JBP scientists and engineers

Coastal vulnerability maps and associated

Technical Report

Final Report

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KEMPSEY Shire Council

JBP Project Manager

Daniel Rodger
Jeremy Benn Pacific
Suite T46, 477 Boundary Street
Spring Hill, QLD 4000
Australia

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Contract

This report describes work commissioned by Ron Kemsley, on behalf of Kempsey Shire Council. Ellie Vahidi, Barney Bedford, Michael Thomson and Daniel Rodger of JBP carried out this work.

Prepared by .... Dr Ellie Vahidi PhD, MEng, BEng
Hydraulic Engineer

Prepared by .... Barney Bedford MSc BSc
Hydraulic Modeller

Reviewed by .... William Prentice BEng, CPEng, NER, MIEAust, FMA
Technical Director

Approved by .... Daniel Rodger BSc MEng CEng CMarEng MIEAust
Director

Purpose

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JBP has no liability regarding the use of this report except to Kempsey Shire Council.

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Executive Summary

JBPacific were commissioned by Kempsey Shire Council to develop a Coastal Vulnerability Area (CVA) map for the Kempsey Local Government Area (LGA). The CVA map is a key output of Stage 2 of the Coastal Management Program (CMP), in compliance with the Coastal Management Act 2016 and the State Environmental Planning Policy (Coastal Management) 2018.

The development of the CVA map has included consideration of seven coastal hazards; (1) beach erosion, (2) shoreline recession (3) coastal lake or watercourse entrance instability, (4) coastal inundation, (5) coastal cliff or slope instability, (6) tidal inundation and (7) erosion and inundation under tides, waves, and catchment floodwaters. This report describes the new technical assessment to review and map the following coastal hazards, which have been added to other available studies to produce the full CVA map.

- **Hazard 1 and 2:** Beach erosion and shoreline recession

  Following a review of available hazard studies, the 'rare' beach erosion and shoreline recession extent within an existing Council study has been used, with minor modifications around approved seawalls.
- **Hazard 3:** Coastal lake or watercourse entrance instability

  A new entrance instability assessment was undertaken for Crescent Head (Killick Creek), Hat Head (Korogoro Creek), and South West Rocks (Saltwater Creek). This assessment utilised historic aerial imagery to map the maximum observed envelope of entrance positions between the 1940s and present day.
- **Hazard 4:** Coastal inundation

  Coastal inundation was simulated using an updated hydraulic model (see Hazard 6). This has used a coastal tidal signature which included a Highest Astronomical Tide, a storm surge component, an allowance for wave setup, and new wave overtopping inputs at Hat Head. Overtopping inputs have been estimated using a separate XBeach model, with the dune represented using data from the NSW Beach Profile Database.
- **Hazard 6:** Tidal inundation

  An existing hydraulic model developed for the Lower Macleay Flood Study (Jacobs, 2019) was updated and used to map tidal and coastal inundation. The model spans the Kempsey coastline and covers the inland area defined by the Lower Macleay River catchment and smaller estuaries. The model has been updated using new field survey data, new structure information, consideration of flood gate operations during typical tidal conditions (where gates are assumed to be in a closed position, except those which are kept open during non-flood/river-rise conditions), and includes new astronomical tide data supplied by Manly Hydraulic Laboratory (MHL).
- **Hazard 7:** Erosion and inundation of foreshores under tides, waves, and catchment flood waters.

  Mapping for the majority of the coastline has been based on a combined flood and tide scenario simulated within the Lower Macleay Flood Study (Jacobs, 2019) that has been adopted by Council. The design event for this hazard combines a 1% Annual Exceedance Probability (AEP) (100-year return period) fluvial flood coinciding with a Higher High Water Spring (HHWS) tidal boundary. The fluvial-tidal interaction is captured at the downstream extents of the catchment where a tidal signature provides a realistic oscillation in flood levels.

  Mapping for Hazard 7 is currently not available for the Saltwater Creek catchment and updating the existing flood study was outside the scope of this project. It is recommended that funding is sought through available grant programs to update the Saltwater Creek flood study using consistent approaches, return periods and planning periods to the Lower Macleay Flood Study. This can then be incorporated within the CVA map.

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Abbreviations

AHD ..... Australian Height Datum
CMP ..... Coastal Management Program
CVA ..... Coastal Vulnerability Area
HAT ..... Highest Astronomical Tide
JBP ..... Jeremy Benn Pacific or JBPacific
KCPHDS ..... Kempsey Coastal Processes and Hazard Definition Study
KSC ..... Kempsey Shire Council
LGA ..... Local Government Area
MHL ..... Manly Hydraulic Laboratory
NSW ..... New South Wales
RDM ..... Resource Design Management
SEPP ..... State Environmental Planning Policy (Coastal Management) 2018

Definitions

Where possible, definitions used in this document are based on the NSW Coastal Management Manual and NSW Coastal Management Glossary. The seven hazards are defined as:

- Hazard 1: Beach erosion: the landward movement of the shoreline and/or a reduction in beach volume, usually associated with storm events or a series of events, which occurs within the beach fluctuation zone. Beach erosion occurs due to one or more process drivers; wind, waves, tides, currents, ocean water level, and downslope movement of material due to gravity.
- Hazard 2: Shoreline recession: the continuing landward movement of the shoreline, that is, a net landward movement of the shoreline, generally assessed over a period of several years. As shoreline recession occurs the beach fluctuation zone is translated landward.
- Hazard 3: Coastal lake or watercourse entrance instability: the variety of potential hazards and risks associated with the dynamic nature of both natural and trained entrances. Coastal lake and watercourse entrances are highly active environments with their shape constantly changing in response to processes such as alongshore sediment transport, tidal flows, storms and catchment flooding.
- Hazard 4: Coastal inundation: a combination of marine and atmospheric processes raises the water level at the coast above normal elevations, causing land that is usually 'dry' to become inundated by sea water. Alternatively, the elevated water level may result in wave run-up and overtopping of natural or built shoreline structures (e.g. dunes, seawalls).
- Hazard 5: Coastal cliff or slope instability: No definition of this hazard is provided in the NSW Coastal Management Manual, however the Manual relates instability to risk to life and property, e.g. from "catastrophic failure of cliffs and headlands and hazards associated with rock platforms".
- Hazard 6: Tidal inundation: the inundation of land by tidal action under average meteorological conditions and the incursion of sea water onto low lying land that is not normally inundated, during a high sea level event such as a king tide or due to longer-term sea level rise.
- Hazard 7: Erosion and inundation of foreshores caused by tidal waters and the action of waves, including the interaction of those waters with catchment floodwaters: This hazard does not have a formal definition within the NSW Coastal Management Glossary.

1 Introduction

JBPacific were commissioned by Kempsey Shire Council (KSC) to develop a Coastal Vulnerability Area (CVA) map for the Kempsey Local Government Area (LGA). This has been developed in accordance with the *State Environmental Planning Policy (Coastal Management) 2018*, as a part of the NSW government coastal planning reforms.

The development of CVA mapping forms a part of the Coastal Management framework for land use planning within the coastal zone. The overall framework includes four coastal management areas:

- Coastal wetlands and littoral rainforests
- Coastal Vulnerability Area (CVA)
- Coastal environment area
- Coastal use area.

The development of the CVA map has included consideration of seven coastal hazards:

1. Beach erosion
2. Shoreline recession
3. Coastal lake or watercourse entrance instability
4. Coastal inundation
5. Coastal cliff or slope instability
6. Tidal inundation
7. Erosion and inundation under tides, waves, and catchment floodwaters.

In addition to this introductory chapter the report contains the following sections:

- **Section 2:** Summary of available mapping for hazards 1, 2, 5 and 7, based on available Council reports.
- **Section 3:** New mapping for Hazard 6: Tidal inundation
- **Section 4:** New mapping for Hazard 4: Coastal inundation
- **Section 5:** New mapping for Hazard 3: Coastal lake or watercourse entrance instability
- **Section 6:** Presents a summary of the new assessments.

2 Available hazard mapping

Existing information has been used to support the development of the CVA maps, based on two comprehensive projects undertaken for the KSC. The Kempsey Coastal Processes and Hazard Definition Study (BMT 2013)[1] provides information on coastal erosion and recession throughout the LGA for a range of likelihoods. The Lower Macleay Flood Study (Jacobs 2019) provides combined catchment and coincident tidal flooding for a range of scenarios. This data has been used to address:

- Hazard 1: Beach erosion
- Hazard 2: Shoreline recession
- Hazard 5: Coastal cliff or slope stability
- Hazard 7: Erosion and inundation of foreshores under tides, waves, and catchment floodwaters:

2.1 Hazard 1: Beach erosion

Beach erosion is defined as:

"the landward movement of the shoreline and/or a reduction in beach volume, usually associated with storm events or a series of events, which occurs within the beach fluctuation zone. Beach erosion occurs due to one or more process drivers; wind, waves, tides, currents, ocean water level, and downslope movement of material due to gravity."

