Assessing the impact of sewage overflows on oyster harvest areas: Nambucca River estuary technical summary

WRL TR 2023/19, May 2025

By M Mason, A J Harrison, Y Doherty and B M Miller

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1 Introduction

1.1 Project overview

The Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Sydney was engaged to undertake an extensive study titled “Assessing the impact of sewage overflows on oyster harvest areas in NSW”. This study was funded through a Department of Regional NSW Storm and Flood Industry Recovery Program (SFIRP) – Sector Recovery and Resilience grant with support from local councils and wastewater authorities.

The study seeks to understand the fate of contaminants and the potential exposure of oyster leases following overflow events under different environmental conditions including tides, wind and catchment runoff. The results of this study provide decision makers with quantitative data to assess exposure risk to specific harvest areas on an individual sewer overflow event basis. These outcomes allow for increased confidence in ensuring consumer safety, and more targeted harvest area closures to reduce the economic impact of widespread closures on local industry.

Sewage overflows into estuaries occur under a range of conditions, often due to malfunctioning or overwhelmed infrastructure. As a result, the environmental conditions in the estuary at the time of an overflow can vary. While experimental data (such as large scale dye release experiments) can be useful to understand contaminant transport in a single set of conditions (or a small number of conditions), it is impractical to collect such data for the broad range of conditions possible across multiple sewage overflow locations. Therefore, the approach of this study is to combine desktop numerical modelling and site-specific field investigations as a cost-effective means to gain sufficient understanding of contaminant transport.

For a detailed background to the study, refer to the User Guide (WRL TR2024/26).

1.2 Report context

This report is focussed on the Nambucca River estuary. It provides technical details of the available data, data collection undertaken, model development and the capabilities of the predictive model.

This report provides specific details for the Nambucca River estuary and should be read in parallel with User Guide WRL TR2024/26 and Technical Summary Report WRL TR2023/32 (Table 1-1). The other reports for each specific estuary are listed in Table 1-2.

Table 1-1 Summary of project reference documents

Report number	Intention
WRL TR2024/26	Project overview and user guide
WRL TR2023/32	Technical summary of fieldwork and modelling methods

Table 1-2 Summary of estuary specific reports

Estuary	Technical summary
Tweed River	WRL TR2023/18
Nambucca River	WRL TR2023/19 (this report)
Hastings River	WRL TR2025/05
Camden Haven River	WRL TR2023/20
Wallis Lake	WRL TR2023/21
Port Stephens	WRL TR2023/22
Clyde River	WRL TR2023/24
Shoalhaven/Crookhaven Rivers	WRL TR2023/23
Wagonga Inlet	WRL TR2023/25
Merimbula Lake	WRL TR2023/26
Pambula Lake	WRL TR2023/27

1.3 Nambucca River site description

The Nambucca River estuary is a coastal river in NSW, Australia, located 400 km north of Sydney and 40 km south of Coffs Harbour. Major towns in the area include Nambucca Heads, Macksville and Bowraville. The river has a catchment of around 1,300 km^2, with major tributaries including Newee Creek, Taylors Arm and Warrell Creek. The tidal extent reaches 30 km upstream and the tidal prism of the estuary was approximately 5.24 x 10^6 m^3 on a spring tide in 1999 (MHL, 1999). The estuary has one training wall, on the north (left) bank. The estuary entrance consists of several channels between fixed islands and mobile sand bars. The entrance configuration is highly variable, and this variability leads to large changes in the hydrodynamics of the system. The estuary has three oyster harvest areas, Lower, Middle and Upper Nambucca, shown in Figure 1-1.

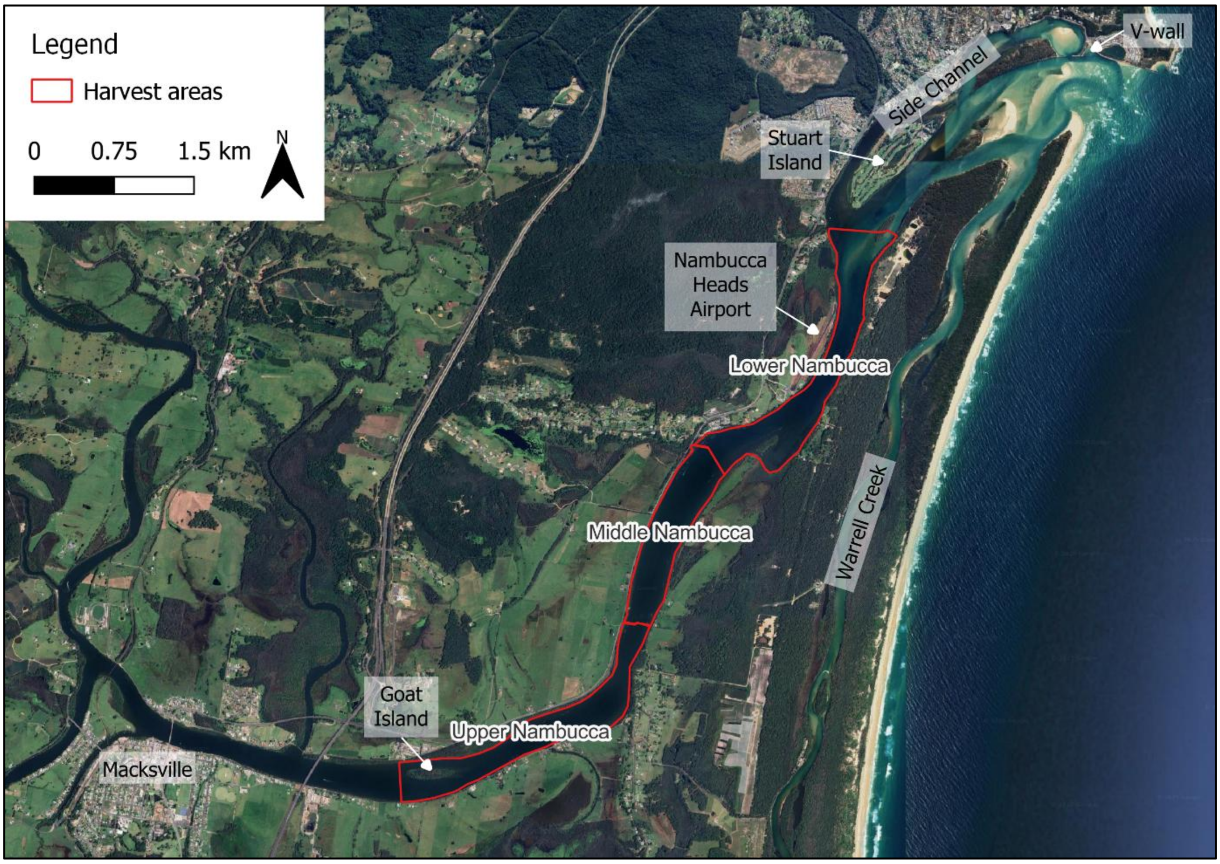

Figure 1-1 Oyster harvest areas on the Nambucca River

1.4 About this report

This report includes the following sections:

- **Section 2: Data collation** – summarising the relevant existing data available to assist in calibration and verification of the numerical model of the estuary, including information on historical sewage overflow locations.
- **Section 3: Field data collection** – summarising the outcomes of a field data collection campaign on the estuary.
- **Section 4: Model development** – outlining the development of the numerical model of the estuary.
- **Section 5: Scenario modelling** – describing the suite of scenarios run for the estuary.

The following appendices are included which provide additional detail:

- **Appendix A: Field data collection**
- **Appendix B: Model calibration**

2 Data collation

2.1 Preamble

Table 2-1 summarises the preexisting available data relevant for development of the numerical hydrodynamic and water quality model.

Table 2-1 Summary of data collated for this project

Data type	Primary sources	Comments	Report section
Long term water level data	MHL (2023a) MHL (2023b)	Long term water level data available at five locations in the Nambucca River estuary and at one nearby ocean tide gauge.	2.2
Tidal flow and water level	MHL (1999)	Tidal flow gauging at eight locations and temporary water level gauging at an additional 12 locations in August/September 1999.	2.2
Catchment discharge	WaterNSW (2023)	Three long term catchment flow monitoring locations.	2.3
Sewage overflows	NSW Food Authority	Data on overflows reported to EPA and NSW Food Authority including volume, duration and closure action.	2.4
Bathymetry	DPIE (2018) OEH (2009) NSW Spatial Services (2009); NSW Spatial Services (2016) NearMap (2024)	Bathymetry primarily sourced from 2018 NSW Marine LiDAR Topo-Bathy survey and 2009 single beam survey, with supplementary data from 2016 and 2009 Digital Elevation Model (DEM) and NearMap aerial images.	2.5

2.2 Water level and tidal flow gauging

Manly Hydraulics Laboratory (MHL) maintain five permanent water level gauges on the Nambucca River, and a nearby ocean tide gauge at Coffs Harbour. Further water level and flow gauging has occurred during the MHL short-term data collection campaign in 1999. These gauging and water level sensor locations are shown in Figure 2-1 and tabulated in Table 2-2 and Table 2-3. Water level and flow gauging locations from the 2023 field campaign (refer to Section 3) are also included in these.

Table 2-2 Summary of water level gauges on the Nambucca River and relevant ocean tide gauges

Water level gauge	Location label	Station number	Provider	Date range	MHL report number
Coffs Harbour Inner Pumpout Jetty		205470	MHL	1996 – present	
Stuart Island	3	205466	MHL	2009 – present	-
Macksville	7	205416A	MHL	1983 – present	-
Utungun	10	205414	MHL	1991 – present	-
Bowraville Downstream	9	205425	MHL	2008 – present	-
Warrell Creek	15	205490	MHL	2010 – present	-
Entrance Site 2	1	-	MHL	01/09/1999 – 28/09/1999	MHL1025
Downstream Island Site 4	2	-	MHL	31/08/1999 – 28/09/1999	MHL1025
Motel Site 9	4	-	MHL	31/08/1999 – 28/09/1999	MHL1025
Newee Creek Entrance Site 21	5	-	MHL	26/09/1999 – 28/09/1999	MHL1025
Newee Creek Upper Site 23	6	-	MHL	01/09/1999 – 28/09/1999	MHL1025
Wonboyne Site 13	8	-	MHL	30/08/1999 – 28/09/1999	MHL1025
Taylors Arm Boat Harbour Bridge Site 26	11	-	MHL	01/09/1999 – 28/09/1999	MHL1025
Warrell Creek Entrance Site 16	12	-	MHL	31/08/1999 – 28/09/1999	MHL1025
Warrell Creek Scott Head Site 18	13	-	MHL	31/08/1999 – 28/09/1999	MHL1025
Warrell Creek Highway Bridge Site 19	14	-	MHL	31/08/1999 – 28/09/1999	MHL1025
Warrell Creek Upstream Site 20	16	-	MHL	26/09/1999 – 28/09/1999	MHL1025
V-wall	17	-	WRL	26/06/2023 – 29/06/2023	
Side Channel Jetty	18	-	WRL	26/06/2023 – 29/06/2023	
Motel	19	-	WRL	27/06/2023 – 29/06/2023	

Table 2-3 Summary of tidal flow gauging locations on the Nambucca River

Tidal flow gauge	Location label	Dates	Study
Side Channel Main Entrance Site 3	A	27/09/1999, 26-29/06/2023	MHL1025, 2023 fieldwork
Stuarts Island Site 5	B	27/09/1999, 26-29/06/2023	MHL1025, 2023 fieldwork
Warrell Point Site 6	C	27/09/1999, 26-29/06/2023	MHL1025, 2023 fieldwork
Warrell Creek Entrance Site 15	D	27/09/1999	MHL1025
Warrell Creek Scotts Head Site 17	E	27/09/1999	MHL1025
Resort Site 8	F	27/09/1999	MHL1025
Showground Site 12	G	27/09/1999	MHL1025
Taylors Arm Site 24	H	27/09/1999	MHL1025
Breakwater Main Channel	I	26-29/06/2023	2023 fieldwork
Breakwater Island	J	26-29/06/2023	2023 fieldwork
Airport	K	26-29/06/2023	2023 fieldwork

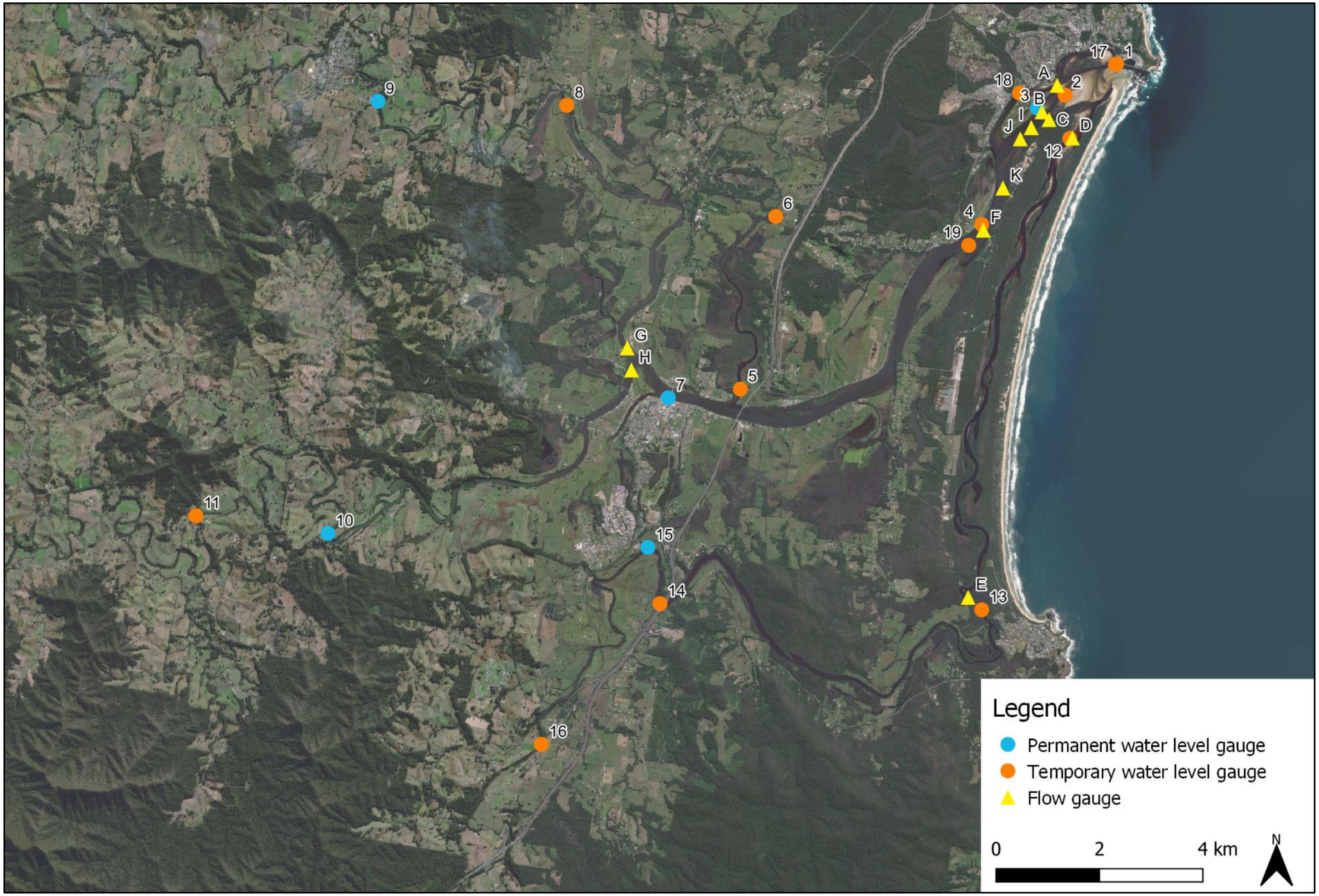

Figure 2-1 Water level and tidal flow gauging locations

2.3 Catchment inflows

Gauged catchment inflows were available from WaterNSW. When these were not at the tidal limit (the model boundary), the flows were scaled up proportional to the additional catchment area using the method in WRL TR2023/32 Section 2.4. There are four model boundary inflows into the Nambucca estuary and continuous flow gauging of discharge and water levels are available from WaterNSW (2023) at three relevant locations: Nambucca River (North Arm) at Bowraville (2006 to present), Taylors Arm at Upper Taylors Arm (2006 to present) and South Creek at Bowraville (2011 to present). Table 2-4 lists the model boundaries, the gauges used and the relevant scaling factor applied. Figure 2-2 shows the locations along with the catchment area flowing into each tidal boundary (solid line polygon) along with the associated portion of that catchment that is upstream of each gauge (hatched). Note the inflows of both the Nambucca River and South Creek inputs are combined and enter the model at a single location.

