Summary Report for the Lower Shoalhaven River Flood Study

59918099 R006

Prepared for
Shoalhaven City Council

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Abbreviations

AEP	Annual Exceedance Probability
ALS	Aerial Laser Survey
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval
ARR87	Australian Rainfall and Runoff 1987 edition
ARR2019	Australian Rainfall and Runoff 2019 edition
BoM	Bureau of Meteorology
DCP	Development Control Plan
DPE	NSW Department of Planning & Environment
FDM	Floodplain Development Manual
FFA	Flood Frequency Analysis
FPL	Flood Planning Level
FRMC	Floodplain Risk Management Committee
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
m^3/s	Cubic metres per second (flow)
mAHD	Metres to Australian Height Datum
mm	Millimetre
m/s	Metres per second (velocity)
NSW	New South Wales
OEH	NSW Office of Environment & Heritage (now DPE)
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SES	State Emergency Service
SCC	Shoalhaven City Council

Glossary

Annual Exceedance 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 have a 1% AEP flood immunity while other roads may be designed to be overtopped in the 20 year ARI or 5% 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.
Floodplain management options	The measures which might be feasible for the management of a particular area.
Flood planning area	The area of land below the flood planning level and thus subject to flood related development controls.
Flood planning levels (FPLs)	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. 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.
Mathematical/computer models	The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with rainfall, runoff, pipe and overland stream flow.
Overland Flow	The flow of water over the ground surface either along formal flowpaths such as roads and formed channels, or informal flowpaths along topographic low points and through properties and open space areas. 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 (PMF)	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.

1 Introduction

Local councils have lead responsibility for managing flood prone areas, and the State Government assists local council by providing financial and technical support under the Floodplain Management Program.

Council's Northern Floodplain Risk Management Committee (the Committee) oversees the Floodplain Risk Management process for the Northern Region of the Shoalhaven Local Government Area. The Committee meets as required and includes representatives from Council, the NSW Department of Planning & Environment (DPE), the NSW State Emergency Service (SES), Councillors and local community representatives.

Shoalhaven City Council (Council) engaged Cardno to assist with the preparation of the Lower Shoalhaven Flood Study. Previous flood information available for the catchment was undertaken using older software and methods. Council is taking the opportunity to update the flood models using the latest software and survey information and expanding the model extents to improve the accuracy and currency of the flood information.

The purpose of the Flood Study is to define flood behaviour and flood risk in the Lower Shoalhaven River catchment which will subsequently be used in the Floodplain Risk Management Study and Plan to identify and recommend appropriate actions to manage current and future flood risks in the Lower Shoalhaven River area.

1.1 Study Context

The Floodplain Management process, as described in the NSW Government Floodplain Development Manual (2005), progresses through 6 stages in an iterative process:

- Stage 1 - Formation of a Floodplain Management Committee;
- Stage 2 - Data Collection;
- Stage 3 - Flood Study;
- Stage 4 - Floodplain Risk Management Study (FRMS);
- Stage 5 - Floodplain Risk Management Plan (FRMP); and
- Stage 6 - Implementation of the Floodplain Risk Management Plan.

This report covers Stages 2 to 3 of the Floodplain Management process.

1.2 Objectives

The objectives of the Flood Study are to:

- Collate and review available flood information for the catchment;
- Develop updated hydrologic and hydraulic models using recent information and software, calibrated and validated to historical events;
- Derive design flood event flows, water levels and other hydraulic parameters through hydraulic modelling;
- Define and document flood risk in the catchment including mapping; and
- Determine impacts of flooding on the community, flood planning levels, flood damages and emergency response considerations.

The completed Flood Study will form the basis of the FRMS&P, which will include identification and analysis of flood risk and the floodplain risk management options assessment.

1.3 Context of This Flood Study Summary Report

The purpose of this Flood Study Summary Report is to provide an abridged version of the Flood Study that outlines the key approach, stages and outcomes of the study in a less technical manner that is more accessible to the community. More detail on each stage and technical description is contained within the full Flood Study Report. The Flood Study report details:

> Data collection and review stage;
> The hydrological model setup;
> The hydraulic model setup;
> Calibration and validation of the models against historic flood events;
> Design event flood estimation;
> Flood modelling of design events, sensitivity testing and Climate Change;
> Flood model results and mapping; and
> Flood damages, flood planning and emergency response considerations.

2 Study Area

2.1 Overview

The floodplain for the Lower Shoalhaven River area was formed by the infilling of an old coastal lagoon and flood behaviour in the area has been extensively modified since European settlement. The southern part of the floodplain is drained by the Crookhaven River, which rises near Nowra, while the northern section is drained by Broughton Creek, which rises upstream of Berry. The present river channel is characterised by a number of flood mitigation works including drainage channels, floodgates, constructed levee embankments and bank stabilisation works.

Two hundred years ago the main entrance and the natural mouth of the river was at Shoalhaven Heads. In approximately 1822 Alexander Berry had a narrow channel excavated between the Shoalhaven River and the Crookhaven River to the west of what is now Comerong Island. This was undertaken to provide a safer access for boats entering the river from the ocean, as there was a dangerous sand bar at Shoalhaven Heads, whilst the Crookhaven River has a deeper, safer, more protected and permanent entrance due to the shelter of the headland. Following the construction of the Berry's Canal the Shoalhaven Heads entrance is now intermittent and is opened by the occurrences of floods and subject to closure by natural onshore oceanic process. The Shoalhaven Heads entrance is artificially opened in accordance with the Shoalhaven River Entrance Management Plan for flood mitigation. Normal flows presently reach the ocean at Crookhaven Heads, via the man-made channel 'Berry's Canal'.

2.2 Catchment Description

The Shoalhaven River has a catchment of approximately 7,250 km^2 and is the sixth largest coastal catchment in NSW. The river rises some 50 kilometres inland of Moruya and follows a generally northerly direction for some 170 kilometres to Tallowa Dam where it is joined by the Kangaroo River from the north. The river then flows east past Nowra to the ocean and is joined by the Etterma/Yalwal Creeks catchment downstream of Tallowa Dam and Nowra and Browns Creeks, Bomaderry Creek and Broughton Creek in its lower reaches. The Shoalhaven River flows into the Tasman Sea along with the Crookhaven River at Crookhaven Heads and through an intermittently open and closed entrance at Shoalhaven Heads. The Shoalhaven River has a length of around 383 kilometres from its headwaters to the mouth. The Study Area is shown on **Figure 2-1**.

The Shoalhaven River valley can be broadly categorised into the following three regions:

> Upstream of Welcome Reef where the catchment is generally a rolling plateau;

> Between Welcome Reef and Nowra, including Kangaroo Valley, where the catchment consists of steep forested country with the main streams entrenched in deep gorges; and

> Downstream of Nowra, the Lower Shoalhaven River coastal estuary and floodplain which consists of approximately 120 square kilometres of primarily rural land.

The major towns that are located around the Shoalhaven River are Nowra, Bomaderry, Berry, Terara, Greenwell Point, Culburra Beach, Orient Point and Shoalhaven Heads. The 2016 census indicated that the population of these significant urban areas was 51,661 people.

2.3 Description of Flood Behaviour

Flooding within the Lower Shoalhaven floodplain can result from any or all of the following:

> Flow from the Shoalhaven River catchment;

> Backwater flooding from the floodplain (e.g. Worrigee Swamp) which initially occurs as a result of local runoff but in larger events is augmented by flow over the river bank elsewhere;

> Overbank flooding from Broughton Creek;

> Contributing flows from Nowra/Browns Creek, Bomaderry Creek and Crookhaven River;

> Local flooding at the Bomaderry, Terara, Shoalhaven Heads, Greenwell Point, Culburra and Orient Point townships; and

> Ocean storm surge and or waves penetrating through the two entrances (Shoalhaven Heads and Crookhaven Heads).

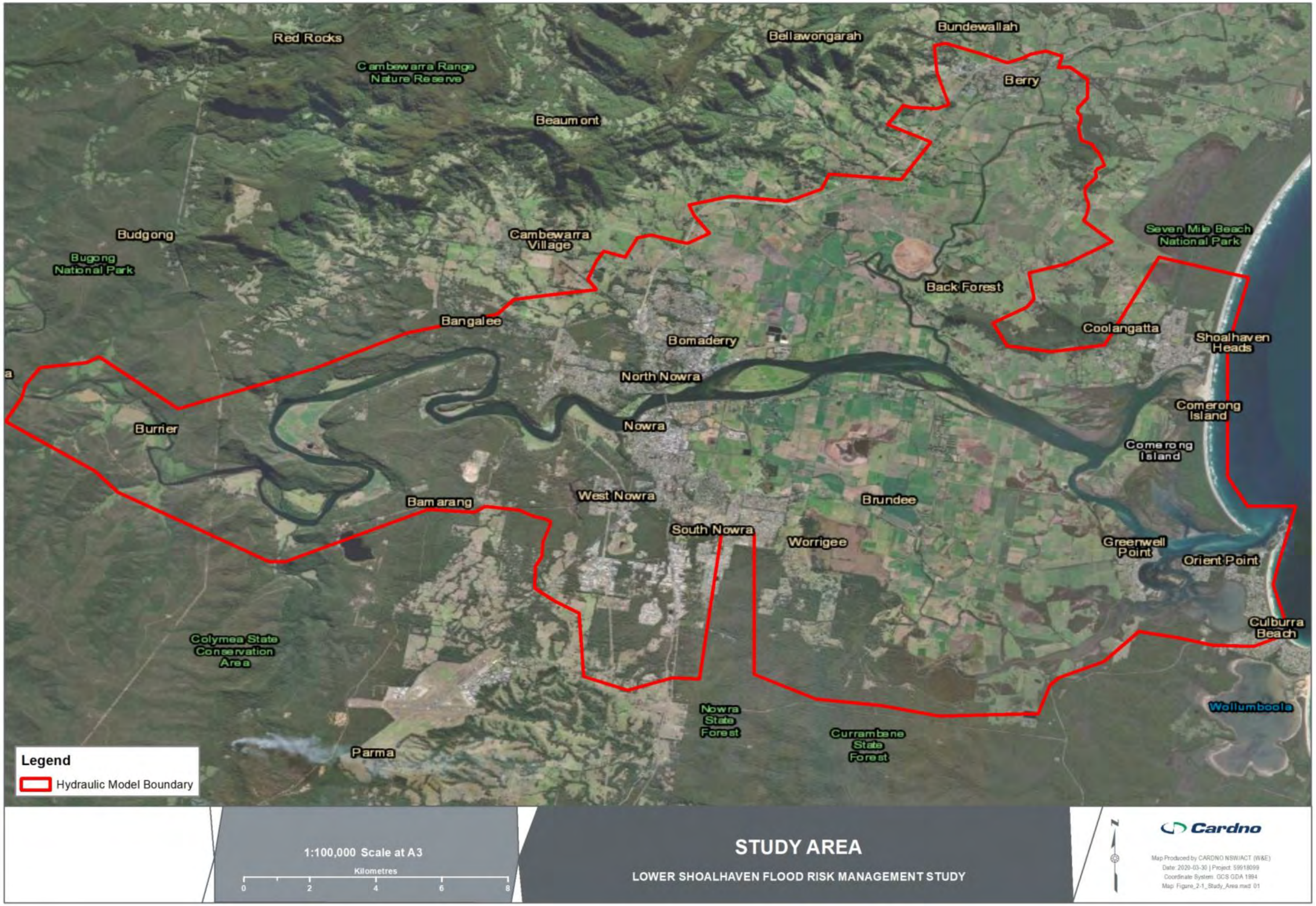

Figure 2-1 Lower Shoalhaven River Study Area

3 History of Flooding

Historical flood records are available since 1860, with the largest floods recorded in 1870, 1873, 1925, 1860, 1978, 1916 and 1891 (in order of magnitude). There is still debate about the exact magnitude of these events. The flood of April 1870 is estimated to have been rarer than a 1 in 200 (0.5%) Annual Exceedance Probability (AEP) event. It inundated the Terara Township by over a metre, and swept away approximately one third of the village. Five lives were lost in rural areas along the Shoalhaven River.

According to some accounts, the earlier 1860 flood was even more devastating and carried away over 50 buildings. Several lives were lost as well as some 79 acres (32 hectares) of land. More recent significant floods occurred in August 1974, June 1975, October 1976 and March 1978. The 1870 flood was 1.2 m higher than the March 1978 event. In the recent past, the Lower Shoalhaven River catchment was flooded in June 2013, August 2015, June 2016 and most recently again in February 2020 and August 2020. **Table 3-1** lists the month and year of the historical floods at Nowra up to the year 2020. Minor flooding also occurred in March 2021,May 2021, March 2022 and July 2022. **Table 3-2** provides the recorded flood levels from the recent flooding at five key locations.

Table 3-1 Historical Floods at Nowra

Month	Year	Flood Level at Nowra Bridge (m AHD)	Month	Year	Flood Level at Nowra Bridge (m AHD)
February	1860	5.7	June	1951	3.0
June	1864	5.2	May	1955	3.2
April	1867	5.1	February	1956	4.6
June	1867	-	July	1958	3.0
March	1870	5.5	October	1959	4.7
April	1870	6.5	March	1961	4.2
May	1871	4.7	November	1961	-
February	1873	6.2	June	1964	3.5
June	1891	5.3	September	1967	3.2
February	1898	5.0	August	1974	4.9
July	1899	2.7	June	1975	4.9
July	1900	4.4	October	1976	4.1
July	1904	3.7	March	1978	5.3
January	1911	3.6	April	1988	4.8
October	1916	5.3	August	1990	4.3
December	1920	4.2	June	1991	4.13
July	1922	4.4	8th August	1998	3.44
11th May	1925	5.4	19th August	1998	3.15
27th May	1925	-	October	1999	3.59
April	1927	2.5	November	2000	-
January	1934	-	June	2013	3.76
February	1934	-	August	2015	3.97
September	1938	-	June	2016	3.40
April	1945	-	February	2020	3.60
May	1948	3.0	August	2020	4.17
June	1949	4.0			

NB: Data prior to 1980 were obtained from the Lower Shoalhaven River Flood History at Nowra Bridge 1860-1980.

Table 3-2 Recorded Levels (m AHD) of Recent Flooding of the Lower Shoalhaven River

Event	Recorded Level (m AHD) at Gauge Location				
	Grassy Gully II Gauge 215216	Grady's Caravan Park MHL Gauge 215430	Nowra Bridge MHL Gauge 215411	Terara MHL Gauge 215420	Shoalhaven Heads MHL Gauge 215470
March 1978	n/a	n/a	5.25	3.6	2.1
June 2013	17.22	11.35	3.76	3.48	2.26
August 2015	17.63	11.94	3.97	3.54	2.22
June 2016	8.68*	10.96	3.40	3.10	2.00
February 2020	9.43*	12.08	3.60	3.40	1.90
August 2020	17.90	13.57	4.17	3.89	1.97

* quality of data during this event is unclear. Possible instrument failure

4 Model Development

4.1 Previous Reports and Studies

A number of previous studies have been conducted within and around the study area. These studies have been reviewed as part of this study to identify relevant information that can inform or be used in this study.

Reports and studies that have been reviewed include:

> Previous Flood Studies of the Shoalhaven River;
> Floodplain Risk Management Studies and Plans for the Lower Shoalhaven River and tributary catchments;
> Shoalhaven River Entrance Management and Coastal Plans and Studies;
> Council Policies; and
> Data Collection Reports.

4.2 Available Data

Available data has been reviewed to inform the study, to provide data to setup the hydrological and hydraulic models, and to allow testing of the models' performance. Where insufficient data was available, additional data was collected such as additional survey and up to date rainfall and water level data.

A more thorough description of available data is provided in the Flood Study. The below list provides a summary of the key data collated for this study:

> Council GIS Database – including Aerial photographs, Cadastre, Drainage, Floodgates, Flood Mitigation Channels, Levees, Wastewater, Water and Water Catchments, and Waterways;
> Terrain data including Aerial Laser Survey, detailed ground survey and bathymetric survey;
> Hydraulic structure data – bridges, culverts, levees, floodgates, flood mitigation channels (survey and GIS database including location, type, inverts and dimensions); and
> Rainfall, Water Level and Streamflow gauge data - within the immediate catchment area there are a number of gauges which have been reviewed for use in model calibration.

4.3 Community Consultation

Consultation with the community and stakeholders is an important component in the development of a Floodplain Risk Management Study and Plan. Consultation provides an opportunity to collect information from observed flood events, feedback and observations from the community on problem areas and potential floodplain management measures. It also provides a mechanism to inform the community about the current study and flood risk within the study area and seeks to improve their awareness and readiness for dealing with flooding.

Community consultation was undertaken in the form of a questionnaire to obtain information from the community about historical flood observations and to obtain community preferences for different types of flood mitigation options. Relevant stakeholder agencies have been corresponded with to obtain relevant data and flood information for use in the study. Further community consultation will be undertaken in futures stages of the study.

The details and outcomes of community engagement activities to date are provided in **Appendix D** of the Flood Study.

4.4 Flood Model Development

The study uses two models which have been setup using current industry standards and available data:

> A hydrological model to simulate the conversion of rainfall into runoff to calculate flows within the catchment; and
> A hydraulic model to simulate the flow of water through a catchment and associated waterways to calculate flood characteristics such as water level and velocity of flow.

The XP-RAFTS software was used to establish a hydrological model to represent the entire Shoalhaven River and Kangaroo River catchments including Tallowa Dam and Danjera Dam.

The Shoalhaven River hydrological model covers a total catchment area of 7,250 km^2 and was divided into sub-catchments using available terrain data (**Figure 4-1**).

Catchments were assessed for their characteristics such as slope, land use, vegetation cover and impervious areas such as roads and buildings to allow assignment of model parameters reflective of current conditions to each sub-catchment. Appropriate model parameters have been selected through a process of calibration and validation against measured flow data from historical events (**Section 4.6**).

Furthermore, based on the results of the calibration of the XP-RAFTS model with the converted WBNM model, 52% of the lag time value was applied to each link for the PMFPMP event to ensure the PMF flows were not underestimated.

The TUFLOW software was used to setup a 2-dimensional hydraulic model to represent the waterways and floodplains within the study area that covers the Lower Shoalhaven River and its floodplains from upstream of Grassy Gully to the Tasman Sea outside Shoalhaven Heads and Crookhaven Heads (**Figure 4-2**). The model includes the main Shoalhaven and Crookhaven River channels, their floodplains and the lower reaches of the major tributaries including Nowra and Browns Creeks, Bomaderry Creek and Broughton Creek. To define the topography/bathymetry of the study area the model uses ground survey and Aerial Laser Survey data and includes structures such as bridges and culverts under roads, levees, flood mitigation drains and floodgates.

The hydraulic model extents cover the Nowra, Bomaderry, Terara, Berry, Greenwell Point, Orient Point, Shoalhaven Heads and part of the Culburra Beach townships and is shown in **Figure 4-2** together with terrain data.

Since the 1990 Flood Study, parts of the topography of the Lower Shoalhaven River floodplain have changed due to new developments and rehabilitation of the Terara levee (in 2005). Including such topographical changes make the model representative of current features in the floodplain. This is critical information when calibrating the models to recent flood events.

For flood event modelling, the model setup includes major infrastructure projects under construction at the time of the study. This includes:

- Berry to Bomaderry Bypass; and
- Nowra Bridge duplication road design finished levels of the road formation and hydraulic structures including bridges and culverts have been included based on the approved designs provided by TfNSW.

Appropriate model parameters are applied to different waterways and land use types and these have been selected both through national guidance literature as well as through the calibration process where model results are compared to recorded water levels from historic events.

The model extends to the ocean where suitable entrance conditions and ocean tidal boundaries have been applied. Flows derived from the hydrological model are applied as inflows to the hydraulic model to assess flood impacts within the study area for a range of storm scenarios.

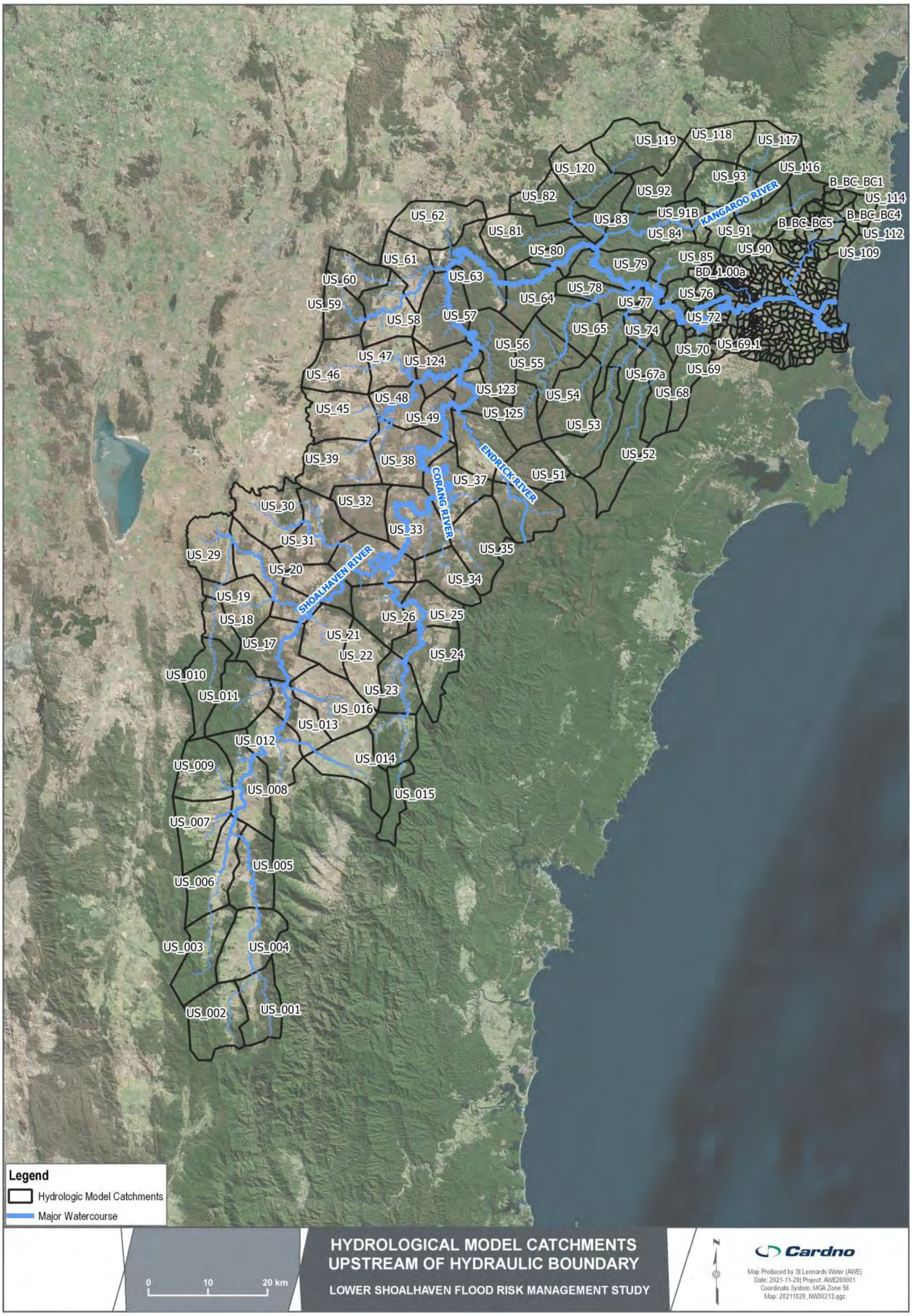

Figure 4-1 Shoalhaven River Catchment

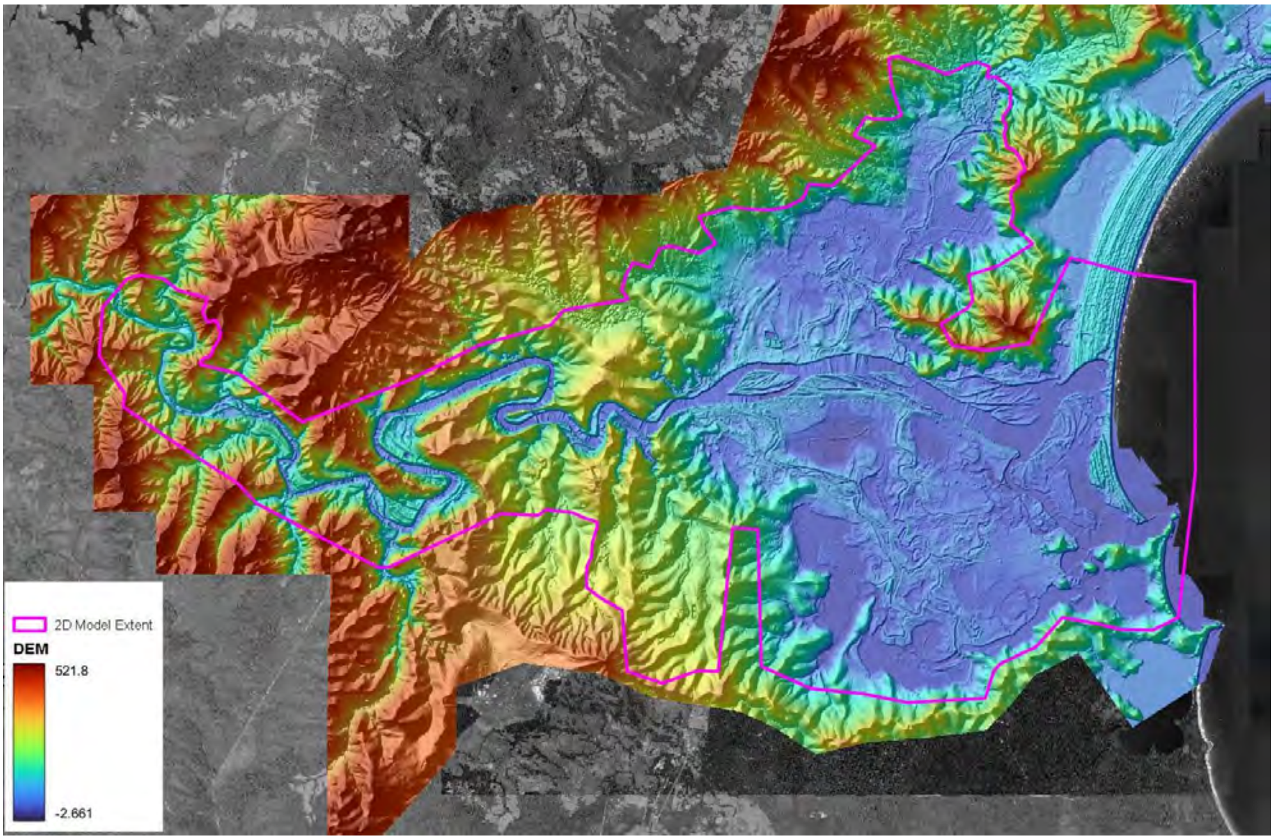

Figure 4-2 LiDAR Terrain Data and Hydraulic Model Extent covering the Lower Shoalhaven River Floodplain

4.5 Shoalhaven Heads Breach Modelling

Crookhaven Heads is a permanently open trained entrance, while Shoalhaven Heads is a dynamic entrance which is typically closed with a coastal beach and berm with a berm height at around 2m AHD or higher. When Shoalhaven Heads is closed, all flood flows in the Lower Shoalhaven River system outlet to the ocean through Crookhaven Heads via Berrys Canal. During flood events, the berm and the entrance shoals will naturally scour once the flood level reaches above the berm and the entrance opens to a width to accommodate the flow magnitude for the relevant event. The entrance will then subsequently enter a closing cycle where sediment is again deposited in the entrance through coastal tide and wave action which creates the flood tide delta which eventually closes the entrance and re-establishes the berm.

Council have an entrance management policy under which Council will, weather conditions permitting, cut a 1m deep (4m wide) notch in the berm when the water level at Nowra Bridge reaches (or is expected to reach) 3.0m AHD or the water level reaches (or is expected to reach) 2.0m AHD at Shoalhaven Heads, to allow the flood flows to begin the breach development of the berm to open the Shoalhaven River entrance at Shoalhaven Heads.

When flood levels become high enough to overtop the lowest point in the berm, flows scour the sand and the breach gets wider and deeper allowing more flow and scouring of the berm and entrance shoals to occur, opening the entrance. The depth of the breach is limited to approximately -3.0m AHD, as determined through survey of the entrance following flood events.

