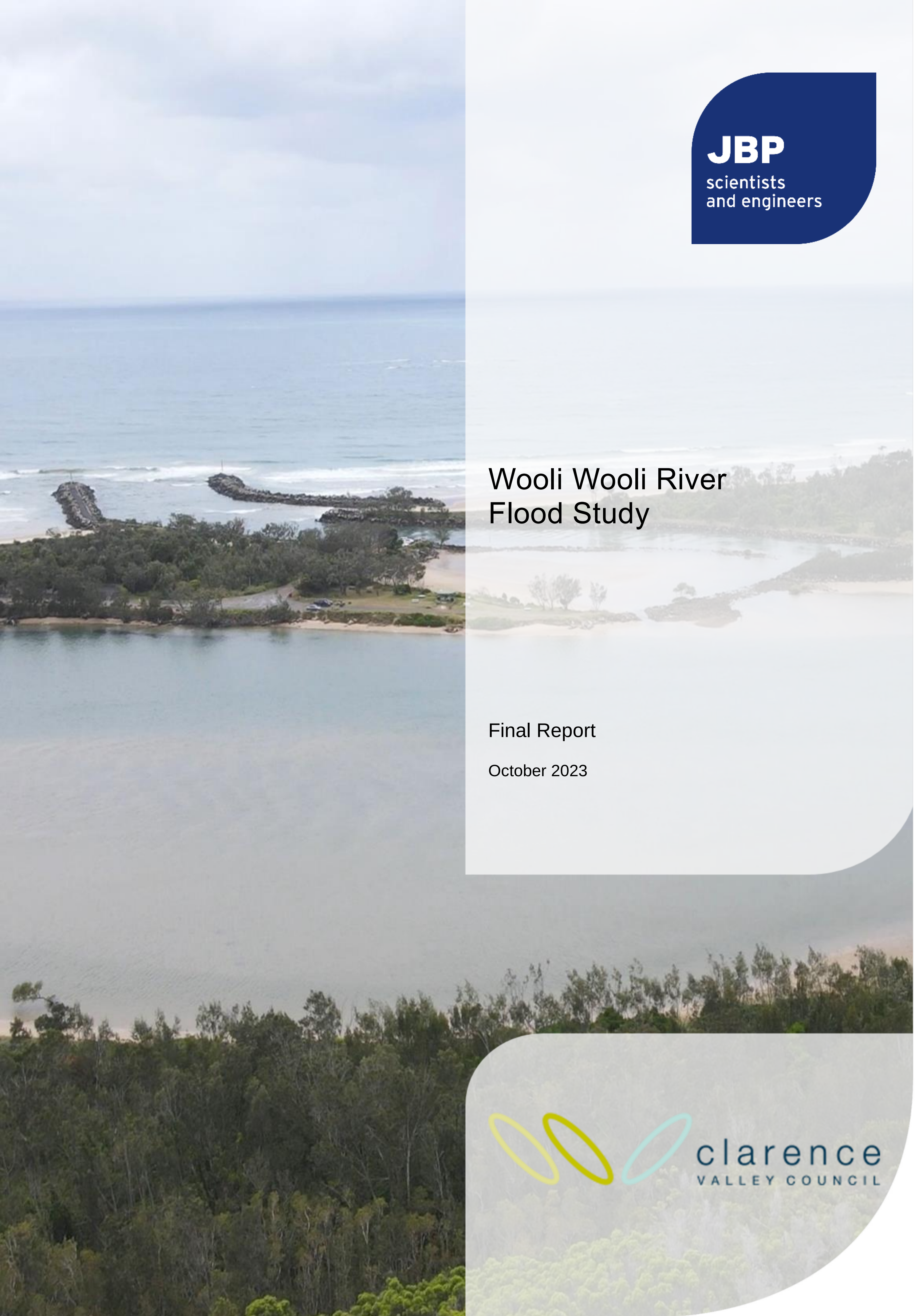

Wooli Wooli River Flood Study

Final Report

October 2023

JBP Project Manager

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Revision History

Revision Ref / Date Issued	Amendments	Issued to
S2-P01 / 3 Sept 2021	Draft Calibration	KM, GM, TC
S2-P04 / 2/ Dec 2021	Draft Final for Comments	GM, TC
A1-C01 / 4 Sept 2023	Final	GM, TC
A2-C02 / 12 October 2023	Updated FFA following FRMC meeting	GM, TC

Contract

This report describes work commissioned by Kieran McAndrew, on behalf of Clarence Valley Council, by an email dated 23 December 2020. Daniel Rodger, Eoghain O'hanlon and Sam Andrews of JB Pacific carried out this work.

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Director

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The conclusions and recommendations contained in this report are based upon information provided by others and upon the assumption that all relevant information has been provided by those parties from whom it has been requested and that such information is accurate. Information obtained by JBP has not been independently verified by JBP unless otherwise stated in the report.

The methodology adopted and the sources of information used by JBP in providing its services are outlined in this report. The work described in this report was undertaken between January 2022 and October 2023 and is based on the conditions encountered and the information available during this period of time. The scope of this report and the services are accordingly factually limited by these circumstances.

Certain statements made in the report that are not historical facts may constitute estimates, projections or other forward-looking statements, and even though they are based on reasonable assumptions as of the date of the report, such forward-looking statements by their nature involve risks and uncertainties that could cause actual results to differ materially from the results predicted. JBP specifically does not guarantee or warrant any estimate or projections contained in this report.

Unless otherwise stated in this report, the assessments made assume that the sites and facilities will continue to be used for their current purpose without significant changes.

Where field investigations are carried out, these have been restricted to a level of detail required to meet the stated objectives of the services. The results of any measurements taken may vary spatially or with time, and further confirmatory measurements should be made after any significant delay in issuing this report.

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Limitations and Assumptions

This flood study has been produced with the support of Council and state government agencies. However, limitations exist due to the availability and accuracy of historical rainfall and river height data, and the uncertainty associated with published rating curves at gauging locations across the catchment. These are discussed throughout this report.

Copyright

Trading as Jeremy Benn Pacific and JBP Scientists and Engineers

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Executive Summary

The Wooli Wooli River catchment is located south-eastern portion of the Clarence Valley Local Government Area (LGA). The catchment is generally undeveloped, with the Wooli village located near the river mouth and rock walls constructed to train the channel. The catchment covers an area of approximately 195km^2 with a steep longitudinal escarpment running north-south along the western boundary of the catchment. The river includes several tributaries, which join the main channel at the middle to lower catchment.

The development of this flood study is to support long-term planning and disaster management throughout the catchment. It has been prepared based on the framework established by the NSW Floodplain Development Manual (NSW Government, 2005) and national best practice as outlined in the Australian Institute for Disaster Resilience Handbook 7: Managing the floodplain: best practice in flood risk management in Australian (AIDR, 2017). Following the processes and direction of the manual, this flood study supports the development of a Flood Risk Management Study and Plan, which aims to:

- Reduce the impact of flooding and flood liability on existing developed areas through flood mitigation works and other measures; and
- Reduce the potential for flood losses for new development areas through the application of ecologically sensitive planning and development controls.

The development of this flood study has utilised a phased process, including numerical model development, calibration and validation, simulation of design events and analysis of flood behaviour. Given the complexity of the catchment, a suite of numerical models were used to conduct hydrologic, hydraulic, tidal and morphologic investigations, each subjected to a separate calibration and validation process. Catchment-driven flooding (i.e. fluvial processes) have used a joint modelling approach, with a hydrologic and hydraulic model run concurrently. The hydrology model has been developed in the Unified River Basin Simulator (URBS) software, which splits the 195km^2 catchment into 154 sub-catchments. The hydraulic model has used the TUFLOW software package, with a regional-scale model developed to span the entire catchment. Runoff inputs are linked throughout the catchment to the URBS model, with a dynamic tidal downstream boundary positioned 3km offshore of the Wooli Wooli River entrance. The performance of the joint modelling approach was evaluated against several metrics, with a comparison of peak water levels, timing, and hydrograph shape compared against gauge records for five events. While several challenges exist for this data-limited catchment, the calibration and validation results indicate that the hydrology and hydraulic modelling approach has achieved a typical accuracy of ±0.16m, which was considered fit-for-purpose for this Flood Study.

The calibrated models were used to simulate design storm events ranging from a 50% Annual Exceedance Probability (AEP) to a Possible Maximum Flood (PMF), shown on Table E1. Peak flood levels were estimated throughout the catchment, with the levels at the Wooli Caravan Park ranging between 1.0m AHD (50% AEP), 2.43m AHD (1% AEP) and 2.9m AHD (0.2% AEP). Flood planning levels will be based on a 1% AEP, 2100 RCP4.5 climate change scenario, which is 2.76m AHD at the Caravan Park (Table E2). The flood study outputs have been compared against the previous adopted Wooli Wooli Flood Study (1995), with the previous 1% peak conditions at the caravan park of 2.72m AHD approximately matching the new 1% AEP RCP4.5 climate change scenario.

Table E-1: Present day peak flood levels for key reporting locations

Design AEP	Catchment AEP	Tidal Boundary	Peak flood level Wooli Caravan Park (m AHD)	Peak flood level Entrance (m AHD)
50%	50%	HHWS(SS)	1.03	0.94
20%	20%	HHWS(SS)	1.36	1.04
10%	10%	HHWS(SS)	1.59	1.14
5%	5%	HHWS(SS)	1.83	1.28
2%	2%	5%	2.24	2.08
1%[1]	1%	1%	2.43	2.17
0.5%	0.5%	1%	2.63	2.33
0.2%	0.2%	1%	2.91	2.49
PMF[2]	PMF	1%	5.96	4.77

Table E-2: 1% AEP peak flood levels for various locations. Showing present day 1% AEP, 2100 RCP4.5 1% AEP, and Wooli Wooli Flood Study (1995).

Location	2100 RCP4.5 1% AEP peak flood level	Present day 1% AEP peak flood level	1995 Flood Study 1% peak flood level
1 (Wooli Swamp)	2.79	2.48	2.98
2	2.77	2.45	2.86
3 (Caravan Park Reporting)	2.76	2.43	2.72
4 (Hotel/Motel)	2.74	2.40	2.68
5	2.73	2.39	2.67
6	2.73	2.37	2.64
7	2.73	2.35	2.64
8 (Bowling Club)	2.73	2.32	2.59
9 (Caravan Park)	2.74	2.30	2.52
10 (Harold Lloyd Park)	2.74	2.29	2.44
11	2.74	2.25	2.25
12	2.74	2.22	2.20
13	2.74	2.19	2.17
14	2.74	2.18	2.17
15 (Entrance Reporting)	2.75	2.17	2.07
16	2.75	2.10	2.11
17 (River Entrance)	2.76	2.10	2.16

1 A combined maximum for the 1% coastal and 1% catchment boundary conditions
2 A combined maximum for the 1% and HHWS(SS) coastal boundary condition

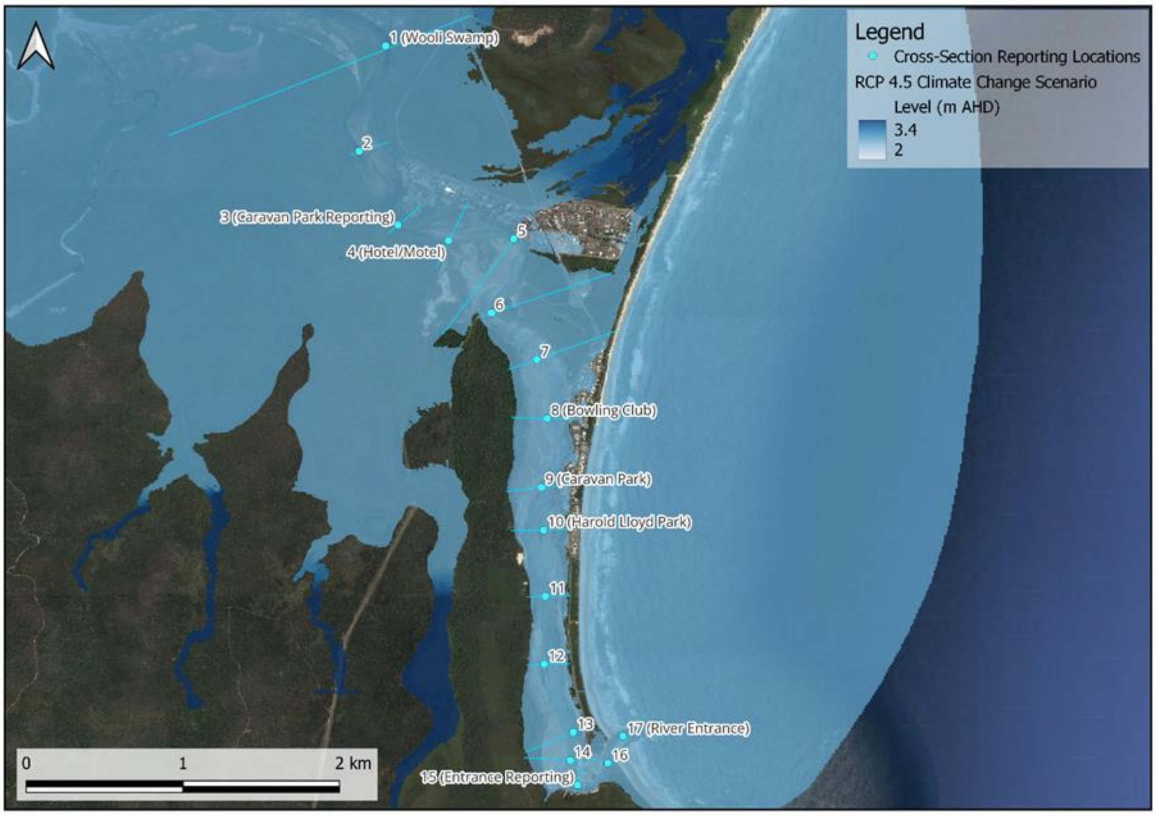

Figure E-1: Reporting Locations

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Abbreviations

AEP .... Annual Exceedance Probability
ARI .... Average Recurrence Interval
AWRA-L .... Australian Water Resource Assessment – Landscape
DPE................................. Department of Planning and Environment
FRMS.............................. Floodplain Risk Management Study
FRMP.............................. Floodplain Risk Management Plan
LiDAR.............................. Light Detection and Ranging remote sensing of ground level information
OEH .... Ex-Office of the Environment and Heritage, now DPE
SES .... State Emergency Services
URBS.............................. Unified River Basin Simulator hydrological modelling software

1 Introduction

The Wooli Wooli River is a river system with a catchment in a largely natural state, it contains a large mid-catchment swamp, a barrier estuary and open trained entrance, located in the mid-north coast region of New South Wales, Australia. The catchment is located in the south-eastern portion of the Clarence Valley Local Government Area (LGA), and is generally undeveloped, with the Wooli village located near the river mouth. The catchment covers an area of approximately 195km^2 with a steep longitudinal escarpment running north-south along the western boundary of the catchment. The river fed by several tributaries which join the main channel at the middle to lower reaches of the catchment.

This Wooli Flood Study has been prepared by JB Pacific on behalf of Clarence Valley Council (CVC), which has been jointly funded by the Department of Planning and Environment (DPE) and CVC. It has been developed to update the previous Wooli Wooli River Flood Study and Flood Risk Management Plan, which were completed in 1995 and 1999 respectively and provides new information to support long-term planning and disaster management throughout the catchment. The study has been undertaken on a phase gate process, which included the development of numerical models, calibration and validation, simulation of design events and analysis of flood behaviour. Given the complexity of the catchment, fluvial and coastal processes, a suite of numerical models have been used, including hydrologic, hydraulic, tidal and sediment transport models, each subjected to separate calibration and validation processes.

The outputs of this Flood Study have been used within a review and update of the previous Wooli River Floodplain Management Plan (FMP), which was commissioned by the then Ulmarra Shire Council. The management actions within the updated FMP have been developed using the new flood modelling information to consider the preferred strategic approach to floodplain management, including non-structural options such as evacuation planning, flood recovery planning and flood forecasting.

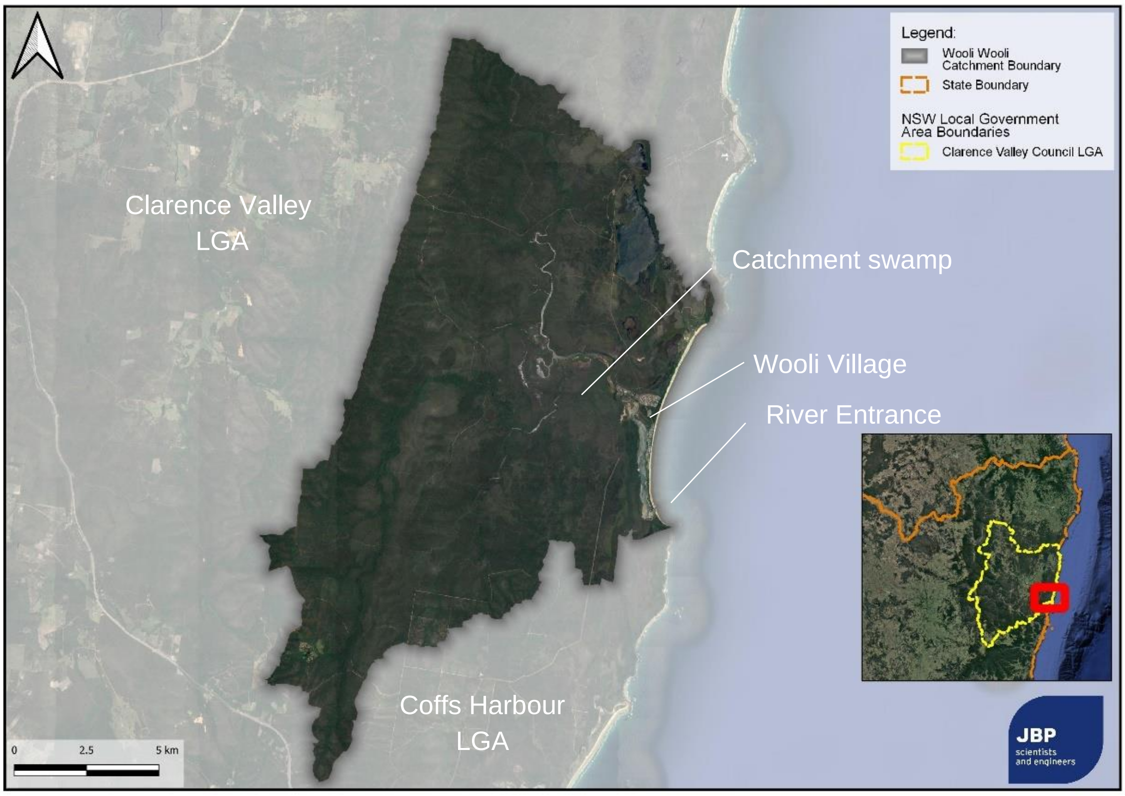

Figure 1-1: The Wooli Wooli River catchment is located in the southeast portion of Clarence Valley.

1.1 Background

The Wooli Wooli River System is located in the south-eastern portion of the Clarence Valley LGA, with a small part of the catchment extending into the Coffs Harbour LGA. The catchment covers an area of approximately 195km^2 with a steep longitudinal escarpment running north-south along the western boundary of the catchment. The catchment topography has a maximum elevation of approximately 266 metres Australian Height Datum (m AHD) on the west, and a minimum elevation of -6.5m AHD in the entrance to the ocean on the east, with an average elevation of approximately 28m AHD. The main reach of the Wooli Wooli River is shown in Figure 1-1, which includes several tributaries which join the main channel towards the middle to lower portion of the catchment.

Downstream of the village the rivermouth has been trained. Prior to construction of the training walls, flood waters have been reported to overtop the sand spit at the entrance, scouring an enlarged passage for flood water to the ocean. Subsequent coastal wind and wave action would see the spit re-build until the next flood or fresh occurred. Over long dry spells the tidal entrance channel would significantly reduce in size. The entrance works were constructed between January 1970 and December 1971 (and modified in 1974) to stabilise the entrance location and provide safe navigation for fishing vessels[3].

Figure 1-2: Wooli Wooli River lower estuary and training walls

1.2 Study purpose

The purpose of this project is to develop a Flood Study that can be used by a variety of stakeholders, including authorities and the community, for land use planning, flood risk management, emergency response, and community education. The outcomes are designed to deliver a robust assessment of flood risk within the catchment, with the overall aim of improving the understanding of flood behaviour and impacts and to better inform the overarching management of flood risk. The project provides an improved understanding of flood behaviour and associated risk to inform:

- Relevant government information systems
- Government and strategic decision-makers on flood risk
- The community and key stakeholders on flood risk
- Flood risk management planning for existing and future development considering a multitude of potential flood protection mechanisms
- Engineers involved in designing, constructing, and maintaining mitigation works
- Emergency management planning for existing and future development, and strategic and development scale land-use planning to manage growth in flood risk

3 PBP (1997) Wooli Beach Coastline Management Plan. Prepared by Patterson Britton and Partners

* Land-use planners involved in strategic planning and planning controls.

1.3 Methodology

This project has been completed following the framework established by the NSW Floodplain Development Manual (NSW Government, 2005) and national best practice as outlined in the Australian Institute for Disaster Resilience Handbook 7: Managing the floodplain: best practice in flood risk management in Australian (AIDR, 2017). The NSW floodplain risk management process and AIDR best practice flood risk management process is shown in Figure 1-3. This report summarises the Data Collection and Flood Study phase, following the process shown in Figure 1-4. The flood events simulated within this project are listed in Table 1-1.

The subsequent Floodplain Risk Management Study and Management Plan have been prepared using the study outputs, and are presented separately.

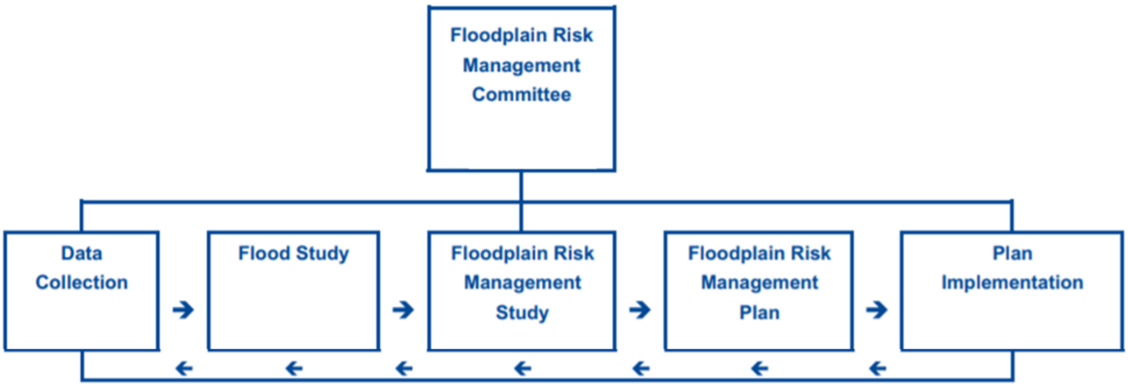

Figure 1-3: Overview of the NSW Floodplain risk management process (abbreviated from the NSW Floodplain Development Manual)

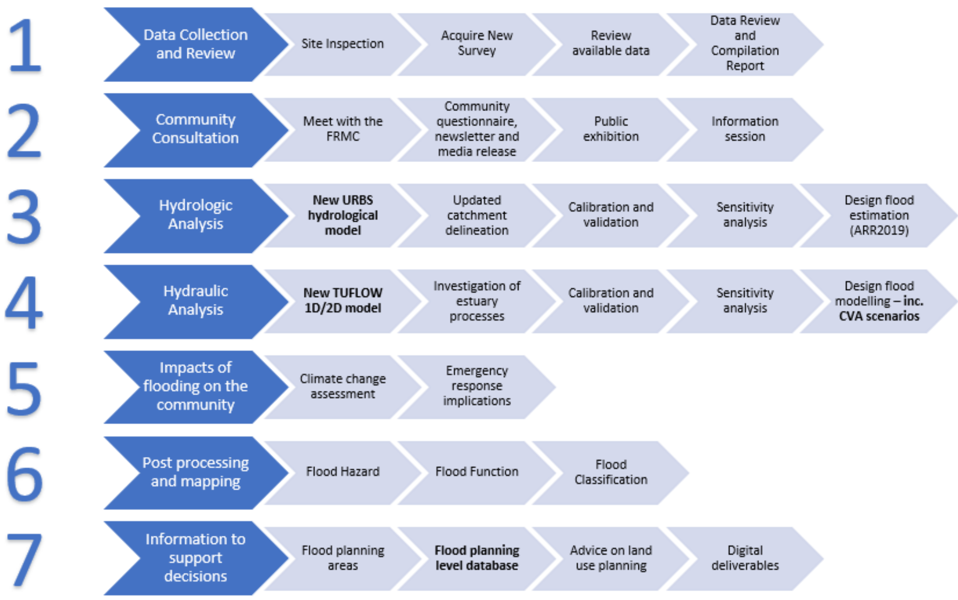

Figure 1-4: Overview of project delivery, showing the various stages of project execution

Table 1-1: Flood events or floodplain conditions to be assessed

Scenario ID	Event	Description/Information
2(B)	Design flood events existing conditions	50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF, including coincident flooding from ocean levels
13	Design events for coastal flooding	5% ocean, 1% ocean, 5% + 2100 SLR

1.4 Report layout

In addition to this introductory chapter, this report includes the following sections.

- **Section 2 (Available Data)** which details a review of previous studies, existing flood model data, topographic data, structure data, flood information and coastal processes.
- **Section 3 (Hydrological Analysis)** which includes a catchment review, description of the hydrologic modelling approach and calibration results
- **Section 4 (Hydraulic Analysis)** which includes a description of the modelling assumptions and limitations, hydraulic model setup, boundary conditions, and the results of calibration and validation testing.
- **Section 5 (Design Flood Estimation)** which includes a Flood Frequency Analysis review, development of Intensity-Frequency-Duration Curves (IFD), analysis of pre-burst rainfall and temporal patterns, extreme rainfall estimates, and design hydraulic model simulations.
- **Section 6 (Flood Behaviour)** which provides a description of how flooding occurs within the catchment, areas and locations impacted by flooding of different magnitudes, progression and timing of flooding through-out the catchment.

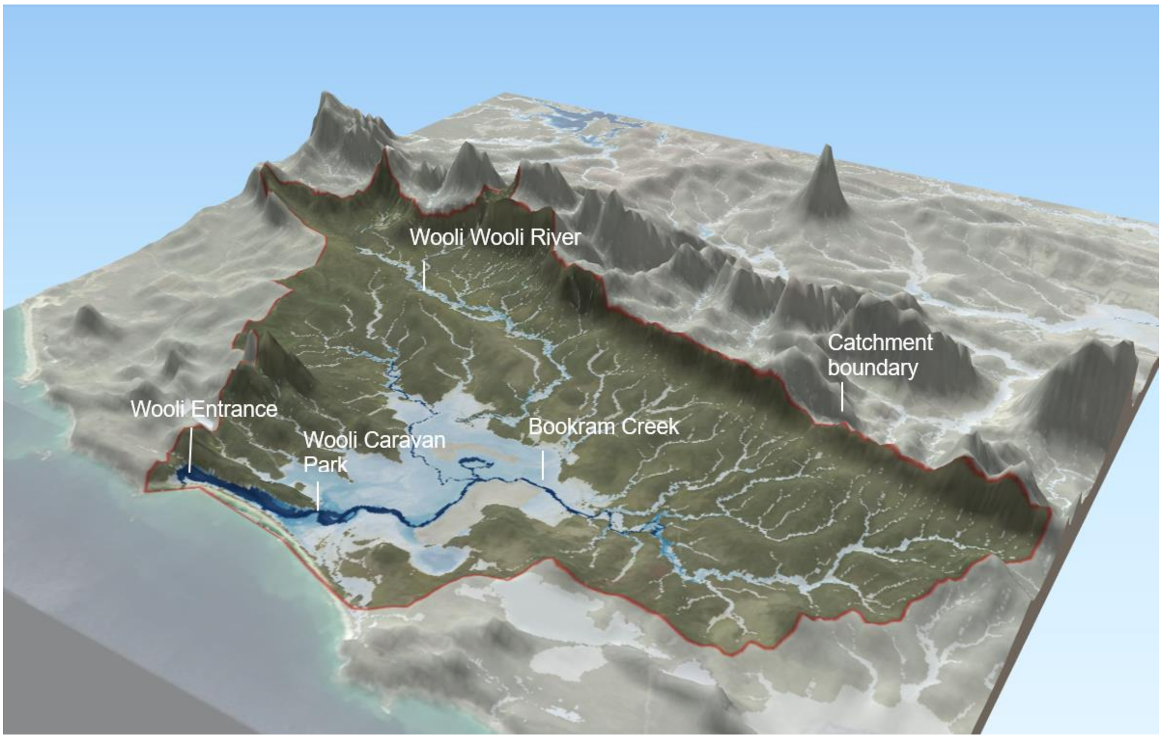

Figure 1-5: Catchment overview with indicative large-scale flood mapping across the catchment

2 Available data

2.1 Previous Studies

2.1.1 Flood study

A Wooli Wooli River Flood Study was developed by the Coast and Flood Policy Brach of the NSW Public Works Department in 1995. This report includes historic flood levels and surveyed debris levels, estimated river scour levels, used a Watershed Bounded Network Model (WBNM) to estimate design hydrology and a 1-Dimensional (1D) MIKE11 hydraulic model to estimate design flood levels. No modelling files are available from this project.

2.1.2 Floodplain risk management study and plan

The Wooli Wooli River Floodplain Management Plan (FMP) was completed in 1999 by Patterson Britton and Partners. The FMP was commissioned by the then Ulmarra Shire Council and developed in line with the Wooli Floodplain Community Committee's preferred strategic approach to floodplain management, including non-structural options such as evacuation planning, flood recovery planning and flood forecasting.

The FMP describes four priority areas for flood risk management within the catchment with an implementation plan that aims to deliver all priority actions subject to State government funding.

2.2 Existing Flood Model Data

A historic WBM hydrological model and MIKE11 model was developed as part of the Wooli Wooli River Flood Study (1995), however, no modelling files are available from the project.

2.3 Topographic Data

2.3.1 Bathymetry

A review of publicly available information identified the following bathymetric information:

- 5m Topo-Bathy DEM derived from NSW Marine LiDAR Project (DPE, 2018)
- Single-beam Bathymetry and Coastal Topography Surveys (NSW OEH, 2003)

The 2018 data was acquired as part of a state-wide program to support coastal management reforms. As shown in Figure 2-1, the coverage is generally good and is considered to provide significant detail of the bathymetry in the Wooli Wooli River estuary. However, a significant flood event occurred in the catchment in February 2020, which may have affected the channel bathymetry. As a result, it is considered good practice to assess the present-day bathymetric conditions. This has been undertaken through a new bathymetric survey, limited to the areas with low coverage.

The 2003 information included point information within the estuary and cross-section information of the major tributaries, which were acquired as part of a hydrographic survey of the Wooli Wooli River.

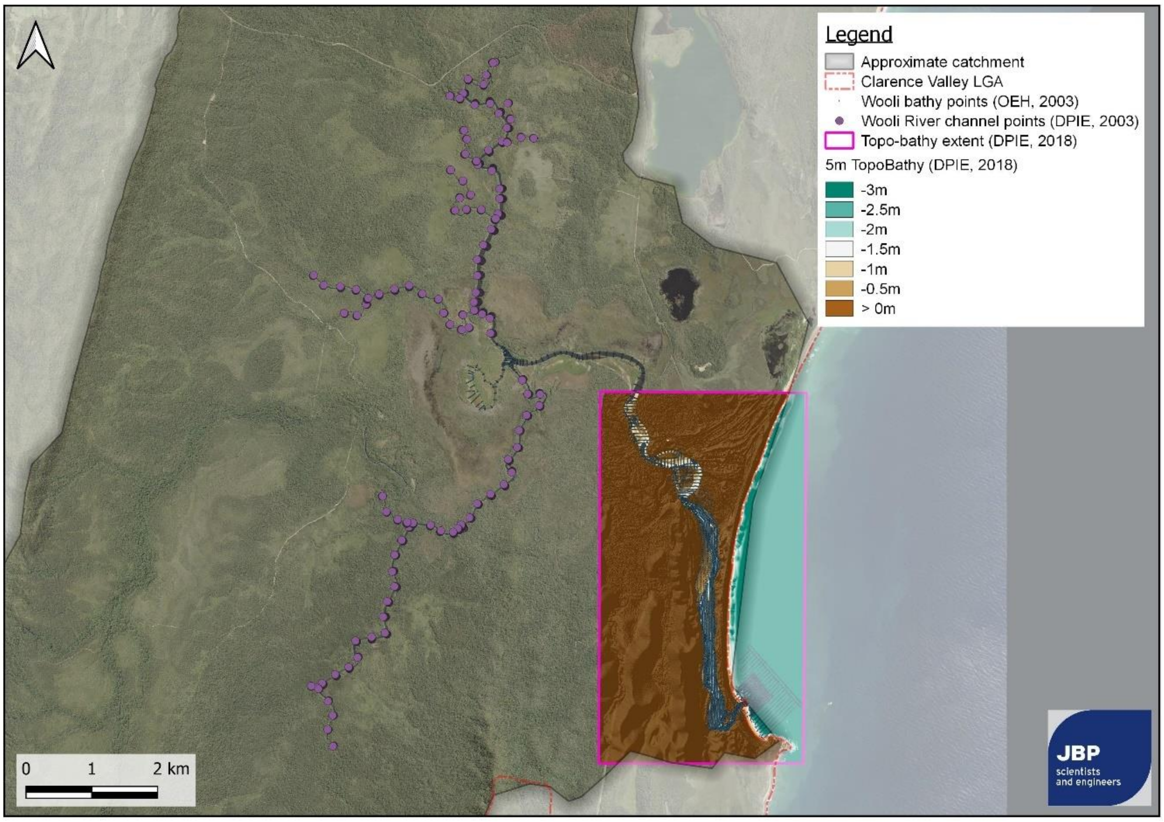

Figure 2-1: Extent of existing bathymetry data derived from NSW Marine LiDAR project (2018)

A detailed review of the 2018 topo-bathy survey acquired from DPE shows isolated areas where the LiDAR derived data has not been able to read the bathymetric bed of the channel. This is not surprising, as LiDAR is known to poorly penetrate water, especially within deeper parts of the estuary. Given the potential changes in bathymetry and the gaps in the existing topo-bathy dataset, additional hydrographic survey was commissioned in the four areas shown in Figure 2-2. The focus areas for the additional survey were:

- Near the entrance – where high-velocity discharge has been observed
- To the west of Carraboi St, Wooli – to validate the existing elevation data in the bathy-topo dataset near this populated area of Wooli
- South west of Olen Close, Wooli – to fill data gaps in the existing topo-bathy dataset and validate the elevation data near this populated area of Wooli.
- West of the Wooli Caravan park - to fill data gaps in the existing topo-bathy dataset.

Figure 2-2: Location of new hydrographic survey of the bathymetry of the Wooli Wooli River estuary.

Hydrographic survey of the estuary bathymetry was completed for the four locations, as shown in Figure 2-3 to Figure 2-6. The surveyed bathymetric information shows that the 2018 Marine Topo-bathy dataset is generally consistent with the present bathymetry.

In the locations where bathymetry data was not available, shown in Figure 2-5 and Figure 2-6, the hydrographic survey has successfully picked up the channel bathymetry. The bathymetric data is considered to have good coverage and quality, therefore is fit-for-purpose to deliver the Wooli Wooli River flood study update.