Beach erosion mapping has been completed within the Kempsey Coastal Processes and Hazard Definition Study (KCPHDS). This mapping has used an evidence base to understand past erosion events and their potential to occur again in the future. Through analysis of photogrammetric data spanning the 1940's to 2011, beach erosion extents have been defined based upon analysis of the most eroded profiles observed within historic records. Three beach erosion likelihoods were produced; reflecting 'almost certain', 'unlikely' and 'rare' extents. These three likelihoods are described as following:

- Almost certain: There is a high possibility the event will occur as there is a history of frequent occurrence
- Unlikely: There is a low possibility that the event will occur, however, there is a history of infrequent or isolated occurrence
- Rare: It is highly unlikely that the event will occur, except in extreme/exceptional circumstances, which have not been recorded historically

Whilst comprehensive, the analysis and modelling were completed in 2011 based on beach erosion data now a decade old. New beach profile data is available from NSW Beach Profile Database, which indicate recent erosion extents may exceed, or be very similar to, the significant erosion observed within the 1970 storms. Based on this new data, and the current practise to include an allowance for reduced foundation capacity within erosion extents, coastal erosion hazard mapping has been based on the 'rare' extents produced within the KCPHDS. This 'rare' erosion hazard map reflects an extent larger than the envelop of historic shoreline positions captured within the 1940-2011 record, which is considered suitable for the CVA map until an updated assessment is undertaken.

One exception has been made at Crescent Head, where the 'unlikely' erosion hazard extents have been adopted for areas behind the rock armour revetment wall that lines the southern side of Killick Creek. Under this 'unlikely' scenario it is assumed the revetment will mitigate any erosion.

1 Kempsey Coastal Processes and Hazards Definition Study (2013) BMT WBM for Kempsey Shire Council

2.2 Hazard 2: Shoreline recession

Shoreline recession is defined as:

"the continuing landward movement of the shoreline, that is, a net landward movement of the shoreline, generally assessed over a period of several years. As shoreline recession occurs the beach fluctuation zone is translated landward."

Shoreline recession mapping has been completed within the KCPHDS (2013) using numerical modelling. The future shoreline position was assessed using the Shoreline Evolution Model (SEM), which simulated the response of the shoreline to sea level change. The SEM model was calibrated against historic field data spanning 1940 to 2011 before being used to project future trends.

The model performance is critically linked to the historic trends within beach profile data. A degree of uncertainty exists within the shoreline recession modelling due to their lack of data since 2011. This has been reviewed based on the expected change in long-term recession rates at Crescent Head, Hat Head, and South West Rocks using the NSW Beach Profile Database. The online Beach Profile tool was used to extract long term annual recession rates at the 2m AHD contour between the two periods; 1942-2011 and 1940-2020. The change in annual rates indicated:

- Less long-term recession is expected at Crescent head using the new data.
    - 1942 - 2011: -0.60 m/yr (R^2=0.70)
    - 1942 - 2020: -0.54 m/yr (R^2=0.76)
- More long-term recession is expected at Hat Head using the new data.
    - 1942 - 2011: -0.08 m/yr (R^2=0.02)
    - 1942 - 2020: -0.16 m/yr (R^2=0.11)
- Less accretion is expected at South West Rocks using the new data.
    - 1942 - 2011: +1.09 m/yr (R^2=0.54)
    - 1942 - 2020: +0.78 m/yr (R^2=0.48)

By projecting these trends forward by 80 years, the inclusion of new data may change the future 2100 shoreline position by around ±10m. Whilst a high-level review only, the inclusion of new data is not expected to substantially change the recession map. Given the variability in long term coastal hazard assessments, this uncertainty has been acknowledged within the CVA mapping, and existing maps recommended for use until a revised recession assessment can be undertaken.

2.3 Hazard 5: Coastal cliff or slope instability:

No definition of this hazard is provided in the NSW Coastal Management Manual, however the Manual relates instability to risk to life and property, e.g. from "catastrophic failure of cliffs and headlands and hazards associated with rock platforms".

A goal of the KCPHDS was to identify areas that may be subject to cliff instability for further investigation. No significant cliff instability areas were identified within the document, and the hazard associated with coastal cliff or slope instability is considered minor. Consequently, no mapping has been produced for hazard.

2.4 Hazard 7: Erosion and inundation of foreshores under tides, waves, and catchment floodwaters

This hazard does not have a formal definition within the NSW Coastal Management Glossary. It is understood to encapsulate all foreshore areas that could be affected by erosion or inundation from combined coastal and fluvial processes.

Mapping for the majority of the coastline has been based on a combined flood and tide scenario simulated within the Lower Macleay Flood Study (Jacobs, 2019) that has been adopted by Council The design event combined a 1% Annual Exceedance Probability (AEP) (100-year return period) fluvial flood coinciding with a Higher High Water Spring (HHWS) tidal boundary. The model includes a number of flood gates, flood control structures and levees that help mitigate flooding throughout the Lower Macleay valley. The fluvial-tidal interaction is captured at the downstream extents of the modelled creeks where a tidal signature provides a realistic oscillation in flood levels. Whilst the modelled inundation extends significantly further than a coastal-only simulation, its inclusion provides consistency with other Council flood risk planning maps.

Mapping for Hazard 7 is currently not available for the Saltwater Creek catchment and updating the existing flood study was outside the scope of this project. It is recommended that funding is sought through available grant programs to update the Saltwater Creek flood study using consistent approaches, return periods and planning periods to the Lower Macleay Flood Study. This can then be incorporated within the CVA map.

3 New Tidal inundation modelling

3.1 Scope

Tidal inundation is defined as:

" the inundation of land by tidal action under average meteorological conditions and the incursion of sea water onto low lying land that is not normally inundated, during a high sea level event such as a king tide or due to longer-term sea level rise."

Tidal inundation mapping has been undertaken using the outputs of a numerical model, which simulated a Highest Astronomical Tide throughout the Kempsey coastline and estuaries.

3.2 Data

Data used within the tidal modelling includes:

- The hydraulic model from the Lower Macleay Flood Study (Jacobs, 2019)
- Astronomical tide data from Manly Hydraulic Laboratory (MHL, 2020)
- New field survey data collected by project partners Resource Design Management (RDM, 2020).

3.2.1 Hydraulic model data

The hydraulic model developed within the Lower Macleay Flood Study (2019) has been updated and used to map this hazard. The model is a 1D-2D hydrodynamic TUFLOW model which covers the lower Macleay River catchment, including estuaries at Hat Head, Crescent Head, Ryans Cut and South West Rocks, with hydraulic links to the Maria River and Hastings River to the south.

The flood study model calibration was originally undertaken for two well-documented events in 2001 and 2013, with good correlation to gauged data. The existing flood model is well calibrated and documented, and is considered a robust tool to use within new Tidal Inundation modelling. A full description of the original model development and calibration is available within the Lower Macleay Flood Study report.

3.2.2 Astronomical tide data

The updated model has been configured to use a time-varying downstream tidal boundary. Two tidal signatures were considered for use as model boundaries. The closest tidal water level gauge and estimated astronomical tide signature to the study area is located at Port Macquarie, however water levels are influenced from the Hastings River. Instead, water levels and a tidal signature from the Coffs Harbour tide gauge was used, which is a representative ocean tidal gauge. All tidal data was provided by Manly Hydraulics Laboratory (MHL) in 2020.

3.2.3 New field survey

A site walkover and topographic survey was conducted in May 2020 by project partners RDM, which included thirty locations. Field survey was used to verify structure information and update any model data.

3.3 Updated boundary conditions

The modelling approach used within the TUFLOW flood model was changed to focus on tidal propagation rather than fluvial flood behaviour. A tidal boundary was applied to the model, spanning the Kempsey LGA coastline, which allows the tides to propagate into any low-lying area. A dynamic (time-varying) tide series was applied at this ocean boundary, starting several tidal cycles earlier than the peak tide level. This allows water levels in the creeks to equalise prior to the peak tide, and ensures the maximum inundation extent is recorded in the outputs. The tidal boundaries were located offshore of the coast, with the fluvial inflow at the models' upstream extent of the Macleay River changed to represent low freshwater flows. No freshwater inflows were used for the smaller creeks, which were assumed to be fully tidally dependent. A summary of the model boundary conditions are as follows:

- The downstream model boundary was defined as a water level versus time using tidal data derived from Coffs Harbour tidal gauge provided by MHL.

- River flow condition was estimated based on river baseflow conditions to purely model the effect of tidal inundation without dominant effect of high flow conditions. The procedure of baseflow estimation will be discussed in more details in Section 3.7.1.

Once the tidal inundation model was setup, calibration to historical tidal gauge records was undertaken against tidal information provided by MHL. Following calibration, a standard astronomic tidal signature was used, which peaks at the Highest Astronomical Tide (HAT). The HAT is the highest tide level due to astronomical processes (i.e. not including the effects of weather). It occurs once over an 18.6 year period, although at some sites high tide levels similar to HAT may occur several times per year during peak tidal conditions. The 1.24mAHD HAT level at Coffs Harbour was adopted for Kempsey, provided by MHL based on the latest water level reviews.

3.4 Topography and river and creek entrances

Initial testing within the hydraulic model was undertaken to consider the importance of the entrance state. The initial testing concluded:

- No changes were made to the Macleay entrance geometry, which suitably reproduced tidal conditions throughout the River.
- Testing within the smaller creeks showed the extent of tidal propagation was sensitive to entrance conditions. Tidal flows could be blocked by a large sand berm or could freely enter the estuary if the entrance was open. To support the estimation of the peak tide conditions, a scoured bed condition was incorporated into the TUFLOW model to reflect an open condition for all small estuaries.

