St Georges Basin/Sussex Inlet, Swan Lake and Berrara Creek Tidal and Coastal Inundation Study

Shoalhaven City Council

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311015-00158-CS_REP-0001

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Executive summary

Advisian has been engaged by Shoalhaven City Council (Council) to undertake a Coastal Management Program (CMP) for the St Georges Basin/Sussex Inlet, Swan Lake and Berrara Creek estuaries. The CMP is intended to build upon the large body of work that has already been completed regarding coastal management for this estuary. The purpose of this Tidal and Coastal Inundation Study is to predict the possible inundation level and extents under design extreme events and regular tidal conditions defined as per Department of Planning and Environment (DP&E) guidelines. The inundation risk assessment and relevant hazard mapping results based on the study will provide input to the scope and nature of coastal management actions for St Georges Basin/Sussex Inlet, Swan Lake and Berrara Creek during the future stages of Council's CMP development and implementation.

The Study assesses both *coastal inundation* and *tidal inundation*.

Coastal inundation is defined in the NSW Coastal Management Manual Part B (DP&E, 2018) as occurring when a combination of marine and atmospheric processes raises ocean water levels above normal elevations, inundating low-lying areas. It is often associated with storms resulting in elevated still water levels (storm surge), wave setup, wave runup and wave overwash flows. For the estuaries, this type of inundation is the result of water levels at the estuary entrances being elevated above normal levels due to coastal storms, with the elevated water levels propagating inside the estuary.

Tidal inundation is defined in the Manual as the 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" or spring tide or more permanent inundation due to land subsidence, changes in tidal range or sea level rise.

A three-dimensional hydrodynamic model of the study area has been developed to investigate how the tide propagates upstream into the estuaries and assess the impacts of tidal and coastal inundation on the coastal zone, including coastal wetlands and littoral rainforests, resources, assets and essential infrastructure, both under present day conditions and under future sea level rise.

It was found that:

- At St Georges Basin, there are extensive areas around Sanctuary Point, Old Erowal Bay, Erowal Bay, Basin View and St Georges Basin Village that will be impacted by 1% *Annual Exceedance Probability*[1] (AEP) coastal inundation, with additional areas impacted under future sea level rise scenarios, and potential for areas to be isolated by inundation for up to several days. The northern foreshore of St Georges Basin is particularly vulnerable to coastal inundation combined with strong southerly winds, which induce both wind and wave setup along the shoreline, elevating water levels above what would otherwise occur in the absence of these winds. Foreshore reserves and waterside infrastructure around Sanctuary Point, St Georges Basin, Erowal Bay and Basin View are currently subject to tidal inundation. The impact to these areas will increase with sea level rise in the next 20 to 50 years, particularly impacting on waterside

[1] *Annual Exceedance Probability (AEP)* refers to the probability that a particular event will be exceeded in any given year. A 1% AEP coastal inundation event refers to coastal inundation that has a 1% chance of being exceeded in any given year, equivalent to an event that would occur, on average, once in 100 years.

infrastructure, critical sewer infrastructure and several residential lots in Sanctuary Point, Erowal Bay and Basin View.

- At Sussex Inlet, the town centre is affected by 1% AEP coastal inundation under present day conditions, with the depth and frequency of inundation expected to increase under future projected sea level rise. Under the various sea level rise scenarios, both coastal and tidal inundation will affect large areas of the town centre and access to and within the township is likely to be cut off by inundation. Tidal inundation is likely to become more common with sea level rise over the next 20 to 50 years with predictions that areas of Sussex Inlet, including the main CBD, will be inundated by more than 20cm up to twice per month during extreme high tides.
- At Swan Lake and Berrara Creek, tidal inundation is expected to have relatively minor impacts. However, under 1% AEP coastal inundation conditions with future sea level rise projections, there is potential for the main access to Berrara and Cudmirrah to be cut off at Collier Drive, and inundation to occur at the caravan park. Coastal inundation of critical water infrastructure at Berrara including a water pumping station and water and wastewater mains is predicted under future sea level rise projections.

Coastal and tidal inundation in combination with future sea level rise has the potential to impact on the aquatic vegetation within the study area, in the following ways:

a) landward migration of macrophyte or coastal vegetation species,

b) shift in dominant species and/or

c) reduced or loss of biodiversity, due to a lack of suitable areas available for migration of macrophyte and coastal vegetation species.

Acronyms and abbreviations

Acronym/abbreviation	Definition
3D	Three-Dimensional
AEP	Annual Exceedance Probability
AHD	Australia Height Datum
DP&E	Department of Planning and Environment
DPI	Department of Primary Industries
GDA	Geocentric Datum of Australia
HD	Hydrodynamic
HHWSS	Higher High Water Springs Solstices tides
ICOLLs	Intermittently Closed and Open Lakes and Lagoons
IOA	Index of Agreement
GDA	Geocentric Datum of Australia

1 Introduction and scope

1.1 Background

This Tidal and Coastal Inundation Study provides combinations of water levels, tidal flows and sea level rise effects for the purposes of a coastal and tidal inundation assessment for the St Georges Basin/Sussex Inlet, Swan Lake and Berrara Creek estuaries. The purpose of the study is to inform the Coastal Management Program (CMP) for these estuaries, by providing information that can be used in the development of coastal management actions.

The Study Area is shown in Figure 1-1.

The Study assesses both *coastal inundation* and *tidal inundation*.

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Note that this study does not include *catchment flooding*[2], so is not to be confused with a conventional flood study, which assesses these effects separately and is carried out under the NSW Flood Management program. Shoalhaven City Council (Council) is currently preparing a Floodplain Risk Management Study and Plan for St Georges Basin/Sussex Inlet, including the preparation of a Flood Study, which was formally adopted by Council in January 2023 (refer https://getinvolved.shoalhaven.nsw.gov.au/review-of-the-St-Georges-Basin-floodplain-risk-management-study-and-plan).

[2] "*Catchment flooding*" refers to flooding driven by heavy rainfall in the catchment area of the estuary and subsequent freshwater inflows. This type of flooding is often associated with the same weather systems as coastal inundation events, which are typically driven by low pressure systems, usually accompanied by intense rainfall.

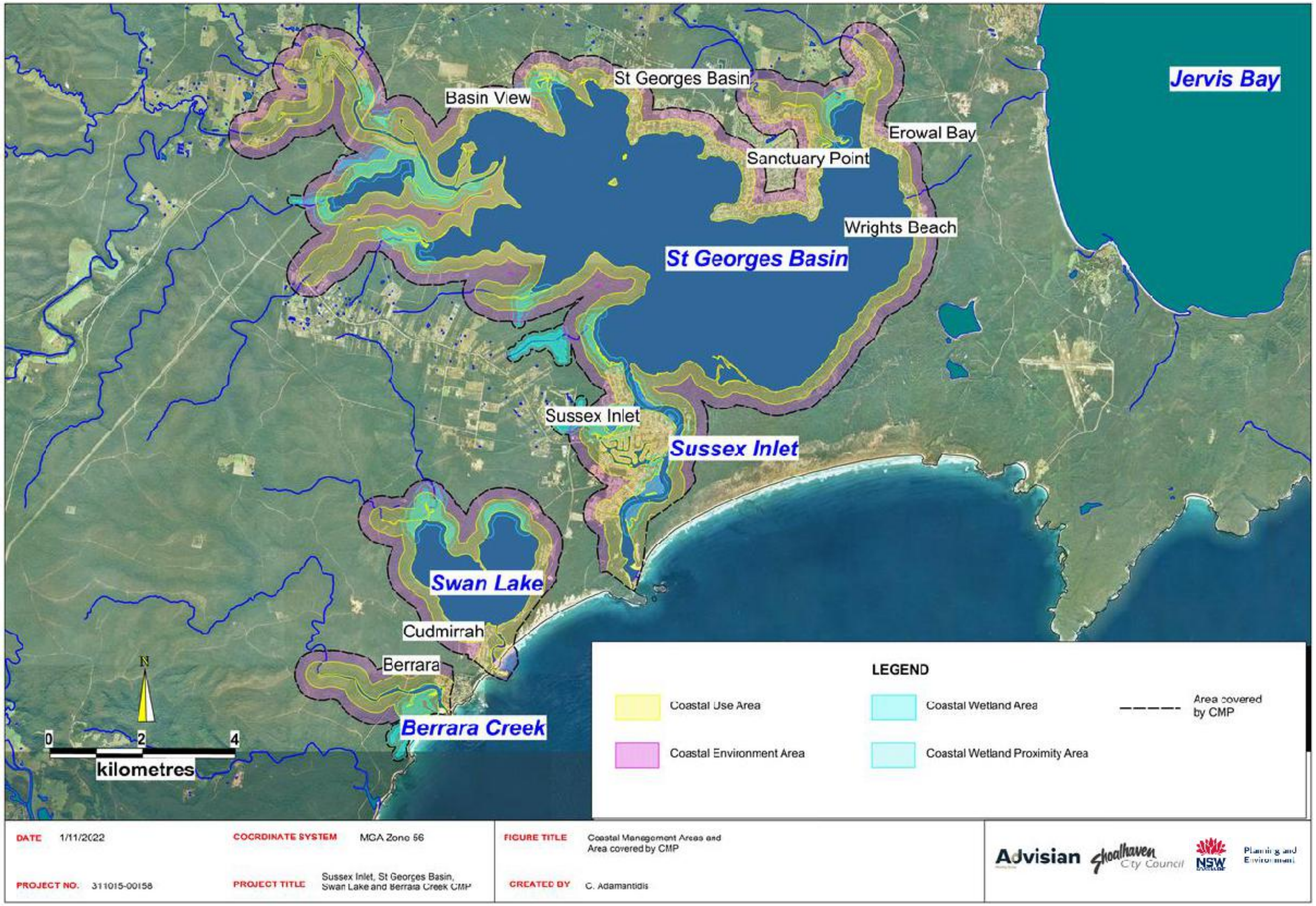


Figure 1-1 – Study Area

1.2 Scope of study

Advisian has completed the following scope of works:

- Development of a tidal inundation and coastal inundation modelling system including a 3D hydrodynamic model. The potential wind and wave effects on water levels within the estuarine water bodies and surrounding areas was also assessed.
- The 3D hydrodynamic tidal and coastal inundation modelling has been calibrated and validated with a range of site measurements, including measured time series of water levels within St Georges Basin and Sussex Inlet.
- The model has been run with a range of scenarios to predicate the water levels under different storm events as defined in the NSW Floodplain Risk Management Guide (OEH 2015), as well as Higher High Water Solstices Springs (HHWSS) tidal levels and under various scenarios for future sea level rise projections.
- The study has provided the model results spatially over the study area and as time series at selected locations for the purposes of the Inundation Risk Assessment and Inundation Hazard Mapping.
- Inundation Risk Assessment and Inundation Hazard Mapping has been undertaken to assess the impact of coastal and tidal inundation on estuarine vegetation and assets.

1.3 Study Datum

Water depths and levels presented in this report are referenced to Australia Height Datum (AHD).

Geographical locations are provided in the Map Grid of Australia (MGA) coordinate system, zone 56, based on Geocentric Datum of Australia (GDA 94) Geodetic Datum, unless stated otherwise. GDA94 coordinates have been used to match the projection of the available data used to develop the hydrodynamic model.

1.4 Conventions

All units are in standard International System of Units unless otherwise stated, with all bearings and directions provided in degrees relative to True North. All directions quoted are in degrees relative to True North. Wind and wave direction quoted is the direction from which wind arrives. Current directions quoted are the direction to which currents flow.

2 Tidal and coastal inundation model

2.1 3D hydrodynamic model

For this inundation study, Advisian has developed a three-dimensional (3D) hydrodynamic model, used to predict water level as the basis for understanding inundation for the project sites.

This model was developed using dynamic MIKE3 Hydrodynamic (HD) numerical modelling software which has one of the most sophisticated solution schemes of its type and is state-of-the-art for the modelling of 3D flow fields in the natural environment.

The MIKE3 HD software provides an integrated system for hydrodynamics (based on shallow water equations). MIKE3 HD numerically solves the three-dimensional incompressible Reynolds Averaged Navier-Stokes equations subject to the assumptions of Boussinesq and of hydrostatic pressure. Thus, the model consists of continuity, momentum, temperature, salinity and density equations, incorporating a turbulent closure scheme.

The free surface is taken into account by using a sigma-coordinate transformation through the vertical water layers. The equations are solved using an unstructured mesh applying a cell-centred finite volume method.

For the modelling water level variation of lake and open marine areas, it is considered that, within the main region of interest, barotropic effects (wind and water level variations) would dominate the flow dynamics and mixing processes. Therefore, tide and wind forcing were applied as the major model drivers, while the currents due to temperature and salinity variations (baroclinic effects) were excluded from the modelling, except that the stratification of flows are captured and may affect the inundation results.

2.2 Model mesh and bathymetry

The model domain shown in Figure 1-1 has covered St Georges Basin, Sussex Inlet, Swan Lake and Berrara Creek within a single model domain. The advantage of using one model domain allows interfacing effects between these three areas to identify joint issues under the design coastal and tidal inundation events. Using one model domain on the same modelling platform also ensures the assessment for these three areas using the same boundary conditions and parameters to maintain the model performance.

The hydrodynamic model incorporates an unstructured triangular computational mesh which allows for higher resolution around areas of specific interest or with complex bathymetry. The size of the computational mesh ranges from 1200 m at the coarsest scale offshore down to 10 m at the finer scale around areas of specific interest along the coastline. The finest scale was used for higher resolution (approximately 3 m) along the inlet and channel, however, within the areas of lesser concern (e.g. offshore areas distant from the estuarine foreshores and locations outside of the study area), the resolutions are up to 50 m. This approach allows for minimisation of the computational time while giving a suitable accuracy across the domain of interest. The unstructured computational mesh of the hydrodynamic model is shown in Figure 2-1.

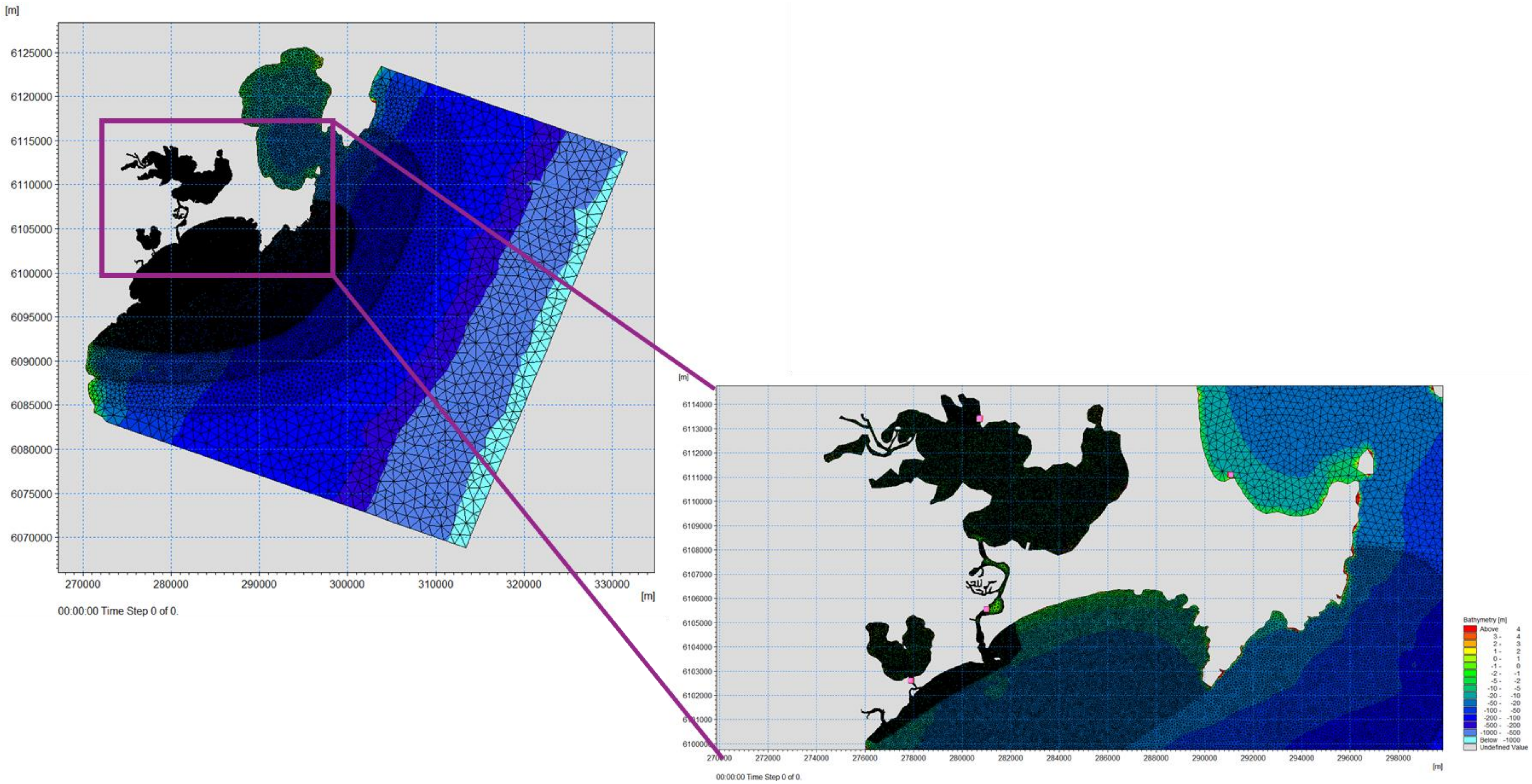


Figure 2-1 - 3D hydrodynamic model domain (model extension for landward to catchment areas, for seaward to approximately 1000 m water depth contour), mesh and bathymetry

The baseline model incorporates bathymetry from local nautical charts (CMap, 2019), as well as a range of bathymetric survey data provided by Council and DP&E for this project as summarised in Table 2-1. For this inundation study, the available bathymetric survey data is sufficient. However, for navigation assessment, tidal current velocities along the navigation channel are sensitive to channel bathymetry, which has been shown to vary on short timescales due to preceding weather and flooding events (Advisian 2022). Updating the model using the most recent bathymetric survey data would improve the model performance in predicting the tidal currents along the channel.

