Eden, Twofold Bay, Towamba River Flood Study

Draft Flood Study

Bega Valley Shire Council | Flood Study | 25 October 2019

Contact Information

Rhelm Pty Ltd
ABN : 55 616 964 517
Level 1, 50 Yeo Street
Neutral Bay NSW 2089
Australia

Lead Author:
Emma Maratea
Emma.maratea@rhelm.com.au

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The report has been prepared and reviewed by suitably qualified persons. The scope of the report is based on the client brief and/or the Rhelm written fee proposal and assumes information provided by the client and sourced from other third parties is fit for purpose unless otherwise stated. The findings rely on a range of assumptions that are noted in the report.

Foreword

The primary objective of the New South Wales (NSW) Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible.

Through the NSW Department of Planning, Industry and Environment (DPIE) and the NSW State Emergency Service (SES), the NSW Government provides specialist technical assistance to local government on all flooding, flood risk management, flood emergency management and land-use planning matters.

The *Floodplain Development Manual* (NSW Government 2005) is provided to assist councils to meet their obligations through the preparation and implementation of floodplain risk management plans, through a staged process. **Figure F1**, taken from this manual, documents the process for plan preparation, implementation and review.

The *Floodplain Development Manual* (NSW Government 2005) is consistent with Australian Emergency Management Handbook 7: *Managing the floodplain: best practice in flood risk management in Australia* (AEM Handbook 7) (AIDR 2017).

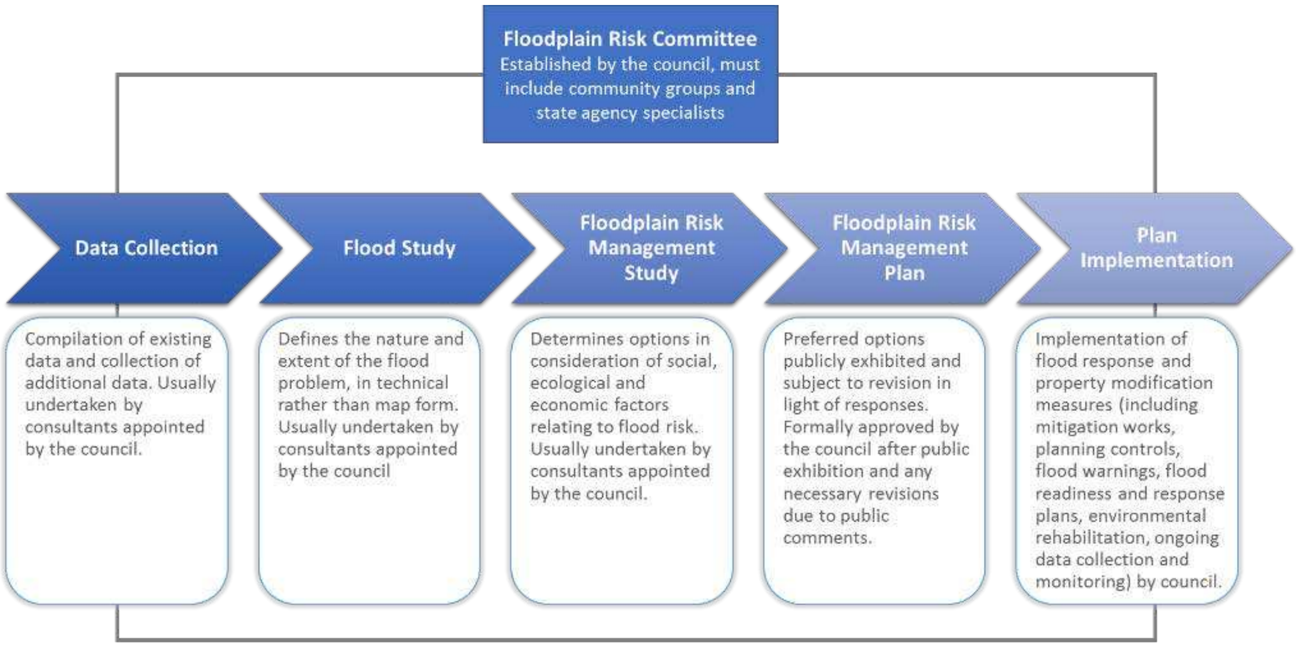

Figure F1 The Floodplain Risk Management Process (source: NSW Government, 2005)

Bega Valley Shire Council is responsible for local land use planning in its service area, including in the Twofold Bay and Towamba River catchment and its floodplain. Through its Floodplain Risk Management Focus Group, Council has committed to prepare a comprehensive floodplain risk management plan for the study area in accordance with the NSW Government's *Floodplain Development Manual* (2005). This document relates to the flood study phase of the process.

Executive Summary

The Eden, Twofold Bay and Towamba River Flood Study has been prepared for Bega Valley Shire Council (Council) to define the existing flood behaviour in the catchment and establish the basis for subsequent floodplain management activities.

Study Area and Scope

The study area covers the entire catchment of Twofold Bay with a focus on understanding the flood behaviour and risk in the foreshore locations of Eden, Quarantine Bay, Boydtown and Munganno Point / Jews Head and the catchment localities of Rocky Hall, Wyndham, New Buildings, Burragate and Towamba. The study area is shown in **Map G101**.

This project is a flood study, which is a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust floodplain risk management plan. It aims to provide a better understanding of the full range of flood behaviour and consequences. It involves consideration of the local flood history, available collected flood data, and the development of hydrologic and hydraulic models that are calibrated and verified, where possible, against historic flood events and extended, where appropriate, to determine the full range of flood behaviour.

Engagement

Comprehensive stakeholder engagement was undertaken throughout the development of the flood study. This involved:

- Engaging agency and industry stakeholder to obtain details of historical flooding, survey data and other relevant data sets. Stakeholders will also be invited to provide feedback on the draft flood study during public exhibition.
- Community engagement has been undertaken through the mail out of an information brochure and brief survey. A series of community drop in sessions were also held in Towamba and Eden. The purpose of the engagement was to raise awareness of the study and flood risk in the catchment, as well and obtain observations of historical flooding to assist in model calibration. Respondents were contacted for further information by phone and email, as required.
- This document will be placed on public exhibition for a period of four weeks. During this time Council will notify residents and property owners in the catchment area to be public exhibition, inviting them to learn more about the draft Flood Study. Another series of information sessions will also be held for community members to get information and ask questions. Council's website will include information about the study, the draft documents and an opportunity to provide submissions. Submission will also be able to be submitted at Council's Customer Service Centre and at the community information sessions.

Hydrological and Hydraulic Modelling

Due to the complex nature of flooding across the study areas, flood modelling been undertaken using a combination of hydrological, hydraulic and hydrodynamic models. This allows flooding to be assessed with regards to coastal processes, estuarine dynamics (in particular entrance scour), riverine flooding and overland flow. Hydrological modelling was undertaken for all study areas using XP-RAFTS, catchment driven flooding was modelled in TUFLOW and estuarine flooding driven primarily by coastal processes was modelled in Delft3D.

The flood models were calibrated and validated to historical flood events, where data was available. Historical flood data was compiled from rainfall and flow gauges as well as community observations. A summary of historical catchment and coastal events used for calibration and validation is shown below. No calibration data was available for Boydtown Creek, Nullica River, Shadrach Creek or Cocora Lagoon.

Historical Flood Events Used for Calibration and Validation

Event	Calibration / Validation Undertaken			Comments
	Towamba River Models	**Eden Overland Flow Model**	**Coastal Models**	
1978 Catchment and Coastal Event	Calibration	Validation of 20% and 1% AEP runs		The community were able to identify several flood levels and extents around Towamba. General observations were collected of flooding in Eden.
March 2011 Towamba River Catchment Event	Calibration			Although this was noted in several references as a major event. The majority of flood recollections provided for Kiah area. One calibration mark surveyed in Towamba for this event.
March 2012 Coastal Event			Calibration	It is one of the largest water level events associated with an entrance breakout. Event allows for the calibration of the entrance breakout of Lake Curalo
June 2016 East Coast Low			Calibration	Lake Curalo entrance was open (i.e. Lake was tidal) during June 2016 ECL. Exact entrance condition at that time is unknown. Event allows for the calibration of the interaction of rainfall runoff and storm surge in the lake. This was limited by the availability of rainfall data.

The hydrological, hydraulic and hydrodynamic models were analysed for the Probable Maximum Flood (PMF), 0.2% AEP, 0.5% AEP, 1% AEP, 2% AEP, 10% AEP and 20% AEP events. The models were analysed for durations ranging from 60 minutes to 36 hours, using the 10 temporal pattern ensemble approach detailed in ARR2016. Critical storm durations and median temporal patterns were determined form the hydrological modelling, with only the critical events applied to the hydraulic model.

Flooding within the Eden study area is driven by both lake flooding and catchment flooding. The extent of influence of lake flooding is limited, affecting primarily undeveloped areas along the lake foreshore. Some low-lying residential properties are impacted by lake flooding along the western edge of the lake. Catchment flooding controls the peak flood levels across much of the study area. Flow is well contained along most flow paths, although increasing levels of break out flow occurring the larger AEP events and PMF. The critical duration across the study area ranged from 2 hours, for those areas with small upstream catchment areas, up to 9 hours, for those areas (such as Palestine Creek) with a larger contributing catchment.

In the coastal lagoons of Shadrachs Creek, Nullica River and Boydtown Creek flooding is generally confined to the creeks and lagoon areas in events up to the 5% AEP event. In larger events, flow begins to break out of the channels. While this largely occurs over vegetated areas or pastureland in Nullica and Boydtown, in Shadrachs, this breakout impacts the adjacent caravan park.

Flooding was assessed at five localities in the Towamba River catchment; Wyndham, Rocky Hall, New Buildings, Burragate and Towamba. Flooding in these locations is as a result of the Towamba River and Mataganah Creek overtopping their banks. Flooding within the Towamba River study areas is typically well defined, with little breakout flow from the main channel occurring, even in large flood events. The critical duration for flooding is long, 9 to 12 hours, due to the large contributing upstream catchment area. Several main access roads and bridges become inundated, isolating residents for the duration of the flood event.

Sensitivity

Sensitivity analysis of the hydraulic and hydrodynamic models to roughness, rainfall intensity and blockage of culverts and bridges was undertaken. The peak flood levels in the Towamba River catchment models were more sensitive to roughness changes than the other study areas, with increases of up to 1m. However, the increases did not result in significant increases to flood extents or number of properties impacted. The model was not particularly sensitive to blockage, with blockage of culverts in Eden only causing localised increases in flooding (i.e. immediately upstream of blocked culverts). Sensitivity to rainfall intensity was assessed through a comparison of the 0.5% AEP and 2% AEP to the 1% AEP event. The assessment showed that the model sensitivity to rainfall intensity increased for Towamba River study areas further downstream. In the upper catchment typical impacts were +/- 0.2 to 0.4 metres. This increased to +/- 0.7 to 1 metre at Towamba. Eden had more modest impacts in the order of +/- 0.1 metres. Shadrachs, Nullica and Boydtown had impacts of less than +/- 0.1.

Climate Change

For the Towamba River models, the impact of changes in rainfall intensity increases for study areas further downstream. In the upper catchment, increases in flood levels as a result of rainfall intensity increases were modest, typically in the range of 0.2 to 0.4 metres. Flood level impacts increased downstream, due to the additional upstream area contributing increased flow. Median increases in flood levels at New Buildings were 0.69 metres, increasing to 0.97 metres at Towamba.

In the coastal study areas, the increase in rainfall intensity had a much smaller impact on peak flood levels. Eden had more modest impacts in the order of +/- 0.1 metres, while Shadrachs, Nullica and Boydtown had impacts of less than +/- 0.1.

Sea level rise only impacts flooding in the coastal study areas. The Towamba River study areas are sufficiently far upstream to not be affected by sea level rise.

Along the northern shore of Lake Curalo, impacts were minimal, with negligible change in flood extent occurring even with a 0.9 metre rise is sea level. Along the western shore, sea level rise of 0.4 metres resulted in no significant increase in flood extent, although 0.9 metre of sea level rise resulted in a lateral expansion of 30 metres at Lakeside Drive that resulted in additional properties becoming flood affected. Along the southern shore, additional inundation, while more wide spread than the northern and western shores, was typically restricted to open space and vegetated corridors. The exception was the aged care centre on Barclay Street, which was fully inundated under a 0.9 metre sea level rise scenario.

The steep terrain at Lake Cocora prevented any significant increase in flood affectation under a 0.4 metre sea level rise scenario. With 0.9 metres of sea level rise, overtopping of Ida Rodd Drive occurred.

Sea level rise at Shadrachs Creek primarily affected the caravan park, with an additional 20 metres and 30 metres of flood affectation occurring under the 0.4 and 0.9 metre sea level rise scenarios respectively. No impacts were shown upstream of the Princes Highway.

The terrain at Nullica and Boydtown prevent any significant expansion of flood extents under climate change scenarios. Increases greater than 0.1 metres in both the 2050 and 2100 scenarios did not extend past Juno Drive in Boydtown. The extent of increases within the channel extended further in Nullica with increases of 1.1 metres observed at Nullica Short Cut Road in the 2100 scenario. Impacts on developed areas were negligible, although increased flood affectation was observed across the pasture land adjacent to the Nullica River.

Conclusion

This report provides an understanding of the flood risk within the study area and provides Council with the tools for planning. This study provides a baseline against which a Floodplain Risk Management Study and Plan can be prepared.

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Glossary

Annual exceedance probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (i.e. a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year. (See also average recurrence interval).
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
Attenuation	Weakening in force or intensity.
Average recurrence interval (ARI)	The long-term average number of years between the occurrence of a flood as big as (or larger than) the selected event. For example, floods with a discharge as great as (or greater than) the 20 year ARI design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. (See also annual exceedance probability).
Catchment	The catchment, at a particular point, is the area of land that drains to that point.
Chart Datum	The level of water that charted depths displayed on a nautical chart are measured from. A chart datum is generally a tidal datum; that is, a datum derived from some phase of the tide. Common chart datums are lowest astronomical tide and mean lower low water.
Design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100 year ARI or 1% AEP flood).
Development	Is defined in Part 4 of the AP&A Act as: • Infill Development: development of vacant blocks of land that are generally surrounded by developed properties. • New Development: development of a completely different nature to that associated with the former land use. • Redevelopment: Rebuilding in an area with similar development.
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
Flood	Relatively high river or creek flows, which overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
Flood Awareness	Awareness is an appreciation of the likely effects of flooding and knowledge of the relevant flood warning, response ad evacuation procedures.

Flood Education	Education that seeks to provide information to raise awareness of the flood problem to enable individuals to understand how to manage themselves and their property in a flood event.
Flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage.
Flood hazard	The potential risk to life and limb and potential damage to property resulting from flooding. The degree of flood hazard varies with circumstances across the full range of floods.
Flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as "stage".
Floodplain	Area of land which is subject to floods up to and including the probable maximum flood.
Floodplain risk management plan	A document outlining a range of actions aimed at improving floodplain management. The plan is the principal means of managing the risks associated with the use of the floodplain. A floodplain risk management plan needs to be developed in accordance with the principles and guidelines contained in the NSW Floodplain Development Manual. The plan usually contains both written and diagrammatic information describing how particular areas of the floodplain are to be used and managed to achieve defined objectives.
Flood planning levels (FPLs)	Flood planning levels selected for planning purposes are derived from a combination of the adopted flood level plus freeboard, as determined in floodplain management studies and incorporated in floodplain risk management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also consider the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of land use and for different flood plans. The concept of FPLs supersedes the "standard flood event". As FPLs do not necessarily extend to the limits of flood prone land, floodplain risk management plans may apply to flood prone land beyond that defined by the FPLs.
Flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
Flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
Floodway	A flow path (sometimes artificial) that carries significant volumes of floodwaters during a flood.

Freeboard	A factor of safety usually expressed as a height above the adopted flood level thus determining the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
Gauging (tidal and flood)	Measurement of flows and water levels during tides or flood events.
Hazard	A source of potential harm or a situation with a potential to cause loss.
Hindcast	A statistical calculation determining probable past conditions.
Historical flood	A flood that has actually occurred.
Hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems, in particular the evaluation of flow parameters such as water level and velocity.
Hydrograph	A graph showing how a river or creek's discharge changes with time.
Hydrologic	Pertaining to rainfall-runoff processes in catchments.
Hydrology	The term given to the study of the rainfall-runoff process in catchments, in particular, the evaluation of peak flows and flow volumes. .
Isohyet	Equal rainfall contour.
Overland Flow	Overland flow flooding is water that flows down to a water course, compared with mainstream flooding that is water that rises from a water source.
Peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
Pluviometer	A rainfall gauge capable of continuously measuring rainfall intensity.
Probable maximum flood (PMF)	An extreme flood deemed to be the maximum flood that could conceivably occur.
Probability	A statistical measure of the likely frequency or occurrence of flooding.
Riparian	The interface between land and waterway. Literally means "along the river margins".
Runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
Stage	See flood level.
Stage hydrograph	A graph of water level over time.
Topography	The shape of the surface features of land.
Velocity	The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, i.e. the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.

Terminology in this Glossary has been adapted from the NSW Government Floodplain Development Manual, 2005, where available.

Abbreviations

1D	One Dimensional
2D	Two Dimensional
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ARF	Areal Reduction Factor
AR&R	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
BVSC	Bega Valley Shire Council
BVDCP	Bega Valley Development Control Plan
BVLEP	Bega Valley Local Environmental Plan
DCP	Development Control Plan
DEM	Digital Elevation Model
DPE	Department of Planning and Environment
DPIE	Department of Planning, Industry and Environment
ECL	East Coast Low
IFD	Intensity Frequency Duration
FPL	Flood Planning Level
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
FPRMSP	Floodplain Risk Management Study & Plan
ha	hectare
HAT	Highest Astronomical Tide
km	kilometres
km^2	Square kilometres
LEP	Local Environmental Plan
LGA	Local Government Area
LiDAR	Light Detection and Ranging
m	metre
m^2	Square metres
m^3	Cubic metres
mAHD	metres to Australian Height Datum
mm	millimetres
m/s	metres per second

MHWS	Mean High Water Spring
MLWS	Mean Low Water Spring
MHWN	Mean High Water Neap
MLWN	Mean Low Water Neap
MSL	Mean Sea Level
NSW	New South Wales
OEH	Office of Environment and Heritage (NSW)
PMF	Probable Maximum Flood
SES	State Emergency Service (NSW)

1 Introduction

The Eden, Twofold Bay and Towamba River Flood Study has been prepared for Bega Valley Shire Council (Council) to define the existing flood behaviour in the catchment and establish the basis for subsequent floodplain management activities.

1.1 Study Location

The study area covers the entire catchment of Twofold Bay with a focus on understanding the flood behaviour and risk in the foreshore locations of Eden, Quarantine Bay, Boydtown and Munganno Point / Jews Head and the catchment localities of Rocky Hall, Wyndham, New Buildings, Burragate and Towamba.

The Twofold Bay catchment is located in the Bega Valley Shire Local Government Area, which is approximately 400 km south of Sydney and 600 km north east of Melbourne along the Princes Highway and approximately 230 km south east of Canberra along the Snowy Mountains Highway on the NSW South Coast.

Twofold Bay is an oceanic embayment which has an open entrance. With the exception of Eden township, the foreshore of Twofold Bay is relatively undeveloped. The key locations of interest on the foreshore of Twofold Bay in this study include Quarantine Bay (Shadrachs Creek), Nullica River and Boydtown, in addition to Eden township.

Eden is partially located within the Lake Curalo Catchment and also within the catchment for Snug Cove, Cattle Bay and Cocora Lagoon, among other overland flow areas draining directly into Twofold Bay. Historical flooding in Eden has been as a result of catchment rainfall causing overland flow and creeks overtopping their banks, as well as foreshore flooding associated with Lake Curalo water levels (caused by both rainfall with a closed entrance and ocean storms with an open entrance).

Towamba River is the main waterway draining the catchment to Twofold Bay. The flood behaviour of the Towamba River carves a path from the foot of the steep escarpment, through rugged hills, flats and granite country, to empty into the ocean at the Kiah inlet. One of the fastest rising rivers in the state, it is joined by the Wog Wog River below Burragate, before it reaches the village of Towamba.

Other waterways located within the study area, and key locations of interest to this study include:

- Ben's Creek
- Mataganah Creek
- Basin Creek
- Stockyard Creek
- Nullica River
- Boydtown Creek
- Reedy Creek
- Palestine Creek
- Two Mile Creek
- Bellbird Creek
- Golf Course Creek
- Shadrach's Creek
- Freshwater Creek
- Lake Curalo
- Quarantine Bay
- Twofold Bay

The study area is shown in **Map G101**.

1.2 Study Objectives

The overall objective of this study is to improve understanding of flood behaviour and impacts, and better inform management of flood risk in the study area through consideration of the available information, and relevant standards and guidelines. The study will also provide a sound technical basis for any further flood risk management investigations in the area.

This project is a flood study, which is a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust floodplain risk management plan. It aims to provide a better understanding of the full range of flood behaviour and consequences. It involves consideration of the local flood history, available collected flood data, and the development of hydrologic and hydraulic models that are calibrated and verified, where possible, against historic flood events and extended, where appropriate, to determine the full range of flood behaviour.

The project provides an understanding of, and information on, flood behaviour and associated risk to inform:

- relevant government information systems;
- government and strategic decision makers on flood risk;
- the community and key stakeholders on flood risk;
- flood risk management planning for existing and future development; and
- emergency management planning for existing and future development, and strategic and development scale land-use planning to manage growth in flood risk.

The outputs of the study will assist this by:

- providing a better understanding of the:
  - variation in flood behaviour, flood function, flood hazard and flood risk in the study area;
  - impacts and costs for a range of flood events or risks on the existing and future community;
  - impacts of changes in development and climate on flood risk; and
  - emergency response situation and limitations.
- facilitating information sharing on flood risk across government and with the community.

The study outputs will also inform decision making for investing in the floodplain; managing flood risk through prevention, preparedness, response and recovery activities, and informing and educating the community on flood risk and response to floods.

1.3 Study Background and Context

The study area is impacted by flooding from various flooding mechanisms:

- The Eden part of the study area is characterised by urban overland flooding as well as backwater from Lake Curalo and Cocora Lagoon;
- The Towamba River is a larger catchment which much longer duration riverine flooding;
- The ICOLLs; Lake Curalo, Cocora Lagoon, Nullica Creek, Shadrachs River and Boydtown Creek are driven by the entrance conditions, coastal behaviour and catchment behaviour; and,
- Inundation and wave action within Twofold Bay are driven by the coastal forces offshore.

There has been historical flooding observed throughout the study area. During 2011, a major flood event on the Towamba River led to the communities at Rocky Hall, Burragate, New Buildings and Towamba being isolated for a number of days as key bridges in those areas were destroyed during the event. More recently during June 2016, a major East Coast Low event saw key wharf structures within Twofold Bay being destroyed or damaged by coastal driven inundation and wave action.

Key development pressure at the Port of Eden, Cattle Bay and Boydtown necessitate some exploration of flood impacts as to the best of Council's knowledge, no comprehensive contemporary flood study for the catchment has ever been undertaken to the current 2005 NSW Floodplain Development Manual guidelines.

The study aims to quantify the flood risk in the study area for both inundation and emergency response issues.

2 Study Area

The study area includes the Towamba River catchment and Twofold Bay, encompassing the watershed areas draining to the Towamba River, Nullica River and Lake Curalo, the Twofold Bay coastal embayment and continental margin of South-east NSW. The interaction of catchment flooding with estuary and coastal water levels is a key consideration of the study requiring an extended study area from the top of catchment to the continental shelf.

2.1 Catchment Description

The entire catchment draining to Twofold Bay is included in the study area. However, due to the focus of flood analysis at key locations, the catchment description has been provided within the context of these focus locations.

2.1.1 Twofold Bay

Twofold Bay receives flows from Towamba River, Boydtown Creek, Shadrachs Creek, Nullica River, and Lake Curalo in addition to other smaller creeks and overland flow areas.

Close to North Head is a conspicuous islet, Mewstone Rock. About 5 kilometres south of the islet is Red Point which forms the southern headland of the bay. Eden and the Port of Eden are located in the bay. The historical town of Boydtown is located in the west of the bay, located on Boydtown Beach which stretches south from the mouth of the Nullica River.

Foreshore flooding around Twofold Bay can occur from a combination of factors, including tides, winds and waves.

2.1.2 Towamba River

The catchment area of the Towamba River is 1,026 km^2. The river rises approximately 9 kilometres north of the Coolangubra Mountain, below Mount Marshall and flows generally south-east and then north-east, joined by twelve tributaries including (ordered by descending elevation) Back Creek (198m), Basin Creek (184m), New Station Creek (177m), Mataganah River (164m), Reedy Creek (158m), Wog Wog River (76m), Pericoe Creek (75m), Camping Ground Creek (57m), Stony Creek (41m), Jingo Creek (39m), Stanleys Creek (9m) and Shelleys Creek (1m), before reaching its mouth, emptying into Nullica Bay, within Twofold Bay , east of Boydtown. The river descends 533 metres over its 86 km course.

The river flows through the South East Forest National Park in its upper reaches and forms the northern boundary of Mount Imlay National Park in the lower reaches.

The Towamba River catchment is bound by the Bega River catchment to the north, the Snowy River catchment to the west and the Genoa River catchment to the south. The Princes Highway crosses the Towamba River at the locality of Kiah.

The Towamba River basin is unregulated – there are no major storages to capture and control flows.

Flooding within the Towamba River study areas is typically well defined, with little breakout flow from the main channel occurring, even in large flood events. However, some farmland and low-lying floodplain pockets adjacent to the channel are impacted in significant events. The critical duration for flooding is long, 9 to 12 hours, due to the large contributing upstream catchment area.