Table 2-4 Summary of scaling factors for model catchment boundaries

Model boundary	Base WaterNSW gauge	Scaling factor
Nambucca River	205015	1.000
Bellwood Creek*	205015	0.018
South Creek	205018	1.000
Taylors Arm	205017	1.745
Warrell Creek*	205017	1.005

*This catchment was ungauged, so the gauge in a nearby catchment was scaled and used.

Flowrates exceeded at various percentiles for each WaterNSW gauge are shown in Table 2-5.

Table 2-5 WaterNSW gauge flow percentiles

Percentile	Nambucca River (North Arm) at Bowraville (205015) ML/d *(m^3/s)*	Taylors Arm at Upper Taylors Arm (205017) ML/d *(m^3/s)*	South Creek at Bowraville (205018) ML/d *(m^3/s)*
5th	17 *(0.20)*	0.91 *(0.01)*	1.1 *(0.01)*
20th	34 *(0.40)*	6.7 *(0.08)*	4.3 *(0.05)*
50th (median)	83 *(0.96)*	31 *(0.36)*	14.9 *(0.17)*
80th	362 *(4.2)*	145 *(1.7)*	80 *(0.93)*
95th	1710 *(20)*	736 *(8.5)*	632 *(7.3)*

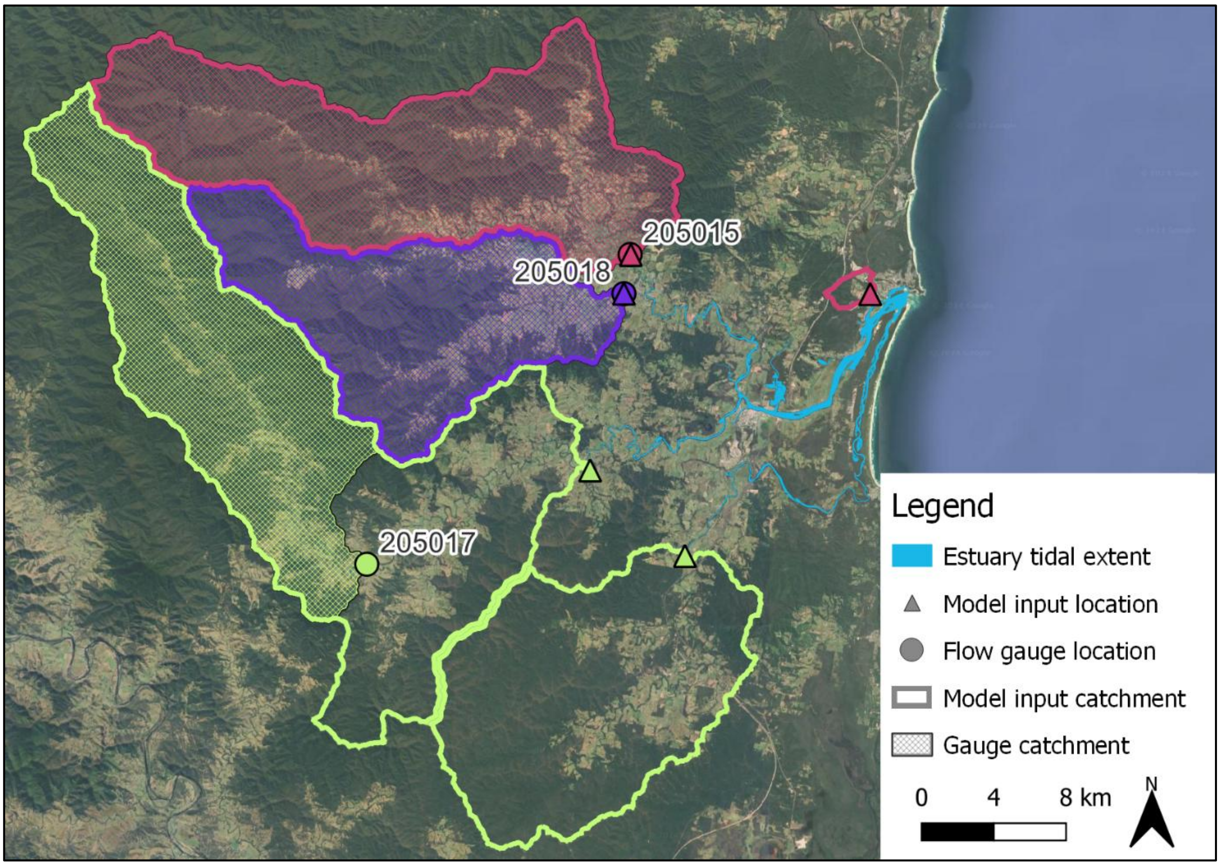

Figure 2-2 Catchment flow gauging stations*

*Hatched areas correspond to upstream catchments of WaterNSW gauges. Outline areas correspond to model input catchment areas. The colour of each outline corresponds to the WaterNSW gauge used for flow scaling.

2.4 Sewage overflow data

Nambucca Valley Council (NVC) is the agency responsible for wastewater treatment and sewage management in the catchment surrounding the Nambucca River estuary. The sewerage system is comprised of a reticulation network of pipes and sewage pumping stations (SPS), in addition to wastewater treatment plants (WWTPs) at Bowraville and Macksville. When sewage overflows occur, NVC is required to notify NSW Food Authority so that appropriate decisions can be made on whether harvest area closures are necessary. Information on sewage overflows between 2016 and 2023 has been provided by the NSW Food Authority and reported overflow locations are shown in Figure 2-3. More information on sewage overflows and why they occur is provided in WRL TR2023/32 Section 2.5.

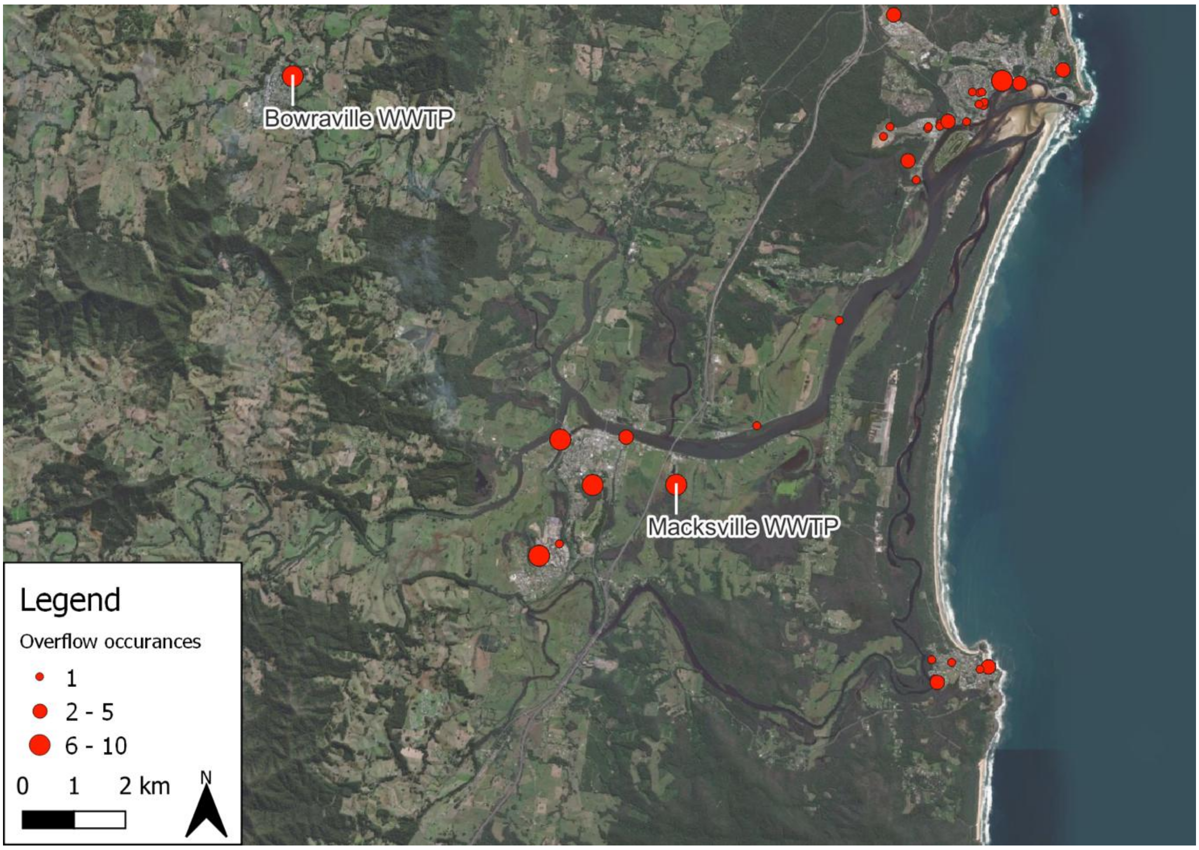

Figure 2-3 Locations of reported sewage overflows on the Nambucca River

2.5 Bathymetry

Two existing bathymetry datasets were sourced for this project:

- Coastal marine LiDAR collected by the former NSW Department of Planning, Industry and Environment (now DCCEEW) in 2018. In the Nambucca area, this survey covers areas 1.5 to 2 km from the coast (shown in Figure 2-4) at a resolution of 5 m.
- Single beam bathymetry data collected in 2009. This dataset was collated and provided by the NSW Office of Environment and Heritage (OEH, now DCCEEW) and is available on the Australian Ocean Data Network (AODN) portal. This data covers the vast majority of the model domain, with higher density coverage in the lower estuary. Transect spacing in the lower estuary is every 25 m, increasing to every 100 m in upstream reaches (refer to Figure 2-5).

For areas where the two surveys overlapped, results were compared and can be seen in Figure 2-6. The bathymetry in the area near Nambucca Heads has changed significantly between the two surveys. Most notably, the entrance during the 2009 survey is relatively unrestricted, however, the entrance bar blocks most of the channel in 2018, meaning the southern channel which flows along Warrell Point follows a less direct path to the ocean. This is not a long term trend, instead representing fluctuations in entrance state over time, further discussed in Section 5.4.2, where examples of the variation in entrance morphology in recent years can be found. Other sand bars have also moved significantly, with bathymetry change of greater than 1 m experienced in most of the main channel between Nambucca Heads Airport and the ocean.

Additional topographic and aerial data utilised include:

- 1 x 1 m DEM LiDAR data, collected in 2009 and 2016 and available from NSW Spatial Services, was used for shallow areas inland of the extent of the 2018 LiDAR survey, provided they were above water level during the 2012 survey.
- High resolution NearMap imagery was used to qualitatively provide information on important bathymetric features, mainly the changes at the entrance over time.