Table 2-1 – Bathymetry survey and elevation data used for model

Item	Received Survey Data	Survey Date
1	Chart data from CMap (2019)	A range of years
2	SwanLke2003	2003
3	NSW_Marine_5m_DEM	DP&E 2019 Marine LIDAR survey
4	NSWWOEH_19920205_StGeorgeBasin	05/02/1992
5	Sussex Entrance Feb. 2011	02/2011
6	Sussex Inlet Council Survey	11/2020
7	Sussex Inlet (DP&E Survey)	27/04/2021
8	Digital 5m DEM LIDAR 5m grid of Australia	Geoscience Australia 2015

2.3 Model parameters

The main model input parameters were as follows:

Vertically, the model domain is divided into 2 layers proportionate to the water depth. These two layers comprise the top and bottom 50% of the local water depth. Since the maximum water depth within the development area is approximately less than 5 m, the 2 layers provide sufficient resolution for the water column to simulate local strong wind and tidal forcing processes.

Horizontal Momentum Diffusivity was modelled with Smagorinsky formulation, c=0.28 (-).

Vertical Eddy Viscosity Diffusion was modelled with log law formulation.

Wind Friction was modelled using linear interpolation between two values based on the wind speed. The friction value is 0.002425 for those wind speed higher than 25 m/s. The value gives generally good results for open sea applications. Field measurements of the drag coefficient collected over lakes indicate that the drag coefficient is larger than open ocean data (Geernaert and Plant, 1990). However, for the tidal and coastal inundation modelling, the value is regarded as valid for the combined lakes and coastal area.

Tidal forcing was included in the model by imposing predicted tidal levels at all open boundaries. The tidal boundary conditions were generated by spatial interpolation of the tidal constituent data (amplitude and phase) from the global TPXO7 tidal model, which is based on Topex/Poseidon tidal altimetry data. The annual (Sa) and semi-annual (Ssa) constituents sourced from the Jervis Bay tidal station were used to account for seasonal changes in mean level.

Annual average tidal planes at Jervis Bay between 2001 and 2020 are provided below in Table 2-2.

Table 2-2 – Average annual tidal planes at Jervis Bay, 2001 – 2020 (https://mhl.nsw.gov.au/Station-216470, MHL 2023).

	Annual Average (m AHD)	Std Deviation (+/-)
TIDAL PLANES		
Highest Astronomical Tide (HAT)	1.14	
Higher High Water Springs Solstice HHWSS	1.027	0.035
Mean High Water Springs MHWS	0.655	0.038
Mean High Water MHW	0.543	0.038
Mean High Water Neaps MHWN	0.43	0.039
Mean Sea Level MSL	0.06	0.032
Mean Low Water Neaps MLWN	-0.31	0.032
Mean Low Water MLW	-0.423	0.033
Mean Low Water Springs MLWS	-0.536	0.034
Indian Springs Low Water ISLW	-0.801	0.049
Lowest Astronomical Tide LAT	-0.88	

2.4 Model Calibration

A model calibration and validation assessment has been carried out for the hydrodynamic model based on existing available data shown in Figure 2-2, which includes tidal gauging and water level data collected by Manly Hydraulics Laboratory and provided by DP&E. A time period in February 2001, representing long-term average conditions without the impact of storm surge, as well as a full neap-spring tidal cycle, was chosen for the calibration. A similar period in July 2001 was chosen for model validation. While there are available data for St Georges Basin, Sussex Inlet, Swan Lake and Jervis Bay, there is no available water level data for model validation in Berrara Creek. Model calibration and validation was, therefore, carried out for these estuaries, with Berrara Creek modelled with an open entrance.

The measured water levels at Swan Lake () indicate the entrance channel is usually closed to the sea. When the lake entrance is closed, the water level within Swan Lake is dominated by catchment inflows rather than tidal inflow and variations are limited by the berm level at the lake entrance. The available measurements inside Swan Lake are not suitable for model calibration, because the water levels inside Swan Lake are very sensitive to the entrance berm bathymetry which is not known precisely, with the entrance typically closing again very quickly after a lake opening, typically within 30 days, but occasionally the lake can remain open for up to 90 days (Advisian 2022). However, the measurements indicate that tidal range in the days following an entrance opening is very low (typically <0.2 m), and the model results also indicate a similar very low tidal range within Swan Lake of 0.2 m.

Plots of the measured water level compared with the model predictions are shown in Figure 2-4. At the three measurement locations, a comparison is provided for a typical winter (July) and summer (February) tidal cycle, to give an indication of seasonal model accuracy. All plots show a very close match and excellent agreement between the model simulation results and the measured water levels.

Model validation was carried out using the most recently available measurements (2021) shown in Figure 2-5, which also indicates agreement between the model simulation results and the measurements.

To support visual observations as well as an indicator to guide the model improvement, model performance for current speed was further validated quantitatively through statistical tests for agreement based on the transect survey data. The quantitative analysis of the model simulation results was performed through use of the Index of Agreement (IOA, Willmott 1981). The IOA, used to assess agreement between time series datasets in a wide variety of literature, is calculated according to the equation:

$$IOA = 1 - \frac{\sum |X_{model} - X_{obs}|^2}{\sum (|X_{model} - \overline{X_{obs}}| + |X_{obs} - \overline{X_{obs}}|)^2}$$

In this equation, X represents the variable being compared and $\bar{X}$ the time mean of that variable. A perfect agreement can be said to exist between two datasets if IOA = 1, and complete disagreement will result in an IOA = 0. While it is difficult to find guidelines for what values of IOA might represent a good agreement, it has been suggested that values equal to or larger than 0.5 represent good agreement (Willmott 1985). This equation is very similar to the Coefficient of Determination equation (R^{2-}, more commonly known as the Regression equation), but that only provides a measure of the strength of the relationship between the modelled and measured values, and does not consider whether the modelled and measured values have a similar magnitude.

Table 2-3 presents the IOA calculated for modelled and measured water levels for both calibration and validation, which indicate that model results and measurements show good agreement (above 0.5) for all the comparisons.

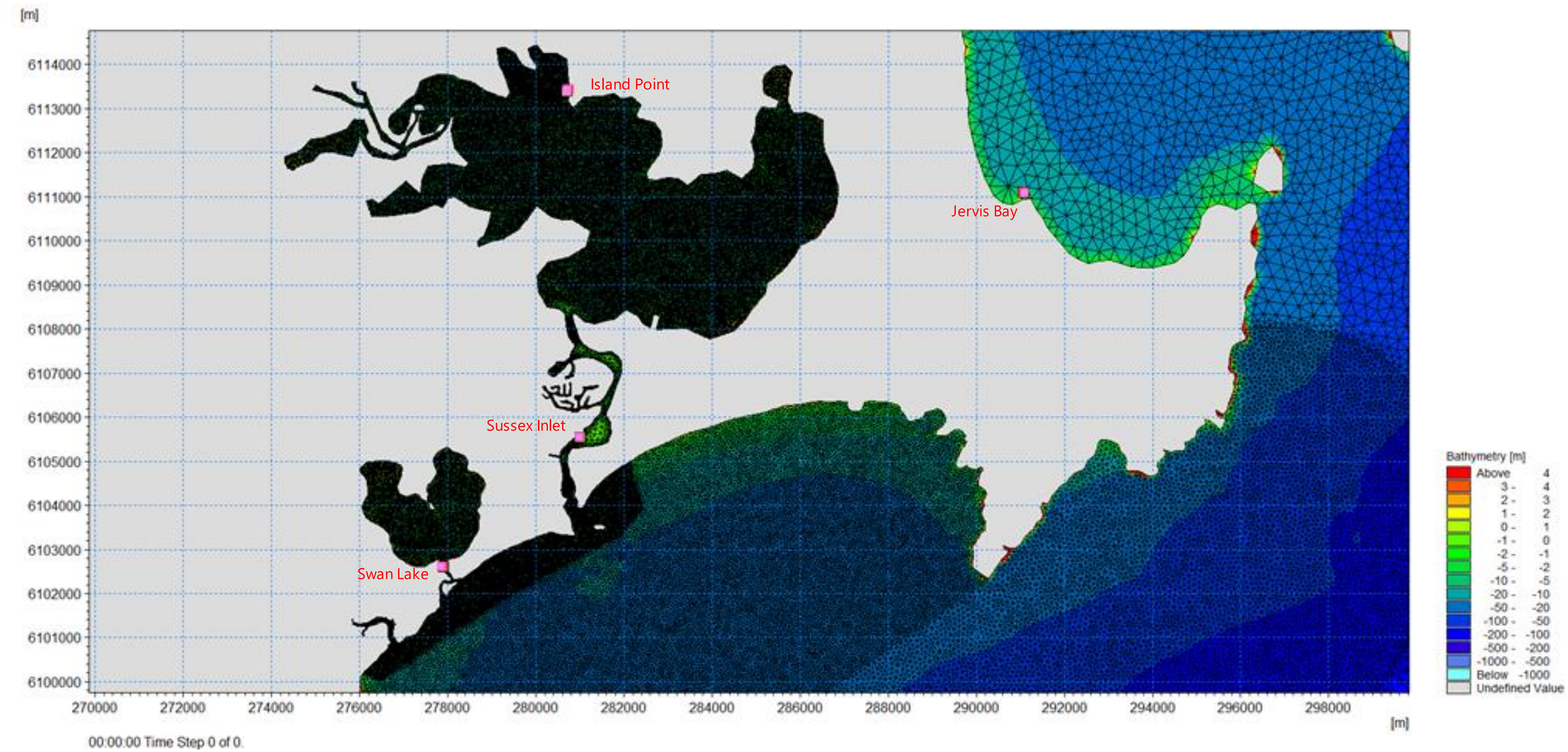


Figure 2-2 - Measured water level measurement sites

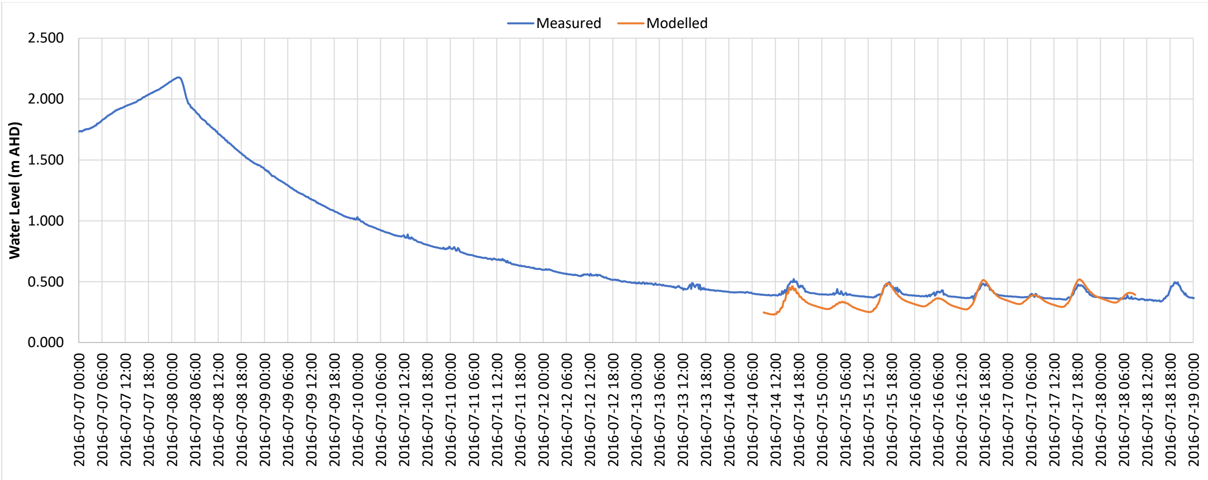


Figure 2-3 - Measured water level at Swan Lake following July 2016 opening event; modelled tidal water level when lake is open, accounting for 0.2 m tidal anomaly as recorded at Crookhaven Heads and Ulladulla (in MHL 2017)

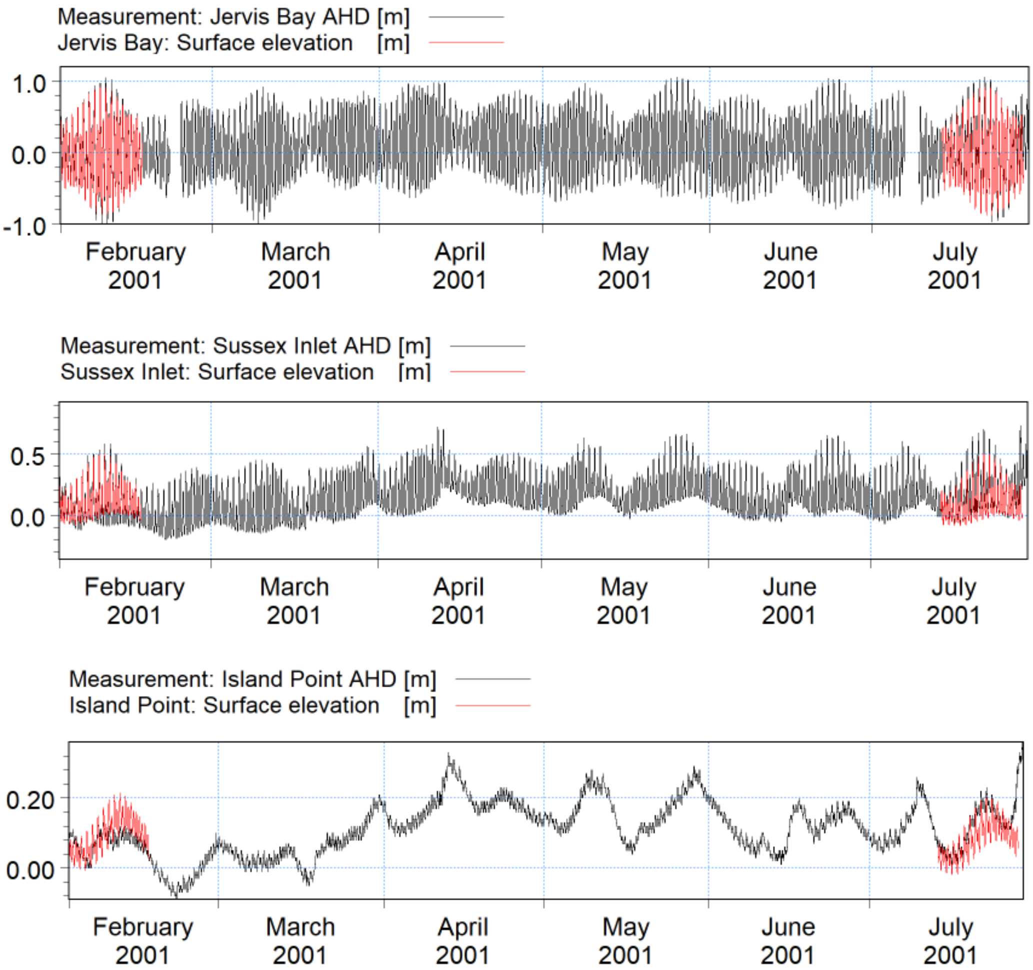


Figure 2-4 - Comparison of model predicted and measured water level for February 2001 and July 2001

Table 2-3 – IOA for modelled and measured water level

Location	IOA for Calibration (Feb. 2001)	IOA for Calibration (July 2001)	IOA for Validation (July 2021)
Jervis Bay	0.99	0.98	0.95
Sussex Inlet	0.86	0.87	0.68
Island Point	0.70	0.77	0.82

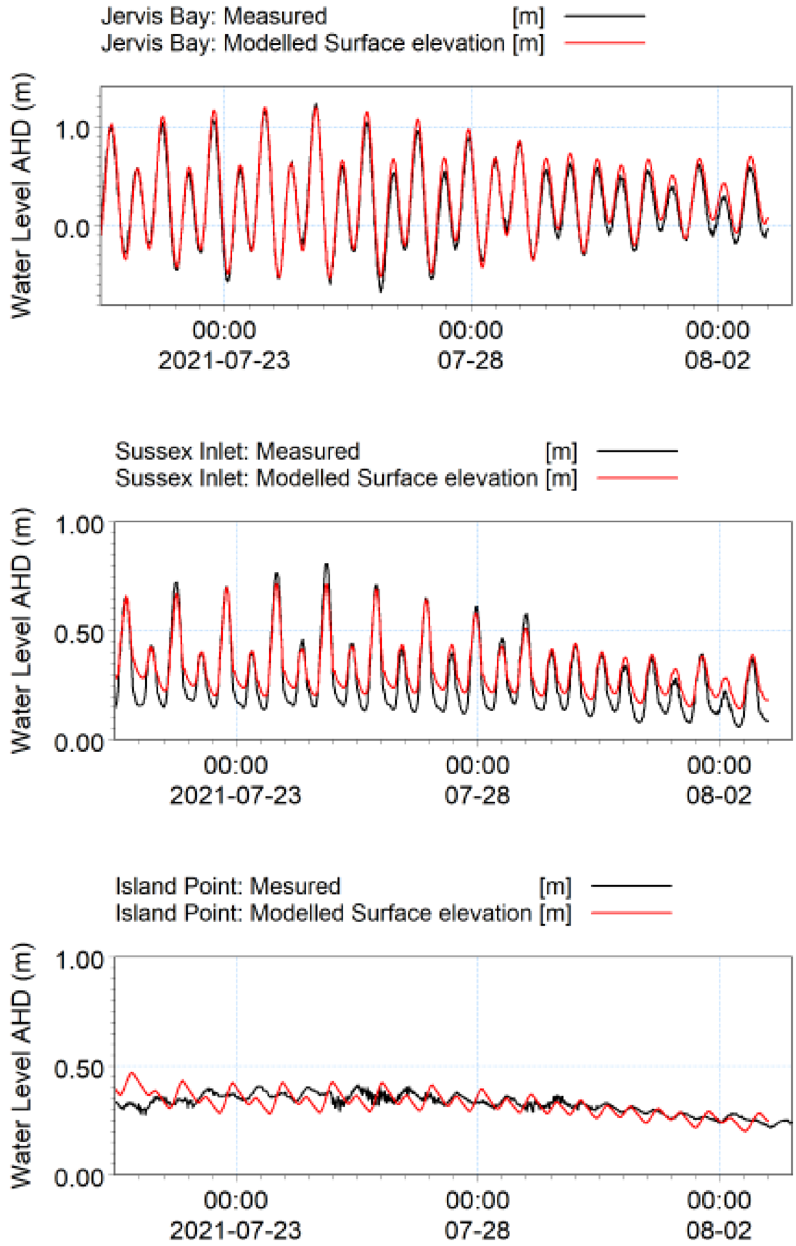


Figure 2-5 - Comparison of model predicted and measured water level for July 2021

2.5 Effect of waves on water levels

Ocean waves can have an impact on the inundation level due to *wave setup*. Wave setup is the elevation of the nearshore still water level resulting from breaking waves and may be perceived as the conversion of the wave's kinetic energy to potential energy. As a result of wave breaking, local waves propagating from offshore to the nearshore can affect the morphology of the estuary entrance areas, by transporting sand into the entrance areas, causing the entrance to shoal (Sussex Inlet) or for Swan Lake and Berrara Creek, close to the sea. The development of a wave transformation model to determine wave setup is not necessary for this study, as the NSW Floodplain Risk Management Guide (The Office of Environment and Heritage (OEH), 2015) has provided appropriate water level boundary conditions for the modelling, which includes the effect of wave setup for different estuary configurations.. The St Georges Basin Flood Study (Cardno 2022) has also adopted ocean boundary conditions for their flood modelling based on those in the NSW Floodplain Risk Management Guide (OEH 2015).