This flood study provides detailed analysis of the flood behaviour at the following key locations within the Towamba River Catchment:

- Wyndham
- Rocky Hall
- New Buildings
- Burragate
- Towamba

These locations are shown on **Map G101**.

Following consultation with the community (**Section 4**) it was identified that Kiah also experiences flood risk to property, assets and life. One of the recommendations of this study is the inclusion of Kiah in the flood analysis as part of the Floodplain Risk Management Study.

2.1.3 Eden and Lake Curalo

Lake Curalo has a waterway area of 0.73 km² and drains a mainly forested catchment of 30.3 km² contained within the Nullica State Forest and Ben Boyd National Park, with the lower portion incorporating part of the Eden township.

Lake Curalo is an intermittently open and closed lagoon (ICOLL). Council have an entrance management policy in place to allow for the mechanical opening of the entrance a specific trigger levels to manage flood risk around the Lake's foreshore areas.

Eden is partially located within the Lake Curalo Catchment and also within the catchment for Snug Cove, Cattle Bay and Cocora Lagoon, among other overland flow areas draining directly into Twofold Bay.

Flooding within the Eden study area is driven by both lake flooding and catchment flooding. The extent of influence of lake flooding is limited, affecting primarily undeveloped areas along the lake foreshore. Some low-lying residential properties are impacted by lake flooding along the western edge of the lake.

Catchment flooding controls the peak flood levels across much of the study area. Flow is well contained along most flow paths, although increasing levels of break out flow occurring the larger AEP events and PMF.

The critical duration across the study area ranged from 2 hours, for those areas with small upstream catchment areas, up to 9 hours, for those areas (such as Palestine Creek) with a larger contributing catchment.

2.1.4 Estuaries

Lake Curalo, along with other the coastal lagoons, including Nullica River, Shadrachs Creek, and Boydtown Creek, have entrances that are dominated by barrier and berm features that are fed by the supply of sediment from offshore via littoral drift to the north, the supply of alluvial sediments from the Towamba River (Boydtown Beach, Whale Beach) and the supply of biogenic material (shell fragments) from a localised nearshore source (Fisheries Beach) (Roy & Hudson, 2007). With the exception of the Towamba River, whose entrance remains open, the connecting waterways to Twofold Bay are defined as Intermittently Closed and Open Lakes and Lagoons (ICOLLs), in that they naturally open and close to the ocean in a constant but irregular cycle (DPI, 2018).

When closed, water levels in the ICOLL will rise as a result of water flowing from the catchment area, in some cases in a matter of hours or days. Once the water level reaches the lowest crest level of the entrance berm, water will start to drain from the ICOLL and quickly scours an entrance channel through the entrance and reopens the ICOLL to the ocean. When ICOLLs are open they become tidal with seawater moving into and out of the estuary with the daily tidal cycle.

This natural mechanism of entrance opening can have a significant impact on lagoon water levels causing flooding either directly (around the lagoon foreshore) or indirectly (by acting as a downstream control on catchment flooding upstream). As a result, Council have instigated a policy of entrance berm level management and mechanical (manual) opening in anticipation of large rainfall (flooding) events, including at Lake Curalo (**Section 2.1.3**).

2.1.4.1 Shadrachs Creek

Shadrachs Creek is an intermittently open and closed lagoon (ICOLL) with a catchment area of 13.2km^2. The catchment is predominantly forested, with some roads and small cleared areas.

The Princes Highway crosses Shadrachs Creek just upstream of its entrance to Twofold Bay. Downstream of the highway there is a caravan park on the southern bank of Shadrachs Creek.

Flood levels downstream of the Princes Highway are driven by ocean levels, while catchment flows have a greater influence over those regions of the model upstream of the highway. Flow past the highway is constricted, resulting in flood storage areas occurring upstream of the highway in the 1% AEP event and larger.

2.1.4.2 Nullica River

The Nullica River is an intermittently open and closed lagoon (ICOLL) with a catchment area of 55km^2. The Nullica River rises below Nullica Hill within Nullica State Forest, approximately 11 kilometres west of Eden. The river flows generally east southeast, joined by one minor tributary, before reaching its mouth and emptying into Nullica Bay, within Twofold Bay. The river descends 137 metres over its 11 kilometres course.

West of the river's mouth, the Princes Highway crosses the Nullica River.

In events up to the 5% AEP, flow within the Nullica River is generally within the channel banks. In larger events, flow begins to break out of the channel and inundate the adjacent pastureland and vegetated areas. Building affectation does not occur until the PMF event.

2.1.4.3 Boydtown Creek

Boydtown Creek has a small catchment area (3.9 km^2), which drains in a principally north-easterly direction to the south western shore of Twofold Bay. The catchment elevations RL 200m to sea level and the catchment topography can generally be described as steep. The majority of the catchment is bushland with only some minor urban subdivision development in the southern fringe of the lower catchment and the historic Sea Horse Inn and a nearby camping ground occupying the only sizeable area of flat ground adjacent to and north of the creek.

The creek system has two main tributaries. The longer arm, Boydtown Creek has its headwaters west of the Princes Highway. The uppermost 0.6 km^2 of this main arm catchment also forms the local catchment of an offline town water supply dam, the Ben Boyd Dam which was built in 1978. Water to fill the Ben Boyd dam is pumped from the nearby Towamba River.

Approximately 250m downstream of the Princes Highway the main arm of the creek junctions with the other main (unnamed) tributary.

The lower reaches of Boydtown Creek form an ICOLL with the entrance to Twofold Bay being closed during non-flood times (Bewsher Consulting, 1989).

Flow within Boydtown Creek is generally well contained in events up to the 0.2% AEP. Some upstream ponding occurs at Juno Drive in events as small as the 10% AEP event.

2.2 Historical Flooding

2.2.1 Towamba River

The flood history of the Towamba River is lengthy, resulting in death to persons and stock, destroying assets, private property, crops, roads and causing significant erosion. During 2011, a major flood event on the Towamba River led to the communities at Rocky Hall, Burragate, New Buildings and Towamba being isolated for a number of days as key bridges in those areas were destroyed during the event.

Towamba's first bridge was built as a high-level truss bridge and was opened in 1911. The 1919 flood washed all bridges from the entire length of the river leaving the river flats and low-lying farms strewn with debris. Local knowledge suggests that the water reached halfway up the counter in the Towamba village store. Debris banked up in front of the bridge causing it to break up, sweeping its timbers downstream where they were found when the level dropped. It was the biggest local flood in living memory. Towamba's second bridge was not as high but gradually as each annual flood brought more sand downriver; it was continually covered and became impassable. It was replaced with the present bridge in 1961.

There have been several devastating floods since. During the 1971 flood two people who were crossing the river on their tractor, were drowned at Rocky Hall.

Significant historical flood events within the Towamba River catchment identified through document reviews and discussions with the community are listed in **Table 2-1**.

Table 2-1 Towamba River Historical Flooding

Flood	Description	Data Source
July 1893	Towamba River in heavy flood.	NSW Water Resources Commission, 1972
May 1900	Heavy rain on the South Coast caused floods south of Pambula.	NSW Water Resources Commission, 1972
March 1919	Severe flooding on the South Coast. Towamba River reached 45 feet at the Princes Highway Crossing. Bridge at Towamba washed away.	NSW Water Resources Commission, 1972 Community consultation 2017
August 1922	Approach to Towamba River bridge at Kiah carried away.	NSW Water Resources Commission, 1972
January 1934	At Towamba, the river crossing was damaged.	NSW Water Resources Commission, 1972
November 1942	Extensive inundation and much damage to roads during to Towamba River flooding.	NSW Water Resources Commission, 1972
August 1943	Towamba River in flood; large areas inundated.	NSW Water Resources Commission, 1972
May 1944	Towamba River in flood for several days.	NSW Water Resources Commission, 1972
June 1945	High flooding in South Coast district.	NSW Water Resources Commission, 1972

Flood	Description	Data Source
May 1948	No details of flooding available apart from date.	NSW Water Resources Commission, 1972
January 1952	No details of flooding available apart from date.	NSW Water Resources Commission, 1972
May 1953	Major flooding occurred in the Towamba River Valley	NSW Water Resources Commission, 1972
February 1956	No details of flooding available apart from date.	NSW Water Resources Commission, 1972
June 1956	No details of flooding available apart from date.	NSW Water Resources Commission, 1972
November 1959	The Towamba River at Kiah rose quickly and at its peak was 18 feet over the bridge, cutting the Princes Highway for three days. Damage to crops.	NSW Water Resources Commission, 1972
July 1960	4 inches of rain caused the Towamba River to rise 14 feet over the Kiah Bridge.	NSW Water Resources Commission, 1972
October 1966	Minor flooding occurred covering the bridge on the Princes Highway by 10 feet.	NSW Water Resources Commission, 1972
February 1971	Water came close to going over the Princes Highway Bridge. Low level timber bridge at Burragate destroyed. Flooding of New Buildings Road at New Buildings, Big Jack Mountain Road at Rocky Hall.	NSW Water Resources Commission, 1972 Community consultation 2017
1978	Flooding experienced at Kiah. Flooding at Towamba.	NSW Water Resources Commission, 1972 Community consultation 2017
1987	Flooding experienced at Kiah.	NSW Water Resources Commission, 1972
1996	Flooding at Towamba.	NSW Water Resources Commission, 1972
1998	Identified as potential calibration events by Council but no additional information regarding the events has been identified	Council's Brief
2010	Identified as potential calibration events by Council but no additional information regarding the events has been identified	Council's Brief
2011	Significant damages to farms at Kiah due to the flood occurring at night time and very little warning provided. Overland flow issues at Burragate. Flood waters reached the top of the bus shelter at Towamba.	Community Consultation 2017

Flood	Description	Data Source
2016	Not as significant along Towamba River as the 2011 event.	Community Consultation 2017

2.2.2 Flooding in Eden and Surrounds

Flooding has been observed in Eden as a result of both overland flooding and coastal storms. Overland flooding has occurred as a result of heavy rainfall on the local catchment, resulting in the small creeks and drainage paths causing flooding of roads, private property and open space. Coastal storms can result in the foreshore of Lake Curalo, Snug Cove, Cattle Bay and Calle Calle Bay.

Local accounts of flooding reported by the community (**Section 4.5**) identified incidences of road crossings over creeks being washed away, foreshore flooding from Lake Curalo, private property access flooding and flooding in the golf course.

A summary of notable flood events for the Eden region is provided in **Table 2-2**.

Table 2-2 Eden Historical Flooding

Flood	Description	Data Source
January 1933	Heavy storm caused landslides and bridges were swept away.	NSW Water Resources Commission, 1972
January 1934	Extensive damage at Eden; bridges washed away and great loss of crops.	NSW Water Resources Commission, 1972
1978	Bridges destroyed at creek crossings upstream of Lake Curalo. Foreshore areas of Lake Curalo inundated. Lake Curalo entrance opened to the south of the current entrance.	Community Consultation 2017
2006 or 2007	Water from Snug Cove inundated Marine Discovery Centre building.	Community Consultation 2017
2011	Highway at Golf Course overtopped.	Community Consultation 2017
January 2015	Overland flow issues were observed within the township of Eden co-incident with the prevailing tide within Lake Curalo.	Community Consultation 2017
2016	Overland flow issues and coastal flooding.	Community Consultation 2017

2.2.3 Boydtown Creek, Nullica River and Shadrachs Creeks

No definitive accounts of historical catchment flooding within these creek systems are available. The Boydtown Creek Flood Study makes a reference to flood of Juno Drive, but it is not clear when this occurred or if it was a result of blockage. In addition, the caravan park at the Shadrachs Creek entrance have noted that sandbagging has been undertaken in the past to protect low lying sites from flooding from Shadrachs Creek after heavy rainfall. Discussion on flooding from coastal events is discussed in **Section 2.2.4**.

2.2.4 Coastal Storms

East Coast Low (ECL) events are intense extra-tropical storm systems that are generally the governing extreme weather system for the south-eastern Australia coastal fringe and surrounding ranges. ECL events are enclosed low-pressure systems that develop over or track into NSW or the adjacent Tasman Sea. The BoM defines an ECL for NSW as "a system with a closed cyclonic circulation at the surface" that forms or strengthens "in a marine environment within the vicinity of the east coast". Extreme winds, rain, waves and elevated coastal water levels are common hazards associated with ECL events in NSW, and the impact of these hazards on the NSW coastline and inland across the Great Dividing Range vary depending on the type, track, intensity and duration of the event. Notable severe ECL's have resulted in major property losses and loss of life.

ECL events generally occur within an area between the NSW coast to 160° E and 25° S to 40° S which includes the Bega valley shire. The spatial distribution of ECL occurrence shows a concentration of ECL events in the Tasman Sea to the east of the NSW coastline. The seasonal spatial plots show more southerly storms in winter directly offshore of Eden, and a bimodal spatial distribution in summer.

Notable ECL events to impact on Eden occurred in June 1998 and June 2016.

In June 2016, an East Coast Low event caused significant damage to wharf infrastructure at Allied Natural Wood Exports wharf at Jew's Head and also nearby Tathra Wharf due to the prevailing wave direction. Photos of this event area shown in **Figure 2-1** and analysis of this event is provided in **Section 5.5**.

	
Boydtown June 2016	Eden June 2016

Figure 2-1 ECL June 2016 - Photos

3 Review of Available Data

3.1 Site Inspections

Field inspection of the study area were undertaken over a period of three days (4 – 6 October 2017) by two Rhelm staff and Council's project manager.

The locations that were inspected and key field notes are provided in **Appendix A**.

The purpose of the site inspections was to gain an appreciation of the catchment and likely flood risks. The site inspections also identified additional survey requirements and assisted with the definition of the hydraulic model extents.

3.2 Previous Studies and Reports

Relevant studies and reports were collated through liaison with Council and DPIE and consultation with agency and community stakeholders. Additional studies have been sourced through internet searches. A summary of the studies and report likely to inform this Flood study is provided in **Table 3-1**.

Table 3-1 Previous Studies and Reports

Document	Relevance to the Study and Comments
Floods of February 1971 on the South Coast (NSW Water Resources Commission, 1972)	Provides a description of the flooding in 1971 as well as a list of previous significant floods. Daily rainfall data provided. Peak discharges provided at four locations for 1971 event and peak flows also provided for one location in 1961 and two locations in 1970. Isohyetal maps for event included.
Lake Curalo Data compilation study (Webb, McKeown and Associates, 1997)	Hydrographic and sedimentation information to inform the Lake Curalo model.
Lake Curalo Estuary Processes Study (ESE, 2002)	Provides information on the catchment, climate, tidal behaviour, lake sediments and entrance dynamics.
Aquatic Ecology Issues for Lake Curalo Estuary Processes Study (The Ecology Lab Pty. Ltd, 2001)	Will provide input to the assessment of impacts of potential options to managing flooding in the next phase of the floodplain risk management process.
Lake Curalo Estuary Management Study and Plan (Nelson Consulting / Lawson & Treloar, 2002)	Estuary management options identified in this study should be reviewed within the context on flood management options identified in the next phase of the floodplain risk management process. It is noted that Council is currently preparing a coastal management program that will supersede this study.
Lake Curalo Sediment Study (Ellis, D. & Beavis, S., 2007)	Information to review regarding sedimentation within Lake Curalo.
Curalo Lake Water Quality Monitoring Report (MHL, 1998)	Will provide input to the assessment of impacts and benefits of potential options to managing flooding in the next phase of the floodplain risk management process.
Estuarine Investigations, Lake Curalo Vibrocore Summary (NSW Department of Land and Water Conservation, 1999)	Sediment data was used in the Lake Curalo hydrodynamic model to better define entrance breakout and scour behaviour.

Document	Relevance to the Study and Comments
Proposed Dredging of Lake Curalo Environmental Impact Statement (Sinclair Knight and Partners, 1988)	Provides background information on water level, flood behaviour and sediment distribution.
Eden Breakwater Wharf Extension (Advisian / NSW Department of Industry – Lands, 2016)	Includes description of existing sediment environment and coastal processes within the study area.
Environmental Impact Assessment – Proposed Marina and Temporary Land Facilities, Cattle Bay Road, Eden	The Cardno wave modelling included in this EIA was referenced in the selection of input parameters to the hydrodynamic model and comparison of results for consistency.
Assessment Report and Recommendation: Marina and wave attenuator at Cattle Bay (Joint Regional Planning Panel, 2014)	This document provides planning context to the wave modelling undertaken by Cardno and included in the EIA (above).
Eden Harbour Safe Boating Options Study	Wave, wind and water level information was reviewed in the preparation of the hydrodynamic model for Twofold Bay.
ICOLL Entrance Management Policies – Review of Environmental Factors	Includes discussion of sediment and hydrological processes and historical aerial photos of the estuary.
Bega Valley Shire Coastal Processes and Hazards Definitions Study	Summary of coastal processes and hazards along the coastal fringe of Bega Valley Shire. Includes identification of erosion and coastal inundation hazards using EVOMOD. Merimbula, Twofold Bay and Wonboyn coastal areas included in assessment. This was reviewed as part of the development of the hydrodynamic model for Twofold Bay.
Boydtown Marina Development; Boydtown Creek Flood Study (Bewsher Consulting, 1989)	Provides a catchment description of Boydtown Creek. The surveyed cross sections will be digitised for use in the current Flood Study model. The study results will be compared against the current study results for design events. No calibration of historical events was undertaken as part of the 1989 study.

3.3 Local Policies and Emergency Management Plans

A variety of relevant planning documents, where available, were also reviewed and considered as part of the study. These documents are listed in **Table 3-2**.

Table 3-2 Policy and Planning Documents

Document	Relevance to the Study
Bega Valley Local Environmental Plan 2013	The LEP's existing flood related planning controls have been reviewed within the context of flood risk and planning within the study area (**Section 7.1**).
Bega Valley Development Control Plan 2013	The DCP's existing flood related planning controls have been reviewed within the context of flood risk and planning within the study area (**Section 7.1**).

Document	Relevance to the Study
Bega Valley Local Emergency Management Plan 2015	This document has been used to identify what flood information is necessary to support emergency management activities.
Eden Foreshore Reserves Plan of Management 2007	This document has been used to inform the assessment of the impacts of flooding on the community and advice on land use planning.
Curalo Lagoon Entrance Management Policy 2016	The opening trigger level has been considered in the development of the lake model.
Water sharing plan for the Towamba River Unregulated and Alluvial Sources	Provides indications of water extractions. None of the water extractions are likely to impact flood behaviour.
South East and Regional Tablelands Strategy	The strategy has been reviewed to inform the understanding of future development and flood risk.
NSW Regional Ports Strategy 2017	The strategy has provided information on existing and potential future uses of Snug Cove. These has been considered when evaluating flood risk.

3.4 Survey Information

3.4.1 Aerial Survey

Aerial survey (LiDAR) has been provided by BVSC for the coastal regions of the Twofold Bay catchment, with the LiDAR extending approximately 2.9km inland from the coast. The LiDAR was provided as a 1m grid DEM for the extent shown in **Map G301.** Outside of this area, satellite derived data was available at approximately 30m grid spacing.

The LiDAR was collected in 2008. Reported accuracies provided with the data set are summarised in **Table 3-3**. The LiDAR DEM was a key input to the establishment of the digital elevation model (DEM) for the coastal areas of the project.

Table 3-3 Reported Accuracy of LiDAR data

Average Point Separation (m)	Vertical Accuracy(m)	Horizontal Accuracy (m)
1.0	0.06	<0.4

3.4.2 Existing Ground Survey

A number of key ground survey data sources were available and are summarised in **Table 3-4**.

Table 3-4 Existing Survey Sources

Source	Information Available
Boydtown Marina Development; Boydtown Creek Flood Study (Bewsher Consulting, 1989)	Creek cross sections along Boydtown Creek.
RMS	Various bridges and culverts. The RMS structures included in the models are described in **Section 3.5**.

3.4.3 Additional Survey

Following a review of the existing survey data available the following additional survey was collected:

- Aerial survey (UAV) of Wyndham, Rocky Hall, New Buildings, Burragate and Towamba. The survey was undertaken using a fixed wing UAV fitted with dedicated high-resolution camera equipment and onboard survey quality RTK GPS. Ground control points were established. The accuracy of the survey is reportedly less than +/-100mm.
- Ground Survey cross sections of Mataganah Creek within the vicinity of Wyndham.
- All major bridge crossings of Mataganah Creek and Towamba River within the study areas of Wyndham, Rocky Hall, Burragate and Towamba.
- Cross sections of Shadrachs Creek from Princes Highway to the outlet. Entrance and berm surveys were also collected at the outlet of Shadrachs Creek.
- Berm survey at the outlet of Nullica River.
- Cross sections of small creeks and several hydraulic structures within Eden. These surveyed features are shown on **Map G302**.

3.4.4 Twofold Bay and Lake Curalo Bathymetric Survey

To provide a complete coverage of the coastal regions of the study area a number of bathymetric data sources were utilised. A base bathymetric dataset covering Eden and within Two-fold Bay is comprised of contours extracted from Electronic Navy Charts (ENC). This base dataset is then supplemented with the higher quality survey data where available. Higher quality data at Eden was available from DPIE (formerly OEH) multibeam survey dataset, collected in 2009, with point data gridded to 20 m resolution. Coverage of the datasets is shown below. All datasets are converted to the same vertical datum, Australian Height Datum (AHD), prior to inclusion in the model.

Attention is paid to merging the coastal bathymetric data with the shoreline/land DEM, to ensure a realistic transition between the two. Berm data was collected at Shadrachs for this purpose.

3.4.5 Historical Flood Marks

Historical flood marks were identified through consultation with the local community. Further details regarding the consultation is provided in **Section 4**. The surveyed flood marks near Towamba, used for calibration are discussed in **Section 5.5.4**.

3.5 Hydraulic Structures

There are various hydraulic structures throughout the study area. The data sources for each of the structures is discussed below.

3.5.1 Towamba River Catchment

Each of the study areas within the Towamba River catchment contain at least one significant bridge and / or crossing. Each of the bridges was surveyed by a registered surveyor as part of this study. One additional culvert is included in the modelling, this culvert is located on Stockyard Creek (at Big Jack Mountain Road). The design details for this culvert were provided by Council. The design details for the New Buildings bridge were provided by RMS.

3.5.2 Boydtown Creek, Nullica River and Shadrachs Creek

Estuary models were developed for the ICOLLs at Boydtown Creek, Nullica River and Shadrachs Creek. There are only a limited number of hydraulic structures impacting these waterways. The design details were obtained through existing data sources as described below.

The design details of the culvert located on Boydtown Creek located at Juno Drive were obtained from the Boydtown Creek Flood Study (Bewsher Consulting, 1989).

The design details of the Princes Highway bridge over Nullica River and Shadrachs Creek were provided by RMS.

3.5.3 Eden

There are numerous hydraulic structures located within Eden, including bridges, culverts and stormwater pipes. Stormwater pipes with a diameter greater than 750mm were included in the model based on Council's existing data set. The design details of bridges and culverts were obtained from Council, RMS and additional ground survey. Following the completion of the survey and during the model set-up, it was identified that limited or no survey data was available for a few structures. The details of these structures were estimated from RMS records and site photos. The data source of each structure included in the Eden hydraulic model is shown on **Map G303**.

3.6 Rainfall Data

There is an extensive network of rainfall gauges (current and discontinued) across the study area operated by the Bureau of Meteorology (BoM). A list of gauges for the area surrounding the catchment is shown in **Appendix B**, together with key information on whether they are pluviometer or daily gauges. The suitability of these gauges for use in calibrating / validating the identified historical storms is also shown in **Appendix B**. The locations of these gauges are shown in **Map G304**.

Further discussion on recorded rainfall data for historical events is presented with the calibration and validation of the models developed for the study in **Section 5.5**.

The Wyndham gauge within the catchment area has an extensive daily record of rainfall depths, covering 128 years, and including the 2011 event.

A frequency assessment was undertaken on the 24-hour rainfall totals for the Wyndham gauge to determine estimates of the 24-hour rainfall intensities for a range of recurrence intervals. Peak annual maxima were extracted from each gauge, with these peaks put through the TUFLOW FLIKE software which generates a probability curve for the data. The estimates derived from FLIKE were then compared to both the ARR2016 and ARR87 24-hour rainfall intensities. The results are shown in detail in **Appendix B**.

The results show that the estimates from both ARR2016 and ARR87 align well with the estimates from the probability assessment and are within the confidence intervals. The ARR2016 intensities show a better match, trending closer to the FLIKE estimate. The ARR87 intensities were higher than the 2016 estimates by 5 – 10%.

This assessment provides some confidence in the rainfall intensities adopted from ARR2016.

3.7 Flow Data

There are three flow gauges within the catchment (both active and discontinued). There is an active flow gauge on the Towamba River at Towamba (ID 220004). This gauge has been in operation from April 1970. Water for NSW provided further data for two closed gauging stations at New Buildings and Rocky Hall. These gauges provided flow data for the 1971 and 1978 events. No other suitable gauges were identified in the catchment. There is no flow data for Eden or the other catchments draining into Twofold Bay.

The gauge data provided included both water level and flow time series. The gauge itself records water levels, with the flow data being generated from these level recordings based on the rating curve of the gauge. While the water level recordings are considered relatively robust (unless noted in the gauge data) the flow data requires calibration and validation of the rating curve, which requires operators to visit the gauge during flood events to record the flows, and to extrapolate estimates to flows above those observed. As such, there is much more confidence in the lower “gauged” flows, than in the higher, given that it is uncommon for operators to visit the gauges during extreme flood events. Each gauge includes the level to which it has been validated. Beyond this, flows are extrapolated, and estimates are less reliable. A review was undertaken on the rating curves for the gauges and this is provided in **Appendix B**.

