1. INTRODUCTION

1.1. Background

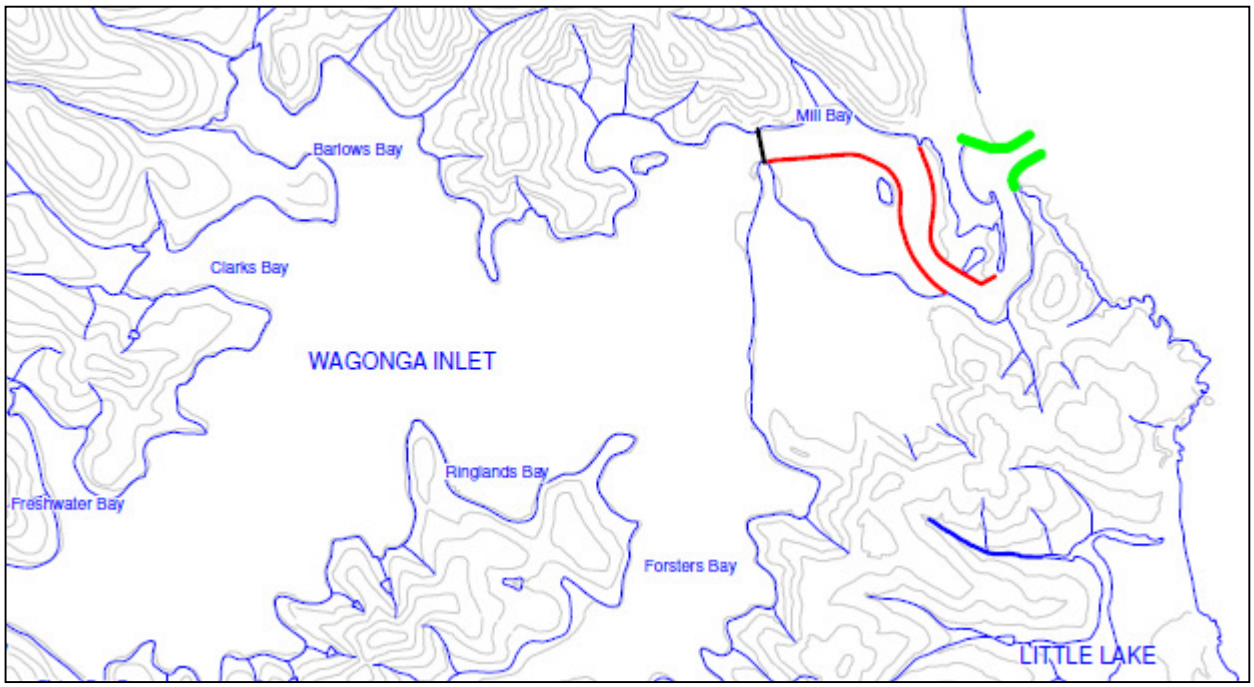
This flood study has been prepared on behalf of Eurobodalla Shire Council (ESC), on the South Coast of New South Wales. It includes four catchments; the Wagonga Inlet, Kianga Lake, "Duck Pond" and Mummuga Lake Catchments, shown in Figure 1. Within this report, the latter two catchments are identified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