The state of the entrance influences water levels inside the entrance around Shoalhaven Heads to Crookhaven Heads, particularly for smaller events, so it is important to understand the entrance dynamics and opening dimensions achieved under various flows to allow the expected entrance condition to be represented in the model. Due to the erodible nature of the berm, flows will scour the entrance to an equilibrium width with dimensions and capacity to convey the relevant flow and limiting water levels. If the entrance was modelled as closed or with too small an opening width, then water levels would be artificially elevated between Shoalhaven Heads and Crookhaven Heads.

A breach development study (provided in **Appendix K** in the Flood Study) was undertaken to quantify the breach development at the Shoalhaven River entrance at Shoalhaven Heads for a range of flood event flows.

The resulting output of the breach modelling provided a relationship between breach width and Shoalhaven River flows (**Figure 4-3**). This relationship was used to model the entrance opening in the hydraulic model to ensure the distribution of flows between Crookhaven Heads and Shoalhaven Heads during an event is modelled as accurately as possible.

Figure 4-3 Relationship between flow at Nowra Bridge and Shoalhaven Heads breach opening width

As such, for the design event modelling, the Shoalhaven River entrance at Shoalhaven Heads was modelled as open with the bathymetry representing the final breach width and depth associated with each flow rate.

Testing in the hydraulic model showed that using a fixed open entrance from the start of the simulation had no influence on the peak flood levels obtained when compared with a simulation allowing the breach to develop to the full width progressively over time following a trigger level of 3m AHD at Nowra Bridge as per the Shoalhaven Heads Entrance Management Plan (**Figure 4-4**).

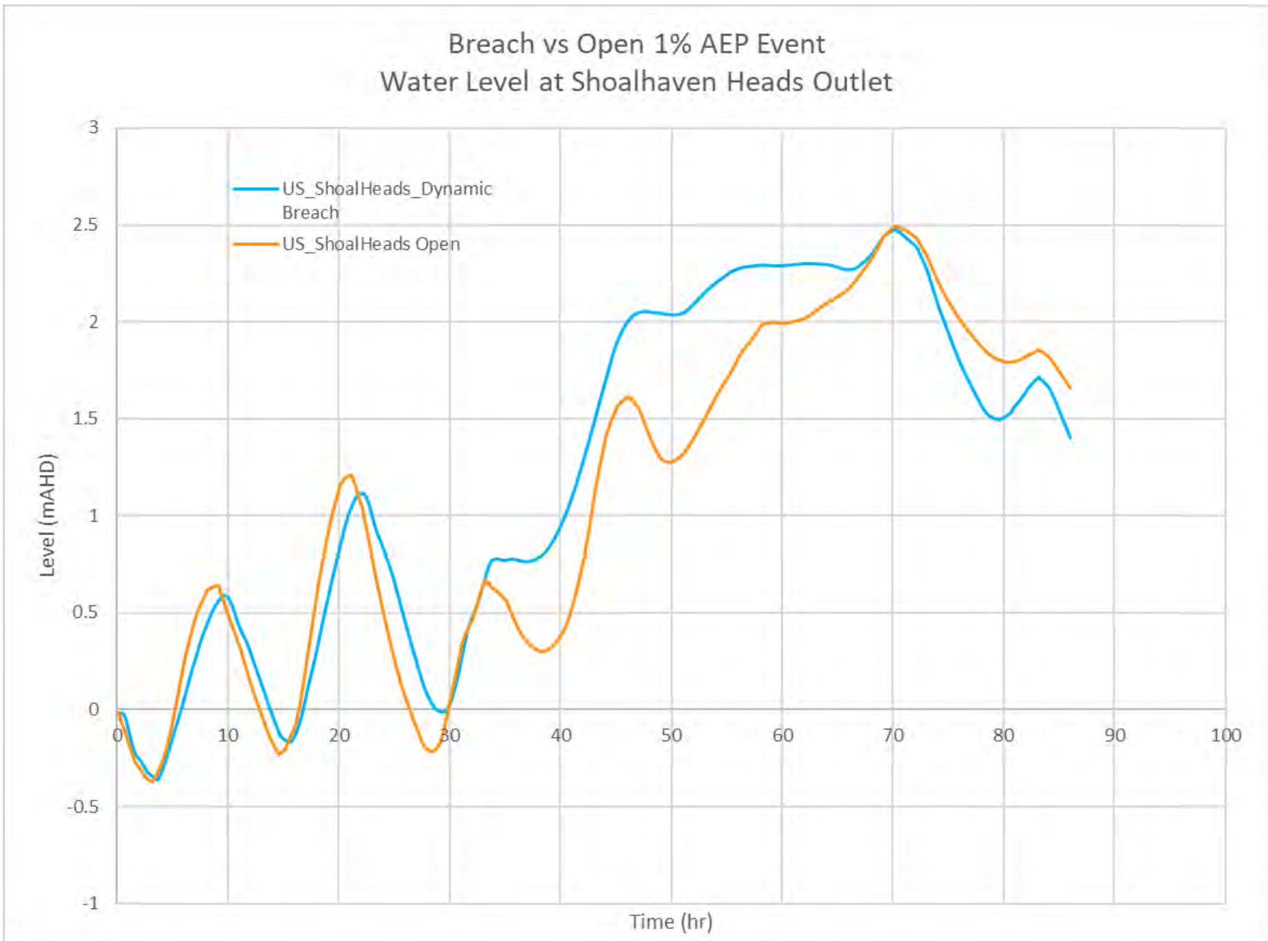

Figure 4-4 Hydraulic model water level sensitivity at Shoalhaven Heads using a dynamic breach opening vs fully open entrance

Note: the earlier adopted PMF result was used to approximate the breach development. Following adoption of higher PMF flows, a sensitivity test was undertaken to assess possible impacts of the higher PMF (leading to a wider opening) on water levels. The sensitivity test showed that the higher PMF would have a limited impact on flood levels. Hence, no updates were undertaken as part of this flood study. However, the entrance breach model could be revised and updated during the FRMS&P phase.

4.6 Model Calibration and Validation

Calibration and validation of the hydrologic and hydraulic models is a key component of the Flood Study, as it ensures the models (developed as described in **Section 4.4**) can reasonably reproduce observed flood behaviour in the catchment for a range of flood event magnitudes. The Shoalhaven River has a long history of flooding and a network of rainfall and stream flow and level gauges from which to gather calibration data.

Calibration involves the selection and adjustment of model parameters to achieve a good match between modelled behaviour and observed behaviour from water level and flow gauges and community flood observations. Validation involves testing the calibrated model against additional historical measured flood events to ensure that the model performs well across a range of events. The model calibration and validation was undertaken in two steps, hydrological model calibration of flows and hydraulic model calibration to water levels.

The August 2015 flood event was chosen for calibration of model parameters as it had the greatest availability of reliable data, including gauged flow and level data and surveyed flood marks provided from Council. It is the largest recent event (prior to the August 2020 flood event) in terms of flood levels in the Lower Shoalhaven River floodplain.

Validation of the model performance was undertaken using the June 2013 and June 2016 events comparing model results against gauged flow and water level data. The March 1978 event was also modelled in the hydrology model to validate that the behaviour and flows would be appropriate for a larger event.

There are twelve flow gauges within the catchment and seven water level gauges in the Study Area available for use in calibration and validation of the model. A further 28 surveyed flood level locations were available for comparison for the August 2015 event. There were 61 respondents to the Community Consultation questionnaire of which 41 indicated that their property had been affected by flooding and 14 respondents provided estimated flood levels/depths for the three recent calibration/validation events.

4.6.1 Flow Calibration

Results showing the comparison of the modelled behaviour with gauge data for historical events are presented in **Appendix B** of the Flood Study.

For the August 2015 calibration event the overall modelled catchment response and peak flows show a good correlation with the available gauge data, particularly around Tallowa Dam and Burrier, albeit with peak flows slightly lower than gauged values at Burrier, which is the main Shoalhaven River inflow to the hydraulic model. There is also a notable early volume of flow in the model which is not observed in the gauge data likely due to the chosen rainfall allocation in the model.

4.6.2 Peak Water Level Calibration

Modelled water levels were compared with gauged water levels at the seven water level gauges within the Lower Shoalhaven/Crookhaven estuary and the results are graphed in **Appendix C** of the Flood Study.

Table 4-1 below shows the peak water level comparison at each gauge location for the August 2015 calibration event.

Table 4-1 August 2015 Event – Peak Water Level Model versus Gauge Comparison

MHL Station No.	Gauge Location	Gauge Data Peak Level (m AHD)	Modelled Peak Water Level (m AHD)	Difference Calibration Less Gauged (m)
215216	Grassy Gully II	17.62	18.27	0.65
215430	Grady's Caravan Park	11.94	12.23	0.29
215411	Nowra Bridge	3.89	3.92	0.03
215420	Terara	3.63	3.62	-0.01
215415	Hay Street	2.23	2.25	0.02
215470	Shoalhaven Heads	2.22	2.24	0.02
215417	Greenwell Point	1.30	1.31	0.01
215408	Crookhaven River	1.03	1.11	0.08

The hydraulic model peak water level results are within +/- 100 mm at most water level gauge locations, excluding Gradys Caravan Park where the model is estimating levels approximately 300mm higher than recorded. A good correlation of peak levels is achieved at the surveyed flood marks and levels/depths reported by the community with almost all having a less than +/-100mm difference. This is discussed in more detail in the Flood Study report. The model is also able to accurately represent the tidal response before the flood flows begin.

Both the hydrological and hydraulic models in combination have been able to adequately represent the August 2015 flood event hydraulic behaviour and the models are considered to be adequately calibrated for use in design flood estimation.

4.6.3 Model Validation

For the June 2013 validation event, the overall hydrologic model flow comparison shows the previously calibrated parameters of the August 2015 event provide a reasonable match with the recorded data. A good correlation is seen at Tallowa Dam, although flows appear to be underestimated at Burrier.

This resulted in hydraulic model peak flood levels around 300mm lower than recorded. The underestimated levels are also likely explained by the opening at Shoalhaven Heads being modelled as larger than what occurred in this event leading to lower levels in the estuary.

For the June 2016 validation event, higher continuing rainfall loss rates needed to be applied to match the recorded behaviour and the overall modelled peak flows at each gauge were slightly higher than recorded. The hydraulic model provides a good correlation with gauged flood levels to within +/- 300mm at most locations, with the higher levels relative to the higher inflows, with all gauges' peak levels higher than recorded.

Validation against the March 1978 event was undertaken in the hydrology model only to demonstrate that an appropriate match to flows at Grassy Gully could be achieved for a larger flow event. The results showed that with the previously calibrated parameters of the August 2015 Calibration Event, a reasonable match with the recorded data is achieved for the March 1978 event. However, rainfall losses needed to be reduced to achieve the observed peak flows.

4.7 Flood Frequency Analysis

At-Site Flood Frequency Analysis (FFA) of historical events is used to validate the modelled design flood event flow estimates. An FFA at gauges with long periods of record is a robust method of estimating the probability of flooding. A full description of the statistics of FFAs and methods is provided in Australian Rainfall and Runoff Book 3 Chapter 2 (Ball et al., 2019).

The FFA uses an Annual Maximum Series (AMS) of historical gauged peak flood flows to develop design flood estimates for various Annual Exceedance Probabilities (AEPs) - the probability that maximum flood discharge in a year exceeds a particular magnitude.

Design flood event discharge calculated using the hydrology model can then be compared against the estimated AEP flows derived from the FFA to ensure that the hydrology model is producing design event flows that align with historical observations at a particular location.

Flood Frequency Analyses were undertaken for the following three gauges:

- Shoalhaven River at Grassy Gully II (215216)
- Shoalhaven River at Warri (215002)
- Kangaroo River at Hampden Bridge (215220)

A description of the rating curve review and flood frequency analysis undertaken at each gauge is provided in **Appendix E** of the Flood Study. As this study is concerned with the Lower Shoalhaven River and due to the long records available at Nowra Bridge, effort was focussed on assessment of flows at Shoalhaven River at Grassy Gully II gauge.

The Grassy Gully II gauge is located on the Shoalhaven River approximately 38 km upstream of Nowra Bridge. This is a valuable location to undertake a flood frequency analysis, as it is sufficiently downstream to capture inflows from the majority of the catchment, and sufficiently upstream to not be tidally influenced (unlike Nowra Bridge), while still being close to the area of interest in the Lower Shoalhaven River.

The outcomes are discussed in **Section 5.2**.

4.8 Sensitivity Analysis

Sensitivity analysis is undertaken to assess how sensitive the hydrology and hydraulic model (based on model results) is to variations in different input parameters. When model results only vary within a reasonable range, then that is a further indication that the developed flood model can adequately represent catchment responses to rainfall for flood modelling purposes.

Sensitivity analysis of the following parameters was undertaken to examine the effect that varying model parameters has on results:

- Changes to flow estimates due to changes in hydrological model parameters;
- Changes to channel Mannings Roughness (representation of different surface area resistance to flow);
- Blockage of structures;
- Closed entrance;
- Alternate tidal boundary condition; and
- Impact of levee removal.

Results of Sensitivity Analysis scenarios are presented in **Appendix H** of the Flood Study as water level difference plots compared with the adopted 1% AEP event peak water levels.

Sensitivity analysis results show that for a 1% AEP, increases in flood levels due to model parameter uncertainties are generally expected to be in the order of 300mm or less and the 1% AEP event is not sensitive to blockage of structures because structures are submerged and are not acting as the main hydraulic control determining flood levels.

5 Hydrology – Design Flood Estimation

The calibrated hydrological model of the Shoalhaven River catchment has been used to calculate design flood event flows in accordance with the current industry standard Australian Rainfall and Runoff 2019 (ARR2019) Guidelines. Data specific to the catchment has been obtained from the ARR Data Hub and Bureau of Meteorology (BoM).

The data was input to the hydrologic model to simulate a range of design events and durations to define flow inputs to the hydraulic model. Design events are defined by an Annual Exceedance Probability (AEP) which is the probability that a flood of a given magnitude will be experienced in any one year. The design events modelled for the Flood Study include the:

- 1 in 5 (20%) AEP event
- 1 in 10 (10%) AEP event;
- 1 in 20 (5%) AEP event;
- 1 in 50 (2%) AEP event;
- 1 in 100 (1%) AEP event;
- 1 in 200 (0.5%) AEP event;
- 1 in 500 (0.2%) AEP event; and,
- Probable Maximum Flood (PMF).

For this study the Probable Maximum Flood event is estimated using the Probable Maximum Precipitation (PMP) and rainfall and flows have been derived for both the Generalised Short Duration Method (GSDM) for shorter storm durations relevant to the tributaries and the Generalised Southeast Australia Method (GSAM) for longer duration storms relevant to the mainstream Shoalhaven River and floodplains.

5.1.1 Design Flood Event Durations and Flows

The focus of this study is the Lower Shoalhaven River mainstream flooding and the critical storm event durations that result in the peak flow. **Table 5-1** shows design event flows and critical durations calculated in the hydrological model for the range of AEP events at Grassy Gully and Nowra Bridge.

It is noted that full validation of the ARR2019 flows has not been undertaken for the tributaries as they are not the focus of this flood study and Council will adopt flood levels for Bomaderry Creek, Broughton Creek and Nowra and Browns Creek based on the corresponding local catchment flood studies which are more detailed in these areas.

Table 5-1 Design Event flow and critical duration from the hydrological model

Event	Critical Duration	Flow (m^3/s)	
		Grassy Gully II	Nowra Bridge
50% AEP	18 hr	1,113	1,143
20% AEP	18 hr	4,084	4,084
10% AEP	18 hr	6,847	7,010
5% AEP	18 hr	9,289	9,340
2% AEP	18 hr	12,102	12,200
1% AEP	18 hr	13,693	13,818
0.2% AEP	36 hr	17,996	18,587
PMP	72 hr	35,382	38,221

5.2 Comparison with FFA

A FFA was undertaken using the most current techniques in ARR2019 (Ball et al, 2019) at Grassy Gully II gauge using a 161 year record of flows (combining Grassy Gully II gauge record and historical water level information from Nowra Bridge). The resulting FFA in **Figure 5-1** and **Table 5-2** shows the FFA design event expected flows at Grassy Gully II gauge (215216) compared with the ARR2019 design events flows calculated by the hydrological model.

The applied continuing losses were varied across the design events to generate flows to match the expected flow from the FFA. Using this method, the design flow estimates compare well with the FFA data across the range of events up to the 1% AEP (**Figure 5-1**).

Table 5-2 FFA derived expected design event flows at Grassy Gully II Gauge (215216) and modelled design event flows

AEP Event	FFA Expected Flow (m^3/s)	Design Flood Event Estimates		
		Peak Flow (m^3/s)	Rainfall continuing Loss (CL) rate (mm/hr)	Critical Duration
50%	1,202	1,113	3.5	18 hr
20%	4,140	4,084	2	18 hr
10%	6,623	6,847	1	18 hr
5%	9,017	9,289	0.5	18 hr
2%	11,832	12,102	0	18 hr
1%	13,641	13,693	0	18 hr
0.2%	-	17,996	0	36 hr
PMP	-	35,382	0	72 hr

The ARR2019 design flow estimates calculated by the hydrology model compare well with the FFA expected flows across the range of events up to the 1% AEP. This shows that the hydrology model is capable of simulating the hydrology of the catchment that aligns with the historical observations.

With an estimated flow of 15,195 m^3/s, the 1870 event and largest on record, is expected to have a recurrence interval around 1 in 270 AEP, with the 1873 event being a 1 in 100 AEP event. This is considered realistic given the available record, and provides greater confidence in the FFA outputs at Grassy Gully II.

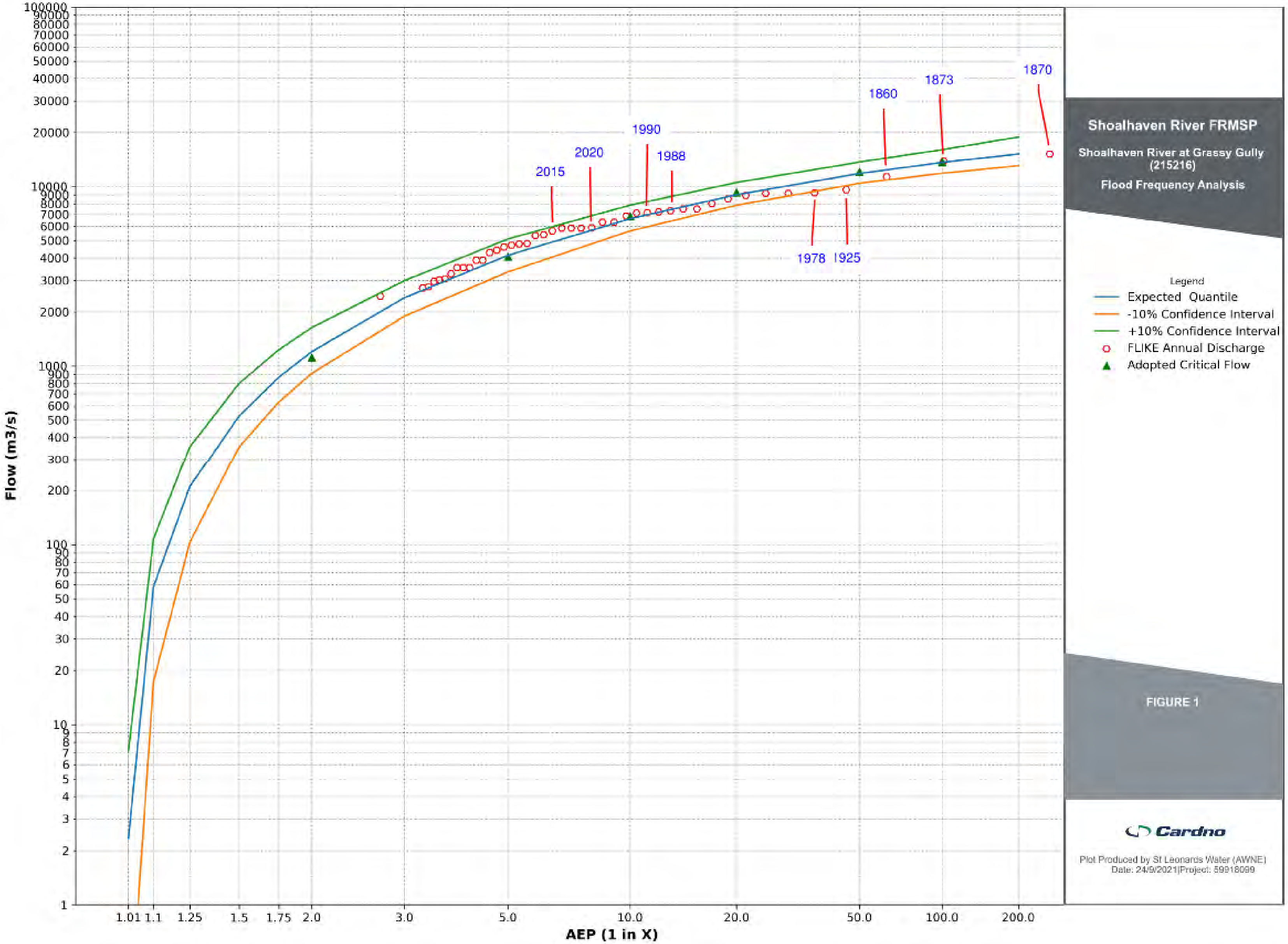

Figure 5-1 Flood Frequency Analysis – Shoalhaven River at Grassy Gully II gauge (215216)

6 Modelled Flood Events

The following sections describe the model scenarios undertaken for the Lower Shoalhaven River flood study.

6.1 Design Events

The models have been run for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP storms and PMF event for the existing, projected 2050 and projected 2100 scenarios.

Suitable ocean boundary conditions for each design event were established in accordance with the *NSW Floodplain Risk Management Guide - Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* (NSW OEH, 2015).

As described in **Section 4.5**, Shoalhaven Heads breach modelling was undertaken, and a relationship derived between the breach width and flows in the Shoalhaven River. For Design Event simulations, Shoalhaven Heads has been modelled as permanently open with bathymetric arrangement setup for the relevant width and depth associated with each particular design event flow.

6.2 Sea Level Rise

NSW sea level rise planning benchmarks in the *NSW Sea Level Rise Policy Statement (2009)* are an increase above 1990 mean sea levels of 40cm by 2050 and 90cm by 2100. However, this policy was repealed by the NSW Government in 2012 and coastal councils were encouraged to adopt their own sea level rise projections.

Shoalhaven City Council, in partnership with Eurobodalla Shire Council, developed the *South Coast Regional Sea Level Rise Policy and Framework* (Whitehead & Associates, 2014) and Councillors adopted the following sea level rise projections on 10 February 2015:

> 100mm for 2030;
> 230mm for 2050; and
> 360mm for 2100.

These sea level rise projections have been adopted for modelling of the Projected 2050 and Projected 2100 scenarios for the full range of design events. The projected 2050 and projected 2100 scenarios are based on current BoM design event Intensity Frequency Duration (IFD) rainfall data (without projected rainfall increases) and Council's SLR projections of 23cm by 2050 and 36cm by 2100.

The NSW projected 2100 sea level rise of 90cm was also investigated to test sensitivity to a large sea level rise projection.

6.3 Climate Change

It is widely accepted that Climate Change will lead to increases in global temperatures which will lead to increases in the intensity of rainfall along with sea level rise. The NSW Government's Floodplain Development Manual (NSW Government, 2005) requires that flood studies and floodplain risk management studies consider the impact of climate change (rainfall increase and sea level rise) on flood behaviour. This Study has assessed the impacts on flooding of both climate change induced rainfall increases and sea level rise using current industry guidelines.

Climate Change scenarios tested have been adopted from ARR2019 along with consideration of the *OEH Floodplain Risk Management Guides: Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* (OEH, 2015) and Practical Consideration of Climate Change (DECC, 2007).

Climate Change predictions are made based on modelling changes to temperature and rainfall in global climate models for various Representative Concentration Pathways (RCPs), which consider projected increases in greenhouse gas concentrations. ARR2019 (Ball et al., 2019) recommends the use of RCP 4.5 and RCP 8.5 values. These values (**Table 6-1**) are available as a percentage that the rainfall should be factored by from the ARR Data Hub.

Table 6-1 ARR Data Hub recommended Climate Change Data

Year	RCP 4.5		RCP 8.5	
	Temperature Increase (°C)	Rainfall Increase	Temperature Increase (°C)	Rainfall Increase
2050	1.081	***5.40%***	1.446	***7.30%***
2090	1.496	***7.60%***	3.09	***16.30%***

6.3.2 Climate Change Scenarios

Based on the above considerations, it was decided to simulate both the rainfall increase with no sea level rise as well as rainfall increase in combination with the expected corresponding sea level rise for two future scenarios – 2050 and 2090. Both RCP 4.5 and RCP 8.5 rainfall increase has been run for each future scenario for both the 5% AEP and 1% AEP events.

7 Results and Discussion

Flooding within the Lower Shoalhaven River area begins with small tributaries and overland flow filling both the Broughton Creek floodplain and the Crookhaven Creek swamp areas. As the flows increase in events up to the 1% AEP, the Shoalhaven River rises and a backwater from the Crookhaven River is seen to start filling back up into the Pyree, Brundee and Numbaa areas before the Terara levees are overtopped and then flows break out of the Shoalhaven River and flow across the Crookhaven Creek/Crookhaven River floodplain towards Crookhaven Heads. Broughton Creek floodplain outlet is constrained by the topography/bathymetry of the Broughton Creek channel outlet to Shoalhaven River, with higher ground along the banks of Broughton Creek and the Shoalhaven River and is further constrained by the Shoalhaven River levels preventing flow from discharging from the floodplain. As levels rise sufficiently, spilling begins to occur from the Shoalhaven River to Broughton Creek north of Pig Island.

In the PMF, the same behaviour is observed and with increased flows, the breakout of the Shoalhaven River channel is more pronounced with deeper depths and with more spilling from the Shoalhaven River into the Broughton Creek floodplain.

While the system is tidal for a large extent upstream past Gradys Caravan Park, riverine flood flows are dominant in determining water levels during floods within the Shoalhaven River upstream of Nowra, with entrance conditions, ocean conditions and sea level rise impacting areas up to approximately Pig Island. The Broughton Creek floodplain is relatively uninfluenced by ocean conditions, and is mainly controlled by the constrained outlet to the Shoalhaven River.

The following sections describe the results and processing of results for determining various flood behaviour parameters. Flood maps for the 20%, 10%, 5%, 2%, 1%, 0.2% AEP and PMF design flood events showing peak flood depths, peak flood levels and contours, velocities, hazard, hydraulic categories are provided in **Appendix G** of the Flood Study.

Whilst results are presented in the Bomaderry Creek, Broughton Creek and Nowra & Browns Creek areas in the mapping, there are limitations with the results due to model grid size being too large to accurately represent smaller tributary creeks and flow calibration/validation has focussed on the mainstream Shoalhaven River. Modelling results from the Bomaderry Creek FRMS&P, Broughton Creek FRMS&P and Nowra & Browns Creek FRMS&P take precedence in these areas.

7.1 Summary of Results

Flood levels for the full range of design events corresponding to the key locations in **Figure 7-1** are presented in **Table 7-1**. Flood depth maps for the range of design events are shown in **Figure G01** to **G07** and flood level maps for the 1% AEP and the PMF event are shown in **Figure G12** and **G14** in **Appendix A**.

For more frequent events up to the 20% AEP, flooding is largely contained within the channel banks of the Shoalhaven River and tributaries, including Bomaderry Creek. Flooding in these frequent events largely affects the following areas:

> Broughton Creek floodplain (with depths of 1.5m or more) including Jaspers Brush, Bolong, Back Forest, Far Meadow and Berry. Bolong Road is affected at the lower end of Broughton Creek;

> Upper Bomaderry Creek and the lower reach of Bomaderry Creek near Shoalhaven River, affecting Bolong Road;

> Swamp area to the east of Nowra between Marriott Park and Millbank Road (with depths generally up to 1.5m), including urban areas around Haigh Avenue and Morton Parade;

> Generally shallow depths (0.5 - 1m) in the swamp area in the north of Brundee;

> Numbaa and Pyree areas including tributaries of Berrys Canal and the Lower Crookhaven River (including Ryans Creek, Macdonald and Salt Pan Creeks) which affect Comerong Island Road and Greenwell Point Road;

> Generally shallow depths (0.5 - 1m) around the Worrigee, Brundee Swamp and Saltwater Swamp areas;

> Low-lying foreshore areas around Shoalhaven Heads (Hay Ave and Jerry Bailey Rd), Coolangatta (affecting Bolong Road), Comerong Island and Culburra Beach; and

> Tributary flows affect properties in Berry, Bomaderry, East Nowra and South Nowra.