A flood frequency analysis (FFA) was undertaken for each of the three gauges. The assessment was undertaken using the TUFLOW FLIKE software, which fits a probability curve to the gauge flows to determine flow estimates for various recurrence intervals.

The details and results of the FFA are presented in **Appendix B**.

Some validation was able to be undertaken on the revised curves for New Buildings by running a steadily increasing hydrograph through the New Buildings 2D hydraulic model (refer **Section 5.5.4** for further details). The water level and flow results were then extracted from the gauge location in the model to generate a rating curve based on the hydraulic model results. This was only possible at New Buildings, as the Rocky Hall and Towamba gauges were located outside of the hydraulic model extents.

3.8 Water Level Data

Historic water level data is available for Lake Curalo, provided by Bega Valley Shire Council for use in this study. Data is available from June 2007 to the present day. Data is recorded every 15mins.

Coastal water levels at Eden are dominated by astronomical tides. The tide at Eden is semi-diurnal with a range of 2.1 m (LAT to HAT). The mean water level at Eden is 1.0 m above lowest astronomical tide (LAT). A full list of tidal planes at Eden are presented in **Table 3-5** in metres below Chart Datum (CD).

Table 3-5 Tidal Planes at Eden Relative to CD which is the lowest astronomical tide (LAT) at Eden, Reproduced from the Australian National Tide Tables (2011)

Tidal Planes at Eden	Water level (m CD)	Water level (m AHD)
Highest Astronomical Tide (HAT)	2.1	1.17
Mean High Water Spring (MHWS)	1.8	0.88
Mean High Water Neap (MHWN)	1.2	0.28
Mean Sea Level (MSL)	1.0	0.08
Mean Low Water Neap (MLWN)	0.8	-0.12
Mean Low Water Spring (MLWS)	0.2	-0.72

A number of factors contribute to the observed water level at the shoreline and river/lake entrances. The factors contributing to total water level include:

1. Astronomical tide;
2. Surge from wind and pressure forcing along the coast;
3. Residual water levels from other oceanographic and meteorological forcing, including coastal trapped waves; and
4. Wave setup inshore of the surf zone.

The largest water levels are typically observed as a result of ECL events, where the surge and wave setup component can be in the order of 0.5 to 1 m. Information on the storm surge component of the tide can also be deemed from the water level records using the highest water level and predicted tidal range. A long-term tide gauge is located at Eden Boat Harbour (37° 4' 25.17661" Lat 149° 54' 27.86128" Long) within Twofold Bay. The data is available from the Bureau of Meteorology (BoM) with measurements from 1986 to current. The data shows that the largest tide level (HAT) has been exceeded on 7 occasions since 1986.

3.9 Coastal Data

The key datasets compiled for use in Baird Australia's East Coast Low Multi-Hazard Event Set Database including the Tasman Sea Ocean Delft3D model which extends into Two Fold Bay are tabulated in **Table 3-6**.

Table 3-6 Summary of datasets compiled for use in Baird Australia's NSW coastal hazard model

Data Type	Description	Source
East Coast Low Track and Intensity	Historical east coast low database	BOM
	Archived mean sea level synoptic charts	BOM: http://www.bom.gov.au/australia/charts/archive/
Meteorological data	Wind speeds, directions and atmospheric pressure and rainfall measurement at key stations	BOM
	Gridded daily rainfall 1970 – 2016: Australian Water Availability Project	BOM: http://www.bom.gov.au/climate/austmaps/metadata-daily-rainfall.shtml
	Modelled global reanalysis wind data: NCEP, CFSR, CFSv2 and Seawinds	NOAA
Tidal predictions	Predicted water levels	National Tidal Centre
Bathymetry	Coastal survey data sets (various along whole coastline)	Office of Environment and Heritage
	Australian hydrographic office navigation chart data sets	Australian Hydrographic Office
Coastal water level data	Measured water levels	Manly Hydraulics Laboratory
	Measured wave height, period and direction	Manly Hydraulics Laboratory

Data Type	Description	Source
Ocean Wave data	Hindcast wave data	Baird
Elevation data	LiDAR 5-m Digital Elevation Model	Geoscience Australia
	Shuttle Radar Topography Mission (SRTM) 30 m resolution Digital Elevation Model	Geoscience Australia

3.10 Future Development Information

In order to establish modelling Scenario 3 (an assessment of cumulative impacts on the flood behaviour in **Section 7.4**), the maximum potential development within the catchments has been incorporated into the model. Development has been represented primarily through simple filling of land, to represent an obstruction to flow. The development potential has been sourced from existing land use types in the Bega Valley Local Environmental Plan (LEP) 2013. Council has provided the LEP land use zones in GIS for this purpose.

Relevant Deferred Matters were also reviewed for the purpose of understanding future development potential.

3.11 GIS Data

Digitally available information such as aerial photography, cadastral boundaries, topography, watercourses, drainage networks, land zoning, vegetation communities and soil landscapes were provided by Council in the form of GIS datasets.

4 Consultation

4.1 Consultation Strategy

The consultation strategy outlined in **Appendix C** describes the approach to consultation in accordance with the IAP2 framework and the requirements of the NSW Governments Floodplain Development Manual (2005).

4.2 Agency Consultation

There are many agencies with flood-related interests in the LGA. To best approach these agencies, a letter of introduction to the study was sent to the key stakeholder agencies to introduce the project and an invitation to be involved in the project. It also included requests for any relevant data or information that they may have.

The agencies contacted as part of this consultation are listed in **Table 4-1** along with the outcomes of the consultation.

All agency stakeholders will be contacted prior to the public exhibition of the draft Flood Study to request their feedback on the document.

Table 4-1 Agency Consultation

Agency Stakeholder	**Outcome of Consultation**
Office of Environment and Heritage	Ongoing guidance and input throughout the project.
Bega Valley Shire Council	
Manager Project Development	Council's contract manager assisted at project inception.
Asset Management Coordinator	Council's project manager providing project direction.
Coastal Management Officer	Provided data relevant to Lake Curalo
Strategic Planning Co-ordinator	Provided overview of key risk areas with regards to potential development exposure.
Lake Curalo Estuary Management Focus Group	Rhelm project manager attended a focus group meeting to gain an appreciation of the flood related issues being raised in the Coastal Management Program for Lake Curalo.
Roads and Maritime Services	Provided design and / or survey details of culverts and bridges.
NSW Port Authority	No response.
NSW DPI – Crown Lands	No response.
NSW DPI – Water	Provided some overview as to the role of DPI Water in floodplain management. Unlikely to provide input to the study. Provided guidance to extracting flow data from the website.
NSW Department of Planning and Environment	No response
State Emergency Service	
State Headquarters	Directed enquiries to the local controller
Deputy Regional Controller Illawarra South East	Directed enquiries to the local controller

Agency Stakeholder	Outcome of Consultation
Local Controller, Bega Valley LGA	To provide ongoing input and review through the focus group.
Eden Unit Controller	No response.
Eden Deputy Unit Controller	No response.
Local Volunteer – Richard Lamacraft	Provided descriptions of historical floods and useful websites for photos and newspaper articles of historical events.
NSW Ambulance – Eden Station Officer	Provided details of access issues during flooding.
Fire and Rescue NSW	No response.
South East Local Land Services	No response.
Department of Defence – Royal Australian Navy	Directed enquiries to NSW Ports.
Towamba Valley History Website	Permission provided to use photos and information on website for the purpose of this study. Additional photographs provided.
Towamba Community Progress Association Inc.	Assisted with circulating the information about the community drop-in sessions.
Port of Eden Marina Inc.	Identified the key relevant data as the Cardno wave modelling report.
Eden Killer Whale Museum	No response.
Eden Chamber of Commerce Inc.	No response.
Allied Natural Woods Exports	No response.

4.3 Website and Media

Council utilised the local newspaper, their own website and Facebook profile to provide updates and request input to the study. The media released to date is summarised in **Table 4-2**. Copies of the media releases are provided in **Appendix C**.

Table 4-2 Media Releases

Media	Date	Purpose
Media statement to local newspaper	28 November 2017	To inform the community of project inception and that Council had engaged Rhelm to undertake the study. Also, to invite community input to the survey and drop-in sessions.
Media statement to local newspaper	11 December 2017	To provide the community with an update on the community engagement being undertaken.
Facebook posts	30 November 2017 4 December 2017 5 December 2017	Inviting attendees to drop-in sessions, requesting flooding photos and providing a link to the online survey.

Media	Date	Purpose
ABC SE Radio	26 October 2017	Bega Valley Shire Council's Project Manager Gary Louie discussed project overview, outcomes and ways that the community can be involved.

4.4 Community Newsletter and Survey

A community newsletter and survey were distributed to property and business owners, as well as residents within the study area. The newsletter and survey were also made available on Council's website, with the survey available to be completed online. A copy of the newsletter and survey is provided in **Appendix C**.

The newsletter provided information on the purpose and scope of the Flood Study and the survey sought information about historical flooding events and other flooding concerns within the community.

The survey was mailed to approximately 500 recipients. A summary was also provided in a media release, informing the community of the Flood Study and advertising that the survey was being undertaken.

From the distribution and availability of the survey on the website, seventeen responses were received, representing a return of only 3.5% of direct distribution. A return rate of 10% is typical for these types of mail-outs. However, it is noted that an additional 30 people attended drop-in sessions to provide input face to face (**Section 4.5**). This represents a total return rate of 9.5%, which is closer to the typical return rate of 10%.

The submissions received provided information and photos on historical flooding. Follow up was undertaken with the respondents to clarify the data received. Ground level survey was captured for several locations around Towamba where historical flood levels had been observed. The ground survey provides flood levels for the calibration of the hydraulic model.

4.5 Community Drop-In Information Sessions

Community drop-in sessions were held during the initial stages of the study to gather information from the community about flooding experiences and concerns. The sessions were held at:

- Towamba Community Hall Wednesday 6th December 3pm to 5pm; and
- Eden Country Club Thursday 7th December 10am - 12pm and 3:30pm - 5:30pm.

There were approximately 30 attendees across the three sessions. Information was received regarding

- flooding in the upper catchment, particularly around Towamba;
- Flooding at Kiah from the Towamba River;
- Foreshore inundation at Boydtown and Eden from coastal storms;
- Foreshore inundation around Lake Curalo;
- Local creek flooding and overland flow within Eden.

A summary of the drop-in sessions notes is provided in **Appendix C**.

4.6 Community and Stakeholder Project Update Emails

Community and agency stakeholders have been invited throughout the duration of the project to register their contact details for project updates. Project updates have been emailed to these recipients on the following dates:

- 27 February 2018

- 28 March 2018
- 17 July 2018

4.7 Public Exhibition

Following the preparation of the draft Flood Study the report will be placed on Public Exhibition to allow the community and other stakeholders to review and comment on the report prior to it being finalised and adopted by Council.

5 Flood Modelling

5.1 Modelling Approach Overview

Due to the complex nature of flooding across the study areas, flood modelling has been undertaken using a combination of hydrological and hydraulic models for both coastal and flooding. This allows flooding to be assessed with regards to coastal processes, estuarine dynamics (in particular entrance scour), riverine flooding and overland flow.

Hydrological modelling was undertaken for all study areas using XP-RAFTS.

The approach adopted for the hydraulic / hydrodynamic analysis was to develop an integrated modelling system comprised of four separate model types:

- Towamba River Catchment Models - Individual TUFLOW 1D/2D hydraulic models for Wyndham, Rocky Hall, Burragate, New Buildings and Towamba;
- Eden Model - A TUFLOW 1D/2D hydraulic model for the overland flooding behaviour for Eden and Lake Curalo;
- Coastal Connected Area Models – Hydrodynamic models in Delft3D of each ICOLL and surrounding low-lying areas, like Boydtown, have been established to enable the dynamic modelling of the interaction of catchment flooding and coastal inundation and the influence of ICOLL entrance berm conditions. A model was also established for Lake Curalo, to understand the entrance breakout, and this model provided input to the Eden TUFLOW 1D/2D model;
- Twofold Bay Model - A hydrodynamic model in Delft3D for Twofold Bay was used to understand the coastal driven water levels, derive boundary conditions at ICOLL entrances and establish inundation at ocean exposed location such as Jews Head and Munganno Point.

The separation of the Twofold Bay models from the Eden Model is important, as it allows different levels of resolution to be adopted between the various models. While it is possible to model the areas in a singular model, each have very different objectives. The Twofold Bay model represents the overall bay modelling shelf and nearshore derived storm surge, while the Lake Curalo and Cocora Lagoon Models look at the interaction of coastal processes driven flooding with catchment flooding by receiving catchment flows from the hydrological model. The Lake Curalo and Cocora Lagoon models are also used to define the downstream boundary condition of the Eden TUFLOW model, which focuses on catchment driven overland flow and the smaller tributaries draining to Lake Curalo and Cocora Lagoon. The Eden model represents the small flowpaths, incorporates smaller scale features like stormwater drainage and culverts and adopts a small-scale grid. It also analyses much shorter duration storms that are likely to govern critical flooding in this area.

By comparison, Boydtown Creek, Nullica River and Shadrachs Creek have been incorporated entirely within coastal connected models. A review of the terrain in these areas would suggest that these locations have a greater influence of coastal events on the flooding behaviour. Further, given the current level of development in these locations, the need for high-resolution models such as the one used for Eden is not required.

5.2 Hydrological Models

Three hydrological models were prepared for study area, with a separate model for each:

- Eden and Lake Curalo catchment;
- Nullica River, Shadrachs Creek and Boydtown; and,
- Towamba River catchment.

The subcatchment breakdowns for these three models are shown in **Maps G501, G502 and G503**.

The hydrological models were developed using XP-RAFTS. Inputs to the model and the data sources for those inputs are summarised in **Table 5-1**.

Table 5-1 Hydrological Model Input Data

Parameter	Data Source
Sub-catchment area and slope	LiDAR data was available for the lower portions of the catchment only, covering the Eden and Twofold Bay areas. In the middle and upper catchment, terrain details were adopted from the freely available STRM satellite data from Geoscience Australia. While this data is too course for hydraulic modelling, the resolution is suitable for defining sub catchment extents and subcatchment slopes.
Percentage impervious	Percentage impervious areas are largely a factor of development intensity and were determined from aerial imagery. High resolution aerial imagery was provided by Council and was supplemented by freely available online imagery and land use maps.
Roughness	Roughness parameters influence how quickly runoff occurs in a sub-catchment. Similar to the percentage impervious, the values were determined from an examination of aerial imagery and were largely dependent on land use. Delineation of roughness zones also referred to Council's LEP mapping, particularly in areas that are undergoing development or redevelopment. Roughness values adopted for the catchments were: ▪ Roads and carparks 0.015 ▪ Parks and open space 0.03 ▪ Cleared grazing land 0.035 ▪ Light vegetation 0.04 ▪ Medium Vegetation 0.06 ▪ Dense Vegetation 0.08 ▪ Forested regions 0.12
Runoff routing	Routing refers to the transfer of flows from one sub-catchment to another. This routing can be done in XP-RAFTS through either specifying a lag time between sub-catchments (10mins for example) or inputting a typical cross section, roughness and length and allowing XP-RAFTS to compute the lag time based on the flow volume. For this model, lag links were used to define the routing. Lag times were determined based on the stream velocity, which was estimated based on the subcatchment grade using QUDM (2018), which provides approximate stream velocities for given slopes.
Rainfall losses Rainfall intensities	Rainfall intensities and hyetographs for the design storms were based on ARR2016, using data in the ARR Data Hub and also the BOM. The study areas

Parameter	Data Source

Rainfall hyetograph	fall within the Southern Slopes region of NSW. Values for rainfall losses were determined as part of the calibration process of the calibration of the hydrological models. The losses adopted were:
	• Pervious
	  • Initial Loss 20 mm
	  • Continuing Loss 1.5mm/hr
	• Impervious
	  • Initial Loss 1 mm
	  • Continuing Loss 0mm/hr

5.2.1 Application of Australian Rainfall and Runoff (2016)

Australian Rainfall and Runoff (ARR) is a national guideline document, data and software suite that can be used for the estimation of design flood characteristics in Australia. The 1st edition was released by Engineers Australia in 1958, and several updates have been released since that time. This study utilised the 3rd edition released in 2016, known as ARR2016.

The ARR2016 has introduced several changes to the hydrological methods that have been traditionally employed. This includes updated design rainfall intensities, new ensemble storms and other catchment parameters such as losses.

The modelling of the ensemble storms was undertaken within the XP-RAFTS model. Peak flow rates and flow volumes were analysed for each set of storms to determine the critical duration and temporal pattern (being the representative median pattern for the corresponding duration). These hydrographs were run in the hydraulic model. For volume driven areas, it was found that the peak flow hydrograph had a volume within 1% of the peak volume hydrograph. As such, the peak flow rate hydrograph was adopted as the critical pattern for all study areas.

5.3 DEM Development

Digital Elevation Models (DEMs) have been developed for input into the hydraulic models. The DEMs have been based on the survey data collected, including the LiDAR, ground survey and UAV survey data.

One of the important components in the development of hydraulic models is to ensure that key hydraulic controls and features are defined appropriately within the DEM. This includes features such as embankment crest details, road levels where roads overtop etc. These have been incorporated these where appropriate through the use of breaklines and other features using 12d.

The following data sets have been used in the development of the DEM:

- 2008 LiDAR Survey;
- Satellite Derived Terrain Data from GeoScience Australia (used to supplement other survey data, as required);
- Collected ground survey;
- Collected UAV survey (used only in Towamba River catchment models);
- Collected bridge and culvert survey; and,
- Bridge and culvert details provided by RMS and BVSC.

5.4 Hydraulic Models

As identified in **Section 5.1**, four separate modelling approaches were adopted for the study area:

- Upper Catchment (Towamba) Models - Individual 1D/2D hydraulic models for the upper catchment locations (e.g. Rocky Hall, Burragate etc);
- Coastal Connected Area Models – Hydrodynamic models of each ICOLL and surrounding low-lying areas, like Lake Curalo and Boydtown, were established to assess the interaction of catchment flooding and coastal inundation and the influence of ICOLL entrance berm conditions;
- Twofold Bay Model - A hydrodynamic model for Twofold Bay would be used to understand the coastal driven water levels, derive boundary conditions at ICOLL entrances and establish inundation at ocean exposed location such as Jews Head and Munganno Point;
- Eden Model - A 1D/2D hydraulic model for the flood behaviour at Eden, with a downstream boundary driven by the Lake Curalo coastal connected area model.

An overview of the process for the flood behaviour in Eden is provided below. The Coastal Connected Area models for Lake Curalo and Cocora Lagoons were run based on inputs from the hydrological model. This provided information on the breakout of these lagoons and the water levels in the lagoons.

These water levels were then provided as a downstream boundary for the Eden TUFLOW Model, which provided the overarching results for the Eden Study Area. This process is summarised below in **Figure 5-1**.

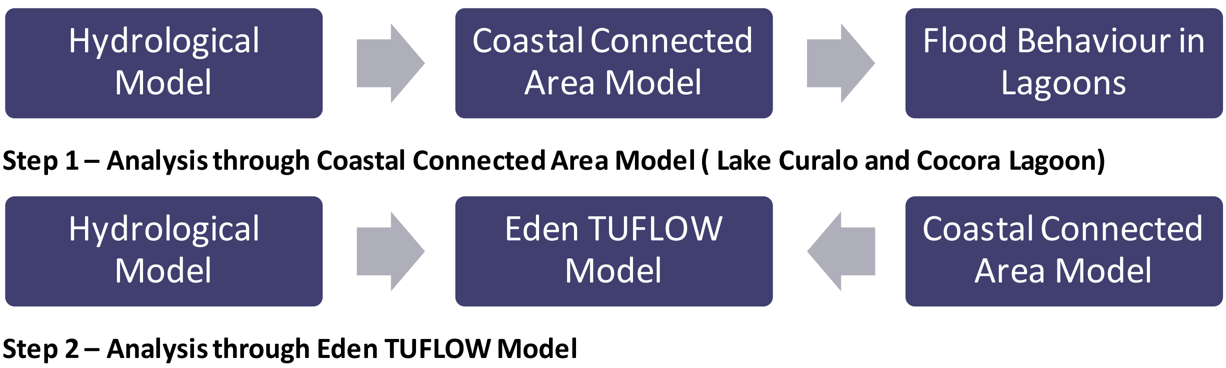

Figure 5-1 Model assessment process

5.4.1 Upper Catchment Models

The upper catchment models include the following study areas:

- Rocky Hall;
- New Buildings;
- Wyndham;
- Burragate;
- Towamba.

The approach adopted for these study areas was to analyse the mainstream flooding characteristics, and to focus the flood models on the key areas of interest. Inflows to the models have been derived based on the hydrological model developed.

All of the models were developed as 1D/2D hydraulic models. Additional survey was collected as part of the study to inform the development of the hydraulic models, namely:

- UAV terrain survey of all five upper catchment regions;
- Cross section survey through the Wyndham study area; and,
- A detailed survey of the bridges within the Towamba and Burragate study areas.

The model areas were developed in collaboration with Council and DPIE through site inspections and review of aerial photographs, topographic maps and the outcomes of the community consultation. The model areas adopted, and the hydraulic model features are shown in **Map G504** to **Map G508**.

The model parameters adopted are discussed below. In order to maintain consistency across the five areas, model parameters have been kept constant across the areas where possible. The discussion below is applicable to all of the upper catchment models, unless noted otherwise.

Grid Cell Resolution

A grid cell size of 5m has been adopted for the upper catchment models. This resolution is sufficiently fine so as to allow the definition the river reaches in the 2D domain, while not adversely affecting model run times.

Roughness Values

Manning's roughness values were determined based on aerial photographs, site inspection photos and land use layers, as well as the review of the rating curves as discussed in **Section 3.7**. The values adopted are summarised in **Table 5-2**.

A sensitivity assessment was undertaken on the roughness values (refer **Section 5.6.3**). The assessment found that the model was reasonably sensitive to roughness values, particularly for those regions with high flows (such as Towamba and Burragate).

Table 5-2 Adopted Roughness Parameters

Land Use	Roughness Value
Cleared pasture for grazing	0.06
Open space (ovals, parks, etc)	0.03
Riparian vegetation	0.04
Medium bushland	0.08
Dense bushland	0.1

Downstream Boundaries

Downstream boundaries for the models were located a sufficient distance downstream of the study area focus to minimise the potential influence on the model results. For each model, a stage-discharge curve was generated for the outlet. To generate these curves a cross section, roughness values and a channel slope is required. TUFLOW is able to generate these curves automatically based on a user specified channel slope. The TUFLOW model then extracts the cross-section data and the roughness values from the 2D domain. This approach was used to define the downstream boundaries for each of the upper catchment models.

5.4.2 Eden Model

The focus of the Eden Model is on representing the overland flow and creek flows in the study area. The model area and its features are provided in **Map G509**. The focus of the model area is on incorporating creeks and flowpaths that are likely to pose a risk to urban and developed areas within the floodplain. These flowpaths and creeks have been incorporated through a combination of 1D and 2D elements. The model area has been refined following site inspections and discussions with Council.

Grid Cell Resolution

The urban area for Eden, which is denser than other parts of the study area, suggests that a higher resolution grid domain would be more appropriate. A grid cell resolution of 2m has been adopted for this study to achieve a reasonable balance in model run times and representation of flow behaviour.

1D Components

Key channels and structures within the study area have been included within the 1D portion of the model, with the overbank areas defined in the 2D domain. Stormwater drainage, to a minimum pipe diameter of 750mm, has been included where it is available in Council's data sets.

Buildings

Buildings have generally been included in the hydraulic model as an increased roughness. Where building lie within key flowpaths, they have been incorporated in the hydraulic model as raised objects. The key flowpaths were identified based on preliminary runs of the 1% AEP event.

Fences

There are numerous ways to incorporate fences within a 2D hydraulic model. While the techniques can be quite advanced, the reality is that the behaviour of fences in flooding can be quite uncertain and difficult to represent appropriately. Fences have been incorporated in the model through a property averaged roughness value.

Interaction with lagoon processes

The downstream boundary conditions of the Eden Hydraulic model are governed by the water levels and entrance breakout processes in Lake Curalo and Cocora Lagoon. These processes are derived from the hydrodynamic models (**Section 5.4.4**).

5.4.3 Twofold Bay Hydrodynamic Model

Baird Australia developed a Delft3D hydrodynamic model of the Tasman Sea and the NSW coastal shelf that extends into Twofold Bay as part of the NSW Coastal Wave Model (developed on behalf of DPIE) and has been calibrated and validated against tides and storm surges. The model covers the coastal fringe from the NSW/Victorian border in the south, up to the northern extent of the NSW coastline at the NSW/Queensland border. The existing Delft3D hydrodynamic model was used to develop a 1,000-year Monte Carlo synthetic East Coast Low (ECL) event set that includes maximum event impact footprints for coastal inundation as well as wind and rainfall. The dataset has been developed from a detailed library of hindcast data for 1,119 ECL events between 1970 and 2016 (46-years) and a novel synthetic track and intensity ECL model. The sequence applied to develop the data set is presented in **Figure 5-2**.

