Flood Study Report

Merimbula Lake and Back Lake Flood Study

59915100

Prepared for
Bega Valley Shire Council

16 March 2017

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Foreword

The NSW Government Flood Prone Land Policy is directed towards providing solutions to existing flood problems in developed areas and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the policy, the management of flood prone land is the responsibility of Local Government. The State Government subsidises flood management measures to alleviate existing flooding problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities. The Commonwealth Government also assists with the subsidy of floodplain management measures.

The Policy identifies the following floodplain management 'process' for the identification and management of flood risks:

1. Formation of a Committee	Established by a Local Government Body (Local Council) and includes community group representatives and State agency specialists.
2. Data Collection	The collection of data such as historical flood levels, rainfall records, land use, soil types etc.
3. Flood Study	Determines the nature and extent of the floodplain.
4. Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed development.
5. Floodplain Risk Management Plan	Involves formal adoption by Council of a management plan for the floodplain.
6. Implementation of the Plan	This may involve the construction of flood mitigation works (e.g. culvert amplification) to protect existing or future development. It may also involve the use of Environmental Planning Instruments to ensure new development is compatible with the flood hazard.

The process is iterative, and following the implementation of the plan, it is important that ongoing monitoring and evaluation is undertaken.

This Flood Study has been prepared for Bega Valley Shire Council by Cardno, and addresses parts 2 and 3 of the Floodplain Management process.

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* Figures are plotted as A3 maps and are attached separately.

Glossary

Annual Exceedence Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded each year; it would occur quite often and would be relatively small. A 1%AEP flood has a low probability of occurrence or being exceeded each year; it would be fairly rare but it would be relatively large.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	The average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration. It is implicit in this definition that periods between exceedances are generally random
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Creek Rehabilitation	Rehabilitating the natural 'biophysical' (i.e. geomorphic and ecological) functions of the creek.
Design flood	A significant event to be considered in the design process; various works within the floodplain may have different design events. E.g. some roads may be designed to be overtopped in the 1 in 1 year or 100%AEP flood event.
Development	The erection of a building or the carrying out of work; or the use of land or of a building or work; or the subdivision of land.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Flash flooding	Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall or rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain which causes it.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse

	and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
Flood fringe	The remaining area of flood-prone land after floodway and flood storage areas have been defined.
Flood hazard	Potential risk to life and limb caused by flooding.
Flood-prone land	Land susceptible to inundation by the probable maximum flood (PMF) event, i.e. the maximum extent of flood liable land. Floodplain Risk Management Plans encompass all flood-prone land, rather than being restricted to land subject to designated flood events.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Floodplain management measures	The full range of techniques available to floodplain managers. These include structural flood modifications to change the way floods behave, property modification options to improve property resilience to floods and emergency response modification options to improve the response of emergency services and the community during flood events.
Floodplain management options	The measures which might be feasible for the management of a particular area. A variety of floodplain management measures are often assessed for a catchment, although only some will ultimately prove to be successful. These successful measures become floodplain management options, which are assessed in further detail.
Flood planning area	The area of land below the flood planning level and thus subject to flood related development controls.
Flood planning levels	Flood levels selected for planning purposes, as determined in floodplain management studies and incorporated in floodplain management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account 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 plains. The concept of FPLs supersedes the “Standard flood event” of the first edition of the Manual. As FPLs do not necessarily extend to the limits of flood prone land (as defined by the probable maximum flood), floodplain management plans may apply to flood prone land beyond the defined FPLs.
Flood storages	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood.
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often, but not always,

	aligned with naturally defined channels. Floodways are areas which, even if only partially blocked, would cause a significant redistribution of flood flow, or significant increase in flood levels. Floodways are often, but not necessarily, areas of deeper flow or areas where higher velocities occur. As for flood storage areas, the extent and behaviour of floodways may change with flood severity. Areas that are benign for small floods may cater for much greater and more hazardous flows during larger floods. Hence, it is necessary to investigate a range of flood sizes before adopting a design flood event to define floodway areas.
Geographical Information Systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
High hazard	Flood conditions that pose a possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty wading to safety; potential for significant structural damage to buildings.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Low hazard	Flood conditions such that should it be necessary, people and their possessions could be evacuated by trucks; able-bodied adults would have little difficulty wading to safety.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of the principal watercourses in a catchment. Mainstream flooding generally excludes watercourses constructed with pipes or artificial channels considered as stormwater channels.
Management plan	A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. It may also include description and discussion of various issues, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.
Overland Flow	The term overland flow is used interchangeably in this report with “flooding”.
Peak discharge	The maximum discharge occurring during a flood event.

Probable maximum flood	The flood calculated to be the maximum that is likely to occur.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Annual Exceedance Probability.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Stormwater flooding	Inundation by local runoff. Stormwater flooding can be caused by local runoff exceeding the capacity of an urban stormwater drainage system or by the backwater effects of mainstream flooding causing the urban stormwater drainage system to overflow.
Topography	A surface which defines the ground level of a chosen area.

* Terminology in this Glossary have been derived or adapted from the NSW Government Floodplain Development Manual, 2005, where available.

Abbreviations

AAD	Average Annual Damage
AEP	Annual Exceedance Probability
ARI	Average Recurrence Intervals
BoM	Bureau of Meteorology
DCP	Development Control Plan
FPL	Flood Planning Levels
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
GIS	Geographic Information System
ha	Hectare
IFD	Intensity Frequency Duration
km	Kilometres
km^2	Square kilometres
LEP	Local Environment Plan
LGA	Local Government Area
m	Metre
m^2	Square metre
m^3	Cubic Metre
mAHD	Metres to Australian Height Datum
mm	Millimetre
m/s	Metres per second
NSW	New South Wales
OEH	Office of Environment & Heritage
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SES	State Emergency Service

1 Introduction

1.1 Report Context

The NSW Floodplain Risk Management Process progresses through the following six stages (also shown diagrammatically in **Figure 1-1**):

1. Formation of a Floodplain Management Committee.
2. **Data Collection.**
3. **Flood Study.**
4. Floodplain Risk Management Study.
5. Floodplain Risk Management Plan.
6. Implementation of the Floodplain Risk Management Plan.

This report addresses aspects of Steps 2 (Data Collection) and 3 (Flood Study).

Figure 1-1 Floodplain Risk Management Process

1.2 Report Objective

The objective of this Stage 3 Report is to provide a Final Flood Study report, which describes the existing flood behaviour of the Merimbula Lake and Back Lake systems. The flood data developed as part of this study will inform Council of the current flood risks within the catchment and assist Council in ensuring that development within the catchment is undertaken with consideration of the flooding risks within the study area.

2 Catchment Description

This flood study focuses on Merimbula and Back Lakes, two estuarine systems adjoining the town of Merimbula on the far south coast of New South Wales.

The Merimbula Lake and Back Lake catchments (**Figure 2-1**) including their tributaries of Millingandi Creek, Boggy Creek, Bald Hills Creek and Merimbula Creek converge at the township of Merimbula where they drain into the Tasman Sea. Their catchment areas to the west and north west of Merimbula are generally heavily forested with some small areas of rural land in the Merimbula Lake catchment. The combined catchment area of the two drainage systems is approximately 75 km^2. The Merimbula Lake catchment is the larger of the two drainage systems contributing a catchment area of some 43 km^2.

The Merimbula Creek flows through the Merimbula township before flowing into the Tasman Sea at Back Lake which is intermittently closed at the southern end of Short Point Beach near Mirador Estate. Millingandi Creek, Boggy Creek and Bald Hills Creek drain into the Merimbula Lake before draining into the Tasman Sea through a sandbar entrance at the northern end of Merimbula Bay at Merimbula Beach. Critical infrastructure such as the regional airport, Princes Highway, Merimbula Sewage Treatment Plant and Merimbula CBD may be affected by creek, lake or ocean water levels.

Merimbula Lake is bordered by Merimbula to its north, the regional airport and coastal dunes to its east and the Princes Highway to the West. Merimbula Lake is divided by a causeway and bridge crossing that permits recreational boat traffic from the nearby boat ramp on its northern side to access the Tasman Sea via a narrow channel traversing estuarine flats and tidal shoals downstream. The causeway divides Merimbula Lake into what are known locally as ‘Main Lake’ and ‘Top Lake’. The sandbar entrance is protected on its north-eastern side by Long Point. A residential area known as Fishpen is directly to the south on the northern tip of the Merimbula coastal dunes. Merimbula Lake and foreshore also support numerous oyster leases, commercial boating operations, boat moorings, recreational aquatic and terrestrial activities. Significant commercial, financial and tourist accommodation infrastructure exists within the CBD adjacent to the lake foreshore. The lake foreshore also adjoins many residential areas.

The headwaters of the main tributaries of Bald Hills Creek, Boggy Creek and Millingandi Creek all begin in the South East Forest National Park before flowing through the rural residential areas of Bald Hills and Millingandi upstream of the Princes Highway before flowing into the top basin of Merimbula Lake. The western lake foreshore also supports commercial developments such as the Pambula-Merimbula Golf Club and the Acacia Ponds Mobile Village. The south-eastern foreshore also supports other infrastructure such as the Merimbula Airport and Merimbula Sewage Treatment Plant. Many localised overland flow drainage issues occur within the Merimbula township and its outer rural residential areas due to the relatively steep topography.

The Back Lake is bordered by the Merimbula township on its southern side, the residential areas known as Mirador and Berambool to its north and Short Point Beach at the Tasman Sea.

A water supply dam, Yellow Pinch Dam, is located at the headwaters of a catchment tributary called Yellow Pinch Creek that traverses the Princes Highway before feeding into Merimbula Creek. The Merimbula Creek headwaters begin in the South East Forest National Park west of the Princes Highway before converging with Yellow Pinch Creek on the western side of the Princes Highway within Bournda Nature Reserve. Merimbula Creek then traverses a regional road known as Reid Street within Merimbula and adjoins the northern fringe of the township that includes commercial accommodation, recreational sporting facilities, housing, the CBD and a primary school before entering the Back Lake.

Back Lake is also impacted by residential development pressure within Mirador Estate, the township and commercial development pressure within the nearby CBD. Properties within the Back Lake catchment are known to experience both mainstream and estuarine flooding dependent on the level of the sand berm at the estuary outlet.

The area for which detailed, reliable information on flooding is required is shown in **Figure 2-2**, located in the ‘Figures’ Appendix at the end of this report.

3 Review of Available Data

3.1 Previous Reports and Studies

A number of relevant studies have previously been conducted. These studies have been reviewed as part of this study and the relevant information will be incorporated, as required. A summary of some of the key studies and data sets are provided in the following sections. The outcome of this review is provided in **Table 3-2** on the following page**.**

3.2 Survey Information

3.2.1 Topography & Bathymetry

The terrain data summarised in **Table 3-1** was supplied by Council for use in this project.

Table 3-1 Summary of Topographic & Bathymetric Data

Data Set	Year
Topographic LiDAR – 1 m Resolution	2013
Topographic LiDAR – 1 m Resolution	2008
Merimbula & Pambula Hydrographic Survey	2003
Merimbula Lake Entrance Historical Photogrammetry	1962, 1972, 1975, 1977, 1979, 1989, 2001, 2007and 2011
Survey of assets around the estuary foreshores of Back Lake, Curalo Lake, Wonboyn Lake and Bega River completed by D. Wiecek (OEH) and K. Crane (BVSC) using RTK GPS and Corsnet NSW VRS RTK Network	2014
Cross Sections of Merimbula Creek at Vicinity of Reid St	Unknown

3.2.2 Structures

Structure survey and design information has been supplied by Council for the following:

- The Imlay Shire Council Bridge Over Merimbula Creek;
- The Reid Street Bridge over Merimbula Creek;
- The Millingandi Deviation from Shand's Corner to the Caravan Park;
- The Bald Hills Creek Culvert;
- The Bridge Over Millingandi Creek at Merimbula Bypass;
- The Culvert on Boggy Creek Road; and
- The Market Street Bridge over Merimbula Lake.

3.2.3 Additional Survey

Following the community consultation, a number of residents indicated that they had records or previous flood heights. These residents were contacted to discuss the accuracy of their records to determine if a flood level survey was appropriate.

Based on discussions with residents, it was decided that a flood level survey was warranted for Sapphire Valley Caravan Park. While staff from the Caravan Park were confident on the flood extents observed, they were unsure about the dates the flooding occurred.

Consequently, the collected survey was not used for calibration, as it could not accurately be tied to a historic flood event. The collection was considered worthwhile however in order to define the pattern of flooding across the caravan park site, and to provide further flood intelligence to Council.

Table 3-2 Summary of Previous Studies and Reports

Study / Report	Year	Author	Description	Relevance to this Flood Study
Back Lagoon, Merimbula Water Quality Monitoring	1999	Manly Hydraulics Laboratory	Analysis of water quality data collected from a gauge in Back Lake from September 1997 to September 1998.	Water level data has been used for calibration and validation purposes for both entrance open and entrance closed condition.
DIPNR Merimbula Lake, Pambula Lake and Back Lagoon Tidal Data Collection SepNov2003	2004	NSW Department of Commerce	Analysis of water level records and ADCP current profiling during collection period from September to November 2003.	Water level and current data has been used for calibration and validation purposes for both entrance open and entrance closed condition. Derived tidal planes and tidal prisms to assist in calibration of hydrodynamic model and tidal inundation modelling.
Flood Risk Assessment BVSC	2006	URS	Floodplain Risk Assessment conducted for Council. The report provides a detailed review of the Councils floodplain risk management status.	Identification of potential flood prone areas for verification of flood modelling results.
Merimbula And Back Lakes Estuary Process Study	1995	Webb, McKeown & Associates	Estuary process study undertaken on Merimbula Lake and Back Lake, addressing general catchment characteristics, sediment characteristics, tidal processes, flood processes and entrance dynamics.	The following were useful for modelling: • Estimates of suspended sediment loads; • Spatial assessment of sedimentary characteristics; • Spatial assessment of tidal planes; • Tidal prism and exchange; • Flood catchment inflows; • Critical storm duration of design flows; • Peak flood discharges and velocities; and • Assessment of entrance dynamics, including breakout details for Back Lake.
Merimbula And Back Lakes Estuary Management Study and Management Plan	1997	Webb, McKeown & Associates	Estuary management plan for Merimbula and Back Lakes, outlining the issues, objectives, and management options for the study area.	Background information relating to land usage, erosion/sedimentation and water quality. Also provides a record of public concerns and issues of the time.
Merimbula Creek Flood Study	1986	Willing and Partners	Report detailing the effects of the installation of the Reid Street Bridge on Merimbula Creek flood levels upstream of Reid Street. Includes hydraulic analysis, water surface profile analysis and tabulated flood levels.	Flood flows and levels upstream of Reid Street bridge for use in model validation and verification.
Merimbula Estuary Management Plan	2003	nghEnvironmental	Supplement to the 1997 Estuary Management Plan.	Background information relating to land usage, erosion/sedimentation and water quality.

Study / Report	Year	Author	Description	Relevance to this Flood Study
Merimbula Lake Tourist Centre Environmental Study	1982	David Grogan Planning Services	Environmental study for then proposed development on the Merimbula Lake foreshore.	Some relevant information in the description of the existing environment, namely regarding historical flooding, particularly the 1971 floods.
Bega Valley Shire Coastal Planning and Management Strategy	2002	WorleyParsons	Details a coastal management strategy intended to serve as a catalyst for the review of existing zoning schemes and development of alternative land use controls to provide better outcomes with regard to coastal planning and management.	Proving background into of local land uses and site characteristics.
Historical Flood Related Newspaper Clippings	Various	Various.	Information regarding flooding for time periods pre-dating water level gauge records.	Providing information regarding floods in 1906, 1913, 1917, 1919, 1934, 1935, 1944, 1946, 1950, 1952, 1955, 1956, 1963, 1971, 1974, 1975 and 1978.
Survey of Erosion and Siltation within the Catchment of Merimbula Lake	1978	Soil Conservation Service of NSW	An assessment of erosion and siltation within the Merimbula Lake and catchment region.	Description of local sediment characteristics informed model set-up and execution.
The Character and Sources of Sediment to Pambula Lake	1994	M. Thomas & M.Bergs (USYD)	As assessment the zonation and potential sources of sediments within the Pambula Estuary system.	Detailed quantitative analysis of sediment composition throughout the estuary, including the entrance – where sediment composition would be expected to be similar to that at the Merimbula Lake entrance.

3.3 Physical Process Data

3.3.1 Water Level Data

Available water level data is summarised in **Table 3-3**.

Table 3-3 Summary of Topographic & Bathymetric Data

Data Set	Availability
MHL Eden Harbour Gauge	1986-2015
MHL Merimbula Wharf Gauge	1991-2015
MHL Merimbula Lake Gauge	1991-2015
MHL Back Lake Gauge	2009-2015
MHL temporary gauges throughout Merimbula Lake	Sep 2003 – Nov 2003

Water level data has been supplied by Manly Hydraulics laboratory for their tide gauge at Eden Harbour. The record length extends from September 1986 to February 2015.

Data has also been supplied from water level gauges operating at Merimbula Wharf and Merimbula Lake from 1991 to present (February 2015), with data supplied from the Back Lake gauge from 2009 to present (February 2015).

Additional water level data for Merimbula Lake was available from tide gauge records collected by Manly Hydraulics Laboratory (MHL, 2004). A tidal gauging exercise was conducted in September – November 2003 and water level data was continuously monitored at several sites in the estuary at the locations shown in **Figure 3-1**.

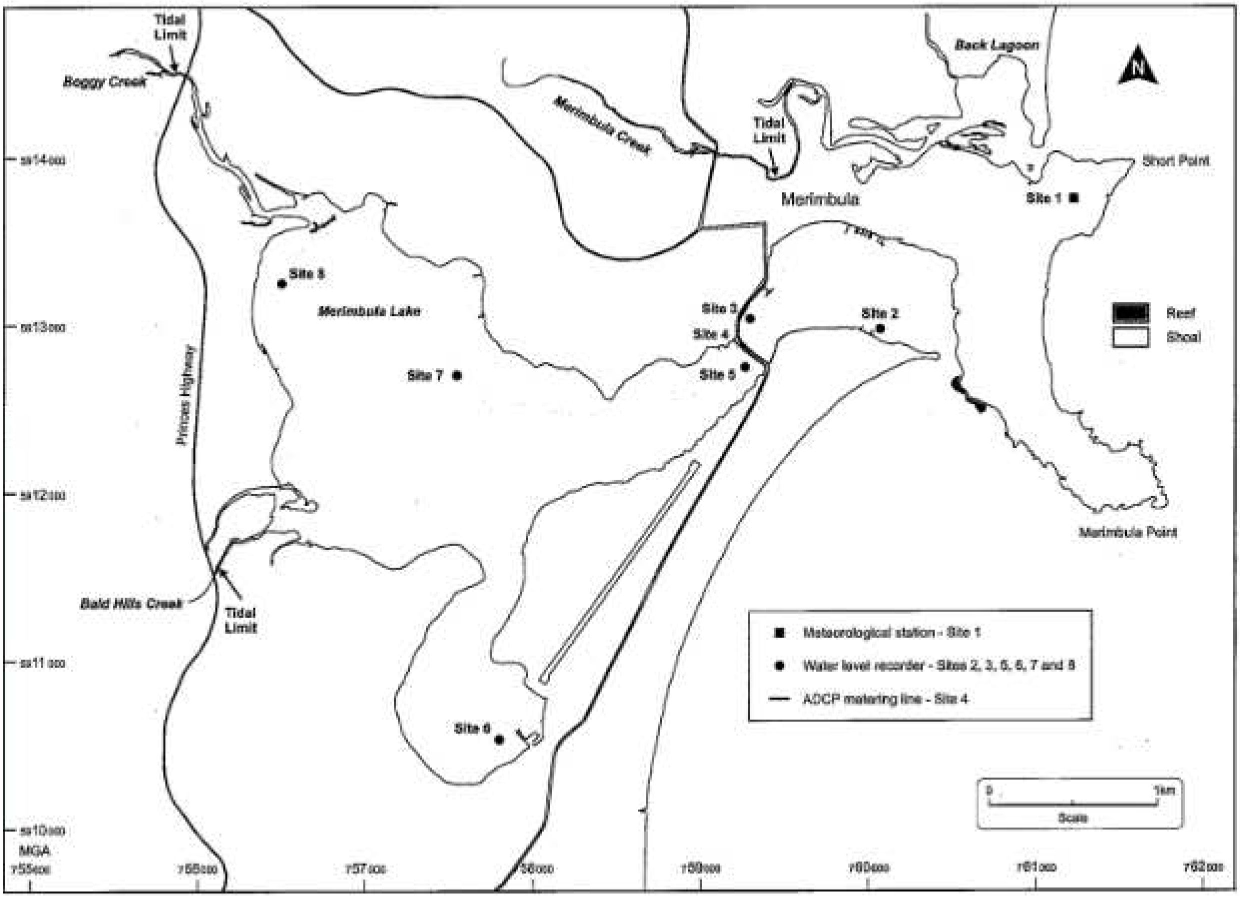

Figure 3-1 MHL Data Locations

3.3.2 Wave Data

Offshore wave data from 1978 to February 2015 from the MHL offshore Eden Waverider buoy (WRB) was supplied by Council for the study. However up until December 2011 this data was non-directional, see **Table 3-4** below. Consequently, additional offshore wave data was obtained from the global/regional NSW WaveWatch III that Cardno developed and calibrated (including calibration at Eden), for OEH (Cardno, 2013).

Table 3-4 Available Offshore Wave Data

Data Set	Availability
Eden WRB - Non-Directional	Feb 1978 to Dec 2011
Eden WRB - Directional	Dec 2011 to Feb 2015
NSW WaveWatch III - Directional	Jan 1979 to Jan 2009

3.3.3 Current Data

Acoustic Dopple Current Profiler (ADCP) transect data for beneath the Merimbula Lake Causeway was available from records collected by Manly Hydraulics Laboratory (MHL, 2004) from September to November 2003 – see **Figure 3-1**.

3.3.4 Sediment Data

The composition of entrance sediments will affect the evolution of lake entrance scour during flood events, and consequently can have significant impacts upon modelled flood levels & durations. It is therefore important to have an accurate understanding of the sediment composition at the respective lake entrances.

Documents such as the Merimbula and Back Lakes Estuary Process Study (Webb, McKeown & Associates, 1995) describe sediments at the entrance of Merimbula Lake and Back Lake as being quartz marine sands of medium grain size. Whilst particle size distribution (PSD) testing was conducted as part of that study, the median grain size of sediments (D50) have not been quantified in the reports, and are described only as being medium grain size (in between 250 and 500 µm).

PSD testing was conducted as part of the report into the Character and Sources of Sediment to Pambula Lake (Thomas et al, 1994). That document reported that sediments at the Pambula Lake entrance were medium size with a mean D50 (over a number of testing locations) of 380 µm.

It is likely that sediments at the Merimbula Lake entrance have a similar D50, as these two estuary entrances are situated within the same coastal sedimentary cell. However, previous experience investigating flood behaviour in wave dominated estuaries, shows that flood levels and durations can be sensitive to the adopted D50 for modelling. Consequently, Cardno proposed that if the sensitivity modelling (**Section 5.4.3**) showed this to be the case, then sediment samples should be collected at the Merimbula Lake and Back Lake entrance berms, and PSD testing conducted in order to quantify D50 at those locations. The sensitivity modelling did not find the model to be sensitive to sediment size, and as such no sediment sampling was undertaken.

3.4 GIS Data

The following Geographic Information System (GIS) data was provided by Council as part of this study:

- Cadastre;
- Environmental data, including:
  - Soils (including soil erosion risk);
  - Geology;
  - NSW AG land classification; and
  - Water bodies, including rivers and creeks.
- Heritage data;
- Land zoning, land capability, land usage and land degradation;
- Stormwater network information; and
- High resolution aerial imagery from 2010 and 2013.

4 Consultation

Consultation with the community and stakeholders is important to obtain information relating to specific flooding experiences within the study area and to allow the community to provide input and feedback to the study.

Consultation was undertaken at key stages of the study. The consultation undertaken to date as part of the study included:

> Initial contact with relevant agencies and request for data inputs;

> Establishment of a project website;

> Media release; and

> Community survey.

Comments received following the public exhibition of the Draft Flood Study have also been incorporated in this Final Flood Study.

4.1 Consultation Strategy

A consultation strategy was developed in the preliminary stages of the project. Details of the strategy are provided below in **Table 4-2** on the following page.

4.2 Agency Consultation

There are a large number of 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 provide an introduction to 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.

Table 4-1 Agency Consultation

Agency	Outcome of Consultation
Bureau of Meteorology (BOM)	Acknowledgement of receipt of letter
Berrambool Sporting Complex	Request to be kept informed of the study progress
Crown Land, Department of Primary Industry	No response received
Land and Property Information (LPI)	Provided LiDAR data for study area
Manly Hydraulics Laboratory (MHL)	Provision of available data for water level gauge in Merimbula Lake
NSW Office of Water (NOW)	Comment that they hold no relevant data.
Office of Environment and Heritage (OEH)	Provided bathymetry data and beach and entrance cross section data
Roads and Maritime Authority (RMS)	Acknowledgement of receipt of letter
State Emergency Service (SES)	Request to be kept informed of the study progress

4.3 Project Website

Cardno prepared and will continue to manage a web page for the Flood Study throughout the duration of the project. The website provides background and context to the Flood Study as well as relevant Council contact details and information on the opportunities for the community to provide input to the study.

The project website can be found at the following address:

https://extranet.cardno.com/merimbulafloodstudy/SitePages/Home.aspx

Table 4-2 Consultation Strategy

Task	Description	Date	Expected Outcome
Media Release	Cardno to draft a media release for Council's consideration and publication.	Early 2015	Public awareness of the study. This will assist in engagement with the community through the brochure and public exhibition. It will also assist in the public acceptance of the study outcomes and implications for development and floodplain risk management in the future.
Stakeholder Consultation – Council	Relevant Council staff attended the inception meeting to discuss various input to the study and the proposed study approach.	February 2015	Ensures that all available information is utilized in the preparation of the flood study. Ensures that the modelling incorporates the high risk areas. Ensures that a full range of Council objectives are achieved by the study.
	Follow up consultation will be undertaken by phone throughout the duration of the study.	Ongoing	
Stakeholder Consultation – Agencies	Cardno to contact relevant agency stakeholders via letter and follow up email and/or phone.	March 2015	Inform the agencies of the study. Obtain relevant information. Provide an opportunity for input from the relevant agencies.
Website	Cardno will prepare and host a project website which will communicate key project information to the community. A link to the website would be provided on Council's website.	April 2015 – September 2016	Provide to the community background information, contact information and key project dates.
Community Brochure and Survey	Preparation of an information brochure and survey to be prepared by Cardno and distributed to properties within the catchment. Responses will be via a reply paid envelope. The brochure and survey will also be available online.	April – May 2015	Inform the community about the study; Identify community concerns; Gather information from the community; and Develop and maintain community confidence in the study results.
Stakeholder Consultation – Committee	A working session with Council's floodplain risk management committee (FMC) or technical working sub-group would be undertaken during Stage 4 of the study.	June 2016	Present the outcomes of the study to the Committee and to gain feedback prior to the preparation of the Draft Document for public exhibition.
Media Release	Cardno to draft a media release for Council's consideration and publication.	August 2016	Inform the community of the draft document and invite submissions. Inform the community of the workshops.
Public Exhibition Period	Council to arrange for the public exhibition of the Draft Flood Study for a period of at least 4 weeks.	August – September 2016	Provide an opportunity for the community to review and provide comment on the Draft Flood Study.
Community Forums	Cardno to prepare materials for and present at two (2) community forums to present the outcomes of the Draft Flood Study.	August – September 2016	Provide the community with an understanding of the outcomes of the Flood Study and provide an opportunity for input.

4.4 Media Release

A media release was issued of the 6th May 2015 to inform the community about the study and the request for community input via the community survey available via mail out and on the project website. A copy of the media release is provided in **Appendix A**.

4.5 Community Survey

Community consultation was undertaken in May 2015. A community survey was distributed to those property and business owners within the Merimbula and Back Lake catchments. A copy of the survey is attached in **Appendix A**. The survey sought information about historical flooding events and flood awareness within the community.

The survey was delivered to approximately 513 property owners within the catchment area. A summary was also provided in a media release, informing residents of the study and advising that the survey was being undertaken.

From the distribution, 50 responses were received, representing a return of approximately 10% of direct distribution. A return rate of 10% is typical for these types of mail-outs.

The survey was conducted outside of peak holiday times, and was mailed to property owners, so the survey does not take into account the flooding knowledge and experiences of the visitors and tourists that visit the region during holiday periods.

A summary of the findings of the resident survey is presented below.

4.5.1 Question 2 – Property Type

The majority of respondents (70%) describe their properties as owner occupied with approximately 13% described as tenant occupied. The breakdown of property types is shown in **Figure 4-1**.

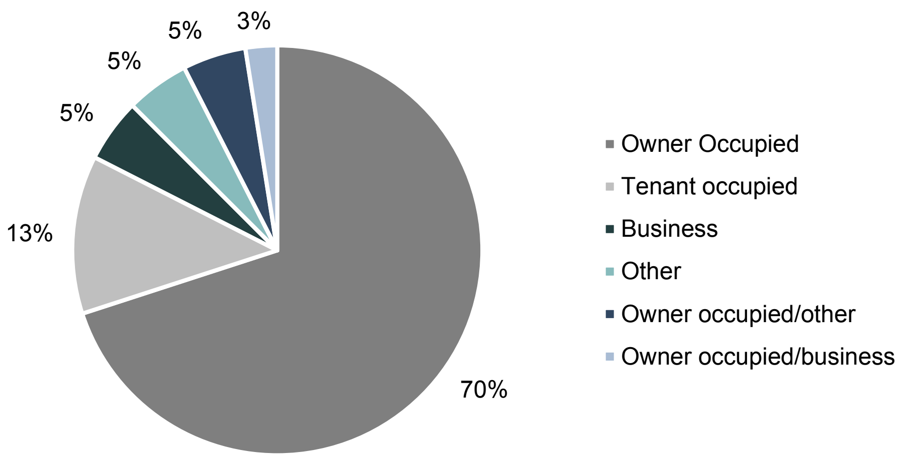

Figure 4-1 Property Type

4.5.2 Question 3 – Period of Occupancy

How long have you lived, worked and/or owned your property?

Figure 4-2 shows the responses for the years that the respondent has lived / worked in the catchment. Time of residence is an important criterion for evaluation of the responses that follow. Specifically, a resident may have lived in the catchment for only a few years and their responses with regards to knowledge and experience of local flooding would be evaluated with this considered.

Seventeen percent (17%) of respondents indicated they have been in the catchment for less than five years which may have an effect on awareness of local flooding, with more recent arrivals to the catchment potentially not having an awareness of historical flood events. Notably, more than 60% of the respondents have lived in the area for more than 10 years, and 32% having lived in the area for more than 20 years.

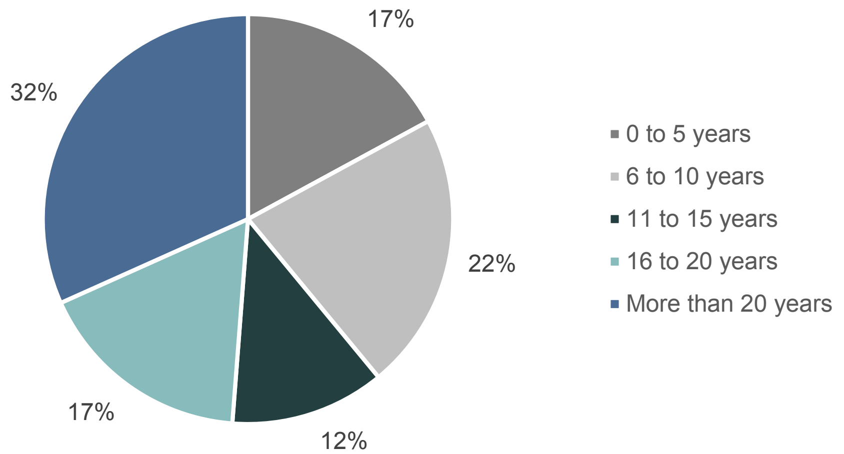

Figure 4-2 Period of Occupancy

4.5.3 <u>Question 4 – Awareness of Flooding</u>

How aware are you of flooding behaviour within the catchment?

Responses to Question 4 regarding awareness of flooding are a guide for general flood exposure in the catchment. However, responses can be influenced by a resident's location and time in the catchment, as well as the period since the last major storm event. This information can assist Council and SES in in the development of appropriate education campaigns to raise awareness of flooding both generally and in relation to specific hazardous locations in the catchment.

Fifty six percent (56%) of respondents indicated they are aware of potential flooding in the catchment (**Figure 4-3**), which is an important objective of the study of defining flood behaviour to enable the community to be informed about potential risks. Based on analysis of the survey results, awareness of flooding in the catchment does not directly relate to the years residing in the catchment as it is also dependent on the respondent's location in the catchment and floodplain extent.

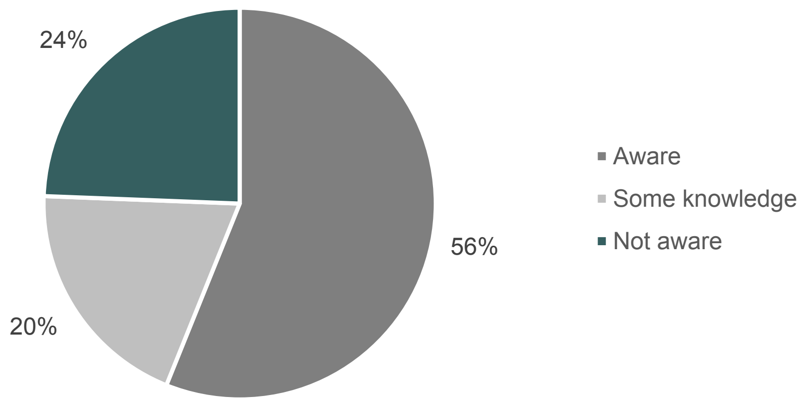

Figure 4-3 Awareness of Flooding

4.5.4 Question 5 – Flooding Experience

Have you ever experienced flooding since living/working/owning your property?

Responses to Questions 5 indicate the general exposure within the catchment to flood risk and property damage in particular areas. The majority of respondents (52%) have not experienced flooding at their property. Of those that have experienced flooding, 32% have had access to their property affected.

Locations reported by residents as having previously experienced issues with property access include:

- Boggy Creek Road, Millingandi;
- Munn Street, Merimbula;
- Sapphire Coast Drive, Merimbula;
- Stringybark Place, Merimbula; and
- Waterside Lane, Millingandi.

Flooding was experienced in April 2010, May 2011 and December 2014.

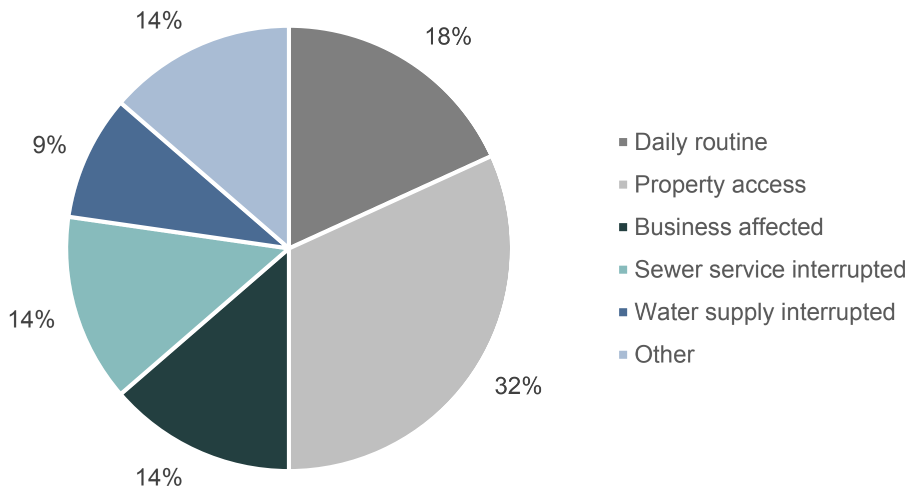

Figure 4-4 Flooding Experience at Property

4.5.5 Question 6 – Flooding Experience

If you have experienced flooding, how did it affect your residential/commercial property?

More detail on the flooding experiences of the respondents was obtained from Question 6. **Table 4-3** summarises the responses provided regarding residential and commercial places affected by flooding.

Table 4-3 Locations Affected by Flooding

Type of flooding	Number of Responses	Locations affected by flooding
Front/back yard	9	Berrambool Drive, Berrambool Boggy Creek Road, Millingandi Henwood Street, Merimbula Munn Street, Merimbula Oaklands Road, Pambula Sapphire Coast Drive, Merimbula Stringybark Place, Merimbula Watershed Drive, Millingandi

Type of flooding	Number of Responses	Locations affected by flooding
Garage/shed	2	Henwood Street, Merimbula Oaklands Road, Pambula
Residential – above floor	2	Sapphire Coast Drive, Merimbula Oaklands Road, Pambula
Commercial – above floor	4	Berrambool Drive, Berrambool Munn Street, Merimbula Sapphire Coast Drive, Merimbula
Commercial – below floor	1	Sapphire Coast Drive, Merimbula

4.5.6 Question 7 – Catchment Flooding

Have you seen flooding in other locations around the catchment area?

This question provides an indication of flooding identified elsewhere within the catchment, such as roadways and other public open space areas that may be transited or otherwise used by members of the public. This information is relevant for the flood model calibration / verification process, and it also assists in capturing data on issues with emergency management and evacuation.

Figure 4-5 indicates the types of locations where respondents had noticed flooding. The following places were specifically noted as having experienced flooding.

- Roads and footpaths:
  - Boggy Creek Road, Millingandi,
  - Millingandi Road, Millingandi,
  - Princes Highway, Pambula,
  - Short Cut Road;
- Rural areas: Boggy Creek;
- Residential:
  - Low properties on Stringybark Place, Merimbula,
  - Properties along Henwood Street, Merimbula,
  - Munn Street back up from ocean; and
- Other: Catchment dam for “Sunny Waters” Estate.

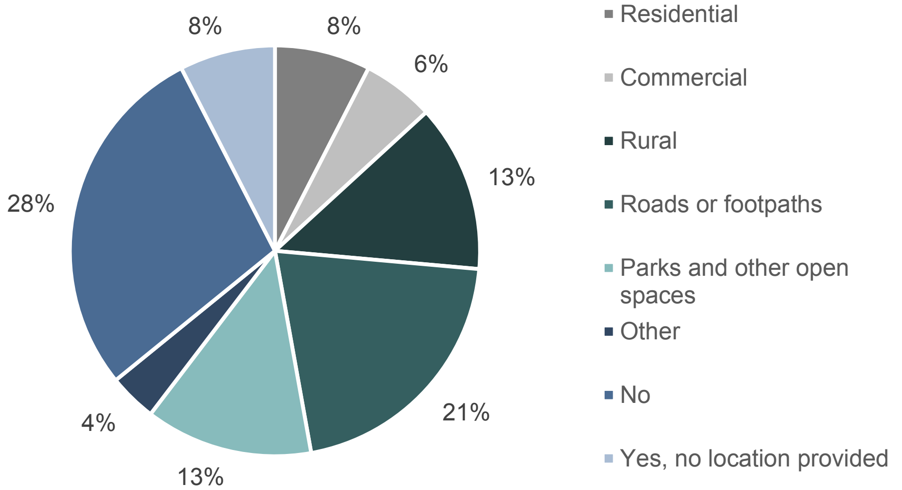

Figure 4-5 Other Flooding in the Catchment

4.5.7 Additional Comments

Respondents were asked if they wished to provide additional information to inform the Flood Study. Respondents identified the following issues:

- Concerns relating to the increasing frequency of opening Back Lake and the potential environmental impacts;
- The Back Lake should be opened early to prevent flooding damage to businesses;
- Concerns that debris is blocking the waterway at the footbridge near the sports oval and causing flooding;
- Concerns that siltation and overgrown vegetation in creek upstream and downstream of Reid Street bridge causes flooding;
- The flooding impacts of storms coinciding with high tides; and
- Concern that the box culvert is causing flooding in Bald Hills Creek as the culvert can dam.

4.5.8 Public Exhibition

Following the preparation of the draft Flood Study document, the report was placed on Public Exhibition in order to allow the community to review and comment on the report prior to it being finalised and adopted by Council.

The public exhibition period was undertaken from 22 August 2016 to 30 September 2016. A media release was issued on 22 August 2016 and 16 September 2016 to inform the community of the exhibition period (copies are provided in **Appendix A**).

As part of the exhibition period, four public information sessions were held to provide the community with the opportunity to discuss the report with Council and Cardno. The sessions were held on:

- 24 August 2016 (13 attendees)
- 25 August 2016 (18 attendees)
- 21 September 2016 (9 attendees)
- 22 September 2016 (6 attendees)

Over the course of public exhibition period, the study received the following from the community:

- 46 attendees at the information sessions;
- Five written submissions; and,
- Three phone calls.

The key issues / comments raised at the information sessions were:

- Most people wanted to understand the flood behaviour at or near to their own dwelling or business;
- Most attendees corroborated the mapping based on experience or understanding of the topography at the location of interest;
- Follow up by one attendee identified issues associated with mapping resolution on two of the report figures;
- Many attendees wanted to understand the planning implications for existing structures and future development;
- Dense vegetation and debris in creeks was of concern; and,
- Potential impacts on flooding as a result of the Princes Highway bridge construction were raised by downstream landowners (erosion) and oyster farmers (sedimentation).

A summary of the written submissions and responses provided by Cardno / Council are provided in **Appendix A**. The written submissions were largely focused on seeking clarification of a number of topics with the report:

- Clarifying the interpretation of the mapping and the resolution and use of the maps provided.
- Clarifying how the dynamic entrance behaviour is included in the modelling.
- Clarifications regarding extent mapping at specific properties.

A number of concerns from the community were also raised with regard to the management of flooding within the study area. These points have been collected by Council and will be incorporated into the future Floodplain Risk Management Study that will examine the risks and damages arising from the flooding behaviour identified in the Flood Study, and will seek to reduce these risks and damages through a range of mitigation options.

5 Modelling Approach

5.1 Introduction

Modelling of the Merimbula Lake and Back Lake systems and physical processes required the use of the calibrated Delft3D Hydrodynamic Model system, as well as the SWAN Wave Model system; operating in coupled mode. Hydrological inputs were developed using RAFTS.

The overarching approach of the hydrodynamic part of this flood study was:

- Modelling of tidal inundation of Merimbula Lake and Back Lake following design events (utilising a post-storm bathymetric descriptions) – hydrodynamics only;
- Modelling of design events (combined catchment and ocean storm events) – coupled hydrodynamic and wave modelling (including sediment transport).

A range of flood events and projected sea level rise scenarios was investigated.

5.2 Model Systems

5.2.1 XP-RAFTS

Cardno utilised the XP-RAFTS model system to undertake the hydological modelling required for this overall investigation. XP-RAFTS is a non-linear runoff routing model used extensively throughout Australia and South East Asia. XP-RAFTS has been shown to work well on catchments ranging in size from a few square meters up to 1,000's of square kilometres of both rural and urban nature. XP-RAFTS can model up to 2,000 different nodes and each node can have any size of subcatchment attached, as well as a storage basin. XP-RAFTS uses the Laurenson non-linear runoff routing procedure to develop a stormwater runoff hydrograph. Probable Maximum Precipitation (PMP) generation is also incorporated, which simulates PMP for Australia for short or long durations. A detailed description of this modelling system can be found in **Appendix B**.

5.2.2 Delft3D

The Delft3D Hydrodynamic Model system was applied for the hydrodynamic modelling component of this study. Investigations of estuarine and coastal processes require the application of a high level model capable of simulating a range of processes including, catchment inflow, ocean wave and tidal forcing, together with morphological changes; with some confidence. Such simulations can be successfully undertaken using the Delft3D modelling system. This modelling system can include, among other processes, wind, pressure, tide and wave forcing, three-dimensional currents, stratification, sediment transport and water quality descriptions, and is capable of using irregular rectilinear or curvilinear coordinate systems that are used to describe the seabed bathymetry. A detailed description of this modelling system can be found in **Appendix B**.

5.2.3 SWAN

The wave model used in this study is based on the third generation wind/wave modelling system, SWAN, which is incorporated as a module into the Delft3D modelling system. This model was developed at the Delft University of Technology and includes wind input (wind-wave cases), combined sea and swell, offshore wave parameters (swell cases), refraction, shoaling, non-linear wave-wave interaction, a full directional spectral description of wave propagation, bed friction, white capping, currents and wave breaking. SWAN also models phase-averaged diffraction based on the model of Holthuijsen *et al.* (1993). SWAN includes a nested grid capability that allows coarser grids in deeper water and finer grids in shallow water, where better definition of seabed form and depth are needed. Output from the model includes significant wave height, dominant wave direction, spectral peak and mean periods and (optionally) the full directional wave spectra at selected grid points.

5.3 Hydrological Modelling of Catchment Flows

The hydrological modelling of the catchment was undertaken using the XP-RAFTS software package. The set-up of the hydrological model is discussed in the following sections.

5.3.1 Sub-Catchments

The sub-catchment layout used in the XP-RAFTS model is shown in **Figure 5-1**. Details of the XP-RAFTS sub-catchments are provided in **Table 5-1**, including the PERN value, which is discussed below.

Permanent water bodies such as the lakes and the adjacent swamps were not included in the hydraulic model.

Similarly, the small isolated catchment area that drains the western batter of the airport was not included in the hydraulic model. This catchment area drains directly to Merimbula Lake. As a result of this areas rapid response time (due to the narrow catchment, any rainfall on this region quickly drains to the lake) any runoff from this catchment will be equalised between the lake and the ocean well in advance of the flood arriving at Merimbula Lake. As such, this catchment area was not included in the hydrological model.