From the range of ocean water level boundary conditions presented in the Floodplain Risk Management Guide, it is evident that the full extent of wave setup would not occur at an open estuary entrance, and that adopting the boundary condition incorporating the highest wave setup values from the Guide would be conservative. However, adjacent to the entrance to Sussex Inlet (Figure 2-6), there is a rocky reef. This is a permanent feature that waves from the southeast will always break on, which means that a large portion of the wave setup from breaking ocean waves will occur there. Other nearby estuaries (e.g. Lake Conjola) do not have this feature, so wave setup will be reduced if the entrance is open, the water in front of the entrance would be relatively deep and wave breaking would be reduced (refer aerial photos shown in Figure 2-7).

OEH (2015) defines five estuary entrance classifications based on the work of Roy *et al.* (2001). The five groups include:

- Group 1 Oceanic Embayments – marine waters with little influence of freshwater inflow, e.g. Botany Bay, Jervis Bay.
- Group 2 Tide Dominated Estuaries – large, deep entrances with tidal ranges similar to the open ocean, also known as "drowned river valleys". e.g. Port Stephens, Hawkesbury River.
- Group 3 Wave Dominated Estuaries – entrances that are constricted by wave-deposited beach sand and flood-tidal deltas, but are permanently open, e.g. Tweed River, Lake Illawarra. Within this group there is significant variation based upon whether the waterway discharges into a bay, port or harbour, whether the entrance is trained (and the degree of training and stability), the relative size of the entrance and potential for the entrance to shoal.
- Group 4 Intermittently Closed Estuaries – also known as Intermittently Closed or Open Lakes or Lagoons (ICOLLs). These are coastal water bodies that become isolated from the sea for extended periods (e.g. Dee Why Lagoon, Lake Conjola).
- Group 5 Freshwater bodies – coastal water bodies that rarely, if ever, are brackish but have occasional connection to the ocean e.g. Cudgen Lake, Myall Lakes.

For this study, Berrara Creek and Swan Lake fall into Group 4, and Sussex Inlet/St Georges Basin can be classified as a Group 3 estuary with an untrained entrance and likely to have very shallow depths across the entrance. OEH (2015) stipulates that Group 4 estuaries and Group 3 estuaries with shallow entrances should adopt "Type C" boundary conditions. Discharges to the ocean from these estuaries are controlled by outlet berm characteristics (height, width, and breadth).

The peak ocean boundary condition levels for each of the five entrance classification types outlined in OEH (2015), together with the level of wave setup that this equates to, are provided in Table 2-4 for estuaries on the NSW coast south from Crowdy Head.

Table 2-4 - Wave setup components for various estuary classifications (adapted from OEH 2015)

Estuary Type	1% AEP Ocean Boundary Condition (m AHD)	Wave setup component (m)	5% AEP Ocean Boundary Condition (m AHD)	Wave setup component (m)
Type A Group 1 (open oceanic embayment) Group 2 (tide dominated estuaries) Group 3 estuaries with trained entrances maintained as navigable ports, or trained entrances draining to bays	1.45	0	1.40	0
Type B Group 3 estuaries with trained entrances not maintained as navigable ports	2.0	0.55	1.90	0.5
Type C Group 4 estuaries (ICOLLS) **(Swan Lake, Berrara Creek)** Group 3 estuaries with untrained entrances or partially trained entrances which are likely to have very shallow slow depths across the entrance **(Sussex Inlet/St Georges Basin)**	2.55	1.1	2.35	0.95

Figure 2-6 - Open entrance in front of Sussex Inlet (photo Google Earth, February 2016)

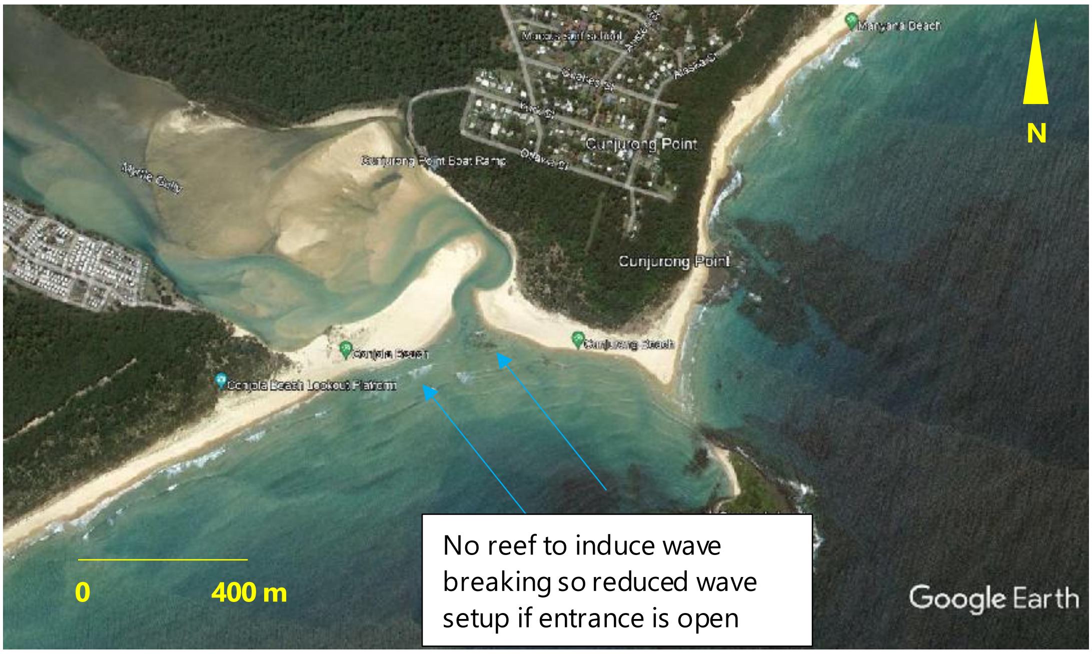


Figure 2-7 - Sand blocked entrance in front of Lake Conjola

2.6 Sea level rise effect on entrance morphology

With sea level rise, it is expected that the entrance morphology would respond roughly in accordance with the diagram in Figure 2-8 below. Advisian has assumed that the entrance bathymetry at the entrance bar would rise by the quantum of sea level rise and translate landward, meaning that the depth over the entrance bar remains constant with respect to future mean sea level. For the modelling, the entrance bar bathymetry has been raised by the amount of sea level rise, in accordance with each of the sea level rise scenarios modelled.

Shoalhaven Council have adopted sea level rise projections for planning purposes of 0.1 m by 2030, 0.23 m by 2050 and 0.36 m by 2100 (Shoalhaven City Council, 2016). The IPCC has recently released its 6th Assessment Report and has published sea level rise projections for selected locations throughout the world, including at Jervis Bay. For Jervis Bay, the sea level rise projections are given in Figure 2-9 below (source https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool?psmsl_id=2312) based on a "medium-high" CO_2 emissions scenario (SSP3-7.0) and a "high" CO_2 emissions scenario (SSP3-8.5)[3]. The full range of IPCC (2022) projections are shown in Table 2-5.

For the model runs, Advisian has modelled the following sea level rise scenarios, which were considered to capture a representative range of IPCC (2022) sea level rise projections as well as Council's adopted sea level rise projections:

- 0 m (existing sea level)
- 0.1 m
- 0.23 m
- 0.36 m
- 0.6 m
- 0.9 m
- 1.2 m

Advisian has also examined the sensitivity of the entrance bathymetry to the results, by carrying out a model run where the entrance bathymetry remains unaltered when compared with today, but with 1.2 m

[3] **SSP1-1.9** holds warming to approximately 1.5°C above 1850-1900 in 2100 after slight overshoot (median) and implies net zero CO2 emissions around the middle of the century.
SSP1-2.6 stays below 2.0°C warming relative to 1850-1900 (median) with implied net zero emissions in the second half of the century.
SSP2-4.5 is approximately in line with the upper end of aggregate Nationally Determined Contribution emission levels by 2030. SR1.5 assessed temperature projections for NDCs to be between 2.7 and 3.4°C by 2100, corresponding to the upper half of projected warming under SSP2-4.5. New or updated NDCs by the end of 2020 did not significantly change the emissions projections up to 2030, although more countries adopted 2050 net zero targets in line with SSP1-1.9 or SSP1-2.6. The SSP2-4.5 scenario deviates mildly from a 'no-additional-climate-policy' reference scenario, resulting in a best-estimate warming around 2.7°C by the end of the 21st century relative to 1850-1900.
SSP3-7.0 is a medium to high reference scenario resulting from no additional climate policy under the SSP3 socioeconomic development narrative. SSP3-7.0 has particularly high non-CO2 emissions, including high aerosols emissions.
SSP5-8.5 is a high reference scenario with no additional climate policy. Emission levels as high as SSP5-8.5 are not obtained by Integrated Assessment Models (IAMs) under any of the SSPs other than the fossil fueled SSP5 socioeconomic development pathway.

sea level rise so that the maximum effect of this can be examined as shown in Figure 2-8. Such a condition would probably only be realistic if the entrance is dredged in the future.

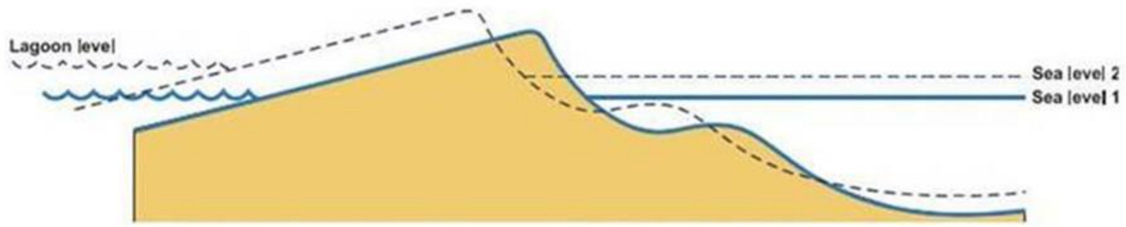


Figure 2-8 - Diagram illustrating sea level rise effect on entrance morphology (Hanslow et al. 2000)

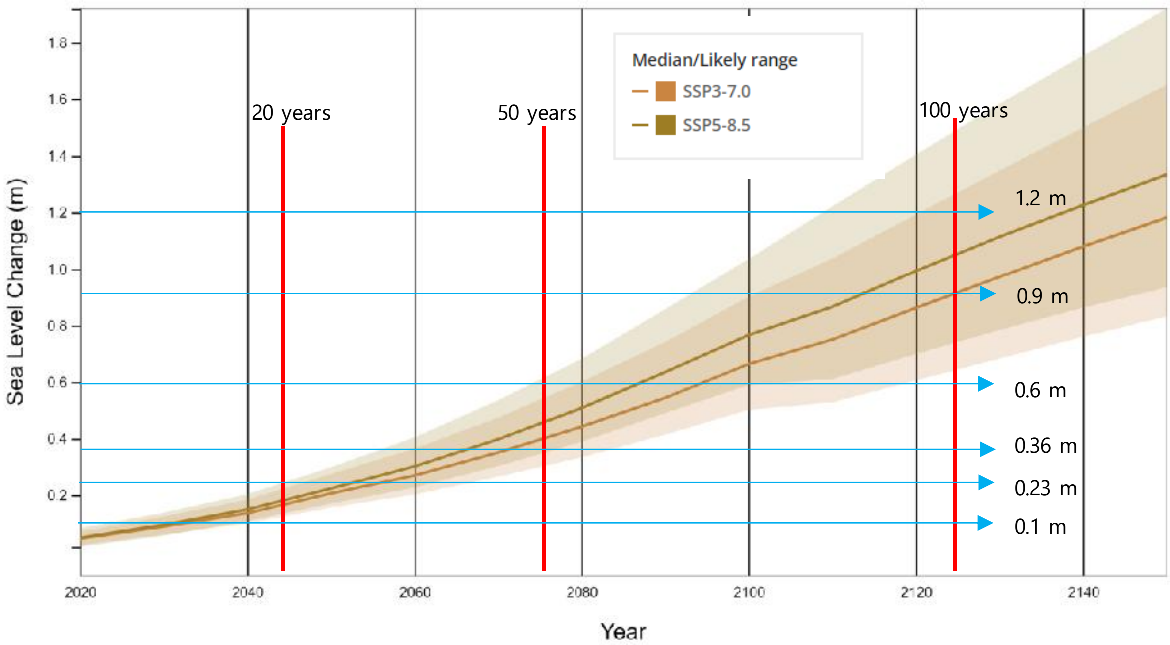


Figure 2-9 – IPCC (2022) sea level rise projections from Sixth Assessment Report at Jervis Bay for SSP3-7.0 and SSP5-8.5, and corresponding sea level rise for 20 year, 50 year and 100 year planning periods. Modelled sea level rise scenarios shown in blue.

Table 2-5 – Sea level rise projections for study area based on IPCC (2022) Sixth Assessment Report, for various sea level rise scenarios. Shoalhaven City Council sea level rise projections shown.

	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5	SSP1-2.6 Low Confidence	SSP5-8.5 Low Confidence	Shoalhaven City Council projection
Total (2030)	0.09 (0.07–0.12)	0.09 (0.06–0.13)	0.09 (0.05–0.13)	0.09 (0.06–0.13)	0.10 (0.06–0.14)	0.09 (0.06–0.15)	0.10 (0.06–0.17)	0.10
Total (2050)	0.16 (0.12–0.22)	0.17 (0.11–0.24)	0.19 (0.13–0.26)	0.21 (0.16–0.28)	0.22 (0.17–0.30)	0.18 (0.11–0.30)	0.23 (0.17–0.40)	0.23
Total (2090)	0.28 (0.17–0.43)	0.33 (0.21–0.49)	0.44 (0.31–0.62)	0.54 (0.41–0.74)	0.64 (0.49–0.86)	0.35 (0.21–0.64)	0.72 (0.49–1.33)	
Total (2100)	0.32 (0.18–0.51)	0.37 (0.23–0.56)	0.51 (0.37–0.73)	0.66 (0.50–0.90)	0.77 (0.59–1.04)	0.39 (0.23–0.74)	0.88 (0.59–1.62)	0.36
Total (2150)	0.48 (0.25–0.79)	0.57 (0.31–0.92)	0.86 (0.57–1.29)	1.18 (0.83–1.65)	1.33 (0.94–1.92)	0.63 (0.31–1.25)	1.99 (0.94–4.77)	

2.7 Wind effect

The available wind data at three Bureau of Meteorology wind stations shown in Figure 2-10 has been investigated, to determine the appropriate wind characteristics for the modelling. The three wind stations are:

- Nowra Station: inland location north of the project site;
- Ulladulla Station: close to shoreline south of the project site; and
- Point Perpendicular/Jervis Bay Station: regarded as wind over marine area near the project site.

Figure 2-11 , Figure 2-12 and Figure 2-13 present the wind rose plots on the wind data between 1990 and 2009. The data at Nowra shows that the two dominant wind directions are from the WNW and South sectors, while the strongest wind comes from the WNW. At Ulladulla, the strong wind dominates from the South, however at Point Perpendicular/Jervis Bay, being a more coastal location, the data shows higher wind speeds compared to those at other the two locations.

Table 2-6 presents the extreme wind speeds for various Annual Exceedance Probabilities (AEPs). Advisian has applied the assessed higher wind speeds sourced at Jervis Bay to input to the model, which is conservative for *wind setup*[4].

[4] *Wind setup* refers to winds pushed up against the coastline by a storm such as an east coast low, that can elevate the nearshore water level above the predicted astronomical tide.