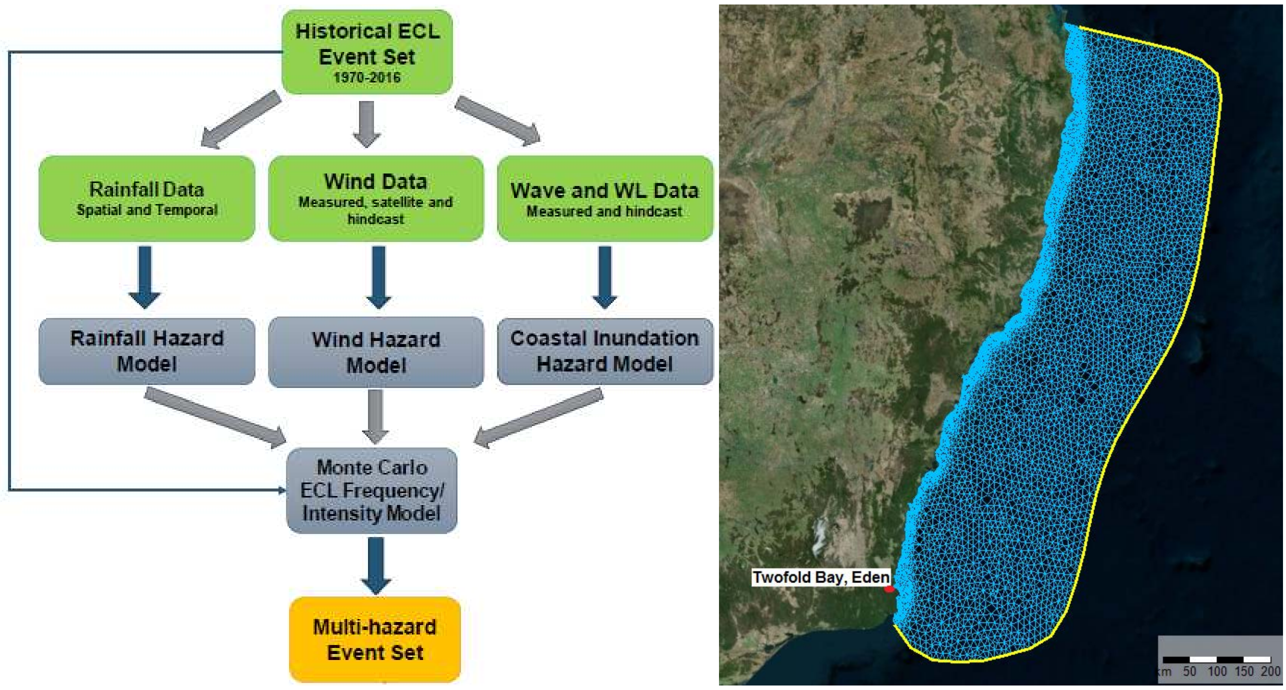

Figure 5-2 Method flow chart for Baird Australia's multihazard ECL Event Set (left) and the Delft3D NSW Tasman Sea Model Domain (right)

The coastal inundation data set defines elevations for total peak steady water level (tide + residual + wave-setup) and maximum wave run-up (≈ 2% exceedance) at 100 m resolution along the NSW open coast shoreline. For NSW, the nearshore wave conditions have been calculated using a validated coastal wave transfer function with high validation metrics compared to limited nearshore wave measurements along the coast. For the total peak steady water levels, a number of factors contribute to the observed water at the shoreline during ECL events. The factors contributing to total water level include:

1. Astronomical tide;
2. Surge from wind and pressure forcing along the coast;
3. Residual water levels from other oceanographic and meteorological forcing, including coastal trapped waves; and
4. Wave setup inshore of the surf zone.

The water levels included in this data set account for the above four components in the assessment of coastal water levels and wave run-up levels. Astronomical tide has been based on a 19-year hindcast of astronomical tide along the NSW coast and covers an entire solar and lunar astronomical tide cycle which is applied in a continuous cycle over the 1,000-year data set period. For a full summary of the data and bathymetry sources used in the model development see **Table 3-6**.

This model is of sufficient resolution (<100m) within Twofold Bay to accurately derive coastal driven water levels along the open coastline and outside of estuaries and will be used to derive design flood levels at Munganno Point and Jews Head. The model was used to provide boundary conditions to more localised and refined models of four ICOLLs and surrounding low lying areas (see **Section 5.4.4**). The coastal inundation levels including wave setup were extracted from the 100 m output point nearest to the ICOL entrance and the appropriate AEP year was applied to the flood event AEP.

5.4.4 Coastal Connected Area Models (ICOLLs)

Consistent with requirements of *Floodplain Risk Management Guide - Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* (OEH, 2015) for Group 4 Waterway Entrance Type (ICOLLs) consideration of dynamic morphology of the ICOLL entrances is important in establishing accurate flood levels in downstream areas of the wider catchment. Four Delft3D model domains were developed for locations where the entrance berm is a significant hydraulic control, including:

- Lake Curalo (refer **Map G509** for model area);
- Nullica River and Boydtown Creek (refer to **Map G510**);
- Shadrachs Creek (refer to **Map G511**); and
- Cocora Lagoon (refer to **Map G509**).

The model boundary was established at the 5 m AHD contour in the models of Nullica and Boydtown, Shadrachs and Cocora. Whereas at Lake Curalo, a model extent out to the 2 m AHD contour was sufficient to model flood behaviour for this system given levels in the lake are moderated by the entrance berm level. Water level boundary conditions were derived from a regional scale Delft-FM model. The sediment transport module of Delft3D was used to dynamically model the entrance breakout process during each flood scenario. The Delft3D models accept catchment inflow data from the broader hydrological catchment model and these were applied across the model domains at creek and stream locations.

The coastal boundary conditions for the events were extracted from the Twofold Bay Hydrodynamic model and applied to a reference tide and surge event from the Eden tide gauge. The coastal inundation level AEPs (wave run-up and total peak steady water level including wave setup) were extracted from the 100 m output point nearest to the ICOLL entrances. The appropriate AEP values, 100% and 5% AEP coastal inundation events, were paired with the 20% and 1% AEP flood events respectively, based on Floodplain Risk Management Guidance within OEH (2015). A representative predicted spring tide based on the measured water levels at the Eden tide gauge was selected. Design peak storm surge was then developed from Baird's stochastic East Coast Low event set that includes discrete event simulation of East Coast Low events along the NSW coast. The resulting peak storm surge was then added to the predicted tide, scaling up and down over a 96-hour period. This is consistent with the guidance with OEH (2015) that applied a similar method using a scaled May 1974 event. The peak of the storm tide was then aligned with the peak in the flood discharge event.

The key bathymetric and elevation datasets compiled for use in the ICOLL models are tabulated in **Table 5-3** in order of priority. Within the four models, culverts and bridge decks were not included in the bathymetry, however bridge abutments were included and the dimensions under the bridge decks, and culvert opening widths were specifically schematised.

Table 5-3 Summary of elevation datasets compiled for the Coastal Connected Area Models (ICOLLs) models

Data Type	Description	Source	Application
Bathymetry Data Source			
Single beam survey, 24th – 26th Oct 2017	Single beam survey comprised of; • Terrestrial Laser Scanner data	NSW DPIE (formerly OEH)	Lake Curalo

Data Type	Description	Source	Application
	• Leica RTK unit beach cross-section ground survey profiles • 5 m along-track binned jetski sounder data		
DXF survey	Survey undertaken at a number of locations including ICOLL entrances.	Veris Surveyors	Nullica River, Shadrachs Creek and Cocora Lagoon
Boydtown Creek cross-sections	Creek cross sections along Boydtown Creek during Boydtown Flood Study.	Boydtown Marina Development; Boydtown Creek Flood Study (Bewsher Consulting, 1989)	Boydtown Creek
Inferred creek depths	0 m Elevation contours were used to define the waterway extents, if no other data was available, river, creek and lagoon depths were developed by interpolating known depths downstream and interpretation of satellite imagery		Nullica River, Boydtown Creek, Shadrachs Creek and Cocora Lagoon
Coastal Contours	Digitized Contours	Navy Charts AU438149	All models
Elevation Data Sources			
1m terrestrial LiDAR	2013 March LiDAR NSW Govt, 1m resolution, AHD	2013 March LiDAR NSW Govt	All models
	2016 LiDAR NSW Govt, 1m resolution, AHD (not ground truthed)	2016 LiDAR NSW Govt	Nullica River entrance
5 m terrestrial LiDAR	Digital Elevation Model (DEM) 5 Metre Grid of Australia derived from LiDAR from 2001-2015. Extracted 1 m contours.	Geoscience Australia (2015)	All models

5.5 Model Calibration

The data review process has allowed for the identification of appropriate calibration events through review of rainfall and water level data and consultation with the community. A summary of key catchment and coastal events is provided in **Table 5-4**. Further discussion on these events is provided in **Section 5.2**. Calibration events did not necessarily require all models to be run, the models run for each of the events is noted in **Table 5-4**.

A comprehensive discussion on the calibration and validation modelling undertaken is presented in **Appendix D**. No calibration data was available for Boydtown Creek, Nullica River, Shadrach Creek or Cocora Lagoon.

Table 5-4 Calibration Events

Event	Calibration / Validation Undertaken			Comments
	Towamba River Models	Eden Overland Flow Model	Coastal Models	
February 1919 Towamba River Catchment Event				One survey mark near Towamba. No rainfall or flow data available for calibration.
February 1971 Towamba River Catchment Event				The community were able to identify several flood levels and extents around Towamba, Rocky Hall and New buildings, but there were periods of missing data in the gauge record, preventing calibration to this event.
1978 Catchment and Coastal Event	Calibration	Validation of 20% and 1% AEP runs		The community were able to identify several flood levels and extents around Towamba. General observations were collected of flooding in Eden for this event.
June 1998 East Coast Low				Listed in Council's brief but no significant water levels were recorded for this event.
February 2010 Towamba River Catchment Event				No reliable flood observations available.
March 2011 Towamba River Catchment Event	Calibration			Majority of flood recollections provided for Kiah area. One calibration mark surveyed in Towamba for this event.
March 2012 Coastal Event			Calibration	It is one of the largest water level events associated with an entrance breakout. Event allows for the calibration of the entrance breakout of Lake Curalo
September 2013 Coastal Event				It is largest water level event associated with an entrance breakout. Rainfall was modest, but lake levels were already elevated behind a closed entrance prior to the event. However, missing Lake Curalo water level data resulted in no calibration being undertaken.
June 2016 East Coast Low			Calibration	Lake Curalo entrance was open (i.e. Lake was tidal) during June 2016 ECL. Exact

Event	Calibration / Validation Undertaken			Comments
	Towamba River Models	Eden Overland Flow Model	Coastal Models	
				entrance condition at that time is unknown. Event allows for the calibration of the interaction of rainfall runoff and storm surge in the lake. This will be limited by the availability of rainfall data.

5.5.1 Twofold Bay Hydrodynamic Model

Baird's NSW Tasman Sea Model, developed for the coastal inundation component of the ECL multi hazard study encompasses Twofold Bay and has been calibrated and validated against tides and storm surges at selected ports along the NSW coastline, including Eden.

The ECL dataset is derived from a combination of data analysis/interpolation and numerical modelling. The modelling captures the tidal variation along the coast, while measured data was used to derive empirical relationships between storm intensity and storm surge (based on 1127 events). This relationship is then applied to the stochastic ECL event track database to derive a long-term population (1,000 years) of storm tide events.

5.5.2 Lake Curalo Hydrodynamic Model

For the calibration of the ICOLL model setups, historical calibration events were run on the Lake Curalo model as there was water level data available from the MHL gauge within Lake Curalo. The model was calibrated against a historical ECL (June 2016) and a breakout event (March 2012). The calibration periods are as follows

- ECL: June 2016: 31st May 2016 – 16th June 2016
- Breakout: March 2012: 24th Feb 2012 – 7th March 2012

The June 2016 event provides water level information to define an ECL event driven by coastal water levels with an open lagoon entrance condition whereas the 2012 event was used in the calibration of a breakout event at Lake Curalo driven by catchment flooding. Measured water levels from the Eden tide gauge and wave parameters from the Eden and Batemans Bay wave buoys were extracted during the calibration periods to provide coastal water level boundary conditions.

5.5.3 Towamba River Catchment Hydrological Models

The XP-RAFTS model was used to run the full set of ensemble storms for durations from 12 to 72 hours, for the 10%, 5%, 2% and 1% AEP events. The median storm flow peak was then plotted on the FFA curves to assess how well the design flows aligned with the results of the FFA assessment. Data was also available to allow a calibration of the 2011 flood at the Towamba Gauge. No other historical events had sufficient data for calibration with gauge data. The results are shown in **Appendix D** and show that the design flows for both the Rocky Hall gauge and the New Buildings gauge align well with the FFA results, plotting well within the confidence limits and on a similar gradient to the FFA line. Both these gauges are located in the upper catchment where the influence of routing lag parameters is reduced. The good match between the XP-RAFTS model and the FFA at these gauges indicate that the catchment characteristics (roughness and slope) are appropriate.

The Towamba gauge does not show as good a match as the other two gauges. The 10% AEP estimate has a reasonable match against the FFA. However, the larger flows increase at a much slower rate than the FFA probability curve. It is interesting to note that the design flow estimates trend in the same way as the observed flood flows, with the exception of the 2011 event, which sits noticeably higher.

Further investigation was undertaken on the Towamba gauge (detailed in **Appendix D**), with some changes made to roughness assumptions for the larger events on the rating curve, as a result of a significant preceding time period without major flood occurring. The revised FFA provided a good match between the XP-RAFTS model and the revised FFA at the Towamba gauge indicate that the catchment characteristics (roughness and slope) are appropriate.

5.5.4 Towamba River Catchment Hydraulic Models

As part of the collection of the additional survey, flood marks from the 2011 and 1978 events were collected in Towamba. Additional observations from the community regarding flood extents were collected as part of the community consultation.

Only the Towamba model was able to be directly calibrated. However, in order to ensure that the Towamba River models are compatible with one another, the hydraulic model parameters determined through the Towamba calibration process have been adopted at the other study areas.

In order to calibrate the Towamba hydraulic model, the revised gauged flows from the 2011 and 1978 events were run through the model. The comparison between modelled results and the community observations are shown in **Map G512** for the 2011 event and **Map G513** for the 1978 event. The figure shows that the hydraulic model results are producing similar flood levels and extents to those observed by the community.

In the 2011 event, the surveyed community flood level in Towamba was 38.34mAHD. The model had a level of 38.54maHD at this location. The comment from the community was that the 2011 flood "reached the text of the sign" at this location, so 0.2m is well within the uncertainty of the survey mark.

Further upstream, community observations placed the flood extant at approximately the 40mAHD contour. The flood level at this location in the model was 39.7mAHD. Given the accuracy of the extent reporting (a community member indicating the flood extent on an A1 map) this is also within the accuracy of the historical reporting.

A community member also provided a photo of the local bus shelter in the 2011 event. Two photos showing the flooding of the bus shelter are provided in **Figure 5-3**. The photos show that the flood reached to the roof of the shelter. The height of the shelter to the underside of the roof was estimated to be approximately 2.4m, suggesting that the flood height was in the order of 2.5 – 3m. The 2011 flood depth from the model at this location was 2.8m.

The 1978 also had a survey point collected, and an extent marked on the map as part of the community drop in workshops. The historical extent indicated by the community member was that the 1978 event fell approximately 40m short of Pericoe Road. The TUFLOW model calibrates well to this observation, reaching to approximately 50m from Pericoe Road.

The flood level surveyed for the 1978 event was marked by a hacksaw on a post near the intersection of Yambulla Road and Towamba Street. The point was surveyed as being at 36.52mAHD. The model at this location has a level of 36.39mAHD, 0.13m lower than the survey mark.

Figure 5-3 Towamba Bus Shelter Flooding in 2011

5.5.5 Eden Hydraulic Model

No reliable calibration data was available relating to overland and creek flooding within Eden for a specific flood event. However, various general accounts of flood behaviour were collected as part of the community information sessions (**Section 4.5**). These observations are in many cases not associated with a specific event, but rather an observation of flooding that occurs with heavy rain, or a vague period of time in which it occurred.

Given this uncertainty on the historical rainfall events, together with the lack of good pluviometer rainfall data in Eden (refer to **Appendix D**), an indirect validation was instead undertaken by comparing the 20% and 1% AEP events to the observations. This ensures that the model is producing similar behaviour to that observed by the community in previous flooding events.

The results of the 20% and 1% AEP event model runs are shown in **Map G514** and **Map G515** along with the community observations of flooding. Although there are only limited flood observations, the results appear to align with what has been observed in the past.

5.6 Model Sensitivity

Sensitivity analysis is a useful tool in understanding the potential variability of model results with different parameter assumptions. The following sensitivity analyses have been undertaken:

- Model roughness;
- Model inflows;
- Blockage assumptions; and,
- ARR87 and ARR2016 comparison.

5.6.1 Roughness

Flood behaviour was found to be sensitive to roughness values along the Towamba River. Within the Towamba River models, peak water level impacts arising from roughness changes increased from +/-0.2 to 0.3 metres at

Wyndham to +/- 0.7 metres at Towamba. The roughness values adopted for the channel and overbank areas (0.06 and 0.1 respectively) are relatively high, so a 20% change represents a significant change to flow conditions (as opposed to a 20% change of 0.02 for example).

In contrast, Eden showed a much lower sensitivity to the roughness values adopted, exhibiting typical changes of +/- 0.05 as a result of a 20% roughness change.

A roughness sensitivity was also undertaken for the study areas at Shadrachs Creek, Nullica River and Boydtown Creek. While the roughness changes slightly affected run off times, it did not impact peak levels as these were all driven by ocean flooding which was not affected by changes to catchment roughness.

Overall, the changes in peak flood levels as a result of changes to roughness values did not result in a significant change in flood extent in any of the study areas.

A summary of the changes in 1% AEP peak flood levels across the catchments for roughness sensitivity are shown in **Table 5-5** and **Table 5-6**. The model results and difference plots in GIS layers for each run have been provided to Council.

Table 5-5 Roughness Increase Sensitivity

Model Area	Max Increase in Flood Levels (m)	Percentile Impacts to Flood Levels (m)				
		5%	25%	5%	75%	5%
Wyndham	0.67	0.17	0.20	0.22	0.24	0.31
Rocky Hall	0.86	0.16	0.25	0.34	0.40	0.47
New Buildings	0.84	0.17	0.29	0.33	0.39	0.51
Burragate	1.14	0.23	0.47	0.56	0.64	0.71
Towamba	0.83	0.60	0.63	0.65	0.70	0.76
Eden	0.27	0.01	0.03	0.05	0.08	0.12
Shadrachs	*Not applicable – flooding driven by ocean levels*					
Nullica / Boydtown	*Not applicable – flooding driven by ocean levels*					

Table 5-6 Roughness Decrease Sensitivity

Model Area	Max Increase in Flood Levels (m)	Percentile Impacts to Flood Levels (m)				
		5%	25%	5%	75%	5%
Wyndham	-0.64	-0.31	-0.26	-0.24	-0.20	-0.14
Rocky Hall	-0.81	-0.52	-0.43	-0.34	-0.24	-0.16
New Buildings	-0.86	-0.51	-0.41	-0.32	-0.29	-0.18
Burragate	-1.41	-0.86	-0.77	-0.69	-0.46	-0.12
Towamba	0.07	0.60	0.63	0.65	0.70	0.76
Eden	-0.30	-0.13	-0.08	-0.05	-0.03	-0.01
Shadrachs	*Not applicable – flooding driven by ocean levels*					
Nullica / Boydtown	*Not applicable – flooding driven by ocean levels*					

5.6.2 Rainfall Intensity

The sensitivity of the models to rainfall intensity was undertaken by comparing the 0.5% AEP and 2% AEP against the 1% AEP, to assess rainfall intensity increases and decreases respectively. The 0.5% AEP intensities were 18% higher than the 1% AEP and the 2% AEP was 14% lower.

A summary of the changes in peak flood levels across the catchments for the 1% AEP rainfall intensity sensitivity are shown in **Table 5-7** and **Table 5-8**. The model results in GIS layers for each run have been provided to Council.

The results show that the Towamba River models were sensitive to rainfall changes, with, the impact of changes in rainfall intensity increases for study areas further downstream. In the upper catchment typical impacts were +/- 0.2 to 0.4 metres. This increased to +/- 0.7 to 1 metre at Towamba.

Eden had more modest impacts in the order of +/- 0.1 metres. Shadrachs, Nullica and Boydtown had impacts of less than +/- 0.1. These locations were relatively insensitive to rainfall changes.

Table 5-7 Rainfall Intensity Increase Sensitivity

Model Area	Max Increase in Flood Levels (m)	Percentile Impacts to Flood Levels (m)				
		5%	25%	50%	75%	95%
Wyndham	0.67	0.20	0.23	0.27	0.30	0.36
Rocky Hall	0.88	0.17	0.29	0.38	0.46	0.56
New Buildings	1.22	0.41	0.61	0.69	1.28	1.71
Burragate	1.05	0.48	0.69	0.77	0.82	0.87
Towamba	1.11	0.88	0.90	0.97	1.02	1.07
Eden	0.51	0.02	0.06	0.08	0.15	0.32
Shadrachs	0.47	-0.05	0.03	0.03	0.06	0.30
Nullica / Boydtown	0.53	0.01	0.04	0.05	0.08	0.33

Table 5-8 Rainfall Intensity Decrease Sensitivity

Model Area	Max Increase in Flood Levels (m)	Percentile Impacts to Flood Levels (m)				
		5%	25%	50%	75%	95%
Wyndham	-0.52	-0.29	-0.25	-0.21	-0.18	-0.16
Rocky Hall	-0.59	-0.43	-0.36	-0.28	-0.21	-0.13
New Buildings	-1.16	-0.72	-0.67	-0.57	-0.39	-0.26
Burragate	-1.03	-0.80	-0.72	-0.63	-0.55	-0.38
Towamba	-1.17	-0.87	-0.71	-0.67	-0.65	-0.63
Eden	-0.27	-0.16	-0.08	-0.05	-0.03	-0.01
Shadrachs	-0.49	-0.21	-0.07	-0.06	-0.06	-0.01
Nullica / Boydtown	-0.33	-0.19	-0.09	-0.05	0.03	-0.01

5.6.3 Blockage

Hydraulic structures were included in the flood models for the following study areas:

- Wyndham (bridge)
- New Buildings (bridge)
- Burragate (bridge)
- Towamba (bridge)
- Eden (culverts)
- Boydtown (culverts)

A blockage assessment was undertaken in line with the guidance provided in ARR2016. Using the ARR2016 guidelines, the blockage factor is based on:

- Debris availability
- Debris mobility
- Debris transportability

The results of the 1% AEP blockage assessment are summarised in **Table 5-9**. The model results in GIS layers for each run have been provided to Council. As shown in the table, a blockage rate of 10% AEO was adopted for the Towamba River models and Boydtown, while a higher blockage of 50% was adopted for Eden (as a result of the small culvert sizes).

The results showed that the impacts of blockage were minimal across the Towamba River and ICOLL study areas. This is reasonable, given the modest blockage rate of 10% that was adopted.

For the Eden model, a significantly higher blockage of 50% was adopted, due to the small sizes of these culverts. This result in higher impacts occurring at the culverts, although the impacts were still limited to the immediate area surrounding the culverts.

Table 5-9 Blockage Sensitivity

Model Area	Blockage Risk	Blockage Factor (1% AEP)	Max Increase	Max Decrease	Percentile Impacts				
					5%	25%	50%	75%	95%
Wyndham	Medium	10%	0.05	-0.03	0	0	0	0	0.01
Rocky Hall	*Not Applicable – low level causeway crossing*								
New Buildings	Medium	10%	0.03	-0.04	0	0	0	0	0.01
Burragate	Medium	10%	0.02	-0.04	0	0	0	0	0.01
Towamba	Medium	10%	0.06	-0.03	0	0	0	0	0.01
Eden	Medium	50%	0.11	-0.81	-0.04	-0.01	0	0	0.23
Shadrachs	*Not Applicable – no structures*								
Nullica / Boydtown	Low	10%	0.07	-0.04	0	0	0	0	0.01

Note: The guidelines resulted in a design blockage of 0% at Nullica. As part of the sensitivity testing, a 10% AEP rate was adopted in line with the other study areas.

5.6.4 Australian Rainfall and Runoff Guidelines

Australian Rainfall and Runoff 2016 (ARR2016) guidelines have been applied to this Flood Study (**Section 5.2.1**). However, as these guidelines are relatively new, it is important to understand the changes from the previous guidelines (Australian Rainfall and Runoff 1987 - ARR87). This comparison was undertaken as a sensitivity assessment in this study.

The hydrological modelling was revised for each study area, adopting the methodology and rainfall intensities detailed in ARR87. Changes in peak flood level are shown in **Map Series G516**.

To demonstrate the differences of the rainfall intensities within the study area, the Towamba FFA plot was updated to also show the ARR87 peak flow estimates. This is shown in **Figure 5-4**.

The figure shows that the ARR87 estimates are significantly higher than the ARR2016 estimates, to the extent that the 20% AEP, 10% AEP and 5% AEP estimates are outside the FFA confidence limits. The increase in peak flow using the ARR87 methodology was in the order of 50% over ARR2016 estimates. This level of increase resulted in substantial changes to peak flood levels across all the study areas.

Across the Towamba models, this resulted in consistent increases across the study areas, ranging from 0.6 metres in the upper catchment areas such as Wyndham and Rocky Hall to 1.2 metres at Burragate and 0.9 metres at Towamba.

Within the Eden model, impacts varied substantially. Within Palestine Creek, increases of up to 1.2 metres were observed, although this occurred upstream of the Princes Highway and did not impact developed areas. Downstream of Government Road, Palestine Creek levels were 0.3 metres higher under the ARR87 scenario.

Across the western and eastern flowpaths, increases in the ARR87 scenario across developed regions were typically between 0.2 and 0.4 metres.

