Clarence Valley Coastline

Tidal and Coastal Inundation Hazard Mapping

Final Technical Report

15 September 2022

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HM0001 A1.C01 / 20 June 2022	Updated Brooms Head Mapping	RC
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Contract

This report describes work commissioned by Robyn Campbell, on behalf of Hydrosphere Consulting Pty Ltd. Daniel Rodger, Michael Thomson, Callan Schonrock, Emma Walker, and Zoe Nehring of JBP carried out this work.

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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 to August 2022 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.

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Acknowledgements

JBP would like to acknowledge the following groups for their support and supply of data for this project: Hydrosphere Consulting, Clarence Valley Council, NSW Department of Planning and Environment and the NSW National Parks and Wildlife Service.

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Executive Summary

This report was undertaken by JBPacific (JBP) in partnership with Hydrosphere Consulting to deliver a Coastal Management Program (CMP) for the Clarence Valley Council (CVC). This CMP sets the long-term strategy for the coordinated management of the Clarence Valley coastline, with a focus on achieving the objects and objectives of the NSW Coastal Management Act 2016 (CM Act). The CMP is being delivered in accordance with the NSW Coastal Management Manual (2018). This process includes five stages:

- Stage 1: Identifies the scope of the CMP
- Stage 2: Determines risks, vulnerabilities, and opportunities
- Stage 3: Identifies and evaluates options
- Stage 4: Prepares, exhibits, finalises, and certifies the CMP
- Stage 5: Implements, monitors, and evaluates the CMP

This report and associated coastal inundation maps have been developed under Stage 2 of the CMP process, which includes a coastal hazard assessment of tidal and coastal inundation. Maps have been developed for the open coastline, the Clarence River lower estuary, Lake Cakora, Sandon River, and the Wooli Wooli River. Hazard mapping has been produced using hydrodynamic modelling and spatial projection methods for present day (2023), + 20 years (2043), + 50 years (2073), and + 100 years (2123) planning timeframes. Each planning horizon includes tidal inundation mapping based on a High High Water Solstices Spring (HHWSS), and coastal inundation maps for a 10% Annual Exceedance Probability (AEP) storm (considered a frequent event), 2% AEP storm (a rare event), and 1% AEP storm (a very rare event). Future time horizons include allowances for sea level rise and are presented in two scenarios based on Shared Socio-economic Pathways (SSPs), where SSP2 represents the Representative Concentration Pathway (RCP) 4.5 and SSP5 represents RCP 8.5.

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Abbreviations

AEP .... Annual Exceedance Probability
AHD .... Australian Height Datum
ARI .... Annual Recurrence Interval
ARR .... Australian Rainfall and Runoff
CM Act .... NSW Coastal Management Act (2016)
CMP .... Coastal Management Program
CVC .... Clarence Valley Council
DEM .... Digital Elevation Model
DPE .... NSW Department of Planning and Environment
ELVIS .... Elevation Information System
EVA .... Extreme Value Analysis
GIS .... Geographic Information Systems
GPD .... Generalised Pareto Distribution
HAT .... Highest Astronomical Tide
HHWSS .... High High Water Solstices Springs
H_s .... Significant Wave Height
ICOLL .... Intermittently Closed and Open Lakes and Lagoons
ICSM .... Intergovernmental Committee on Surveying and Mapping
IPCC .... Intergovernmental Panel on Climate Change
LGA .... Local Government Area
LiDAR .... Light Detection and Ranging
MHL .... Manly Hydraulics Laboratory
NCCARF .... National Climate Change Adaptation Research Facility
OEH .... NSW Office of Environment and Heritage (Now DPE)
POT .... Peak Over Threshold
RCP .... Representative Concentration Pathways
SEED .... Sharing and Enabling Environmental Data
SSP .... Shared Socio-economic Pathways
TIN .... Triangular Irregular Network
T_p .... Wave period
WRB .... Wave Rider Buoy

Definitions

Within this report the following definitions have been used:

- Tidal inundation - inundation of land by tidal action under average meteorological conditions. Tidal inundation may include shorter-term incursion of seawater onto low-lying land during an elevated water level event such as a king tide or more permanent inundation due to land subsidence, changes in tidal range or sea level rise.
- Coastal inundation related to storm events - the temporary flooding of a portion of land within the coastal zone which is generally related to storm events. Coastal inundation occurs when a combination of marine and atmospheric processes raises ocean water levels above normal elevations and inundates low-lying areas or overtop dunes, structures and barriers. It is often associated with storms resulting in elevated still water levels (storm surge), wave setup, wave run-up and over-wash flows.

1 Introduction

This study was completed by JBPacific (JBP) in association with Hydrosphere Consulting for the Clarence Valley Council (CVC). It has been prepared to support the Coastal Management Program (CMP) for the Clarence Valley Coastline and Estuaries. This program sets the long-term strategy for the coordinated management of the Clarence Valley coastline, with a focus on achieving the objects and objectives of the Coastal Management Act 2016 (CM Act). The CMP is being delivered in accordance with the Coastal Management Manual (2018). This includes the following five stages:

- Stage 1: Identifies the scope of the CMP
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- Stage 5: Implements, monitors, and evaluates the CMP

To support Stage 2 of the CMP, this study provides a coastal hazard assessment of tidal and coastal inundation, and creates new hazard maps. Maps have been developed for the open coastline, the Clarence River lower estuary, Lake Cakora, Sandon River, and the Wooli Wooli River. This mapping spans the area shown in Figure 1-1.

All maps have been developed for present day and future planning horizons of +20 years (2043), + 50 years (2073), and +100 years (2123). Each planning horizon includes tidal inundation mapping based on a High High Water Solstices Spring (HHWSS) tide, and coastal inundation maps for a 10% Annual Exceedance Probability (AEP) storm (considered a frequent event), 2% AEP storm (a rare event), and 1% AEP storm (a very rare event).

In addition to this introduction section, this report contains the following chapters:

- **Section 2:** Coastal processes, hazards, and available data
- **Section 3:** Clarence River Inundation Modelling
- **Section 4:** Brooms Head/Lake Cakora Inundation Modelling
- **Section 5:** Sandon River Inundation Modelling
- **Section 6:** Wooli Wooli River Inundation Modelling
- **Section 7:** Open coast projection mapping
- **Section 8:** Modelling limitations
- **Appendix A:** Tidal and Coastal Inundation Maps

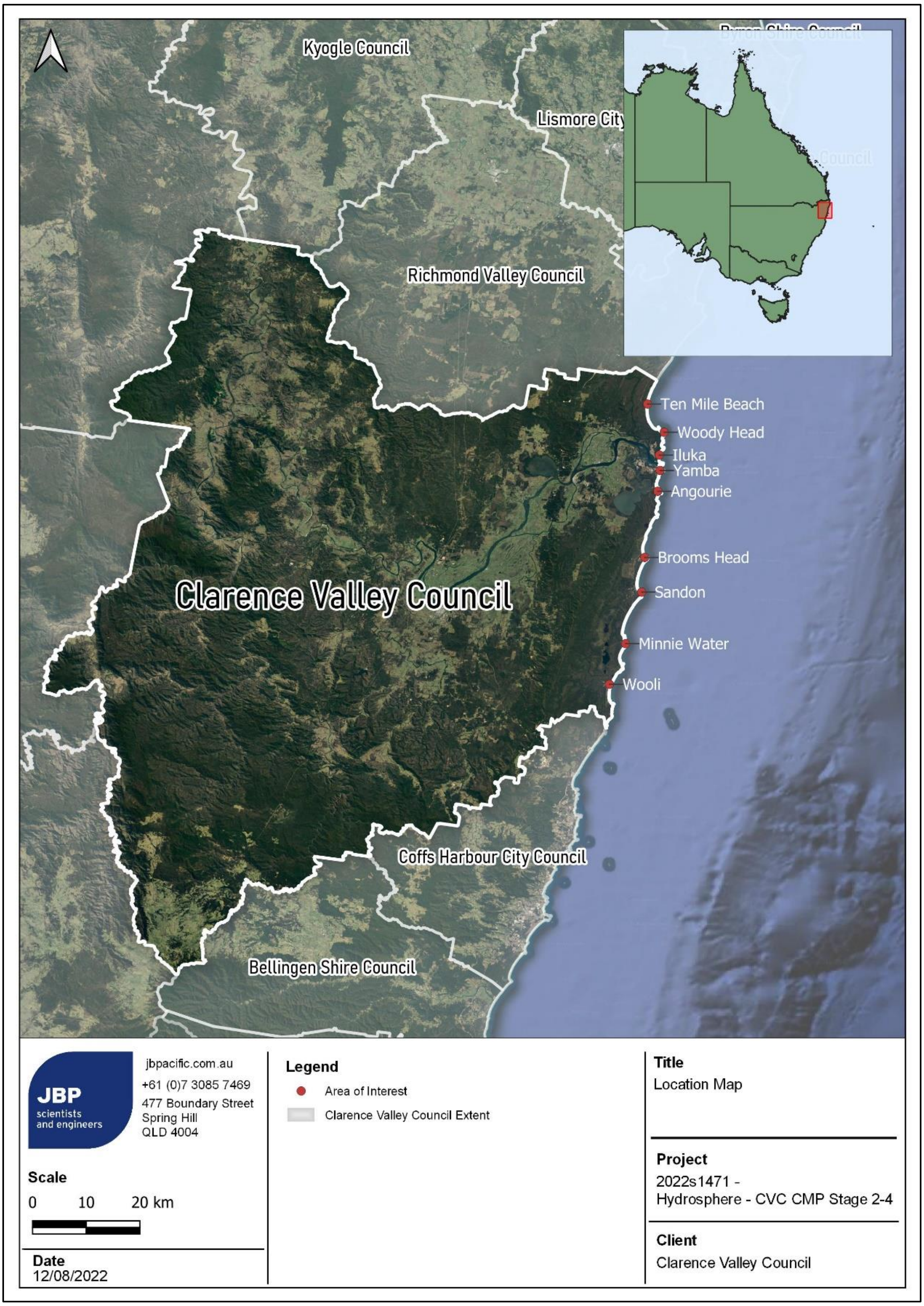

Figure 1-1: Clarence Valley Coastal Management Program study area

2 Coastal processes, hazards, and available data

2.1 Background to coastal processes

Before undertaking any calculations or modelling of coastal and estuarine processes it is first important to understand the processes that are driving coastal risk at the location. Coastal and tidal inundation are complicated processes, affected by a number of wave, hydrodynamic and morphologic processes as shown in Figure 2-1. For any coastal hazard investigations, it is also important to consider how any engineered structures will interact with these processes, such as seawalls. At present there is no single numerical model capable of simulating all processes, and instead a suite of numerical models are typically applied and used to create hazard maps.

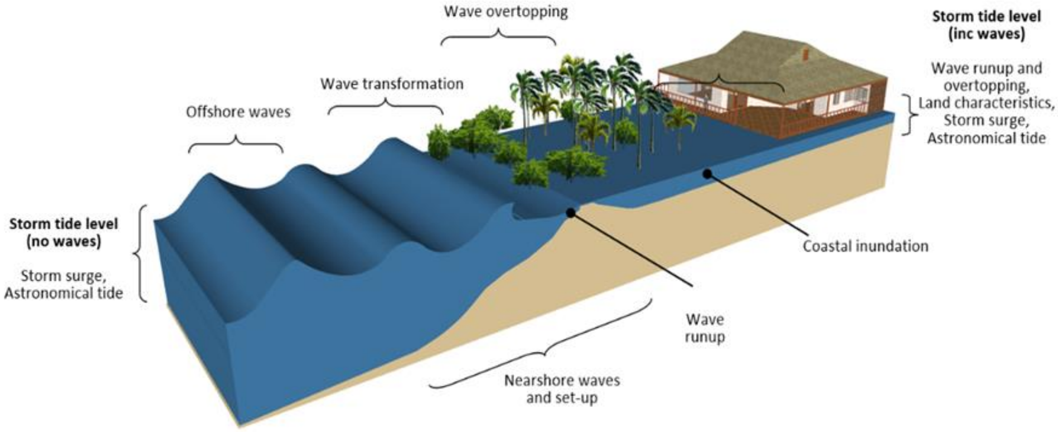

Figure 2-1: Drivers of coastal risk

The way in which different coastal processes interact will determine the tide, wave, inundation and erosion conditions experienced at any location. These may include the following:

- Astronomical tide: This is the regular periodic variation in water levels due to the gravitational effects of the moon and sun, which can be predicted with generally very high accuracy at any point in time (past and present) if sufficient measurements are available. The highest expected tide level at any location is termed the Highest Astronomical Tide (HAT) and occurs once every 18.6 year period, although in northern NSW a common peak tide level is the High High Water Solstices Spring (HHWSS).
- Storm surge: This is the combined result of the severe atmospheric pressure gradients and wind shear stress of the storm acting on the underlying ocean. The storm surge is a long period “wave” capable of sustaining above-normal water levels over several hours or even days. The wave travels with and ahead of the storm and may be amplified as it progresses into shallow waters or is confined by coastal features. The magnitude of the surge is affected by several factors such as storm intensity, size, speed, and angle of approach to the coast and the coastal bathymetry.
- Wind-driven waves: winds blowing across a water surface apply a shear stress which is converted to wave energy. The height (and energy) of a wave train is directly related to the speed of the blowing wind, the linear distance of water over which the wind is applied, and the duration that the wind blows for. Within estuaries, the distance and duration of wind stress, and hence the size of waves, is limited by the size of the estuary.
- Wave setup: As waves break, they create a localised effect to increase the sea level, known as breaking wave setup. It predominately occurs at a sloping beach or structure and becomes less significant within river mouths or protected low-lying mangrove or swampy lands
- Wave runup and overtopping: If broken waves reach the shoreline any residual energy may intermittently run up and down the beach face, known as wave runup. This may cause localised impacts as waves can reach elevations higher than the underlying extreme sea level. The vertical elevation the waves may reach will be dependent on the slope of the shoreline, the porosity, vegetation and the coastal (wave and sea) conditions. In extreme cases, wave impact and runup can lead to overtopping of the frontal dune or barrier structure, leading to coastal inundation.

2.2 Available data

A range of studies and datasets are available at a regional scale throughout the Clarence Valley region. These provide information on tides, extreme sea levels, waves, bathymetric and topographic data, hydrology, and spatial characteristics.