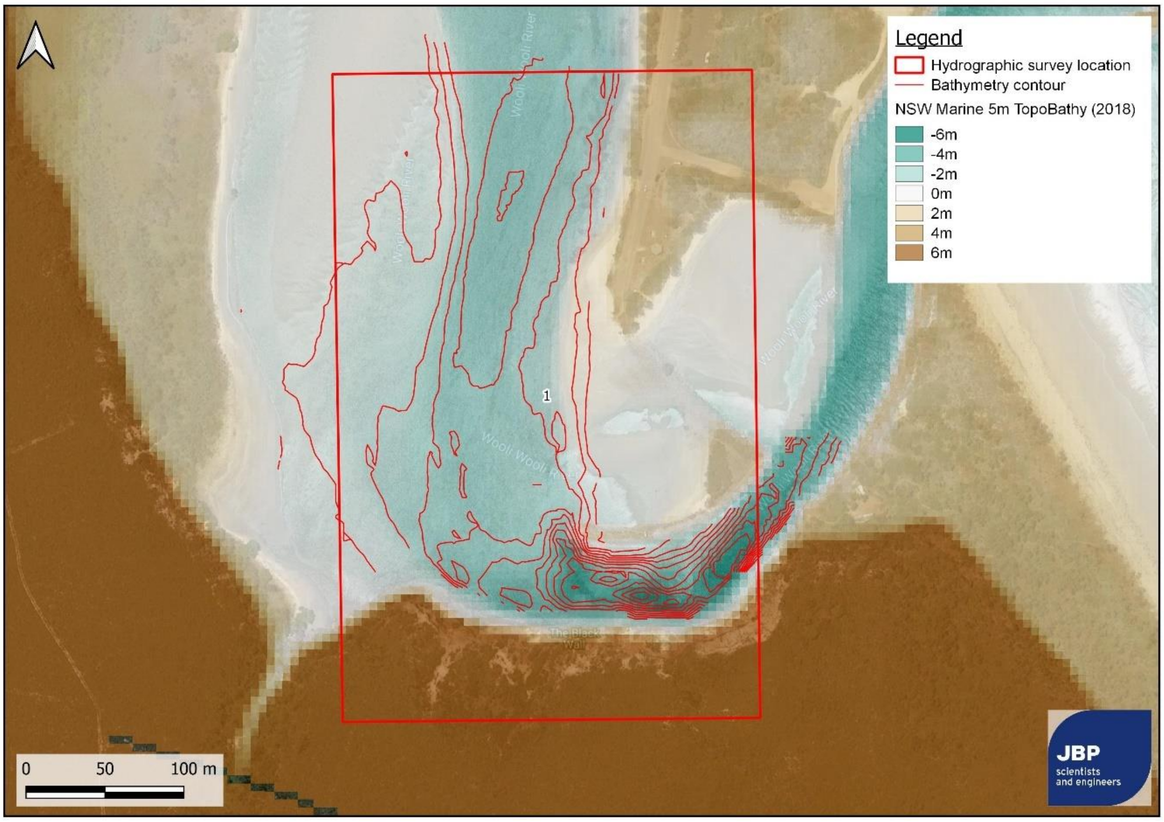

Figure 2-3: Hydrographic survey of estuary bathymetry near the Wooli Wooli River entrance

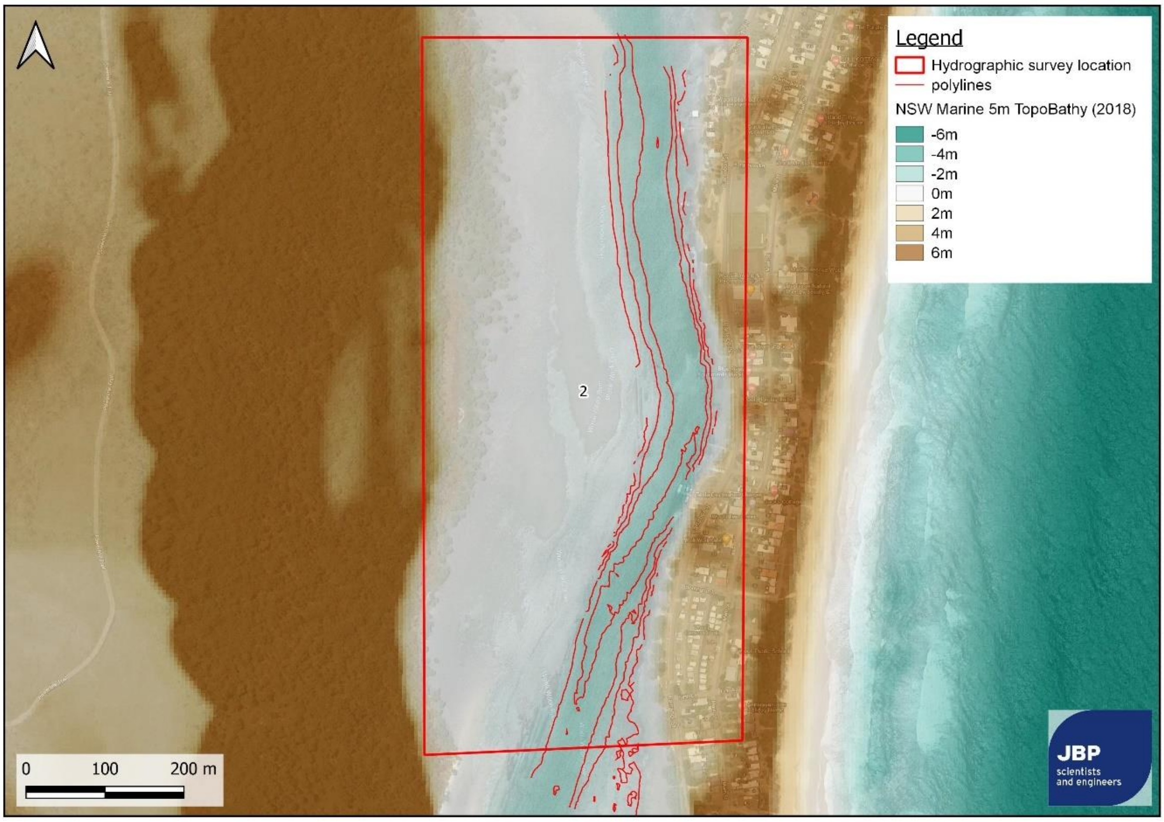

Figure 2-4: Hydrographic survey of estuary bathymetry near Carraboi St, Wooli

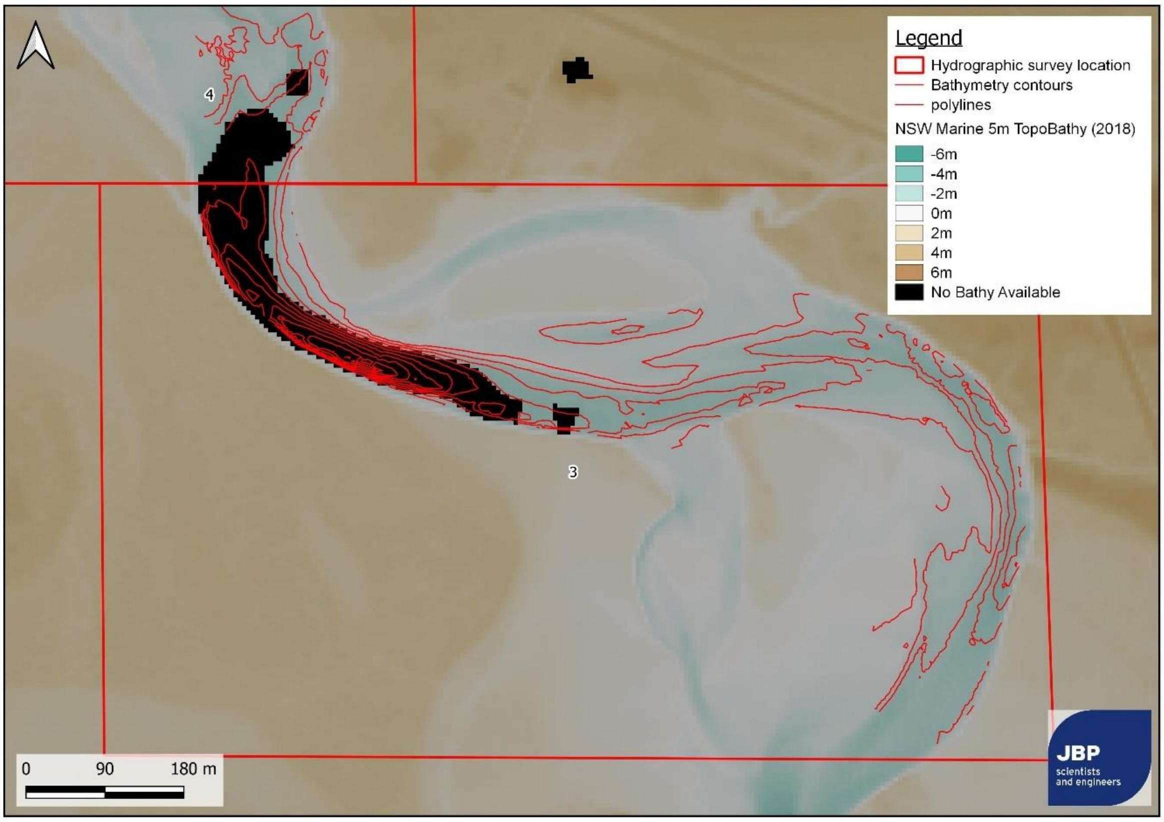

Figure 2-5: Hydrographic survey of estuary bathymetry near Olen Close, Wooli

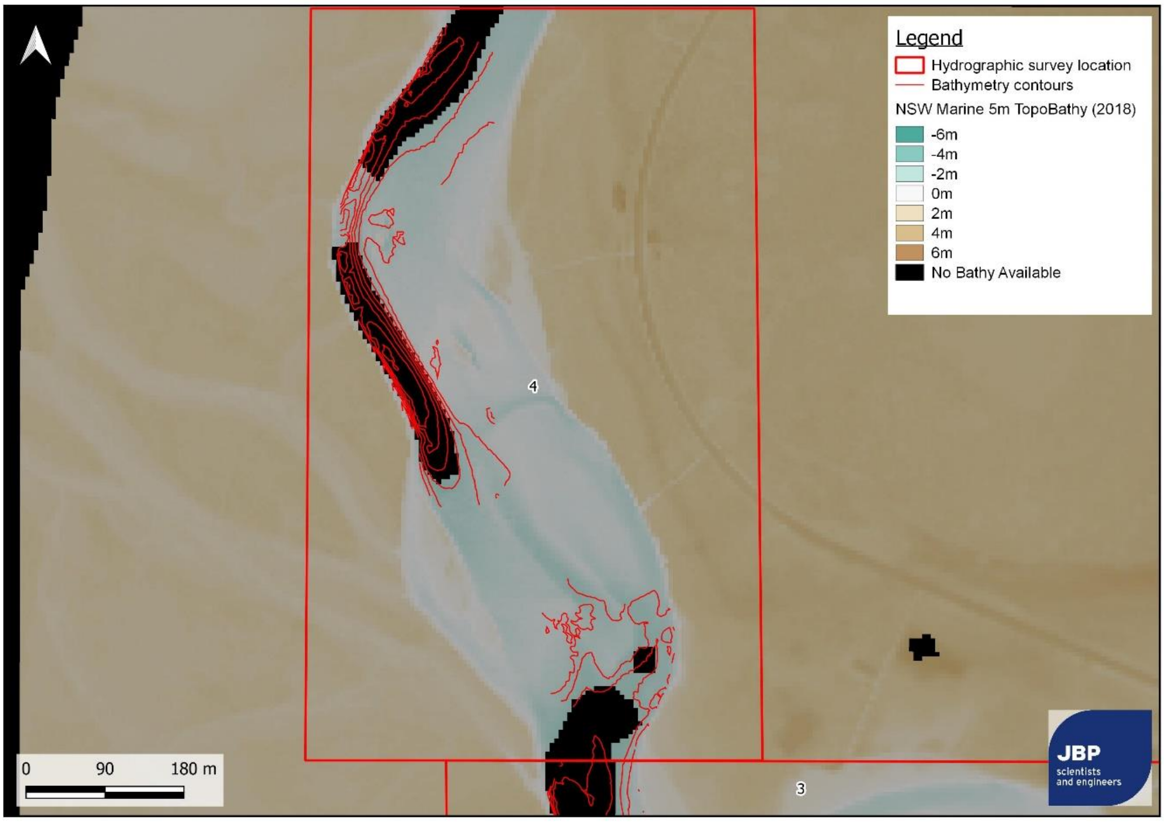

Figure 2-6: Hydrographic survey of estuary bathymetry west of the Wooli caravan park

2.3.2 Topography

There are three sources of topographic information in the catchment and are summarised in Table 2-1. Topographic information has mostly been derived from LiDAR data. The available LiDAR-derived topography datasets have been captured over the past 10+ years and cover some or all of the catchment. Where coverage is noted, the approximate portion (as a percentage) of the total catchment area is reported in Table 2-1 and shown spatially in Figure 2-7.

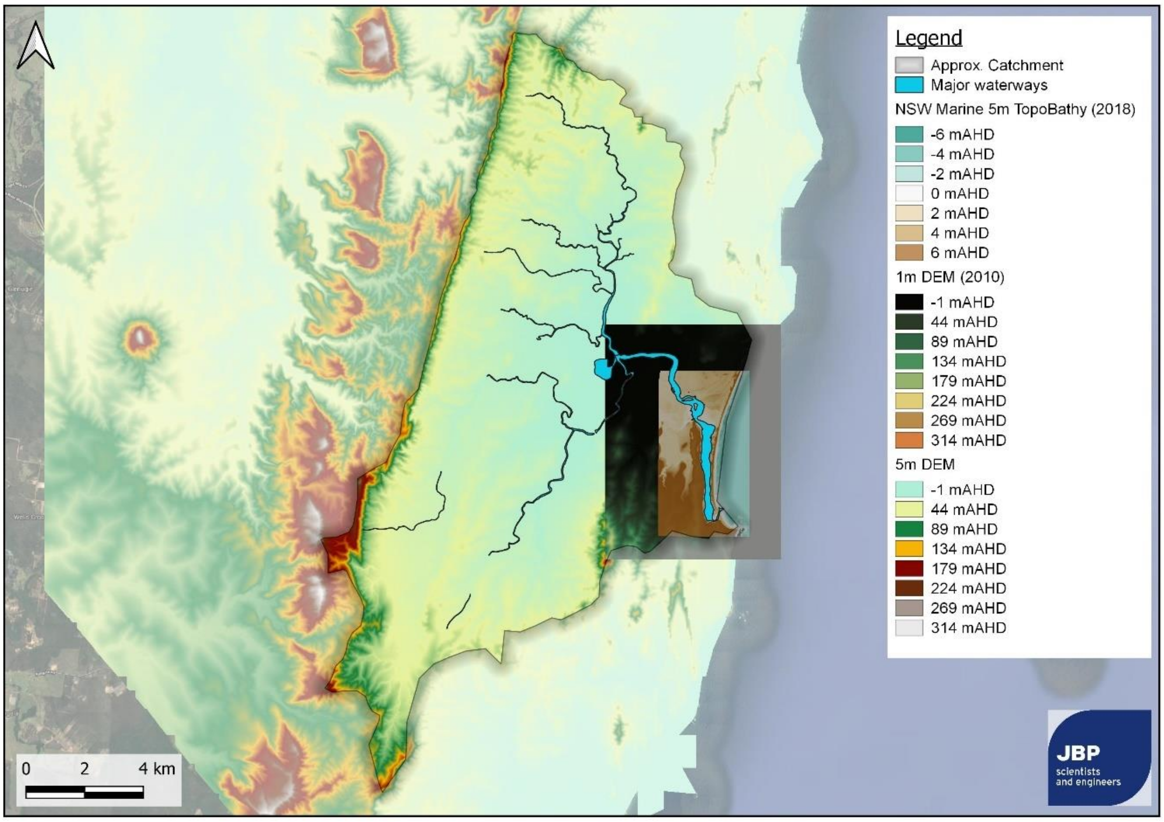

Figure 2-7: Overview of topographic information available within the catchment

Table 2-1: Summary of Topographic information

Dataset	Resolution	Coverage	Year of Capture	Relevance
LiDAR	1m	7%	2010	High
LiDAR	5m	100%	2001 - 2015	High
Topo-Bathy LiDAR	5m	17%	2018	High

Following a review of the topographic information, the relevance, timeline, and coverage of the 1m and 5m LiDAR-derived datasets, particularly when merged with bathymetry data, is considered reasonable and fit-for-purpose in the development of the hydrologic and hydraulic models for the Wooli Wooli River catchment.

The hydraulic model grid will use three spatial datasets within the hydraulic model extent to better define catchment features such as waterway crossing and major stormwater infrastructure.

2.4 GIS Data

2.4.1 Hydrolines

A GIS shapefile layer of the Wooli Wooli catchment hydrolines was extracted from the NSW Open Data portal. As shown in Figure 2-8, the hydrolines dataset names the tributaries, including Matenga Creek, Musicians Creek, Woodduck Creek, Bookram Creek, and Corkscrew Wanderer Creek, and Barcoongere Creek.

2.4.2 Culverts

A GIS shapefile layer was supplied by CVC, containing 175 structure data points. As shown in Figure 2-9, 95 structures are located within the catchment, with the remaining 80 located in the adjacent catchments.

The culvert information was supplied as a point dataset, which was not readily usable within the hydraulic model. This data has subsequently been used in conjunction with site inspections, aerial imagery and georeferenced as-constructed drawings.

2.4.3 Bridges

A GIS shapefile layer was supplied by CVC, containing point data for ten bridges. As shown in Figure 2-10, and listed below, three bridges are located within the catchment, and seven lay outside to the Wooli Wooli River catchment.

- Wooli Road at Falconer Creek
- Wooli Road at Matenga Creek
- Wooli Road at Bookram Creek

2.4.4 Surface Drainage

A GIS shapefile layer was supplied by CVC, containing point data for 42 surface drains. As shown in Figure 2-11, all 42 surface drains are located within the Wooli Wooli River catchment, within the urban areas of the catchment. As this study is focused on catchment flooding, it is unlikely that surface water drainage information will be required. However, a review of the coverage and completeness of data has been undertaken for thoroughness.

2.4.5 Land Zoning

A GIS shapefile layer was supplied by CVC containing land zoning polygon data, shown in Figure 2-12. A small portion of the southern area of the catchment is located outside of the Clarence Valley LGA – in the Coffs Harbour City Council LGA. From aerial photography, it is evident that this part of the catchment is undeveloped and is natural heavily forested state. We obtained NSW Government land zoning data for the missing area and updated the missing records.

The data appears to provide coverage across the catchment and is considered fit-for-purpose. The data is limited to future (planned) use only and does not include current land uses. Information on current land use was digitised using aerial imagery to support the development of the hydrological and hydraulic models.

2.4.6 Cadastral Information

A GIS shapefile layer was supplied by CVC containing cadastre and road reserve polygon data shown in Figure 2-13. The cadastre and road reserve information appears to include full coverage across the catchment and deemed fit-for-purpose.

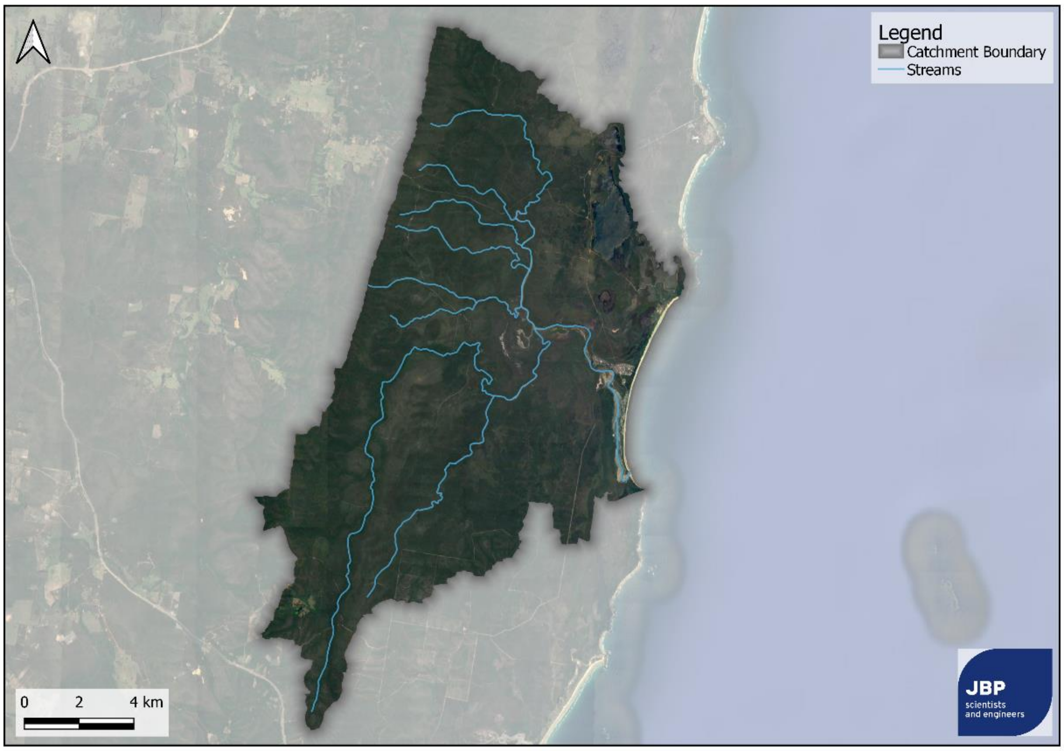

Figure 2-8: NSW Open Data Portal hydrolines

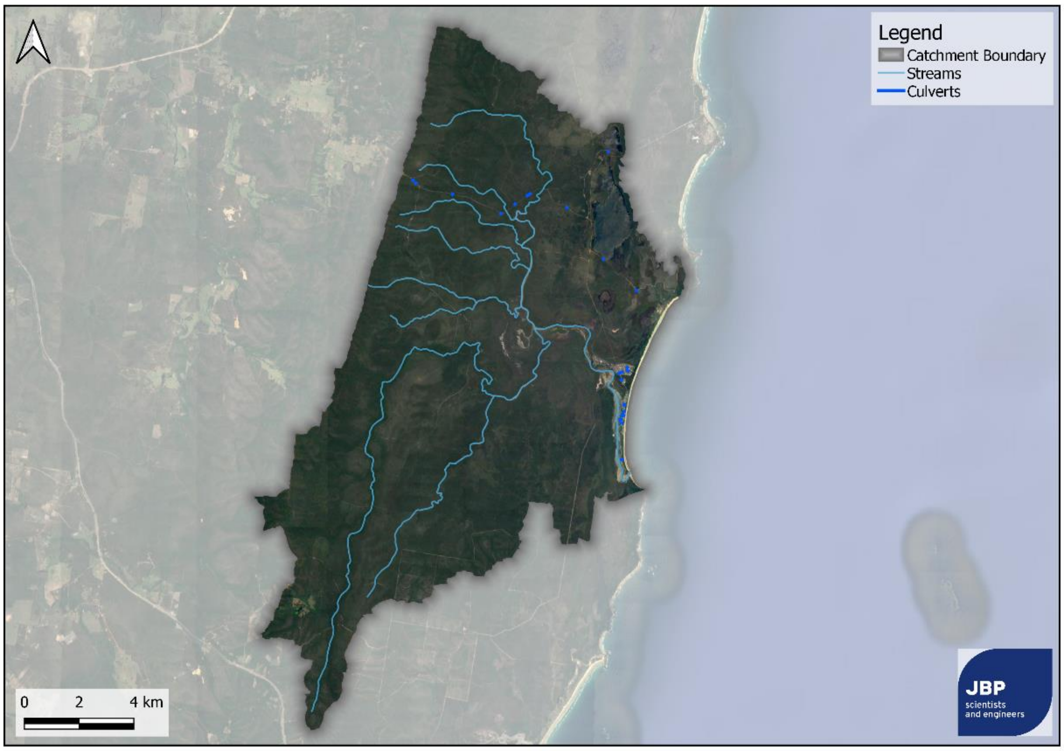

Figure 2-9: Location of GIS culvert data

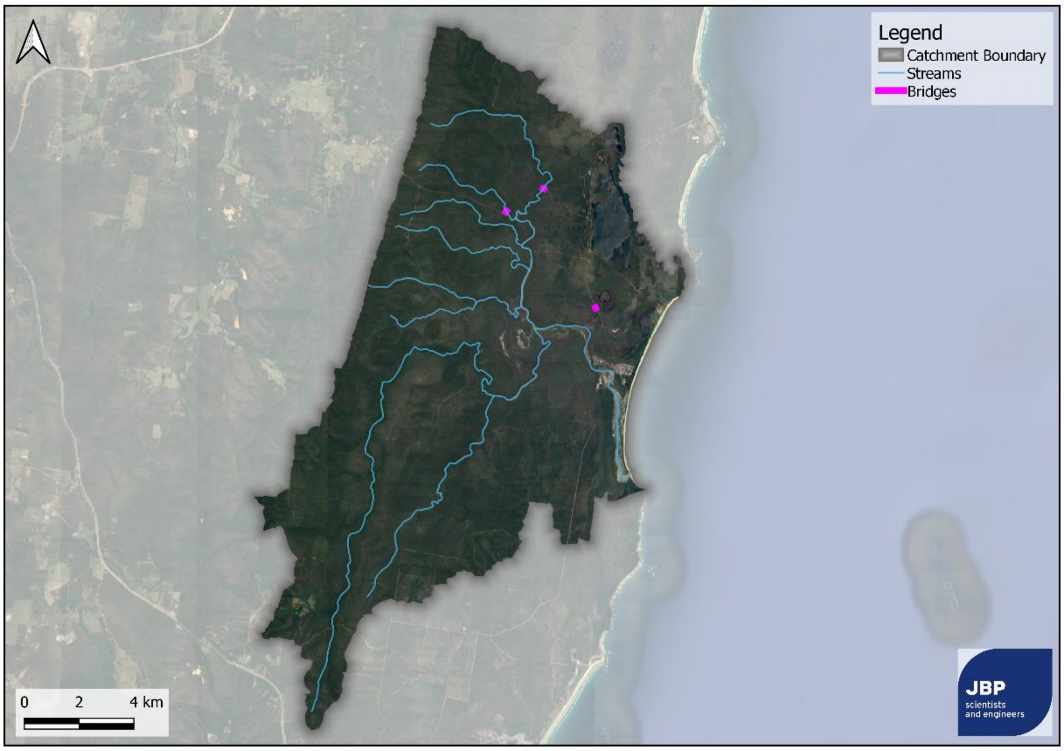

Figure 2-10: Location of GIS bridge data

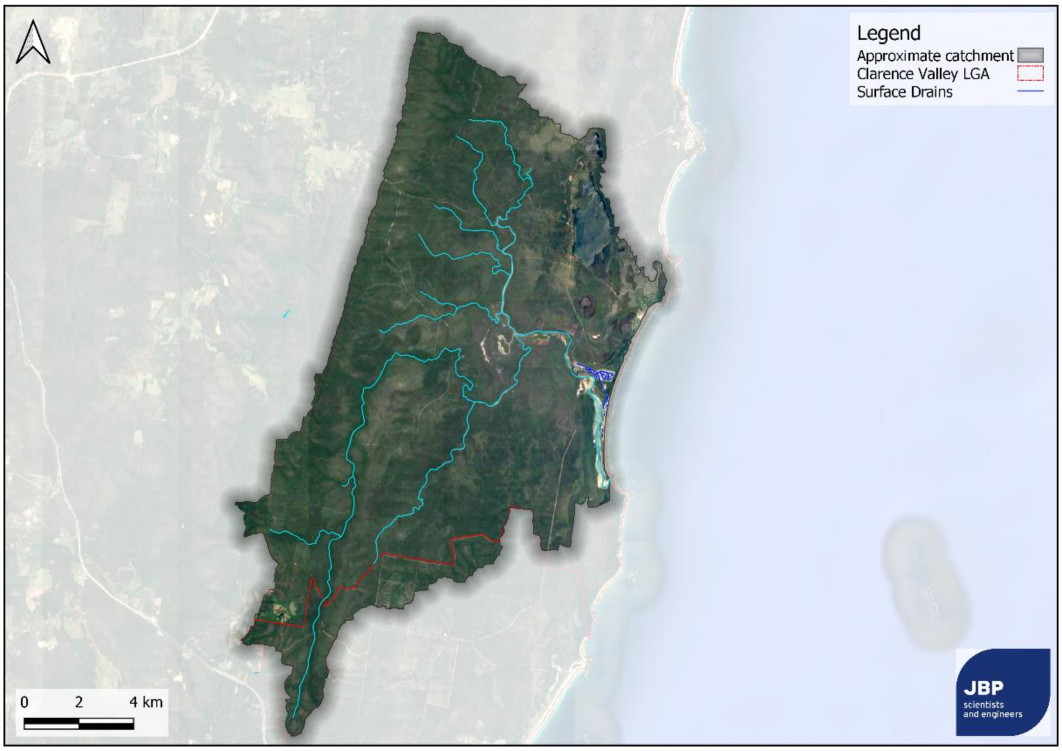

Figure 2-11: Location of GIS surface drainage data

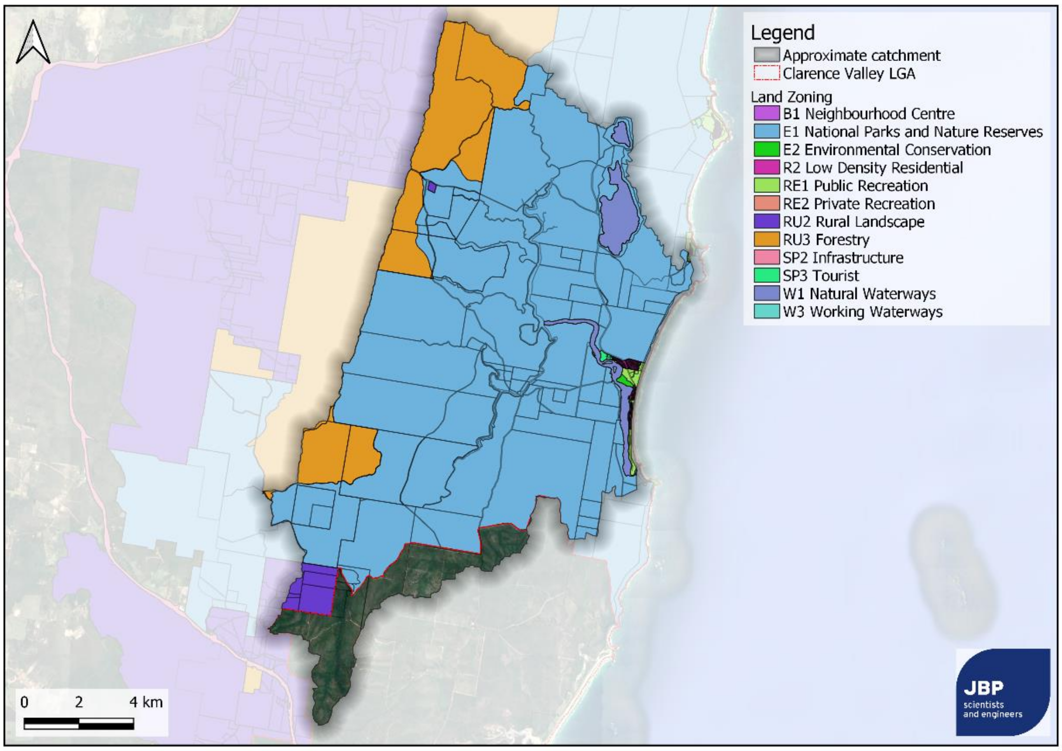

Figure 2-12: Location of GIS land zoning data

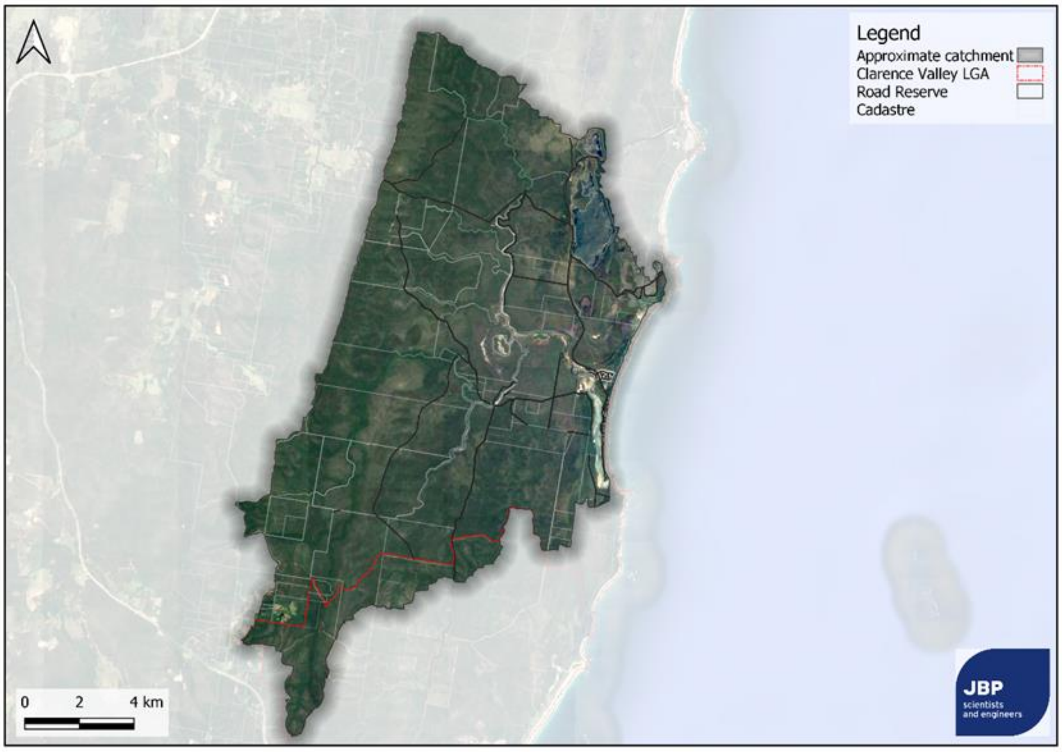

Figure 2-13: Location of GIS cadastre information

2.5 Structure Data

As noted in the review of GIS data, three bridges on Council-owned roads have been identified within Wooli Wooli River catchment (Falconer Creek, Matenga Creek and Bookram Creek). Structure information has been provided for the Matenga Creek and Bookram Creek bridges. This includes three design drawings of Bookram Creek crossing of unknown date, completed for Ulmarra Council as shown in Figure 2-14.

The supplied information also includes a ten-page drawing set of Matenga Creek crossing of unknown date, completed for Ulmarra Council as shown in Figure 2-15. Information on the bridge along Wooli Road at Falconer Creek has not been included in the data package. The supplied data was caveated with the need to field-check levels as the drawings may have been assumed rather than linked back to the Australian Height Datum (AHD).