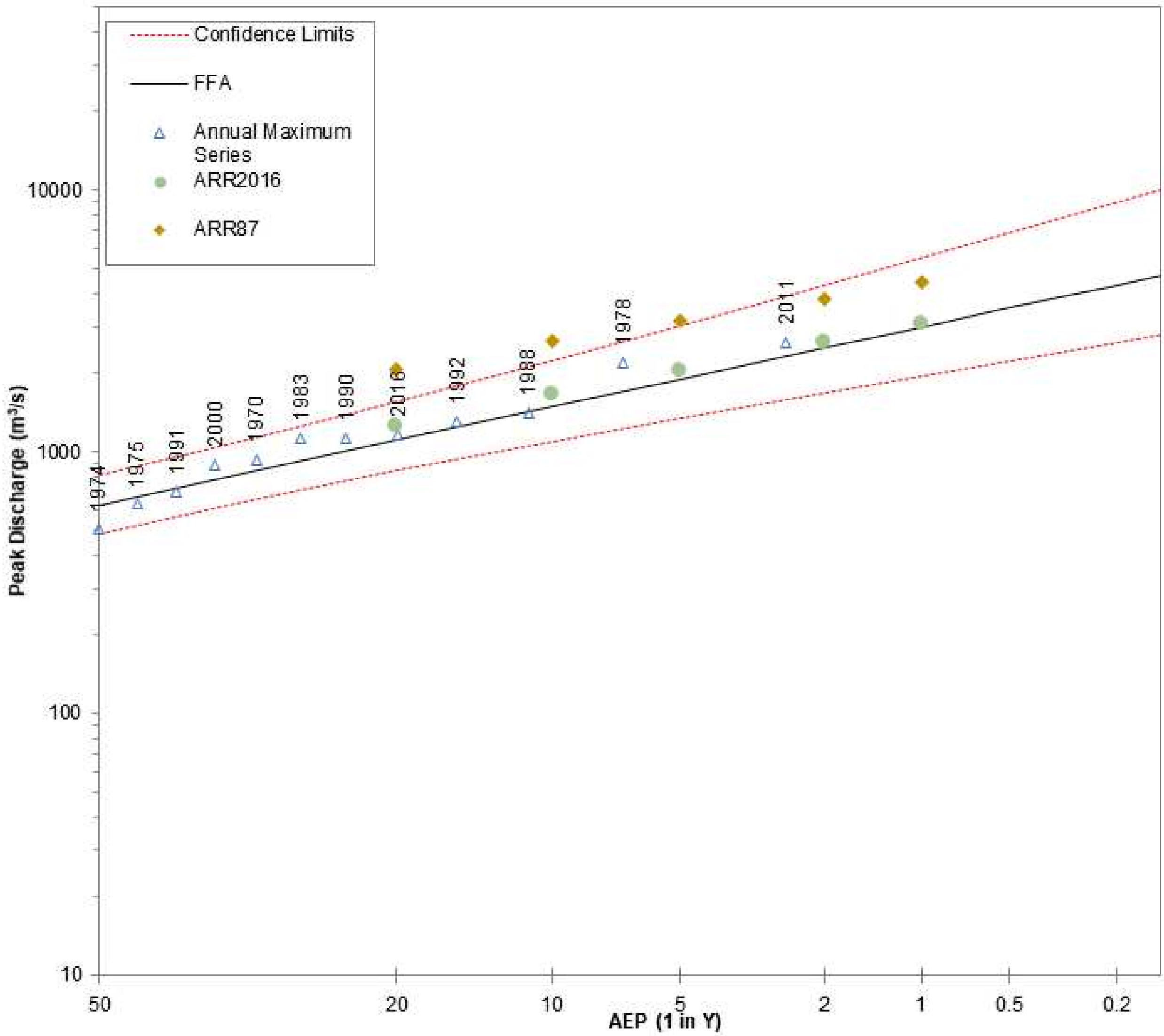

Figure 5-4 Comparison of ARR16 and ARR87 flows at Towamba Gauge

5.7 Design Flood Events

The hydrological and hydraulic models were analysed for the PMF, 0.2% AEP, 0.5% AEP 1% AEP, 2% AEP, 5% AEP and 10% AEP events. Each event was run for durations from 30 minutes to 12 hours to determine the critical duration(s) for each event. As per the ARR2016 methodology, each event / duration combination was run for 10 temporal patterns, with the temporal pattern first above the median adopted as the design event.

The full set of runs was run through the hydrological model, with only the one temporal pattern run through the hydraulic model. The critical durations adopted for each event in each model area are summarised in **Table 5-10**. Some models have a different critical duration in the upper and lower reaches of the model.

Table 5-10 Event Critical Durations (hours)

Location	PMF	0.2% AEP	0.5% AEP	1% AEP	2% AEP	5% AEP	10% AEP
Wyndham	9	9	9	9	9	9	9
Rocky Hall	9	9	9	9	9	9	9

Location	PMF	0.2% AEP	0.5% AEP	1% AEP	2% AEP	5% AEP	10% AEP
New Buildings	9	9	9	9	9	9	9
Burragate	9	9	9	9	9	9	9
Towamba	9	9	9	9	9	9	9
Eden	2, 9	2, 9	2, 9	2, 9	1.5, 6	1.5, 6	1.5, 6
Shadrachs	6, 9	6, 9	6, 9	6, 9	6, 12	6, 12	6, 12
Nullica / Boydtown	6, 9	6, 9	6, 9	6, 9	6, 9	6, 12	6, 12

5.8 Climate Change

Climate change has the potential to influence flood behaviour. In the Eden and Towamba River catchment this is most likely to occur through impacts on rainfall and / or sea level rise. A sensitivity analysis on rainfall and the downstream boundary was the most appropriate approach to assess the potential changes to the flood behaviour as a result of climate change. This sensitivity analysis is useful to understand the potential variance in flood levels, flood behaviour and associated planning under climate change conditions.

To assess potential climate change impacts, the following was undertaken:

- Comparison of 1% AEP and 0.5% AEP flooding behaviour (representing a 19% increase in rainfall intensity;
- Mapping of the 1% AEP ocean event with a 0.4 metre sea level increase; and,
- Mapping of the 1% AEP ocean event with a 0.9 metre sea level increase.

The results of the comparison between the 1% AEP and 0.5% AEP events are presented in **Table 5-11**.

The mapping results for the coastal study areas are provided in **Map G517**.

The results show that for the Towamba River models, the impact of changes in rainfall intensity increases for study areas further downstream. In the upper catchment, increases were modest, typically in the range of 0.2 to 0.4 metres. Impacts increased downstream, due to the additional upstream area contributing increased flow. Median increases at New Buildings were 0.69 metres, increasing to 0.97 metres at Towamba.

In the coastal study areas, the increase in rainfall intensity had a much smaller impact on peak flood levels. Eden had more modest impacts in the order of +/- 0.1 metres, while Shadrachs, Nullica and Boydtown had impacts of less than +/- 0.1.

Sea level rise only impacts the coastal study areas. The Towamba River study areas are sufficiently far upstream to not be affected by sea level rise. The comparison of the design scenario with 0.4 metre and 0.9 metre sea level increases showed that impact varied across the coastal study areas.

Along the northern shore of Lake Curalo, impacts were minimal, with negligible change in flood extent occurring even with a 0.9 metre rise is sea level.

Along the western shore, the 0.4 metre increase extents showed little change, although the 0.9 metre increase did result in a lateral expansion of 30 metres at Lakeside Drive that resulted in additional properties becoming flood affected.

Along the southern shore, additional inundation, while more wide spread than the northern and western shores, was typically restricted to open space and vegetated corridors. The exception was the aged care centre on Barclay Street, which was fully inundated under a 0.9 metre sea level rise scenario.

The steep terrain at Lake Cocora prevented any significant increase in flood affectation under a 0.4 metre sea level rise scenario. With 0.9 metres of sea level rise, overtopping of Ida Rodd Drive occurred.

Sea level rise at Shadrachs Creek primarily affected the caravan park, with an additional 20 metres and 30 metres of flood affectation occurring under the 0.4 and 0.9 metre sea level rise scenarios respectively. No impacts progressed upstream of the Princes Highway.

Table 5-11 Impacts of Rainfall Intensity Increase

Model Area	Max Increase	Percentile Impacts				
		5%	25%	50%	75%	95%
Wyndham	0.67	0.20	0.23	0.27	0.30	0.36
Rocky Hall	0.88	0.17	0.29	0.38	0.46	0.56
New Buildings	1.22	0.41	0.61	0.69	1.28	1.71
Burragate	1.05	0.48	0.69	0.77	0.82	0.87
Towamba	1.11	0.88	0.90	0.97	1.02	1.07
Eden	0.51	0.02	0.06	0.08	0.15	0.32
Shadrachs	0.47	-0.05	0.03	0.03	0.06	0.30
Nullica / Boydtown	0.53	0.01	0.04	0.05	0.08	0.33

6 Understanding Flood behaviour

6.1 Design Flood Behaviour

Peak flood depths (with water level contours) and velocities are provided in **Map Series G601** and **G602** respectively**.** Maps have been prepared for the 10% AEP, 1% AEP and PMF events. The full set of data for all design events (PMF, 0.2% AEP, 0.5% AEP 1% AEP, 2% AEP, 5% AEP and 10% AEP events) has been provided to Council in a digital format.

6.1.1 Towamba River Catchment Study Areas

The five Towamba River catchment study areas all exhibit similar flood behaviour. The major flow path through each area is a large riverine flowpath. Flows within the river channel are typically well contained at all sites for events up to and including the 1% AEP.

In the PMF event, flood extents expand significantly, as a result of the substantially higher flow in this event. Peak flow rates at each of the Towamba River study areas are summarised in **Table 6-1**. The table shows that the PMF is approximately 3 times larger than the 1% AEP at Towamba, and up to nearly 6 times higher in the upper catchment at Wyndham.

As would be expected given these flows, velocities through the main channel are significant at all sites, with peak river velocities of between 5 and 6 metres per second occurring at all sites in the 1% AEP event.

Access routes along the river (not the crossings) are typically outside the 1% AEP event, and are only affected in the PMF event. The exception being Big Jack Mountain Road in New Buildings, which is inundated in the 1% AEP event. Further details on road closures and bridge and crossing overtopping is provided in **Section 7.3**. Further site-specific information for each of the Towamba River study area is provided in the following sections.

Table 6-1 Towamba River Model Peak Flows

Location	10% AEP	1% AEP	PMF	PMF / 1% AEP
Wyndham	60	110	640	5.8
Rocky Hall	355	610	3455	5.7
New Buildings	960	1660	7920	4.8
Burragate	1375	2000	9075	4.5
Towamba	1950	3435	12100	3.5

6.1.1.1 Wyndham

Located in the northern region of the wider Towamba River catchment, the Wyndham township has the smallest contributing catchment area of the five Towamba River study areas.

The township lies adjacent to Mataganah Creek, which discharges into the Towamba River 10 km downstream of Wyndham. It is the only Towamba River study area that does not lie directly on the Towamba River.

Flooding is well contained within the creek in all events, up to and including the PMF. The PMF encroaches onto private property but does not affect any buildings.

Downstream of the township, Mount Darragh Road crosses over Mataganah Creek. The bridge is inundated in the PMF only.

A long section through the study area is provided in **Figure 6-1**. The long section shows that the AEP events have depths in the order of 2 to 5 metres, the PMF event has depths of up to 10 metres, which explains the significant increase in flood extent from the 1% AEP event to the PMF event.

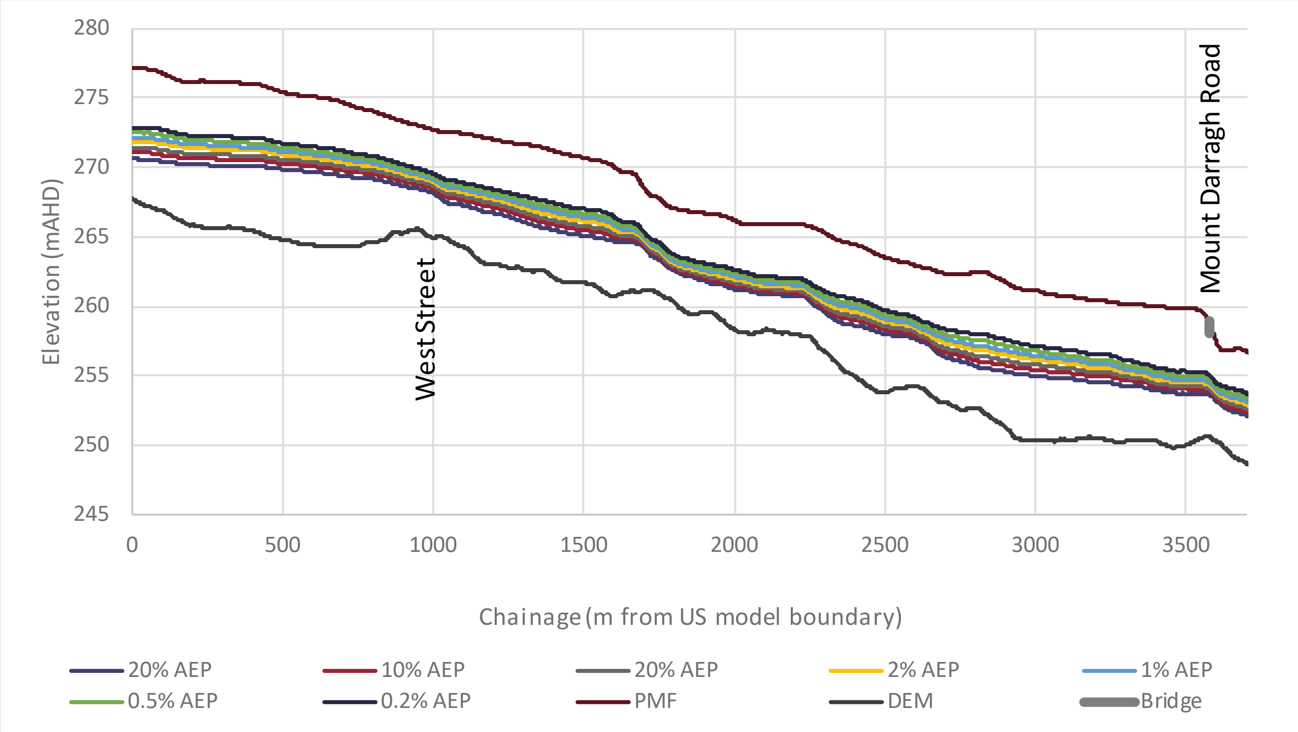

Figure 6-1 Wyndham Long Section

6.1.1.2 Rocky Hall

Rocky Hall is located in the north-west of the wider Towamba River catchment. It is the most upstream catchment of the study areas located along the Towamba River.

The Towamba River runs through the centre of the village, with a large tributary, Cow Ball Creek, joining the Towamba River in the middle of the study area, and a smaller tributary, Black Log Creek, joining the Towamba River downstream of the study area.

Flow is typically well contained along those reaches between tributaries. Where the tributaries join the river, flow breaks out of the banks of both tributary and river some 200 to 300 metres upstream of the actual confluence. This breakout flow at the Cow Bali Creek confluence results in overtopping of Big Jack Mountain Road in events as small as the 10% AEP event.

Immediately downstream of the Black Log Creek confluence there is a small causeway that crosses the Towamba River providing access to a number of farms. This causeway is inundated in events as small as the 20% AEP event.

A long section through the study area is provided in **Figure 6-2**. The long section shows that, similar to Wyndham, the PMF is typically twice as high as the 0.2% AEP event.

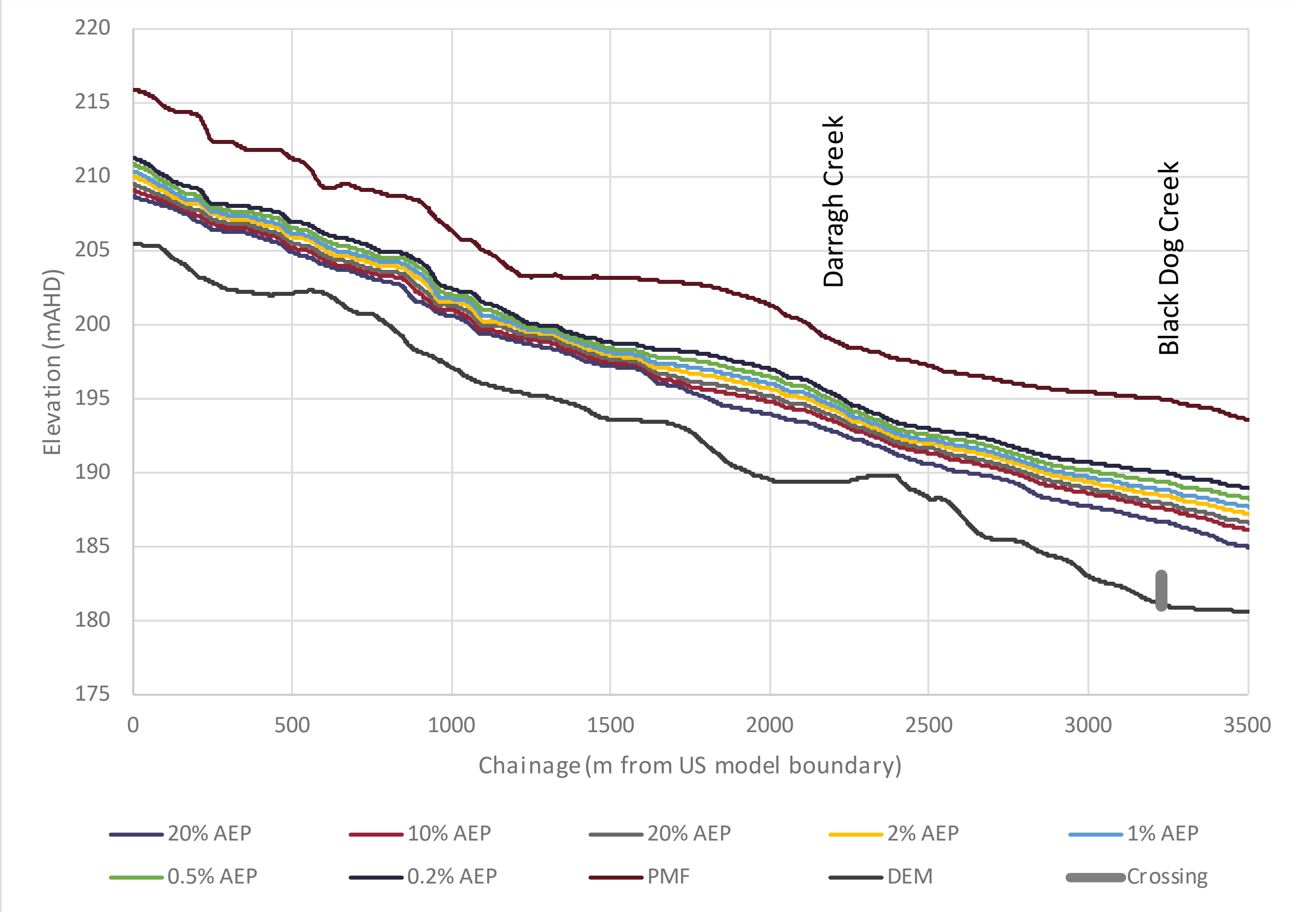

Figure 6-2 Rocky Hall Long Section

6.1.1.3 New Buildings

The locality of New Buildings lies adjacent to Towamba River 3.5 kilometres downstream of Rocky Hall, immediately upstream of the Mataganah Creek confluence.

Flow is fully contained with the channels in the 10% AEP, with some minor breakout flows occurring in the 1% AEP at the Mataganah Creek confluence. The PMF has a sharp increase in flood extent, although due to the terrain, the flow is still relatively well constrained, and no major breakouts are observed.

New Buildings Road crosses the Towamba River in the centre of the study area, 400 metres upstream of the Mataganah Creek confluence. The bridge is first inundated in the 0.5% AEP event. However, the approaches to the bridge are lower, and are inundated in the 1% AEP event.

Big Jack Mountain Road runs along the southern side of the Towamba River. At the location of the New Buildings Road bridge, the road passes close to the Towamba River. The road is right on the flood extent of the 1% AEP event, and experiences some minor overtopping in the 0.5% AEP and 0.2% AEP. In the PMF, the increased flood extent results in inundation of Big Jack Mountain Road for a distance of approximately 1 kilometre.

Buildings within New Buildings remain unaffected by direct flooding in the events up to and including the PMF.

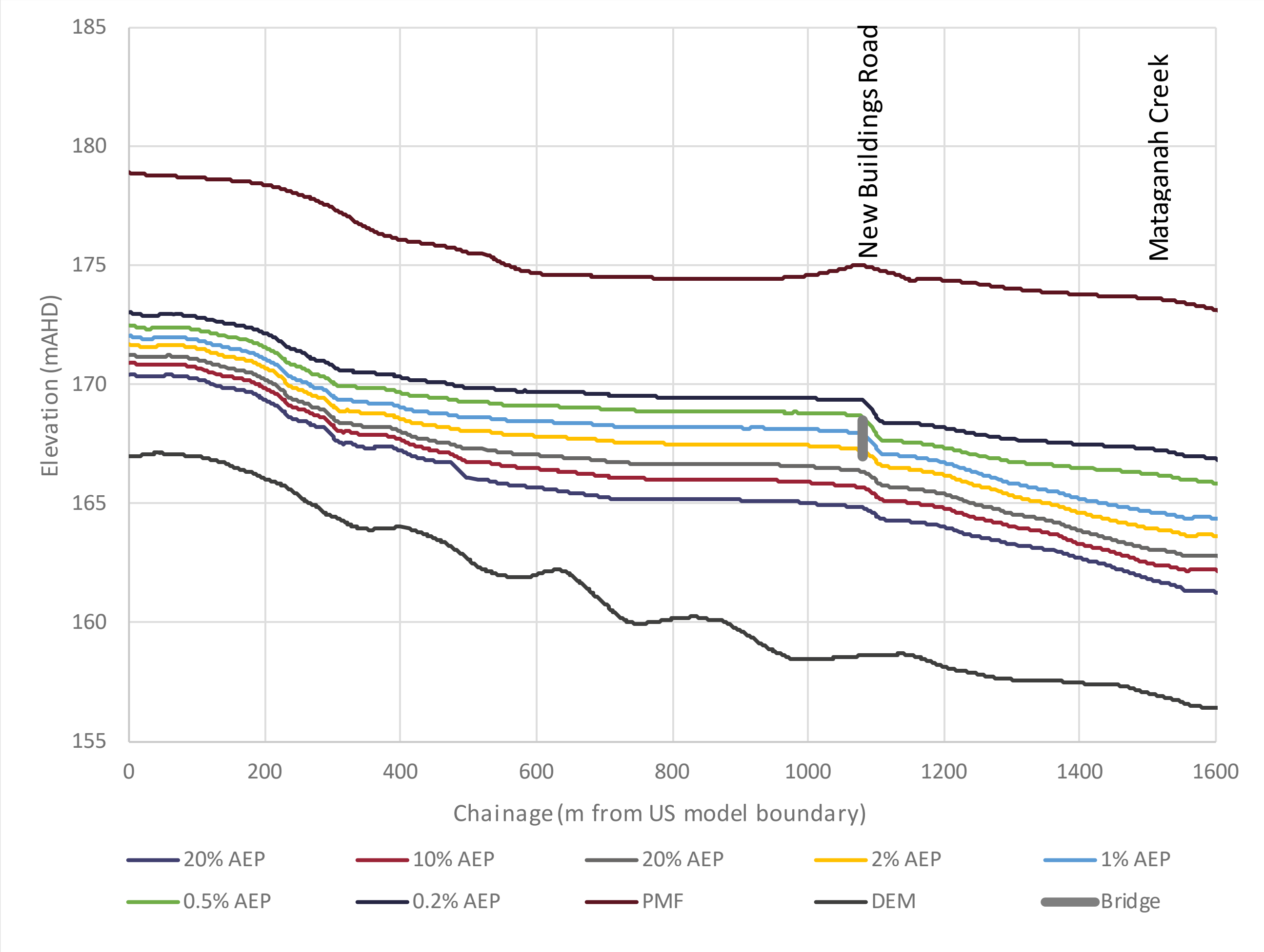

Figure 6-3 New Buildings Long Section

6.1.1.4 Burragate

Burragate is located on the Towamba River, 6 kilometres downstream of New Buildings. Unlike Rocky Hall and New Buildings, there is a reasonable level of development at Burragate. The development is rural and large lot residential, and is generally located on the eastern bank of the Towamba River.

The flow through the river is well contained in events up to the 0.2% AEP. Much of the development is set back from the river, and remains unaffected in this event. In the PMF, the flood extent increases significantly. This results in a wider flooded area along the main river, as well as substantial backwatering up local tributaries.

Big Jack Mountain Road crosses the Towamba River upstream of the township. The bridge is at a low level and experiences overtopping in events as small as the 20% AEP event.

The major access road through the township, Towamba Street, first experiences flooding in the PMF, where a 300 metre length of road becomes inundated.