Table 5-1 XP-RAFTS Sub-Catchment Details

Catchment	Area (ha)	Manning's 'n'	Impervious %	Slope (%)
B1	138.44	0.033	2	15.99
B10	91.16	0.033	2	6.65
B11	126.44	0.033	8.2	5.73
B12	248.53	0.032	18.8	5
B13	223.97	0.03	2.8	5.77
B2	143.65	0.033	2	8.45
B20	255.02	0.033	2	8.05
B21	147.11	0.033	2	13.26
B21	147.11	0.033	2	13.26
B22	181.83	0.033	2	8.16
B23	198.34	0.033	2	6.9
B3	194.83	0.033	2	3.89
B30	141.32	0.033	2	10.32
B31	133.47	0.033	2	11.2
B32	129.09	0.033	2	8.38
B4	207.07	0.033	2	4.69
B5	147.41	0.033	2	7.99
B6	193.52	0.033	2	9.59
B7	99.74	0.033	2	6.98
B8	101.43	0.033	2	7.76
B9	100.03	0.033	2	8.19
M1	76.75	0.033	2	18.52
M2	106.67	0.033	2	11.03
M20	113.78	0.033	2	9.8
M21	92.43	0.033	2	10.22
M22	177.72	0.03	2	7.23
M23	176.51	0.028	2	7.54
M24	231.46	0.033	2	5.96
M25	170.02	0.03	2	3.56
M26	125.79	0.033	4.1	3.47
M3	109.73	0.033	2	11.48
M30	182.67	0.028	2	6.83

Catchment	Area (ha)	Manning's 'n'	Impervious %	Slope (%)
M31	106.7	0.028	2	9.53
M32	216.22	0.033	2	5.83
M33	110.88	0.03	2	4.24
M34	159.27	0.033	2	5.62
M35	356.93	0.03	2	3.83
M36	138.59	0.033	32	8.14
M37	141.22	0.032	50	6.36
M4	256.67	0.033	2	6.59
M5	132.72	0.033	2	5.48
M6	183.48	0.03	2	4.21
M7	128.53	0.03	2	4.14
M8	146.85	0.033	2	11.63
M9	92.6	0.03	2	9.32

5.3.1.2 Manning's 'n' Values

The XP-RAFTS Manning's 'n' values adopted in the hydrological model are shown below in **Table 5-2**. The sub-catchments were delineated on the basis of the above regions and a single 'n' value was generated based on the relative areas of each of the above regions within the sub-catchment. The 'n' values adopted for each sub-catchment are shown above in **Table 5-1**.

Table 5-2 Manning's 'n' Values Adopted

Manning's Value	Description
0.015	Impervious Areas
0.025	Urban Pervious Areas
0.05	Rural / Pastureland
0.10	Forested Catchment Areas

5.3.1.3 Rainfall Losses

XP-RAFTS has two methods for determining rainfall losses:

- Initial and continuing loss – this method removes an initial volume of rainfall from the start of the event, and then applies a smaller continuing loss for the remainder of the storm event; and,
- Australian Representive Basin Model (ARBM) – this method considers soil parameters and infiltration rates to groundwater in order to determine the rainfall run-off during a storm event.

The ARBM is a more complex loss methodology that allows for infiltration rates to vary over time. As the critical durations are relatively short, and the fact that there are not multiple storm bursts in the hyetograph, the initial and continuing loss method was adopted for this study.

The initial and continuing losses applied to the model are summarised in **Table 5-3**.

Table 5-3 PERN Values Adopted

Area Type	Initial Loss (mm)	Continuing Loss (mm/hr)
Pervious	10	2.5
Impervious	1.5	0

5.3.1.4 Lag Links

RAFTS allows two overland connection types between catchments; a lag link and a routing link. The lagging link shifts the hydrograph by a specified time, with no attenuation of the peak flow, or changes to the hydrograph shape.

The routing link allows a typical section of a channel to be entered into the model, and flow through the link is dependent on the section. The flow hydrograph experiences both attenuation of the peak, and a delay of the peak.

The XP-RAFTS model developed for the study adopted lag links for all connections. The lag between sub-catchments was calculated based on the sub-catchment length (the longest distance that a drop of water would be required to travel within the sub-catchment) and a typical flow rate through the sub-catchments of 1m/s.

5.3.1.5 Rainfall Stations

There is only one rainfall gauge within the catchment, located at Merimbula airport. As shown in **Table 5-4** however, this gauge only has data available for the March 2011 event.

The nearest rainfall gauge for which data is available for the other calibration events is 20km west of the catchment area. Lacking other suitable data, the rainfall from this gauge was used for the 1998 and 2010 events.

A number of daily read rainfall gauges located within the study area boundary. However, daily read rainfall gauges do not provide a sufficient level of detail of the distribution of rainfall intensity throughout the event for use in a calibration exercise. The modelling undertaken in this study requires pluvio data in order to develop historic rainfall series.

It is noted that the travel time from the upper to lower catchment is in the order of 2 to 3 hours. This is relatively quick, and as such, changes in rainfall intensity are not expected to significantly alter downstream flood levels, particularly given that the tidal and entrance effects are the dominant flood driver in the system.

As a result of the lack of gauges within the catchment area, it was not possible to determine if rainfall intensities varied across the catchment area, and it was assumed that the rainfall intensities recorded at the gauges were representative of the full catchment.

The lack of temporal and spatial distribution of the rainfall data was raised as a concern during the public exhibition period. In response to this, more detailed assessment of possible rainfall intensity distributions across the catchment may be considered by Council as part of the Floodplain Risk Management Study.

Table 5-4 Rainfall Stations

Station ID	Record Start Date	Record End Date	Data Type	Data for Calibration		
				Jun 1998	**Feb 2010**	**Mar 2011**
69147	Sep 2010	Aug 2015	1min records			Yes
69066	Jan 1993	May 2013	Pluviograph	Yes	Yes	Yes

5.3.2 <u>Validation of Hydrological Model</u>

There are no flow gauges within the catchments, which prevented the hydrological model being calibrated to historical events. Therefore, to assist in improving confidence in the results of the hydrological model, sub-catchment flows were compared against the peak flow estimates from the Probabilistic Rational Method (PRM), as described in AR&R (1987).

The PRM was developed to estimate peak flows from small to medium sized rural catchments. However, there are a number of problems associated with the use of the Rational Method. Most of these problems are associated with the estimation of parameter values such as the time of concentration and the runoff coefficient. The draft Project 13 Report (Engineers Australia, 2014), which examines the PRM as part of the current update to AR&R, suggests that the PRM not be used to calibrate hydrological flows unless a study has been undertaken to calibrate the parameters to the study area in question.

Given this, the results of the PRM should be used only as a general calibration tool, to ensure that the observed peak flows are of the right order of magnitude.

The results of the comparison with the PRM are shown in **Table 5-5**.

Overall, the rational method generally correlates with the flows observed in the XP-RAFTS model. One catchment had a variance of 14%, while the other three catchments assessed had variances of less than 10%. The flow estimates from the PRM were all lower than the XP-RAFTS peak flows. This indicates that the XP-RAFTS flows may be slightly conservative. As peak levels within both Merimbula Lake and Back Lake are driven more by entrance conditions and ocean behaviour, conservative estimates of catchment flows are not expected to significantly affect the flood behaviour. The flow volumes were indirectly assessed further as part of the calibration process for the hydrodynamic model (**Section 5.4.4**).

Furthermore, sensitivity testing of the hydrodynamic model (**Section 5.4.3**) showed that the Delft3D model was relatively insensitive to changes in catchment flow timings, as a result of the significant storage in both lakes, with peak levels within the lakes being controlled more by ocean and entrance conditions than upstream catchment timings.

As a result of this insensitivity, and the general agreement in peak flows between the XP-RAFTS model and the PRM, the flows from the hydrological model are considered suitable for use in the hydrodynamic model.

Table 5-5 Comparison of XP-RATS and PRM Peak Flows (m3/s)

Catchment ID	XP-RAFTS	PRM	Difference
B20	60.8	59.9	1%
B21	48.0	41.2	14%
B31	41.6	38.2	8%
M30	50.5	48.2	5%

5.4 Hydrodynamic Modelling of Tidal Inundation

5.4.1 Introduction

An assessment has been undertaken of the threat posed by the peak of high spring tide episodes (in the absence of wave processes and catchment derived flood events) submerging low-lying foreshore landforms, structures and infrastructure in both the Merimbula and Back Lakes regions. As a small wave dominated barrier estuary system, there is likely to be significant attenuation of tidal range through the confined Merimbula Lake entrance and a gradual attenuation of tidal range from the entrance towards the tidal limits. In contrast, water levels in ICOLLs such as Back Lake vary depending on opening and closing regimes; whilst open they operate like small barrier estuaries or tidal lakes, while closed water levels vary according to the balance between inflows and evaporation. Maximum water levels are generally controlled by the beach berm height.

Morris *et al*. (2013) showed that the so called ‘bathtub approach’ to modelling tidal inundation in estuaries can lead to under or over estimation of the risks since tidal characteristics are not taken into account. Hence, in order to map the extent of estuarine areas inundated by the peak of high spring tides, Cardno proposed a more complex approach informed by the use of numerical modelling. This approach comprised the following tasks:

- The High High Water Solstice Springs (HHWSS) tidal planes were calculated (as a proxy for the highest astronomic tide) for current day conditions at the Merimbula Wharf and Merimbula Lake tide gauge stations - based on at least 5 years of recorded data at each station.
- The calibrated and verified hydrodynamic model was used to model the reduction (or possibly amplification for sea level rise scenarios) of the tidal range throughout the estuary from the ocean entrance upstream to the tidal limit.
- Hydrodynamic modelling was then conducted for sea level rise projections of 0.4 m at 2050 and 0.9 m at 2100. In order to account for potential morphological change of the estuary entrance, for each sea level rise projection, two (2) simulations were conducted, namely:
    - One where the bed of the entrance (noting that the Merimbula Lake entrance in this case is defined as the area from the ocean entrance to the Merimbula bridge) has risen at the same rate as sea level rise; and
    - One where the bed of the entrance has not risen with sea level rise.

Consequently, a total of five (5) simulations has been conducted - one for the present day sea level condition, two for 2050 and two for 2100 taking into account Sea Level Rise (SLR), see **Table 5-6**.

5.4.2 Hydrodynamic Model Setup

The hydrodynamic model system was established using a three domain model that covered both the Merimbula and Back Lake catchments and estuaries and also extended offshore into the Tasman Sea to a depth of approximately -100 m AHD. The three domains were linked using Delft3D's domain decomposition functionality (see **Appendix B**). For the purposes of computational efficiency, grid cell resolution (grid cell size) differs between the three model domains. The offshore model domain resolution is 100 m, with a resolution of approximately 30 m for the intermediate grid. The nearshore grid has a resolution of approximately 10 m and encompasses both Merimbula Lake and Back Lake, as well as the suburbs of Merimbula, Berrambool, Mirador and Millingandi. It extends offshore to an approximate 30 m depth. The topographic and bathymetric data incorporated into the model are outlined in **Chapter 3**. The hydrodynamic model set-up and model bathymetry of the Merimbula and Back Lake model domains are depicted in **Figure 5-1, Figure 5-2** and **Figure 5-3**, respectively.

Table 5-6 Summary of Hydrodynamic Tidal Inundation Simulations

Type	Number of Simulations	Additional Information
Present Day	1	To spatially assess tidal range throughout the estuary
2050	2	1 x Entrance bed has not risen with SLR 1 x Entrance bed has risen 0.4 m with SLR
2100	2	1 x Entrance bed has not risen with SLR 1 x Entrance bed has risen 0.9 m with SLR
Total	5	

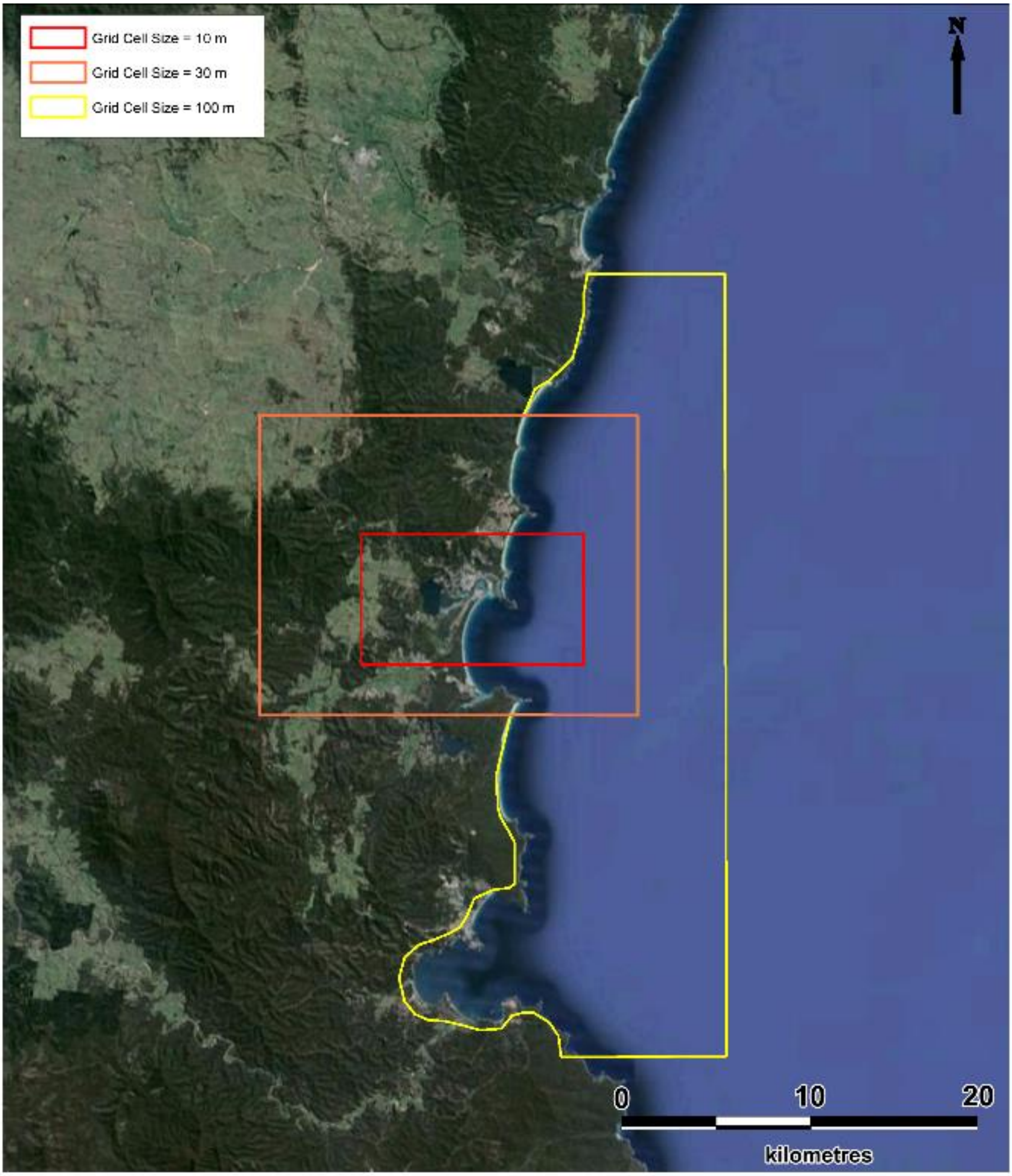

Figure 5-2 Hydrodynamic Model Grid Extents

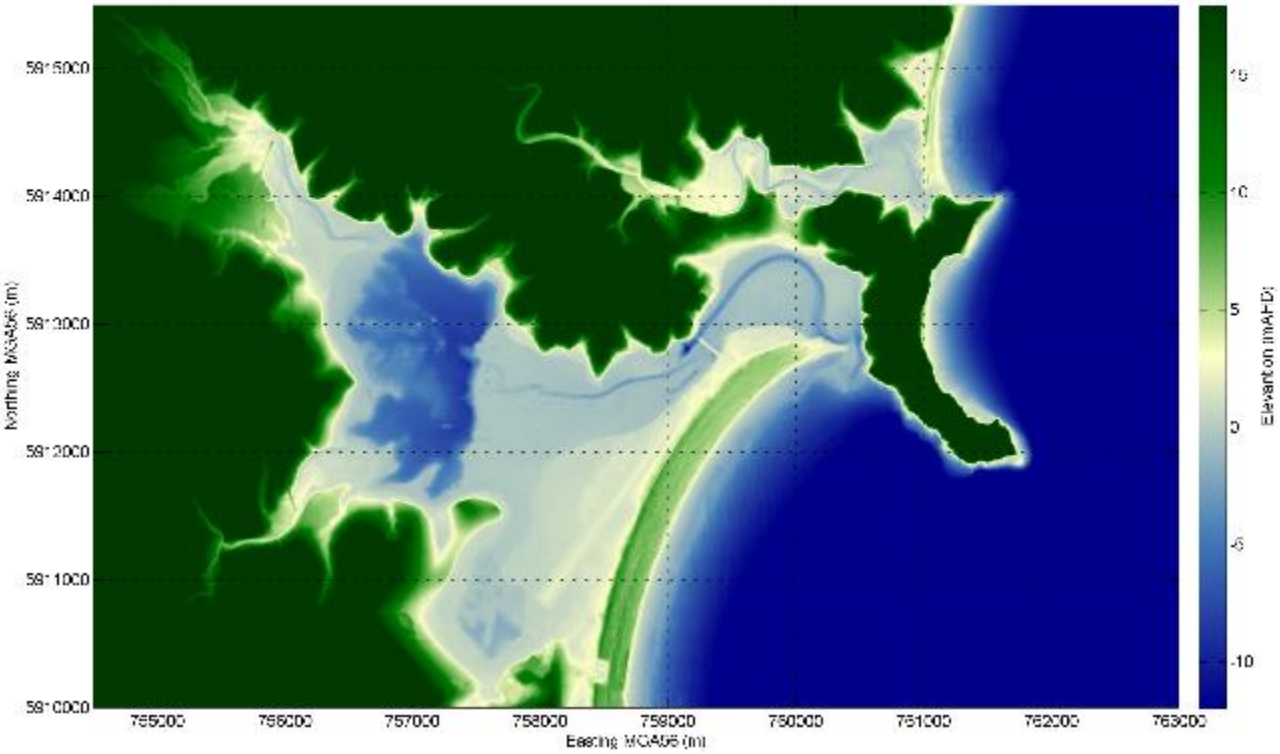

Figure 5-3 2D Representation of Merimbula and Back Lake Model Domain Bathymetry (note: colour scale narrowed for a more detailed visual representation of the lake & surrounds)

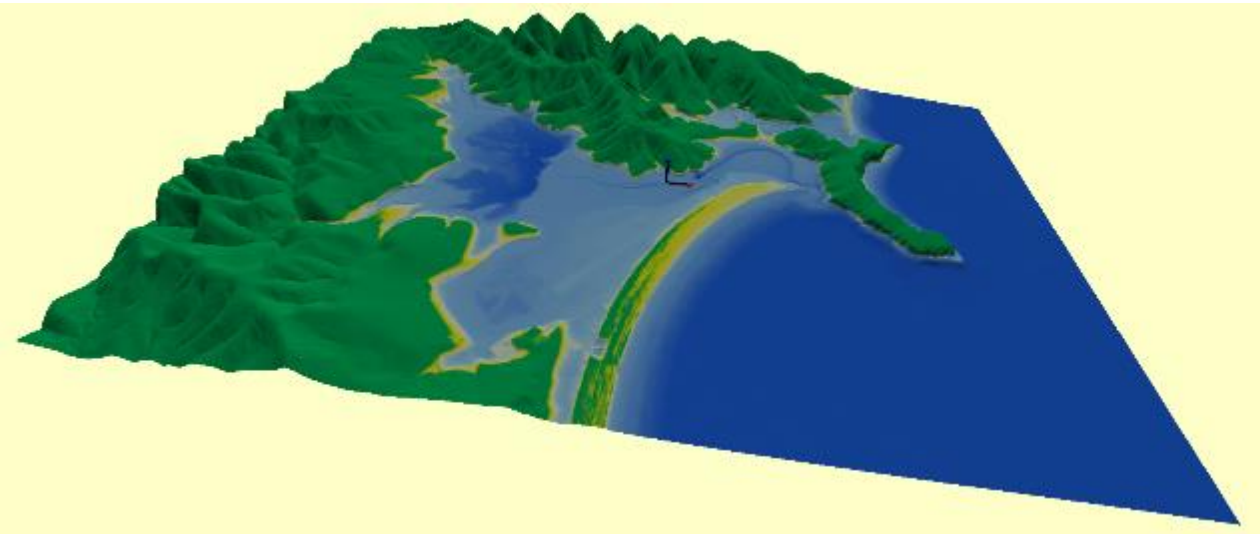

Figure 5-4 3D Representation of Merimbula and Back Lake Model Domain Bathymetry (note: colour scale narrowed for a more detailed visual representation of the lake & surrounds)

5.4.3 <u>Hydrodynamic Model Sensitivity</u>

Sensitivity testing undertaken on the hydrodynamic model is outlined in **Appendix C**. The outcomes showed that the hydrodynamic model is relatively sensitive to the following parameters:

- Model bed roughness (flood levels in Merimbula Lake); and
- Entrance condition/Ocean connectivity (flood levels in Merimbula Lake).

For the hydrodynamic modelling of tidal inundation, a spatially varying Chezy bed roughness through the Merimbula Lake entrance has been employed, ensuring accurate modelling of coastal flooding in this lake.

A conservative approach (in terms of resulting flood levels) was taken to the flood modelling of Merimbula Lake applying a high degree of ocean connectivity so that a coastal storm tide is able to propagate more fully into the estuary. To this end, the post-storm bathymetry of the model validation simulation (Cardno, 2015b) that has been undertaken for the storm event of 14 to 16 February 2010 was utilised as the initial bed level for the tidal inundation simulations in the Merimbula and Back Lakes area.

5.4.4 Hydrodynamic Model Calibration and Validation

Calibration of the hydrodynamic model was undertaken using:

- A non-flood period when water level data was recorded and entrance bathymetric data was also available; and
- A catchment event for Back Lake: 21-22 March 2011.

Validation was then undertaken using:

- The ocean storm tide event for Merimbula: 23-24 June 1998; and
- The flooding event of 14-16 February 2010, which included both extreme rainfall as well as storm tide. Whilst the overall levels in Merimbula Lake didn't reach flood levels due to the surge coinciding with a low, neap tide, the model can be validated to the surge nonetheless.

Details of the model calibration and validation are provided in **Appendix C**.

5.4.5 Model Boundary Conditions

The offshore boundaries of the hydrodynamic model are driven by recorded tide at Eden. Due to the apparent "bumpiness" of the recorded tide signal, a low-pass filter has been applied to the data with a cut-off frequency of 3 hours. This process ensures a smooth tidal signal is applied to the model boundary, preventing boundary driven hydrodynamic instabilities. The simulation period for all five tidal inundation model runs is 19 December 2011 until 30 January 2012. This time period includes three full spring-neap cycles.

5.5 Modelling of Design Events

5.5.1 Introduction

Merimbula Lake is a wave dominated barrier estuary that is at an intermediate stage in its evolution (Roy *et al*., 2001). Back Lake is an intermittently closed saline coastal lagoon that is at a semi-mature stage in its evolution (Roy *et al*., 2001). Consequently, Merimbula Lake and Back Lake (when open) are exposed to inundation risk from both catchment and coastal flooding. Catchment flooding will tend to dominate in the upper reaches while coastal flooding is likely to dominate towards the downstream boundary (the ocean entrance). However, the upstream and downstream estuary boundaries comprise a relatively small proportion of the overall estuary foreshore, and so inundation risk at any given location within the estuaries will depend on the balance of coastal and catchment flood processes, the estuaries' local geography, and their degrees of connectivity to the ocean.

Therefore, design storm modelling was conducted in which joint catchment and ocean flooding was considered. The design inputs to the model were determined to be:

- Design Storm Tide Level and time-series;
- Catchment rainfall event hydrographs; and
- Design significant wave height conditions.

5.5.2 Joint Occurrence of Catchment and Ocean Flooding

The joint occurrence of these design ocean and catchment conditions has been determined using the Floodplain Risk Management Guide (OEH, 2015). This document provides guidelines for the modelling of the interaction of catchment flooding and oceanic inundation in coastal waterways. It states that:

"The interaction of catchment flooding and coastal processes is an important consideration in determining overall flood risk in coastal waterways. The influence of these two factors on flooding varies with ocean level,

due to both tidal fluctuations and storm impacts, the condition of the entrance interface between the coastal waterway and the ocean, distance from the ocean, and the size and shape of the waterway and catchment draining to the entrance."

Consequently, a set of eight (8) base cases has been set up – see **Table 5-7**.

Table 5-7 Summary of Hydrodynamic Simulations of Design Events

Type	Catchment Inflow	Ocean Water Level	Ocean Wave
20% AEP	20% AEP	HAT	20% AEP
10% AEP	10% AEP	HAT	10% AEP
5% AEP	5% AEP	HAT	5% AEP
2% AEP	2% AEP	5% AEP	5% AEP
1% AEP	1% AEP	5% AEP	5% AEP
1% AEP	5% AEP	1% AEP	1% AEP
0.5% AEP	0.5% AEP	1% AEP	1% AEP
PMF	PMF	1% AEP	1% AEP

5.5.3 Flood Duration

Each of these cases has been modelled for a set of four catchment rainfall durations (referred to as catchment inflow durations from here on in), as well as time lags in relation to the occurrence of the peak water level, such that the peak combined catchment inflow over all discharge locations occurs *before* the peak of the ocean water level, see **Table 5-8**. Short duration catchment inflows (two to three hours) govern the peak flood levels in upstream creeks, whereas longer duration catchment inflows (six hours) are important in the lake body.

In summary, a total of 24 design event simulations have been conducted.

Table 5-8 Summary of Catchment Inflow Duration

Type	Catchment Inflow Duration	Time Lag w.r.t. Peak Ocean Water Level
2 hrs	2 hours	-
3 hrs	3 hours	-
6 hrs	6 hours	-
6 hrs - 3	6 hours	-3 hours

5.5.4 Coupled Hydrodynamic and Wave Model Setup

Modelling of the design events required coupling of the hydrodynamic model and the SWAN wave model. The hydrodynamic model setup has been described in **Section 5.4.2**. The SWAN wave model system was established using three nested grids that covered both the Merimbula and Back Lake catchments and estuaries and also extended offshore into the Tasman Sea to a depth of approximately -120 m AHD so that it encompasses the hydrodynamic model. The three domains were linked using SWAN's nested grid capability (see **Appendix B**). For the purposes of computational efficiency, grid cell resolution (grid cell size) differs between the three model domains. The offshore model domain resolution is 250 m, with a resolution of 75 m for the intermediate grid. The nearshore grid has a resolution of 25 m and encompasses both Merimbula Lake and Back Lake shoreline and entrance areas. It extends offshore to depths ranging from approximately -20 m to -35 m AHD. For the topographic and bathymetric data incorporated into the model, reference is made to **Section 5.4.2**.

5.5.5 Coupled Hydrodynamic and Wave Model Calibration and Sensitivity

In addition to the parameters mentioned in **Section 5.4.3**, the coupled hydrodynamic and wave model results are relatively sensitive to the following parameters:

- Sediment composition (flood duration in Back Lake);
- Peak flow and storm tide phasing;
- Merimbula Lake entrance condition; and
- Back Lake entrance berm height.

A physically realistic D_{50} value has been used in Back Lake based on available sediment size data to ensure the accurate modelling of flood duration in Back Lake.

Sensitivity analyses showed (Cardno, 2015b) that, due to the large volume of flood storage available within the Merimbula Lake, the modelled peak flood levels in Merimbula Lake are relatively unaffected by the timing of catchment inflows with the tide. However, timing of catchment flooding may be more important in the upstream creeks for higher recurrence interval catchment events where the volume of catchment inflow may be significantly higher than for the March 2011 event, and so additional simulations have been conducted using larger inflows and a time lag between catchment flooding and coastal inundation (see **Section 5.5.3**).

5.5.5.1 Back Lake Berm Level

A major point worthy of consideration for the modelling of design flood events in Back Lake was the setting of the closed entrance condition berm level. Flood levels inside Back Lake are extremely sensitive to the entrance berm level, and that parameter will largely govern the resulting flood levels – as shown by the calibration modelling. Therefore, careful consideration was given to the setting of this level. From a physical perspective, the berm level will be the product of a period of sustained beach building under day to day (modal) wave and wind conditions. Wainwright (2010) suggests that significant sediment deposition does not occur landward of the 2% run-up elevation ($R_{2\%}$). For modal offshore wave conditions, the $R_{2\%}$ wave run-up height will be about 1.4 m (using EurOtop and observed beach slopes from survey). Therefore, a berm level of around 2.6 m AHD could be expected based on the extent of the swash zone under modal conditions. However, with prolonged closure, the lagoon entrance berm height may also be further increased by aeolian dune building processes.

Hanslow (2000) suggests that for ICOCLL's with Back Lake's D_{50} and beach slope, a potential berm level of 2.6 to 2.8 m AHD may be expected.

Inspection of historical water level data in Back Lake (which only dates back to 2009, see **Figure 5-4**) suggests that the berm level was at, or very close to, 2.4 m AHD during the 2010 and 2011 Back Lake flood events depicted below – allowing for some head above the lowest shore normal profile level on the berm.

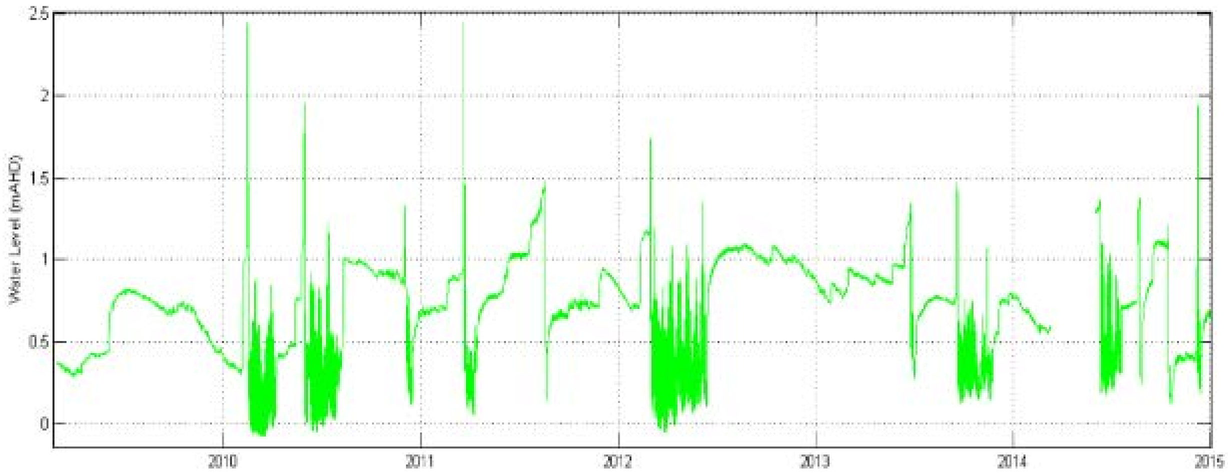

Figure 5-5 Historical Water Level – Back Lake

Back Lake berm survey data provided by Council (from date unknown) depicts a number of shore normal profiles across the entrance berm. It shows that at the time of the survey the peak berm level ranged from 3.0 to 3.1 m AHD. Historical berm level information is too sparse to ascertain whether this berm level is common or atypically high; or represents flow path limitations. Data from the 2003 survey has berm crest levels at 2.4 – 2.5 m AHD.

The findings of Cardno's literature review would appear to suggest that setting the berm level at the approximate level of the extent of swash zone run-up is appropriate. By Cardno's calculations this would be at around 2.6-2.8 m AHD. However, there is some uncertainty around this figure, due to other factors which may affect beach berm building, such as proximity to headlands and reefs, offshore bathymetry, the frequency of opening and the time available for incipient dune development by onshore winds.

Therefore, given the availability of survey data, which suggest entrance berm levels have historically reached 3.1 m AHD – Cardno has adopted this level for the design flood modelling. The typical width of the berm, which affects the time required for entrance opening, will be based on the existing survey at Back Lake.

5.5.6 Model Boundary Conditions

5.5.6.1 Design Still Water Levels

OEH (2015) provides detailed advice on how to derive ocean water level boundary conditions. Based on entrance type and location along the NSW coast, these water levels are (see **Table 5-9**):

Table 5-9 Design Still Water Levels

AEP (%)	Design Still Water Level (m AHD)	Source
1	1.45	OEH (2015)
2	1.40	OEH (2015, Not Used)
5	1.37	OEH (2015, Interpolation)
10	1.35	OEH (2015)
1 exceedence per year	1.25	OEH (2015)
HAT	1.10	Eden Tide Gauge

Additional water levels required for the design flood modelling are HAT and the 20% AEP design still water level (DSWL), see **Table 5-7**. HAT was calculated utilising the Eden tide gauge data and estimated to be 1.1 m AHD. The 20% AEP DSWL was estimated by a best fit (see **Figure 5-5**) for the data presented in **Table 5-9**.

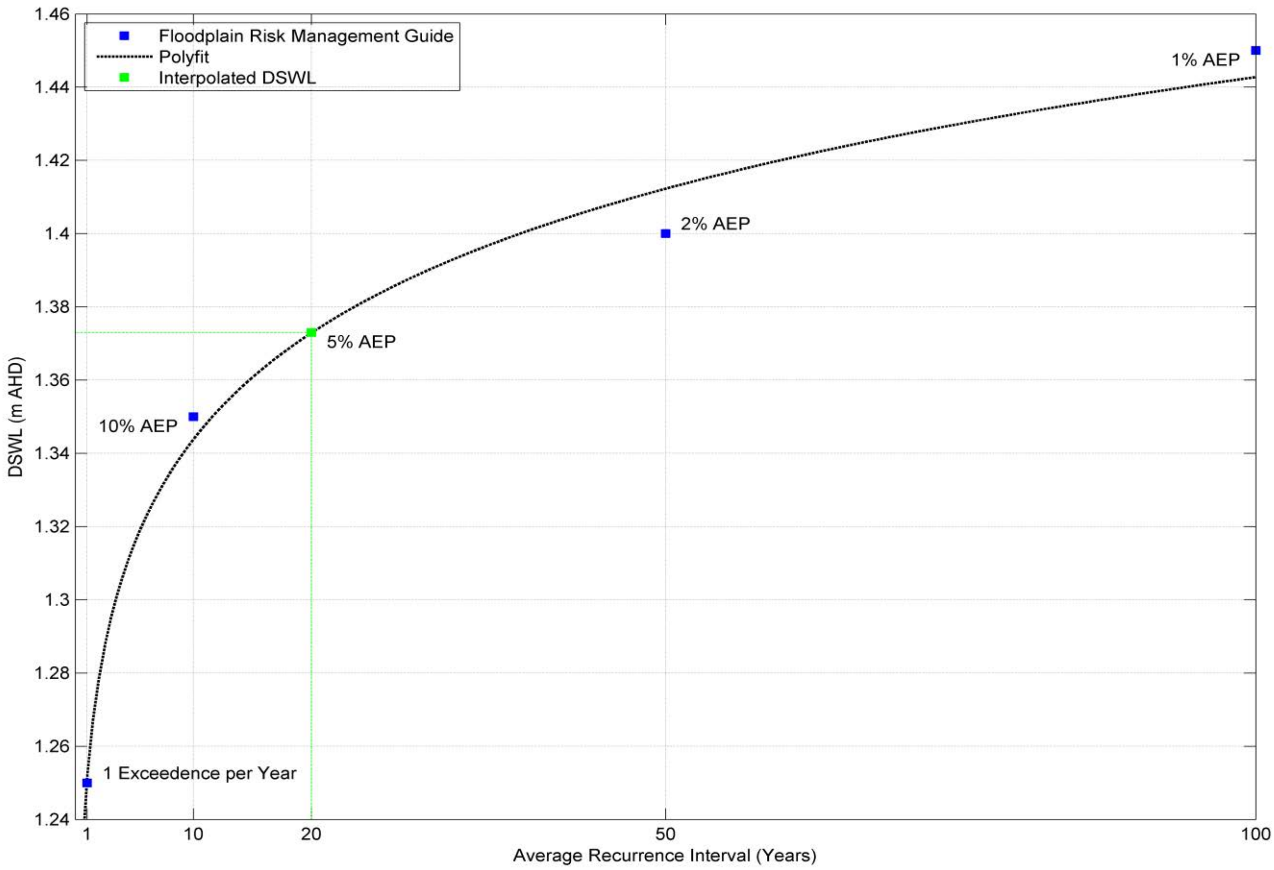

Figure 5-6 Design Still Water Level Interpolation

These DSWLs in combination with the tidal amplitude at the site (1.1 m) were utilised to construct a synthetic time-series for each of the design event model simulations. This was done based on the method used by Carley and Cox (2003) for development of time-series data for design storms that served as input to their beach erosion model.

5.5.6.2 Design Wave Heights

Design significant wave heights (H_s) have been taken from Cardno (2012). This study presents the Extreme Value Analysis (EVA) of Hs for the, among others, Eden Waverider buoy data (1998 – 2009). This data is presented in **Table 5-10**.

Table 5-10 Extreme Value Analysis based on Measured Eden Waverider Buoy Data (1998-2009)

AEP	H_s (m)
100%	5.71
50%	6.20
20%	6.82
10%	7.26
5%	7.70
2%	8.26
1%	8.68

Associated peak wave periods (T_p) have been calculated using the following relation:

$T_p = 1.05*H_s + 5.14$

This relation is the estimated outcome of a correlation analysis of Hs and Tp of the Eden Waverider Buoy data utilising a best fit for significant wave heights of 5.5 m and over (see **Figure 5-6**).

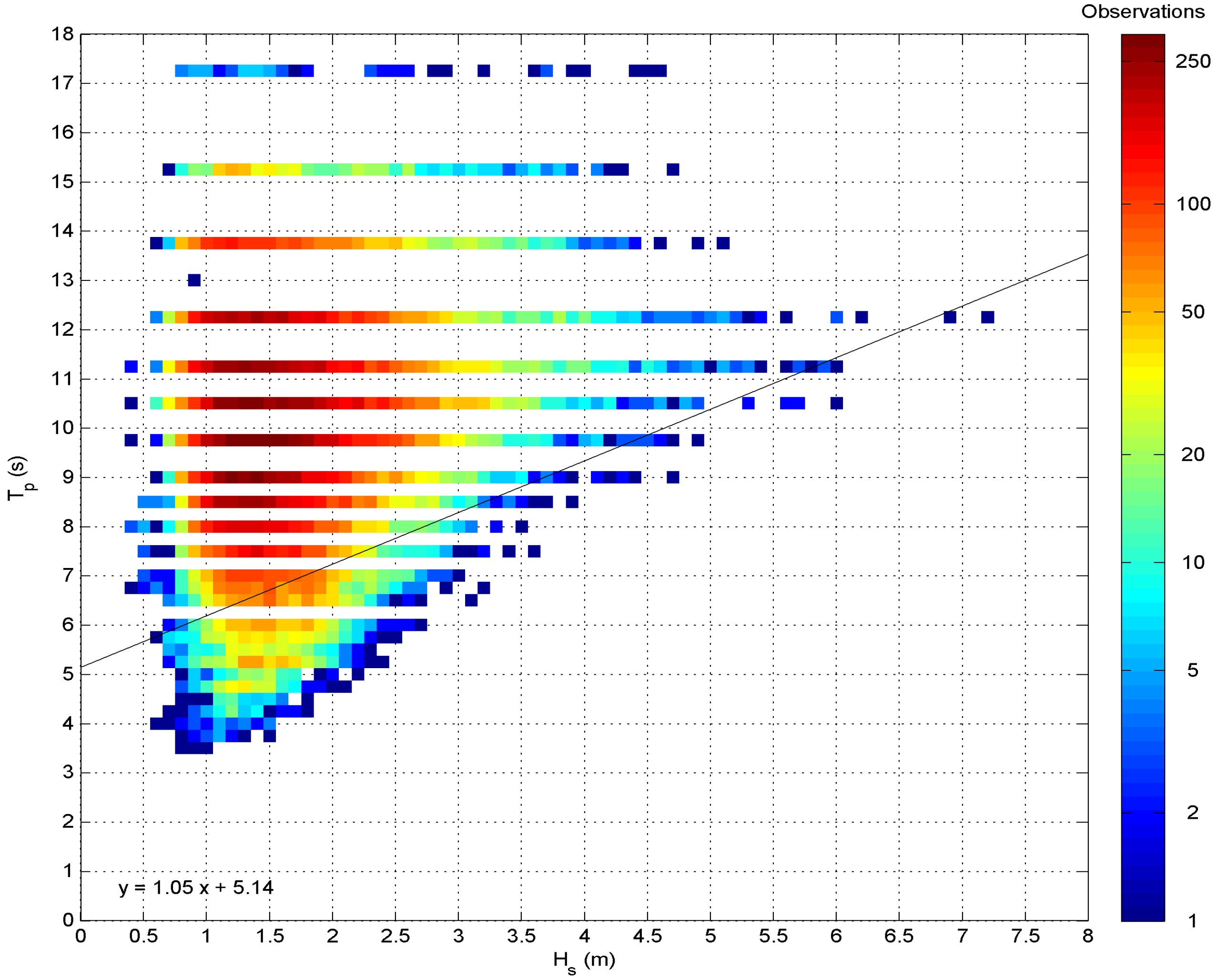

Figure 5-7 Correlation Analysis H_s vs T_p (Eden Waverider Buoy, 1998-2009)

The assumed wave direction has been taken to be southeast (SE) for all model simulations, as extreme swell waves are generated in storms in the Southern Ocean passing to the south of Australia.

Similar to the DSWL time-series, design storm wave time-series have been generated utilising the Carley and Cox (2003) method for developing time-series data for design storms that served as input to their beach erosion model (see **Section 5.5.6.1**).

5.5.6.3 Design Catchment Inflow Events

Inflow into the Merimbula and Back Lake catchments for the 0.5%, 1%, 2%, 5%, 10%, 20% AEP and PMF events was introduced into the model via a number of discharge locations based on the hydrological model simulations in XP-RAFTS (see **Section 5.3**). These discharge locations are presented in Figure 5-7.

The design flood simulations were set up such that the peak of the envelope inflow (see **Figure 5-8**) coincided with the peak ocean water level (except where a time lag was applied – see **Section 5.5.3**).

The potential impacts of climate change were assessed through sensitivity runs adopting increases to sea level and rainfall.

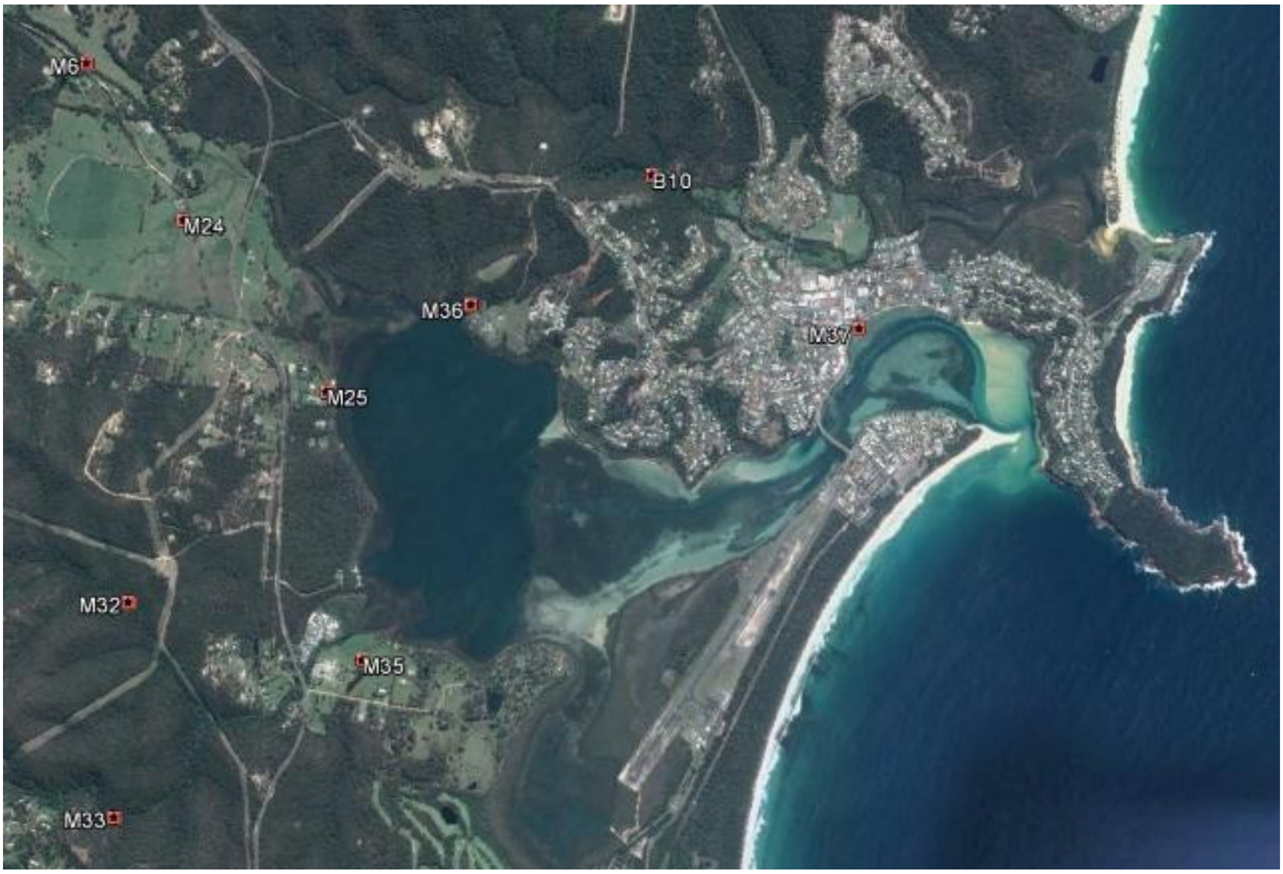

Figure 5-8 Catchment Inflow Locations

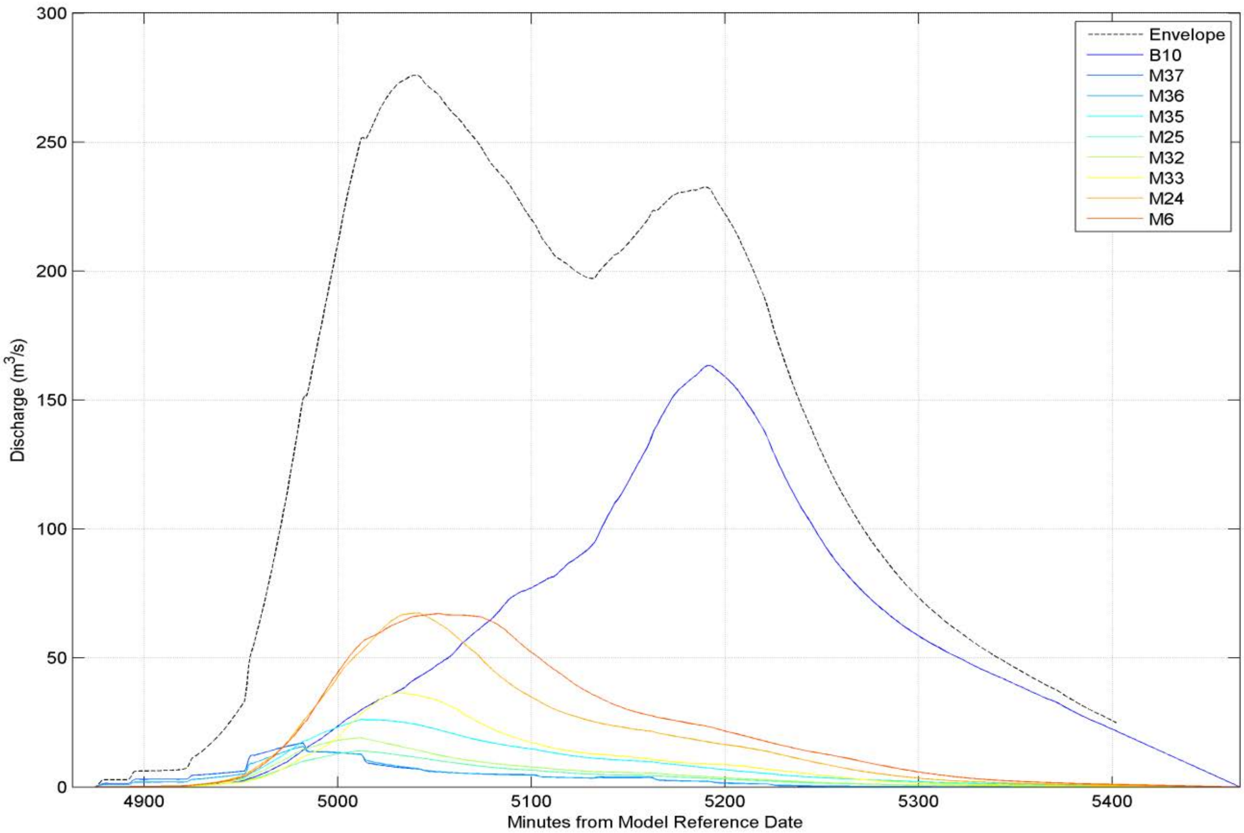

Figure 5-9 Catchment Inflows for the 20% AEP Event

6 Tidal Inundation Flooding

6.1 Results

Tidal planes analyses of six years of data (June 2008 to June 2014) of the Merimbula Wharf and Merimbula Lake tide gauge stations have resulted in the following HHWSS tidal planes at these locations (**Figure 3-1**):

- Merimbula Wharf (Site 3): +0.55 mAHD;
- Merimbula Lake (Site 8): +0.32 mAHD.