2.2.1 Datums

All vertical elevations have been measured from the Australian Height Datum (AHD), which normally approximates mean sea level within a range of several centimetres.

2.2.2 Event frequencies and likelihood

Coastal hazards may be defined in terms of a likelihood or event frequency. Standard industry practice is to use statistical definitions, based on an Annual Exceedance Probability (AEP). Alternatively, an event likelihood can be used as a qualitative description, useful to aid community and stakeholder understanding of risk. The former is used in preference within this report, however both approaches are described below.

- Event frequencies: This report has adopted the industry accepted terminology for event frequency description outlined in Book 1, Chapter 2.2.5 of Australian Rainfall and Runoff (ARR)[1]. Very frequent events, occurring at least once per year, are referred to by exceedances per year (EY). Rare events are referred to by Annual Exceedance Probability (AEP). For ease of reading, AEP events may be referred to by their respective Annual Recurrence Interval (ARI) in the first instance, however the ARI frequency terminology is being phased out by industry.
- Likelihood: Often a qualitative definition of a hazard frequency is required to support the understanding of any hazard mapping. This is described in ARR Chapter 2.2.5, which has been used to assign the following likelihoods to events simulated in this study:
    - Frequent: 10% AEP (1 in 10-year ARI)
    - Rare: 2% AEP (1 in 50-year ARI)
    - Very Rare: 1% AEP (1 in 100-year ARI).

2.2.3 Tides

Tidal conditions have been based on the ten-year analysis undertaken by the then Office of Environment and Heritage (OEH)[2], now Department of Planning and Environment (DPE) between 1990 and 2010. Within the analysis, tidal planes are published for Ballina, Yamba and Wooli. No tidal planes or water level gauges are available for other target locations, including Woody Head, Lake Cakora and the Sandon River. At these locations the HHWSS tide level has been estimated through a linear interpolation of published values at Ballina, Yamba and Wooli. These are considered estimates only and may not match local tide conditions, which has the potential to influence model results. The derived tidal planes are shown in Table 2-1, with the High High Water Solstice Spring (HHWSS) tide used in tidal inundation mapping. Other standard tide definitions are:

- HHWSS: High High Water Solstice Springs
- MHWS: Mean High Water Springs
- MHW: Mean High Water
- MHWN: Mean High Water Neaps
- MSL: Mean Sea Level
- MLWN: Mean Low Water Neaps
- MLW: Mean Low Water
- MLWS: Mean Low Water Springs
- ISLW: Indian Spring Low Water

1 Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) Australian Rainfall and Runoff: A Guide to Flood Estimation, © Commonwealth of Australia (Geoscience Australia), 2019

2 OEH (2012) NSW tidal planes analysis 1990-2010 harmonic analysis report mhl2053, October 2012

Table 2-1: Interpolated tidal planes (m AHD) based on OEH 2012.

Tide	Shark Bay	Woody Head	Iluka	Yamba Offshore	Brooms Head	Sandon	Wooli River Entrance
HHWSS	1.06	1.06	1.06	1.07	1.02	0.97	0.92
MHWS	0.66	0.66	0.66	0.67	0.64	0.60	0.57
MHW	0.51	0.51	0.51	0.52	0.50	0.47	0.45
MHWN	0.36	0.36	0.37	0.38	0.36	0.34	0.328
MSL	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
MLWN	-0.39	-0.39	-0.39	-0.39	-0.37	-0.35	-0.34
MLW	-0.54	-0.54	-0.54	-0.54	-0.51	-0.48	-0.46
MLWS	-0.68	-0.68	-0.68	-0.69	-0.65	-0.62	-0.59
ISLW	-0.97	-0.97	-0.97	-0.97	-0.92	-0.88	-0.84

2.2.4 Extreme water levels

Three sources of extreme water level data are available for the Clarence Valley region:

- Risk Frontiers (2021) Physical Climate Risk Assessment Coastal Flood and Sea Level Rise Supplementary Report S6 for the Clarence Valley Council[3]
- Manly Hydraulics Laboratory (MHL) (2018) NSW Extreme Ocean Water Levels[4] based on the closest available reporting point at Coffs Harbour
- OEH (2015) Floodplain Risk Management Guide; modelling the interaction of catchment flooding and oceanic inundation in coastal waterways[5]

Risk Frontiers (2021) estimated the 1% AEP extreme water level varies between 1.58 to 1.62 m AHD along the CVC coastline. This is presented in Table 2-2 for a range of coastal postcodes, which has been used within the new mapping.

OEH (2015) provides a guideline for establishing coincident design coastal levels and catchment flood conditions when investigating inundation in coastal waterways. The guideline provides a range of extreme water level estimates for different return periods and for varying shoreline types. This information has been used to derive additional return periods, based on the Risk Frontiers 1% AEP open coast level. This method was adopted to continue the use of the Risk Frontiers estimates where possible, which have now been incorporated into Council planning. This has been achieved in a two-part process:

- First, additional return periods have been created. A 2% (50-year) and 10% (10-year) extreme water level has been created based on their relative difference from the 1% (100-year) Risk Frontiers level. Relative differences have been adopted from the OEH (2015) published values, where a 2% AEP is -0.05m below and a 10% AEP is -0.10m below the 1% AEP respectively. This is shown in Table 2-2.
- The second adjustment accounts for shoreline or estuary type, with OEH (2015) recommending an additional allowance to account for entrance effects within trained rivers and Intermittently Closed and Open Lakes and Lagoons (ICOLLs). This is shown in Figure 2-2. The final extreme water level for any location is:
  - Open coasts: Use Table 2-2
  - Group 2: Tide dominated estuaries: No change to open coast values shown in Table 2-2
  - Group 3, Type A Estuary (trained entrances, navigable for large vessels). No change to open coast values shown in Table 2-2. Clarence River (2464) has a 1% AEP of 1.61mAHD.

3 Risk Frontiers (2021). Physical Climate Risk Assessment; Coastal Flood and Sea Level Rise supplementary report S6

4 MHL (2018) NSW Extreme Ocean Water Levels, Final Report MHL2236. Prepared for Office of Environment and Heritage.

5 OEH (2015) Floodplain Risk Management Guide; modelling the interaction of catchment flooding and oceanic inundation in coastal waterways

- Group 3, Type B Estuary (trained entrances, navigable for small vessels). Increase water level by +0.55m. Wooli River (postcode 2462) has a 1% AEP of 2.13mAHD.
- Group 3, Type C Estuary (ICOLLS and untrained/partially trained small entrances): Increase water level by +1.1m. Lake Cakora and Sandon (postcode 2463) has a 1% AEP of 2.7mAHD.

Table 2-2: Estimated extreme water level elevation (m AHD) per postcode in the Clarence Valley.

Postcode	1% AEP (Risk Frontiers)	2% AEP	10% AEP
Open Coastline			
2462 - Wooli Coastline	1.58	1.53	1.48
2463 - Brooms Head/Sandon	1.60	1.55	1.50
2464 - Yamba/Clarence River	1.61	1.56	1.51
2466 - North Clarence River	1.62	1.57	1.52
2469 - Upstream Clarence River	1.62	1.57	1.52
Adjusted allowance for estuaries			
Clarence River (+0)	1.61	1.56	1.51
Wooli River (+0.55)	2.13	2.08	2.03
Lake Cakora and Sandon (+1.1)	2.70	2.65	2.60

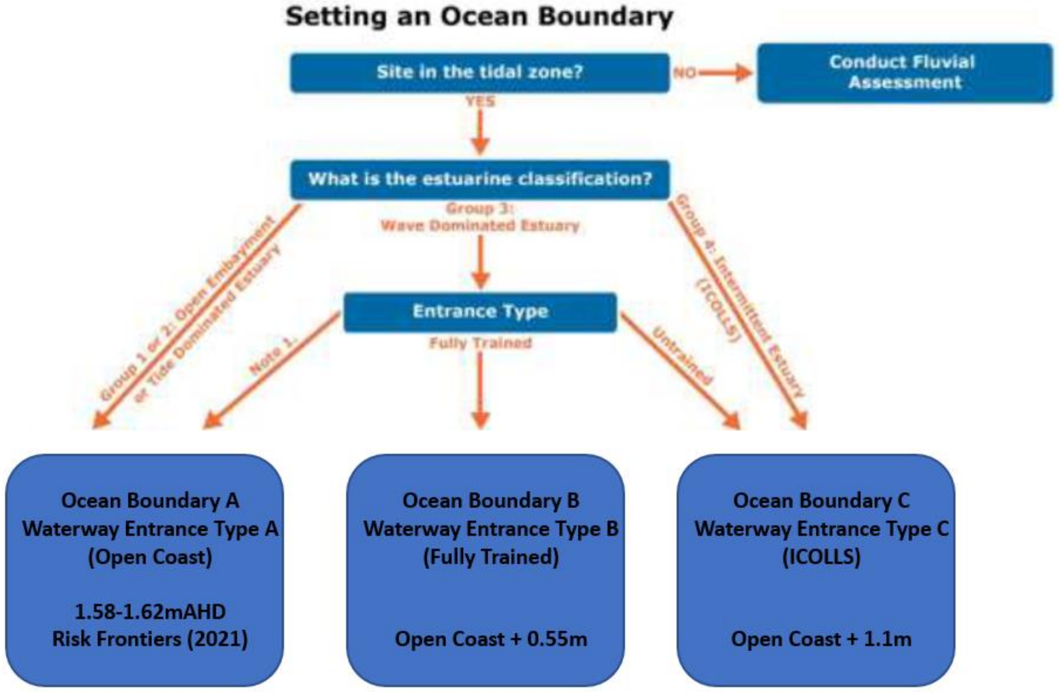

Figure 2-2: Water level boundary conditions (adapted from OEH 2015).

2.2.5 Wave conditions

The Clarence coastline does not have a long-term wave buoy or recorded wave data. Instead, wave conditions are based on the Coffs Harbour wave rider buoy (WRB). This buoy is located 9km offshore Coffs Harbour approximately 50km south of the southern extent of the Clarence LGA. Recorded data is available from 1976 to present day and includes significant wave height (H_s), wave direction, and wave period (T_p). A wave rose is shown in Figure 2-3, which presents a predominate south-easterly wave direction from 1976 to present day.

Extreme value analysis (EVA) has been conducted on the historic wave record to estimate extreme wave conditions at the buoy. A peak over threshold (POT) approach has been used to identify extreme events within the recorded data and a Generalised Pareto Distribution (GPD) model has been used to estimate extreme wave conditions. This analysis produced a range of return periods for extreme Significant Wave Height (H_s) with the associated peak wave period (T_p) derived using a linear relationship to the recorded data.

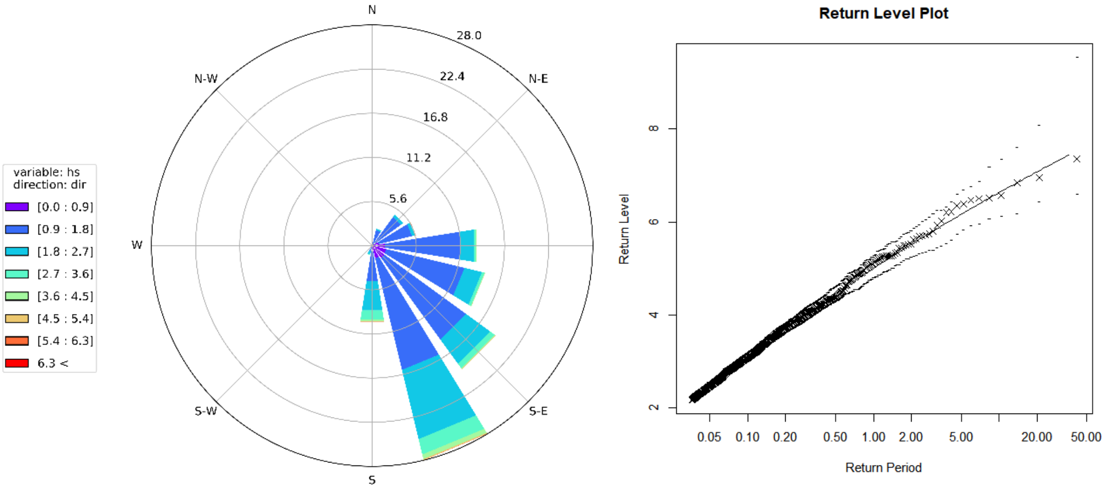

Figure 2-3: Coffs Harbour offshore buoy wave rose (1976 to 2021) (left) and extreme wave estimates (right).

Table 2-3: Extreme offshore wave conditions (Coffs Harbour wave buoy)

Event, AEP (ARI)	Significant wave height, H_s (m)	Peak wave period, T_p (s)
10% (10-year)	6.6	13.0
2% (50-year)	7.6	14.0
1% (100-year)	8.0	14.5

2.2.6 Climate change estimates

Planning horizons include present day, +20 years (2043), +50 years (2073), and +100 years (2123) from present, as specified within the NSW Coastal Management Manual[6]. The likelihood scenarios for mapping have been set by the CVC project team in conjunction with State Government feedback and include 10% AEP (frequent), 2% AEP (rare), and 1% AEP (very rare) hazard maps.

Two climate change scenarios have been used in this assessment, using predicted changes to sea level (sea level rise) as presented by the Intergovernmental Panel on Climate Change (IPCC). The scenarios follow different Shared Socio-economic Pathways (SSP), which consider how socio-economic factors may change over the next century. These consider changes to population, economic growth, education, urbanisation and the rate of technological development. They are complimentary to Representative Concentration Pathway (RCP) terminology, which considers the effect of different levels of greenhouse gases and other radiative forcings. The two climate change scenarios used in this study are:

- SSP2 represents a pathway where the world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. It considers intermediate greenhouse gas emissions, with carbon dioxide (CO_2) emissions maintaining current levels until 2050, then falling, but not reaching net zero by 2100. It reflects an RCP of 4.5.
- SSP5 represents the highest level of fossil fuel use, food demand, energy use and greenhouse gas emissions. It includes very high greenhouse gas emissions, where CO_2 emissions triple by 2075. However, it also includes a socio-economic pathway where competitive markets, innovation and participatory societies are able to produce rapid technological progress to achieve sustainable development over the long-term. It reflects an RCP of 8.5.

