlet basin area while the 2 hour design storm duration was critical along the tributaries discharging into the Inlet. An envelope of the two durations was adopted to determine the peak results across the catchment.

11.3. Kianga

The initial assessment found that either the 2 hour or the 9 hour design storm durations were critical across the whole Kianga Lake catchment for the 1% AEP event. The 9 hour design storm duration was mostly critical within the lake area, downstream of the Kianga Sewage Treatment Plant (STP) and the 2 hour design storm duration was critical across the remaining area. The peak flood level difference between the two durations was also fairly significant at ± 0.36 m. Again this warranted the assessment of both duration events and it was appropriate to adopt an embedded design storm for the entire catchment, using the 2 hour design storm burst within the 9 hour design storm, adjusted to maintain the correct 9 hour total rainfall depth.

For the PMF it was found that the 45 minute, 1 hour or the 2 hour design storm durations were critical across the whole Kianga Lake catchment. The 45 minute design storm duration was mostly critical in the southern watercourse that discharges directly into the ocean without flowing into Kianga Lake. Downstream of the Kianga STP, the critical storm duration was the 2 hour event. In the area adjacent to and upstream of the Kianga STP, the critical storm duration was the 1 hour event. An envelope of the 45 minute, 1 and 2 hour event results was adopted to determine the peak results across the catchment.

11.4. Dalmeny

Within the Duck Pond catchment area, the 2 hour and the 9 hour design storm durations were critical across the whole catchment for the 1% AEP event. The 9 hour design storm duration was mostly critical within the entrance and lake area and the 2 hour design storm duration was critical across the remaining area. The peak flood level difference between the two durations was ± 0.15 m, again a significant enough variation to warrant the assessment of both storm durations. An embedded design storm for the entire catchment was adopted, using the 2 hour design storm burst within the 9 hour design storm, adjusted to maintain the correct 9 hour total rainfall depth.

The 2 hour, 9 hour or 48 hour design storm durations were critical across the whole Mummuga Lake catchment area for the 1% AEP event. The 48 hour design storm duration was mostly critical within the entrance and volume dominated lake area. Along the tributaries that cross the Princes Highway and discharge into the lake the 9 hour event was critical. Within the residential areas subject to overland flow (and not affected by backwater from the lake) the critical storm burst was the 2 hour.

An envelope of peak flood level produced by the 2, 9 and 48 hour storm durations was adopted across the Mummuga Lake catchment.

Within the Duck Pond catchment area, either the 30 minute or the 1 hour design storm durations were critical across the whole catchment for the PMF event. With either the 1 hour, 2 hour or 6 hour design storm durations critical across the whole Mummuga Lake catchment in the PMF. An envelope of the durations was adopted to determine the peak results across the catchment.

12. DESIGN FLOOD MODELLING – RESULTS

12.1. Wagonga Inlet

The design events investigated include the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events and the PMF event. Figure F 1 provides an overview of key result locations and summary of the results at key locations is provided below.

The results from this study are presented as:

- Peak level profiles in Figure F 2 and Figure F 3;
- Flow and level hydrographs in Figure F 4; and
- Peak flood depths and level contours in Figure F 5 to Figure F 11.

Table 31: Wagonga Inlet – Peak Flood Levels (m AHD) at Key Locations

Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Barlows Bay	1.1	1.1	1.2	2.0	2.1	2.2	3.3
Narooma Public Wharf	1.0	1.0	1.1	1.9	2.0	2.1	3.0
Narooma - Corner of Lynch St and Nichelsen St	1.1	1.2	1.2	2.0	2.1	2.2	3.3
Narooma - Corner of Barker Pde and McMillan Rd	1.6	1.6	1.6	2.0	2.1	2.2	3.2

Flooding in the 20% AEP is mainly contained to the main waterway areas with the exception of inundation occurring in the yards of properties on Riverview Road in Barlows Bay. Relatively shallow overland street inundation also occurs through the Narooma Flat area in the vicinity of McMillan Road and Bill Smyth Oval. Pilot Street is also overtopped by shallow depths (less than 0.3 m) between Bay Street and Narooma Crescent. For each design event, depth and extent of inundation increases with properties in the vicinity of Lynch Street becoming inundated in the 5% AEP event.

Wide spread inundation occurs through the Narooma Flat area in the 2% AEP, with a maximum depth of 0.7 m and an average of 0.3 m. The extent of inundation up to the PMF extends as far as McMillan Road and Bill Smyth Oval, with depths in excess of 1 – 2 m through the Narooma Flat area in the PMF event.

Table 32: Wagonga Inlet – Peak Flows (m^3/s) at Key Locations

Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Wagonga Heads	434.2	452.6	479.8	619.6	653.6	711.0	1391.0
Princes Highway	384.5	402.5	431.9	557.0	613.6	699.9	805.5
Downstream Freshwater Bay	323.7	429.3	550.0	701.7	826.1	958.5	2017.6
Downstream Punkally Creek	124.4	157.8	196.0	230.0	273.2	316.2	731.1
Downstream Junction of Burrimbidgee Ck and Billabilba Ck	283.9	344.5	424.4	511.8	598.3	685.0	1480.2

12.2. Kianga

The design events investigated include the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events and the PMF event. Figure G 1 provides an overview of key result locations and summary of the results at key locations is provided below.

The results from this study are presented as:

- Peak level profiles in Figure G 2 and Figure G 3;
- Flow and level hydrographs in Figure G 4; and
- Peak flood depths and level contours in Figure G 5 to Figure G 11.

Table 33: Kianga Catchment – Peak Flood Levels (m AHD) at Key Locations

Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Downstream of Kianga Lake (Traversing Dalmeny Drive)	2.4	2.6	2.9	3.2	3.4	3.5	4.4
Kianga Creek (Downstream of STP)	2.5	2.7	2.9	3.3	3.4	3.6	4.6
Kianga Creek (Downstream of the Princes Highway)	6.2	6.3	6.4	6.6	6.8	7.0	7.9
Kianga Creek (Upstream of the Princes Highway)	7.2	7.5	7.7	7.8	7.9	8.0	8.7
Kianga Southern Watercourse (Dalmeny Drive)	6.2	6.3	6.3	6.4	6.4	6.5	6.7

During the 20% AEP Charley's Gully, a tributary to Kianga Creek, inundates the Princes Highway with depths of up to 0.5 m. Widespread inundation occurs at the Kianga Creek crossing in the 5% AEP with depths increasing to 0.8 m in the 1% AEP event. The ponds at the Kianga STP are also inundated in the 20% AEP event, with wider inundation occurring in the 0.5% AEP event. The waterway to the south of Kianga Lake inundates the side road off Dalmeny Drive in the 5% AEP with depths up to 0.3 m. Dalmeny Drive is also inundated by Kianga Lake to depths less than 0.3 m in the 5% AEP event. The yards of properties on Lakeside Drive begin to be inundated in the 20% AEP event, with wide spread flooding occurring in the 0.5% AEP to depths of 1 m.

Table 34: Kianga Catchment – Peak Flows (m^3/s) at Key Locations

Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Downstream of Kianga Lake (Traversing Dalmeny Drive)	29.1	41.2	52.0	87.3	108.9	138.5	344.8
Kianga Creek (Downstream of STP)	65.5	80.0	100.6	122.4	141.5	162.4	375.5
Kianga Creek (Traversing Princes Highway)	58.4	73.7	92.7	113.5	132.9	155.1	386.6
Kianga Southern Watercourse (Dalmeny Drive)	3.7	5.5	7.9	10.3	12.8	15.7	41.8

12.3. Dalmeny

The design events investigated include the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events and the PMF event. Figure H 1 provides an overview of key result locations and summary of the results at key locations is provided below.

The results from this study are presented as:

- Peak level profiles in Figure H 2 and Figure H 3;
- Flow and level hydrographs in Figure H 4; and
- Peak flood depths and level contours in Figure H 5 to Figure H 11.

Table 35: Dalmeny Catchment – Peak Flood Levels (m AHD) at Key Locations

Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Pedestrian Footbridge	2.0	2.2	2.4	2.6	2.8	3.0	3.8
Princes Hwy crossing Lawlers Creek	3.1	3.2	3.4	3.5	3.7	3.8	4.8
Princes Hwy crossing Spring Creek	18.0	18.6	18.8	18.9	19.0	19.0	19.6
Mort Ave crossing Spring Creek	2.0	2.2	2.5	2.7	2.9	3.1	4.0

Mort Avenue at the rural fire station is inundated to depths of up to 0.4 m in the 20% AEP event, with depths increasing to 1.5 m in the 1% AEP event. Properties on the southern side of Mort Avenue are also inundated in the 20% AEP event to a depth of up to 0.5 m and up to 1.8 m in the 1% AEP event. During the 1% AEP event inundation spreads to Emma Close in the west and Thompson Parade in the East. Dalmeny Drive at Binalong St is overtopped by shallow depths of up to 0.15 m during the 20% AEP event with widespread inundation of up to 0.5 m depth during the 1% AEP. The yards of properties in Myuna Street backing on to the lake experience inundation in the 10% AEP event. Acacia Close is also overtopped by 0.3 m depth during the 1% AEP event.

Dalmeny Drive at Duck Pond is first overtopped in the 5% AEP event with depths up to 0.2 m, increasing to 0.5m in the 1% AEP event.