Results of the tidal inundation modelling are presented in the form of maps showing the tidal plane High High Water Solstice Springs (HHWSS) as well as the tidal extent in both Merimbula Lake and Back Lake. HHWSS was calculated by extracting water level time-series in each of the grid (with a resolution of approximately 10 m) points inside Merimbula Lake and Back Lake. Subsequently, a tidal harmonic analysis of each of these time-series (provided that that particular output location did not fall dry at any point in time) was performed. The simulation time (six weeks) provided a sufficiently long period to enable the identification of the required tidal constituents and their frequencies and amplitudes. The following formula and tidal constituents (amplitudes) were then used to calculate the HHWSS tidal plane (Morris, 2013):

$$HHWSS = M2 + S2 + (1.4 * (K1 + O1)) \text{ [m]}$$

Where: M2 = principal lunar semidiurnal constituent, S2 = principal solar semidiurnal constituent, K1 = luni-solar declinational diurnal constituent, and O1 = principal lunar declinational diurnal constituent

Lastly, the HHWSS level was extrapolated to determine the flood extent of the different scenarios, utilising the available LiDAR topographic data.

Figure 6-1 to **Figure 6-5** depict the HHWSS level inside Merimbula Lake and Back Lake for the different scenarios. **Figures 6.6 to 6.10** show the flooding extent of these scenarios.

Figure 6-1 HHWSS Tidal Levels – Present Day

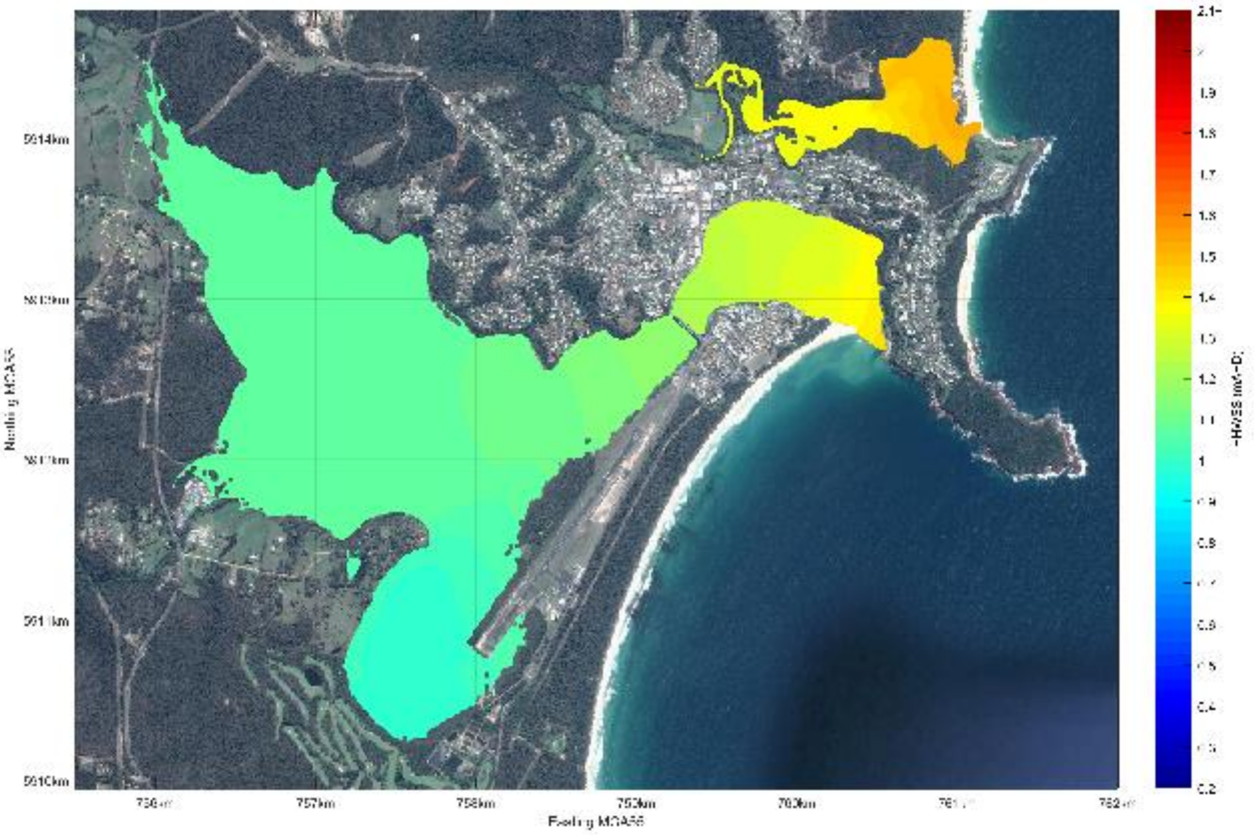

Figure 6-2 HHWSS Tidal Levels – 2050 (Bed Not Raised)

Figure 6-3 HHWSS Tidal Levels – 2050 (Bed Raised)

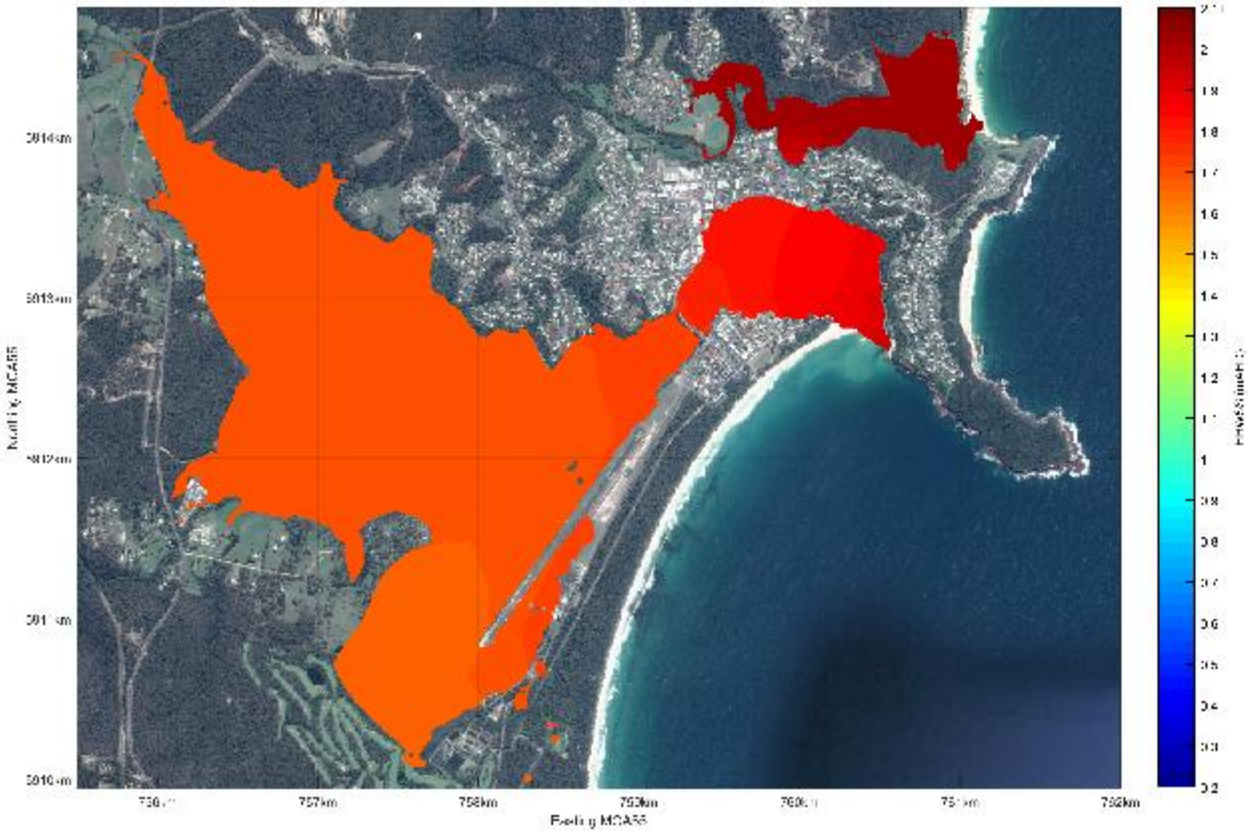

Figure 6-4 HHWSS Tidal Levels – 2100 (Bed Not Raised)

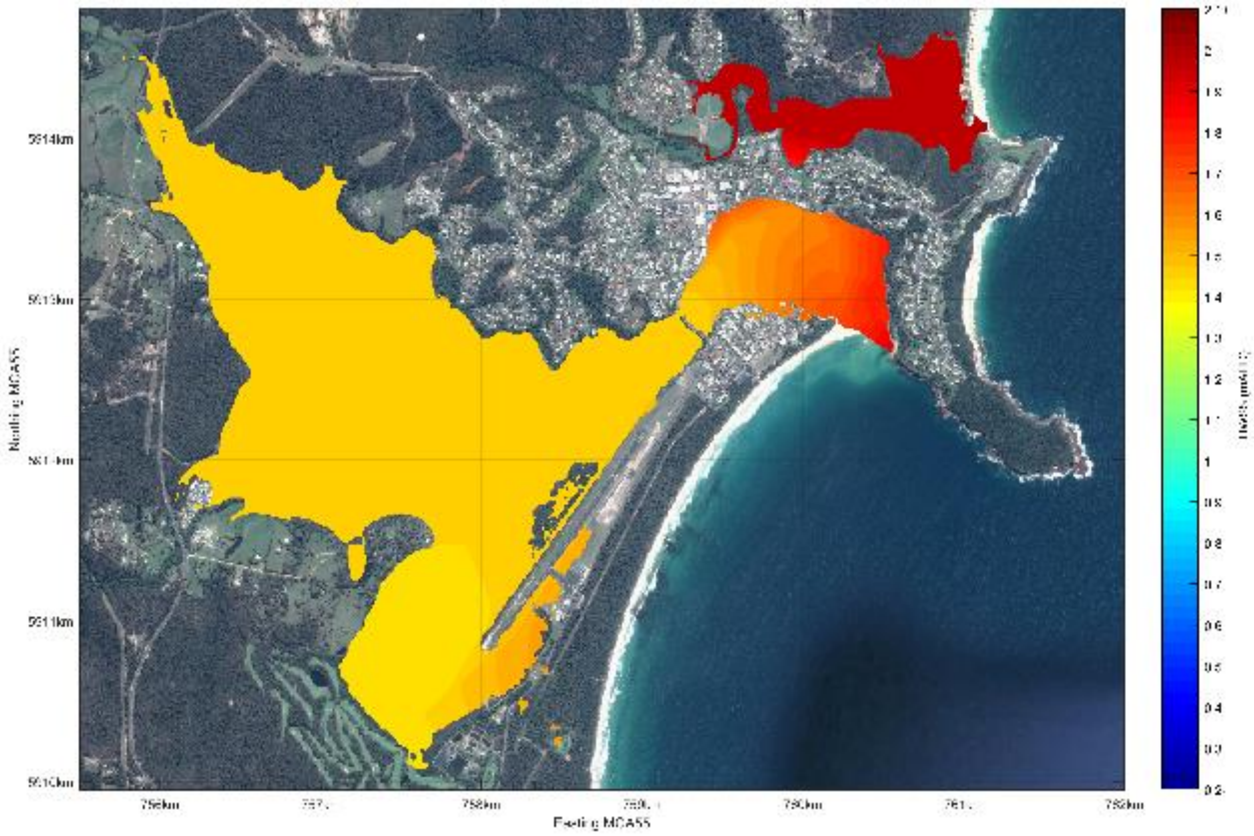

Figure 6-5 HHWSS Tidal Levels – 2100 (Bed Raised)

Figure 6-6 HHWSS Tidal Extents – Present Day

Figure 6-7 HHWSS Tidal Extents – 2050 (Bed Not Raised)

Figure 6-8 HHWSS Tidal Extents – 2050 (Bed Raised)

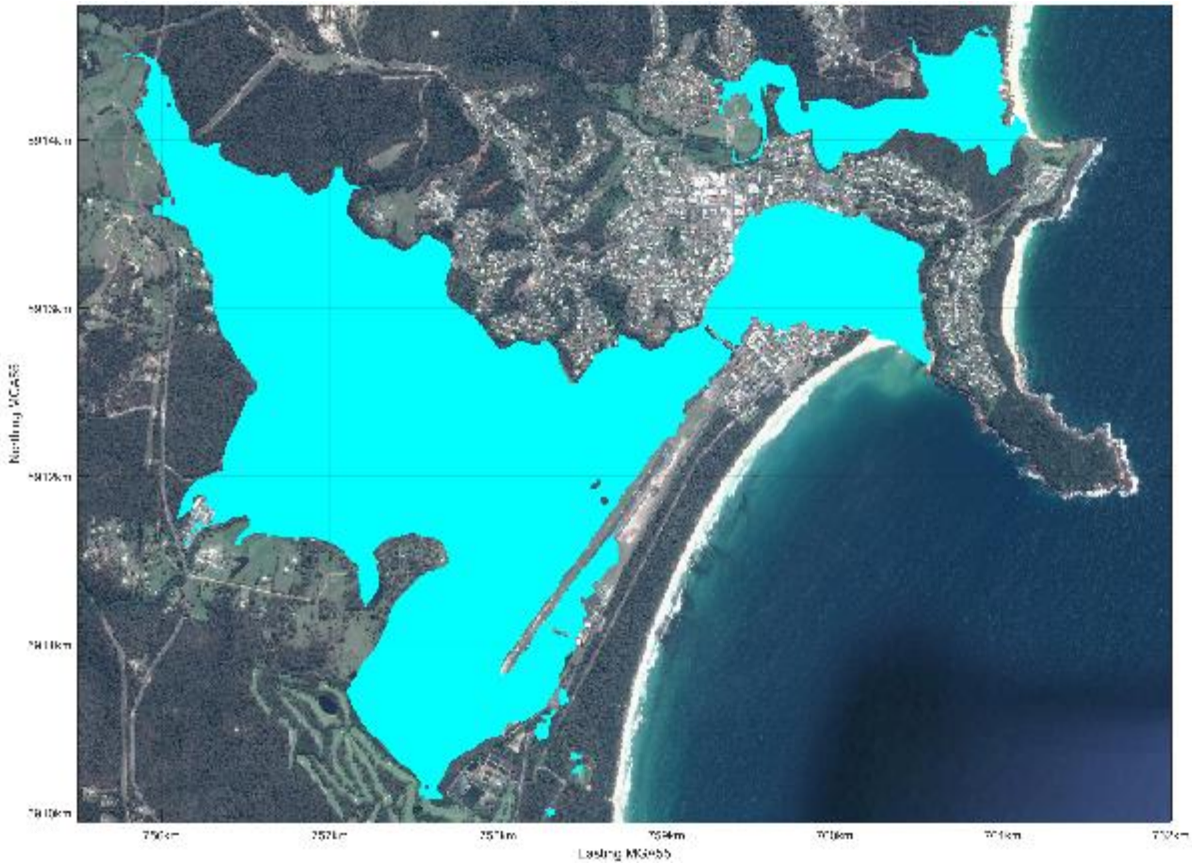

Figure 6-9 HHWSS Tidal Extents – 2100 (Bed Not Raised)

Figure 6-10 HHWSS Tidal Extents – 2100 (Bed Raised)

6.2 Discussion

Consisted with a more open entrance caused by catchment flooding and entrance scour, the HHWSS tidal planes are in the order of 0.3 m higher for these post-flood simulations (Present Day, see **Figure 6-1**) than the levels determined from the six years of recorded data at Merimbula Wharf and in Merimbula Lake (see **Section 6.1**). It is noted however that the recorded water levels are affected by the catchment runoff and perceived HHWSS would be higher than calculated.

Figure 6-1 to **Figure 6-5** show that the tide range inside Merimbula Lake is reduced significantly with respect to the ocean tide range, as a result of the presence of the relatively long and narrow entrance. Comparing the Sea Level Rise cases, it can be seen that this effect is reduced inside Merimbula Lake when the sea bed does not rise with the sea level. In other words, there is less attenuation (compare **Figure 6-2** to **Figure 6-3** and **Figure 6-4** to **Figure 6-5**) of the tide inside Merimbula Lake and a (slightly) larger tidal extent depending on foreshore slopes.

This effect is less obvious in Back Lake (which is less affected by attenuation of the tide due to the entrance) for the 2100 case and even more so for the 2050 (again compare **Figure 6-2** to **Figure 6-3** and **Figure 6-4** to **Figure 6-5**).

7 Design Event Flooding

7.1 Results

Results are presented in the form of maximum water depth maps for the events with Annual Exceedence Probabilities (AEP) of 20%, 10%, 5%, 2%, 1% and 0.5% as well as the PMF event (see **Table 5-7**). The maximum water depth was calculated by taking the maximum depth, in any output location (gridded, 10 m) inside Merimbula Lake and Back Lake that was wet at some stage during a simulation, over the different flood duration and tidal lag simulation cases. The results are presented in **Figure 7-1** to **Figure 7-7** (provided in Figure Appendix). These maps, plotted on a cadastral back-ground, show the flooding extent of the different AEP events at the same time.

Peak water levels for the 1% AEP are shown in **Figure 7-8**.

Peak velocities are presented in **Figure 7-9** to **Figure 7-15**.

Outputs such as maximum depth-averaged velocity and maximum water level have been used to calculate hazard and hydraulic categories (see **Section 8**).

7.2 Discussion

Detailed discussion on existing design flood behaviour is provided in **Section 8**. The outcomes of the climate change sensitivity design event simulations are presented in **Section 9**.

8 Existing Flood Behaviour

8.1 Existing Flood Results

Flood modelling of design storms was undertaken for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events and the PMF event.

The numbers of property lots that experience overland flooding in each design event are summarised in **Table 8-1**. Note that each number represents all lots that experience some flooding. It does not indicate that structures on the lot are subject to flooding.

Table 8.1 shows that flooding in the study area is typically well confined, with only small changes in property affectation observed between events. The largest jump in affectation was between the 1% AEP and the 0.5% AEP events.

Table 8-1 Properties Flooded in Design Events by Catchment Overland Flow

Flood Event	Number of Property Lots Flood Affected	Increase Over Previous Event
20% AEP	219	-
10% AEP	229	10
5% AEP	246	17
2% AEP	248	2
1% AEP	255	7
0.5% AEP	310	55
PMF	323	13

8.1.2 Merimbula Lake Behaviour

Flooding within the Merimbula Lake catchment is typically well defined, with flooding largely contained to creeks and open space Properties on Main Street between Spencer Park and Beach Street that are adjacent to the lake begin to experience inundation in the 20% AEP event. Depths at the rear of the property are increase from 0.4m in the 20% AEP to 1.1m in the 1% AEP. The majority of the lot areas remain unaffected of flooding in events up to the 1% AEP. The exception is those properties adjacent to Spencer Park that have flooding across the lots of 0.15m in the 1% AEP event.

Downstream of the market street bridge, properties on Beach Street, Market Street and Fishpen Road are first inundated in the 20% AEP by depths of up to 0.1m. These depths increase to 0.3m in the 1% AEP and 0.5m in the PMF.

Due to the topography of the study area, there was very little change in extents observed between flood events. Generally, the PMF extent is within 30m of the 20% AEP extent.

An exception to this lack of lateral expansion is the regional airport site. The airport site remains flood free in the 5% AEP event. The buildings and infrastructure, excluding the runway, are first inundated in the 2% AEP event by 0.02m. Flooding depths at buildings increase to 0.15m in the 1% AEP and 0.55m in the PMF event.

The airport runway only experiences overtopping in the PMF event, although flood waters reach the runway edge in the 1% AEP event.

8.1.3 Back Lake Behaviour

In a manner similar to Merimbula Lake, flooding within the Back Lake system is typically well confined. Between the lake entrance and Henwood Street, flooding up to and including the PMF is contained within the creek system and adjacent open space areas.

Between Henwood Street and Reid Street, low lying properties are inundated by floodwaters, in events as small as the 20% AEP event. All affected residential properties back onto the creek, so that flooding begins from the rear of the properties. In all cases, due to the relatively sharp rise in the terrain from the creek, no driveways or roadways are cut, so all affected properties retain open road access in events up to and including the PMF.

The only exception to the above is the Berrambool Sport Field buildings, located in the centre of the Berrambool sportsground. These buildings are inundated in the 20% AEP event by depths of 0.49m. Depths increase to 1.03m and 2.03m in the 1% AEP and the PMF, respectively.

Upstream of Reid Street, flooding is largely contained, and with the exception of the Sapphire Valley Caravan Park, does not affect development.

The caravan park is first inundated in the 10% AEP event, and access to and from the site is lost in the 5% AEP event. Caravans and buildings are first affected in the 5% AEP event, with depths of 0.17m occurring onsite. These depths increase to 0.48m in the 1% AEP and to 2.23m in the PMF.

8.2 Provisional Hazard Categorisation

Provisional flood hazard is determined through a relationship developed between the depth and velocity of floodwaters and is based strictly on hydraulic considerations (Appendix L; NSW Government, 2005). The Floodplain Development Manual (NSW Government, 2005) defines two categories for provisional hazard – high and low. The definition of these categories is shown in **Figure 8-1**.

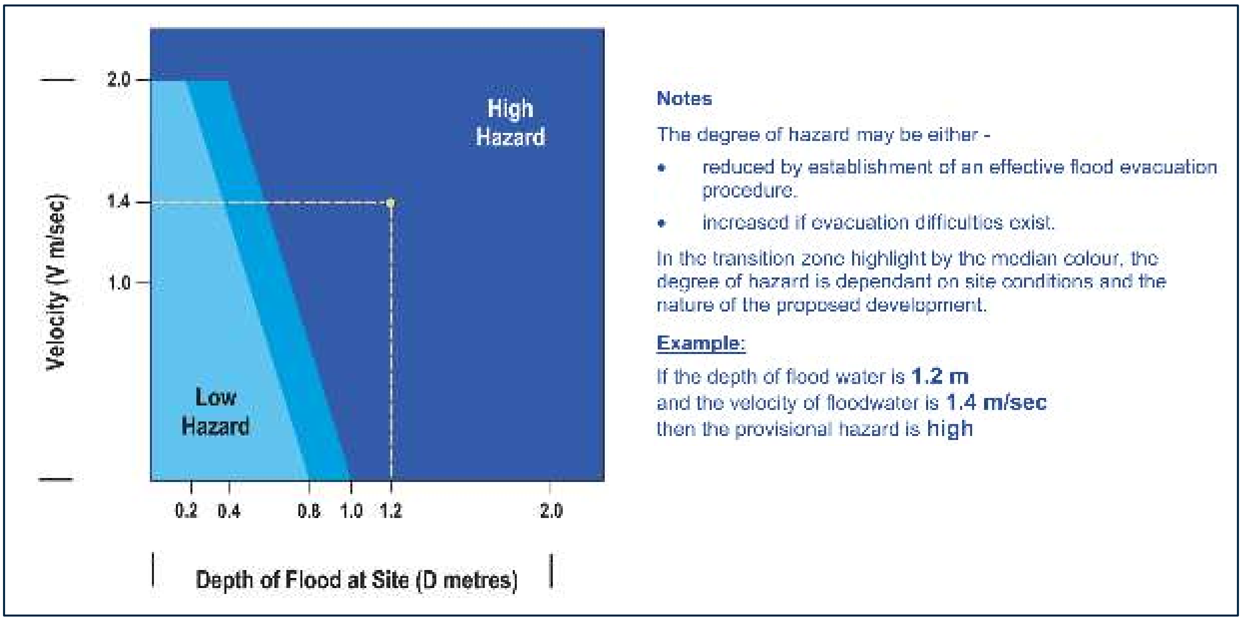

Figure 8-1 Provisional Hazard Categories (from Appendix L of the Floodplain Development Manual)

Plots for the provisional flood hazard for the 1% AEP and the PMF event are provided in **Figure 8-2** and **Figure 8-3**.

The figures show that in the 1% AEP event, while the majority of flooding is high hazard, it is largely contained within the lake systems. Properties affected by high hazard flooding are typically on the edge or either Merimbula Lake or Back Lake, and are classed as high hazard as a result of flood depth.

In the PMF event, the high hazard flood region is larger, and affects a greater region of developed zones.

8.3 True Flood Hazard

Provisional flood hazard categorisation based around the hydraulic parameters described above in **Section 8.2**, does not consider a range of other factors that influence the "true" flood hazard. In addition to water depth and velocity, other factors contributing to the true flood hazard include the:

- Size of the flood;
- Effective warning time & Flood readiness;

- Rate of rise of floodwaters;
- Duration of flooding;
- Ease of evacuation;
- Effective flood access;
- Type of development in the floodplain.

True flood hazard will be assessed as part of a future Floodplain Risk Management Study and Plan.

8.4 Hydraulic Categories

Hydraulic categorisation of the floodplain is used in the development of the Floodplain Risk Management Plan. The Floodplain Development Manual (2005) defines flood prone land to be one of the following three hydraulic categories:

- 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 Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.
- 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.

Floodways were determined for the 1% AEP event by considering those model branches that conveyed a significant portion of the total flow. These branches, if blocked or removed, would cause a significant redistribution of the flow. The criteria used to define the floodways are described below (based on Howells et al, 2003).

As a minimum, the floodway was assumed to follow the creekline from bank to bank. In addition, the following depth and velocity criteria were used to define a floodway:

- Velocity x Depth product must be greater than 0.25 m^2/s and velocity must be greater than 0.25 m/s; OR
- Velocity is greater than 1 m/s.

Flood storage was defined as those areas outside the floodway, which if completely filled would cause peak flood levels to increase by 0.1m and/or would cause peak discharge anywhere to increase by more than 10%. The criteria were applied to the model results as described below.

To determine the limits of 10% conveyance in a cross-section, the depth was determined at which 10% of the flow was conveyed. This depth, averaged over several cross-sections, was found to be 0.2m (Howells et al, 2003). Thus the criteria used to determine the flood storage is:

- Depth greater than 0.2m
- Not classified as floodway.

All areas that were not categorised as Floodway or Flood Storage, but still fell within the flood extent, are represented as Flood Fringe.

The hydraulic categories for the 1% AEP and the PMF event are provided in **Figure 8-4** and **Figure 8-5**.

Property flooding in the 1% AEP event is largely categorised as flood storage or flood fringe. Developed areas are largely outside of floodways in the 1% AEP, save for properties adjacent to Boggy Creek Tributary on Millingandi Road in the north-west corner of the study area.

8.5 Impact of Hydraulic Structures on Flood Behaviour

There are four major hydraulic structures in the study area with the potential to influence flood behaviour. These structures are:

- Princes Highway bridge over Yellow Pinch Creek;
- Princes Highway bridge over Milingandi Creek;
- Princes Highway bridge over Bald Hills Creek; and,
- Reid Street Bridge over Merimbula Creek.

For each structure, an assessment was undertaken to determine the influence of structure blockage on flood behaviour for the 10% AEP and 1% AEP events. The assessment modelled the impact of 0%, 10%, 20% and 30% blockage rates on flood behaviour at the structure.

8.5.1 Princes Highway Bridge over Yellow Pinch Creek

The Princes Highway Bridge over Yellow Pinch Creek is a single span bridge, with a height of approximately 8m above the creek bed level. The bridge is constructed on piers that are 15m apart. The creek and overbank areas are highly vegetated with both established trees and ground level species along the length of the creek.

The bridge is located in the upper reaches of the catchment, immediately upstream of the confluence of Yellow Pinch Creek with Merimbula Creek.

For both the 10% AEP and the 1% AEP event, the blockage rate of the structure has very little impact on flood levels. As the bridge has a significant unused conveyance area, even in large events, the loss of capacity as a result of blockage resulted in minor level increases upstream, but did not affect the volume of flow through the bridge. As such, no impacts were observed downstream.

With the highest blockage level assessed, the bridge roadway still remains flood free in the 1% AEP event.

8.5.2 Princes Highway Bridge over Millingandi Creek

The Princes Highway Bridge over Millingandi Creek is an 85m long structure with a height of 8 – 12m between ground level and the bridge soffit. The bridge is constructed on piers that are 17m apart.

As with the Yellow Pinch Creek Bridge above, the bridge has a significant unused conveyance area, even in large events. For the Millingandi Bridge, there remains a 5m clearance between the bridge and the peak PMF level. No impacts were observed downstream of the bridge in either the 10% AEP or 1% AEP events. There were some minor increases observed upstream of less than 0.05m for both events, which were localised and were contained to open space areas.

With the highest blockage level assessed, the bridge remains flood free in the 1% AEP event.

8.5.3 Princes Highway Culverts at Millingandi Road

The Princes Highway crossing of Boggy Creek near Millingandi Road is comprised of three 3.6m by 2.7m concrete box culverts. The Princes Highway is elevated approximately 3m above the channel invert. Flows through the culvert are highly influenced by the downstream water level in Merimbula Creek. The elevated highway results in ponding of upstream flows occurring behind the roadway.

The terrain upstream of the Princes Highway has relatively high grades, which results in relatively small changes in flood extents for changes in flood height. Upstream of the highway, the PMF is 1m higher than the 1% AEP, but the flood extent only expands by 10 – 12m. The PMF extent is fully contained within the channel and overbank regions, and does not impact development.

In both the 10% AEP and the 1% AEP events, the downstream levels remained controlled by the levels in Merimbula Lake and were not affected by changes in the culvert blockage rate.

Upstream of the culvert in the 10% AEP event, there were increases of 0.1m between the unblocked scenario and the 30% blockage scenario. This impact did not affect developed areas, and the Highway remained flood free, even under the high blockage scenario.

In the 1% AEP, Highway overtopping depths increased by 0.14m between the unblocked scenario and the 30% blockage scenario. The 5hr period of inundation over the highway was not affected by the blockage rate, and the time when the access was first lost remained the same; only the peak was affected by the blockage.

The peak overtopping depth in the 30% AEP was 0.18m. Based on the velocity across the highway, an overtopping depth of 0.2m is safe for vehicles, so while driving through flood waters is not recommended, access along the Princes Highway may be available for emergency vehicles even when blockage occurs.

8.5.4 Reid Street Bridge over Merimbula Creek

Reid Street crosses Merimbula Creek immediately downstream of the Sapphire Valley Caravan Park, and immediately upstream of the Berrambool Sports Field. The bridge spans 41m, with a single pier in the centre and a clearance of approximately 6 – 7m above the channel invert.

For both the 10% AEP and the 1% AEP, blockage rates had no impact on downstream flood behaviour. Localised reductions were observed immediately adjacent to the bridge, but these changes did not progress beyond 10m of the bridge. After this, the flooding remained controlled by levels in Back Lack.

Upstream of the bridge, blockage of the bridge had some impact in both the 10% AEP and 1% AEP events.

In the 10% AEP event, there was no impact due to a 10% blockage rate, while levels increased by 0.12m between the unblocked scenario and the 30% blockage scenario. This increase affected some portions of the caravan park closest to the bridge with increases of up to 0.05m occurring, but the increases did not affect flood levels across the rest of the caravan park.

In the 1% AEP event, the observed impacts were greater with a difference of 0.3m at the bridge between the unblocked and 30% blocked scenarios. This increase resulted in increases of 0.05 – 0.10m occurring across much of the caravan park.

In the 1% AEP event, the 30% blockage scenario still had sufficient capacity to convey the upstream flows without overtopping Reid Street.

8.6 Assessment of Infrastructure Flood Risk

Within the study area is infrastructure that either plays a role during flood events (such as SES, Police, Fire Brigade) or developments that are likely to house high risk residents (such as aged care facilities and schools). The infrastructure locations assessed as part of this study are provided in **Figure 8-6**. It should be noted that other properties not assessed as part of this study may also include high risk residents.

The flood affectation of these locations are summarised in **Table 8-2**.

Table 8-2 Flood Affectation of Key Infrastructure

Location	Flood Affectation
Emergency Responders	
Merimbula Police Station	The police station is located outside of the PMF extent and access from the station is not flood affected.
Merimbula Fire Station	The fire station is located outside of the PMF extent and access from the station is not flood affected.
SES	There are no SES facilities located within the study area.
Merimbula Ambulance Station	The ambulance station is located outside of the PMF extent and access from the station is not flood affected.
Merimbula Medical Centre	The centre is located outside of the PMF extent and access from the centre is not flood affected.

Location	Flood Affectation
Main Street Medical Centre	The centre is located outside of the PMF extent and access from the centre is not flood affected.
Hospitals	There are no hospitals located within the study area.
Marine Rescue Merimbula	The Marine Rescue site is first inundated in the 20% AEP event by depths of up to 0.6m. These depths increase to 1.1m in the 1% AEP and 1.3m in the PMF The duration of flooding is typically dependent on the tidal cycle of the lakes, with flood water receding as the tide drops. It is noted that the flooding of the boat access ramp will also impact the deployment of water rescue craft during a flood event. The impact of this on emergency response will be considered in the subsequent Floodplain Risk Management Study and Plan.
Schools	
Merimbula Public School	The school is located outside of the PMF extent and access from the school is not flood affected.
Merimbula-Tura Kindergarten	The kindergarten is located outside of the PMF extent and access from the school is not flood affected.
Aged Care Facilities	
Acacia Ponds	The Acacia Ponds retirement complex was classified as a high hazard zone in the 1% AEP and the PMF, and a low flood island in the emergency response classification. The site is first inundated in the 5% AEP event, although depths are low (0.02m). Depths of 0.16m occur in the 1% AEP, and increase further to 0.56m in the PMF. The duration of flooding is typically dependent on the tidal cycle of the lakes, with flood water receding as the tide drops.
Sewer Treatment	
Sewerage treatment plant	The treatment facility is located outside of the PMF extent. Access is lost in the PMF to the north along Arthur Kaine Drive towards Merimbula but remain open in the PMF to the south, towards Pambula.
Caravan Parks	
Merimbula Lake Holiday Park	The park is located outside of the PMF extent. Access along the Pacific Highway is lost in the PMF to the north, but remains open to the south towards Pambula.
Sapphire Valley Caravan Park	The caravan park experiences flooding at the edge of the site over internal roadways in the 20% AEP. Caravans and buildings are first affected in the 5% AEP event, with depths of 0.17m occurring onsite. These depths increase to 0.48m in the 1% AEP and to 2.23m in the PMF. The site is a high risk area as it operates as a low flood island, losing access along the driveway before the caravans themselves are inundated. The duration of flooding is typically dependent on the tidal cycle of the lakes, with flood water receding as the tide drops.

Location	Flood Affectation
Regional Airport	
Merimbula Airport	The airport runway only experiences overtopping in the PMF event, although flood water encroach right up to the runway edge in the 1% AEP event. The associated building and infrastructure are first inundated in the 2% AEP event by 0.02m. Flooding depths at buildings increase to 0.15m in the 1% AEP and 0.55m in the PMF event. Access is lost along Arthur Kaine Drive to the north in the PMF event and to the south in the 2% AEP event.
Princes Highway Culverts at Millingandi Road	
Princes Highway	In the 1% AEP the highway overtops for approximately 5 hours. Although driving through flood waters is not recommended, based on the depths expected across the highway, access along the Princes Highway may be available for emergency vehicles even when blockage occurs.

8.7 Flood Emergency Response Classification of Communities

Flood emergency response classification provides an indication of the relative vulnerability of the community and provides the NSW SES with valuable information in managing emergency responses to flood events.

The classifications for the PMF event are shown in **Figure 8-7**.

The classification has been undertaken in accordance with the floodplain risk management guideline 'Flood Emergency Response Planning Classification of Communities' (DECC 2007).

The Flood Emergency Response Planning Classifications are:

- High Flood Island – region not inundated by the PMF, but which is surrounded by floodwaters
- Low Flood Island – region is first surrounded, and then impacted by flooding in the PMF
- High Trapped Perimeter – region is not inundated by the PMF but access may be restricted
- Low Trapped Perimeter – region is first isolated, and then impacted by flooding in the PMF
- Overland Escape Route – region and access impacted by PMF. People can escape rising flood waters by moving overland to higher ground
- Rising Road Access – regions where access roads rise steadily to flood free ground and allow egress as flood waters rise
- Indirectly Affected Areas – regions that are outside the flood limit that retain access throughout the event

The classifications may be further revised based on the results of the true hazard assessment undertaken as part of the future Floodplain Risk Management Study and Plan.

9 Climate Change Assessment

Climate change scenarios incorporating a 0.4m and a 0.9m rise in sea levels were modelled for the 1% AEP event, representing 2050 and 2100 climatic conditions.

The assessment examined the impacts on both tidal extents and flood behaviour.

The changes in flood behaviour are summarised in **Table 9-1**.

The results show that flooding increases vary significantly across properties. Those properties near the lake edges are most prone to affectation by sea level rises, while the impacts are reduced for those properties located further upstream. While the average flood increase across affected properties was 0.22m in 2050 and 0.45m in 2100, peak impacts were almost double these heights; 0.38m and 0.87m in 2050 and 2100 respectively.

Sea level rise was found to result in an additional 20 lots being inundated in 2050 and 27 in 2100. It should be noted that this assessment was based on cadastral boundaries and these increases may not result in similar increases in the incidence of overfloor flooding. A more comprehensive assessment of overfloor flooding will be undertaken in the Floodplain Risk Management Study as part of the subsequent stage of the Floodplain Management Process.

Table 9-1 Changes in property flooding as a result of climate change

	2050	2100
% of properties currently affected by flooding with increased flood levels	68%	74%
Additional lots experiencing flooding	20	27
Maximum flood level increase (m)	0.38	0.87
Average increase for affected properties (m)	0.22	0.45
25th percentile increase for affected properties (m)	0.23	0.30
75th percentile increase for affected properties (m)	0.24	0.32

9.1.2 Impact of Climate Change on Entrance Management

Sea level rise as a result of climate change is expected to result in changes to the Back Lake entrance. Current predictions are that the entrance berm will rise in line with the sea level (Haines & Thom, 2014). As a result, the entrance is predicted to be 0.4m higher in 2050 and 0.9m higher in 2100.

This change in entrance level does not necessitate a change in entrance management, and the current trigger level would still be required in order to prevent inundation of properties.

Maintaining the existing trigger level does have some consequences. If the same trigger level is maintained:

- The maximum level in the system remains the same.
- There will be a reduced head difference between creek water levels and ocean water levels at the time of breakout, which will result in less sand being scoured from the entrance.
- The entrance will require more frequent openings, as the trigger level would be reached sooner.
- The entrance will be more difficult to keep open, as a result of the reduced scour.

The Floodplain Risk Management Study and Plan, prepared as part of the next stage of the Floodplain Management Process, will comment further on the Back Lake entrance, and how potential mitigation options may allow for alternative entrance management procedures.

10 Flood Planning Level Review

10.1 Background

The Flood Planning Level (FPL) for the majority of areas across New South Wales has been traditionally based on the 1% AEP flood level plus a freeboard. The freeboard for habitable floor levels is generally set between 0.3 – 0.5m for residential properties, and can vary for industrial and commercial properties.

A variety of factors are worthy of consideration in determining an appropriate FPL. Most importantly, the flood behaviour and the risk posed by the flood behaviour to life and property in different areas of the floodplain and different types of land use need to be accounted for in the setting of an FPL.

The Floodplain Development Manual (NSW Government, 2005) identifies the following issues to be considered:

- Risk to life;
- Long term strategic plan for land use near and on the floodplain;
- Existing and potential land use;
- Current flood level used for planning purposes;
- Land availability and its needs;
- FPL for flood modification measures (levee banks etc.);
- Changes in potential flood damages caused by selecting a particular flood planning level;
- Consequences of floods larger than the flood planning level;
- Environmental issues along the flood corridor;
- Flood warning, emergency response and evacuation issues;
- Flood readiness of the community (both present and future);
- Possibility of creating a false sense of security within the community;
- Land values and social equity;
- Potential impact of future development on flooding;
- Duty of care.

These issues are dealt with collectively in the following sections.

10.2 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;
- 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.

The Guideline states that, unless there are exceptional circumstances, councils should adopt the 1% AEP flood as the FPL for residential development. The need for another FPL to be adopted would be based on an assessment local flood behaviour, flood history, associated flood hazards or a particular historic flood.

10.3 Likelihood of Flooding

As a guide, **Table 10-1** has been reproduced from the NSW Floodplain Development Manual (2005) to indicate the likelihood of the occurrence of an event in an average lifetime to indicate the potential risk to life.

Analysis of the data presented in **Table 10-1** gives a perspective on the flood risk over an average lifetime. The data indicates that there is a 50% chance of a 1% AEP event occurring at least once in a 70 year period. Given this potential, it is reasonable from a risk management perspective to give further consideration to the adoption of the 1% AEP flood event as the basis for the FPL. Given the social issues associated with a flood event, and the non-tangible effects such as stress and trauma, it is appropriate to limit the exposure of people to floods.

Note that there still remains a 30% chance of exposure to at least one flood of a 0.5% AEP magnitude over a 70 year period. This gives rise to the consideration of the adoption of a rarer flood event (such as the PMF) as the flood planning level for some types of development.

Table 10-1 Probability of Experiencing a Given Size Flood or Higher in an Average Lifetime (70yrs)

Likelihood of Occurrence in any year (AEP)	Probability of experiencing at least one event in 70 years (%)	Probability of experiencing at least two events in 70 years (%)
10%	99.9	99.3
5%	97	86
2%	75	41
1%	50	16
0.5%	30	5

10.4 Risk to Life

Flooding in the Merimbula and Back Lakes region poses a significant risk to life for the community. Large flood events result in the creation of low flood islands, and the loss of road access for pockets within the region.

These risks increase with flood severity. Unless the PMF is adopted as the FPL, there will be a residual flood risk within the community, even if all development is built at the FPL.

The community should be helped to understand that adhering to flood development controls does not mean that they are free of flood risk. Strategies to increase community engagement and awareness will be developed as part of the future Floodplain Risk Management Study and Plan.

10.5 Land Use and Planning

The hydrological regime of the catchment can change as a result of changes to the land-use, particularly with an increase in the density of development. The removal of pervious areas in the catchment can increase the peak flow arriving at various locations, and hence the flood levels can be increased. However, as the catchment areas are currently largely fully developed for their land use, it is unlikely that the study area will see a significant increase in impervious area as a result of future development.

A potential impact on flooding can arise through the intensity of development on the floodplain, which may either remove flood storage or impact on the conveyance of flows. In general, *DCP 2013* limits development in flood prone regions to development types that are suited to the flood behaviour such that impacts on flood behaviour are minimised.

Given this, land use and planning is not considered to be a significant issue with regard to setting the FPL within the catchment.

To assist in minimising the impact of development on flooding, it would be recommended to control development such that any increase in impervious area is countered by appropriate use of on-site detention. However, it is noted that the use of on-site detention in this catchment may be of limited use given the occurrence of lake driven flooding events, upon which OSD will have no effect.

10.6 Changes in Potential Flood Damages between Flood Events

For assessing the damage cost differential between design events, a typical overfloor flood damage of $50,000 for a property was assumed. This damage amount represents damages caused by overfloor flooding depths of 0.5m, based on the OEH residential damage curves. The incremental difference in Annual Average Damage (AAD) for overfloor flooding occurring in different recurrence intervals is shown in **Table 10-2**. The table shows the AAD of a given property that experiences overfloor flooding in each design event, and the net present value (NPV) of those damages over 50 years at 7%.

Table 10-2 indicates that the largest incremental difference between AAD per property occurs between the more frequent events. The greatest difference between damages occurs between the 50% and 20% AEP events. It can be seen that the differences between the 5% and 1% AEP event, and the 1% AEP event and the PMF are relatively small, suggesting that increasing the FPL beyond the 5% AEP level does not significantly alter the savings achieved from a reduction in damages.