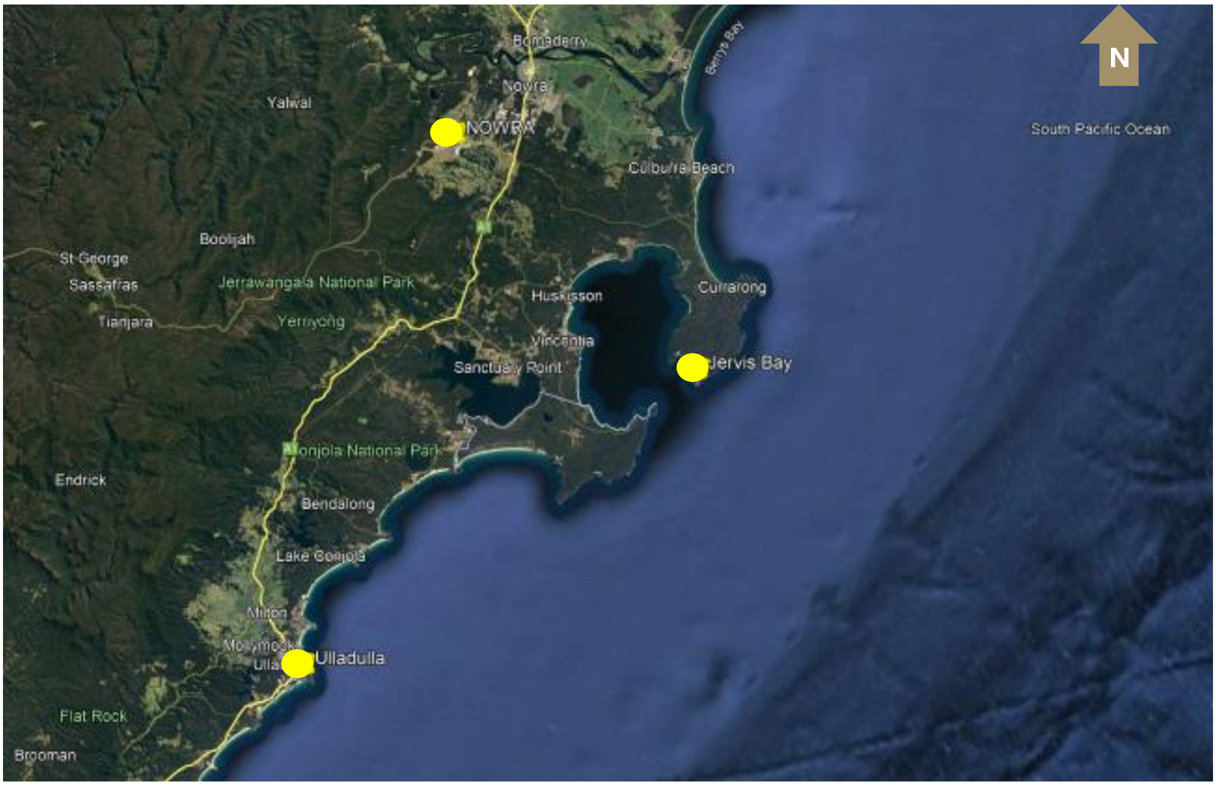


Figure 2-10 - Wind locations for project sites

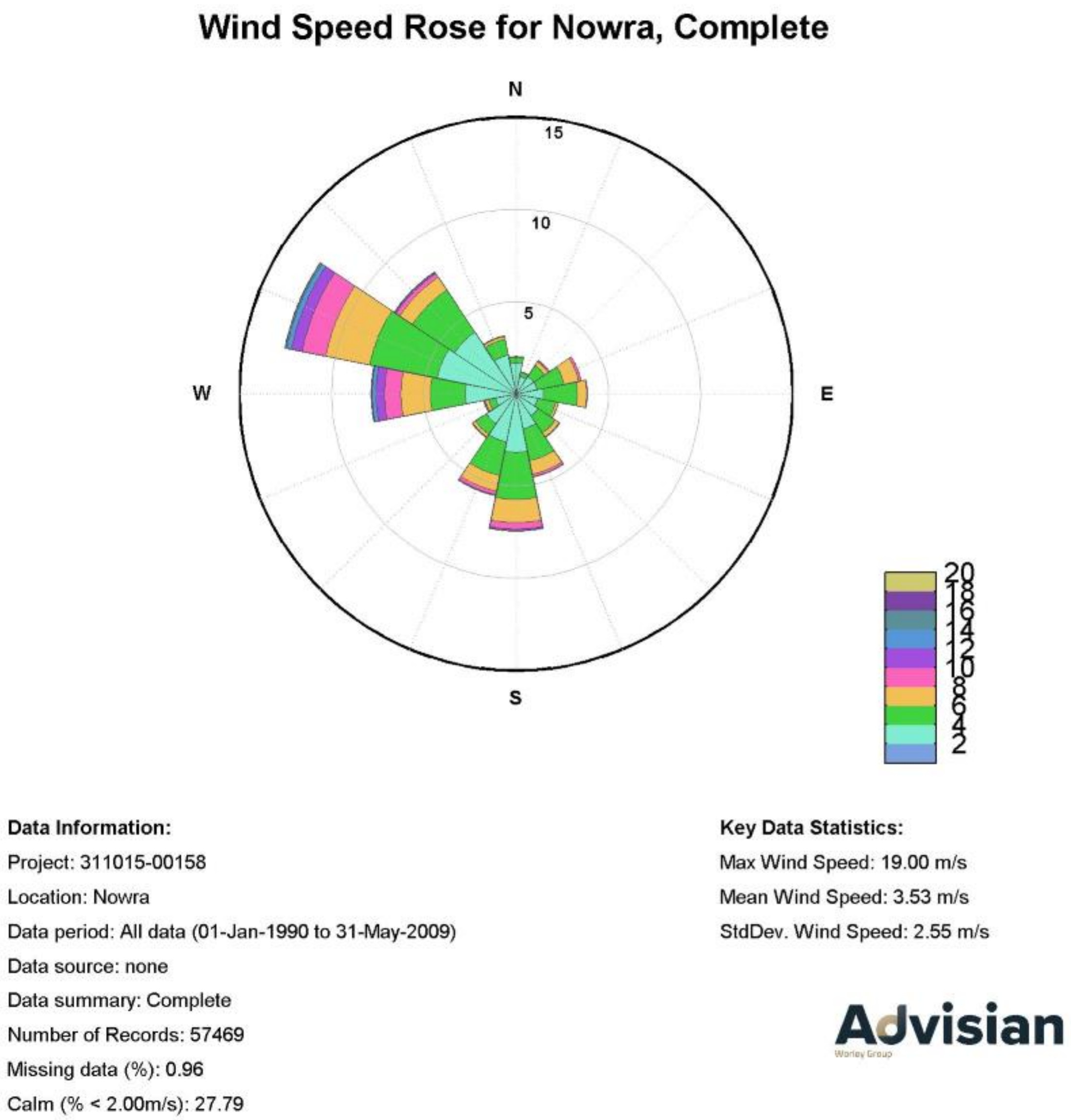


Figure 2-11 – Wind rose plot for Nowra (01 Jan. 1990 to 31 May 2009)

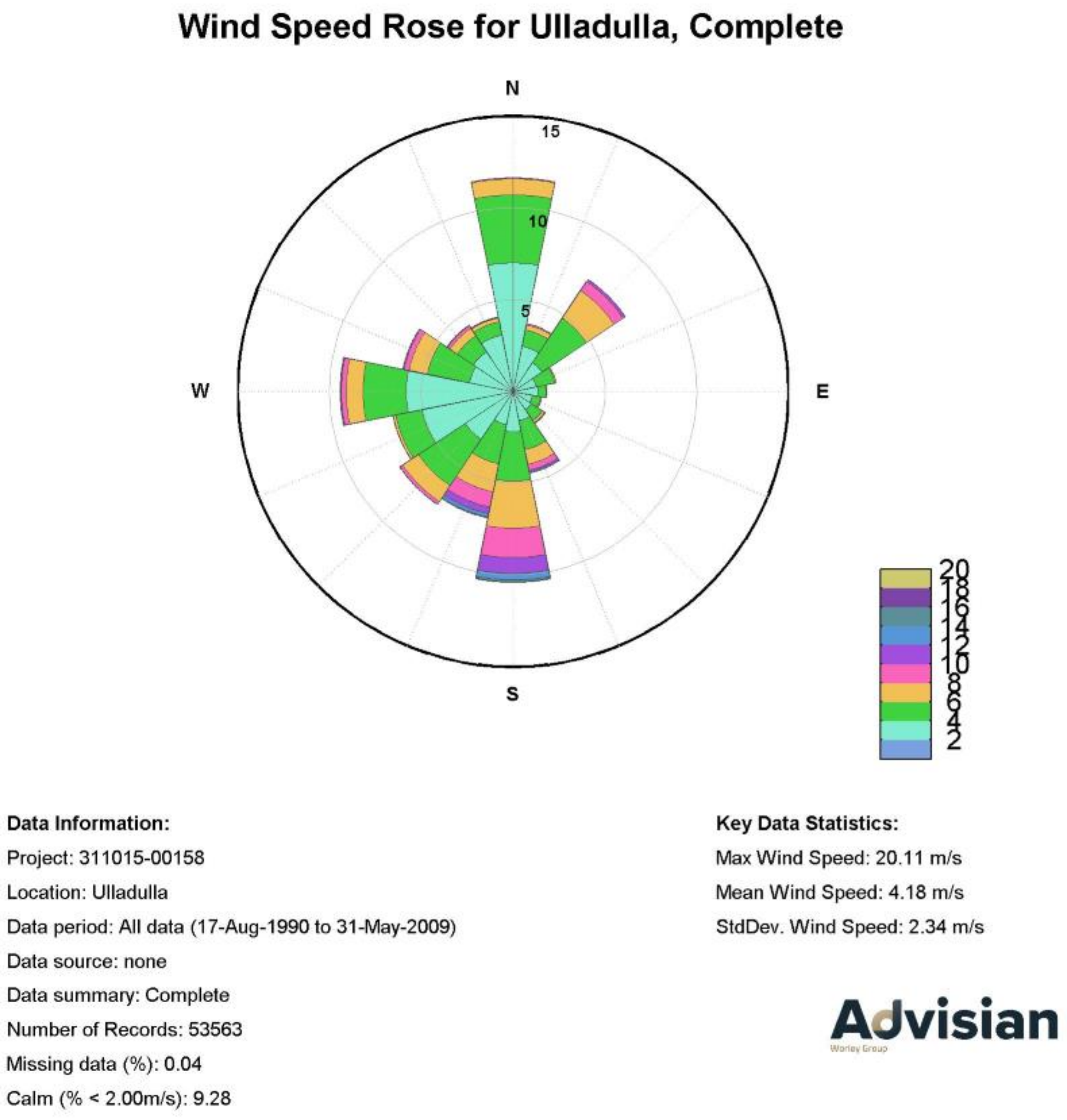


Figure 2-12 - Wind rose plot for Ulladulla (17 Aug. 1990 to 31 May 2009)

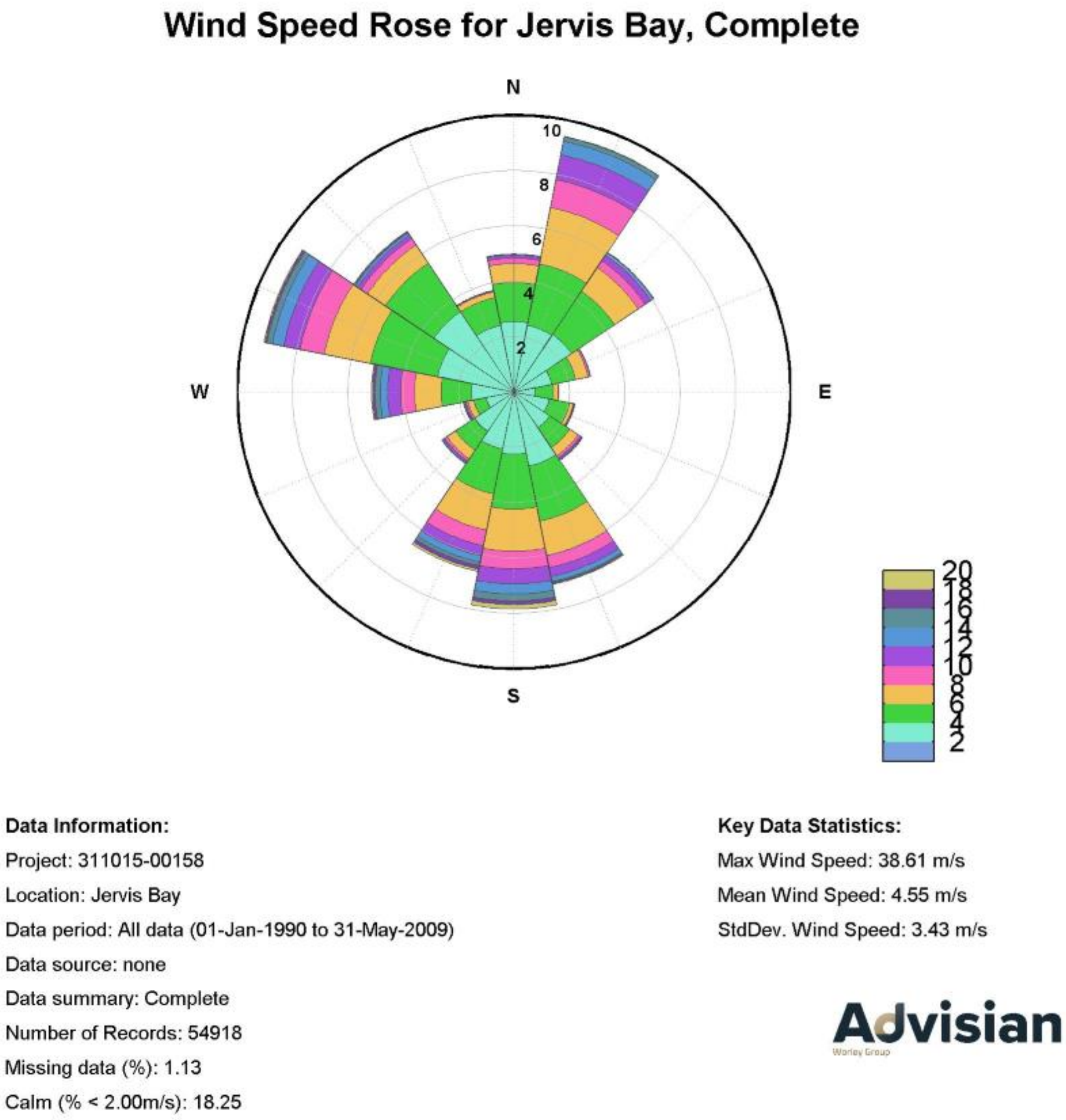


Figure 2-13 - Wind rose plot for Jervis Bay (01 Jun. 1990 to 31 May 2009)

Table 2-6 - Summary of Extreme Wind Speed (on Hourly Mean)

Average Recurrence Interval (year)	Annual Exceedance Probability (AEP, %)	Jervis Bay Wind Speed		Nowra Wind Speed		Ulladulla Wind Speed	
		m/s	**km/hr**	**m/s**	**km/hr**	**m/s**	**km/hr**
1	90	21.3	76.7	15.9	57.2	15.5	55.8
5	20	26.4	95.0	17.7	63.7	18	64.8
10	10	28.9	104.0	18.3	65.9	19.2	69.1
25	4	32.4	116.6	19.1	68.8	21	75.6
50	2	35.3	127.1	19.6	70.6	22.4	80.6
75	1.33	37	133.2	19.8	71.3	23.2	83.5
100	1	38.3	137.9	20	72.0	23.8	85.7
200	0.5	41.4	149.0	20.5	73.8	25.3	91.1
500	0.2	45.6	164.2	21	75.6	27.4	98.6

2.8 Tidal and coastal inundation modelling scenarios

2.8.1 Coastal Inundation

OEH (2015) has determined a dynamic boundary based upon the May 1974 storm as recorded at the Fort Denison Gauge in Sydney Harbour for tidal and coastal inundation model application.

For this study, under Group 4 (Intermittently Closed Estuaries – (also known as intermittently closed and open lakes and lagoons (ICOLLs)) and Waterway Entrance Type C conditions, Advisian has completed the modelling scenarios listed in Table 2-7. The boundary conditions named A.3 and A.6 sourced from OEH (2015) and shown in Figure 2-14 were input to the model runs.

Table 2-7 - Modelling Scenarios – Coastal Inundation

Model Scenario	Water Level Boundary	Wind	Sea Level Rise (m)	Entrance Berm Level	Comments
01	1% AEP (100 year ARI)[5] Group 4 Ocean Time series A.3	Jervis Bay, 100y ARI, south (38.3 m/s)	0	Present day level	Present day
02	1% AEP (100 year ARI) Group 4 Ocean Time series A.3	Jervis Bay, 100y ARI, south (38.3 m/s)	0.1	Raise by 0.1m	Council SLR projections
02a	1% AEP (100 year ARI) Group 4 Ocean Time series A.3	Jervis Bay, 100y ARI, south (38.3 m/s)	0.23		Water elevations interpolated from results of 0.1 m and 0.36 m sea level rise scenarios.
03	1% AEP (100 year ARI) Group 4 Ocean Time series A.3	Jervis Bay, 100y ARI, south (38.3 m/s)	0.36	Raise by 0.36m	Council SLR projections
04	1% AEP (100 year ARI) Group 4 Ocean Time series A.3	Jervis Bay, 100y ARI, south (38.3 m/s)	0.6	Raise by 0.6m	50 year planning period SLR

[5] A 1% AEP event refers to an event that has a 1% probability of being exceeded in any given year. It is equivalent to a 100 year Average Recurrence Interval (ARI) event, i.e. an event that has a probability of being exceeded around once in 100 years.