Table 36: Dalmeny Catchment – Peak Flows (m^3/s) at Key Locations

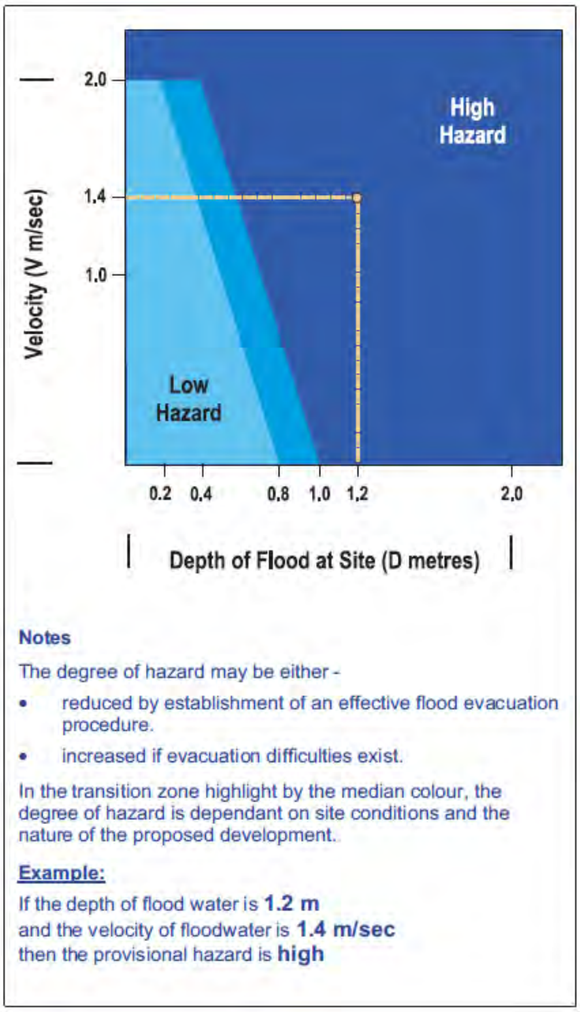
Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Pedestrian Footbridge	32.3	51.0	80.0	120.5	157.0	194.0	378.2
Princes Hwy crossing Lawlers Creek	87.1	105.7	130.0	156.5	181.9	209.1	607.7
Princes Hwy crossing Spring Creek	0.0	7.3	21.2	35.2	44.9	54.2	226.8
Mort Ave crossing Spring Creek	9.2	14.2	30.4	47.3	60.3	71.6	271.0

13. DESIGN FLOOD MODELLING – RESULTS ANALYSIS

13.1. Provisional Hydraulic Hazard Categorisation

Provisional Hydraulic Hazard categories were determined in accordance with Appendix L of the NSW Floodplain Development Manual, the relevant section of which is shown in Diagram 18. For the purposes of this report, the transition zone presented in Diagram 18 (L2) is considered to be high hazard.

Diagram 18: (L2) Provisional Hydraulic Hazard Categories (NSW State Government, 2005)



13.2. Hydraulic Categorisation

The hydraulic categorises, namely floodway, flood storage and flood fringe, are described in the Floodplain Development Manual (NSW State Government, 2005). However, there is no technical definition of hydraulic categorisation that would be suitable for all catchments, and different approaches are used in different studies and by different authorities, based on the specific features of the study catchment in question.

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

- *Floodway* is defined as areas where:
    - the peak value of velocity multiplied by depth (V x D) > 0.25 m^2/s **AND** peak velocity > 0.25 m/s, **OR**
    - peak velocity > 1.0 m/s **AND** peak depth > 0.15 m

  The remainder of the floodplain is either Flood Storage or Flood Fringe,
- *Flood Storage* comprises areas outside the floodway where peak depth > 0.5 m; and
- *Flood Fringe* comprises areas outside the Floodway where peak depth < 0.5 m.

13.3. Discussion – Hazard and Hydraulic Categories

13.3.1. Wagona Inlet

- Provisional hydraulic hazard in Figure F 12 to Figure F 14;
- Provisional hydraulic categorisation in Figure F 15 to Figure F 17;
- Preliminary flood emergency response classification of communities in Figure F 18; and
- Preliminary flood planning areas in Figure F 19.

During the 5% AEP event, high hazard areas are confined to the Inlet waterway area, with low hazard areas within Narooma Flat. The low hazard area extends over a greater area of Narooma Flat in the 1% AEP event and high hazard areas begin to extend into Narooma Flat from Riverside Drive up to McMillian Road and Brice Street. The PMF event resulted in very few areas of low hazard, with the whole Narooma Flat area classified as high hazard.

Portions of the lake act as a floodway during the 5% AEP event. Typically floodways are a continuous area of flow conveyance, in this case the slow moving water in the lake results in a break in the floodway. Other areas have been classified as flood storage and flood fringe.

13.3.2. Kianga

- Provisional hydraulic hazard in Figure G 12 to Figure G 14;
- Provisional hydraulic categorisation in Figure G 15 to Figure G 17;
- Preliminary flood emergency response classification of communities in Figure G 18; and
- Preliminary flood planning areas in Figure G 19.

The waterways within the Kianga catchment were classified high hazard in all events and the fringe areas were classified as low hazard. As the magnitude of the storm event increases (from the 5% AEP event, up to the PMF) the high hazard area extends further covering the majority of flood prone area.

Portions of the lake act as a floodway during the 5% AEP event. Typically floodways are a continuous area of flow conveyance, in this case the slow moving water in the lake results in a break in the floodway. Other areas have been classified as flood storage and flood fringe.

13.3.3. Dalmeny

- Provisional hydraulic hazard in Figure H 12 to Figure H 14;
- Provisional hydraulic categorisation in Figure H 18 to Figure H 17;
- Preliminary flood emergency response classification of communities in Figure H 18; and
- Preliminary flood planning areas in Figure H 19.

During the 5% AEP event, high hazard areas are located in the Lake and waterway areas, as well as localised high hazard in the residential area between Mort Avenue, Emma Close and Tatiara Street. The backyards of properties adjacent to Mummuga Lake along Myuna Street are affected by low hazard flooding in the 5% AEP event. In the 1% AEP event, the low hazard area within properties along Myuna Street become high hazard areas and more properties are affected by high hazard within the residential area between Mort Avenue, Emma Close and Tatiara Street. The PMF event increases the extent of high hazard affectation in the areas identified as high hazard in the 1% AEP event.

Portions of the lake act as a floodway during the 5%, 1% AEP and PMF events. Typically floodways are a continuous area of flow conveyance, in this case the slow moving water in the lake results in a break in the floodway. Other areas have been classified as flood storage and flood fringe.

13.4. Preliminary Flood Emergency Response Classification of Communities

The Floodplain Development Manual (NSW State Government, 2005) requires flood studies to address the management of continuing flood risk to both existing and future development areas. As continuing flood risk varies across the floodplain so does the type and scale of emergency response problem and therefore the information necessary for effective Emergency Response Planning (ERP). Classification provides an indication of the vulnerability of the community in flood emergency response and identifies the type and scale of information needed by the State Emergency Services (SES) to assist in emergency response planning (ERP).

Criteria for determining flood ERP classifications and an indication of the emergency response required for these classifications are provided in the Floodplain Risk Management Guideline, 2007 (Flood Emergency Response Planning: Classification of Communities). Table 37 summarises the response required for areas of different classification. However, these may vary depending on local flood characteristics and resultant flood behaviour, i.e. in flash flooding or overland flood areas.

Table 37: Response Required for Different Flood ERP Classifications

Classification	Response Required		
	Resupply	Rescue/Medivac	Evacuation
High Flood Island	Yes	Possibly	Possibly
Low Flood Island	No	Yes	Yes
Area with Rising Road Access	No	Possibly	Yes
Area with Overland Escape Routes	No	Possibly	Yes
Low Trapped Perimeter	No	Yes	Yes
High Trapped Perimeter	Yes	Possibly	Possibly
Indirectly Affected Areas	Possibly	Possibly	Possibly

In undertaking this assessment for the coastal inlet catchments, all roads have been considered trafficable in a flood event, both paved and dirt. The suitability for use of particularly dirt roads should be reviewed with the SES.

13.4.1. Wagona Inlet

Mapping of the preliminary flood emergency response classification of communities for the Kianga catchment is shown on Figure F 18. Narooma Flat is classified as Low Flood Island as the practical access is cut and they are inundated during an event. The properties on Riverview Road, adjacent to Barlows Bay are classified as Rising Road Access as the properties are inundated but flood free access roads provide a retreat to flood free land.

13.4.2. Kianga

Mapping of the preliminary flood emergency response classification of communities for the Kianga catchment is shown on Figure G 18. The majority of Kianga is classified as High Trapped Perimeter Area as the practical access roads are inundated during a flood event but there is enough flood free land to retreat and the direct risk to life is limited. The properties on Lakeside Drive directly backing on to Kianga Lake are classified as Rising Road Access as the properties are inundated but flood free access roads provide a retreat to flood free land.

13.4.3. Dalmeny

Mapping of the preliminary flood emergency response classification of communities for the Dalmeny catchment is shown on Figure H 18. The properties on Myuna Street and Nioka Street, properties between Haddrill Parade and Cresswick Parade and properties adjacent to Duck Pond on Eucalyptus Drive and Maculata Circuit are classified as Rising Road Access. This is due to parts of the property (although not necessarily the house or building on the property) subject to inundation but flood free access roads provide a retreat to flood free land. The properties on Acacia Close are classified as High Trapped Perimeter Area as the practical access roads are inundated during a flood event but there is enough flood free land to retreat to and the direct risk to life is limited. The properties in the vicinity of Mort Avenue, Emma Close and Tatiara Street, have their access cut and become inundated during a flood event. They are therefore classified as Low Flood Island. The properties on Tatiara Street backing on to Thompson Parade are classified as Areas with Overland Escape Routes as the properties are inundated but flood free access for retreat to flood free land is provided by an overland escape route.

13.5. Road Access

The catchments present a number of challenges for emergency response as significant evacuation routes can become inundated and blocked to traffic during an event. Current revisions being undertaken on Australian Rainfall and Runoff discuss appropriate safety criteria for vehicles (Engineers Australia, 2011). The criteria proposed, as of February 2011, are presented in Table 38.

Table 38: Draft interim criteria for stationary vehicular stability (Engineers Australia, 2011)

Class of vehicle	Limiting still water depth	Limiting high velocity flow depth (velocity >= 3 m/s)	Limiting Velocity	Equation of stability *
Small passenger	0.3	0.1	3.0	$DV \leq 0.3$
Large passenger	0.4	0.15	3.0	$DV \leq 0.45$
Large 4WD	0.5	0.2	3.0	$DV \leq 0.6$

** DV refers to the multiplication of depth and velocity*

The application of this criteria allows an assessment of the trafficability of key roads within the catchments to be undertaken.

It should be noted that the critical storm duration used for the design events is based upon the storm duration that produces the maximum flood level. This storm duration may not be the same as the storm duration that would produce the longest time of inundation for the road crossings. It is therefore possible for the roads to be cut for longer periods than those estimated above, or possibly for multiple storm peaks to cut the road at separate times.

