EUROBODALLA SHIRE COUNCIL

TOMAKIN, MOSSY POINT, BROULEE AND MOGO FLOOD STUDY

DRAFT REPORT – FOR PUBLIC EXHIBITION

APRIL 2016

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Project Tomakin/Mossy Point/Broulee/Mogo Flood Study	**Project Number** 114088
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LIST OF ABBREVIATIONS

1D	One (1) Dimensional
2D	Two (2) Dimensional
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AR&R	Australian Rainfall and Runoff
ALS	Airborne Laser Scanning
DEM	Digital Elevation Model
E/Y	Exceedances per Year
GSAM	Generalised South-East Australia Method (for PMP calculations)
GSDM	Generalised Short-Duration Method (for PMP calculations)
ICOLL	Intermittently Closed and Open Lake or Lagoon
IFD	Intensity-Frequency-Duration
LGA	Local Government Area
LiDAR	Airborne Light Detection and Ranging Survey
NPWS	National Parks and Wildlife Services
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
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.

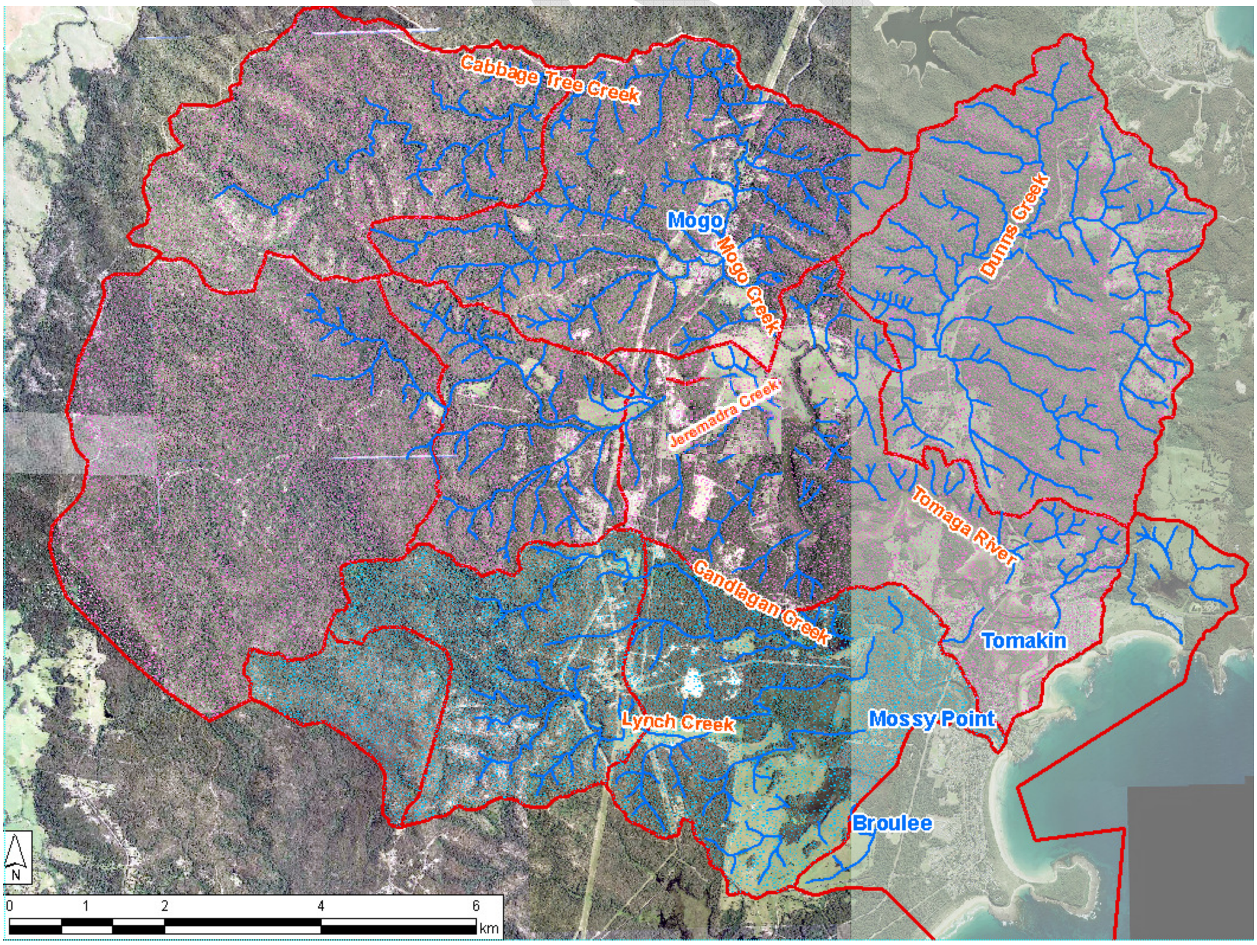
1. INTRODUCTION

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 covers the areas of Tomakin, Mossy Point, Broulee and Mogo (Figure 1) over two major catchments. The first catchment has an approximate area of 94 km^2 which drains to the Tomaga River while the second catchment has an approximate area of 26 km^2 draining to Candlagan Creek.

Tomakin, Mossy Point and Broulee are mostly residential while Mogo is characterised by commercial areas with some residential land-use. Mogo with an upstream catchment area of approximately 27 km^2 is subject to both local flooding from Mogo Creek and flooding from Cabbage Tree Creek. Dunns Creek and Jeremadra Creek with approximate catchment areas of 19 km^2 and 30 km^2 respectively are two other major tributaries of the Tomaga River. Lynch Creek is a tributary of Candlagan Creek. Tomakin is located beside the Tomaga River mouth (catchment area of 94 km^2), Broulee is located beside the Candlagan Creek mouth (catchment area of 26 km^2) while Mossy Point is situated in between the two.

Diagram 1: Major Creeks Catchments



1.2. Objectives

The purpose of this Flood Study is to define the flood behaviour under current catchment conditions. This objective is achieved 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.

Following endorsement of the calibration report, assessment of the 20%, 10%, 5%, 2%, 1% and 0.5% AEP design events as well as the Probable Maximum Flood (PMF) has been carried out. 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.