This approach is likely to produce a more conservative result as tidal propagation, as it considers all entrances in an open state.

Figure 3-1: Saltwater Creek in a closed condition, 20 May 2020 (Source: RDM drone)

3.4.1 Updates to hydraulic model

In addition to modifying the TUFLOW boundaries, the flood model was updated to include new field survey, structure information and gate opening procedures.

- Using new field data collected by RDM surveyors, levee crest levels were confirmed within the TUFLOW structure geometry. This was based on new survey undertaken at Frederickton, the Macleay River near Pola Creek, Hat Head, Crescent Head, Big Hill, and South West Rocks. A section of Point Plomer Rd in Big Hill and levee crest levels in Pelican Island on the Macleay River were updated based on topographic survey.
- Flood gates are used within the existing hydraulic model to protect against tidal inundation unless they are opened during a fluvial flood event. Several updates have been made to gates that have experienced changes since 2019. The Yarrahapinni flood gate was opened within the model, which had been decommissioned since the Lower Macleay Flood Study was completed. Similarly, the Yarrahapinni drain extending north through the wetlands has been enforced within the model to provide a passage for tidal flows, which is known to penetrate to the Boringalla water level gauge, as noted within new gauge data provided by MHL.
- New data provided by Council was used to update some structure information. The Killick Cut floodgates were updated to reflect a crest of 1.8 mAHD based on constructed drawings provided by Council.
- Discussions were held with Council on how flood gates should be represented within the model, based on standard opening procedures during tide-only or storm tide conditions. The following gates are open in the model (all others remain closed):
  - Christmas Creek
  - Euroka Creek
  - Korogoro Creek at Hat Head Levee (the "Choke")
  - Belmore River main floodgate
  - Kinchela Creek floodgate.

3.5 Model calibration

The updated hydraulic model was calibrated against tidal conditions during January, February and March 2020. Calibration data was provided by MHL for the tidal river gauges, which are located along the Macleay River, at Crescent Head (Killick Creek), Hat Head (Korogoro Creek), and South West Rocks (Saltwater Creek), as shown in Figure 3-2. This period was selected due to its lack of rainfall, with the gauge records primarily representing the tidal signature. The model tidal boundaries were based on data recorded at Coffs Harbour. The fluvial inflows at the Macleay River were set to typical baseflow conditions, based on stream gauge records at Turners Flat between the years of 1970 to 2020. The model calibration process involved adjusting the hydraulic roughness parameter value (Manning's n) along the river channel to obtain a good agreement with recorded water levels at several tidal water level gauges.

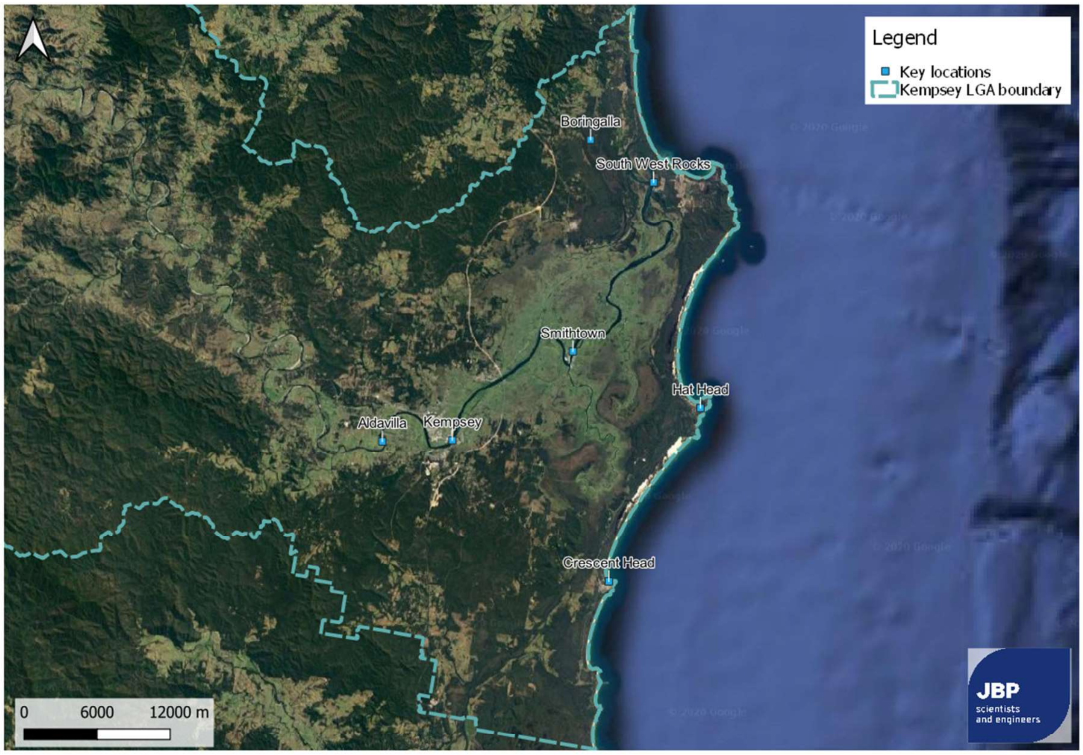

Figure 3-2: Study area and key locations

3.5.1 January 2020

The calibration period extended between 1 and 4 January 2020, during a period with no recorded rainfall. Initial water levels in Macleay River were selected based on water level gauges. A comparison of recorded and modelled levels throughout the simulation is presented for river gauges in Figure 3-3. The modelled peak and minimum water level were compared to the recorded values and summarised in Table 3-1.

In the lower reaches there is a good agreement between model and recorded data, with the simulated peak high tide within 0.003m. Simulated tides are considered representative throughout the estuary to Smithtown, where the high tide values are within 0.1m of recorded. Small changes to tidal phase occur as it propagates past Kempsey to Aldavilla, where the model slightly overpredicts the high tide by around 0.1m.

Table 3-1: Calibration of water level, January 2020 (m AHD)

Gauge location	Difference (maximum water level), m	Difference (minimum water level), m
Aldavilla	0.095	0.022
Kempsey	0.078	0.051
Smithtown	0.026	0.011
South West Rocks	0.003	0.131
Coffs Harbour	0.021	0.046

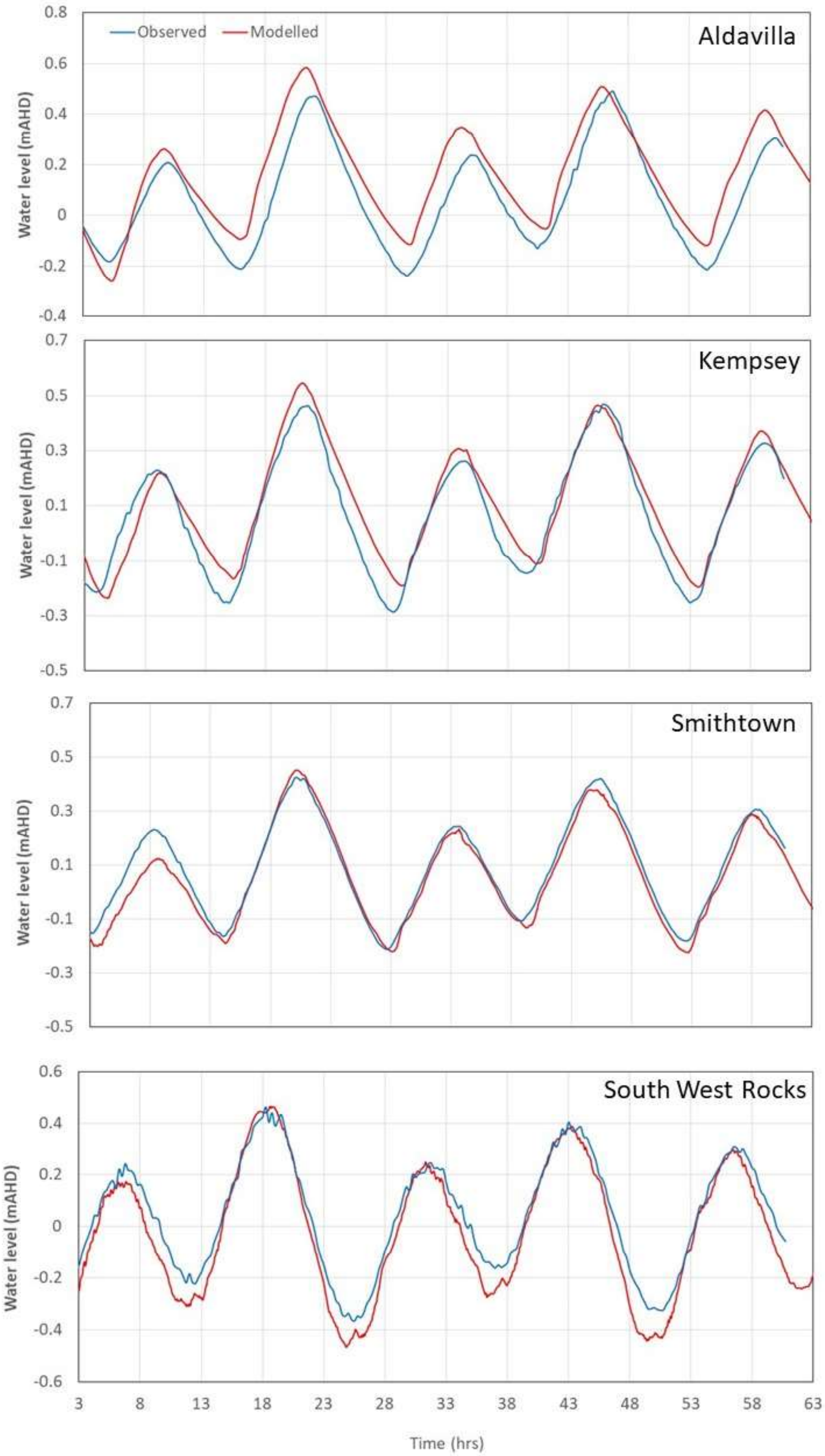

Figure 3-3: Observed vs modelled water level, January 2020

3.5.2 March 2020

The calibration period spanned 14th to 16th of March, during a dry period between small rainfall events (see Figure 3-4). The initial water level within the model was estimated based on the water level values at the start of the calibration period.