13.5.1. Wagonga Inlet

Table 39: Wagonga Inlet – Road Trafficability (Duration above depth)

Location	Duration (hr) Depth > 0.3 m	Duration (hr) Depth > 0.4 m	Duration (hr) Depth > 0.5 m
20% AEP Event			
Princes Highway (from Riverside Dr to Wharf St)	0.0	0.0	0.0
10% AEP Event			
Princes Highway (from Riverside Dr to Wharf St)	0.0	0.0	0.0
5% AEP Event			
Princes Highway (from Riverside Dr to Wharf St)	6.0	4.4	2.8
2% AEP Event			
Princes Highway (from Riverside Dr to Wharf St)	7.2	5.9	4.2
1% AEP Event			
Princes Highway (from Riverside Dr to Wharf St)	8.7	7.6	6.5

13.5.2. Kianga

Table 40: Kianga Catchment – Road Trafficability (Duration above depth)

Location	Duration (hr) Depth > 0.3 m	Duration (hr) Depth > 0.4 m	Duration (hr) Depth > 0.5 m
20% AEP Event			
Dalmeny Drive (Downstream of Kianga Lake)	0.0	0.0	0.0
Lakeside Drive (Residential Section)	0.0	0.0	0.0
Lakeside Drive (STP Section)	9.7	9.6	9.5
Princes Highway (Crossing Kianga Creek)	0.0	0.0	0.0
Dalmeny Drive (Kianga Southern Watercourse)	0.5	0.0	0.0
10% AEP Event			
Dalmeny Drive (Downstream of Kianga Lake)	0.0	0.0	0.0
Lakeside Drive (Residential Section)	0.0	0.0	0.0
Lakeside Drive (STP Section)	9.9	9.8	9.7

Princes Highway (Crossing Kianga Creek)	0.0	0.0	0.0
Dalmeny Drive (Kianga Southern Watercourse)	0.7	0.1	0.0
5% AEP Event			
Dalmeny Drive (Downstream of Kianga Lake)	0.0	0.0	0.0
Lakeside Drive (Residential Section)	0.0	0.0	0.0
Lakeside Drive (STP Section)	10.2	10.1	10.0
Princes Highway (Crossing Kianga Creek)	0.0	0.0	0.0
Dalmeny Drive (Kianga Southern Watercourse)	0.9	0.4	0.0
2% AEP Event			
Dalmeny Drive (Downstream of Kianga Lake)	0.9	0.0	0.0
Lakeside Drive (Residential Section)	0.0	0.0	0.0
Lakeside Drive (STP Section)	10.8	10.7	10.6
Princes Highway (Crossing Kianga Creek)	0.3	0.0	0.0
Dalmeny Drive (Kianga Southern Watercourse)	1.2	0.6	0.0
1% AEP Event			
Dalmeny Drive (Downstream of Kianga Lake)	1.5	1.0	0.0
Lakeside Drive (Residential Section)	0.0	0.0	0.0
Lakeside Drive (STP Section)	11.1	10.9	10.8
Princes Highway (Crossing Kianga Creek)	0.6	0.3	0.0
Dalmeny Drive (Kianga Southern Watercourse)	1.4	0.8	0.2
0.5% AEP Event			
Dalmeny Drive (Downstream of Kianga Lake)	2.0	1.6	1.2
Lakeside Drive (Residential Section)	0.0	0.0	0.0
Lakeside Drive (STP Section)	11.5	11.4	11.3
Princes Highway (Crossing Kianga Creek)	0.9	0.6	0.3
Dalmeny Drive (Kianga Southern Watercourse)	1.5	1.0	0.4

13.5.3. Dalmeny

Table 41: Dalmeny Catchment – Road Trafficability (Duration above depth)

Location	Duration (hr) Depth > 0.3 m	Duration (hr) Depth > 0.4 m	Duration (hr) Depth > 0.5 m
20% AEP Event			
Dalmeny Drive (Downstream of Duck Pond)	0.0	0.0	0.0
Mort Avenue (Fire Station)	8.3	0.0	0.0
Mort Avenue (Downstream of Spring Creek)	0.8	0.0	0.0
Princes Highway (Downstream of Spring Creek)	0.0	0.0	0.0
Princes Highway (Downstream of Lawlers Creek)	0.0	0.0	0.0
10% AEP Event			
Dalmeny Drive (Downstream of Duck Pond)	0.0	0.0	0.0
Mort Avenue (Fire Station)	13.9	10.5	7.2
Mort Avenue (Downstream of Spring Creek)	2.8	0.0	0.0
Princes Highway (Downstream of Spring Creek)	1.3	0.0	0.0
Princes Highway (Downstream of Lawlers Creek)	0.0	0.0	0.0
5% AEP Event			
Dalmeny Drive (Downstream of Duck Pond)	0.3	0.0	0.0
Mort Avenue (Fire Station)	17.3	14.2	11.5
Mort Avenue (Downstream of Spring Creek)	3.9	1.3	0.0
Princes Highway (Downstream of Spring Creek)	2.6	1.4	0.5
Princes Highway (Downstream of Lawlers Creek)	0.0	0.0	0.0
2% AEP Event			
Dalmeny Drive (Downstream of Duck Pond)	0.9	0.2	0.0
Mort Avenue (Fire Station)	21.9	18.3	15.4
Mort Avenue (Downstream of Spring Creek)	5.1	2.1	1.1
Princes Highway (Downstream of Spring Creek)	3.8	2.4	1.4
Princes Highway (Downstream of Lawlers Creek)	0.0	0.0	0.0
1% AEP Event			
Dalmeny Drive (Downstream of Duck Pond)	1.1	0.6	0.0
Mort Avenue (Fire Station)	24.9	21.0	17.8
Mort Avenue (Downstream of Spring Creek)	6.4	3.3	1.8

Princes Highway (Downstream of Spring Creek)	5.0	3.6	2.2
Princes Highway (Downstream of Lawlers Creek)	0.0	0.0	0.0
0.5% AEP Event			
Dalmeny Drive (Downstream of Duck Pond)	1.3	0.8	0.4
Mort Avenue (Fire Station)	28.3	24.4	21.0
Mort Avenue (Downstream of Spring Creek)	9.0	4.9	2.5
Princes Highway (Downstream of Spring Creek)	6.4	5.0	3.0
Princes Highway (Downstream of Lawlers Creek)	0.0	0.0	0.0

14. DESIGN FLOOD MODELLING – SENSITIVITY ANALYSIS

14.1. Introduction

14.1.1. Background

The following sensitivity analyses were undertaken for the 1% AEP event to establish an understanding of the variability of design flood levels that may occur if different conditions or parameters were adopted:

- Manning's 'n' Roughness Value: The hydraulic roughness values were increased and decreased by 20% across the catchment;
- Time of Concentration: Sensitivity to the coincidence between the rainfall flood hydrograph and the ocean flood hydrograph were assessed by varying the coincidence by ± 3 hours;
- Ocean Boundary Condition: The ocean level was increased by 0.3 m;
- Climate Change (Sea Level Rise) (See Section 14.1.2): Sea level rise scenarios of 0.4 m and 0.9 m were assessed; and
- Climate Change (Rainfall Increase) (See Section 14.1.3): Sensitivity to rainfall/runoff estimates were assessed by increasing the rainfall intensities by 10%, 20% and 30%.

It should be noted that the parameters are not independent and adjustment of one parameter (such as the Manning's *n* value) would generally require adjustment of other values (such as impervious percentage) in order for the model to produce the same level at a given location. The aim of the sensitivity analysis is to give an estimate of the potential variability of design flood levels.

14.1.2. Sea Level Rise Scenario

The *NSW Sea Level Rise Policy Statement* was released by the NSW Government in October 2009. This Policy Statement was accompanied by the *Derivation of the NSW Government's sea level rise planning benchmarks* (NSW State Government, 2009) which provided technical details on how the sea level rise assessment was undertaken. Additional guidelines were issued separately by OEH, including the *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments 2010*.

The 2009 Policy Statement says that:

> *"Over the period 1870-2001, global sea levels rose by 20 cm, with a current global average rate of increase approximately twice the historical average. Sea levels are expected to continue rising throughout the twenty-first century and there is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that current trends will be reversed… The 4th Intergovernmental Panel on Climate Change in 2007 also acknowledged that higher rates of sea level rise are possible"*
> (NSW State Government, 2009)

Subsequent to the commencement of this Flood Study (and in progress), the NSW Government announced its Stage One Coastal Management Reforms on the 8th September 2012. As part of these reforms, the NSW Government no longer recommends state-wide sea level rise benchmarks for use by local councils, with councils having the flexibility to consider local conditions when determining local future hazards.

Accordingly, ESC, in partnership with Shoalhaven City Council, commissioned Whitehead and Associates (Environmental Consultants) Pty Ltd and Coastal Environment Pty Ltd to undertake the *South Coast Regional Sea-level Rise Planning and Policy Response Framework* Report. The exhibition draft was completed in July 2014.

The key scientific findings were summarised as:

- *There is no compelling reason to not adopt the projections of the Intergovernmental Panel on Climate Change (IPCC) as the most widely accepted and competent information presently available.*
- *Recent sea level rise trends offshore of New South Wales are similar to the global average.*
- *Recent changes in sea level have been very similar between Sydney and the Shoalhaven and Eurobodalla coasts.*
- *Future NSW sea-level rise will likely be similar to the global average with only minor variation.*

The report provided locally adjusted projections of sea level rise derived from the IPCC's Assessment Report 5. Within this framework four Representative Concentration Pathway (RCP) scenarios were prescribed. These were based upon pathways for atmospheric greenhouse gas and aerosol concentrations, combined with land use changes. The RCP's were denoted as RCP8.5, RCP6.0, RCP4.5 and RCP2.6 that were consistent with the W/m^2 of the radiative forcing increase comparative to the conclusion of the 21st century.

Table 42 shows the locally adjusted projections of sea level rise as extracted from the *South Coast Regional Sea-level Rise Planning and Policy Response Framework* Report.