6 State of NSW and NSW Office of Environment and Heritage (2018). Our future on the coast; NSW Coastal Management Manual Part A: Introduction and mandatory requirements for a coastal management program

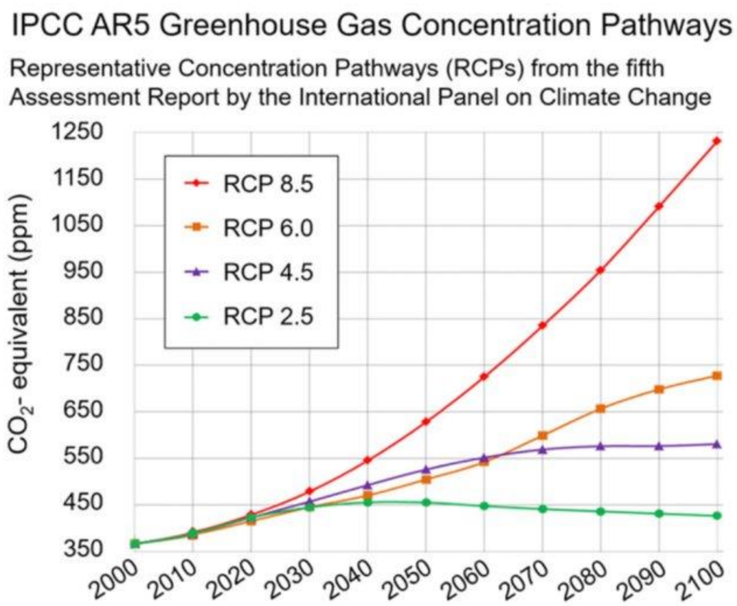

Figure 2-4: Differences in RCPs for future time periods (Hanna, J. W et al. (2020)).

Sea level rise estimates for each planning horizon were based on the IPCC 6th Assessment Report (AR6) Sea Level Projections, derived from the NASA Sea Level Projection Tool[7]. All tide and coastal inundation modelling has used a median projection of regional sea level rise, based on a reporting point at Yamba, which is presented relative to a 1995-2014 baseline. Sea level rise projections for SSP2 and SSP5 scenarios are shown in Table 2-4. Median estimates for planning horizons 2043, 2073, and 2123 are shown in Table 2-5, and were obtained through a linear interpolation.

Table 2-4: Median Sea level rise estimates for Yamba (IPCC, 2021)

Year	SSP2 / RCP 4.5 (m from present)	SSP5 / RCP 8.5 (m from present)
2020	0.05	0.06
2030	0.10	0.11
2040	0.15	0.17
2050	0.21	0.25
2060	0.27	0.33
2070	0.35	0.43
2080	0.42	0.54
2090	0.50	0.68
2100	0.57	0.82
2110	0.66	0.92
2120	0.73	1.05
2130	0.81	1.18

Table 2-5: Interpolated median sea levels for planning horizons 2043, 2073, and 2123.

Year	SSP2 / RCP 4.5 (m from present)	SSP5 / RCP 8.5 (m from present)
2043	0.17	0.19
2073	0.37	0.46
2123	0.76	1.09

7 Available at: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool?psmsl_id=310

2.2.7 Baseflow

Coastal inundation models have included baseflow to account for low level fluvial inputs. Baseflow was estimated using techniques described in the ARR (2019), Book 5 - flood hydrograph estimation[8]. The calculation of baseflow requires an understanding of streamflow, which is linked to rainfall intensity. All present day rainfall inputs were obtained from the ARR Datahub for each estuary. Future planning horizons have increased rainfall due to climate change, and therefore greater baseflow. This has been estimated using procedures outlined in ARR (2019), Book 1, Section 6.3 - Interim Climate Change Guidelines. This method indicates a 28% increase in rainfall intensity may occur by 2123.

2.2.8 Landuse and model roughness

Roughness layers are applied to a hydrodynamic model to represent different groundcover and vegetation types (e.g., grassland, waterways, buildings, infrastructure). This effects flow velocity over the computational grid and influences the inundation depth.

Roughness zones have been based on three types of landuse mapping:

- Any existing model has continued the adopted landuse. E.g., no changes have been made to the Clarence River and Wooli Wooli River models.
- Sentinel 2 Satellite global land use classification has been accessed through ESRI 2020 Global Landuse Mapping. This is considered the most recent landuse dataset of the NSW coastline, and used where recent changes are observed to estuarine vegetation
- Alternatively, NSW Land Use Mapping and mangrove coverage has been sourced from the NSW Spatial Data Portal, which has a published date of 2010. Whilst not as recent as the Sentinel dataset, this provides state government adopted layers that are relevant for stable estuarine areas.

These landuse maps have been classified into a Manning's 'n' value, as shown in Table 2-6.

Table 2-6: Model roughness classes

Classification	Hydraulic Roughness (Manning's n value)
Roads Reserve & Dirt Track	0.025
Environmental Conservation	0.16
Managed Vegetation	0.06
Light Vegetation	0.07
Medium Dense Vegetation	0.11
Dense Vegetation	0.12
Swamp	0.09
Residential Areas	0.20
Waterways	0.035
Sandy Coastline	0.033
Mangroves	0.15
Buildings	0.20
Oceans	0.02

8 Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) Australian Rainfall and Runoff: A Guide to Flood Estimation, © Commonwealth of Australia (Geoscience Australia), 2019, Book 5.

2.2.9 Existing model inputs

The following models and studies have been used to complete this study:

- Wooli Flood Study (JBP, 2022): This study included a new hydrology, flood mapping and flood risk study for the Wooli Wooli River and estuary. The project included the collection and review of hydrologic data including rainfall and gauge records, new ground and bathymetric data collection, development of a hydrological model and TUFLOW hydrodynamic model for the catchment, and the development of an estuarine Delft3D model to understand the interaction between fluvial and geomorphology processes. The project outputs included new flood mapping to support land use planning and disaster management. This model was re-run for this project using new tide and coastal inundation estimates.
- Two hydrodynamic Tuflow models were supplied for the Clarence River.
    - Clarence River Flood Study Model developed by BMT (2014)
    - Clarence River 'Pacific Model' which includes the Pacific Motorway Upgrade by Pacific Complete (2020)

The newer Clarence River 'Pacific Model' was used within this study as the alternate 2014 model was of a lower resolution and did not include the Pacific Motorway upgrade, considered a significant structure in the coastal floodplain. The Pacific Model was completed in 2020 and provided to CVC by a third party (Pacific Complete) when upgrading the Pacific Highway. Whilst the model was not independently assessed or verified by Council, it represents the most recent status of the floodplain. The Pacific Model is based on the official CVC model developed by BMT in 2014. It is a multi-domain Tuflow hydrodynamic model, with varying sub-domain grid resolution for the Clarence River (60m to 30m), north and south Grafton (30m to 10m), and Maclean (30m to 10m). The model was used for the tide and coastal inundation mapping, with results trimmed to show the coastline only. The model includes several open channel waterways, bank crest elevations and other training structures, although does not consider sub-surface connections created by the stormwater network which may require consideration when interpreting the data, and during future planning and management.

3 Clarence River model

3.1 Approach

Hydrodynamic modelling was used to map coastal inundation along the open coast between Yamba and Woody Bay, and within the lower Clarence River estuary including Whiting Beach.

Modelling was undertaken using a Tuflow hydrodynamic model, which was adapted from the 'Pacific Model' discussed in Section 2.2.9. A range of enhancements were made to the model in order for it to be used along the coastline. These enhancements included:

- Alteration of internal and external model boundaries. This extended the downstream tidal boundary further along the coastline
- Changes to the terrain:
  - Addition of new Light Detection and Ranging (LiDAR) data, cross-sectional and bathymetric data
  - Enforcement of crest and gully lines for road corridors and drainage channels in the lower estuary
- Update of model hydraulic roughness using land use maps
- Alteration of upstream inflows, changing fluvial (river) flood conditions to baseflows (as described in Section 2.2.7). The addition of baseflow within the upstream rivers and creeks improved model stability when compared to removing all fluvial inputs. However, the applied baseflow rates are negligible compared to tidal and water level flows introduced from the ocean boundary.
- The published mapping focussed on the downstream areas only.

The updated model domain, which includes the increased downstream boundary which spans from Yamba to Woody Head, is shown in Figure 3-1.

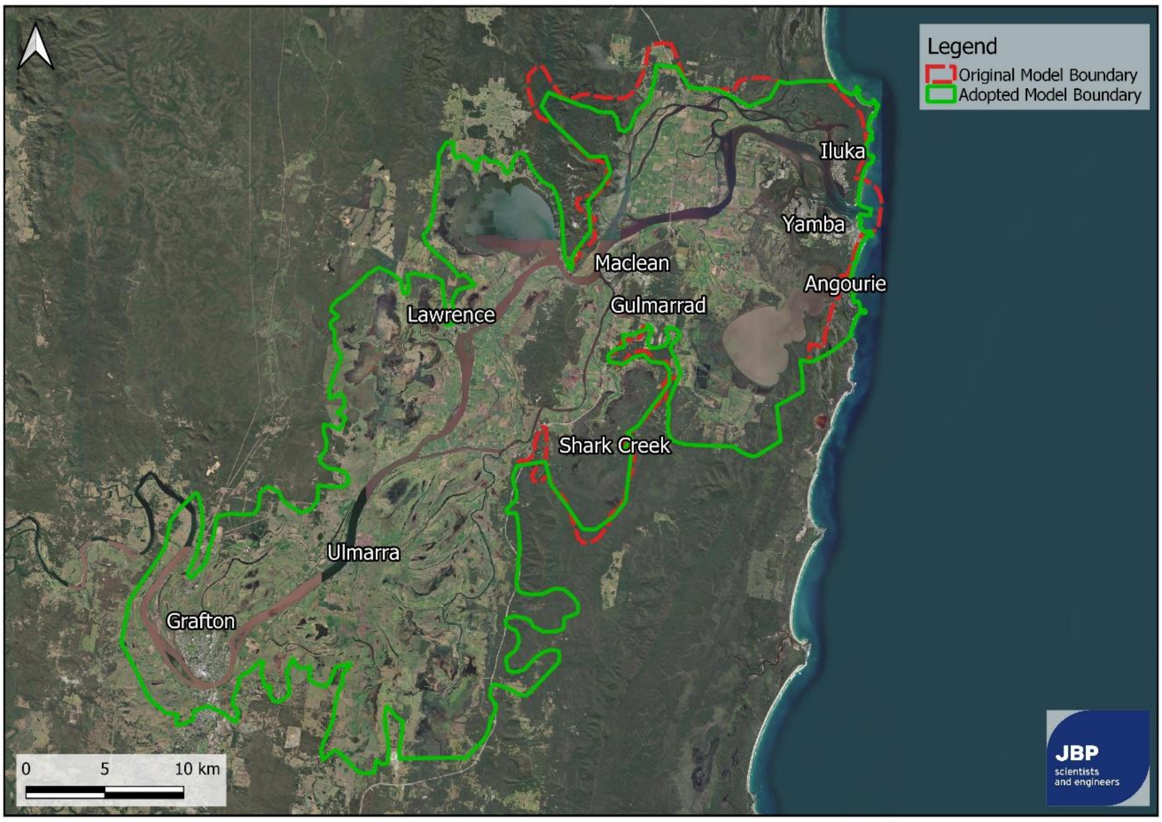

Figure 3-1: Clarence River updated model domain

3.2 Hydrodynamic model

3.2.1 Elevation

Three available sources of topographic information were used in the Clarence River hydrodynamic model. A summary of the available topographic data, its sampling data, resolution, and sources are summarised in Table 3-1.

- Topo-Bathymetric Data: 5m resolution bathymetry data was obtained from the NSW DPE portal for Sharing and Enabling Environmental Data (SEED) portal[9]. This bathymetric data was prioritized below 0mAHD and merged with the topographic data with smoothing performed at the data intersection.
- Topographic Data: 1m resolution DEM, obtained for the Woodburn region from the Intergovernmental Committee on Surveying and Mapping (ICSM) Elevation Information System (ELVIS)[10]. This data was derived using a Triangular Irregular Network (TIN) method to formulate a regular grid with an accuracy of 0.3m (95% confidence interval) vertical and 0.8m (95% confidence interval) horizontal.
- Bathymetric data: Bathymetric data was sourced from the STAX survey dataset obtained from the NSW OEH[11]. STAX surveys contain any combination of data from single-beam bathymetry surveys, terrestrial laser scanner elevation, all-terrain vehicle plotted elevation, and cross-sectional beach elevation/bathymetry.

Table 3-1: Summary of topographic information

Dataset	Timeliness	Resolution	Source
Topo-Bathy LiDAR	2018	5m	NSW Marine LiDAR Project
LiDAR	2010	1m	ELVIS
STAX Surveys	1978~ 2018	Varying interval CS Data	NSW Office of Environment & Heritage

3.2.2 Roughness

Roughness values are based on land use types in the original model, with any updates around the new coastal boundary based on Sentinel 2 Satellite global land use classifications available within the ESRI 2020 Global Landuse Mapping. Figure 3-2 illustrates the spatial distribution of land use types and Table 2-6 shows the associate roughness value per land use category.