2.1. Topographic Data

The catchment topography was defined by Airborne Light Detection and Ranging (LiDAR) survey, bathymetric hydrosurvey and cross-sectional levels from design drawings. Using only ground strikes and water strikes a Triangular Irregular Network (TIN) was generated. Note, the ground strike resolution for Broulee was insufficient consequently for that area, all available strikes were used for generating the TIN as detailed in Section 2.1.1. The resulting TIN was sampled at a regular spacing of 2 m by 2 m and creeks/rivers cut out utilising bathymetric survey and cross-sectional information to create a Digital Elevation Model (DEM). The DEM (discussed further in Section 6.3 and shown in Figure 2) constitutes the basis for the two-dimensional hydraulic model utilised for the study.

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 2012 originates from the NSW Department of Land and Property Information (LPI). A description of the strike types and their respective classification is shown in Table 1.

The metadata description sheet for the Batemans Bay area LiDAR data indicates an average point density of 1.61/m^2 corresponding to an accuracy in the order of:

- +/- 0.3 m in the vertical direction (to one standard deviation); and
- +/- 0.8 m in the horizontal direction (to one standard deviation).

The accuracy of the LiDAR data can be influenced by a number of factors. LiDAR strike penetration is limited through water and consequently any deeper water areas were supplemented with bathymetric survey and cross-sectional information. Similarly, vegetation (tree or shrub canopy) and structures (buildings or bridges) artificially elevate ground levels and therefore these strikes were discounted with the exception of the Broulee area where true ground strike resolution was insufficient. For the Broulee area, a large concentration of points was unclassified or classified as medium to high vegetation and inclusion of these categories was required to obtain sufficient resolution for the TIN in that area. On the ground verification of apparent anomalies in the resulting TIN by WMAwater engineers found the features to be in fact similar to that observed in the generated TIN. Overall, no observed discrepancy was conclusive enough to justify manually manipulating grid levels for the Broulee area.