For the 10% AEP, flood results show similar affected areas but with greater flood depths and increased flood extents. Properties in low-lying foreshore areas become more flood affected particularly around Culburra Beach, Shoalhaven Heads and Greenwell Point. Protection is afforded to Terara from the Terara levees up to approximately the 10% AEP event, however, overtopping is observed south of Pig Island. Flooding to the west of Millbank Road increases as the swamp areas begin to fill with greater depths. Greenwell Point will begin to become isolated with depths on Greenwell Point Road becoming unsafe for vehicles.

For events larger than the 5% AEP event:

> Flooding is widespread throughout the Shoalhaven and Crookhaven River floodplain with depths becoming greater, commonly exceeding 2m with the various tributaries becoming interconnected to a combined floodplain;

> Depths within the Broughton Creek floodplain are greater than 3m over large areas. The Broughton Creek floodplain becomes connected to the Shoalhaven River;

> Terara Levees are overtopped south of Pig Island;

> More properties around the foreshore areas become inundated including:

  > Shoalhaven Heads - Jerry Bailey Road and Shoalhaven Heads Road.

  > Greenwell Point – widespread flooding of low-lying streets including Adelaide Street, Comarong Street, West Street, South Street, Hasler Road, Keith Avenue, Leonore Avenue, Fraser Avenue, Greens Road, Bailey Avenue, Crookhaven Drive.

  > Orient Point – Orama Crescent.

  > Culburra Beach – Orient Point Rd, Addison Rd, Whistler St and Brighton Parade with sections of Prince Edward Ave becoming submerged.

The 2% AEP event has similar flood extents to the 5% AEP with greater flood depths with some newly flooded areas around East Nowra and near Moorhouse Park/Scenic Drive to the west of Nowra Bridge.

The 1% AEP again has greater depths and extents, particularly around the lower Crookhaven and Greenwell Point and Culburra Beach.

The Riverview Road levee will provide protection from Shoalhaven River flooding up to the 0.2% AEP event with areas behind the levee inundated in the 0.2% AEP event as a result of backwater flooding from the Crookhaven Creek area. In the 0.2% AEP event, almost the entire floodplain now has depths exceeding 3m. Greenwell Point and Culburra Beach becoming significantly affected along with East Nowra and Terara.

The PMF affects large areas of the Broughton Creek, Lower Shoalhaven and Crookhaven River floodplain as well as the tributaries and overland flow areas. Depths are greater with the backwater affecting parts of Nowra, Bomaderry and Berry as well as more severe flooding of the foreshore areas in the lower reaches.

Flow velocities in the 1% AEP event are generally greater than 3m/s in the Shoalhaven River main channel upstream of Pig Island, with 2-3m/s velocities in the Shoalhaven River (downstream of Pig Island) and Berrys Canal. Velocities are generally 1.5 m/s within the tributaries and >3 m/s in steeper sections. Low flow velocities of typically around 0.5m/s but up to 1m/s are observed within the floodplain areas due to the water depths.

Flow velocities in the Probable Maximum Flood generally vary from 4 to 6 m/s in the Shoalhaven River main channel upstream of Pig Island, with 2-3m/s velocities in the Shoalhaven River (downstream of Pig Island) and Berrys Canal. Velocities are greater than 3m/s through the entrances. Velocities are generally 1.5 – 2.0 m/s within the tributaries and >3 m/s in steeper sections. Velocities within the floodplain areas are greater as they begin to convey more flow with more areas up to 1m/s and localised flowpaths with up to 1.5m/s.

Table 7-1 Peak flood level at reference locations for design events – existing scenario

ID	Location	Water Level (m AHD)						
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.2% AEP	PMF
1	Grassy Gully	16.50	20.16	22.86	25.39	26.72	29.84	41.62
2	Gradys Caravan Park	10.99	14.46	16.75	18.68	19.64	22.47	32.69
3	Bomaderry Creek	4.59	5.17	5.54	5.28	5.48	5.56	7.02
4	Nowra Bridge	3.01	4.19	4.83	5.22	5.38	6.22	8.85
5	Terara Gauge	2.87	3.99	4.61	5.01	5.19	5.70	7.46
6	Terara Town	Not Affected	Not Affected	3.90	4.09	4.25	4.97	6.88
7	Broughton Creek US	3.48	3.93	4.25	4.13	4.31	4.95	6.93
8	Jorams and Broughton Confluence	2.09	3.03	3.70	4.13	4.31	4.94	6.92
9	Broughton Creek Confluence	2.13	2.98	3.60	3.97	4.14	4.76	6.68
10	Hay Street Gauge	1.74	1.98	2.36	2.49	2.92	3.74	5.63
11	Shoalhaven Heads	1.73	1.93	2.22	2.34	2.70	3.46	4.99
12	Crookhaven River and Crookhaven Creek Confluence	1.24	1.29	1.69	2.47	3.00	3.95	6.06
13	Greenwell Point Gauge	1.20	1.24	1.60	2.32	2.71	3.66	5.70
14	Crookhaven Heads Gauge	1.14	1.16	1.41	2.16	2.43	3.30	4.94

*Refer to **Figure 7-1** for reference locations.*

7.2 Sea Level Rise

Sea Level Rise predominantly affects the lower reaches of the system towards the entrances, the low lying areas around the foreshore (Shoalhaven Heads, Comerong Island, Greenwell Point, Orient Point and Culburra Beach) and within the Crookhaven River floodplain areas. The following statements are made for each sea level rise scenario:

- The SCC projected 2050 sea level rise of +0.23m results in typically less than 150mm of water level increase and no impacts upstream of the Broughton Creek confluence;
- The SCC projected 2100 sea level rise of +0.36m results in typically less than 200mm of water level increase and no impacts upstream of the Broughton Creek confluence; and
- The NSW 2100 sea level rise of +0.90m results in typically less than 550mm of water level increase locally near the entrances and within the Crookhaven River decreasing moving upstream into the swamp areas to the west. Minor increases of up to 50mm are observed in the Broughton Creek floodplain while in the Shoalhaven River, no impacts are observed upstream of Terara.

For Projected 2050 scenario including 0.23m Sea Level Rise and Projected 2100 scenario including 0.36m Sea Level Rise, flood extent maps showing peak flood depths and peak flood levels with contours are provided in **Appendix G** of the Flood Study.

Water level differences compared with existing (no sea level rise) are shown in **Table 7-2** and presented in **Appendix G** of the Flood Study.

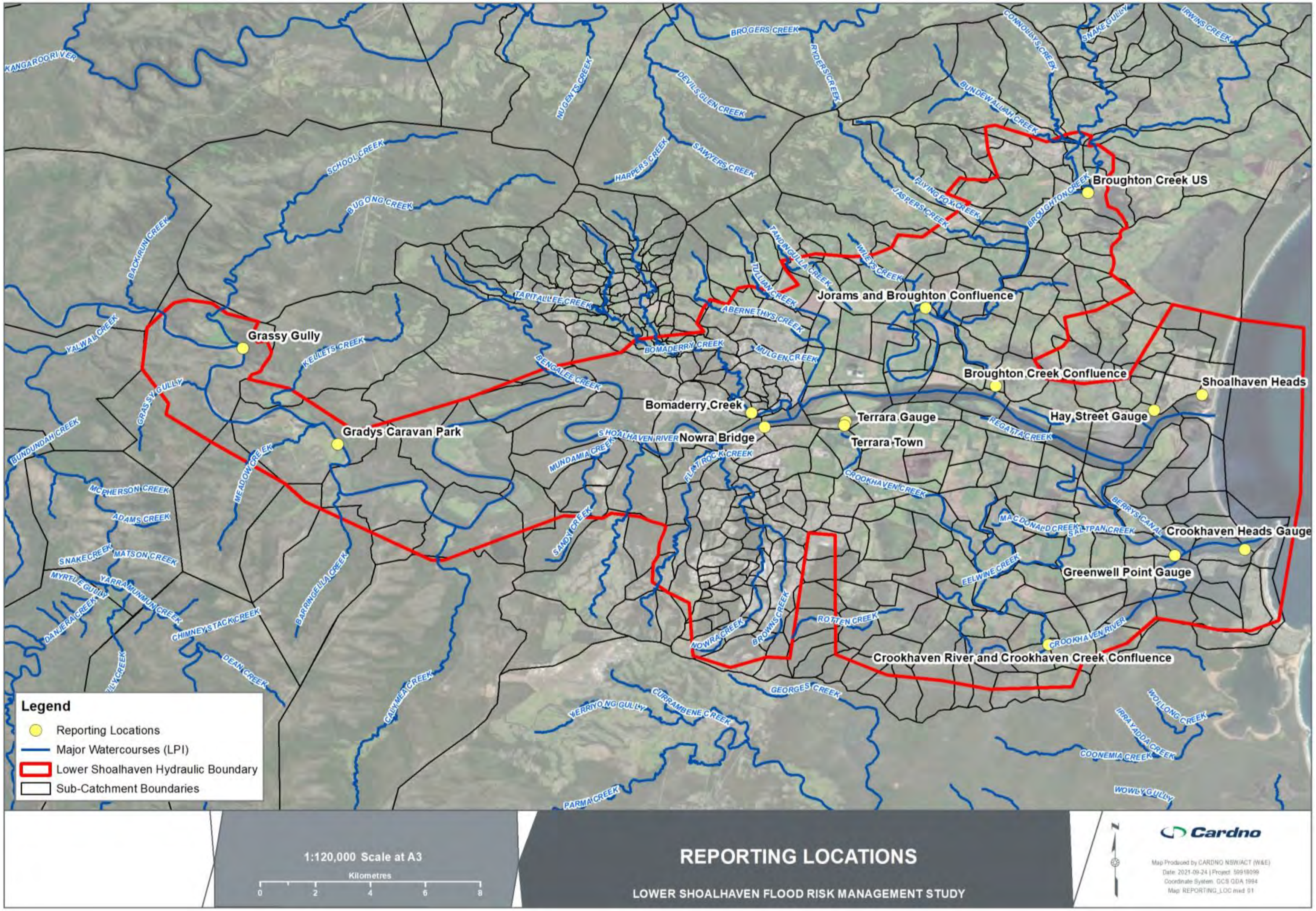

Figure 7-1 Key Reporting Locations

Table 7-2 Sea Level Rise – 1% AEP water level difference

ID	Location	1% AEP	SCC 2050 (+0.23m)		SCC 2100 (+0.36m)		NSW 2100 (+0.90m)	
		WL (mAHD)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)
1	Grassy Gully	26.72	26.72	0.00	26.72	0.00	26.72	0.00
2	Gradys Caravan Park	19.64	19.64	0.00	19.64	0.00	19.64	0.00
3	Bomaderry Creek	5.48	5.48	0.00	5.48	0.01	5.49	0.01
4	Nowra Bridge	5.38	5.38	0.00	5.38	0.00	5.38	0.00
5	Terara Gauge	5.19	5.19	0.00	5.19	0.00	5.19	0.00
6	Terara Town	4.25	4.25	0.00	4.25	0.00	4.26	0.01
7	Broughton Creek US	4.31	4.31	0.00	4.32	0.01	4.35	0.04
8	Jorams and Broughton Confluence	4.31	4.31	0.00	4.32	0.01	4.35	0.04
9	Broughton Creek Confluence	4.14	4.14	0.01	4.15	0.01	4.18	0.05
10	Hay Street Gauge	2.92	3.01	0.09	3.07	0.15	3.36	0.44
11	Shoalhaven Heads	2.70	2.82	0.12	2.89	0.19	3.23	0.54
12	Crookhaven River and Crookhaven Creek Confluence	3.00	3.08	0.09	3.14	0.14	3.42	0.43
13	Greenwell Point Gauge	2.71	2.83	0.12	2.90	0.19	3.25	0.54
14	Crookhaven Heads Gauge	2.43	2.57	0.15	2.66	0.23	3.07	0.64

*Refer to **Figure 7-1** for reference locations.*

7.3 Comparison with Previous Flood Study Results

Previous flood study results, along with historical event flood levels have been sourced from Table 2 of the Lower Shoalhaven River Floodplain Risk Management Plan (Webb, McKeown & Associates, 2008). This is replicated in **Table 7-3** with the current study flood levels for comparison.

The historical event estimated AEP has been updated with the AEP determined for the tabulated historical events from the statistical Flood Frequency Analysis described in Section 4.7 of this report.

It is noted that water levels are typically lower than the previous flood study results. It is observed that:

- Water levels are 300mm to 500mm lower at Nowra Bridge than the 1990 flood study for the 20% AEP and 5% AEP events;
- Water levels are generally significantly lower by 900mm than the previous flood study at Nowra Bridge in the 1% AEP, due to the lower flows adopted in the current study;
- The Riverview Road levee was previously expected to be overtopped in the 1% AEP event, however, with reductions in the calculated 1% AEP flow and levels at Nowra Bridge, the levee is not expected to be overtopped until a 0.2% AEP event or rarer in the current study; and
- The PMF event yields water levels that are very close (50mm lower than) the previous Lower Shoalhaven River Flood Study (Public Works, 1990) Extreme event at Nowra Bridge.

It is also noted that different methodologies are used in these two studies, i.e. different hydrology, up-to-date data, modelling software and methods, and different tailwater boundary and entrance conditions.

However, comparison of the modelled peak flood levels of each AEP event with the estimated AEP of historical events shows that the current study correlates well with observed data, generally within 100mm of the expected flood level for the equivalent return period. Such differences are to be expected given the uncertainty of accuracy of historical flood level values, uncertainty of the consistency of reporting location, localised water level variations due to hydraulic phenomena and changes in flood behaviour due to construction of various Nowra Bridge configurations and the Terara levees.

For example, the 1978 event is estimated to have a 2.8% AEP and a flood level of 4.7m AHD at Terara. This lies between the modelled 5% AEP and 2% AEP flood levels.

Table 7-3 Peak flood level of major floods (mAHD) – comparison with previous Flood Study and historical floods – existing scenario

Location	Historical Events				1990 Flood Study Design Events				Current Study Design Events			
	1860	1870	1974	1978	5% AEP	2% AEP	1% AEP	Ext	5% AEP	2% AEP	1% AEP	PMF
Nowra Bridge	5.5	6.55	4.9*	5.3*	5.3	5.8	6.3	8.9	4.83	5.22	5.38	8.85
Shoalhaven River at Terara	4.8	5.7	4.4*	4.7*	4.8	5.1	5.5	7.4	4.61	5.01	5.19	7.46
Numbaa	U	U	U	3.7#	3.3	3.6	4.1	6.0	3.60	3.97	4.14	6.68
Shoalhaven Heads (Wharf Rd)	U	U	U	U	2.7	2.9	3.3	4.2	2.22	2.49	2.92	4.99
Greenwell Point	U	U	1.65#	U	2.4	2.9	3.4	5.2	1.69	2.47	3.00	5.70
Orient Point	U	U	U	U	2.2	2.6	3.0	4.7	1.41	2.16	2.43	4.94
Estimated AEP at Nowra Bridge**	1.6%	0.4%	6.9%	2.8%								
Estimated Average Recurrence Interval (ARI) at Nowra Bridge	62 years	270 years	14 years	35 years								

Note: Exact locations of 1990 Flood Study results are unknown and there may be some differences in the reported location.

The levels for the 1860 and 1870 floods at Nowra Bridge and in the Shoalhaven River at Terara are estimated as no actual levels were recorded. The levels shown are based on historical flood data taken from the Lower Shoalhaven River Flood History at Nowra Bridge 1860-1980.

* Recorded level taken from the Lower Shoalhaven River Flood History at Nowra Bridge 1860-1980.

Recorded level in Shoalhaven River Flood Study Compendium of Data

estimated AEP derived from the FFA at Grassy Gully based on equivalent flows based on the level at Nowra Bridge. It is noted that the AEP is for the level adjusted to current day catchment conditions as described in **Section 4.7.

7.4 Flood Hazard

Hazard categorisation developed by the revised ARR manual Book 6: Flood Hydraulics, Section 7.2.7 (Ball et al. 2019) determines hazard through a relationship developed between the depth and velocity of floodwaters using six categories based on the stability of children, adults, the elderly, vehicles and buildings in floodwaters. The ARR2019 hazard curves are shown in **Figure 7-2**.

Hazard mapping for Design Events, Projected 2050 and Projected 2100 scenarios are provided in **Appendix G** of the Flood Study. Flood hazard categories for the 1% AEP and the PMF event are shown in **Figure G22** and **Figure G24** in **Appendix A**.

In the 1% AEP event almost the entire Broughton Creek and Lower Shoalhaven/Crookhaven River floodplain areas are classified as H5 due to the significant flood depths. In the 0.2% AEP event parts of the floodplain become H6 hazard category, with the remainder H5.

In the PMF event, H5 to H6 hazard regions dominate the flood extent, with only the outer flood fringe classed as H1 to H3 hazard. These H5 to H6 hazard regions may impact properties along the foreshore areas of Greenwell Point, Orient Point and Culburra Beach.

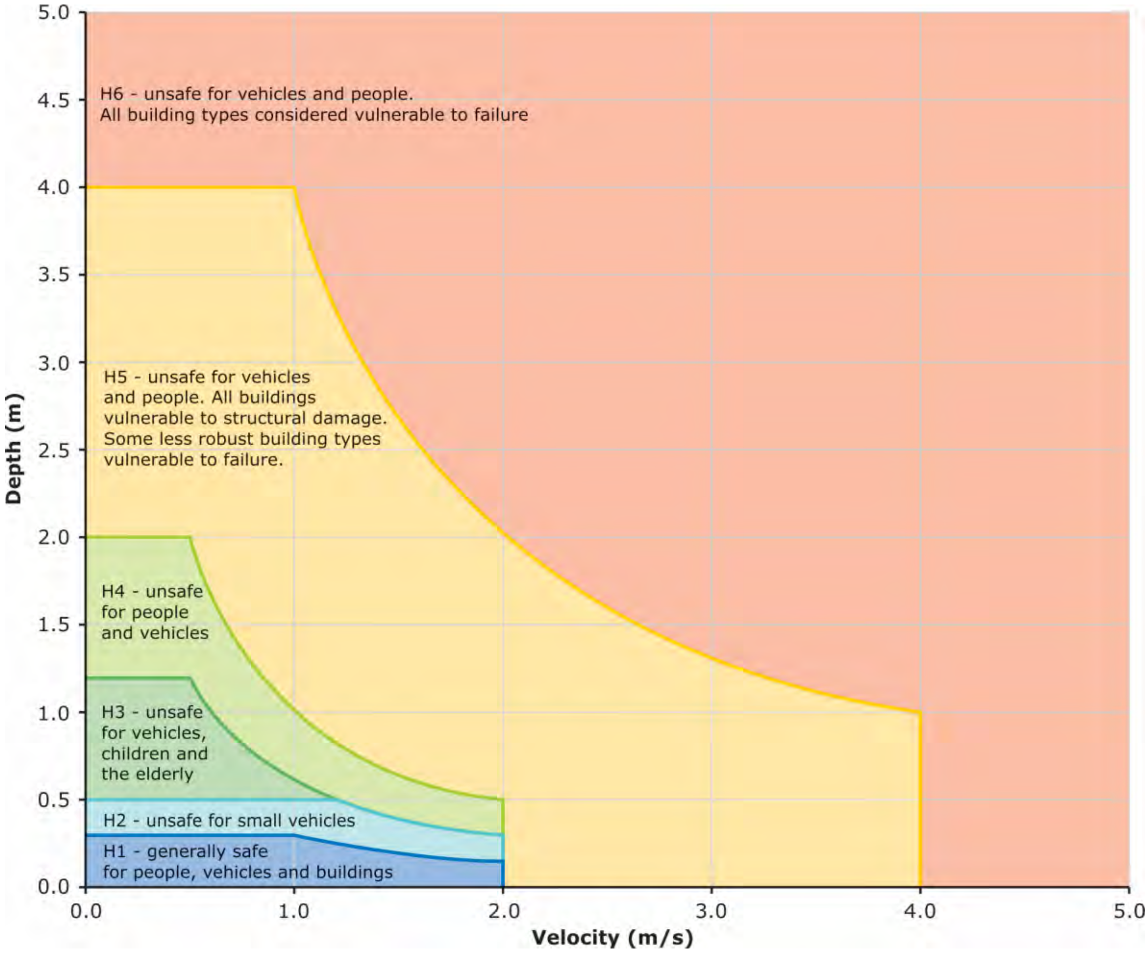

Figure 7-2 Hazard Categories from ARR 2019

7.5 Climate Change Scenarios

The study also assessed the potential impacts of both Climate Change induced rainfall increases and sea level rise using current recommended ARR2019 values based on global climate modelling. Results of Climate Change scenarios are presented in **Appendix H** of the Flood Study as water level difference plots compared with the adopted 1% AEP event peak water levels. Difference maps have been derived by subtracting the existing 1% AEP event water surface level from the Climate Change Scenario water surface level.

Peak water levels for each Climate Change Scenario at the water level gauging stations and reference locations are shown in **Table 7-4** and **Table 7-5** for the 1% AEP event. The table also shows water level difference compared to the adopted 1% AEP peak water levels.

Increased rainfall due to climate change has the biggest impact in the Shoalhaven River upstream of Nowra Bridge due to the increased flows and the incised valley. The increased flow dominates changes in expected flood levels to approximately Terara, with sea level rise having impacts in the Shoalhaven River downstream of Terara and in the Crookhaven River/Crookhaven Creek floodplain. Only minor increases in flood level are observed in the Broughton Creek floodplain.

For the 1% AEP, with rainfall increases of 16.3% due to Climate Change, associated increased flows may result in increases in flood levels in the Shoalhaven River upstream of Nowra by up to almost 1.4m at Grassy Gully and 1.1m at Gradys Caravan Park reducing to 200mm at Nowra Bridge. Increases in the lower floodplain areas are generally less than 150mm for all scenarios up to 7.6% rainfall increase with increases typically 150 – 250 mm for the 16.3% (2090 RCP 8.5) rainfall increase.

In combination with Sea Level Rise a further increase in water levels may be expected around low-lying foreshore areas and up to 400mm total water level increases near the Shoalhaven and Crookhaven River entrances. Little to no additional increase in water levels due to sea level rise is seen upstream of approximately Pig Island or within the Broughton Creek floodplain.

Table 7-4 Climate Change – 1% AEP Rainfall Increase (Existing sea level) water level difference

ID	Location	1% AEP	CC 2050 RCP4.5		CC 2050 RCP8.5		CC 2090 RCP4.5		CC 2090 RCP8.5	
		WL (mAHD)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)
1	Grassy Gully	26.72	27.19	0.47	27.36	0.64	27.38	0.66	28.09	1.37
2	Gradys Caravan Park	19.64	20.01	0.37	20.13	0.49	20.15	0.51	20.73	1.09
3	Bomaderry Creek	5.48	5.49	0.01	5.49	0.02	5.49	0.02	5.52	0.04
4	Nowra Bridge	5.38	5.45	0.06	5.47	0.09	5.47	0.09	5.58	0.20
5	Terara Gauge	5.19	5.24	0.05	5.26	0.07	5.26	0.07	5.35	0.16
6	Terara Town	4.25	4.33	0.08	4.35	0.11	4.35	0.11	4.48	0.23
7	Broughton Creek US	4.31	4.37	0.06	4.39	0.08	4.40	0.09	4.49	0.18
8	Jorams and Broughton Confluence	4.31	4.37	0.06	4.39	0.08	4.39	0.08	4.49	0.18
9	Broughton Creek Confluence	4.14	4.19	0.06	4.21	0.08	4.22	0.08	4.31	0.17
10	Hay Street Gauge	2.92	2.99	0.08	3.02	0.10	3.02	0.11	3.15	0.23
11	Shoalhaven Heads	2.70	2.76	0.07	2.79	0.09	2.79	0.10	2.90	0.20
12	Crookhaven River and Crookhaven Creek Confluence	3.00	3.09	0.10	3.13	0.13	3.13	0.14	3.28	0.28
13	Greenwell Point Gauge	2.71	2.79	0.08	2.82	0.11	2.83	0.12	2.96	0.25
14	Crookhaven Heads Gauge	2.43	2.49	0.07	2.52	0.09	2.52	0.09	2.62	0.20

*Refer to **Figure 7-1** for reference locations.*

Table 7-5 Climate Change – 1% AEP Rainfall Increase + SLR water level difference

ID	Location	1% AEP	CC 2050 RCP4.5 + SLR2050 (SCC)		CC 2050 RCP8.5 + SLR2050 (SCC)		CC 2090 RCP4.5 + SLR 2100 (SCC)		CC 2090 RCP8.5 + SLR 2100 (SCC)	
		WL (mAHD)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)
1	Grassy Gully	26.72	27.19	0.47	27.36	0.64	27.38	0.66	28.09	1.37
2	Gradys Caravan Park	19.64	20.01	0.37	20.13	0.49	20.15	0.51	20.73	1.09
3	Bomaderry Creek	5.48	5.49	0.02	5.50	0.02	5.50	0.02	5.53	0.05
4	Nowra Bridge	5.38	5.45	0.06	5.47	0.09	5.47	0.09	5.59	0.21
5	Terara Gauge	5.19	5.24	0.05	5.26	0.07	5.26	0.07	5.35	0.16
6	Terara Town	4.25	4.33	0.08	4.36	0.11	4.36	0.11	4.48	0.23
7	Broughton Creek US	4.31	4.38	0.07	4.40	0.09	4.40	0.09	4.50	0.19
8	Jorams and Broughton Confluence	4.31	4.37	0.07	4.40	0.09	4.40	0.09	4.50	0.19
9	Broughton Creek Confluence	4.14	4.20	0.06	4.22	0.08	4.23	0.09	4.33	0.19
10	Hay Street Gauge	2.92	3.08	0.16	3.11	0.19	3.16	0.25	3.27	0.35
11	Shoalhaven Heads	2.70	2.87	0.18	2.90	0.20	2.97	0.27	3.06	0.37
12	Crookhaven River and Crookhaven Creek Confluence	3.00	3.17	0.17	3.20	0.21	3.25	0.26	3.39	0.39
13	Greenwell Point Gauge	2.71	2.90	0.19	2.93	0.22	3.00	0.29	3.11	0.40
14	Crookhaven Heads Gauge	2.43	2.63	0.20	2.65	0.22	2.73	0.30	2.82	0.39

*Refer to **Figure 7-1** for reference locations.*

8 Impacts of Flooding on the Community

8.1 Impacts of Flooding

The community within the Lower Shoalhaven catchment is susceptible to extensive flooding, most notably in low lying foreshore areas of Shoalhaven Heads, Coolangatta, Comerong Island, Greenwell point, Orient Point and Culburra Beach, throughout the Broughton Creek and Crookhaven River floodplains as well as properties around East Nowra, southern Bomaderry and Berry. Numbers and types of properties affected and associated damages are presented in **Section 8.3.2**.

Table 8-1 summarises the number of affected properties for each design flood event in the areas within the Lower Shoalhaven River. The number of buildings with predicted overfloor flooding for each design flood event has been calculated based on a database of actual surveyed floor levels which has been supplemented with some assumed floor levels based on building type for buildings where the actual floor level was unknown at the time of this Flood Study preparation. The number of buildings with predicted overfloor flooding for each design flood event can be updated as part of the Floodplain Risk Management Study & Plan following the completion of additional floor level survey. Flood extents are shown on flood maps in **Appendix A**.

8.1.1 Shoalhaven Heads, Coolangatta and Comerong Island

Properties in Shoalhaven Heads around Hay Avenue are exposed to above floor flooding in events as frequent as the 50% AEP event when Shoalhaven Heads is closed with five properties affected by over floor flooding. Two properties are impacted in a 20% AEP event, which is a large enough event to trigger entrance management intervention and hence opening of the entrance which mitigates flood levels. The number of properties impacted increases to nine in the 10% AEP event with properties around the Jerry Bailey Road – Renown Ave intersection being impacted. This number increases to 20 in a 5% AEP event as more properties on Jerry Bailey Road experience flooding above floor levels. The Shoalhaven Heads caravan park would also be impacted.

Almost 85 properties will experience above floor flooding in the 1% AEP event with most properties on Hay Avenue and Jerry Bailey Road south of Davenport Road affected along with some properties on Shoalhaven Heads Road, including the three caravan parks – Mountain View Resort, Ingenia Holidays and Coastal Palms. In a 0.2% AEP event a significant number of properties along Jerry Bailey Rd south of Shoalhaven Heads Road will be impacted along with properties around the Hay Avenue – Jerry Bailey Road intersection. Some 258 properties in addition to the caravan parks would have flooding above floor level in a PMF event, including all properties along Jerry Bailey Road and adjacent cross streets, properties on Scott Street, Ablett Circuit and Discovery Place, as well as properties along Bolong Road.