9 NSW DPE (2018). NSW Marine LiDAR Topo-Bathy 2018 Geotif. Accessed from: https://datasets.seed.nsw.gov.au/dataset/marine-lidar-topo-bathy-2018

10 ICSM ELVIS (2010). WOODBURN, 2kmx2km 1 metre Resolution Digital Elevation Model. Accessed from: https://elevation.fsdf.org.au/

11 NSW OEH (ND). Single-beam Bathymetry and Coastal Topographic Surveys, Clarence River Compilation and Clarence River Entrance Data. Accessed from https://portal.aodn.org.au/

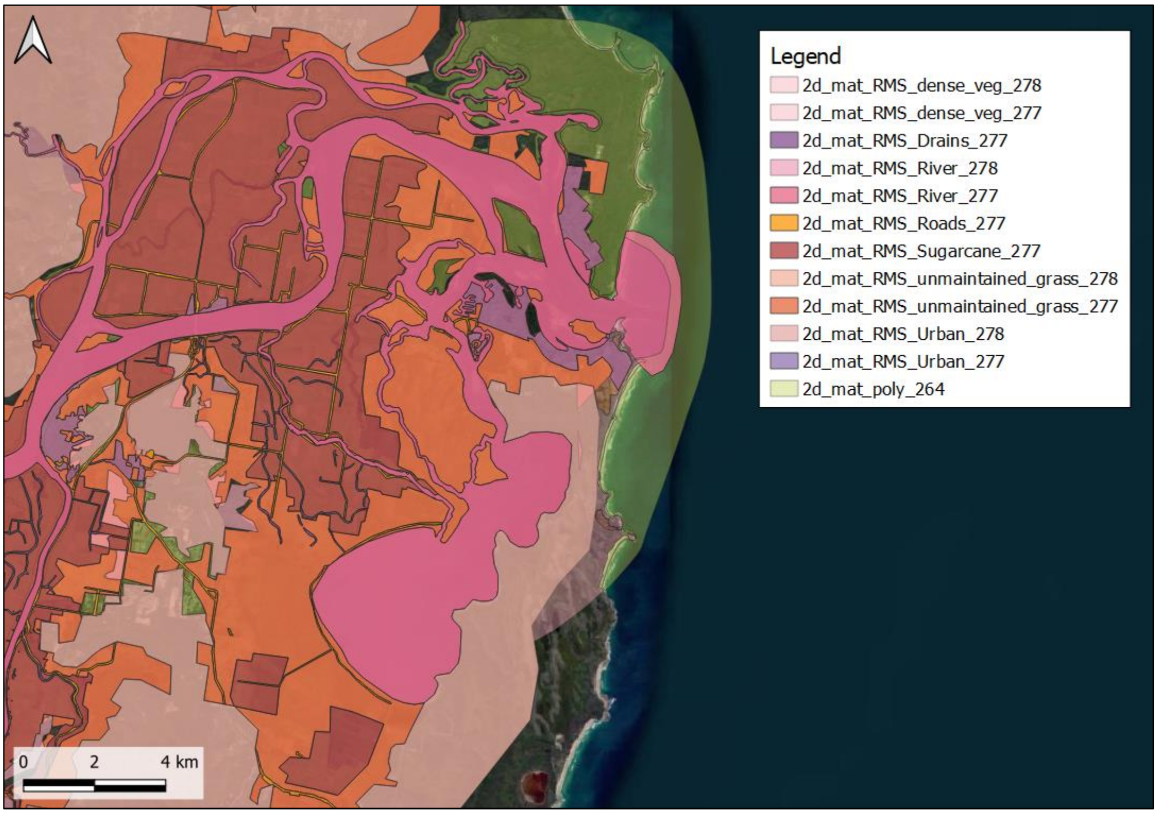

Figure 3-2: Land Use Types in the Clarence Valley LGA.

3.2.3 Structures

The wider model includes bridges, culverts, pipes, stormwater, sewerage, water supply floodgates, and levees, and has 1710 drainage lines within the model domain. These structures are either located on rail, road or levee embankments. Roughly 1000 drainage crossings have backflow prevention devices installed and operate as directional flow structures. Figure 3-3 shows these structures with and without backflow prevention devices, which have not been altered for this project (i.e., they remain in their configured open or closed state, based on the original Pacific Model supplied for this project). Table 3-2 lists the structures that were present in the model provided. However, given the model is used to map tides and coastal inundation around the open coastline and lower estuary only, the position of upstream flood gates is not expected to have a significant impact on results along the coastal floodplain. Any upstream results have been removed from the reporting figures, given they are not the focus of this project.

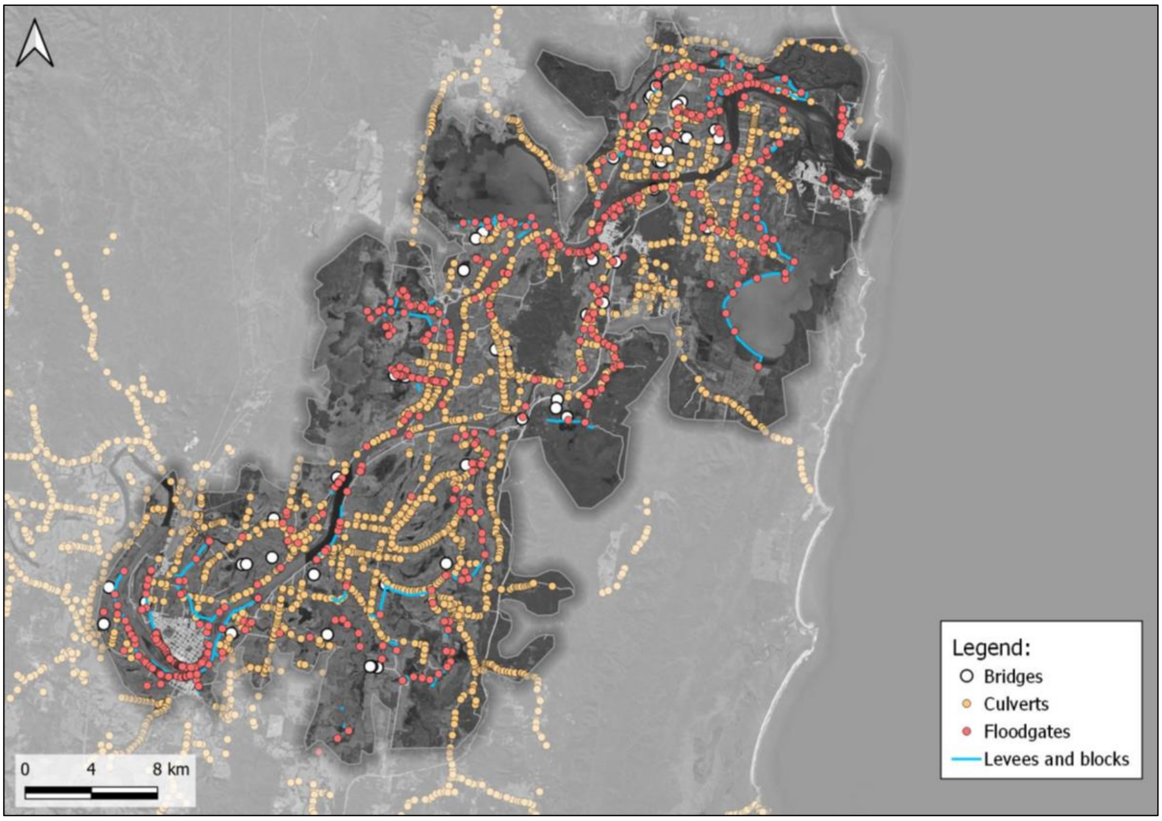

Figure 3-3: Drainage crossings in the Clarence River Model domain

Table 3-2: Structure numbers in supplied model

Identifier	Description	Number of Structures
1D Structures		
B	Bridges	7
C	Culverts	125
CU	Uni-Directional Circular Culverts	33
R	Box Culverts	17
RU	Uni Directional Box Culverts	31
S	Open Channel Segments	126
W	Weir	2
2D Structures		
2d_fc	Flow Constriction Bridges	16
2d_lfcsh	Layered Flow Constriction Bridges	22

3.3 Boundaries

3.3.1 Hydrologic inflows

The Pacific Model was originally developed to simulate extreme fluvial event (i.e. river flows and catchment runoff) and have large freshwater inflows. Upstream boundaries have been converted to represent baseflow from creeks and local catchments only. Whilst baseflow rates are low, they are important during a coastal storm event that occurs in the summer 'wet season'. However, the modelling does not represent a coincident storm and coastal surge event. Baseflow was extracted from streamflow data as described in Section 2.2.7.

3.3.2 Summary of extreme water levels

Modelling has used a tidal signature based on the Coffs Harbour tidal gauge. Tidal data is available within the Clarence valley at Wooli and Yamba, although are influenced by river conditions. The use of the Coffs Harbour gauge has a greater representation of tides only, without the influence of fluvial processes. The tidal signal from the Coffs Harbour gauge has been scaled to have a peak tidal elevation representing a HHWSS tide at Yamba (Table 2-1).

Two consecutive tidal peaks have been simulated. The first tide allows the foreshore to be inundated, with the second then reaching the peak water level. In addition to present day conditions, the tidal signal has been increased to reflect two climate change pathways based on the median (50th percentile) sea level rise estimates.

3.4 Tidal and coastal inundation mapping results

Tidal and coastal inundation maps were merged into the Open Coast mapping discussed in Section 7. Maps are provided in Appendix A, which includes the following:

- Tidal inundation and coastal inundation
- Present day, 2043, 2073 and 2123 planning horizons
- For tidal inundation maps: HHWSS tide
- For coastal inundation maps:
    - 10% AEP (10-year)
    - 2% AEP (50-year)
    - 1% AEP (100-year)
- Each scenario includes SSP2 (RCP4.5) and SSP5 (RCP8.5) climate change conditions.

4 Brooms Head/Lake Cakora model

4.1 Approach

A new hydrodynamic model has been developed for Brooms Head and Lake Cakora. It uses a downstream tidal signal, storm surge inputs, additional allowances to account for entrance effects, and catchment baseflows. The model extent is shown in Figure 4-1 which includes Cakora Point, Lake Cakora and approximately three kilometres of the northern watercourse.

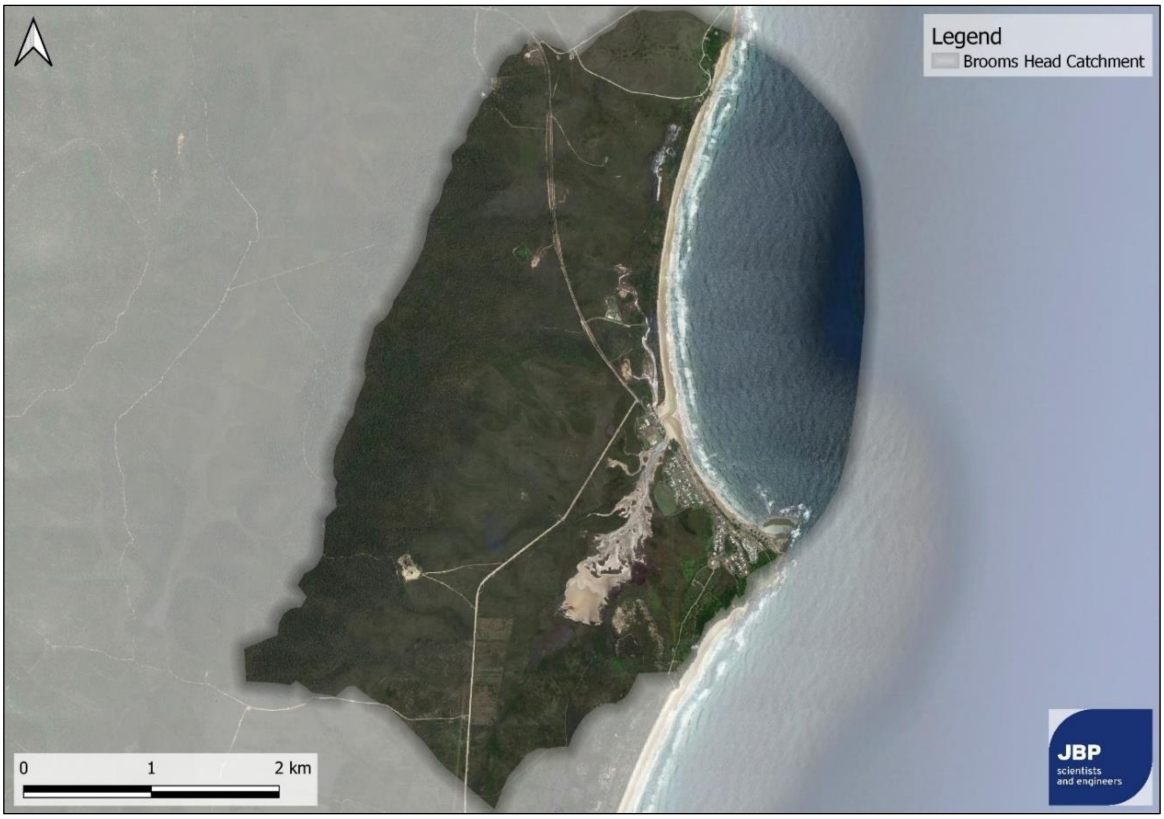

Figure 4-1: Brooms Head and Lake Cakora model domain

4.2 Hydrodynamic model

4.2.1 Elevation data

Two available sources of topographic and bathymetric information were used in the Brooms Head/Lake Cakora hydrodynamic model. A summary of the available topographic data, its sampling data, resolution, and sources is provided in Table 4-1. The available topographic data shows a moderate berm height, which allows some tidal flow into the southern (main arm), however prevents tidal flow into the northern channel. In reality, the local entrance conditions are dynamic and can range from times with large sand accumulation or scoured conditions, which can either block tidal propagation or allow tides to flow into the northern channel. As such, the simulated model represents a single scenario only, during a blocked condition. The uncertainty around entrance conditions is partially offset in the extreme event modelling by using elevated water levels, which are higher than the open water conditions, as discussed in Section 4.3.2.

- Topographic Data: Elevation data above mean sea level (MSL) is available through the 5 Metre LiDAR Grid from Geoscience Australia[12]. This data represents a National 5 metre (bare earth) DEM which has been derived from ~236 LiDAR surveys between 2001 and 2015.
- Topo-Bathymetric Data: 5m resolution NSW Bathymetry data was obtained from the NSW SEED portal[13]. This bathymetric data was prioritized below 0mAHD and merged with the topographic data with smoothing performed at the data intersection. This bathymetry is based on LiDAR and limited survey., A berm is present within the survey at the entrance to Lake Cakora and partially blocking tidal ingress to the region. This berm was present at the time of the survey and therefore is present in the model.

Table 4-1: Brooms Head topographic dataset information

Dataset	Timeliness	Resolution	Source
LiDAR	2015	5m	Geoscience Australia
Topo-Bathy Marine LiDAR	2018	5m	SEED / NSW Marine LiDAR Project

4.2.2 Roughness

Roughness layers have been applied across the model using Sentinel 2 Satellite global land use data and ESRI 2020 Global Landuse Mapping as outlined in Section 2.2.8. This was used in preference to other data due to its more recent completion. The adopted roughness grid is shown in Figure 4-2.