Table 1: LiDAR Point Cloud Classification Scheme

Number	Point Class	Description
0	Unclassified	Created, never classified
1	Default	Unclassified
2	Ground	Bare ground
3	Low Vegetation	0-0.3m (essentially sensor 'noise')
4	Medium Vegetation	0.3-2m
5	High Vegetation	>2m
6	Buildings, Structures	Buildings, houses etc.
7	Low/High Points	Spurious point return (unusable)
8	Model Key Points	Reserved for 'model key points' only
9	Water	Any point in water
10	Bridge	Any bridge overpass
11	Not used	Reserved for future definition
12	Overlap Points	Flight line overlap points
13-31	Not used	Reserved for future definition

2.1.2. Bathymetric Survey

The bathymetric survey for the Tomaga River is available from the Office of Environment and Heritage (OEH) website. The website indicates that the data (shown in Figure 2) was collected in December 1998. High resolution data is available for the river mouth as far as the George Bass Drive Bridge. Cross-sectional data at regular 200-300 metre intervals is available further upstream as far as approximately where Tomakin Road crosses Dunns Creek.

2.1.3. Cross-sectional Levels

Available bridge and road drawings for the study area were provided by Eurobodalla Shire Council. Drawings including site survey were used to inform levels particularly for Candlagan Creek.

2.2. Culvert and Bridge Data

Roads and Maritime Services provided GIS data for drainage assets within the study area particularly culverts traversing the Princes Highway and Mogo Bridge.

Additionally, Eurobodalla Shire Council provided Culvert and Bridge data. All major bridges shown in Figure 3 were independently verified by site visit and where not provided, bridge parameters were estimated from visual inspection. Similarly, where culvert dimensions were not available, diameters were estimated from visual inspection.

Bridge and culvert structures included in the hydraulic model are shown in Figure 4.

2.3. 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 as shown in Figure 4.

The stormwater pipe data detailed the dimensions of the ESC-owned structures across the study areas. The invert level of the upstream and downstream end of the pipes were provided for the most part and these were used to inform pit invert levels. Where invert levels were not available, levels were estimated by subtracting an assumed cover and the pipe diameter from the TIN levels.

2.4. Historic Water Level Data (Continuous)

A water level recorder is available within the Tomaga River catchment situated at George Bass Drive. The gauge is operated by Manly Hydraulics Laboratory (MHL) and was commissioned in August 1996. The water level gauge is summarised in Table 2 and shown in Figure 5.

Table 2: Water Level Stations Operated by MHL within the Study Area

Station Number	Station Name	Operating Authority	Date Opened
216455	George Bass Drive	MHL	28/08/1996

The water level data supplied is reported as having an accuracy range in the order of +/- 0.02 m and is tidally affected. There are no other publicly available water level records for the Tomaga River and Candlagan Creek catchments.

2.5. Historic Ocean Tide Datum (Continuous)

The ocean tide stations closest to the study area are summarised in Table 3. The gauges are operated by Manly Hydraulics Laboratory (MHL).

Table 3: Ocean Tide Level Stations

Station Number	Station Name	Operating Authority	Distance from centre of catchment (km)	Date Opened
216410	Batemans Bay Clyde River at Princess Jetty	MHL	13	01/12/1985
216471	Ulladulla Harbour	MHL	59	06/12/2007
219470	Bermagui	MHL	68	29/07/1987
216470	Jervis Bay	MHL	93	01/09/1989

Data was provided in 15 minute increments in Australian Eastern Standard Time (AEST). The vertical datum of the Princess Jetty data and Ulladulla Harbour data is AHD. The Bermagui data was provided in Bermagui Local Hydro Datum (BLHD = -0.714 m AHD) and the Jervis Bay data was in Chart Datum (CD = -1.070 m AHD).

2.5.1. 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 Ulladulla Harbour station is shown in Table 4.

Table 4: Tidal Planes Analysis Results for Ulladulla Harbour Gauge (MHL, 2012)

Tidal Planes	Annual Average Amplitude (m AHD)
High High Water Solstices Springs (HHWSS)	0.960
Mean High Water Springs (MHWS)	0.617
Mean High Water (MHW)	0.510
Mean High Water Neaps (MHWN)	0.403
Mean Sea Level (MSL)	0.040
Mean Low Water Neaps (MLWN)	-0.325
Mean Low Water (MLW)	-0.431
Mean Low Water Springs (MLWS)	-0.538
Indian Spring Low Water (ISLW)	-0.783

2.6. Historic Rainfall Data

There are a number of rainfall stations close to the study area. This includes daily read stations and continuous pluviometer stations. The daily read stations record total rainfall for the 24 hours to 9am of the day being recorded. For example, 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.