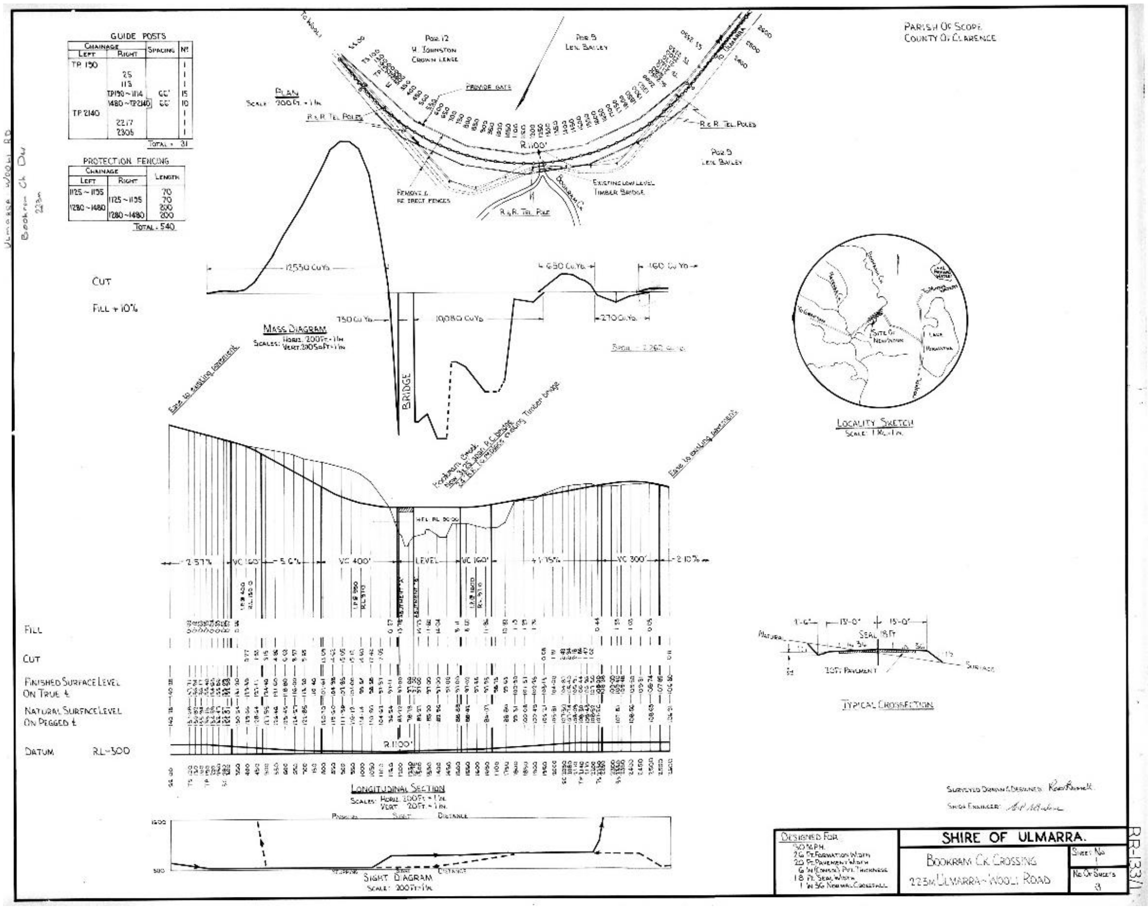

Figure 2-14: Design drawing for Bookram Creek crossing

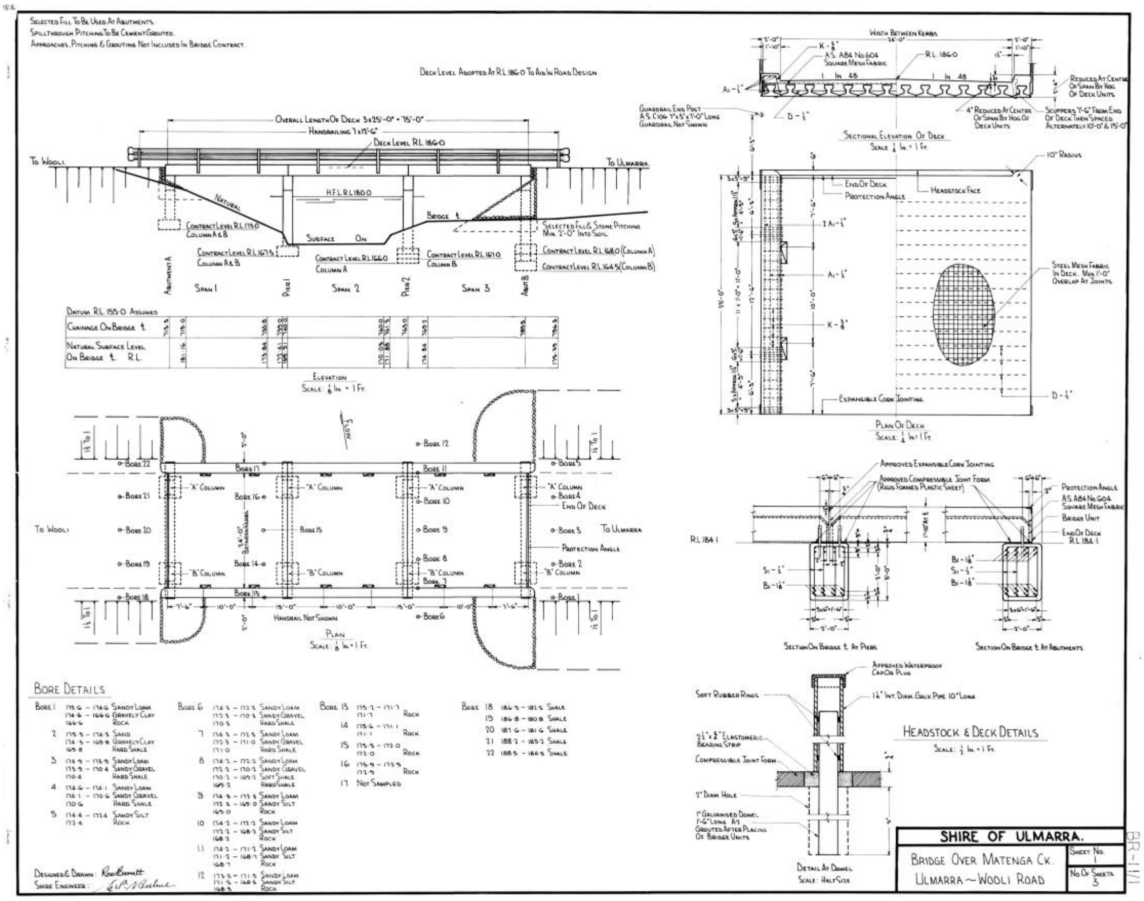

Figure 2-15: Design drawing for Matenga Creek crossing

2.6 Flood Information

2.6.1 Flood Gauges

Flood gauge information was supplied for four flood stations within the catchment. These gauging stations provided continuous data on rainfall and water levels in the catchment. Details for each gauge location was obtained from the Manly Hydraulics Laboratory (MHL) website and are presented in Table 2-2 and shown in Figure 2-16.

Table 2-2: Summary of gauge data

Station No	BoM No	Description	Type	Ownership
205462	559044	Wooli River at Wooli Entrance	Water Level	MHL
558060	558060	Wooli Caravan Park Rain	Rainfall	MHL
205463	558060	Wooli River at Wooli Caravan Park	Water Level	Council
58222	58222	Minnie Water (Pump Shed)	Rainfall	Council

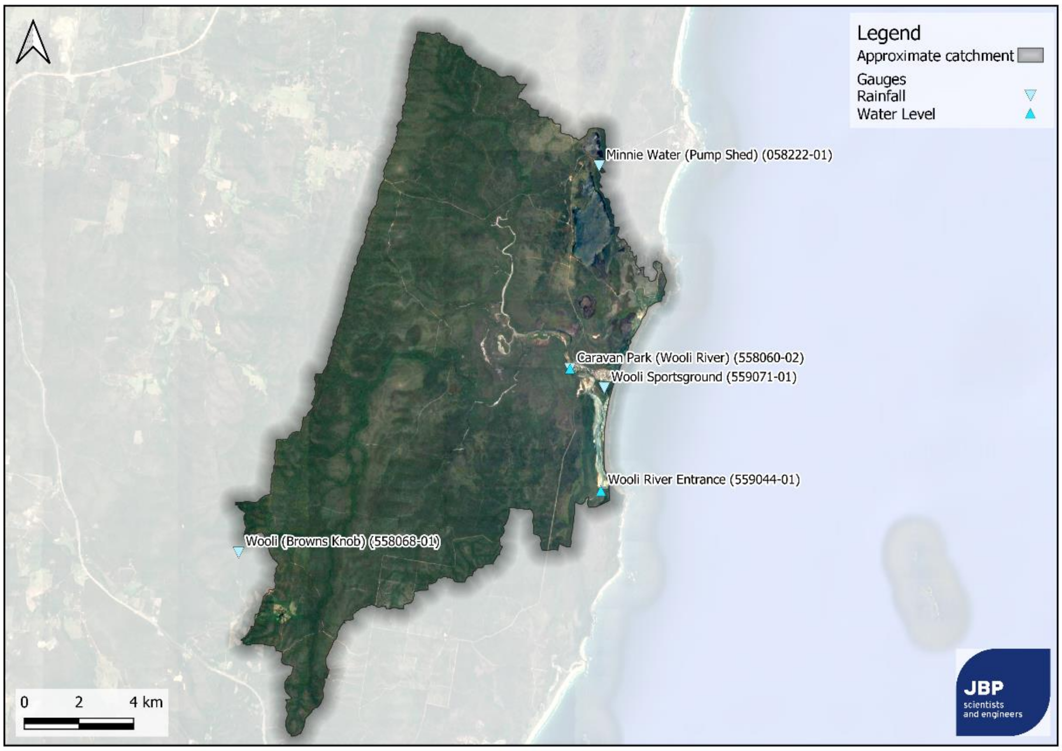

Figure 2-16: Location of flood gauges in the catchment

The available gauge records were provided by Council and, as shown in Figure 2-17 to Figure 2-19 to provide a significant period of record. The rainfall gauge record dates from 1997 (23 years) however, there is a gap in the rainfall record of nearly 4.5 years from July 2011 until November 2015. The longest period of continuous record is 14 years, from 1997 to 2011. The river height gauges were installed in the first half of 1991 and provided 30 years of continuous water level data.

The supplied rainfall data provides a good record length, of high-quality continuous rainfall data and are considered fit-for-purpose to support the flood study. While the rainfall and river height information provides good historical data, relying on only one rainfall gauge in the lower catchment will limit the spatial variability of historical rainfall events. It may be necessary to obtain data from rainfall gauges outside the catchment or from adjoining local governments, such as Coffs Harbour City Council to the south. A review of the MHL website indicates there are no known rainfall gauges in nearby catchments. If additional rainfall gauge information is made available, this will assist with flood model calibration and validation.

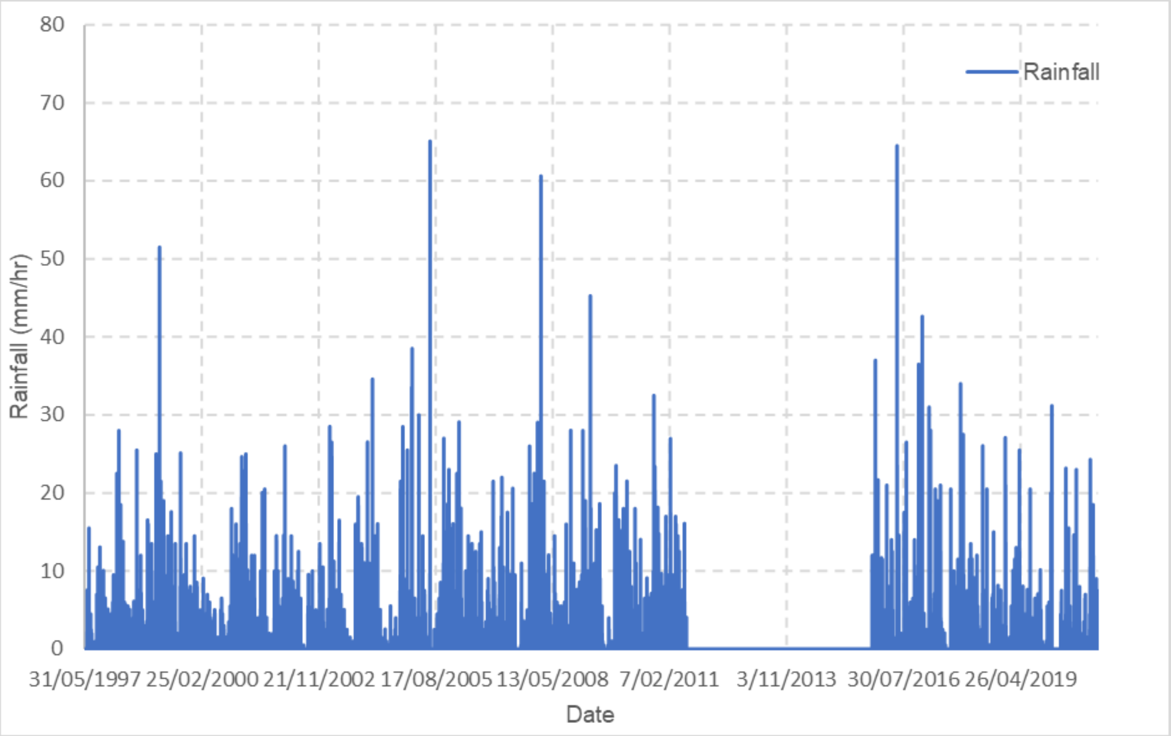

Figure 2-17: Rainfall records at Wooli Caravan Park Rain gauge (558060)

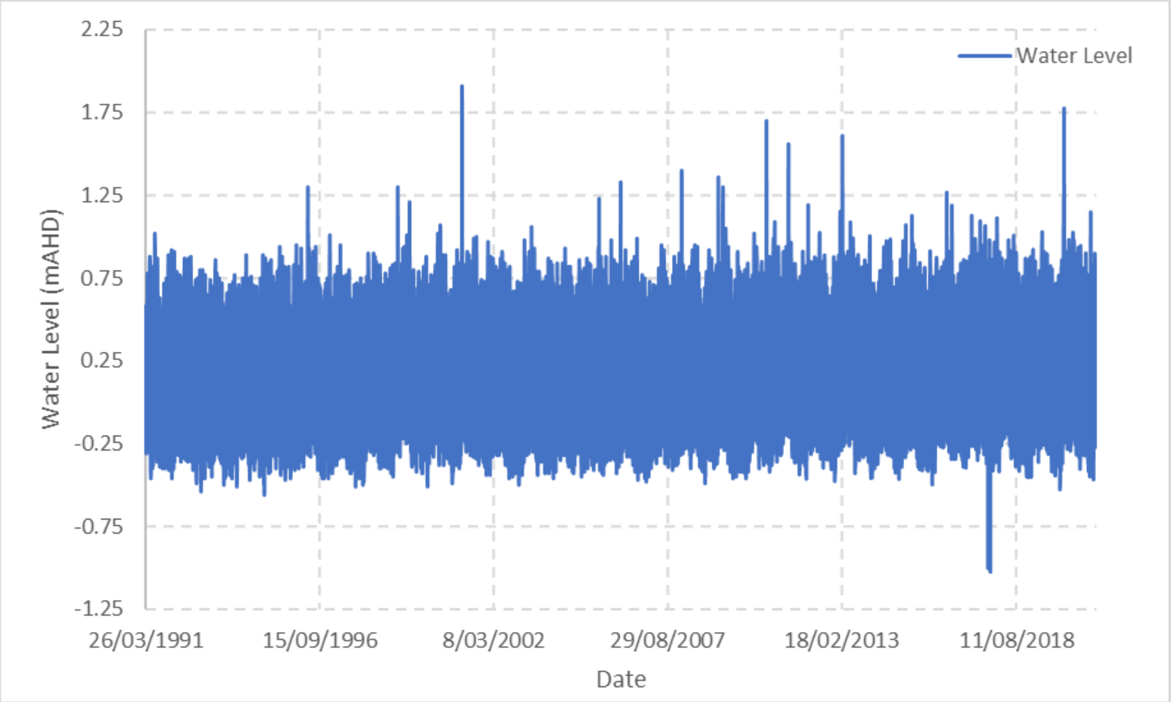

Figure 2-18: Water Level records at Wooli River at Wooli Caravan Park gauge (559044)

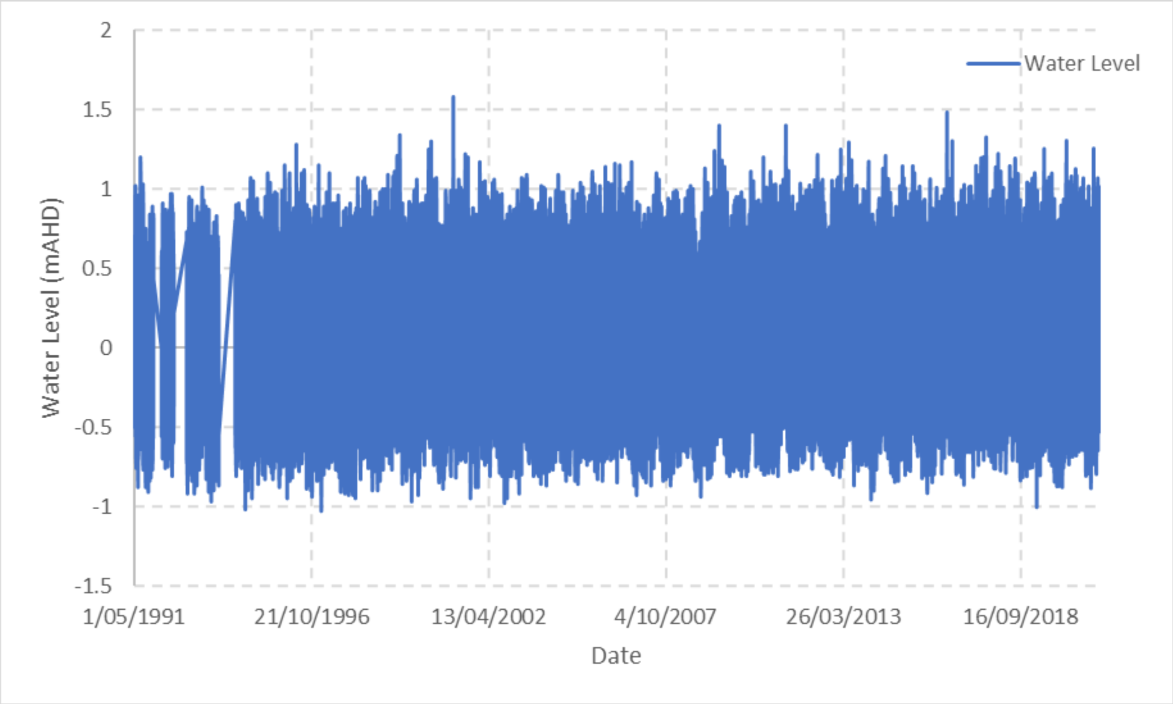

Figure 2-19: Water Level records at Wooli River at Wooli Entrance (558060)

2.6.2 Historical flood event survey

Post-event flood surveys of debris lines and flood inundation extents can be valuable in calibrating and validating flood models. In the case of the Wooli Wooli River, historical flood-survey data was obtained from the 1995 flood study report, the surveyed data points for 1974 flood event are shown in Figure 2-20.

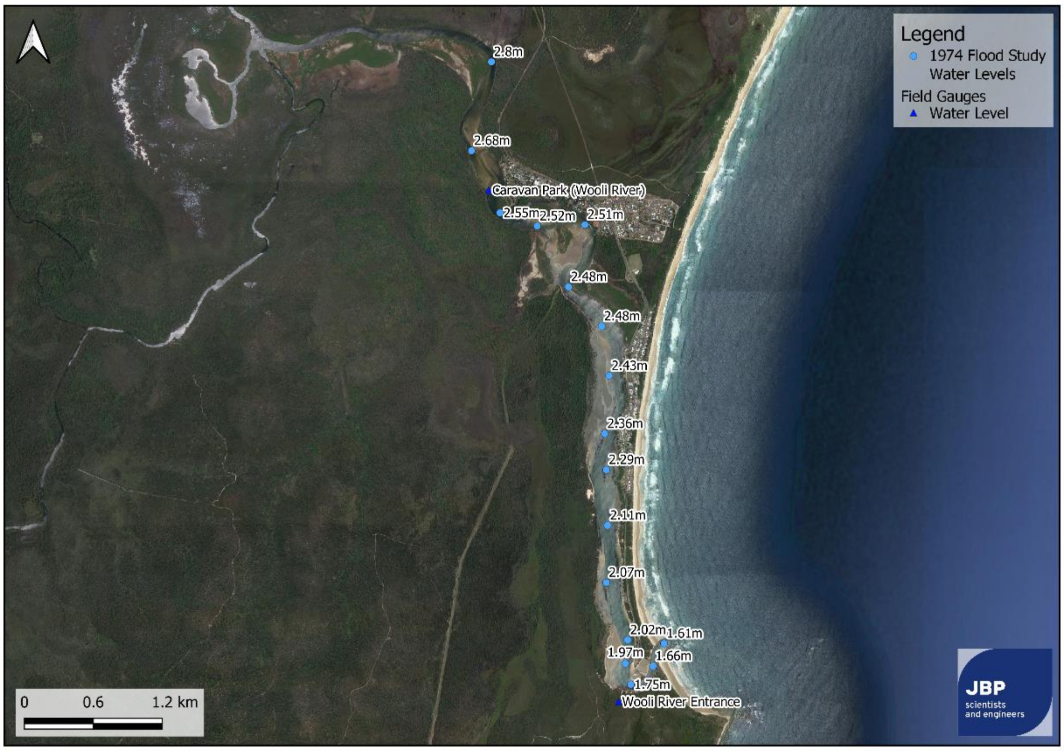

Figure 2-20: 1974 Flood levels from the 1995 Flood Study

2.7 Coastal processes

2.7.1 Tidal records

Tidal planes are available from the NSW tidal planes analysis (1990-2010)[4] and are presented in Table 2-3 for the two water level gauges:

- Wooli River Entrance, AWRC No: 205462
- Wooli River Caravan Park, AWRC No: 205463

Table 2-3: Tide levels from OEH Tide Analysis

Tidal Plane	Annual average	
	Entrance	Caravan Park
HHWSS	0.923	0.733
MHWS	0.572	0.418
MHW	0.450	0.360
MHWN	0.328	0.303
MSL	-0.006	0.097
MLWN	-0.340	-0.109
MLW	-0.462	-0.167
MLWS	-0.858	-0.225
ISLW	-0.835	-0.449
*Annual average tidal plane between 1990-2010. The information supplied has been collected for use by the OEH, and the tidal plane heights only approximately relate to Australian Height Datum (AHD).		

2.7.2 Extreme sea levels

Extreme sea level estimates to be used for flood studies are available from two sources, the Manly Hydraulics Lab (MHL) and DPE (Formerly the NSW Office of Environment and Heritage (OEH)).

The latest sea level statistics, not including any setup components, were published by the MHL in 2018 for a range of NSW coastal locations[5]. The closest available reporting point is Coffs Harbour, located approximately 50km south. These estimates are provided in Table 2-4.

The OEH, 2015 Guideline on modelling the interaction of catchment flooding and oceanic inundation in coastal waterways presents a range of extreme sea levels which includes setup and other flood planning requirements. These are split into several groups, as shown below.

- Group 1: Open embayments
- Group 2: Tide dominated estuaries
- Group 3, Type A Estuary (trained entrances, navigable for large vessels)
- Group 3, Type B Estuary (trained entrances, navigable for small vessels).

Under the guideline, the Wooli Wooli River estuary is classified as a group 3, Type B estuary, and recommended to use a 2.0m AHD 5% AEP downstream boundary and 2.1m AHD 1% downstream boundary. These levels have been adopted for this study.

Table 2-4: Extreme sea-level estimates for the open coast

Station	20-year ARI level (m AHD)			100-year ARI level (m AHD)		
	Model	Lower limit	Upper limit	Model	Lower limit	Upper limit
Coffs Harbour	1.43	1.39	1.59	1.49	1.42	1.86

4 OEH (2011) NSW Tidal Planes Analysis 1990-2010 Harmonic Analysis

5 MHL (2018) NSW extreme ocean water levels. Final Report MHL2236. Prepared for Office of Environment and Heritage

2.7.3 Tidal behaviour at the entrance

JB Pacific captured additional data on tidal current velocities near the entrance using a 'drifter'– which uses Global Positioning Satellite (GPS) technology in floating buoys, shown in Figure 2-21. The drifters record current velocity on rising and falling tides, as shown in Figure 2-22. The tidal current velocity data will be used to calibrate modelling completed as part of the analysis of the coastal process within the Wooli Wooli River estuary.

Figure 2-21: Drifter technology used to measure tidal current velocity

Figure 2-22: Recorded tidal current velocity near the Wooli Wooli River entrance

3 Hydrological Analysis

3.1 Catchment review

The catchment covers an area of approximately 195km^2 with a steep longitudinal escarpment running north-south along its western boundary. The catchment is generally undeveloped, except for the Wooli village near the river's confluence with the Pacific Ocean. The catchment topography has a maximum elevation of approximately 266m AHD on the west, which falls to sea level at the river entrance. The main reach of the Wooli Wooli River can be seen in Figure 3-1, which shows several tributaries joining the main channel towards the middle to lower portion of the catchment.

3.2 Hydrologic modelling approach

Catchment-wide hydrologic conditions have been analysed using a hydrological model developed in the Unified River Basin Simulator (URBS) software. URBS is a semi-distributed nonlinear rainfall-runoff model, which combines the rainfall-runoff and runoff routing components of the modelling process and allows users to configure the model to match the characteristics of individual catchments. The model was developed for use in a real-time environment in addition to design flood estimation. Adopting URBS for the hydrologic analysis is consistent with industry-standard approaches and provides a robust approach to the estimation of rainfall-runoff across the catchment. It also allows for simple inclusion to a flood forecasting system, to assess real-time rainfall and flow conditions, to aid in the prediction of flooding for flood disaster management.

3.3 Digital Elevation Model

The catchment is mostly covered a 1m resolution LiDAR DEM. 5m LiDAR DEM tiles provide coverage in the upper extent of the catchment, outside of the 1m DEM coverage. The two data sets have been merged to provide a single seamless coverage of the catchment. All DEM tiles were sourced from the requested ELVIS service.

3.4 Model Reporting Locations

Prior to the catchment delineation, a review of the gauges within and around the catchment was performed. These gauges were sourced from the BoM gauge network and the client-provided data. Influential hydraulic structures were also identified. Where possible, sub-catchments were delineated to appropriately capture the listed reporting locations to accommodate hydrological model calibration and hydraulic model inputs.

Table 3-1. Key Reporting Locations

Location	Type
558060 – Caravan Park (Wooli River)	Level Gauge
559044 – Wooli River Entrance	Level Gauge
7738-BR-0001 Falconer Creek	Bridge
7738-BR-0001 Matenga Creek	Bridge
7738-BR-0001 Bookram Creek	Bridge

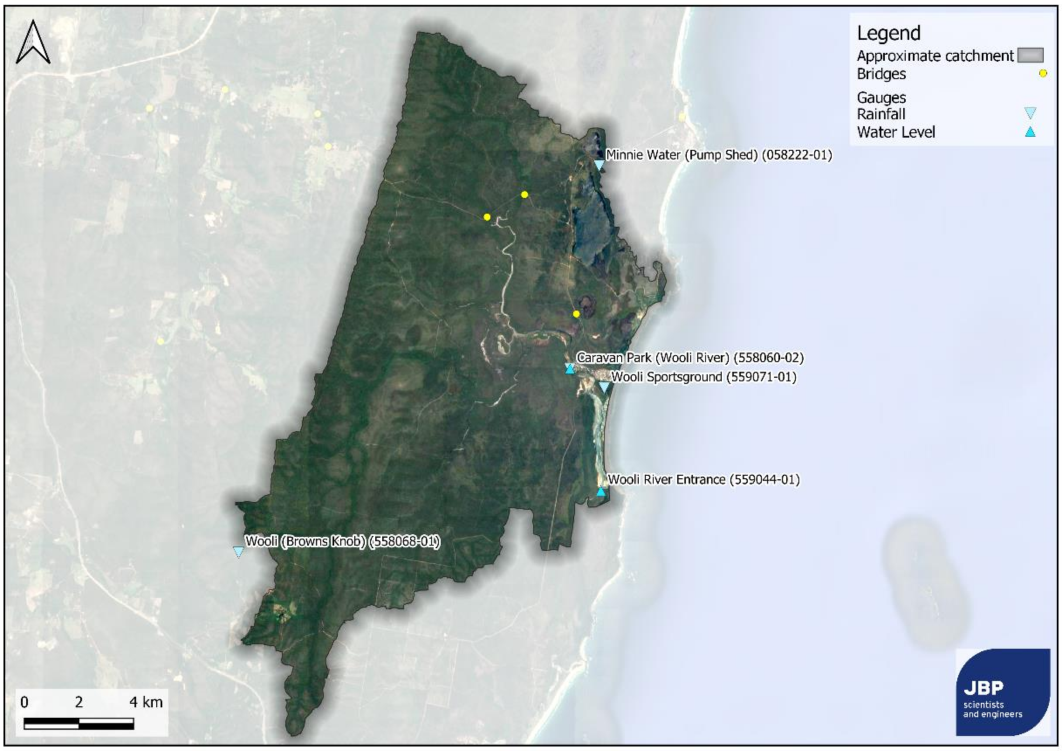

Figure 3-1. Key reporting locations in Wooli Wooli River

3.5 Sub-catchment delineation

Identified real-time water level gauges and critical reporting locations were prioritised when delineating the catchment, which will serve as calibration locations. The process of delineating the catchment involved the iterative use of CatchmentSIM and QGIS, where manual sub-catchment delineation was performed in areas of low gradients. The key sub-catchment information from the URBS model schematisation is summarised in Figure 3-2.

Table 3-2. Sub-catchment parameters

Model	Number of sub-catchments	Maximum sub-catchment area	Minimum sub-catchment area	Average sub-catchment area
URBS	142	339 ha	25 ha	124 ha

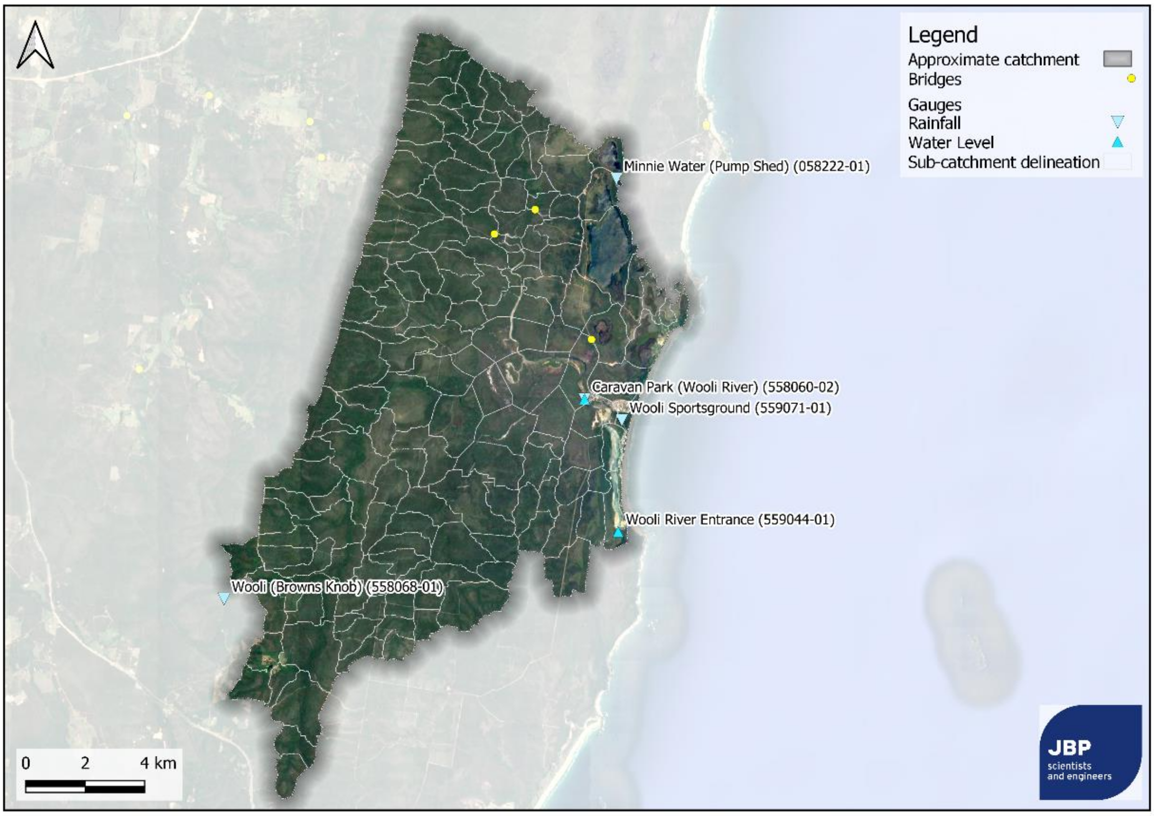

Figure 3-2. Sub-catchment delineation and gauges/reporting locations

3.6 URBS Model Calibration

The hydrologic model was calibrated to match recorded water level data. This has been undertaken through a joint-calibrating process, using the outputs of the hydrological and hydraulic model to estimate flows and water levels. This section describes the hydrologic model calibration, using a rating table to convert flow estimates to water level estimates. Hydraulic model development and calibration is described in Section 4.

The URBS hydrological calibration was performed for four flood events with historically recorded water levels in the catchment:

- March 2021
- February 2020
- June 2016
- February 2013

The initial URBS model used default model parameters and losses based on Australian Rainfall and Runoff (ARR 2019) guidelines. As shown in Figure 3-3 initial losses between 20mm and 50mm are expected around the Wooli Wooli catchment, with continuing losses between 2mm/hr and 6mm/hr.

Flows were calculated in the hydrologic model and used as inputs to the hydraulic model, which simulated the resulting water level. Hydrologic model parameters were updated within URBS to provide revised flows to be re-run through the hydraulic model to improve predictions. This approach benefited through the incorporation of the dynamic downstream tidal conditions for the calibration events. This is a process in URBS that is limited to the use of tide-varying rating tables. Flow vs water level rating tables were developed from the hydraulic model results, which were incorporated into URBS to speed up the calibration process, this enabled the calculation of water level predictions without simulating the hydraulic model. The development of rating tables is discussed in Section 3.6.1.

This joint calibration improved confidence in both models in comparison to having a predeveloped rating curve. Successful calibration was achieved when peak water levels were reasonably achieved in both the hydrological and hydraulic models.

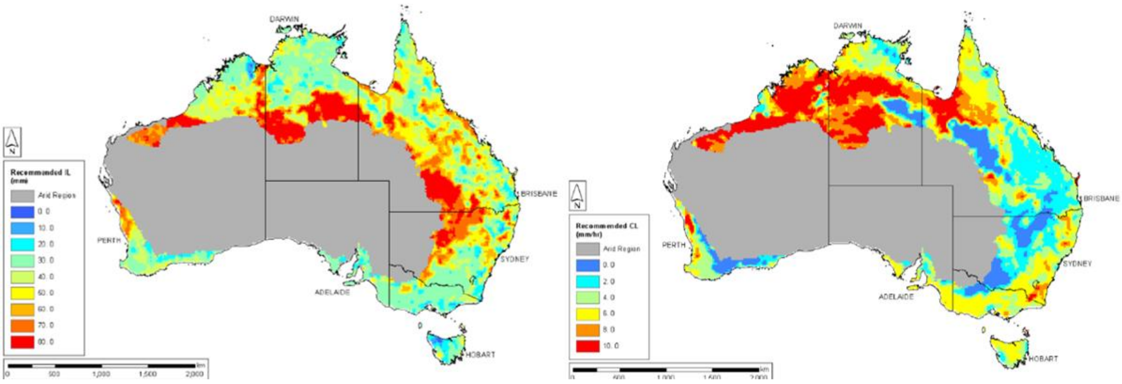

Figure 3-3: ARR Initial Loss (left) and Continuing Loss (right) estimates

3.6.1 Model derived rating curve

No existing rating curves are available for the water level gauges within the catchment. A new rating table was developed for the Caravan Park gauge using the results of the hydraulic model. Several calibration simulations were used to develop the lower-order flow vs level relationship shown in Figure 3-4.

The upper limit points (>450m^3/s) were adopted from the 1995 flood study[6], representing the water level and flow for the 5%, 2% and 1% flood. Trying to extract flows of this magnitude from a hydraulic model can be difficult due to the large floodplain. By combing hydraulic outputs and historical flood study values, the rating curve can estimate both low and high flows.

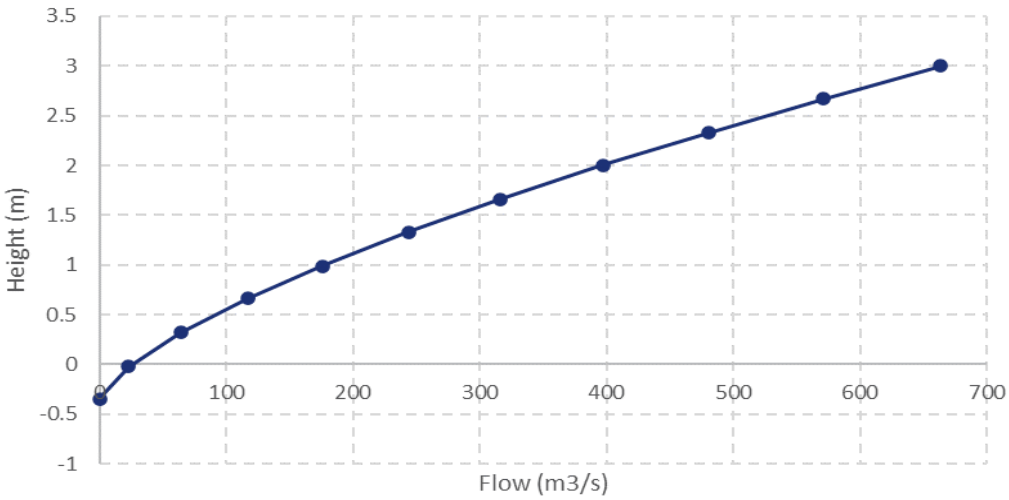

Figure 3-4: Rating curve for Caravan Park gauge (558060)

6 NSW Public Works (1995). Wooli Flood Study. Report Number 90016.

3.6.2 Calibration and validation for March 2021

Rainfall data was provided for two gauges for the March 2021 event:

- Minnie Water (58222), and
- Wooli Caravan Park (558060).