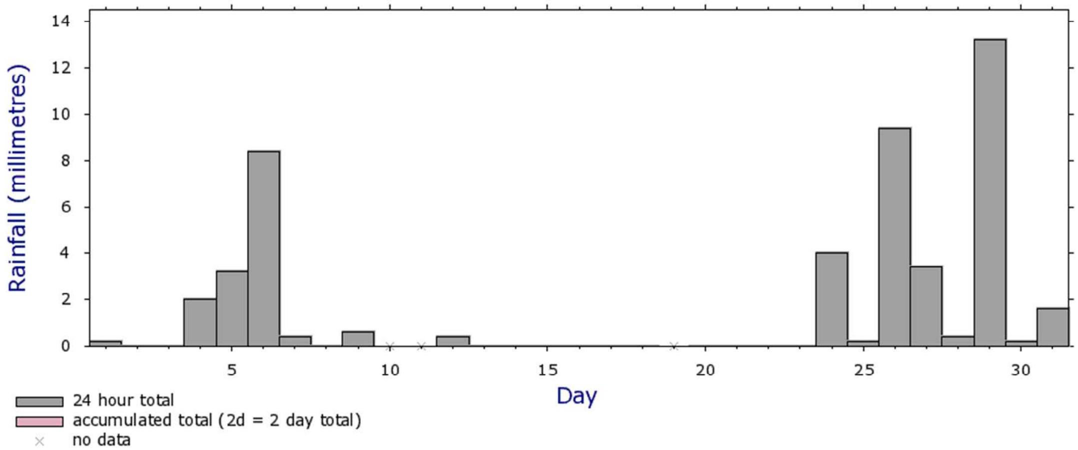

Figure 3-4: Daily rainfall, Kempsey Airport AWS, March 2020

3.5.3 Calibration summary

The modelled water levels for the calibration period were compared to the recorded tide data, as shown in Figure 3-5. The modelled maximum and minimum water levels were compared to the recorded values and summarised in Table 3-2.

In the lower reaches there is a good agreement between model and recorded data, with the simulated peak high tide within 0.001m. Simulated tides are well represented throughout the estuary at Smithtown and Kempsey, where the high tide values are within 0.06m of recorded values. At these gauges, the simulated peak tide level aligns well with the highest recorded tide, while the timing of the simulated peak occurred slightly after the observed peak. Some variation exists at Aldavilla, with tides either under or over-estimating by around 0.1m, with an average error of 0.003m.

The water level gauge in Borigalla Creek, at the upstream extent of Yarrahapinni wetlands is tidally affected but shows a dominance of fluvial flows in its overall water level. In wetter periods, the tidal series is perched on top of a higher water level and the tidal signature is attenuated. This explains some of the poor reproduction of observed water levels at this location within the calibration simulations.

Table 3-2: Calibration of water level, March 2020 (m AHD)

Gauge location	Difference (maximum water level), m	Difference (minimum water level), m
Aldavilla	0.003	0.013
Kempsey	0.030	0.006
Smithtown	0.060	0.008
South West Rocks	0.001	0.077
Coffs Harbour	0.057	0.026

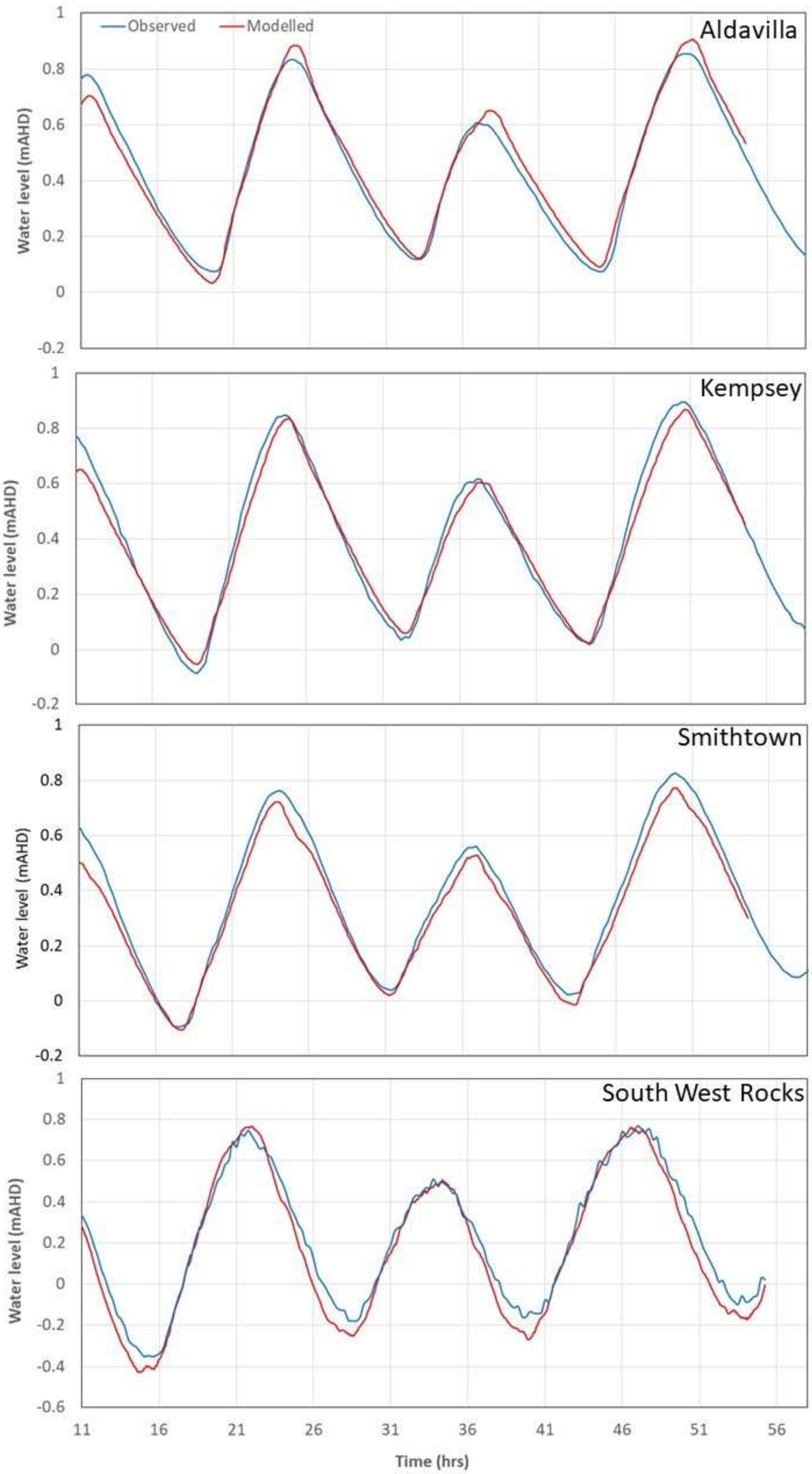

Figure 3-5: Observed vs modelled water level, March 2020

3.6 Model Sensitivity

3.6.1 Roughness sensitivity

The Tuflow flood model development during within the Lower Macleay River flood study included a robust and comprehensive analysis of roughness sensitivity in line with current industry practice and guidelines. Given the good calibration of the updated model to historical tide gauge readings, detailed roughness sensitivity testing was not repeated.

3.6.2 Boundary sensitivity

The updated tidal model uses a dynamic tidal ocean boundary. Any variations to this ocean boundary will have the greatest influence of tidal inundation along the coastal areas. The upstream fluvial boundary has been adopted based on normal (dry weather) flow conditions. Given the modelling approach was to investigate the tidal inundation using the calibrated model, sensitivity to the fluvial boundary was not investigated.

3.6.3 Blockage sensitivity

The Tuflow flood model development during within the Lower Macleay River flood study included a robust and comprehensive analysis of blockage in line with current industry practice and guidelines. Given the good calibration of the updated model to historical tide gauge readings, detailed blockage sensitivity testing was not repeated.