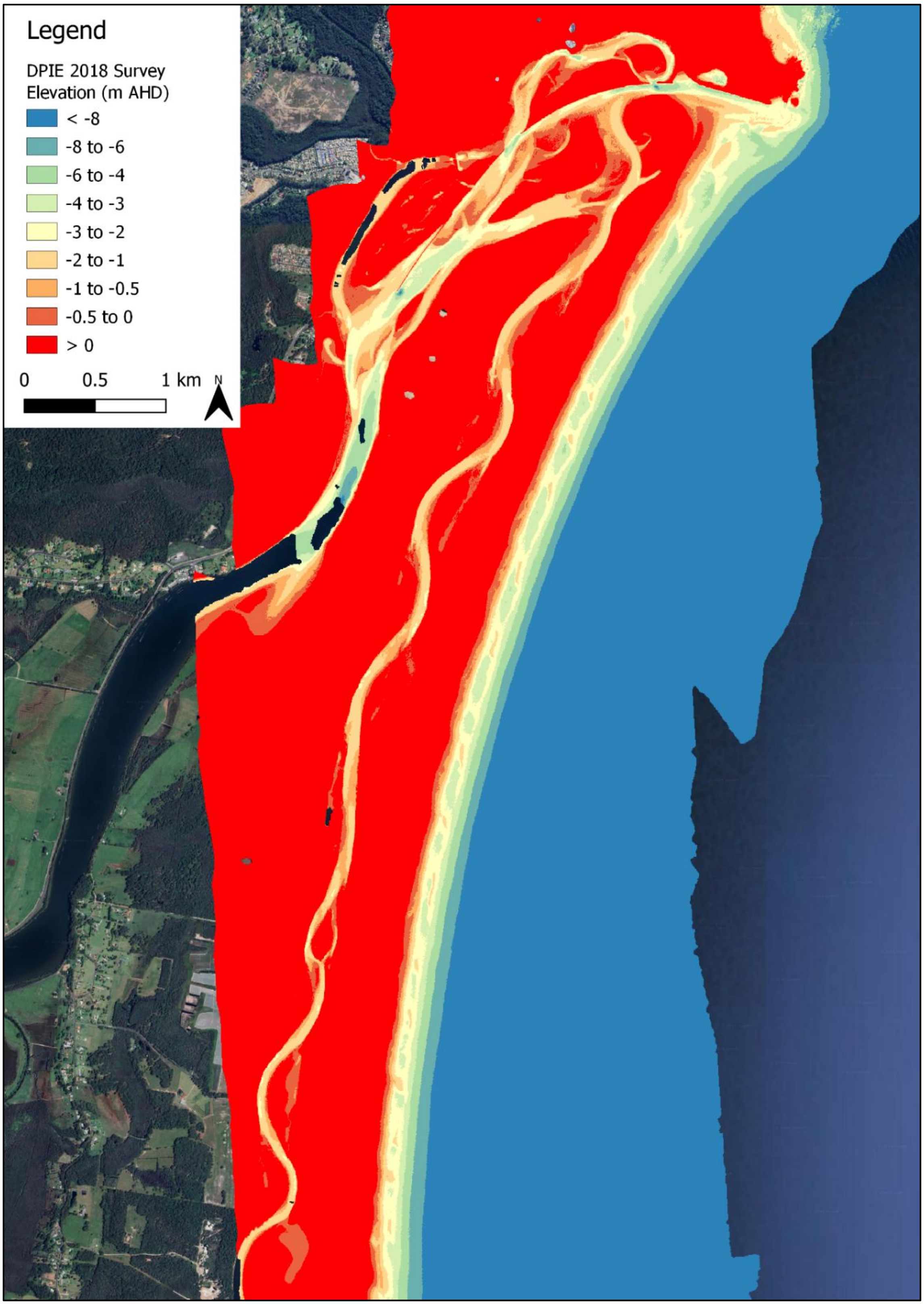

Figure 2-4 Coverage of 2018 LiDAR survey data

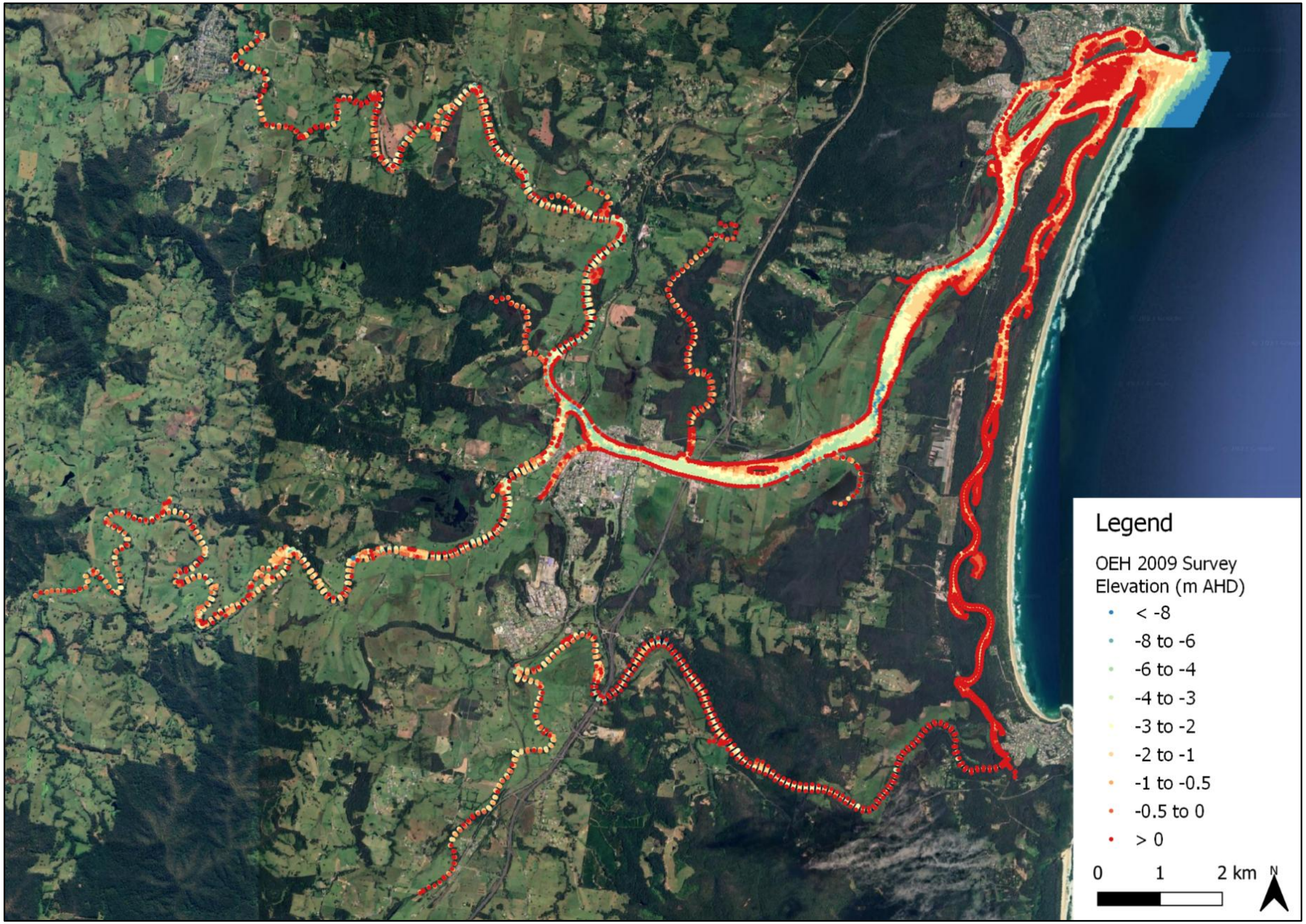

Figure 2-5 Coverage of 2009 single beam data

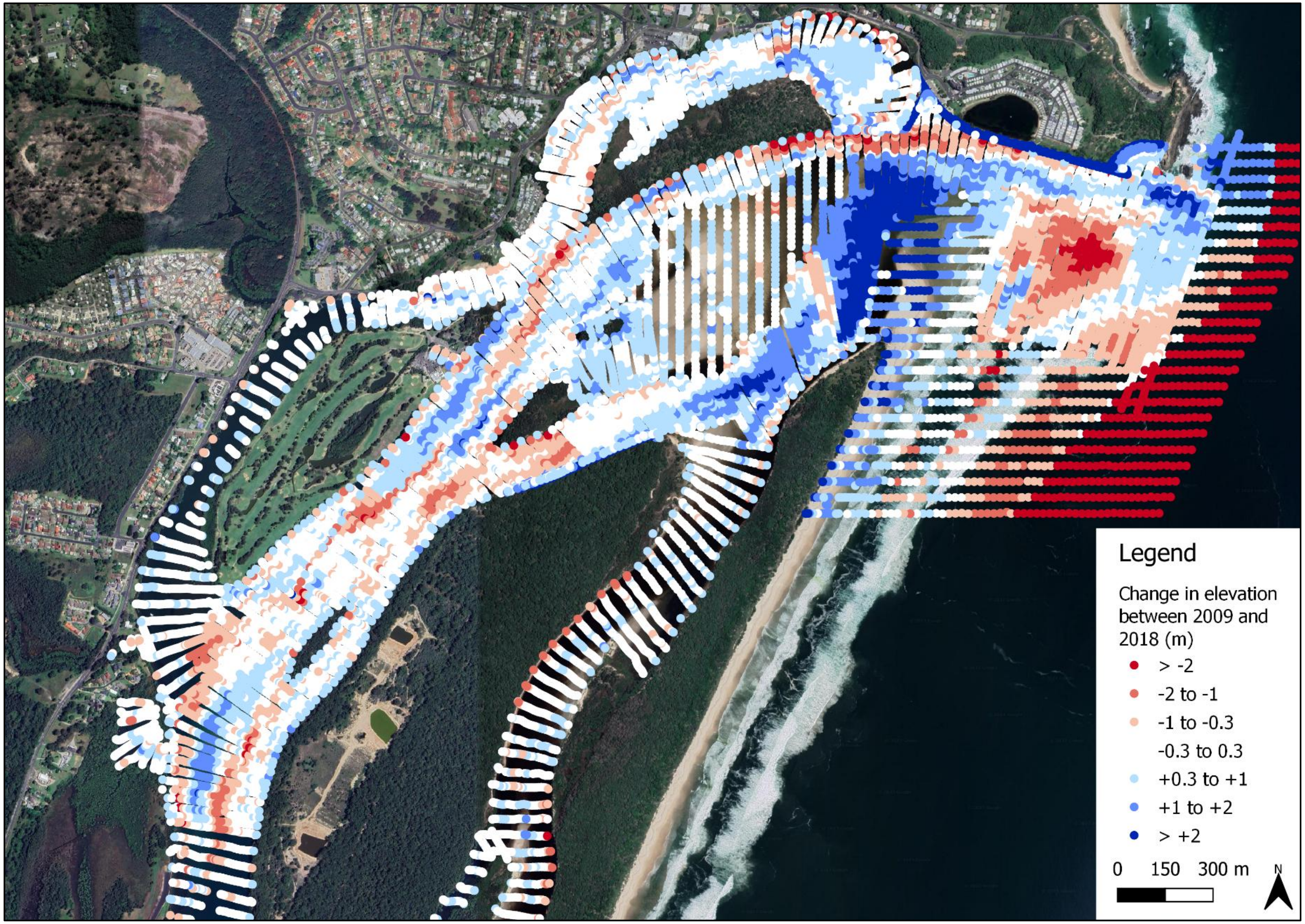

Figure 2-6 Bathymetry change between 2009 survey and 2018 marine LiDAR. Red represents erosion and blue represents accretion

3 Field data collection

3.1 Preamble

A data collection campaign was completed on 27 to 29 June 2023 by WRL Engineers, Margot Mason and Alice Harrison. Field data collection included:

- Monitoring of current velocities and volumetric flow using an ADCP
- Monitoring of dispersion and advection using Rhodamine WT dye
- Monitoring of surface current speed and flow paths using GPS drifter drogues
- Water level monitoring at three sites in addition to collation of data from MHL water level monitoring sites
- Conductivity measurements

3.2 Weather and tides

Data collection on the Nambucca River was undertaken on both ebb and flood tides. Tides during field investigations were similar both days, with tidal ranges between approximately -0.2 to 0.50 m AHD at Stuarts Island, near the estuary entrance. The observed water levels at Stuarts Island, alongside the timing of key fieldwork components is shown in Figure 3-1. Predicted and observed tides at the nearby MHL ocean tide station at Coffs Harbour are shown in Figure 3-2. Although the observed tide is noisy, the tides correspond well, except for a positive anomaly experienced on the final day of fieldwork, which is explained by low pressure (MHL, 2023a).

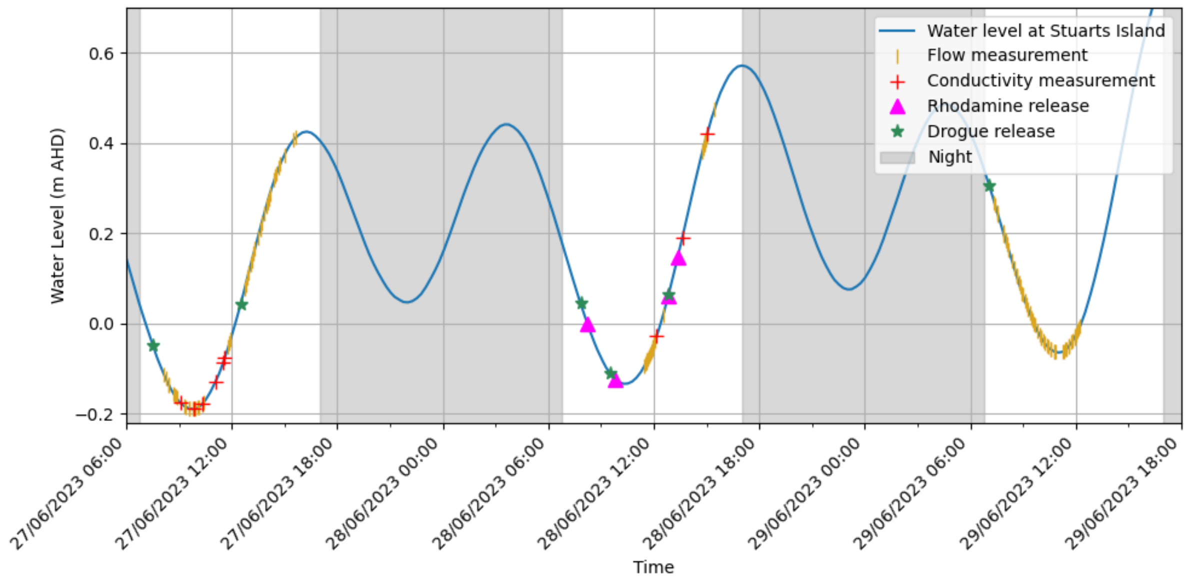

Figure 3-1 Tides at Stuarts Island with timing of key data collection events

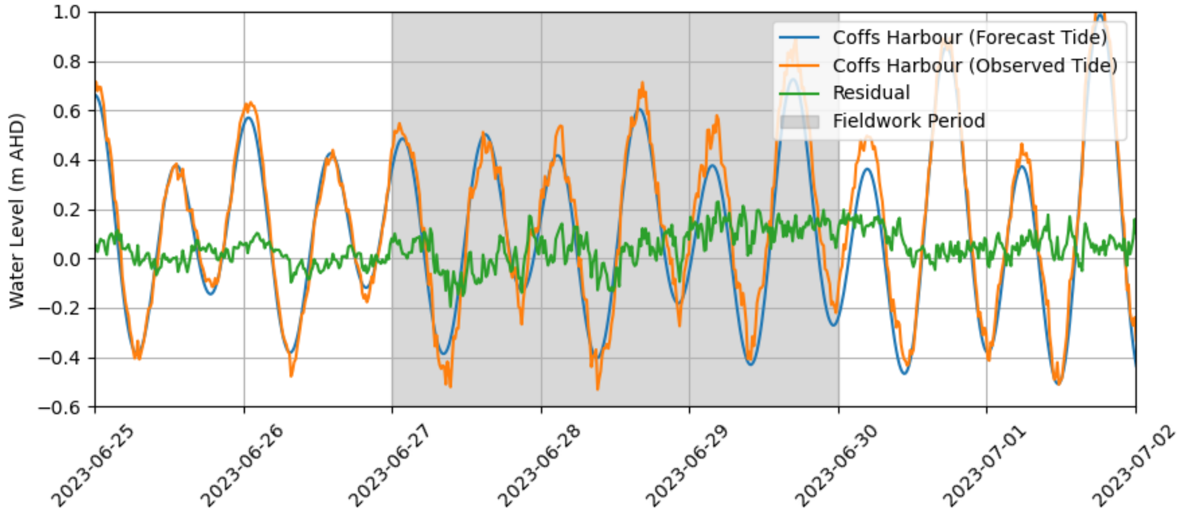

Figure 3-2 Forecasted and observed tides at Coffs Harbour

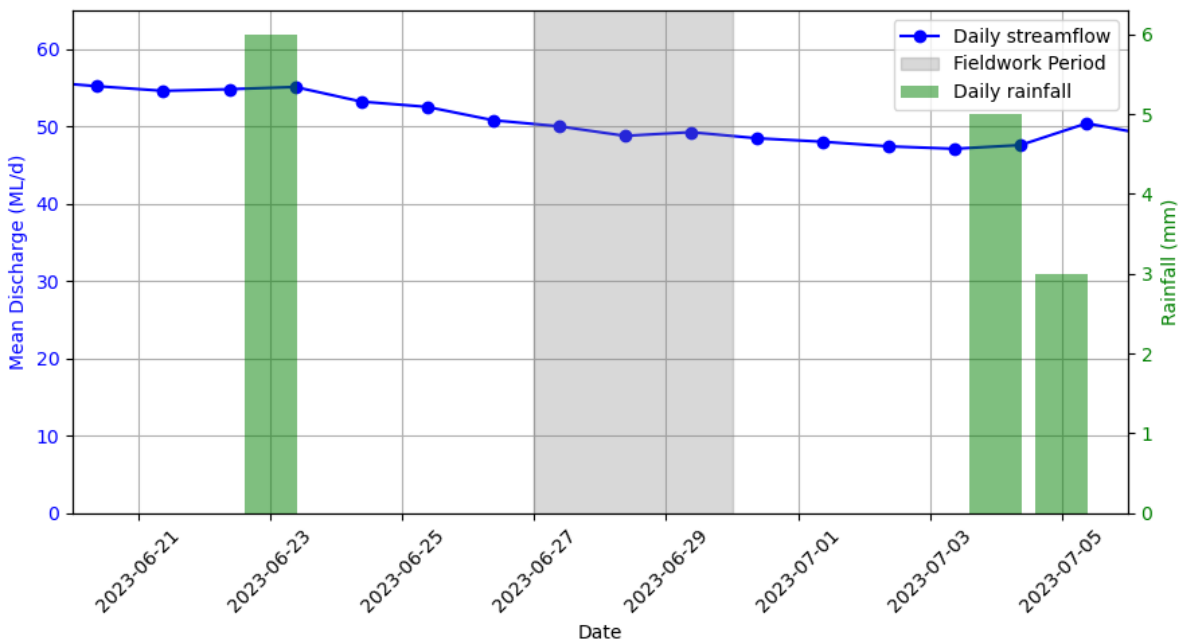

Figure 3-3 Rainfall recorded at Bellwood and streamflow recorded at Nambucca River at Bowraville for the period surrounding fieldwork

While no rain fell during fieldwork, 6 mm was observed at Bellwood (BoM station 059150) during the week preceding fieldwork (refer to Figure 3-3). As can be seen in Figure 3-3, freshwater inflows from the upstream catchments were low. Streamflows were all below median flows at the WaterNSW gauges upstream of Nambucca estuary, discussed in Section 2.3. Wind speeds were less than 15 km/hr from the west and south west on 27 and 28 June 2023, and increased to approximately 40 km/hr (from the south west) in the afternoon of 29 June.