This data was distributed across the catchment using the URBS sub-rain feature. The channel routing parameter (α) and the catchment routing parameter (β) were adjusted to calibrate the hydrological model's routing. Continuing losses were calibrated to match the modelled hydrograph response time and discharge. While initial loss values were considered, these were less influential because the gauge locations were heavily tidally influenced.

Calibration to the March 2021 recorded hydrograph resulted in a fair correlation of timing of the peak hydrograph and a good calibration of the peak magnitude of the hydrograph. Modifications to the catchment delineation and the improved stage-discharge relationship achieved as part of the hydraulic model joint calibration improved the calibration of the URBS model to this event.

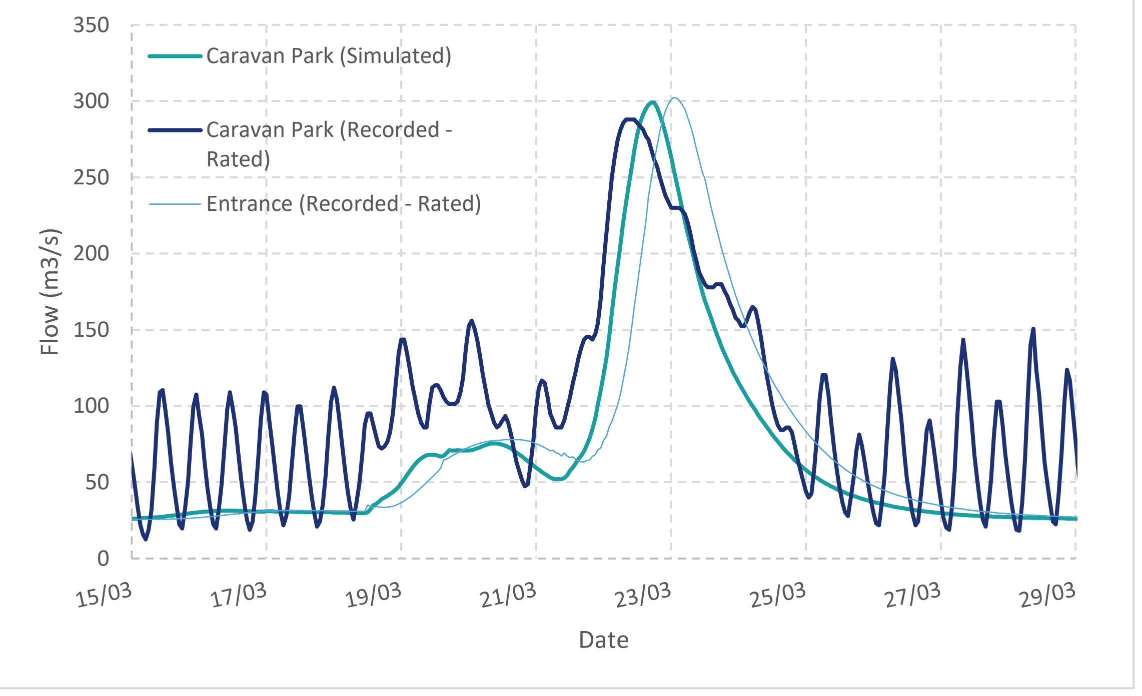

Figure 3-5: March 2021 hydrology model calibration - Wooli Caravan Park (558060)

3.6.3 Calibration and validation for February 2020

Rainfall data was provided for two gauges for the February 2020 event:

- Minnie Water (58222), and
- Wooli Caravan Park (558060).

This data was distributed across the catchment using the URBS sub-rain feature, channel routing parameter (α), catchment routing parameter (β), and losses used for calibration.

Calibration to the February 2020 recorded hydrograph resulted in a good correlation of timing of the peak hydrograph and a good calibration of the peak magnitude of the hydrograph. Modifications to the catchment delineation and the improved stage-discharge relationship achieved as part of the hydraulic model joint calibration improved the calibration of the URBS model to this event.

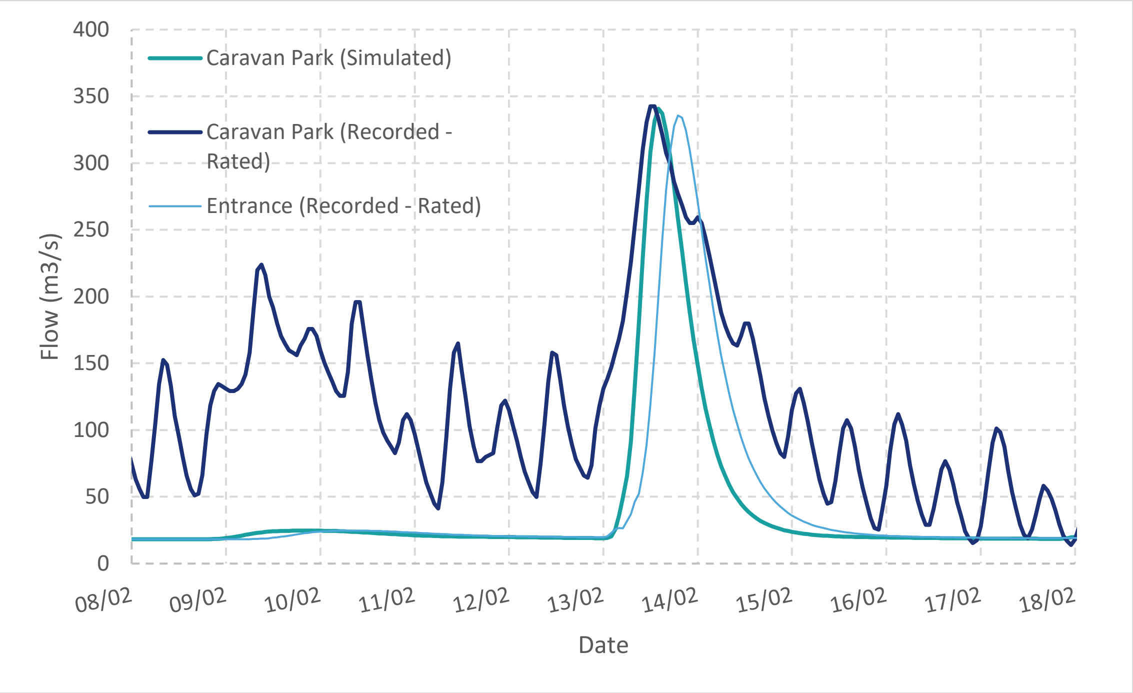

Figure 3-6: February 2020 hydrology model calibration - Wooli Caravan Park (558060)

3.6.4 Calibration and validation for June 2016

Rainfall data was provided for three gauges for the June 2016 event:

- Minnie Water (58222),
- Wooli Caravan Park (558060), and
- Browns Knob (558065).

This data was distributed across the catchment using the URBS sub-rain feature, and channel routing parameter (α), catchment routing parameter (β), and losses used for calibration.

Calibration to the June 2016 event was difficult as the event was dominated by elevated sea levels caused by a storm surge. The peak fluvial flows were predicted to occur during a low tide, limiting their peak magnitude. The timing of the peak hydrograph is considered to be good (however masked by the tides), and peak magnitude is deemed to be fair. Modifications to the catchment delineation and the improved stage-discharge relationship achieved as part of the hydraulic model joint calibration improved the calibration of the URBS model to this event.

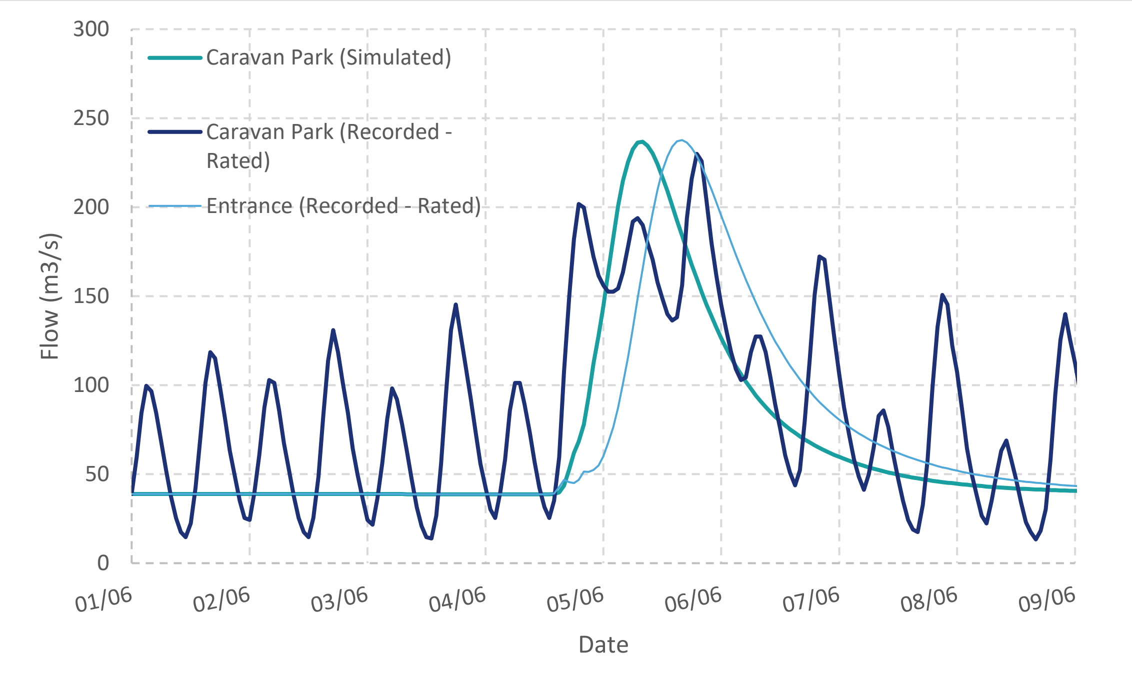

Figure 3-7: June 2016 hydrology model calibration - Wooli Caravan Park (558060)

3.6.5 Calibration and validation for February 2013

Rainfall data was provided for two gauges for the February 2013 event:

- Minnie Water (58222), and
- Wooli Caravan Park (558060).

This data was distributed across the catchment using the URBS sub-rain feature, channel routing parameter (α), catchment routing parameter (β), and losses used for calibration.

Calibration to the February 2013 recorded hydrograph resulted in a modest correlation of timing of the peak hydrograph and a good calibration of the peak magnitude of the hydrograph. Modifications to the catchment delineation and the improved stage-discharge relationship achieved as part of the hydraulic model joint calibration improved the calibration of the URBS model to this event.

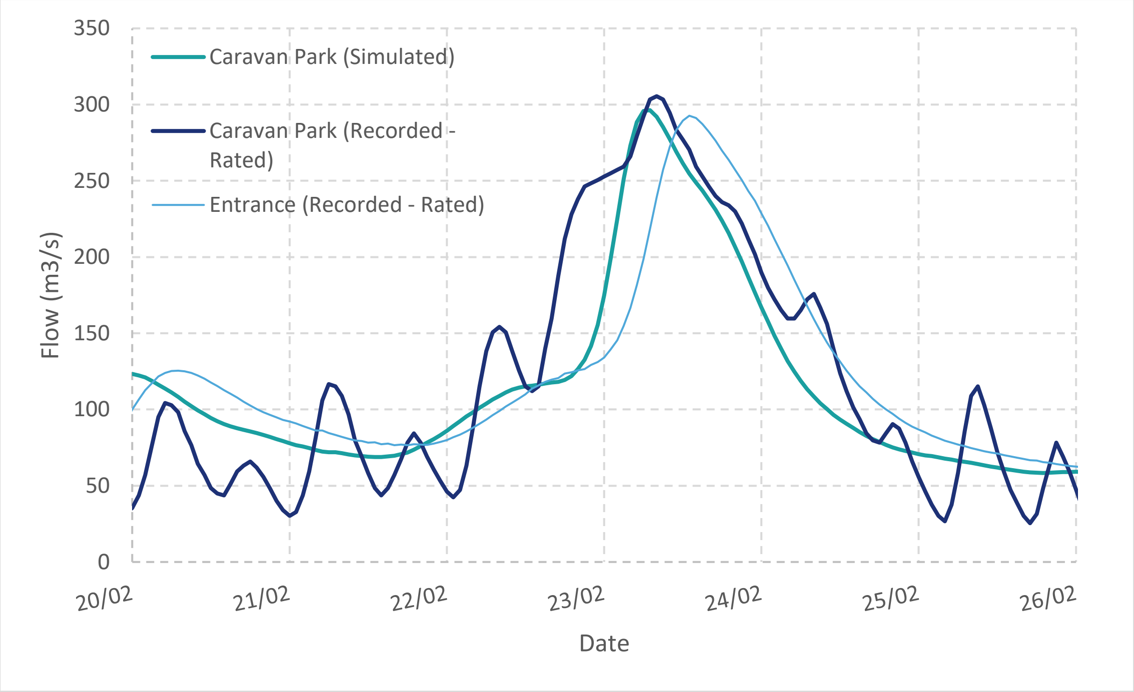

Figure 3-8: February 2013 hydrology model calibration - Wooli Caravan Park (558060)

3.7 Calibration Results

The URBS hydrological calibration was performed for four flood events with historically recorded water levels in the catchment, with the latter converted to flows through a (non-tidal) model-derived rating table. The URBS model predicts infiltration, runoff, routing and flow hydrographs. The performance of the hydrology to predict flows has been compared against rated recorded data, in addition to a visual comparison of the timing and shape of the hydrograph, which is considered equally important. This assessment is shown in Table 3-3 for the Caravan Park gauge. The model was found to have a good representation of the timing and shape of the hydrograph, although challenges exist due to the tidal interactions. The accuracy when predicting flows directly from the URBS model was typically ±4%.

Table 3-3: Hydrological model comparison at Caravan Park

Event	Recorded peak (m^3/s)	Simulated peak (m^3/s)	Difference (m^3/s, %)	Timing comparison	Shape comparison
Feb 2020	342.51	340.72	-1.79, -1%	Good	Good
March 2021	287.92	299.03	11.11, 4%	Fair	Good
June 2016	229.96	236.77	6.81, 3%	Good	Fair
Feb 2013	305.49	296.34	-9.15, -3%	Fair	Good

Average hydrologic model parameters were determined from the results of the four calibrated events. A summary of the calibration values for each calibration event are shown in Table 3-4. The average URBS parameters across each calibration event was adopted for the hydrological model when simulating design hydrology. These parameters are shown in Table 3-4 with the exception of the initial loss value. Due to the strong tidal influence at the calibration location, accurately capturing initial values for each event is difficult. The catchment representative parameters in Table 3-5 were adopted for the design hydrology estimates. Choosing an appropriate initial loss value to represent the catchment will be discussed in the design flood estimation section

Table 3-4: Summary of URBS calibration parameters

Event	March 2021	February 2020	June 2016	February 2013
alpha	0.20	0.12	0.18	0.13
beta	0.10	0.40	0.80	0.40
IL	2	0	0	0
CL	3	1	14*	0
*Omitted from the calculation of average model parameters due to magnitude				

Table 3-5: Adopted URBS parameters

Parameter	Adopted Avg. Value
alpha	0.15
beta	0.40
IL	2*
CL	2

3.7.1 Joint Calibration

The hydraulic TUFLOW model was jointly calibrated with the URBS model to achieve a better representation of measured and simulated water levels. Section 0 demonstrates the hydraulic model calibration, and validation process is in more detail.

4 Hydraulic analysis

4.1 Overview

The hydrodynamic flood, tidal and storm surge processes occurring throughout the Wooli Wooli catchment has been simulated using hydraulic modelling software. The TUFLOW modelling package was used to develop the two-dimensional (2D) hydraulic model. Two models have been developed; a regional-scale model covers the entire Wooli Wooli River watershed used for design simulations (see Figure 4-1), and a reduced extent (local) model covers the Wooli township used for hydrology model calibration and to generate rating curves. The local model is a sub-model of the regional model and shares the model setup steps described in the following sections.

4.2 Modelling assumptions and limitations

Modelling of cross drainage structures has been limited to major infrastructure considered to influence riverine flooding significantly. This includes structures with individual or a combined width of 0.6m or greater. Modelling the minor stormwater drainage network throughout the Wooli township was not included due to the scale of flood model, which would result in small drainage entities becoming sub-grid features that will not be well represented within the model.

Model roughness has been based on current land use types within Council zoning data. Missing data outside the Clarence LGA (the Wooli Wooli catchment extends into the Coffs Harbour LGA) has been sourced from the publicly available NSW land use data layer (2017).

The model extends 3km into the nearshore coastal region, which is used with recorded or predicted tide conditions at the Yamba of Coffs Harbour tide gauges. Due to the distance from Wooli, the gauge needs a timing correction of approximately ±1hr to match the conditions experienced at the site. For calibration, the preference has been to use the Coffs Harbour tide gauge record, which is located in the harbour precinct and is protected from waves.

4.3 Hydraulic model setup

An overview of the model setup is shown in Figure 4-1, which shows the regional TUFLOW model extent through to the downstream boundary. The model replicates the storage effects of the low-lying swampland throughout large areas of the lower catchment, which can have a significant influence on the model results. The model development has included the following steps:

- Establishing internal and external model boundaries
- Terrain modelling; Building a digital terrain using Light Detection and Ranging (LiDAR), DEM, cross-sections and bathymetric data
- Developing a model roughness grid using land use maps
- Incorporating hydraulic structures
- Specifying model outputs include plot objects, gauge plots, flood monitoring receptors for buildings, and critical drainage crossings.
- Developing workflows to ensure outputs can be used within the Floodplain Risk Management Plan, such as evacuation route planning and hazard mapping.

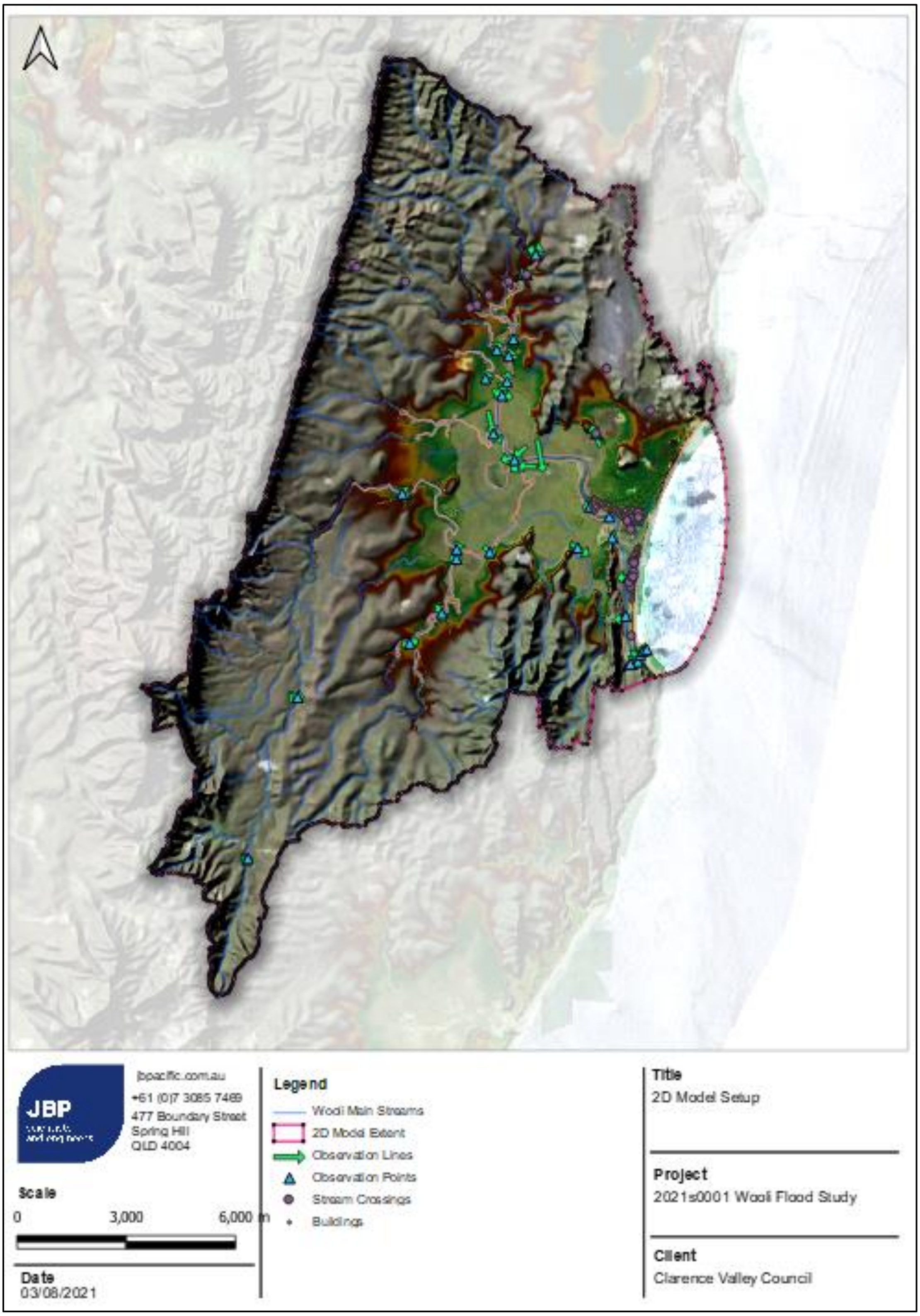

Figure 4-1: Hydraulic model layout

4.4 Digital Elevation Model

Multiple elevation datasets were used in setting up the model topography. These include:

- 1m resolution LiDAR data. Source: ELVIS Data Portal
- 5m Topo-Bathy DEM. Source: NSW DPE Marine LiDAR Project 2018
- Bathymetric Survey (2020). Source: Resource Design & Management (RDM) Pty Ltd
- Wooli Wooli River section data (STAX 2003). Source: DLWC NSW
- Wolli offshore bathymetry (STAX 2007). Source: DECC NSW
- Results of a Delft3D morphologic model, as discussed in Section 5.8.5.

4.4.1 Topographic Adjustments

The elevation and bathymetric data were reviewed and processed before being merged into the model topography. The following amendments were carried out.

- Bathymetric survey (2020). The supplied data was converted from Computer Aided Drafting (CAD) format into a Geo-Tiff format. Both the new survey data and the publicly available Topo-Bathy DEM bathymetric data showed a strip of missing data, which was interpolated using terrain modifier polygon (Z-shape) in TUFLOW.
- Road centre lines. The road centreline layer was used to define a road crest height. The road centreline layer obtained from the NSW geospatial database was filtered to reflect the current road geometry using available aerial imagery. The vector layer was then converted into a 10m interval points layer and sampled using the latest DEM data to assign crest heights. This was used to reinforce crest heights in the Sub-Grid Sampled (SGS) model. The enforcement of crest heights prevents water from leaking through any road embankment.
- Stream centre lines. Elevation along the stream centre line was lowered using the traditional approach of simulating efficient flow paths in the TUFLOW model. By using the SGS technique, the model reads riverbed levels to the nearest measured values and does not require stream burning.
- Topographic adjustments at bridge crossings. The 2D bridge modelling approach required 'open river' crossing to model bridge losses. Some of the bridge superstructures were not removed from the LiDAR when it was originally processed, and as a result, the streambed has been filled to this height within the DEM. These bridge embankments were removed manually using 2d_zsh geometry modification layers in TUFLOW. This reads the riverbed elevations upstream and downstream of the bridge and interpolates across the road corridor.
- Channel bathymetry. The Wooli Wooli River has unique floodplain characteristics with swamp land extending 15km inland with water generally sitting at a mean sea level during recent LiDAR surveys. LiDAR was not observed to penetrate this standing water, which may have been due to its colour at the time. The channel bed level was incorporated into the model using the advanced triangulation techniques available in TUFLOW, which have extruded surveyed river sections to create the bathymetry, as shown in Figure 4-2.

4.4.2 Quadtree and Sub-Grid Sampling

The TUFLOW model was built by incorporating the latest model enhancements of Quadtree and Sub-Grid Sampling. Quadtree allows for the refinement of cell resolution, with two layers of nesting applied throughout the domain. The regional base layer has a 10m grid cell resolution, while the quadtree regions have a 5m resolution, mainly focusing on Wooli Township.

Sub-Grid Sampling has been implemented, which removes all saw-tooth sidewall loss artefacts created by cell orientation. It brings cell size-independent accuracy into the model where the topography is adequately defined (i.e., with 1m resolution terrain data).

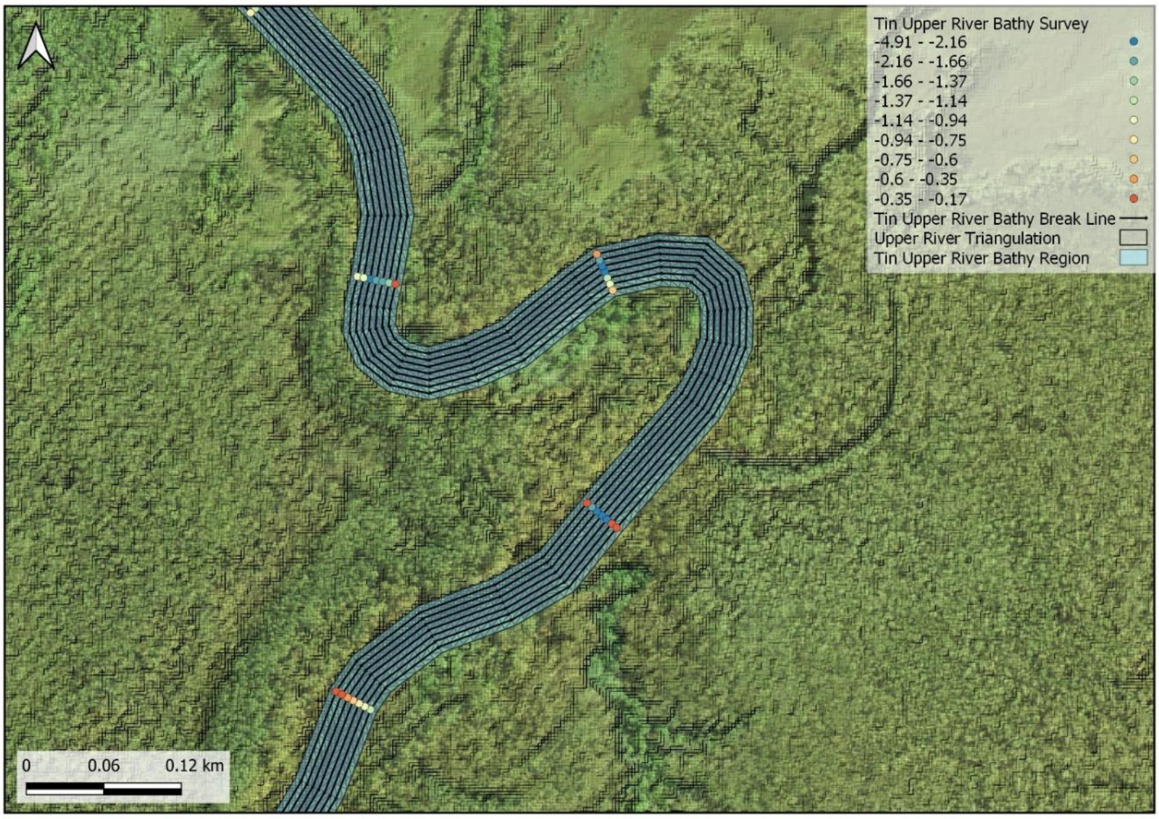

Figure 4-2: Riverbed triangulation input and output modelling layers

4.5 Modelling Structures

Modelled cross drainage structures included bridges and large culverts, which are described in the following sections.

4.5.1 Bridges

Three bridge crossings have been incorporated along Wooli Road at Matenga Creek, Bookram Creek and Falconer Creek. The bridge at Matenga Creek has been established based on as-constructed engineering drawings. Whilst no as-constructed information was available for the Bookram Creek bridge, given its similarity to the Matenga Bridge, the superstructure dimensions have been copied. No as-constructed information is available for the Falconer Creek Bridge, which is the shortest structure. The deck level has been based on LiDAR, and the bridge has been assumed to have no piers under the bridge deck. Table 4-1 lists bridge crossing details sourced from design drawings & supplied GIS data.

Table 4-1: Bridge Crossing Details

Bridge Crossing Name	Length	Width	Obvert
Bookram Creek	24.50	5.00	5.04
Falconer Creek	7.80	7.00	2.06
Matenga Creek	22.80	7.00	3.82

4.5.2 Culverts

Cross drainage structures greater than 0.6m width were included in the hydraulic model. The cross-drainage database has been supplied as a point layer, which was processed into a line vector perpendicular to the road centre line, with the inlet and outlet locations shifted to the nearest upstream and downstream headwall structure seen in aerial imagery.

4.6 Boundary conditions

4.6.1 Inflow Boundaries

Inflow Q-T boundaries were established using the hydrologic model sub-catchment delineation. Runoff was discharged at the lowest elevation of the sub-catchment outlet point to freely flow over the model terrain and combine to form the dominant flow paths. The sub-catchment delineation is shown in Figure 4-3.

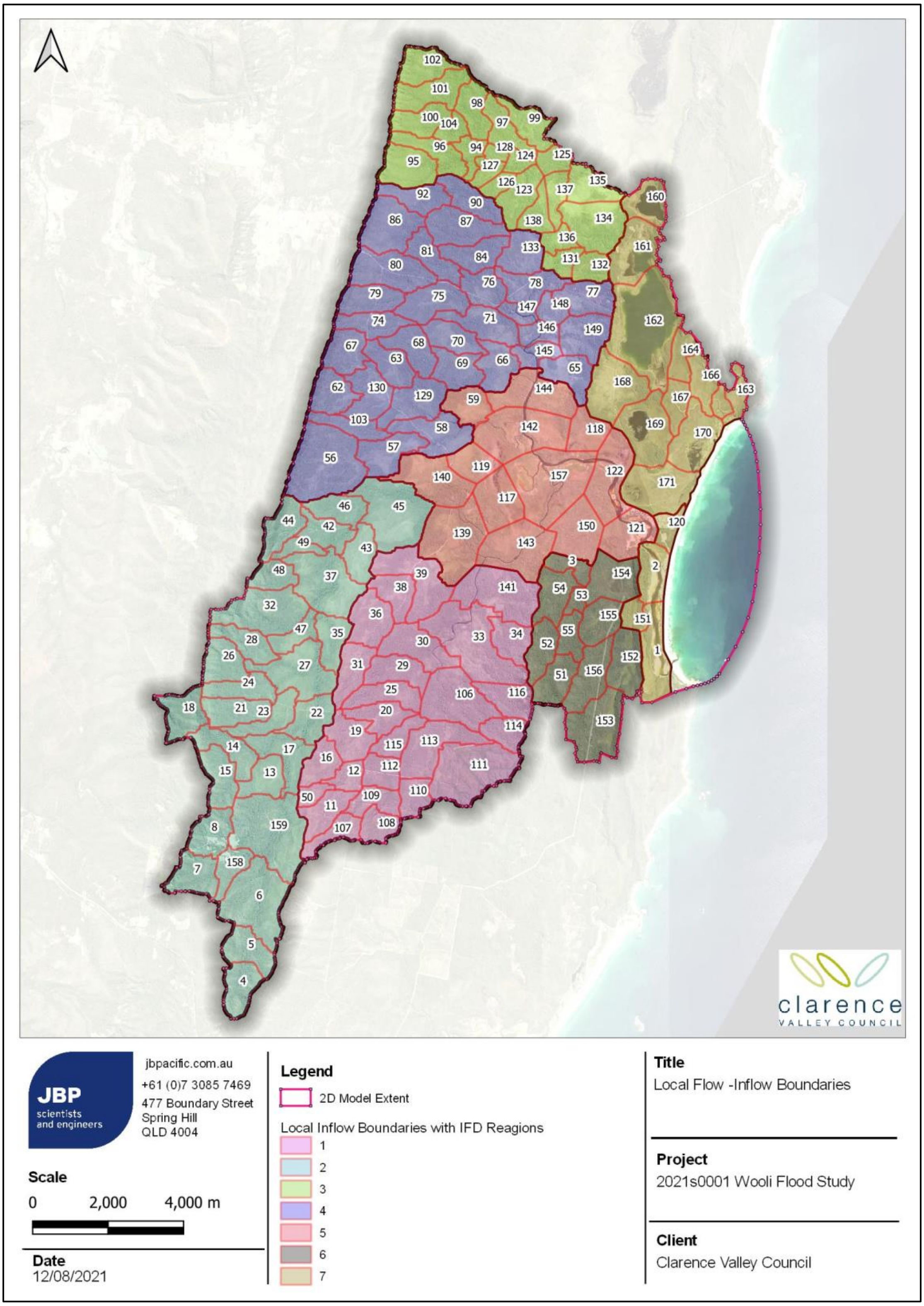

Figure 4-3: TUFLOW inflow boundaries

4.6.2 Downstream Boundaries

The ocean boundary extends 3km offshore from the Wooli Wooli River entrance. This is positioned well away from the river mouth to remove boundary impacts on water levels whilst capturing the nearshore region and any associated sandbars.

4.7 Hydraulic model roughness

Land use data obtained from CVC was used to define roughness categories initially. Additional processing then included:

- Superimposing the water corridor layers based on GIS data.
- Manually updating a building GIS dataset that represents permanent structures with high roughness values.
- Adding permeable and impermeable surfaces based on the road reserve GIS data.

The final material roughness is expressed in terms of Manning's n value. The hydraulic model roughness parameters are shown in Table 4-2, and the spatial distribution of roughness categories are shown in Figure 4-4.

Table 4-2 Hydraulic roughness classifications

Material ID	Hydraulic roughness Description	Manning's Roughness Value
1	Roads & Dirt Track	0.025
2	Environmental Conservation	0.16
3	Forestry	0.075
4	Infrastructure	0.06
5	Residential	0.20
6	Swamp	0.09
7	Natural Waterways	0.03
8	Neighbourhood Centre	0.065
9	Light Vegetation	0.07
10	Managed Vegetation	0.06
11	Medium Vegetation	0.11
12	Dense Vegetation	0.12
13	Waterways	0.035
14	Sandy Coast	0.033
15	Ocean	0.02
16	Buildings	0.20
17	Inland Sand	0.05

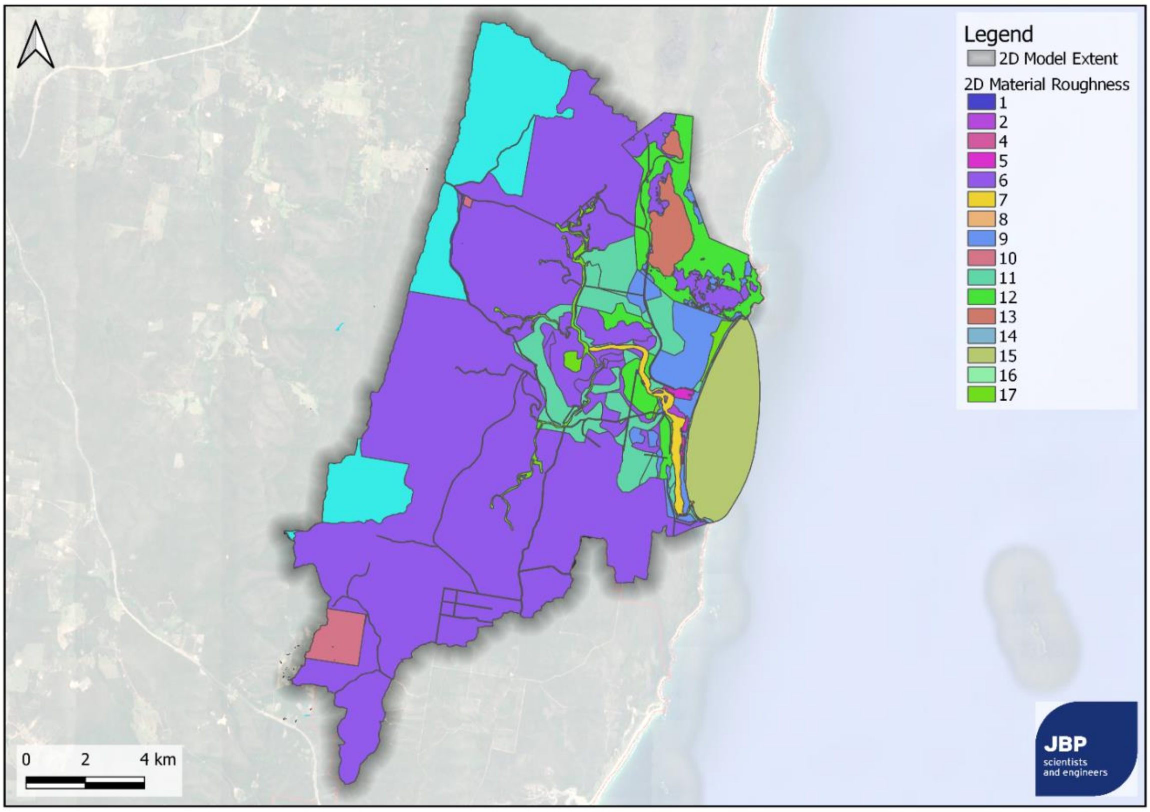

Figure 4-4 Roughness Definition

4.8 Model outputs

The following model outputs have been configured within the model:

- Map outputs - flood depth, velocity, height, and hazard
- Tabular results -water level and discharge values at points of interest
- Gauge outputs - inundation times relating to gauge locations, i.e., buildings and waterway crossings
- Flood hazard classifications (in conjunction with GIS post-processing) - flood function, the safety of pedestrians & motor vehicles.