Table 42: Locally Adjusted Projections of Sea-level rise for Shoalhaven and Eurobodalla

Year	RCP2.6			RCP4.5			RCP6.0			RCP8.5		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.03
2030	0.05	0.07	0.10	0.05	0.07	0.10	0.05	0.06	0.10	0.06	0.07	0.10
2040	0.10	0.12	0.16	0.09	0.12	0.16	0.08	0.12	0.15	0.11	0.14	0.17
2050	0.13	0.17	0.23	0.14	0.18	0.24	0.13	0.17	0.23	0.16	0.20	0.26
2060	0.15	0.21	0.30	0.18	0.24	0.32	0.16	0.22	0.30	0.21	0.29	0.37
2070	0.18	0.27	0.37	0.22	0.31	0.41	0.21	0.29	0.39	0.29	0.39	0.50
2080	0.21	0.31	0.44	0.25	0.38	0.51	0.25	0.36	0.50	0.35	0.49	0.64
2090	0.23	0.36	0.51	0.30	0.44	0.60	0.31	0.44	0.61	0.44	0.61	0.79
2100	0.25	0.41	0.58	0.34	0.50	0.69	0.36	0.53	0.72	0.53	0.74	0.98

ESC adopted the RCP6.0 High scenario at the Ordinary Council Meeting on the 25 November 2014.

Herein, the 2030, 2050, 2070 and 2100 projections were investigated as they relate to strategic planning horizons, to assess the sensitivity to projected sea level rise on the catchments' flood behaviour. The projected sea level rise values were 0.10m, 0.23m, 0.39m and 0.72m respectively.

14.1.3. Increased Rainfall Scenario

The Bureau of Meteorology has indicated that there is no intention at present to revise design rainfalls to take account of the potential climate change, as the implications of temperature changes on extreme rainfall intensities are presently unclear, and there is no certainty that the changes would in fact increase design rainfalls for major flood producing storms. There is some recent literature by CSIRO that suggests extreme rainfalls may increase by up to 30% in parts of NSW (in other places the projected increases are much less or even decrease); however this information is not of sufficient accuracy or certainty as yet (NSW State Government, 2007).

Any change in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment. It has also been suggested that the cyclone belt may move further southwards. The possible impacts of this on design rainfalls cannot be ascertained at this time as little is known about the mechanisms that determine the movement of cyclones under existing conditions.

Projected increases to evaporation are also an important consideration because increased evaporation would lead to generally dryer catchment conditions, resulting in lower runoff from rainfall. Mean annual rainfall is projected to decrease, which will also result in generally dryer catchment conditions. The influence of dry catchment conditions on river runoff is observable in climate variability using the Indian Pacific Oscillation (IPO) index (Westra et. al., 2009). Although mean daily rainfall intensity is not observed to differ significantly between IPO phases, runoff is significantly reduced during periods with fewer rain days.

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events within the catchments under warmer climate scenarios.

In light of this uncertainty, the NSW State Government (2007) advice recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be analysed.

15. DESIGN FLOOD MODELLING – SENSITIVITY RESULTS

15.1. Wagonga Inlet

15.1.1. Manning's 'n' Roughness Value

Peak flood level results were shown to be relatively insensitive to universal variations in the roughness parameter, Manning's 'n' value. Overall, the results were found to be within ± 0.2 m of design results across the whole catchment, with sensitivity generally decreasing towards the ocean. Furthermore, singularly increasing the roughness parameter applied to heavy density vegetation was found to increase peak flood levels by up to 0.1 m in the tributaries discharging into the Inlet Basin. Generally, it was found that the Inlet Basin area (from east of Hobbs Bay) was less sensitive to roughness variations than the tributaries flowing into the Inlet Basin (located to the west of Hobbs Bay). The peak flood extent was likewise found to be insensitive to variations in the roughness parameter.

15.1.2. Timing of Ocean Peak

Generally, varying the coincidence of the ocean peak with the rainfall peak affects the catchment according to distance from the outlet. This is due to the rainfall runoff peak occurring earlier with increasing distance from the outlet. Conversely, the timing of the ocean level peak occurs later with increasing distance from the outlet.

Varying the timing of the ocean peak to occur earlier and later resulted in little to no variation from design results, in locations upstream of the junction of Billabilba Creek and Burrmbidgee Creek, and up to 1km into Punkally Creek.

For other areas of the catchment, varying the timing of the ocean peak to occur 3 hours later than the design scenarios was found to result in a peak flood level variation of ± 0.1 m from design results. Generally, increases in the peak flood level occurred in the tributaries and decreases in the peak flood level occurred in the Inlet Basin and Narooma Flat. This is due to the rainfall runoff peak occurring earlier in the tributaries. As the tributaries were not the primary area of interest, the earlier rainfall runoff peaks in the tributaries do not coincide with ocean peaks in the design events. Whereas, in the 3 hour later ocean peak scenario the rainfall runoff peak coincides with a higher ocean level (that is the high tide that occurs 12 hours prior to the peak ocean level).

Varying the timing of the ocean peak to occur 3 hours earlier than the design scenarios was found to increase peak flood levels. Between the Princes Highway Bridge and Hobbs Bay, the increase in peak flood level was in the order of 0.25 m. From Hobbs Bay to the junction of Billabilba Creek and Burrmbidgee Creek, and from Hobbs Bay to approximately 1km up the Punkally Creek, the peak flood level increased by up to 0.35 m.

15.1.3. Climate Change (Sea Level Rise)

The sea level rise scenarios were found to propagate impacts as far inland as the junction of Billabilba Creek and Burrmbidgee Creek, and approximately 1km into Punkally Creek. The peak flood level impact was relatively uniform across the area of affectation, with very little dampening effect. In the 2030 scenario peak flood levels increased by 0.10 m and in the 2050 scenario (in which sea levels were increased by 0.23 m) the area of affectation was found to have a peak flood level increase of 0.22 m to 0.23 m compared to the design results. In the 2070 scenario (in which sea levels were increased by 0.39 m) the area of affectation was found to have a peak flood level increase of 0.38 m to 0.39 m compared to the design results. In the 2100 scenario (in which sea levels were increased by 0.72 m) the area of affectation was found to have a peak flood level increase of 0.70 m to 0.72 m compared to the design results.

15.1.4. Climate Change (Rainfall Increase)

Increasing the design rainfalls by 10%, 20% and 30% resulted in impacts on peak flood levels observed throughout the study area. Increasing the design rainfall by 10% resulted in increases to the peak flood level up to 0.25 m; 20% resulted in increases up to 0.5 m; and 30% resulted in increases up to 0.7 m. Increasing the design rainfalls also resulted in an expansion of the peak flood extent, predominantly within the Narooma Flat area. The 1% AEP event with a rainfall increase of 30% results in runoff approximately equivalent to a 0.2% AEP event under present day conditions.

15.2. Kianga

15.2.1. Manning’s ‘n’ Roughness Value

Peak flood level results were again shown to be relatively insensitive to universal variations in the roughness parameter, Manning’s ‘n’ value. Overall, the results were found to be within ± 0.15 m of design results across the whole catchment. Furthermore, singularly increasing the roughness parameter applied to heavy density vegetation was found to produce results within ± 0.10 m in the tributaries discharging into the Kianga Lake area, with the Lake area itself relatively insensitive. The peak flood extent was likewise found to be insensitive to variations in the roughness parameter.

15.2.2. Timing of Ocean Peak

Peak flood level results were found to be insensitive to variations in coincident time of peak ocean levels and peak rainfall runoff. This is due to the sand berm and Dalmeny Drive Bridge acting as the predominant hydraulic control mechanism at the interface between the ocean and Kianga Lake.

15.2.3. Climate Change (Sea Level Rise)

Sea level rise impacts were found in the Kianga Lake area between the Dalmeny Drive Bridge and the Kianga STP. The Dalmeny Drive Bridge was the hydraulic control structure that limited the flood level increase within Kianga Lake, such that the flood level increase was less than the sea level rise increase, shown in Table 43.

Table 43: Projected sea level rise comparative to the flood level increase within Kianga Lake

Year	Projected Sea Level Rise (m)	Flood Level Increase (m)
2030	0.10	0.03
2050	0.23	0.07
2070	0.39	0.12
2100	0.72	0.23

The increase in ground elevation that occurs at the Kianga STP (shown in Figure G 2 and Figure G 3) was the factor controlling the propagation of impacts further upstream into the catchment. The remaining catchment area was relatively insensitive to sea level rise.

15.2.4. Climate Change (Rainfall Increase)

The effect of increasing the design rainfalls by 10%, 20% and 30% have been evaluated for the 1% AEP rainfall event with impacts on peak flood levels observed throughout the catchment. Increasing the design rainfall by 10% resulted in increases to the peak flood level up to 0.2 m; 20% resulted in increases up to 0.3 m; and 30% resulted in increases up to 0.5 m.

15.3. Dalmeny

15.3.1. Manning’s ‘n’ Roughness Value

Peak flood level results were shown again to be relatively insensitive to universal variations in the roughness parameter, Manning’s ‘n’ value. Overall, the results were found to be within ± 0.25 m of design results across the whole catchment. Furthermore, singularly increasing the roughness parameter applied to heavy density vegetation was found to increase peak flood levels by up to 0.25 m in the tributaries discharging into the Mummuga Lake area. Generally, it was found that the Lake area was less sensitive to variations in roughness parameters than the tributaries. The peak flood extent was likewise found to be insensitive to variations in the roughness parameter.

15.3.2. Timing of Ocean Peak

Varying the timing of the ocean peak to occur 3 hours earlier or later than the design scenarios was found to decrease peak flood levels by up to 0.25 m from design results. The area impacted was confined to the Mummuga Lake area, from where Lawlers Creek crosses the Princes Highway and Mort Avenue crosses Spring Creek.

15.3.3. Climate Change (Sea Level Rise)

The sea level rise scenarios were found to propagate impacts within the Mummuga Lake area, downstream from where Lawlers Creek crosses the Princes Highway and Mort Avenue crosses Spring Creek. The sand berm was found to mitigate the sea level rise impacts; with flood levels within Mummuga Lake increasing less than the sea level rise increase, shown in Table 44.

Table 44: Projected sea level rise comparative to the flood level increase within Mummuga Lake

Year	Projected Sea Level Rise (m)	Flood Level Increase (m)
2030	0.10	0.01
2050	0.23	0.03
2070	0.39	0.09
2100	0.72	0.28

Sea level rise impacts in the Duck Pond area were found in two distinct areas differentiated by two hydraulic control structures. The first hydraulic control is the sand berm and the second hydraulic control is the Dalmeny Drive culvert. The former prevents the propagation of sea level rise impacts upstream in the 2030 projection. The latter prevents the propagation of impacts upstream in the 2030 and 2050 projection. Between the sand berm and the Dalmeny Drive culvert were the greatest impacts; up to 0.38 m in the 2100 projection. Within the Pond (bounded by Dalmeny Drive and Eucalyptus Drive) the sea level rise impacts were up to 0.07 m in the 2100 projection.