In Coolangatta area, most properties along the Shoalhaven River foreshore are impacted between the 20% AEP and 5% AEP event, with a small number of properties not impacted above floor level until the 1% AEP event. However, these properties would be isolated as Bolong Road becomes inundated in events more frequent than the 5% AEP event.

Properties on Comerong Island closest to Shoalhaven Heads foreshore begin to be impacted from as little as the 50% AEP event with most properties experiencing above floor flooding in the 5% AEP event. Properties on the remainder of Comerong Island are protected from Shoalhaven River flooding by the levee up to approximately the 20% AEP event, however, flood waters back up from the south from Berrys Canal/ Crookhaven River with floodwaters inundating most land. All properties will have above floor flooding in a 5% AEP event as the levee overtops and the Island experiences flooding from both the north and south.

8.1.2 Greenwell Point

Greenwell Point is significantly affected by flooding and becomes isolated with Greenwell Point Road – the only egress – experiencing flooding over the road between a 20% AEP and 10% AEP event and becoming cut off in events rarer than the 10% AEP. Overfloor flooding begins in a 5% AEP event with some 44 foreshore properties impacted as well as the Pine Park and Coral Tree caravan parks becoming inundated, however, this jumps significantly to 250 properties in a 2% AEP event. The number of impacted properties continues to climb with increasing flood depths with almost 310 properties impacted in a 1% AEP event and 433 in the PMF event.

8.1.3 Orient Point and Culburra Beach

Properties along the river foreshore areas of Culburra Beach begin to experience flooding above floor in a 5% AEP event. The number of affected properties increases to almost 70 in a 2% AEP event with nine properties in Orient Point having overfloor flooding. The low point on Prince Edward Avenue near The Strand becomes impassable to vehicles between the 5% AEP event and 2% AEP event. Properties north of this low point would be isolated except for egress by foot via the beachfront. Over 94 properties would have above floor flooding in the 1% AEP event and more than 349 properties in the PMF event with significant flood depths.

Table 8-1 Flood affected properties by location

Event	50% AEP		20% AEP		10% AEP		5% AEP		2% AEP		1% AEP		0.2% AEP		PMF	
Location	**B**	**Y**	**B**	**Y**	**B**	**Y**	**B**	**Y**	**B**	**Y**	**B**	**Y**	**B**	**Y**	**B**	**Y**
SHOALHAVEN HEADS	5	68	2	68	9	84	20	134	34	145	84	192	188	259	258	263
GREENWELL POINT	0	41	0	46	0	55	44	303	249	404	307	428	399	442	433	446
ORIENT POINT	0	0	0	0	0	0	0	3	9	24	12	26	20	33	31	36
CULBURRA BEACH	0	91	0	95	0	95	5	114	59	168	82	204	170	283	318	320
CROOKHAVEN RIVER FLOODPLAIN	1	227	0	223	14	271	80	333	189	344	252	347	299	352	373	392
BROUGHTON CREEK FLOODPLAIN	2	175	5	180	26	184	53	187	63	189	77	191	88	196	153	209
BOMADERRY	0	65	3	71	9	86	18	95	26	101	30	105	36	118	74	144
NOWRA	14	147	14	160	16	188	28	264	40	351	54	383	226	602	737	879
NORTH NOWRA	0	2	1	2	1	2	1	2	1	2	1	2	2	2	2	2
UPSTREAM NOWRA	0	0	0	12	0	15	2	16	4	16	5	16	7	16	13	16
TOTAL	**24**	**816**	**79**	**943**	**197**	**1,293**	**601**	**1,616**	**755**	**1,728**	**1,015**	**1,878**	**1,448**	**2,287**	**2,392**	**2,707**

B – Buildings with overfloor flooding

Y – Yards with flooding

8.1.4 Crookhaven River Floodplain

The Crookhaven River floodplain includes the Terara, Numbaa, Brundee, Worrigee, Mayfield and Pyree areas. Extensive flooding is experienced throughout this floodplain with various swamp areas and floodwaters backing up from Crookhaven River/Crookhaven Creek as well as from the Shoalhaven River breaking its banks around Numbaa. Parts of Comerong Island Road are inundated in the 20% AEP event with properties in the Numbaa and Pyree areas experiencing above floor flooding from the 10% AEP event. Almost 15 properties are affected in the 10% AEP event as well as some properties south of Terara. The Riverview Road and Terara levees provide protection from Shoalhaven River flooding to the Terara township up to almost the 10% AEP event when the Terara levee begins to be overtopped south of Pig Island. Once the levee is overtopped, there is extensive flooding throughout the floodplain with around 80 properties impacted in the 5% AEP event, 190 in a 2% AEP event including Shoalhaven Caravan Village, climbing to more than 250 in the 1% AEP event and around 337 properties in the PMF event.

8.1.5 Nowra

Properties in East Nowra may experience flooding above floor in frequent events, largely from overland flow downstream of Marriott Park including urban areas around Haigh Avenue, Plunkett Street and Morton Parade. Properties adjacent to the swamp area to the east of Nowra experience above floor flooding in the 10% AEP and 5% AEP events with around 30 properties in the Haigh Ave, Morton Parade, Plunkett Street and Dryden Close areas being affected.

The 2% AEP event has similar flood extents to the 5% AEP with greater flood depths with some newly flooded areas around East Nowra, Ferry Lane and Moss Street and near Moorhouse Park/Scenic Drive to the west of Nowra Bridge. In a 1% AEP event, more properties in Ferry Lane as well as Amalfi Crescent become impacted with a total of 54 properties in Nowra affected by overfloor flooding. The number of affected properties jumps to 226 in the 0.2% AEP event as properties around Lyrebird Drive, Moss St, Moorhouse Park and adjacent to Harry Sawkins Reserve become impacted. In a PMF event, there is extensive numbers of above floor flooded properties (some 737) around the edge of the floodplain and south of the river in the Riverview Road areas to Moss Street and adjacent to Moorhouse Park and Harry Sawkins Reserve.

Properties behind Riverview Road levee will be protected from River flooding up to the 1% AEP event, with this area impacted primarily from backwater flooding from the Crookhaven Creek area in events greater than approximately the 0.5% AEP up to the PMF event when flooding is also experienced from overtopping of the levee and the Princes Highway from upstream of Nowra Bridge. The below table provides the level of service for the Riverview Road levee. The levee has one metre or more freeboard in the 1% AEP event, but is close to overtopping near Nowra Bridge in the 0.2% AEP event with a reasonable amount of freeboard (0.7m - 1m) east of Hawthorn Avenue. The levee will overtop along almost its entire length in a PMF event.

Table 8-2 Riverview Road levee level of service

Location	Wharf Road (near Nowra Bridge)	Western End (Hawthorn Avenue)	Mid-point	Eastern End (Ferry Lane)
Levee Crest (m AHD)	6.50	6.52	6.43	6.11
1% AEP (m AHD)	5.43	5.05	5.16	5.25
0.2% AEP (m AHD)	6.30	5.56	5.37	5.42
PMF (m AHD)	8.90	8.63	7.82	6.79

8.1.6 Upstream Nowra, North Nowra and Bomaderry

Upstream of Nowra Bridge the Shoalhaven Ski Park will become impacted in the 10% AEP event, two properties will have overfloor flooding in the 5% AEP event, increasing to five in the 1% AEP event and 13 in the PMF event. Properties in North Nowra are largely on high ground and do not experience flooding even in a PMF event with the exception of Nowra Golf Club and properties along the banks of Bomaderry Creek west of the Princes Highway.

Three properties in Bomaderry around Bolong Road adjacent to Bomaderry Creek and Brinawarr Street will experience overfloor flooding in a 20% AEP event. These impacts increase with increasing flood depths with rarer events largely influenced by backwaters from the Shoalhaven River. Almost 20 properties have overfloor flooding in the 5% AEP event with around 30 properties in the 1% AEP event, while some 74 properties will be impacted in the PMF event around the perimeter of the low lying areas.

8.1.7 Broughton Creek Floodplain

Properties along Bolong Road on the northern bank of the Shoalhaven River will have overfloor flooding from the 20% AEP event along with some isolated properties throughout the floodplain. Approximately 25 properties are impacted in a 10% AEP event, primarily in the lower Broughton Creek floodplain in the Bolong area along Jennings Lane. Flooding reaches overfloor levels for more properties on Jennings Lane along with properties on Hanigans Lane in the 5% AEP and 2% AEP events. In the 1% AEP event there are some 80 properties with above floor flooding with more properties along Hanigans lane affected. Properties around the perimeter of the floodplain are impacted in the PMF with a total of 153 properties having overfloor flooding.

Properties in the Berry area upstream of the railway and highway experience above floor flooding primarily from tributary flooding.

8.2 Flood Planning Levels

The Flood Planning Level (FPL) is a combination of flood levels and freeboard selected for planning purposes above which future developments must construct their floor levels to reduce flood risk to life and damage. Freeboard is applied to the selected planning flood to account for uncertainties in flood model accuracy, potential increases due to rainfall increases associated with Climate Change and other factors such as impacts of structure blockage or localised water level differences due to wave action.

The FPL is typically defined as the 1% AEP flood event plus 500mm freeboard for most residential and commercial developments. However, a larger flood event could be selected to determine the FPL based on a catchments flood risk.

The FPL was initially determined for this study based on the 1% AEP DFE. But following comparison against the currently adopted Council FPLs, it was identified that this would result in a reduction in FPL due to the reduced 1% AEP flow in this study. Hence, it was identified that there was an opportunity to adopt a higher DFE to determine the FPL. This approach is supported by changes to the NSW Government Flood Prone Land package and findings from the NSW Flood Inquiry.

The Flood Planning Area (FPA) is all land below the FPL. The Flood Planning Area (FPA) mapping for this study has been determined by adding 500mm freeboard to the 0.5% AEP flood level and extending the surface laterally to intersect with the adjacent terrain to define the area within the FPL. The FPA has been determined for the existing, projected 2050 and projected 2100 scenarios and draft Flood Planning Area maps for the projected 2050 and projected 2100 scenarios are provided in **Figures I02** to **I03** in **Appendix A**.

In determining appropriate FPLs, consideration may be given to ensuring areas sensitive to sea level rise, blockage and Climate Change impacts are fully considered in the Flood Planning Area.

Previous flood study results are deemed to have been conservative with regards 1% AEP flow estimates. This Flood Study uses current industry standard guidelines along with up-to-date data, modelling software and methods and the resulting flood levels are considered to be accurate and appropriate.

Taking into consideration the different flood processes in different areas of the Lower Shoalhaven River and to simplify the adoption of different flood planning levels and freeboard in different areas, it is recommended as a minimum to adopt the 1% AEP 2090 Climate Change scenario (RCP 8.5 16.3% rainfall increase and 0.36m Sea Level Rise) as the planning defined flood event with a standard 500mm freeboard as the FPL. Thus, for example, a house with a life span of 70 years would have an FPL based on the flood level estimated to be applicable in about 80 years' time. However, given the 1% AEP flood level is lower than the previous Flood Study, adopting a higher defined flood event (such as a 0.5% AEP event) for the FPL would maintain a similar FPL to what has currently been adopted across the Lower Shoalhaven River floodplain and could further reduce future flood risk.

8.3 Flood Damages Assessment

The economic impact of flooding can be defined by what is commonly referred to as flood damages. Flood damages are generally categorised as either tangible (direct and indirect) or intangible damage types; these types are summarised in **Table 8-3**.

Table 8-3 Types of Flood Damages

Type of Flood Damage	Description
Direct	Building contents (internal) Structure (building repair and clean) External items (vehicles, contents of sheds etc.)
Indirect	Clean-up (immediate removal of debris) Financial (loss of revenue, extra expenditure) Opportunity (non-provision of public services)
Intangible	Social – increased levels of insecurity, depression, stress General inconvenience in post-flood stage

The direct damage costs, as indicated in **Table 8-3**, are just one component of the entire cost of a flood event. There are also indirect costs. Together, direct and indirect costs are referred to as tangible costs. In addition to tangible costs, there are intangible costs such as social distress. The flood damage values discussed in this report are the tangible damages and do not include an assessment of the intangible costs which are difficult to calculate in economic terms.

A flood damage assessment for the existing catchment conditions has been completed as part of this study.

The assessment is based on damage curves for residential, commercial and industrial properties that relate the depth of flooding on a property to the likely damage cost within the property.

A floor level database was developed by Council (2021) for all the properties within the PMF flood extent and included data from ground level and floor level survey undertaken by Council in 2001. Where survey data was unavailable, the floor level was estimated based on average building heights relative to ground level for different property types such as whether it is slab on ground, on piers, commercial, industrial etc.

To inform the damages analysis, flood level results for the full range of AEP events were assessed to determine the depth of over-floor flooding and over-ground flooding for each flood affected lot.

8.3.2 Total Damages

Flood damages (for each design event) for each property are calculated by using the damage curves described above. The total damage for a design event is determined by adding all the individual property damages for that event. A summary of the total damage incurred for each flood event the Lower Shoalhaven catchment is shown in **Table 8-4.**

Note: the new PMF extents result in additional properties being impacted for which floor level assessment has not been undertaken. Food damages assessment should be revisited during the FRMS&P process following further floor level survey and also using the recently revised DPE flood damages analysis tools.

8.3.3 Average Annual Damage

Average Annual Damage (AAD) attempts to quantify the flood damage that a floodplain would receive on average each year using a probability approach based on the flood damages calculated for each design event. Based on the analysis described above, the calculated AAD for the Lower Shoalhaven floodplain under existing conditions is **$8,988,900**.

Table 8-4 Flood Damages Assessment Summary

Property Type	Properties with Overfloor Flooding	Average Overfloor Flooding Depth (m)	Maximum Overfloor Flooding Depth (m)	Properties with Overground Flooding	Total Damage ($May 2021)
PMF					
Residential	2,093	2.46	19.24	2,363	$ 368,865,298
Commercial	280	2.60	6.64	313	$ 35,016,784
Industrial	20	1.60	4.34	32	$ 2,936,932
Total	**2,393**			**2,078**	**$ 406,819,014**
0.2% AEP					
Residential	1,241	1.10	8.63	2,020	$ 179,962,050
Commercial	183	1.28	3.38	255	$ 20,470,950
Industrial	11	0.71	2.33	28	$ 1,007,950
Total	**1,435**			**2,303**	**$ 201,440,900**
1% AEP					
Residential	750	0.66	5.24	1,639	$ 96,806,050
Commercial	147	0.77	2.75	232	$ 13,496,350
Industrial	7	0.61	1.46	23	$ 611,150
Total	**904**			**1,894**	**$ 110,913,550**
2% AEP					
Residential	551	0.45	4	1493	$ 68,226,600
Commercial	118	0.66	2.57	228	$ 10,396,250
Industrial	5	0.64	1.03	23	$ 509,100
Total	**674**			**1744**	**$ 79,131,950**
5% AEP					
Residential	168	0.35	2.04	1216	$ 25,724,300
Commercial	79	0.51	2.14	215	$ 6,250,200
Industrial	4	0.53	0.91	20	$ 366,900
Total	251			1451	**$ 32,341,400**
10% AEP					
Residential	44	0.34	1.66	758	$ 7,550,200
Commercial	29	0.43	1.47	207	$ 2,583,300
Industrial	2	0.43	0.72	15	$ 172,050
Total	**75**			**980**	**$ 10,305,600**
20% AEP					
Residential	15	0.43	1.05	657	$ 3,949,300
Commercial	9	0.49	0.86	186	$ 1,289,700
Industrial	1	0.4	0.4	14	$ 106,700
Total	**25**			**857**	**$ 5,345,700**
50% AEP					
Residential	13	0.29	0.93	623	$ 3,481,250
Commercial	9	0.40	0.81	180	$ 1,130,600
Industrial	0	0	0	13	$ 39,000
Total	**22**			**816**	**$ 4,650,850**

9 Conclusion

This Flood Study has developed hydrological and hydraulic models that have been successfully calibrated and validated to four historical events. Design flood flows calculated by the models have been validated against a Flood Frequency Analysis of historical observed flood levels and flows which provides confidence in the design flood event flow estimates. The models are considered to provide a good representation of flood behaviour in the catchment and can be used with confidence in assessing design flood behaviour.

The study uses the current industry standard methods and guidelines in flood estimation using Australian Rainfall and Runoff 2019 and a series of DPE floodplain management guidelines to define flood behaviour in the Lower Shoalhaven River area for a range of representative design flood events.

The modelling approach, model setup, parameters, FFA, calibration and design flow estimates have been peer reviewed by an independent consultant on behalf of Council.

The models have been run for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP storms and Probable Maximum Flood (PMF) event for the existing, Projected 2050 and Projected 2100 scenarios and flood levels, depths and velocities mapped. Provisional hazard, hazard, hydraulic categories and combined hazard and hydraulic categories have also been mapped.

Assessment of the impacts of rainfall increases and sea level rise due to Climate Change was undertaken along with assessment of tidal inundation and sensitivity to various model parameters.

The report also provides guidance on the adoption of Flood Planning Levels and Emergency Response parameters for use in planning and by the NSW SES.

The 1% AEP design flood levels in the current Flood Study are lower than those derived from the previous 1990 flood study modelling that Council has adopted. This is due to the design flow estimates being lower using updated data and methods along with differences in model setup and using up-to-date survey to reflect current catchment conditions.

The study will be used by Council and various stakeholders to inform flood planning and emergency management in the Study Area. The outputs of the Flood Study will provide information on current and future flood risk which is important for increasing community awareness and for building resilience.

9.1 Next Stage in Floodplain Risk Management Process

Following Council, DPE and NSW SES review and acceptance of the flood study results, the following steps will be undertaken:

- Present to the Floodplain Risk Management Committee;
- Undertake flood modification options assessment;
- Develop Emergency Management and Planning options; and
- Prepare the Floodplain Risk Management Study and Plan.

The Floodplain Risk Management Study will provide an understanding of potential emergency response, planning and flood modification measures for managing flood risk in the catchment, benefit cost analysis and development of the Floodplain Risk Management Plan.

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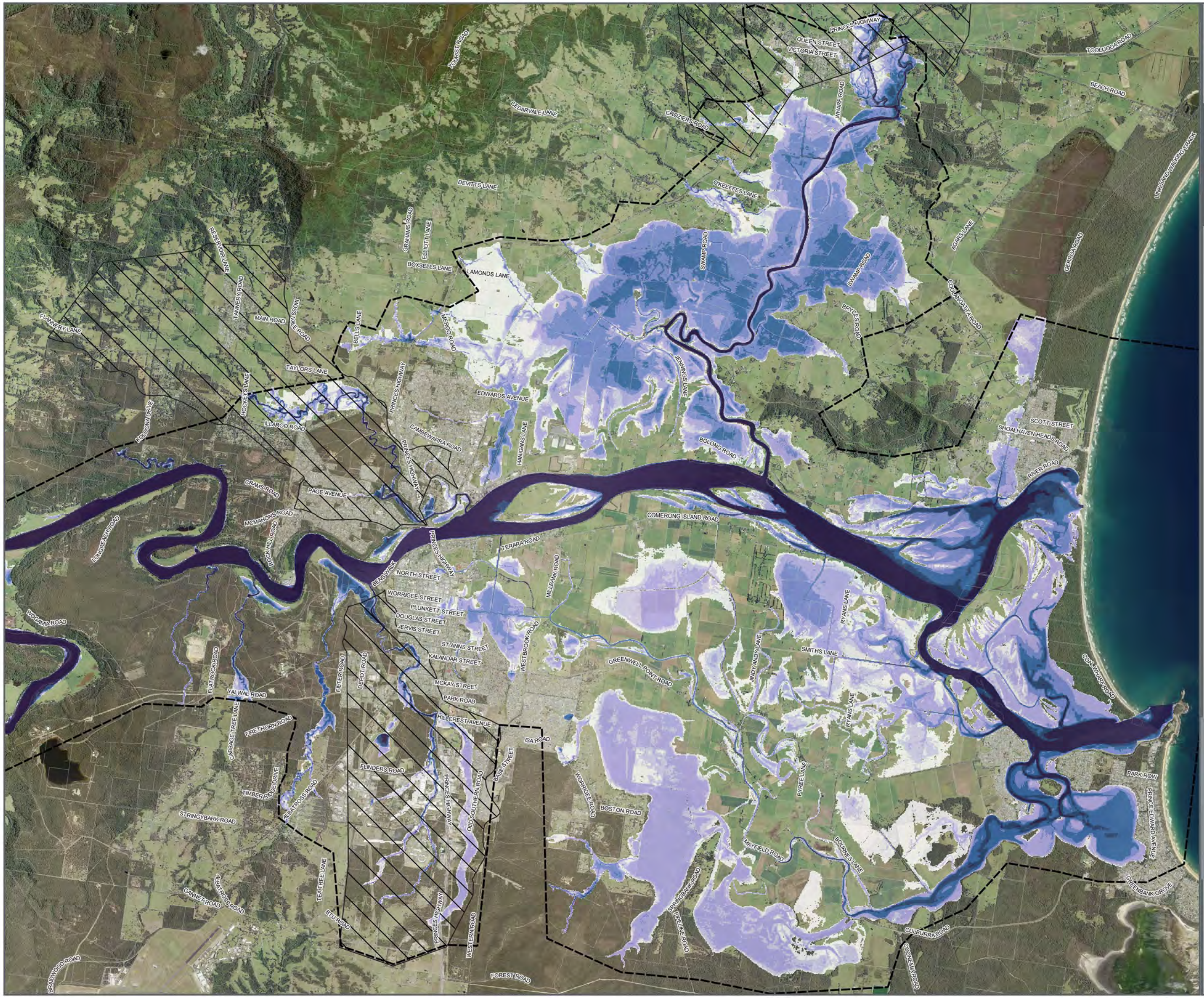
APPENDIX

A

KEY FLOOD MAPS

Figure List:



Existing 20% AEP Flood Depth

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Flood Depth (m)

- < 0.3
- 0.30 to 0.50
- 0.50 to 1.00
- 1.00 to 1.50
- 1.50 to 2.00
- 2.00 to 3.00
- > 3.00

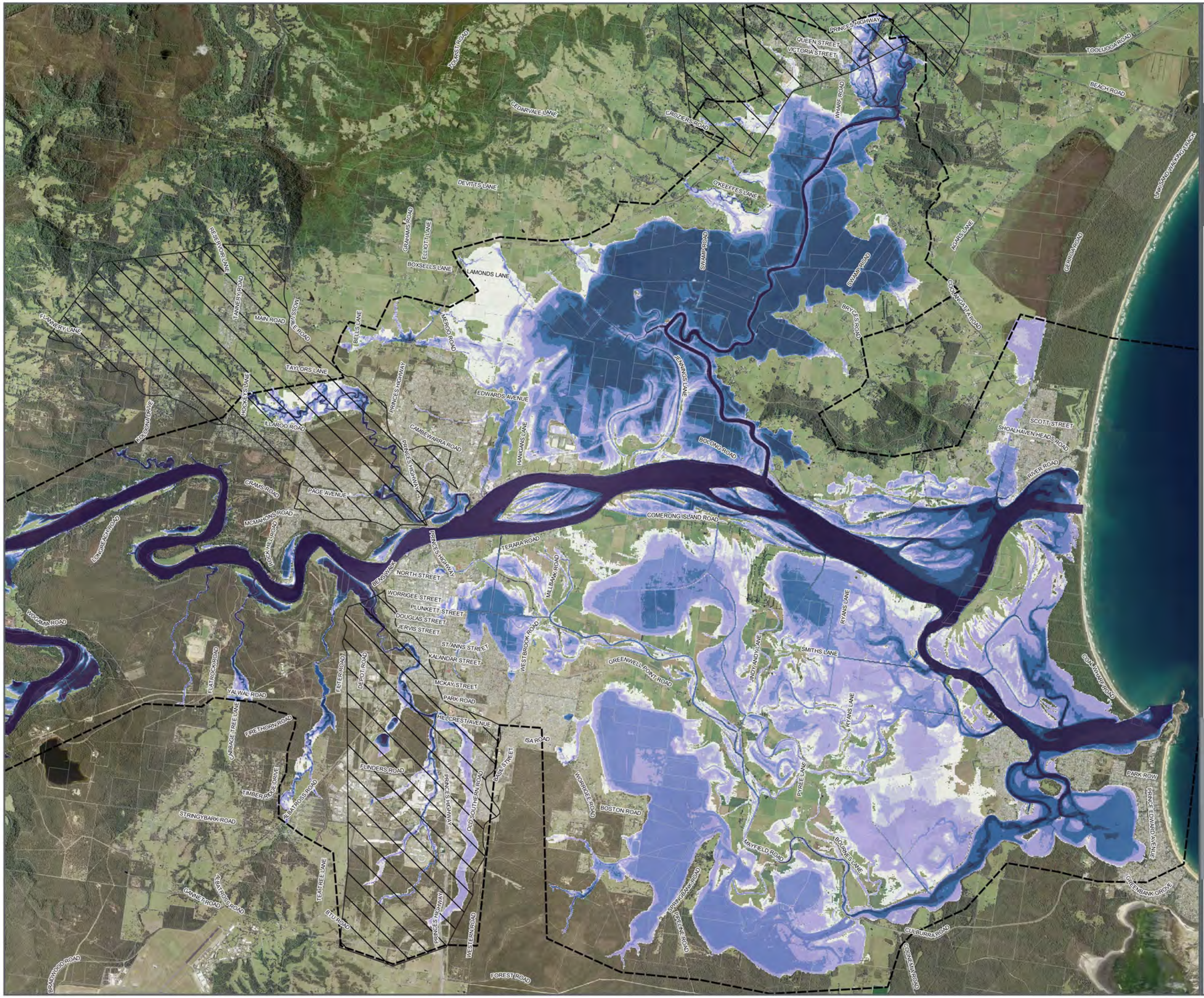
FIGURE G01

1:75,000 Scale at A3

0 800 1,600 2,400 3,200 4,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-17| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing
10% AEP Flood Depth

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Flood Depth (m)

- < 0.3
- 0.30 to 0.50
- 0.50 to 1.00
- 1.00 to 1.50
- 1.50 to 2.00
- 2.00 to 3.00
- > 3.00

FIGURE G02

1:75,000 Scale at A3

0 800 1,600 2,400 3,200 4,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
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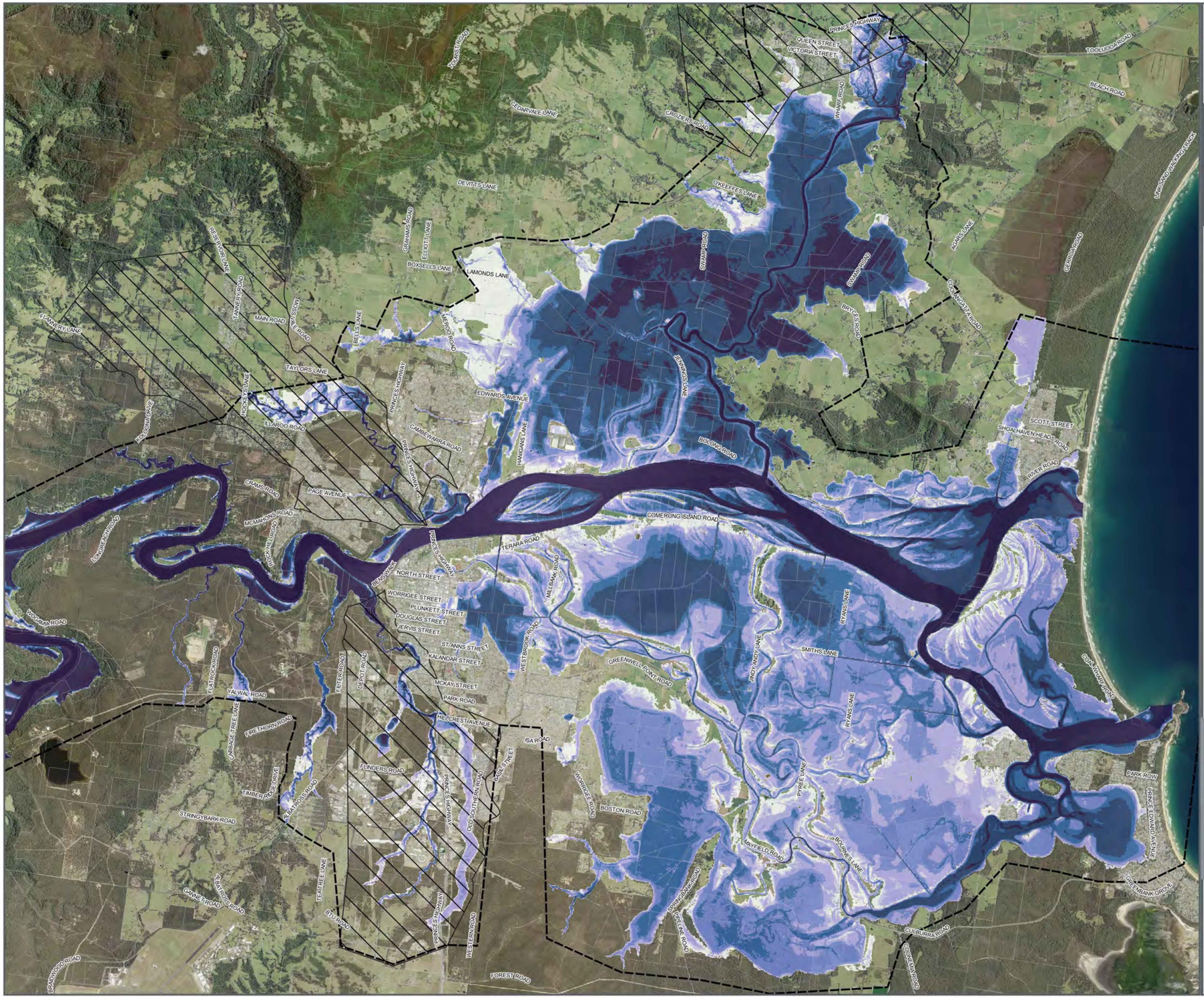
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing 5% AEP Flood Depth