4.9 Calibration and validation

A dual calibration has been undertaken with the URBS hydrology model, as discussed in Section 3. Following an iterative process to calibrate the URBS model using rating tables defined using the local model, full regional model calibration was undertaken for one event and validated against four additional events.

- Calibration: February 2020 (the largest event that has occurred since 2010).
- Validation: March 2021, June 2016, February 2013 and the historic 1974 event.

Due to the majority of bathymetric survey and LiDAR data being captured between 2007 and 2013, events after 2010 are considered to be more representative of historical events within the model. However, these recent events have not been significant in water level compared to historical events, with most maintaining in-bank flow. It was necessary to validate the model against a significant event to ensure extreme flood behaviour matches historical records. An additional validation simulation included the 1974 event based on digitised hydrologic inputs from the 1995 Wooli Flood Study report, although it maintains the present-day bathymetry.

4.9.1 Methodology

The calibration and validation process has used gauge records for post-2010 events and surveyed flood marks for the 1974 event. The river gauges at the Caravan Park (558060) and the River Entrance (559044) provide a long-term time series of observed water levels and were used to support the calibration process.

Both water level gauges are tidally influenced. The River Entrance gauge experiences the strongest tidal signal, which is positioned approximately 600m upstream of the entrance training walls. Whilst located around 5km further upstream, the tide signal at the Caravan Park remains strong, although fluvial processes are dominant during large rainfall events.

During calibration, it was necessary to continually amend inflow hydrographs and storm surge components of the tidal signal to achieve a satisfactory match to recorded levels. The hydraulic model calibration was achieved through the following methods:

- The use of a joint hydrologic-hydraulic calibration process to facilitate the continued improvement of model calibration (see description of this process in Section 3.6).
- Changes to inflow hydrographs generated in the URBS hydrologic model
- Changes to the coastal boundary to consider external effects such as storm surge, wave setup and wind setup at the river heads.
- Roughness calibration, particularly in the swamp region

4.9.2 Inflow boundaries

Local sub-catchment flows were derived from the runoff generated by the hydrologic model. Catchment flow routing was verified at gauge locations by comparing routed flow hydrographs and adjusted hydrologic model parameters.

4.9.3 Coastal boundary

The downstream boundary is an offshore ocean boundary located 3km from the river entrance. No data-derived tidal harmonics exist for this location, these were adopted from nearby gauges using the following process:

- A historical astronomical tide series was generated for Coffs Harbour gauge using tidal constituents.
- The astronomical tide was shifted to represent a time delay at the Wooli Wooli River entrance. This was estimated to have a 1 hr offset, based on a comparison of the Entrance and Coffs Harbour gauge records.
- Storm-surge components have been estimated based on recorded data at Coffs Harbour and through an iterative process to account for any local wave and wind setup.

4.10 Calibration and validation results

4.10.1 February 2020 calibration event

The February 2020 event is the second-largest event recorded between 1991 and 2021 and the largest post-2010 flood event. It had a peak water level of 1.77m AHD at the Caravan Park gauge and 1.3m AHD recorded at the Entrance gauge. Figure 4-5 shows the model calibration, which is considered to satisfactorily match both gauges with a peak difference of -0.16m at the Caravan Park gauge and -0.03m at the Entrance gauge.

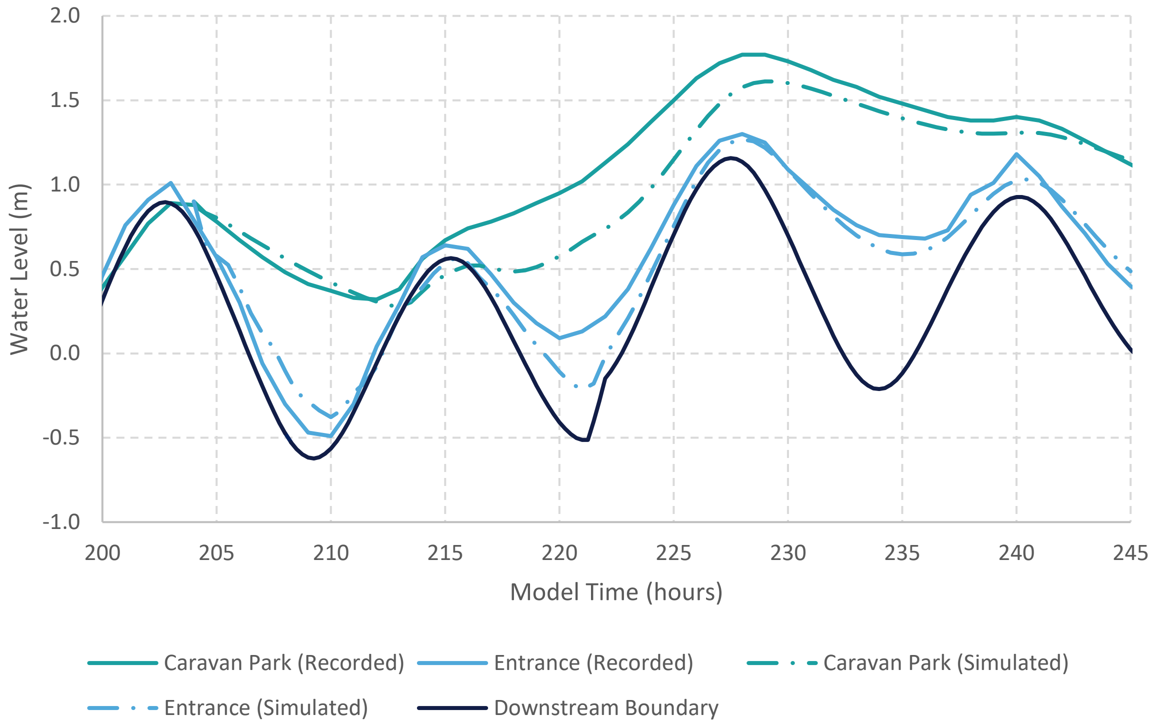

Figure 4-5: February 2020 hydraulic model calibration

4.10.2 February 2013 validation event

The February 2013 flood event was a high-volume event caused by several days of rainfall. The downstream tidal boundary experienced an intermediate storm surge. However, peak runoff coincided with a high tide. Compared to recorded data, the model estimates a good water level calibration at the Caravan Park gauge (-0.1m) and Entrance (+0.01m). Figure 4-6 shows the calibrated water levels for Entrance and Caravan Park gauges.

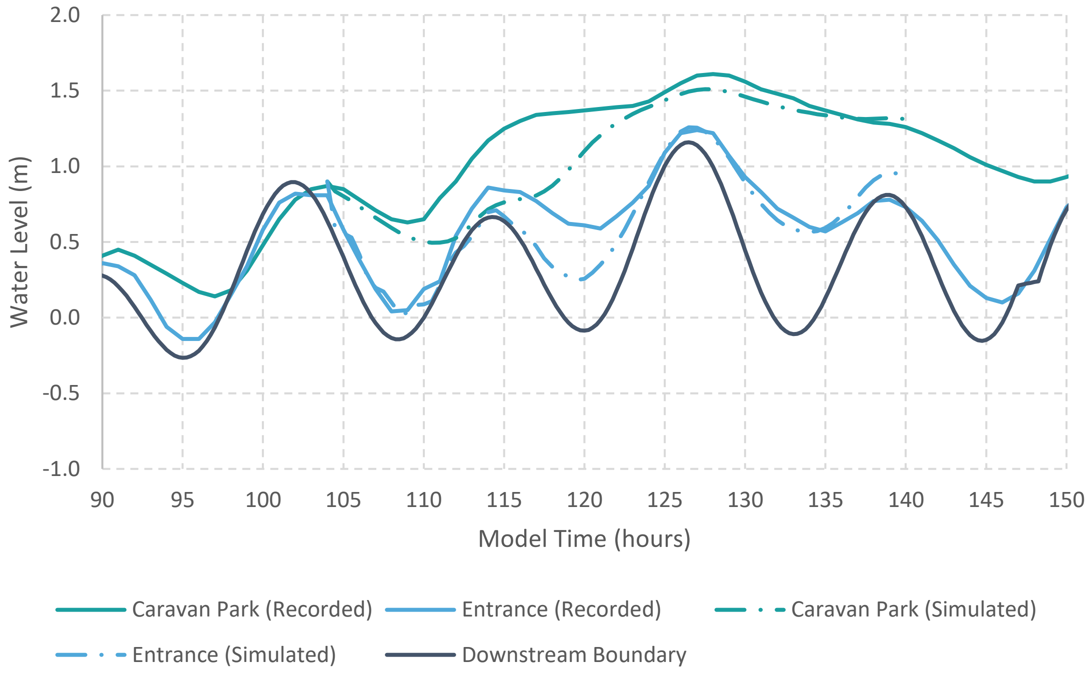

Figure 4-6: February 2013 hydraulic model calibration

4.10.3 June 2016 validation event

During the June 2016 event, the Entrance gauge recorded the second-highest water level due to high tides and a storm surge. The recorded water levels at the entrance were higher than the Caravan Park gauge. Three peaks were recorded within the hydrograph, caused by a combination of tides, storm surges and fluvial flows, in a complex situation. Figure 4-7 shows the recorded and simulated water levels.

The hydraulic model calibration produced moderate results. At the Caravan Park gauge, the model simulated a two-peaked hydrograph, whilst three were recorded. This may be attributed to upper catchment rainfall variability not captured within the hydrology model. The peak water level difference was +0.28m at the Caravan Park gauge.

Performance was better at the downstream end of the model, which captured the three peaks, with a difference of -0.12m at the Entrance gauge.

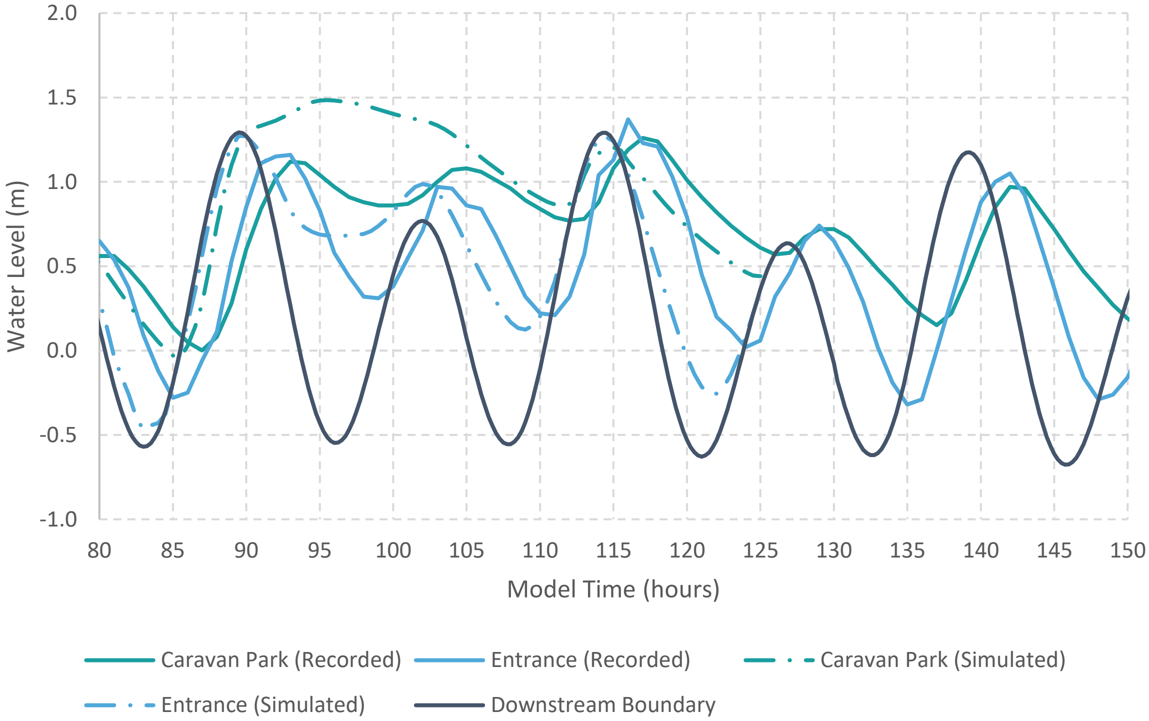

Figure 4-7: June 2016 hydraulic model calibration

4.10.4 March 2021 validation event

The March 2021 event is the third largest recorded event from the post-1990 data, however, it is the most recent flood event. The epicentre of the event is located adjacent to the Corindi River catchment, located 20km south, which experienced widespread flooding and damage. However, it did not result in significant flooding within Wooli, which is attributed to a number of reasons.

As discussed in Section 0, rainfall data was provided for two gauges for the event, located at Minnie Water (58222) and the Wooli Caravan Park (558060). Whilst this rainfall was significant, based on radar images, the rainfall in the upper catchment was not as severe, reducing the flood conditions. The peak fluvial hydrograph also occurred during a small tide, with astronomic conditions reaching approximately 0.6m AHD representing a mean high water spring, with little storm surge.

Figure 4-8 shows recorded and estimated water levels at Caravan Park and River Entrance gauges. The model over-predicted the water levels at Wooli, primarily due to varying rainfall conditions not captured within the two coastal gauges. At the Caravan Park, the model simulated peak conditions within +0.2m of the gauge record and at the Entrance by approximately +0.2m.

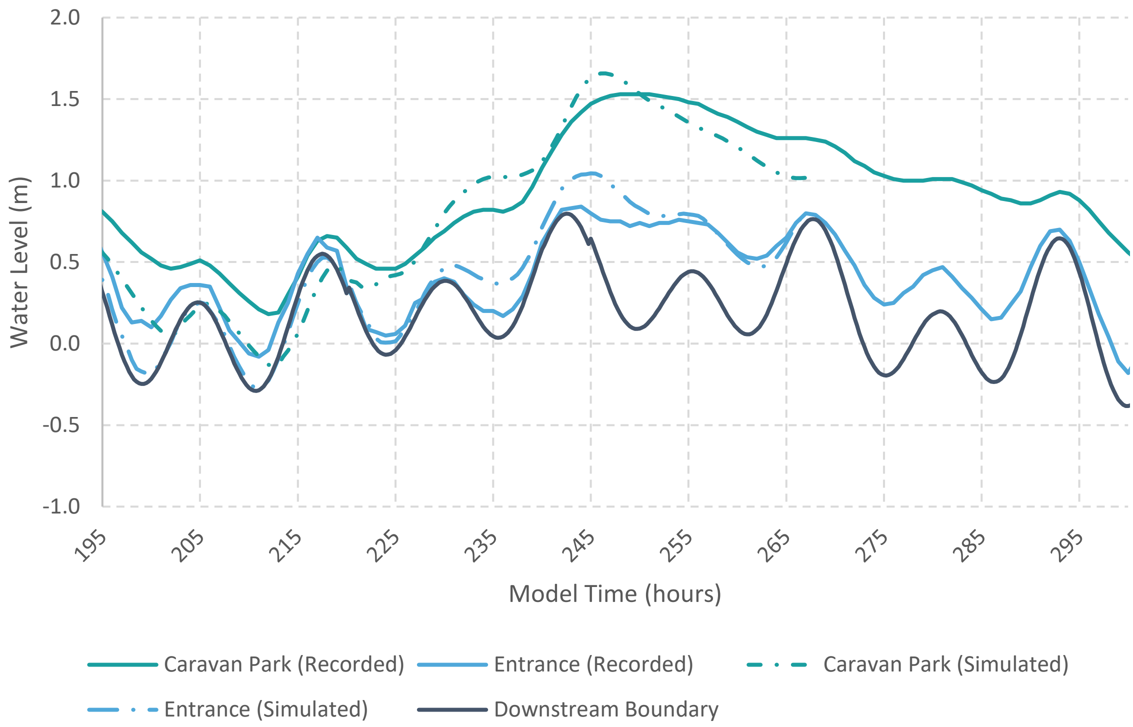

Figure 4-8: March 2021 hydraulic model calibration

4.10.5 1974 validation event

The 1974 event is a historic and significant flood event that had a data set of surveyed flood marks, allowing model validation. It was the calibration event used within the 1995 Wooli Flood Study and has now been used as a validation of this new model.

Inputs to the TUFLOW model have been based on digitised hydrograph inflows and downstream tide levels published within the 1995 report. The new TUFLOW model results have been compared at measurements taken at the Caravan Park and throughout the Wooli Township, with the simulated peak water levels presented against the original study results in Figure 4-9. Given the uncertainty in the digitised hydrographs and different bathymetric conditions, the model is considered to represent the event well.

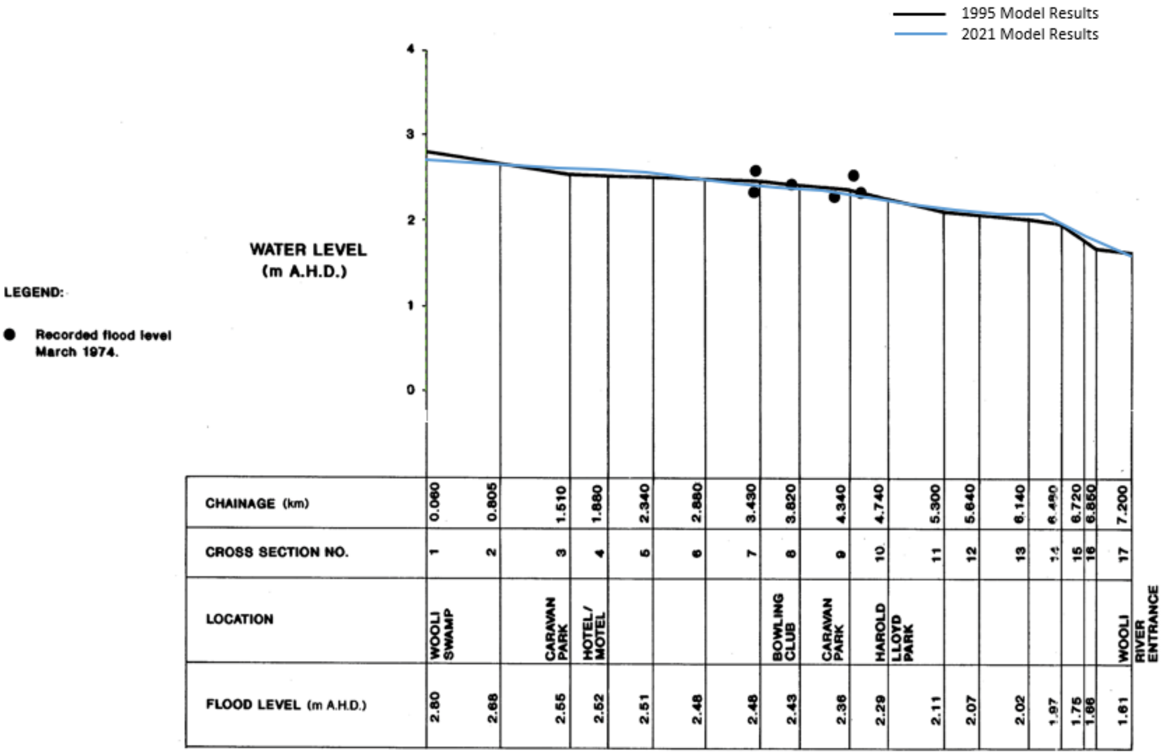

Figure 4-9: 1975 hydraulic model calibration, shown as a long section against historic results

4.11 Summary of hydraulic model performance

The ability of the hydraulic model to represent past flood conditions is dependent on the quality of rainfall and coastal inputs and the effectiveness of the hydrology model in representing the infiltration, runoff and storage of the upper catchment. Its performance can be summarised in terms of peak water levels and the timing and shape of the hydrographs. This assessment is shown in Table 4-3 and Table 4-4 for the Caravan Park and Entrance gauges. Whilst several challenges exist for this data-limited area, the calibration and validation results indicate the model can simulate the majority of events with a typical accuracy of ±0.16m.

Table 4-3: Hydraulic model comparison at Caravan Park

Event	Recorded peak (m AHD)	Simulated peak (m AHD)	Difference (m, %)	Timing comparison	Shape comparison
Feb 2020	1.77	1.61	-0.16, -9%	Good	Good
March 2021	1.53	1.66	0.13, -8%	Good	Fair
June 2016	1.26	1.54	0.28, 22%	Fair	Fair
Feb 2013	1.61	1.51	-0.1, -6%	Good	Good
Historic 1974	2.55	2.67	0.12, 5%	NA	NA

Table 4-4: Hydraulic model comparison at Entrance

Event	Recorded peak (m AHD)	Simulated peak (m AHD)	Difference (m, %)	Timing comparison	Shape comparison
Feb 2020	1.3	1.27	-0.03, -2%	Good	Good
March 2021	0.94	1.04	0.1, 11%	Good	Good
June 2016	1.37	1.25	-0.12, -9%	Good	Fair
Feb 2013	1.24	1.25	0.01, 1%	Good	Good
Historic 1974	1.61	2.09	0.48, 30%	NA	NA

5 Design Flood Estimation

5.1 Flood Frequency Analysis review

A flood frequency analysis (FFA) has been undertaken to estimate the general magnitude of extreme floods based on recorded data. However, this is to be treated an approximation only, as performing FFA in tidal areas is challenging due to the complex interplay of astronomical tides, storm surges, and riverine flow, making it difficult to isolate and model individual flood events.

Thirty years (1991 - 2021) of recorded water level data for the Wooli Caravan Park (558060) gauge. This length of data is regarded as being statistically reliable to estimate peak levels for a FFA. To remove the tidal influence, peak water levels above the Higher High Water Solstices Springs (HHWSS) of 0.73m AHD was extracted and the historical annual maxima series plotted by Log-Pearson Type III. Results are shown in Figure 5-1 and tabulated in Table 5-1, indicating a 1% AEP water level is expected to be of the order 2.2m AHD.

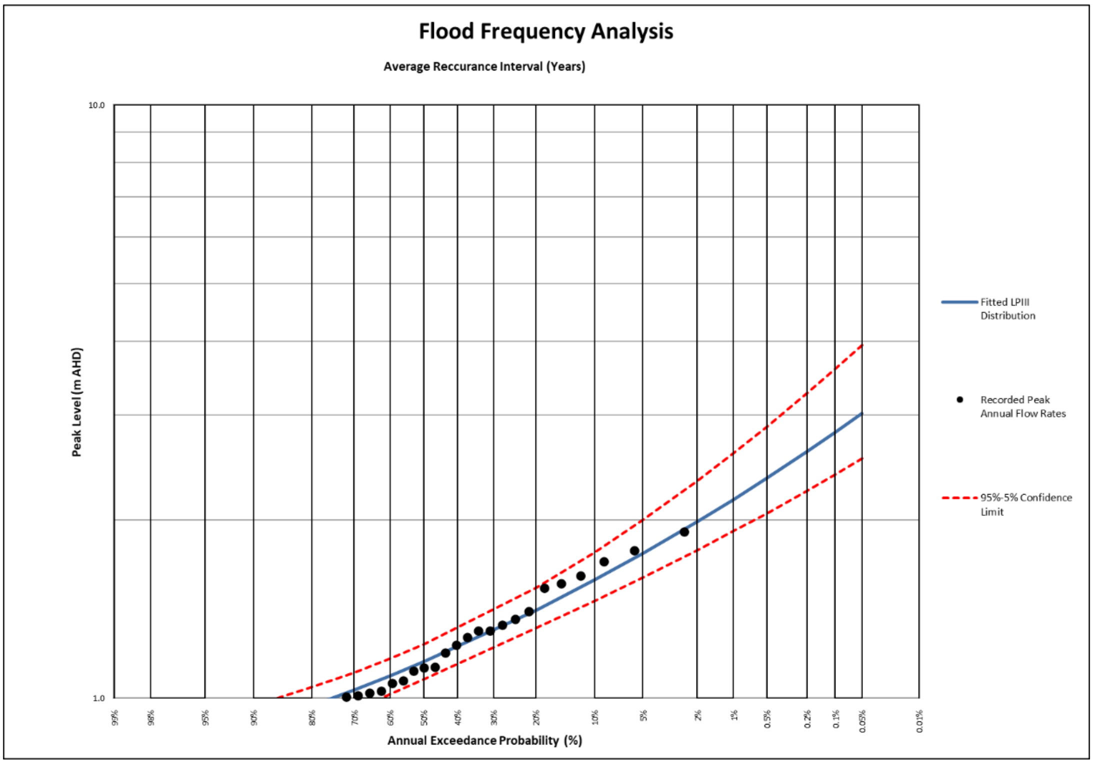

Figure 5-1. Log-Pearson Type III analysis of historical annual maxima series

Table 5-1. Design Flood Event peak flood estimates

Design Flood Event (%AEP)	Peak Level (m AHD)
1% AEP	2.2
2% AEP	2.0
5% AEP	1.8
10% AEP	1.6
20% AEP	1.4
50% AEP	1.2

5.2 Intensity-Frequency-Duration Curves (IFD)

5.2.1 At site IFD review

It is not uncommon in the northern rivers of NSW and Southeast Queensland for discrepancies difference between local rainfall and published Intensity-Frequency-Duration data, which is generally a result of the gauge selection used during the BoM 2016 IFD review. Consequently, detailed flood studies should include a review of rainfall records. With limited gauges available and only short-term records, the Wooli Caravan Park gauge was selected for analysis. Historical gauge data was provided by MHL, although a large data gap exists, as displayed in Figure 5-2, limiting its data length.

The rainfall data were processed by calculating the maximum rainfall accumulation for each standard duration. A Gumbel distribution was fitted to the accumulated maximums to obtain the revised IFD values. The BoM 2016 IFD data for the Wooli Caravan Park is shown in Table 5-2, and the differences to the revised IFD are shown in Table 5-3.

The BoM intensity data is larger for the 1 hr storm duration and the rare 96-hour durations. For the majority of the return periods and storm durations, the BoM intensity estimates are smaller than the revised assessment. Typically, the revised assessment has between 10% to 30% higher rainfall intensities. However, given the available rainfall dataset is short and contains large data gaps, this is not considered a reliable rainfall gauge. Instead, the BoM IFD data has continued to be used, with future updates recommended as more local rainfall data is captured.

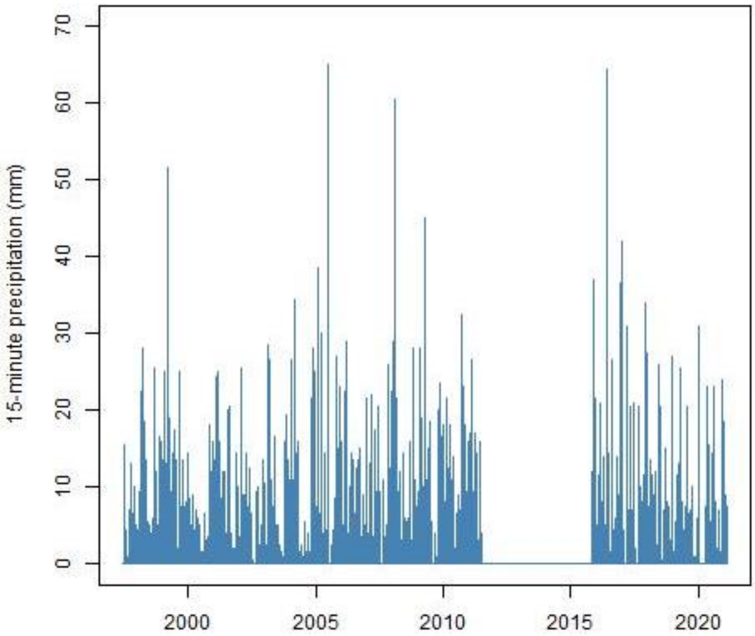

Figure 5-2: Rainfall record at Wooli Caravan Park gauge

Table 5-2: BoM Published IFD at Wooli Caravan Park

Duration	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
1 hr	42	57	68	79	94	106
2 hr	52	71	85	99	120	136
3 hr	58	80	97	113	138	157
6 hr	71	100	121	144	175	202
12 hr	89.4	128	156	187	229	263
24 hr	117	169	208	249	304	349
48 hr	155	226	278	332	403	459
72 hr	180	263	323	385	464	525
96 hr	196	286	351	417	500	566

Table 5-3: Comparison of at-site IFD and BoM published IFD (Positive [red] indicates revised data is larger than BoM)

Duration	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
1 hr	-21%	-21%	-19%	-15%	-8%	-4%
2 hr	-9%	0%	7%	14%	23%	32%
3 hr	7%	15%	17%	19%	19%	19%
6 hr	24%	31%	33%	32%	32%	30%
12 hr	34%	38%	37%	34%	30%	27%
24 hr	31%	33%	29%	25%	20%	16%
48 hr	19%	18%	14%	9%	3%	-1%
72 hr	12%	9%	4%	-2%	-8%	-13%
96 hr	12%	7%	0%	-7%	-14%	-20%

5.2.2 Determining IFD application across the catchment

Due to rainfall variability across the catchment, one IFD station cannot accurately represent the extreme rainfall for the whole catchment. The catchment was delineated into nine regions, as shown in Figure 5-3, with the centroids of each region assigned IFD statistics from the ARR DataHub. The URBS sub-catchments assignment to each IFD is summarised in Table 5-4.

Table 5-4. Allocation of IFDs to hydrological sub-catchment

IFD ID	Contained URBS sub-catchments	Total sub-catchments	Centroid Latitude	Centroid Longitude
1	11,12,16,19,20,25,29,30,31,33,34,36,38,39,50,106,107,108,109,110,111,112,113,114,115,116,141	27	-29.897	153.2
2	4,5,6,7,8,13,14,15,17,18,21,22,23,24,26,27,28,32,35,37,42,43,44,45,46,47,48,49,158,159	30	-29.899	153.16
3	94,95,96,97,98,99,100,101,102,104,123,124,125,126,127,128,131,132,134,135,136,137,138	23	-29.769	153.221
4	56,57,58,62,63,65,66,67,68,69,70,71,74,75,76,77,78,79,80,81,84,86,87,90,92,103,129,130,133,145,146,147,148,149	34	-29.809	153.204
5	59,117,118,119,121,122,139,140,142,143,144,150,157	13	-29.845	153.228
6	3,51,52,53,54,55,152,153,154,155,156	11	-29.884	153.245
7	1,2,120,151	4	-29.875	153.263

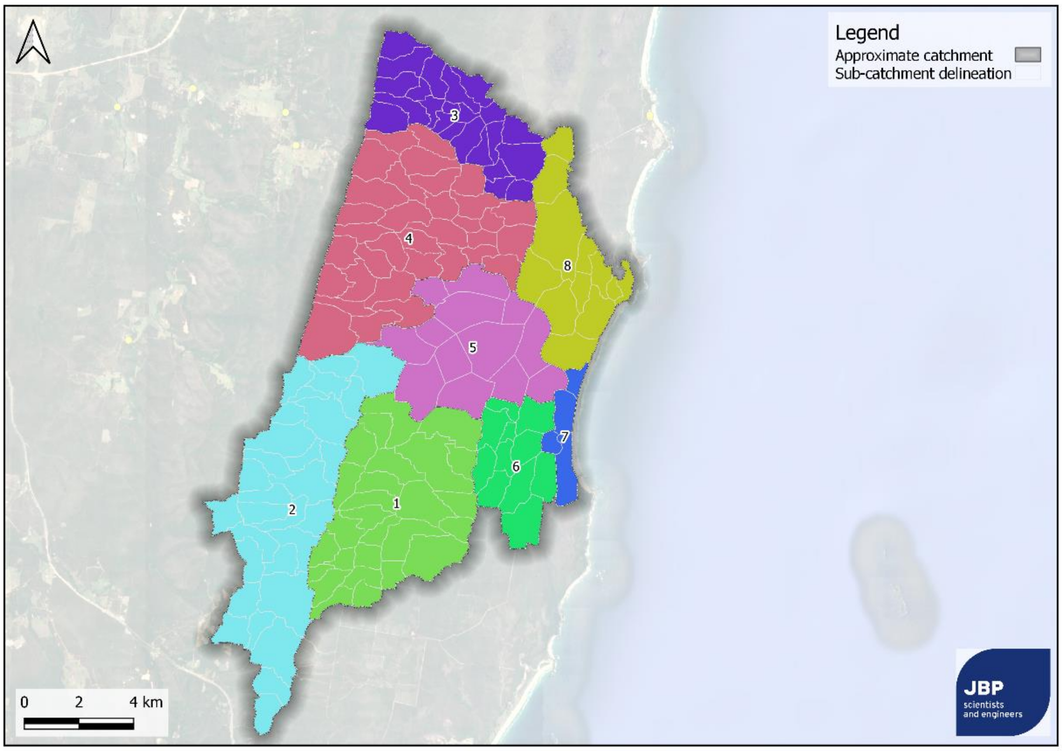

Figure 5-3. Application of IFDs to hydrological modelling across the catchment

5.3 Pre-burst rainfall and temporal patterns

Pre-burst was incorporated into the URBS model by using the IFD from the ARR DataHub.

The DataHub was used to obtain temporal pattern ensembles for the catchment. Four sets of temporal patterns were obtained, which represent "frequent", "intermediate", "rare" events and events within the areal "East Coast South" region for 200km^2 catchments. The frequent, intermediate, and rare temporal pattern sets contained storm durations of 15 mins, 30 mins, 45 mins, 1 hour, 1.5 hours, 2 hours, 3 hours, 4.5 hours, 6 hours, 9 hours, 12 hours, 18 hours, 24 hours, 30 hours, 36 hours, 48 hours, and 72 hours while the areal set contained storm durations of 12 hours, 18 hours, 24 hours, 36 hours, 48 hours, and 72 hours. Each of the four temporal pattern sets contained ten ensembles for each duration. Figure 5-4 shows the variability that can be expected between storm frequencies and ensembles for a 1-hour storm duration.