15.3.4. Climate Change (Rainfall Increase)

The effect of increasing the design rainfalls by 10%, 20% and 30% have been evaluated for the 1% AEP rainfall event with impacts on peak flood levels observed throughout the catchment. Within the Mummuga catchment, increasing the design rainfall by 10% resulted in increases to the peak flood level up to 0.25 m; 20% resulted in increases up to 0.45 m; and 30% resulted in increases up to 0.7 m.

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Figures

FIGURE 1
STUDY AREA

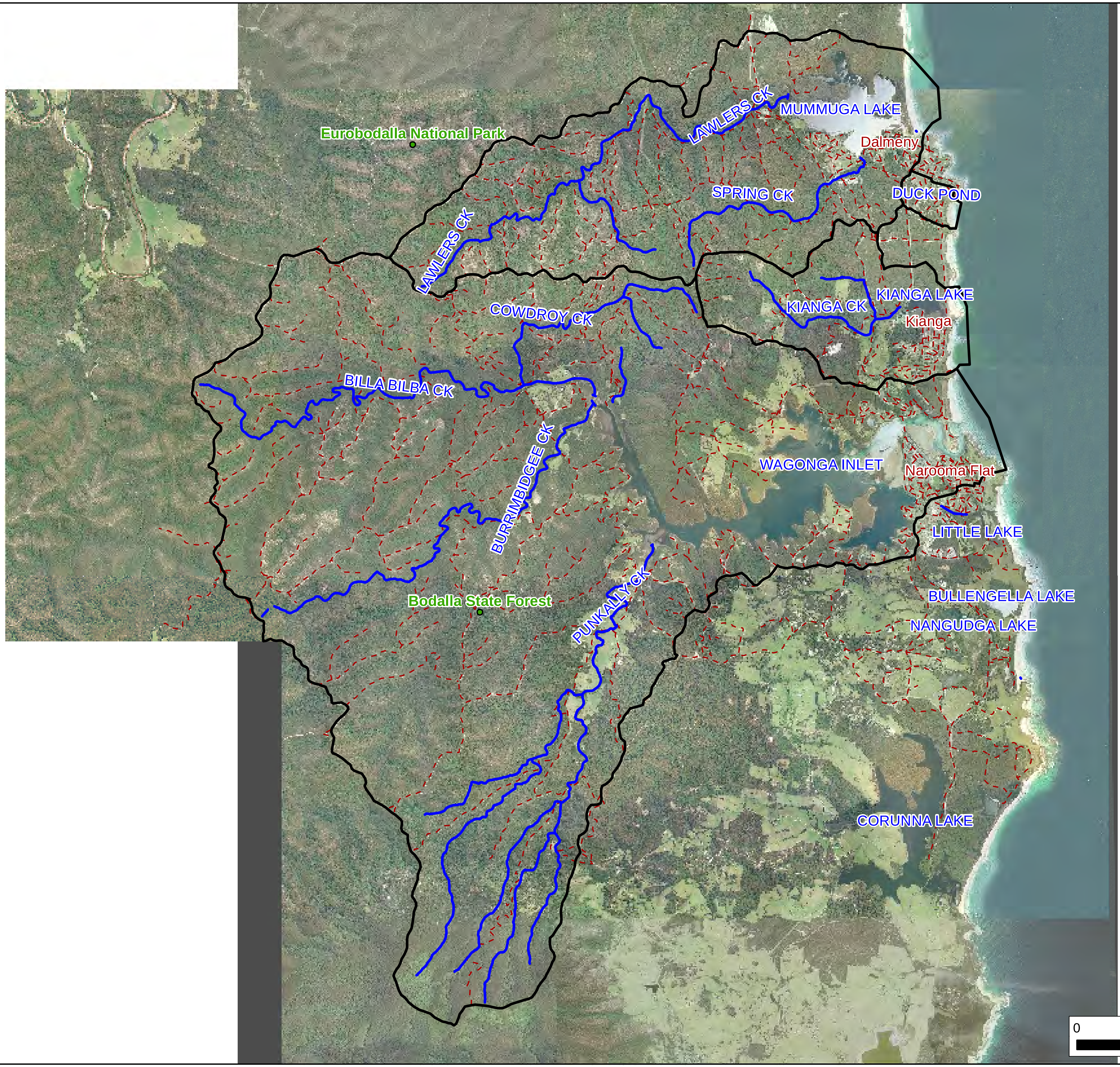

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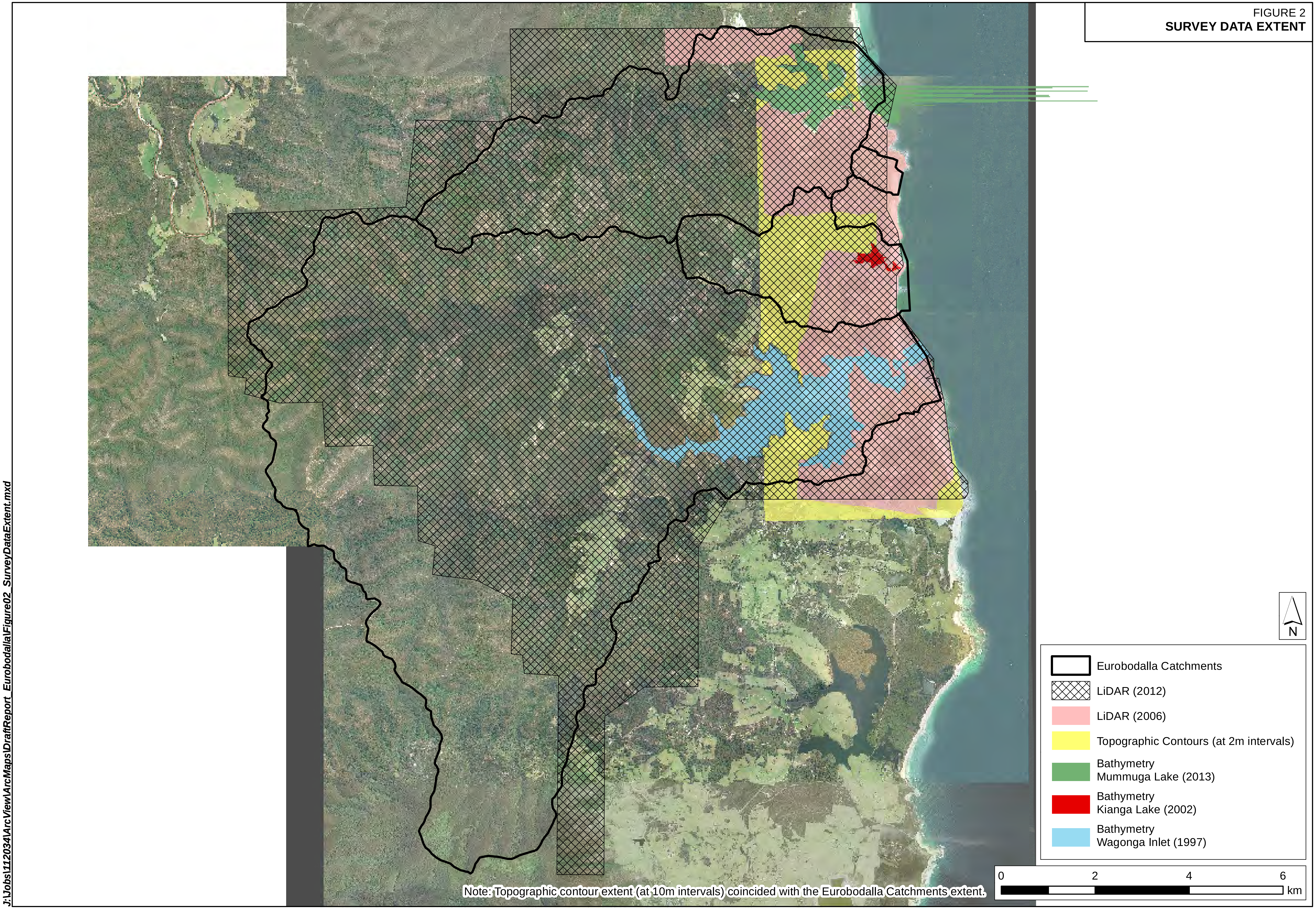
FIGURE 2
SURVEY DATA EXTENT



Note: Topographic contour extent (at 10m intervals) coincided with the Eurobodalla Catchments extent.

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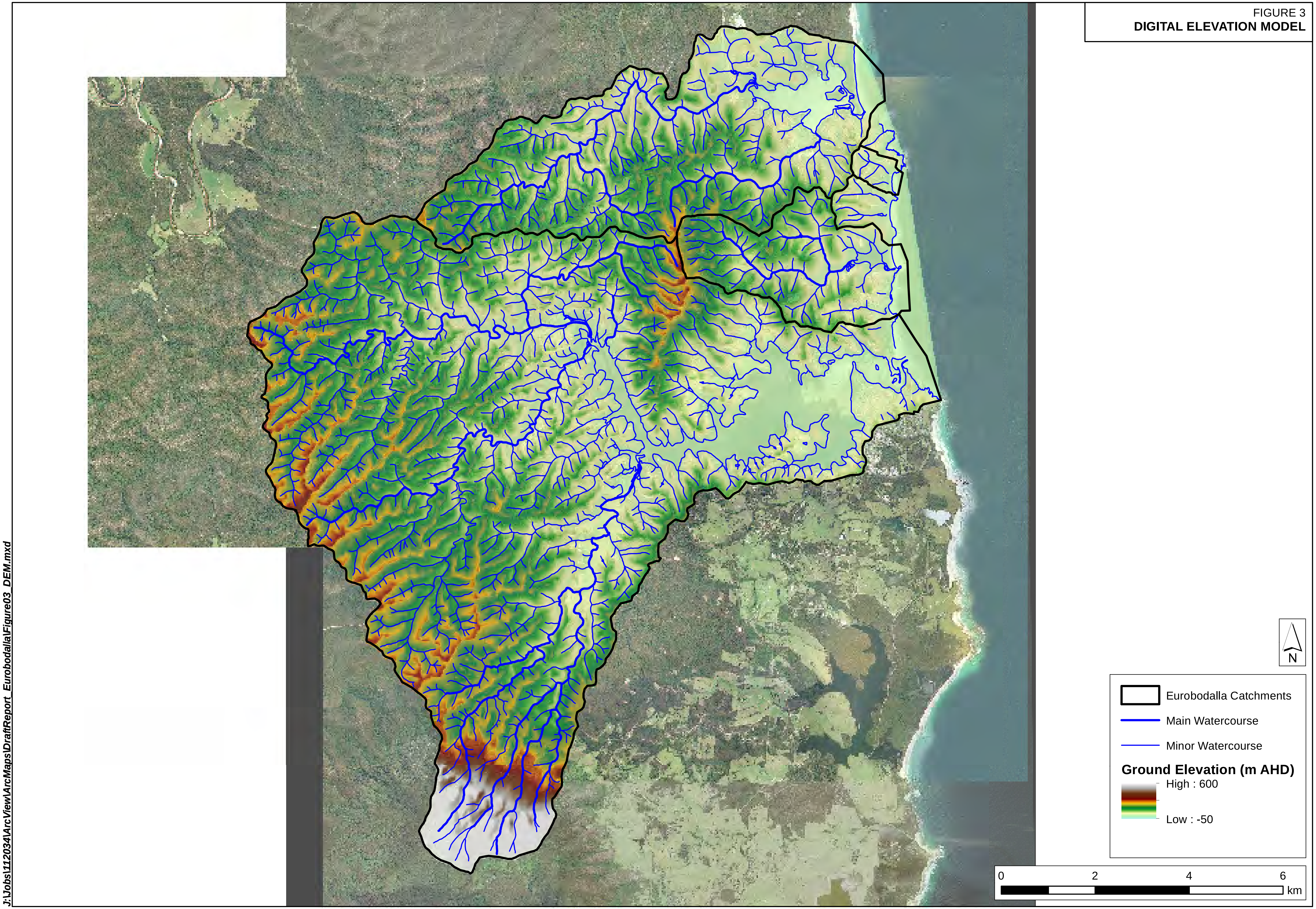
FIGURE 3
DIGITAL ELEVATION MODEL