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Flood Depth (m)

- < 0.3
- 0.30 to 0.50
- 0.50 to 1.00
- 1.00 to 1.50
- 1.50 to 2.00
- 2.00 to 3.00
- > 3.00

FIGURE G03

1:75,000 Scale at A3

0 800 1,600 2,400 3,200 4,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
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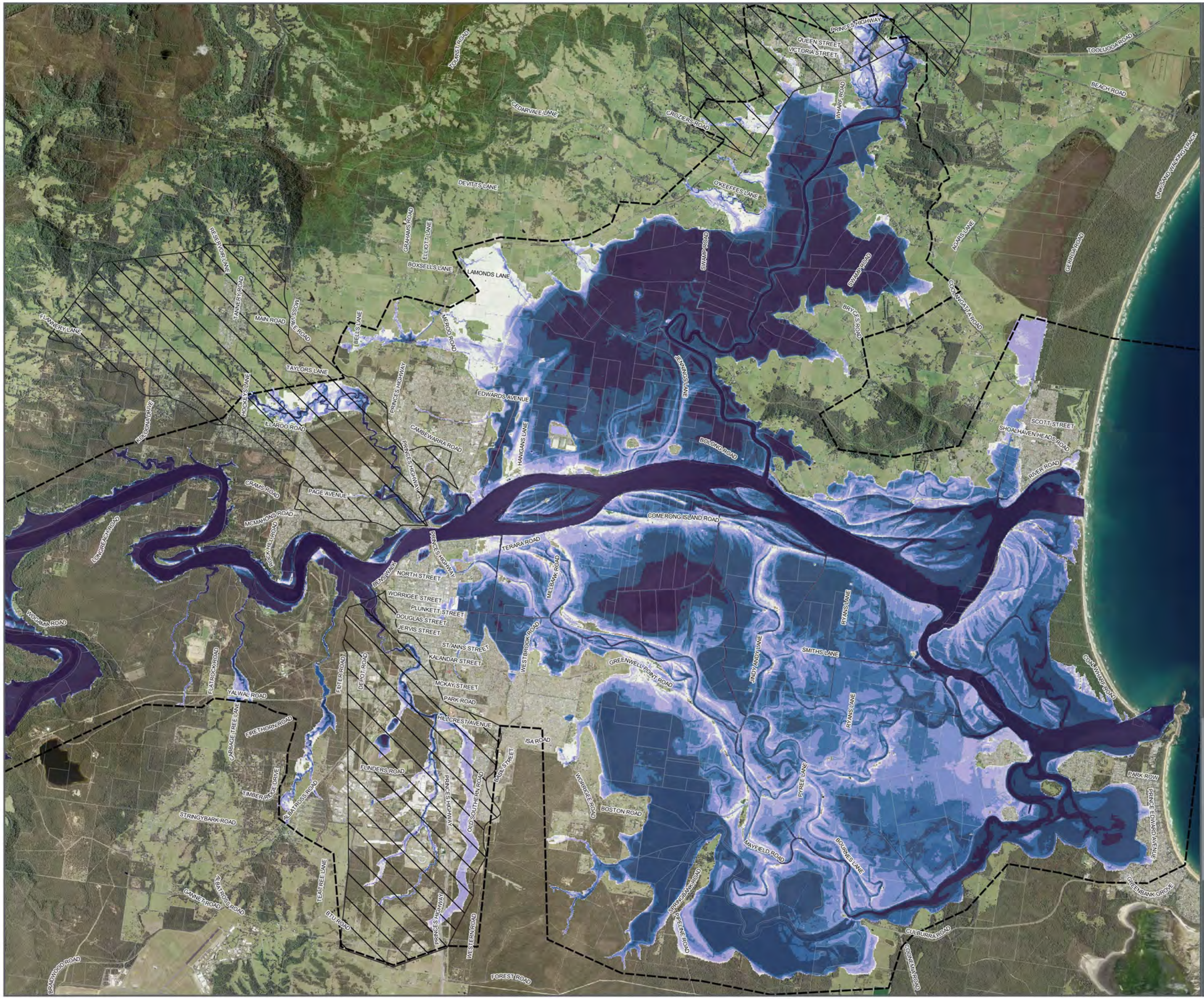
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing 2% AEP Flood Depth

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Flood Depth (m)

- < 0.3
- 0.30 to 0.50
- 0.50 to 1.00
- 1.00 to 1.50
- 1.50 to 2.00
- 2.00 to 3.00
- > 3.00

FIGURE G04

1:75,000 Scale at A3

0 800 1,600 2,400 3,200 4,000 m

Cardno

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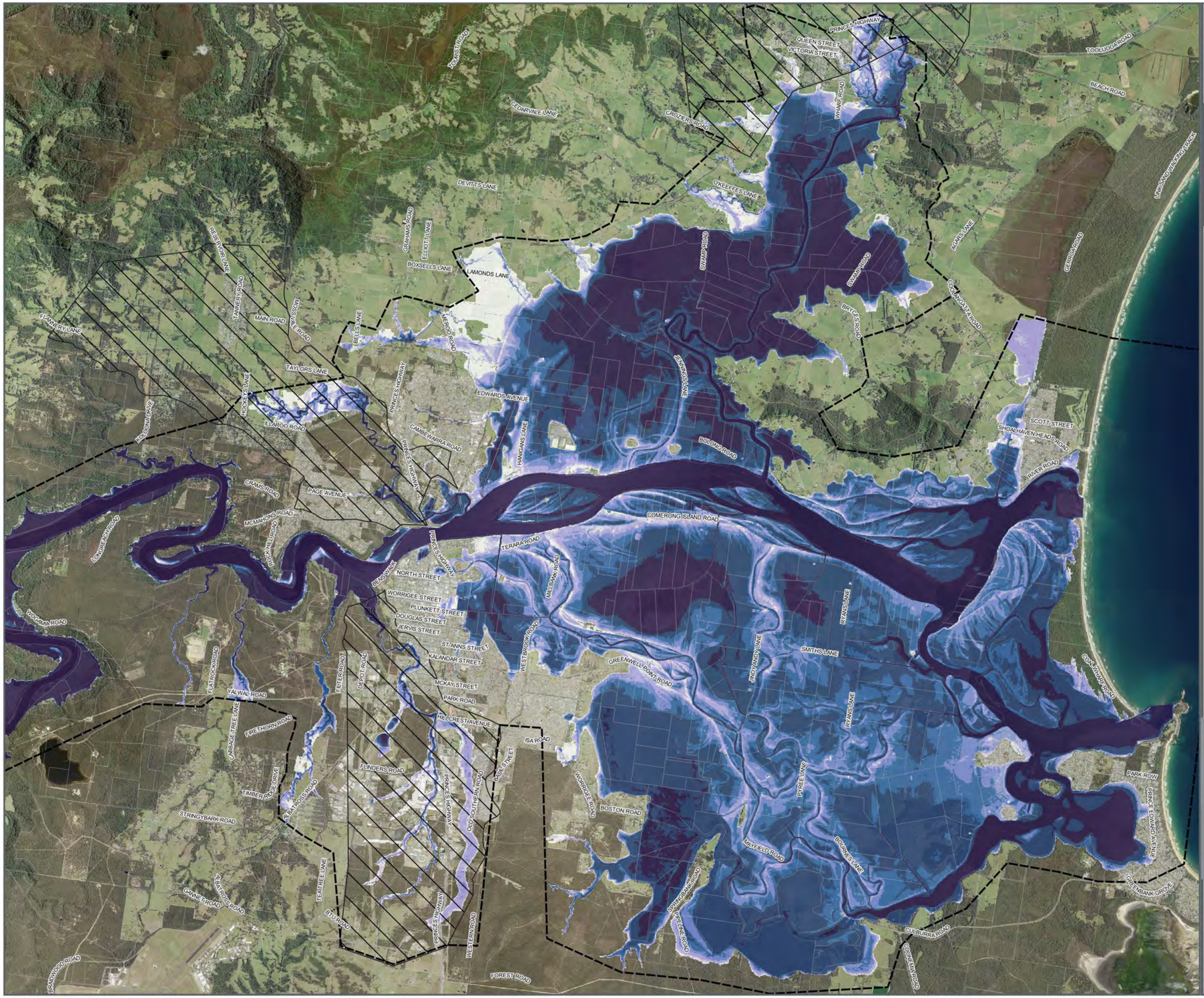

Existing 1% AEP Flood Depth

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Flood Depth (m)

- < 0.3
- 0.30 to 0.50
- 0.50 to 1.00
- 1.00 to 1.50
- 1.50 to 2.00
- 2.00 to 3.00
- > 3.00

FIGURE G05

1:75,000 Scale at A3

0 800 1,600 2,400 3,200 4,000 m

Cardno

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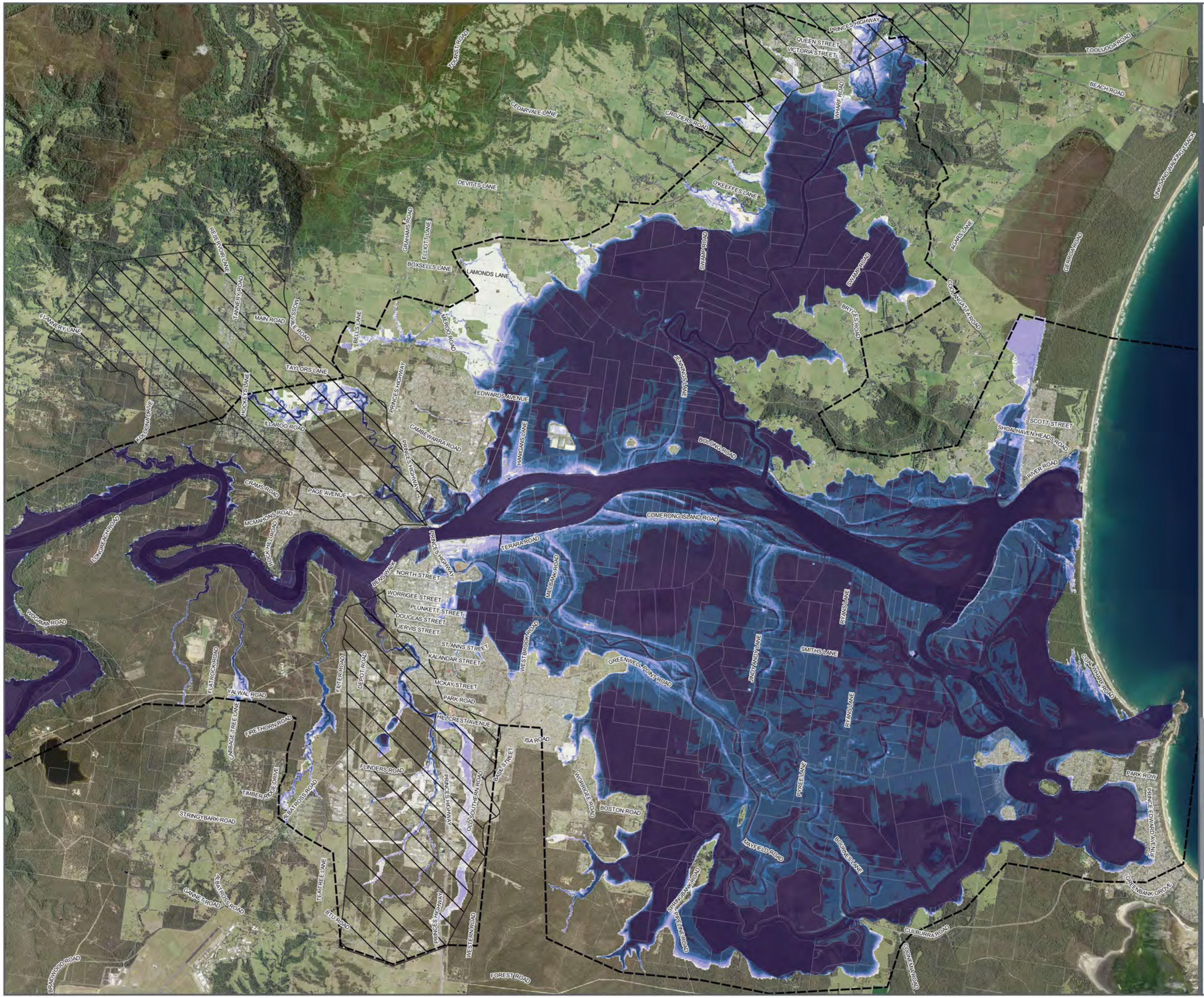

Existing 0.2% AEP Flood Depth

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Flood Depth (m)

- < 0.3
- 0.30 to 0.50
- 0.50 to 1.00
- 1.00 to 1.50
- 1.50 to 2.00
- 2.00 to 3.00
- > 3.00

FIGURE G06

1:75,000 Scale at A3

0 800 1,600 2,400 3,200 4,000 m

Cardno

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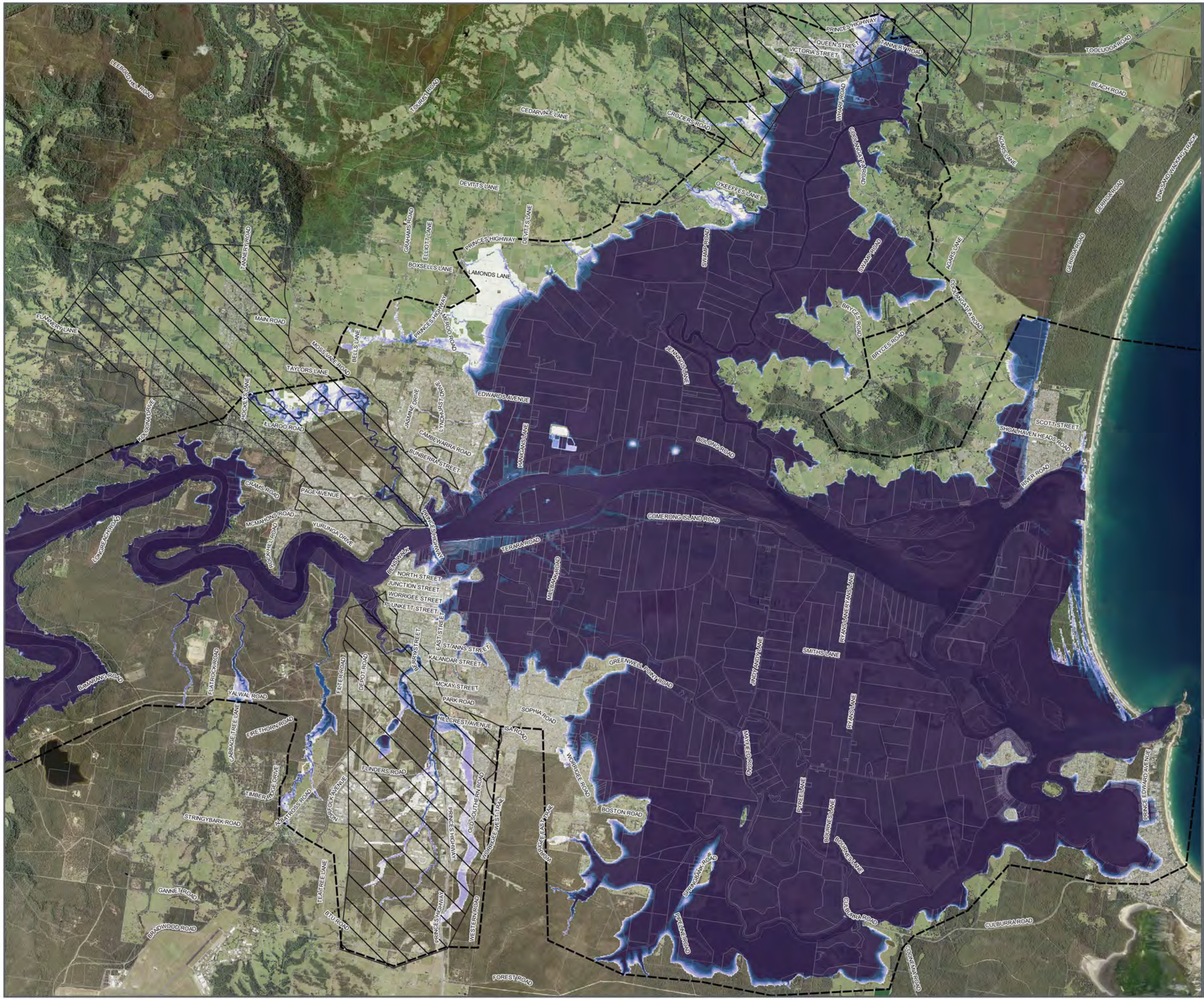

Existing PMF Flood Depth

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Flood Depth (m)

- < 0.3
- 0.30 to 0.50
- 0.50 to 1.00
- 1.00 to 1.50
- 1.50 to 2.00
- 2.00 to 3.00
- > 3.00

FIGURE G07

1:75,000 Scale at A3

0 800 1,600 2,400 3,200 4,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
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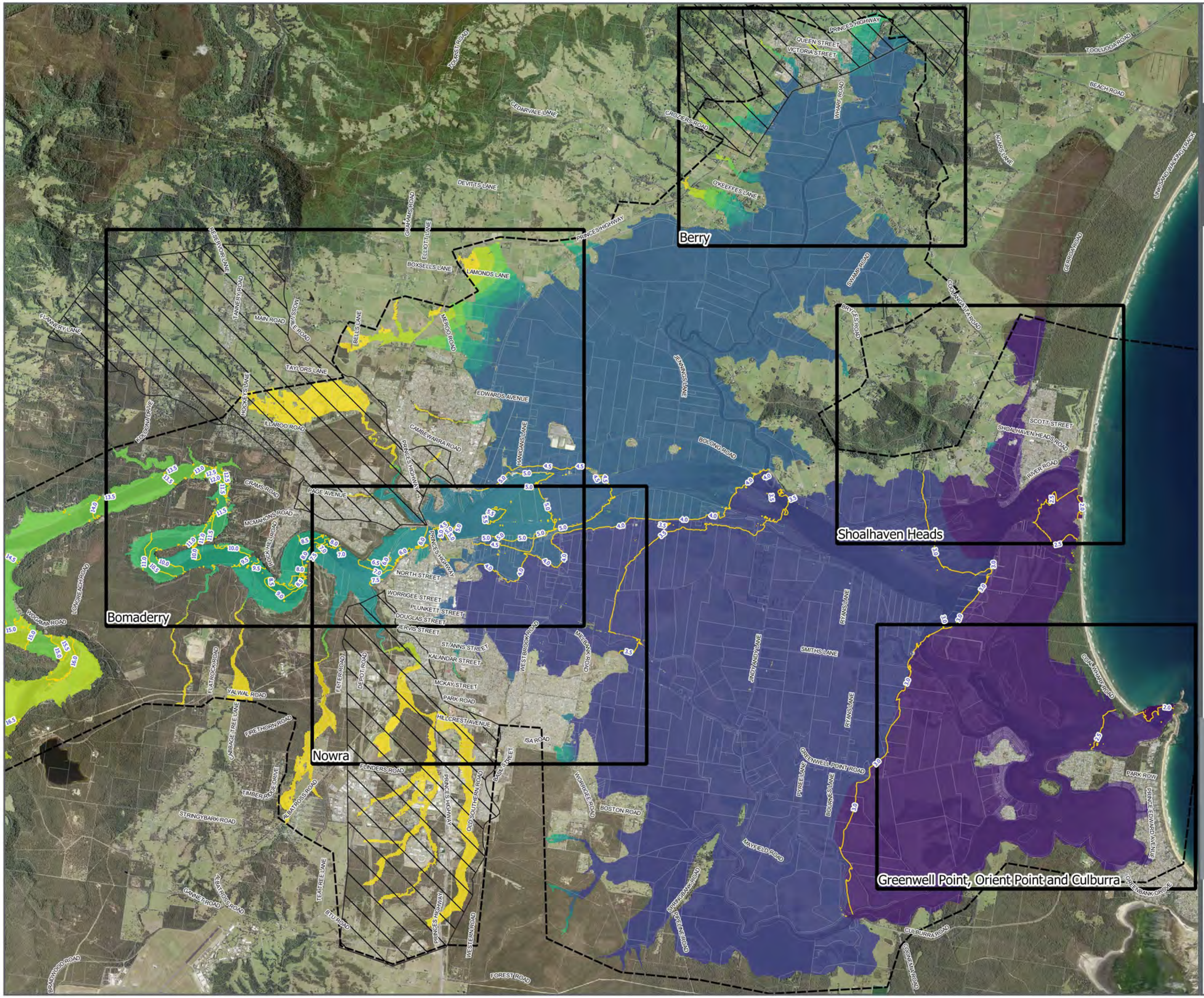


Existing 1% AEP Water Level Overview

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Water Level Contours (0.5m)

Water Level (m AHD)

- < 2.00
- 2.00 to 3.00
- 3.00 to 4.00
- 4.00 to 5.00
- 5.00 to 6.00
- 6.00 to 8.00
- 8.00 to 10.00
- 10.00 to 12.00
- 12.00 to 15.00
- 15.00 to 20.00
- > 20.00

FIGURE G12

1:75,000 Scale at A3

0 800 1,600 2,400 3,200 4,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-17 | Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz

Existing 1% AEP Water Level Nowra

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Water Level Contours (0.5m)

Water Level (m AHD)

- < 2.00
- 2.00 to 3.00
- 3.00 to 4.00
- 4.00 to 5.00
- 5.00 to 6.00
- 6.00 to 8.00
- 8.00 to 10.00
- 10.00 to 12.00
- 12.00 to 15.00
- 15.00 to 20.00
- > 20.00

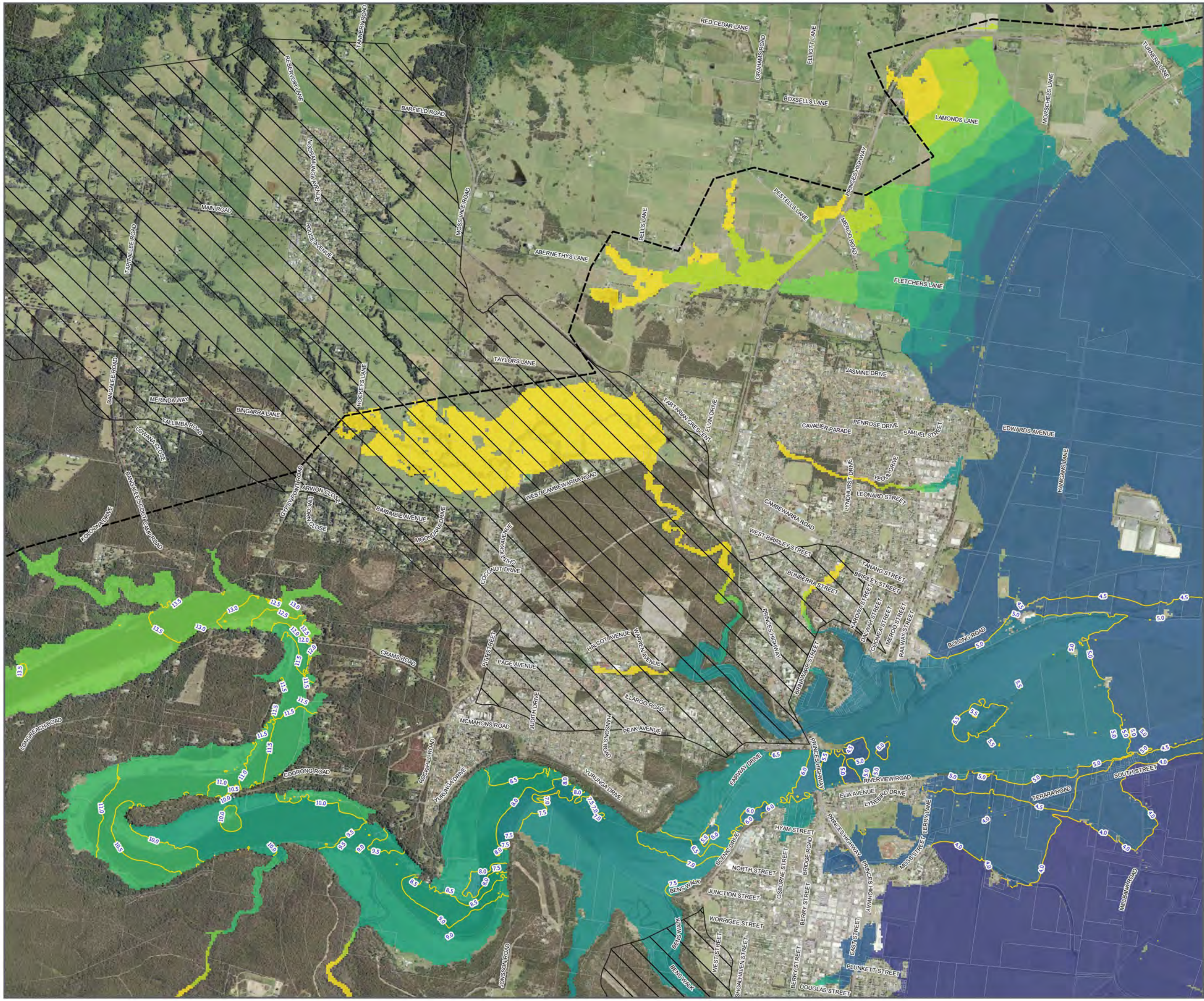
FIGURE G12.1

1:21,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing 1% AEP Water Level Bomaderry

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Water Level Contours (0.5m)

Water Level (m AHD)

- < 2.00
- 2.00 to 3.00
- 3.00 to 4.00
- 4.00 to 5.00
- 5.00 to 6.00
- 6.00 to 8.00
- 8.00 to 10.00
- 10.00 to 12.00
- 12.00 to 15.00
- 15.00 to 20.00
- > 20.00