Table 5 presents a summary of the official rainfall gauges located close to or within the catchment. These gauges are operated by the Bureau of Meteorology (BOM) for the most part and Eurobodalla Shire Council (ESC) operates the tipping bucket located at Deep Creek Dam. As shown in Figure 5, while these stations are situated proximate the catchment area, none are actually located within the Tomaga River and Candlagan Creek catchments.

Table 5: Rainfall Stations Proximate the Tomaga River/Candlagan Catchments

Station Number	Station Name	Operating Authority	Latitude	Longitude	Height (m AHD)	Distance from Catchment Boundary (km)	Distance from Centre of Catchment (km)	Date Opened	Date Closed	Type
69006	Bettowynd (Condry)	BOM	-35.7	149.79	165	25.7	33.1			Daily
69018	Moruya Heads Pilot Station	BOM	-35.91	150.15	17	5.9	11.6	1/01/1875	-	Daily
69023	Nelligen (Thule Rd)	BOM	-35.65	150.15	5	12.1	17.5	1/01/1898	-	Daily
69033	Moruya (Burra Creek)	BOM	-35.9	149.96	20	12	18.7	1/01/2001	-	Daily
69035	Bettowynd (Nobbys Hill)	BOM	-35.76	149.82	240	21.1	28.6	1/01/2001	-	Daily
69042	Moruya (The Lagoon)	BOM	-35.77	149.94	70	10.3	17.8	1/01/1960	-	Daily
69048	Upper Deua (Warawitcha)	BOM	-35.76	149.82	166	21.2	28.6	1/01/2011	-	Daily
69052	Batemans Bay - Buckenbowra	BOM	-35.73	150.05	30	4	11.3	1/01/1943	-	Daily
69127	**Araluen Lower (Araluen Rd)**	**BOM**	**-35.69**	**149.84**	**145**	**22**	**29.4**	**1/01/1980**	**-**	**Continuous**
69134	Batemans Bay (Catalina Country Club)	BOM	-35.72	150.19	11	4.4	11	1/01/1985	-	Daily
69142	Moruya (Kiora)	BOM	-35.92	150.04	20	9.3	15.1	1/01/1969	-	Daily
69148	**Moruya Airport AWS**	**BOM**	**-35.9**	**150.14**	**4**	**4.8**	**10.4**	**1/01/1999**	**-**	**Continuous**
D	**Deep Creek Dam**	**ESC**	**-35.76**	**150.18**	**44**	**1.3**	**6.4**	**3/12/1996**	**-**	**Continuous**

2.6.1. Analysis of Pluviometer Data

Continuous pluviometer stations provide a more detailed description of temporal variations in rainfall. As shown in Table 5, three continuous stations are situated close to the Tomaga River and Candlagan Creek catchments. The Moruya Airport and Araluen Lower pluviometers are operated by the BOM and were established in January 1999 and January 1980 respectively while the Deep Creek Dam tipping bucket is operated by Eurobodalla Shire Council and was established in December 1996. Table 6 summarises the largest events on record for the three respective pluviometers. The highest rainfall total over 24 hours of any gauge was recorded at Moruya Airport for the 15/02/10 event. The same event ranked sixth on the Deep Creek Dam gauge which is located north of the catchment (while Moruya Airport Gauge is located south). Araluen gauge is located to west of the catchment but it is substantially further away from the study area than the other two gauges and is on the other side of the low mountain range delimiting the Tomaga River/Candlagan Creek Catchments.

Table 6: Maximum Recorded Storm Depths at Pluviometers (in mm)

Moruya (69148)		
	Start of Event	24 hr Rainfall (mm)
1	**15/02/2010 2:30**	**193.4**
2	13/04/2002 19:30	141.97
3	20/10/2004 6:00	121.6
4	11/11/2013 6:00	120.2
5	6/02/2002 16:00	118.2
6	16/08/2014 19:00	117
7	5/08/2008 9:30	114.6
8	17/01/2001 19:00	110
9	26/08/2001 19:00	107.6
10	30/10/2005 14:30	101.8

Deep Creek Dam (D)		
	Start of Event	24 hr Rainfall (mm)
1	30/10/2005 16:00	176
2	21/10/2004 2:00	166
3	24/10/1999 4:00	162
4	28/01/1999 5:00	150.5
5	17/08/2014 7:00	145.5
6	**14/02/2010 22:00**	**133**
7	10/11/2012 1:00	133
8	30/10/2005 22:00	132
9	18/08/1998 2:00	118
10	8/07/1998 1:00	114.5