4.2.3 Structures

Brooms Head has a major bridge crossing the Lake Cakora outlet. The bridge was modelled using a combination of structural details provided by Council, 1m LiDAR elevation data, and by including a blockage factor derived from detailed design drawings. Input parameters are summarised in Table 4-2.

12 Geoscience Australia, 2015. Digital Elevation Model (DEM) of Australia derived from LiDAR 5 Metre Grid. Geoscience Australia, Canberra. Accessed from: http://pid.geoscience.gov.au/dataset/ga/89644

13 NSW DPE (2018). NSW Marine LiDAR Topo-Bathy 2018 Geotif. Accessed from: https://datasets.seed.nsw.gov.au/dataset/marine-lidar-topo-bathy-2018

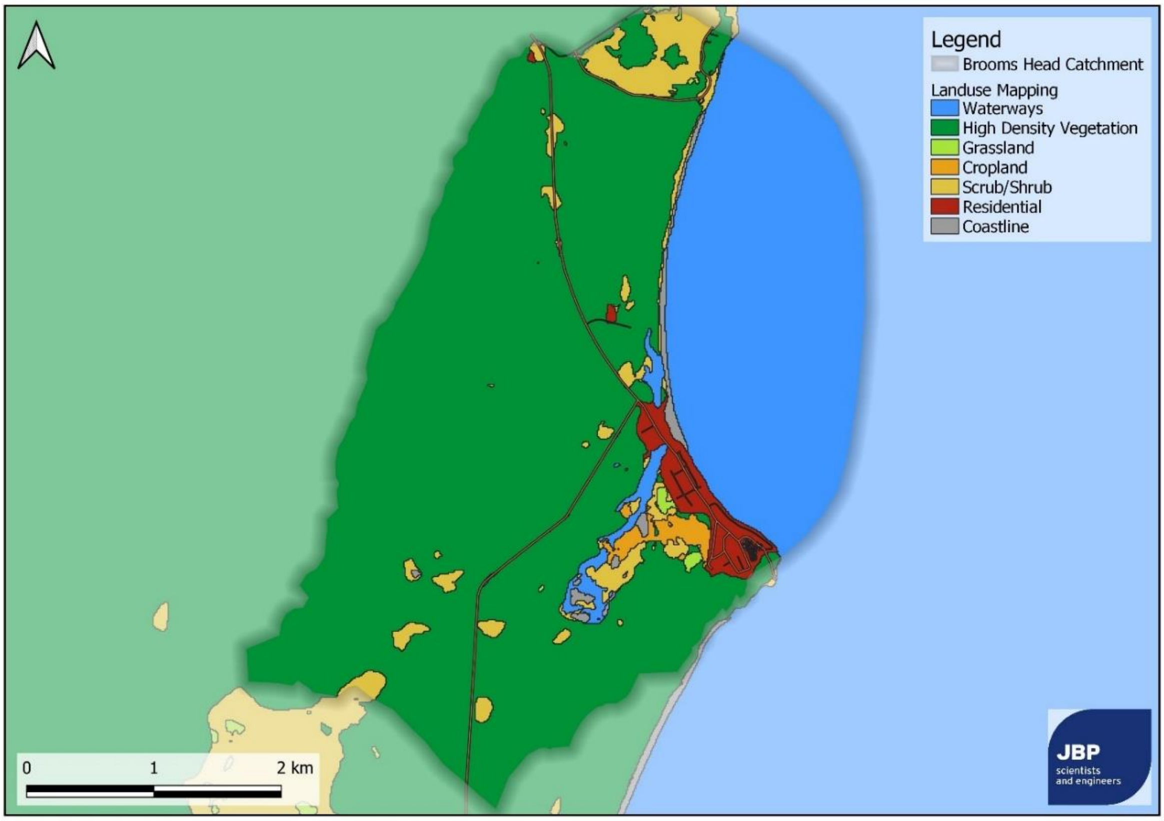

Figure 4-2: Brooms Head spatial land use classification

Table 4-2: Brooms Head bridge input parameters

Design Parameter	Value	Units
Deck Level	2.50	Meters AHD
Deck Thickness	0.73	Meters
Obvert	1.77	Meters AHD
Deck width	8.33	Meters
Guardrail Height	0.99	Meters
Guardrail Blockage	0.25	
Pier Type	Headstock on Piles (circular)	
Pier Width	0.43	Meters
Skew Angle	0.00	Degrees
Width to Flow	0.43	
Number of Piers	5.00	
Spacing	7.62	Meters
Total Pier Blockage	1.73	Meters Squared
Total Blockage	5.4%	

4.3 Boundaries

The model boundaries include downstream (tide, storm surge) and upstream (baseflow) inputs. Wave overtopping inputs have also been considered along the coastal frontage. Wave overtopping has been observed at Brooms Head Beach along the rock armour adjacent to the Caravan Park. However, given the new model uses an elevated extreme water level (see Section 4.3.2) the calculation and use of coincident wave overtopping was considered to an over-estimation.

4.3.1 Tidal simulations

Two consecutive tidal peaks have been simulated. The first tide allows for the foreshore to be inundated in the model, and the second tide then reaching peak conditions. In addition to present day conditions, the tidal signal has been increased to reflect two climate change pathways based on the information provided in Section 2.2.6.

4.3.2 Coastal inundation simulations

A storm surge was added to the tidal signature, with a peak coinciding with the HHWSS to form the peak extreme water level. Lake Cakora is classed as a Type C estuary entrance (ICOLLS, untrained or partially trained small entrances) based on the descriptions in Section 2.2.4. The open coast level peak extreme sea level was consequently increased by 1.1m to represent potential entrance blockages, as shown in Table 4-3.

Table 4-3: Lake Cakora model extreme water level boundary (m AHD)

Postcode	1% AEP (Risk Frontiers)	2% AEP	10% AEP
Open Coastline			
2463 - Brooms Head/Sandon	1.60	1.55	1.50
Adjusted allowance for estuaries			
Lake Cakora (+1.1)	2.70	2.65	2.60

4.3.3 Hydrologic inflows

Baseflow from creeks and local catchments were introduced to maintain partial full river/creek channel conditions and model stability. Baseflow has been estimated by first undertaking catchment delineation, with a subcatchment resolution between 30 and 130 hectares. The catchment delineation is shown in Figure 4-3 and subcatchment characteristics are shown in Table 4-4. An URBS hydrology model was created and used to estimate peak flow rates for the 39.35% AEP (1 in 2 year) event, with baseflow estimated as discussed in Section 2.2.7.

Table 4-4: Brooms Head subcatchment characteristics summary

Model	Number of sub-catchments	Max area (ha)	Min area (ha)	Average sub-catchment area (ha)
URBS	17	132	36.0	76.3

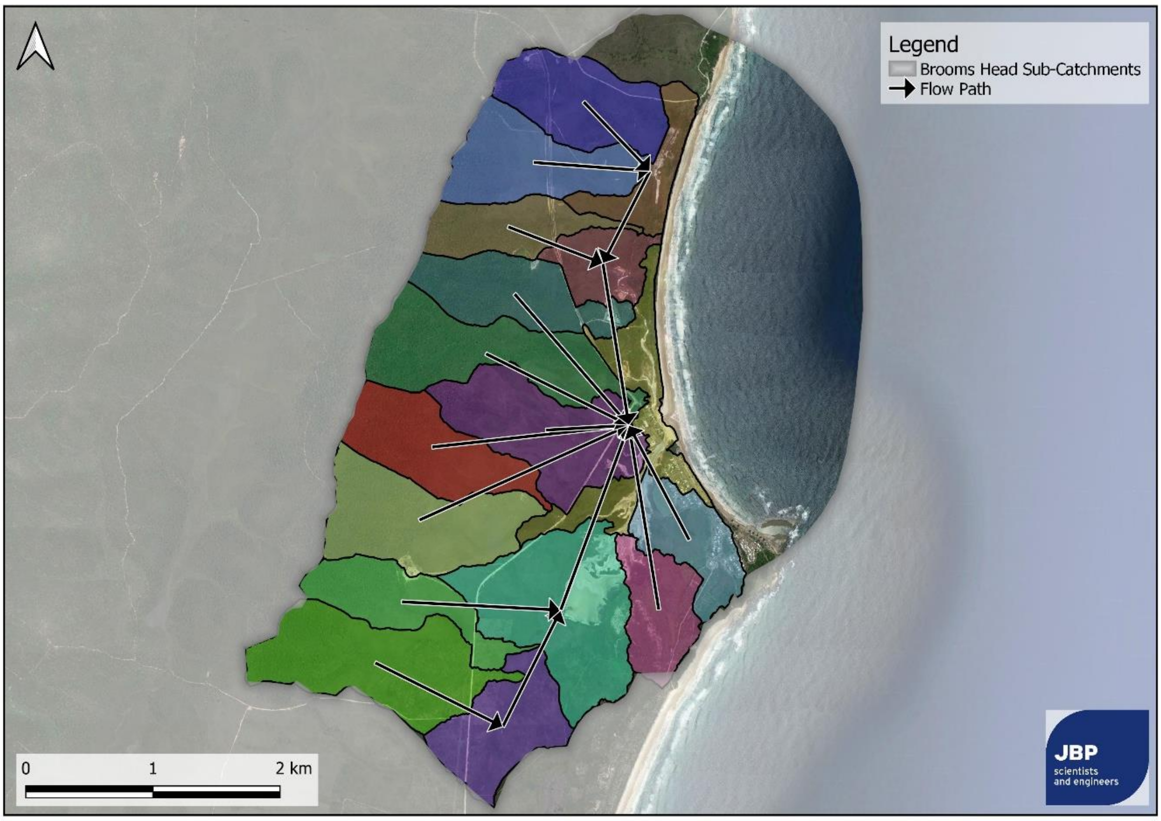

Figure 4-3: Brooms Head subcatchment breakup

4.4 Tidal and coastal inundation mapping results

Tidal and coastal inundation maps were merged with the open coast mapping discussed in Section 7. Maps are provided in Appendix A, which include the following:

- Coastal inundation
- Present day, 2043, 2073 and 2123 planning horizons
- For tidal inundation maps: HHWSS tide
- For coastal inundation maps:
  - 10% AEP (10-year)
  - 2% AEP (50-year)
  - 1% AEP (100-year)
- Each scenario includes SSP2 (RCP4.5) and SSP5 (RCP8.5) climate change conditions.

Mapping of present-day tide scenarios shows some differences between the simulated peak tide levels and debris/wrack/tide marks observed in aerial imagery. This shows the simulated HHWSS tide levels are lower than observed tide marks in the creek. This is likely due to:

- The use of a HHWSS tide in model simulations, whereas higher tides may occur and are likely to be the conditions which create the debris/wrack/tide marks around the creek.
- Differences in bathymetric conditions at the time of survey, as discussed in Section 4.2.1.
- The accuracy of tidal plane information used in simulations, with Lake Cakora interpolated from other sites, as discussed in Section 2.2.3. This also relies on the accuracy of the published tidal data, which assumes there has been no variation in tidal conditions since publication (2010).

5 Sandon River model

5.1 Approach

A new hydrodynamic model has been developed for the Sandon River. This uses a downstream tidal signal and catchment baseflows. There are no water level records within the estuary, meaning the model has not been calibrated. The potential model variability was investigated under different mangrove conditions as a sensitivity test.

The model extent is shown in Figure 5-1 and includes northern and southern tributaries of the river, although does not span the entire upstream catchment. At these upper catchment locations a hydrology model was used to derive baseflow inputs.

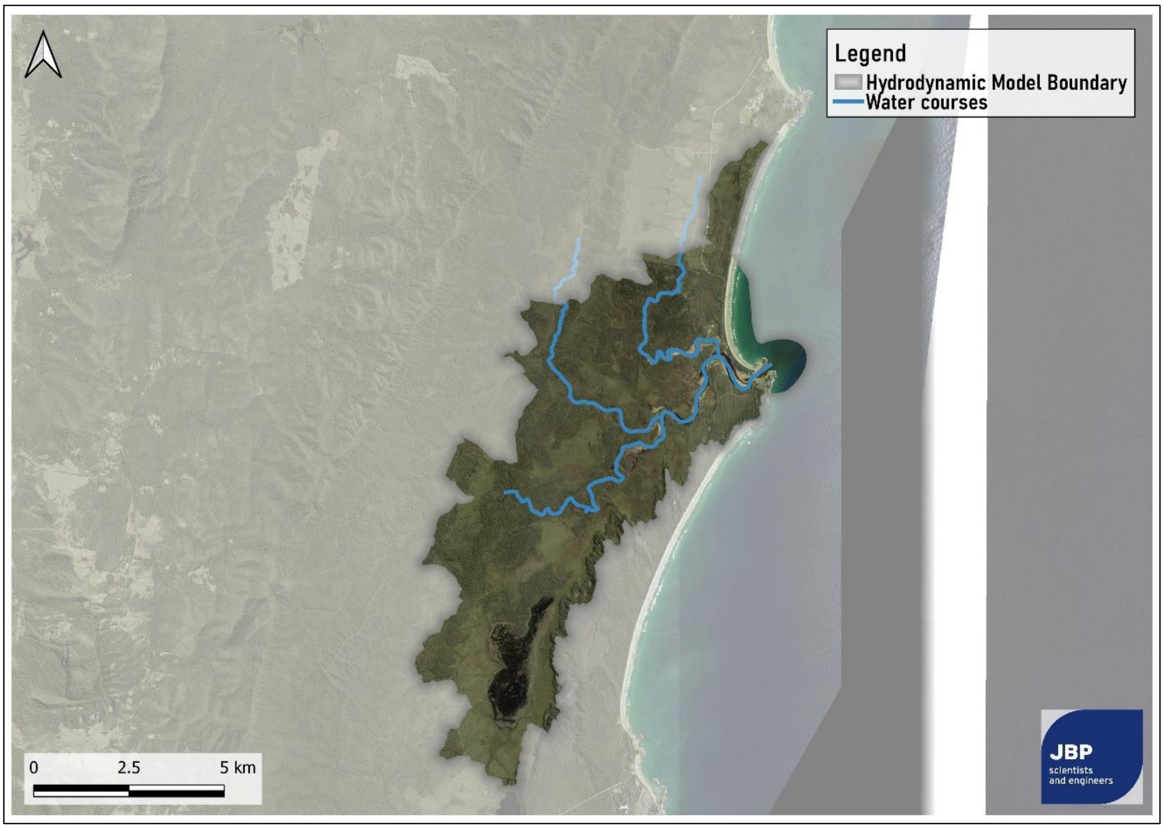

Figure 5-1: Sandon hydrodynamic model extent

5.2 Hydrodynamic model

5.2.1 Elevation data

Three available sources of topographic and bathymetric data were used in the Sandon River model. A summary of the available topographic data, its sampling data, resolution, and sources is provided in Table 5-1.