3.3 Tidal flow gauging

Flow was measured using a boat mounted SonTek RiverSurveyor M9 ADCP at four targeted locations across a range of ebb and flood tidal stages. More information on methods used for tidal gauging can be found in WRL TR2023/32 Section 4.2. Flow measurements in the Nambucca River estuary are summarised in Table 3-1, with locations shown in Figure 3-4. For a table of tidal gauging measurements refer to Appendix A2, and for plots of tidal flows refer to Appendix B1.7.

Table 3-1 Summary of 2023 fieldwork tidal flow gauging locations

Location	Location label*	27 August # transects	28 August # transects	29 August # transects
Side Channel Main Entrance Site 3	A	2	-	1
Stuarts Island Site 5	B	4	-	4
Warrell Point Site 6	C	4	-	6
Breakwater Main Channel	I	21	-	19
Breakwater Island	J	6	-	11
Airport	K	11	20	11

* Location labels correspond to locations shown in Figure 2-1.

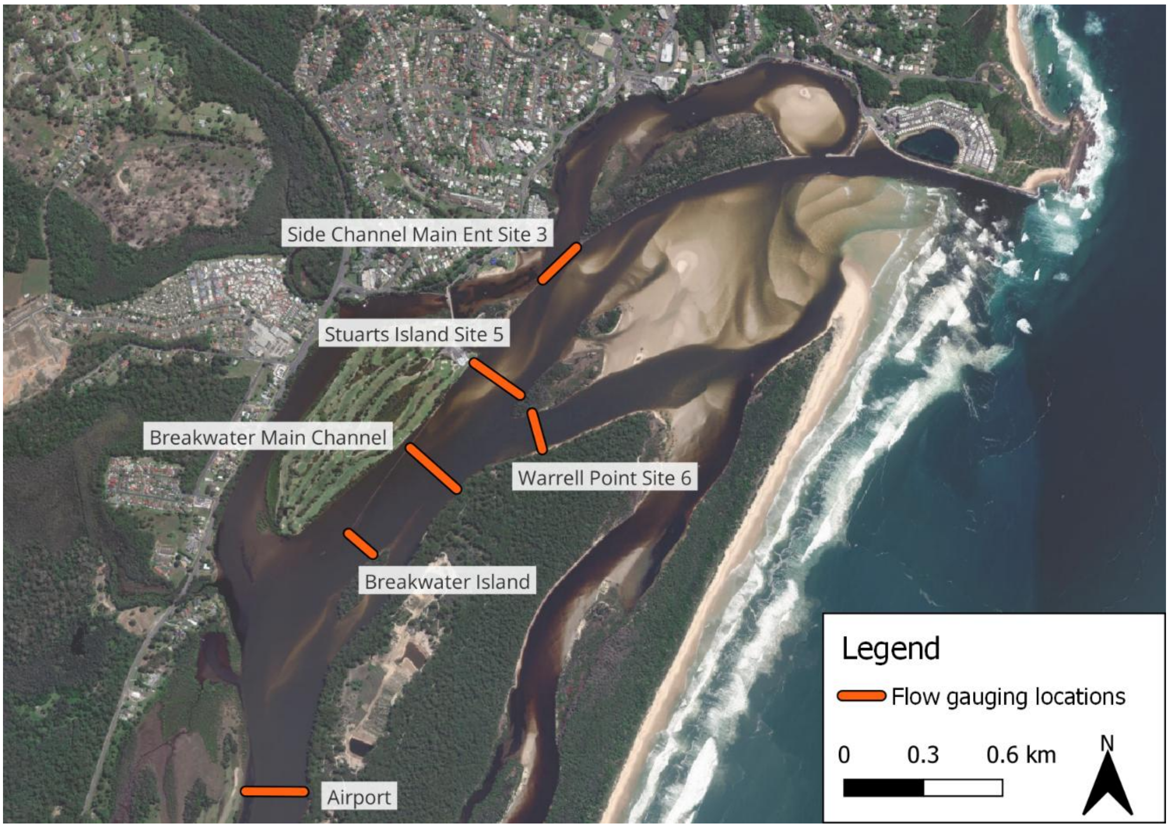

Figure 3-4 Tidal flow gauging locations from 2023 fieldwork

In addition to measuring total flow, ADCP data collected along each transect was used to understand flow and velocity distributions across the channel. Refer to Appendix A3 for figures of ebb and flood channel velocity distribution for all gauging transects.

Vertical velocity distribution for incoming and outgoing flows was also assessed for each gauging transect, which is useful for assessing the validity of assumptions associated with using a two-dimensional depth averaged model. Depth varying vertical velocity profiles were observed on the ebb tide at the airport location, which is indicative of tidal straining, discussed further in Section 4.7.2. Velocity depth profiles for each gauging location are presented in Appendix A4.

3.4 Bathymetry and elevation surveys

During the ADCP data collection campaign, an RTK-GPS unit collected vertical position data to an accuracy of 10 cm. By pairing depth soundings and elevation data, bathymetry was captured for all flow gauging locations (refer to WRL TR2023/32 Section 4.3 for details on methods used for bathymetric surveys). Bathymetry data for all locations is shown in Figure 3-5, and the change between the 2018 LiDAR data and field captured bathymetry is shown in Figure 3-6, highlighting the dynamic nature of this area. As noted in Section 2.5, the bathymetry of the entrance and lower estuary is extremely variable and a change of greater than 1 m has been experienced in many locations. The state of the entrance during fieldwork differs from the 2009 or 2018 bathymetries in that the south and north channel have separate outlets to the ocean, rather than both joining to form one channel which runs along the northern training wall. NearMap imagery shows this southern outlet developed sometime between 6 June and 18 July 2022.

Figure 3-5 Bathymetry collected during 2023 fieldwork

Figure 3-6 Change between 2018 LiDAR and 2023 fieldwork bathymetry. Red represents erosion and blue represents accretion

3.5 Rhodamine WT dye releases

To simulate pollutant advection and dispersion in the Nambucca estuary, four Rhodamine WT dye releases were performed on the second day of the field campaign (refer to WRL TR2023/32 Section 4.4 for methods). These are summarised in Table 3-2, with locations shown in Figure 3-7. The initial release concentration was 200,000,000 ppb in all instances.

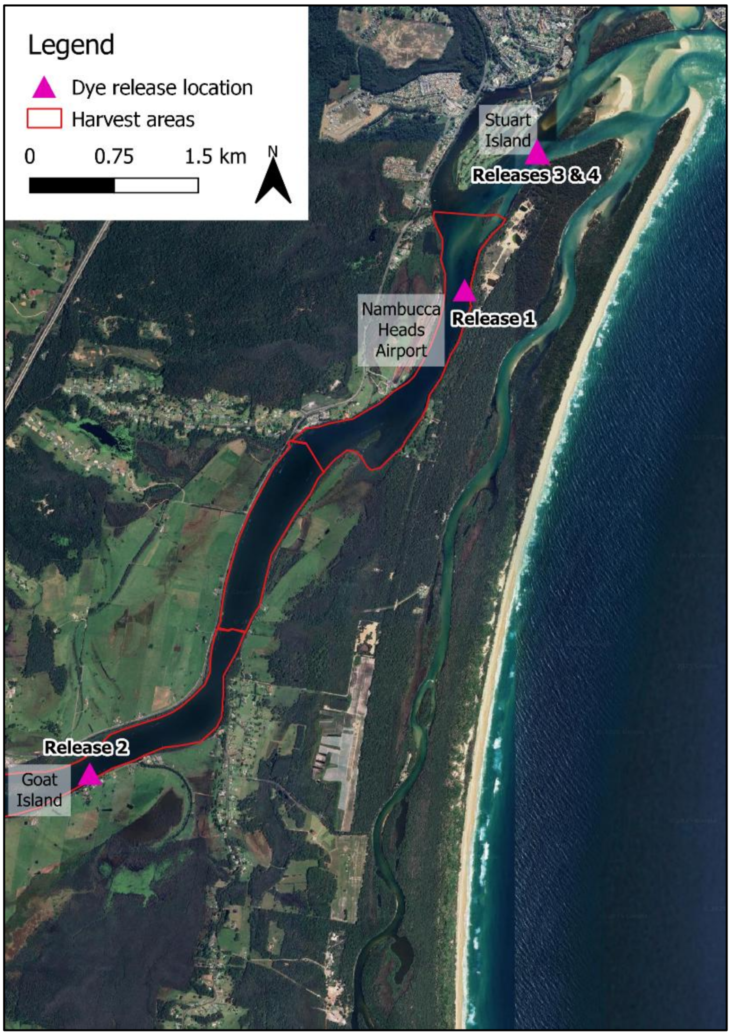

Figure 3-7 Rhodamine WT dye release locations

Table 3-2 Summary of dye releases

No.	Date	Time released	Tracked until	Volume of dye released (mL)	Location	Tide
1	28/06/2023	8.13am	9.06am	500	Nambucca Heads Airport	Ebb
2	28/06/2023	9.48am	11.04am	500	Downstream of Goat Island	Ebb
3	28/06/2023	12.49pm	12.55pm	500	Stuart Island	Flood
4	28/06/2023	1.22pm	2.10pm	500	Stuart Island	Flood

3.5.1 Release 1 – Airport

Dye release 1 was completed near the north end of Nambucca Heads Airport (see Figure 3-7) This release was completed to understand the transport of pollutants entering the shoaled zone stretching from the airport to the entrance of the river. The release occurred at 8.13am, on an outgoing tide, and was tracked for 53 minutes. Figure 3-8 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

Heading downstream towards the conjunction with the side channel, the plume was transported quickly through the shallow channel between the left bank and the sandbar in the centre of the channel. The plume had a highly elongated shape during this time. Approximately 15 minutes after the dye was released, it was approximately 10 m wide by 100 m long. The entrance to the side channel was reached at 18 minutes. Some of the plume is likely to have entered the side channel, however, shallow bathymetry meant this part of the plume could not be tracked. In this region, the plume experienced significant widening, becoming approximately 100 m wide. At around 30 minutes after the release, the plume approached the area of still water in between Stuarts Island and the training wall, with peak concentrations around 10 ppb. The plume began spilling over and around the submerged tip of the training wall and flowing into the main channel from around 35 minutes after release. Peak concentrations observed downstream of the training wall were 4 ppb, however it was difficult to track the peak of the plume in this region. Additionally, it is possible that part of the plume may have flowed directly down the main channel earlier, rather than getting trapped and spilling around the training wall. At 53 minutes since the dye release, after tracking the plume into the main channel, concentrations in the area behind the training wall were measured once again. By this time, most of the dye had left the area behind the training wall (concentrations <1 ppb).

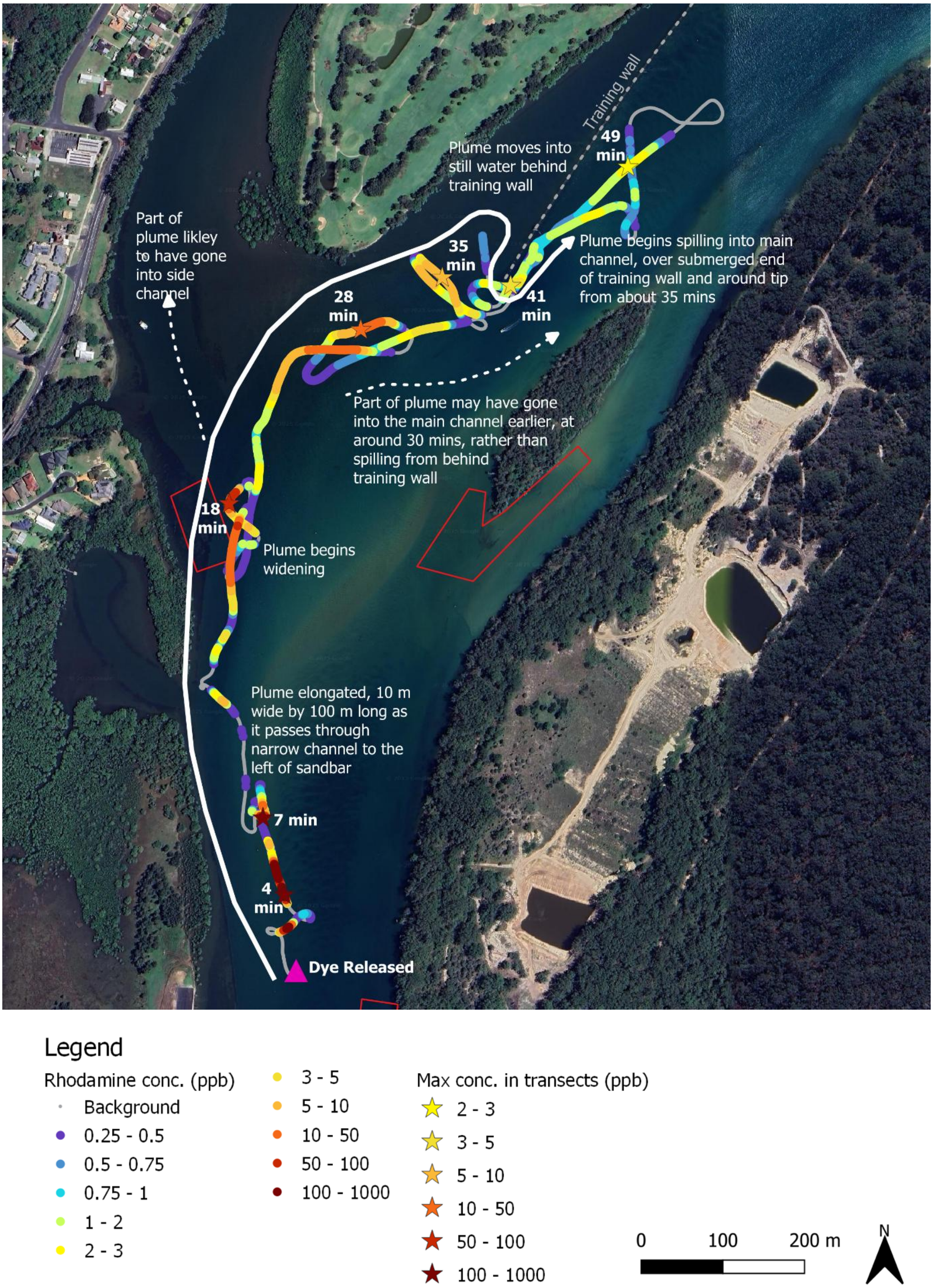

Figure 3-8 Dye release 1 off the Nambucca Heads Airport. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)

3.5.2 Release 2 – Goat Island

Dye release 2 was conducted immediately downstream of Goat Island, approximately 3 km downstream of Macksville. The release was completed on an outgoing tide, to understand the transport of pollutants from the Macksville area through the oyster harvest areas in the main channel. The release occurred at 9.48am and was tracked for 1 hour and 15 minutes. Figure 3-9 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

The plume stayed relatively circular as it moved downstream, with dimensions of approximately 20 m wide and 30 m long, at 12 minutes after release. The plume had very little dispersion, with concentrations greater than 200 ppb observed 28 minutes after the release. At this time, the plume extended over most of the width of the river, however some dye was found at depths deeper than the instrument, hence the data may underestimate width, especially on the right bank. As the plume approached the bend in the river, it moved toward the left bank, and became somewhat more elongated (approximately 125 by 200 m). Tracking ceased at 74 minutes after the release, when concentrations in the peak of the plume were still very high, at approximately 60 ppb. It is suspected that this dye plume experienced such low dispersion due to reduced mixing caused by salinity stratification (see Section 3.5.2 for further discussion).