Araluen (69127)		
	Start of Event	24 hr Rainfall (mm)
1	29/04/1988 14:00	167.57
2	5/07/1988 9:00	164.43
3	27/06/1997 9:30	163.87
4	10/07/1991 9:30	160.55
5	2/04/1981 9:00	160.07
6	16/09/2013 15:00	150.2
7	23/06/2013 14:30	144.6
8	1/08/1990 9:00	128.58
9	23/10/1999 20:00	123.28
10	14/06/2007 22:00	122.6
138	**14/02/2010 22:00**	**33.2**

2.6.2. 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. As per the pluviometer gauges, no daily read gauge is located within the Tomaga River/Candlagan Creek catchments. However as illustrated in Figure 5, a number of gauges are distributed around the catchments' periphery and these are summarised in Table 7. The daily totals from these gauges provide the means by which a total rainfall depth surface can be triangulated across the study area to facilitate a tentative calibration exercise.

Pluviometric information shows that the February 2010 event commenced prior to the 9:00 gauge recording of the 15th of February and contributed to some/most of the rainfall recorded at 9:00 on the 16th of February. The ratio of the total depth recorded by the Moruya pluviometer for the most intense 24 hour period during the event over the sum of the two reading recorded by the Moruya daily read gauge was applied to each respective gauge. This normalised the total rainfall for each gauge while taking account of the fact that the event occurred on either side of the 9:00am reading time.

Table 7: Rainfall Stations Proximate the Tomaga River/Candlagan Catchments used to Derive Rainfall Depth for 15/02/2010 Event

Station Details		**Daily Read Depth (mm at 9:00)**		**Cumulative Depth**	**Normalised Depth for Event**
Station Number	Station Name	15/02/2010	16/02/2010	15/02/2010 + 16/02/2010	24hr Total
	Moruya Pluviometer*	67.2	149.8		
69018	Moruya Heads Pilot Station	78.3	158	236.3	193.40
69023	Nelligen (Thule Rd)	80.2	53.2	133.4	109.18
69033	Moruya (Burra Creek)	56	57	113	92.48
69042	Moruya (The Lagoon)	80.4	43.4	123.8	101.32
69052	Batemans Bay - Buckenbowra	70.4	53	123.4	101.00
69134	Batemans Bay (Catalina Country Club)	92.6	64.6	157.2	128.66
69142	Moruya (Kiora)	84	124	208	170.24
69148	Moruya Airport AWS	69	153	222	181.70
***Note Moruya Pluviometer shows less than Moruya Heads Pilot Station because the totals only include the 24 hr event rainfall and not rainfall that occurred that day but outside of event**					

There was insufficient pluviometer data for the 1934, 1974 and 1991 events (for which anecdotal evidence was provided and discussed in Section 3.3) and so these events were not modelled for calibration purposes. However, to provide some context for these events, the daily read data was analysed for the largest daily total for the years specified at the Moruya Heads Pilot Station (69018). From this, an approximate ARI was calculated from the design rainfall intensity-frequency-duration (IFD) data corresponding to each daily read gauge location.

For the 1934 event, two gauges were in operation and the data is shown in Table 8. However, the Nelligen gauge (69023) had a gap in the data available spanning December 1933 and January 1934. Of the 1934 data available at the Nelligen gauge, the largest daily total was approximately half the largest daily total recorded at Moruya Heads Pilot Station in 1934, and was therefore not analysed.

Table 8: Rainfall Depth and Approximate ARI for the 8th January 1934

Station Number	Station Name	Daily Read Depth (mm at 9:00)	Approximate ARI
69018	Moruya Heads Pilot Station	206.8	10 – 20 year ARI event
69023	Nelligen (Thule Rd)	N/A	N/A
***Note: the Nelligen gauge (69023) had a gap in the data available, spanning December 1933 and January 1934.**			

Four gauges were in operation in 1974 and the data is shown in Table 9. However, the Nelligen gauge (69023) had a gap in the data available spanning 1966 through to 1999. By comparison, the Moruya gauge (69042) had no gap in data for that year, however recorded a value of 0 mm of rainfall on the 20th April 1974.