Model Scenario	Water Level Boundary	Wind	Sea Level Rise (m)	Entrance Berm Level	Comments
04a	1% AEP (100 year ARI) Group 4 Ocean Time series A.3	Jervis Bay, 100y ARI, south (38.3 m/s)	0.9		Water elevations interpolated from results of 0.6 m and 0.9 m sea level rise scenarios.
05	1% AEP (100 year ARI) Group 4 Ocean Time series A.3	Jervis Bay, 100y ARI, south (38.3 m/s)	1.2	Raise by 1.2m	100 year planning period
05a	1% AEP (100 year ARI) Group 4 Ocean Time series A.3	Jervis Bay, 100y ARI, south (38.3 m/s)	1.2	As per 2021	100 year planning period
06	1% AEP (100 year ARI) Group 4 Ocean Time series A.3	Jervis Bay, 100y ARI, west (38.3 m/s)	0	Present day level	Sensitivity run to test westerly wind
07	5% AEP[6] (20 year ARI) Group 4 Ocean Time series A.6	Jervis Bay, 20y ARI, south (32 m/s)	0	Present day level	Present day
08	5% AEP (20 year ARI) Group 4 Ocean Time series A.6	Jervis Bay, 20y ARI, south (32 m/s)	0.1	Raise by 0.1m	Council SLR projections

[6] A 5% AEP event refers to an event that has a 5% probability of being exceeded in any given year. It is equivalent to a 20 year Average Recurrence Interval (ARI) event, i.e. an event that has a probability of being exceeded around once in 20 years.

Model Scenario	Water Level Boundary	Wind	Sea Level Rise (m)	Entrance Berm Level	Comments
08a	5% AEP (20 year ARI) Group 4 Ocean Time series A.6	Jervis Bay, 20y ARI, south (32 m/s)	0.23		Water elevations interpolated from results of 0.1 m and 0.36 m sea level rise scenarios.
09	5% AEP (20 year ARI) Group 4 Ocean Time series A.6	Jervis Bay, 20y ARI, south (32 m/s)	0.36	Raise by 0.36m	Council SLR projections
10	5% AEP (20 year ARI) Group 4 Ocean Time series A.6	Jervis Bay, 20y ARI, south (32 m/s)	0.6	Raise by 0.6m	50 year planning period SLR
10a	5% AEP (20 year ARI) Group 4 Ocean Time series A.6	Jervis Bay, 20y ARI, south (32 m/s)	0.9		Water elevations interpolated from results of 0.6 m and 0.9 m sea level rise scenarios.
11	5% AEP (20 year ARI) Group 4 Ocean Time series A.6	Jervis Bay, 20y ARI, south (32 m/s)	1.2	Raise by 1.2m	100 year planning period
12	5% AEP (20 year ARI) Group 4 Ocean Time series A.6	Jervis Bay, 20y ARI, west (32 m/s)	0	Present day level	Sensitivity run to test westerly wind
12a	5% AEP (20 year ARI) Group 4 Ocean Time series A.6	0 m/s	0	Present day level	Sensitivity run to test no wind

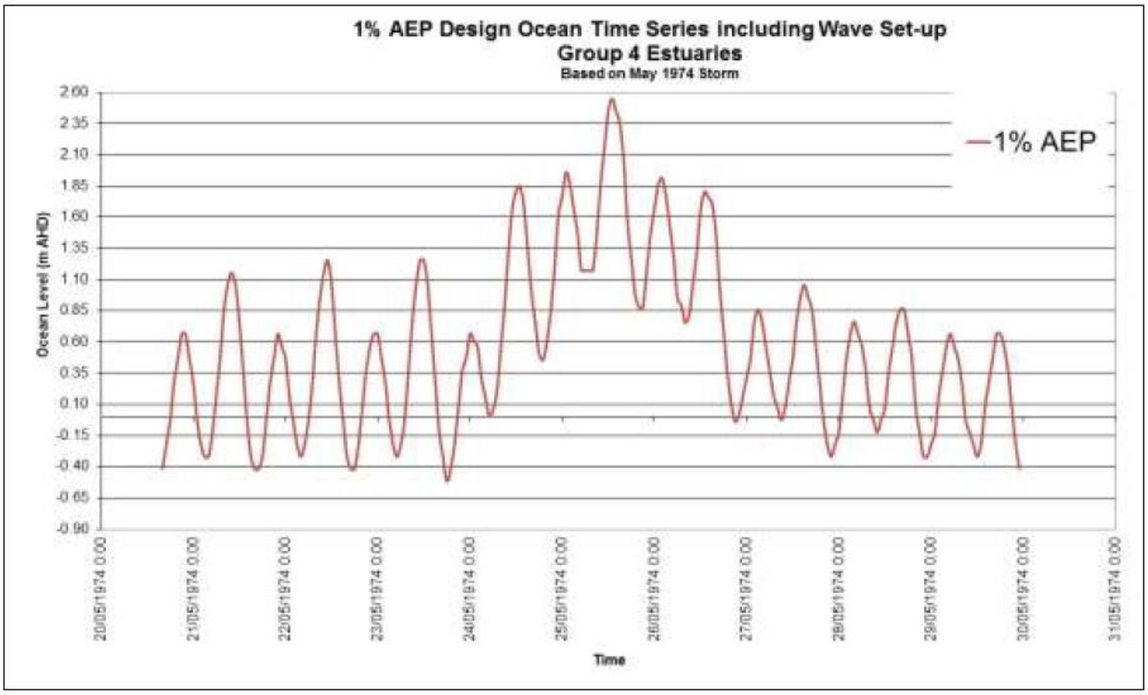


Figure A.3 Waterway Entrance Type C - Group 4 Estuary Time Series for an Untrained Entrance or ICOLL– 1% AEP Ocean Boundary Time Series Fort Denison May 1974 with 1.1m wave setup (South of Crowdy Head)

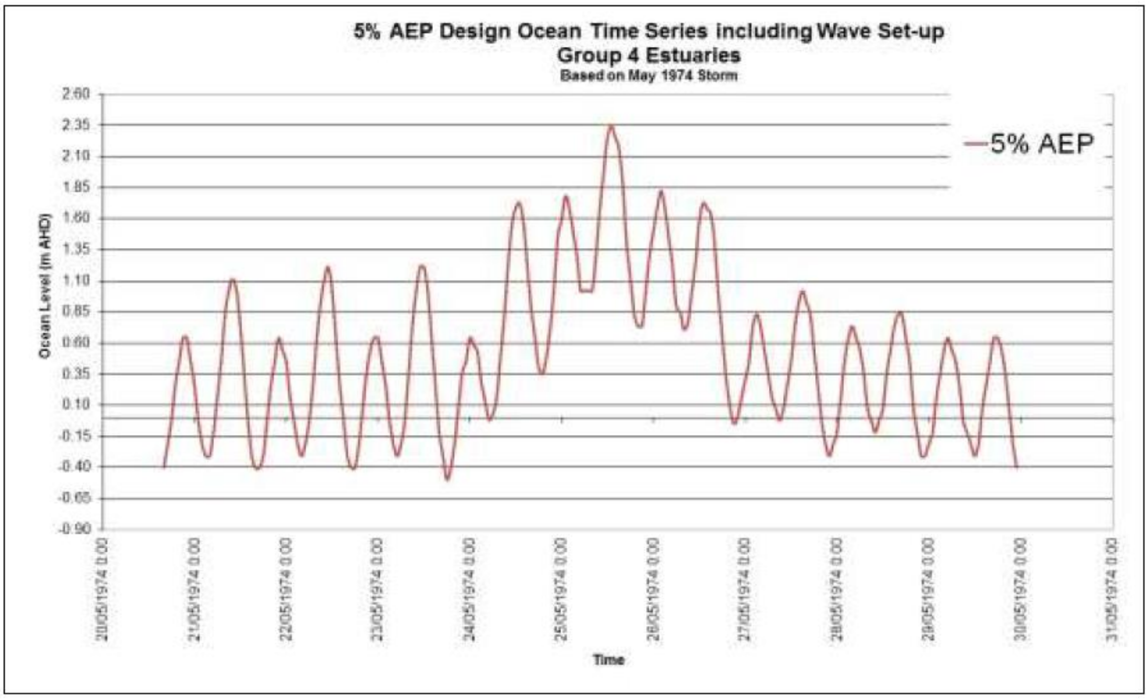


Figure A.6 Waterway Entrance Type C - Group 4 Estuary Time Series for an Untrained Entrance or ICOLL – 5% AEP Ocean Boundary Time Series Fort Denison May 1974 with 0.95m wave setup (South of Crowdy Head)

Figure 2-14 – Ocean boundary conditions for 1% AEP and 5% AEP storm events for Type C Group 4 estuaries south of Crowdy Head (OEH 2015)

2.8.2 Tidal Inundation

In addition to coastal inundation, tidal inundation under present day conditions and under projected sea level rise was modelled to assess the potential for inundation to occur under regular tidal conditions. The model was used to map tidal inundation over the study area, for the scenarios presented in Table 2-8.

Table 2-8 - Modelling Scenarios – Tidal Inundation

Model Scenario	Water Level Boundary	Wind	Sea Level Rise (m)	Entrance Berm Level	Comments
013a	High High Water Solstice Springs (HHWSS[7], 1.027 m AHD)	0 m/s	0	Present day level	Present day
013b	HHWSS + Sea Level Rise (SLR)	0 m/s	0.1	Raise by 0.1m	20 year planning period
013c	HHWSS + SLR	0 m/s	0.23	Raise by 0.23m	Council 2050 projection
013d	HHWSS + SLR	0 m/s	0.36	Raise by 0.36m	50 year planning period
013e	HHWSS + SLR	0 m/s	0.6	Raise by 0.6m	100 year planning period (low-range projection)
013f	HHWSS + SLR	0 m/s	0.9	Raise by 0.9m	100 year planning period (mid-range projection)
013g	HHWSS + SLR	0 m/s	1.2	Raise by 1.2m	100 year planning period (upper-range projection)

[7] High High Water Solstice Springs (HHWSS) refers to the average of the highest high tide that occurs around the summer and winter solstice, twice per year.

3 Model results

The model results have been generated as both time series and spatial results. The results were output in ASCII format (Appendix A) to allow the generation of inundation maps for all the scenarios in Table 2-7 and Table 2-8 covering the study area.

Time series of the results were extracted to allow an analysis of the duration of inundation at 12 key locations within the study area as described below (Figure 3-1).

The locations were chosen to assess the duration of coastal and tidal inundation in areas where there would be potential impacts on surrounding infrastructure, as well as to assess tidal current velocities in the channel for navigation purposes. Table 3-1 presents the spatial coordinates of these locations, as well as the maximum water level and current speeds under the design 1% and 5% annual exceedance probability (AEP) events at the extracted locations.

For the 1% AEP event, along Sussex Inlet, the current speed can reach 1.5 m/s at P6, while the water level is up to 2.6 m AHD at P1 (Table 3-1). Within Swan Lake at P7, the water level is up to 2.6 m AHD (note that this assumes an open lake entrance). P8 at the entrance of Berrara Creek, indicates a higher water level of up to 3.0 m AHD (for an open estuary entrance) and lower currents of up to 0.2 m/s. For the extracted 4 points (P9 to P12) within St Georges Basin, the water level is up to 3.0 m AHD at P12 and the current speed is up to 0.5 m/s at P10.

For the 5% AEP event, along Sussex Inlet, the current speed can reach 1.3 m/s at P6, while the water level is up to 1.8 m AHD at P1, P5 and P6. Within Swan Lake at P7, the water level is up to 1.8 m AHD. The P8 at the entrance of Berrara Creek, indicates higher water level of 2.3 m AHD and lower currents up to 0.1 m/s. At the extracted 4 points (P9 to P12) within St Georges Basin, the water level is up to 2.1 m AHD at P12 and the current speed is up to 0.5 m/s at P10.

These results are presented in graphical form in Appendix A. The results for Sussex Inlet indicate that during coastal inundation events, flood tide velocities are higher than ebb-tide velocities, which could result in an import of sediments into the entrance area during storm conditions.

The maximum water levels for Scenario 1 (1% AEP, refer Table 2-7) and Scenario 7 (5% AEP, refer Table 2-7) are presented spatially in Appendix A. The maximum water level results for all the scenarios have been used to generate inundation hazard maps for coastal and tidal inundation in Appendix B.

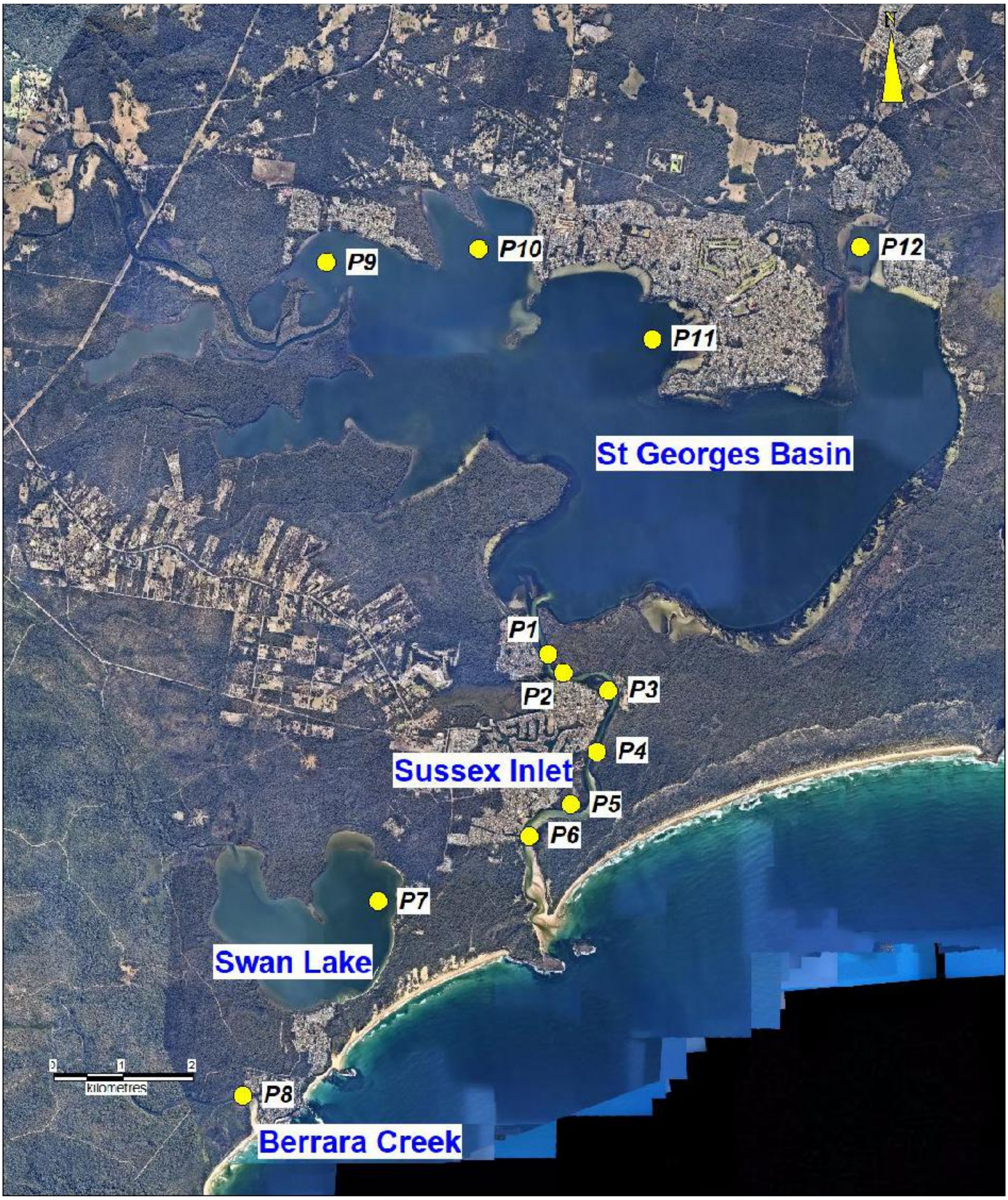


Figure 3-1 – Key locations that have been selected for time series analysis of inundation duration for Berrara Ck, Swan Lake and Sussex Inlet

Table 3-1 - Extracted Points Coordinates and model results for maximum water level and current velocity, 1% and 5% AEP scenarios with southerly wind

Points	Location	Coordinates (MGA 56)		Scenario 1 (1% AEP with southerly wind)		Scenario 7 (5% AEP with southerly wind)	
		East	North	Maximum Water Level (m AHD)	Maximum Flow Velocity (m/s)	Maximum Water Level (m AHD)	Maximum Flow Velocity (m/s)
1	Sussex Inlet (upstream of Badgee Lagoon)	280915.7	6107731	2.56	1.07	1.75	0.91
2	Sussex Inlet (downstream of Badgee Lagoon)	281141.5	6107455	2.54	0.93	1.74	0.83
3	Sussex Inlet (near Sussex Inlet Marine Centre)	281781.1	6107205	2.53	0.72	1.73	0.64
4	Sussex Inlet (opposite the Quays Canals)	281618	6106327	2.50	1.24	1.71	1.09
5	Sussex Inlet (near Pelican Shores Marina)	281241.8	6105562	2.53	0.84	1.77	0.73
6	Sussex Inlet (near Lions Park)	280652.4	6105110	2.49	1.56	1.77	1.34
7	Swan Lake (near Ski Beach, open Lake entrance)	278481.2	6104173	2.63	0.18	1.75	0.15
8	Berrara Creek (near Lakeland Avenue, open creek entrance)	276529.6	6101385	2.95	0.17	2.25	0.11
9	St Georges Basin (near Basin View)	277737.1	6113350	2.89	0.18	2.01	0.15
10	St Georges Basin (near Pelican Point)	279927.6	6113537	2.90	0.54	2.01	0.45
11	St Georges Basin (near Sanctuary Point)	282415.2	6112251	2.81	0.28	1.94	0.23
12	St Georges Basin (near Erowal Bay)	285407.3	6113564	2.97	0.12	2.09	0.35

4 Inundation Risk Assessment and Inundation Hazard Mapping

Mapping of inundation depth covering the study area for all scenarios modelled is provided in Appendix B. Mapping of Endangered Ecological Communities with respect to tidal inundation depth for various sea level rise scenarios, together with potential locations for migration of mangroves and saltmarsh with sea level rise is provided in Appendix C, and mapping of built assets at risk under coastal and tidal inundation scenarios is provided in Appendix D.