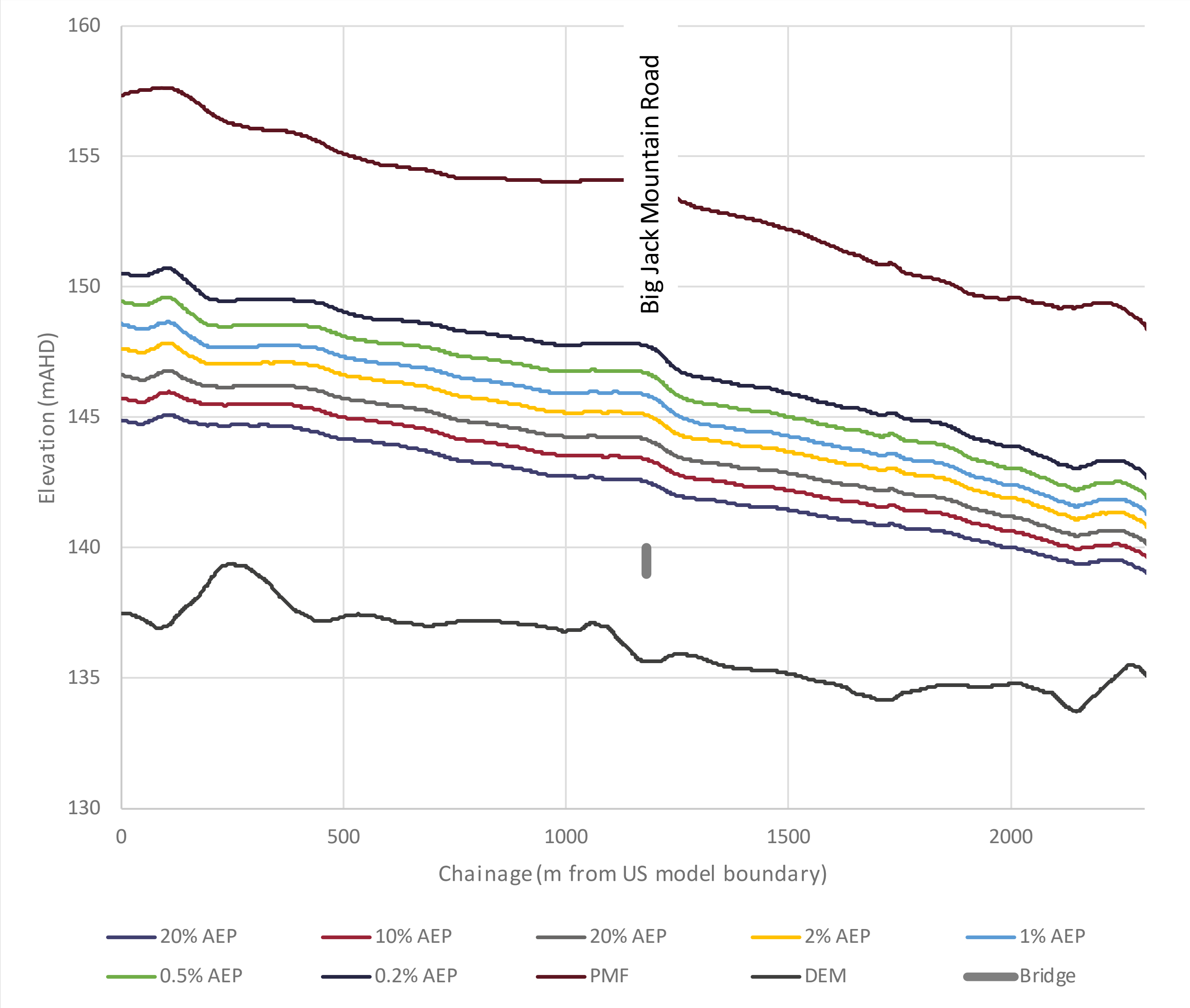

Figure 6-4 Burragate Long Section

6.1.1.5 Towamba

The Towamba study area is the most downstream study area along the Towamba River, and experiences the greatest flows. It is also the study area that has the greatest level of development. The bulk of the development is located on the southern bank of the river, with some large lot rural properties located on the northern bank.

It is located 19 kilometres downstream of Burragate, and 33 kilometres upstream from the Towamba River outlet.

The Towamba study area is unique in that the 1% AEP has a substantially larger flood extent than the 10% AEP event due to breakouts of the channel. While the majority of the flow is well contained, some breakouts do occur in the central portion of the model at the major bend in the river. Flow both short cuts the bend in events larger than the 5% AEP event, and breaks out onto the northern banks in events above the 20% AEP. These breakouts inundated both Towamba Road and Towamba Street in the 1% AEP event, but do not impact residential developments.

In the PMF event, the flood extent increases significantly. The extent of road inundation increases, with both Towamba Road and Towamba Street impacted for over 1 kilometre each. The PMF also impacts buildings on both the northern and southern banks.

Pericoe Road crosses the Towamba River upstream of the major bend in the river, and connects Towamba Road, which runs along the northern side of the river, and Towamba Street, which runs along the southern side. The bridge is overtopped in events as small as the 20% AEP event.

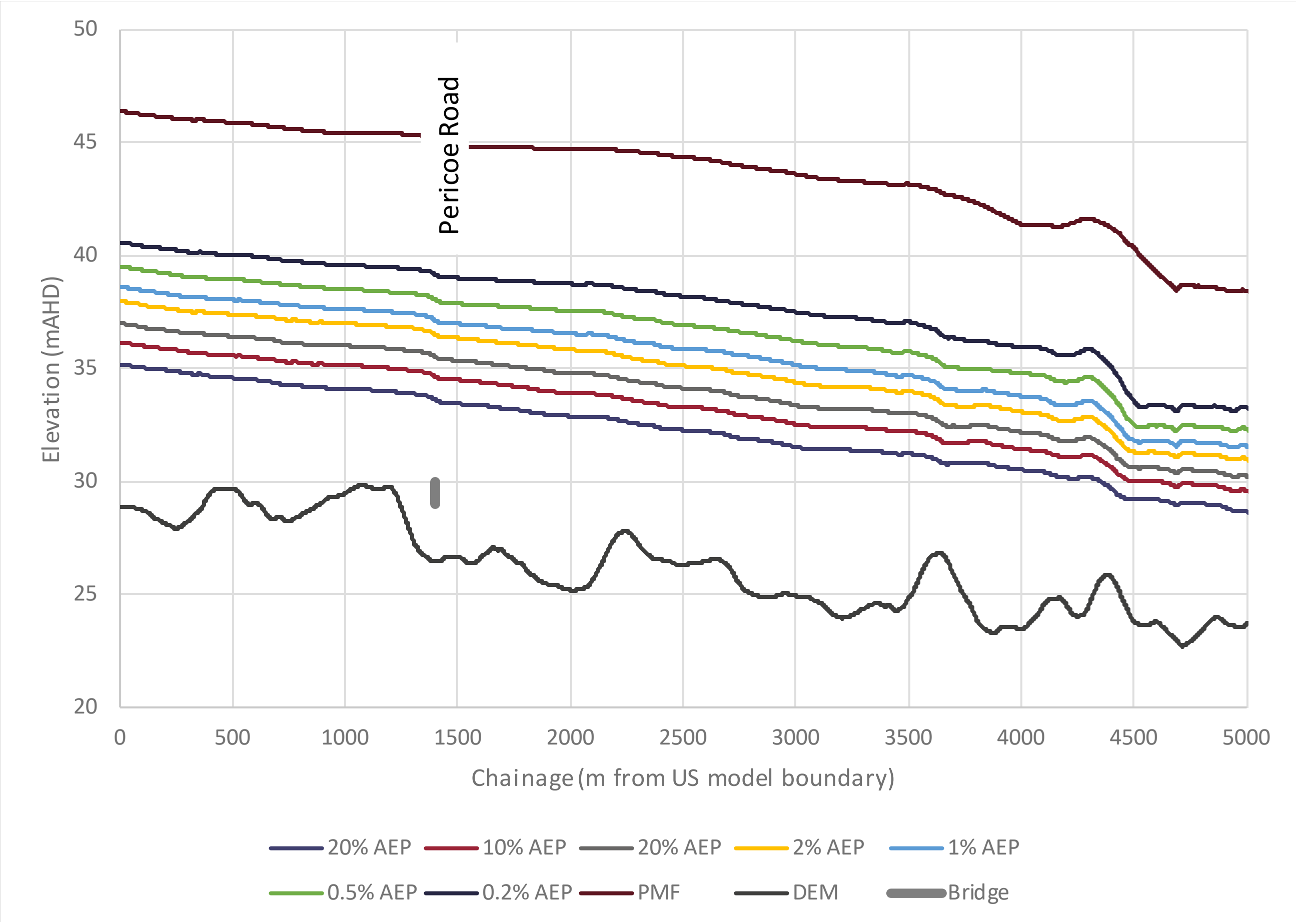

Figure 6-5 Towamba Long Section

6.1.2 Eden and Lake Curalo

The model developed for the Eden township covers both Lake Curalo and Lake Cocora. The flooding associated with Lake Curalo is discussed here, with Lake Cocora discussed below.

Lake Curalo lies between the township of Eden on its northern, western and southern boundaries, and Twofold Bay on the east. It is fed by a number of upstream tributaries.

On the northern side are one major tributary and three additional flowpaths (refer **Figure 6-6**). The north-western flowpath is the major tributary, which is the major source of water for Lake Curalo, Palestine Creek. The upper reaches of Palestine Creek are largely vegetated, before transitioning into cleared fields at the extent of the hydraulic model. Immediately upstream of Lake Curalo, Palestine Creek passes through an industrial area before discharging into the Lake.

The flow is typically well contained in events up to and including the 2% AEP event. In the 1% AEP event, flow begins to break out of the creek, and affects the adjacent industrial properties. The PMF event shows a marked increase in extent. Much of this increase occurs over pastureland, although flooding through the industrial precinct is also exacerbated.

The central flowpath runs from north to south. It crosses Government Road, but otherwise flooding is restricted to bushland or pastureland for all design events.

The eastern northern flowpath, located on the eastern side of the study area, is relatively minor, in the main driven by local overland flow from the residential development at the point. The tributary generates nuisance flooding, particularly in events larger than the 1% AEP, but does not affect any properties.

The final flowpath passes through the industrial area south and west of Palestine Creek. It is largely contained with the vegetated channel, although some breakout occurs in the 1% AEP at the Palestine Creek confluence.

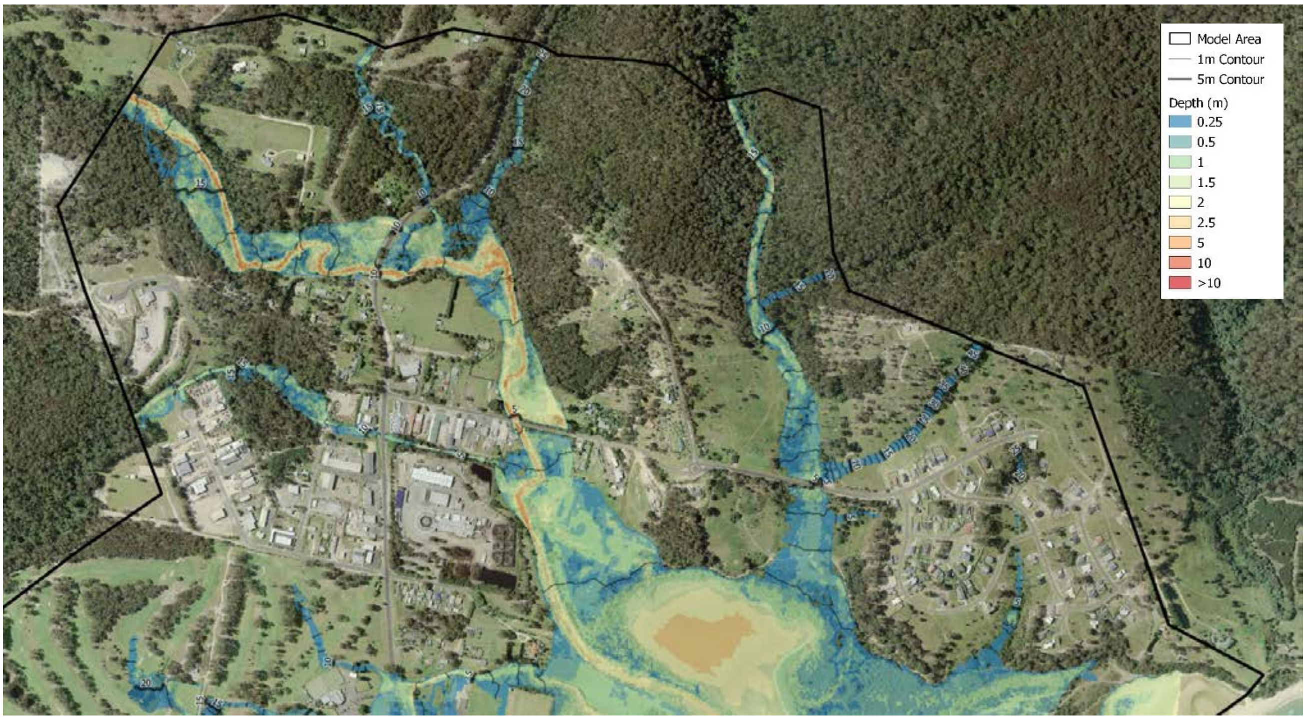

Figure 6-6 Lake Curalo Northern Tributaries (with 1% AEP flooding)

There is a single flowpath into the lake on the western side refer (**Figure 6-7**). It commences in the bushland upstream of the golf course, before passing through the golf course, over the Princes Highway and discharging into the lake via a small open channel that runs along the northern boundary of the sports fields. For events up to the 0.2% AEP event, the flow is reasonably contained within the flowpath. There is some expansion of flow as it moves through the golf course, but buildings and the sports fields remain unaffected.

In the PMF event however, there is substantial overbank flow, largely driven by the increased lake levels (refer **Figure 6-10**) that results in inundation of the sports fields, and property flooding along Clare Crescent and Cook Drive. Lakeside Drive properties are also flooded in the PMF, but this is driven by lake levels, rather than catchment flow.

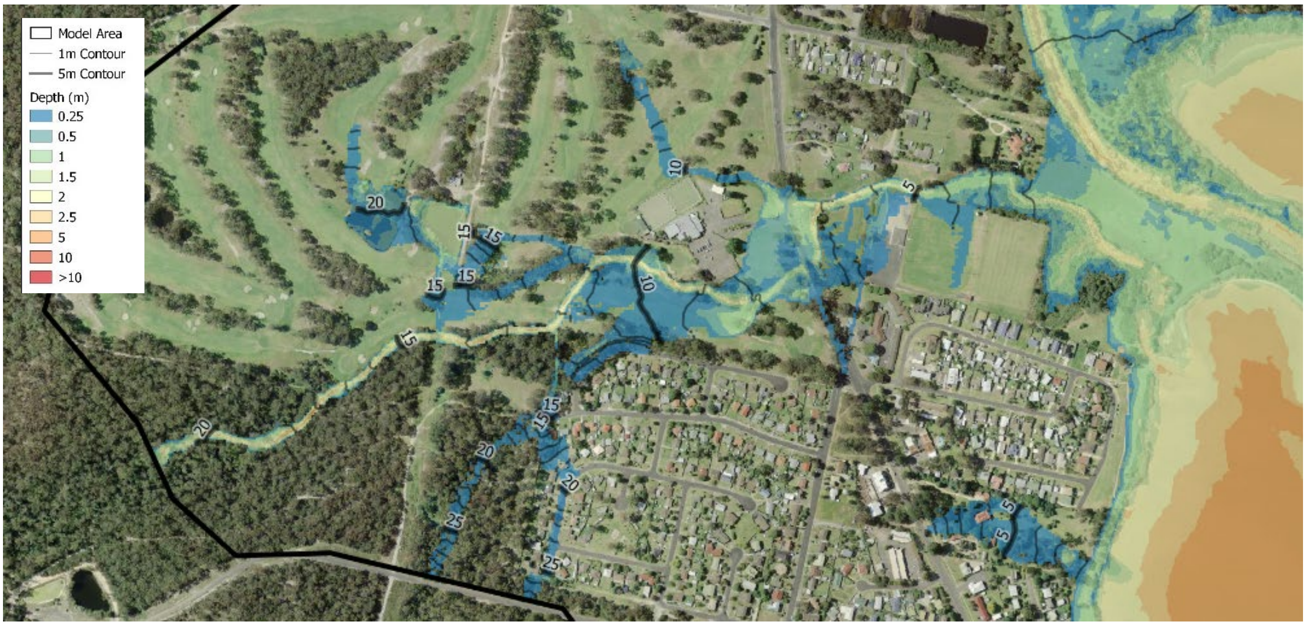

Figure 6-7 Lake Curalo Western Tributaries (with 1% AEP flooding)

On the southern side of the lake, there are two flowpaths (refer **Figure 6-8**). The western flowpath is Freshwater Creek and conveys water from the bushland to the east and south of the study area. The Creek runs behind properties on West Street, before passing beside the Eden Gateway Holiday Park. From here, the creek passes under the Pacific Highway and runs along the northern side of the Garden of Eden camping park.

The flow upstream of the Princes Highway is typically well contained for events up to and including the 0.2% AEP. In the PMF, flow from the Creek impacts properties on West Street, as well as much of the Eden Gateway Holiday Park.

Downstream, particularly in the PMF, flooding is largely driven by backwatering from the Lake, rather than flow through the Creek. The Garden of Eden Camping Park is inundated in events as small as the 20% AEP, as are properties along Emblem Street.

The second flowpath runs through the residential area immediately south of the lake. The flowpath is primarily overland flow, running behind properties and down roadways. At Wave Street, it enters a small open channel, which passes to the south and east behind the Bupa Aged Care centre. After crossing Barkley Street, the flowpath discharges into the lake.

In events up to and including the 0.2% AEP, flooding is largely nuisance flooding. Where residential lots are impacted, depths are shallow (less than 0.2m).

In the PMF however, driven by increased lake levels, a large region of residential development is undated, including the Aged Care centre, and properties along Curalo Street and Dolphin Crescent, by depths of 0.5 to 1 metre.

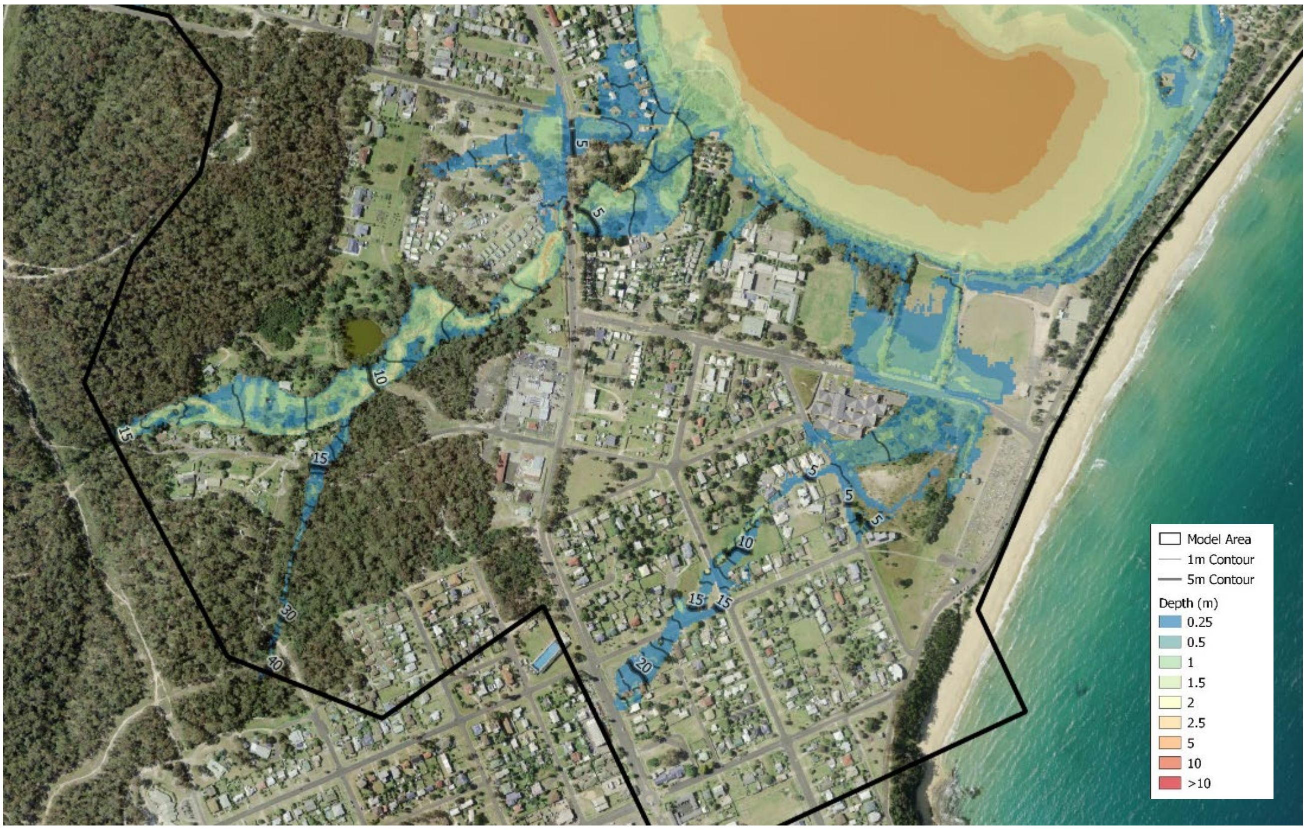

Figure 6-8 Lake Curalo Southern Tributaries (with 1% AEP flooding)

Peak flood levels within Lake Curalo drive the flood behaviour and extent across the foreshore areas (refer **Figure 6-9**). The PMF sees a large lateral increase in flood extent, due to a significant increase in lake levels (from 1.7mAHD in the 1% AEP to 3.8mAHD in the PMF). Along the northern edge, this increase does not impact development, with the land affected being bushland.

As previously noted, lake flooding is responsible for property flooding along the western and southern sides at Lakeside Drive, Emblen Street, Curalo Street and Dolphin Crescent.

In addition to these locations, the lake also impacts Reflection Holiday Park, which lies between the Lake and the Bay. The site first becomes flood affected in the 2% AEP, although access remains open up to and including the 0.2% AEP event. In the PMF however, the full site in inundated, and access is lost.

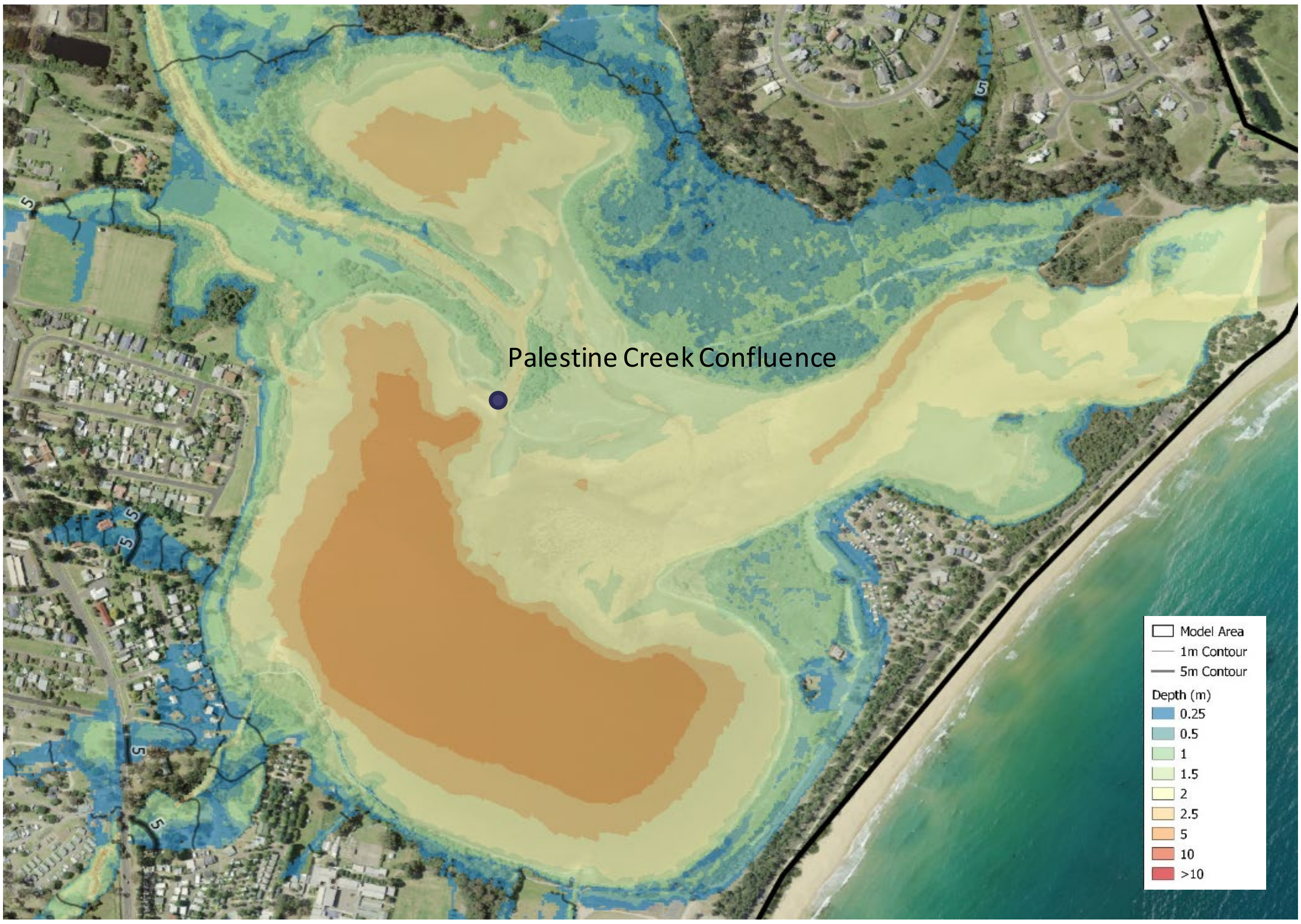

Figure 6-9 Lake Curalo Flooding (with 1% AEP flooding)

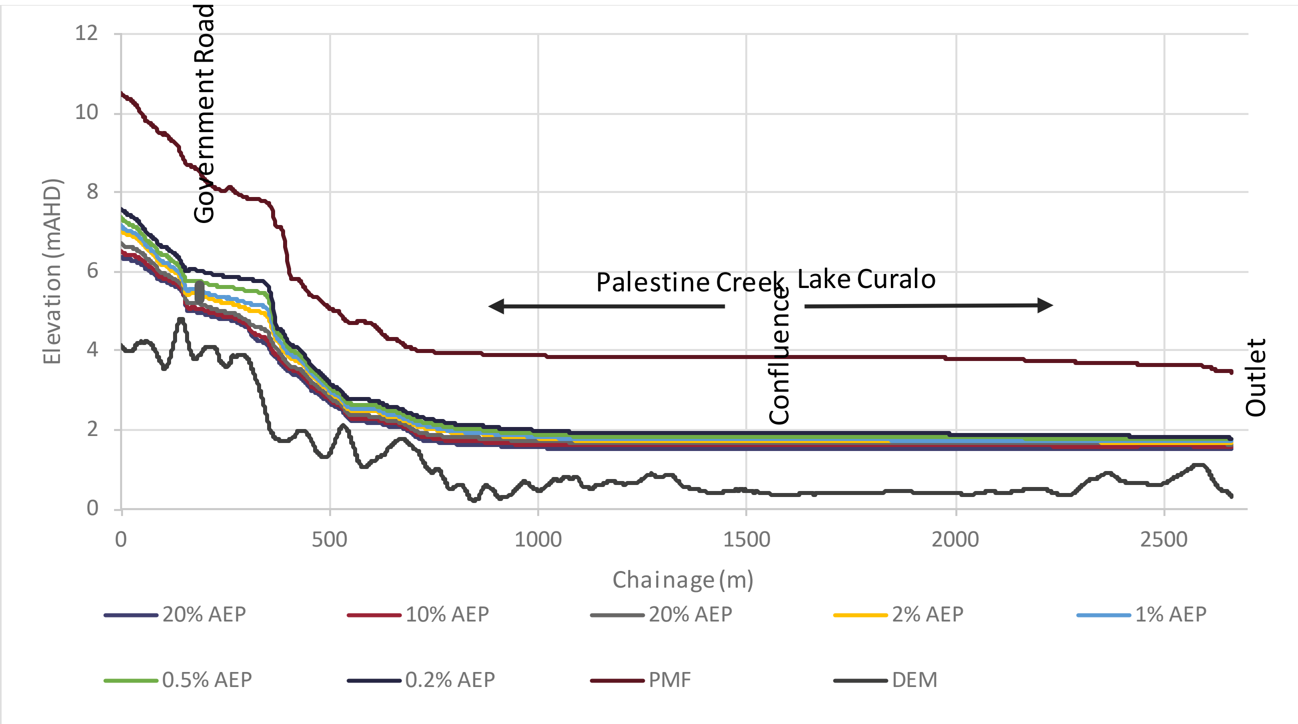

Figure 6-10 Lake Curalo Long Section

6.1.3 Lake Cocora

Flooding with the Lake Cocora region is well contained within creek extents for events up to and including the 0.2% AEP. This is due to both the terrain, which rises relatively steeply from the channels, as well as the small catchment area that feeds into Lake Cocora.

