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.