10. DESIGN FLOOD MODELLING – OCEANIC COINCIDENCE

10.1. Background

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

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

10.2. Modelling Approach

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

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

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

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

10.3. Geographic Location

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

10.4. Waterway Entrance Type

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

11. DESIGN FLOOD MODELLING – RAINFALL CRITICAL DURATION

11.1. Introduction

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

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

11.2. Wagonga

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

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

11.3. Kianga

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

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

11.4. Dalmeny

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

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

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

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

12. DESIGN FLOOD MODELLING – RESULTS

12.1. Wagonga Inlet

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

The results from this study are presented as:

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

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

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

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

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

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

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

12.2. Kianga

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

The results from this study are presented as:

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

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

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

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

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

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

12.3. Dalmeny

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

The results from this study are presented as:

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

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

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

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

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

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

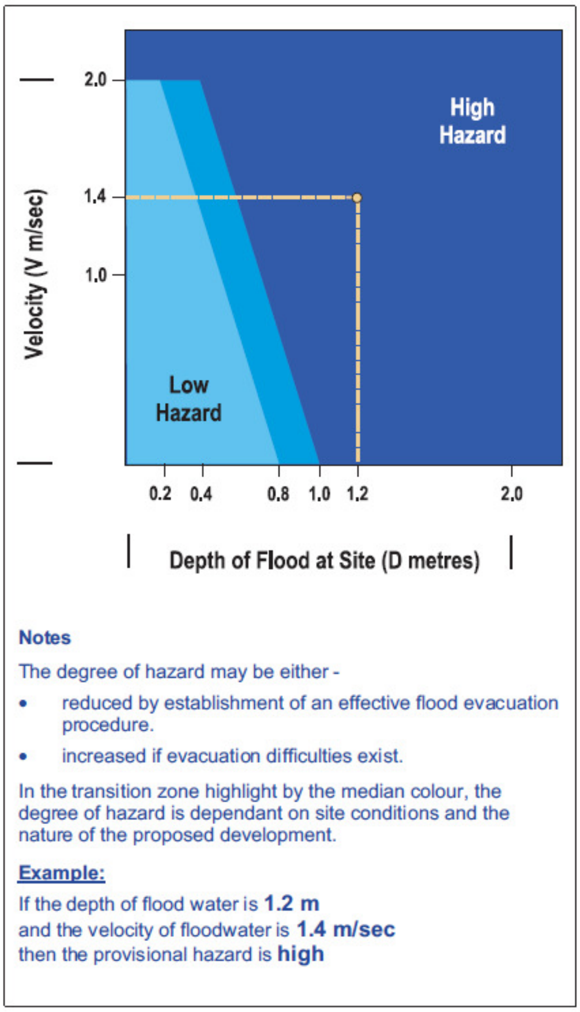
Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Pedestrian Footbridge	32.3	51.0	80.0	120.5	157.0	194.0	378.2
Princes Hwy crossing Lawlers Creek	87.1	105.7	130.0	156.5	181.9	209.1	607.7
Princes Hwy crossing Spring Creek	0.0	7.3	21.2	35.2	44.9	54.2	226.8
Mort Ave crossing Spring Creek	9.2	14.2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

13. DESIGN FLOOD MODELLING – RESULTS ANALYSIS

13.1. Provisional Hydraulic Hazard Categorisation

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

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



Notes

The degree of hazard may be either -

- reduced by establishment of an effective flood evacuation procedure.
- increased if evacuation difficulties exist.

In the transition zone highlight by the median colour, the degree of hazard is dependant on site conditions and the nature of the proposed development.

Example:

If the depth of flood water is **1.2 m**
and the velocity of floodwater is **1.4 m/sec**
then the provisional hazard is **high**

13.2. Hydraulic Categorisation

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

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

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

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

13.3. Discussion – Hazard and Hydraulic Categories

13.3.1. Wagona Inlet

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

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

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

13.3.2. Kianga

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

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

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

13.3.3. Dalmeny

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

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

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

13.4. Preliminary Flood Emergency Response Classification of Communities

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

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

Table 37: Response Required for Different Flood ERP Classifications

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

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

13.4.1. Wagona Inlet

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

13.4.2. Kianga

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

13.4.3. Dalmeny

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

13.5. Road Access

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

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

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

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

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

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

13.5.1. Wagonga Inlet

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

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

13.5.2. Kianga

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

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

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

13.5.3. Dalmeny

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

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

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

14. DESIGN FLOOD MODELLING – SENSITIVITY ANALYSIS

14.1. Introduction

14.1.1. Background

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

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

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

14.1.2. Sea Level Rise Scenario

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

The 2009 Policy Statement says that:

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

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

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

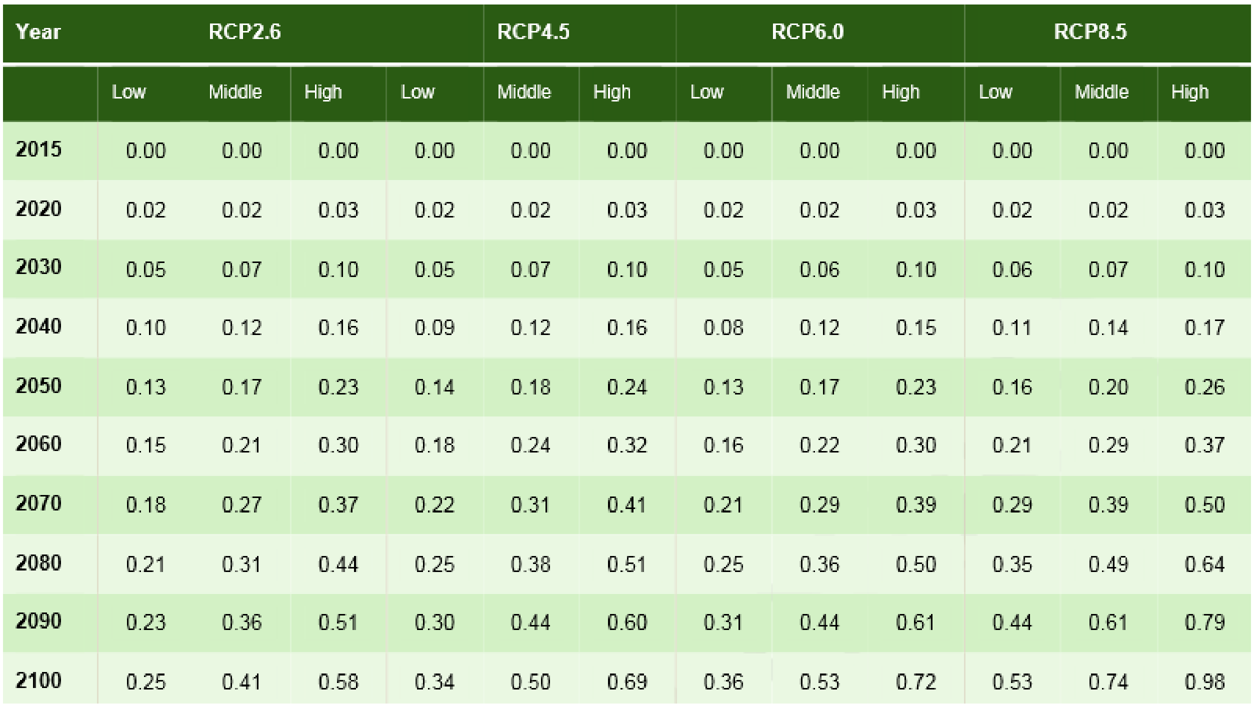
The key scientific findings were summarised as:

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

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

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

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



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

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

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

14.1.3. Increased Rainfall Scenario

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

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

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

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

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

15. DESIGN FLOOD MODELLING – SENSITIVITY RESULTS

15.1. Wagonga Inlet

15.1.1. Manning’s ‘n’ Roughness Value

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

15.1.2. Timing of Ocean Peak

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

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

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

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

15.1.3. Climate Change (Sea Level Rise)

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

15.1.4. Climate Change (Rainfall Increase)

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

15.2. Kianga

15.2.1. Manning's 'n' Roughness Value

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

15.2.2. Timing of Ocean Peak

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

15.2.3. Climate Change (Sea Level Rise)

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

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

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

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

15.2.4. Climate Change (Rainfall Increase)

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

15.3. Dalmeny

15.3.1. Manning's 'n' Roughness Value

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

15.3.2. Timing of Ocean Peak

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

15.3.3. Climate Change (Sea Level Rise)

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

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

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

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

15.3.4. Climate Change (Rainfall Increase)

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

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