The PMF event, as a result of the greater rainfall intensity, does result in a slight lateral increase in flood extents arising from a substantial increase in lake levels(refer **Figure 6-11** and **Figure 6-12**). This results in additional road inundation, and some minor property affection. Buildings remain outside the flood extent, but some properties along Ida Rodd Drive experience flooding of their front yards. The lake level is 1.4 metres higher in the PMF than the 0.2% AEP event, but the terrain prevents a significant lateral expansion of the flood extent.

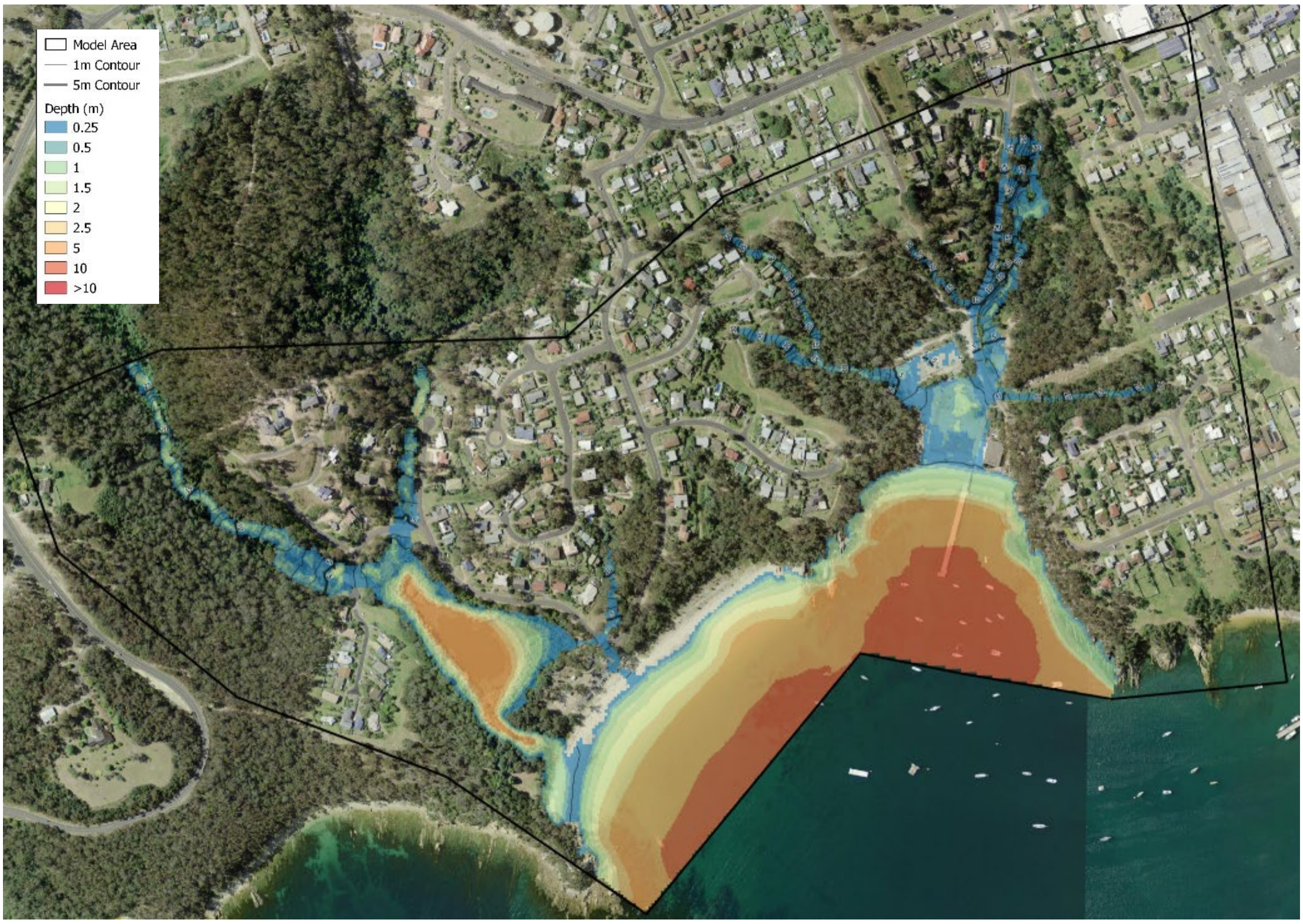

Figure 6-11 Lake Cocora 1% AEP Flooding

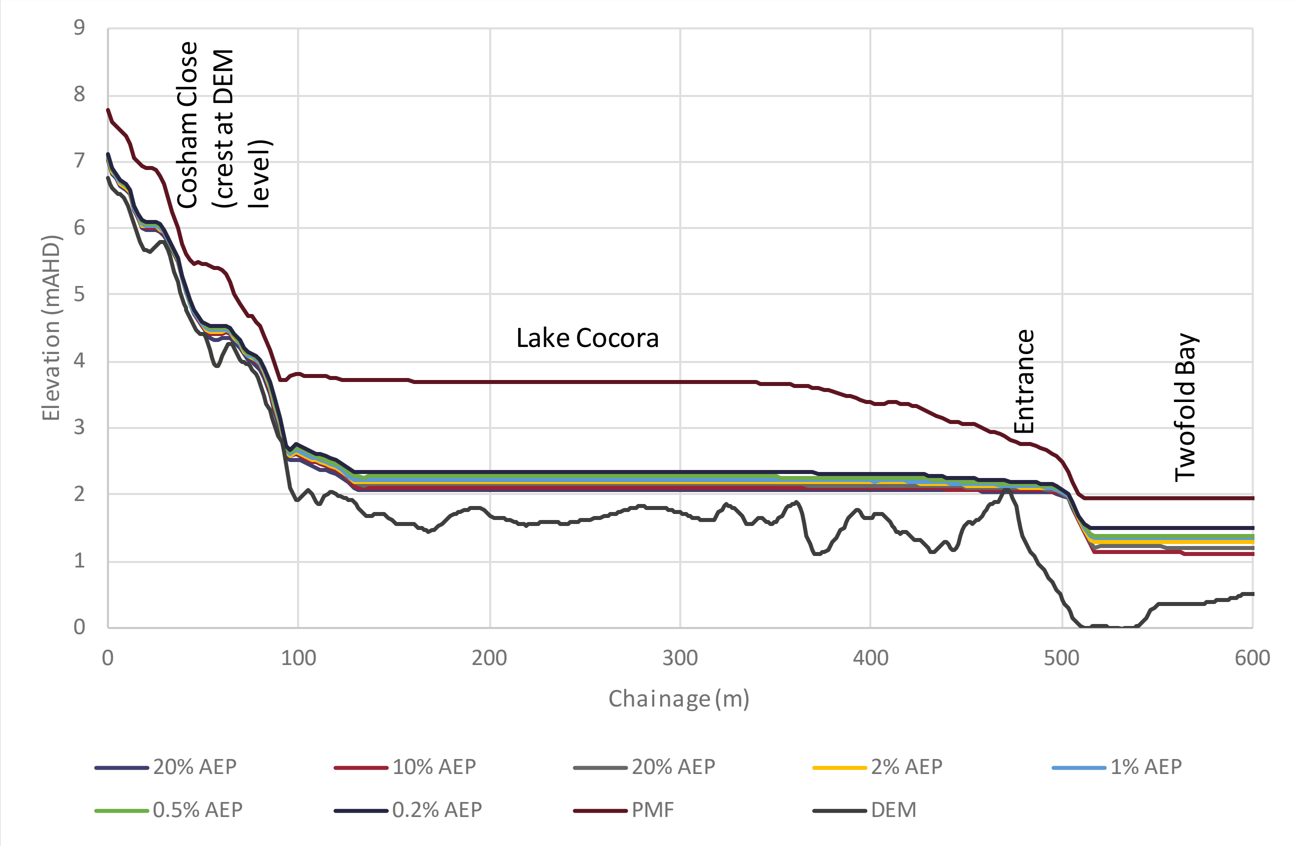

Figure 6-12 Lake Cocora Long Section

6.1.4 Shadrachs

Unlike the previous study areas discussed, Shadrachs Creek shows significant break out from the banks occurring in the 10% AEP event and larger. In the 10% AEP, the breakout reaches the access road to the caravan park, but does not result in road inundation. In events larger than the 10% AEP, the caravan park begins to be inundated (refer **Figure 6-13**). Upstream of the Princes Highway, the breakout flows are limited to pastureland in events up to the 0.2% AEP.

In the PMF event, the breakout flow affects the full region of the caravan park, as well as properties north of the Princes Highway.

6.1.5 Nullica & Boydtown

Much of the flooding occurring within the Nullica and Boydtown model is restricted to open space and vegetated areas in events up to the 1% AEP (refer **Figure 6-14**). While buildings remain unaffected in events up to the 0.2% AEP, road access throughout the study area is lost in the 2% AEP event, and larger.

Although Boydtown is located close to the foreshore, it is not impacted directly by ocean flooding, as it is located on a local rise that keeps developed properties flood free in all design events save the PMF.

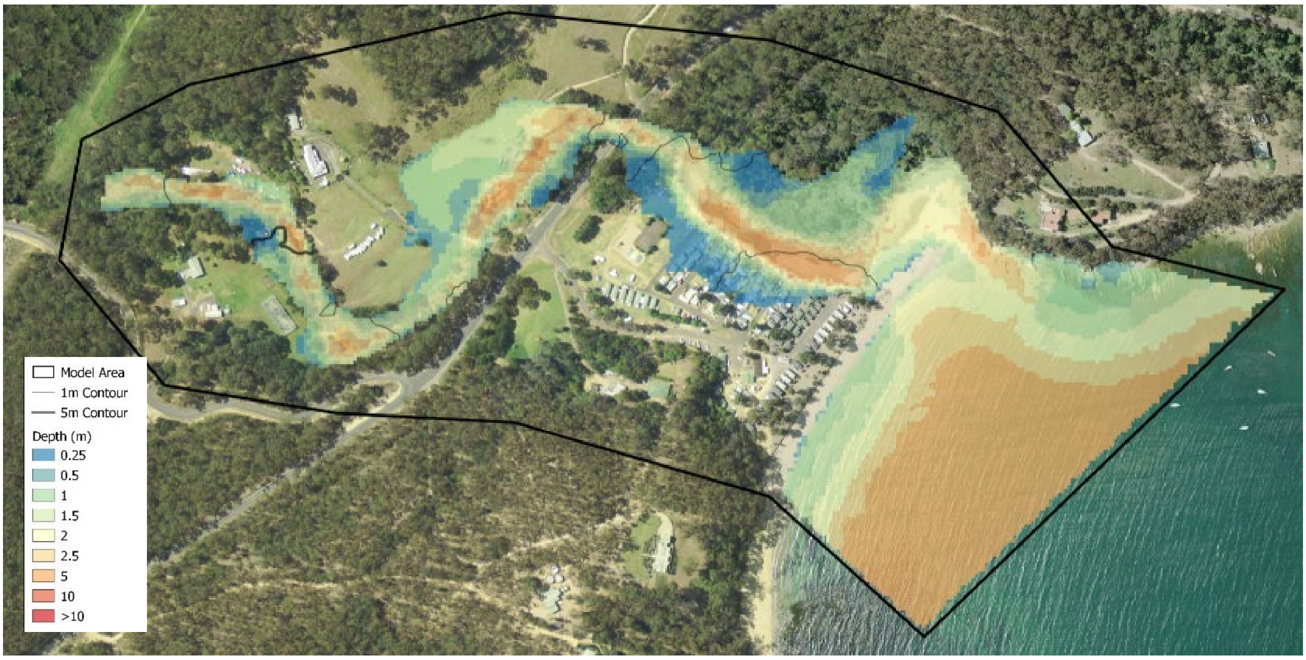

Figure 6-13 Shadrachs 1% AEP Flooding

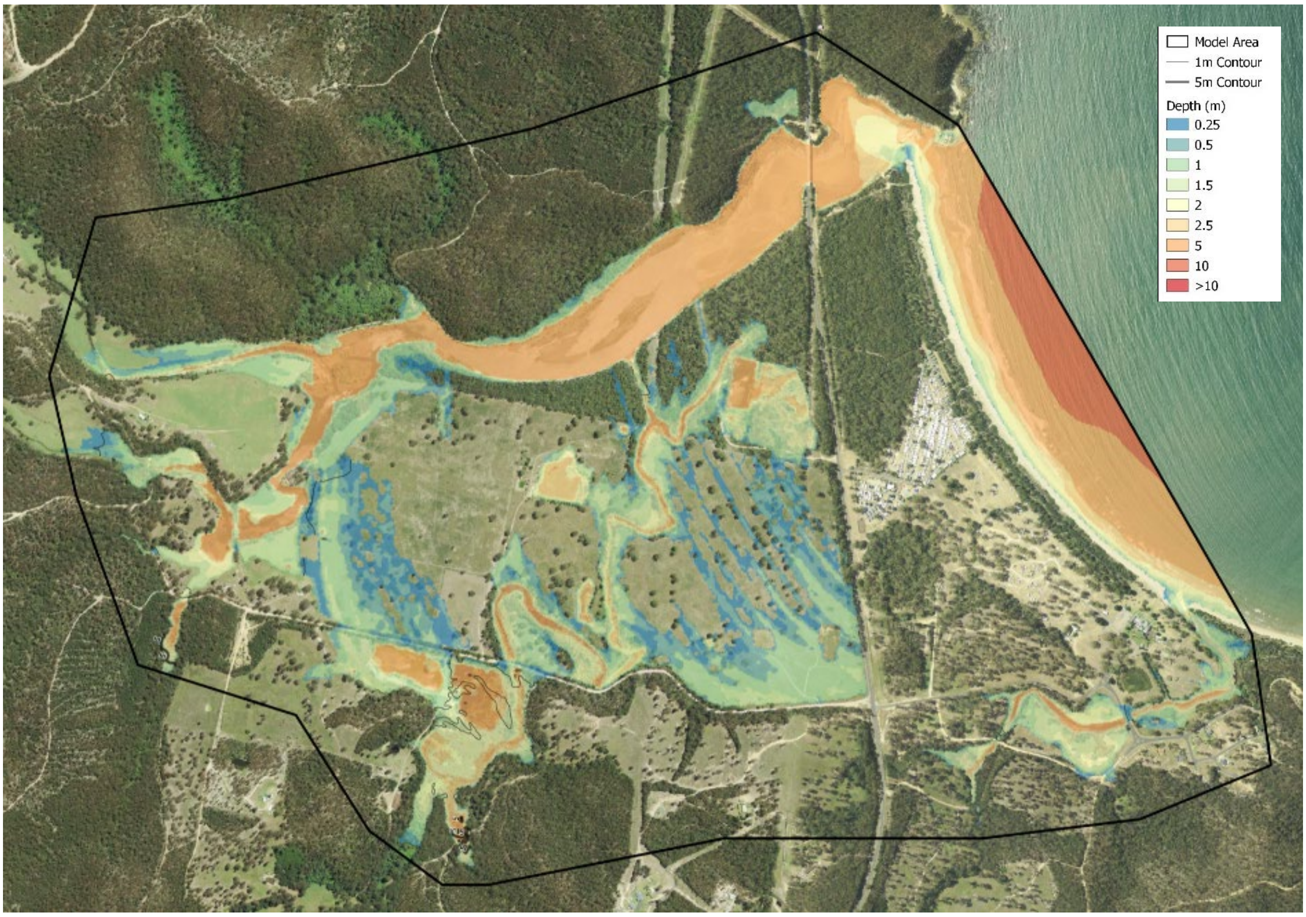

Figure 6-14 Nullica Boydtown 1% AEP Flooding

6.2 Flood Hazard

Flood hazard varies with flood severity (i.e. for the same location, the rarer the flood the more severe the hazard) and location within the floodplain for the same flood event. This varies with both flood behaviour and the interaction of the flood with the topography.

It is important to understand the varying degree of hazard and the drivers for the hazard, as these may require different management approaches. Flood hazard can inform emergency and flood risk management for existing communities, and strategic and development scale planning for future areas.

The hazard categories mapped are summarised in **Table 6-2** and **Figure 6-15**. These are based on the categories as defined in the AIDR (2017) Guideline.

Table 6-2 Hazard Categories

Hazard Category	Description
H1	Generally safe for vehicles, people and buildings
H2	Unsafe for small vehicles
H3	Unsafe for vehicles, children and the elderly
H4	Unsafe for vehicles and people
H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure

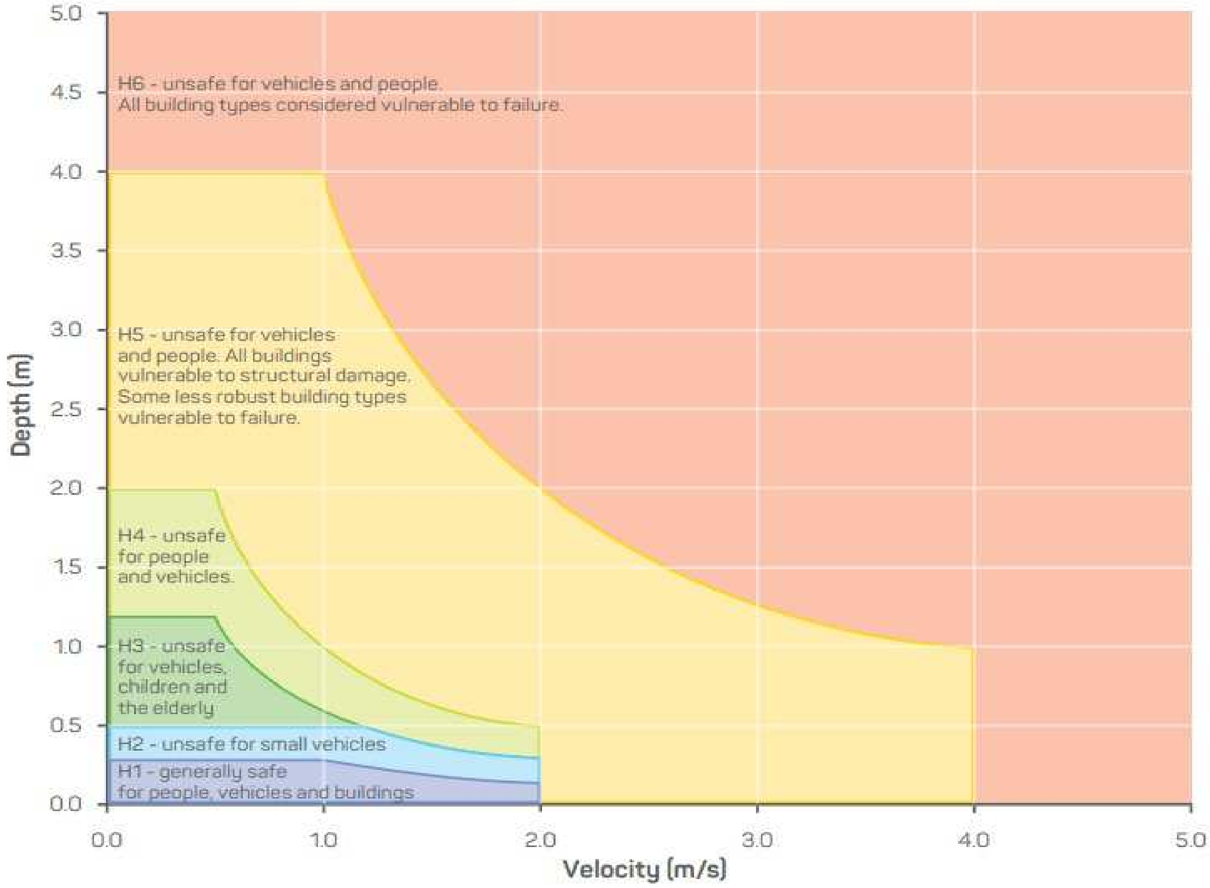

Figure 6-15 Flood Hazard Categories (AIDR, 2017)

Flood hazard mapping is provided for the 1% AEP and PMF events in **Map Series G603**. Hazard data for the full set of design events has been provided to Council.

The Towamba River study areas had a similar pattern of hazard. A wide band of H6 covering the river and overbank areas, with a fringe of lower hazard zones at the edges of the flood extent. In the PMF event, H6 and H5 hazard categories covered the majority of the flood extent, with only a thin band of H1 to H4 at the fringes. As a result of the rising terrain, these lower hazard regions often only applied to the outer 5-10 metres of the flood extent. In the 1% AEP event, the H5 and H4 classes took up a greater area, but the lower hazard classes were still restricted to the flood fringe.

In the township of Eden, for the PMF event, the major flowpaths were classified as H5 or H6, with the smaller overland flowpaths categorised as H1 and H2. In the 1% AEP event, H5 and H6 hazard zones were restricted to the creeks and rivers and did not impact developed areas.

Within the Shadrachs Creek study area, H5 and H6 categories were restricted to the main channel for events up to the 1% AEP. In the 1% AEP, flooding across the caravan park was H1 and H2. In the PMF event however, the extent of the H5 category expanded to cover much of the caravan park.

In Nullica and Boydtown for the 1% AEP, high hazard H5 and H6 regions were typically within the creek channels, or across pastureland, and did not affect development. Overbank flows were typically H1 or H2. In the PMF, while the H5 and H6 categories did extent further beyond the creeks, lower hazard ratings of H2 and H3 occurred across developed areas.

6.3 Flood Function

Maintaining the flood function of the floodplain is a key objective of best practice in flood risk management in Australia, because it is essential to managing flood behaviour. The flood function of areas of the floodplain will vary with the magnitude in an event. An area which may be dry in small floods may be part of the flood fringe or flood storage in larger events and may become an active flow conveyance area in an extreme event. In general flood function is examined in the defined flood event (DFE), so it can be maintained in this event, and in the PMF so changes in function relative to the DFE can be considered in management.

The hydraulic categories (also known as flood function), as defined in the Floodplain Development Manual (2005), are:

- Floodway - areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- Flood Storage - areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges.
- Flood Fringe - remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

It is noted that there is no “one size fits all approach” to hydraulic category / flood function definition. Thomas & Golaszewski (2012) investigated a number of different approaches in some case study catchments. However, it was emphasised in this paper to test the underlying assumptions through methods such as “encroachment”, testing the impact of reducing or increasing the floodway.

An initial categorisation (based on Thomas & Golaszewski, 2012) was undertaken based on the criteria below:

- Floodway – VelocityxDepth Product is greater than 0.5m^2/s;
- Flood Storage – VelocityxDepth product is less than 0.5m^2/s and depth is greater than 0.5m; and
- Flood Fringe – areas in the flood extent outside of the above criteria.

Encroachment testing was undertaken on the flood models. Testing was undertaken for the Wyndham and Towamba model areas for the 1% AEP event. For each model, the terrain outside of the floodway described by the criteria above was raised above the peak 1% AEP flood level, effectively restricting the full flow to only the floodway zone. This initial run demonstrated minimal impacts on peak flood levels. Levels at Wyndham increased by less than 0.03m, Towamba by less than 0.05m.

A second run was then undertaken by reducing the flow width along the river by 5m at each bank, for a total reduction of 10m across the flowpath. This run resulted in significantly increased levels at both sites; up to 0.7m at Wyndham and 1.2m at Towamba.