5.4 URBS ARR19 Design Rainfall Inputs

The following additional inputs are required for URBS to perform the design rainfall results and analysis. Details of these inputs can be found in the URBS manual:

- ARRTPZone = East Coast South
- IL = 2
- CL = 2
- FAF = 1
- TAF = 1
- longARF = 0.327, 0.241, 0.448, 0.36, 0.00096, 0.48, -0.21, 0.012, -0.0013
- shortARF = 0.287, 0.265, 0.439, 0.36, 2.26E-03, 0.226, 0.125, 0.0141, 0.213, 0.021
- usePreBurst = True (median)
- IFD = IFDs applied to each appropriate subcatchment, sourced from BoM
- ARI = 10%, 5%, 1%, 0.5%, 0.2%, PMP
- Durations = 1hour, 1.5hours, 2hours, 3hours, 6hours, 12hours, 18hours, 24hours, 30hours, 36hours, 48hours, 72hours, 96hours, 120hours, 144hours, 168hours

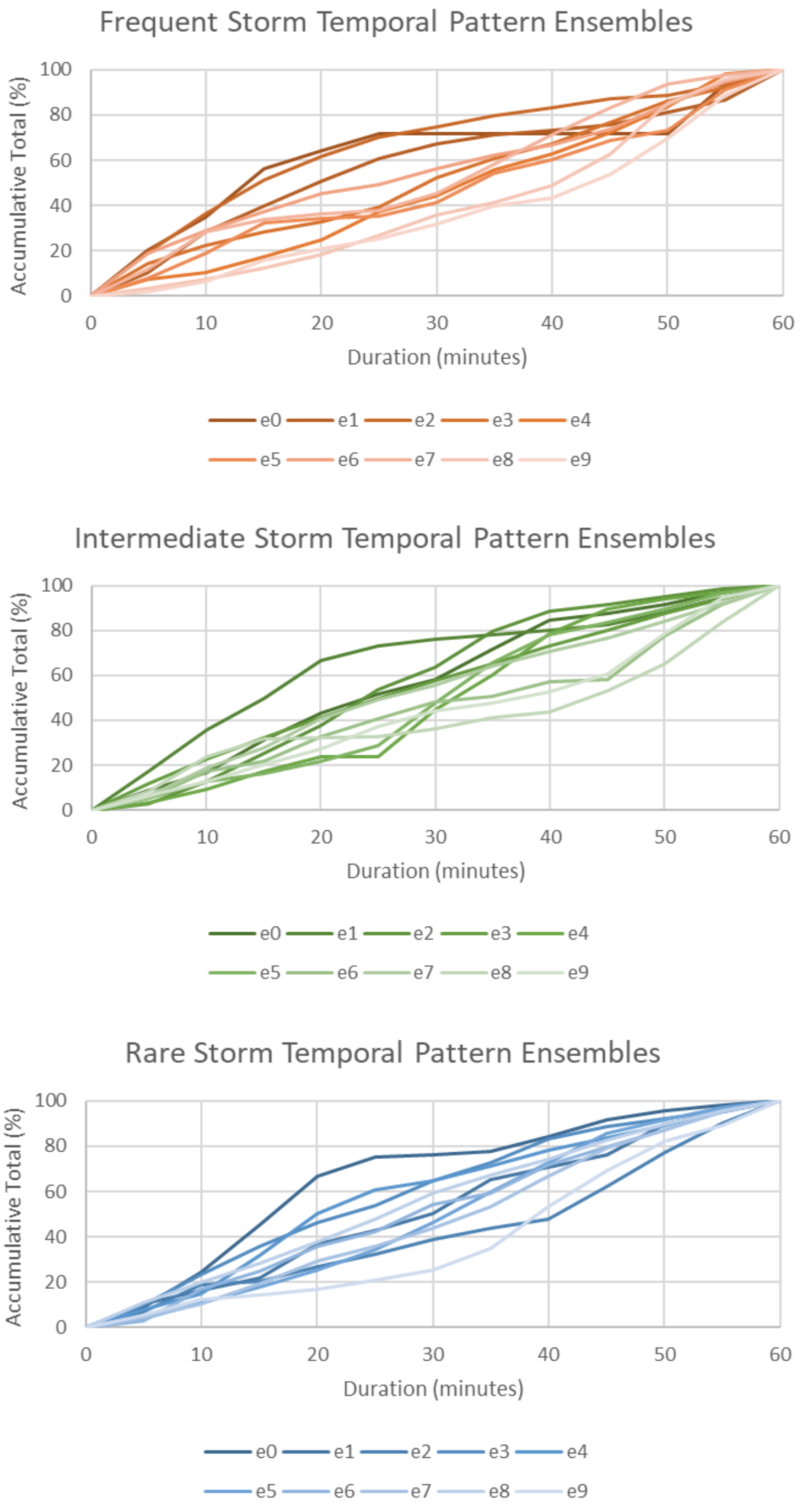

Figure 5-4. Temporal pattern ensemble variability for a 1-hour duration.

5.5 Extreme Rainfall and PMP Estimates

5.5.1 Procedure to calculate rainfall estimates

Following ARR 2019 guidance, the procedure used to calculate rainfall estimates for return periods greater than 1 in 100-year AEP, including the Probable Maximum Precipitation (PMP), is as follows:

1. Estimate the AEP of the PMP

As described in ARR19, estimation of the AEP of the PMP is done by using the catchment area against the curve presented in Figure 5-5. With a catchment area of 195 km^2, the AEP estimate for the Wooli Wooli catchment is 1 in 9,000,000.

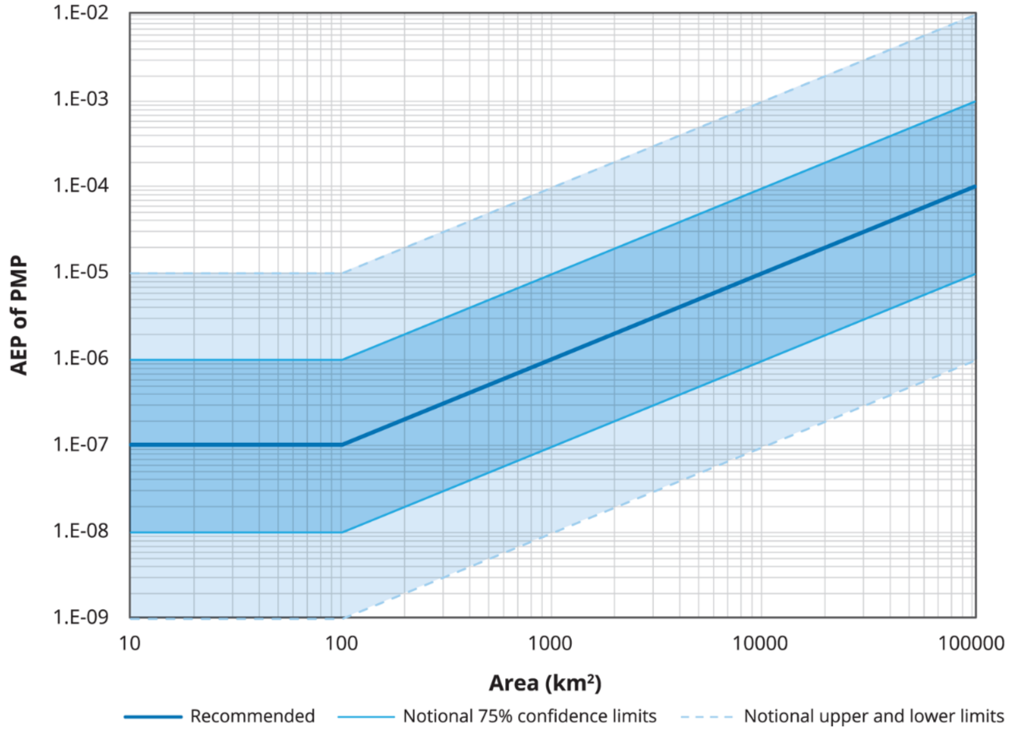

Figure 5-5: Recommended Regional Estimates for the AEP of the PMP

2. Determine Probable Maximum Precipitation Zones

The Wooli Wooli catchment is in the GTSMR Coastal Zone, as shown in Figure 5-6. The Generalised Short Duration Method (GSDM) was used to calculate PMP estimates for durations up to six hours, while the Revised Generalised Tropical Storm Duration Method (GTSMR) was used to calculate PMP estimates for durations greater than six hours.

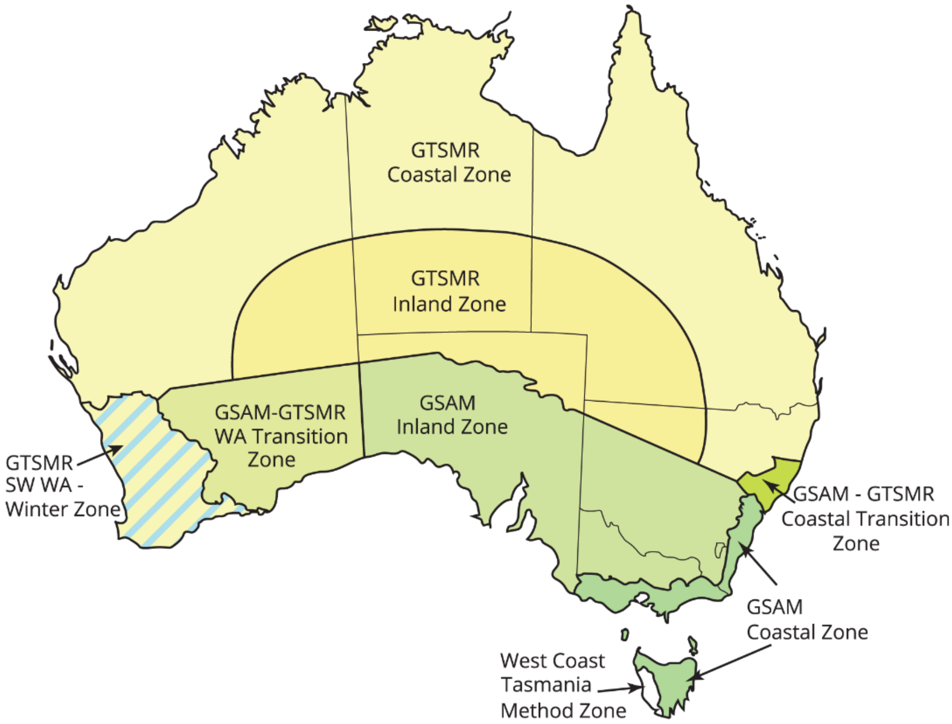

Figure 5-6: Generalised Long-Duration Probable Maximum Precipitation Zones (Bureau of Meteorology, 2006)

3. Complete GSDM and GTSMR calculation sheets as described in each guideline to calculate the PMP estimate curve

   Both the GSDM and GTSMR calculation sheets were used to calculate the PMP estimates for each duration. Zonal statistic processes were performed to calculate the Topographical Adjustment Factor (TAF), Decay Amplitude Factor (DAF), Annual Extreme Precipitable Water (EPWa) and the Winter Extreme Precipitable Water (EPWw) from the national catchment factor grids. In combination with the initial mean rainfall depth tables, rounded PMP estimates were calculated and plotted as shown in Figure 5-7. Estimates of the PMP were calculated for both winter and annual conditions, although the winter estimates were significantly lower. It was deemed not necessary to perform design flow estimates for the lower winter estimates.

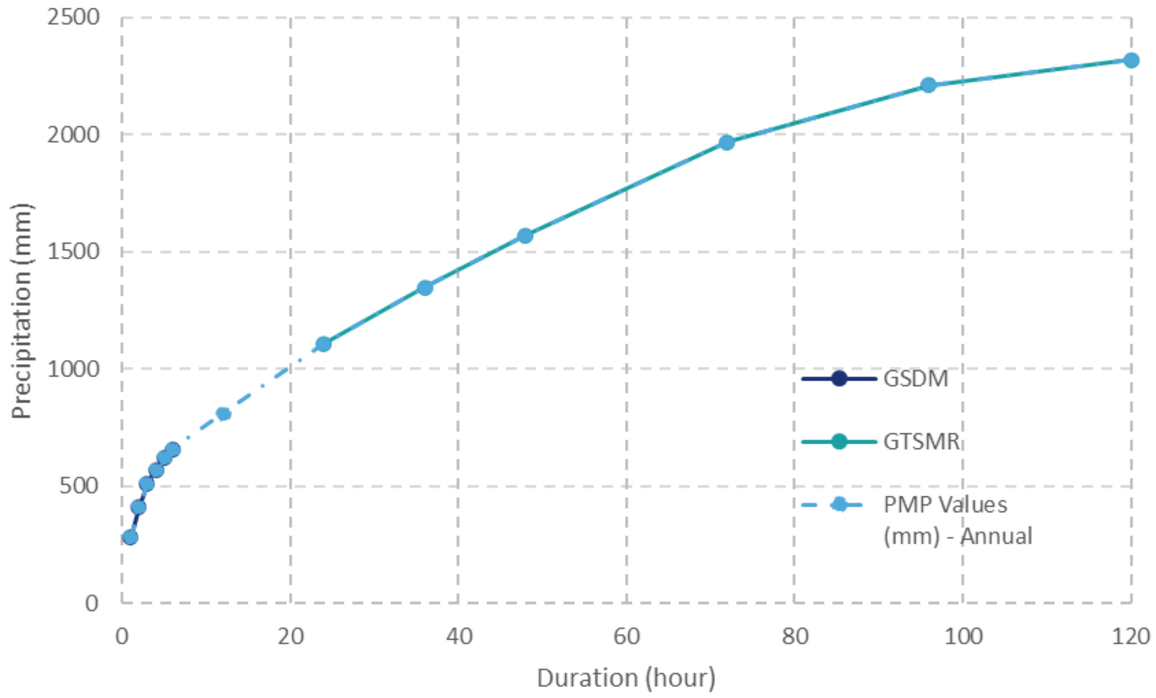

Figure 5-7: Annual PMP estimates for the Wooli Wooli catchment

4. Calculate rainfall intensities for return periods between 1 in 100-year AEP and 1 in 500-year AEP for durations less than or equal to 24 hours using ARR19 growth factors

For durations less than or equal to 24 hours, growth factors can be applied to the standard IFD curves up to return periods of 1 in 2000 AEP. These growth factors are prescribed in the ARR19 guidelines and are displayed in Table 5-5.

Table 5-5: Growth curve factors for derivation of sub-daily rainfalls standardised by the 1 in 100 AEP rainfall depth

AEP (1 in Y)	100	200	500	1000	2000
Growth Factor	1	1.14	1.344	1.513	1.698

5. Calculate rainfall intensities for return periods between 1 in 100-year AEP and 1 in 500-year AEP for durations greater than 24 hours using the ARR19 interpolation process

For durations longer than 24 hours, rainfall intensities were estimated using the interpolation procedure as described in ARR19. The standard IFD values for the 1 in 50-year AEP and 1 in 100-year AEP were used in conjunction with the PMP AEP and PMP intensity to interpolate the required return period intensities for each duration. The interpolation procedure is described in Figure 5-8.

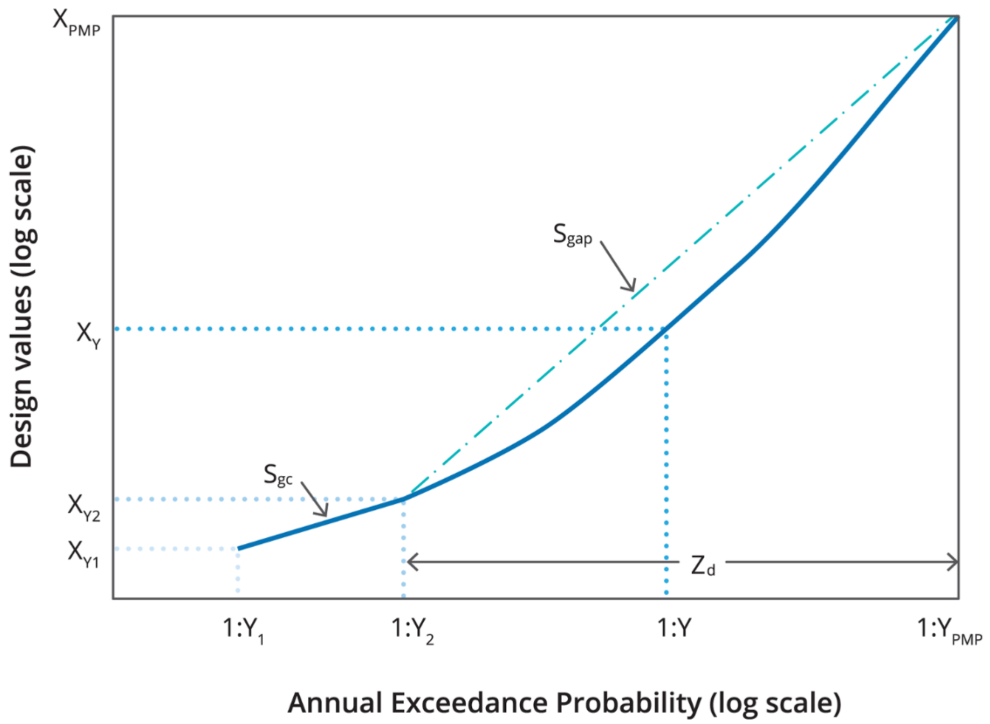

Figure 5-8: Schematic Illustration of Interpolation Procedure

5.5.2 Design rainfall intensities

Multiple methods were used to calculate the final structure of the design rainfall IFD. Table 5-6 outlines the source of rainfall intensity method for each duration and return period appropriate to this study.

Table 5-6: Methods of calculating design rainfall intensities

<table>
<tr><th>Duration</th><th>1 in 10 AEP</th><th>1 in 20 AEP</th><th>1 in 50 AEP</th><th>1 in 100 AEP</th><th>1 in 200 AEP</th><th>1 in 500 AEP</th><th>PMP AEP</th></tr>
<tr><td>1hr</td><td colspan="4" rowspan="12">BoM IFD</td><td colspan="2" rowspan="6">ARR19 Growth Factors</td><td rowspan="4">GSDM</td></tr>
<tr><td>2h</td></tr>
<tr><td>3h</td></tr>
<tr><td>6h</td></tr>
<tr><td>12h</td><td rowspan="8">GTSMR</td></tr>
<tr><td>24h</td></tr>
<tr><td>30h</td><td colspan="2" rowspan="6">ARR19 Interpolation Procedure</td></tr>
<tr><td>36h</td></tr>
<tr><td>48h</td></tr>
<tr><td>72h</td></tr>
<tr><td>96h</td></tr>
<tr><td>120h</td></tr>
</table>

5.6 URBS ARR19 Results

Due to the high variability in temporal patterns, selecting the ensemble member closest to the median was used. Figure 5-9 show the ensemble results for each duration and return period as box and whisker plots.

A summary of the critical duration which produces peak median flow at each critical reporting location is summarised in Table 5-7. It is noted that these critical durations may differ from the hydraulic model critical durations as any floodplain storage will be more accurately modelled in the hydraulic model. It is also noted that the low flow channel in the waterway upstream of the Pacific Highway is naturally very winding and is not accounted for in the hydrological model in the way that it is simulated in the hydraulic modelling.

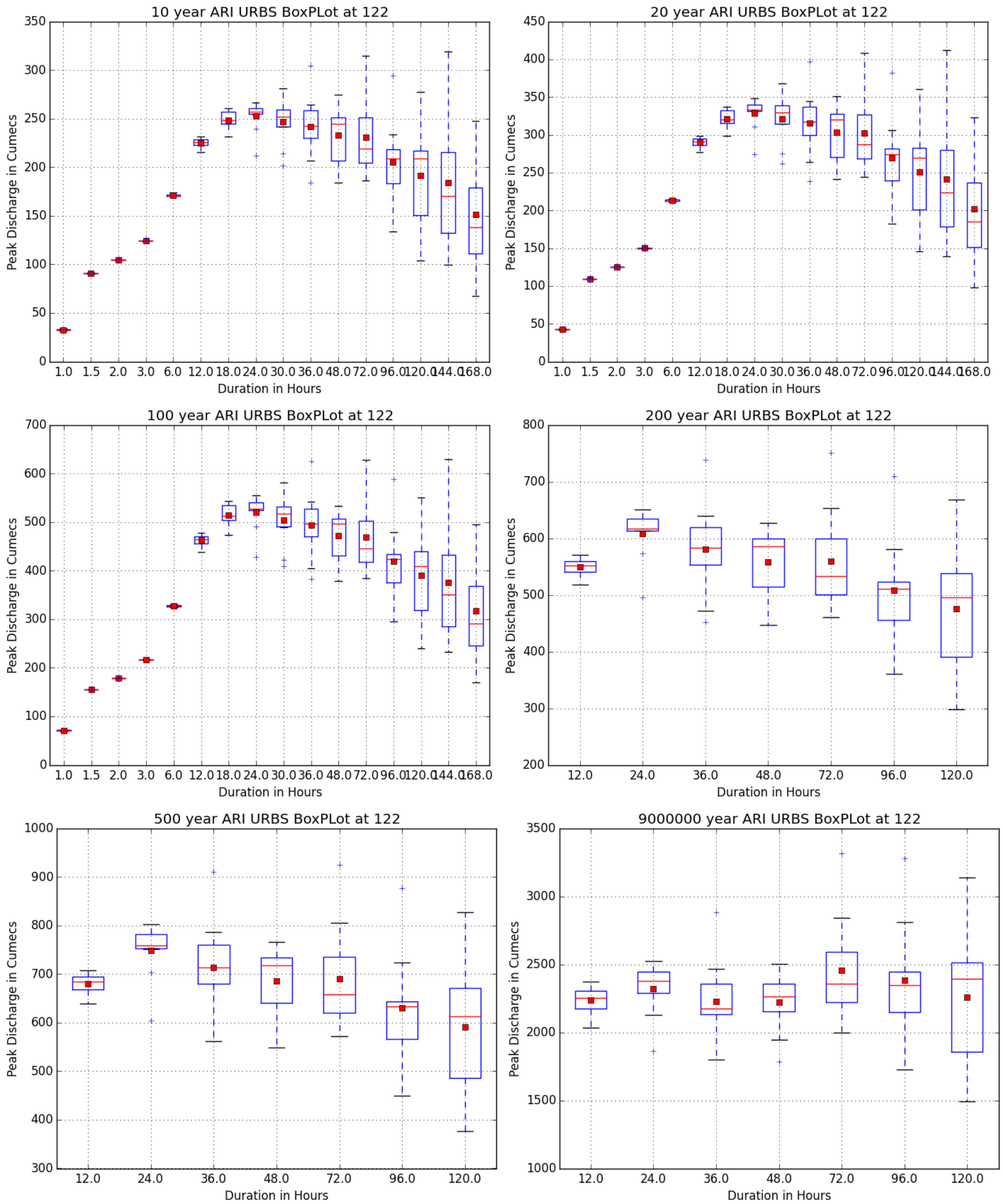

Figure 5-9. Box and whisker plot of ensemble temporal patterns modelled in the URBS

hydrological model. Reported at Wooli Caravan Park gauge

Table 5-7: Summary of critical duration at each reporting location

Location	URBS ID	1 in 10-year AEP	1 in 20-year AEP	1 in 100-year AEP	1 in 200-year AEP	1 in 500-year AEP	PMF AEP
IFD 1 Outlet	141	12hr	12hr	12hr	12hr	12hr	120hr
IFD 2 Outlet	45	24hr	24hr	24hr	24hr	24hr	120hr
IFD 3 Outlet	131	12hr	12hr	24hr	12hr	12hr	120hr
IFD 4 Outlet	145	24hr	24hr	24hr	12hr	12hr	120hr
Caravan Park Gauge	122	24hr	24hr	24hr	24hr	24hr	120hr
IFD 6 Outlet	154	12hr	12hr	12hr	12hr	24hr	120hr
IFD 7 Outlet	1	24hr	24hr	24hr	24hr	24hr	120hr
IFD 8 Outlet	169	24hr	24hr	24hr	12hr	24hr	120hr

Table 5-8: Summary of critical flow at each reporting location

Location	URBS ID	1 in 10-year AEP (m^3/s)	1 in 20-year AEP (m^3/s)	1 in 100-year AEP (m^3/s)	1 in 200-year AEP (m^3/s)	1 in 500-year AEP (m^3/s)	PMF AEP (m^3/s)
IFD 1 Outlet	141	76	96	147	169	205	723
IFD 2 Outlet	45	68	87	134	156	191	577
IFD 3 Outlet	131	55	69	104	121	146	548
IFD 4 Outlet	145	81	105	164	192	136	780
Caravan Park Gauge	122	253	326	513	599	737	2467
IFD 6 Outlet	154	23	29	44	49	59	217
IFD 7 Outlet	1	257	334	528	616	759	2427
IFD 8 Outlet	169	32	40	61	65	85	307

5.7 Design hydraulic model simulations

The interaction of catchment flooding and coastal processes is an essential consideration in determining overall flood risk in coastal waterways. The influence of these two factors on flooding varies with ocean level, due to both tidal fluctuations and storm impacts, the condition of the entrance interface between the coastal waterway and the ocean, distance from the ocean, and the size and shape of the waterway and catchment draining to the entrance.

The NSW Government's (2015) Floodplain Risk Management Guide on modelling the interaction of catchment flooding and oceanic inundation in coastal waterways[7] was referenced to determine the combination of catchment flooding and coastal scenarios to develop a flood envelope curve. The development of a flood envelope curve helps in understanding the interaction of catchment flooding and oceanic inundation within the estuary. The scenarios listed in Table 5-9 were adopted to produce an envelope of peak flood levels.

The results of the catchment hydrology model were used to provide inflows to the above scenarios. Due to the large catchment, multiple locations were used to assess the catchments critical duration in the hydrology model, which was carried forward to the design hydraulic scenarios. Table 5-10 contains details of the hydrological inputs to model the envelope curve, where several scenarios required multiple storm durations to be assessed.

7 OEH (2015) Floodplain Risk Management Guide - Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways.

Table 5-9: Combinations of Catchment Flooding and Oceanic Inundation Scenarios - Floodplain Risk Management Guide

Design AEP for peak levels	Catchment Flood Scenario	Ocean Water Level Boundary Scenario
50% AEP	50% AEP	HHWS(SS)
20%	20% AEP	HHWS(SS)
10%	10% AEP	HHWS(SS)
5%	5% AEP	HHWS(SS)
2%	2% AEP	5% AEP
1%	Coastal dominated sim: 5% AEP	1% AEP
	Catchment dominated sim: 1% AEP	5% AEP
0.5%	0.5% AEP	1% AEP
0.2%	0.2% AEP	1% AEP
PMF	PMF	1% AEP
1% catchment	1%	HHWS(SS)
PMF catchment	PMF	HHWS(SS)

The Higher High-Water Spring (HHWS) tidal level was adopted from OEH Tide Analysis (see Section 2.7.1). The 5% and 1% tidal levels were adopted from NSW Floodplain Risk Management (2015) Guide based on a Group 3 (Wave Dominated), Type B (open, trained entrance) estuary. This represents systems with an ocean entrance constricted by wave-deposited beach sand and flood-tidal deltas but is permanently open. The downstream tidal boundary was applied as a tidal signal rather than a static water level. The tidal signal used was adopted and translated from the Coffs Harbour gauge records.

Table 5-10. Summary of design hydraulic model simulations and temporal ensemble members

Design AEP	Catchment AEP	12hr	24hr	120hr	Tidal Boundary
50%	50%	TP 6	TP 5	-	HHWS(SS)
20%	20%	TP 6	TP 5	-	HHWS(SS)
10%	10%	TP 6	TP 5	-	HHWS(SS)
5%	5%	TP 6	TP 5	-	HHWS(SS)
2%	2%	TP 6	TP 5	-	5%
1% (coastal)	5%	TP 6	TP 5	-	1%
1% (catchment)	1%	TP 6	TP 5	-	5%
0.5%	0.5%	TP 6	TP 5	-	1%
0.2%	0.2%	TP 6	TP 5	-	1%
PMF	PMF	-	-	TP 9	1%
1%catchment	1%	TP 6	TP 5	-	HHWS(SS)
PMF catchment	PMF	-	-	TP 9	HHWS(SS)
Note: Temporal Pattern (TP) reference relates ensemble member naming convention TP0-TP9 for the ten temporal patterns in the rainfall ensemble.					

5.7.1 Maximum Flood Envelope

Each design event was processed using a max-max approach to derive a single flood map for each AEP event. This was applied to analyse two common variables:

- Catchment focussed scenarios can include multiple durations and temporal patterns. The max-max approach uses the largest resulting flood throughout the catchment.
- The 1% AEP event includes coastal-dominated and a fluvial-dominated scenarios. The coastal dominated scenario used a 1% AEP downstream boundary and was found to be dominant within the entrance heads, although the restriction caused by the training walls

caused peak levels to reduce as it propagated upstream. The catchment-dominated scenario uses 1% AEP upstream conditions and results in the peak water levels through the majority of the catchment, down to the training walls. The 1% AEP modelling 'envelope' is shown graphically in Figure 5-10, where the max-max post-processing was used to derive a single combined peak map.

Peak flood level results from the design simulations are summarised in Table 5-11 for the Wooli Caravan Park and Entrance.

The final flood maps representing the modelled scenarios outlined in Table 5-9 can be found in Appendix A: Hydraulic model maximum flood envelope maps.

Table 5-11. Summary of design hydraulic model simulation peak flood levels

Design AEP	Catchment AEP	Tidal Boundary	Peak flood level Wooli Caravan Park (m AHD)	Peak flood level Entrance (m AHD)
50%	50%	HHWS(SS)	1.03	0.94
20%	20%	HHWS(SS)	1.36	1.04
10%	10%	HHWS(SS)	1.59	1.14
5%	5%	HHWS(SS)	1.83	1.28
2%	2%	5%	2.24	2.08
1% (coastal)	5%	1%	2.07	2.09
1% (catchment)	1%	5%	2.43	2.17
0.5%	0.5%	1%	2.63	2.33
0.2%	0.2%	1%	2.91	2.49
PMF	PMF	1%	5.96	4.77
1%catchment	1%	HHWS(SS)	2.35	1.67
PMF catchment	PMF	HHWS(SS)	5.95	4.76

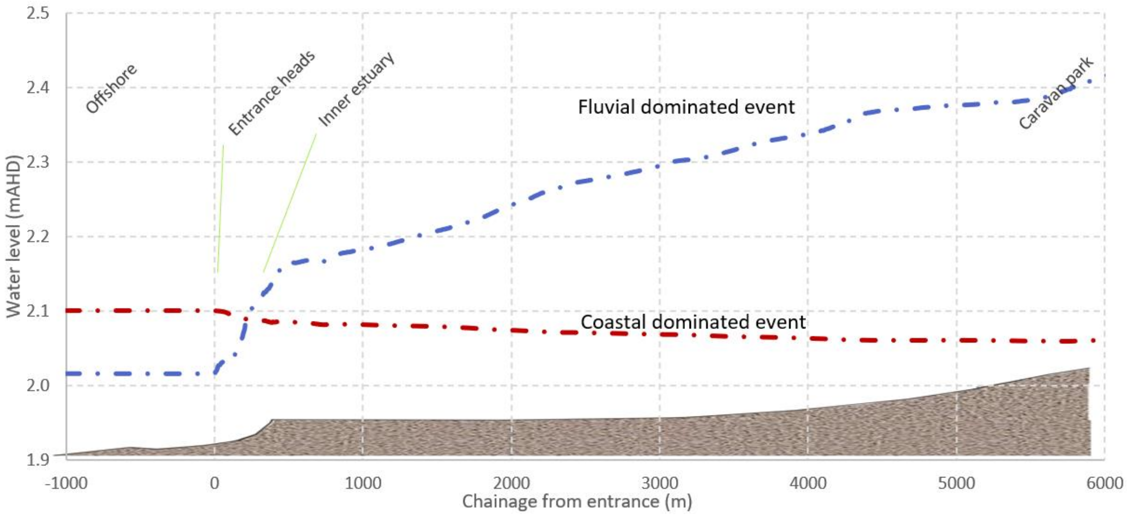

Figure 5-10: Hydraulic model envelope curve long section

The updated 1% AEP combined peak flood levels were compared against the 1995 Flood Study 1% AEP simulated peak flood levels. In the upper Wooli village areas the updated 1% AEP combined peak flood levels decreased in comparison to the 1995 flood study, which transition back to an approximately similar level to the historic study in the lower estuary. A summary of the flood levels for the two flood studies are provided in Table 5-12.

The updated 1% AEP of 2.43m AHD is similar to the estimated 1% AEP flood frequency FFA described in Section 5.1 of 2.30m AHD. Considering the uncertainties in the tidally-based FFA, this is considered a suitable match.

Table 5-12. 2021 Hydraulic model 1% flood levels compared to 1995 Flood Study 1% flood levels

Location	1% combined peak flood level	1995 Flood Study 1% peak flood level
1 (Wooli Swamp)	2.48	2.98
2	2.45	2.86
3 (Caravan Park Reporting)	2.43	2.72
4 (Hotel/Motel)	2.40	2.68
5	2.39	2.67
6	2.37	2.64
7	2.35	2.64
8 (Bowling Club)	2.32	2.59
9 (Caravan Park)	2.30	2.52
10 (Harold Lloyd Park)	2.29	2.44
11	2.25	2.25
12	2.22	2.2
13	2.19	2.17
14	2.18	2.17
15 (Entrance Reporting)	2.17	2.07
16	2.10	2.11
17 (River Entrance)	2.10	2.16

5.7.2 Climate Change Scenario

Two future climate change scenarios have been simulated to represent a 2100 planning horizon for the 1% AEP. These events were simulated based on the guidance provided in NSW Floodplain Risk Management Guide (OEH, 2019). Rather than simulating scenarios from the 2019 Australian Rainfall and Runoff RCP trajectories, the NSW guidelines recommend using the present day 1 in 200-year AEP and present day 1 in 500-year AEP to simulate the RCP 4.5 and RCP 8.5 trajectories. This approach is recommended for the 2090 horizon, but it was determined that this approach was suitable for the 2100 horizon after reviewing rainfall increases projected in the Floodplain Risk Management Guideline.

Table 5-13 below compares rainfall intensities between the BoM IFDs and the NSW Floodplain Risk Management Guideline 2090 projections for the 24hr storm duration and the 1% AEP, 0.5% AEP and 0.2% AEP events.

The ARR19 climate change projections were also compared to ensure the recommended approach was suitable for the 2100 planning horizon. Table 5-14 below summarises the rainfall intensity increases for each trajectory as suggested by the ARR19 Data Hub. Both ARR19 trajectories for the 2100 planning horizon are less than the projections provided by the Floodplain Risk Management Guidelines, therefore it was deemed acceptable to represent the 2100 1% AEP RCP 4.5 and RCP 8.5 scenarios by modelling the present-day 0.5% AEP and 0.2% AEP.

Table 5-13: Rainfall intensity increases for rare scenarios

Duration	1 in 100-year AEP	1 in 200-year AEP	1 in 500-year AEP
24hr (BoM IFD)	14.5 mm/hr	16.53 mm/hr	19.48 mm/hr
24hr (% increase to 1 in 100-year AEP)	-	14%	34%
NSW FRM Guide 2090	-	15% (1% AEP RCP 4.5)	30% (1% AEP RCP 8.5)

Table 5-14: ARR19 RCP trajectory rainfall intensity increases

Horizon	RCP4.5	RCP8.5
2090 (ARR DataHub)	9.5%	19.7%
2100 (ARR DataHub)	10.89%	21.83%
2120 (ARR DataHub)	12.71%	26.81%

Changes to sea levels have been based on (draft) Risk Frontier extreme sea level assessment (In Prep.) by adopting the RCP 8.5 trajectory which uses the following increases:

- 2020: + 0.00 sea level rise
- 2050: + 0.27 sea level rise
- 2070: + 0.47 sea level rise
- 2090: + 0.66 sea level rise
- 2100: + 0.75 sea level rise

The two scenarios that were simulated are summarised in Table 5-15 with the peak depth and extent results for the RCP 4.5 and RPC 8.5 provided in Figure 5-11 and Figure 5-12 respectively.