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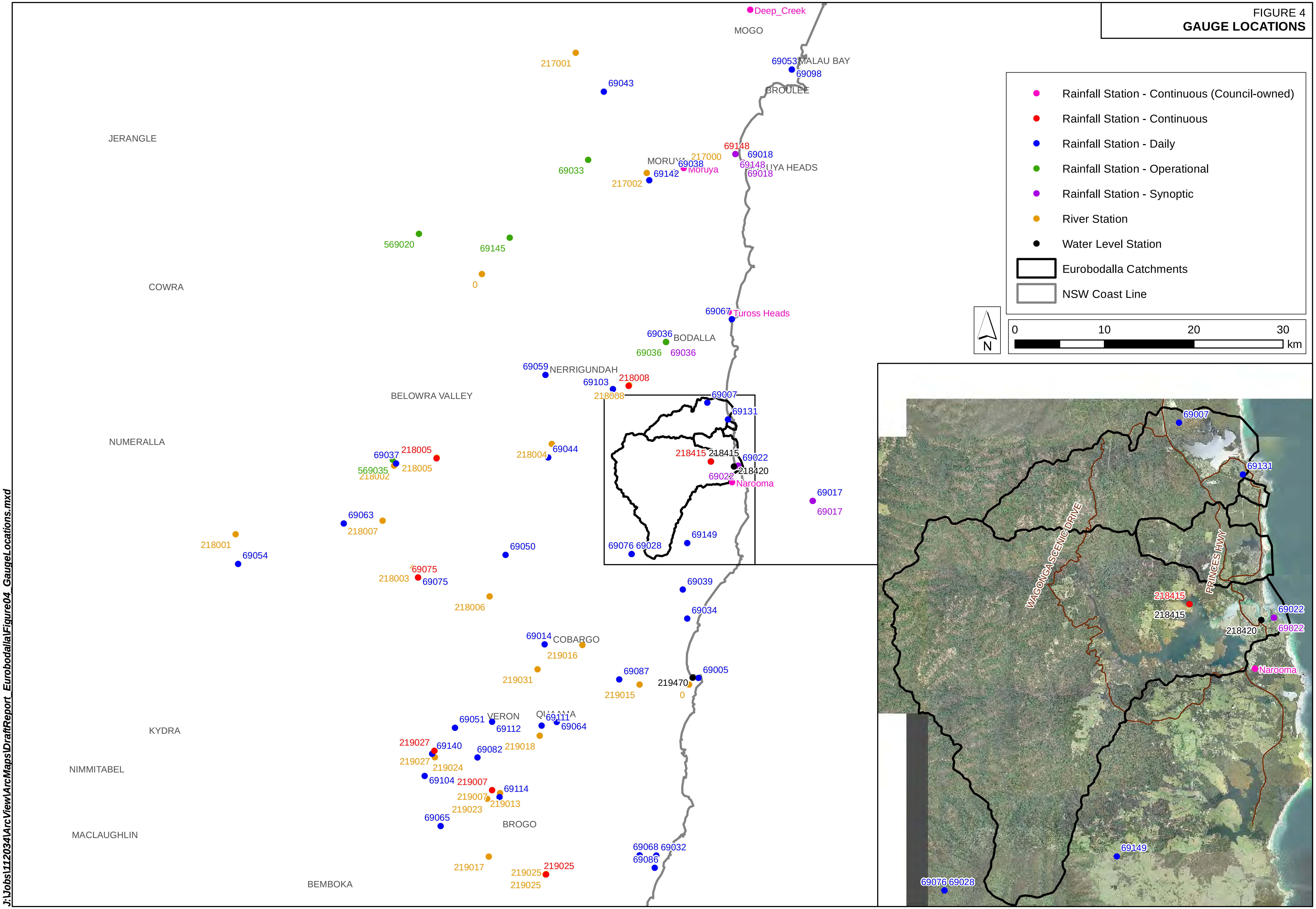

FIGURE 4
GAUGE LOCATIONS

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FIGURE 5
HYDROLOGIC MODEL LAYOUT

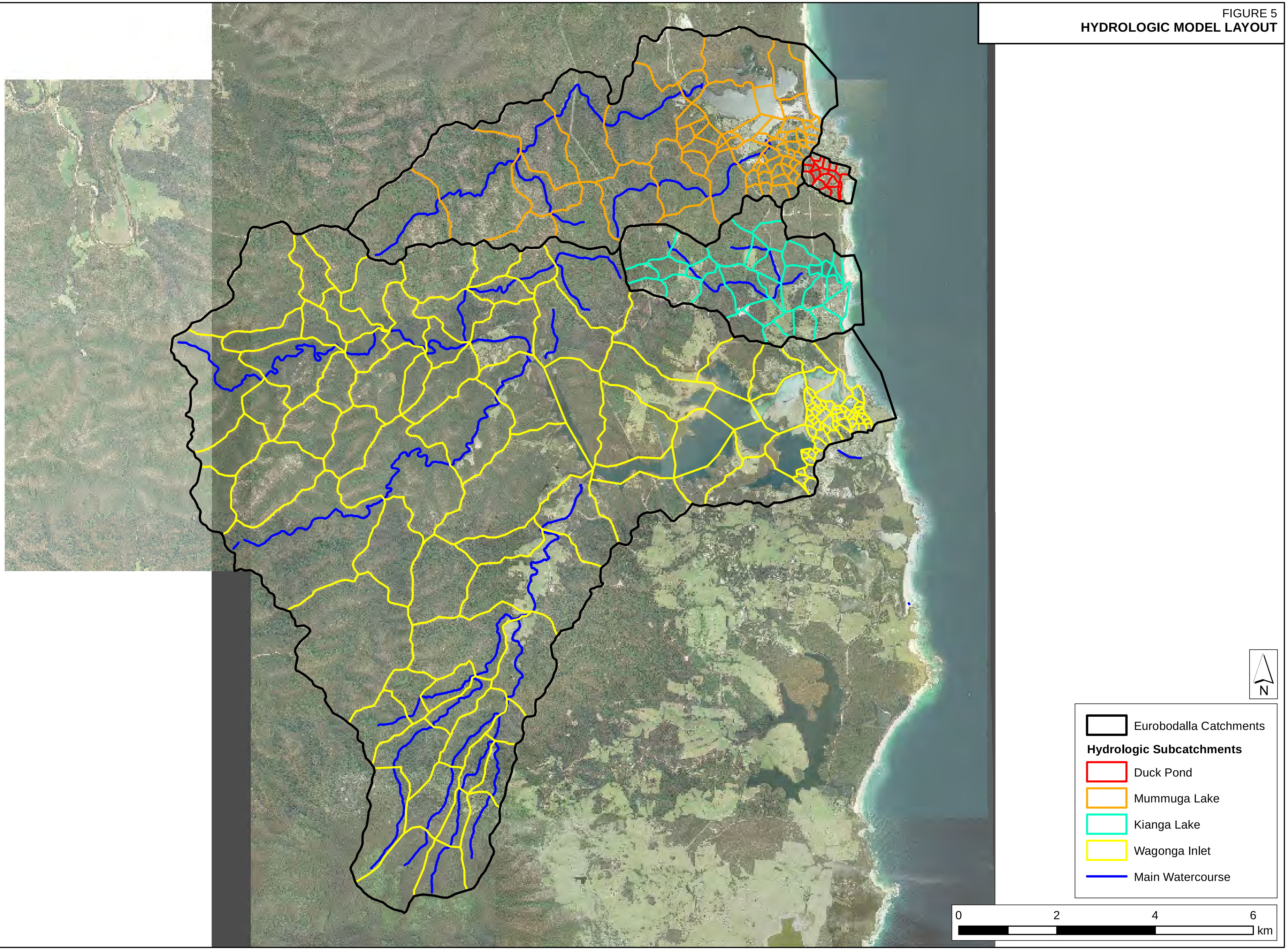

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FIGURE 6
HYDRAULIC MODEL LAYOUT