Table 10-2 Differential Damage Costs between AEP Events

Event (AEP)	AAD	Change in AAD	NPV of AAD	Change in NPV
50%	$25,000	-	$345,000	-
20%	$10,000	$15,000	$138,000	$207,000
10%	$5,000	$5,000	$69,000	$69,000
5%	$2,500	$2,500	$34,500	$34,500
1%	$1,000	$1,500	$13,800	$20,700
PMF	$500	$500	$6,900	$6,900

10.7 Incremental Height Differences Between Events

Consideration of the average height difference between various flood levels can provide another measure for selecting an appropriate FPL.

Based on the existing flood behaviour, the average and maximum incremental height differences between events is shown in **Table 10-3** for selected events. These are determined based on the maximum flood levels determined at each of the property lots within the catchment and *not* at the actual floor levels of the buildings on these properties.

Table 10-3 indicates that there is not a significant difference between 1% AEP event and the 2% AEP and 5% AEP events (on average 0.12m and 0.25m respectively). Therefore, the adoption of the 1% AEP event would provide an increased level of risk reduction over both the 2% AEP and the 5% AEP event without a significant increase in the flood planning level.

In contrast, the average PMF water level is 0.61m higher than the 1% AEP.

It should be noted that the assessment was undertaken using cadastral lots, as property survey data was not available. It is recommended that the assessment be repeated as part of Floodplain Risk Management Study and Plan once the property survey has been collected in order to remove open space and recreation lots from the assessment.

Table 10-3 Relative Differences Between Design Flood Levels

Event (AEP)	Difference to PMF Average / Maximum	Difference to 1% AEP Average / Maximum	Difference to 2% AEP Average / Maximum	Difference to 5% AEP Average / Maximum
1%	0.61m / 2.89m	-	-	-
2%	0.73m / 3.03m	0.12m / 0.64m	-	-
5%	0.86m / 3.10m	0.25m / 0.80m	0.13m / 0.48	-
20%	1.05m / 3.22m	0.44m / 1.09m	0.32m / 0.78	0.19m / 0.64

10.8 Consequence of Adopting the PMF as a Flood Planning Level

Analysis of the flood damages above indicates that the choice of the PMF event over the 1% AEP event as the FPL would result in limited economic benefits (in annualised terms) to the community.

Although the average difference in peak flood levels between the 1% AEP and the PMF event was 0.61m, the difference at some locations within the study area was up to 2.89m difference between these events. In these locations where there is a large difference between the 1% AEP and the PMF, adopting the PMF as the FPL would result in higher economic costs and inconvenience to the community. In addition, the incremental AAD per building from the 1% AEP to the PMF is relatively low.

Given this, the economic costs may in fact outweigh the benefits of using the PMF event as the FPL. The use of the PMF level as the FPL may also conflict with other development/building controls in Councils DCPs.

10.9 Environmental and Social Issues

The FPL can result in housing being placed higher than it would otherwise be. This can lead to a reduction in visual amenity for surrounding property owners, and may lead to encroachment on neighbouring property rights. This may also cause conflict with other development controls already present within the Council's development assessment process.

10.10 Consequences of Flooding

The selection of an appropriate FPL also depends on the potential consequences of flooding on different development types. For example, consideration could be given for different FPLs for industrial, commercial and residential properties, which have different implications should overfloor flooding occur.

Vulnerable infrastructure, such as hospitals, fire stations and electricity sub-stations have wider spread implications should inundation occur. As such, FPLs are typically selected for these types of structures higher than for residential, commercial or industrial properties.

10.11 Climate Change

Sea level rise associated with climate change, is projected to increase flood levels and the extent of floodwaters over coastal floodplains. As sea levels rise, a FPL based on the existing 1% AEP flood event will become progressively less effective in providing the same level of protection against flood events as in the present day.

The 2009, NSW Government Sea Level Rise Policy required that Council consider, as a minimum, 0.40m sea level rise by 2050 and 0.90m rise by 2100. The NSW Government Sea Level Rise Policy has now been repealed by the State Government which now encourages each council to adopt their own sea level rise projections. Gosford Council has adopted values in its DCP that are in accordance with the repealed NSW Government Policy (i.e. 0.4m and 0.9m).

Climate change impacts were found to vary significantly across the study area. The greatest impacts were observed at the entrance and lake foreshores, with impacts reducing further up the catchment.

As a result of this variability, it is recommended that Council consider incorporating climate change in the FPL through adjustment to the design flood level rather than including an allowance for climate change within the freeboard. This may involve the following scenarios:

- Current 1% AEP level plus freeboard for minor extensions to existing development
- 2050 1% AEP level plus freeboard for major extensions and new single developments
- 2100 1% AEP plus freeboard for subdivisions and multi-dwelling developments.

As this Flood Study has not undertaken detailed climate change modelling for all sea level conditions, entrance conditions and various rainfall patterns, it is recommended that as an interim, Council allow for the uncertainty of the impacts of climate change on flood levels within the freeboard.

More comprehensive modelling of climate change scenarios may be undertaken as part of the Floodplain Risk Management Study to better inform planning levels.

10.12 Freeboard Selection

The freeboard may account for factors such as:

- Changes in the catchment;
- Changes in the creek/channel vegetation;
- Accuracy of model inputs (e.g. accuracy of ground survey, accuracy of design rainfall inputs for the area);
- Model sensitivity;
- Local flood behaviour (e.g. due to local obstructions etc.);
- Wave action (e.g. wind-induced waves or wash from vehicles or boats);
- Culvert blockage; and,
- Climate change (affecting ocean water levels and / or rainfall patterns and intensity).

The impact of typical elements factored into a freeboard can be summarised as follows:

- Afflux (local increase in flood level due to a small local obstruction not accounted for in the modelling) (0.1m) (Gillespie, 2005);
- Local wave action (allowances of ~0.1 m are typical) (truck wash etc.);
- Accuracy of ground/ aerial survey ~ +/-0.1m;
- Sensitivity of the model to sea level rise and changes in rainfall ~ +0.2m in 2050; and,
- Sensitivity of the model ~ +/-0.1m.

Based on this analysis, the total sum of the likely variations is in the order of 0.6m. This estimate is conservative as it assumes the maximum level of uncertainty for each element. As such, a more realistic freeboard of 0.5m is considered suitable for the study area.

It should be noted that the allowance for climate change is based on the average flood impacts for a 2050 planning horizon. For the 2100 scenario, there will be some locations along the lake foreshores that experience flood level increases of up to 0.88m. It is recommended that the flood planning level be revised in the future as additional climate change information becomes available in order to ensure that develop in the foreshore region is appropriate for the expected future flood levels.

Consequently, the recommended FPL for the study area is the 1% AEP + 0.5m or the PMF, whichever is the lower for a given location. The PMF has been taken as the maximum extent of flooding within the study area. Therefore, the lower of the two levels has been recommended to be used to prevent development being forced to build higher than the highest expected flood level to comply with FPL requirements.

The Flood Planning Area (FPA) resulting from this FPL is provided in **Figure 10-1**.

The FPA has also been trimmed to the PMF extents, as the PMF was taken to define the extent of the floodplain. Thus if properties are outside the PMF flood extent, they are taken to be flood free, even if floor levels are within 0.5m of the 1% AEP level.

10.13 Duty of Care

As noted above the adoption of the 1% AEP +0.5m level as the FPL for Merimbula and surrounding townships, while suitable, results in a residual flood risk for properties affected by the PMF. It is important that these properties be made aware of the residual risk, and that they are assisted in developing appropriate strategies to manage their safety during large flood events.

Strategies to increase community awareness and engagement will be investigated as part of the future Floodplain Risk Management Study and Plan.

11 Conclusions and Recommendations

Flood modelling has been undertaken for the Merimbula Lake and Back Lake catchment areas in the Bega Valley Shire LGA in order to determine the existing flood behaviour, as part of the NSW Floodplain Management Process.

Modelling was undertaken in XP-RAFTS and Delft3D, for the hydrological and hydraulic models respectively.

A range of sensitivity tests were undertaken to determine the influence of a number of model parameters on model outputs, namely:

- Catchment roughness;
- Sediment composition;
- The entrance condition; and,
- The adopted breaking wave coefficient.

The sensitivity assessment found that changes to model parameters had relatively small impacts on the majority of the study area, with all observed changes in peak flood levels within 0.1m.

The XP-RAFTS hydrological model was validated against an alternative runoff calculation using the Probalistic Rational Method from AR&R. The validation demonstrated a good correlation between estimated catchment flows from both calculation methods.

The hydraulic model was calibrated to both tidal and flood conditions based on recorded date from four historical events. The process demonstrated a good correlation between modelled and historical levels.

The validated models were used to asses a range of design events, namely:

- 20% AEP;
- 10% AEP;
- 5% AEP;
- 2% AEP;
- 1% AEP;
- 0.5% AEP; and,
- The Probable Maximum Flood (PMF)

Each event was run for a range of durations in order to determine critical durations for the study area. Peak water levels, depth and velocities, as well as provisional flood hazards and hydraulic categories were determined.

An assessment was undertaken to recommend an appropriate Flood Planning Level (FPA) for the study area. Based on a review of a number of factors including land uses, overfloor flooding damages in design events, and differences between design event levels, an FPA of the 1% +0.5m was recommended for the study area. This may be revised during the development of the Floodplain Risk Management Study and Plan for the study area following a detailed analysis of existing land use, future development and true hazard mapping.

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13 Qualifications

This report has been prepared by Cardno for Bega Valley Shire Council and as such should not be used by a third party without proper reference.

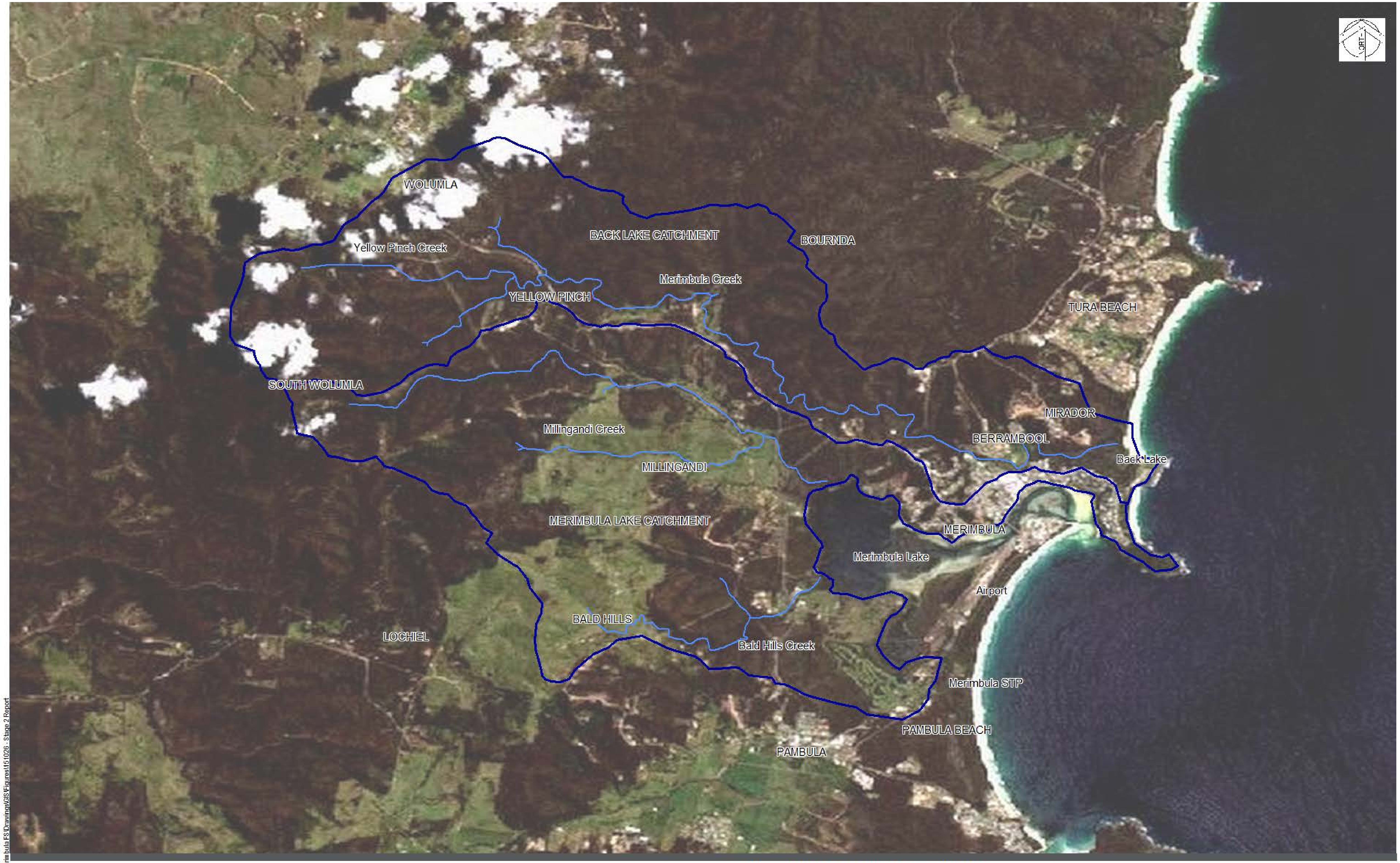
The investigation and modelling procedures adopted for this study follow industry standards and considerable care has been applied to the preparation of the results. However, model set-up and calibration depends on the quality of data available. The flow regime and the flow control structures are complicated and can only be represented by schematised model layouts.

Hence there will be a level of uncertainty in the results and this should be borne in mind in their application.

The report relies on the accuracy of the survey data provided.

Study results should not be used for purposes other than those for which they were prepared.

FIGURES



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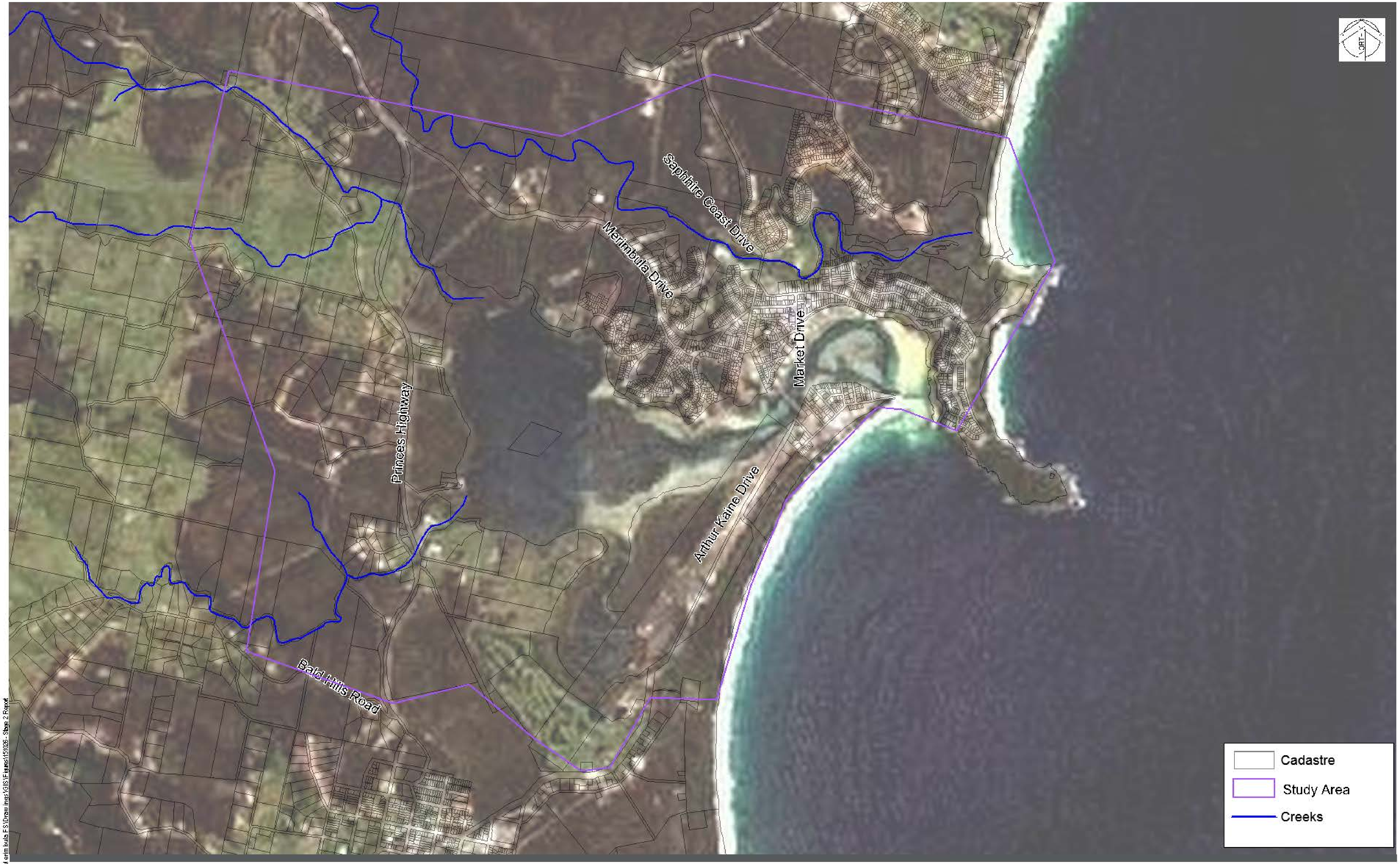
Cardno
Shaping the Future

BEGA VALLEY SHIRE COUNCIL

MERIMBULA & BACK LAKES FLOOD STUDY

CATCHMENT AREA

Date	Scale	Size
30/05/2016	1 : 50,000	A3
Figure 2-1		01
Drawing Number		Revision



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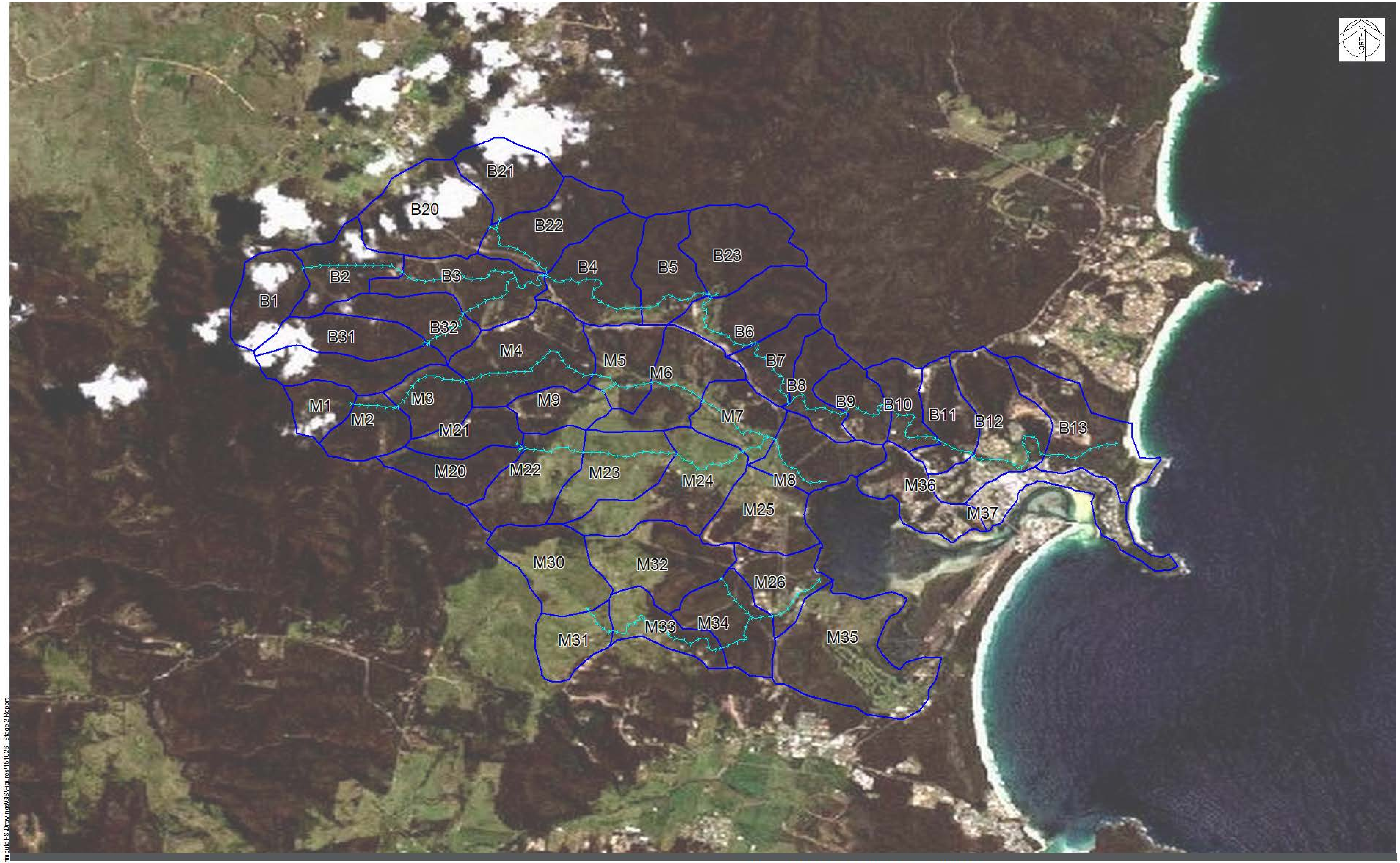
STUDY AREA

Date	Scale	Size
30/05/2016	1 : 30,000	A3

Drawing Number	Revision
Figure 2-2	01



Cardno
Shaping the Future

BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

XP-RAFTS SUBCATCHMENTS

Date	Scale	Size
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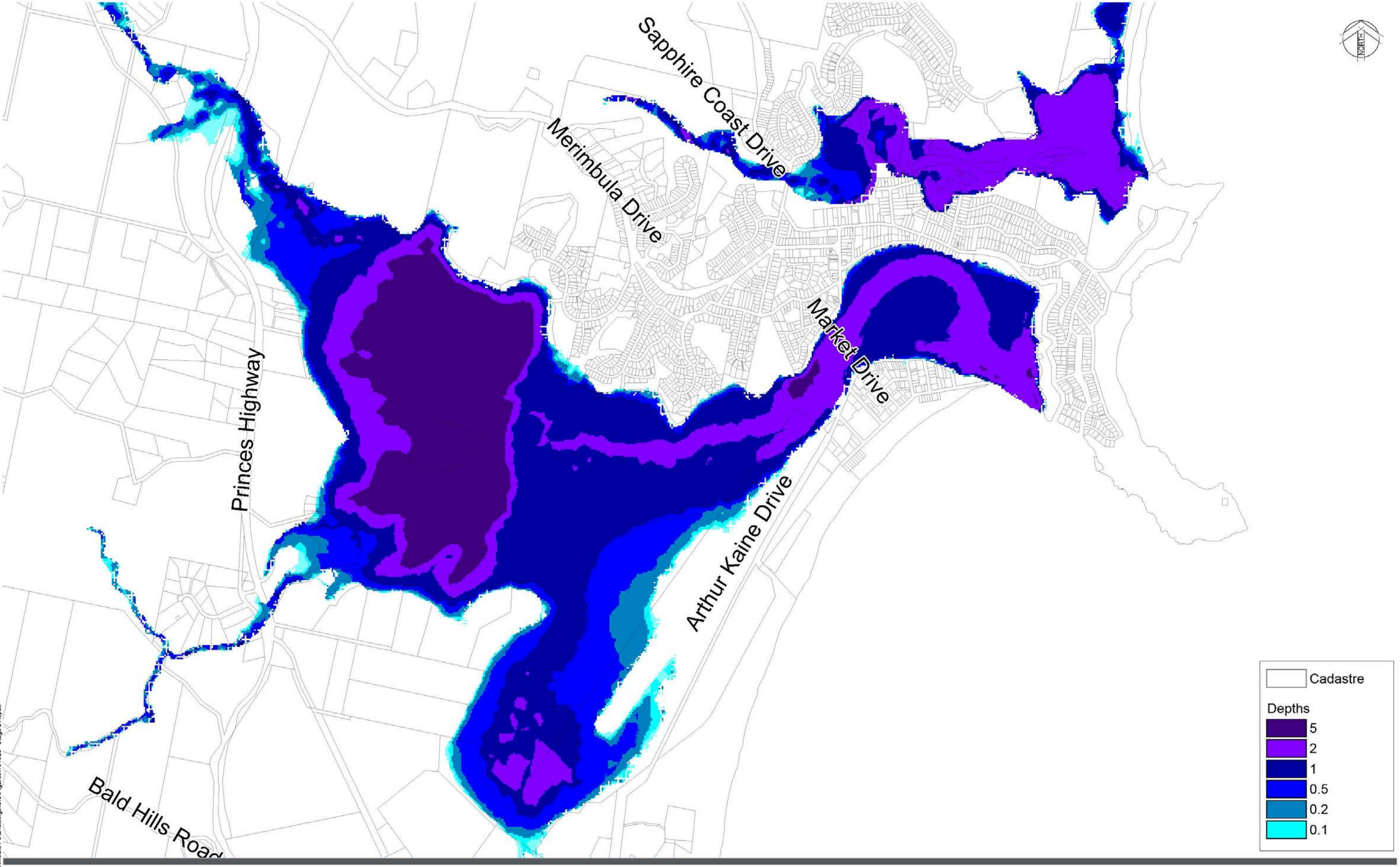
Figure 5-1		01
Drawing Number		Revision



BEGA VALLEY SHIRE COUNCIL

MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD DEPTH (M)
20% AEP

Date	Scale	Size	
30/05/2016	1 : 20,000	A3	
Figure 7-1		01	
Drawing Number		Revision	

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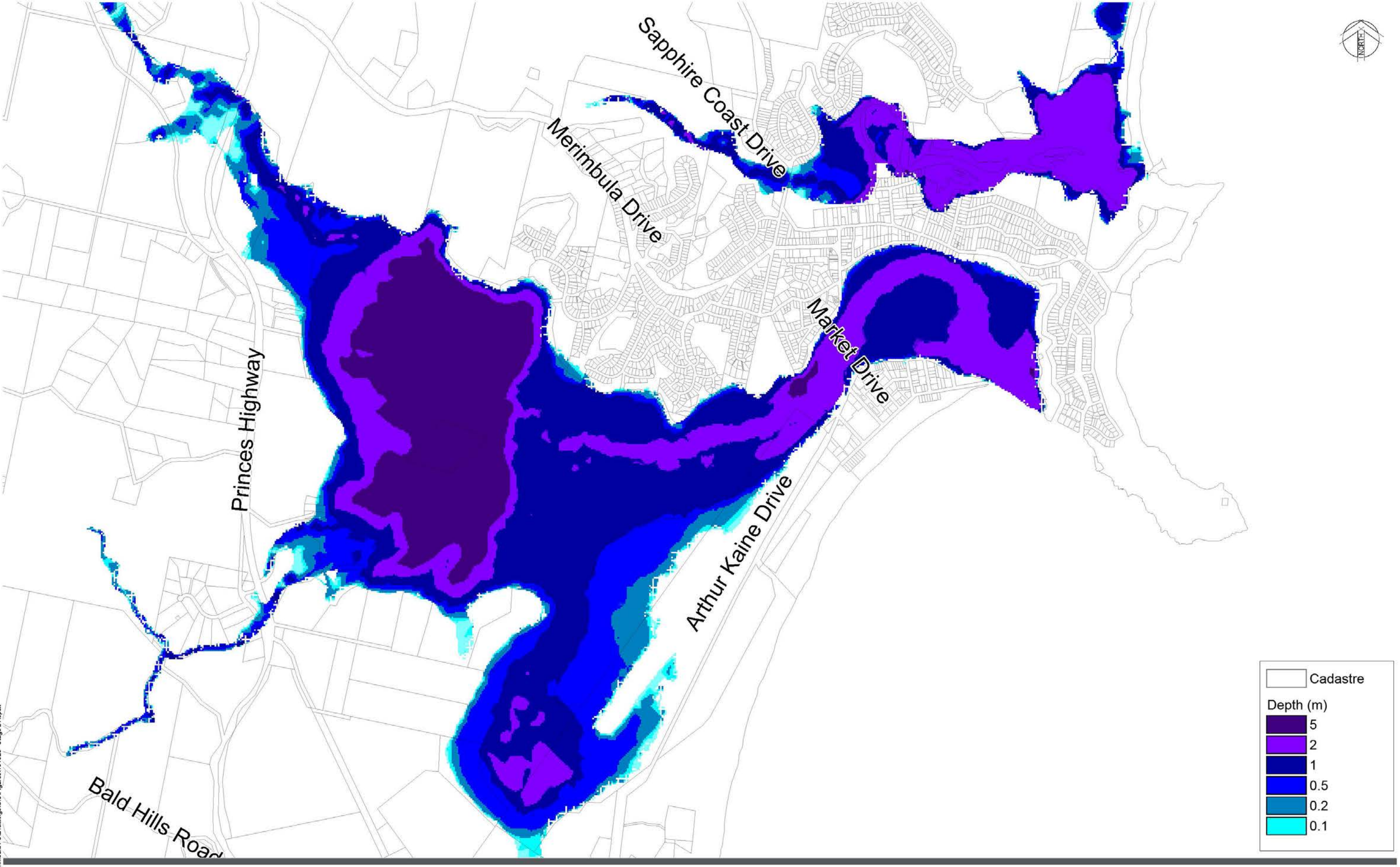
DATE PLOTTED: 26/10/2015 BY: Luke Evans
FILE: N:\Projects\599\FY15\100_Merimbula FS\Drawings\GIS\Figures\151026 - Stage 2 Report



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BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD DEPTH (M)
10% AEP

Date		Scale	Size
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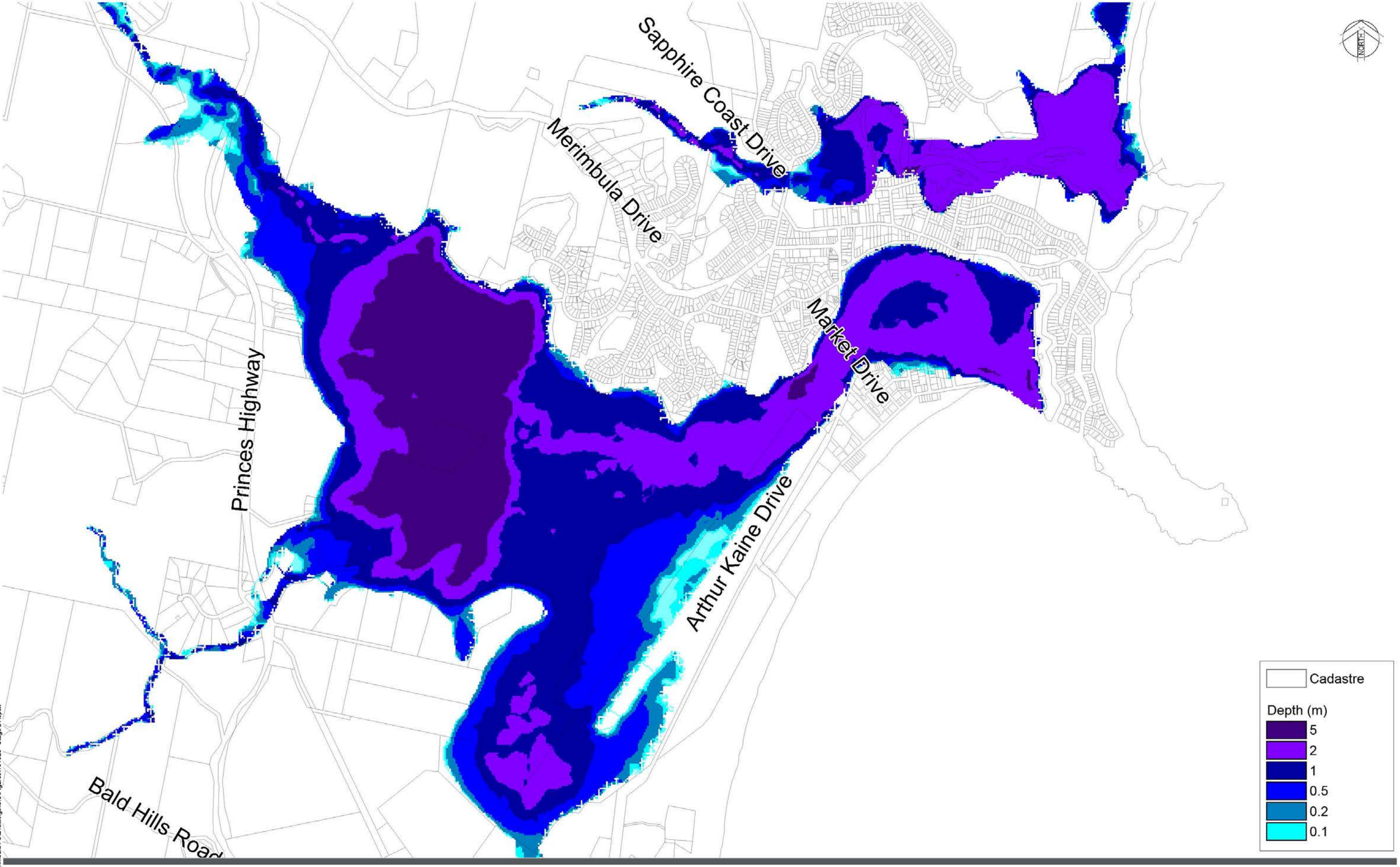
Figure 7-2			01
Drawing Number			Revision



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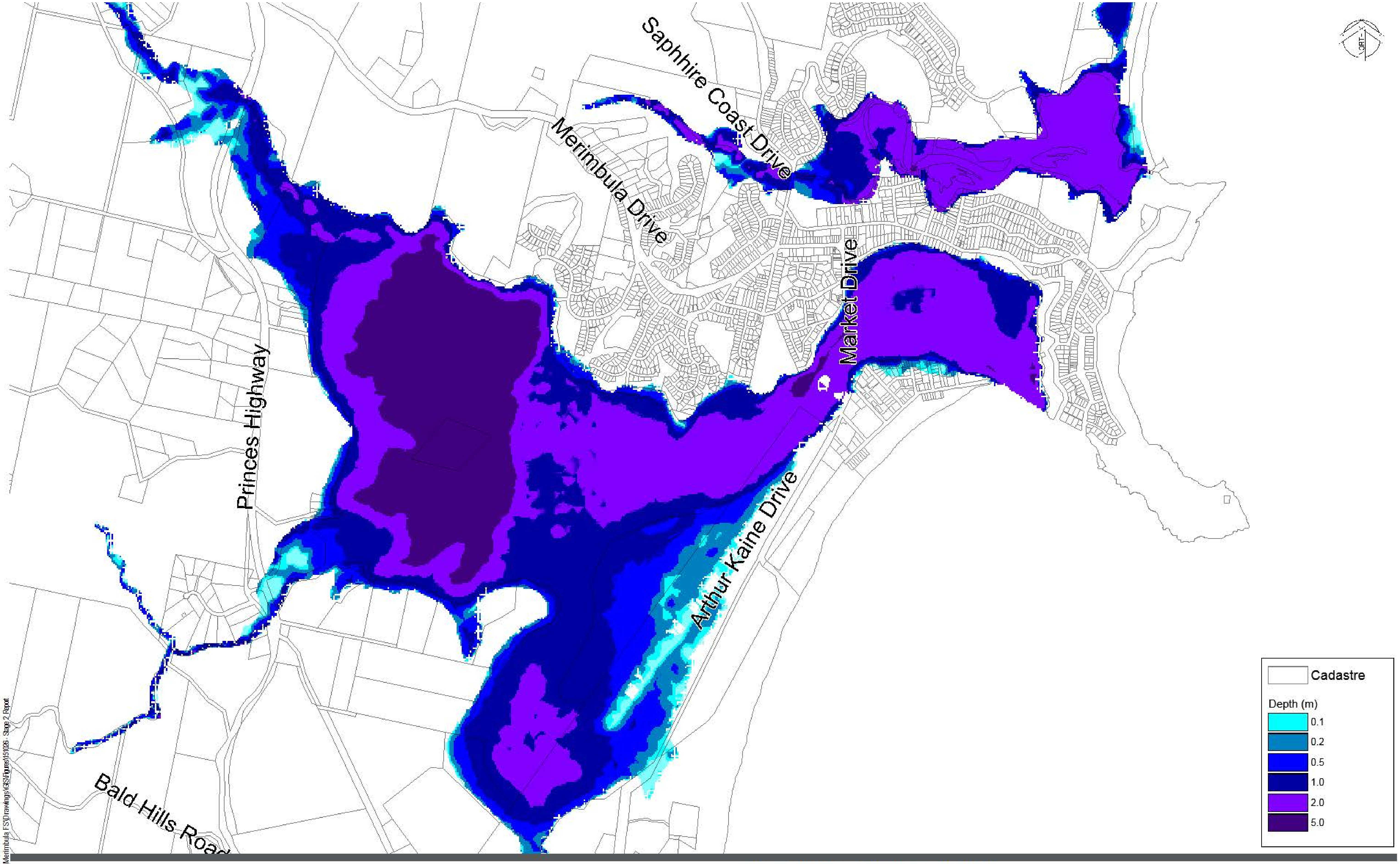
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD DEPTH (M)
5% AEP

Date	Scale	Size
30/05/2016	1 : 20,000	A3

Drawing Number	Revision
Figure 7-3	01



BEGA VALLEY SHIRE COUNCIL

MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD DEPTH (M)
2% AEP

Date	Scale	Size
30/05/2016	1 : 20,000	A3

Figure 7-4
Drawing Number

01
Revision

Cardno
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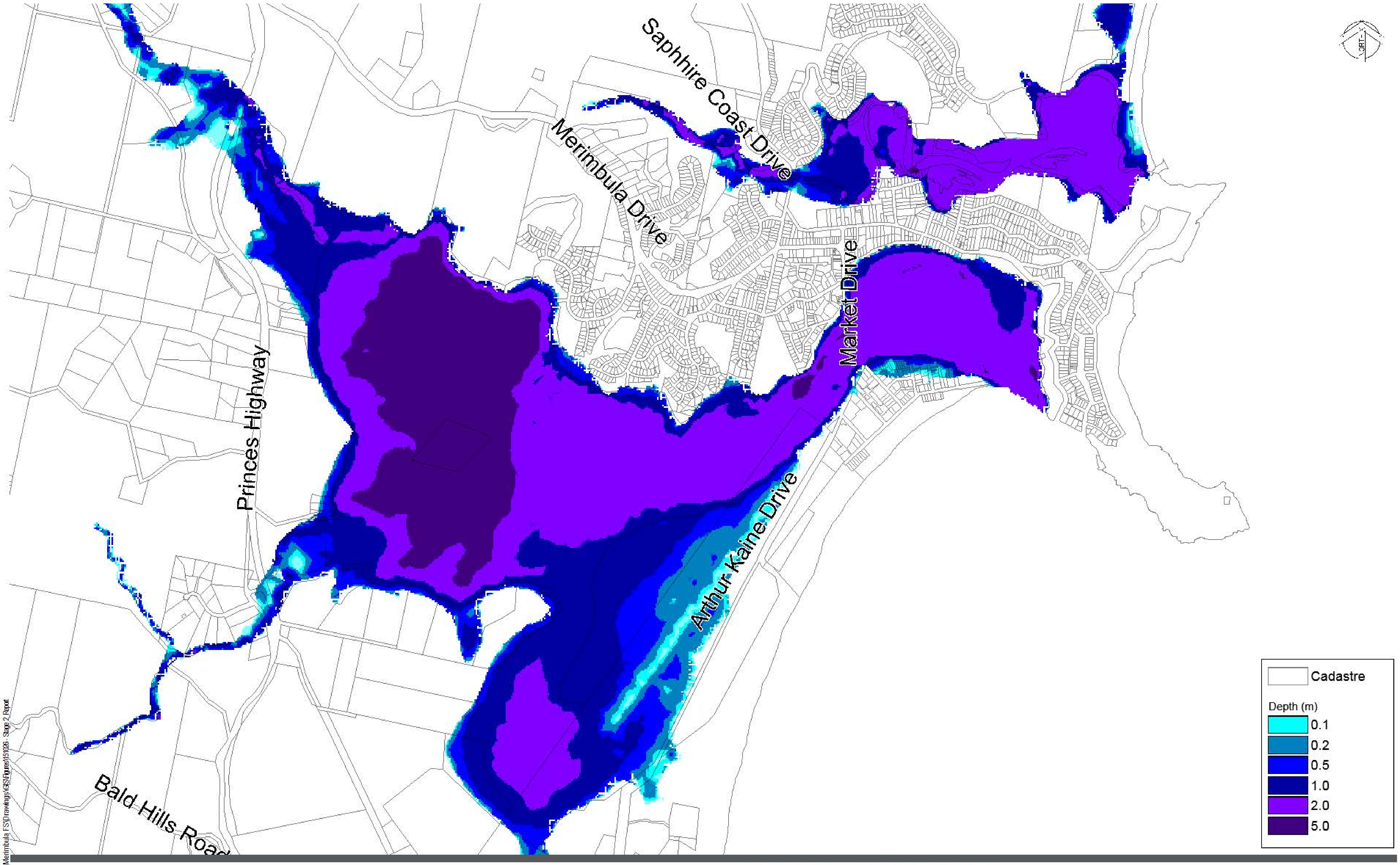

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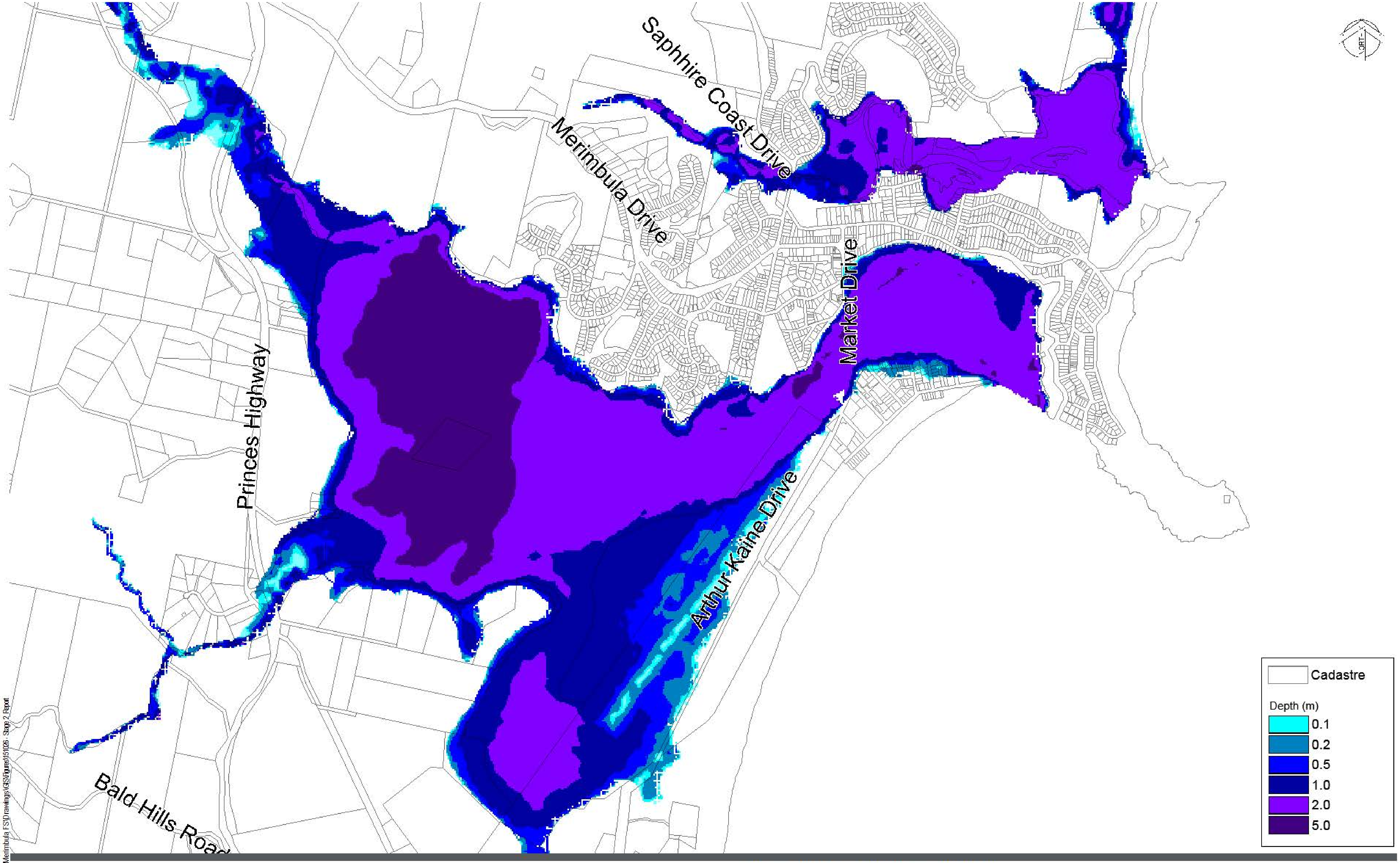
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD DEPTH (M)
1% AEP