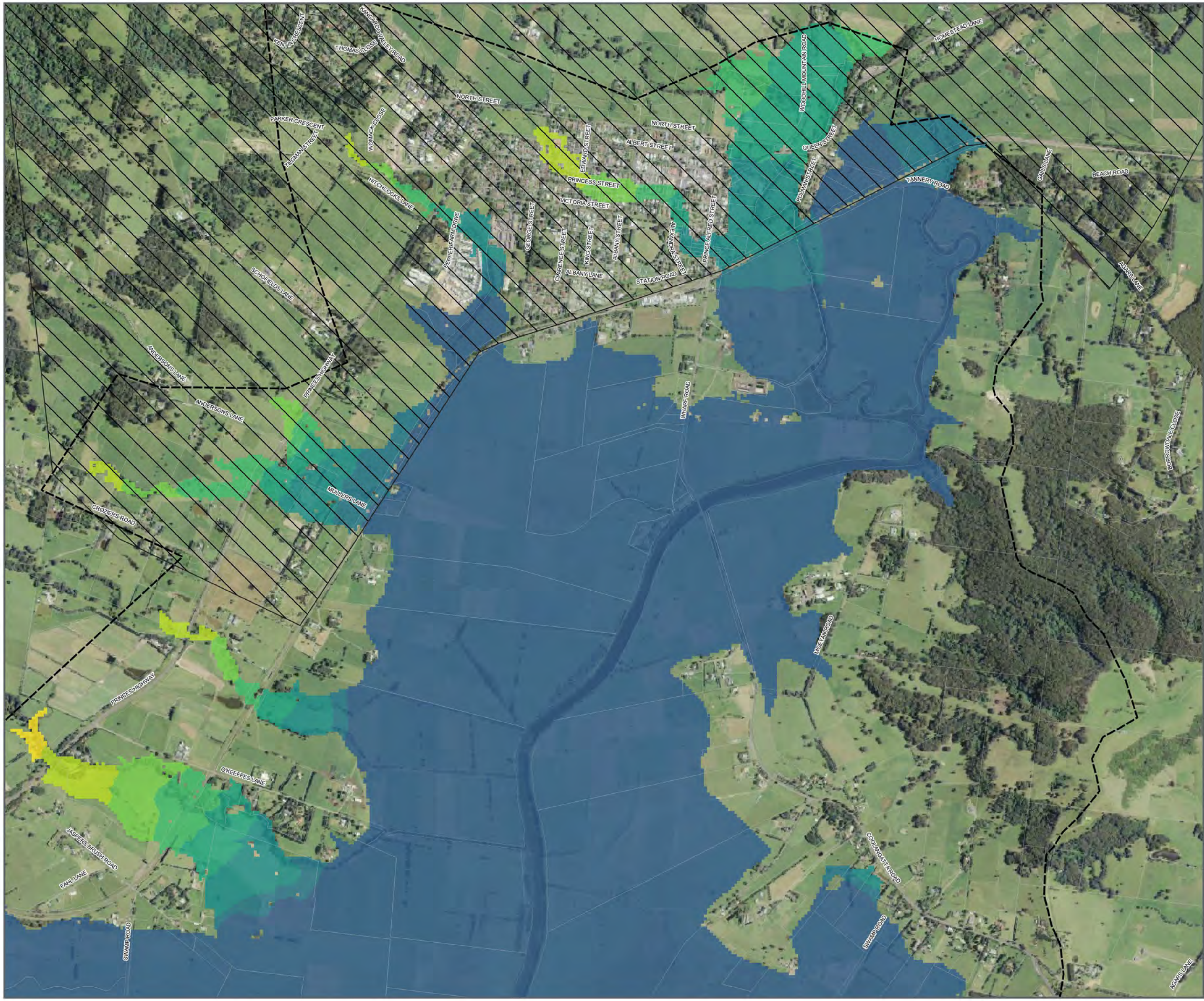
FIGURE G12.2

1:30,000 Scale at A3

0 300 600 900 1,200 1,500 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing 1% AEP Water Level Berry

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Water Level Contours (0.5m)

Water Level (m AHD)

- < 2.00
- 2.00 to 3.00
- 3.00 to 4.00
- 4.00 to 5.00
- 5.00 to 6.00
- 6.00 to 8.00
- 8.00 to 10.00
- 10.00 to 12.00
- 12.00 to 15.00
- 15.00 to 20.00
- > 20.00

FIGURE G12.3

1:18,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
Coordinate System: MGA Zone 56
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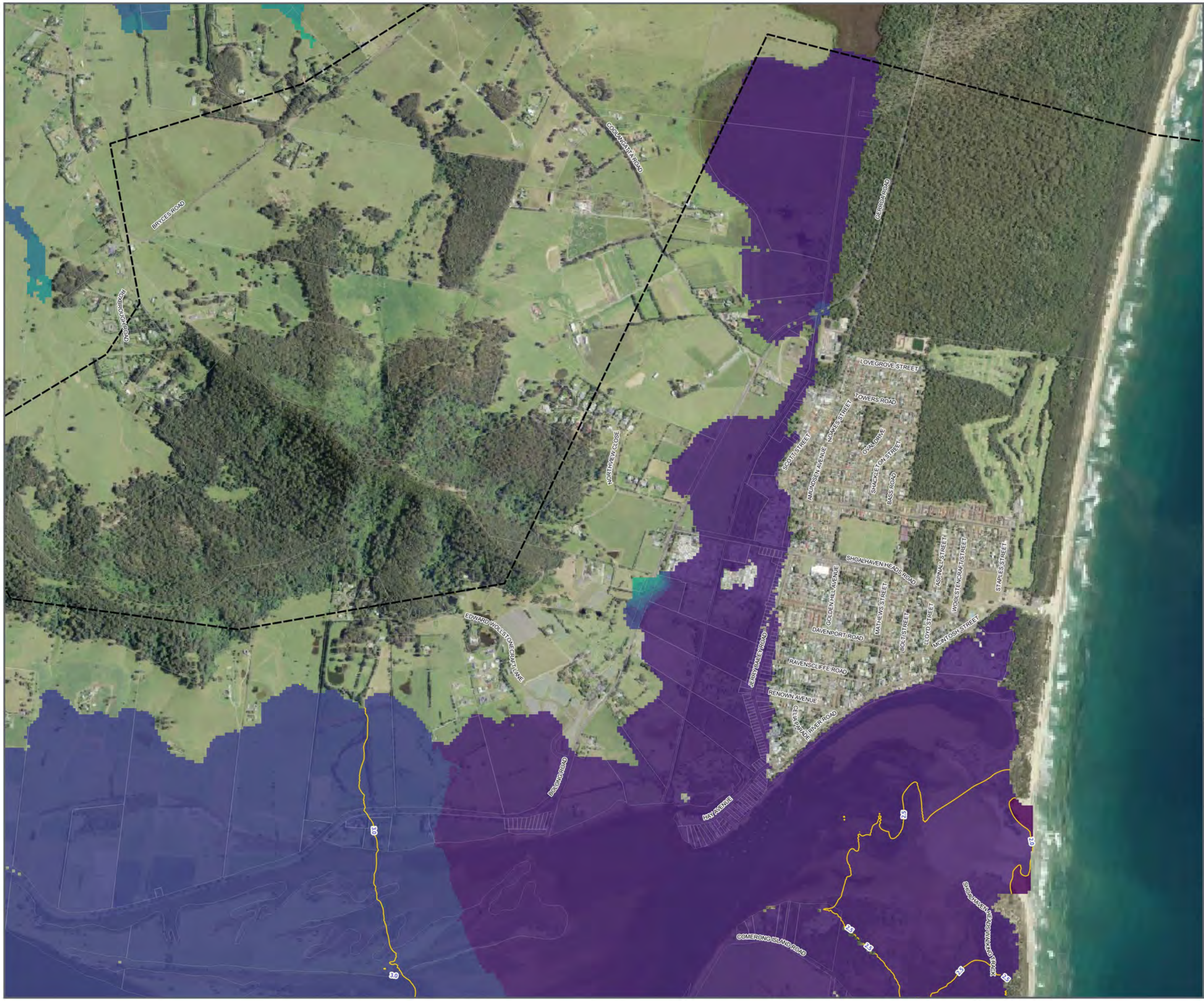

Existing 1% AEP Water Level Shoalhaven Heads

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Water Level Contours (0.5m)

Water Level (m AHD)

- < 2.00
- 2.00 to 3.00
- 3.00 to 4.00
- 4.00 to 5.00
- 5.00 to 6.00
- 6.00 to 8.00
- 8.00 to 10.00
- 10.00 to 12.00
- 12.00 to 15.00
- 15.00 to 20.00
- > 20.00

FIGURE G12.4

1:18,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
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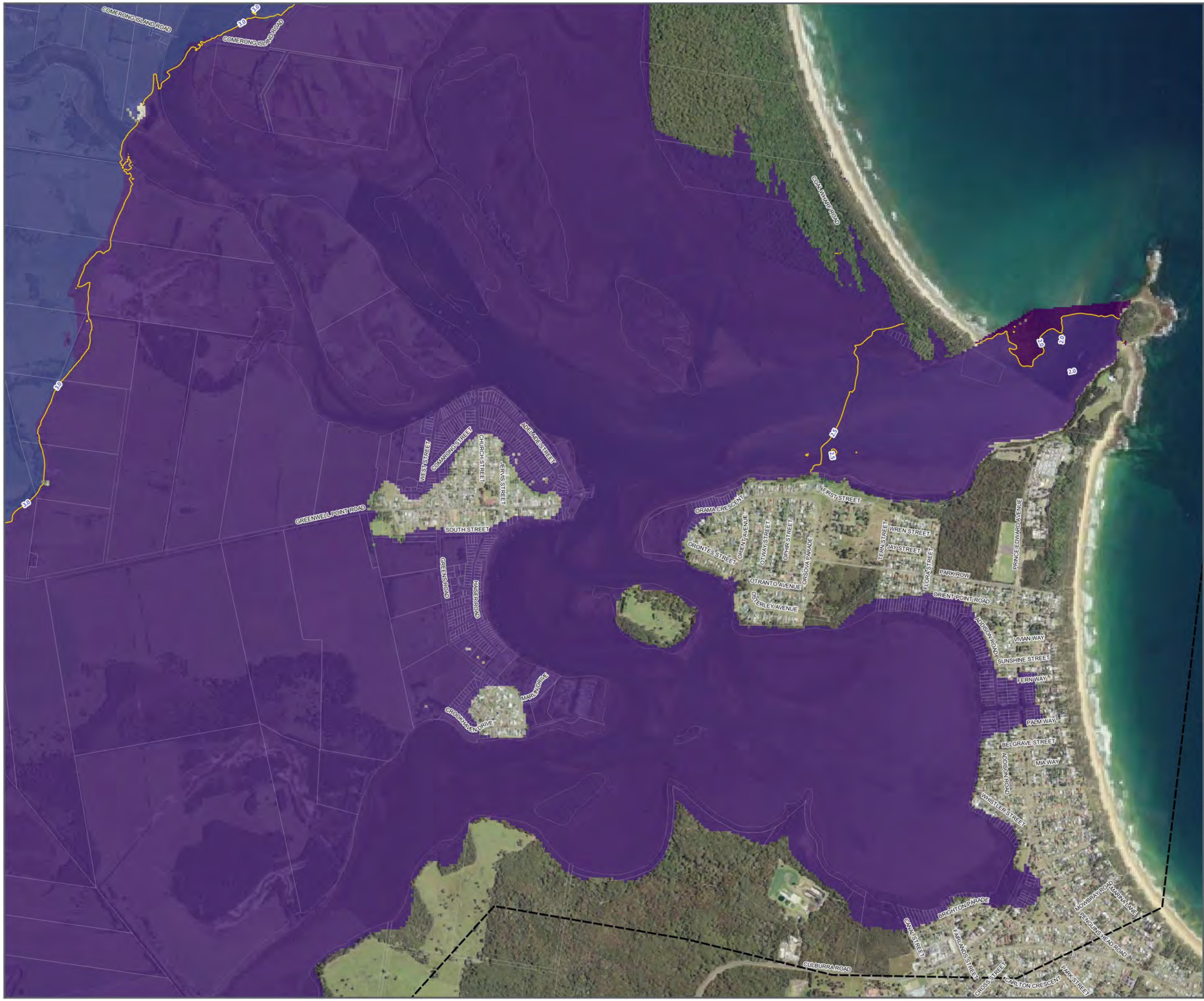

Existing 1% AEP Water Level Greenwell Point, Orient Point and Culburra Beach

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Water Level Contours (0.5m)

Water Level (m AHD)

- < 2.00
- 2.00 to 3.00
- 3.00 to 4.00
- 4.00 to 5.00
- 5.00 to 6.00
- 6.00 to 8.00
- 8.00 to 10.00
- 10.00 to 12.00
- 12.00 to 15.00
- 15.00 to 20.00
- > 20.00

FIGURE G12.5

1:20,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
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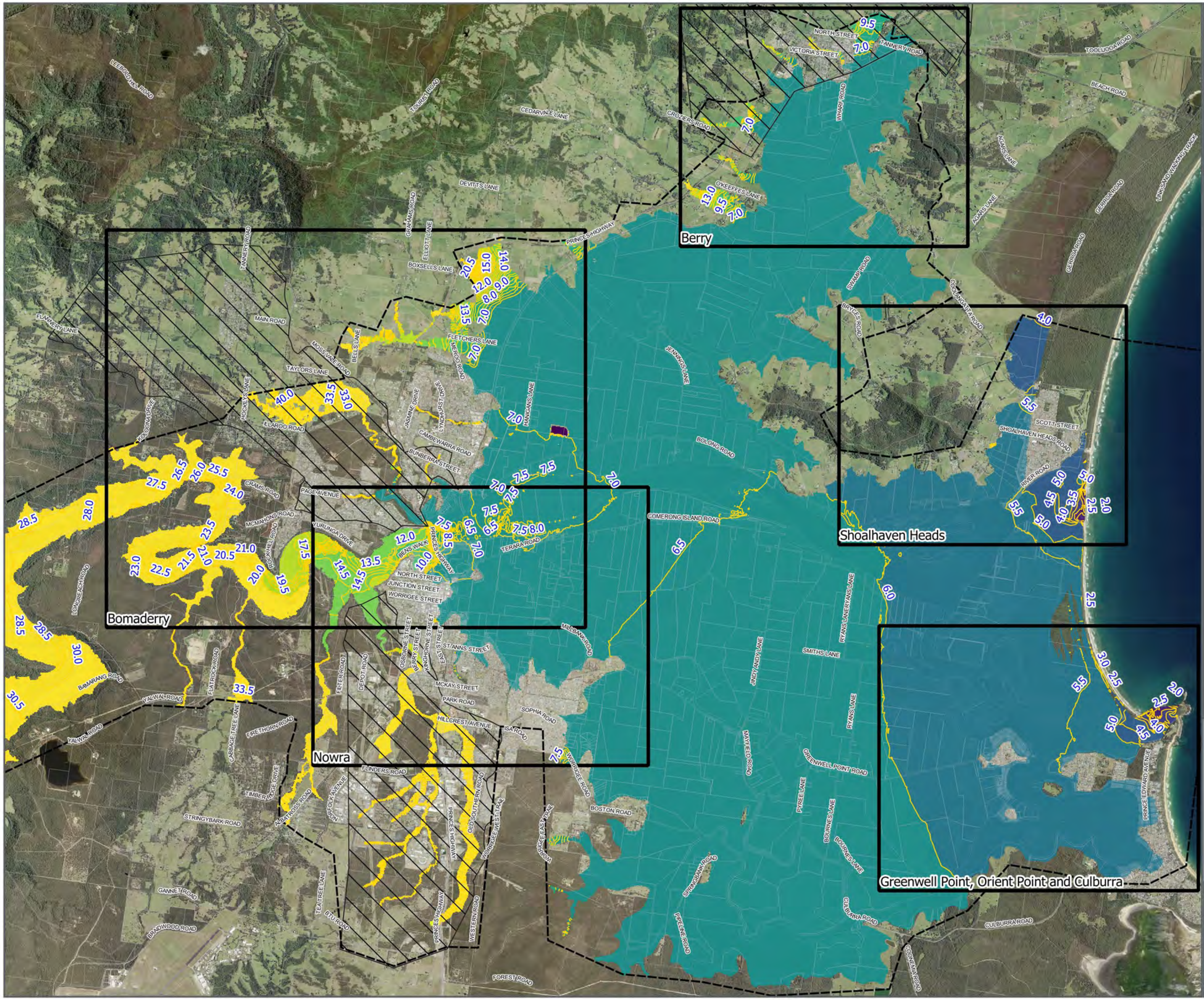
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing PMF Water Level Overview

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Water Level Contours (0.5m)

Water Level (m AHD)

- < 2.00
- 2.00 to 3.00
- 3.00 to 4.00
- 4.00 to 5.00
- 5.00 to 6.00
- 6.00 to 8.00
- 8.00 to 10.00
- 10.00 to 12.00
- 12.00 to 15.00
- 15.00 to 20.00
- > 20.00

FIGURE G14

1:75,000 Scale at A3

0 800 1,600 2,400 3,200 4,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
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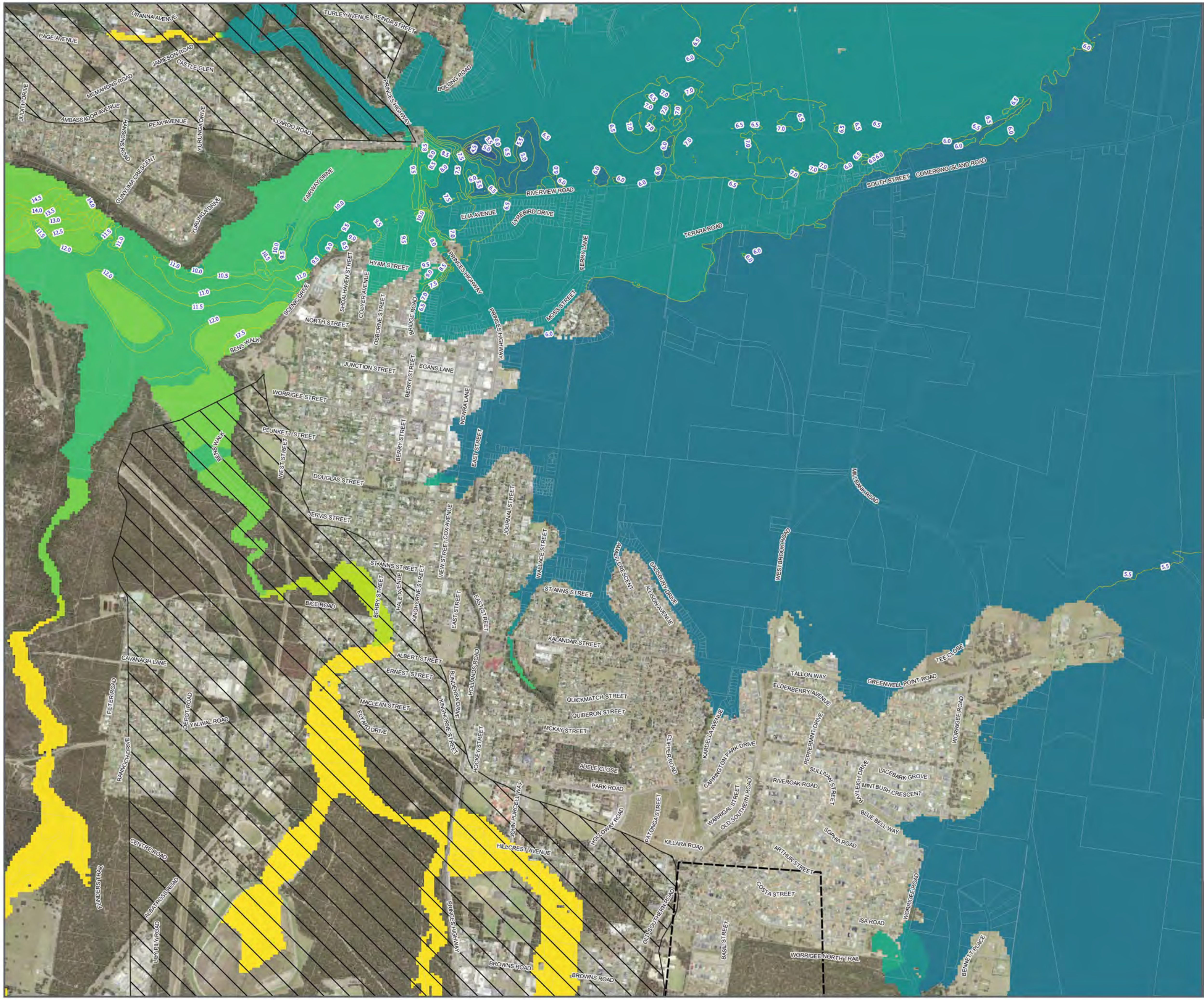

Existing PMF Water Level Nowra

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Water Level Contours (0.5m)

Water Level (m AHD)

- < 2.00
- 2.00 to 3.00
- 3.00 to 4.00
- 4.00 to 5.00
- 5.00 to 6.00
- 6.00 to 8.00
- 8.00 to 10.00
- 10.00 to 12.00
- 12.00 to 15.00
- 15.00 to 20.00
- > 20.00

FIGURE G14.1

1:21,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
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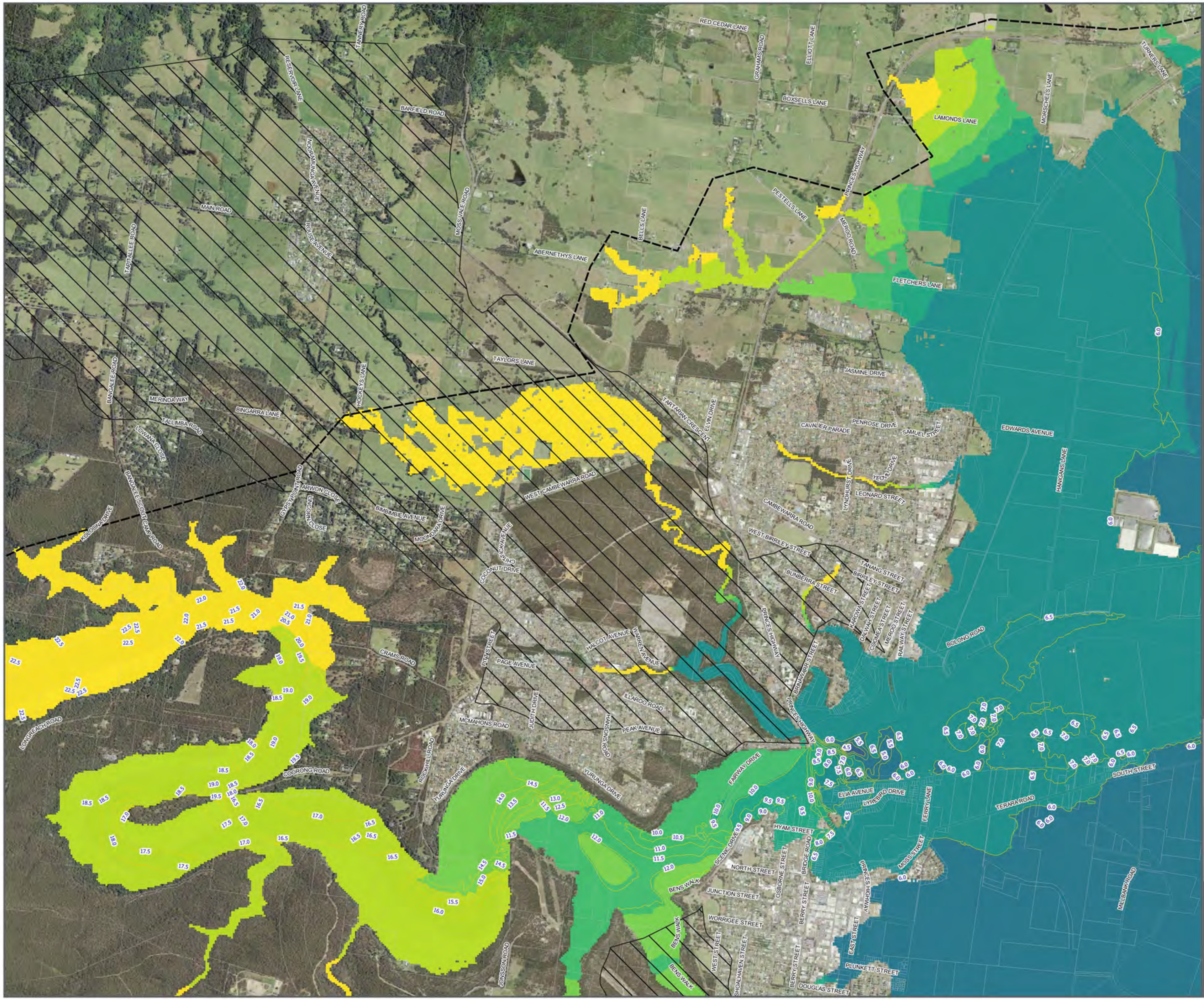
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing PMF Water Level Bomaderry

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Water Level Contours (0.5m)

Water Level (m AHD)

- < 2.00
- 2.00 to 3.00
- 3.00 to 4.00
- 4.00 to 5.00
- 5.00 to 6.00
- 6.00 to 8.00
- 8.00 to 10.00
- 10.00 to 12.00
- 12.00 to 15.00
- 15.00 to 20.00
- > 20.00

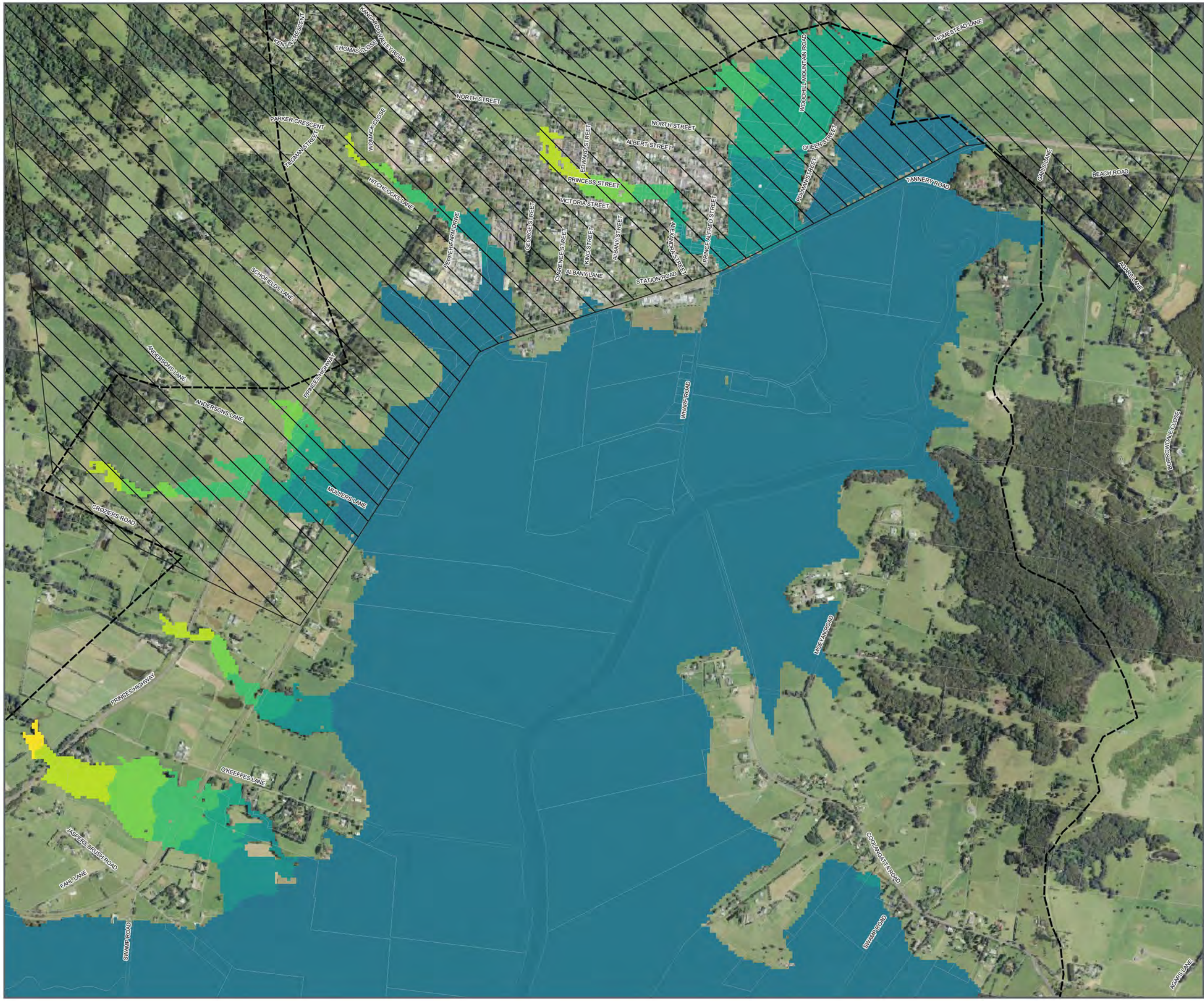
FIGURE G14.2

1:30,000 Scale at A3

0 300 600 900 1,200 1,500 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing PMF Water Level Berry

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Water Level Contours (0.5m)

Water Level (m AHD)

- < 2.00
- 2.00 to 3.00
- 3.00 to 4.00
- 4.00 to 5.00
- 5.00 to 6.00
- 6.00 to 8.00
- 8.00 to 10.00
- 10.00 to 12.00
- 12.00 to 15.00
- 15.00 to 20.00
- > 20.00

FIGURE G14.3

1:18,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz

Existing PMF Water Level Shoalhaven Heads

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Water Level Contours (0.5m)

Water Level (m AHD)