3.7 Design tidal Inundation

The design tidal simulation represents the tidal event equivalent to a HAT. Tidal boundaries were based on water level gauge data provided by MHL at the Coffs Harbour Inner Jetty (Station no: 205470). This site is considered representative of the Kempsey coastline. Three design scenarios have been run, reflecting present day (2020), estimated 2050 and 2100 conditions.

MHL analysis on recorded tide data spanning 1995 to 2014 estimates the HAT level to be 1.24m AHD (Maddox, S. 2018)[2]. This has been increased for future planning horizons based on national and international projections of sea level rise along the NSW coast, which estimates a rise in sea level of 40 cm by 2050 and 90 cm by 2100 (New South Wales Government, 2009). This has been applied as a constant increase to the present-day baseline tidal signature. The HAT values are:

- Present day HAT: 1.24 m AHD
- Estimated 2050 HAT: 1.64 m AHD
- Estimated 2100 HAT: 2.14 m AHD.

For each of the simulations, a dynamic (time-varying) tidal series was used within the model. This was based on actual tide data that reached a HAT level. The model started several tidal cycles earlier than the peak HAT, which allowed the water levels in the creeks to equalise prior to the HAT occurring. The tidal signatures used in the design simulations are shown in Figure 3-6.

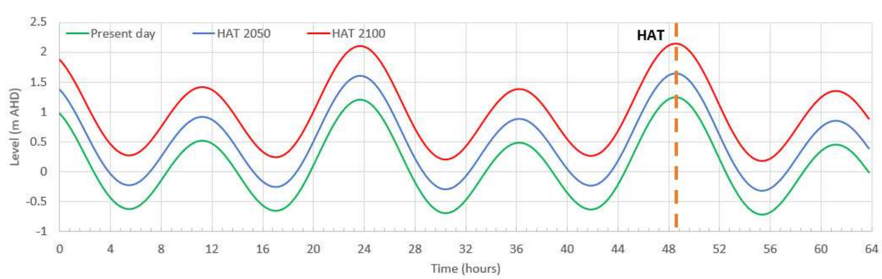

Figure 3-6: Tidal signatures for present day, 2050 and 2100

2 Maddox, S. (2018). NSW Ocean and river entrance tidal levels annual summary 2017–2018. Manly Hydraulics Laboratory Report MHL2618. (State of New South Wales: Sydney, NSW, Australia.)

3.7.1 Fluvial flow conditions

The purpose of the tidal inundation model was to assess tidal inundation, excluding coincident fluvial flooding. For this reason, the fluvial inflows were set to typical baseflow or low flow conditions.

Data from the WaterNSW website was used to estimate a typical baseflow for the Macleay River, based on analysis of the stream gauge at Turners Flat, located directly upstream of the study area. The data from the Turners Flat gauge was extracted and is shown in Figure 3-7 for the period between 1970 to 2020. The baseflow was estimated using digital filters as described in ARR Project 7. It was calculated based on the historic events (1970-2020) with a recurrence interval of less than one year to acquire best estimation of low flow conditions in river. The Eckhardt (2005) method was used with an alpha parameter of 0.98, which estimated the baseflow to be 16.4 m^3/s. This was applied as a constant Q-T boundary for the Macleay River inflow boundary.

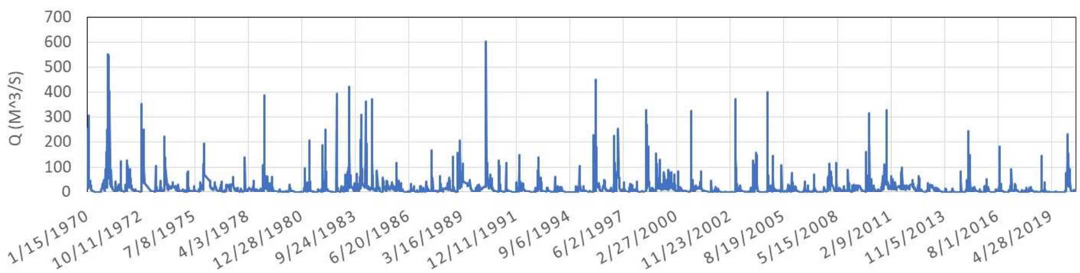

Figure 3-7: Estimated baseflow in Turners Flat gauge

3.8 Model Results

The modelled water level surfaces have been mapped to create tidal inundation extents for present day (2020) and future planning horizons at 2050 and 2100. The modelled HAT values for each gauging station is shown in Table 3-3, and peak HAT extents shown in Figure 3-8.

Comparing the tidal inundation extents over the planning horizons shows similar inundation extents for areas with formalised channels, particularly in the upstream reaches. The greatest changes were observed in lowlying areas at the lower estuary, including Borigalla Creek, Yarrahapinni Wetlands and the lower Macleay River.

Table 3-3: Modelled peak water level (m AHD)

Location	2020	2050	2100
Aldavilla	1.01	1.41	1.96
Kempsey	1.03	1.54	2.16
Smithtown	0.85	1.26	1.73
South West Rocks	1.07	1.40	1.77
Boringalla	0.39	0.75	1.24
Saltwater Lagoon	1.08	1.64	2.13
Macleay Entrance	1.24	1.64	2.14
Hat Head	1.24	1.64	2.14
Crescent Head	1.24	1.64	2.14