Date	Scale	Size
30/05/2016	1 : 20,000	A3

Drawing Number	Revision
Figure 7-5	01



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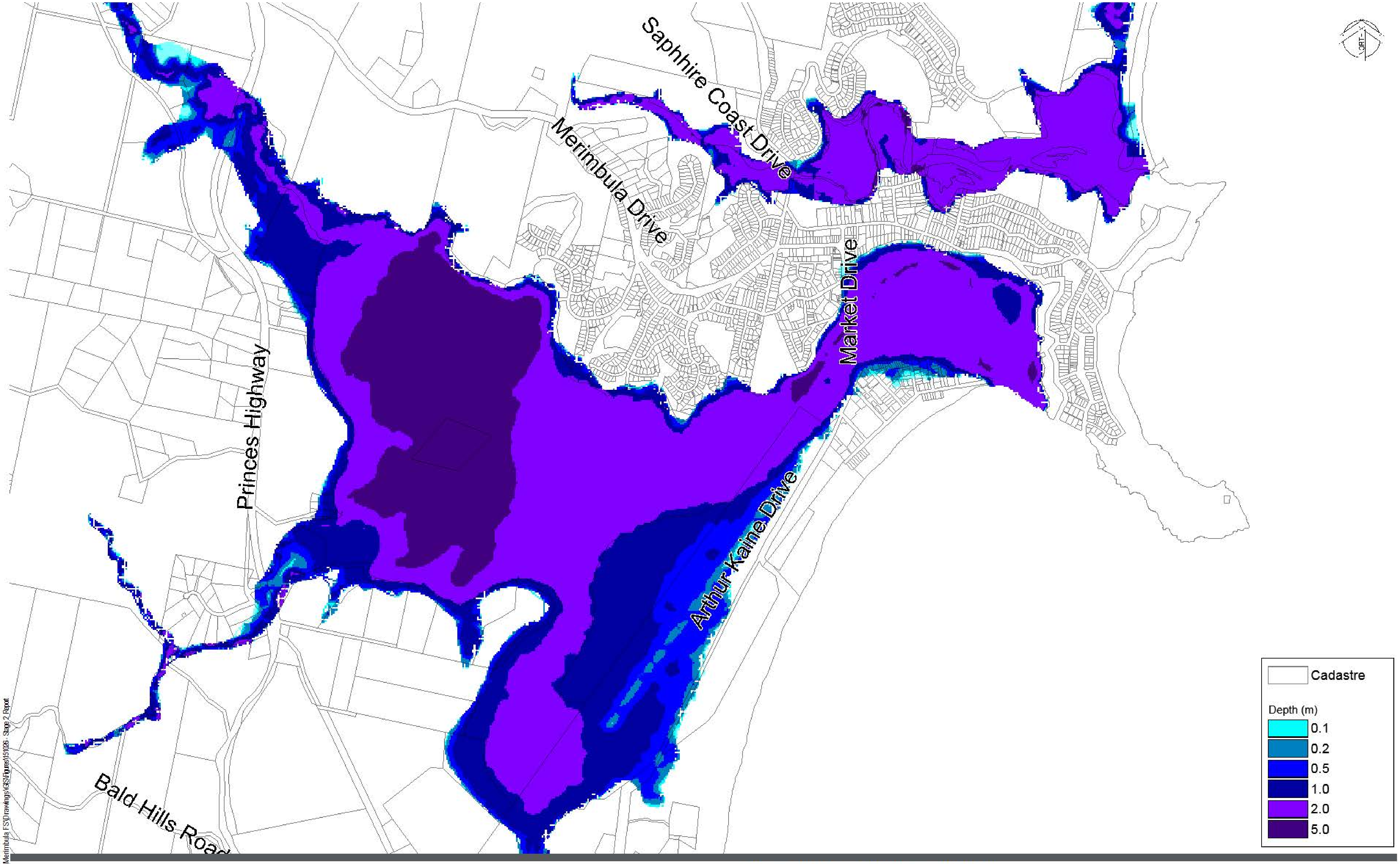
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD DEPTH (M)
0.5% AEP

Date	Scale	Size
30/05/2016	1 : 20,000	A3

Figure 7-6
Drawing Number

01
Revision



BEGA VALLEY SHIRE COUNCIL

MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD DEPTH (M)
PMF

Date	Scale	Size
30/05/2016	1 : 20,000	A3

Figure 7-7
Drawing Number

01
Revision

Cardno
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DATE PLOTTED : 26/10/2015 BY: Luke Evans
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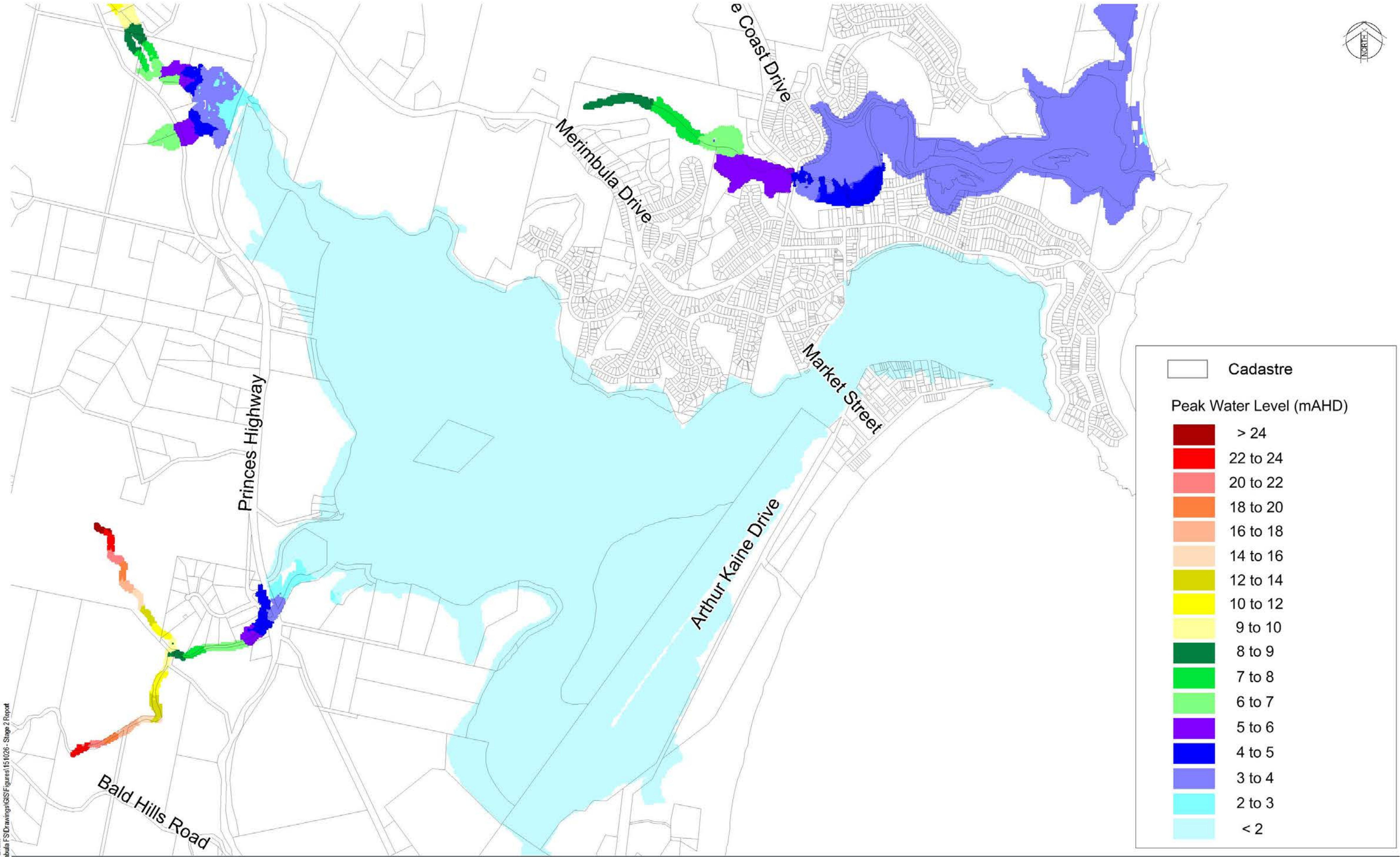

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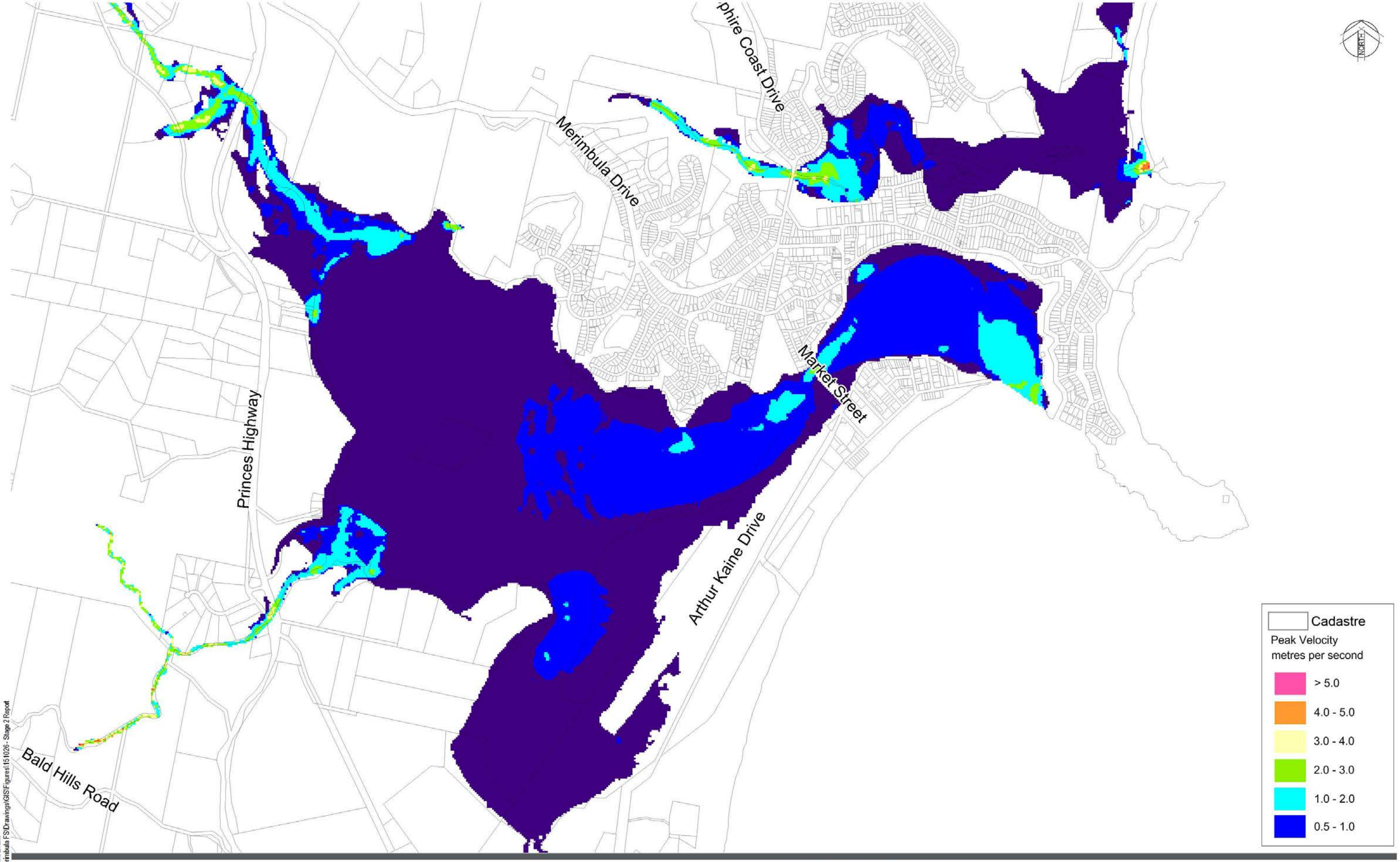
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD WATER LEVEL (MAHD)
1% AEP

Date	Scale	Size
30/05/2016	1 : 20,000	A3

Figure 7-8
Drawing Number

01
Revision



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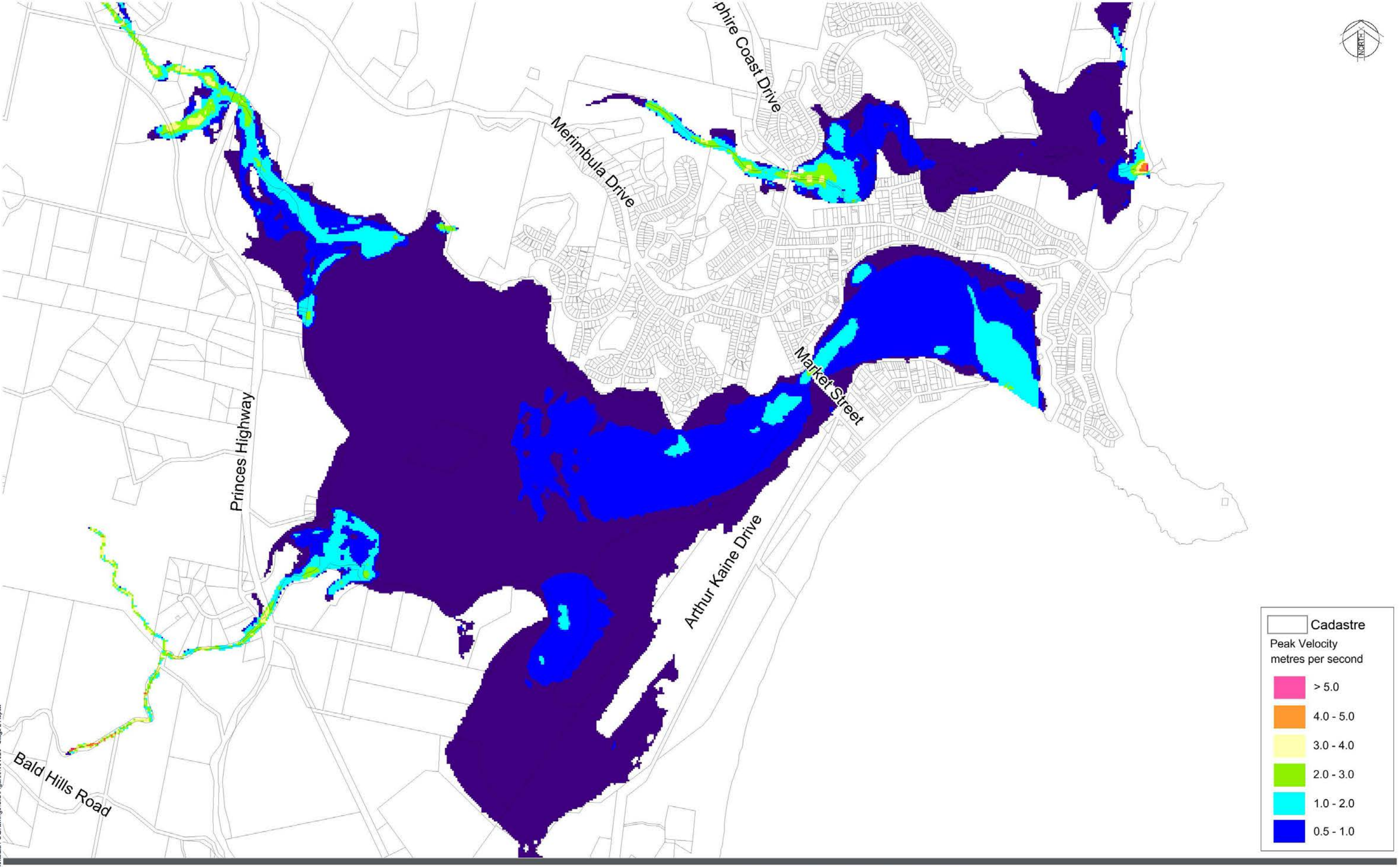
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD VELOCITY (M/S)
20% AEP

Date	Scale	Size
30/05/2016	1 : 20,000	A3
Figure 7-9 Drawing Number		01 Revision



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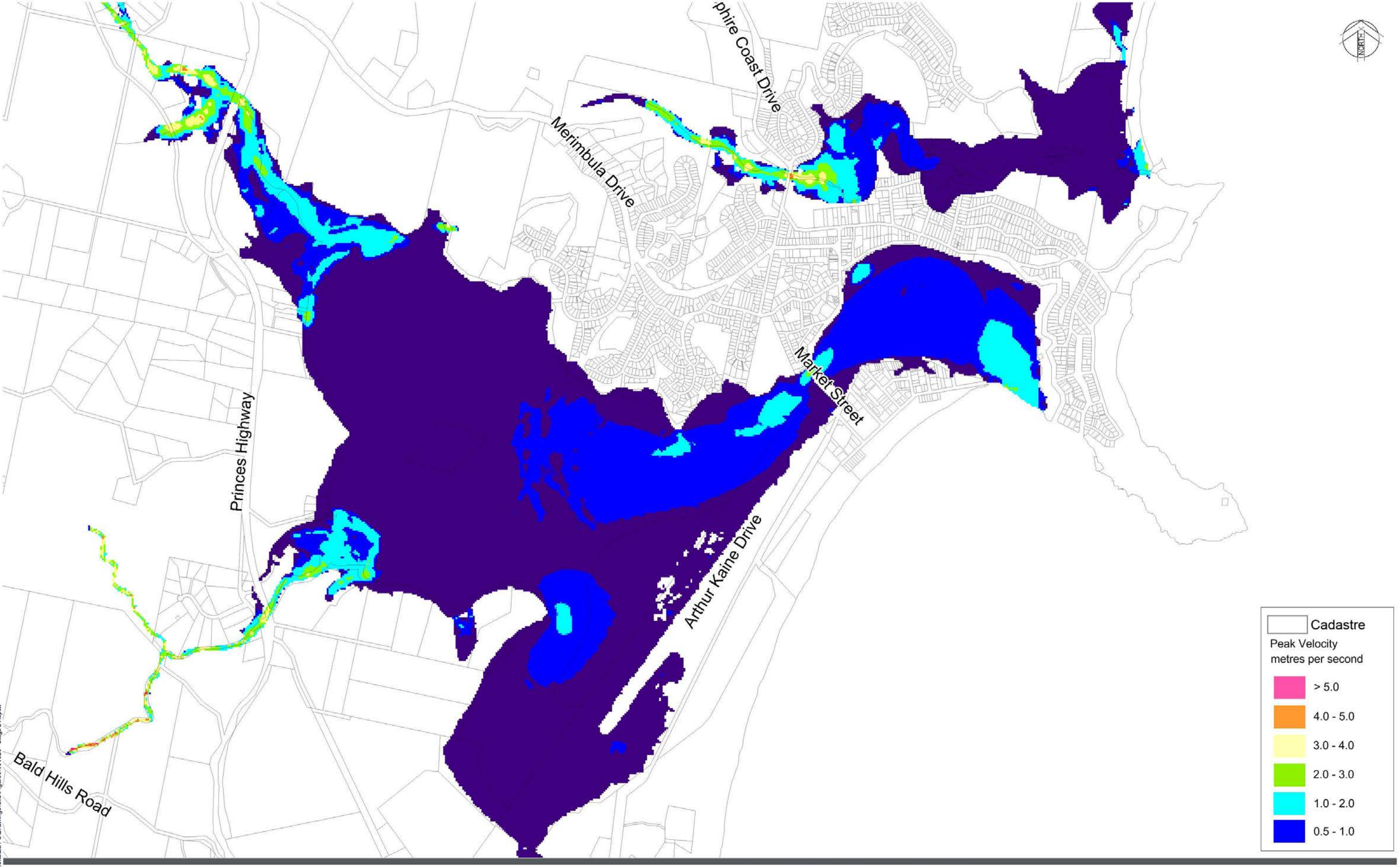
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD VELOCITY (M/S)
10% AEP

Date	Scale	Size
30/05/2016	1 : 20,000	A3
Figure 7-10		01
Drawing Number		Revision



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BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD VELOCITY (M/S)
5% AEP

Date	Scale	Size
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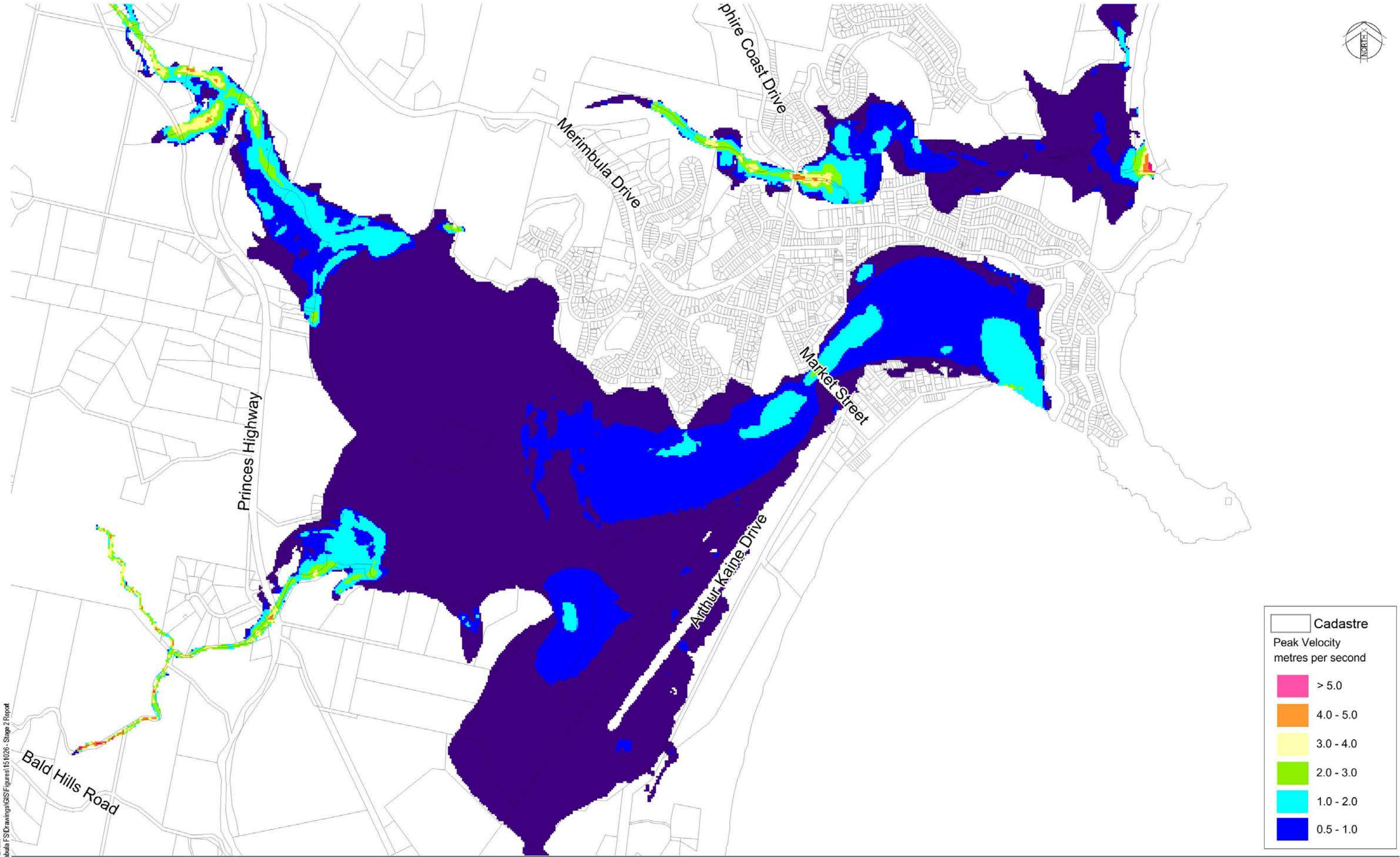
Figure 7-11 Drawing Number		01 Revision



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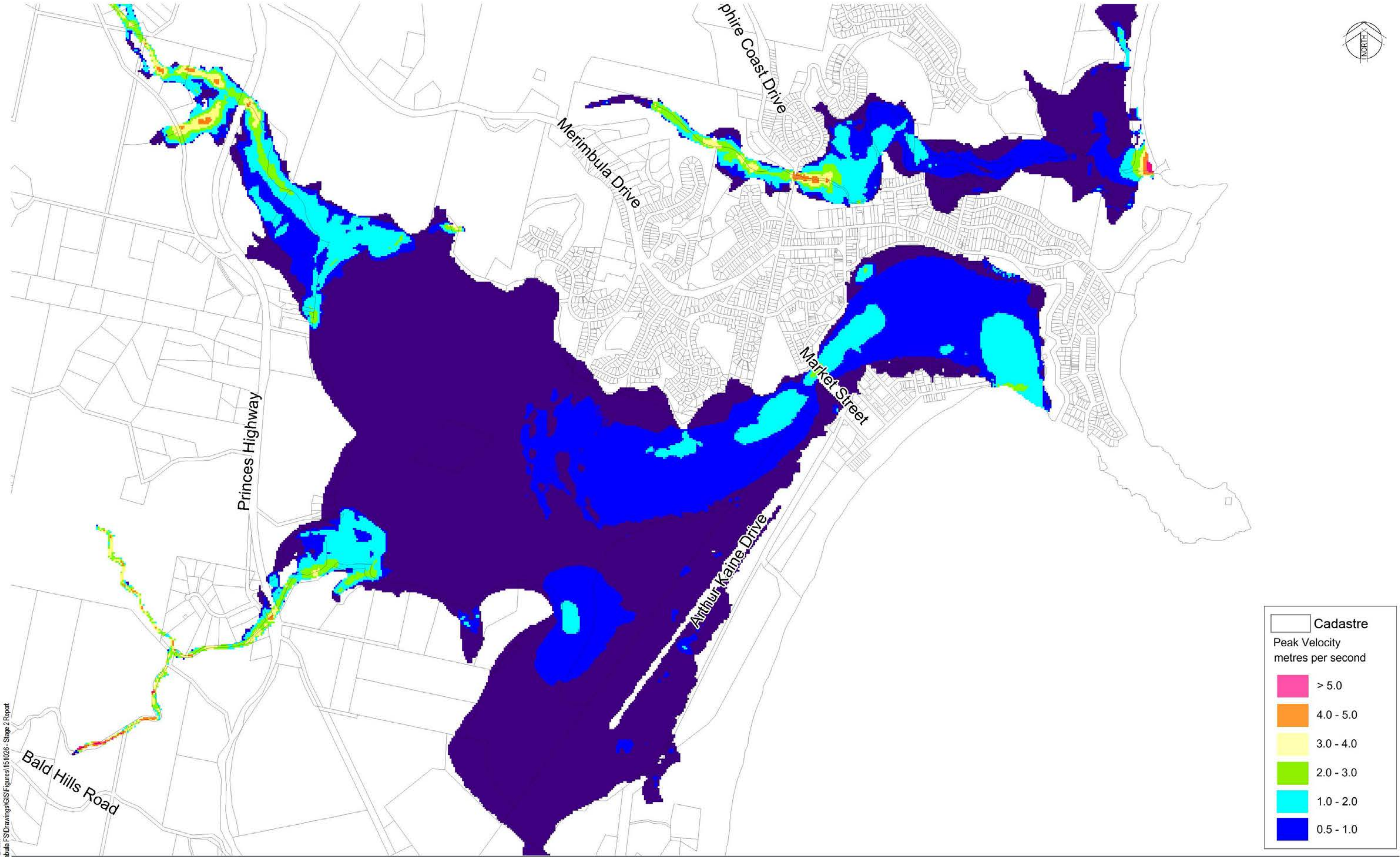
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD VELOCITY (M/S)
2% AEP

Date	Scale	Size
30/05/2016	1 : 20,000	A3
Figure 7-12		01
Drawing Number		Revision



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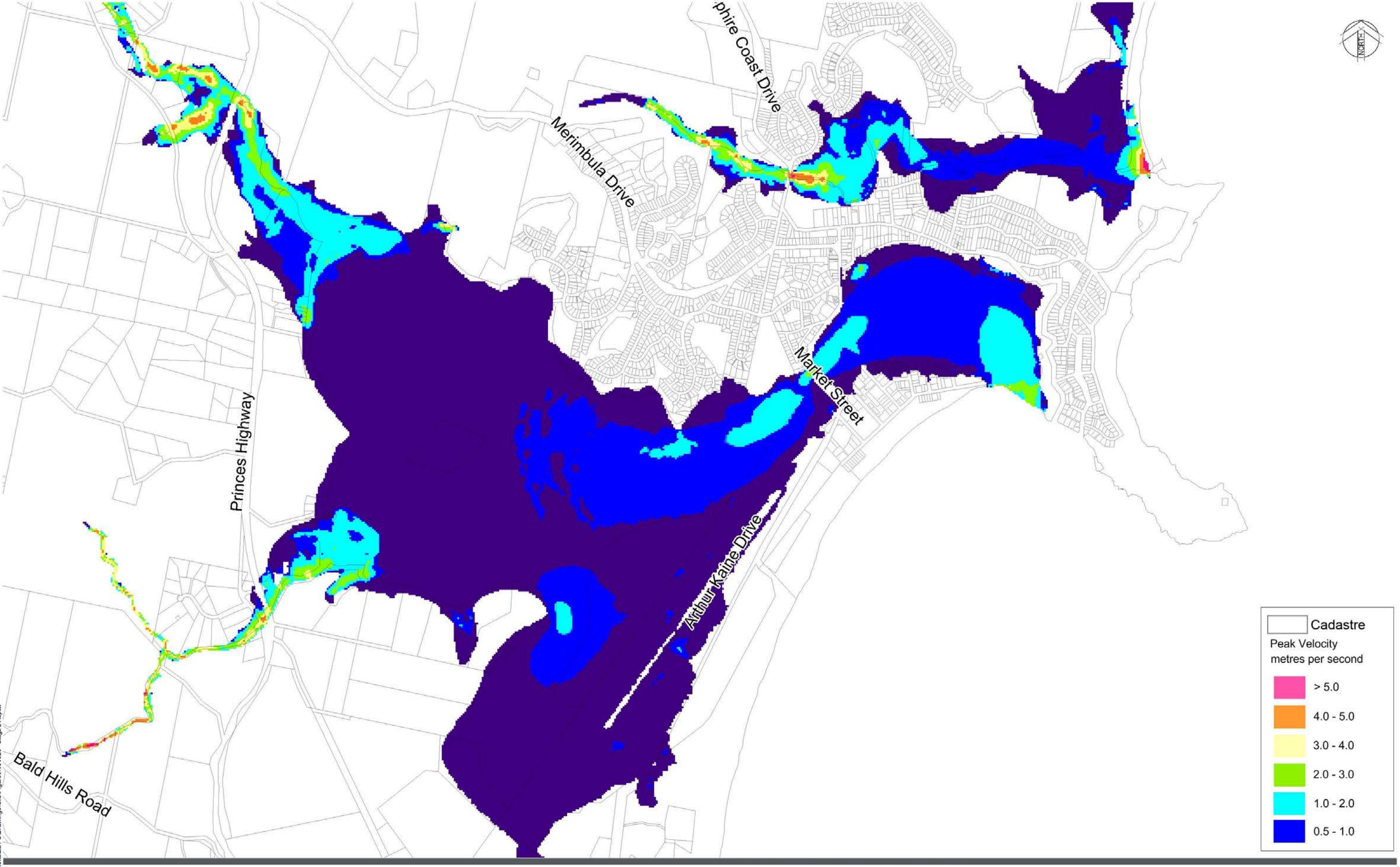
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD VELOCITY (M/S)
1% AEP

Date	Scale	Size
30/05/2016	1 : 20,000	A3
Figure 7-13		01
Drawing Number		Revision



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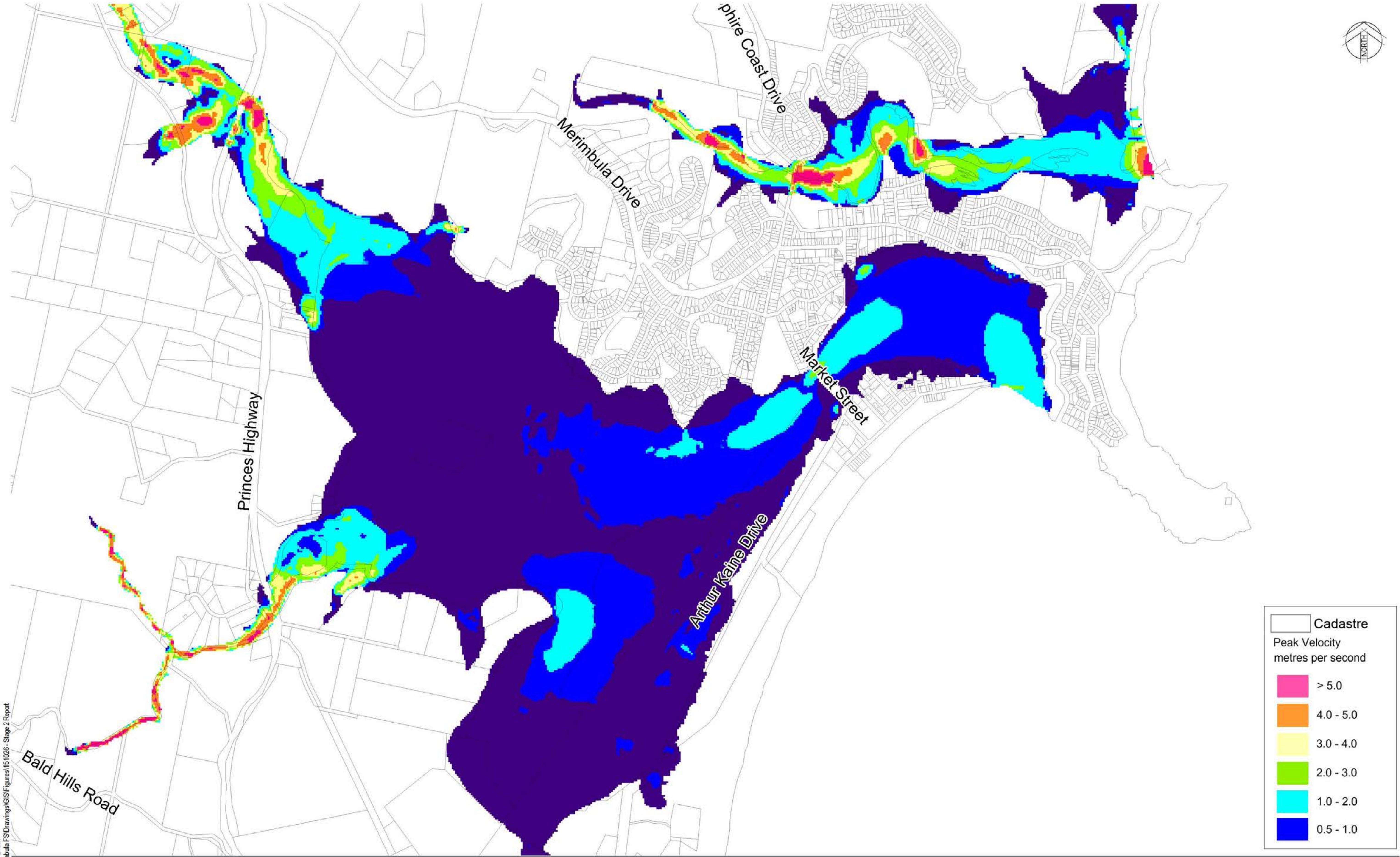
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD VELOCITY (M/S)
0.5% AEP

Date	Scale	Size
30/05/2016	1 : 20,000	A3
Figure 7-14 Drawing Number		01 Revision



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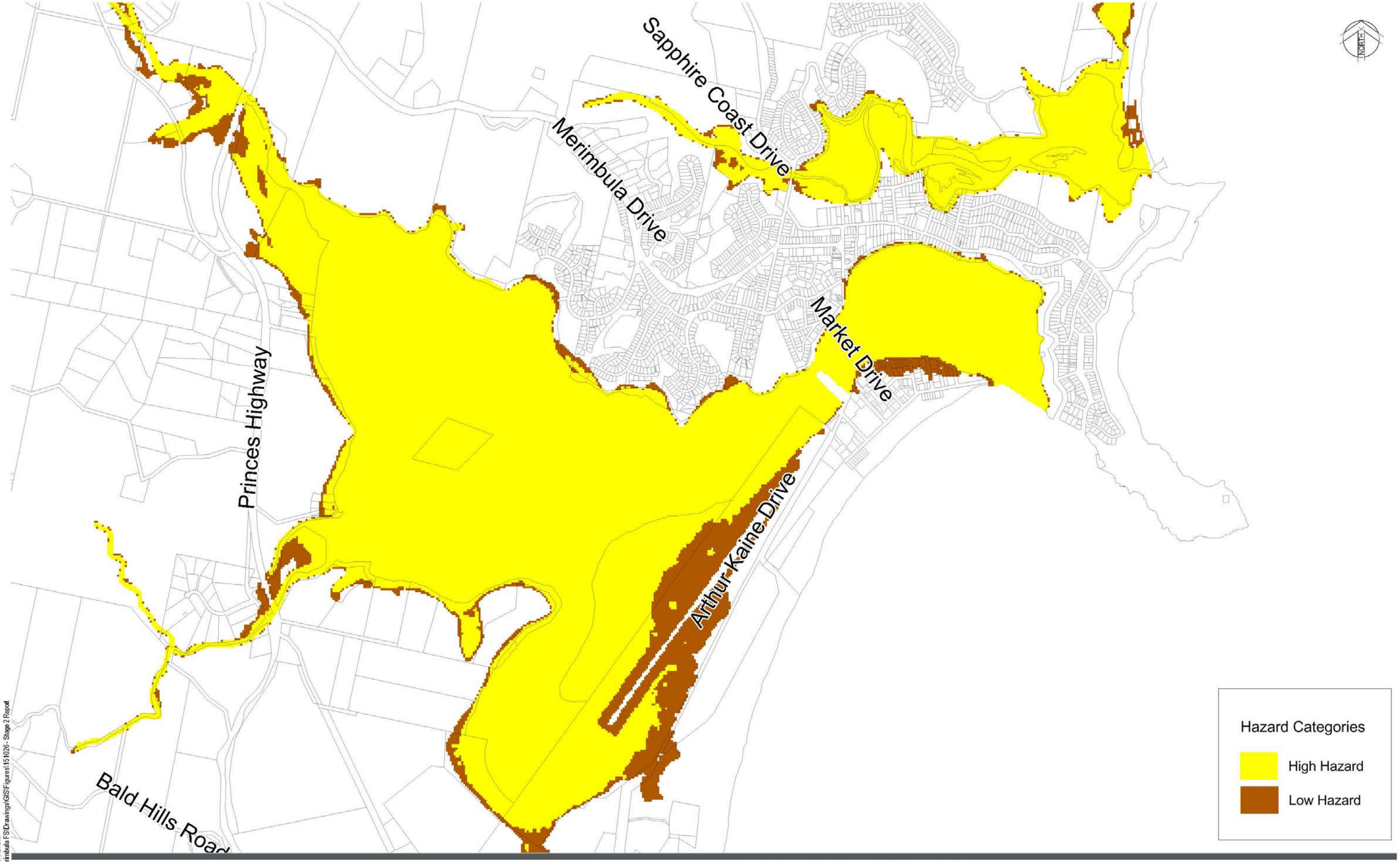
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

PEAK FLOOD VELOCITY (M/S)
PMF

Date	Scale	Size
30/05/2016	1 : 20,000	A3

Figure 7-15
Drawing Number

01
Revision



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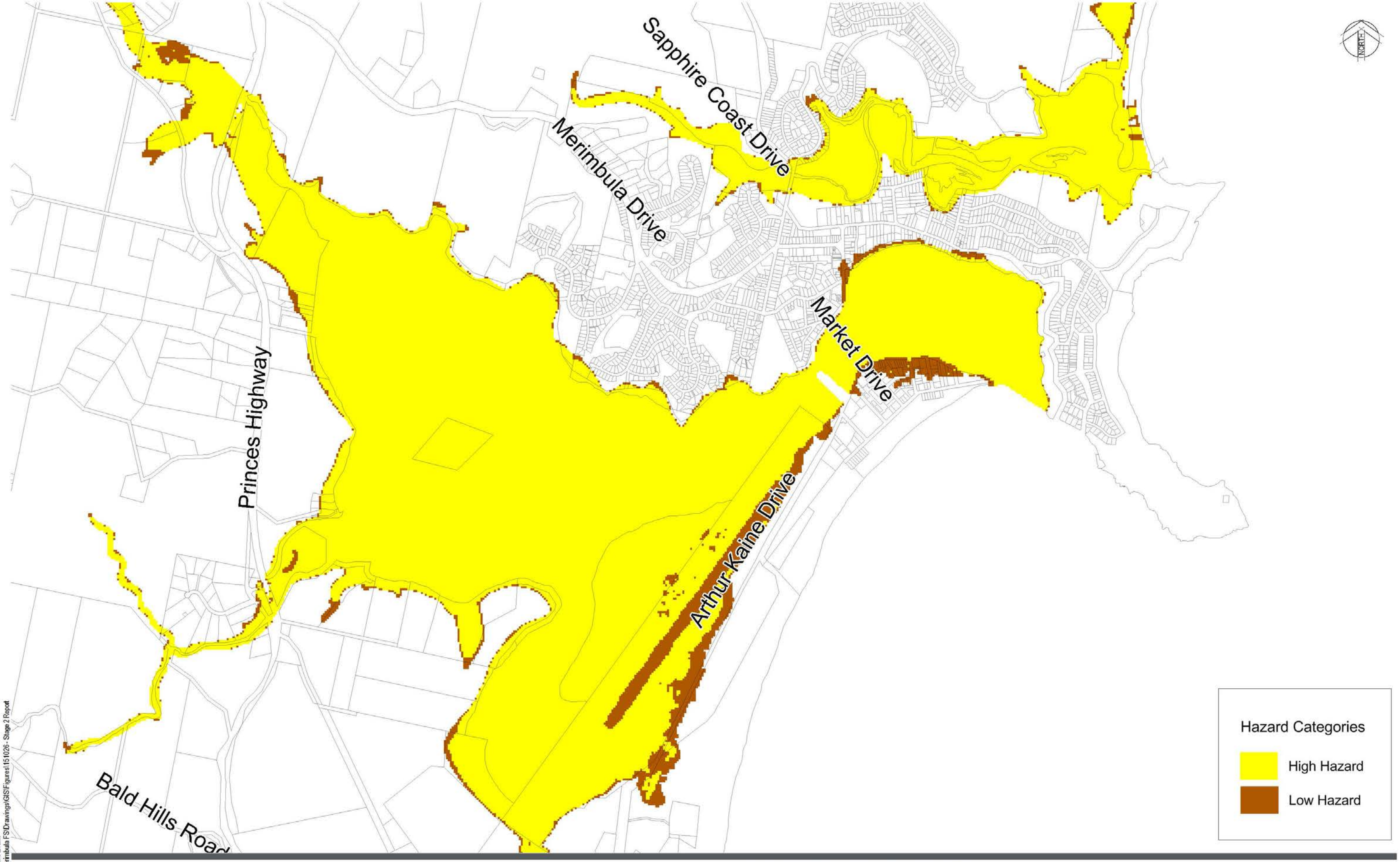
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

1% AEP
HAZARD CATEGORIES

Date	Scale	Size
30/05/2016	1 : 20,000	A3
Figure 8-2		01
Drawing Number		Revision



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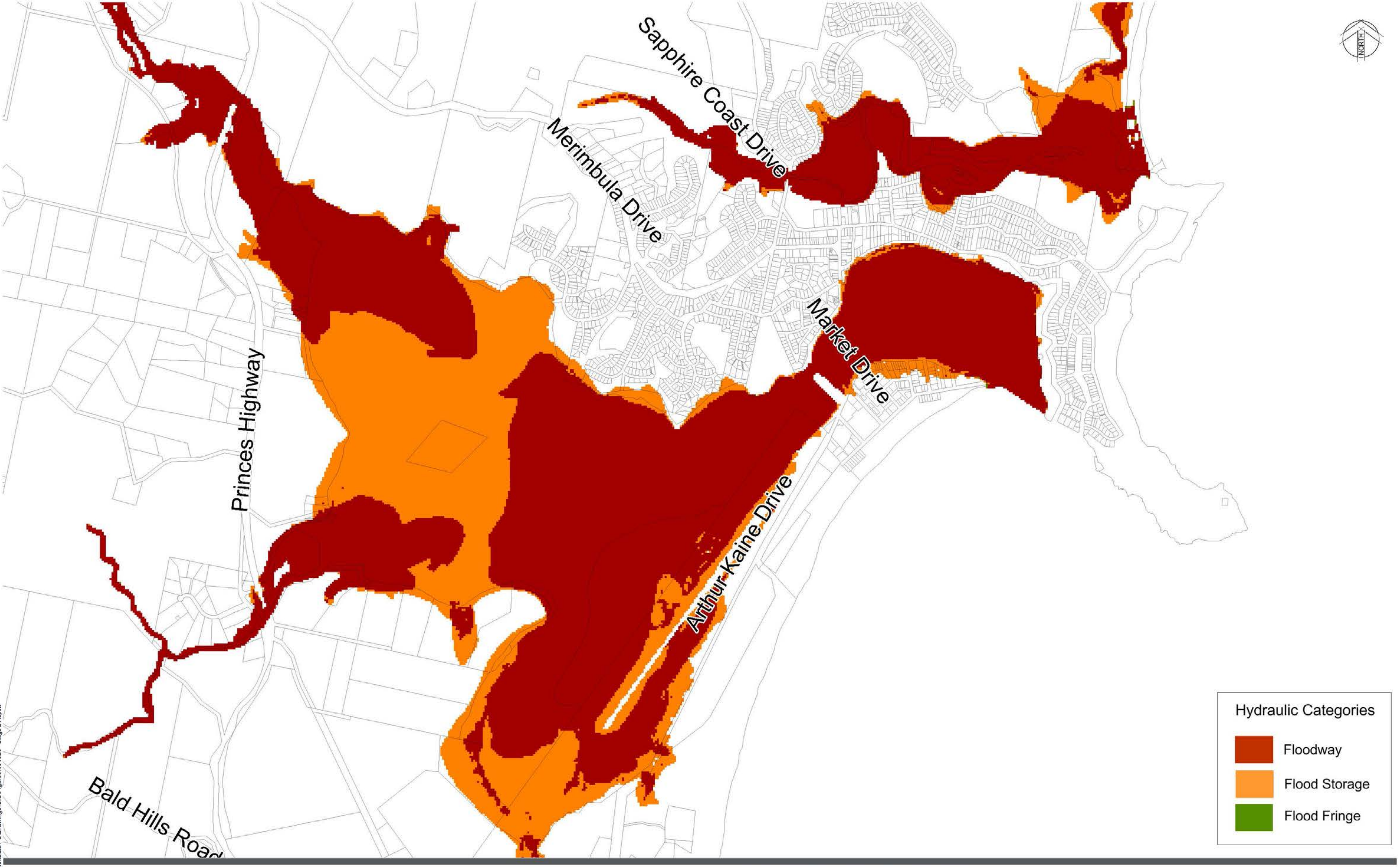
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