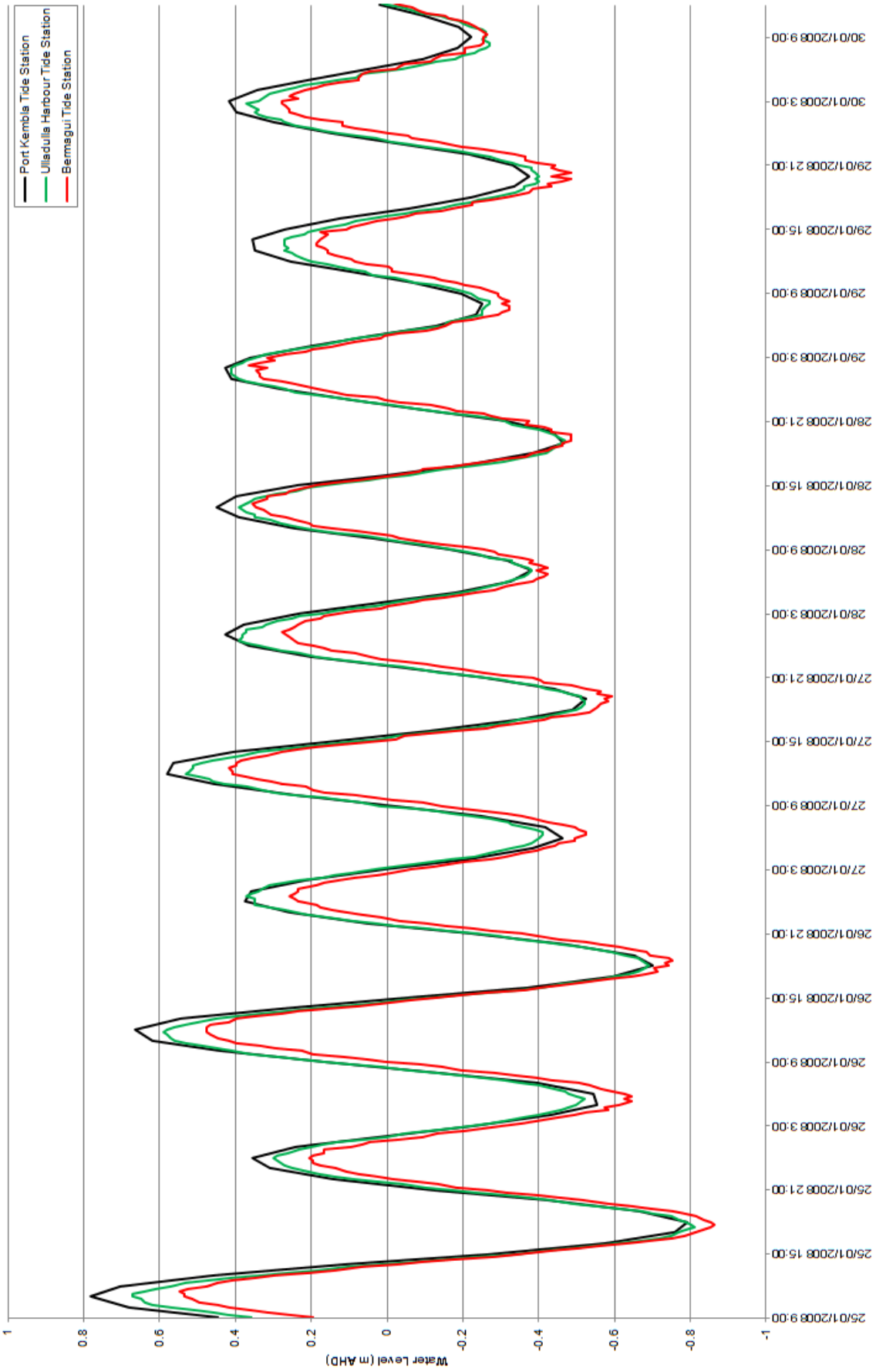
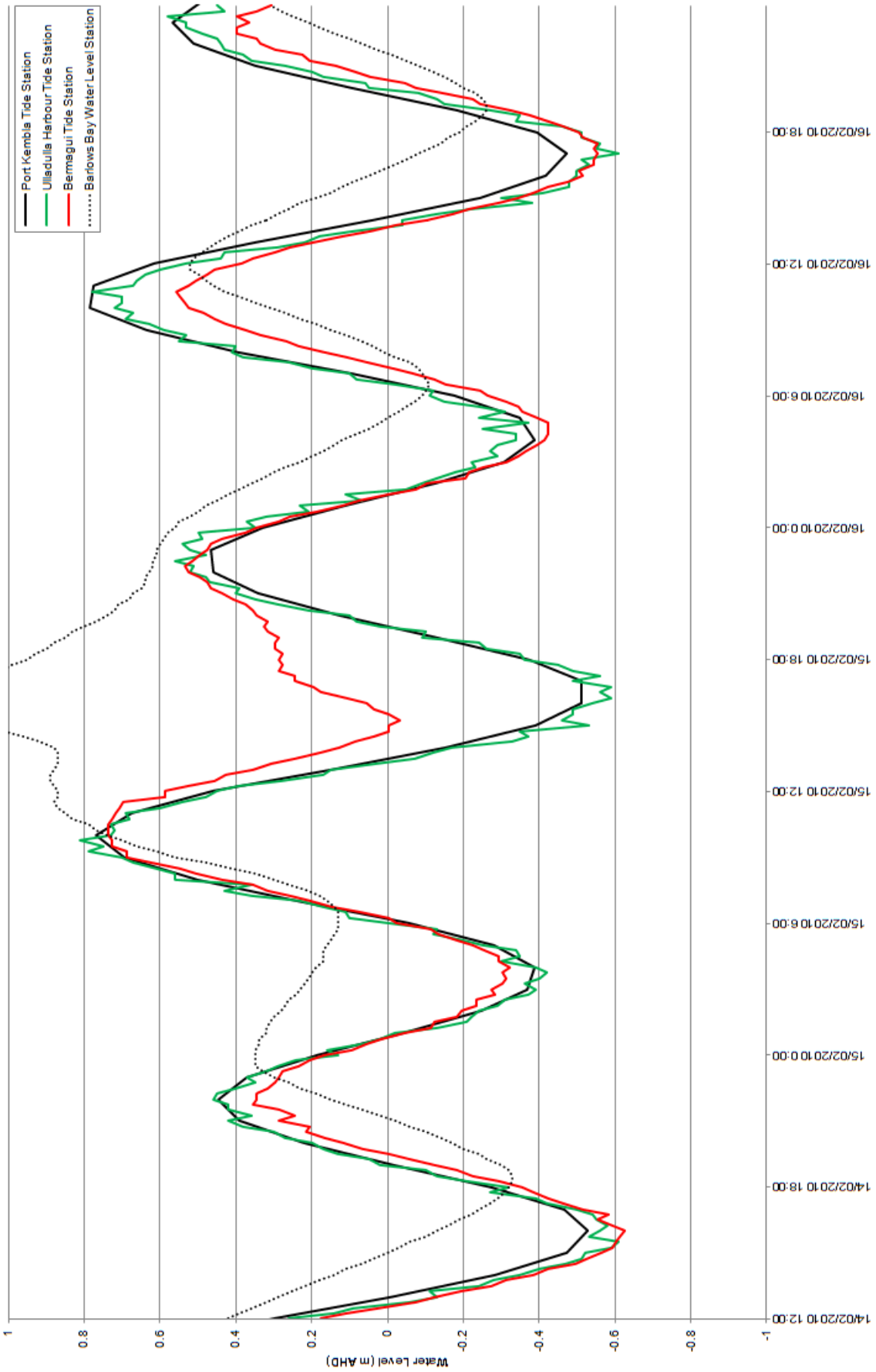