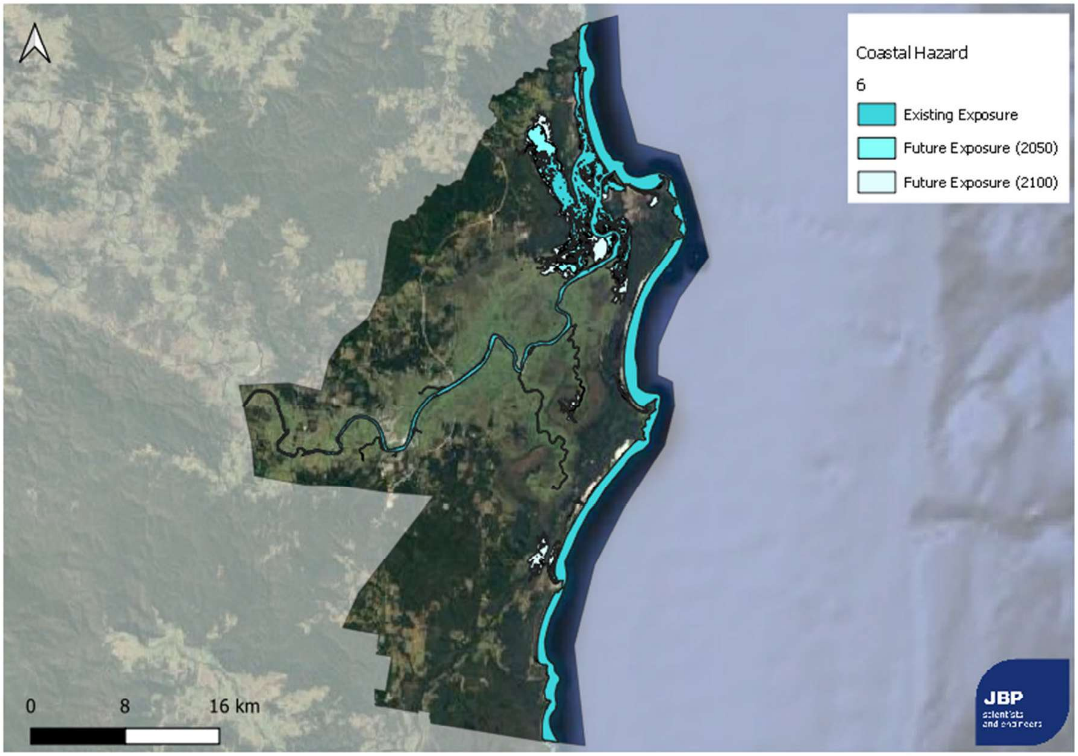

Figure 3-8: Tidal inundation extents for years 2020, 2050 and 2100

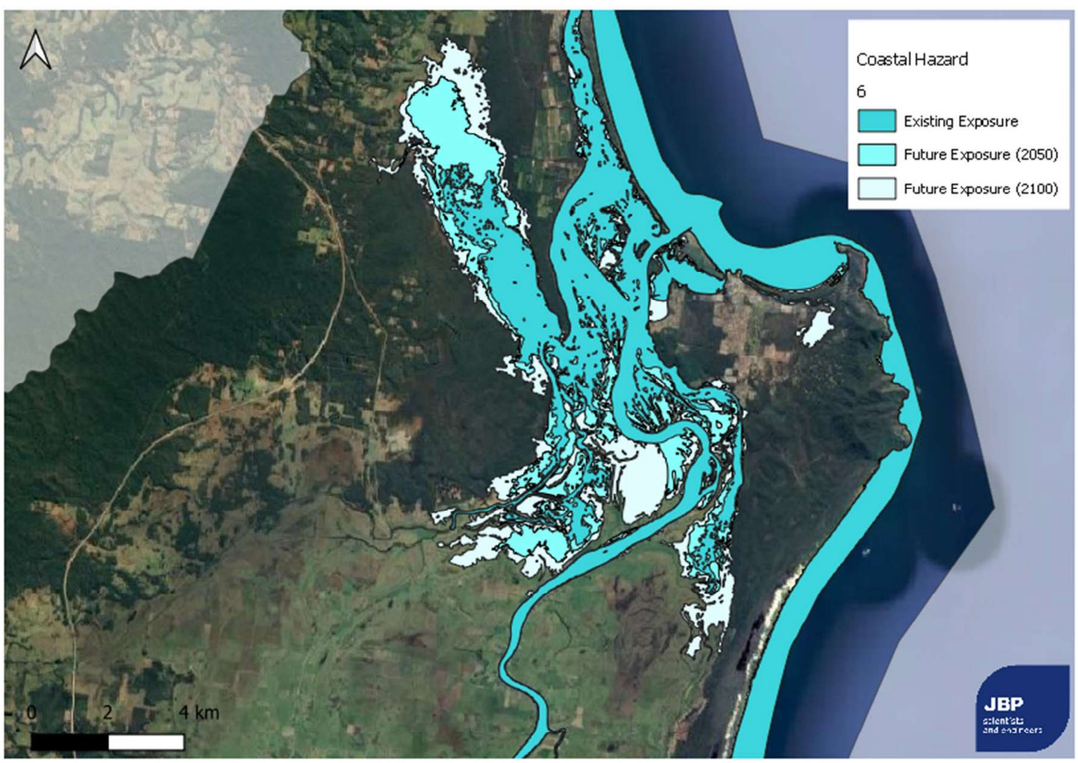

Figure 3-9: Tidal inundation extents for years 2020, 2050, 2100 - Macleay entrance

4 New coastal inundation modelling

Coastal inundation is described as occurring when:

" a combination of marine and atmospheric processes raises the water level at the coast above normal elevations, causing land that is usually 'dry' to become inundated by sea water. Alternatively, the elevated water level may result in wave run-up and overtopping of natural or built shoreline structures (e.g. dunes, seawalls)."

Coastal flooding is a complicated process, affected by several dependent and independent variables, as shown in Figure 4-1. In order to map the coastal inundation occurring behind the shoreline, consideration has had to be given to the underlying astronomical tide, storm surge and the wave effects.

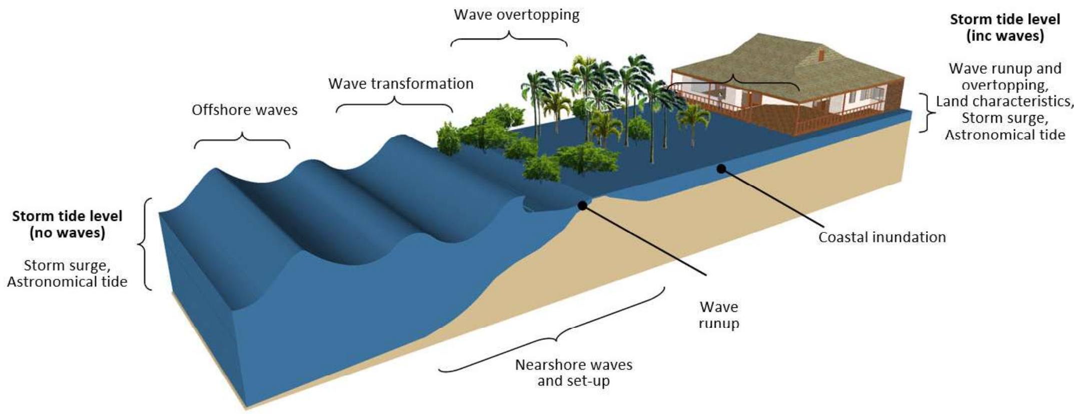

Figure 4-1: Coastal risk drivers

Coastal inundation was simulated using the updated hydraulic model described in Section 2. In addition to the tidal signature, the model was updated to include a component of storm surge and wave setup within the coastal boundaries, and new wave overtopping inputs at Hat Head.

4.1 Storm surge and wave setup estimation

The tidal boundary within the updated model reflects a typical tidal signature for the Kempsey Shire open coastline, which is simulated several tidal cycles before and after a HAT of 1.24m AHD. A 24-hour storm surge was introduced within the model, following a triangular shape with a peak surge coinciding with the HAT. The magnitude of the surge was established to produce the 100-year peak extreme coastal inundation level estimated within the KCPHDS. This level consists of tide, surge and wave setup components. Extreme sea levels used at the coastal boundary for each planning horizon are listed below. For additional information refer to the KCPHDS.

- 2.7m AHD
- 3.2m AHD
- 3.8m AHD[3]

4.2 Wave overtopping boundaries

If waves reach the shoreline any residual energy may intermittently run up and down the beach face, known as wave run-up. This may cause localised impacts as waves can reach elevations higher than the coastal inundation level. The Hat Head township is situated behind a sandy dune which has the potential to erode and overtop during a coastal storm. The extent and depth of this overtopping has been assessed within the TUFLOW model by incorporating a new time-varying overtopping discharge, calculated using the high-detail XBeach model. This incorporates the latest

3 BMT (2013) Kempsey Coastal Processes and Hazards Definition Study. Table 3-8: Adopted coastal inundation levels

research from a consortium of international organisations, including the US Army Corps of Engineers, UNESCO-IHE, Deltares, Delft University of Technology, the University of Miami, and University of Western Australia. The software is publicly available, and free to use.

A one-dimensional (1D) XBeach model has been used to simulate wave breaking, runup and overtopping over a bathymetric and topographic computational grid. The grid has been based on data accessed from the NSW Beach Profile Database (BPD), which collates aerial survey data of NSW beaches dating back over 80 years. The BPD includes 28 beach profiles adjacent to the Hat Head township, with additional cross sections available to the north. Following a review of the data, the profile at 'Block 2 No 10' was selected for modelling, as it represented an average cross section with moderate dunes, positioned near the centre of the town. Five beach profiles are available at the location, representing varying crest heights and widths. Two beach profiles were developed from the data:

- A relatively high dune profile, which adopted the 75th percentile elevation from the data envelope. This represents a dune in good condition, just below the highest recorded levels.
- An eroded profile, which adopts the lowest envelope of any beach cross section within the data. This represents a dune that has just been eroded during a storm.

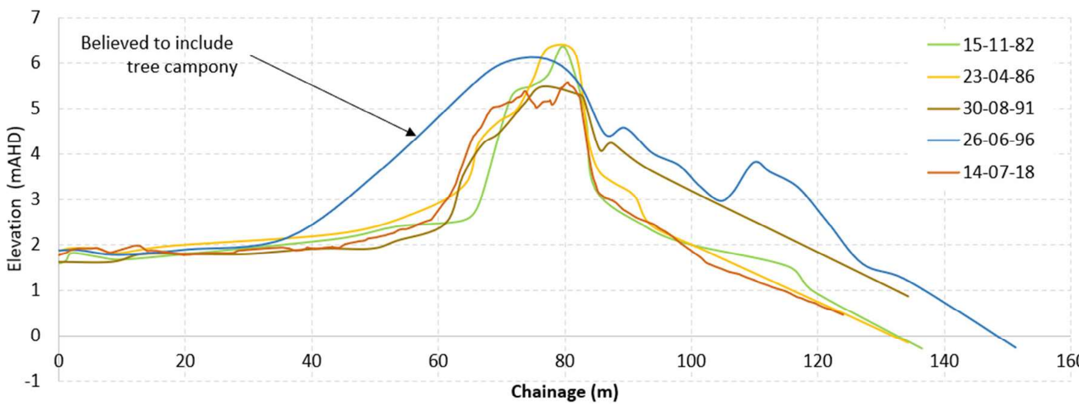

Figure 4-2: Coastal profiles at Hat Head (Block 1, Profile 10)

XBeach simulated a tidal signature from the KCPHDS with a 24-hour storm surge added to create a peak water level equalling the tide plus surge (excluding setup[4]) level from the KCPHDS. Wave conditions have been based on the 100-year, 1-hour duration wave height estimated within the KCPHDS, based on prior MHL analysis[5]. The following boundary conditions were used at each planning horizon, run for both the high and eroded beach profile:

- Wave conditions:
  - Present day: 8.6m, 12.9s
  - 2050: 9.12m, 13.68s
  - 2100: 10.12m, 15.18s
- Peak tide plus surge (excluding setup):
  - Present day: 1.4m AHD
  - 2050: 1.8m AHD
  - 2100: 2.3m AHD

The volume of overtopped water was captured as it flowed over the dune crest within the XBeach model. There was a significant difference in overtopping volume between the high and low dunes over the duration of the storm. During a storm of approximately three hours, which spanned the high tide, between 10 and 74 m^3 was overtopped per linear metre of dune, for the high and eroded dune respectively (see Table 4-1).

4 Setup was excluded as a boundary condition to avoid 'double counting' as it is calculated within the XBeach model.
5 BMT (2013) Kempsey Coastal Processes and Hazards Definition Study. Section 2.3.2.1 Significant Wave Height

Both the high and eroded dune simulations used an unerodable bathymetry in the model, however during a storm some erosion is expected. Rather than modelling time-dependent erosion within the model, the results from the high and eroded dunes scenarios were integrated post-simulation. This eliminated variance in the model's erosion mechanism, instead taking the dunes "non-eroded" and "eroded" states from real profile data (high and low profiles, respectively). This method represents an uneroded dune at the start of the simulation and an eroded dune at the end, and resulted in a total of 42 m^3/m overtopped water during the tidal cycle for the present-day scenario. The complete timeseries of overtopped water was used within the TUFLOW model, input directly landward of the dune at Hat Head.