- < 2.00
- 2.00 to 3.00
- 3.00 to 4.00
- 4.00 to 5.00
- 5.00 to 6.00
- 6.00 to 8.00
- 8.00 to 10.00
- 10.00 to 12.00
- 12.00 to 15.00
- 15.00 to 20.00
- > 20.00

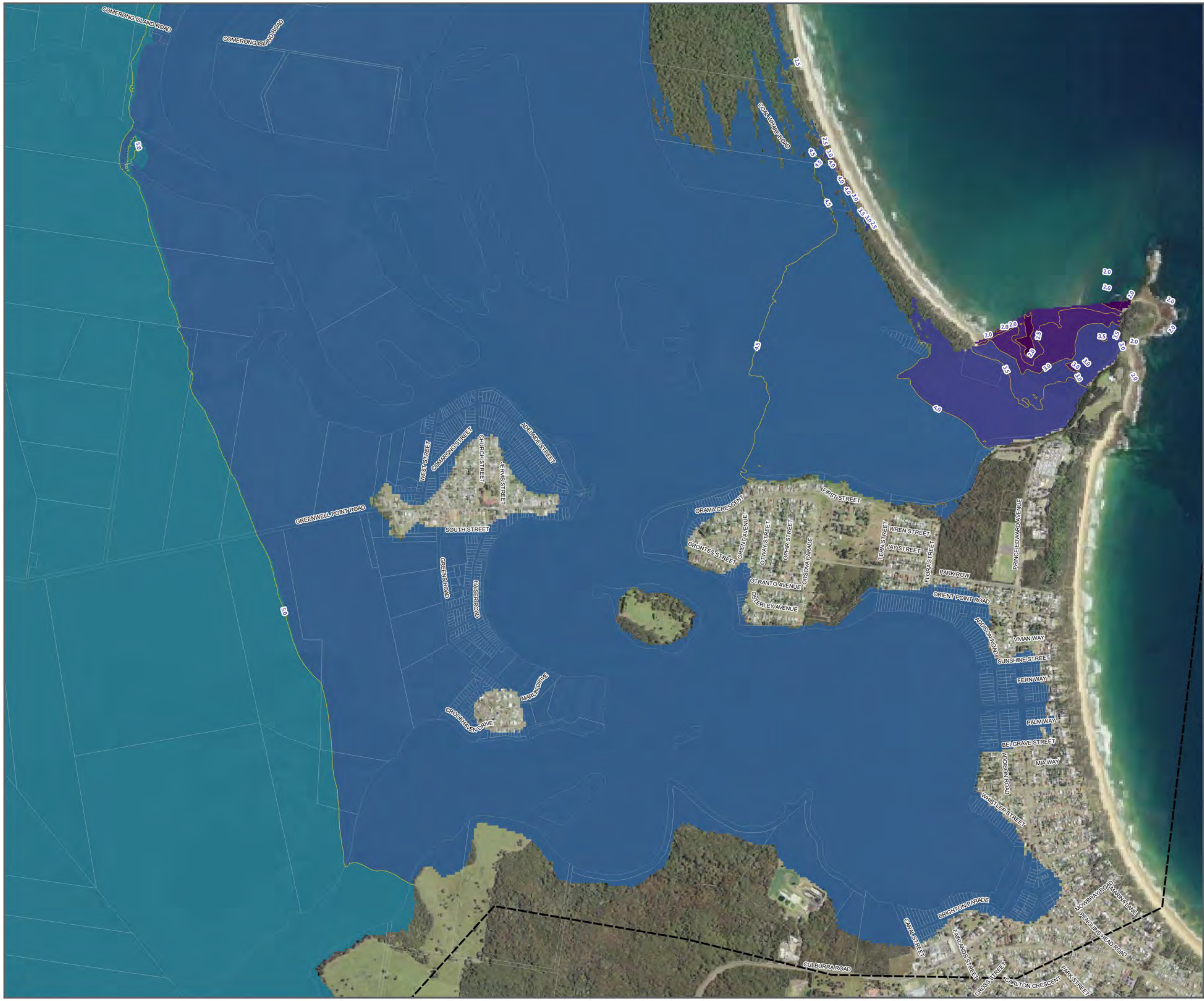
FIGURE G14.4

1:18,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing PMF Water Level Greenwell Point, Orient Point and Culburra Beach

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Water Level Contours (0.5m)

Water Level (m AHD)

- < 2.00
- 2.00 to 3.00
- 3.00 to 4.00
- 4.00 to 5.00
- 5.00 to 6.00
- 6.00 to 8.00
- 8.00 to 10.00
- 10.00 to 12.00
- 12.00 to 15.00
- 15.00 to 20.00
- > 20.00

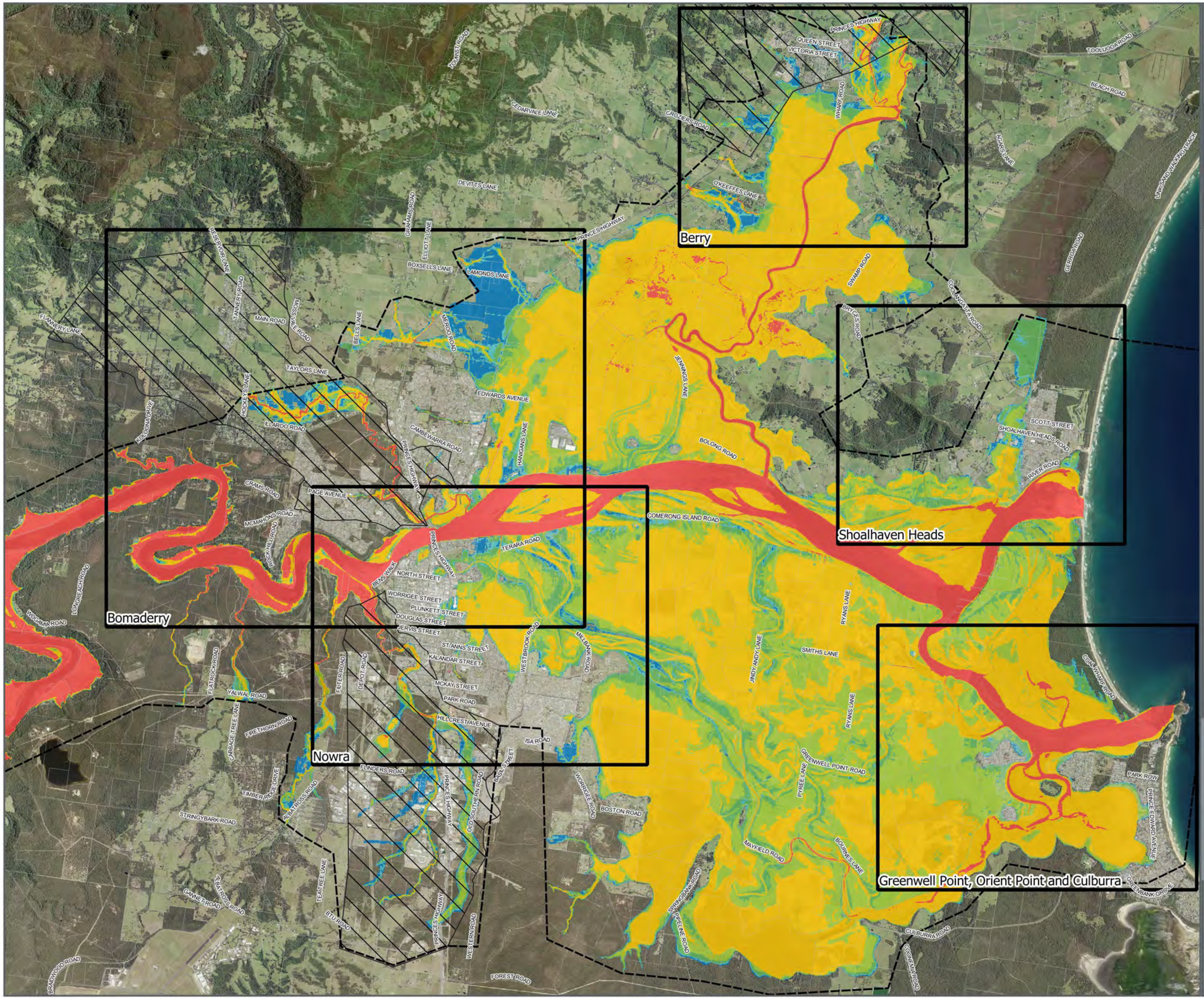
FIGURE G14.5

1:20,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing 1% AEP Hazard Overview

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Hazard (AEMI H1-H6)

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

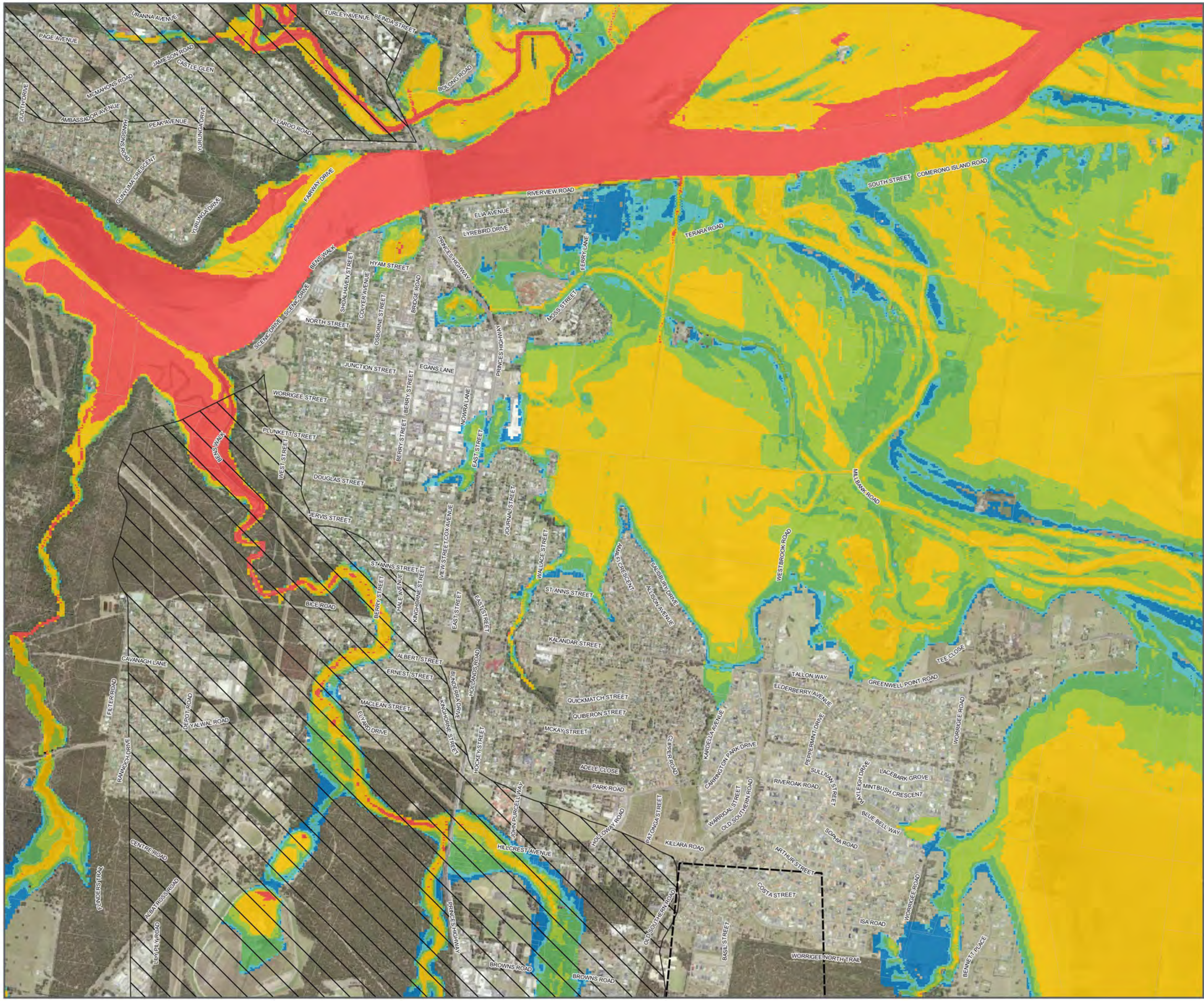
FIGURE G22

1:75,000 Scale at A3

0 800 1,600 2,400 3,200 4,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-17| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing 1% AEP Hazard Nowra

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Hazard (AEMI H1-H6)

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

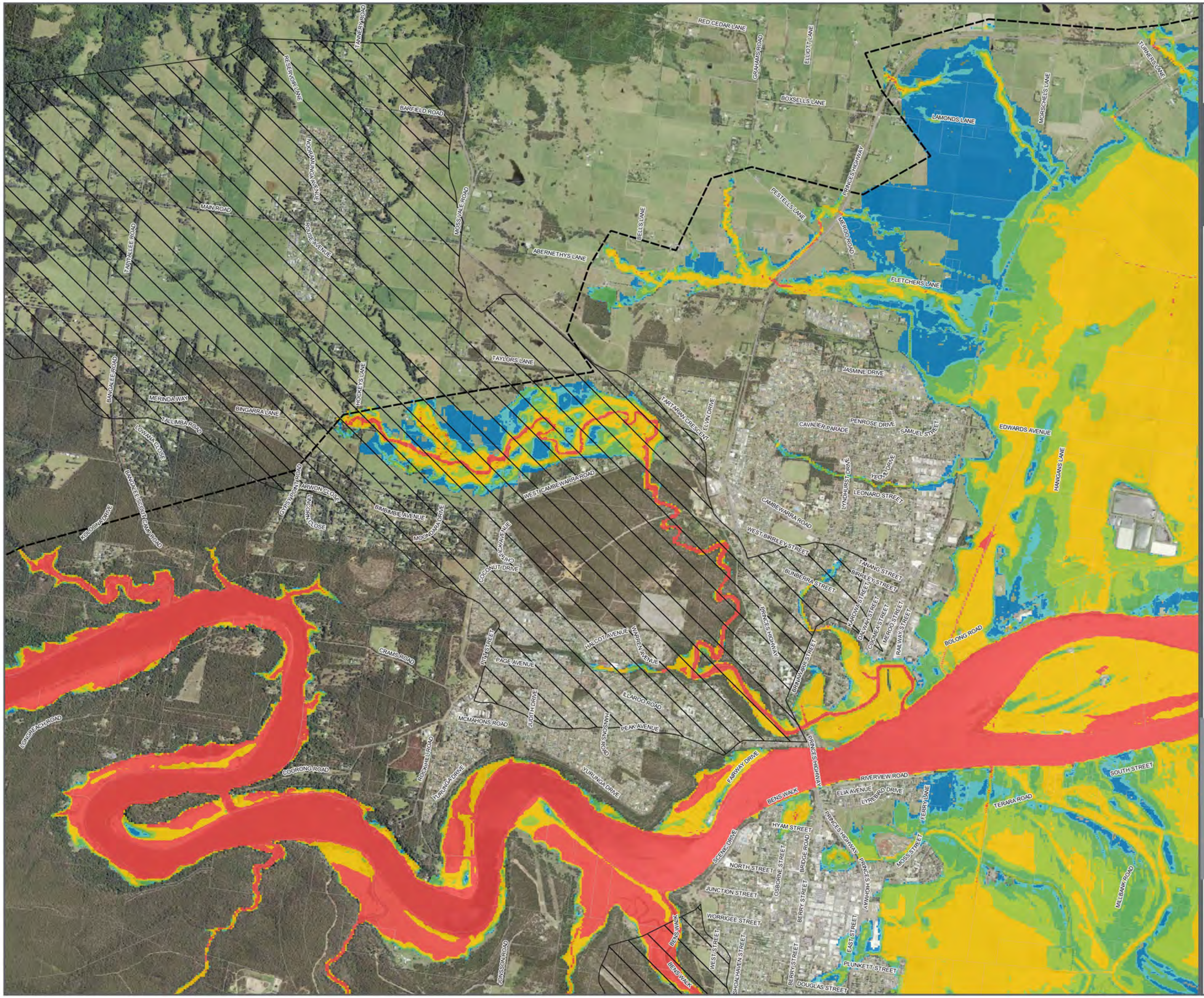
FIGURE G22.1

1:21,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing 1% AEP Hazard Bomaderry

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Hazard (AEMI H1-H6)

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

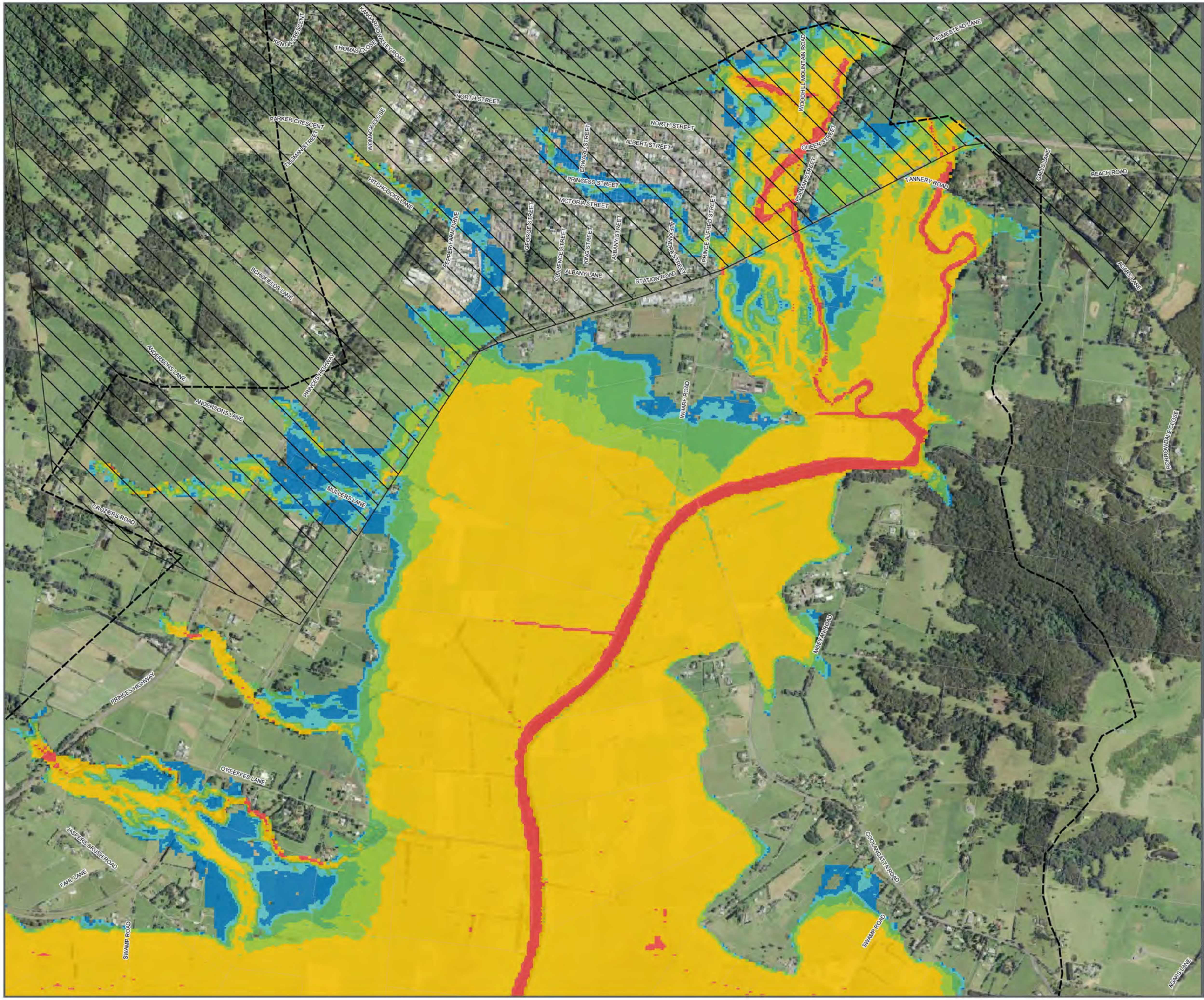
FIGURE G22.2

1:30,000 Scale at A3

0 300 600 900 1,200 1,500 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing 1% AEP Hazard Berry

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Hazard (AEMI H1-H6)

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

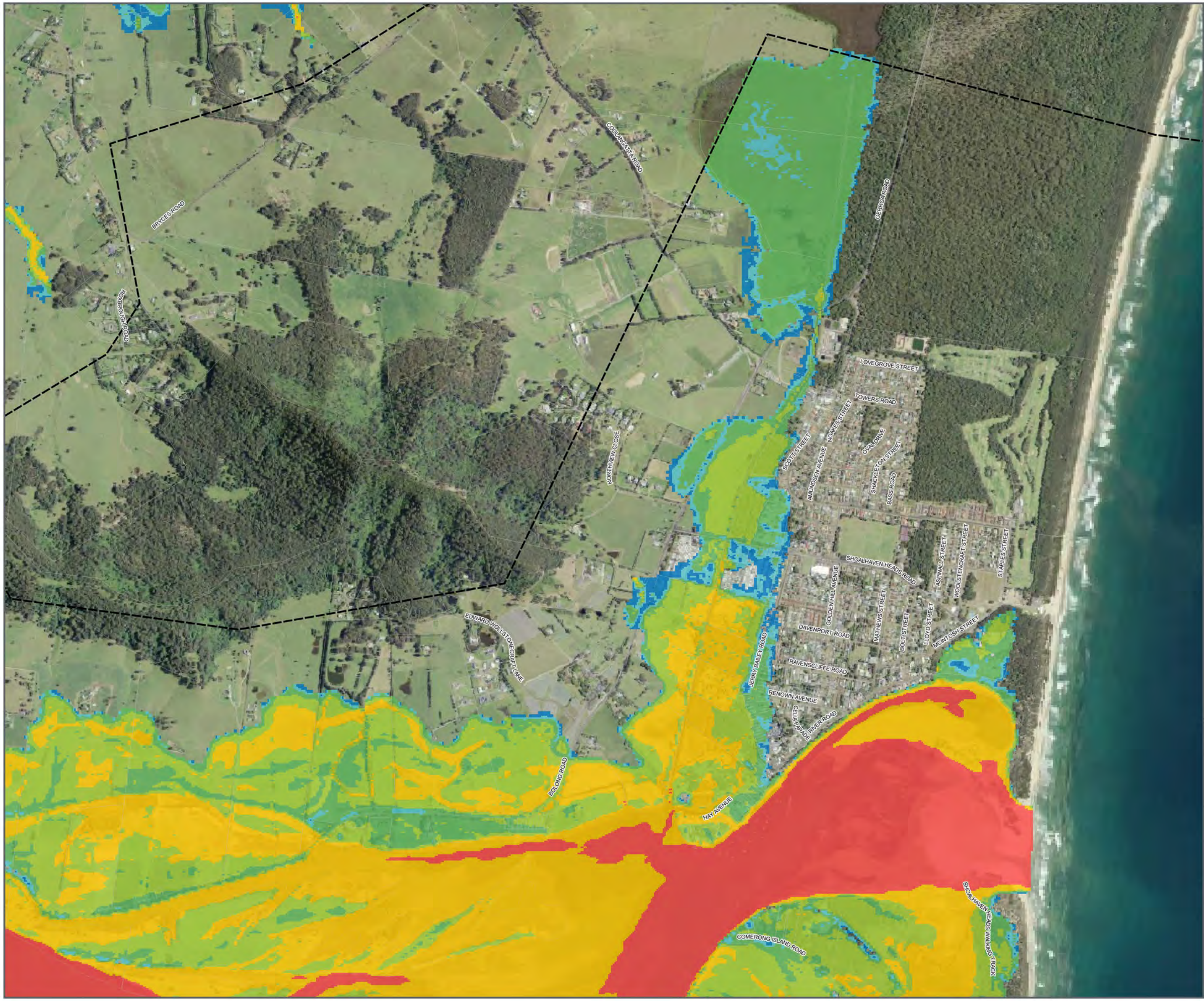
FIGURE G22.3

1:18,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing 1% AEP Hazard Shoalhaven Heads

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Hazard (AEMI H1-H6)

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

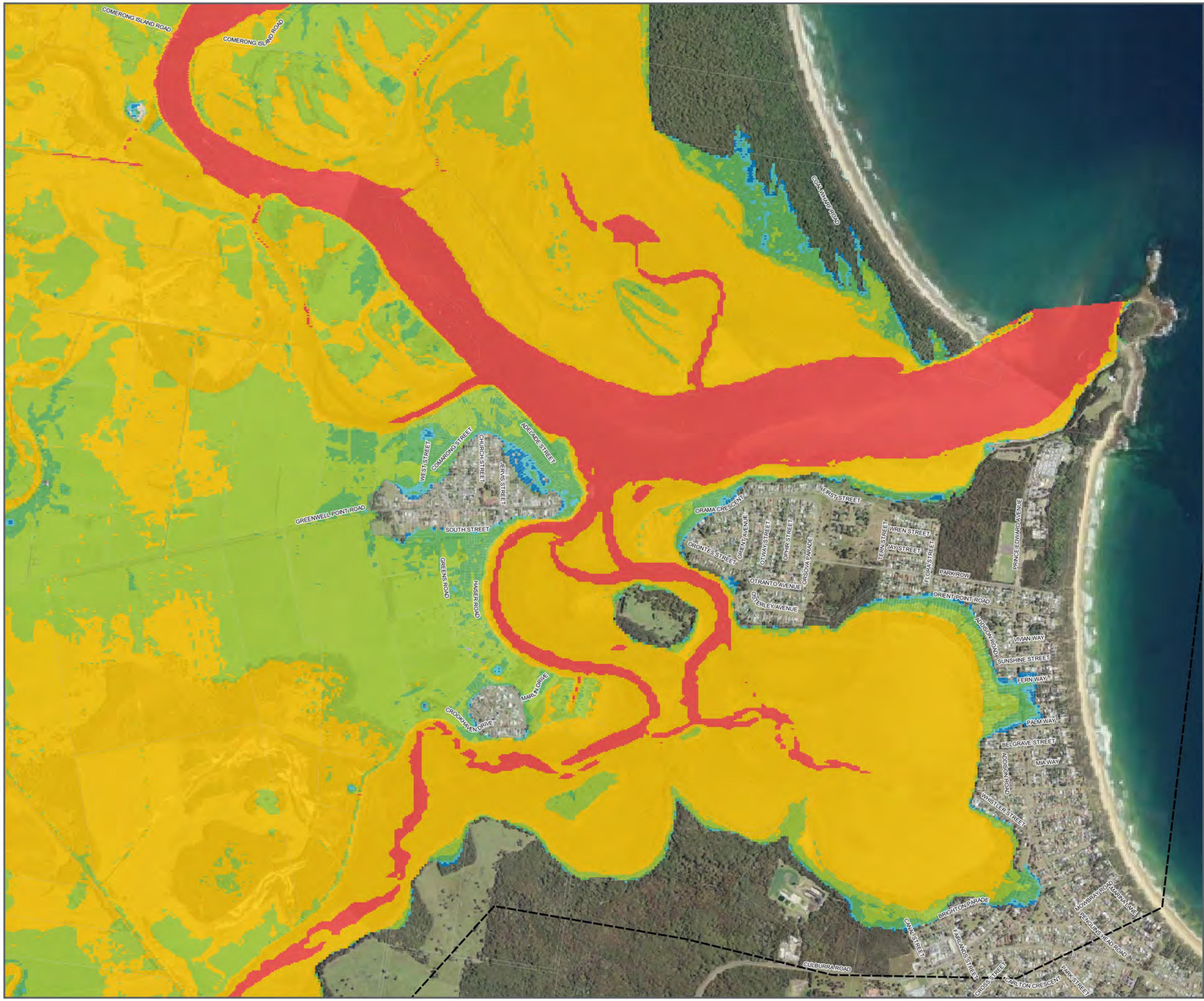
FIGURE G22.4

1:18,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing 1% AEP Hazard Greenwell Point, Orient Point and Culburra Beach

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Hazard (AEMI H1-H6)