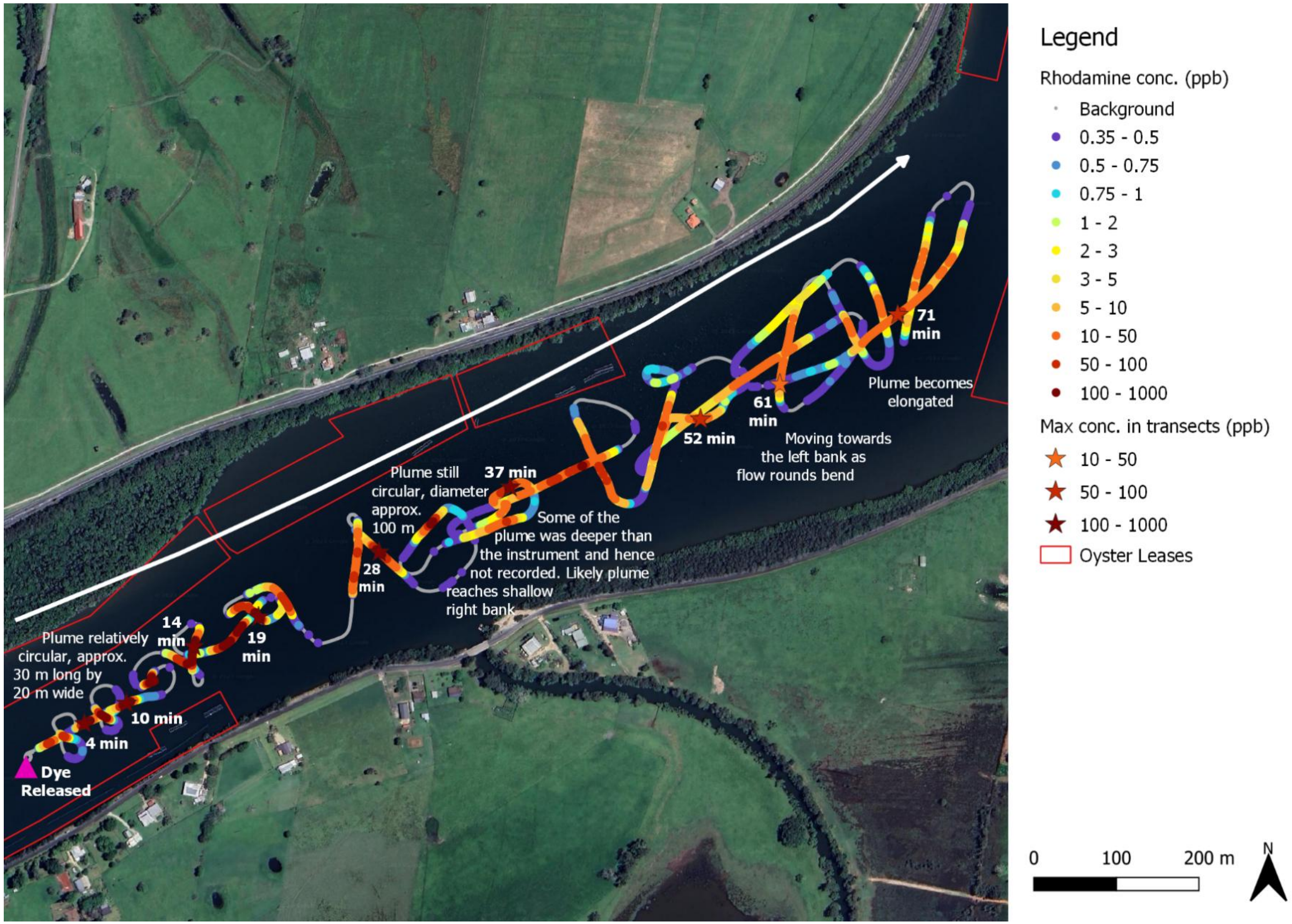

Figure 3-9 Dye release 2 downstream of Goat Island. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)

3.5.3 Release 3 – Stuarts Island

Dye release 3 was completed off the training wall structure at Stuarts Island at 12.49pm. This dye quickly dropped in the water column and began advecting at around 1 m depth and below. Due to equipment malfunctions, the instrument measuring the dye was unable to be lowered, hence tracking was abandoned, and the boats motors were used to disperse the dye. Release 4 was a repeat of this release.

3.5.4 Release 4 – Stuarts Island

Dye release 4 was a repeat of release 3, and occurred near Stuarts Island. This release was conducted to further understand transport through the shoaled section between the entrance and the airport. The release occurred at 1.22pm, on an incoming tide, and was tracked for 48 minutes. Figure 3-10 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

Unlike release 3, the plume did not sink quickly, and was instead transported near the surface. Similar to release 1, the plume was transported quickly and became elongated (approximately 20 by 70 m at 10 minutes after release). As the plume reached the shallower water near the unnamed island between the training wall tip and the right bank, the plume accelerated and elongated further. Tracking became difficult in the shallow channel between the unnamed island and the sandbar, as the bathymetry was shallow. Transects could not be done in this area, and it is likely that the boat was not travelling in the peak of the plume. It is also likely that part of the plume travelled in the main channel, to the river left of the sandbar. The plume emerged on the other side of the island around 25 to 30 minutes after release. At this point, the plume was still moving quickly, difficult to see, and spread over a wide area. It is unclear whether the front of the plume was crossed and measured by the boat at any point, or whether background concentrations found during this part of the tracking were the sides of the plume. Tracking ceased at 48 minutes after release.

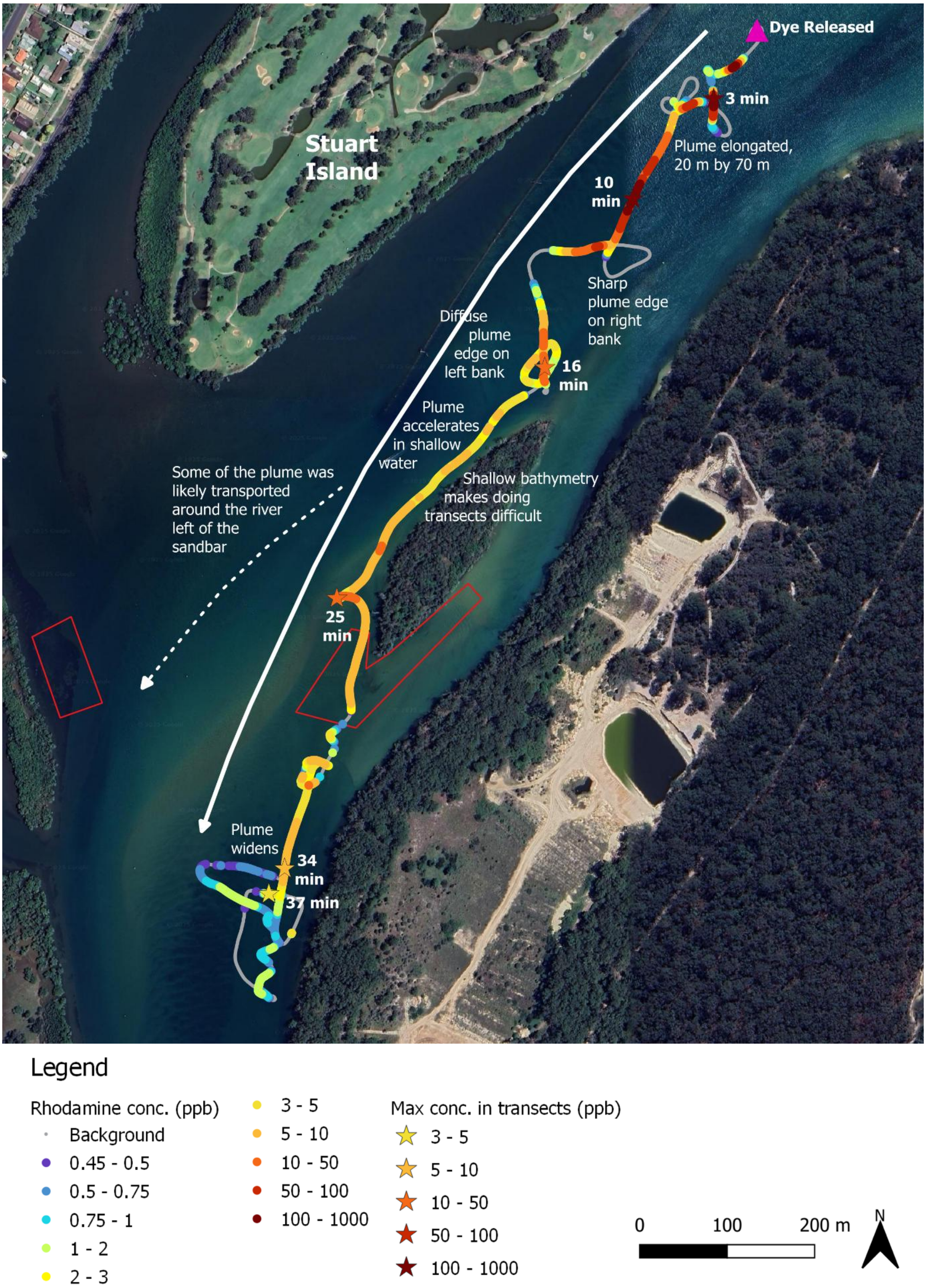

Figure 3-10 Dye release 4 off the Stuart Island training wall. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)

3.5.5 Field derived dispersion values

Field dye experiments were used to obtain estimates of plume spreading dispersion rates in the Nambucca River, using the methods described in WRL TR2023/32 Section 7.3. During each dye release, transects were taken across the plume to capture the plume width and peak concentration at a point in time. From the set of all transects, a subset of representative peak concentrations was compared to theoretical estimates of maximum plume concentrations over time. This is shown in Figure 3-11.

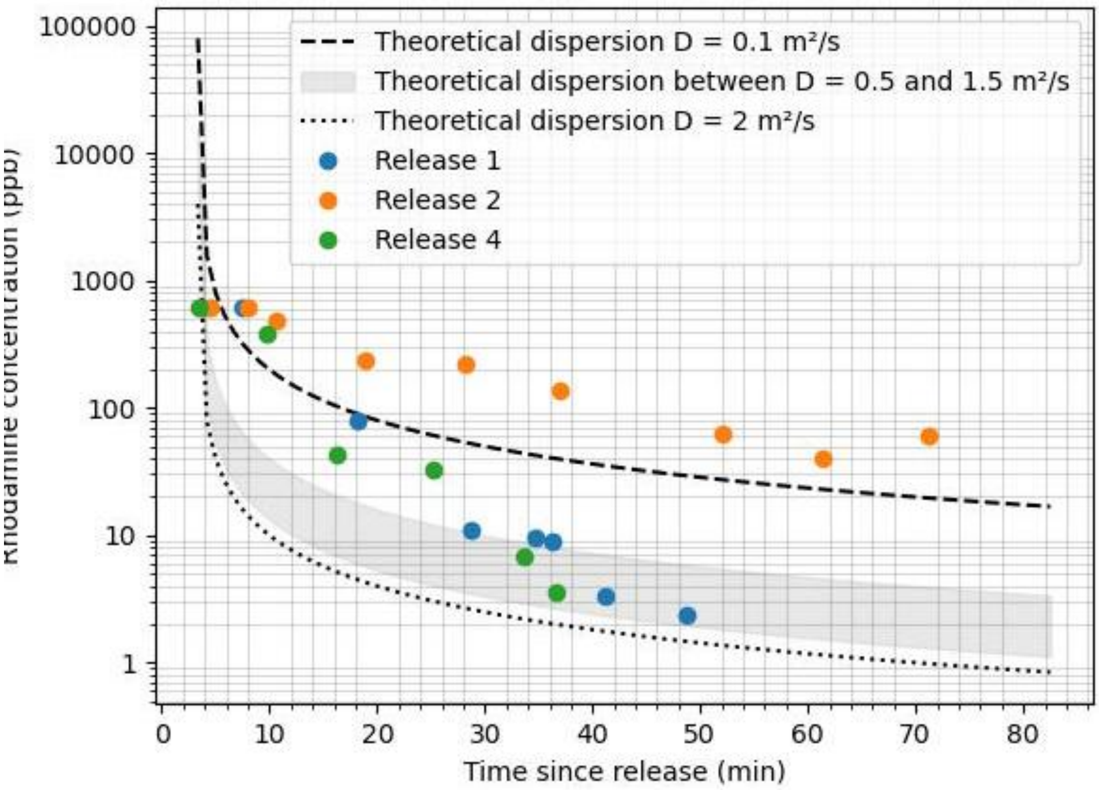

Figure 3-11 Peak concentration of select transects plotted against theoretical dispersion

Measurements of field dispersion across the state for this project showed dispersion was spatially and temporally variable typically between D = 0.1 and 2 m^2/s, with the most common range being 0.5 to 1.5 m^2/s. When comparing the observed peak observations to theoretical dispersion, dye release 1 and 4 were largely within D = 0.5 to 1.5 m^2/s. For release 2, the low dispersion values are suspected to be caused by reduced mixing due to salinity stratification (refer to Section 3.5.2).

3.6 GPS drifter drogue releases

To monitor surface current speeds and flow paths in the Nambucca estuary, GPS drifter drogues were deployed at strategic locations throughout the field campaign (refer to WRL TR2023/32 Section 4.5 for further information on drifter drogues). Table 3-3 lists the details of drogue releases. The GPS tracks for the drogue releases are shown in Appendix A1.

Table 3-3 Summary of drogue releases

No.	Date	Time	Tide	Duration (h)	Location	Comments
Day 1 Drop 1	27/06/2023	7.33am	Ebb to flood	7:43	Goat Island	
Day 2 Drop 1	28/06/2023	7.50am	Ebb	4:09	Goat Island	
Day 2 Drop 2	28/06/2023	9.33am	Ebb	2:28	Middle Nambucca harvest area	
Day 2 Drop 3	28/06/2023	12.44pm	Flood	1:30	Stuart Island	Released with dye drop 4
Day 3 Drop 1	29/06/2023	7.06am	Ebb	2:27	Goat Island	

3.7 Water level monitoring

To supplement the water level data available from the five long term MHL water level gauges on the Nambucca River estuary, three water level loggers were installed during the 2023 fieldwork: at the "V-wall" near the entrance, in the side channel behind Stuarts Island and near the location of Motel Site 9 gauging during the 1999 MHL campaign. (refer to Figure 3-12). Plots of collected water level data can be seen alongside model results in Appendix B1.8.

Figure 3-12 Location of water level monitoring during 2023 fieldwork

3.8 Conductivity measurements

To measure saline intrusion, conductivity profiles were taken during the fieldwork campaign with a Sontek EXO3, as detailed in WRL TR2023/32 Section 4.7. Conductivity profiles were recorded in various locations on the second day of field monitoring, mainly on the incoming tide. These profiles provide insight into whether there is density (salinity) stratification in the water column (water increases in density and salinity throughout the water column). Weak salinity stratification (defined as a difference of more than 5,000 µS/cm across the water column) was observed upstream of the airport on the incoming tide. Unfortunately, no measurements were taken in this section of the river on the outgoing tide, although it is suspected that strong stratification occurs on this tide, as described in Section 4.7.2. Figure 3-13 shows the timing of conductivity profiles, while Figure 3-15 shows locations and Figure 3-14 plots some sample profiles for both stratified and unstratified locations.