- Topographic Data: Elevation data above mean sea level is available through the 5 Metre LiDAR Grid from Geoscience Australia.
- Topo-Bathymetric Marine Data: 5m resolution topography and bathymetry was obtained from the NSW SEED portal. This bathymetric data was prioritized below 0mAHD and merged with the topographic data with smoothing performed at the data intersection.

* Sandon River Bathymetric Data: This data was sourced from the NSW OEH Single-beam Bathymetry and Coastal Topography Surveys (NSW OEH, 2003) for the Sandon River[14]. It was collected in September 2010 by the NSW Department of Land and Water Conservation (DLWC) Estuary Management Program .

Table 5-1: Summary of Sandon River topographic data

Dataset	Timeliness	Resolution	Source
Topo-Bathy Marine LiDAR	2018	5m	NSW Marine LiDAR Project
LiDAR	2015	5m	Geoscience Australia
River Bathymetry	2010	~6m at ~50-100m spacing	NSW OEH "STAX" data

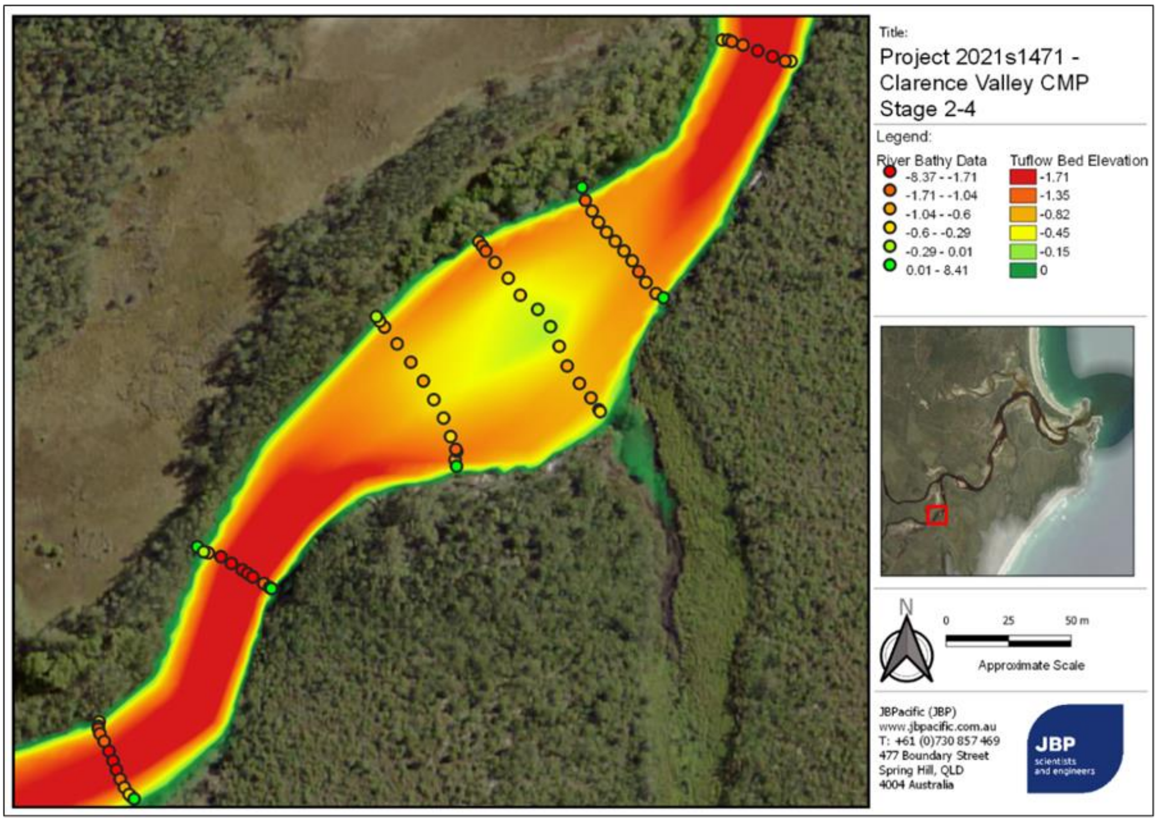

Figure 5-2: Sandon Riverbed interpolation

14 NSW OEH (2010). Single-beam Bathymetry and Coastal Topography Surveys, Wooli River. Accessed from: http://data.aodn.org.au/NSW-OEH/Single-beam/2010/20100916_SandonRiver

5.2.2 Roughness

The Sandon Estuary is an area of significant coastal biodiversity. It contains estuaries, mangrove forest, wetlands, and rivers, each able to influence the extent and depth of coastal flooding. During stakeholder discussions, the use of the NSW SEED Land Use Mapping (2010) and mangrove coverage was identified as the preferred source, which was downloaded from NSW Spatial Data Portal as shown in Figure 5-3. This has been applied using the hydraulic roughness values shown in Section 2.2.8. The mangrove properties have also been varied within sensitivity tests to consider how they may change tide and storm surge propagation in the future.

5.2.3 Structures

No significant structures were identified that may change the coastal inundation extent. The Sandon River has no identified bridge or culvert structures downstream, and only minor crossings were identified far upstream.

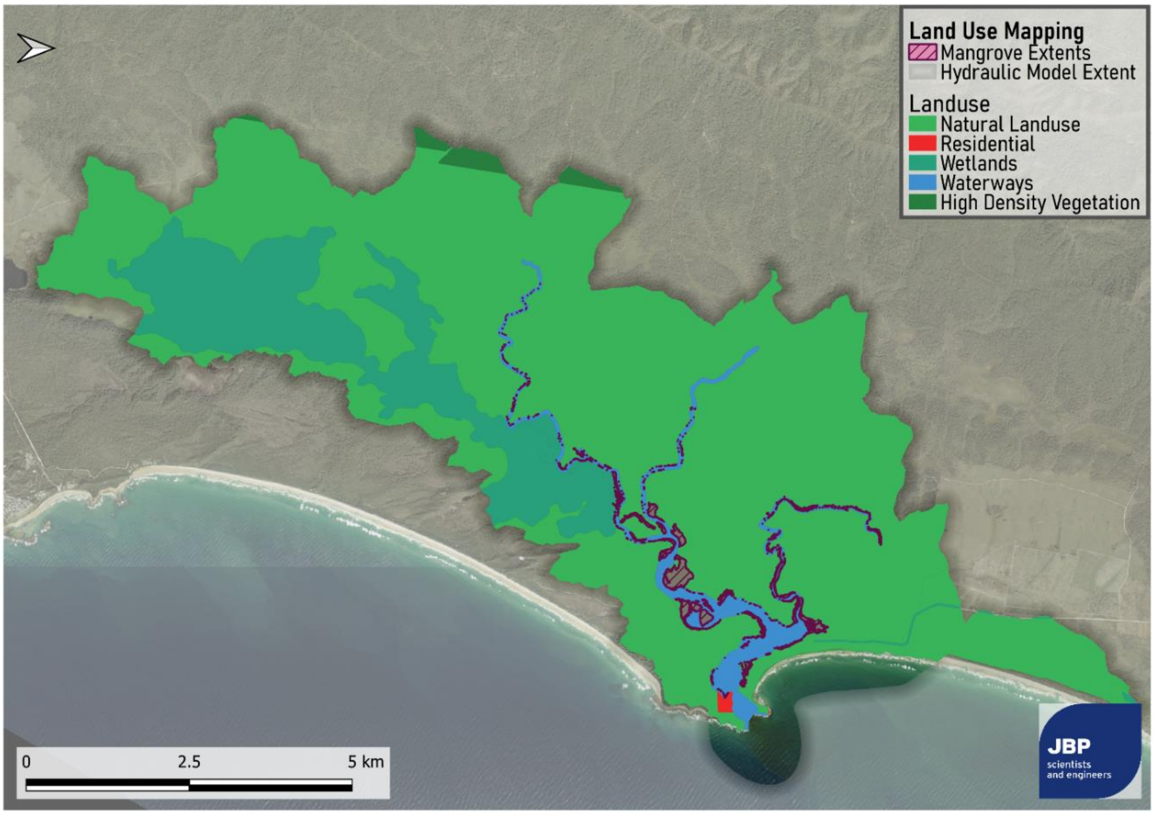

Figure 5-3: Land use spatial delineation

5.3 Boundaries

The model boundaries include downstream (tide, storm surge) and upstream (baseflow) inputs.

5.3.1 Tidal simulations

Two consecutive tidal peaks have been simulated. The first tide peak allows the foreshore to be inundated with the second tide then reaching the peak water levels. In addition to present day conditions, the tidal signal has been increased to reflect two climate change pathways based on the information provided in Section 2.2.6.

5.3.2 Coastal inundation simulations

A storm surge was added to the tidal signature, with a peak coinciding with the HHWSS to form the peak extreme water level. During project team meetings with CVC and State Government, the Sandon River entrance was discussed and agreement made to treat it as a Type C estuary entrance (ICOLLS, untrained or partially trained small entrances) based on the descriptions in Section 2.2.4. This is due to the headland and rocky shelf connecting to Plover Island and the narrow restriction adjacent to the camping ground, as shown in Figure 5-4. The peak extreme water level was consequently increased by 1.1m (as per Figure 2-2) to represent potential entrance effects, using the peak levels shown in Table 5-2. This value allows for the effect of sand berms, wave setup and tide/flow interactions at the narrow entrance. It is not considered to be reflective of a single entrance bathymetric state, however its use is justified given it follows the recommendations within the OEH (2015) Floodplain Risk Management Guide.

Figure 5-4: Sandon River entrance, showing natural features similar to training walls

Table 5-2: Sandon River model extreme water level boundary (m AHD)

Postcode	1% AEP (Risk Frontiers)	2% AEP	10% AEP
Open Coastline			
2463 - Brooms Head/Sandon	1.60	1.55	1.50
Adjusted allowance for estuaries			
Sandon River (+1.1)	2.70	2.65	2.60

5.3.3 Hydrologic inflows

Baseflow from creeks and local catchments were introduced to maintain partial full river/creek channel conditions and improve model stability. Baseflow has been estimated by first undertaking catchment delineation, with a subcatchment resolution between 50 and 150 hectares. The catchment delineation is shown in Figure 5-5 and subcatchment characteristics are shown in Table 5-3. An URBS hydrology model was created and used to estimate peak flow rates for the 39.35% AEP (1 in 2 year) event, with baseflow estimated as discussed in Section 2.2.7.

Table 5-3: Sandon River subcatchment characteristics summary

Model	Max area (ha)	Min area (ha)	Average sub-catchment area (ha)	Max area (ha)
URBS	147	150.2	52.0	93.4

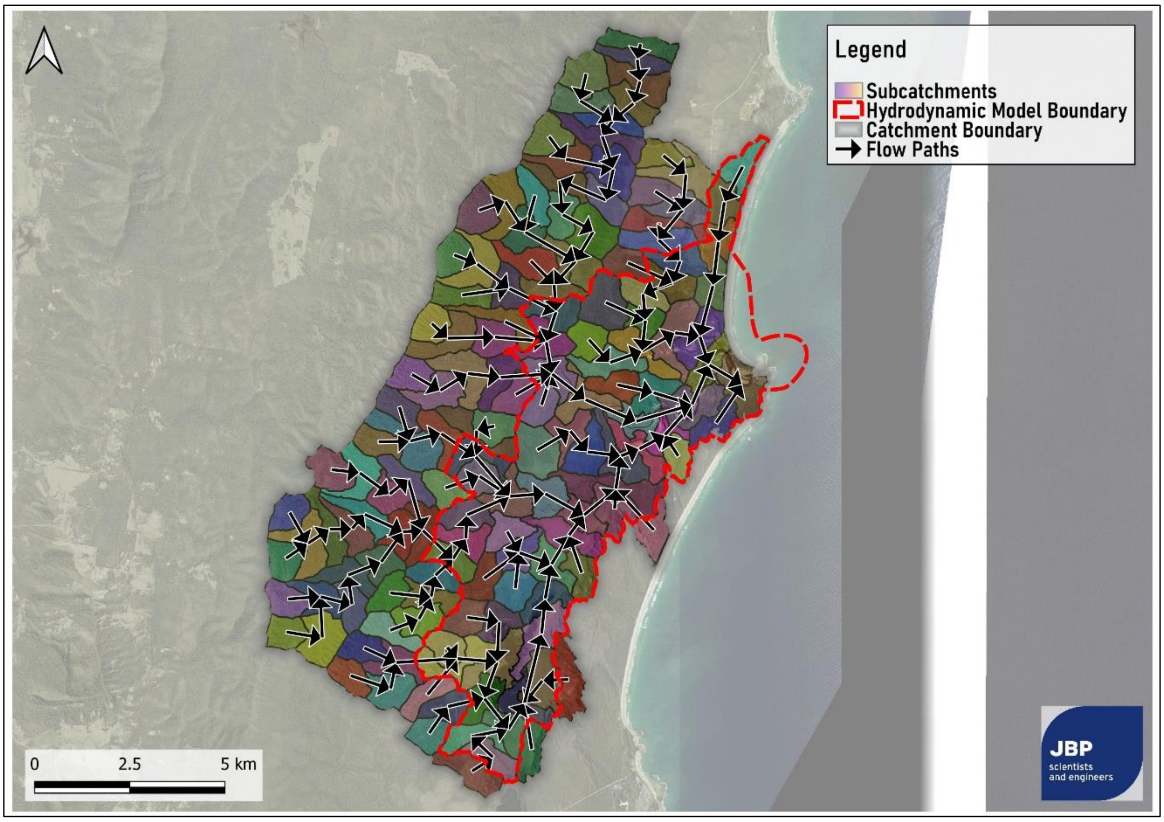

Figure 5-5: Sandon River subcatchment breakup

5.4 Sensitivity testing with mangroves

The Sandon River has considerable areas of mangrove coverage. A sensitivity analysis was performed by varying the hydraulic roughness values over the range of 'n' = 0.1 to 0.2. The key differences in model results were isolated to upstream areas, where the upper limit of tidal propagation is reduced when using the higher roughness values. Around the lower estuary and at the Sandon township the change in peak water levels were less than 0.005m (0.5cm), as shown in Figure 5-6.