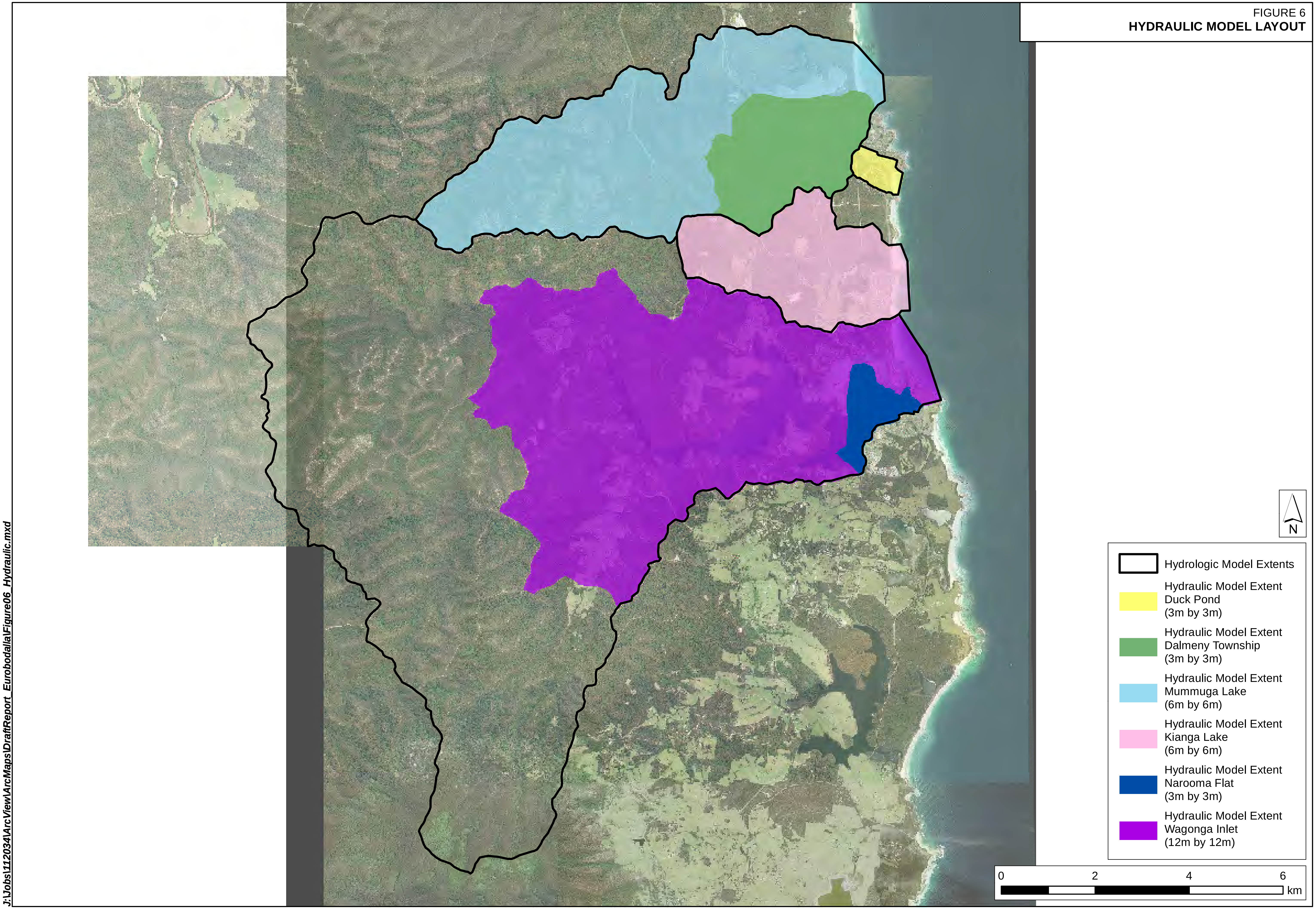

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FIGURE 7
HYDRAULIC MODEL INFLOWS

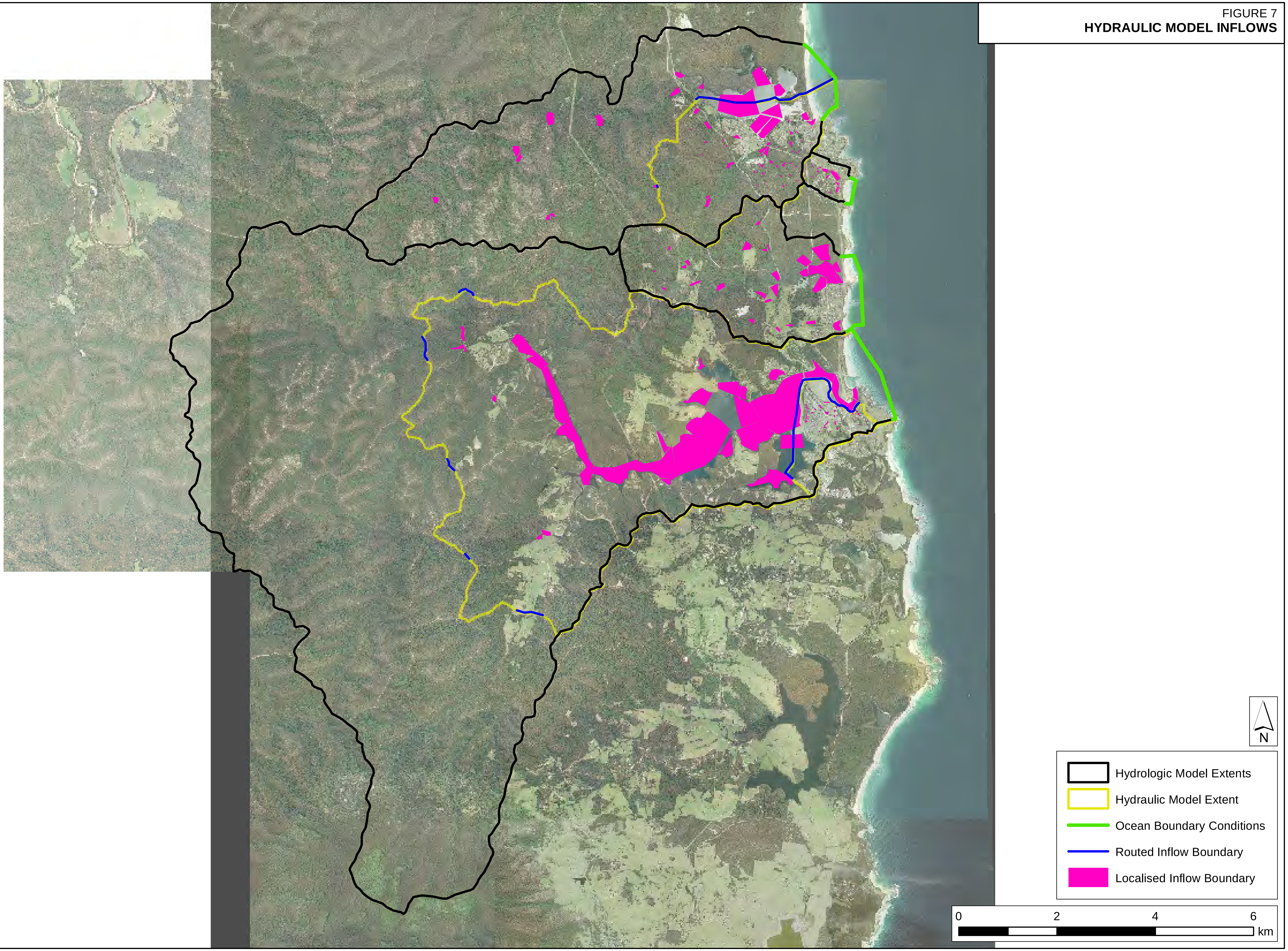

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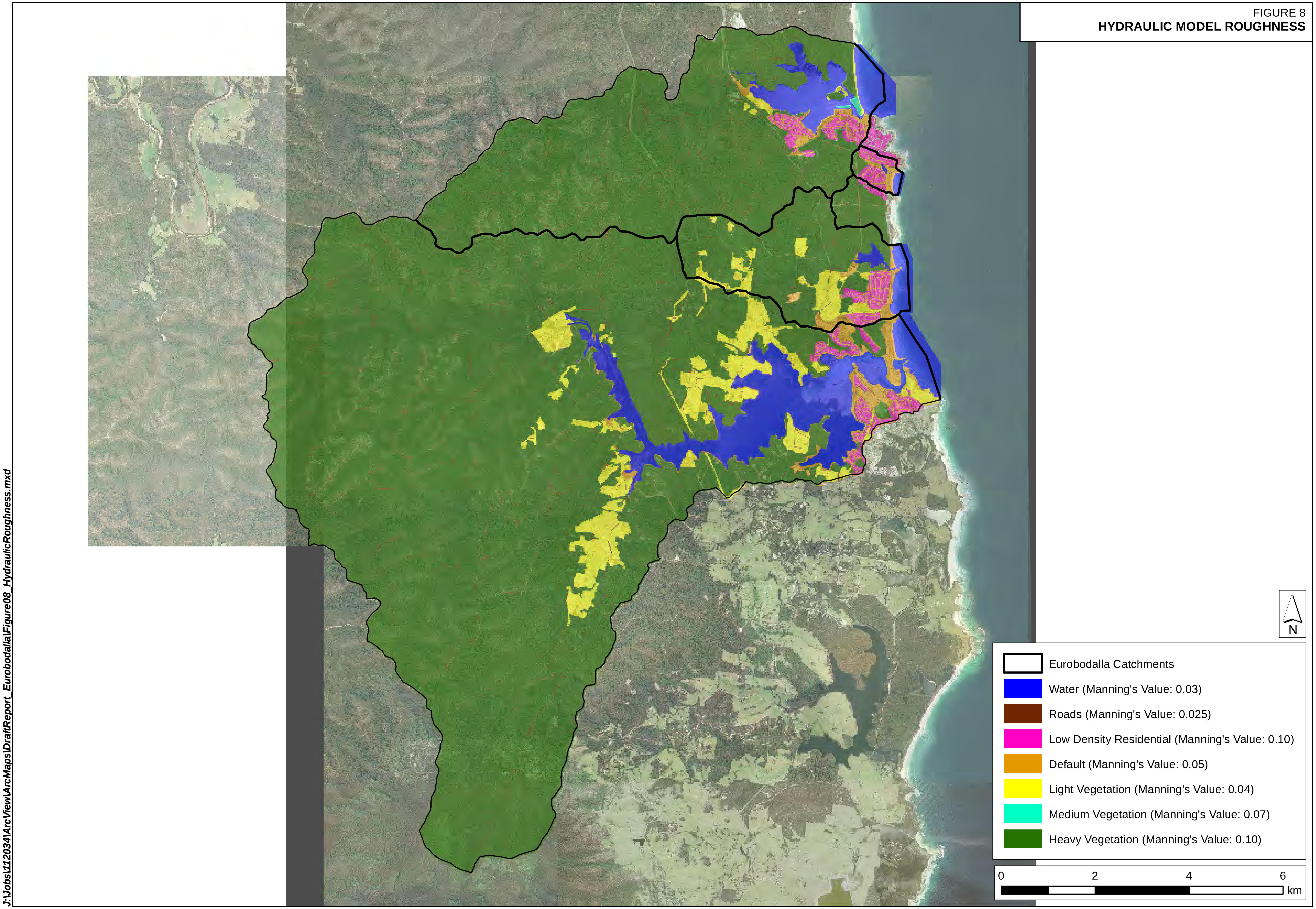
FIGURE 8
HYDRAULIC MODEL ROUGHNESS