The above indicates that the filtering adopted is appropriate for an initial definition of hydraulic categories. Minor manual edits were then undertaken to ensure that floodways were continuous, and to remove small isolated zones of floodway or flood storage occurring within the wider flood fringe zone.

The mapping is provided for the PMF and the 1% AEP in **Map Series G604**.

For the Towamba River models, the flood extent has been classified as only floodway or fringe; no areas were classified as storage. This is due to the river having a very well defined channel, that rises steadily so there are no wide areas available at higher levels. Furthermore, what minor local storage is available, it is swamped by the volume of flow passing through the river, so does not serve as a temporary storage of a significant volume of water during a flood event.

Eden, in contrast, does have some regions classified as storage. These are typically areas that sit adjacent to the flowpaths, and are able to hold a reasonable volume of water with respect to the total flow through the channel. In the 1% AEP, when flow through the lake has a lower velocity, much of the lake is also classed as storage.

Shadrachs, Nullica and Boydtown had little in the way of flood storage, due to the relatively shallow nature of the overbank flow. These study areas were characterised by floodways through the major flowpaths with the majority of the remaining flood area being classed as flood fringe, save for some minor pockets of storage.

Note that flood function mapping has not been undertaken within Lake Curalo. As the distinction between floodway and flood storage in this region is arbitrary.

6.4 Twofold Bay Foreshore Inundation

A number of factors contribute to observed water levels and resulting damage along the NSW coast during East Coast Low events. The contributing factors include astronomical tide, surge (from wind and pressure forcing), residual water levels (from other oceanographic and meteorological forcing, including coastal trapped waves), and wave setup inshore of the surf zone. The response at a given coastal location will be dependent on the exposure and alignment of a site and the location, approach and intensity of the ECL. For example, infrastructure on the southern portion of Twofold Bay were significantly impacted during the June 2016 due to the North-easterly wave directions to which they are particularly exposed. Such a wave direction is relatively rare for such extreme events.

Baird Australia have developed a multi-hazard database of ECL events across the NSW coast that includes rainfall, wind and coastal inundation (as a result of tides, surge and waves) at 100m alongshore spacing. The database includes a detailed library of hindcast data for 1,119 ECL events between 1970 and 2016 (46-years) and a synthetic event dataset (derived from Monte Carlo simulation) representative of a 1,000 year record. The climatology of the synthetic dataset has been validated against the historical event set which included the June 2016 storm.

Using this data set, Baird has developed inundation extents for Twofold Bay for the 1% AEP event under existing and climate change (0.9m sea level rise) scenarios.

The results are shown **in Map Series G605**.

Within the Lake Curalo region of Eden, coastal inundation under existing conditions did not affect developed areas, save for the Reflections Holiday Park on the eastern shore of the lake. Coastal inundation extended approximately 50 metres into the site.

Affectation in the 0.9 metre sea level rise scenario was more substantial. Within the Reflections Holiday Park, coastal flooding extended approximately 160 metres, covering much of the site. Additional developed areas were also inundation along the western and southern shores at:

- Residential properties along Lakeside Drive (0.15 metre road overtopping);
- Residential properties along Emblen Street (the road remains flood free); and,
- Barclay Street at the Bupa Aged Care Facility by up to 0.5 metres (the facility remains flood free).

The Eden Beach Front Holiday Park on the banks of Shadrachs Creek was inundated in both scenarios. Under existing conditions, the coastal flood extended approximately 45 metres into the park, while in the climate change scenario, the flood extended 90 metres and covered much of the site.

Within the study areas of Eden South (Lake Cocora), Nullica and Boydtown, both existing and climate change coastal inundation did not impact development.

6.5 Tidal Inundation Extents

The Delft3D models of waterways connected to Twofold Bay were used to model and define the extent of areas inundated by peak high spring tides, by defining the High Water Solstice Springs (HHWSS) tidal plane.

The attenuation or amplification of the tide through the estuary system was defined by a dynamic tidal simulation under open entrance conditions where the boundary condition peaks at the HHWSS tide plane derived from a long-term analysis of measured water levels.

The results, for existing, 0.4 sea level rise and 0.9 metre sea level rise are shown in **Map Series G606**.

The results show that impacts arising from tidal inundation are limited in all scenarios. The two exceptions are the Reflections Holiday Park on Lake Curalo and the Eden Beach Front Holiday Park on Shadrachs Creek which both being to experience tidal inundation in the 0.4 sea level rise scenario.

In the north of Lake Curalo, large regions become tidally affected in the 0.9 metre sea level rise scenario, but these regions are environmental zones or open space. No development is affected as a result of this wider tidal inundation.

7 Understanding Flood Risk

7.1 Advice on Land Use Planning

Within the study area, development is largely controlled through the Bega Valley Local Environmental Plan 2013 (BVLEP 2013) and a series of Development Control Plans (DCP). The LEP is an environmental planning instrument (EPI) which designates land uses and development in the study area, while the DCPs regulate development with specific guidelines and parameters. There are also a number of EPIs and related planning documents that can affect the development of property within the study area. These may be in the form of State Environmental Planning Policies (SEPP) such as:

- SEPP Exempt and Complying Development Codes (2008);
- SEPP Educational Establishments and Child Care Facilities (2017);
- SEPP Infrastructure (2007);
- SEPP - Housing for Seniors and People with a Disability (2004);
- SEPP 65 – Design Quality of Residential Apartment Development (2002),
- SEPP 36 - Manufactured Home Estates (1993);
- SEPP – Affordable Rental Housing 2009,
- SEPP Coastal Management (2018);
- SEPP – Aboriginal Land 2019.
- Other SEPPs as relevant to land use and/or development type; and
- Other Council plans, policies or other publications.

Development related to public infrastructure (including works for floodplain and stormwater management) is generally controlled through the State Environmental Planning Policy (Infrastructure) 2007 (ISEPP).

All relevant planning controls for individual land parcels are summarised in a Section 10.7 certificate (formerly a Section 149 certificate) issued under the Environmental Planning and Assessment Act, 1979.

This Flood Study provides a review of flood-related controls covered by the LEP, relevant DCPs, Council policies and plans and makes recommendations for updates that could be undertaken to improve the management of flood risk.

This review does not specifically deal with matters related to building construction (such as the National Construction Code, which includes the Building Code of Australia, both of which are updated every three years by the Australian Building Codes Board, the most recent version at the time of preparation of this report coming into force in NSW on 1 May 2019). However, it is important to note that these types of controls are sometimes called or referenced in planning controls and therefore their content and direction are of relevance. In this regard, how they are applied is directed under the NSW Planning System via numerous mechanisms but primarily via Building System Circulars issued by the Department of Planning, Infrastructure and Environment (DPIE). The most relevant circular is BS 13-004, dated 16 July 2013 entitled *The NSW Planning System and the Building Code of Australia 2013: Construction of Buildings in Flood Hazard Areas*. Importantly the BCA deals with the concept of the 'defined flood event' (DFE) and imposes minimum a construction standard across Australia for specified building classifications 'flood hazard areas' (FHA) up to the DFE. These requirements will be referenced when developing appropriate recommendations for policy and planning approaches within the study area.

7.1.1 SEPP Exempt and Complying Development Codes (2008)

The SEPP Exempt and Complying Development Codes (referred to generally as the 'Codes SEPP) allows for development to occur without seeking consent under the provisions of Part 4 of the Environmental Planning and Assessment Act, 1979 where it can be classified as either exempt or complying (defined in the SEPP). To overcome the potential for inappropriate development to occur in areas of hazard or risk, the concept of 'flood control lots' is incorporated in the SEPP.

Part 3 Division 2 Clause 3.5 requires that for a development on a flood control lot to be complying it must not be located on the part of the land affected by any of the following: a flood storage area, floodway area, flow path, high hazard area or high risk area. The mapping relating to these is provided in this Flood Study. It is noted that current best practice provides flood hazard mapping in accordance with the AIDR (2017) Guideline. For the purposes of this SEPP, high hazard areas are those identified as H5 and H6. This is discussed in more detail in **Section 6.1.6**.

7.1.2 Bega Valley Local Environmental Plan 2013

The Bega Valley Local Environmental Plan 2013 (BVLEP 2013) is a legal document that sets the direction for land use and development in the study area by providing controls and guidelines for development. It determines what can be built, where it can be built and what activities can occur on land.

The BVLEP 2013 is an EPI based on a standard format (referred to as the 'Standard Template') used by all Councils in NSW and can be viewed on the NSW legislation website (www.legislation.nsw.gov.au).

The objectives for land at or below the flood planning level are outlined in Clause 6.3 of the BVLEP. Sub-clause (5) defines the flood planning level as the 1% AEP flood extent plus a 0.5 m freeboard.

The BVLEP also provides objectives for coastal risk planning in Clause 6.4. This clause could also apply to flooding within the study area that are impacted by coastal inundation. This clause applies to land in the coastal zone below the 3 mAHD contour, or land at or below the level of a 1:100 ARI coastal inundation event. It is important to note that there are provisions within the Coastal SEPP 2018 with respect to coastal vulnerability that are likely to over-ride these provisions once vulnerability mapping is incorporated within the SEPP. At the time of preparation of this report the vulnerability mapping had not yet been incorporated in the SEPP.

The BVLEP 2013 objectives and consent considerations are generally consistent with the LEP standard template. However, it is noted that the current LEP standard template local provisions provided by the Department of Planning and Environment (now DPIE) (https://www.planning.nsw.gov.au/Plans-for-your-area/Local-Planning-and-Zoning/Resources) allow for a more flexible definition of the flood planning level and also allow for the inclusion of climate change in the flood planning provisions.

The BVLEP 2013 specifically defines the Flood Planning Level (FPL) to be 1% AEP + 0.5m. This effectively removes the ability for Council to use an alternative design event or freeboard in defining the flood planning level. It is recommended that Council consider updating the LEP to define the FPL for each floodplain as per the adopted Flood Study or Floodplain Risk Management Plan for each floodplain. In the absence of an adopted study, the FPL could still be defined by the 1% AEP + 0.5m. This is consistent with the local provisions template. In the event that a flood planning level more stringent than the 1%AEP + 0.5 m is recommended, then an exemption would need to be sought for this purpose from DPIE (see below).

The BVLEP 2013 flood planning provisions do not make any reference to the impacts of climate change on flood risk and associated flood planning requirements. This is inconsistent with the objectives and controls outlined in the Bega Valley DCP 2013. It is recommended that consideration of climate change be included in the BVLEP 2013 to ensure the DCP controls are given statutory effect in the LEP.

Further discussion on the flood planning level, flood planning area, freeboard and the consideration of climate change for the study area is provided in **Section 7.1.5**.

7.1.3 Bega Valley Development Control Plan (BVDCP) 2013

A Development Control Plan (DCP) is prepared by Council and gives effect to the requirements of the LEP by specifying detailed development guidelines and controls.

The following sections of the existing DCP have relevance to floodplain management:

- Section 5.8.1 Flood Planning
- Section 5.8.5 Climate Change
- Section 6.1 Roads & Easements
- Section 6.3 Soil & Stormwater Management

The BVDCP objectives refer to the *NSW Floodplain Development Manual 200*5. It is noted that state government is currently reviewing this document. Any future updates of the BVDCP will need to consider the updated manual.

The BVDCP requires "*new residential building applications"* to include the impact of 0.4m sea level rise in the determination of the flood planning level. All "*new subdivision or major development applications*" must include the impact of 0.9m sea level rise. It is recommended that consideration of sea level rise should be given as part of any significant residential modifications (e.g. major renovation), not only new residential development. Further discussion on the flood planning level, flood planning area, freeboard and the consideration of climate change for the study area is provided in **Section 7.1.5**.

The BVDCP does not make reference to the land between the flood planning level and the PMF. As such, flood related controls do not apply to this land. It is recommended Any updates in this regard should consider Planning Circular PS 07-003, which is discussed in more details in **Section 7.1.4**.

There is no reference to overland flow flooding in the BVDCP. It is therefore assumed that development controls are applied to all flooding (i.e. mainstream and overland flow) in the same way. This may not be appropriate in all catchments. However, for the study areas included in this study, all flooding can be considered mainstream flooding for the purposes of planning controls.

7.1.4 Planning Circular PS 07-003

The Planning Circular was released by the NSW Department of Planning in January 2007 and provides advice on a number of changes concerning flood-related development controls on residential lots. The package included:

- An amendment to the Environmental Planning and Assessment Regulation 2000 in relation to the questions about flooding to be answered in section 149 planning certificates (now Section 10.7 certificates);
- A revised ministerial direction regarding flood prone land (issued under section 117 of the Environmental Planning and Assessment Act 1979); and,
- A new Guideline concerning flood-related development controls in low flood risk areas (I.e. above the flood planning level).

At the time of preparation of this report, consideration was being made of revising this circular to reflect contemporary floodplain management. This revision, which is concurrent with the revision of the NSW Floodplain Development Manual, is unlikely to substantively alter what can already be achieved under the existing exemption provisions.

7.1.5 Flood Planning Area

The Planning Circular (31 January 2007, see Section 7.1.4) states that, unless there are exceptional circumstances, councils should adopt the 1% AEP flood as the FPL for residential development. The flood behaviour assessed in this flood study did not identify exceptional circumstances and as such the Flood Planning Area is represented by the 1% AEP flood extent plus a freeboard of 0.5 metres. The results of the analysis are provided in **Map Series G701-1**. The consideration of sea level rise impacts the flood planning area within Eden, Nullica, Shadrachs and Boydtown. The flood planning areas under sea level rise scenarios of 0.4m and 0.9m are also provided in **Map Series G701-1**. Where the Flood Planning Area extended beyond the PMF extent, the Flood Planning Area was restricted to the PMF event.

7.2 Emergency Response Classification

Flood Emergency Response Classification aims to categorise the floodplain based upon differences in isolation due to the potential for entrapment of an area by floodwaters, potentially in combination with impassable terrain. It also considers the potential ramifications for an isolated area based upon its potential to be completely submerged in the probable maximum flood (PMF) or a similar extreme flood (AIDR, 2014).

Flood Emergency Response Classification mapping is a useful tool for emergency services and evacuation planning for a floodplain.

AIDR (2017) provides guidance on emergency response classification mapping, which is intended to be undertaken at the community or precinct scale (i.e. not at the lot scale). A summary of the classifications is provided in **Table 7-1**. These are presented in **Map Series G702**. It is noted that the Flood Free category was not shown on the map, and that lake and ocean flooding have been removed.

Across all study areas, communities were typically classified as overland escape route (FEO) or rising road (FER). This is largely due to the nature of flooding, where flow emanates from a single waterway. While the Eden region has multiple creeks and flowpaths, these are sufficiently separated that that there is very little interaction between them. As a result, as the flood waters rise, people will generally be able to escape in advance, either along roadways or overland.

A number of locations within Eden, Shadrachs, Nullica and Boydtown were classed as high flood islands, becoming isolated as flood waters rise. Nullica was the only region to have a low flood island present. A large portion of the central floodplain is isolated in the 1% AEP event, and subsequently fully flooded in the PMF. The land is presently undeveloped and used as pasture.

Flood Emergency Response Classification mapping has not been undertaken for the Towamba River regions. While individually, they would all be classed as either rising road or overland escape, this does not consider the isolation due to the loss of access between townships. The key information for these areas to assist SES in responding to flood events and warnings is the road inundation information presented in **Section 7.3**.

Table 7-1 Emergency Response Classifications (AIDR, 2017)

Primary Classification	Description	Secondary Classification	Description	Tertiary Classification	Description
Flooded (F)	The area is flooded in the PMF	Isolated (I)	Areas that are isolated from community evacuation facilities (located on flood-free land) by floodwater and/or impassable terrain as waters rise during a flood event up to and including the PMF. These areas are likely to lose electricity, gas, water, sewerage and telecommunications during a flood.	Submerged (FIS)	Where all the land in the isolated area will be fully submerged in a PMF after becoming isolated.
				Elevated (FIE)	Where there is a substantial amount of land in isolated areas elevated above the PMF.
		Exit Route (E)	Areas that are not isolated in the PMF and have an exit route to community evacuation facilities (located on flood-free land).	Overland Escape (FEO)	Evacuation from the area relies upon overland escape routes that rise out of the floodplain.
				Rising Road (FER)	Evacuation routes from the area follow roads that rise out of the floodplain.
Not Flooded (N)	The area is not flooded in the PMF			Indirect Consequence (NIC)	Areas that are not flooded but may lose electricity, gas, water, sewerage, telecommunications, and transport links due to flooding.
				Flood Free (NFA)	Areas that are not flood affected and are not affected by indirect consequences of flooding.

7.3 Flood Impacts on Transport and Infrastructure

There are a number of transportation routes through the study area, both major arterials (such as the Princes Highway and secondary roads providing access to properties (such as those connecting the Towamba River study areas). Understanding when these routes are overtopped by floodwaters and the duration in which they are flooded is useful, particularly for emergency response planning.

An analysis was undertaken on when overtopping first occurs (based on an overtopping depth of 0.1m), and the 1% AEP overtopping depth.

This information is presented in **Map Series G703**.

Roads throughout the study areas are cut in events as small as the 20% AEP, including river crossings at Rocky Hall, New Buildings and Burragate. The estuary study areas typically had smaller overtopping depths. The Towamba River models, however, had significant overtopping depths of up to 7.25 metres at Towamba in the 1% AEP event.

It is important to note that regional access routes between the study areas (and outside of the current model extents) are also likely to be cut in major flood events.

The merits of increasing flood immunity of roads in the study area and regional access during a flood event should be investigated as part of the Floodplain Risk Management Study.

7.4 Cumulative Impacts of Development

Development within the study areas is ongoing. An assessment was undertaken to determine what changes in flood behaviour may be expected if all land within the catchment was fully developed in line with the permissible land uses under Council's LEP (BVLEP 2013). Reference was also made to relevant Deferred Matters.

7.4.1 Towamba River Models

For the Towamba River catchment study areas, future development is unlikely to significantly impact any of the assessed study areas. The two primary land uses currently zoned for the Towamba River are Environmental Uses (45%) and Rural (54%). Major development within the environmental zones is not permitted, so future development will not affect the runoff characteristics of these regions. Review of aerial photographs shown that the 'Rural' land zones have already been primarily cleared, and major development, or increased development densities are not permitted under this zone. As such, 99% of the catchment is currently as fully developed as it can be under existing controls.

Of the remaining 1% of catchment, the 0.04% classed as residential land uses is the only zone that would allow any substantial change in development and density. Given how small this percentage is compared to the overall catchment area, future development within the Towamba River catchment will not significantly impact flood behaviour in the region.

7.4.2 Eden

The BVLEP 2013 land use zones were used to identify all the potential areas of further urban development within the Eden catchment. The impacts of fully developing the available land use zones are shown in **Map Series G704**. Also shown on the map are the residential zones that still have development capacity. The map series shows results for the 1% AEP event. The full set of design events have been modelled and the data supplied to Council.

In the north east of Eden, the increase of low-density residential areas would result in a minor increase on the flowpath through the existing development area. Flood levels would increase by up to 0.06 metres but would not result in a significant lateral expansion of flood extents. The flowpath remained fully contained within the vegetated corridor.

In the west of Eden, parcels of land currently fully vegetated are zoned as low density residential, and the eastern corner of the golf course is zoned as medium density residential. Development of these areas could result in increases in flood levels along the western flowpath of up to 0.1 metres. The impacts only occurred within areas governed by catchment flooding. The regions for which flooding is controlled by the lake showed no impacts.

In the south, the existing low-density residential development has the potential to be expanded under the current zoning. This additional development could result in an increase in flood levels of up to 0.06 meters along the flowpath. Increases were only observed where catchment flows control flooding. There was no change in the lateral extent of the flood.

In the South Eden region draining to Cocora Lagoon, a large portion of currently vegetated land is zoned as medium density residential. Fully developing this region could result in flood levels increasing by 0.04m along the flowpath. The increases are only minor, as the contributing catchment area is relatively small, so the effect of the changes is limited, and could be managed by sensible development. The modelling flood level increases occurred over the currently cleared site adjacent to the pier.

7.4.3 Shadrachs, Nullica and Boydtown

Similar to the Towamba River catchment, the bulk of the catchment area is already fully developed in terms of current LEP zoning. Of the total catchment area 96.5% is zoned for environmental uses, or for forestry, which prevent large scale clearing or development.

There are some regions of the catchment zoned low density residential and business that are currently undeveloped. These zones are at the downstream end of the catchment, between the Princes Highway and Twofold Bay (refer **Figure 7-1**). The hydrological model was updated to include this development. As it is located at the far downstream end, it had no impact on peak flows through the study areas, and consequently, no impact on peak flood levels. However, development within this region would have implications for the local drainage network, which would need to be assessed as part of the development of this region.

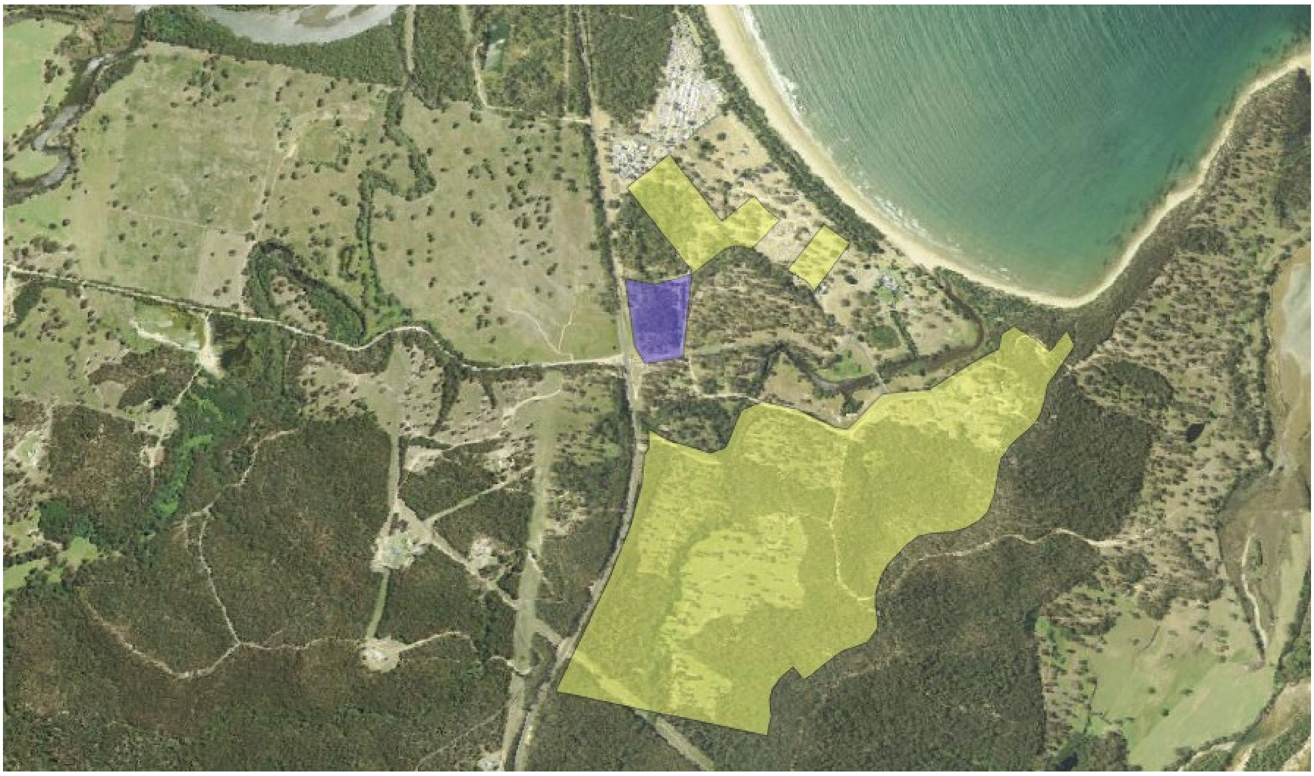

Figure 7-1 Regions of Permissible Future Development (Residential shaded yellow, Business shaded purple)

8 Conclusions and Recommendations

The Eden, Twofold Bay and Towamba River Flood Study has been prepared for Bega Valley Shire Council to define the existing flood behaviour across these areas, and to establish the basis for subsequent floodplain management activities.

This project is a flood study, which is a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust floodplain risk management plan. It aims to provide a better understanding of the full range of flood behaviour and consequences. It involves consideration of the local flood history, available collected flood data, and the development of hydrologic and hydraulic models that are calibrated and verified, where possible, against historic flood events and extended, where appropriate, to determine the full range of flood behaviour.

Hydrological modelling was undertaken using RAFTS. Hydraulic modelling was undertaken through a combination of TUFLOW and Delft3D for catchment and ocean flooding respectively.

Calibration and validation was undertaken across the various locations, through:

- A flood frequency assessment at flow gauges in Rocky Hall, New Buildings and Towamba;
- A comparison against historical flood levels in Towamba; and,
- A comparison against community observations of historical flooding in Eden.

The hydrological and hydraulic models were analysed for the Probable Maximum Flood (PMF), 0.2% AEP, 0.5% AEP, 1% AEP, 2% AEP, 5% AEP, 10% AEP and 20% AEP events. The models were analysed for storm durations from 60 minutes to 24 hour. Details and descriptions of the flood behaviour associated with these events has been provided.

In order to provide Council with an indication of future flood behaviour arising from climate change in the future, two climate change scenarios were modelled. These scenarios incorporated both rainfall intensity increases and sea level rise (where appropriate).

From the results developed, planning and emergency response data has been prepared for use by Council and emergency services, including:

- Hazard mapping;
- Flood emergency response classification; and,
- Identification of road and crossing inundation and duration.

The assessment undertaken provide a thorough understanding of the existing flood behaviour and floodplain risks present in the study areas.

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