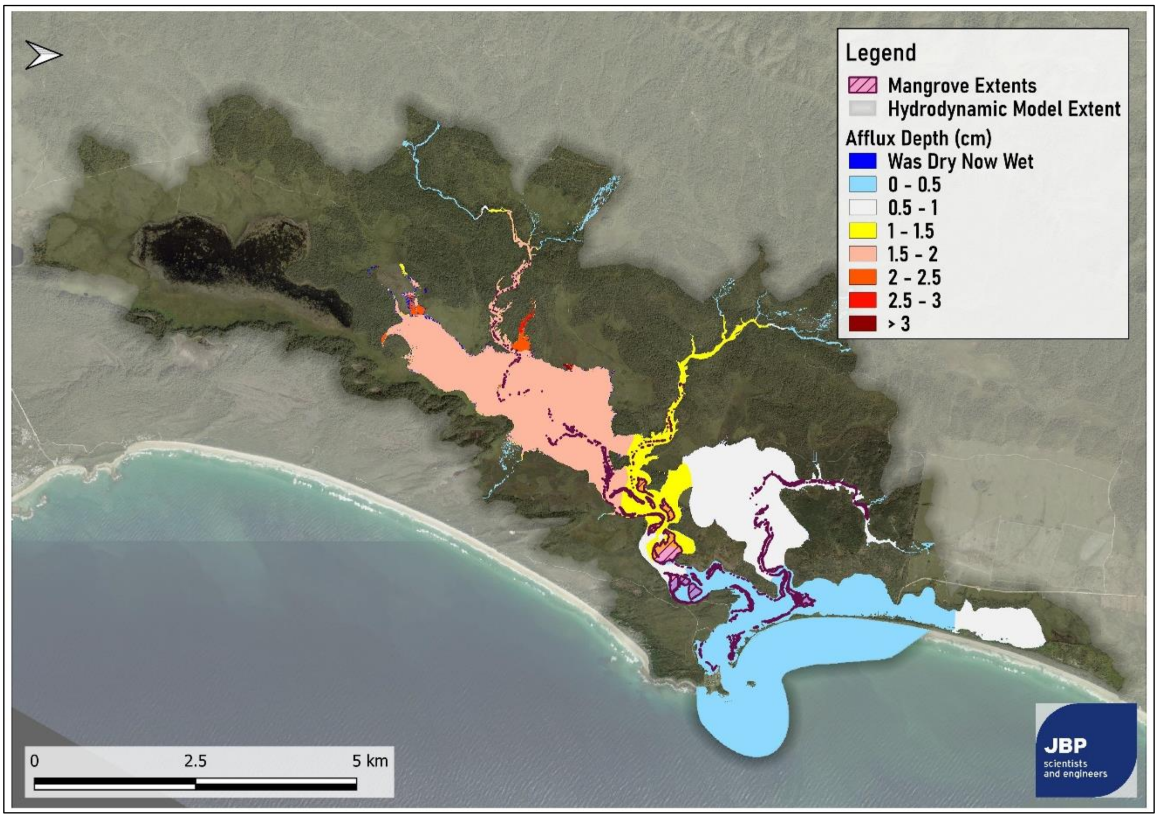

Figure 5-6: Sandon River mangrove sensitivity

5.5 Tidal and coastal inundation mapping results

Tidal and coastal inundation maps were merged with the open coast mapping discussed in Section 7. Maps are provided in Appendix A, which include the following:

- Tidal inundation and coastal inundation
- Present day, 2043, 2073 and 2123 planning horizons
- For tidal inundation maps: HHWSS tide
- For coastal inundation maps:
  - 10% AEP (10-year)
  - 2% AEP (50-year)
  - 1% AEP (100-year)
- Each scenario includes SSP2 (RCP4.5) and SSP5 (RCP8.5) climate change conditions.

Mapping of present-day tide scenarios shows some differences between the simulated peak tide levels and debris/wrack/tide marks observed in aerial imagery. This shows the simulated HHWSS tide levels are lower than observed tide marks in the creek.

- The use of a HHWSS tide in model simulations, whereas higher tides may occur and are likely to be the conditions which create the debris/wrack/tide marks around the creek.
- Differences in bathymetric conditions at the time of survey
- The accuracy of tidal plane information used in simulations, levels interpolated from other sites. This also relies on the accuracy of the published tidal data, which assumes there has been no variation in tidal conditions since publication (2010).

6 Wooli Wooli River model

6.1 Approach

An existing hydrodynamic model has been used to model tides and coastal inundation throughout the Wooli catchment. This is based on the hydrology model and Tuflow hydrodynamic model created for the Wooli Flood Study (JBP, 2022), which has been calibrated over a range of flood and tide events occurring in March 2021, February 2020, June 2016 and February 2013. This has included new validation against tidal drifters established within the lower river during the model development (see Figure 6-2). The model extent is shown in Figure 6-1, which includes the entire catchment extending to the great dividing range. The model includes a downstream tide and storm surge boundary, and allowances for upper catchment baseflow.

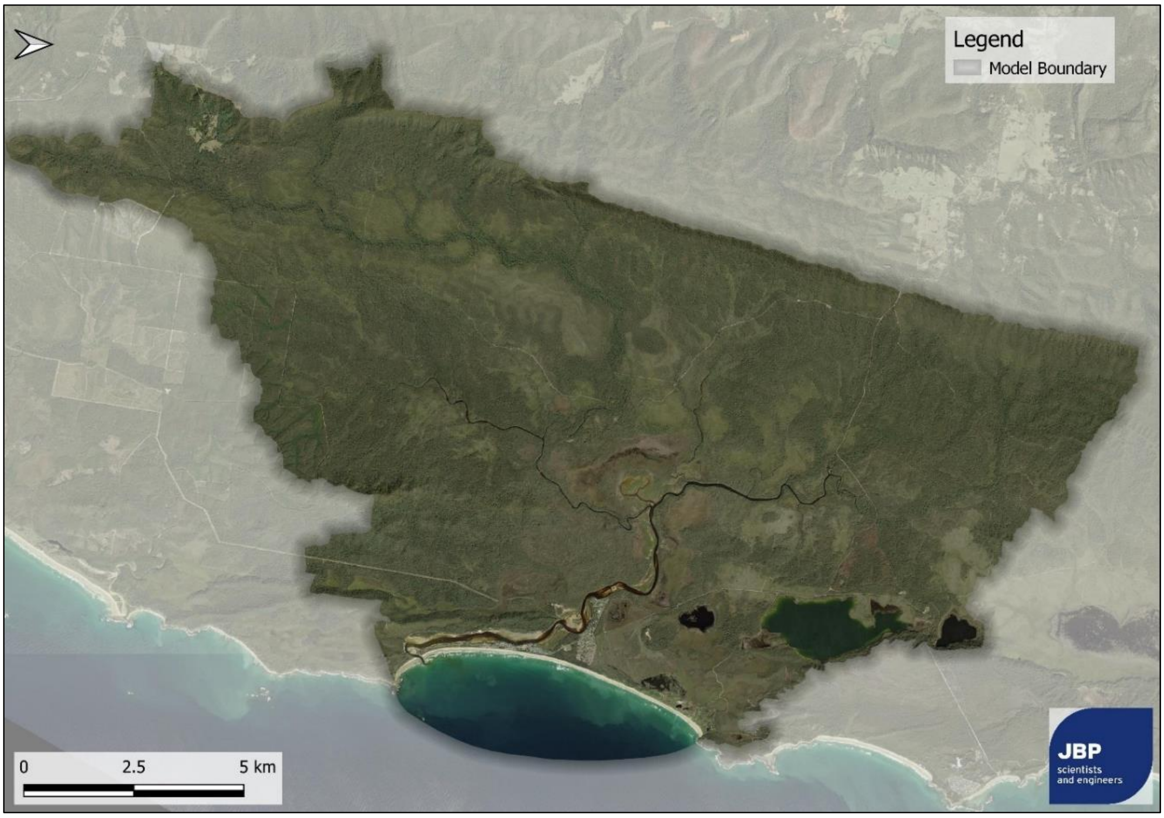

Figure 6-1: Wooli Wooli River catchment

Figure 6-2: Drifters and recorded tidal current velocity

6.2 Hydrodynamic model

6.2.1 Elevation data

The bathymetry was not changed from the original model which used multiple sources of recorded and simulated data as shown below and in Table 6-1.

- Topographic LiDAR: 1m Digital Elevation Model (DEM) was obtained from the Intergovernmental Committee on Surveying & Mapping (ICSM) Elevation Information System (ELVIS)[15]. The dataset is over the Bare Point region and was collected in 2010. It was derived using a Triangular Irregular Network (TIN) method to formulate a regular grid with an accuracy of 0.3m (95% confidence interval) vertical and 0.8m (95% confidence interval) horizontal.
- Topo-Bathymetric LiDAR: 5m resolution NSW Bathymetry data was obtained from the NSW SEED portal. This bathymetric data was prioritized below 0mAHD and merged with the topographic data with smoothing performed at the data intersection.
- Bathymetric survey: Bathymetric survey was sourced from the hydrographic survey taken in 2020 by Resource Design & Management (RDM) Pty Ltd[16]. The extent of this bathymetry data is shown in Figure 6-3.
- Wooli Wooli River bathymetry: This data was sourced from the NSW OEH Single-beam Bathymetry and Coastal Topography Surveys (NSW OEH, 2003) for the Wooli Wooli River[17]. It was collected in February 2003 by the NSW Department of Land and Water Conservation (DLWC) Estuary Management Program.
- Wooli offshore bathymetry: Bathymetry data for the Wooli Offshore Solitary Island was sourced through the NSW OEH Single-beam Bathymetry and Coastal Topographic Surveys (NSW OEH, 2007) [18]. It was surveyed by the NSW Department of Climate Change (DECC) coastal and floodplain unit in October 2007.
- Delft 3D morphologic model: Results of a Delft3D morphologic model for the Wooli Wooli River Flood Study has been used to simulate, merge and smooth datasets.

15 ICSM ELVIS (2010). BARE POINT 2010-04-28 2kmx2km 1 metre Resolution Digital Elevation Model. Accessed from ELVIS: https://elevation.fsdf.org.au/

16 RDM (2020). Wooli Wooli River Hydrographic Survey

17 NSW OEH (2003). Single-beam Bathymetry and Coastal Topography Surveys, Wooli River. Accessed from: http://data.aodn.org.au/NSW-OEH/Single-beam/2003/20030201_WooliRiver

18 NSW OEH (2007). Single-beam Bathymetry and Coastal Topographic Surveys, Wooli Offshore Solitary Isld data. Accessed from: https://catalogue-imos.aodn.org.au/geonetwork/srv/eng/catalog.search#/metadata/8b2ddb75-2f29-4552-af6c-eac9b02156a6

Table 6-1: Summary of topographic data

Dataset	Timeliness	Resolution	Source
Topographic LiDAR	2010	1m	ELVIS portal
Topo-Bathymetric LiDAR	2018	5m	NSW Marine LiDAR Project
Bathymetric survey	2020	0.5m	RDM Pty Ltd
Wooli Wooli River bathymetry	2003	~6m at ~50-100m spacing	NSW DLWC
Wooli offshore bathymetry	2007	~50m	NSW OEH
Delft 3D morphologic model	2022	1m	JBP

Figure 6-3: Location of new (2020) hydrographic survey of the bathymetry of the Wooli Wooli River estuary.

6.2.2 Roughness

Ground cover has been mapped from the NSW SEED Land Use Mapping database and applied using the hydraulic roughness values shown in Section 2.2.8. The model roughness values are shown in Figure 6-4.

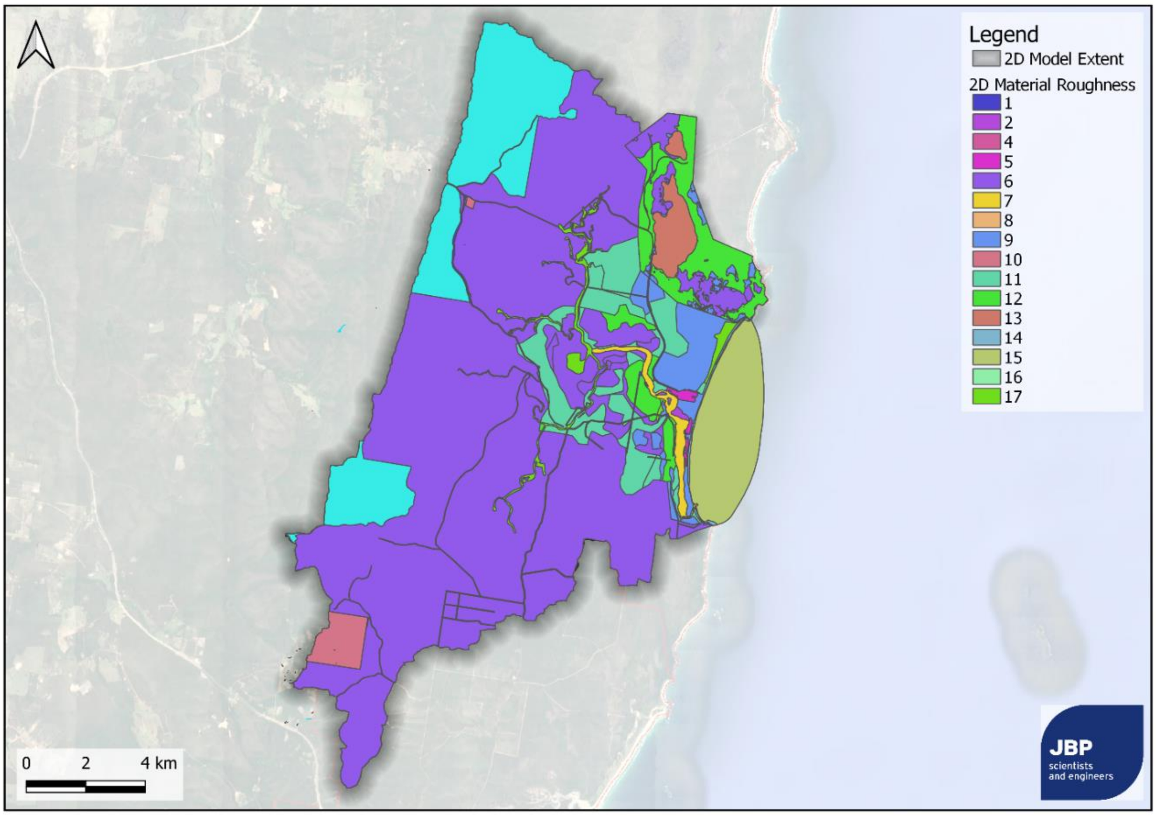

Figure 6-4: Spatial distribution of model roughness

6.2.3 Structures

The model includes bridges and large culverts. Three bridge crossings have been incorporated along Wooli Road at Matenga Creek, Bookram Creek and Falconer Creek. All cross drainage structures greater than 0.6m width were included in the hydraulic model, based on a CVC asset database.