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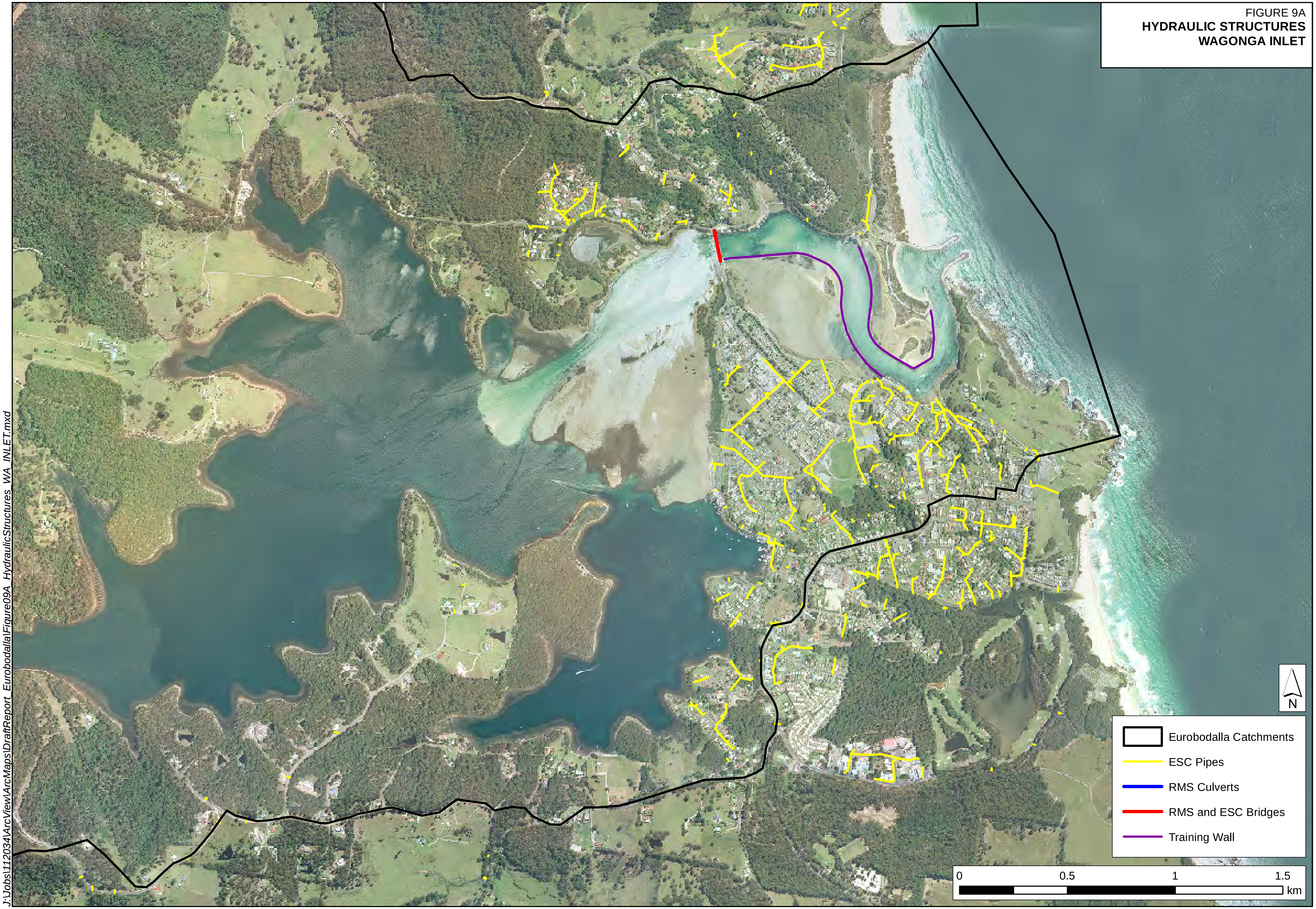

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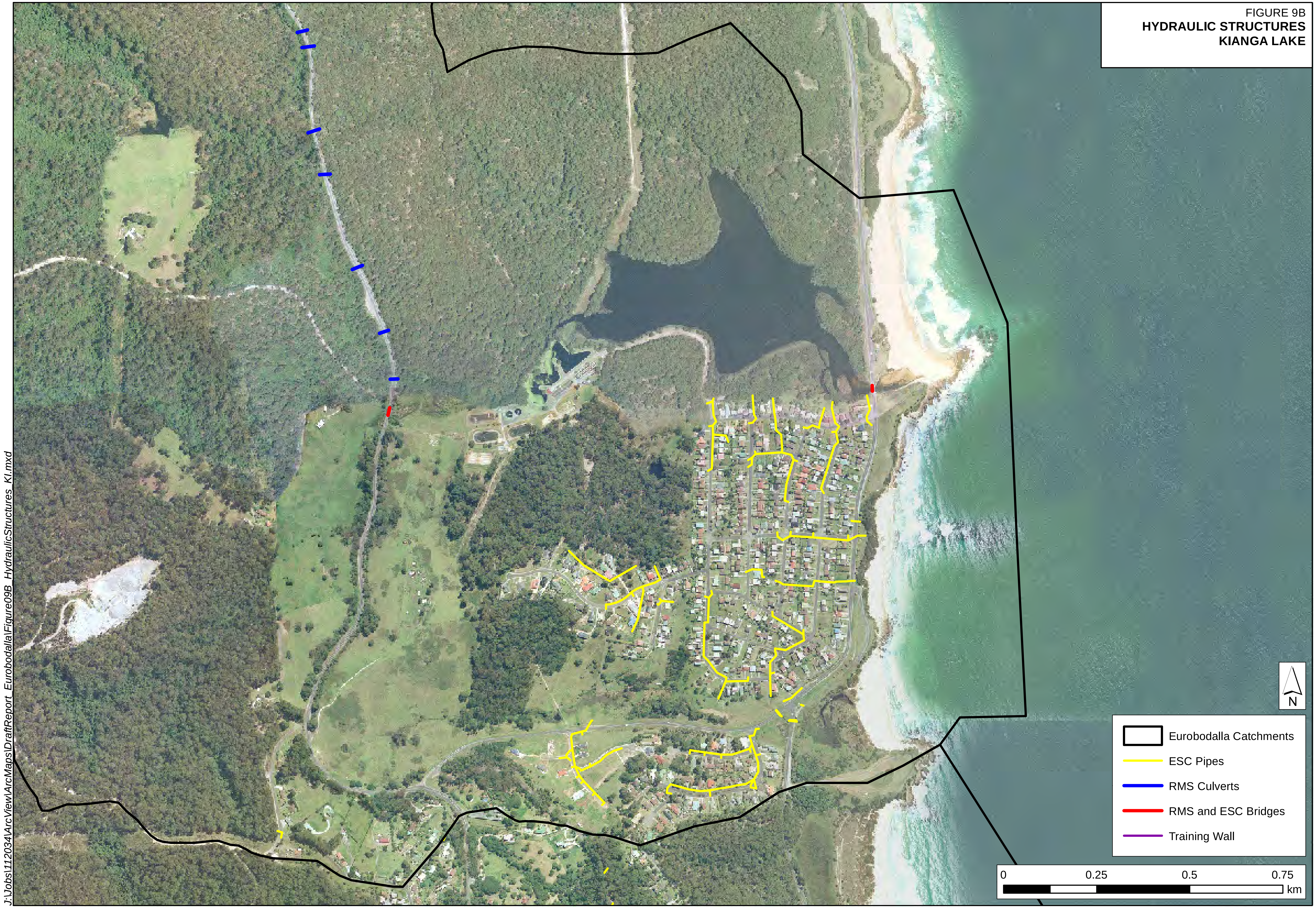
FIGURE 9B
HYDRAULIC STRUCTURES
KIANGA LAKE
Eurobodalla Catchments
ESC Pipes
RMS Culverts
RMS and ESC Bridges
Training Wall
0
0.25
0.5
0.75
km
N
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FIGURE 9C
HYDRAULIC STRUCTURES
DUCK POND
Eurobodalla Catchments
ESC Pipes
RMS Culverts
RMS and ESC Bridges
Training Wall
0
0.1
0.2
0.3
km
N
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FIGURE 9D
HYDRAULIC STRUCTURES
MUMMUGA LAKE
Eurobodalla Catchments
ESC Pipes
RMS Culverts
RMS and ESC Bridges
Training Wall
0
0.25
0.5
0.75
km
N
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FINAL DRAFT

Appendix A

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils
Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.

Annual Exceedance Probability (AEP)
The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).

Australian Height Datum (AHD)
A common national surface level datum approximately corresponding to mean sea level.

Average Annual Damage (AAD)
Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.

Average Recurrence Interval (ARI)
The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.

caravan and moveable home parks
Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.

catchment
The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.

consent authority
The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.

development
Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act).

infill development: refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development.

new development: refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.

redevelopment: refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.

disaster plan (DISPLAN) A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.

discharge The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).

ecologically sustainable development (ESD) Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.

effective warning time The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.

emergency management A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.

flash flooding Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.

flood Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

flood awareness Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.

flood education Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.

flood fringe areas The remaining area of flood prone land after floodway and flood storage areas have been defined.

flood liable land Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).

flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammetic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the Aflood liable land@ concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL=s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the Astandard flood event@ in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of

	floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves:
	$ the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or
	
	$ water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These

conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or

$ major overland flow paths through developed areas outside of defined drainage reserves; and/or

$ the potential to affect a number of buildings along the major flow path.

mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State=s rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. **major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
modification measures	Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.

Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to Awater level@. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.