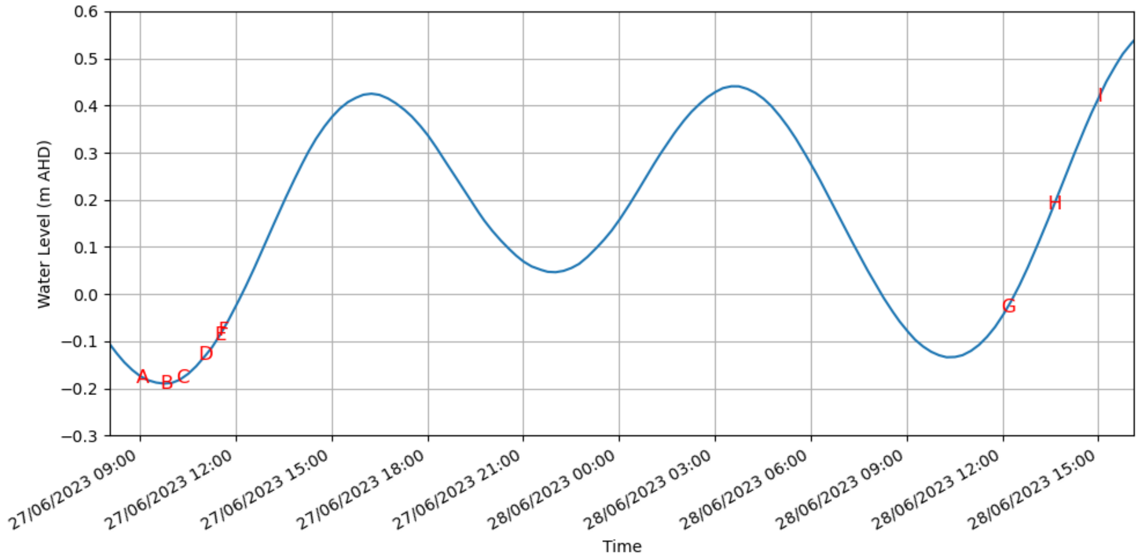

Figure 3-13 Timing of conductivity profiles (labelled with letters) relative to the tide at Stuarts Island

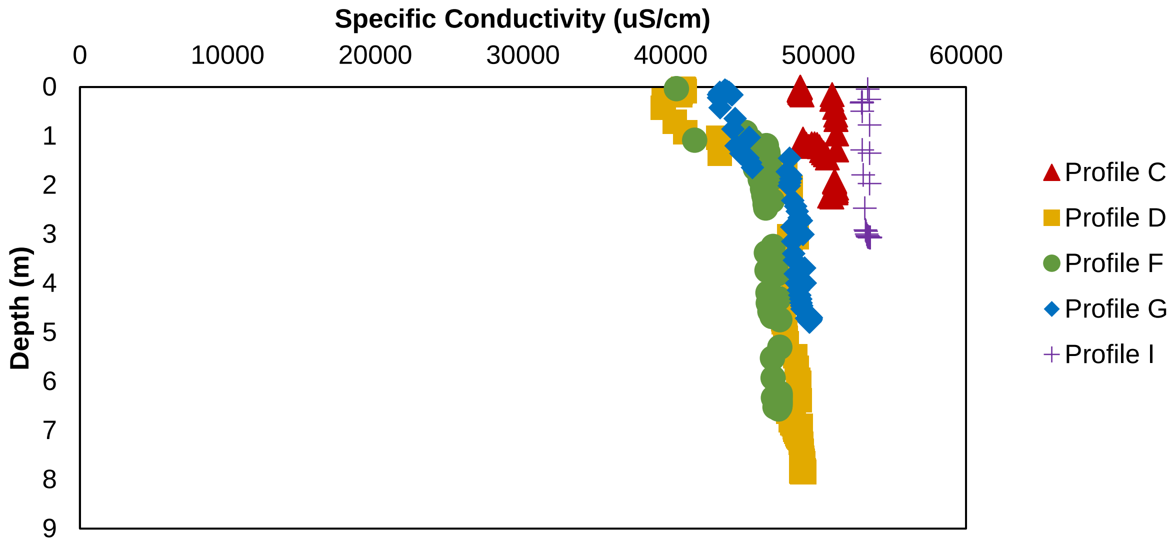

Figure 3-14 Conductivity profiles at select locations labelled with letters corresponding to timing on Figure 3-13

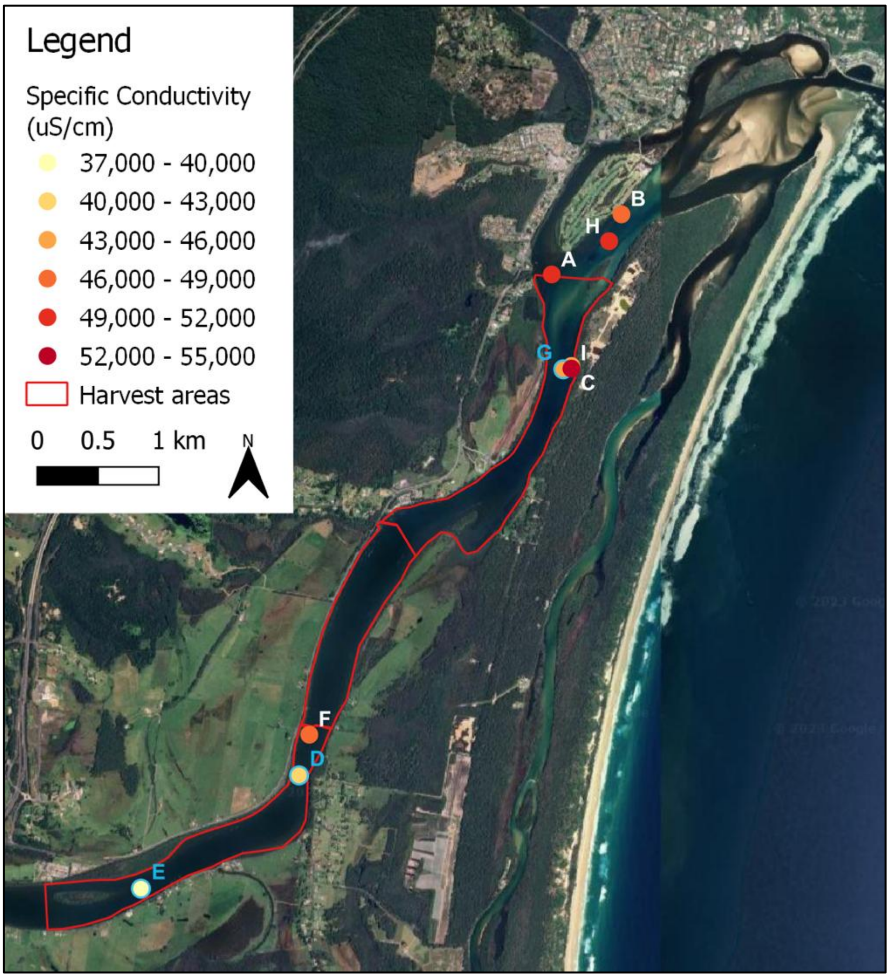

Figure 3-15 Conductivity measurements labelled with letters corresponding to timing on Figure 3-13. Letters in blue show locations which had stratification of at least 5,000 uS/cm, while colour shows surface conductivity (for stratified locations) or average conductivity for unstratified sites

4 Model development

4.1 Preamble

The model used for this project consists of both a hydrodynamic and a water quality model. Initially, a hydrodynamic pilot model was developed which identified data gaps to be targeted during field data collection. After incorporating new data from the field, the hydrodynamic model was iteratively refined through calibration based on the MHL data collection campaign in 1999, and verification based on field data collected for this project in 2023. The hydrodynamic model was then used as an input for the water quality model. This model was informed by dye release experiments and was then used to run sewage overflow scenarios. A schematic of this process can be seen in Figure 4-1. For a detailed overview of the model development used for the broader project, refer to WRL TR2023/32 Sections 6 and 7.

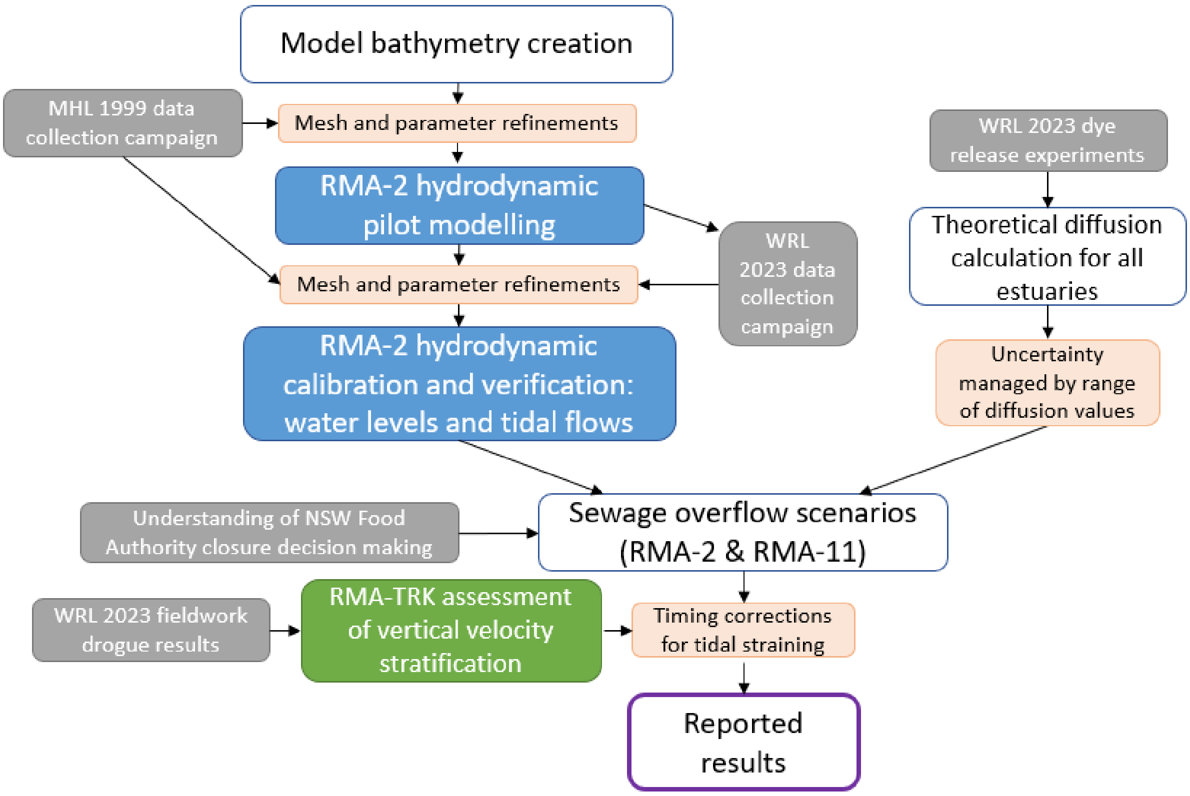

Figure 4-1 Overview of modelling approach

4.2 Model mesh development

The model domain extends from approximately 300 m offshore of the ocean entrance of the Nambucca River, to the tidal limits of the river and its major tributaries (refer to Figure 4-2). The model mesh consists of over 16,000 nodes and 5,000 two dimensional elements varying in size from 4 m^2 to over 40,000 m^2. A two-dimensional, depth averaged model mesh was chosen for the Nambucca River, where advective transport is largely driven by tidal and riverine flow (not wind). A discussion on the impact of model dimensionality is provided in WRL TR2023/32 Section 6.2.2.

Mesh resolution is highest in the lower estuary, and higher in the upper reaches. Refer to WRL TR2023/32 Section 6.2.3 for a discussion of model resolution.

4.3 Model bathymetry

As the Nambucca River has a morphodynamically variable entrance, multiple model bathymetries were required to simulate the hydrodynamic variability of the system. Three main model bathymetries were constructed with the available data: a 2023, 2018 and 2009 bathymetry, based on the data sources discussed in Section 2.5. Bathymetry is mainly variable in the shallow sections downstream of the airport, hence the bathymetry from here upstream remained unchanged in the three versions of model bathymetry, and was based on the OEH (2009) survey. Downstream of the airport, the 2009 bathymetry was based on the OEH (2009) survey, the 2018 bathymetry was based on the DPIE (2018) survey, and the 2023 bathymetry was based on the OEH (2009) survey with adjustments based on the 2023 field data, NearMap imagery and engineering judgement.

These different bathymetries, with different entrance conditions are referred to in model scenarios as E1 (2018), E2 (2009) and E3 (2023). Nodal elevations for these three model variations can be seen in Figure 4-4, Figure 4-5 and Figure 4-6, respectively. Figure 4-3 shows the nodal elevations of the entire model domain, for bathymetry E1. In general:

- E1 represents a relatively closed entrance condition, with only one channel, adjacent to the training wall.
- E3 represents a more open entrance condition, with two channelised entrances separated by a sandbar.
- E2 represents a case similar to E3, with slightly more shoaling on the southern side of the channel and less on the northern side.

Hydrodynamic and scenario results using E2 were largely intermediate between E1 and E3, thus only E1 and E3 were used for final scenarios. Sensitivity to bathymetry and its implications are discussed further in Section 5.4.2. Additionally, a variant of the model with a widened culvert under the bridge to Stuarts Island, in the side channel, was run for each model bathymetry in the final scenarios, to account for uncertainty in the conveyance of the culvert. See Section 5.4.1 for more details.

4.4 Model boundaries

The model includes four upstream catchment flow boundaries, shown in Figure 4-2 and discussed in Section 2.3. Note the scaled inflows of both the Nambucca River and South Creek are combined and enter the model at a single location, labelled Nambucca River in Figure 4-2. A tidal elevation boundary was included in the model offshore of the Nambucca River entrance (refer to Figure 4-2). This modelled water level boundary was based on observed tidal elevation data collected by MHL at Coffs Harbour (station number 205470). This data was then smoothed to remove signal noise to increase model stability. For modelling water quality scenarios, all boundaries (upstream and ocean) were set to a constant constituent concentration of zero (e.g. no pollutant inflows from these boundaries).