4.1 Coastal Inundation

Key locations where coastal inundation threatens infrastructure, with estimated depth and duration of inundation are tabulated in Table 4-1 and mapped in Appendix D, for various model scenarios. It should be noted that these impacts do not include additional impacts that may be expected under catchment-derived flooding, which can occur during the same weather systems that cause coastal inundation. "Catchment-derived flooding" refers to flooding driven by heavy rainfall in the catchment area of the estuary and subsequent freshwater inflows. This type of flooding is often associated with the same weather systems as coastal inundation events, which are typically driven by low pressure systems, usually accompanied by intense rainfall. Analysis of the joint probability between weather systems that cause coastal inundation and those that lead to intense rainfall that cause catchment-derived flooding is captured within the St Georges Basin Flood Study, which was formally adopted by Council in January 2023 (refer https://getinvolved.shoalhaven.nsw.gov.au/review-of-the-St-Georges-Basin-floodplain-risk-management-study-and-plan).

From Table 4-1 and the maps in Appendix D it can be seen that:

- At St Georges Basin, there are extensive areas around Sanctuary Point, Old Erowal Bay, Erowal Bay, Basin View and St Georges Basin Village that will be impacted by coastal inundation, with additional areas impacted under future sea level rise projection. In addition there is potential for areas to be isolated by inundation for up to several days (e.g. Erowal Bay, Sanctuary Point near Cessna Avenue).

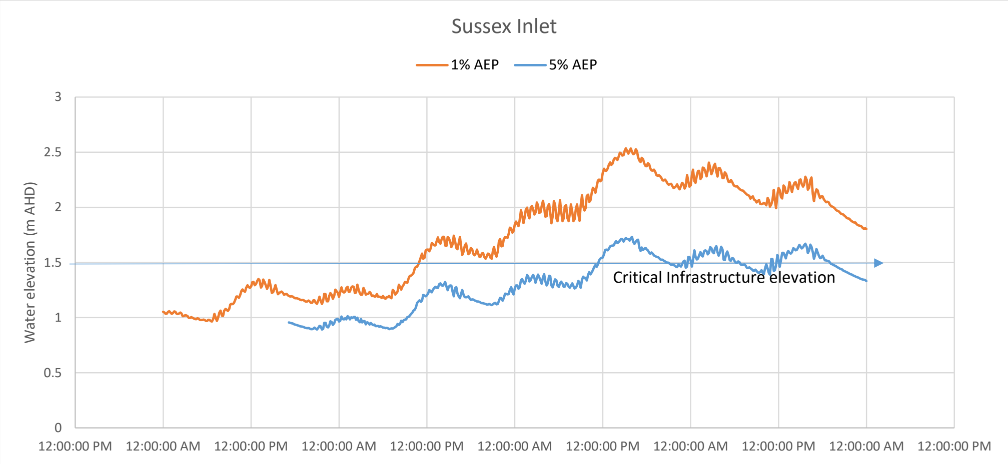
- At Sussex Inlet, the town centre is affected by 1% AEP coastal inundation under present day conditions, with the depth and frequency of inundation expected to increase under future projected sea level rise. Under the various sea level rise scenarios, both coastal and tidal inundation will affect large areas of the town centre and access to and within the township is likely to be cut off by inundation.

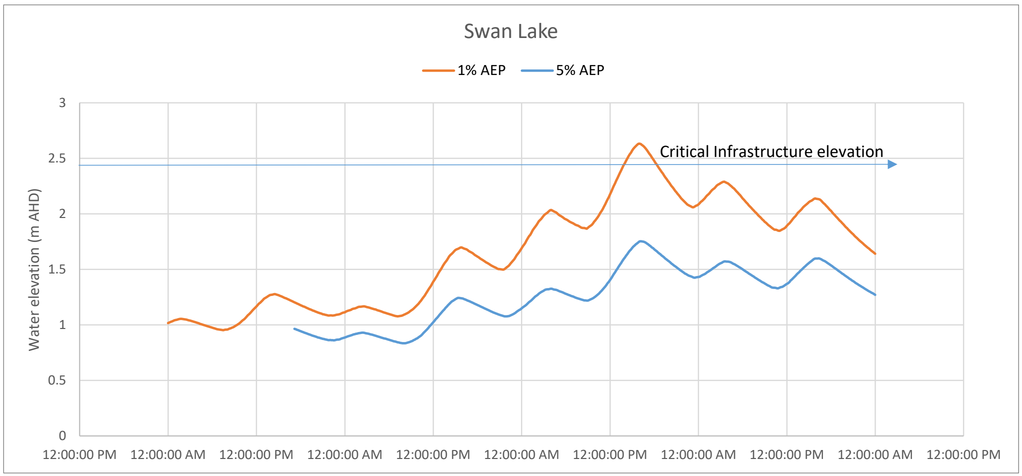
- At Swan Lake and Berrara Creek, there is the potential for the main access to Berrara and Cudmirrah to be cut off at Collier Drive, and coastal inundation to occur at the caravan park in the 1% AEP event, under 0.1 m or higher of sea level rise. Coastal inundation of critical water infrastructure at Berrara including a water pumping station and water and wastewater mains is predicted in a 1% AEP event under future sea level rise of 0.9 m or higher.

4.1.1 Duration of Coastal Inundation

Time series of predicted water levels for a 1% and 5% AEP event under present day conditions at St Georges Basin, Sussex Inlet, Swan Lake and Berrara Creek are plotted in Figure 4-1 and Figure 4-2, together with the level at which critical infrastructure (key roads, sewer lines/pumping stations, water infrastructure, public buildings) can be inundated. It can be seen that coastal inundation can persist for several days at St Georges Basin and Sussex Inlet, and for several hours at Swan Lake and Berrara Creek. This is due to critical infrastructure around parts of St Georges Basin and Sussex Inlet being at a generally lower elevation than at Swan Lake and Berrara Creek.

Figure 4-1 – Time series showing duration of inundation of critical infrastructure at St Georges Basin, 1% and 5%AEP





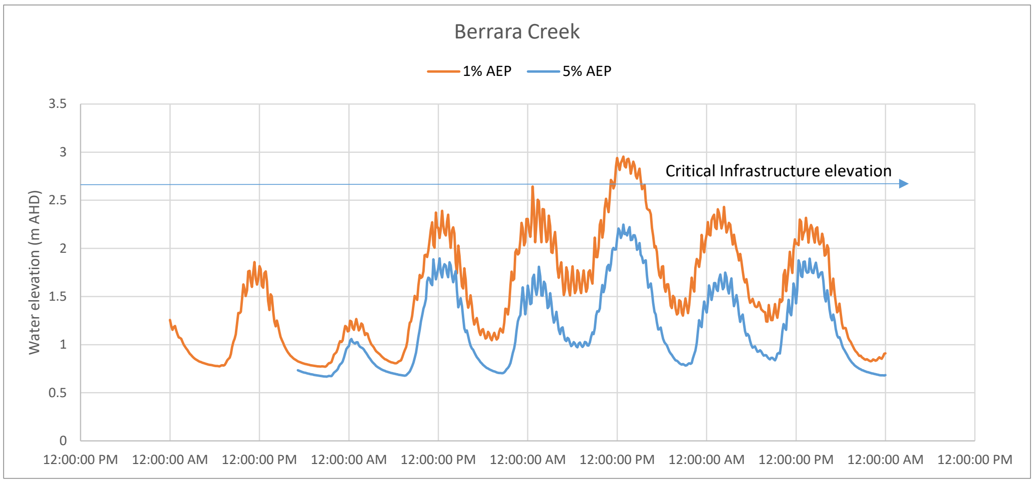


Figure 4-2 – Time series showing duration of inundation of critical infrastructure at Sussex Inlet, Swan Lake and Berrara Creek

Table 4-1 – Locations where infrastructure is impacted by coastal inundation for the 1% AEP

Location	Scenario	0.1 m SLR	0.36 m SLR	0.6 m SLR	0.9 m SLR	1.2 m SLR
Old Erowal Bay Erowal Bay Wrights Beach	1% AEP	Inundation of lots along McGowan Street > 1m depth Inundation of pressure mains and 4 x sewage pumping stations > 1 m depth Inundation of waterside infrastructure at Naval Parade > 1m maximum depth Inundation duration ~72 hours	As per 0.1 m SLR plus inundation of ~3 lots at Kallaroo Road and inundation of Prentice Road. Increase in duration of 8 – 12 hrs for areas inundated at lower sea level rise scenarios	As per 0.36m SLR plus inundation of Naval Parade cutting access to Erowal Bay for up to 72 hours. Increase in duration of 12– 24 hrs for areas inundated at lower sea level rise scenarios	As per 0.6m SLR plus inundation of some additional lots at Kallaroo Road, Prentice Avenue and MacGibbon Parade. Increase in duration of 24 – 48 hrs for areas inundated at lower sea level rise scenarios	As per 0.9 m SLR plus inundation of waterside infrastructure at Reid Street Wrights Beach, inundation of ~3 lots at Killarney Road Erowal Bay. Increase in duration of 24 – 72 hrs for areas inundated at lower sea level rise scenarios
Sanctuary Point	1% AEP	Inundation of precinct around The Park Drive, Mountain Street and Larmer Avenue Inundation of several lots around Sanctuary Point Road Inundation of lots at Fairway Drive Inundation of waterside infrastructure along Sanctuary Pont Road	As per 0.1m SLR plus: Inundation of precinct around The Park Drive, Mountain Street and Larmer Avenue > 1m maximum depth Inundation extending inland at Paradise Beach to several lots along Macleans Point Road Inundation of additional lots at Fairway Drive, Sanctuary Point Road	As per 0.36mSLR plus: Inundation of additional lots at Roulstone Cres and Fairview Drive Inundation of several lots around The Wool Road Isolation of some lots around Sanctuary Point Road near Cessna Avenue Increase in duration of 12 – 24 hrs for areas inundated at lower sea level rise scenarios	As per 0.6mSLR plus: Inundation of additional lots at Roulstone Cres and Fairview Drive Inundation of several lots around The Wool Road Additional inundation at Collett Place Increase in duration of 24 – 48 hrs for areas inundated at lower sea level rise scenarios	As per 0.9 m SLR plus: Inundation of additional lots at Roulstone Cres and Fairview Drive, maximum depth > 1m Isolation of additional lots around Sanctuary Point Road Inundation of additional lots at Paradise Beach at Imer Avenue and Macleans Point Road with maximum depth > 1m Increase in duration of 24 – 72 hrs for areas

Location	Scenario	0.1 m SLR	0.36 m SLR	0.6 m SLR	0.9 m SLR	1.2 m SLR
		Inundation of wastewater pressure mains and sewage pumping stations Inundation of reserve and low-lying lots along Imer Avenue, Paradise Beach Inundation duration ~ 4 days	Inundation of low-lying sections of The Wool Road Inundation of several lots at Roulstone Cres Increase in duration of 8 – 12 hrs for areas inundated at lower sea level rise scenarios			inundated at lower sea level rise scenarios
St Georges Basin	1% AEP	Inundation of several lots at Loralyn Avenue Inundation of waterside infrastructure at Loralyn Avenue Access over Loralyn Avenue cut Inundation of low-lying lots at Graham Ave, Kevin Cres and Collet Pl Inundation of parts of Aloha Caravan Park Inundation of wastewater pressure mains and pumping stations Inundation duration ~3 days	As per 0.1m SLR plus: Additional lots at Loralyn Avenue affected Access over Loralyn Avenue cut at 3 locations for longer duration Additional lots at Graham Avenue, Kevin Cres and Collet Pl affected Waterside infrastructure within lots at Island Point Road affected Increase in duration of 8 – 12 hrs for areas inundated at lower sea level rise scenarios	As per 0.36 m SLR plus: Approximately six additional lots at Loralyn Avenue affected Loss of access between St Georges Basin and Basin View over The Wool Road near Deane Street Inundation of several lots at Panorama Road and Waterpark Road Inundation of four lots at Park Road Inundation of critical water mains Increase in duration of 12 – 24 hrs for areas inundated at lower sea level rise scenarios	As per 0.6 m SLR plus: Additional lots at Loralyn Avenue affected Inundation of additional length of critical water mains Increase in duration of 24 – 48 hrs for areas inundated at lower sea level rise scenarios	As per 0.9 m SLR plus: Additional lots at Loralyn Avenue affected, maximum depth exceeding 1 m in some areas Additional lots at Graham Avenue, Kevin Cres and Collet Pl affected Loss of access over The Wool Road to Basin View at Park Road Inundation of several lots at Park Road Inundation of additional lots at Panorama Road and Waterpark Road Increase in duration of 24 – 72 hrs for areas inundated at lower sea level rise scenarios

Location	Scenario	0.1 m SLR	0.36 m SLR	0.6 m SLR	0.9 m SLR	1.2 m SLR
Basin View	1% AEP	Inundation of waterside infrastructure at lots along Basin View Parade Inundation of Harris Avenue and isolation of lots along Harris Avenue south of Watersedge Avenue Inundation of critical sewer mains and pumping stations Inundation ~ 2 days	As per 0.1 m SLR plus: Inundation of several lots at Harris Avenue and Watersedge Avenue Increase in duration of 8 – 12 hrs for areas inundated at lower sea level rise scenarios	As per 0.36 m SLR plus: Inundation of additional lots at Watersedge Avenue and Harriss Avenue Inundation of several lots at Clarendon Cres and Riverside Espl The Wool Road cut off at Atherton Street and Tallyan Point Road Increase in duration of 12 – 24 hrs for areas inundated at lower sea level rise scenarios	As per 0.6 m SLR plus: Inundation of additional lots at Watersedge Avenue and Harriss Avenue Inundation of additional lots at Clarendon Cres and Riverside Espl Increase in duration of 24 – 48 hrs for areas inundated at lower sea level rise scenarios	As per 0.9 m SLR plus: Inundation of additional lots at Watersedge Avenue and Harriss Avenue, maximum depth over Harriss Avenue exceeding 1 m. Inundation of additional lots at Clarendon Cres and Riverside Espl Increase in duration of 24 – 72 hrs for areas inundated at lower sea level rise scenarios
Sussex Inlet	1% AEP	Inundation of most of town centre, depth ~ 1 m Inundation of low-lying parts of lots at The Quays ~0.1 m depth No access to Jacobs Drive east of Sussex Inlet Road Area of Sussex Inlet north of Badgee Lagoon isolated, although a flood-free access road linking Badgee Lagoon to the Golf Course is currently being planned.	As per 0.1 m SLR plus: Additional depth of inundation at The Quays Maximum depth exceeding 1 m over large areas of the Sussex Inlet town centre Loss of access into Cudmirrah and Berrara along Sussex Inlet Road Inundation at Inasmuch Retirement Village Inundation of lots at Riviera Avenue,	As per 0.36 m ALR plus: Inundation at Lakeshore Parade Inundation at "The Moorings" village Inundation of low-lying parts of Peacehaven Way, Seaberry Street, Murre Street and Buttonwood Close Inundation of additional lots at Lakehaven Drive. Driftwood Ave, Beachcomber Ave,	As per 0.6 m ALR plus: Inundation of additional lots at Lakehaven Drive. Driftwood Ave, Beachcomber Ave, Greentree Ave Further inundation of lots at Riviera Avenue, Edgewater Avenue, Glanville Road and Lakehaven Drive near Lions Park for up to 8 hours. Increase in duration of 24 – 48 hrs for areas	As per 0.9 m SLR plus: Inundation of several lots at Lakeshore Parade and River Road Increase in duration of 24 – 72 hrs for areas inundated at lower sea level rise scenarios

Location	Scenario	0.1 m SLR	0.36 m SLR	0.6 m SLR	0.9 m SLR	1.2 m SLR
		Inundation of Sussex Palms Holiday Park Inundation of Bowling Club and RSL Inundation of Alamein Caravan Park and The Cove Inundation of waterside infrastructure and low-lying parts of lots at Fairview Cres Inundation of lots at Cater Cres Inundation of critical sewer mains and pumping stations Inundation duration ~3 – 4 days	Edgewater Avenue and Lakehaven Drive near Lions Park Inundation of lots at Corang Avenue Inundation of lots at Suncrest Ave Inundation of lots at Ridge Avenue Loss of access to Surf Club at Alamein Rd and Pacificana Dr Increase in duration of 4 – 6 hrs for areas inundated at lower sea level rise scenarios	Greentree Ave, Glanville Road Further inundation of lots at Riviera Avenue, Edgewater Avenue and Lakehaven Drive near Lions Park for up to 2 hours. Increase in duration of 4 – 24 hrs for areas inundated at lower sea level rise scenarios	inundated at lower sea level rise scenarios	
Swan Lake and Berrara Creek	1% AEP	Inundation at The Springs Cottages Swanhaven <0.1 m Inundation of low-lying parts of Holiday Haven Swan Lake caravan park and potential for road access to Cudmirrah and Berrara to be cut across Collier Drive Inundation of foreshore reserve at Lakeland Avenue Berrara	As per 0.1 m SLR plus: Inundation affecting lots at Lakeland Avenue Berrara Increased risk of access to Berrara being cutoff across Collier Drive Loss of access into Cudmirrah and Berrara from Princes Highway along Sussex Inlet Road Increase in duration of 4 hrs for areas inundated	As per 0.36 m SLR plus Access to Cudmirrah and Berrara cut off at The Springs Road east of bridge for up to 8 hours Further inundation at Holiday Haven Swan Lake caravan park Inundation of fourteen lots at Lakeland Ave, Beachview Ave and Waterhaven Ave Berrara	As per 0.6 m SLR plus Access to Cudmirrah and Berrara cut off at The Springs Road for over 12 hours, The Springs Road inundated near Ski Beach Further inundation at Holiday Haven Swan Lake caravan park Inundation of four additional lots at Lakeland Ave, Beachview	As per 0.9 m SLR plus: Inundation of low-lying parts of Kangaroo Cabins, Berrara No access to Berrara west of the Lakeland Ave bridge, inundation depth >1m over Lakeland Avenue Inundation of sewage pumping station and critical wastewater main at Swan Lake

Location	Scenario	0.1 m SLR	0.36 m SLR	0.6 m SLR	0.9 m SLR	1.2 m SLR
		Inundation duration ~4 – 6 hours	at lower sea level rise scenarios	Inundation of water main at Berrara Increase in duration of 4 – 6 hrs for areas inundated at lower sea level rise scenarios	Ave and Waterhaven Ave Berrara Inundation of water main and pumping station at Berrara Increase in duration of 6 – 12 hrs for areas inundated at lower sea level rise scenarios	Increase in duration of 6 – 18 hrs for areas inundated at lower sea level rise scenarios

4.2 Tidal Inundation

Key locations where tidal inundation (for HHWSS tides) threatens infrastructure, with estimated depth and duration of inundation are tabulated in Table 4-2, for various sea level rise scenarios. Tidal inundation is expected to occur for at least two hours around the highest tides for a few days in any given month, and is therefore a high-frequency event when compared with coastal inundation driven by coastal storms. Mapping of key risk areas and infrastructure for tidal inundation depth at HHWSS at St Georges Basin, Sussex Inlet, Swan Lake and Berrara Creek is provided in **Appendix D**, for the 0.6 m and 1.2 m sea level rise scenarios.