Table 4-1: Overtopped water volume during tidal cycle (m^3/m)

	Overtopped volume (m^3/m)	Overtopped volume (m^3/m)	Overtopped volume (m^3/m)
Dune state	Present Day	2050	2100
High dune	10.5	63.1	101.8
Eroding dune (adopted for TUFLOW model)	42.2	226.5	524.9
Eroded dune	73.9	389.9	948.0

4.2.1 Dune height sensitivity

The beach profiles used to simulate wave run-up and overtopping shows a significant difference in overtopped volume for high and low dunes. The influence of this variable overtopping rate has been investigated through sensitivity tests within the TUFLOW model. New simulations were run for the high and low dune crest overtopping. The simulations produced a similar extent, as overtopped water flowed landward into Korogoro Creek, which was then recirculated back into the ocean. The peak water level difference varied by approximately 0.1m, with largest changes directly behind the dune. A mid-range scenario was developed to prevent a significant over or under-estimation. The overtopping results from these two dunes profiles were integrated, which resulted in a single overtopping discharge representing an uneroded dune at the start of the simulation and eroded dune at the end. These flows were implemented within the TUFLOW model.

4.3 Model results

The modelled water level surfaces have been mapped to create coastal inundation extents for present day (2020) and future 2050 and 2100 planning horizons. The peak water level surface extents is shown in Figure 4-3. Generally, the main impact of the coastal inundation hazard and elevated water levels during a storm relates to the inundation of low-lying areas such as estuary, lake and lagoon connected with ocean. Results show that elevated ocean levels (which include tide, storm surge, wave set up, and potentially sea level rise) propagates into estuaries and lead to inundation of low-lying coastal floodplains, including lower Macleay River, Borigalla Creek and Yarrahapinni Wetland (Figure 4-4). Comparing the coastal inundation extents over different planning horizons shows similar inundation extents for the upstream reaches, particularly for areas with formalised channels, while significant changes are observed in downstream areas. These maps show that an increasing downstream area is inundated by coastal inundation due to sea level rise.

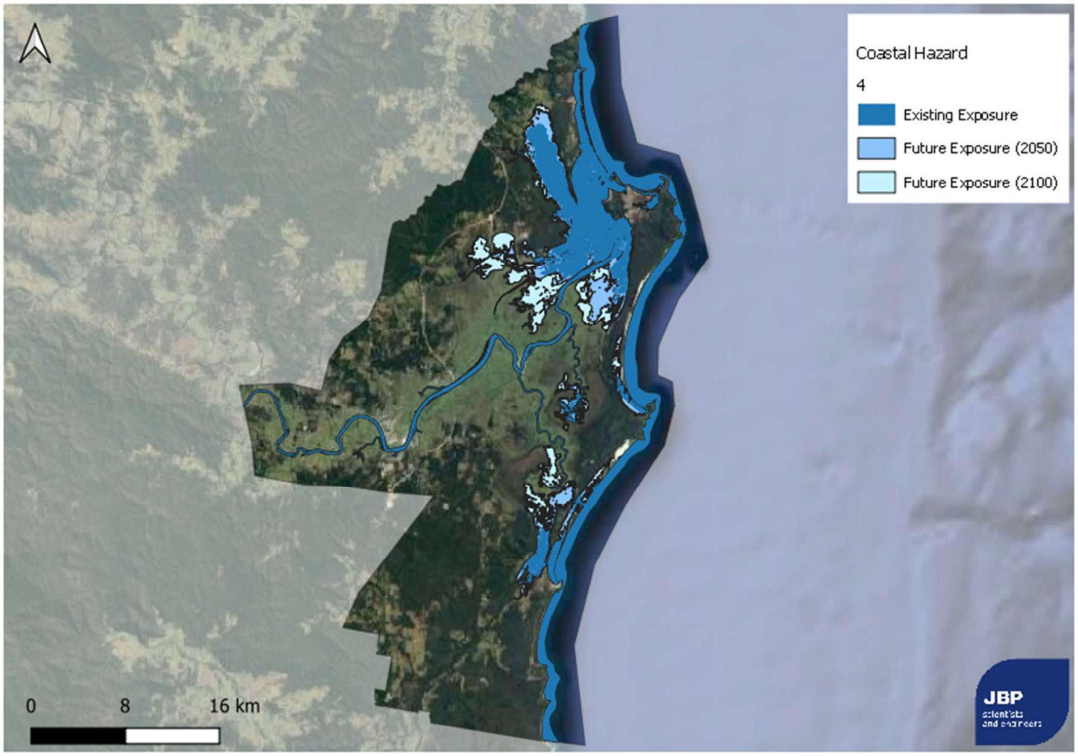

Figure 4-3. Coastal inundation extents for years 2020, 2050 and 2100

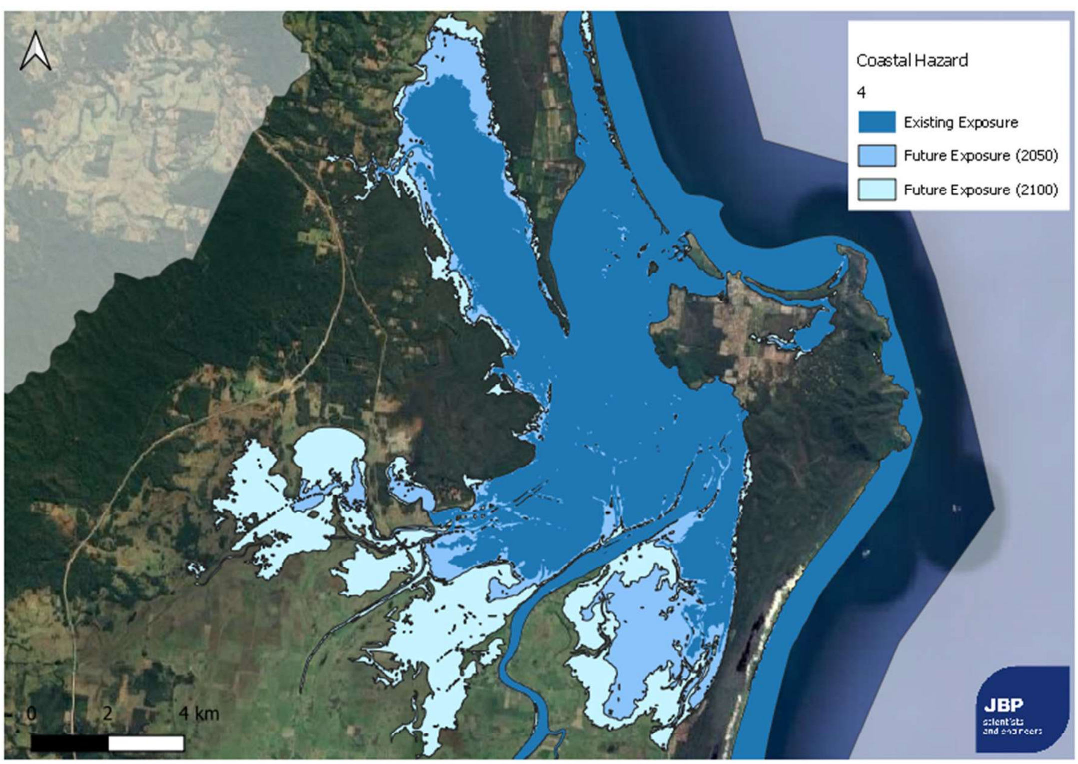

Figure 4-4. Coastal inundation extents for years 2020, 2050, 2100 - Macleay entrance

5 New watercourse entrance instability mapping

Coastal lake or watercourse entrance instability is described as:

" the variety of potential hazards and risks associated with the dynamic nature of both natural and trained entrances. Coastal lake and watercourse entrances are highly active environments with their shape constantly changing in response to processes such as alongshore sediment transport, tidal flows, storms and catchment flooding."

At many untrained coastal estuaries and rivers, there is inherent variability of the coastal entrance position. While some estuary channels and entrances are relatively stable through time and are held by natural geomorphic features (e.g. Korogoro Creek), others have historically broken through at various positions along the coast. Other causes for entrance instability can be artificial openings or new engineered structures being introduced into the coastal system, such as the large-scale changes made to the Macleay River.

Mapping of beach erosion and shoreline recession within the KCPHDS does not consider the dynamic position of the estuary entrances. Several estuaries within the Kempsey LGA are trained and considered relatively stable, such as the Macleay River. A new entrance instability assessment was undertaken for Crescent Head (Killick Creek), Hat Head (Korogoro Creek), and South West Rocks (Saltwater Creek). This has used historic aerial imagery to map the maximum observed envelope of entrance positions. Aerial images are dated from the 1940s to present day. The creek entrances were traced based on their open waterway area, which targeted the upper banks. In many cases their position was partially obscured by overhanging tree canopies, with additional challenges due to poor image quality and difficulties in georeferencing the earliest images.