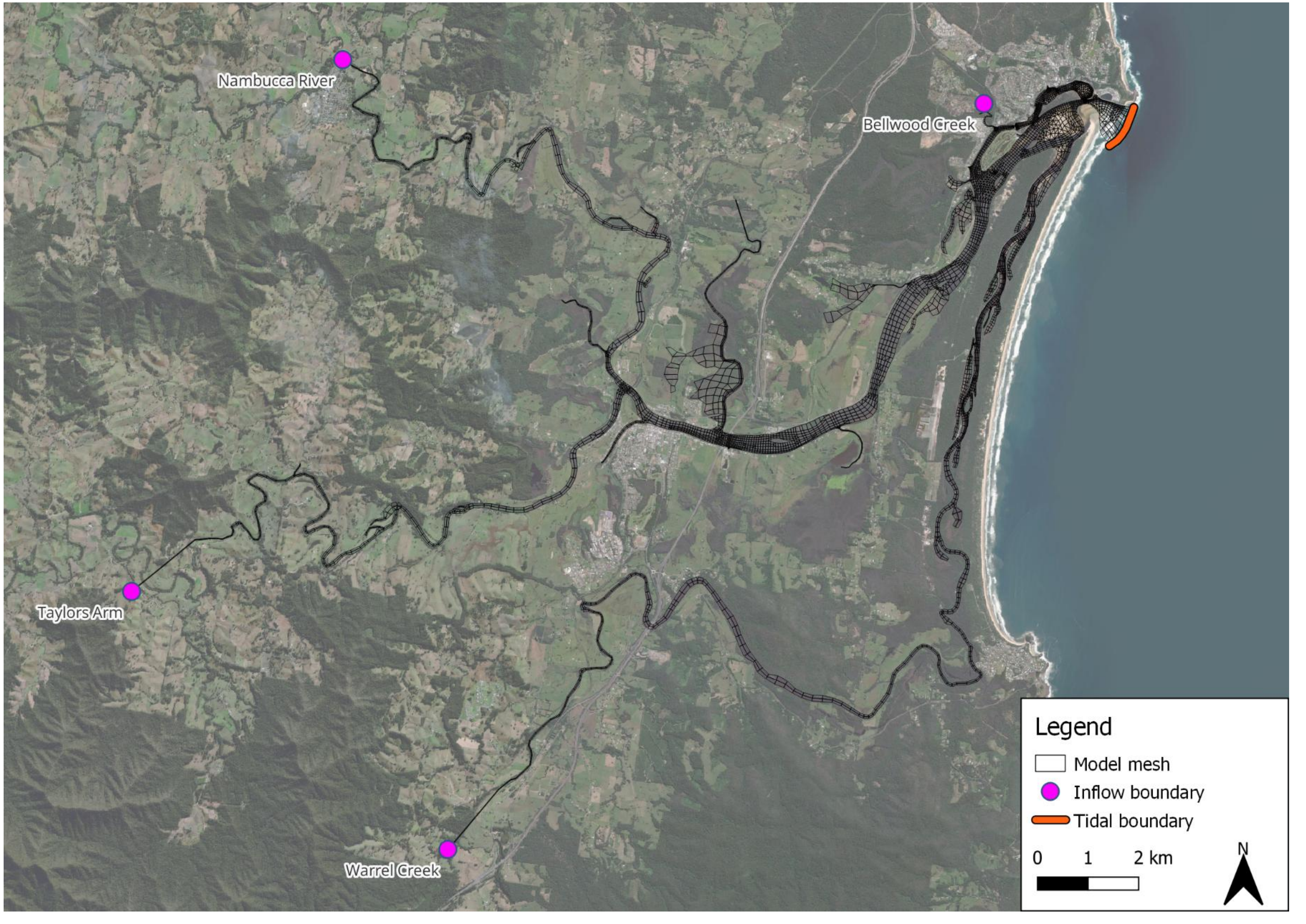

Figure 4-2 RMA model mesh (E1 bathymetry) showing boundary condition locations

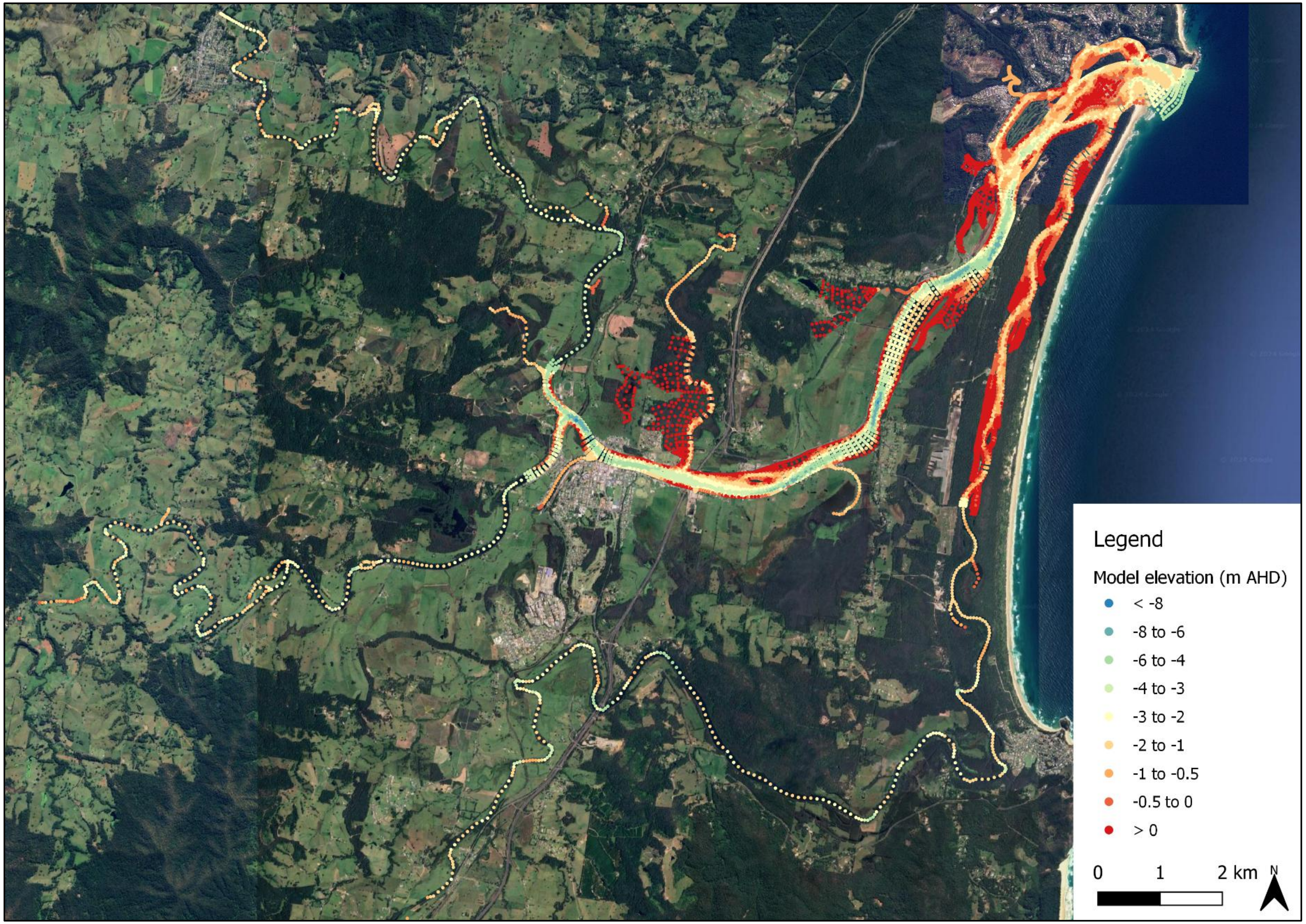

Figure 4-3 RMA model bathymetry for 2018 (E1)

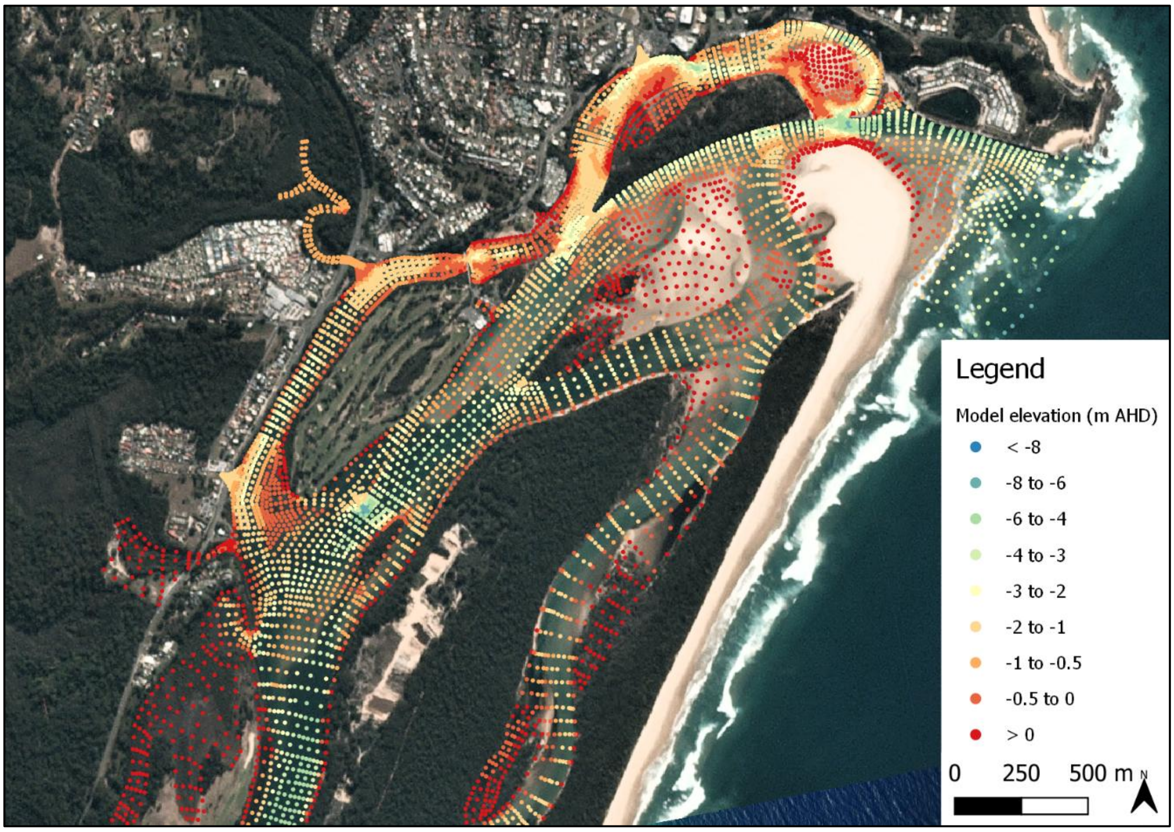

Figure 4-4 RMA model entrance bathymetry for 2018 (E1, background imagery from June 2018)

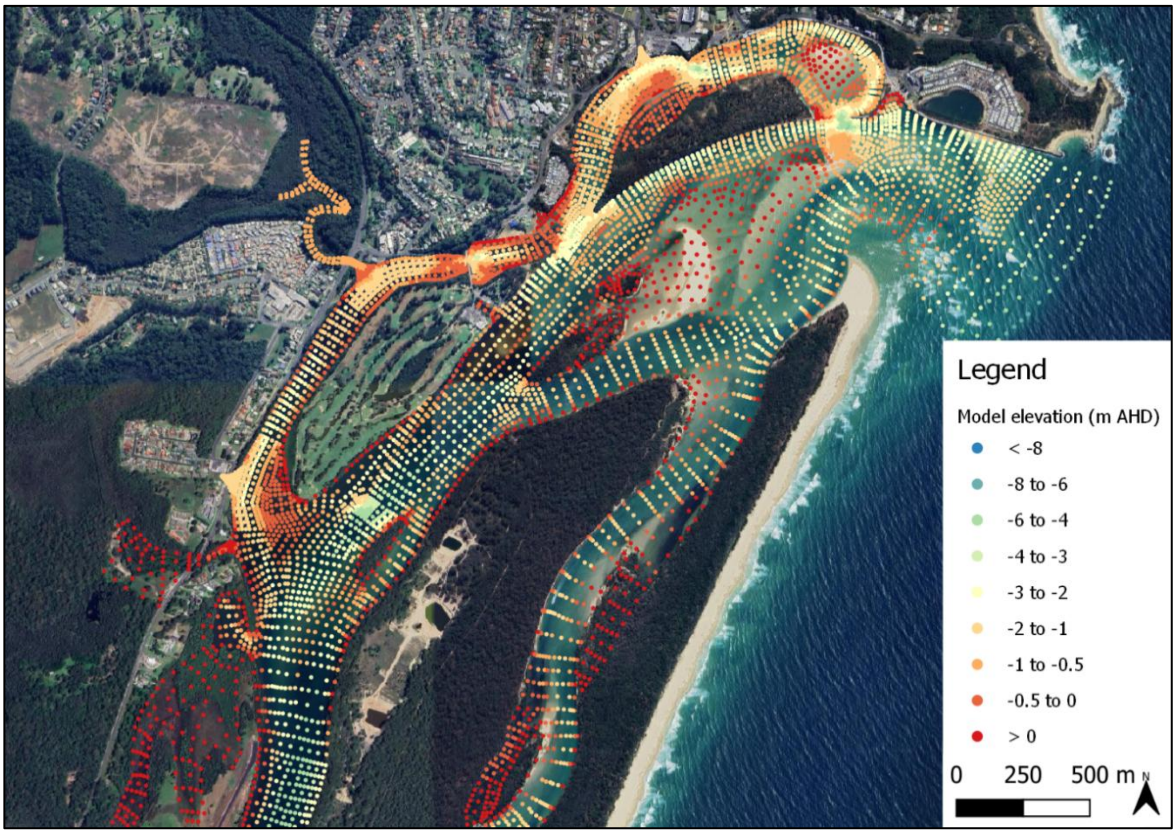

Figure 4-5 RMA model entrance bathymetry for 2009 (E2, background imagery from a different period)

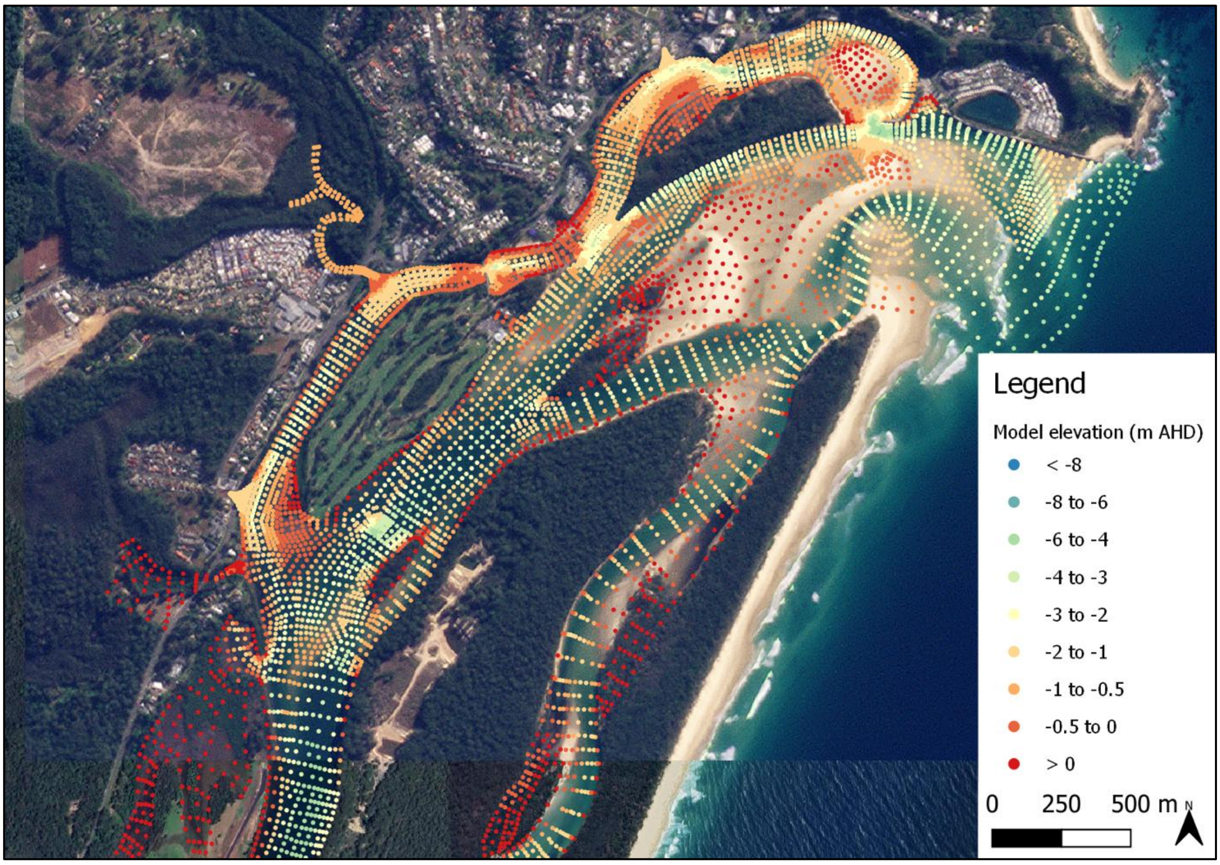

Figure 4-6 RMA model entrance bathymetry for 2023 (E3, background imagery from June 2023)

4.5 Pilot model

Initially, a hydrodynamic pilot model was developed using the existing data described in Section 2. For more details on pilot modelling and its purpose refer to WRL TR2023/32 Section 3. This initial modelling was used to identify data gaps to be targeted during fieldwork. The large sensitivity to bathymetry was identified. As there was no bathymetry data from near the 1999 hydrodynamic data collection, this was problematic. Thus there was a focus on collecting supplementary bathymetry data and additional water level and flow data to allow for calibration to the 2023 field period.