It can be seen that:

- At St Georges Basin, there are areas around Sanctuary Point that will become impacted by tidal inundation with sea level rise in the future, particularly waterside infrastructure, critical sewer infrastructure and several lots around Park Drive. Foreshore reserves and waterside infrastructure around Sanctuary Point, St Georges Basin, Erowal Bay and Basin View are currently subject to tidal inundation. The impact to these areas will increase with sea level rise in the next 20 to 50 years, particularly impacting on waterside infrastructure, critical sewer infrastructure and several residential lots in Sanctuary Point, Erowal Bay and Basin View.

- At Sussex Inlet, low-lying foreshore reserves are affected by tidal inundation at present, but parts of the main town centre will become affected by inundation under relatively low levels of sea level rise. Tidal inundation is likely to become more common with sea level rise over the next 20 to 50 years with predictions that areas of Sussex Inlet, including the main CBD, will be inundated by more than 20cm up to twice per month during extreme high tides. Under further sea level rise, there is the potential for access to parts of the town to be cut off by inundation, as well as for most of the main town centre to be affected by periodic inundation.

- At Swan Lake and Berrara Creek, while tidal inundation is not as big a risk due to water levels mainly being driven by catchment flooding and berm levels when the estuary entrances are closed, there is the potential for tidal inundation to impact low-lying areas, especially around Lakeland Avenue and at Collier Drive. There is also the potential for the Cudmirrah and Berrara villages to be isolated periodically due to tidal inundation with future sea level rise, which could occur within the next 50 years under currently projected rates of future sea level rise.

Table 4-2 – Locations where infrastructure is impacted by tidal inundation

Location	Scenario	0.1 m SLR	0.36 m SLR	0.6 m SLR	0.9 m SLR	1.2 m SLR
Old Erowal Bay Erowal Bay Wrights Beach	HHWSS	Inundation of foreshore reserves ~2hrs/ twice per month	As per 0.1 m SLR plus inundation of low lying parts of Prentice Avenue	As per 0.36 m SLR plus inundation sewage pumping stations at Prentice Avenue and Kallaroo Road, ~2hrs/ twice per month More frequent inundation of low-lying foreshore reserves, ~2hrs >4 times per month	As per 0.6 m SLR plus inundation of some additional lots at Prentice Avenue, ~2hrs/ twice per month	As per 0.9 m SLR plus inundation of McGowen Street and waterside sewer infrastructure at Naval Parade, Erowal Bay, ~2hrs/ twice per month.
Sanctuary Point	HHWSS	Inundation of foreshore reserves ~2hrs/twice per month	As per 0.1 m SLR plus: Additional inundation depth at foreshore reserves, ~2hrs/twice per month	As per 0.36 m SLR plus: Additional inundation depth at foreshore reserves, ~2hrs/four times per month Inundation of Sewage Pumping Station at Walmer Avenue	As per 0.6 m SLR plus: Inundation of several lots around The Park Drive Inundation of several lots at Walmer Avenue, Paradise Beach. ~2hrs /twice per month	As per 0.9 m SLR plus: Inundation of additional lots at Walmer Avenue, Paradise Beach Inundation of additional lots at The Park Drive, Larmer Avenue and Mountain Street, more frequent inundation ~4 times per month at high tides Inundation of critical wastewater infrastructure,

Location	Scenario	0.1 m SLR	0.36 m SLR	0.6 m SLR	0.9 m SLR	1.2 m SLR
						~2hrs/twice per month
St Georges Basin	HHWSS	Inundation of waterside infrastructure at Loralyn Avenue Inundation of low-lying parts of lots at Panorama Rd ~2hrs/twice per month	As per 0.1 m SLR plus: Inundation of low-lying parts of rural properties at The Wool Road east of Park Road ~2hrs/twice per month	As per 0.36 m SLR plus: Inundation of six low-lying lots at Panorama Road ~2hrs/twice per month	As per 0. 6 m SLR plus: Inundation of critical sewer mains ~2hrs/twice per month	As per 0.9 m SLR plus: Inundation of critical sewer mains and pumping stations Inundation of waterside infrastructure at Loralyn Ave, Island Point Road ~2hrs/twice per month
Basin View	HHWSS	Inundation of waterside infrastructure at lots along Basin View Parade ~2hrs/twice per month	As per 0.1 m SLR plus: Inundation of waterside infrastructure at lots along Basin View Parade ~2hrs/twice per month	As per 0.36 m SLR plus: Inundation of low-lying parts of four lots at Harriss Avenue ~2hrs/twice per month	As per 0. 6 m SLR plus: Inundation of waterside infrastructure at lots along Basin View Parade including critical sewer infrastructure ~2hrs/twice per month	As per 0.9 m SLR plus Inundation of low lying parts of an additional four lots at Harris Av ~2hrs/twice per month
Sussex Inlet	HHWSS	Inundation of waterside infrastructure at Fairview Cres Inundation of waterfront reserves	As per 0.1 m SLR plus: Additional depth of inundation at all waterfront reserves Inundation of sewer infrastructure plus	As per 0.36 m ALR plus: Inundation of lots and sewage pumping stations at River Road south of the RSL	As per 0. 6 m ALR plus: Inundation of lots at Fairview Cres Inundation of significant sections of	As per 0.9 m SLR plus: Most of town centre area subject to tidal inundation, more frequently ~4 times

Location	Scenario	0.1 m SLR	0.36 m SLR	0.6 m SLR	0.9 m SLR	1.2 m SLR
		and waterside infrastructure at Sussex Inlet RSL and along frontage upstream from Jacobs Drive Inundation of low-lying portions of lots at The Quays Inundation of low-lying portions of reserve at Lions Park Inundation duration ~2hrs/twice per month	several lots at The River Road Inundation duration ~2hrs/twice per month	Inundation of parts of the Riverside Caravan Park Inundation duration ~2hrs/twice per month	town centre with depth over 0.2m including at Wunda Avenue, Jacobs Drive and River Road Inundation of entire River Road precinct south of RSL Inundation of parts of Alamein, The Cove, Seacrest Caravan Park and Sussex Palms caravan park Inundation duration ~2hrs/twice per month	per month at high tides. Potential for access to Sussex Inlet, Berrara and Cudmirrah to be cut off at Sussex Inlet Road west of The Springs Road Inundation duration ~2hrs/4 times per month
Swan Lake and Berrara Creek	HHWSS	No significant impact	Inundation of low-lying portions of foreshore reserves, ~2hrs /twice per month if Lake entrance is open	As per 0.36 m SLR plus Additional inundation at low-lying areas of foreshore reserves ~2hrs/twice per month if Lake entrance is open	As per 0. 6 m SLR plus Inundation at Lakeway Ave reserve and in low-lying areas near Swan Lake Bridge, ~2hrs/twice per month if Lake entrance is open	As per 0.9 m SLR plus: Inundation of foreshore shared path between Swanhaven and Cudmirrah Potential for inundation at Collier Drive Access to Princes Hwy cut off at Sussex Inlet Road ~2hrs/four times per month (if Lake entrance is open)

4.3 Estuarine Vegetation Inundation Risk

Sea level rise due to climate change is a key identified risk in the CMP associated with a permanently raised water depth, increased inundation frequency and extents in particular areas due to regular tidal inundation, or storm events causing more frequent and/or extensive inundation.

There are three potential impact scenarios to the Coastal Wetland/Littoral Rainforest Areas including:

a) landward migration of macrophyte or coastal vegetation species,

b) shift in dominant species (e.g. mangroves encroaching into current saltmarsh areas, or saltmarsh encroaching into swam oak forests) or

c) reduced or loss of biodiversity.

It is likely that a combination of these impacts will occur, however prediction of responses is complex and dependent on a range of factors. These include changes in tidal flows, drainage, hydrology, hypsometry (land elevation relevant to sea level rise), turbidity changes as well as the availability of suitable habitat absent from sea walls and urban developments, to allow for the migration to occur inwards (Davies et al. 2016; NSW DPI 2013).

In addition to those above, the response of vegetation is very dependent on the individual species preferred salinity range, preferred depth range, rate of recolonisation and resilience of species. Within the present day, Posidonia is the dominant seagrass type in St. Georges Basin with smaller areas of Zostera. Previous modelling studies in another NSW estuary (Port Stephens) predicted that in areas of mixed Posidonia and Zostera, then Zostera may dominate under sea level rises, as is more resilient to wave action and has a quicker recovery following disturbances such as frequent inundations (Campbell and McKenzie 2004; Davis et al. 2016). Saltmarshes and mangroves which are dominant in Sussex Inlet, may decline and be replaced by terrestrial reed species such as *Phragmites australis* (NSW DPI 2013). Areas of terrestrial EEC that become permanently inundated, may be replaced by estuarine or coastal macrophytes. The impacts from storm events depend on the extent and duration of inundation. Inundation for extended periods with freshwater can kill some species, such as Samphire saltmarsh (NSW DPI 2013). The impacts on seagrasses from a 1% AEP coastal inundation event may be more associated with turbidity changes, which can persist for days/weeks after levels subside, and the resilience of the species.

Inundation mapping overlaid with available macrophyte and endangered ecological community (EEC) mapping are provided in Appendix C. The mapped scenarios included tidal inundation at HHWSS with 0.6 m, 0.9 m and 1.2 m sea level rises.

Protected aquatic and terrestrial vegetation with potential to be impacted by sea level rises and/or inundation are shown in Table 4-3.

Table 4-3 - Coastal Wetland and Littoral Rainforest Species

Family/group	Likely species	Area/s known to be mapped
Halophila	*Halophila ovalis* or *Halophilia decipiens* (NSW DPI 2007)	St. Georges Basin, Berrara Creek (NSW DPI 2022)
Posidonia	*Posidonia australis* (NSW DPI 2007)	St. Georges Basin, Sussex Inlet (NSW DPI 2022)
Zostera	*Zostera capricorni* or *Zostera muelleri* (NSW DPI 2007)	St. Georges Basin, Sussex Inlet (NSW DPI 2022) Berrara Creek (NSW DPI 2004)
Ruppia	*Ruppia maritima, Ruppia megacarpa* or *Ruppia polycarpa* (NSW DPI 2007)	Swan Lake (NSW DPI 2004)
Saltmarsh (EEC)	Various species, with coastal species in NSW including: *Baumea juncea* *Samolus repens* *Ficinia nodosa* *Zoysia macrantha* *Sarcocornia quinqueflora* *Sporobolus virginicus* *Suaeda australis* *Juncus kraussii* *Triglochin striata* *Selliera radicans* (NSW DPI 2013)	St. Georges Basin, Sussex Inlet, Swan Lake, Berrara Creek (NSW DPI 2004)
Mangroves	*Aegiceras corniculatum* or *Avicennia marina* (NSW DPI 2008)	St. Georges Basin, Sussex Inlet
Other EEC's	Swamp Oak Floodplain Forest Swamp Sclerophyll Forest Bangalya Sand Forest	Conjola National Park

4.3.1 Inundation Mapping

Inundation mapping overlaid with available macrophyte and endangered ecological community (EEC) mapping are provided in **Appendix C**. The mapped scenarios included tidal inundation at HHWSS under 0.6 m, 0.9 m and 1.2 m sea level rises. These maps and scenarios were used to make predictive informed assumptions on risks to estuarine and aquatic vegetation in relation to climate change or changes to water quality in the coastal environment as well as the coastal wetland/littoral rainforest management areas.

Mapping within all estuaries show that the risk to macrophytes is proportional to sea level rises in terms of the depth of inundation and extent of inundated area of land. More extensive impacts would be expected from 0.9 or 1.2 m sea level rises.

4.3.1.1 St Georges Basin

Within St. Georges Basin, mapping in **Appendix C** shows that areas with potential to become inundated are predominantly around the tributary inlets including Bae-Al Creek inlet, Booroowungan Creek inlet, Wandandian Creek and Tullarwalla inlets, Northwest bays (off Waterpark Road), Tomerong Creek inlet (and Sanctuary Point) and Erowal Bay.

These areas primarily support seagrasses (Posidonia, Zostera, Halophilia or Ruppia) but there are also small patches of saltmarsh in the northern bays and around the Tomerong Creek inlet (NSW DPI 2022).

The mapping shows the following:

- A 0.6 m sea level rise was modelled to have maximum tidal inundation at HHWSS between <0.25 m – 0.5 m within these areas, typically lasting for around 2-4 hours twice per month, and more frequent where the maximum depth approaches 0.5 m.
- A 0.9 m sea level rise was modelled to have maximum tidal inundation at HHWSS between <0.25 m – 1.0 m within these areas. Where the maximum depth >0.5 m, these areas would become permanently intertidal or subtidal.
- A 1.2 m sea level rise was modelled to have maximum tidal inundation at HHWSS between <0.25m - > 1.0 m within these areas. The largest areas of inundation are around the Wandandian Creek, Tullarwalla inlets and Tomerong Creek inlets. Where the maximum depth >0.5 m, these areas would become permanently intertidal or subtidal.

As discussed above, the response of vegetation is very dependent on the individual species preferred salinity range, preferred depth range, rate of recolonisation and resilience of species. Within the present day, Posidonia is the dominant seagrass type in St. Georges Basin with smaller areas of Zostera (NSW DPI 2022). Zostera may dominate under sea level rises, as is more resilient to wave action and has a quicker recovery following disturbances such as frequent inundations (Campbell and McKenzie 2004; Davis et al. 2016). Areas of terrestrial EEC that become permanently inundated, may be replaced by estuarine or coastal macrophytes. Posidonia seagrasses currently occur below low tide level, with Zostera occurring on tidal flats. With sea level rise, there is potential for the Zostera beds to extend over areas currently covered in mangroves and saltmarsh, and for Posidonia to migrate shoreward onto areas that are currently tidal flats, that would be expected to be permanently inundated. As sub-tidal seagrasses rely on light penetration, deeper water due to sea level rise may increase attenuation of sunlight and impact the Posidonia beds.

Saltmarsh inhabits the upper inter-tidal areas, above MHWS. With sea level rise, areas of existing saltmarsh will be inundated more often and with greater depth, with the saltmarshes having the potential to migrate to areas that will be in the upper intertidal zone with future sea level rise, displacing other vegetation communities including Swamp Oak forest and areas that are currently terrestrial ecosystems. The potential areas where this could occur have been mapped in **Appendix C**.

4.3.1.2 Sussex Inlet

Within Sussex Inlet, the mapping in **Appendix C** shows areas predicted to become inundated are Badgee Lagoon, the whole north-eastern point of the inlet, small areas along the eastern side of the inlet and some areas within the canals.

The macrophytes mapped within Sussex Inlet in these areas include seagrasses and mangroves with smaller pockets of saltmarsh (NSW DPI 2022). There are large areas of terrestrial EEC mapped on the southwest and northwest sides of the channel.

The mapping shows the following:

- A 0.6 m sea level rise was modelled to have maximum tidal inundation at HHWSS between <0.25 m – 0.5 m within these areas, typically lasting for around 2-4 hours twice per month, and more frequent where the maximum depth approaches 0.5 m..
- A 0.9 m sea level rise was modelled to have inundation between <0.25 m – 1.0 m within these areas. Where the maximum depth >0.5 m, these areas would become intertidal.
- A 1.2 m sea level rise was modelled to have maximum tidal inundation at HHWSS between 0.25m - 1.0 m within these areas. The largest areas of inundation are around the Wandandian Creek, Tullarwalla inlets and Tomerong Creek inlets. Where the maximum depth >0.5 m, these areas would become intertidal, and where maximum depth >1 m the areas may become subtidal.

At Sussex Inlet, areas that are currently intertidal may become subtidal with sea level rise, which may increase the potential habitat for seagrass where currently there are mangroves and saltmarsh. Areas in the mid-sections of the channel where tidal velocities are high currently have mobile sand bedforms where seagrass is unable to grow. With sea level rise, the width of the channel and mobile bedforms could increase, with the potential for areas which are currently habitat for seagrass beds to become smothered.

With sea level rise, areas of existing saltmarsh will be inundated more often and with greater depth, with the saltmarshes having the potential to migrate to areas that will be in the upper intertidal zone with future sea level rise. The potential areas where this could occur have been mapped in **Appendix C**.