PMF
HAZARD CATEGORIES

Date	Scale	Size
30/05/2016	1 : 20,000	A3

Figure 8-3
Drawing Number

01
Revision



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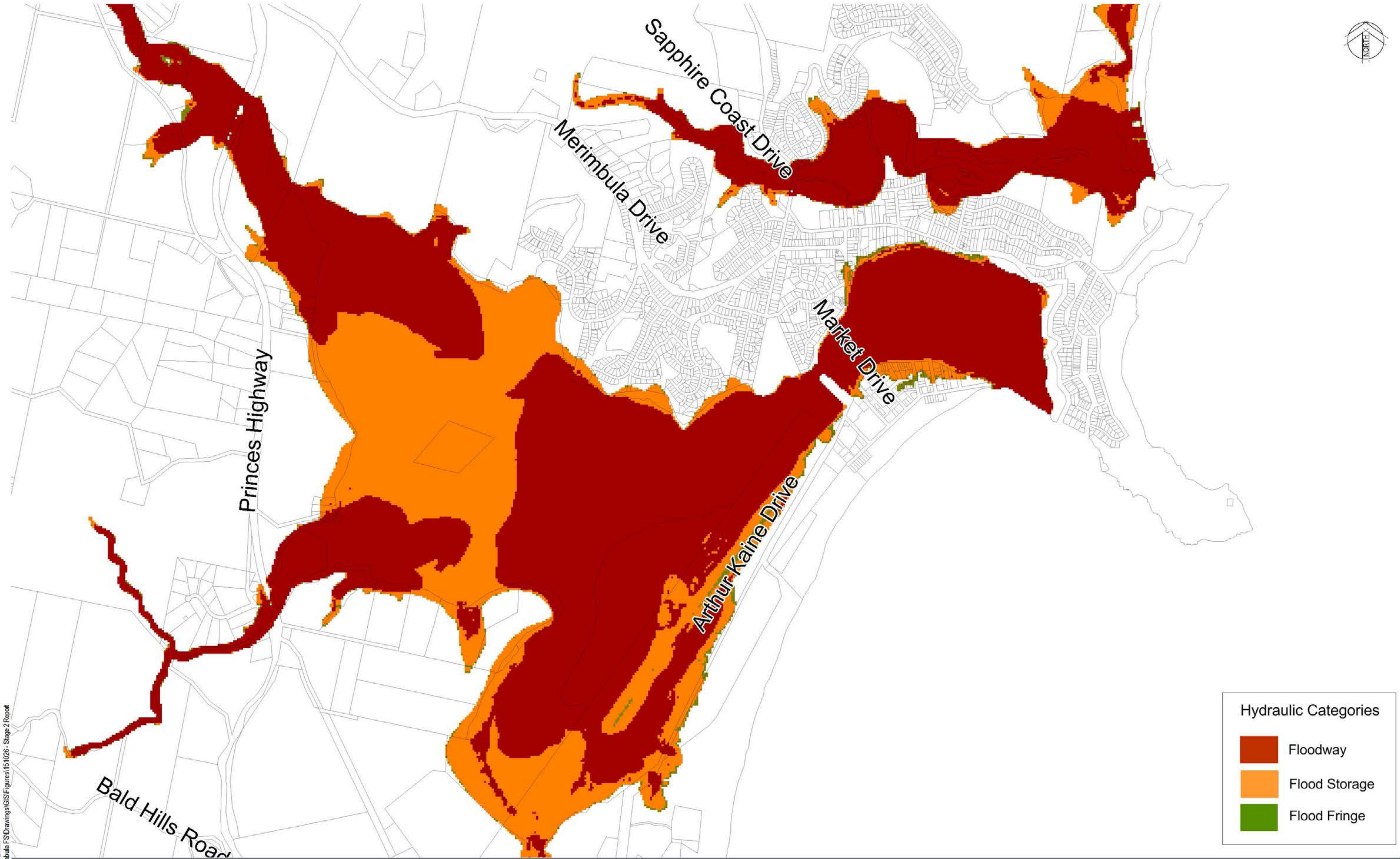
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

1% AEP
HYDRAULIC CATEGORIES

Date	Scale	Size
30/05/2016	1 : 20,000	A3

Figure 8-4
Drawing Number

01
Revision



BEGA VALLEY SHIRE COUNCIL

MERIMBULA & BACK LAKES FLOOD STUDY

PMF

HYDRAULIC CATEGORIES

Date	Scale	Size
30/05/2016	1 : 20,000	A3

Figure 8-5

Drawing Number

01

Revision

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DATE PLOTTED: 26/10/2015 BY: Luke Evans
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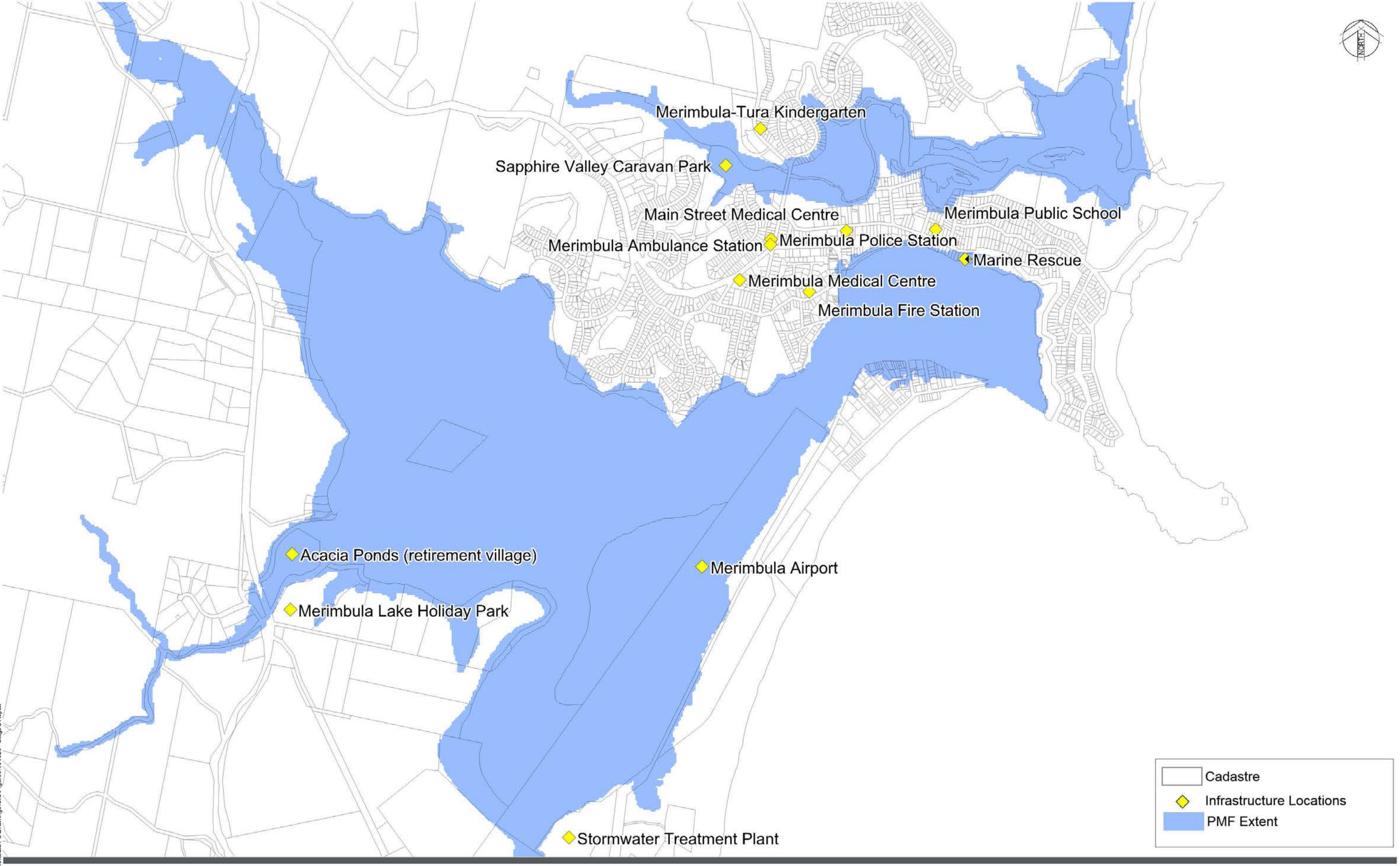

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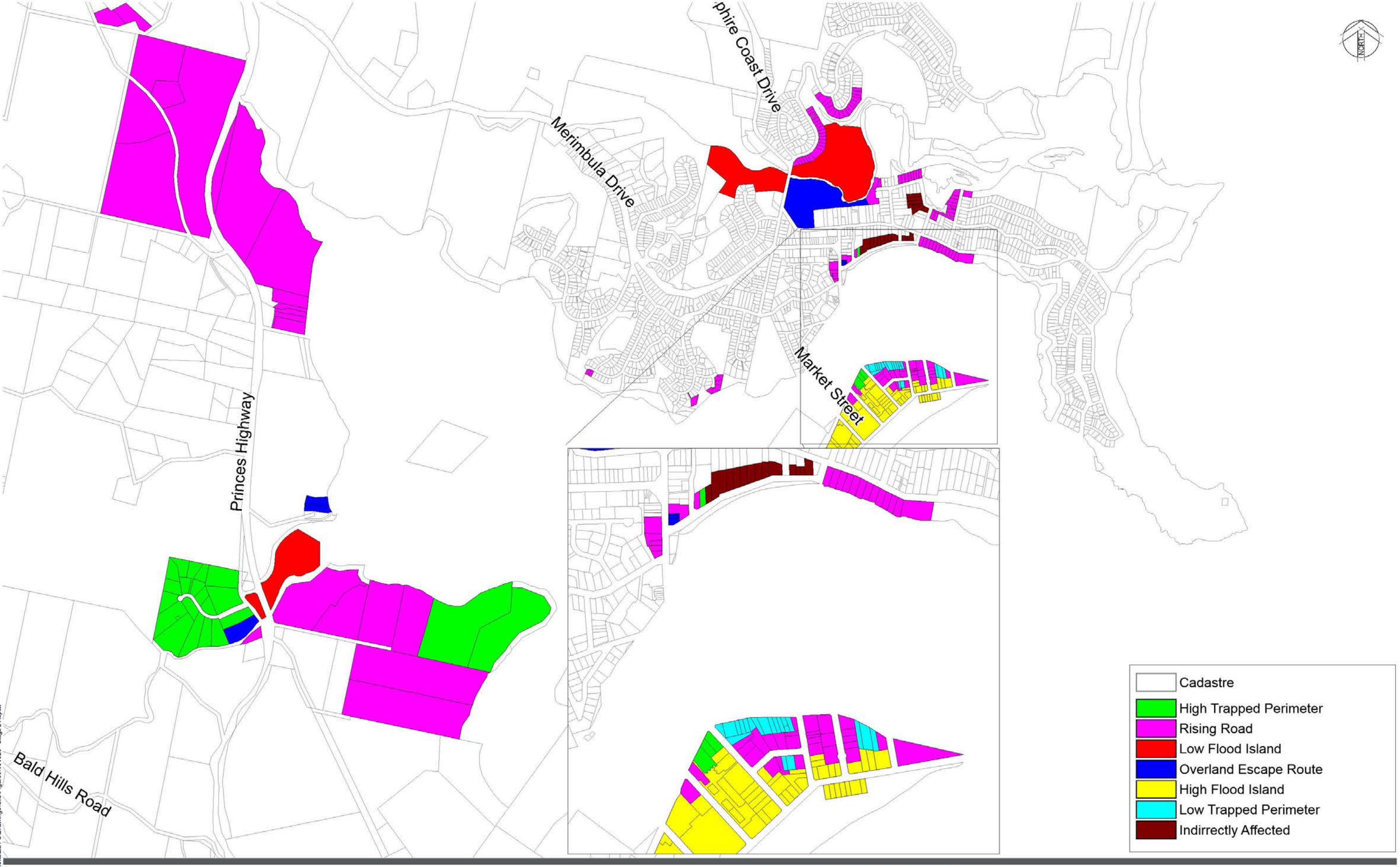
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

INFRASTRUCTURE LOCATIONS

Date	Scale	Size
30/05/2016	1 : 20,000	A3

Drawing Number	Revision
Figure 8-6	01



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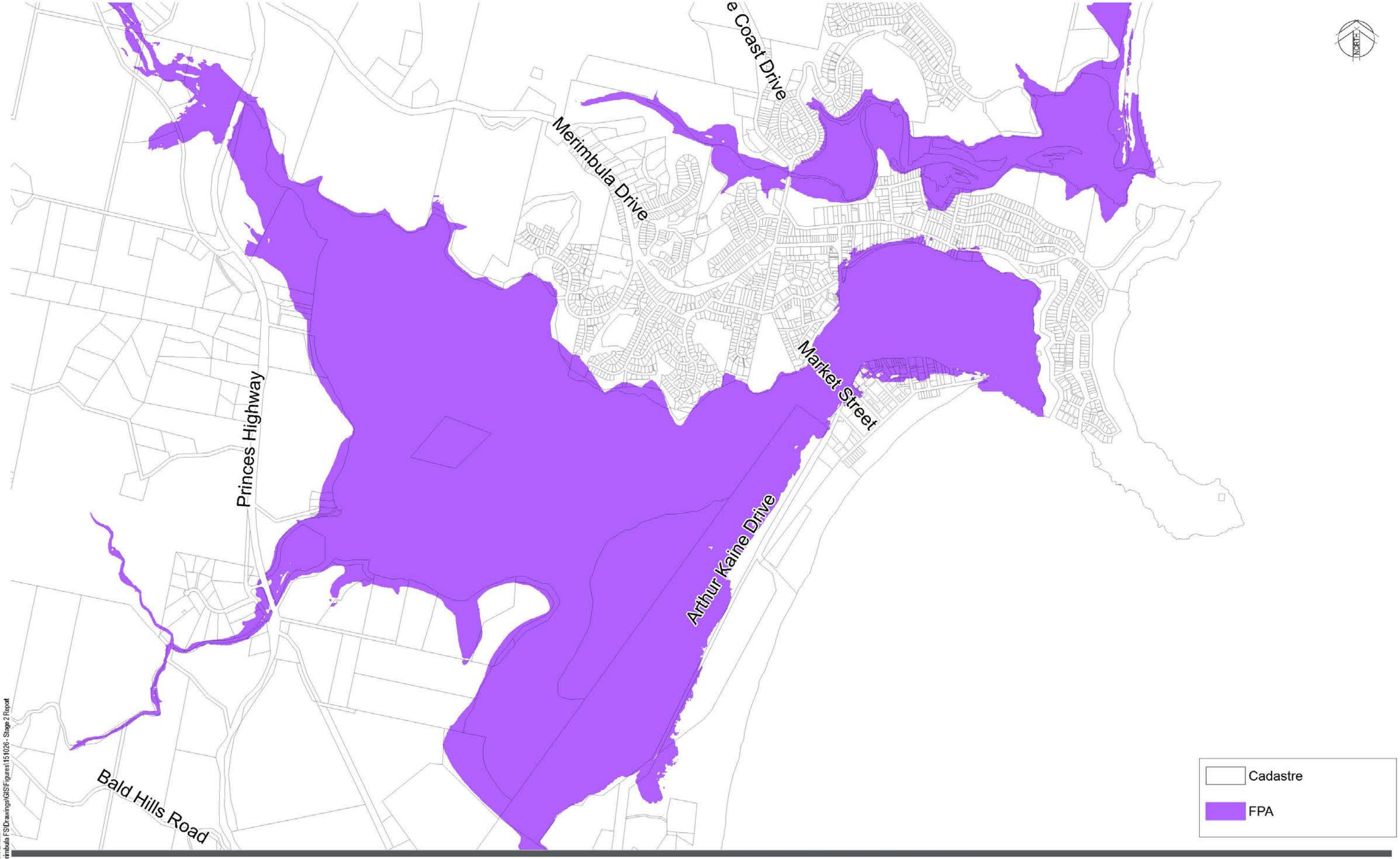
BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

FLOOD EMERGENCY RESPONSE
CLASSIFICATIONS FOR COMMUNITIES

Date	Scale	Size
30/05/2016	1 : 50,000	A3
Figure 8-7		01
Drawing Number		Revision



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BEGA VALLEY SHIRE COUNCIL
MERIMBULA & BACK LAKES FLOOD STUDY

FLOOD PLANNING AREA (FPA)

Date	Scale	Size
30/05/2016	1 : 20,000	A3

Figure 10-1
Drawing Number

01
Revision

Appendix A

Consultation Materials

MEDIA RELEASE
Contact: Jeff Donne | Communications Coordinator
02 6499 2106 | 0417 882 074

Information sought for lakes flood study

Wednesday 29 April 2015

Bega Valley Shire Council and its consultant Cardno have commenced a flood study of the Merimbula Lake and Back Lake catchments.

The study seeks to define the current and future flood behaviour of the catchments that include the lakes and their tributaries, including Millingandi, Boggy, Bald Hills and Merimbula Creeks.

Council's Asset Management Coordinator Gary Louie said Council has taken the initiative to do the flood study to help with planning for and managing the risk to the community from flooding.

He said the NSW Office of Environment and Heritage and the Federal Ministry of Police and Emergency Services are supporting Council by providing technical assistance and grant funding for the project through the Natural Disaster Resilience Scheme.

"The study is being prepared to meet the objectives of the NSW State Government's Flood Prone Land Policy and will establish the basis for subsequent floodplain management activities," Mr Louie said.

"Under the State Policy, Councils are responsible for identifying and managing the risk to life and property from flooding.

"One of the most important steps in this process is increasing our community's awareness of flooding so that people can understand and plan for the flood risks they face.

"The participation of the community is critical to the success of the study, particularly when it comes to flood information.

"Council and Cardno are eager to receive input from all affected residents and business owners within the study area through a brochure and questionnaire that is being mailed this month and is also available on-line.

"Residents' and business owners' local knowledge and personal experience of flooding in this area are an invaluable source of data.

"We are specifically interested in any historical records that residents and businesses might hold such as photographs, videos, flood marks or observations.

"The questionnaire presents a great opportunity for the community to contribute to the success of the study findings."

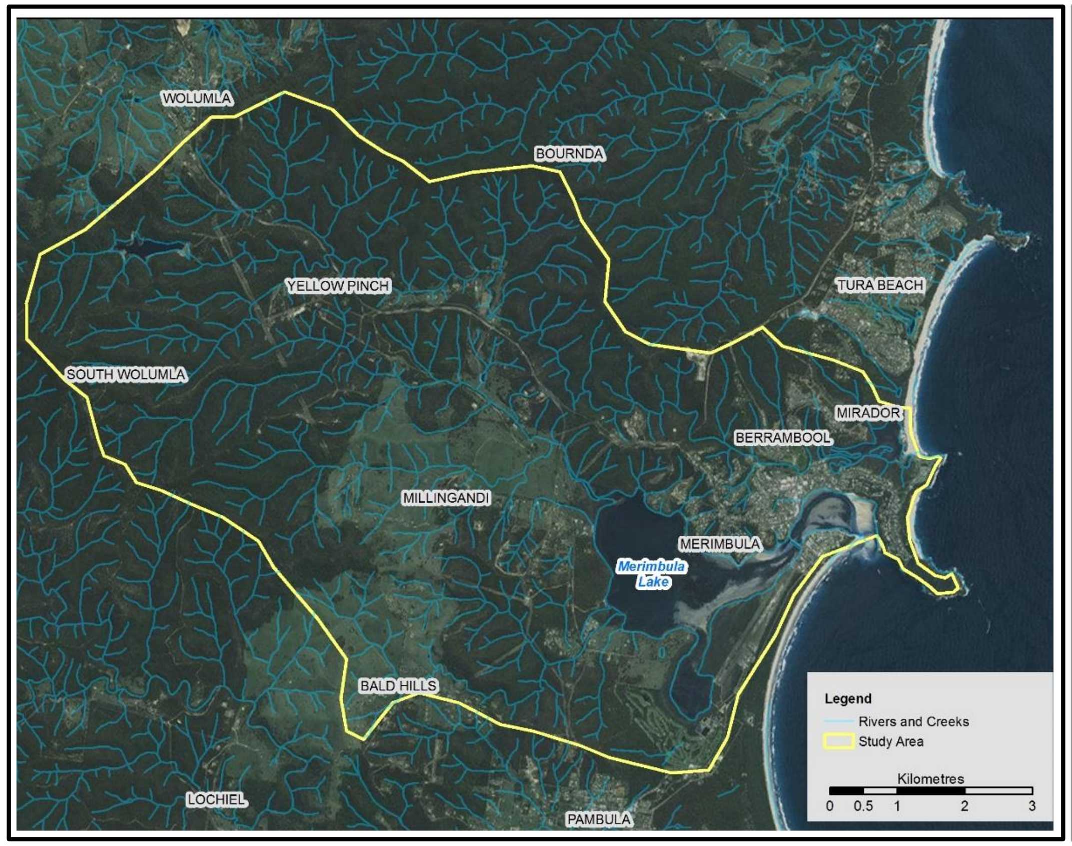
Contact: Jeff Donne | Communications Coordinator
02 6499 2106 | 0417 882 074

Questionnaires should be returned it to Council by Friday 29 May, 2015.

For further information or to complete the questionnaire online, go to this dedicated project website, https://extranet.cardno.com/merimbulafloodstudy or phone Gary Louie on 6499 2222.

Photograph: Waiting image from Vanessa…

END



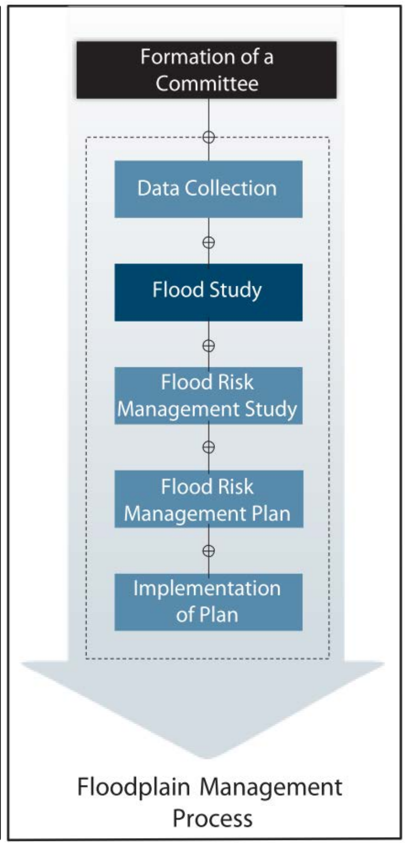


Figure: The Study Area

If you have any further comments that relate to the Flood Study, please provide them in the space below (or attach any additional pages if necessary):

....

....

....

....

....

....

....

....

Thank you for providing the above information. Please return all pages in the reply paid envelope by Friday 29 May 2015. A representative from Cardno may contact you in the near future to discuss your response.

Contact Us

YOUR PERSONAL INFORMATION WILL REMAIN CONFIDENTIAL

If you have any queries, please contact

Bega Valley Shire Council

Gary Louie

P: (02) 6499 2222
F: (02) 6499 2200
E: GLouie@begavalley.nsw.gov.au

This project is supported by the NSW Government's Floodplain Management Program.

Merimbula Flood Study

Local Resident/Land Owner Survey | April 2015

Cardno, on behalf of Bega Valley Shire Council, is carrying out a Flood Study for the Merimbula Lake and Back Lake catchment area (see study area figure on page 4). The study will look to define the existing flood behaviour of the study area for a range of flood events.

Flooding is a nature driven event that poses risk to human lives, services, goods and properties. In the past, flooding in the study area has caused damage to businesses and infrastructure, and resulted in restricted access through a number of areas. Flooding can occur both from catchment flows from rainfall events, as well as from elevated water levels in Merimbula Lake and Back Lake as a result of ocean storm surges. Flood risk can be mitigated through a staged floodplain management process, of which this study constitutes the first step.

Do you have any records or local knowledge of flooding in your area? Council would like to hear from you by filling in this short questionnaire. Your responses will help us collect historical flood data and help Council understand the current flooding problems in more detail. Local knowledge and personal experiences of flooding are an invaluable source of data.

Please tell us about your experiences and return the questionnaire in the reply paid envelope by Friday 29 May 2015.

Local Resident/Landowner Survey

Q1. Could you please provide us with the following details? We may wish to contact you to discuss some of the information you have provided us with.

Name: ....

Address: ....

....

Daytime Ph: ....

Email: ....

Q2. Is your property (please tick)

☐ Owner occupied ☐ Occupied by a tenant ☐ A business ☐ Other

Q3. How long have you lived, worked and/or owned your property?

.... Months .... Years

Q4. How aware are you of flooding behaviour within the catchment? (please tick)

- ☐ Aware
- ☐ Some knowledge
- ☐ Not aware

Q5. Have you ever experienced flooding since living/working/owning your property? (please tick relevant boxes)

- ☐ Yes, my daily routine was affected e.g. difficult to get to work (date/location ..../..........)
- ☐ Yes, access to my property was affected e.g. roads were flooded (date/location ..../..........)
- ☐ Yes, my business was unable to operate (date/location ..../..........)
- ☐ Yes, the sewer service was interrupted during flooding (date ....)
- ☐ Yes, the water supply was interrupted during flooding (date ....)
- ☐ Other, please specify ....
- ☐ No, I have not experienced flooding. Go to Q7.

Q6. If you have experienced flooding, how did it affect your residential/commercial property? (please tick relevant boxes)

- ☐ Front yard or backyard (date/location ..../..........)
- ☐ Garage or shed (date/location ..../..........)
- ☐ Residential: below floor level (date/location ..../..........)
- ☐ Residential: above floor level (date/location ..../..........)
- ☐ Commercial: below floor level (date/location ..../..........)
- ☐ Commercial: above floor level (date/location ..../..........)

Q 7. Have you seen flooding in other locations around the catchment area? (please tick)

☐ Yes, I have seen flooding in locations other than my property (please tick). If possible, please indicate where the flooding occurred on the map on page 4.

- ☐ Residential (date/location ..../..........)
- ☐ Commercial (date/location ..../..........)
- ☐ Rural (date/location ..../..........)
- ☐ Roads or footpaths (date/location ..../..........)
- ☐ Parks or other open spaces (date/location ..../..........)
- ☐ Other, please specify (date/location ..../..........)

☐ No, I have not seen flooding in other areas.

Q 8. Would you be interested in receiving further correspondence in relation to this proposal?

- ☐ Yes.
- ☐ No.

If yes, what is your preferred method of communication?

☐ Mail out ☐ Newspaper Article

☐ Email ☐ Council Meetings

Q 9. Do you have any material showing past floods? For example: photos, videos, watermarks on wall, or rainfall records.

- ☐ Yes, please specify ....
- ☐ No, I don't have any material.

Q 10. Would you be willing to share your material with us for the purposes of this study?

- ☐ Yes, I would be willing to share my material.
- ☐ No, I would not be willing to share my material

Q11. If you are the owner of the property identified in Q1, do you give consent for surveyors to access your property for the purposes of collecting any flood marks?

- ☐ Yes.
- ☐ No.

Q12. What is your level of confidence regarding the information you have provided?

- ☐ Not very confident.
- ☐ Reasonably confident.
- ☐ Very confident.

MEDIA RELEASE
Contact: Jeff Donne | Communications Coordinator
02 6499 2106 | 0417 882 074

Merimbula Lake and Back Lake Flood Study on public exhibition

Monday 22 August 2016

Bega Valley Shire Council will work with the people from the Merimbula Lake and Back Lake catchment areas to finalise the draft Merimbula Lake and Back Lake Flood Study findings.

Project manager, Gary Louie, said the communities had already made a significant contribution to the current draft study findings during the May 2015 community survey and Council is hoping to continue the discussion now during the public exhibition of the draft report.

“Our aim is to inform the community about the draft study findings, identify concerns, gather information and opinions on the identified flood behaviour and maintain community confidence in the study results,” he said.

“As part of the public exhibition of the draft flood study, Council invites community members to attend one of the four drop-in information sessions in Merimbula for an opportunity for questions and to find out about the draft study findings.

“This will assist any residents who wish to make written submissions period which will assist the finalisation of the flood study report that will form a key input into any future floodplain risk management study or plan for Merimbula Lake and Back Lake,” Mr Louie said.

The community drop-in sessions will be held at Club Sapphire, Merimbula, on Wednesday, 24 August from 5pm to 7pm, Thursday, 25 August from noon to 2pm, Wednesday, 21 September from 5pm to 7pm and Thursday, 22 September from noon to 2pm. Each session will involve a 10 minute project presentation with opportunity for questions and private discussion afterwards. Check Council’s website or call 6499 2222 for more details.

The public exhibition period will run from Monday, 22 August until Friday, 30 September 2016. The draft flood study will be placed on Council’s “Have Your Say” webpage for comment during that time.

To visit the project page go to www.begavalley.nsw.gov.au and click on “Have Your Say” at the top of the page.

END

Contact: Jeff Donne | Communications Coordinator
02 6499 2106 | 0417 882 074

Draft Merimbula Lake and Back Lake Flood Study Public Exhibition

Friday 16 September 2016

Discussions are continuing with two local communities about how best to manage the risk of flooding in their area.

Council is working with the people from the Merimbula Lake and Back Lake catchment areas to finalise the draft Flood Study for both lakes.

The NSW Office of Environment and Heritage and the Federal Ministry of Police and Emergency Services are supporting Council by providing technical assistance and grant funding through the Natural Disaster Resilience Scheme.

The study is being prepared to meet the objectives of the NSW State Government's Flood Prone Land Policy and will establish the basis for subsequent floodplain management activities.

Project Manager, Gary Louie said the Merimbula Lake and Back Lake communities had already made a significant contribution during workshops held in August.

“The two workshops were well attended by a range of residents, community groups and the Mayor,” Mr Louie said.

“A very helpful dialogue was held with a presentation of the draft findings, as a result some minor amendments were identified and substantial progress was made towards finalising the study,” he said.

As part of the ongoing public exhibition for the draft Merimbula and Back Lake Flood Study, Council invites the community to attend another two drop-in information sessions.

The sessions are an opportunity for questions and to find out about the draft study findings and provide comment.

The sessions will help inform any residents who wish to make a written submission before the public exhibition period closes on Friday, 30 September 2016.

Contact: Jeff Donne | Communications Coordinator
02 6499 2106 | 0417 882 074

The community drop-in sessions will be held on Wednesday, 21 September from 5.00-7.00pm and Thursday, 22 September from 12.00–2.00pm in the Sapphire Room at Club Sapphire, Merimbula. Each session will involve a 10 minute presentation with opportunity for questions and private discussion afterwards.

Interested locals should post or email submissions before 4.00pm on Friday, 30 September, online submissions and comments can also be made through Council's Have Your Say webpage.

Visit the project page at www.begavalley.nsw.gov.au and click on "Have Your Say" at the top of the page. For more information call Bega Valley Shire Council on (02) 6499 2222.

Photograph: Merimbula Lake from Fishpen

END

Appendix B

Model Systems

The following model systems have been utilised in this study.

RAFTS

Cardno utilised the XP-RAFTS model system to undertake the hydological modelling required for this overall investigation. XP-RAFTS is a non-linear runoff routing model used extensively throughout Australia and South East Asia. XP-RAFTS has been shown to work well on catchments ranging in size from a few square meters up to 1,000's of square kilometres of both rural and urban nature. XP-RAFTS can model up to 2,000 different nodes and each node can have any size subcatchment attached as well as a storage basin. XP-RAFTS uses the Laurenson non-linear runoff routing procedure to develop a stormwater runoff routing procedure to develop a stormwater runoff hydrograph. PMP generation is also incorporated, which simulates PMP for Australia for short or long durations.

Hydrograph Generation

The Laurenson runoff routing procedure used in XP-RAFTS:

> Offers a flexible model to simulate both rural and urban catchments

> Allows for non-linear response from catchments over a range of event magnitudes

> Considers time-area and subcatchment shape

> Offers an efficient mathematical procedure for developing rural, urban and mixed runoff hydrographs at any subcatchment outlet.

Any local IFD information may be used to generate hydrographs. Rainfall input can be of two types; Design Rainfall or Historic Events.

Design rainfall may be entered as a dimensionless temporal pattern with average rainfall intensity or in Australia may be extracted directly from AR&R. With the automatic storm generator, the intensity information may be entered from AR&R and the appropriate intensity for the given AEP and duration will be computed automatically. The zone may be entered and the appropriate temporal patter will be automatically selected from the inbuilt standard temporal patterns from AR&R.

Historical events may be entered by the used in either fixed time steps or variable time steps allowing long lengths of record to be defined relatively easily. Alternatively the rainfall data may be read from an external file. User defined fiel types can be created to read text of spreadsheet data.

Loss Models

The rainfall excess may be computed used either of the following methods:

> Initial / Continuing – The initial depth of rainfall which is lost is specified along with a continuing rate of loss.

> Initial / Proportional – the initial depth of rainfall which is lost is specified along with a proportion of any further rain which will be lost.

> ARBM Loss Method – Infiltration parameters to suit Philip's infiltration equation using comprehensive ARBM algorithims are used to simulate catchment infiltration and subsequent rainfall excess for a particular rainfall sequence and catchment antecedent conditions.

PMP Estimation

The PMP estimation tool has been incorporated to estimate the PMP for Australia for short and long durations. This tool adopts the methodology described in the GSDM, GSAM and GTSMR Guidebooks by the Australia Bureau of Meteorology.

PMP Storms can be generated and simulated for any short or long duration depending on the location of the study area.

DELFT3D

Cardno proposes to utilise the Delft3D model system to undertake the hydrodynamic modelling required for this overall investigation. Delft3D is a world leading hydrodynamic, sediment transport and water quality modelling system developed by Deltares (formally Delft Hydrodynamics) in the Netherlands. Delft3D has been applied in major estuarine & coastal and ocean investigations and engineering studies worldwide. In the field of sediment transport and morphological modelling, Delft3D is arguably the world's leading model system. In the last 10-years Delft3D has led modelling innovations such as coupled online wave and hydrodynamic forcing, and also the implementation of the latest generation of sediment transport models such as van Rijn (2004), which are significantly more accurate than earlier models.

The Delft3D modelling system includes wind, pressure, tide and wave forcing, three-dimensional currents, stratification, rainfall/evaporation, sediment transport and water quality descriptions and is capable of using irregular, rectilinear or curvilinear coordinates. The site is suited ideally to the curvilinear grid and domain decomposition systems, which will enable a detailed, yet efficient description of the flow structure in the estuary.

The Delft3D modelling system has been applied to morphological investigations at many international locations, as well as within Australia by Cardno, other consultants and universities. It is comprised of several modules that provide the facility to undertake a range of studies. All studies generally begin with the Delft3D-FLOW (hydrodynamic) module. From Delft3D-FLOW, details such as velocities, water levels, density, salinity, vertical eddy viscosity and vertical eddy diffusivity can be provided as inputs to the other modules. The wave and sediment transport modules work interactively with the FLOW module through a common communications file.

Hydrodynamic Numerical Scheme

The Delft3D FLOW module is based on the robust numerical finite-difference scheme developed by G. S. Stelling (1984) of the Delft Technical University in The Netherlands. Since its inception the Stelling Scheme has undergone considerable development and review by Stelling and others. Other programs utilising the Stelling scheme include the floodplain applications of Delft-FLS (WL|Delft).

The Delft3D Stelling Scheme arranges modelled variables on a staggered Arakawa C-grid. The water level points (pressure points) are designated in the centre of a continuity cell and the velocity components are perpendicular to the grid cell faces. Finite difference staggered grids have several advantages including:-

- Boundary conditions can be implemented in the scheme in a rather simple way
- It is possible to use a smaller number of discrete state variables in comparison with discretisations on non-staggered grids to obtain the same accuracy
- Staggered grids minimise spatial oscillations in the water levels.

Delft3D can be operated in 2D (vertically averaged) or 3D mode. In 3D mode, the model uses the σ coordinate system first introduced by N Phillips in 1957 for atmospheric models. The σ coordinate system is a variable layer-thickness modelling system, meaning that over the entire computational area, irrespective of the local water depth, the number of layers is constant. As a result a smooth representation of the bathymetry is obtained. Also, as opposed to fixed vertical grid size 3D models, the full definition of the 3D layering system is maintained into the shallow waters and until the computational point is dried.

From a user point of view, the construction of a 3D model from a 2D model using the σ coordinate system in Delft3D is simple and takes a matter of seconds. The model is set-up as a 2D model and the user enters the number of layers are required and the percentage of the depth for each layer. It is most common to define more resolution at the surface and at the bed where the largest vertical gradients occur. Boundary conditions can also be adjusted from depth averaged to specific discharges and concentrations per layer also.

Horizontal solution is undertaken using the Alternating Direction Implicit (ADI) method of Leendertse for shallow water equations. In the vertical direction (in 3D mode) a fully implicit time integration method is also applied. Vertical turbulence closure in Delft3D is based on the eddy viscosity concept. Rainfall and evaporation rates can be included.

Standard and Special Features

Delft3D has several pre- and post-processing tools. They include: -

- RGF-Grid – Pre-processing of grid schematisation. Includes linkage with ArcView GIS.

- Quickin – Translation of bathymetric details to the model grid. Includes linkage with ArcView GIS.
- Quickplot – Powerful post-processing and visualisation program developed in MATLAB. Visualisation of model results as spatial colour, contour and vector maps; graphing of horizontal and vertical profiles; and generation of AVI or ASCII results. It can be directly linked to MATLAB to expand post processing capabilities user developed scripts.
- DIDO – An innovative interactive grid editor and coupling tool for Delft 3D hydrodynamic simulations to Delft3D-WAQ. DIDO has the ability to aggregate hydrodynamic grid results both horizontally and vertically with horizontal aggregation generally being in areas not important to the Water Quality analysis, thus allowing considerable reduction in computational effort. It is not essential for WAQ/ECO modelling.
- Delft-3D to ArcView Translator - Tool to import results directly into Arc-View for detailed interrogation of results and enhanced visual display against GIS data such as aerial photography, cadastral and land boundaries etc.

Ability to Incorporate a Varying Mesh Size

Bathymetric discretisation and modelling can be undertaken in Delft3D on a rectilinear or curvilinear grid, and include domain decomposition. The Delft3D model is specifically written and most widely used to undertake hydrodynamic flow and transport modelling arising from tidal and meteorological forcing on a curvilinear boundary fitted grid.

The curvilinear grid system enables grid sizes to vary so that better resolution can be used within the estuary and adjacent interconnecting channels, with less resolution in the sea where less detail is required. Additionally, the curvilinear grid system can be better set-up to follow the flow streamlines and boundaries, thereby providing a better description of the currents.

Additional refinement of the grid can be applied at any time during the study. The RGFGrid program, used to setup the Delft3D grid, offers a number of features to provide additional computational cell discretisation in an area of interest.

The domain decomposition module will be used also to prepare a fine grid area near the respective estuary entrances in order to ensure that the hydrodynamic and morphological processes are resolved adequately. The Delft3D numerical scheme is very robust and stable and can simulate steep hydrodynamic gradients such as those which occur during entrance opening.

Wetting and Drying of Intertidal Areas

Many estuaries and embayments contain shallow intertidal areas; consequently Delft3D incorporates a robust and efficient wetting and drying algorithm for handling this phenomenon.

Cardno have utilised Delft3D in many applications where inter-tidal flats exist. Through experience in these areas of application, Cardno propose and use in practice a method of careful refinement in the intertidal areas and appropriate setting of dry depths to minimise discontinuous movement of the boundaries.

This process ensures oscillations in water levels and velocities are minimised and the characteristics of the intertidal effects are modelled accurately.

With regard to water quality modelling and conservation of mass, when a cell dries out, the substance mass is still kept within the cell. When the cell re-wets, as occurs on a rising tide, this mass is then re-diluted.

Conservation of Mass

Problems with conservation of mass, such as a ‘leaking mesh’, do not occur within the Delft3D system. However, whilst the Delft3D scheme is unconditionally stable, inexperienced use of Delft3D, as with most modelling packages, can result in potential mass imbalances.

Potential causes of mass imbalance and other inaccuracies include:-

- Inappropriately large setting of the wet/dry algorithm and unrefined inter-tidal grid definition
- Inappropriate bathymetric and boundary definition causing steep gradients

> Inappropriate time step selection (i.e. lack of observation of the scheme's allowable Courant Number condition) for simulation.

Model Boundary Conditions

The downstream model boundary will be set in the open sea in a depth of about 80m and defined as a water level and wave boundary. This boundary can also include time-series of parameters such as salinity, temperature, sediment concentration and nutrient concentration. However, it is common practice to set boundaries sufficiently distant from the active estuarine area for these parameters to be constant in time (other than water level and wave conditions).

Domain Decomposition

Delft3D provides the facility to adopt a modelling approach known as 'domain decomposition'. Domain decomposition is a technique in which a model is divided into several smaller model domains that are dynamically coupled with each other. The subdivision is based on the horizontal and vertical model resolution required for adequately simulating physical processes. Computations can be carried out separately, yet concurrently, on these domains. The communication between the domains takes place along internal boundaries. Computations are carried out concurrently, via parallel computing, thus reducing the turn-around time of multiple domain simulations. Domain decomposition allows for local grid refinement, both in the horizontal direction and in the vertical direction in 3D models. Grid refinement in the horizontal direction means that in one domain smaller mesh sizes (fine grid) are used than in other domains (coarse grid). In the case of vertical grid refinement one domain, for example, uses ten vertical layers and another domain five layers, or a single layer (depth-averaged).

Domain decomposition is widely recognised as an efficient and flexible tool for the simulation of complex physical processes. The structured multi-domain approach combines the advantages of the modelling flexibility of the single-domain unstructured approach with the efficiency and accuracy of the single-domain structured approach.

Sediment Transport Processes

The module applied to the sediment transport analyses is the Online Sediment Module with the van Rijn 2004 sediment transport module. This system makes it possible to undertake time-series sediment transport modelling using combined tide, wind, wave and fresh water flows. The bed levels, water levels and currents within the wave module are updated at specified time intervals (typically 15 minutes to one hour) and the calculated wave conditions (wave heights and radiation stress maps) used for the next hydrodynamic phase.

Changes in currents and water levels then affect wave process calculations in the next wave model step and those new outcomes are then used in the next hydrodynamic and morphological steps. It is based on the van Rijn (2004) sediment transport algorithm. This algorithm incorporates time varying flow conditions in the calculation of bed roughness and reference concentrations. Cardno will also employ a bed-form roughness model which can be particularly important when simulating hydrodynamic and sediment transport processes in an entrance system under flood flow condition. At Lake Illawarra, Cardno has demonstrated the importance of careful selection of an appropriate bed roughness model to simulate the hydrodynamic processes in a narrow entrance system with a steep hydrodynamic gradient.

SWAN Wave Modelling System

The wave model Cardno proposes to use in this study is based on the third generation wind/wave modelling system, SWAN, which is incorporated as a module into the Delft3D modelling system. This model was developed at the Delft Technical University and includes wind input (local sea cases), combined sea and swell, offshore wave parameters (swell cases), refraction, shoaling, non-linear wave-wave interaction, a full directional spectral description of wave propagation, bed friction, white capping, currents and wave breaking. SWAN also includes phase-averaged diffraction based on the model of Holthuijsen et al.

SWAN includes a nested grid capability that allows coarser grids in deeper water and finer grids in shallow water where better definition of seabed form and depth are needed. Output from the model includes significant wave height, dominant wave direction, spectral peak and mean periods and (optionally) the full directional wave spectra at selected grid points.

Appendix C

Hydrodynamic Model Inputs, Sensitivity and Calibration

1 Introduction

This report details the work undertake as part of Stage 2 of the Flood Study, namely:

> Establishment of the hydrological and hydrodynamic models;

> Sensitivity testing of model parameters; and

> Calibration and validation of the hydrological and hydrodynamic models.

1.1 Report Context

The NSW Floodplain Risk Management Process progresses through the following six stages (also shown diagrammatically in **Figure 1-1**):

1. Formation of a Floodplain Management Committee.
2. Data Collection.
3. **Flood Study.**
4. Floodplain Risk Management Study.
5. Floodplain Risk Management Plan.
6. Implementation of the Floodplain Risk Management Plan.

This report addresses aspects of Step 3 (Flood Study).

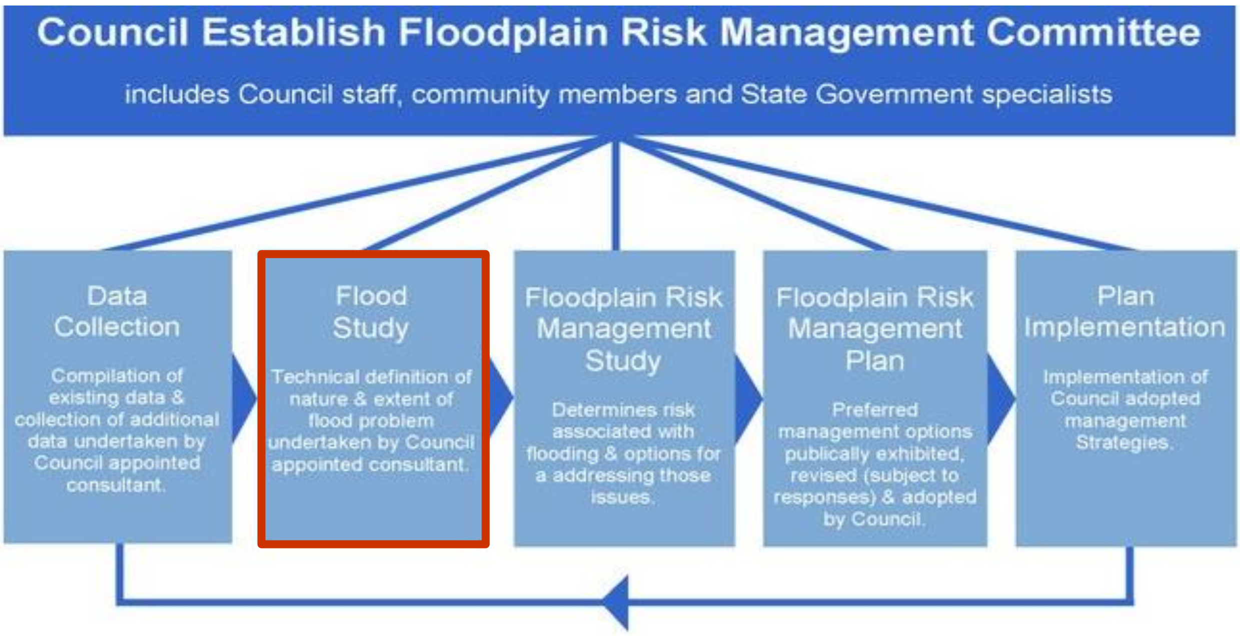


Figure 1-1 Floodplain Risk Management Process

1.2 Report Objectives

The objective of the Stage 2 Report is to provide the details of the hydrological and hydrodynamic models developed for the study area. This includes the details of the model construction, sensitivity testing to determine the influence model parameters have over the results, and calibration and validation of the models to historical flood events.

Following Council's approval of the hydrological and hydrodynamic models, they will be used to assess the design flood events for Merimbula Lake and Back Lake.