The instability area was limited to the estuary mouth. It extends around the envelope of historic shoreline positions, following logical cadastre lot boundaries. The width of the instability zone has been reduced in areas where the historic entrance position has now been formalised by an approved training structure. Along the western banks of the Korogoro Creek entrance at Hat Head, the existing training wall, boat ramp and historic entrance positions are in close proximity of each other. Due to the age, condition and vegetation obscuring the exact location of the training wall crest, it was not used to limit the width of the mapped instability zone.

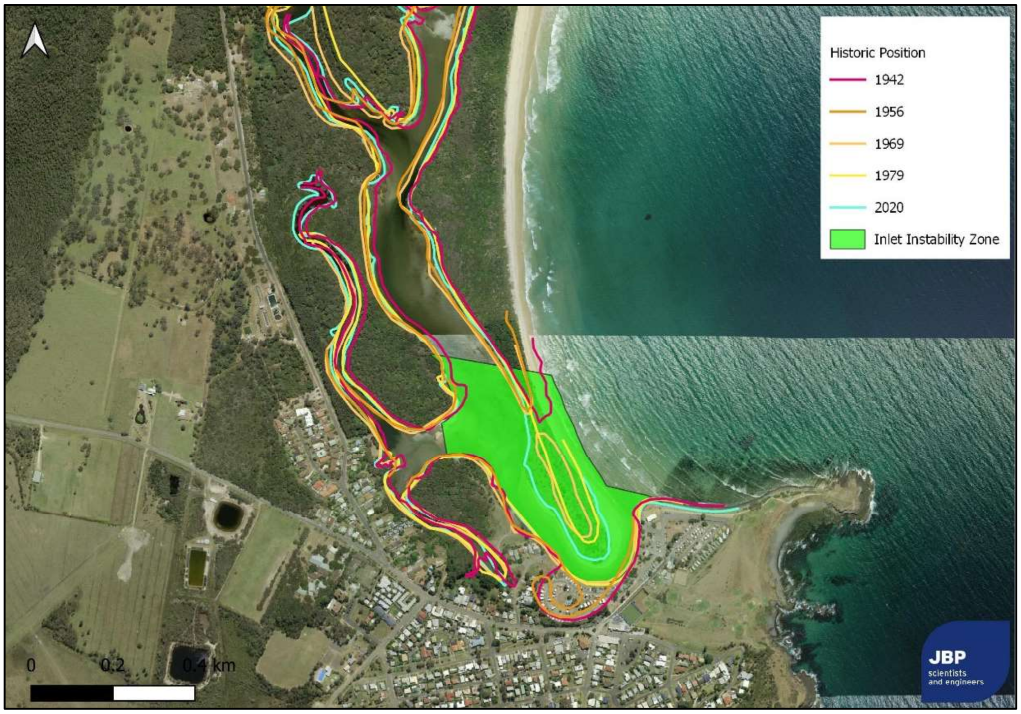

Figure 5-1: Entrance instability zone at Killick Creek, Crescent Head

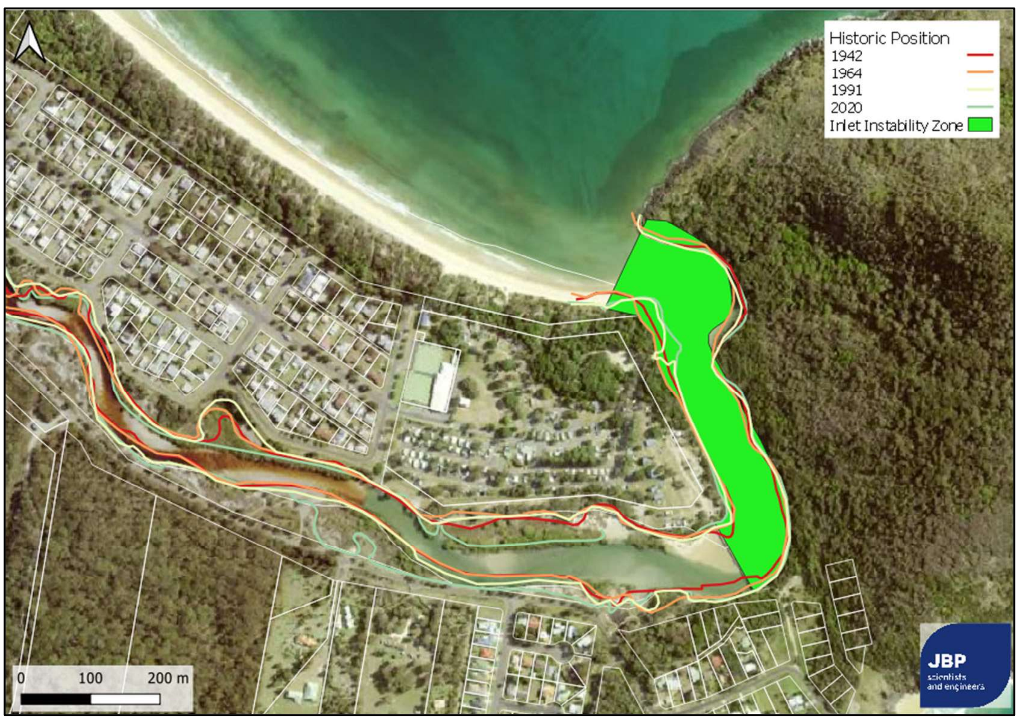

Figure 5-2: Entrance instability zone at Korogoro Creek, Hat Head

Figure 5-3: Entrance instability zone at Saltwater Creek

6 Summary

JBPacific were commissioned by Kempsey Shire Council to undertake tidal inundation modelling and mapping and to develop a Coastal Vulnerability Area (CVA) map for the Kempsey Local Government Area (LGA). The CVA mapping will be the key output of Stage 2 of the Coastal Management Program (CMP) development for Council, in compliance with the Coastal Management Act 2016 and the State Environmental Planning Policy (Coastal Management) 2018.

The development of the CVA map has included assessment of seven coastal hazard mapping components; (1) beach erosion, (2) shoreline recession (3) coastal lake or watercourse entrance instability, (4) coastal inundation, (5) coastal cliff or slope instability, (6) tidal inundation and (7) erosion and inundation under tides, waves, and catchment floodwaters.

This report describes the new technical assessment to review and map the following coastal hazards, which have been added to other available studies to produce the CVA map:

- **Hazard 1 and 2:** Beach erosion and shoreline recession

  Following a review of available hazard studies, the 'rare' beach erosion and shoreline recession extent within an existing Council study has been used, with minor modifications around approved seawalls.

- **Hazard 3:** Coastal lake or watercourse entrance instability

  A new entrance instability assessment was undertaken for Crescent Head (Killick Creek), Hat Head (Korogoro Creek), and South West Rocks (Saltwater Creek). This assessment utilised historic aerial imagery to map the maximum observed envelope of entrance positions between the 1940s and present day.

- **Hazard 4:** Coastal inundation

  Coastal inundation was simulated using an updated hydraulic model (see Hazard 6). This has used a coastal tidal signature which included a Highest Astronomical Tide, a storm surge component, an allowance for wave setup, and new wave overtopping inputs at Hat Head. Overtopping inputs have been estimated using a separate XBeach model, with the dune represented using data from the NSW Beach Profile Database.

- **Hazard 6:** Tidal inundation

  An existing hydraulic model developed for the Lower Macleay Flood Study (Jacobs, 2019) was updated and used to map tidal and coastal inundation. The model spans the Kempsey coastline and covers the inland area defined by the Lower Macleay River catchment and smaller estuaries. The model has been updated using new field survey data, new structure information, consideration of flood gate operations during typical tidal conditions (where gates are assumed to be in a closed position, except those which are kept open during non-flood/river-rise conditions) and includes new astronomical tide data supplied by Manly Hydraulic Laboratory (MHL).

- **Hazard 7:** Erosion and inundation of foreshores under tides, waves, and catchment flood waters.

  Mapping for the majority of the coastline has been based on a combined flood and tide scenario simulated within the Lower Macleay Flood Study (Jacobs, 2019) that has been adopted by Council. The design event for this hazard combines a 1% Annual Exceedance Probability (AEP) (100-year return period) fluvial flood coinciding with a Higher High Water Spring (HHWS) tidal boundary. The fluvial-tidal interaction is captured at the downstream extents of the catchment where a tidal signature provides a realistic oscillation in flood levels.

  Mapping for Hazard 7 is currently not available for the Saltwater Creek catchment and updating the existing flood study was outside the scope of this project. It is recommended that funding is sought through available grant programs to update the Saltwater Creek flood study using consistent approaches, return periods and planning periods to the Lower Macleay Flood Study. This can then be incorporated within the CVA map.

JBP
scientists and engineers

Offices in
Australia
Cambodia
Ireland
Romania
Singapore
UK
USA

Registered Office
477 Boundary Street,
Spring Hill QLD 4000
Australia

t: +61 (0)7 3085 7470
e:info@jbpacific.com.au

JBA Pacific Scientists and Engineers Pty Ltd 2021
ABN: 56 610 411 508
ACN: 610 411 508

Visit our website
www.jbpacific.com.au