4.3.1.3 Swan Lake and Berrara Creek

There are large areas of terrestrial EEC mapped around most of Swan Lake and saltmarsh within the inlet. Ruppia seagrasses are mapped within the northern bays of Swan Lake, although the mapping data is dated (NSW DPI 2004). There are small areas of EEC mapped within Berrara Creek within the inlet peninsula.

Within Swan Lake and Berrara Creek, the mapping in **Appendix C** shows that the risks to vegetation from inundation from sea level rises is low compared to the other estuaries. However, the risks during 1% AEP are high within Swan Lake as there are large areas of terrestrial EEC that fringe the northern bays within Conjola National Park that would be inundated.

The mapping shows the following:

- No significant areas of tidal inundation were modelled in these estuaries as a result of a 0.6 m sea level rise.

- A 0.9 m sea level rise was modelled to have small areas of tidal inundation between <0.25 m at the Teacreek Creek inlet in Swan Lake and at the mouth of Berrara Creek. The areas of inundation overlap with mapped EEC and seagrass (Ruppia in Swan Lake). Tidal inundation frequency would be limited to only when the Lake is open, as the Lake levels are controlled by the berm levels at the Lake entrance.
- A 1.2 m sea level rise was modelled to have inundation of small areas of saltmarsh between < 0.25 m – 0.5 m within peninsula within the inlets of both estuaries and areas of EEC and seagrass (Ruppia) within the northern bays of Swan Lake. The inlet at Teacreek Creek and Mondayong Creek inlet in Swan Lake was mapped to have large, inundated areas. Tidal inundation frequency would be limited to only when the Lake is open, as the Lake levels are controlled by the berm levels at the Lake entrance. Large areas at the northern end of the Lake could become inundated for extended periods depending on the level of the Lake entrance berm, which could increase on average with future sea level rise.

When the Lake entrance is closed, the water level in the Lake is controlled by the level of the entrance berm. Managing the berm levels via the Entrance Management Policy for Swan Lake will have an impact on the depth and duration of inundation of the mapped Coastal Wetland areas and EECs in the areas north of the northern bays of the Lake, which depend on occasional inundation. Examination of LIDAR data covering this area indicates that a lake level of 2.5 m AHD would be required to provide full inundation coverage of the wetland at the north-eastern end of the lake, and a minimum lake level of 2.3 m AHD would be needed to provide inundation of most of the mapped coastal wetland areas within Swan Lake. The implications of this are discussed further in Advisian (2022b). In addition, Ruppia habitat is limited to areas with depth of around 2 m. With sea level rise, the beach berm levels are expected to increase by approximately the quantum of sea level rise, which would increase the typical depth of the Lake, leading to a potential shoreward migration of the Ruppia habitat.

4.3.2 Mapping of Potential Mangrove and Saltmarsh Migration Areas

With sea level rise, there is the potential for mangroves and saltmarsh to migrate landwards into new habitat areas, provided that suitable land is available for this to occur.

The potential areas for migration of mangrove and saltmarsh areas have been examined for the following sea level rise scenarios:

- 0.9 m SLR
- 1.2 m SLR.

Maps that show the potential migration areas which may be suitable for mangrove and saltmarsh habitat under future sea level rise are provided in **Appendix C**. The methodology for this mapping was as follows:

- Areas with a predicted depth of 0.2m to 0.5m at HHWSS tides for 0.9 m and 1.2 m SLR scenarios were assumed to be suitable areas for saltmarsh, based on the existing distribution of saltmarsh in the estuaries as mapped by the NSW Fisheries Spatial Data Portal (accessed August 29, 2023).
- Areas with a predicted depth of 0.5m to 0.9m at HHWSS tides for 0.9 m and 1.2 m SLR scenarios were assumed to be suitable areas for mangroves, based on the existing distribution of mangroves in the estuaries as mapped by the NSW Fisheries Spatial Data Portal (NSW DPI 2022, accessed August 29, 2023).

- Where these areas overlapped with existing residential lots (e.g. within the Sussex Inlet main CBD area), it was assumed that mangroves or saltmarsh would not be allowed to expand into these areas. However, the mapping assumed that mangroves or saltmarsh may be allowed to expand into the portions of rural lots or foreshore reserves where limited built infrastructure exists.

It can be seen that:

- For St Georges Basin, there is potential for saltmarsh and mangroves to expand in the low-lying areas around Old Erowal Bay, and in fringing areas along the shoreline around Sanctuary Point and Basin View as well as around Wandandian Creek and Tullarwalla Inlet.
- For Sussex Inlet, there is potential for saltmarsh and mangroves to expand in the areas around Badgee Lagoon, as well as low-lying areas to the east of the main channel, around the boundaries of existing areas of mangroves and saltmarsh and in some limited locations along the existing foreshore reserves.
- For Swan Lake, there is potential for saltmarsh to expand into the coastal wetland areas in the north of the Lake, and some limited potential for expansion around the Lake foreshores.
- For Berrara Creek, there is potential for saltmarsh to expand into the existing coastal wetland area to the west of the creek channel, and some potential for mangroves and saltmarsh to colonise the fringes of the lake foreshore and within the reserve at Lakeway Avenue.

5 Discussion, Conclusions and Potential Management Actions

5.1 Discussion and Conclusion

This Tidal and Coastal Inundation Study provides combinations of water levels, tidal flows and sea level rise effects for the purposes of an inundation assessment for the St Georges Basin/Sussex Inlet, Swan Lake and Berrara Creek estuaries. The purpose of this Tidal and Coastal Inundation Study is to predict the possible inundation level and extents under design extreme events and regular tidal conditions defined as per DP&E guidelines (OEH 2015).

Tidal and coastal inundation mapping of the study area has been carried out to cover a range of sea level rise scenarios, representing 20 year, 50 year and 100 year planning timeframes. It should be noted that catchment-induced flooding is not included in this study. Flooding due to the combined effects of rainfall/runoff and elevated ocean water levels due to coastal storms is covered in the local flood studies for these estuaries, which are done under the NSW Floodplain Management Program.

This study has found that the study area will be affected significantly by tidal and coastal inundation with future sea level rise, due to generally low-lying infrastructure. It can be concluded that:

- At St Georges Basin, there are extensive areas around Sanctuary Point, Old Erowal Bay, Erowal Bay, Basin View and St Georges Basin Village that will be impacted by 1% *Annual Exceedance Probability*[8] (AEP) coastal inundation, with additional areas impacted under future sea level rise scenarios, and potential for areas to be isolated by inundation for up to several days. The northern foreshore of St Georges Basin is particularly vulnerable to coastal inundation combined with strong southerly winds, which induce both wind and wave setup along the shoreline, elevating water levels above what would otherwise occur in the absence of these winds. Foreshore reserves and waterside infrastructure around Sanctuary Point, St Georges Basin, Erowal Bay and Basin View are currently subject to tidal inundation. The impact to these areas will increase with sea level rise in the next 20 to 50 years, particularly impacting on waterside infrastructure, critical sewer infrastructure and several residential lots in Sanctuary Point, Erowal Bay and Basin View.

- At Sussex Inlet, the town centre is affected by 1% AEP coastal inundation under present day conditions, with the depth and frequency of inundation expected to increase under future projected sea level rise. Under the various sea level rise scenarios, both coastal and tidal inundation will affect large areas of the town centre and access to and within the township is likely to be cut off by inundation. Tidal inundation is likely to become more common with sea level rise over the next 20 to 50 years with predictions that areas of Sussex Inlet, including the main CBD, will be inundated by more than 20cm up to twice per month during extreme high tides.

- At Swan Lake and Berrara Creek, tidal inundation is expected to have relatively minor impacts. However, under 1% AEP coastal inundation conditions with future sea level rise projections,

[8] *Annual Exceedance Probability (AEP)* refers to the probability that a particular event will be exceeded in any given year. A 1% AEP coastal inundation event refers to coastal inundation that has a 1% chance of being exceeded in any given year, equivalent to an event that would occur, on average, once in 100 years.

there is potential for the main access to Berrara and Cudmirrah to be cut off at Collier Drive, and inundation for several hours up to 0.25 m depth at low lying parts of the Holiday Haven Swan Lake caravan park. Coastal inundation of critical water infrastructure at Berrara including a water pumping station and water and wastewater mains is predicted under future sea level rise projections.

Coastal and tidal inundation due to future sea level rise has the potential to impact on the aquatic vegetation within the study area, in the following ways:

a) landward migration of macrophyte or coastal vegetation species,

b) shift in dominant species and/or

c) reduced or loss of biodiversity.

Mapping of the potential migration areas which may be suitable for mangrove and saltmarsh habitat under future sea level rise is provided in **Appendix C**. This mapping shows that:

- For St Georges Basin, there is potential for saltmarsh and mangroves to expand in the low-lying areas around Old Erowal Bay, and in fringing areas along the shoreline around Sanctuary Point and Basin View as well as around Wandandian Creek and Tullarwalla Inlet
- For Sussex Inlet, there is potential for saltmarsh and mangroves to expand in the areas around Badgee Lagoon, as well as low-lying areas to the east of the main channel, around the boundaries of existing areas of mangroves and saltmarsh and in some limited locations along the existing foreshore reserves
- For Swan Lake, there is potential for saltmarsh to expand into the coastal wetland areas in the north of the Lake, and some limited potential for expansion around the Lake foreshores.
- For Berrara Creek, there is potential for saltmarsh to expand into the existing coastal wetland area to the west of the creek channel, and some potential for mangroves and saltmarsh to colonise the fringes of the lake foreshore and within the reserve at Lakeway Avenue.

5.2 Potential Management Actions

Key issues relating to coastal and tidal inundation within the study area include:

- Damage to public infrastructure and critical services due to increased frequency and duration of inundation due to future sea level rise and coastal/tidal inundation.
- Increasing depth, duration and frequency of coastal and tidal inundation of urban areas.
- Whether Council's existing sea level rise projections for planning purposes are appropriate, given the most recent advice from the Intergovernmental Panel on Climate Change (IPCC)
- Sea level rise and coastal inundation have the potential to raise water tables in low-lying areas; the impact of this on the foundations of existing and future development is poorly understood.
- Threat to public safety as a result of increased frequency and duration of coastal and tidal inundation events.

These issues and some suggested potential estuary-wide management actions to address these issues for consideration in Stage 3 are outlined in Table 5-1, with location-specific actions outlined in Table 5-2.

Table 5-1 – Key Estuary-wide Issues and Potential Management Actions relating to Inundation and Sea Level Rise

ID	Coastal Management Area	Issue	Existing Controls	Potential Management Action
EW-I01	Coastal Vulnerability	Damage to public infrastructure and critical services due to increased frequency and duration of inundation due to future sea level rise and coastal/tidal inundation.	Council is drafting a Climate Change Adaptation Plan that includes actions to adapt to sea level rise on a city-wide scale. These actions include undertaking risk assessments for council assets to identify and prioritise areas, infrastructure, and assets at risk from coastal inundation, storms, and flooding, and ensuring that asset management plans consider risk of storms, sea level rise and inundation for Council assets and infrastructure.	This action involves investigating the feasibility of moving identified vulnerable public infrastructure landward, e.g. sewage network and managing sewage overflows. While the St Georges Basin Floodplain Risk Management Study and Plan covers catchment flooding and includes emergency management aspects, many of the actions in that Plan are relevant for coastal and tidal inundation hazards. Specific actions for individual public assets identified as being at risk from coastal inundation (e.g. sewage pumping stations, water and sewer mains, roads, access paths etc.) have been developed separately, depending on the severity of the risk. Council should review and update all Asset Management Plans relevant to each asset at risk from coastal inundation. Specific activities may include implementing one way valves for stormwater, encouraging the installation of rainwater tanks, and upgrades to stormwater infrastructure drainage. Consultation with Transport for NSW would be required with respect to actions involving roads. Learn from program of pothole repairs implemented following the East Coast Low events of March and April 2022 to improve response, continue to monitor performance/condition of infrastructure following coastal hazard events.

ID	Coastal Management Area	Issue	Existing Controls	Potential Management Action
EW-I02	Coastal Vulnerability	Increasing depth, duration and frequency of coastal and tidal inundation of urban areas.	Development controls, monitoring, flood warning system and flood evacuation procedures.	This action involves supporting the implementation of actions from the Shoalhaven Flood Risk Management Plan and Council Climate Change Adaptation Plan, and identification of specific actions from these Plans to mitigate against sea level rise and coastal inundation in the CMP. There is also the need to ensure consistency between the actions in all three documents. Engage with NSW SES to update the Shoalhaven City Local Flood Plan with the results of coastal hazard studies to help manage coastal hazard emergencies.
EW-I03	Coastal Vulnerability	The Intergovernmental Panel on Climate Change (IPCC) has revised global sea level rise projections in 2022 through its Sixth Assessment Report. The Shoalhaven Council Sea Level Rise Framework are no longer consistent with the most recent advice from the IPCC.	Shoalhaven Council Sea Level Rise Framework.	The Shoalhaven Sea Level Rise Framework requires review to ensure that sea level rise projections for planning purposes reflect state government policies, as well as the most recent science and advice from the IPCC.
EW-I04	Coastal Vulnerability	Sea level rise and coastal inundation have the potential to raise water tables in low-lying areas; the impact of this on the foundations of existing and future development is poorly understood.	Council Development Control Plan	Investigate impact of rising water tables and engineering measures to mitigate against or prevent groundwater damage to building foundations and services. Include these in development controls for new DAs.
EW-I05	Coastal Vulnerability	Threat to public safety as a result of increased frequency and duration of coastal and tidal inundation events.	Development controls, monitoring, flood warning system and flood evacuation procedures.	Prepare and implement Coastal Zone Emergency Action Subplan (CZEAS): This action would involve the preparation of a Coastal Zone Emergency Action Subplan (CZEAS) for Sussex Inlet, St Georges Basin, Swan Lake and Berrara Creek. This would primarily

ID	Coastal Management Area	Issue	Existing Controls	Potential Management Action
				address emergency response to coastal inundation events and would need to be consistent with the Shoalhaven City Local Flood Emergency Sub Plan 2014.

Table 5-2 – Location-specific Issues and Potential Management Actions relating to Inundation and Sea Level Rise

ID	Location	Issue	Potential Management Action
I01	St Georges Basin - Basin View	Impact of SLR on tidal inundation at Harriss Ave, risk of isolation	Investigate risk of inundation of bridge and undertake rectification works if required - Implementation of findings of the St Georges Basin Floodplain Risk Management Study and Plan (including emergency management aspects)
I02	St Georges Basin - The Wool Road	Impact of SLR on tidal inundation at The Wool Road, risk of isolation	Investigate risk of inundation of bridge and undertake rectification works if required - Implementation of findings of the St Georges Basin Floodplain Risk Management Study and Plan (including emergency management aspects)
I03	St Georges Basin - The Wool Road	Impact of SLR on tidal inundation on sporting grounds, parks and recreation facilities	Upgrade of materials for park furniture/playgrounds to improve resilience against inundation, emergency asset assessments and prioritisation for upgrades
I04	Sussex Inlet	Impact of SLR on tidal inundation on public and private assets	Investigate impact of raised groundwater levels on building foundations, review development controls for floor levels for residential buildings
I05	Sussex Inlet	Impact of SLR on tidal inundation on public and private assets	Investigate potential to raise local roads and provide drainage channels/culverts for tidal inundation

ID	Location	Issue	Potential Management Action
I06	Sussex Inlet	Tidal and coastal inundation of low-lying caravan parks on Crown Land	Investigate tidal and coastal inundation risk to two low-lying caravan parks on Crown Land in St Georges Basin and work with low-lying caravan parks to update their emergency response plans to prepare for and respond to coastal hazards (short term)
I07	Sussex Inlet	Potential for community isolation in an inundation event, emergency management	Community education on risk of not following evacuation orders, community education to enhance understanding of inundation risk, works to raise key evacuation routes above inundation levels
I08	Sussex Inlet	Potential for community isolation in an inundation event, emergency management	Community education on risk of not following evacuation orders, community education to enhance understanding of inundation risk, works to raise key evacuation routes above inundation levels
I09	Swan Lake	Potential for community isolation in an inundation event, emergency management	Community education on risk of not following evacuation orders, community education to enhance understanding of inundation risk, works to raise key evacuation routes above inundation levels
I10	Swan Lake	Potential for community isolation in an inundation	Adaptation planning, raising/moving of at-risk infrastructure or access points. Updated development controls within Coastal Vulnerability Area (CVA) mapped areas.

ID	Location	Issue	Potential Management Action
		event, emergency management	
I11	Sussex Inlet	Potential for community isolation in an inundation event, emergency management	Community education on risk of not following evacuation orders, community education to enhance understanding of inundation risk, works to raise key evacuation routes above inundation levels
I12	Swan Lake	Inundation of low-lying sections of caravan park	Undertake regular maintenance of stormwater system in this area to ensure adequate drainage and reduce risk of inundation
I13	Swan Lake	Inundation of access to The Springs Road cabins	Raise access track to The Springs Cabins to allow continued access during high lake levels
I14	Swan Lake	Inundation of footpath at Springs Road	Raise footpath and provide cross-drainage to allow tidal inundation to occur without impacting local infrastructure and amenity
I15	Swan Lake	Impact of bridge on inundation levels	Consider impact of future inundation levels on bridge when bridge is due to be replaced
I16	Berrara Creek	Impact of SLR on tidal inundation on	Upgrade of materials for park furniture/playgrounds to improve resilience against inundation

ID	Location	Issue	Potential Management Action
		public and private assets	
I17	Swan Lake	Impact of SLR on tidal inundation on public and private assets	Upgrade of materials for park furniture/playgrounds to improve resilience against inundation
I18	Sussex Inlet	Impact of SLR on tidal inundation on public and private assets	Upgrade of materials for park furniture/playgrounds to improve resilience against inundation
I19	Sussex Inlet	Increased frequency of damage to roads from inundation	Implement learnings from previous storm events to make roads more resilient against increased inundation frequency, e.g. investigate more resilient pavement design, repair methodology

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