Table 9: Rainfall Depth and Approximate ARI for the 20th April 1974

Station Number	Station Name	Daily Read Depth (mm at 9:00)	Approximate ARI
69018	Moruya Heads Pilot Station	115.4	1 – 2 year ARI event
69023	Nelligen (Thule Rd)	N/A	N/A
69042	Moruya (The Lagoon)	0	N/A
69052	Batemans Bay - Buckenbowra	136.6	1 – 2 year ARI event
***Note the Nelligen gauge (69023) had a gap in the data available, spanning 1966 to 1999.**			

For the 1991 event, five gauges were in operation and the data is shown in Table 10. Similar to the 1974 event, the Nelligen gauge (69023) had a gap in the data available. The Batemans Bay gauge (69134) also had a gap in the data available spanning 1987 to October 1991.

Table 10: Rainfall Depth and Approximate ARI for the 9th June 1991

Station Number	Station Name	Daily Read Depth (mm at 9:00)	Approximate ARI
69018	Moruya Heads Pilot Station	131.4	2 – 5 year ARI event
69023	Nelligen (Thule Rd)	N/A	N/A
69042	Moruya (The Lagoon)	190.0	5 – 10 year ARI event
69052	Batemans Bay - Buckenbowra	247.0	10 – 20 year ARI event
69134	Batemans Bay (Catalina Country Club)	N/A	N/A
***Note the Nelligen gauge (69023) had a gap in the data available, spanning 1966 to 1999. The Batemans Bay gauge (69134) had a gap in the data available, spanning 1987 to October 1991.**			

2.7. 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 11: Rainfall IFD Data at the George Bass Drive Water Level Gauge (216455)

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
5Mins	93.1	121	157	179	208	247	277
6Mins	87.2	113	148	168	195	232	260
10Mins	71.5	93	122	140	163	195	219
20Mins	52.4	68.5	91.7	106	124	149	169
30Mins	42.7	56	75.6	87.7	103	125	142
1Hr	29	38.2	52	60.7	71.9	87.2	99.2
2Hrs	19.1	25.2	34.3	40	47.3	57.4	65.3
3Hrs	14.9	19.5	26.5	30.8	36.5	44.1	50.1
6Hrs	9.62	12.6	17	19.6	23.1	27.9	31.6
12Hrs	6.23	8.16	10.9	12.6	14.9	17.9	20.2
24Hrs	4.02	5.28	7.13	8.27	9.77	11.8	13.4
48Hrs	2.52	3.33	4.58	5.36	6.38	7.76	8.86
72Hrs	1.87	2.47	3.42	4.01	4.78	5.83	6.68

2.8. Previous Reports

Little historical flooding has been reported in Tomakin, Mossy Point and Broulee. To date, studies have focused on Mogo which has experienced a number of flood events. Development pressures in Tomakin, Mossy Point and Broulee as well as elsewhere in the Tomaga River catchment (specifically along Dunns Creek Road) provides the impetus for the catchment-wide flood study.

2.8.1. Report on Mogo Flood Study

Residential, commercial and light industrial development in Mogo accelerated in the mid-1980's creating pressure to develop potentially flood prone land adjacent Cabbage Tree Creek. Consequently the Mogo Flood Study (Reference 1) was commissioned by Eurobodalla Shire Council to clarify the existing flood affection of Mogo. The study established the flood extent and levels of the 20% AEP, 5% AEP and 1% AEP events within and in the vicinity of the town of Mogo.

2.8.2. Mogo Floodplain Management Study

Subsequent to the completion of the Mogo Flood Study, the next phase of the Floodplain management process was undertaken comprising of the Mogo Floodplain Management Study (Reference 2). Both structural and non-structural measures to reduce the flood risk were considered. The study considered filling and channel upgrade to be the two most appropriate structural measures. However preference toward non-structural measures such as zoning and development controls which do not permit new building on land affected by flooding was expressed and no structural measure has been actioned.

2.8.3. Mogo Commercial Area Drainage Study

The Mogo Commercial Area Drainage Study (Reference 3) identified the preferred works for formalising a depression drain located on the east side of the Princes Highway, north of Tomakin Road.