Table 5-15. 2100 planning horizon peak flood results

Planning horizon	Design AEP	Tidal Boundary	Peak flood level Wooli Caravan Park (m AHD)	Peak flood level Entrance (m AHD)
2100 - RCP 4.5	1%	PD 5% extreme sea level + 0.75m	2.76	2.75
2100 - RCP 8.5	1%	PD 5% extreme sea level +0.75m	2.99	2.84

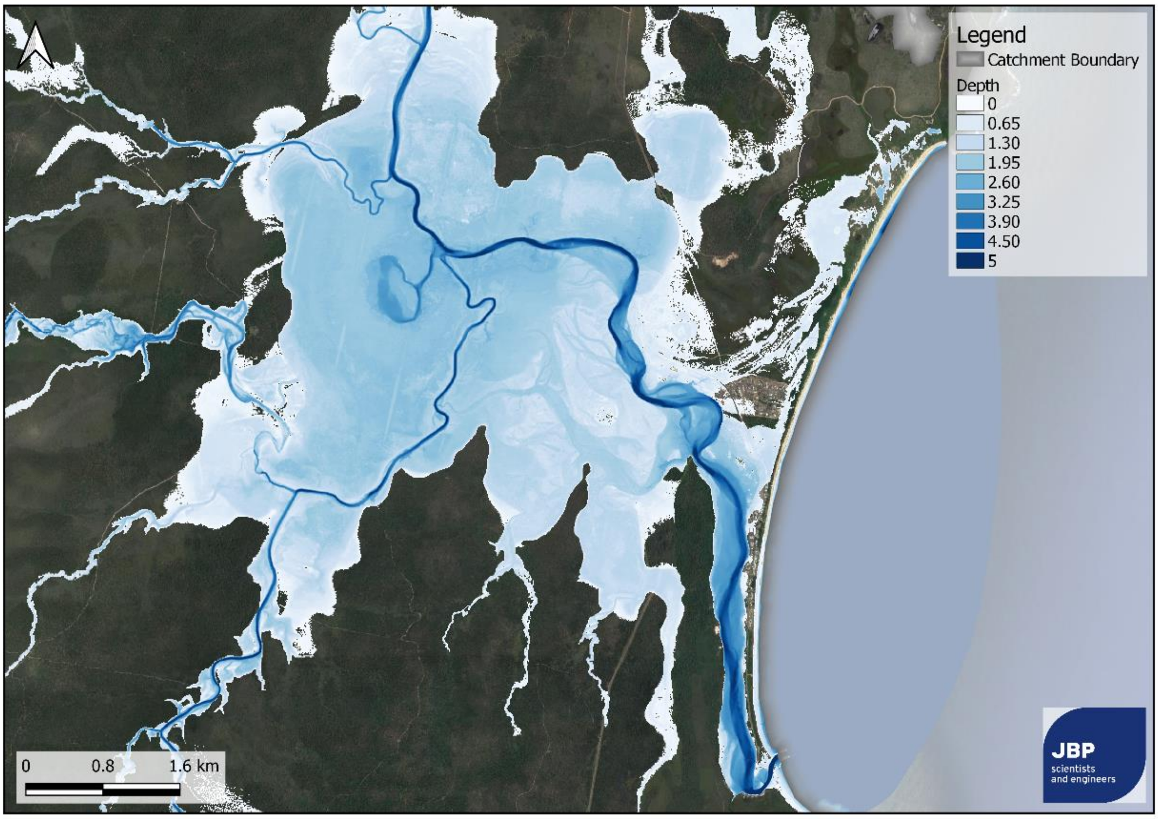

Figure 5-11: 2100 1% RCP 4.5 peak flood depths and extents

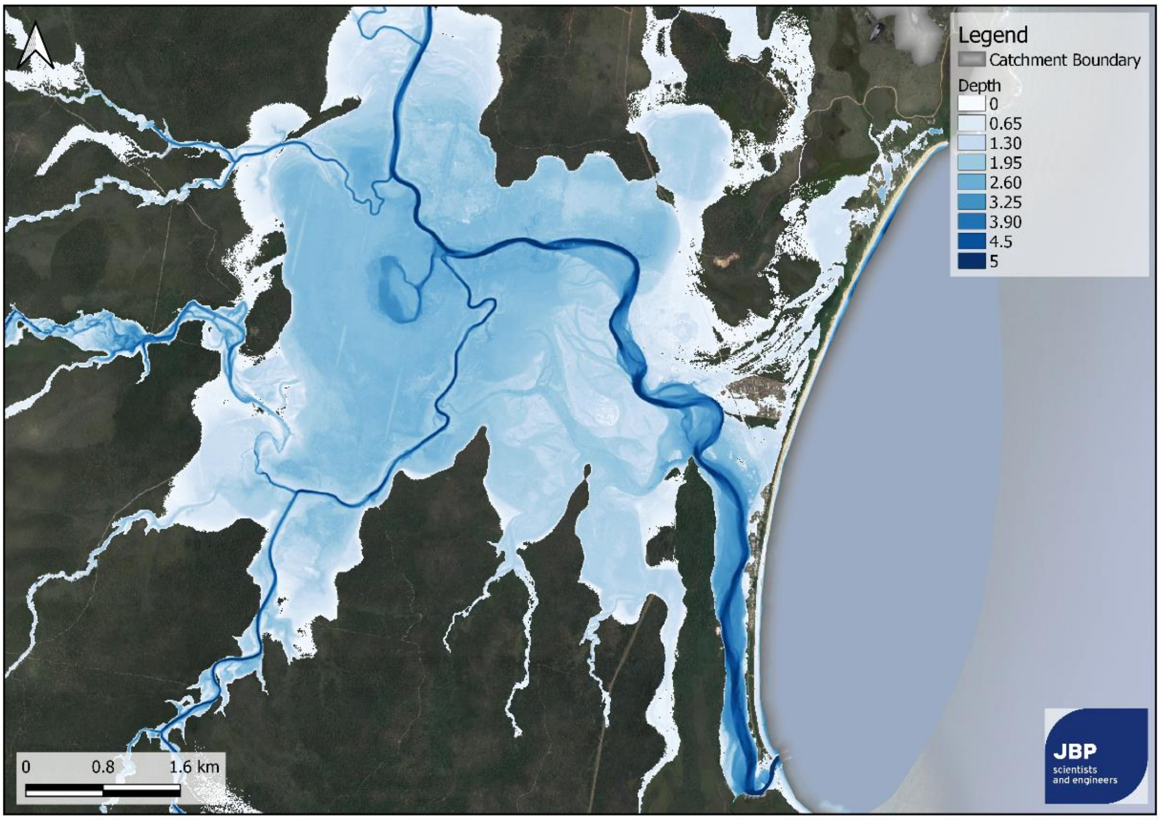

Figure 5-12: 2100 1% RCP 8.5 peak flood depths and extents

5.8 Sensitivity analysis

The sensitivity of the hydraulic model results was assessed in four categories:

1. Consideration of inflow timing
2. Review of initial water levels and storage capacity of the swamp
3. Consideration of structure blockage
4. Consideration of hydraulic roughness
5. Consideration of riverbed changes during an extreme event

5.8.1 Flood peak timing

The sensitivity of flood peak timing was investigated using the February 2020 calibration simulation, where peak catchment flow and tidal water levels were aligned. The timing of inputs was shifted to provide three sensitivity scenarios:

- Catchment flows coincide with tides at the Caravan Park
- Catchment flows coincide with tides at the Swamp
- Catchment flows coincide with tides at the Entrance

A summary of results at both gauges is recorded in Table 5-11 and Table 5-12 for the Caravan Park gauge and Entrance gauge.

By adjusting the timing of inflows to coincide with peak tide levels, only one scenario resulted in a larger peak flood level. This scenario was when the peak levels coincided at the Caravan Park location, and the increase in peak flood level was 0.01m. Figure 5-13 displays the peak flows for each sensitivity scenario.

Table 5-16: Hydraulic model coinciding peak sensitivity comparison at Caravan Park gauge

Event	Simulated peak (m AHD)	Difference (m, %)
Base Model - Observed	1.61	-
Coincide at Caravan Park	1.59	-1%
Coincide at Swamp	1.60	-1%
Coincide at Entrance	1.48	-8%

Table 5-17: Hydraulic model coinciding peak sensitivity comparison at Entrance gauge

Event	Simulated peak (m AHD)	Difference (m, %)
Base Model - Observed	1.27	-
Coincide at Caravan Park	1.28	1%
Coincide at Swamp	1.26	-1%
Coincide at Entrance	1.24	-2%

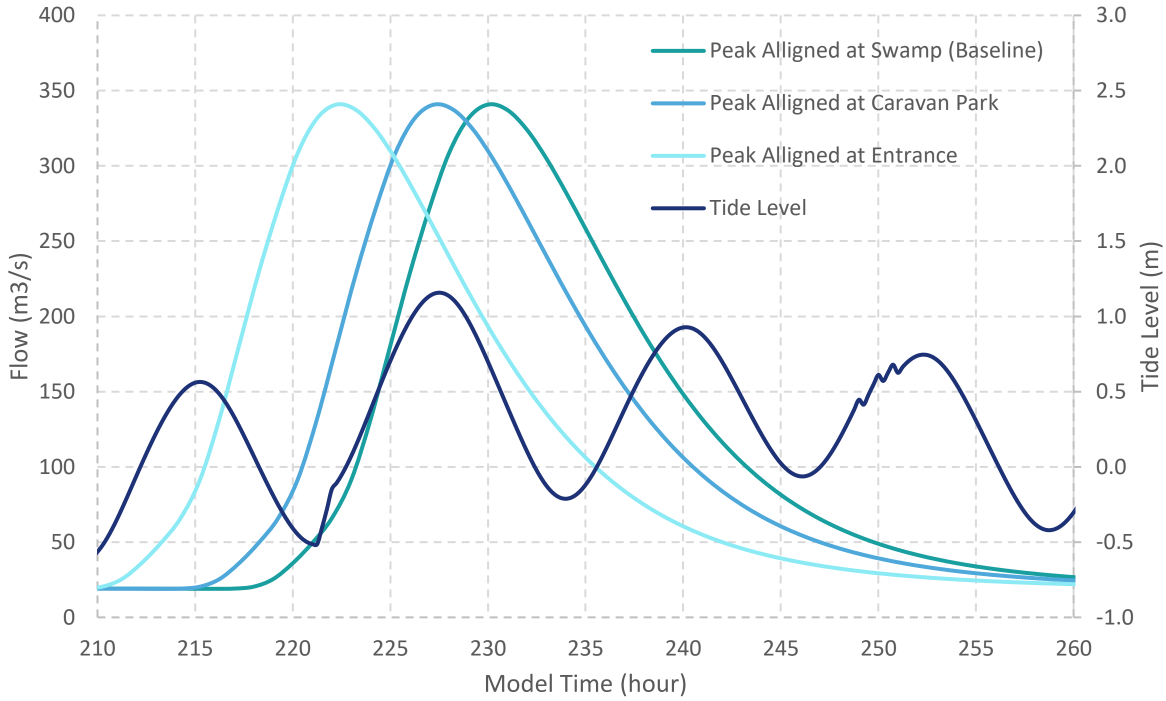

Figure 5-13: Peak flows for inflow timing sensitivity scenarios

5.8.2 Initial water level in the swamp

The swamp areas of the catchment act as flood storage, which have been investigated using the February 2020 calibration simulation. The flood event was simulated with varying initial water levels within the swamp. The base model scenario used during calibration of the model used an initial water level of 0.9m throughout the swamp and the waterway. Additional testing included 1m AHD, 0.75m AHD and 0m AHD, with the resulting peak flood levels compared at the Caravan Park gauge and Entrance gauge.

Compared to the simulated base model for the February 2020 event, the results show that the initial water level had a minor influence on the peak simulated water level at both gauges. Upon inspection of the time series, the available water storage within the swamp area can be quickly drained or filled depending on the scenario by the oscillating tide signal, as shown in Figure 4-5.

Table 5-18: Hydraulic model initial water level sensitivity comparison at Caravan Park gauge

Event	Simulated peak (m AHD)	Difference (m, %)
Base Model	1.61	-
1m Swamp Initial Water Level (+)	1.61	0%
0.75m Swamp Initial Water Level (-)	1.59	-1%
0m Swamp Initial Water Level	1.59	-1%

Table 5-19: Hydraulic model initial water level sensitivity comparison at Entrance gauge

Event	Simulated peak (m AHD)	Difference (m, %)
Base Model	1.27	-
1m Swamp Initial Water Level (+)	1.27	0%
0.75m Swamp Initial Water Level (-)	1.26	-1%
0m Swamp Initial Water Level	1.26	-1%

5.8.3 Structure blockage

The capacity of drainage systems can be severely impacted by structure blockage. However, there are situations where the significant blockage may not affect flood behaviour to any great extent. Determination of possible blockage levels at drainage crossings is an essential consideration in quantifying flood behaviour.

Numerous structures are present within the catchment, but only a few can influence downstream flood conditions. Five structures were identified as appropriate to perform a blockage assessment. Guidance from the ARR19 blockage assessment was followed to determine blockage potential for the identified structures. It was estimated that the likely average debris material would consist of large materials from the upstream natural catchment and the possibility of vehicle blockage during rare events. Therefore, debris length was assumed to be 2.5m to 3m long. Table 5-23 contains the derived design blockage from the structure blockage assessment.

The results of the structure blockage sensitivity are below in Table 5-24 to Table 5-27. While blockage factors had no influence on the peak water level at the caravan park or river entrance, small increases in water levels were noticed at the blocked structures in addition to increased flood level and extent in the eastern most part of the Wooli township. This is show in Figure 5-14 for the 1% AEP blockage scenario.

Table 5-20: Debris attributes and classification

Structure ID	Diameter	Debris Availability	Debris Mobility	Debris Transportability	Debris Potential
Wooli Rd M_5	0.75m	High – dense forest, thick vegetation.	Low – main source areas well away from streams.	Low – flat bed slopes.	DPMedium - (HLL)
Wooli Rd M_1	0.6m	High – dense forest, thick vegetation.	Low – main source areas well away from streams.	Low – flat bed slopes.	DPMedium - (HLL)
Wooli Rd M_8	0.75m	High – dense forest, thick vegetation.	Low – main source areas well away from streams.	Low – flat bed slopes.	DPMedium - (HLL)
Wooli Rd M_4	1.5m	High – dense forest, thick vegetation.	Low – main source areas well away from streams.	Low – flat bed slopes.	DPMedium - (HLL)
Wooli Rd M_9	0.375m	High – dense forest, thick vegetation.	Low – main source areas well away from streams.	Low – flat bed slopes.	DPMedium - (HLL)

Table 5-21: AEP adjusted site debris potential

Event AEP	At Site 1% AEP Debris Potential - DPMedium
< 5% AEP (frequent)	Low
5% AEP - 0.5% AEP	Medium
> 0.5% AEP (rare)	High

Table 5-22: At-site debris potential for inlet widths less than average debris length

Control Dimension Inlet Width W (m)	At Site 1% AEP Debris Potential		
	High	Medium	Low
W < L10	100%	50%	25%

Table 5-23: Design inlet blockage

Event AEP	Blockage Design %
AEP > 5% (frequent)	Low – 25%
AEP 5% - AEP 0.5%	Medium – 50%
AEP <0.5% (rare)	High – 100%

Table 5-24: 5% AEP blockage scenario

Location	5% AEP with HHWS(SS) Tidal Boundary	
	Peak WSL (m AHD)	Medium Blockage (50%) Peak WSL (m AHD)
Caravan Park Gauge	1.83	1.83
Entrance Gauge	1.28	1.28
Afflux to baseline	-	0

Table 5-25: 1% AEP blockage scenario

Location	1% AEP with 5% AEP DSWL	
	Peak WSL (m AHD)	Medium Blockage (50%) Peak WSL (m AHD)
Caravan Park Gauge	2.43	2.43
Entrance Gauge	2.17	2.17
Afflux to baseline	-	0

Table 5-26: 0.2% AEP blockage scenario

Location	0.2% AEP with 1% AEP DSWL	
	Peak WSL (m AHD)	High Blockage (100%) Peak WSL (m AHD)
Caravan Park Gauge	2.91	2.91
Entrance Gauge	2.49	2.49
Afflux to baseline	-	0

Table 5-27: PMF blockage scenario

Location	PMF with 1% AEP DSWL	
	Peak WSL (m AHD)	High Blockage (100%) Peak WSL (m AHD)
Caravan Park Gauge	5.96	5.96
Entrance Gauge	4.77	4.77
Afflux to baseline	-	0

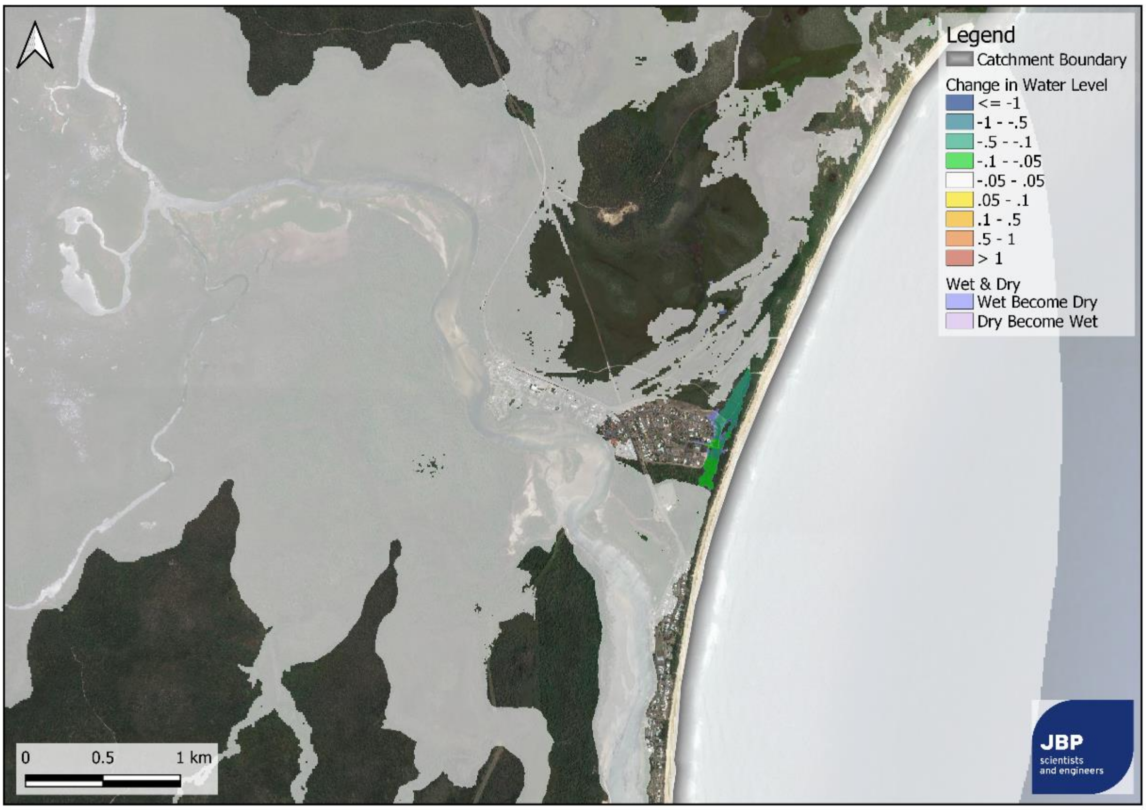

Figure 5-14: 1% AEP blockage scenario change in water level

5.8.4 Hydraulic roughness

Hydraulic model sensitivity was completed to test the impact of hydraulic roughness in the TUFLOW model. Two sensitivity runs were undertaken for four return periods, with the hydraulic roughness parameter increased by 10% and reduced by 10%.

The results of the sensitivity scenarios were analysed at the two key reporting locations. The results are shown in Table 5-28 to Table 5-31 and show the maximum peak water surface level variation. On average, the change in hydraulic roughness values results in a +/- 0.05m across the four scenarios at both reporting locations. Afflux mapping is displayed in Figure 5-15 and Figure 5-16 for the 10% decreased hydraulic roughness and 10% increased hydraulic roughness.

Table 5-28: Sensitivity results for TUFLOW hydraulic roughness

Location	5% AEP with HHWS(SS) DSWL		
	Peak WSL (m AHD)	Roughness sensitivity peak water level (m AHD)	
		Minus 10%	Plus 10%
Caravan Park Gauge	1.83	1.78	1.87
Entrance Gauge	1.28	1.26	1.29
Average afflux	-	-0.035 m	+0.025 m

Table 5-29: Sensitivity results for TUFLOW hydraulic roughness

Location	1% AEP with 5% AEP DSWL		
	Peak WSL (m AHD)	Roughness sensitivity peak water level (m AHD)	
		Minus 10%	Plus 10%
Caravan Park Gauge	2.43	2.38	2.48
Entrance Gauge	2.17	2.16	2.19
Average afflux	-	-0.03 m	+0.035 m

Table 5-30: Sensitivity results for TUFLOW hydraulic roughness

Location	0.2% AEP with 1% AEP DSWL		
	Peak WSL (m AHD)	Roughness sensitivity peak water level (m AHD)	
		Minus 10%	Plus 10%
Caravan Park Gauge	2.91	2.85	2.96
Entrance Gauge	2.49	2.47	2.51
Average afflux	-	-0.04 m	+0.035 m

Table 5-31: Sensitivity results for TUFLOW hydraulic roughness

Location	PMF with 1% AEP DSWL		
	Peak WSL (m AHD)	Roughness sensitivity peak water level (m AHD)	
		Minus 10%	Plus 10%
Caravan Park Gauge	5.96	5.87	6.05
Entrance Gauge	4.77	4.76	4.78
Average afflux	-	-0.05 m	+0.05 m

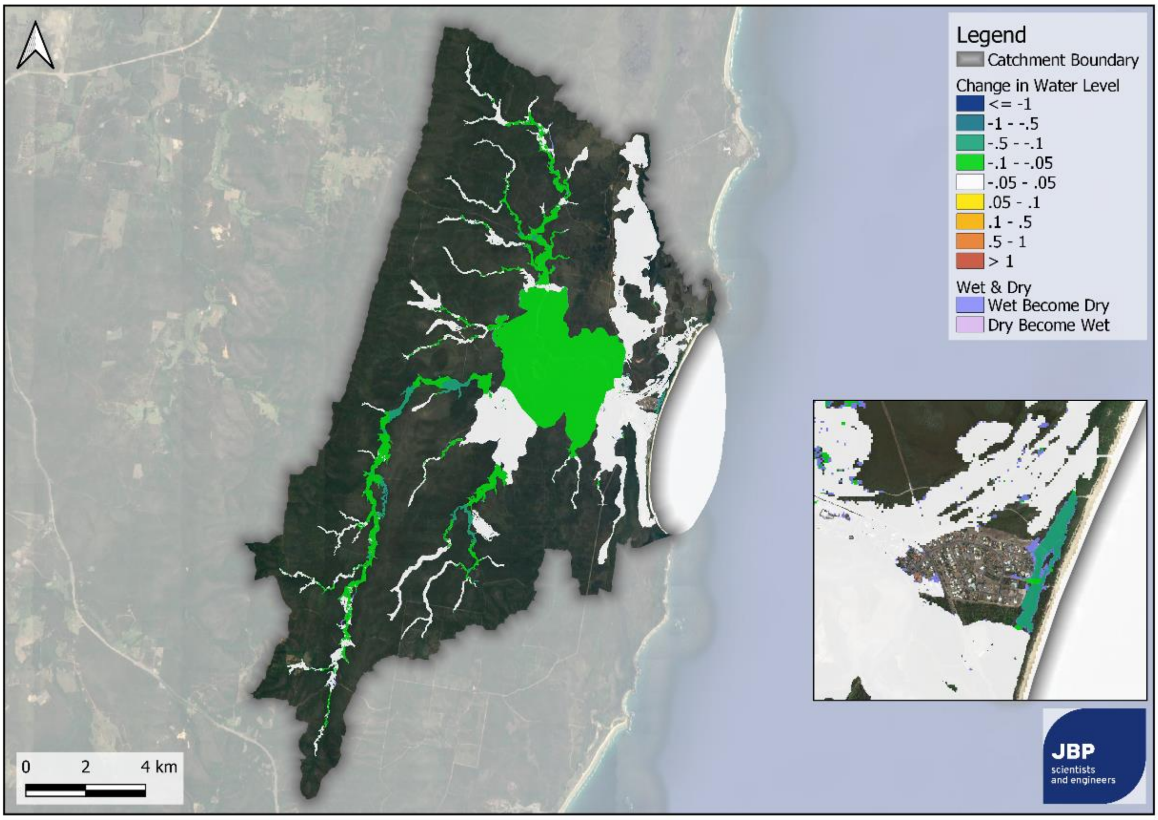

Figure 5-15: 1% AEP with 5% AEP DSWL afflux mapping for 10% reduced hydraulic roughness

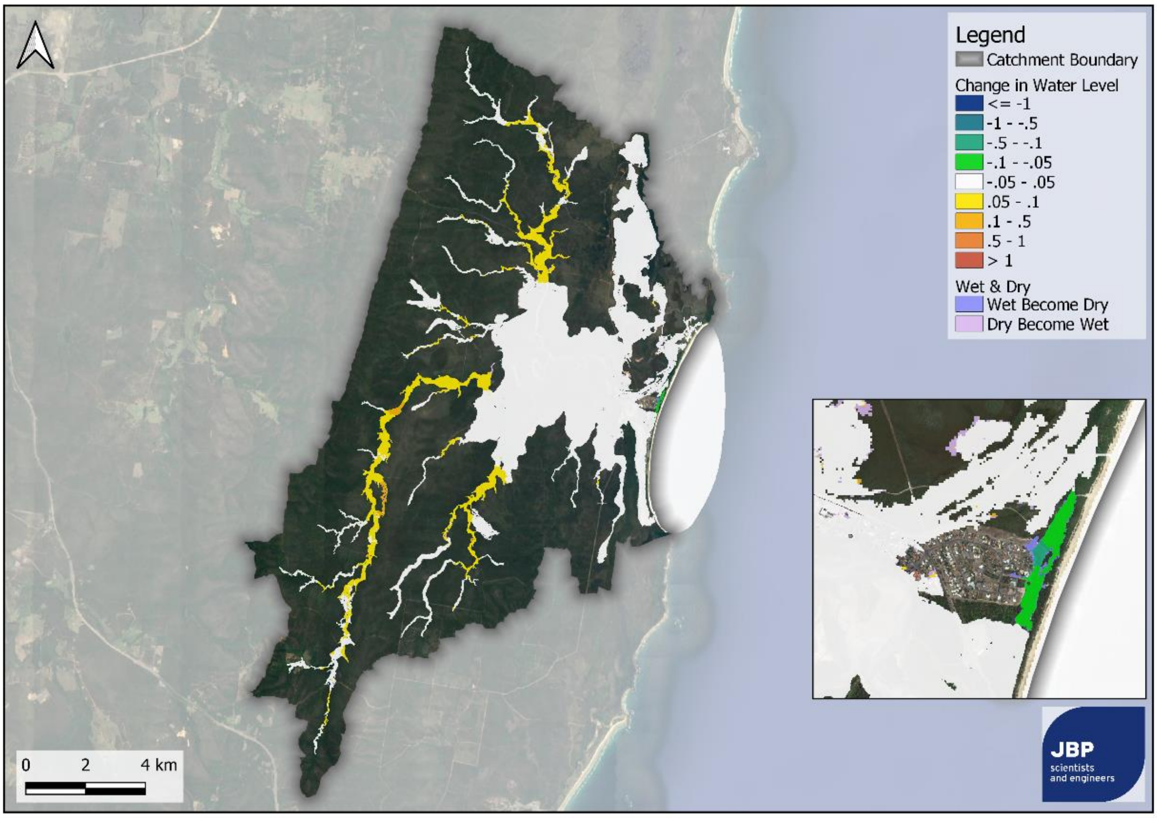

Figure 5-16: 1% AEP with 5% AEP DSWL afflux mapping for 10% increase hydraulic roughness

5.8.5 Bathymetry and scour

The sensitivity to the model downstream bed levels has been tested using post-flood bathymetry. This has been created using the sediment transport and morphologic numerical model Delft3D. As schematised in Figure B-1, several modules of Delft3D can be used within modelling scenarios. For this assessment the Delft3D-FLOW module was used to simulate hydrodynamics, coupled with the Sediment Transport Module, and an updating bed morphologic model. A full description of the model is contained within Appendix B: Coastal modelling

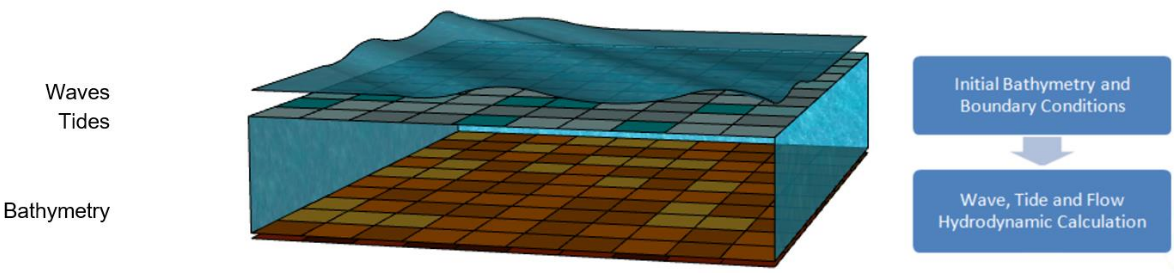

Figure 5-17: Delft3D hydrodynamic and wave calculations

The model was established for the downstream estuary, spanning the Wooli Caravan Park into the nearshore coastal zone. The model bathymetry has been based on the sources described in Section 0. The model was calibrated against five days of observed tide data at the Wooli Wooli River Entrance gauge location from 6 to 10 February 2021. This period was chosen as it aligned with the dates of the drifter field investigation. The modelled tide levels at the Wooli Wooli River Entrance gauge showed a good agreement, with an average error of 0.045m. Simulated velocity measurements matched the drifter field data, confirming an average observed current speed of 0.56m/s.

A design flood event was adopted based on the largest inland flood event observed at the Wooli Caravan park gauge. This event occurred in March 2001 and recorded a maximum water level of 1.91m AHD at the gauge. This event's recorded water level time series has been applied to the Delft3D model upstream boundary, and the scour and bed movement patterns simulated. Significant erosion (approaching 10m) was observed during the event in the most narrow, trained section of the inlet. This sediment was deposited beyond the river channel's mouth as a large sand slug (see Figure 5-18).

The final bathymetry level has been extracted and used to represent a post-storm state of the estuary. This has been applied to the TUFLOW hydraulic model to the sensitivity of model results. This has been applied to the 1% coastal dominated and 1% fluvial dominated design events, with the resulting water levels compared at the Caravan Park gauge and Entrance gauge (see Table 5-32). The results show a reduction in peak water level in both scenarios, with the greater reduction being at the Entrance gauge location. The decrease in water level ranges up to 0.05m, or less than a 2% reduction. Figure 5-19 and Figure 5-20 display the afflux mapping results for the 1% coastal dominated bathymetry scour scenario and the 1% fluvial dominated bathymetry scour scenario.

The results show the model has a low sensitivity to the depth of the waterway channel through the entrance heads. This is considered to be due to other factors dominating in this area, likely to be the friction and inefficiency of the 180-degree bend around the rock walls.

Table 5-32: Bathymetry and scour sensitivity comparison

Event	Event	Base Case Simulated peak (m AHD)	Bathymetry Sensitivity Test Simulated peak (m AHD)	Difference (m , %)
1% Coastal dominated	Caravan Park gauge	2.07	2.07	0, 0%
	Entrance gauge	2.09	2.07	-0.02m, -0.96%
1% Fluvial Dominated	Caravan Park gauge	2.43	2.4	-0.03m, -1.2%
	Entrance gauge	2.17	2.13	-0.04m, -1.84%

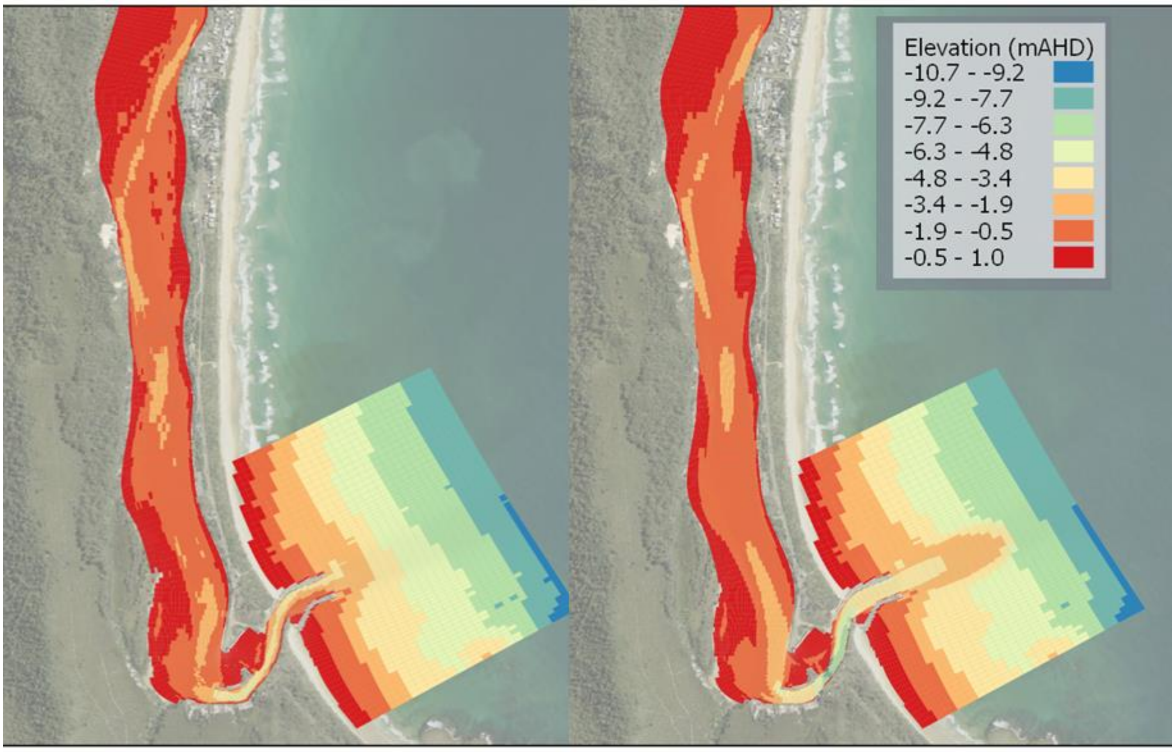

Figure 5-18: Initial (left) and final (right) bed elevation following Delft3D morphologic simulation

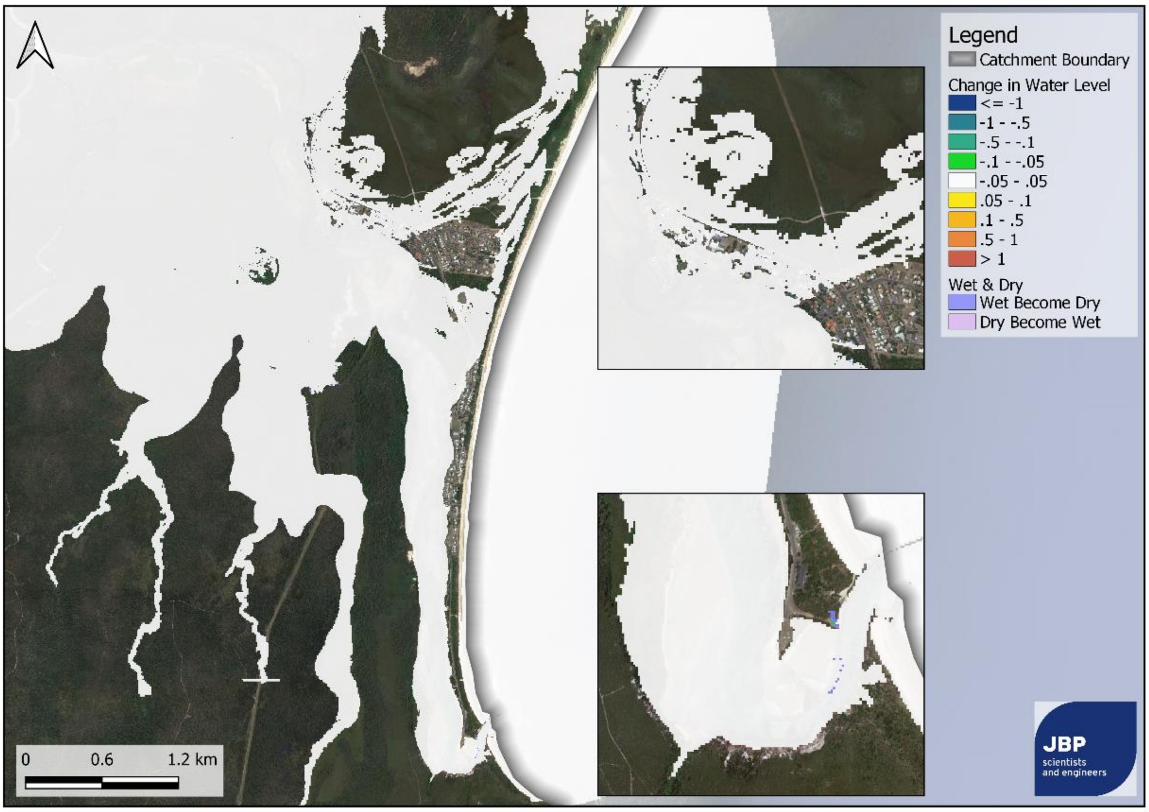

Figure 5-19: 1% Coastal dominated bathymetry scour scenario

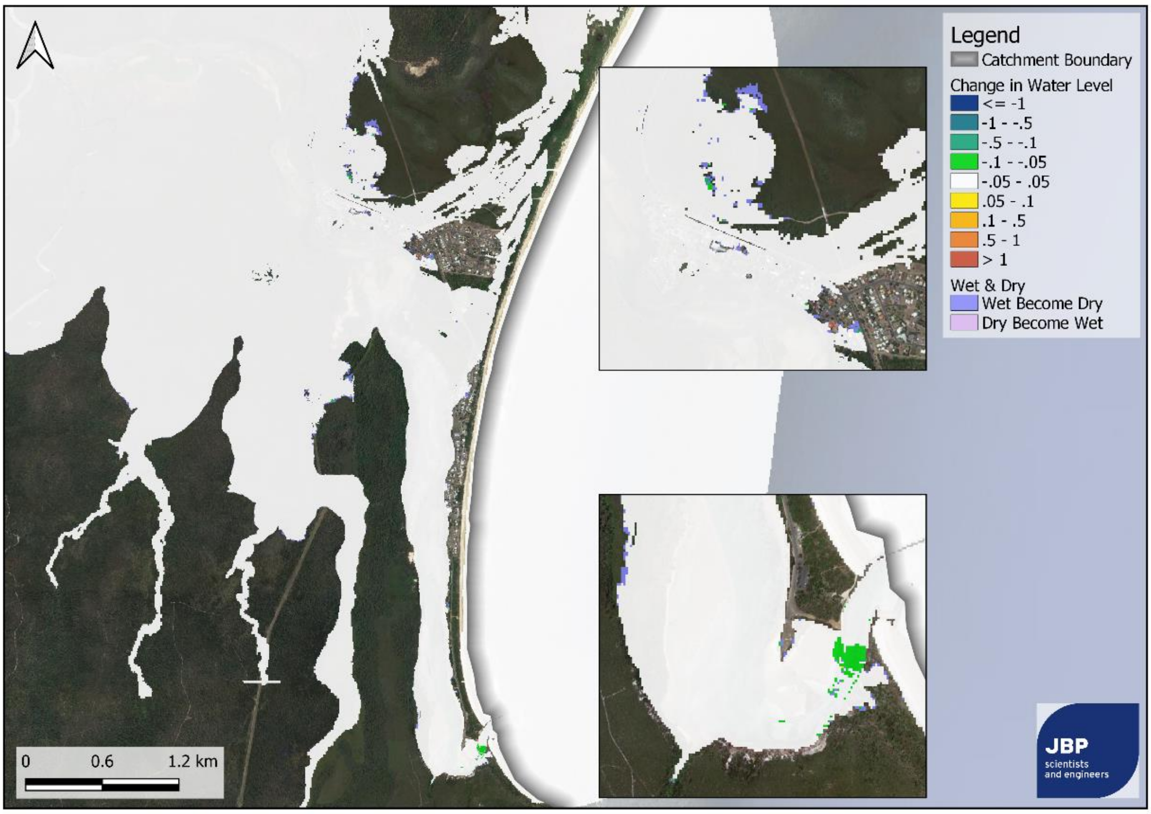

Figure 5-20: 1% Fluvial dominated bathymetry scour scenario

6 Flood Behaviour

Handbook 7 Managing the Floodplain (Commonwealth of Australia, 2018) guidance notes "understanding flood behaviour is essential for understanding and mapping flood risk". The behaviours have been reviewed under progressively rarer flood events, to understand the mechanisms of flooding in the lower catchment. This has included a review of flooded property and the road network, with further analysis undertaken in the Flood Risk Management Plan to consider:

- Number of residential properties at risk
- Frequency of properties at risk
- Number of homes at risk
- Frequency of homes at risk
- Population at risk
- Vulnerability
- Number of properties at risk in the future (climate change)
- Number of businesses and commercial properties at risk
- Road immunity and hazard classification.