6.3 Boundaries

The model boundaries include downstream (tide, storm surge) and instream baseflow inputs.

6.3.1 Tidal simulations

Two consecutive tidal peaks have been simulated. The first tide peak allows for the foreshore to be inundated with the second then reaching the peak water level. In addition to present day conditions, the tidal signal has been increased to reflect two climate change pathways based on the information provided in Section 2.2.6.

6.3.2 Coastal inundation simulations

A storm surge was added to the tidal signature, with a peak coinciding with the HHWSS to form the peak extreme water level. The river has a Type B entrance (Trained entrances, navigable for small vessels), as shown in Figure 6-5. The open coast level was consequently increased by 0.55m to represent potential entrance effects, as shown in Table 5-2.

Table 6-2: Wooli Wooli River model extreme water level boundary

Postcode	1% AEP (Risk Frontiers)	2% AEP	10% AEP
Open Coastline			
2462 - Wooli Coastline	1.58	1.53	1.48
Additional allowance for estuaries			
Wooli River (+0.55)	2.13	2.08	2.03

Figure 6-5: Wooli Wooli River entrance, showing training walls

6.3.3 Hydrologic Inflows

Baseflow from creeks and local catchments were introduced to maintain partial full river/creek channel conditions and improve model stability. The methodology for baseflow extraction from streamflow data is outlined in Section 2.2.7.

6.4 Tidal and coastal inundation mapping results

Tidal and coastal inundation maps were merged into the Open Coast mapping discussed in Section 7. Maps are provided in Appendix A, which includes the following:

- Tidal inundation and coastal inundation
- Present day, 2043, 2073 and 2123 planning horizons
- For tidal inundation maps: HHWSS tide
- For coastal inundation maps:
  - 10% AEP (10-year)
  - 2% AEP (50-year)
  - 1% AEP (100-year)
- Each scenario includes SSP2 (RCP4.5) and SSP5 (RCP8.5) climate change conditions.

7 Open coast projection mapping

The tidal and coastal inundation mapping along the open coast was undertaken using a GIS-based projection modelling approach where land below the open coast water level are considered to be inundated. The use of a projection modelling approach is acknowledged to be conservative, by assuming there is sufficient time and volume within the extreme water level profile to fill all low-lying land up to the given water level. This method also assumes that all elevations below the open coast water level are inundated, regardless of a having a direct connection to the open coast or estuary. This limitation causes secluded areas of water 'ponding' within the inundation mapping. This has been subject to post-processing to remove these isolated ponded areas, although some smaller areas remain within the final maps. For these reasons, this method has been used for the open coast only, where limited population is exposed to coastal processes. The detailed hydrodynamic model results have been used in preference for the Clarence River lower estuary, Brooms Head/Lake Cakora, Sandon River and Wooli Wooli River catchments.

The general process of projection modelling is illustrated in Figure 7-1.

1. Extreme water levels have been established for each postcode region, based on Table 2-2.
2. A polyline is extended from the coastal point landwards until it intersects with the natural topography.
3. A water surface elevation grid is interpolated between individual extreme water level polylines.
4. The ground surface is subtracted from the water surface elevation grids to produce flood depth grids and incremental flood outlines developed to cover all areas with a positive flood depth.
5. Small wet 'islands' are removed that are less than 1 hectare and are not connected to the coastline.
6. The detailed hydrodynamic model inundation maps are merged into the projection maps (see Figure 7-2).

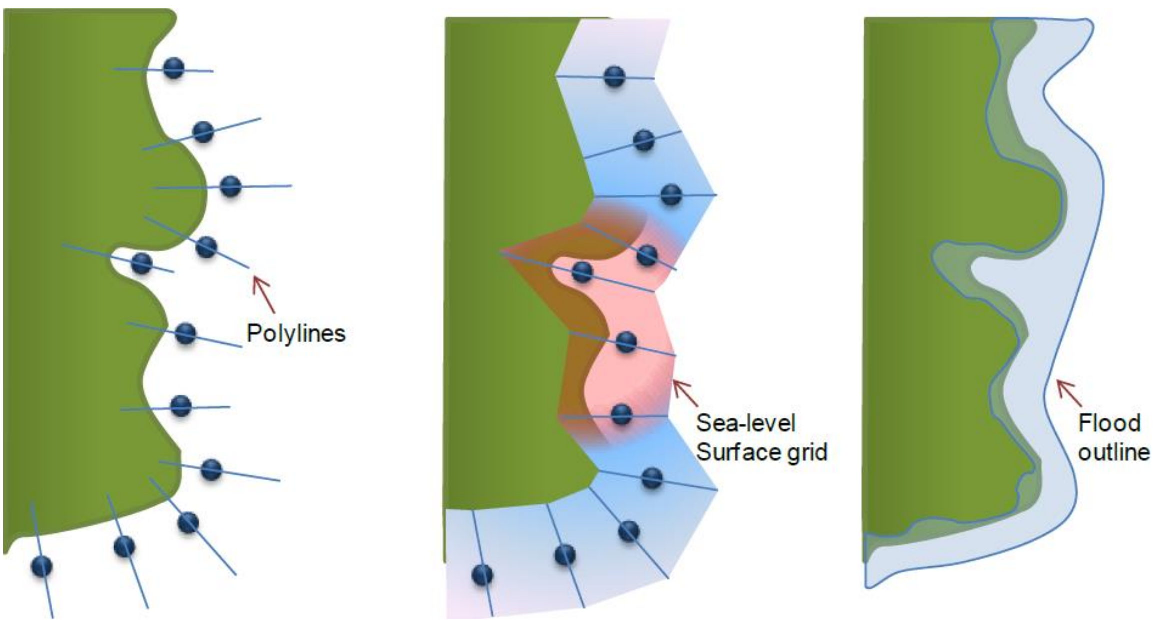

Figure 7-1: Schematic of the projection modelling approach.

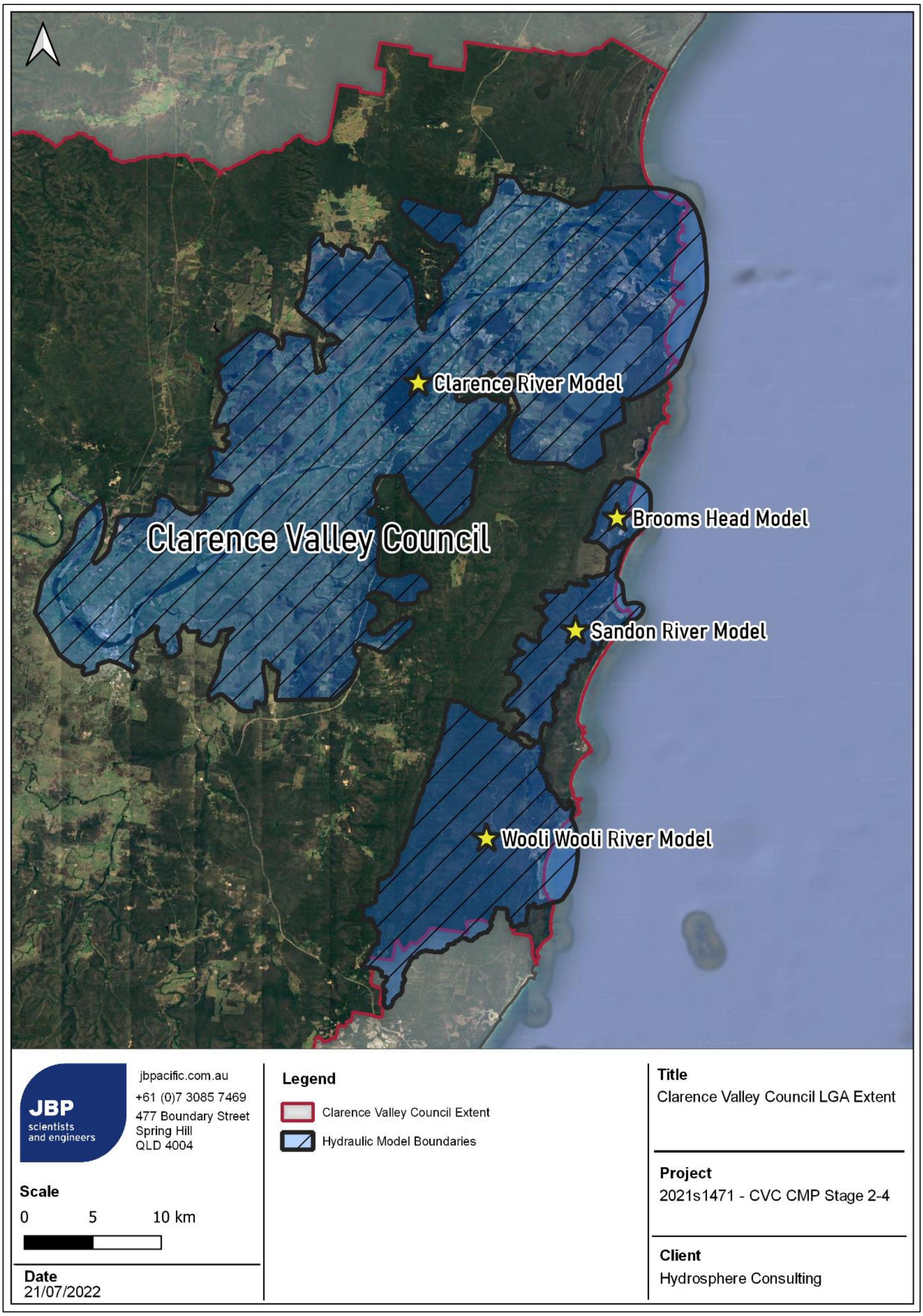

Figure 7-2: Areas of hydrodynamic inundation mapping (blue) over projection maps

8 Modelling limitations

Uncertainty exists within any numerical model. This can be due to the inputs used, the source of bathymetry, the classification of return period and planning horizons, the model type and computational approach. These have been discussed throughout this report, and are summarised in this section, which aims to address questions and comments received by stakeholders or the public when using the mapping results.

All model limitations

- Elevation:
    - All hydrodynamic models need elevation information to represent the channel, underwater areas, banks and foreshore. This information does not exist as a single source and needs to be combined from many datasets. Each of these datasets is a single 'snapshot' of the conditions at the time of the survey and may not represent the most recent conditions. Many of the elevation datasets used in these models are over 10 years old and it is assumed no significant changes have occurred since the time of survey. This uncertainty has been minimised by using the most recent datasets first, with older datasets used to fill remaining gaps.
    - All inundation models use a single combined elevation dataset, which is simulated for present day and future planning horizons. This is a limitation to future inundation mapping as the future channel, bank or beach position may change.
- Tides
    - Modelled tidal conditions were based on the average of a 10-year dataset between 1990 and 2010, which was over 10 years outdated at the time of this modelling. Additionally, published data is only available at Ballina, Yamba and Wooli, with other locations estimated using a linear interpolation.
    - Simulations have used a HHWSS tide, which is a statistical level based on long-term tidal analysis. Higher tides will occur.
- Catchment influences
    - Simulations have not included significant rainfall inputs, and do not consider coincident flood events. A minor baseflow was included in the modelling to account for low level runoff. This has introduced small areas of water 'ponding' in low-lying areas due to the way baseflows have been introduced into the model. Any large ponding area has been removed through post-processing, although some smaller ponded areas remain within the final maps.
- Stormwater network
    - The models do not consider sub-surface connections created by the stormwater network which may require consideration during future planning and management.

Additional Clarence River model limitations

- The Clarence River 'Pacific Model' was completed by a third party (Pacific Complete) and has not been independently assessed or verified by council.

Additional Brooms Head/Lake Cakora model limitations

- The elevation used in this model was collected from LiDAR in 2015 when a moderate berm height was present. Whilst tides can flow into the southern (main arm), the sandy berm prevents tidal flow into the northern channel. In reality, the local entrance conditions are dynamic and can range from times with large sand accumulation or scoured conditions, which can either block tidal propagation or allow tides to flow freely into the channel. As such, the simulated model represents a single scenario only, during a partially blocked condition. The uncertainty around entrance conditions is partially offset in the extreme event modelling by using elevated water levels, which are higher than the open water conditions.

Additional Sandon River model limitations

- The topographic survey data used in the Sandon River inundation modelling has a limited extent that does not reach the upstream swamp areas. This is believed to limit the mapped tidal extent in the upper catchment within the HHWSS maps.

Additional Wooli Wooli River model limitations

- A large number of elevation datasets have been combined within the model. These range between 0.5m to 100m resolution and have been collected between 2003 and 2020. Whilst the elevation datasets were merged together, they do not reflect a single bathymetric profile.

Additional open coast projection mapping

- Along the open coastline the tide and coastal inundation has been mapped using a projection mapping approach (also known as bathtub mapping). The open coast water levels are overlaid onto the DEM to show the expected inundation extent. This method assumes a connection is made between any low-lying area and the main coastline or estuary and can cause secluded areas of water 'ponding'. This has been subject to post-processing to remove these isolated ponded areas, although some smaller areas remain within the final maps
- This method neglects terrain roughness, timing and duration of the event. The use of a projection modelling approach is acknowledged to be conservative, by assuming there is sufficient time and volume within the extreme water level profile to fill all low-lying land up to the given water level.

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