The depression drain with a catchment area of 41.4 hectares discharges into Cabbage Tree Creek via two existing 0.9 m diameter culverts across the Princes Highway immediately north of Tomakin Road. The assessment considered the 1 year, 5 year, 20 year and 100 year ARI events and design flood flows were computed using the RAFTS-XP rainfall-runoff model. For the 100 year event, peak local flows of 14.3 m^3/s and peak Cabbage Tree Creek of 195.7 m^3/s were obtained.

The EXTRAN-XP hydraulic model was used to assess a number of pipe arrangement options to mitigate peak flood levels consisting of:

- A 1.35 m diameter pipe capable of discharging the 5 year ARI event into Cabbage Tree Creek;

- 0.45 m low flow pipe located along the centreline of the 10 m drainage easement and discharging into one of the existing 0.9 m pipes; and
- A trapezoidal shaped grassed open drain within the 10 m easement capable of discharging the 20 year ARI event.

While the proposed measures assist in alleviating flooding from the local catchment, the ability of a large event from Cabbage Tree Creek to backwater through the enhanced drainage system as well as the influence of an elevated sea level requires further consideration. The above works require further consideration and have not been actioned.

3. COMMUNITY CONSULTATION

3.1. Online Media

Following approval by the state government for a grant to assist in funding the flood study, the Bay Post – Moruya Examiner published details of the project advising the community that their input would be desired and that community consultation as well as a public exhibition period would be part of the study.

The article is available online at http://www.batemansbaypost.com.au/story/2148834/tomago-river-flood-study-funded/ and similar notice was provided on the Eurobodalla Shire Council website.

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 15th of April 2015 (see Section 3.3).

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

3.3. Drop-in Session

Eurobodalla Shire Council and WMAwater organised a drop-in session that was held at the Tomakin Community Hall between 4:00pm and 7:00pm on the 15th of April 2015. Present were representatives from Eurobodalla Shire Council, OEH and WMAwater as well as the wider social network. The community was informed of this meeting via the community information sheet.

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.

The drop-in session proved to be popular with over 30 attendees being present including two previous shire engineers, members of the Mossy Point Association as well as members of the Mogo Business Association.

Anecdotal evidence suggests that the largest event to take place in living memory was in 1934. Other significant events took place in 1974 and 1991. Subsequent to the 1974 event, the shire engineer (present at the drop-in session) marked telegraph poles on Elizabeth Drive approximately 0.3 metre above the peak flood level for the event and these are shown in Figure 6. Reports of more recent flooding were used to verify flood extents as part of the hydraulic model calibration.

These reports were characterised by shallow overland flow runoff for the majority of the catchment with the exception of Mogo where more significant and regular flooding was documented. Consequently, a further meeting was scheduled where WMAwater engineers met with Mogo Business owners and were shown local landmarks that have been historically flood affected.

3.4. Consultation – Public Exhibition

Further consultation will be undertaken when the Report is placed on Public Exhibition. This will be documented as part of the Final Report.

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.).