6.1 Flood behaviour

The design flood event mapping provided in Appendix A has been analysed for the events between a 50% to a PMF.

In a 50% AEP event flooding remains largely within the banks of the river, with minor pooling and water backing into open drains.

- Pooling occurs around the Wooli Sportsground.
- Flood water backs up into Little River Close and adjacent drain.
- Minor inundation occurs to the north of the Wooli Solitary Island Marine Park Resort.
- Road access remains uncompromised along the main roads through the Wooli township. Minor inundation occurs in the north-western corner of the Wooli township although trafficability is still possible. (there are no road names in maps for this area)

In a 20% AEP event the flooding continues to pool and back up open drains, with floodwaters beginning to inundate property.

- There is greater inundation around Little River Close, with floodwaters spreading into Olen Close and adjacent 7 properties.
- There is greater inundation to the north and centre of the Wooli Solitary Island Marine Park Resort.
- Road access remains uncompromised along the main roads throughout Wooli. Inundation increases in the north-western corner of the Wooli township where trafficability starts to become limited. A breakout of the riverbank occurs near Little River Close, which causes localised inundation where trafficability starts to become limited. Flood waters begin to cross the northern end of Riverside Drive, but due to the flood storage on the other side of the road depths sustained on the road are minimal.

In a 10% AEP event, floodwaters begin to break out along Riverside Drive with property and several other local roadways experiencing low-level flooding.

- Inundation of the commercial premises to the west of Riverside Drive, e.g. Wooli Seafood Coop.
- Inundation to the rear of properties at east Lawson Close.
- Greater inundation occurs around Little River Close, with floodwaters spreading into Olen Close and adjacent 8 properties.

- Greater inundation to the north and centre of the Wooli Solitary Island Marine Park Resort, with water backing up to the rear of the Wooli Store.
- Road access along North Street at the showground begins to be cut, limiting access from Main Street.

In a 5% AEP event greater inundation of private property occurs.

- Inundation of 3 dwellings immediately south of the Main Street/Riverside Drive junction
- Inundation of 5 dwellings along north Carraboi Street.
- Inundation at the Wooli Store, adjacent to the Wooli Solitary Island Marine Park Resort.
- Inundation is now experienced to 59 residential lots and 4 commercial lots.
- Floodwaters begin increasing along Wooli Road and North Street, which may start limiting access in and out of Wooli.

In a 2% AEP event widespread flooding occurs, with the majority of the northern riverside community experiencing flooding, in addition several areas within the southern village become isolated from the northern village.

- Inundation to 4 properties around southern Main Street
- Inundation of the majority of the Wooli Solitary Island Marine Park, however the Wooli Hotel remains flood free and may serve as a safe refuge.
- Inundation of the majority of Little River Close and adjacent property.
- Inundation crosses northern Carraboi Street, inundating the properties on either side.
- Inundation is experienced to 88 residential lots and 4 commercial lots.
- Road access becomes completely cut at the Main Street/Riverside Drive junction, isolating all properties south of there.

In a 1% AEP event the extent of flooding is similar to the 2% AEP event, with a greater depth and hazard.

- Inundation of new properties along southern Olen Close
- Wooli Sportsground completely inundated
- Greater inundation along Carraboi Street
- Inundation is experienced to 111 residential lots and 4 commercial lots.
- Road access into Wooli is cut, with the greatest floodwater depths occurring upstream of Wooli along Wooli Road.

For events exceeding a 0.5% AEP (1 in 200-year) event the floodwaters exceed the typical immunity level of infrastructure, with water breaking over the central roadway in new locations.

- Inundation overtops Main Street (south Wooli Road) behind Olen Close and begins to inundate the eastern residential zone.
- Access is continuously cut along local roads
- As events increase in severity, progressive inundation to private property occurs, with the Possible Maximum Flood (PMF) considered possible to inundate the majority of properties in the village.

6.2 Residential land and buildings

The flood behaviour review shows the potential for flooding to residential land and property. There are 111 residential lots shown to be at risk of flooding in the 1% AEP flood event. Generally, the count of residential land exposed to flooding increases up to the 1-in-200 AEP flood event, beyond which a significant increase occurs, which is attributed to the exceedance of typical design standards. This is not uncommon, as the development controls for residential use is typically focused on flood events up to the 1% AEP flood event.

Using building footprint information an assessment of residential dwelling exposure was undertaken to determine the number of homes at risk and population at risk. All building footprints, that were zoned for residential purposes were assessed against the flood inundation mapping. As shown in Figure 6-1, the number of dwellings exposed to flooding rises from 111 in the 1% AEP flood event to 210 dwellings in the 1-in-500 AEP flood event.

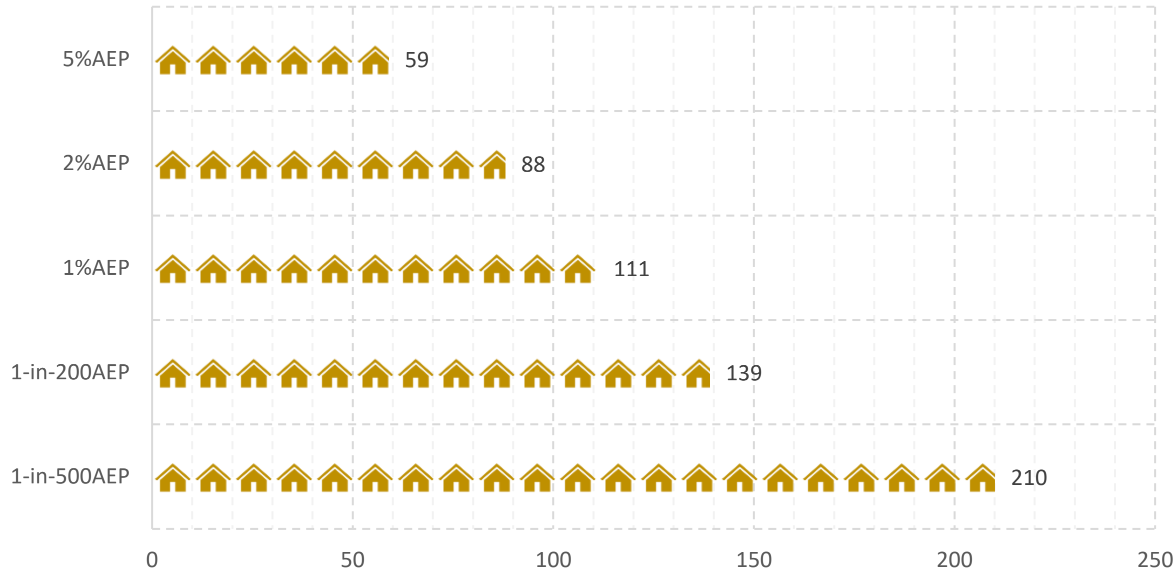

Figure 6-1. Residential buildings exposed to flooding across the floodplain

Figure 6-2. Location of buildings potentially exposed to flood inundation in a 1% AEP event.

6.3 Road network

The ability for the community and emergency services to maintain access and egress across the catchment is an important attribute in understanding the exposure of the community to flood impacts. The Council road reserve layer was used to quantify accessway hazards. The dataset includes several bush access tracks and unformed road reserves throughout the forested conservation areas to the south-west of the catchment, which are unlikely to be accessible during a flood event and were removed from the dataset. The road immunity was mapped to identify trafficability under each return period.

The road network was assessed using hazard classification from the Australian Emergency Management Institute (AIDR, 2014). This adopted a 'H2' threshold which defines the safe limit for small vehicles. This uses a hazard threshold (depth x velocity) of 0.6, still water depth of 0.5, and velocity of 2 m/s. As shown in Figure 6-3, the immunity of the local road network is generally greater than 1 in 200-year AEP, however loss of safe access into the village occurs as low as a 5% AEP event.

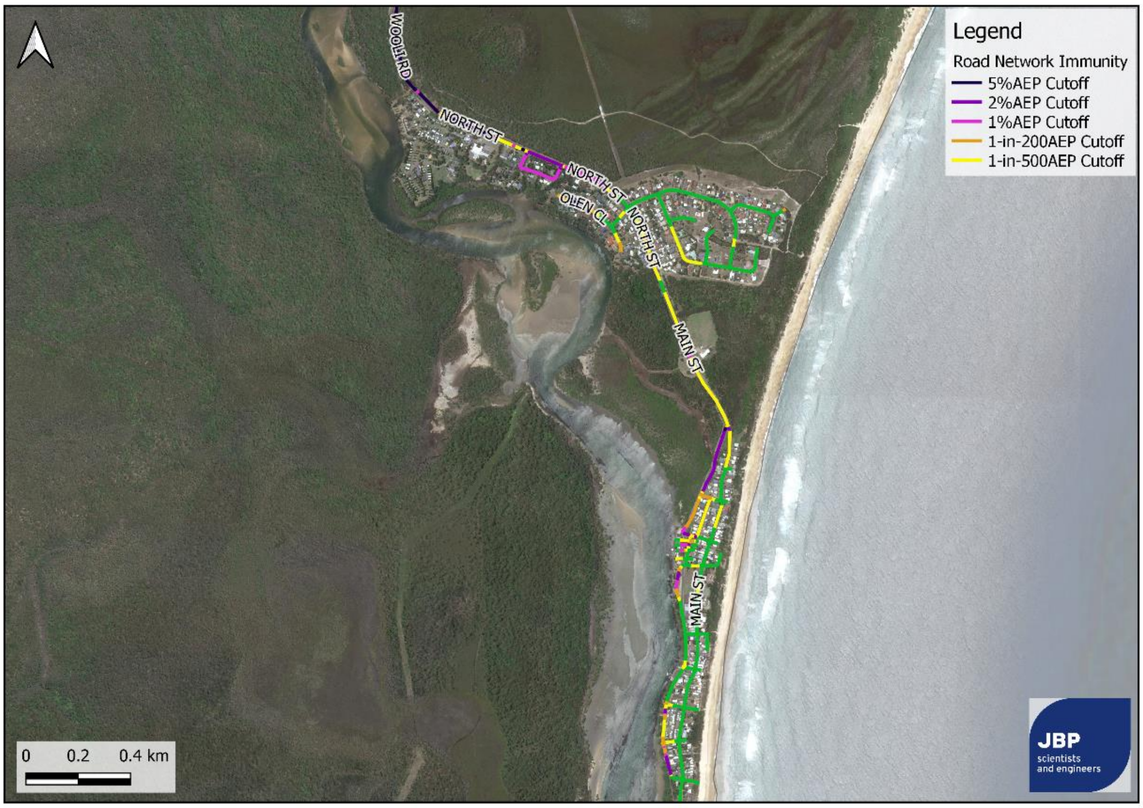

Figure 6-3. Road network evaluation examples showing network trafficability and duration of closure information.

Appendices

Appendix A: Hydraulic model maximum flood envelope maps

Supplied separately.

Appendix B: Coastal modelling

Coastal and morphologic numerical modelling has been undertaken using Delft3D, an integrated model capable of estimating tides, extreme water levels, currents, cyclones and wave conditions. It is an open-source model[8]. As schematised in Figure B-1, several modules of Delft3D can be used within modelling scenarios. For this assessment, the Delft3D-FLOW module was used to simulate hydrodynamics, coupled with the Sediment Transport Module.

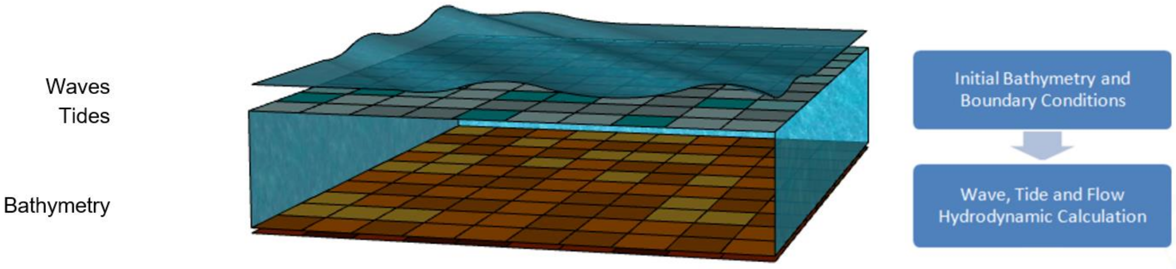

Figure B-1: Delft3D hydrodynamic and wave calculations

Modelling extent

The curvilinear grid has been used to model the shape and bends of the estuary. The grid extends from approximately 500m offshore of the river inlet to 5km up the estuary. Two boundaries have been applied:

- A downstream, tide only boundary positioned at the offshore grid limit, at a depth of -0m AHD
- An upstream tide plus flood level boundary positioned 5km upstream of the river inlet

The Wooli Wooli River model was constructed using a curvilinear grid with a spatially-varying grid resolution. A spatially-varying grid allows for high resolution at areas of interest whilst optimising model run time. The minimum cell size in the grid is 1m through the river curves. The maximum cell size is 15m at the offshore boundary. A bathymetry grid was constructed for the model domain based on the data sources described in the previous Sections.

This data was processed and merged over the Delft3D grid. Once merged, the grid was inspected to ensure that the locations where datasets intersected did not contain abnormal changes in bathymetry, which could distort coastal processes. Any gaps in the bathymetry were smoothed and averaged with the adjacent grid cell.

Modelling structures

The Wooli Wooli River inlet is a trained and fully open estuary. The river entrance is maintained by two groynes to the north and south of the inlet. Within the inlet, the river bend is trained to the north and south by rock walls and a natural cliff face. The rock walls to the north form a small lagoon during high tides. These structures have been reinforced in the model as impervious "thin dam" cells.

8 Website: http://oss.deltares.nl/web/delft3d/download

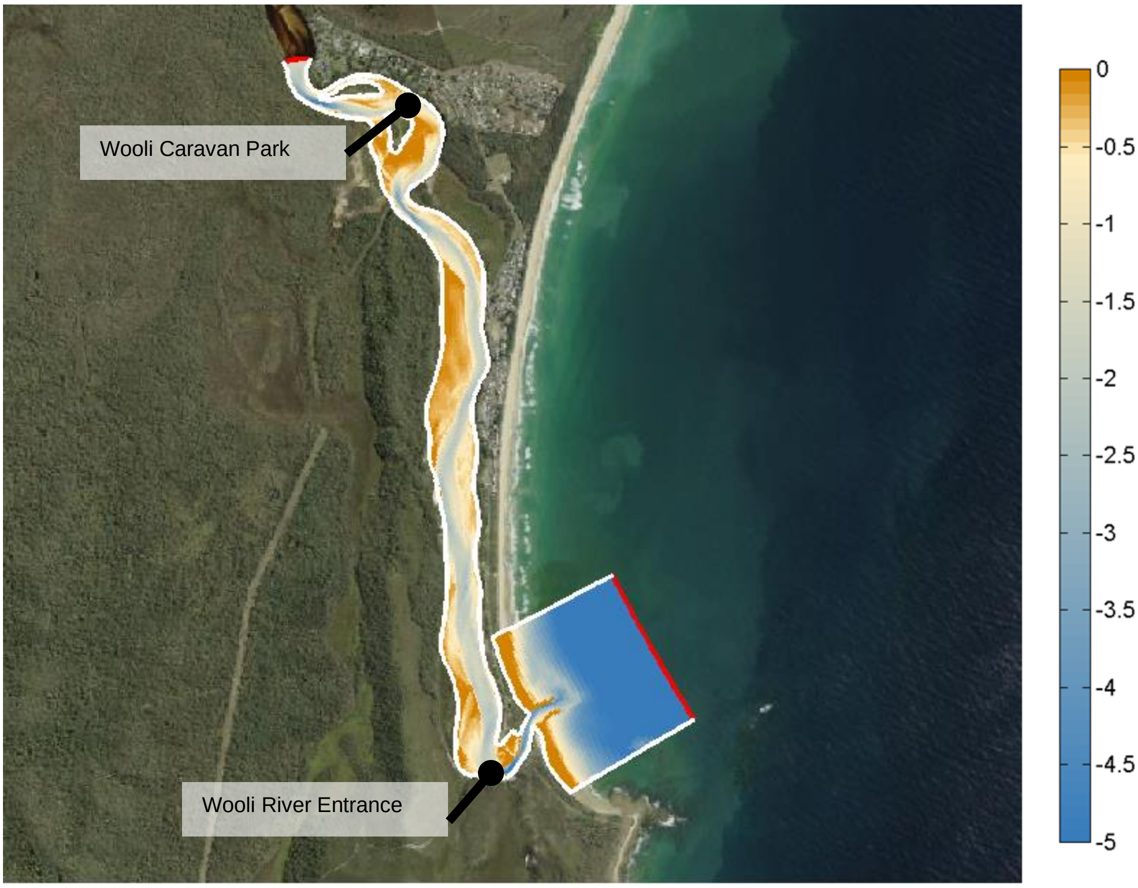

Figure B-2: Computational grid extent and bathymetry for Delft3D model, open boundaries shown in red.

Boundary conditions

Offshore tidal conditions

Offshore tidal conditions have been sourced from the astronomical record at Yamba. Analysis of the recorded Yamba and Wooli River gauge data showed a tidal latency due to the distance between the two locations. This was accounted for by shifting the Yamba record by 1 hour to align with the Wooli Wooli River recorded tidal peaks. The corrected astronomical tide levels were applied as a time series at the offshore boundary.

Upstream water level conditions

Upstream water level conditions have been sourced from the water level gauge at Wooli Caravan Park, as shown in Figure B-2. Data from this gauge shows the influence of tides as well as inland flood events. This water level data was applied as a time series to the upstream boundary.

Model Calibration and sensitivity

Calibration event

The model was calibrated against five days of observed tide data at the Wooli Wooli River Entrance gauge location from 6 to 10 February 2021. This period was chosen as it aligned with the dates of the drifter field investigation. Figure B-3 shows a comparison of recorded and modelled tide levels at the Wooli Wooli River Entrance gauge location. The results of calibration showed a good agreement, with an average error of 0.045m.

Discrepancies between the modelled and astronomical data may be attributed to nonlinear tide-surge interactions, including contributions from frictional and shallow water effects within the Delft3D model. These errors are considered within an acceptable range to proceed with the design stage of modelling.

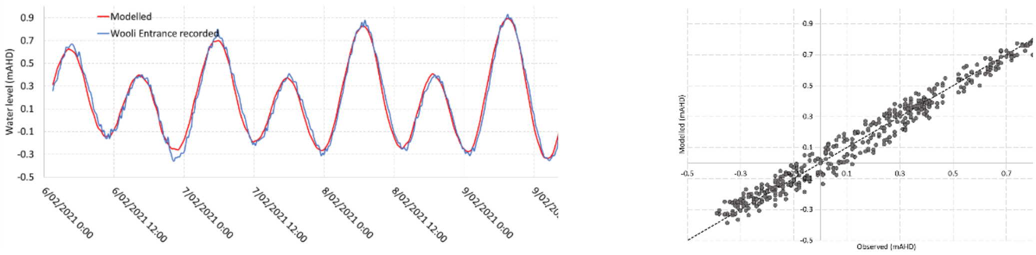

Figure B-3: Time series (left) and scatterplot (right) comparison of observed and modelled tide levels from 6 to 10 February 2021 at Wooli Wooli River Entrance gauge.

Validation against current speed field investigation

The modelled current speeds in the main estuary channel were compared against recorded drifter data taken during field investigation of the Wooli Wooli River estuary during a receding tide on 9 February 2021. Recorded data was undertaken by deploying current drifters in the main channel, each with an onboard GPS tracking system. Figure B-4 shows the drifter instruments used in this study. Drifters were deployed at 10:30 AM on 9 February 2021 on a receding tide.

Figure B-4: Drifter instrumentation used during Wooli Wooli River current speed investigation

Figure B-5 shows the modelled depth-averaged tidal velocity within the channel for the period over which the drifters were deployed. Analysis of the drifter field data confirmed an average observed current speed of 0.56m/s during the investigation. This agrees well with the modelled tidal currents during the same period.

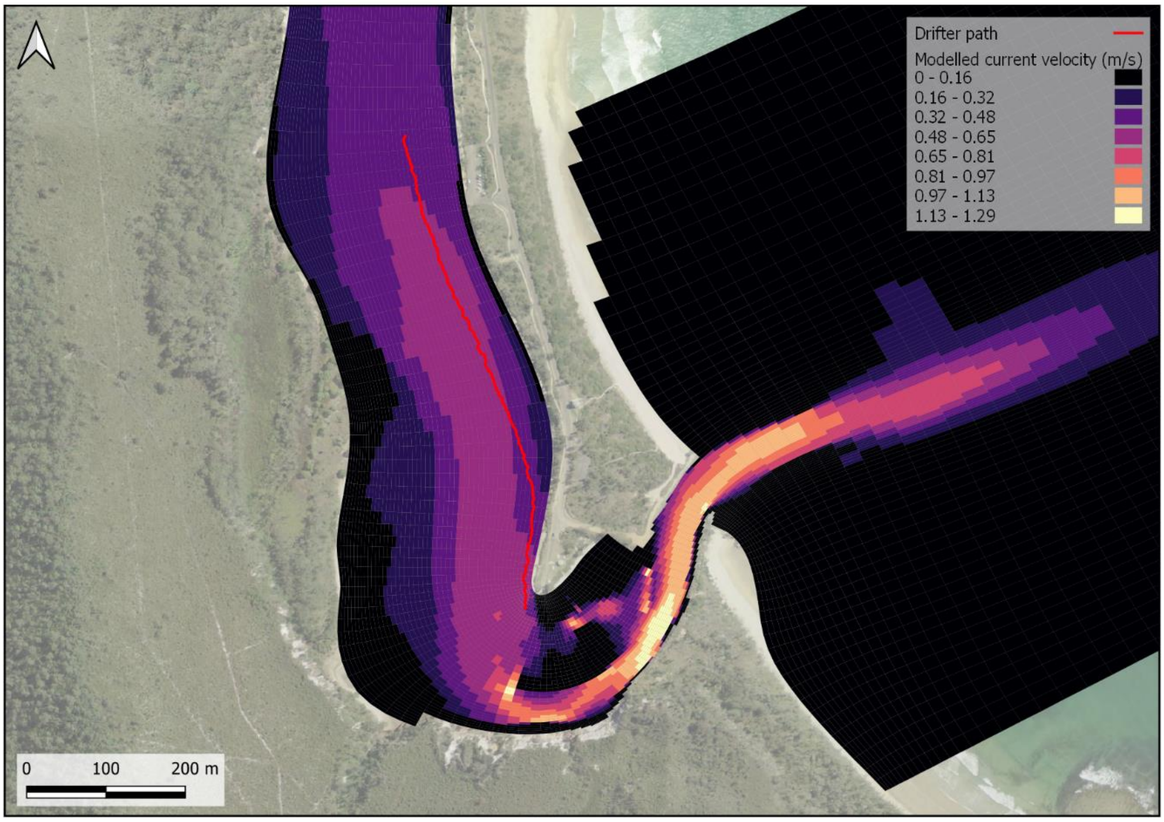

Figure B-5: Modelled depth-averaged velocities in the Wooli Wooli River estuary and path of drifter during field investigation.

Sediment transport

The Delft3D morphological model can choose from several sediment transport formulae, with the default being the Van Rijn (2007) formula. The default transport formula resulted in unexpected sedimentation results at river bends and was therefore changed to the Engelund-Hansen (1967) formula. This method has been proven to be better suited to rivers and estuaries and does not include the effects of waves.

Grain size

The morphological model was determined to be sensitive to sediment grain size. Standard grain size of 0.2mm has been applied uniformly to the model.

Morphological design run

A design flood event was adopted based on the largest inland flood event observed at the Wooli Caravan park gauge. This event occurred in March 2001 and recorded a maximum water level of 1.91m AHD at the gauge. The recorded water level time series from this event has been applied to the model upstream boundary.

The offshore boundary has been applied as tide only, extracted from the Yamba storm tide gauge for the same period and realigned to account for tidal latency between Yamba and Wooli. Figure B-6 shows upstream and downstream boundary conditions for the design flood event.

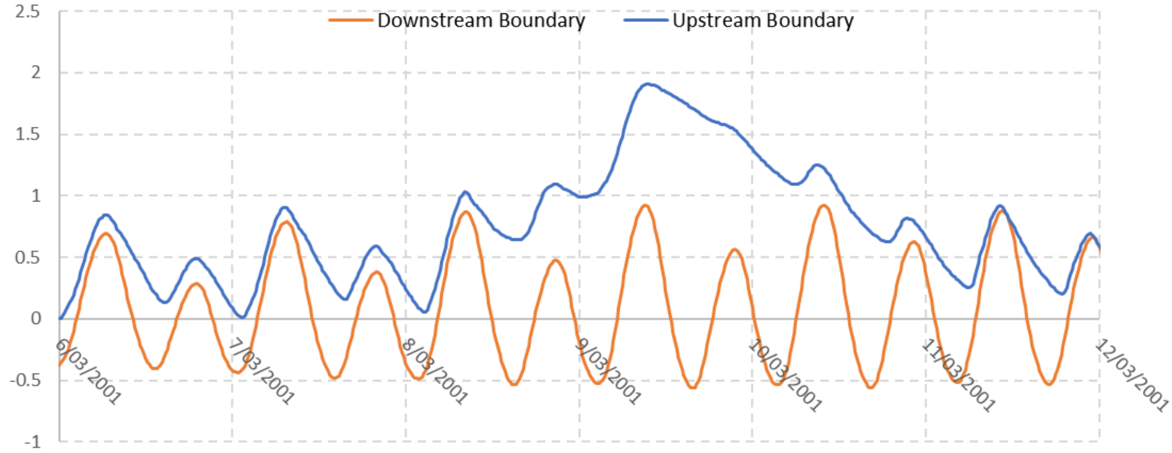

Figure B-6: Design flood conditions applied to the upstream and downstream boundaries

The initial and final bed levels during the design flood within the Wooli Wooli River estuary are shown in Figure B-6. Figure B-8 shows the total morphological change within the estuary as cumulative sedimentation and erosion from the design event. These results show significant erosion of up to 10m in the narrow, trained section of the inlet. This sediment has been deposited beyond the mouth of the channel as a large sand slug.

The final bed level within the estuary has been extracted as a grid. This grid output represents the post-storm state of the estuary, within erosion and sedimentation occurring due to a large upstream flood. This grid has been applied to the TUFLOW hydraulic model to test sensitivity to changes in estuary bed level due to a large storm event.

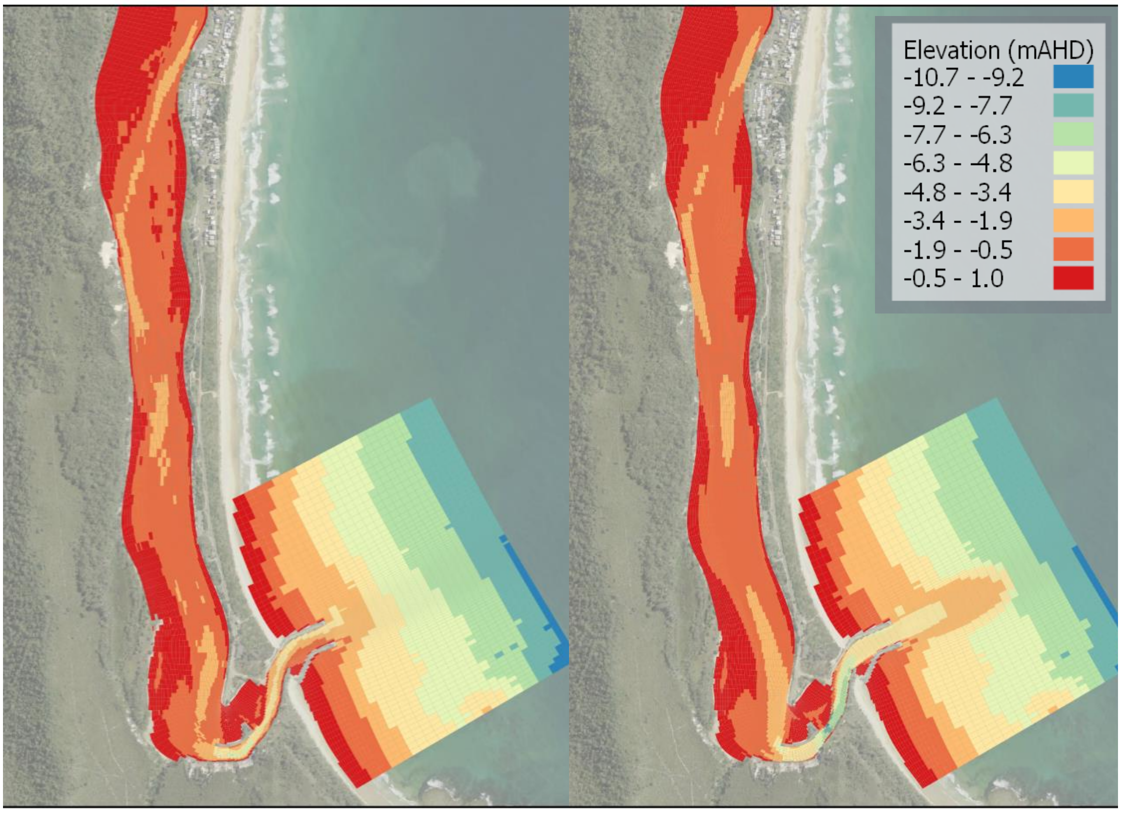

Figure B-7: Initial (left) and final (right) bed elevation within the Wooli Wooli River estuary, following design flood event.

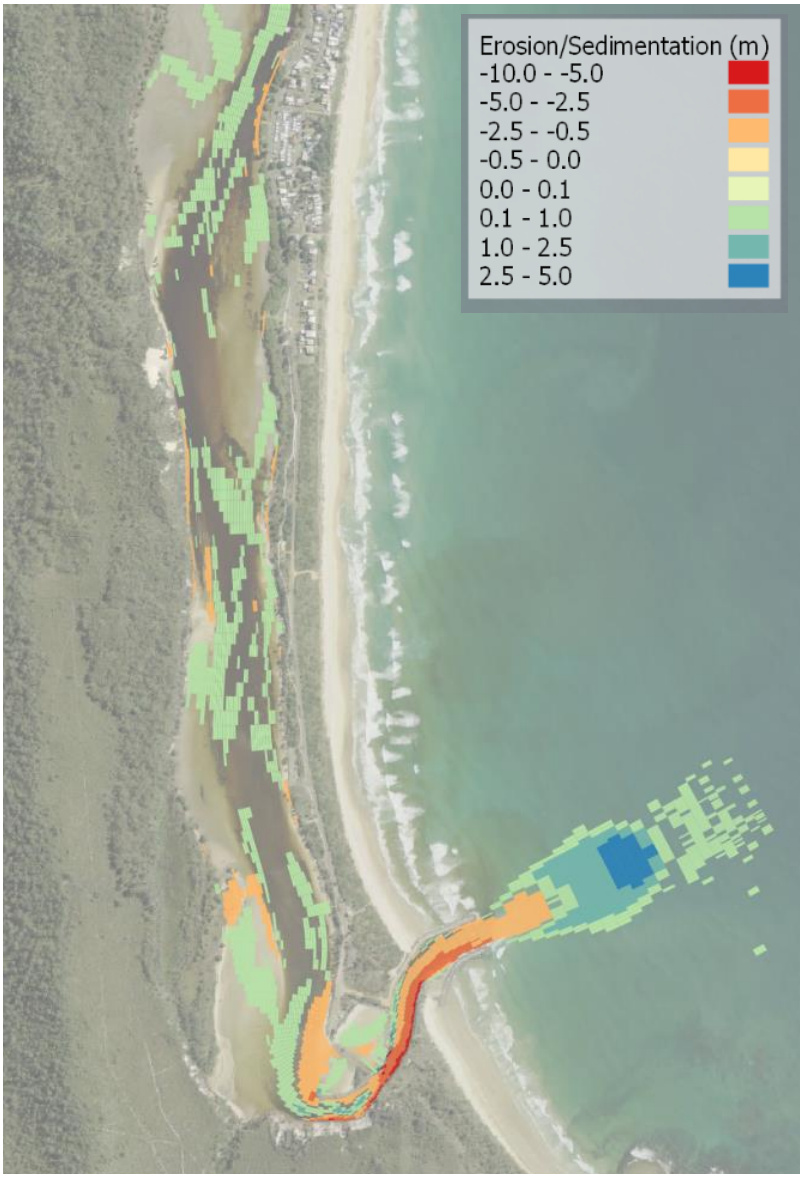

Figure B-8: Cumulative sedimentation (green to blue) and erosion (orange to red) for the Wooli Wooli River estuary during design flood event

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