2 Model Set Up

2.1 Available Data

The key data utilised in developing the hydrological and hydrodynamic flood models was:

> Topographic LiDAR data with a 1m resolution, collected in 2013;

> Hydrographic survey of Merimbula and Pambula, collected in 2003;

> Design and construction drawings for hydrodynamic structures within the study area;

> Rainfall data from two local gauges, with a combined record from 1993 to 2015

> Water level data from five local gauges, with a combined record from 1983 to 2015;

> Wave data from an offshore wave rider bouy with a record from 1978 to 2015; and,

> Sediment data from the lake entrances for Merimbula Lake and Back Lake.

A full review of all available data was provided in the Stage 1 Report.

2.2 Hydrological Model Development

The hydrological modelling of the catchment was undertaken using the XP-RAFTS software package. The set-up of the hydrological model is discussed in the following sections.

2.2.1 Sub-Catchments

The sub-catchment layout used in the XP-RAFTS model is shown in **Figure 2-1**. Details of the XP-RAFTS sub-catchments are provided in **Table 2-1**, including the PERN value, which is discussed below.

Table 2-1 XP-RAFTS Sub-catchment Details

Catchment	Area (ha)	Manning's 'n'	Impervious %	Slope (%)
B1	138.44	0.033	2	15.99
B10	91.16	0.033	2	6.65
B11	126.44	0.033	8.2	5.73
B12	248.53	0.032	18.8	5
B13	223.97	0.03	2.8	5.77
B2	143.65	0.033	2	8.45
B20	255.02	0.033	2	8.05
B21	147.11	0.033	2	13.26
B21	147.11	0.033	2	13.26
B22	181.83	0.033	2	8.16
B23	198.34	0.033	2	6.9
B3	194.83	0.033	2	3.89
B30	141.32	0.033	2	10.32
B31	133.47	0.033	2	11.2
B32	129.09	0.033	2	8.38
B4	207.07	0.033	2	4.69
B5	147.41	0.033	2	7.99
B6	193.52	0.033	2	9.59
B7	99.74	0.033	2	6.98
B8	101.43	0.033	2	7.76
B9	100.03	0.033	2	8.19

Catchment	Area (ha)	Manning's 'n'	Impervious %	Slope (%)
M1	76.75	0.033	2	18.52
M2	106.67	0.033	2	11.03
M20	113.78	0.033	2	9.8
M21	92.43	0.033	2	10.22
M22	177.72	0.03	2	7.23
M23	176.51	0.028	2	7.54
M24	231.46	0.033	2	5.96
M25	170.02	0.03	2	3.56
M26	125.79	0.033	4.1	3.47
M3	109.73	0.033	2	11.48
M30	182.67	0.028	2	6.83
M31	106.7	0.028	2	9.53
M32	216.22	0.033	2	5.83
M33	110.88	0.03	2	4.24
M34	159.27	0.033	2	5.62
M35	356.93	0.03	2	3.83
M36	138.59	0.033	32	8.14
M37	141.22	0.032	50	6.36
M4	256.67	0.033	2	6.59
M5	132.72	0.033	2	5.48
M6	183.48	0.03	2	4.21
M7	128.53	0.03	2	4.14
M8	146.85	0.033	2	11.63
M9	92.6	0.03	2	9.32

2.2.1.2 Manning's 'n' Values

The XP-RAFTS Manning's 'n' values adopted in the hydrological model are shown below in **Table 2-2**.

The sub-catchments were delineated on the basis of the above regions and a single 'n' value was generated based on the relative areas of each of the above regions within the sub-catchment. The 'n' values adopted for each sub-catchment are shown above in **Table 2-1**.

Table 2-2 Manning's 'n' Values Adopted

Manning's Value	Description
0.015	Impervious Area
0.025	Urban Pervious Area
0.05	Rural / Pastureland
0.12	Forested Catchments

2.2.1.3 Rainfall Losses

XP-RAFTS has two methods for determining rainfall losses:

> Initial and continuing loss – this method removes an initial volume of rainfall from the start of the event, and then applies a smaller continuing loss for the remainder of the storm event; and,

> Australian Representive Basin Model (ARBM) – this method considers soil parameters and infiltration rates to groundwater in order to determine the rainfall run-off during a storm event.

The ARBM is a more complex loss methodology that allows for infiltration rates to vary over time. As the critical durations are relatively short, and the fact that there are not multiple storm bursts in the hyetograph, the initial and continuing loss method was adopted for this study.

The initial and continuning losses applied to the model are sumamrised in **Table 2-3**.

Table 2-3 PERN Values Adopted

Area Type	Initial Loss (mm)	Continuing Loss (mm)
Pervious	10	2.5
Impervious	1.5	0

2.2.1.4 Lag Links

RAFTS allows two overland connection types between catchments; a lag link and a routing link. The lagging link shifts the hydrograph by a specified time, with no attenuation of the peak flow, or changes to the hydrograph shape.

The routing link allows a typical section of the channel to be entered into the model, and flow through the link is dependent on the section. The flow hydrograph experiences both attenuation of the peak, and a delay of the peak.

The XP-RAFTS model developed for the study adopted lag links for all connections. The lag between sub-catchments was calculated based on the sub-catchment length (the longest distance that a drop of water would be required to travel within the sub-catchment) and an average flow rate through the sub-catchments of 1m/s.

2.2.1.5 Rainfall Stations

There is one rainfall gauge within the catchment, located at Merimbula airport. As shown in **Table 2-4** however, this gauge only has data available for the March 2011 event.

The nearest rainfall gauge for which data is available for the other calibration events is 20km west of the catchment area. Lacking other suitable data, the rainfall from this gauge was used for the 1998 and 2010 events.

As a result of the lack of a gauges within the catchment area, it was not possible to determine if rainfall intensities varied across the catchment area, and it was assumed that the rainfall intensities recorded at the gauges was representative of the full catchment.

Table 2-4 PERN Values Adopted

Station ID	Record Start Date	Record End Date	Data Type	Data for Calibration		
				Jun 1998	**Feb 2010**	**Mar 2011**
69147	Sep 2010	Aug 2015	1min records			Yes
69066	Jan 1993	May 2013	Pluviograph	Yes	Yes	Yes

2.3 Hydrodynamic Model Development

The Delft3D hydrodynamic modelling system was applied for the hydrodynamic modelling component of this study. Investigations of estuarine and coastal processes require the application of a high level model capable of simulating a range of processes including, ocean wave and tidal forcing, with some confidence. Such simulations can be successfully undertaken using the Delft3D modelling system. This modelling system can include wind, pressure, tide and wave forcing, three-dimensional currents, stratification, sediment transport and water quality descriptions and is capable of using irregular rectilinear or curvilinear coordinates. A detailed description of the modelling system can be found in **Appendix A**.

Flooding in the Merimbula Lake and Back Lake estuaries is likely to be influenced by a number of different processes, including:

> Catchment discharge;
> Coastal water levels (storm tide);
> Nearshore wave conditions (and resulting wave set-up at the shoreline and estuary entrance);
> Entrance morphology - the state of the entrance at the beginning of the flood, and the evolution of entrance scour through the duration of the flood event; and
> The existence of any underlying bed rock beneath the entrance bed sands, which my limit entrance scour.

By utilising its coupled hydrodynamic, wave and morphological modules, Delft3D has the ability to model all of the relevant physical processes simultaneously.

2.3.1 Model Domain Set-Up and Extent

The coupled hydrodynamic, wave and sediment transport model system was established using a three domain model that covered both the Merimbula and Back catchments and estuaries, and also extended offshore into the Tasman Sea to a depth of approximately -100 m AHD. The three domains were linked using Delft3D’s domain decomposition functionality (see **Appendix A**). For the purposes of computational efficiency, grid cell resolution (gird cell size) differs between the three model domains. The offshore model domain resolution is approximately 100 m, with resolution of 30 m for the intermediate grid. The nearshore grid has a resolution of 10 m and encompasses both Merimbula Lake and Back Lake, as well as the suburbs of Merimbula, Berrambool, Mirador and Millingand. It extends offshore to approximately 30 m depth.

The topographic and bathymetric data incorporated into the model is outlined in **Section 2.1** and described in the Stage 1 Report.

The model set-up is depicted in **Figure 2-1**, with model bathymetry of the Merimbula and Back Lake model domain presented in **Figures 2-2** and **2-3**.

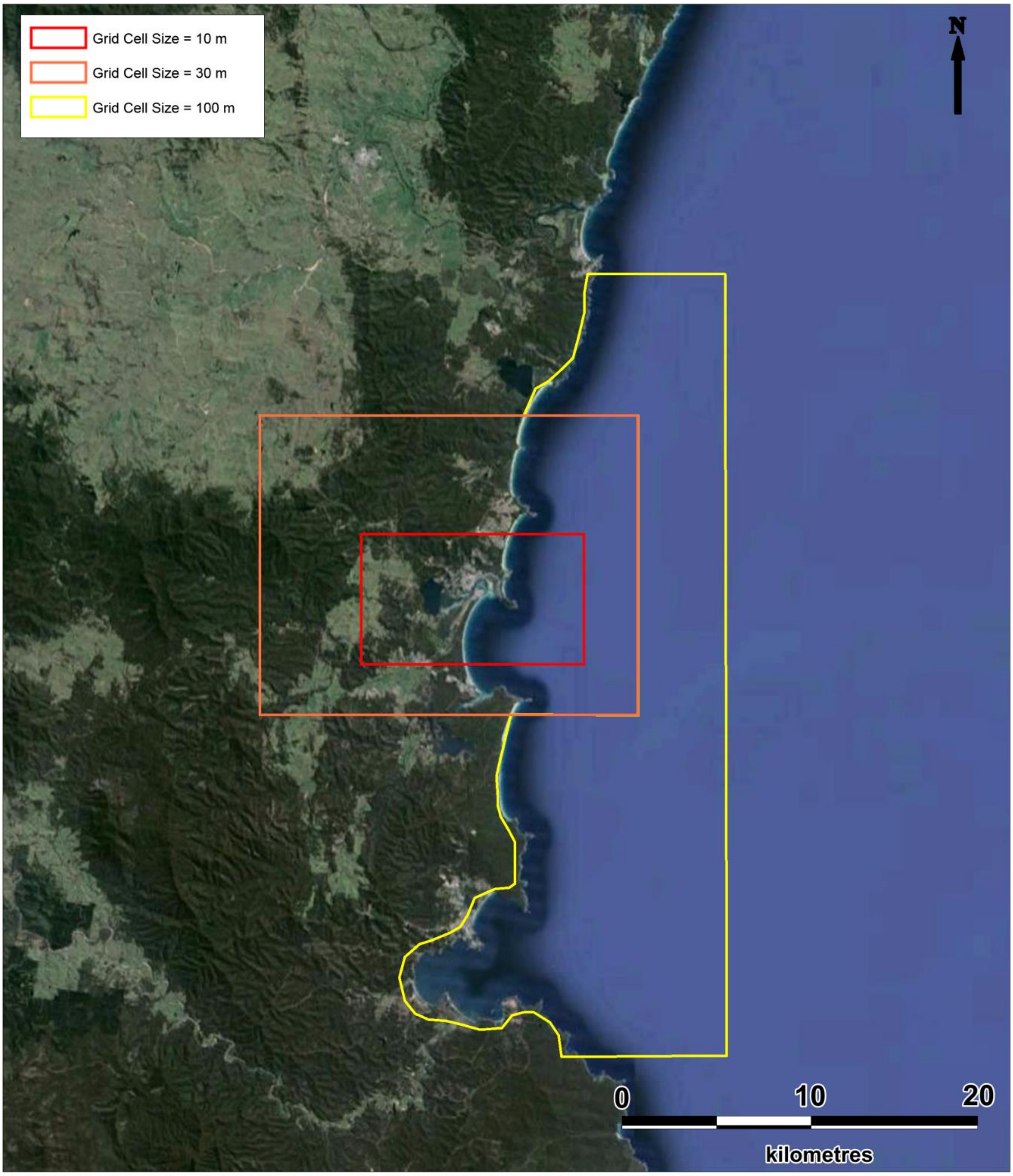


Figure 2-1 2D representation of Merimbula and Back Lake model domain bathymetry (note: colour scale narrowed for a more detailed visual representation of the lake surrounds)

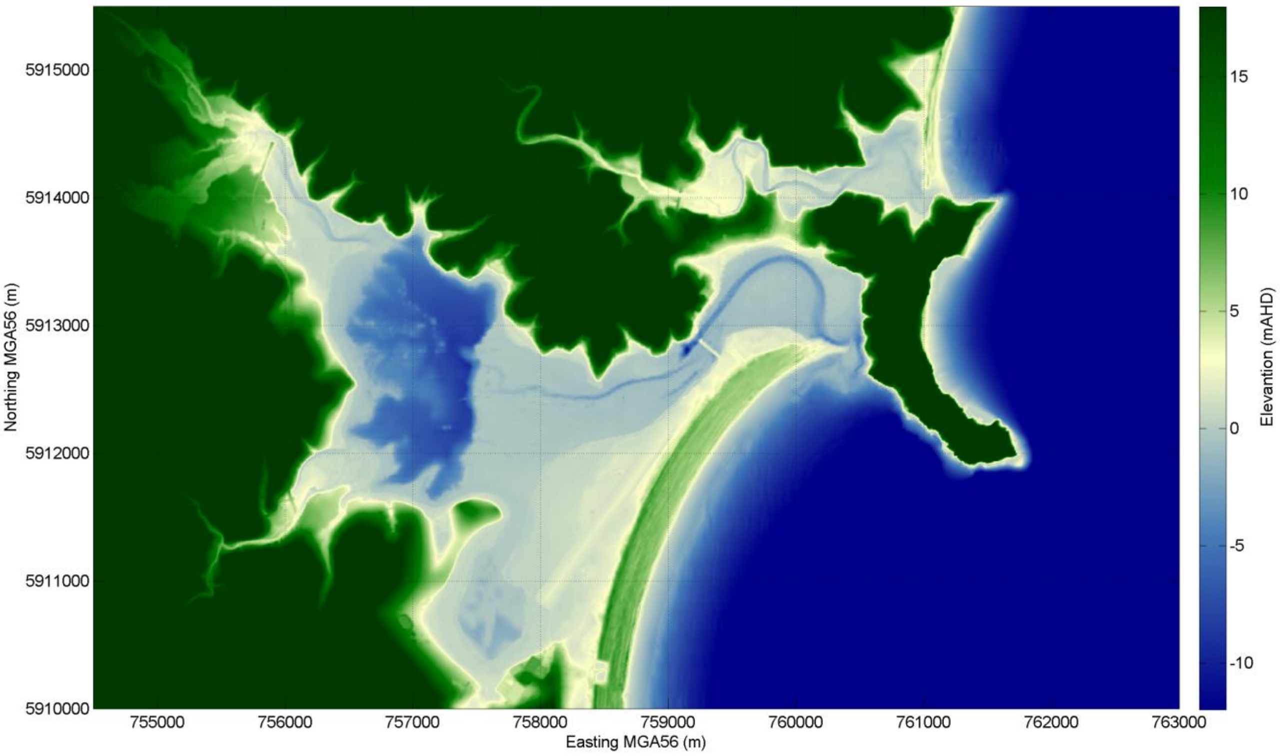


Figure 2-2 2D representation of Merimbula and Back Lake model domain bathymetry (note: colour scale narrowed for a more detailed visual representation of the lake & surrounds)

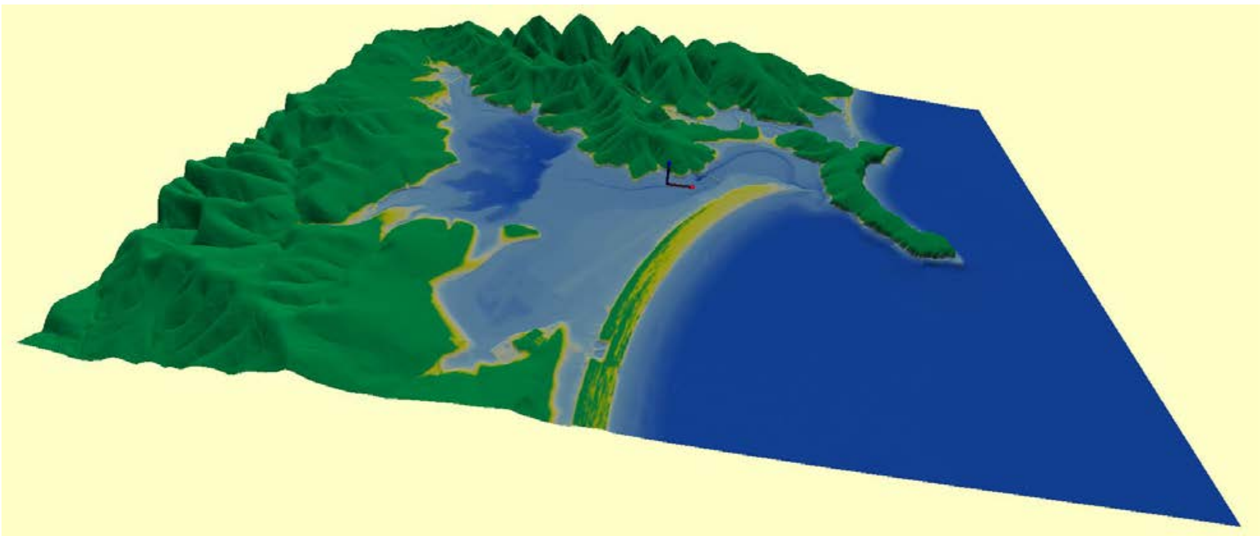


Figure 2-3 3D representation of Merimbula and Back Lake model domain bathymetry (note: colour scale narrowed for a more detailed visual representation of the lake & surrounds)

2.3.2 Model Boundary Conditions

The offshore boundaries of the hydrodynamic model are driven by recorded tide at Eden. Due to the apparent “bumpiness” of the recorded tide signal, a low-pass filter is applied to the data with a cut-off frequency of 3 hours. This process ensures a smooth tidal signal is applied to the boundary, preventing boundary driven hydrodynamic instabilities.

The offshore boundaries of the coupled wave model are driven by Eden Wave Rider Buoy (WRB) data. As discussed in the Stage 1 report, the Eden WRB has only recorded directional wave data from December 2011 onwards. Therefore for the calibration and validation modelling, where offshore wave directions were required for period pre-December 2011, additional offshore wave data was obtained from the global/regional NSW WaveWatch III that Cardno developed and calibrated (including at Eden), for OEH (Cardno, 2013).

2.3.3 Catchment Flows

Upstream catchment flows used in the modelling were included as point source time-series discharges. For the sensitivity testing, calibration and validation modelling upstream flow data was obtained from the results of the XP-RAFTS modelling. Care was taken in the application of these discharges to ensure that point source discharges situated along the same flow path did not 'double count' flows.

2.3.4 Model Roughness

Merimbula Lake is a wave dominated barrier estuary containing a narrow entrance system with a steep hydrodynamic gradient. Therefore the description of the bed roughness can be particularly important when simulating hydrodynamic and sediment transport processes in an entrance system under flood flow conditions. Furthermore, as in overland flow studies, the model roughness is a very important and spatially variable parameter that dominates the hydrodynamic solution (as opposed to viscosity terms in coastal and oceanographic settings), and must be given careful consideration in order to accurately determine the inundation extent and associated flood hazard.

The bottom roughness can be computed with several formulae in Delft3D, and roughness coefficients can be specified for both the *x* and *y* directions. Roughness coefficients can be specified as a uniform value or as a spatially variable map.

For regions affected by overland flow, roughness coefficients were adopted as determined through numerical flume calibration by Cardno (2013). Coefficients were applied for a range of land use types including road, residential/commercial, parkland/forest and open grassland. The application of these roughness values to land parcels was undertaken through analysis of land use specified in Cadastral information supplied by Council.

For regions not affected by overland flow, roughness coefficients were determined through the model sensitivity and calibration process described in **Sections 3** and **4**.

2.3.5 Entrance Morphology

The rock shelf that lies beneath some areas of the entrance (to both estuaries) has been included as a non-erodible, sand covered (at least initially) bar with rock set at levels based on inspection of photogrammetry data and available aerial images. No other reliable data was available depicting the levels of the rock at either estuary entrance. The presence of underlying bed rock may act to reduce the potential entrance scour depth during floods and increase flood levels and/or flood duration. Sediment characteristics such as median grain size (D50) have been adopted based on available information, though sensitivity testing has been conducted regarding this parameter to assess whether these estimates are critical in the model behaviour (see **Section 3**).

2.4 Storm Events for Sensitivity, Calibration and Validation Simulations

The Merimbula and Back Lake estuaries are exposed to inundation risk from both catchment and coastal flooding. Back Lake is a small wave dominated barrier estuary system and so flooding will generally be controlled by the upstream catchment flow and the entrance berm level (WMA, 1995). For the Merimbula Lake estuary, catchment flooding will tend to dominate in the upper reaches while coastal flooding dominates downstream towards the estuary entrance (WMA, 1995). However, the upstream and downstream estuary boundaries comprise a relatively small proportion of the overall estuary foreshore, and so inundation risk at any given location the estuaries will depend on the balance of coastal and catchment flood processes, the estuaries local geography, and its degree of connectivity to the ocean.

It should be noted that in the selection of storm events for the sensitivity, calibration and validation modelling, it is imperative that appropriate data is available to calibrate and validate the model results with, including data for rainfall, ocean tides, ocean wave and lake water levels. Several historical storm events have triggered significant flooding in Merimbula and Back Lake estuaries; for which little suitable data is available. The 1971 flood event, for instance, is considered to be one of the significant flooding events observed in these estuaries. However, there is little in the way of accurate and reliable data regarding observed levels. Consequently the selection of historical flooding events is limited to the historical window for which reliable environmental data is available.

Another consideration was the predominant flooding mechanisms for the two estuaries. With Back Lake flooding being dominated by catchment inflows, and Merimbula Lake affected by both catchment flows at the upstream reaches and coastal flooding at the downstream reaches, it was necessary to employ a selection of storm events that included catchment flooding as well as coastal flooding.

In order to select appropriate historical storm events for the sensitivity, calibration and validation simulations, water level gauge records were inspected in order to identify major flooding events in the two estuaries. For these purposes water level data has been supplied by Manly Hydraulics Laboratory for their water level gauges operating at Merimbula Wharf and Merimbula Lake from 1991 to present, with data supplied for the Back Lake gauge from 2009 to present. The selected storm events were agreed upon in discussion with Council, and are described below.

2.4.1 Storm Event: 23-24 June 1998

The highest water levels recorded within Merimbula Lake and at Merimbula Wharf occurred during the East Coast Low (ECL) event of 23-24 June 1998. This ECL event reached a minimum barometric pressure of 985 hPa by late afternoon of the 23rd June before slowly beginning to move away towards the southeast. The event generated strong southerly to south-easterly winds offshore of Merimbula, while the Eden WRB recorded offshore significant wave heights of up to 6 m (see **Figure 2-4**). Around 78 mm of rainfall were recorded at the Bureau of Meteorology's (BoM) rain gauge at Merimbula Airport. It is the most significant storm tide event to have affected Merimbula Lake from 1991 to present. Recorded data from Back Lake is not available during this period.

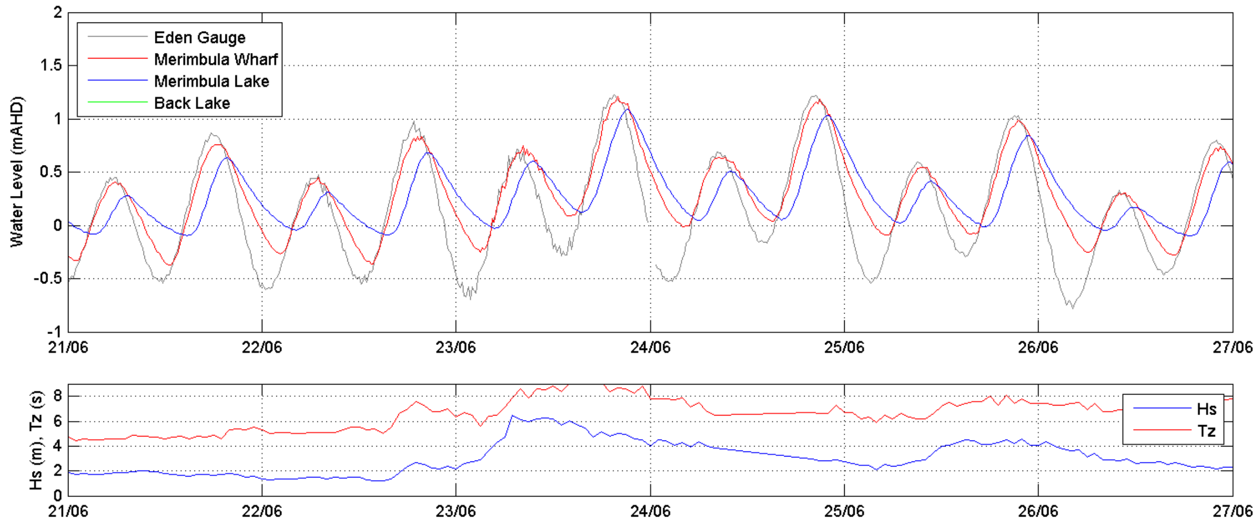


Figure 2-4 23-26 June 1998 East Coast Low event – recorded water levels and waves

2.4.2 Storm Event: 21-22 March 2011

The highest water levels recorded at Back Lake (noting that the record only extends back to 2009), occurred during the severe storm event of 21-22 March 2011 (**Figure 2-6**). This storm event resulted in a period of intense rainfall, with around 83 mm recorded at the BoM rain gauge at Merimbula Airport during the event. Water levels in Merimbula Lake were only slightly elevated, and a without significant contribution of catchment flooding. The event generated significant flooding in Back Lake, with water levels of around 2.4 m AHD being reached before entrance breakout occurred. No information is available regarding the level of the Back Lake entrance berm at the time of breakout.

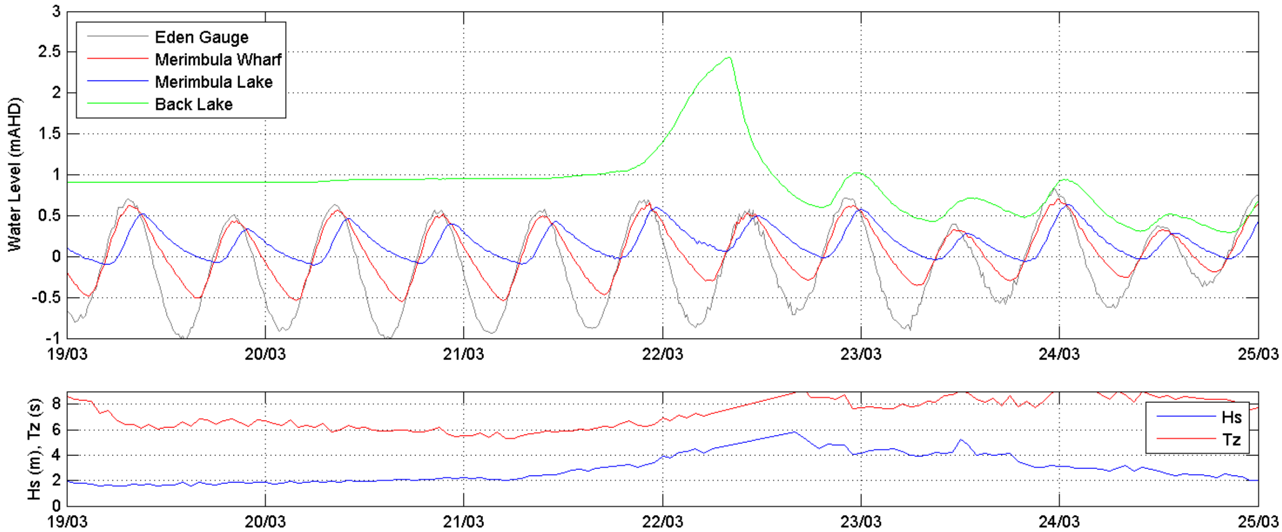


Figure 2-5 21-22 March 2011 storm event – recorded water levels and waves

2.4.3 Storm Event: 14-16 February 2010

Another significant storm event to have affected the region was the event of 14-16 February 2011. This storm event resulted in a period of extreme rainfall, with around 242 mm recorded at the BoM rain gauge at Merimbula Airport during the event. As for the March 2011 event, water levels in Merimbula Lake were elevated, but without significant flooding due to the event coinciding with a neap tide. The event generated significant flooding in Back Lake, with water levels of around 2.4 m AHD reached before entrance breakout. No information is available regarding the level of the Back Lake entrance berm at the time of breakout.

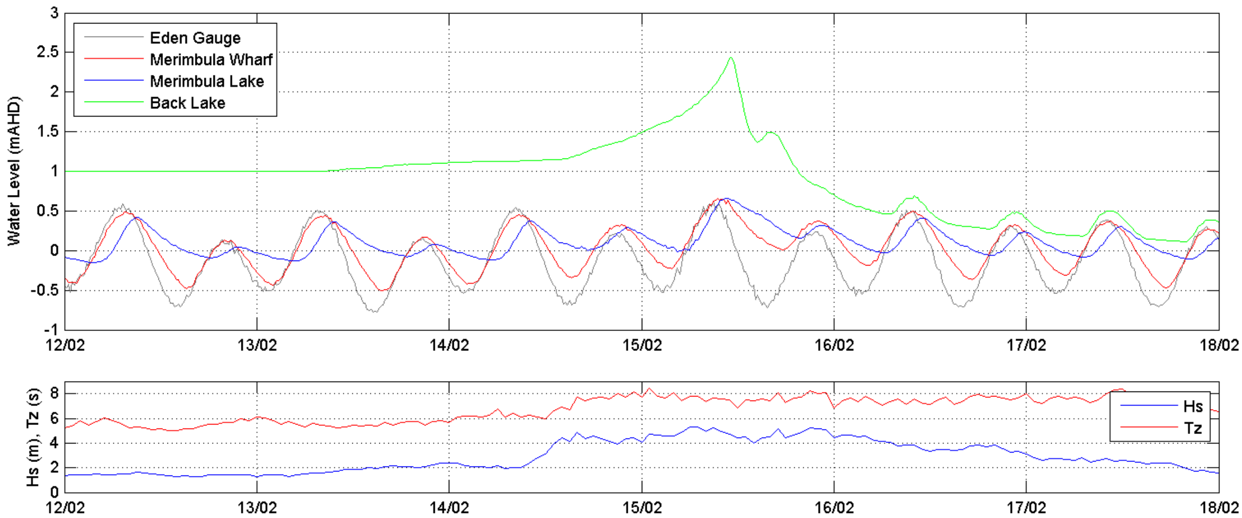


Figure 2-6 14-16 February 2010 storm event – recorded water levels and waves

2.4.4 Modelling Rationale

Given the flooding mechanism of the two estuaries, the following approach was adopted.

Calibrate to both:

> A non-flood period when water level data was recorded and entrance bathymetric data was also available; and

> A catchment event for Back Lake: 21-22 March 2011.

Then, validate to:

> The ocean storm tide event for Merimbula: 23-24 June 1998

> The flooding event of 14-16 February 2010, which included both extreme rainfall as well as storm tide. Whilst the overall levels in Merimbula Lake didn't reach flood levels due to the surge coinciding with a low, neap tide, the model can be validated to the surge nonetheless.

3 Sensitivity Testing

3.1 Overview

In order to fully understand the limitations of the hydrodynamic modelling, it is imperative to understand the sensitivity of the modelling to various model parameters and the consequent effect they have on the model results. Therefore a regiment of modelling scenarios was devised to test the sensitivity of physical parameters (and their representation in the model), that were likely to impact flood levels and durations.

For this reason, the following model parameters were selected for sensitivity testing.

1. Model Bed Roughness: Delft3D has the functionality of employing a spatially variable bed roughness, which can be given as either a Chezy Coefficient, or Mannings *n*. Testing of this parameter is vital to describing the attenuation of tidal energy through the respective estuary entrances.
2. Breaking Wave Parameter: The adopted breaking wave parameter will affect nearshore wave breaking and consequently the regional wave set-up and storm tide level at the estuary entrances (i.e. tail water levels for upstream flooding).
3. Sediment Composition: The composition of entrance sediments will affect the evolution of entrance scour during flood events, and consequently can have significant effects upon modelled flood levels.
4. Entrance Condition: The state of the entrance condition (that is, the degree of connectivity to the ocean), will have a significant effect upon both the incursion of ocean inundation and the release of catchment flood waters.
5. Peak Flow and Storm Tide Phasing: The phasing of peak catchment discharge (upstream boundary) with respect to ocean tide levels (downstream boundary);

As part of the sensitivity modelling, an initial baseline simulation was conducted adopting typical values for the above parameters, see **Table 3-1**. Then for each of the five model parameters discussed above, sensitivity testing for two additional input conditions/values was undertaken, with the results then compared back to the baseline simulation.

Table 3-1 Sensitivity Testing Simulations

Type	Number of Simulations	Additional Information
Baseline Simulation	1	Roughness: Constant Chezy coefficient: 65 D50: 0.30 mm Entrance Condition: Based on 2003 bathymetric survey Peak Catchment Discharge: Coinciding with High Tide
Bed Roughness	2	1 x Adopted bed roughness: Chezy coefficient: 45 1 x Adopted bed roughness: Chezy coefficient: 85
Inclusion of Waves and Breaking Wave Coefficient	3	1 x Waves included with breaking wave coefficient: γ = 0.60 1 x Waves included with breaking wave coefficient: γ = 0.70 1 x Waves included with breaking wave coefficient: γ = 0.80
Sediment Composition	2	1 x Entrance sediments modelled with local D50 + 5µm 1 x Entrance sediments modelled with local D50 - 5µm
Entrance Condition:	2	1 x Higher end of observed ocean connectivity 1 x Lower end of observed ocean connectivity
Timing of Catchment and Ocean Flooding:	2	1 x Peak catchment discharge coinciding with High Tide +3 hours 1 x Peak catchment discharge coinciding with High Tide +6 hours

3.2 Sensitivity Modelling

3.2.1 Roughness

The selection of model bed roughness for the sensitivity analysis was based on typical Chezy roughness values for numerical modelling in wave dominated barrier estuaries with limited ocean connectivity and significant energy losses through the entrance. For the flood modelling in Stage 3, a spatially variable Chezy bed roughness will be employed, with values adopted being based on model calibration. Most of those Chezy values will be between 15 and 60 (based on Cardno's experience modelling tidal flows through constricted estuary entrance channels), where Chezy 15 constitutes a greater level of roughness and Chezy 60 a lower roughness. Consequently the sensitivity modelling used these numbers as constant values to depict the likely extent of the sensitivity to these values.

Results depicted in **Figure 3-1** and **Table 3-2** show that flood levels in Merimbula Lake are marginally sensitive to model roughness, with peak flood levels approximately 0.06 m lower for the Chezy 15 than the Chezy 60 roughness simulations at the Merimbula Lake and Wharf locations. This can be attributed to the increased roughness of the Chezy 15 simulation causing greater tidal energy losses through the estuary entrance – resulting in a lower tidal range inside Merimbula Lake. The results show no significant difference in flood levels inside Back Lake.

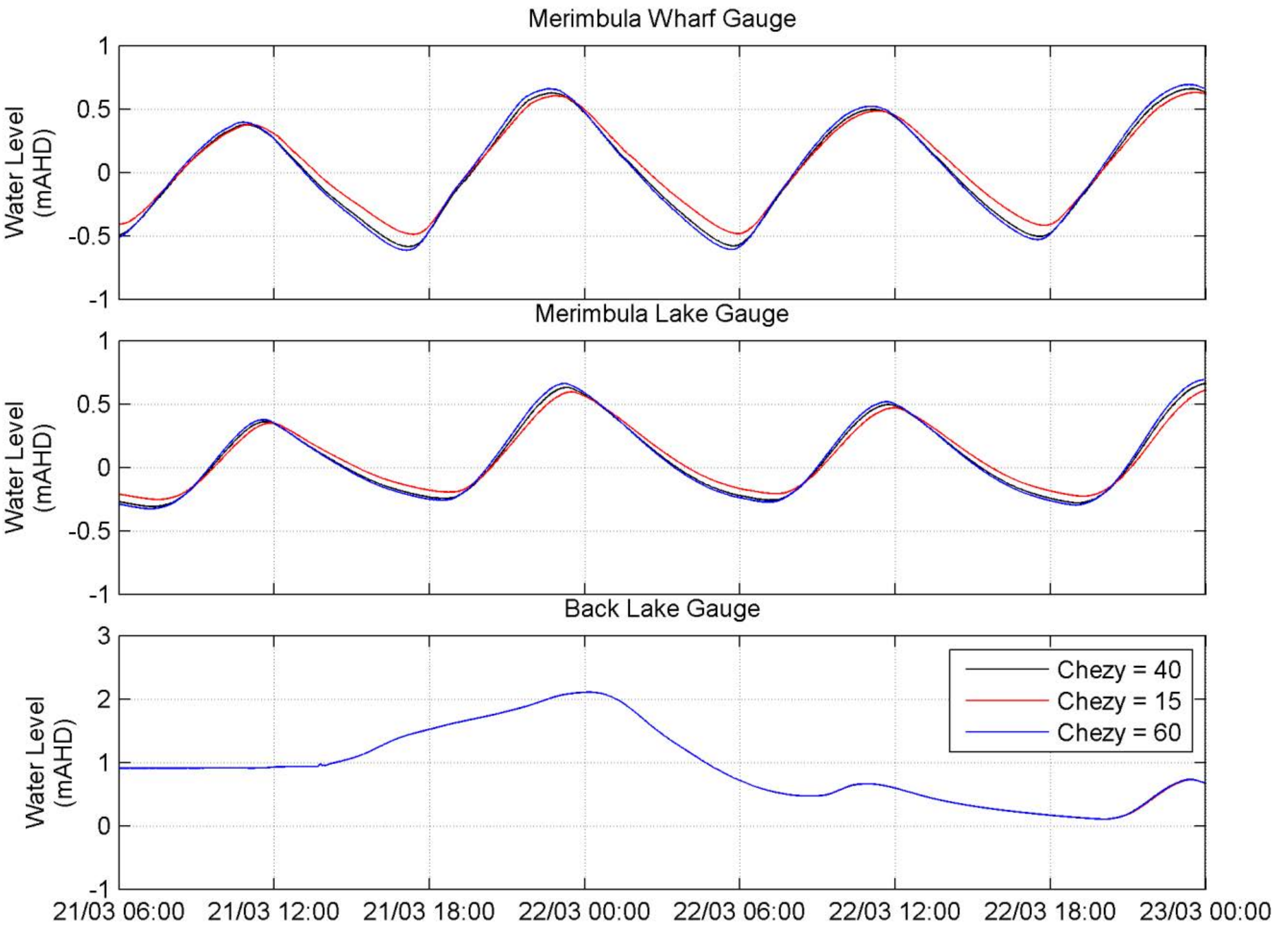


Figure 3-1 Sensitivity Testing – Bed Roughness

Table 3-2 Sensitivity Testing – Bed Roughness

	Flood Level m AHD		
Simulation	**Merimbula Wharf**	**Merimbula Lake**	**Back Lake**
Baseline: Chezy 40	0.66	0.66	2.10
Chezy 15	0.63	0.62	2.10
Chezy 60	0.69	0.69	2.10

3.2.2 Inclusion of Waves and Breaking Wave Coefficient

In order to investigate the influence on wave set-up at the estuary entrances and the sensitivity of the modelled flood levels to the adopted breaking wave parameter (ɣ), simulations were conducted using values for ɣ that lie within the range of physically realistic values. The breaking wave parameter describes the ratio of wave height to water depth that will induce wave breaking. That is, if ɣ = 0.8, then a wave with a wave height (crest to trough) of 1 m would break in a water depth of 1.25 m. Similarly, with ɣ = 0.6, waves would break in a water depth of 1.67 m (further offshore).

The baseline hydrodynamic simulation was run without a coupled wave model. The sensitivity simulations each utilised the coupled wave model, with ɣ of 0.6, 0.7 and 0.8, respectively.

Results depicted in **Figure 3-2** and **Table 3-3** show that peak flood levels in Merimbula Lake are several centimetres higher inside Merimbula Lake when a coupled wave model is included. This can be attributed to the fact that the coupled wave model replicates wave set-up at the estuary entrance. Furthermore, after the peak of the flood, when the entrance has undergone scour, and therefore has higher ocean connectivity, the flood levels inside the lake increase by up to 0.1 m as a result of the coupling of the hydrodynamic and wave models. In terms of the sensitivity to ɣ, the impact on peak flood levels is only minor, however, variations of up to 0.08 m between simulation results with ɣ = 0.8 and ɣ = 0.6 were observed at subsequent high waters.

The results also show that peak water levels inside Back Lake are unaffected by the inclusion of wave set-up, because the peak flood levels occur when the lake is closed. However, after the peak of the flood event, when the entrance is fully scoured, the inclusion of wave set-up increases water levels within the lake by up to 0.5 m – although these levels are well below flood peaks.

It should be noted that the offshore Hs for this event was ~ 6 m, and greater increases in lake water levels would be expected with higher offshore wave heights.

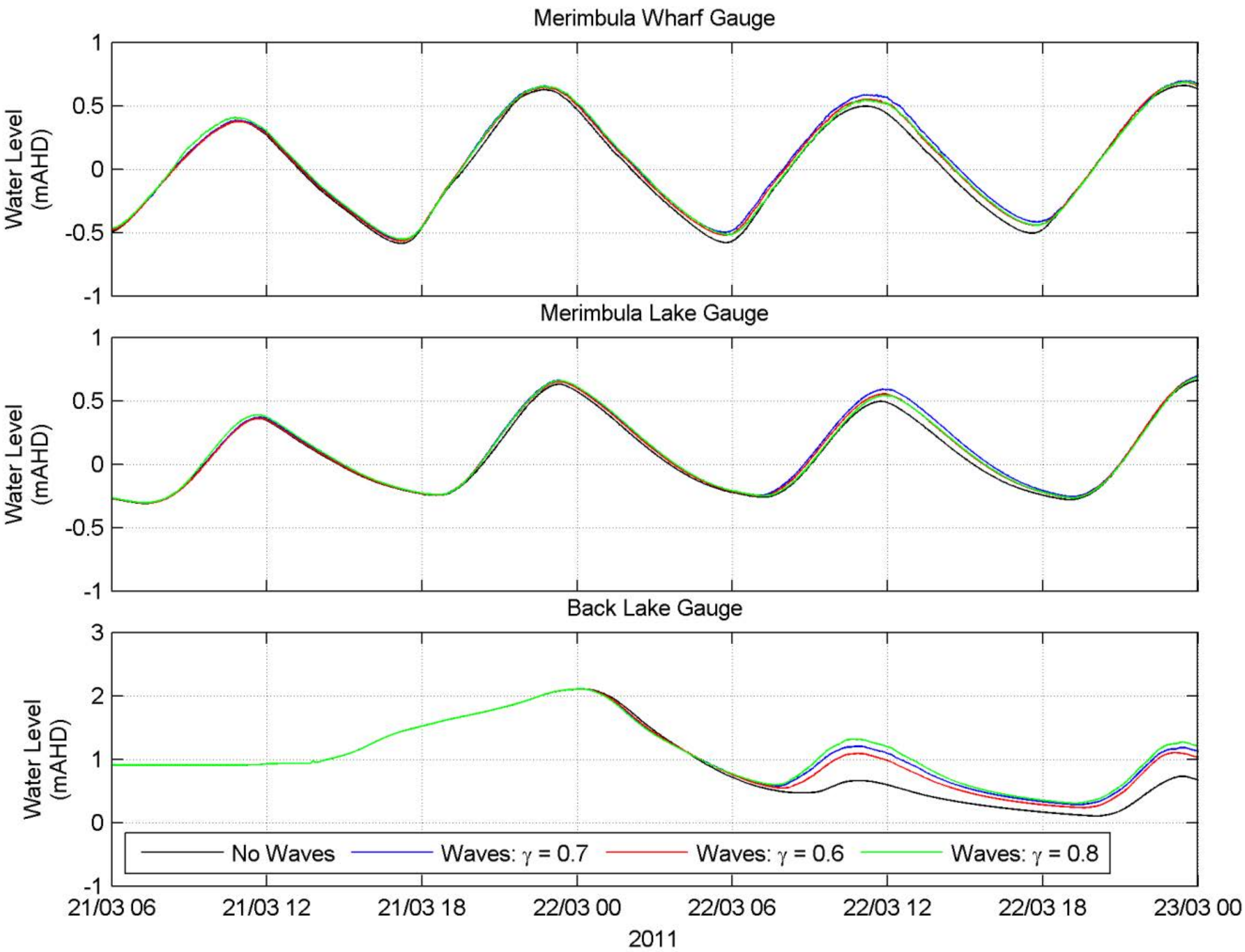


Figure 3-2 Sensitivity Testing – Breaking Wave Coefficient Size

Table 3-3 Sensitivity Testing – Breaking Wave Coefficient

Simulation	Flood Level m AHD Merimbula Wharf	Merimbula Lake	Back Lake
Baseline: No Waves	0.66	0.66	2.10
Waves: ɣ = 0.7	0.69	0.69	2.10
Waves: ɣ = 0.6	0.69	0.69	2.10
Waves: ɣ = 0.8	0.69	0.69	2.10

3.2.3 Sediment Composition

The selection of modelled sediment size (characterized by D_{50}), for the sensitivity analysis was assessed on the basis of available sediment information. As discussed in the Stage 1 report, WMA (1995) describe sediments at the entrance of Merimbula Lake and Back Lake to be quartz marine sands of medium grain size, with a D_{50} between 250 and 500 µm. Thomas et al (1994) conducted PSD testing of sediment at the Pambula Lake entrance and found the sediment had a D_{50} of approximately 380 µm. Kidd (1978) determined sediments at the Merimbula beach and Merimbula Lake entrance to have a D_{50} between 280 and 320 µm.

Consequently, the baseline simulation was assigned the best available estimate of D_{50} at the Merimbula and Back Lake entrances of 300 µm, based on Kidd (1978). The modelled D_{50} for the sensitivity analyses were assigned as the likely lower and upper limits of the likely D_{50} at the site, namely 200 and 500 µm, respectively.