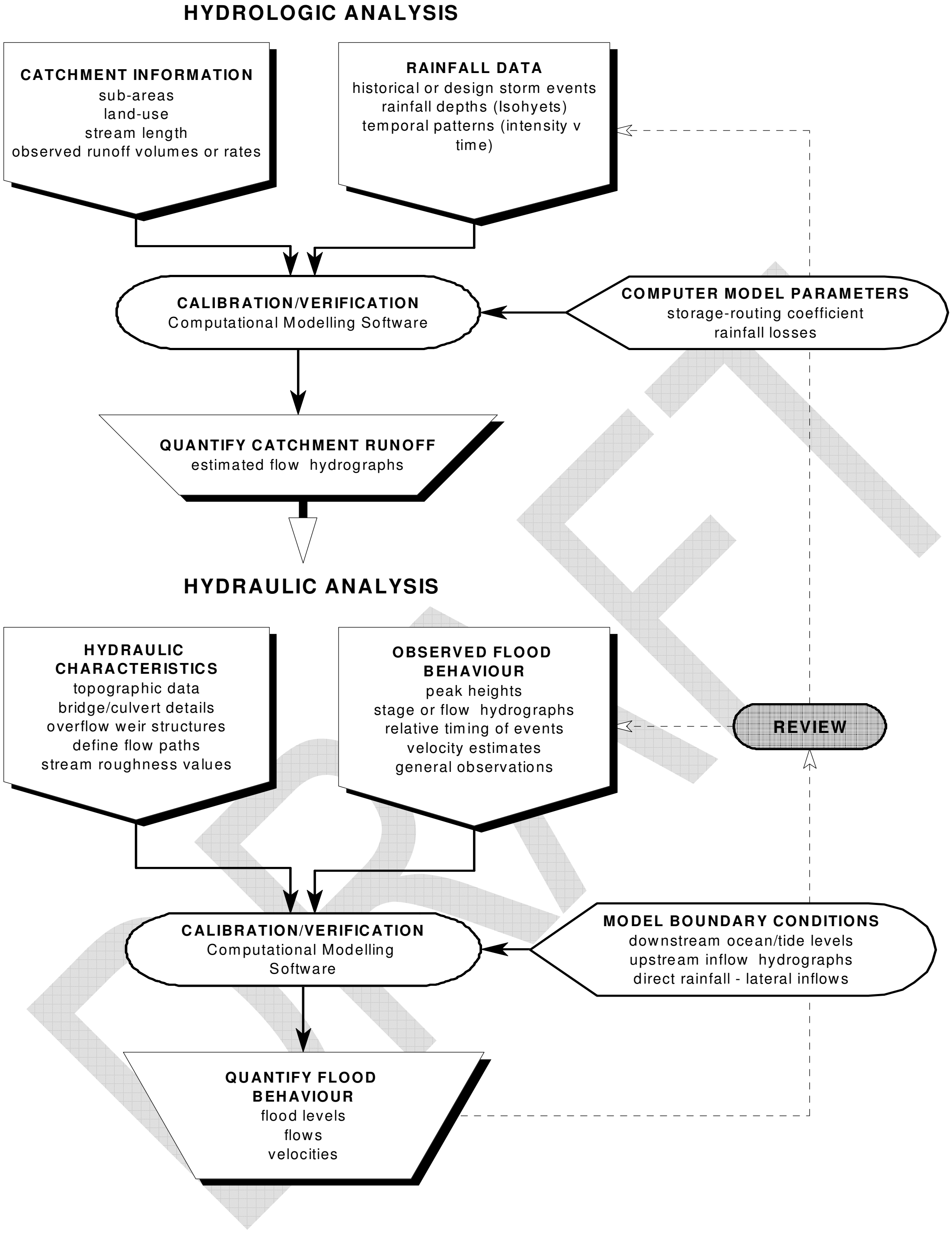
Flood estimation in urban catchments generally presents challenges for the integration of the hydrologic and hydraulic modelling approaches, which have been treated as two distinct tasks as part of traditional flood modelling methodologies. As the main output of a hydrologic model is the flow at the 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 verified against flooding reported by the community and flow estimates from the Regional Flood Frequency Estimate method.

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

A diagrammatic representation of the Flood Study process is shown in Diagram 2.

Diagram 2: 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.

Within the Tomaga River and Candlagan Creek catchments, smaller sub-catchment areas were delineated based on LiDAR survey and contours where LiDAR 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 7.

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 and the value adopted in the nearby catchments from the Wagonga Inlet, Kianga and Dalmeny Flood Study (2016).

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 (the location of which are sown in Figure 7) 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 are adopted based on available data in similar nearby catchments. Table 6.2 of ARR (1987) recommends that for catchments east of the dividing range in New South Wales, in the absence of calibration data, 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 20 mm was adopted with a continuing loss of 3.5 mm/hr.

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 discretisation of layers considered impermeable, namely roads and buildings, is shown in Figure 8. The proportion of these impervious surfaces within the sub-catchment area was adopted as the impervious percentage of each respective sub-catchment area.

5.3.5. Summary of Model Parameters

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

- Lag Parameter (C) – 1.7
- Pervious Area Initial Rainfall Loss – 20 mm
- Pervious Area Continuing Rainfall Loss – 3.5 mm/hour
- Impervious Area Initial Rainfall Loss – 1 mm
- Impervious Area Continuing Rainfall Loss – 0 mm/hour

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

- Lag Parameter (C) – 1.7
- Pervious Area Initial Rainfall Loss – 20 mm
- Pervious Area Continuing Rainfall Loss – 3.5 mm/hour
- Impervious Area Initial Rainfall Loss – 1 mm
- Impervious Area Continuing Rainfall Loss – 0 mm/hour