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

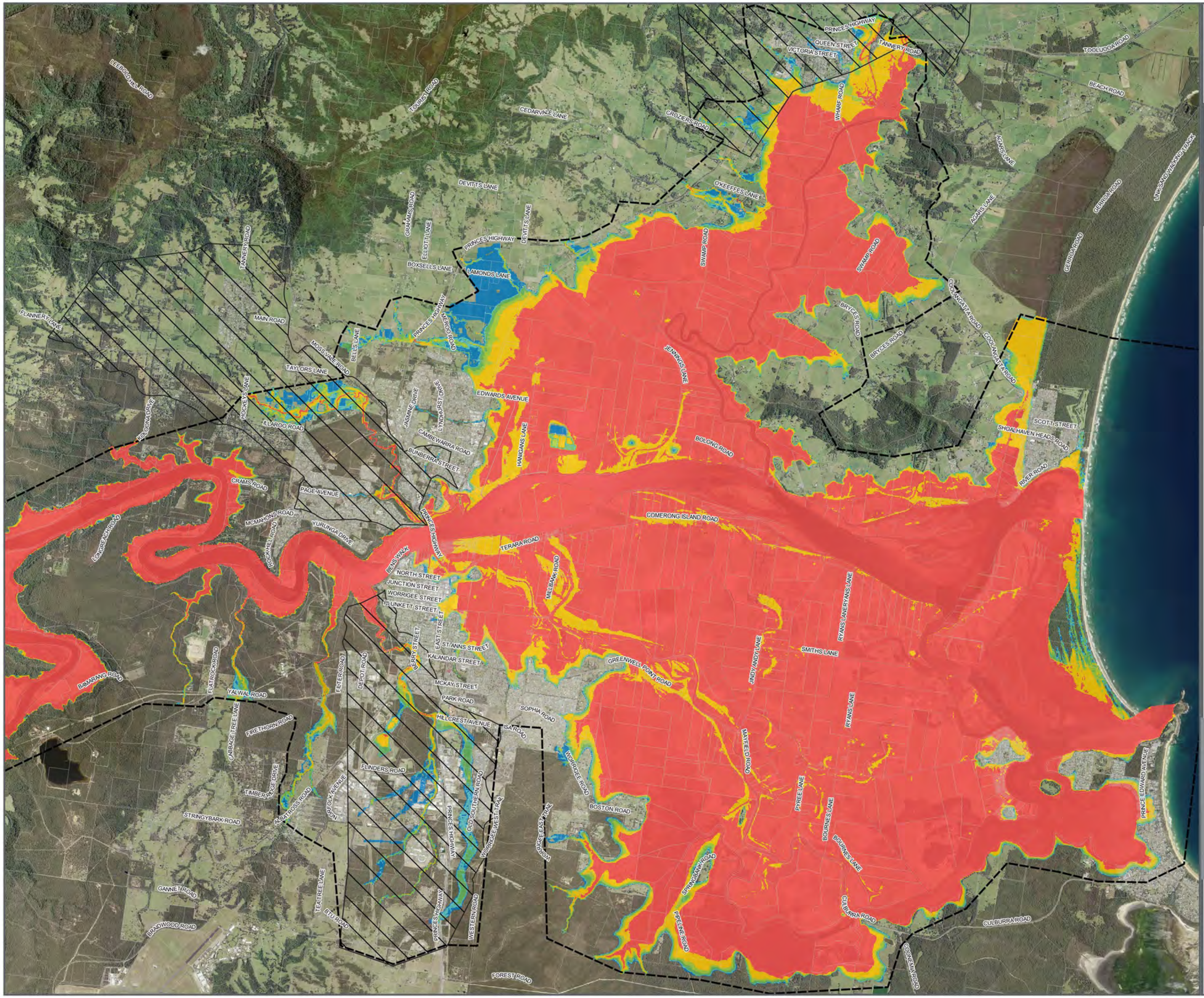
FIGURE G22.5

1:20,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-2-16| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Existing PMF Hazard

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas

Hazard (AEMI H1-H6)

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

FIGURE G24

1:75,000 Scale at A3

0 800 1,600 2,400 3,200 4,000 m

N

Cardno

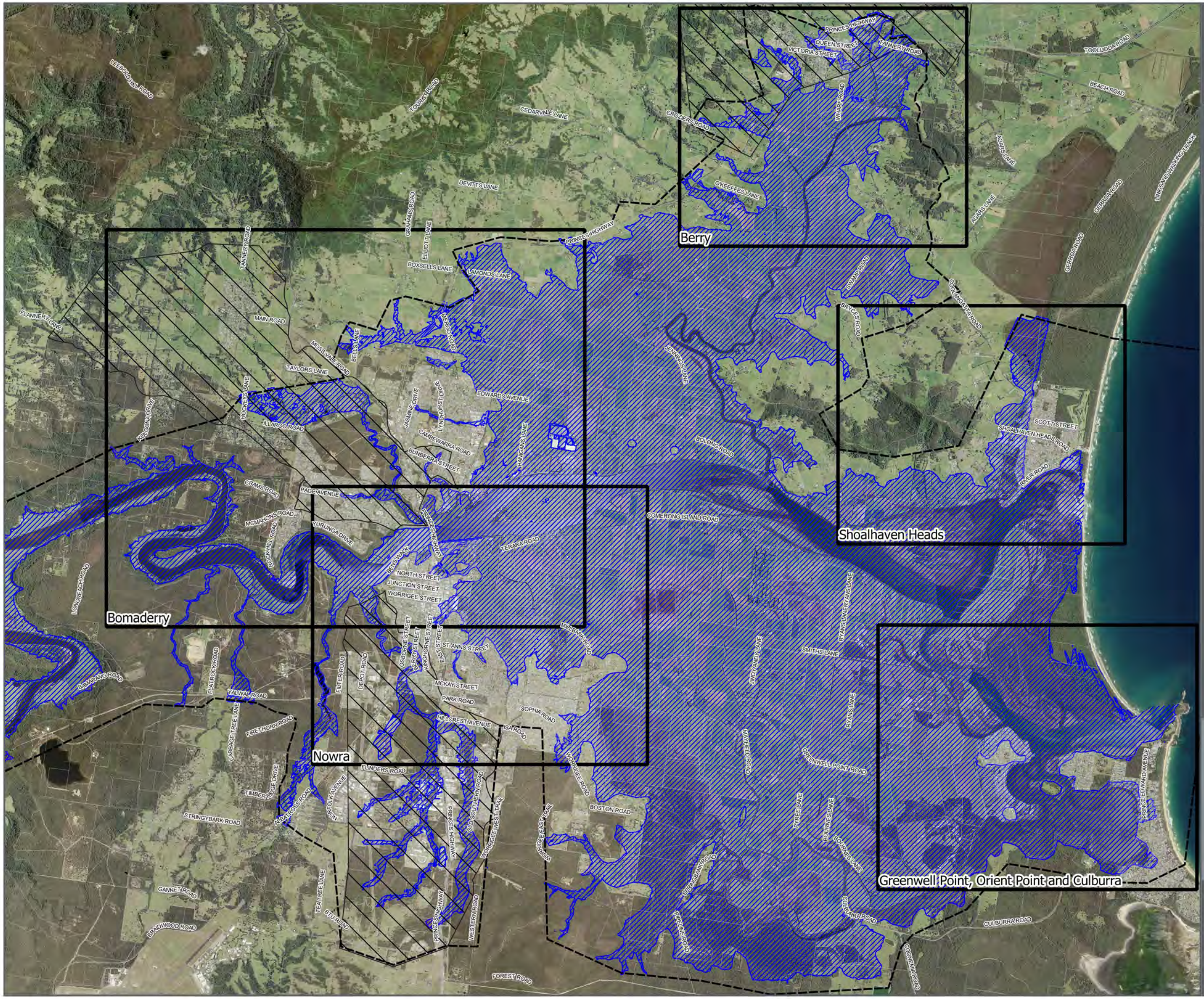
Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-11-15| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz

APPENDIX

B

FLOOD PLANNING AREA MAPS

Figure List:



Projected 2050 Flood Planning Area Overview

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Flood Planning Area

FIGURE I02

1:75,000 Scale at A3

0 800 1,600 2,400 3,200 4,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-11-15| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz

Projected 2050 Flood Planning Area Nowra

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Flood Planning Area

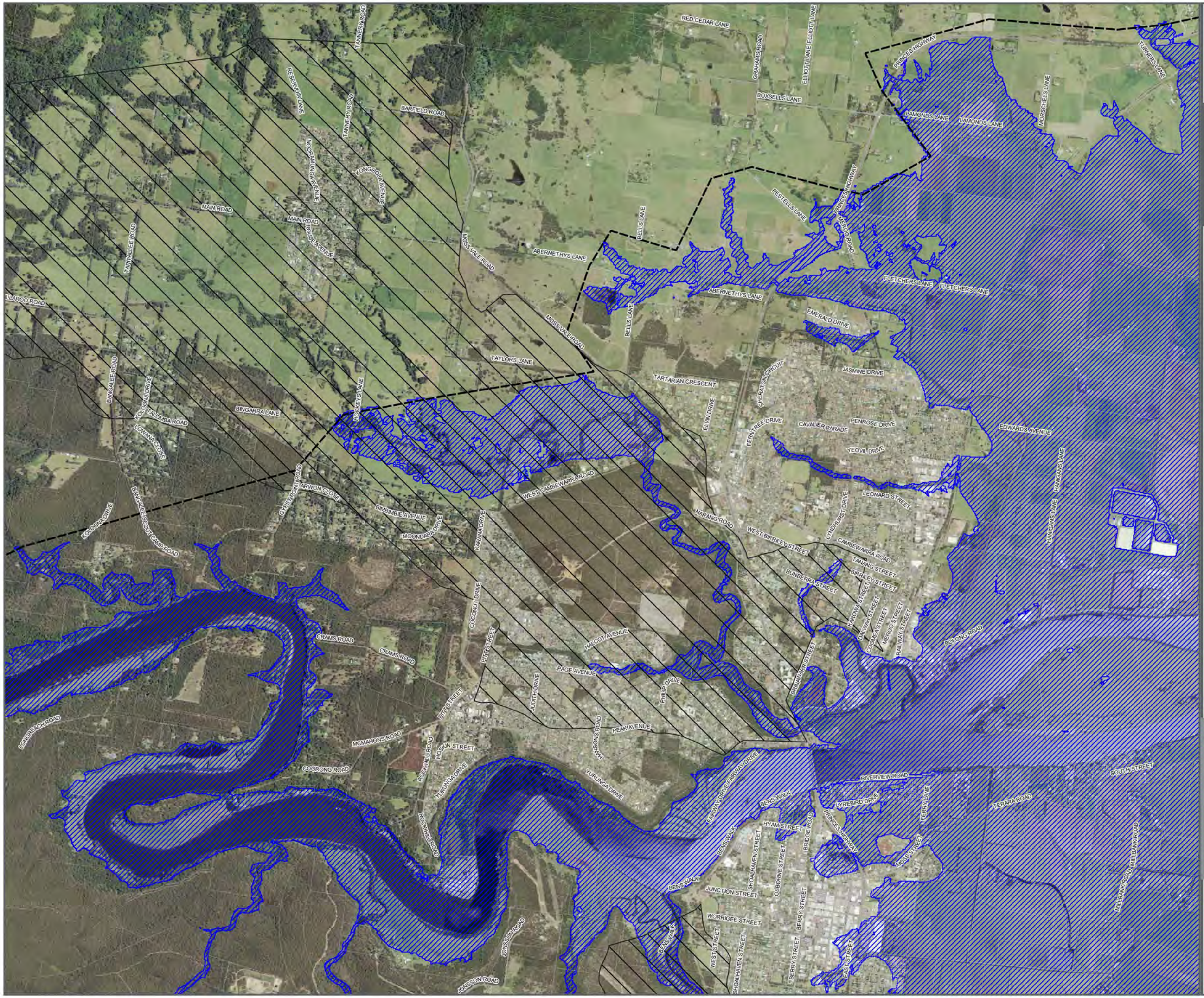
FIGURE I02.1

1:21,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-11-15| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Projected 2050 Flood Planning Area Bomaderry

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Flood Planning Area

FIGURE I02.2

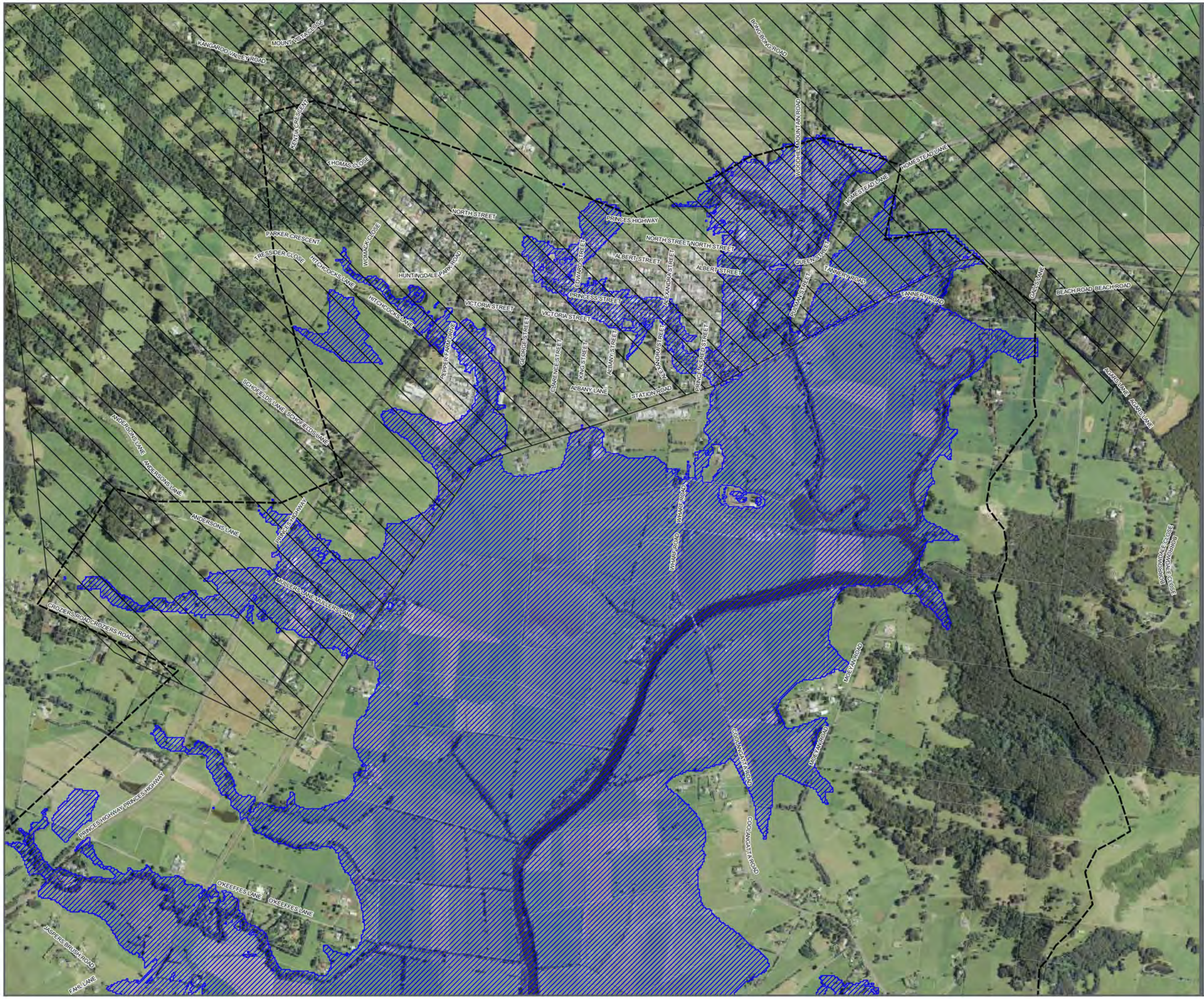
1:30,000 Scale at A3

0 300 600 900 1,200 1,500 m

N

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-11-15| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Projected 2050 Flood Planning Area Berry

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Flood Planning Area

FIGURE I02.3

1:18,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-11-15| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz

Projected 2050 Flood Planning Area Shoalhaven Heads

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Flood Planning Area

FIGURE I02.4

1:18,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-11-15| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz

Projected 2050 Flood Planning Area Greenwell Point, Orient Point and Culburra Beach

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Flood Planning Area

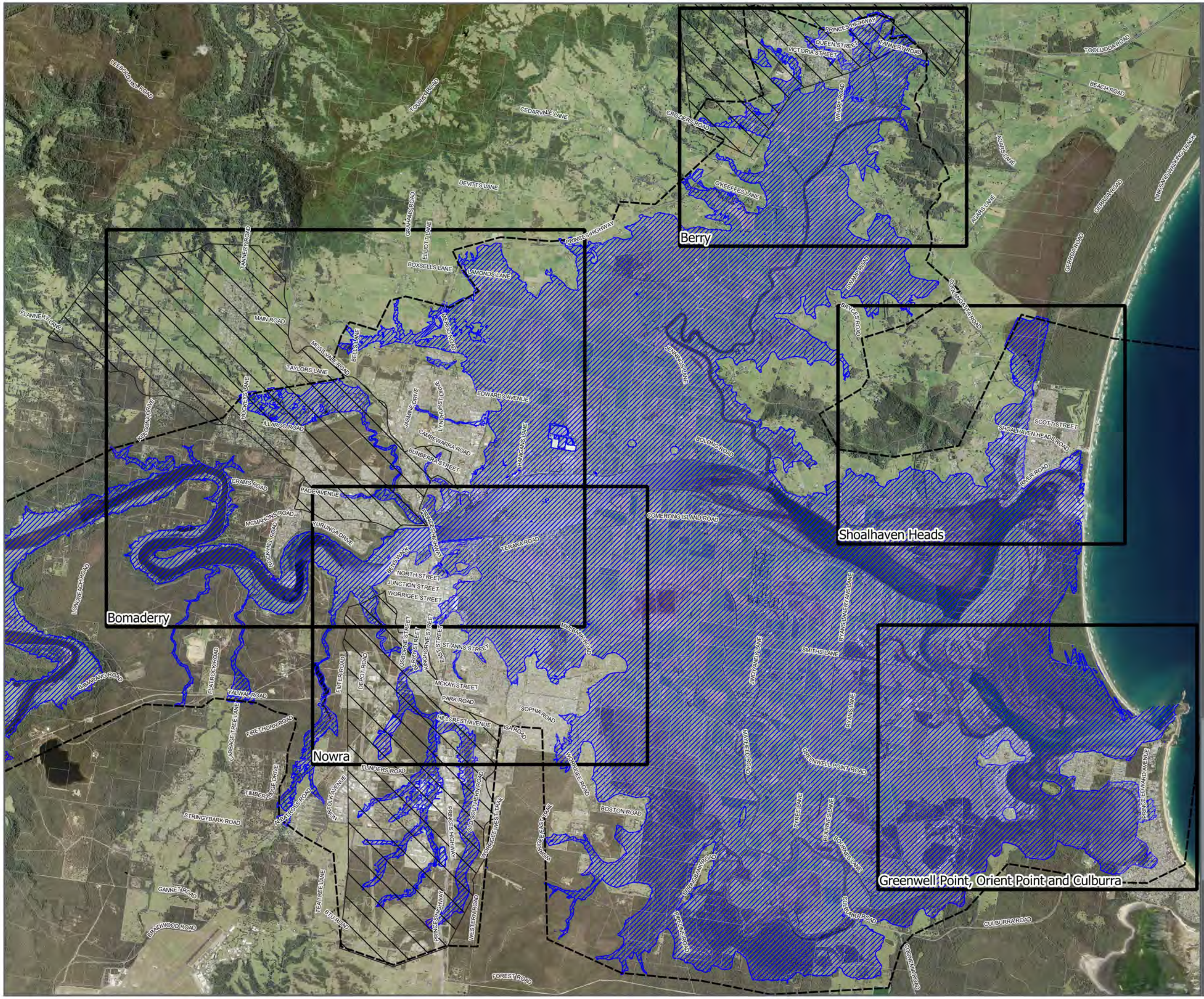
FIGURE I02.5

1:20,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-11-15| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Projected 2100 Flood Planning Area Overview

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Flood Planning Area

FIGURE I03

1:75,000 Scale at A3

0 800 1,600 2,400 3,200 4,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-11-15| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz

Projected 2100 Flood Planning Area Nowra

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Flood Planning Area

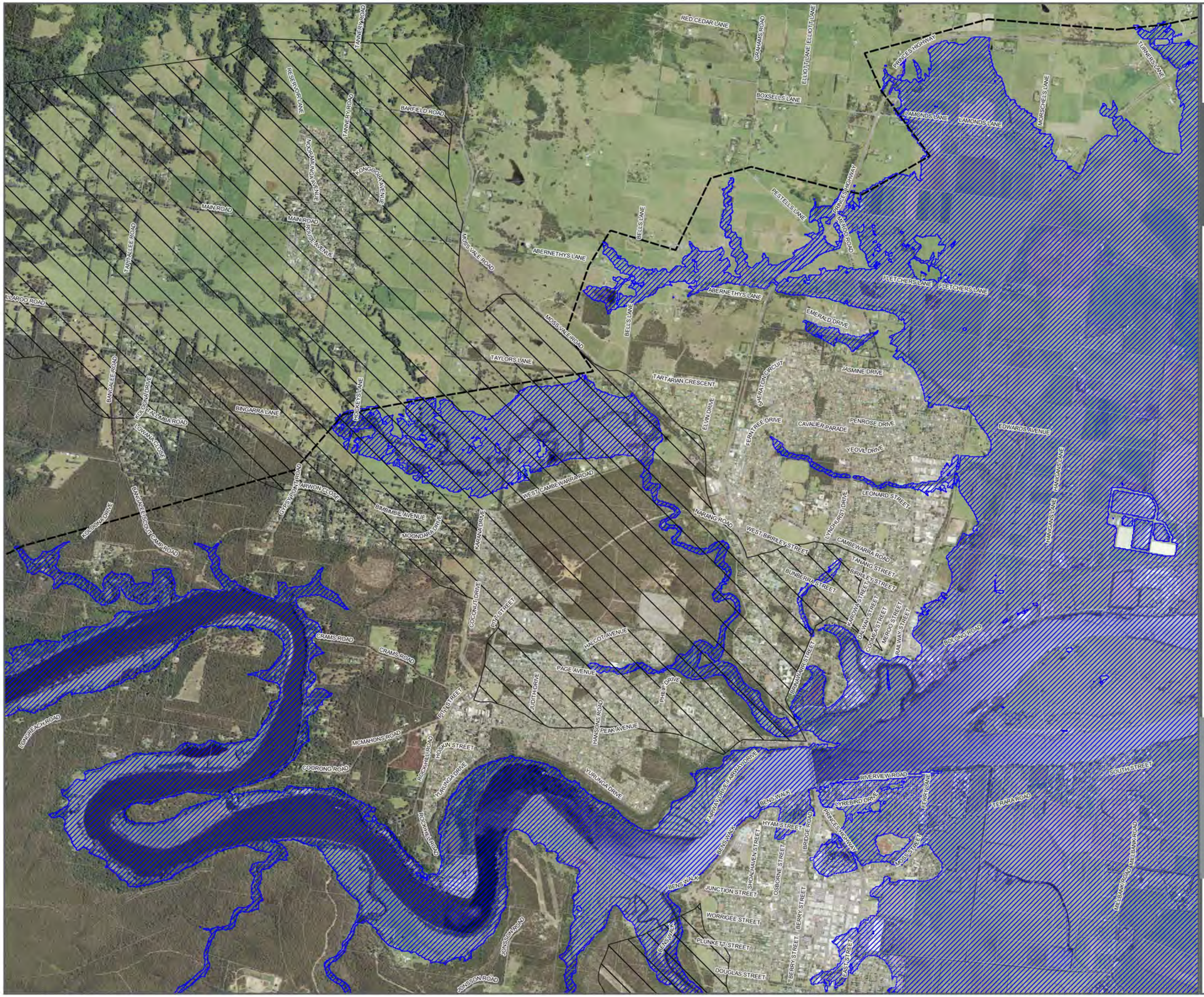
FIGURE I03.1

1:21,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-11-15| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Projected 2100 Flood Planning Area Bomaderry

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Flood Planning Area

FIGURE I03.2

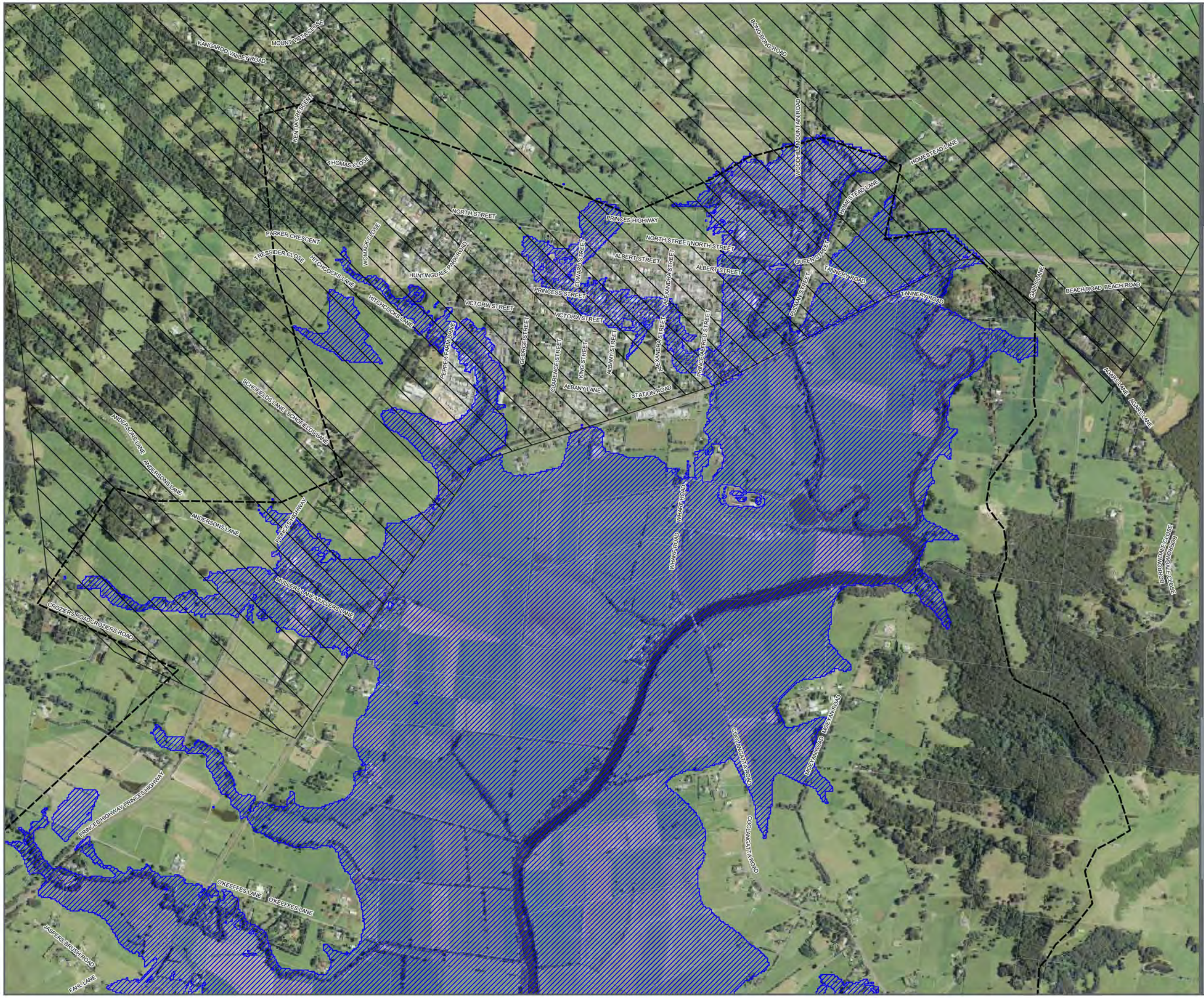
1:30,000 Scale at A3

0 300 600 900 1,200 1,500 m

N

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-11-15| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz



Projected 2100 Flood Planning Area Berry

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Flood Planning Area

FIGURE I03.3

1:18,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-11-15| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz

Projected 2100 Flood Planning Area Shoalhaven Heads

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Flood Planning Area

FIGURE I03.4

1:18,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-11-15| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz

Projected 2100 Flood Planning Area Greenwell Point, Orient Point and Culburra Beach

Lower Shoalhaven River Flood Study

Legend

- Cadastre (NSW Spatial Services, 2019)
- Hydraulic Model Boundary
- The adopted local FRMS&P takes precedence in these areas
- Flood Planning Area

FIGURE I03.5

1:20,000 Scale at A3

0 200 400 600 800 1,000 m

Cardno

Map Produced by Cardno NSW/ACT Pty LTD (NatW&E)
Date: 2022-11-15| Project: 59918099
Coordinate System: MGA Zone 56
Map: 20211012_Lower_Shoalhaven_Flood_Figures.qgz