Results depicted in **Figure 3-3** and **Table 3-4** show that flood levels in both estuaries are only slightly sensitive to D_{50}, with less than 0.01 m difference in flood levels at the three locations. However, the results do show that flood duration in Back Lake is sensitive to D_{50}. In fact the increase in the D_{50} from 200 to 500 µm caused an increase in the duration for which flood levels persist above 1.0 m AHD in Back Lake of approximately 3 hours. This can be attributed to the fact that coarser sediments require higher flow velocities to mobilise, and consequently the entrance channel scours/erodes more slowly.

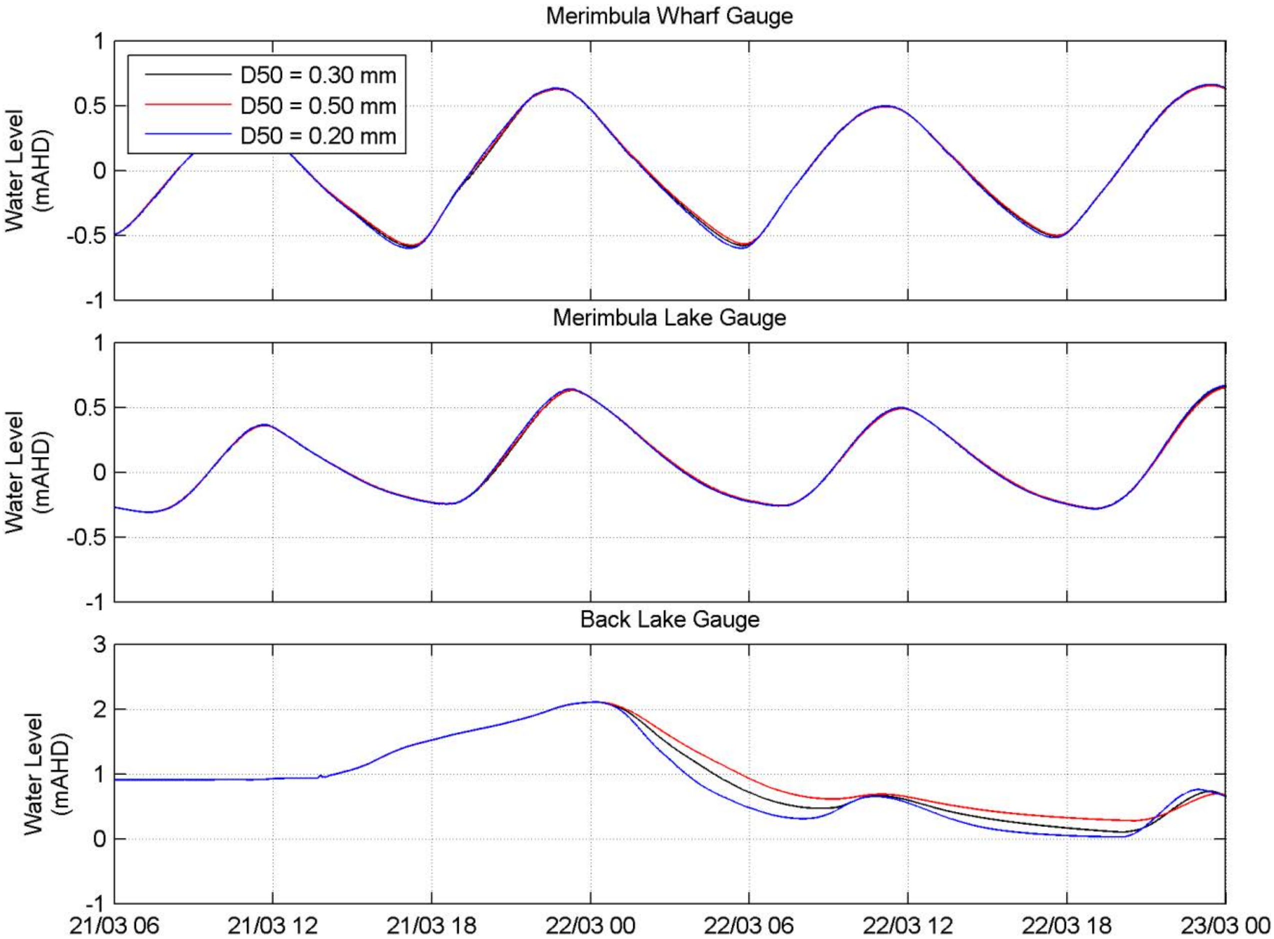


Figure 3-3 Sensitivity Testing – Sediment Size

Table 3-4 Sensitivity Testing – Sediment Size

Simulation	Flood level m AHD			
	Merimbula Wharf	Merimbula Lake	Back Lake	Back Lake Flood Duration
Baseline D50: 0.30 mm	0.66	0.66	2.10	14.5 hours
Sensitivity: 0.50 mm	0.66	0.66	2.10	13 hours
Sensitivity: 0.20 mm	0.66	0.66	2.10	16 hours

3.2.4 Entrance Condition

As part of this assessment, an investigation was conducted into the sensitivity of the modelled flood levels inside Merimbula Lake to the condition of the entrance – that is, to the entrance's degrees of ocean connectivity. For this task, the baseline simulation was undertaken using the most detailed available bathymetry, which was the 2003 hydro-survey of the lake and lakes' entrances conducted by MHL.

Sensitivity simulations were conducted for entrance conditions that represented the higher and lower ends of historical entrance connectivity, respectively, for Merimbula Lake. Data regarding the historical entrance connectivity was available in the form of photogrammetric data. The photogrammetric data was available for a number of years from 1962-2011 (details provided in the Stage 1 report), which covered the entrance spit. In order to estimate the lower end of historical entrance connectivity, an envelope approach was adopted whereby for each photogrammetric profile the highest historical bed level at each chainage point was adopted. Conversely, to estimate the higher end of connectivity, the lowest historical bed level at each chainage point was adopted.

Results depicted in **Figure 3-4** and **Table 3-5** show that peak flood levels in Merimbula Lake are slightly higher inside Merimbula Lake for the higher entrance connectivity. This can be attributed to the fact that a greater degree of connectivity causes less energy losses as tides propagate into the estuary, and therefore an increased tidal range inside. The difference between peak water levels for high and low entrance connectivity for this event was in the order of 0.06 m inside Merimbula Lake, though differences are likely to be greater in instances of larger ocean tide ranges.

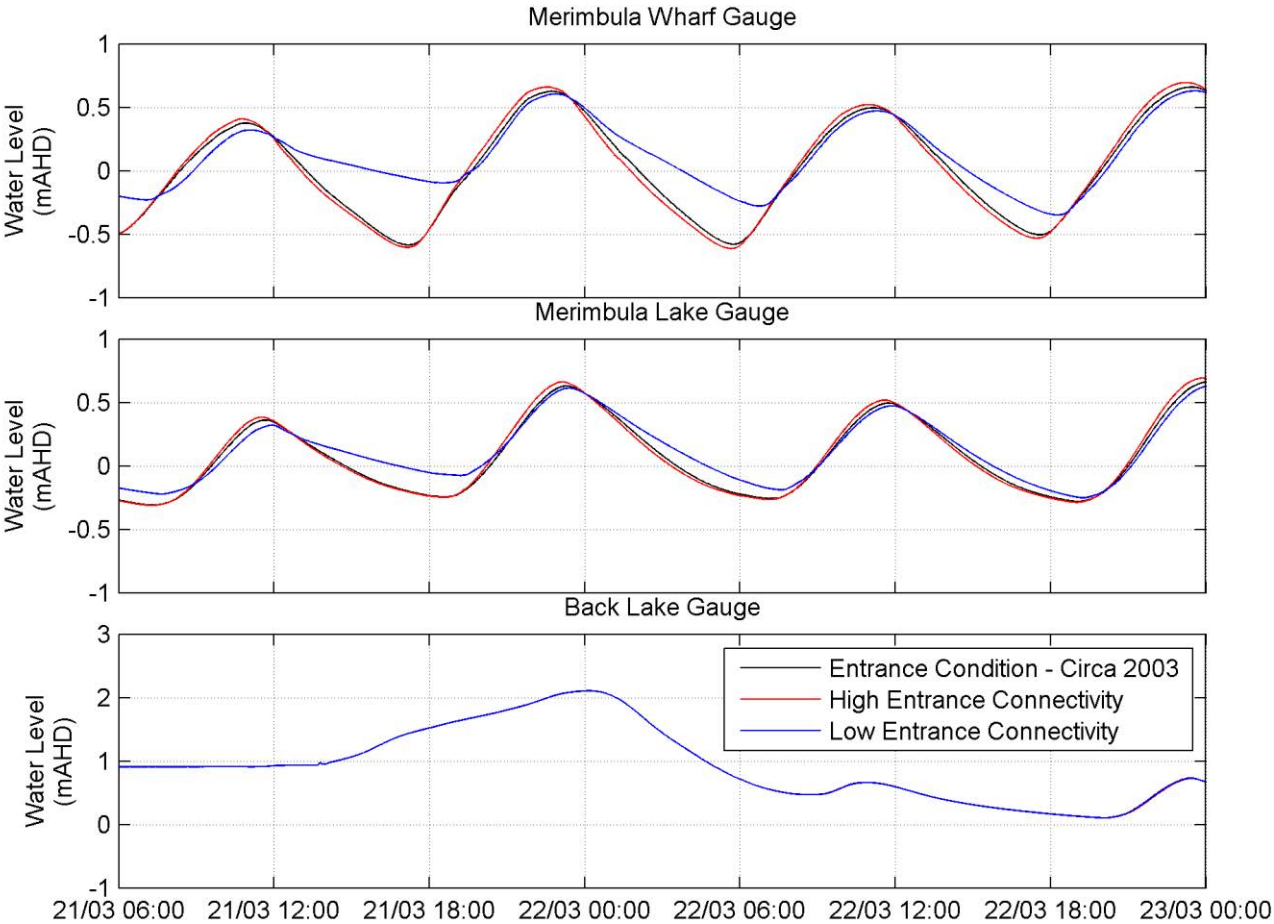


Figure 3-4 Sensitivity Testing – Sediment Size

Table 3-5 Sensitivity Testing – Breaking Wave Coefficient

	Flood Level m AHD		
Simulation	Merimbula Wharf	Merimbula Lake	Back Lake
Baseline: 2003 Entrance	0.66	0.66	2.10
Connectivity: High	0.69	0.69	2.10
Connectivity: Low	0.63	0.63	2.10

3.2.5 Timing of Catchment and Ocean Flooding

As part of this assessment, an investigation was conducted into the sensitivity of the modelled flood levels inside Merimbula Lake and Back Lake to the relative timing of catchment flooding and oceanic inundation, because in some circumstances this can influence peak flood levels in wave dominated barrier estuaries.

Sensitivity simulations were conducted for peak catchment inflows that were offset by 3 and 6 hours respectively from the base peak high tide in Merimbula Lake case (noting that there is a small lag between the high tide at the Merimbula Wharf and Merimbula Lake output locations).

Results depicted in **Figure 3-5** and **Table 3-6** show that peak flood levels in Merimbula Lake are relatively unaffected by the timing of catchment inflows (in the lake body at least) for this particular flood event. This can be attributed to the amount of flood storage available inside the Merimbula Lake body. This is the reason that the predominant driver of flooding inside the Lake is the insurgence of coastal flooding. It should be noted that timing of catchment flooding may be more important for higher recurrence interval catchment events where the volume of catchment inflow may be significantly higher than for the March 2011 event; especially relative to the available storage.

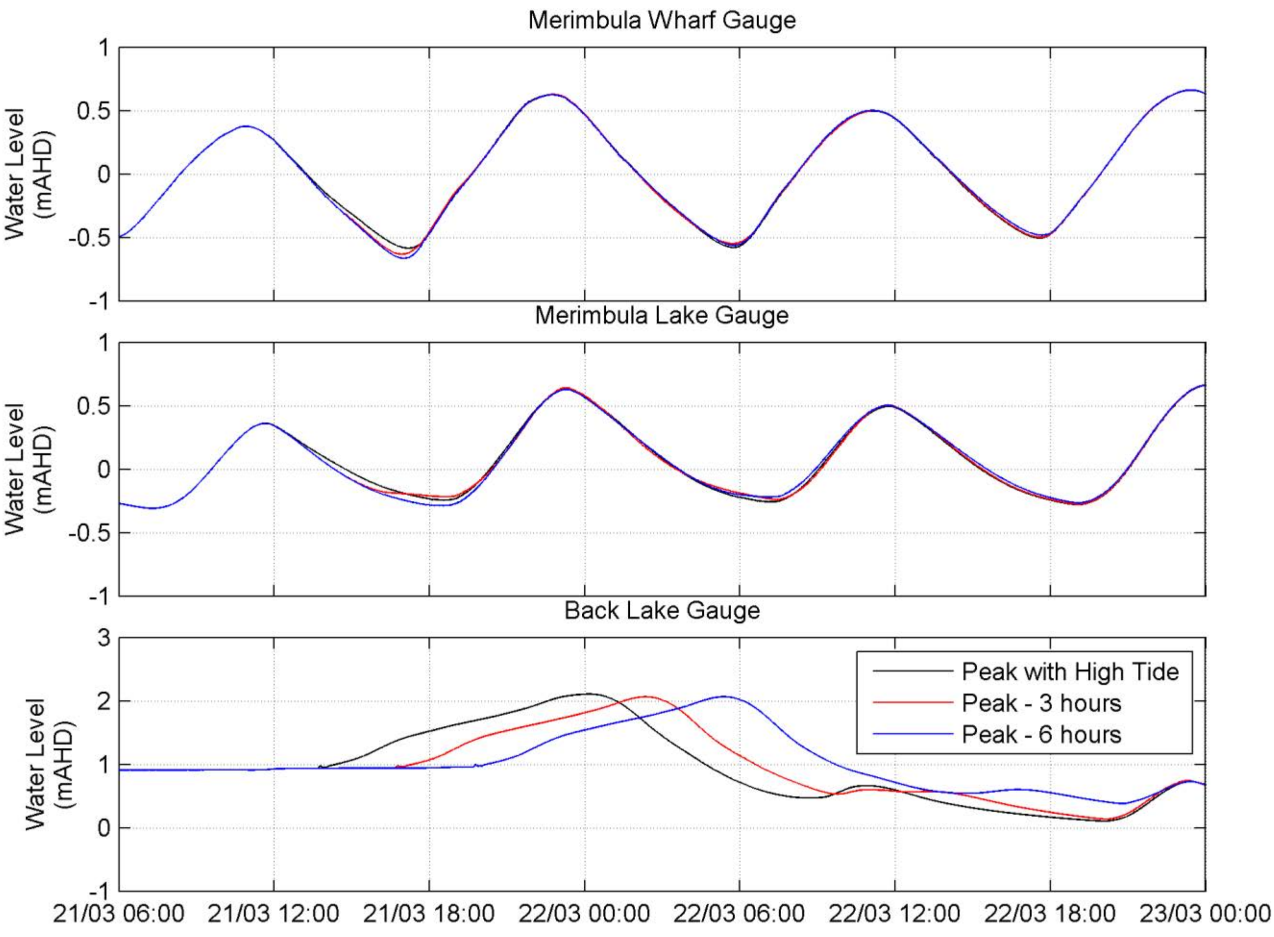


Figure 3-5 Sensitivity Testing – Timing of Catchment and Ocean Flooding

Table 3-6 Sensitivity Testing – Timing of Catchment and Ocean Flooding

	Flood Level m AHD		
Simulation	**Merimbula Wharf**	**Merimbula Lake**	**Back Lake**
Baseline: Coincident with High Tide	0.66	0.66	2.10
High Tide + 3 hours	0.66	0.66	2.10
High Tide + 6 hours	0.66	0.66	2.10

3.3 Outcomes

Model Bed Roughness: Given that coastal flooding is such a major component of Merimbula Lake flood levels, the selection of bed roughness and resultant tidal energy losses through the estuary entrance will be very important. The sensitivity analysis showed that within the range of realistic bed roughness values, peak flood levels are relatively sensitive to the adopted Chezy value. For the flood modelling in Stage 3, a spatially variable Chezy bed roughness will be employed, and calibration of the bed roughness through the Merimbula Lake entrance will be critical to ensuring accurate modelling of coastal flooding into the lake. In order to properly conduct this calibration, it will be necessary to undertake tidal (non-flood) calibration over a period where Merimbula Lake water level data and entrance bathymetry exist over a coincident time period (see **Section 4.2**) – such as in October 2003 (see the Stage 1 report).

Inclusion of Waves and the Breaking Wave Parameter: The sensitivity analyses showed that the adoption of a coupled hydrodynamic and wave models, and the resultant inclusion of local wave set-up and storm tide level at the estuary entrances, is crucial to accurately modelling peak flood level inside Merimbula Lake. In terms of breaking wave parameter, the results do not show particular sensitivity to this parameter, though greater differences in lake flood levels may be observed under higher wave conditions. Consequently, this parameter should be assessed in the model calibration phase.

Sediment Composition: The sensitivity analysis showed that while peak flood levels did not appear to be overly sensitive to the adopted D_{50} value, this parameter is influential on flood duration in Back Lake. Consequently, a physically realistic D_{50} value is important for the modelling of flood durations in Back Lake. Based on the available information from WMA (1995), Thomas et al (1994) and Kidd (1978), sediment size data is available with a high enough degree of certainty to proceed with the flood modelling in Stage 3 without additional data collection.

Entrance Condition: Sensitivity modelling showed that the historical extremes of high and low entrance conductivity at Merimbula Lake can affect flood levels by several centimetres, or more. Therefore, a conservative approach should be taken to the flood modelling of Merimbula Lake that applies a high degree of ocean connectivity so that coastal storm tide can more fully propagate into the estuary. Given the sensitivity of the tidal propagation to the entrance condition, a tidal (non-flood) calibration of the model will be necessary over a period where Merimbula Lake water level data and entrance bathymetry exist over a coincident time period (see **Section 4.2**) – such as in October 2003 (see the Stage 1 report).

Timing of Catchment and Ocean Flooding: Sensitivity analyses showed that, due to the large volume of flood storage available within the Merimbula Lake, for the modelled peak flood levels in Merimbula Lake are relatively unaffected by the timing of catchment inflows with the tide. However, timing of catchment flooding may be more important for higher recurrence interval catchment events where the volume of catchment inflow may be significantly higher than for the March 2011 event, and so it is recommended that as part of Stage 3, sensitivity analyses be conducted using larger inflows of design flood (100-years-ARI).

Other Issues: Another issue worthy of consideration, though not modelled as part of the sensitivity analyses, is the Back Lake entrance berm height. Generally speaking, the height of the entrance berm is likely to dictate flood levels inside Back Lake, because once the flood levels exceed the entrance berm height, overtopping begins and entrance scour commences. Therefore, for the flood modelling in Stage 3, a reasonable berm level should be adopted based on necessary conservatism and in discussion with Council.

4 Calibration & Validation

4.1 Hydrological Model Calibration

There are no flow gauges within the catchments, which prevented the hydrological model being calibrated to historical events. Therefore, to assist in improving confidence in the results of the hydrological model, sub-catchment flows were compared against the peak flow estimates from the Probabilistic Rational Method (PRM), as described in AR&R (1987).

The PRM was developed to estimate peak flows from small to medium sized rural catchments. However, there are a number of problems associated with the use of the Rational Method. Most of these problems are associated with the estimation of parameter values such as the time of concentration and the runoff coefficient. The draft Project 13 Report (Engineers Australia, 2014), which examines the PRM as part of the current update to AR&R, suggests that the PRM not be used to calibrate hydrological flows unless a study has been undertaken to calibrate the parameters to the study area in question.

Given this, the results of the PRM should be used only as a general calibration tool, to ensure that the observed peak flows are of the right order of magnitude.

The results of the comparison with the PRM are shown in **Table 4-1**.

Overall, the rational method generally correlates with the flows observed in the XP-RAFTS model. One catchment had a variance of 14%, while the other three catchments assessed had variances of less than 10%. The flow estimates from the PRM were all lower than the XP-RAFTS peak flows. This indicates that the XP-RAFTS flows may be slightly conservative. As peak levels within both Merimbula Lake and Back Lake are driven more by entrance conditions and ocean behaviour, conservative estimates of catchment flows are not expected to significantly affect the flood behaviour. The flow volumes will be indirectly assessed as part of the calibration process for the hydrodynamic model.

Furthermore, sensitivity testing of the hydrodynamic model showed that the Delft3D model was relatively insensitive to changes in catchment flow timings, as a result of the significant storage in both lakes, with peak levels within the lakes being controlled more by ocean and entrance conditions than upstream catchment timings.

As a result of this insensitivity, and the agreement in peak flows between the XP-RAFTS model and the PRM, the flows from the hydrological model are considered suitable for use in the hydrodynamic model.

Table 4-1 Comparison of XP-RATS and PRM Peak Flows (m^3/s)

Catchment ID	XP-RAFTS	PRM	Difference
B20	60.8	59.9	1%
B21	48.0	41.2	14%
B31	41.6	38.2	8%
M30	50.5	48.2	5%

4.2 Hydrodynamic Model Calibration

4.2.1 Non-Flood Tidal Calibration – October 2003

In order to properly calibrate the model bed roughness for the hydrodynamic model, it was necessary to conduct tidal (non-flood) calibration over a period of time where data jointly existed for Merimbula Lake water level and entrance bathymetry. Fortunately such contemporaneous data exists. Water level data for Merimbula Lake was available from tide gauge records collected by Manly Hydraulics Laboratory (MHL, 2004). A tidal gauging exercise was conducted in September – November 2003 and water level data was continuously monitored at six locations within the estuary as shown in **Figure 4-1**. Additionally, a hydrographic survey of the Merimbula Lake estuary and entrance was also conducted during this period. Therefore, a tidal calibration was undertaken for a 16 day period during this time, enough to cover a full spring/neap tide cycle.

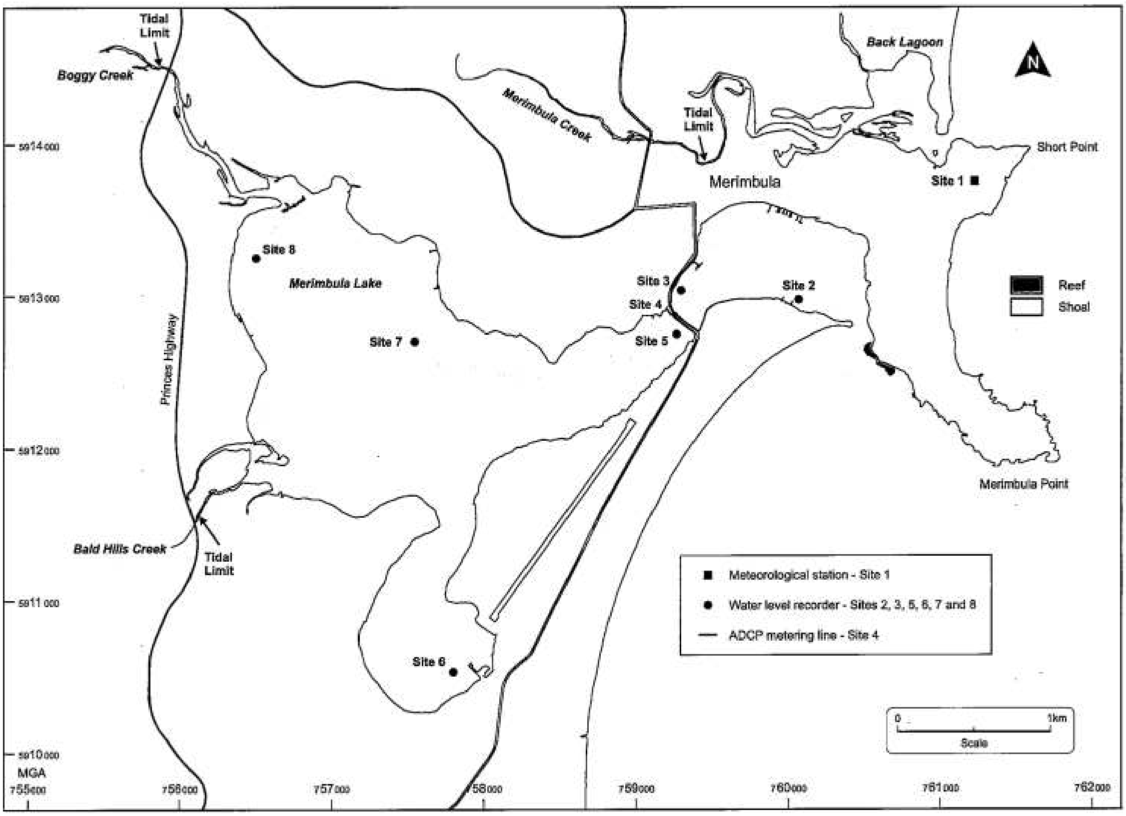


Figure 4-1 MHL Data Locations

Using this data, the model bed roughness map was varied until the measured and modelled results showed good agreement. The resultant model roughness is depicted in **Figure 4-2**, with resultant measured and modelled water levels presented in **Figure 4-3**.

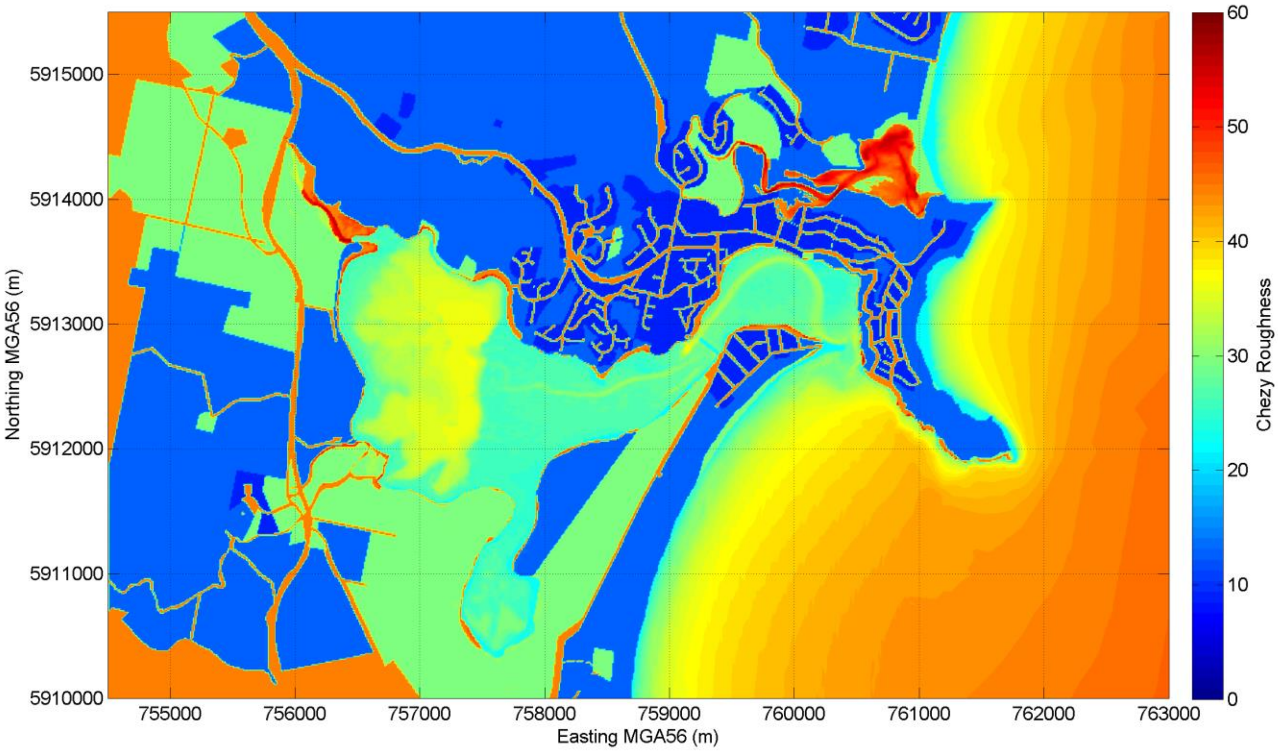


Figure 4-2 Adopted Model Roughness

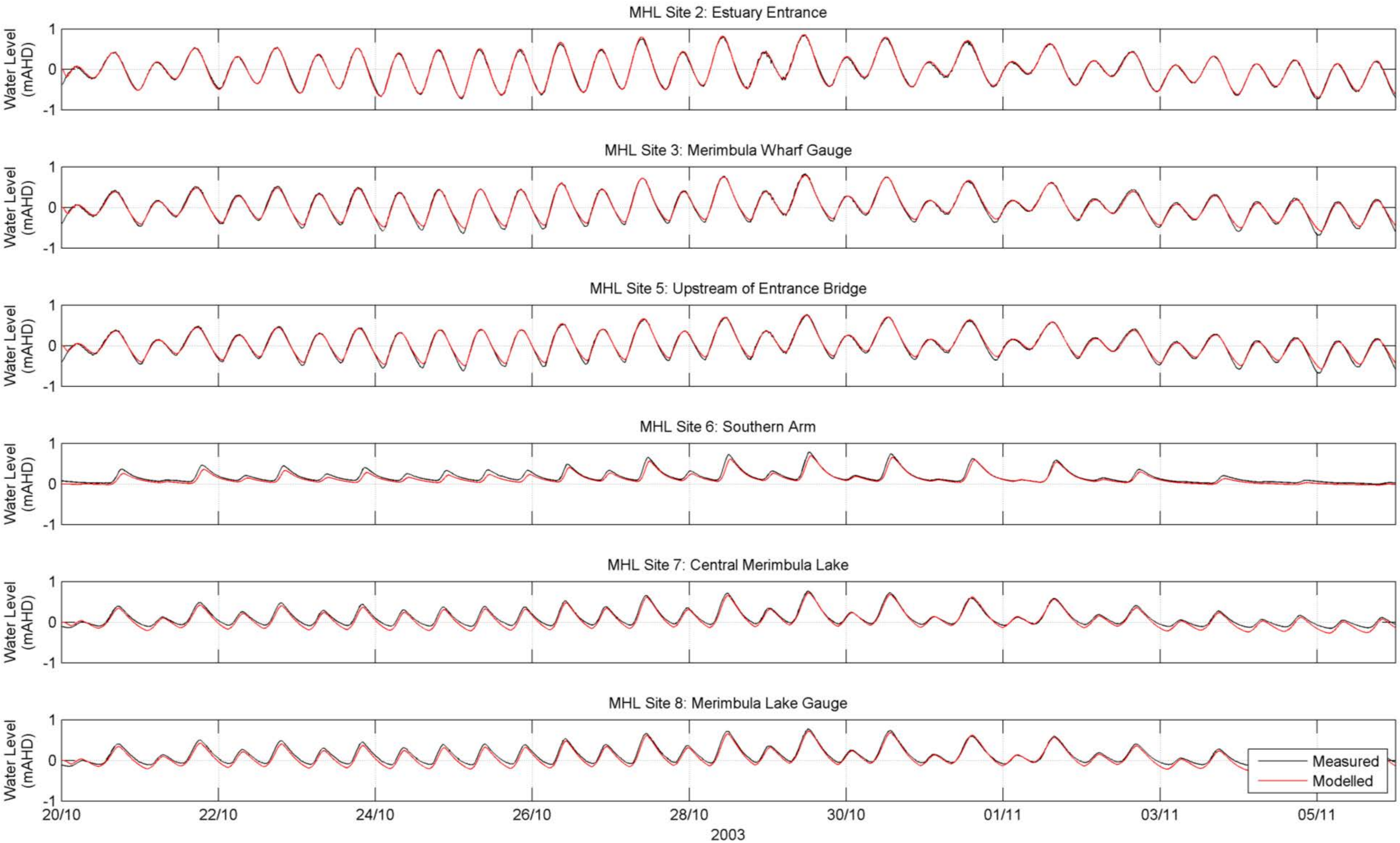


Figure 4-3 Model Calibration – non-flood (tidal) calibration

The modelled results shown in **Figure 4-3** show that where time-stamped bathymetric data exists, the model is capable of representing the spatial variation of water levels within the estuary.

4.2.2 Storm Event: 21-22 March 2011

Cardno successfully calibrated the model to the 21-22 March 2011 storm event. The event was predominantly a catchment event, with only a minor storm tide component. The simulation included environmental inputs for recorded water levels and waves on the model boundary, as well as catchment inflows (from the RAFTS modelling outcomes), rainfall and wind.

The results are provided in **Figure 4-2** in terms of recorded water levels at the Merimbula Lake and Merimbula Wharf tide gauges. The results generally show good agreement at Merimbula Wharf and Merimbula Lake in terms of tidal amplitude and phasing. The agreement of water levels inside Merimbula Lake was achieved through use of the spatially variable roughness map derived through the tidal calibration. Calibration for water levels in Back Lake was conducted by modifying the level of the entrance berm at Back Lake. The berm level required to achieve the agreement in Back Lake flood levels was 2.50 m AHD, with a small “notch” at 1.40 m AHD representing a mechanical breakout facilitation (noting that 1.40m AHD is the level at which mechanical breakout is facilitated under Council’s entrance management program). It should be noted that the recorded data shows Back Lake filling up later in time, but more rapidly than the modelled results. This is likely attributable to the fact that the rainfall data used in the RAFTS modelling, (from which the catchment flows for this simulation were derived) may not accurately represent the rainfall hydrograph used in the modelling. Nonetheless, the results provide evidence that the hydrodynamic model is capable of replicating recorded peak flood levels inside the two estuaries.

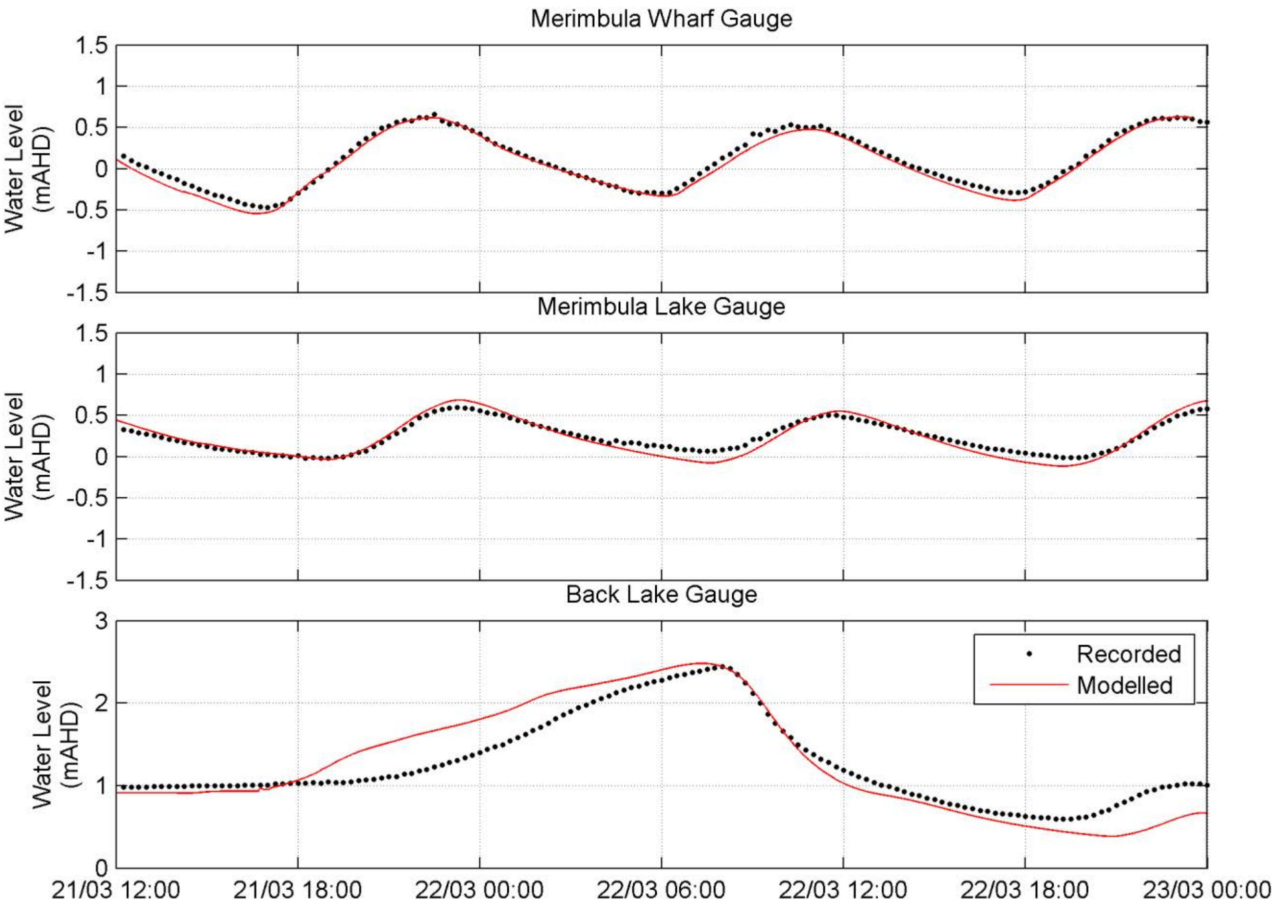


Figure 4-4 Model Calibration: Storm Event 21-22 March 2011

4.3 Hydrodynamic Model Validation

4.3.1 Storm Event: 23-24 June 1998

Cardno successfully validated the hydrodynamic model to the June 1998 storm event, which included environmental inputs for recorded tides and waves on the model boundary, as well as catchment inflows (from the RAFTS modelling outcomes), rainfall and wind. It should be noted that data relating to Back Lake water levels was not available, and hence this component was excluded from the calibration exercise. Validation of Back Lake water levels was achieved in the second validation simulation (see **Section 4.3.2**).

The results are provided in **Figure 4-5** in terms of recorded water levels at the Merimbula Lake and Merimbula Wharf tide gauges. The results generally show good agreement at Merimbula Wharf in terms of tidal amplitude and phasing. The agreement is particularly good with regards to peak water levels at Merimbula Wharf, with the modelled results differing from the recorded data by around 0.01 – 0.05 m. There are some slight differences in peak water levels at the Merimbula Lake gauge, with modelled peak flood levels approx. 0.07 m higher than recorded levels. Nonetheless, given the uncertainty around the condition of the entrance at the time of the storm event, the results are in relatively good agreement.

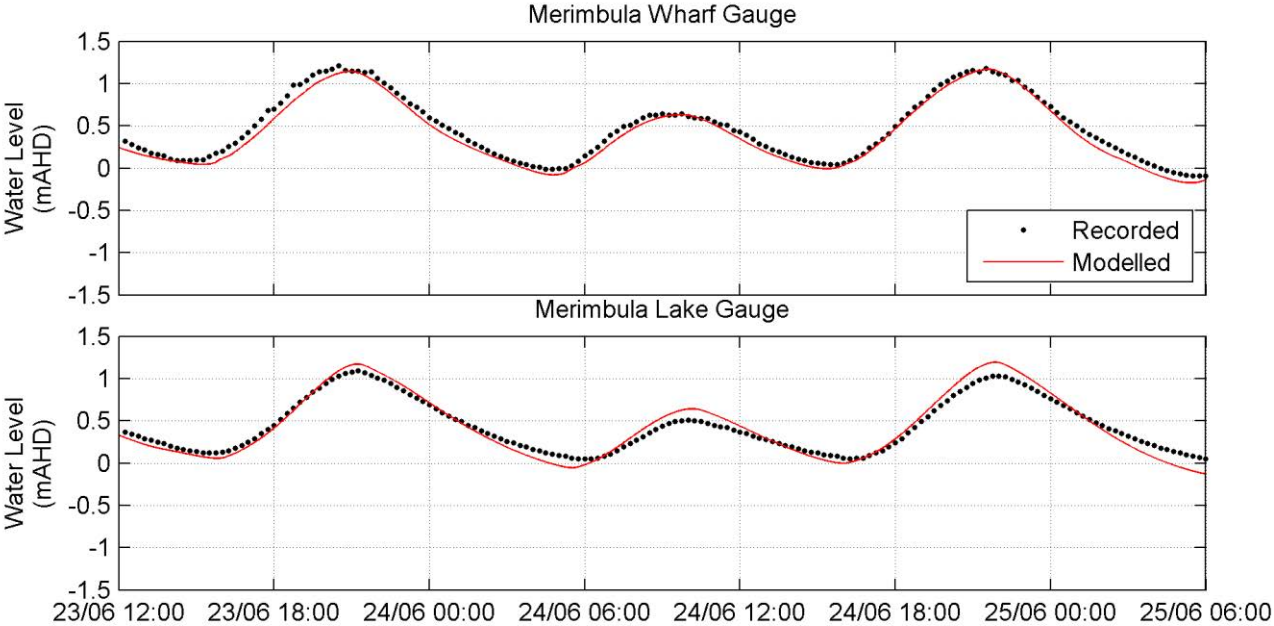


Figure 4-5 Model Validation – Storm Event 23-24 June 1998

4.3.2 Storm Event: 14-16 February 2010

Cardno successfully validated the hydrodynamic model to the 14-16 June 2010 event, which included environmental inputs for recorded tides and waves on the model boundary, as well as catchment inflows (from the RAFTS modelling outcomes), rainfall and wind.

The results are provided in **Figure 4-6** in terms of recorded water levels at the Merimbula Lake, Merimbula Wharf and back lake water level gauges. The results show reasonable agreement at Merimbula Wharf, with modelled levels being about 0.08 m lower. The agreement is particularly good with regards to timing of peak water levels inside Merimbula Lake. There are some slight differences in peak water levels at the Merimbula Lake gauge, with modelled levels approximately 0.1 m higher than recorded levels. Modelled peak flood levels in Back Lake are slightly higher than the recorded flood levels, and this can be attributed to the uncertainty around the level of the entrance berm, which was assumed to be the same as for the 2011 event (as recorded flood level were very similar). The modelled water levels in Back Lake also show a more sudden increase in water levels, with a more sustained peak. Nonetheless, the recorded and modelled results are in relatively good agreement given the availability of data.

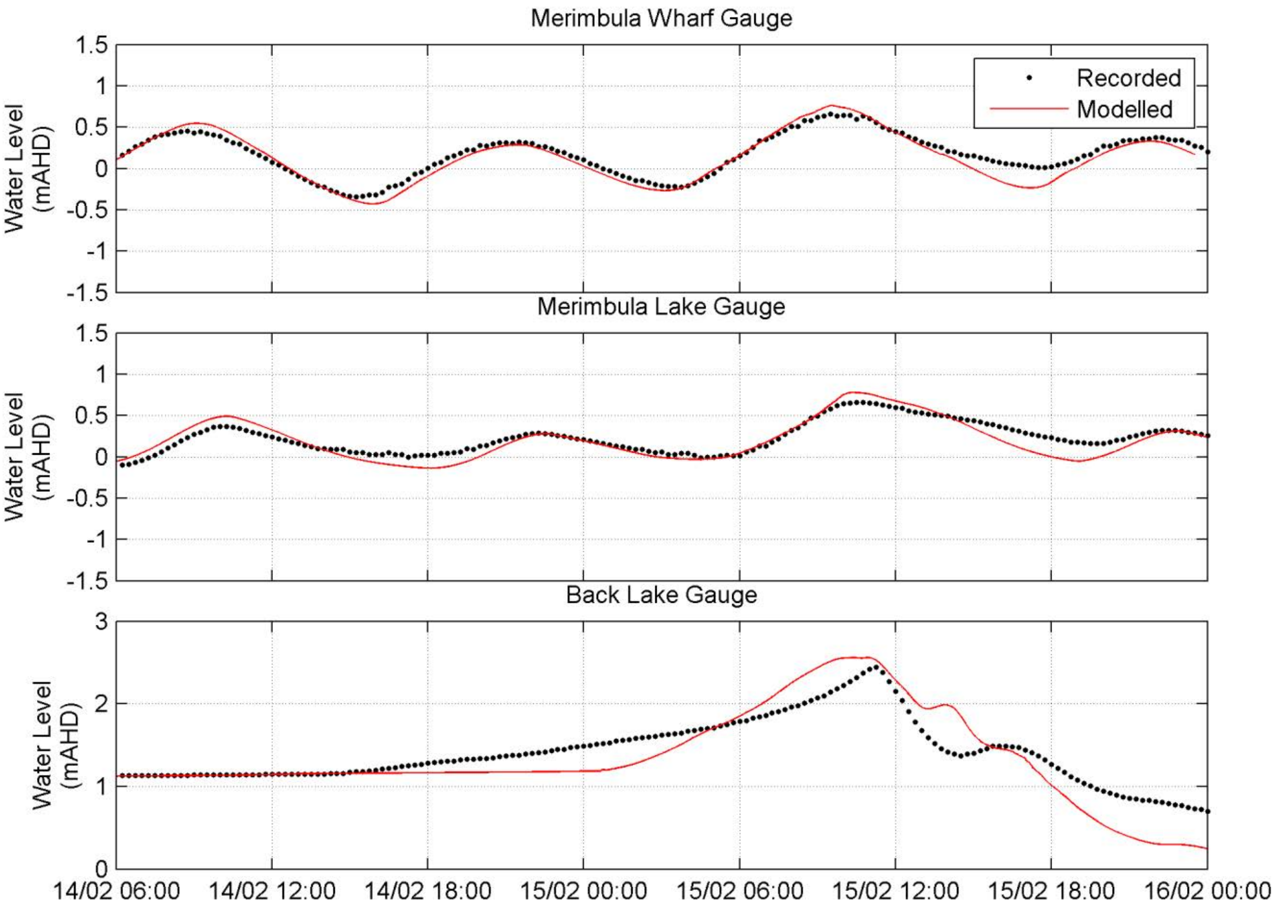


Figure 4-6 Model Validation – Storm Event 14-16 February 2010

4.4 Outcome of Calibration & Validation

The model has been calibrated to recorded tidal data and the results of the calibration demonstrate that where time-stamped bathymetric data exists, the model is capable of representing the spatial variation of water levels within the estuary quite well. Given the uncertainty around the entrance conditions of the two estuaries, the validation exercise shows that the hydrodynamic model is capable of replicating physical processes within the estuary relating to both coastal and catchment flooding. Calibration results in terms of peak flood levels are presented in **Table 4-2**.

Table 4-2 Calibration and validation Results

Simulation	Levels (m AHD)					
	Merimbula Wharf		Merimbula Lake		Back Lake	
	Measured	Modelled	Measured	Modelled	Measured	Modelled
Calibration: 21-22 March 2011	0.65	0.63	0.60	0.68	2.45	2.48
Validation: 23-24 June 1998	1.21	1.19	1.09	1.16	N/A	N/A
Validation: 14-16 February 2010	0.66	0.74	0.66	0.76	2.44	2.54