Diagram 3: Ocean Tide Station Comparison – 2010 storm event



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.

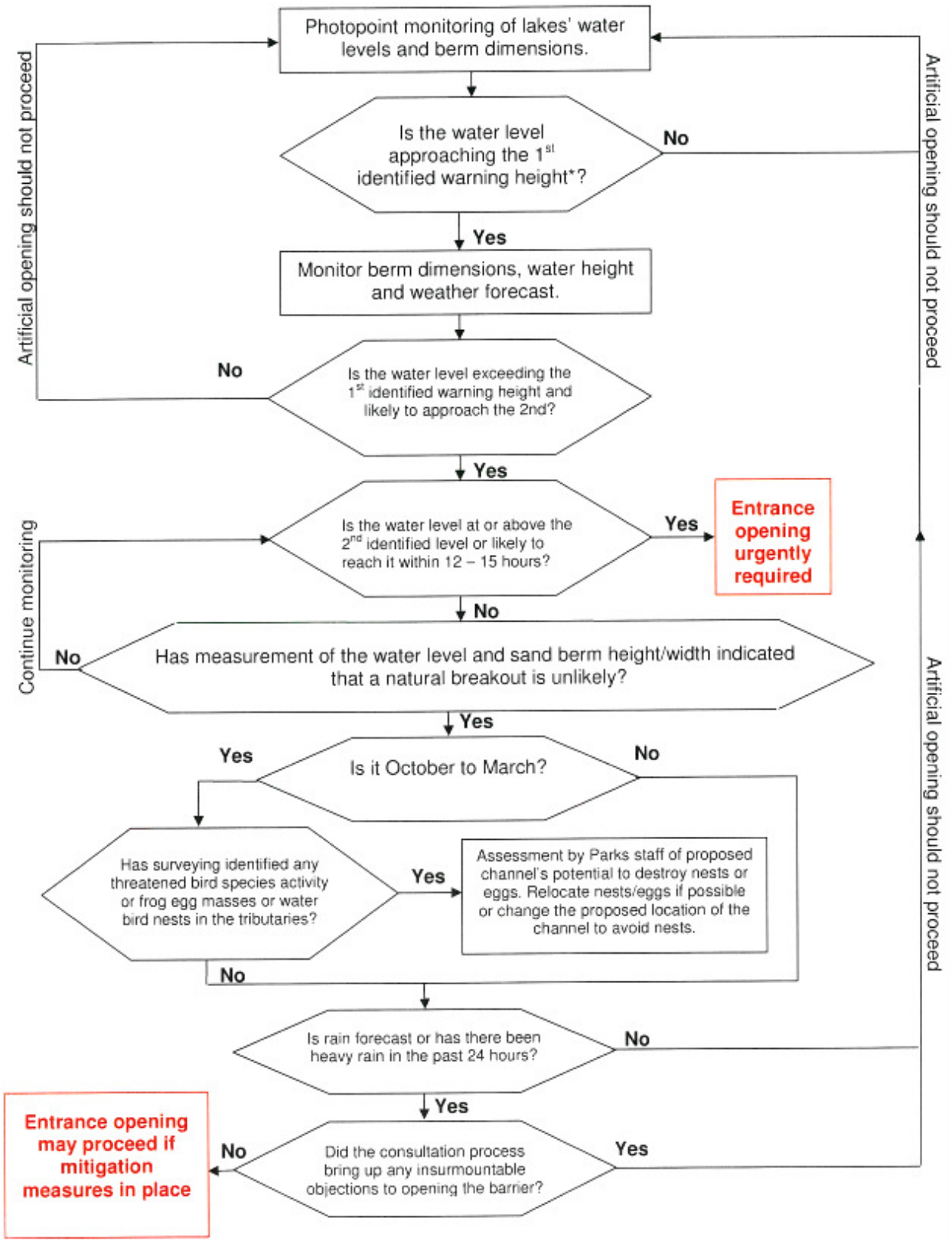
The report included the indicators necessary to initiate an artificial opening of the entrances and some history of when the ICOLL's have been open previously, both naturally and artificially.

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)				