4.6 Hydrodynamic calibration and verification

Hydrodynamic calibration should be based on flow, velocities and water levels at several locations throughout the estuary. For more details on calibration and how models were determined to be fit for purpose refer to WRL TR2023/32 Section 6.4. The large variability of the hydrodynamics of the system due to bathymetry change, along with the lack of through bathymetry survey data, which is temporally close to hydrodynamic data collection periods, made calibration difficult. Thus, emphasis was instead placed on sensitivity analysis to bathymetry, and capturing a wide variety of bathymetric states, as future hydrodynamics are unlikely to be close to those in the calibration periods.

Initially the model was calibrated using the hydrodynamic data from the 1999 MHL campaign, then the 2023 WRL data collection campaign period was used to verify the model, after bathymetry was updated. Both calibration and verification also considered MHL long term water level gauges available at two to five locations in the Nambucca estuary (see Section 2.2). Due to the lack of bathymetry data from 1999, the model was also verified against water levels in 2009 and 2018, using the respective bathymetries. For each period, a minimum 3 day model warmup period was run.

4.6.1 September 1999 calibration period

During the 1999 MHL data collection campaign on the Nambucca River estuary, water level data was available at 13 gauges (including two permanent gauges) and tidal flow data was available at eight transects (refer to Section 2.2). The model parameters were calibrated to this period. Measured tide levels were applied at the ocean boundary and scaled measured catchment inflows were applied at the four upstream model inflow boundaries. As the WaterNSW tide gauges discussed in Section 2.3 were not yet installed, catchment inflows were scaled from data from a historic gauge on the Nambucca River at Bowraville, provided in MHL (1999).

As can be seen in Figure 4-7, the bathymetry of the entrance in May 1999, 4 months before the gauging period, was that of a single entrance channel. However, this channel was wider than the channel in 2018 (E1) and there was a large sandbar off the south western side of the northernmost island, which is not present in any of the bathymetry data available.

Figure 4-7 Aerial imagery of the Nambucca entrance from 29 May 1999 (MHL, 1999)

The lack of bathymetry data from around 1999 made calibration difficult. All three model bathymetries were run for the 1999 calibration period and all results can be seen in Appendix B1.1 and B1.2, with select results shown below. Although model fit is poor in places, the variation is sometimes within the variation of the three model bathymetries (see Figure 4-10 to Figure 4-13 for examples).

To verify that the issue was bathymetry changes in the lower estuary, the mesh was truncated at the Resort Site flow transect, and the water levels measured at the Motel Site were used as a boundary condition. These results are shown in Appendix B1.3 and B1.4, with select results shown below. This provided an improved fit to the upstream flows and water levels (see Figure 4-8 and Figure 4-9 for examples), and allowed confidence in the model in the more bathymetrically stable area upstream of the airport.

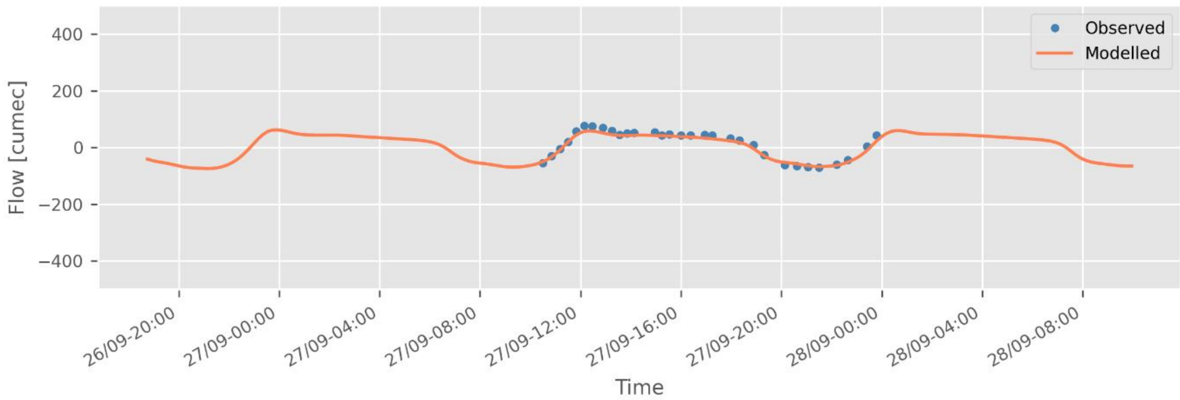

Figure 4-8 1999 tidal flow calibration (using mesh cropped at Resort Site 8) – Location G – Showground Site 12

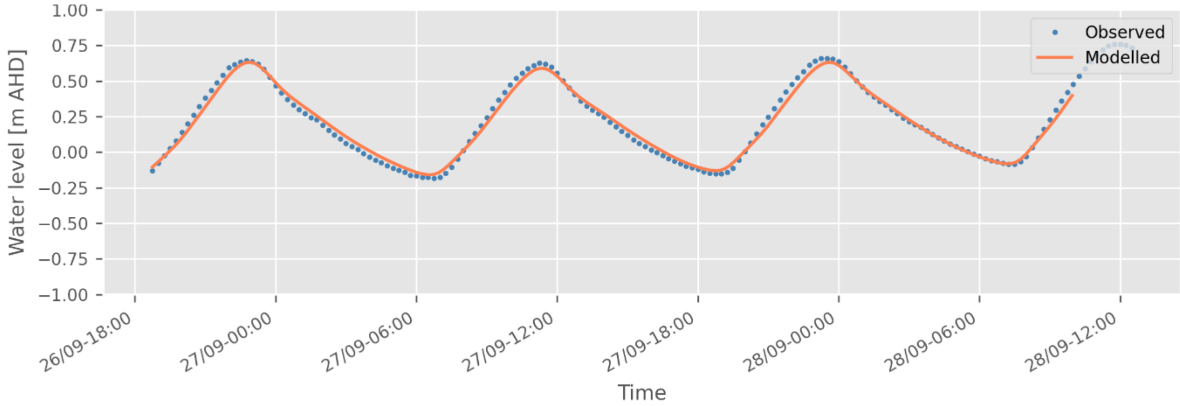

Figure 4-9 1999 water level calibration (using mesh cropped at Resort Site 8) – Location 8 – Womboyne Site 13

Most water levels and flows were within or were close to the range of the three bathymetries, however the model achieved a poor fit at some locations, as discussed below. The flow at Warrell Point Site 6 (Figure 4-10) was overestimated by all model bathymetries, which is likely due to changes in the bar shape and increased shoaling in the southern channel compared to the 2018 bathymetry. The flow at Stuarts Island (Figure 4-11) and Side Channel Main Entrance (Figure 4-12) achieves a good fit, and these are in the locations most likely to affect overflows from the Nambucca Heads township. However, the flow at the Resort Site (Figure 4-13) was underestimated by all model bathymetry variations. As the flow at Side Channel Main Entrance (Location A in Figure 2-1), Stuarts Island (Location B in Figure 2-1) and Warrell Point Site 6 (Location C in Figure 2-1) are all either well fitted to the model, or overestimated (Location C), it is uncertain where substantial extra flow at the Resort Site originated from. This area was targeted during field investigations to collect additional flow data to understand the flow paths in this area.

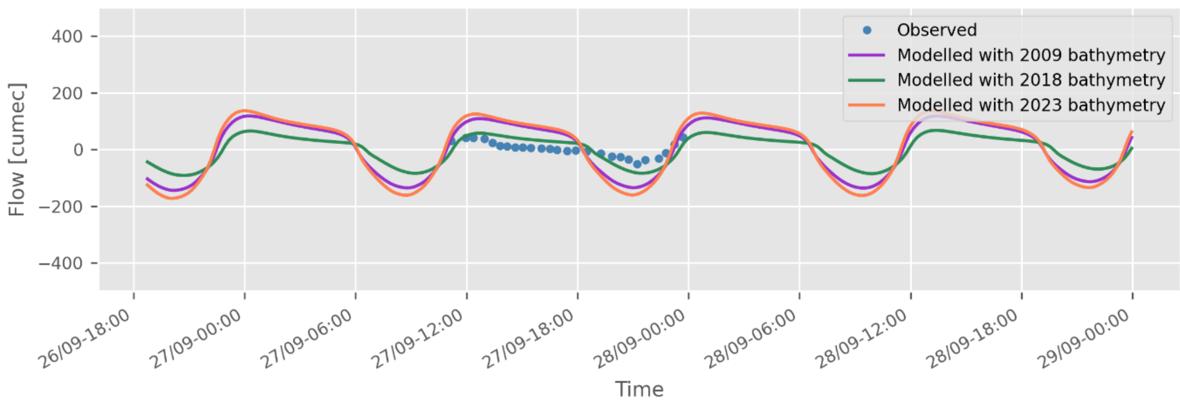

Figure 4-10 1999 tidal flow calibration – Location C – Warrell Point Site 6

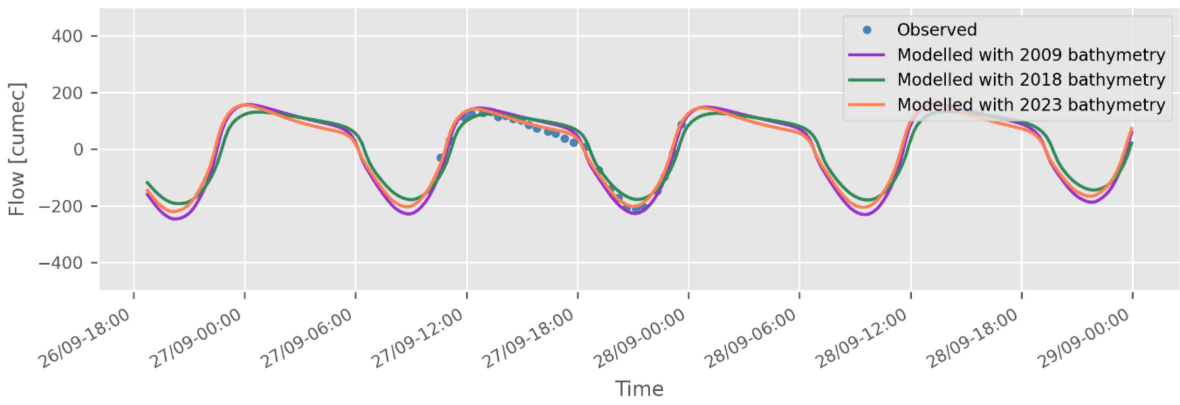

Figure 4-11 1999 tidal flow calibration – Location B – Stuarts Island Site 5

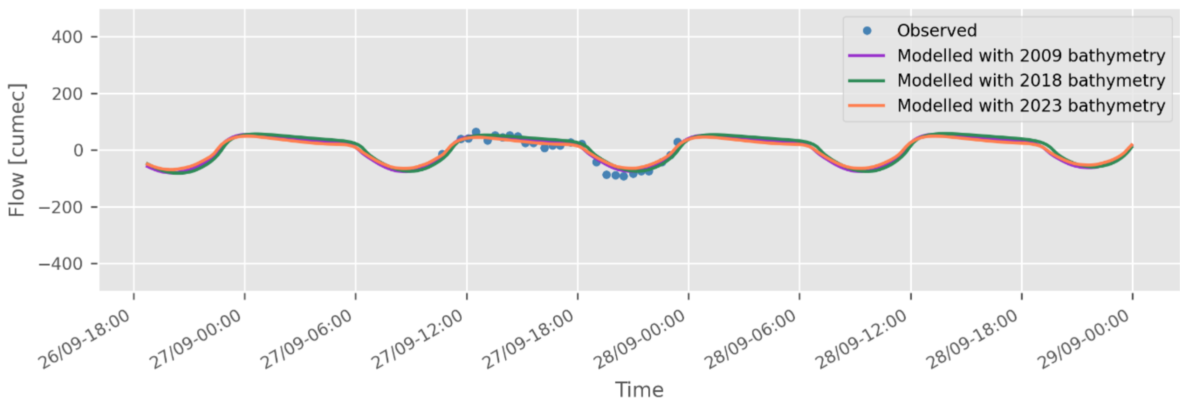

Figure 4-12 1999 tidal flow calibration – Location A – Side Channel Main Entrance Site 3

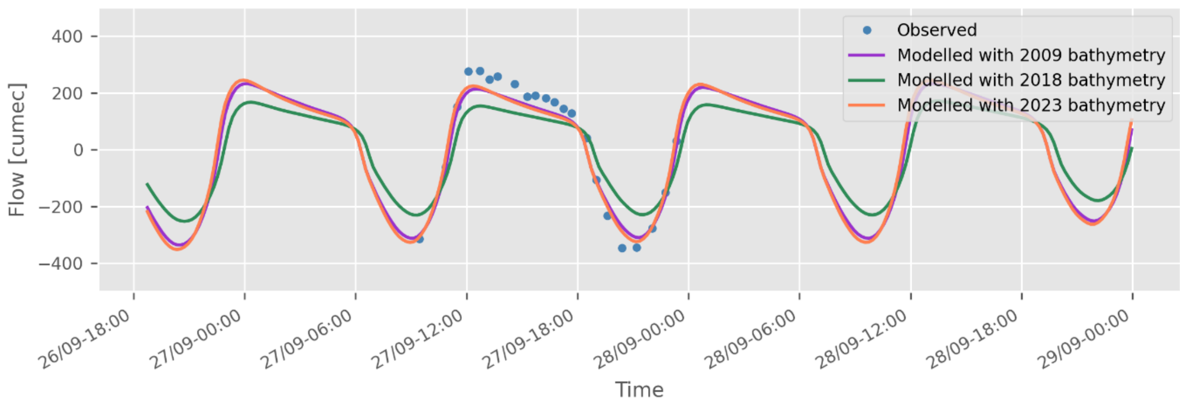

Figure 4-13 1999 tidal flow calibration – Location F – Resort Site 8

There was substantial rain on 27, 28 and 29 September 1999, the effects of which can be seen in the water levels at upstream gauges. Approximately twice as much rain fell at Stuarts Island and Utungun (51 and 63 mm, respectively) as Bowraville (28 mm) on 27 September (MHL, 1999). As the inflows were based on gauging at Bowraville, this could result in inflows for Taylors Arm and Warrell Creek being underestimated, and explain the insufficient increase in water level at these locations post rain (Figure 4-14 and Figure 4-15).

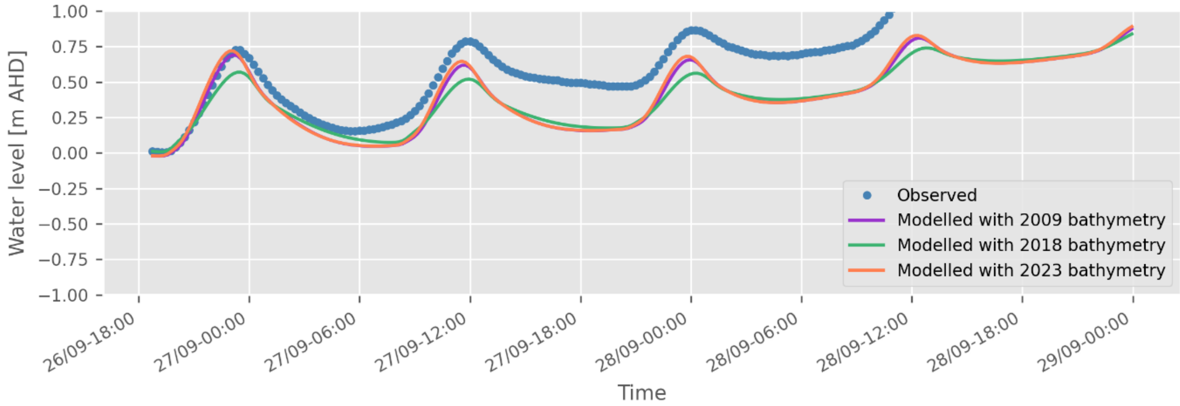

Figure 4-14 1999 water level calibration – Location 11 – Taylors Arm Boat Harbour Bridge Site 26

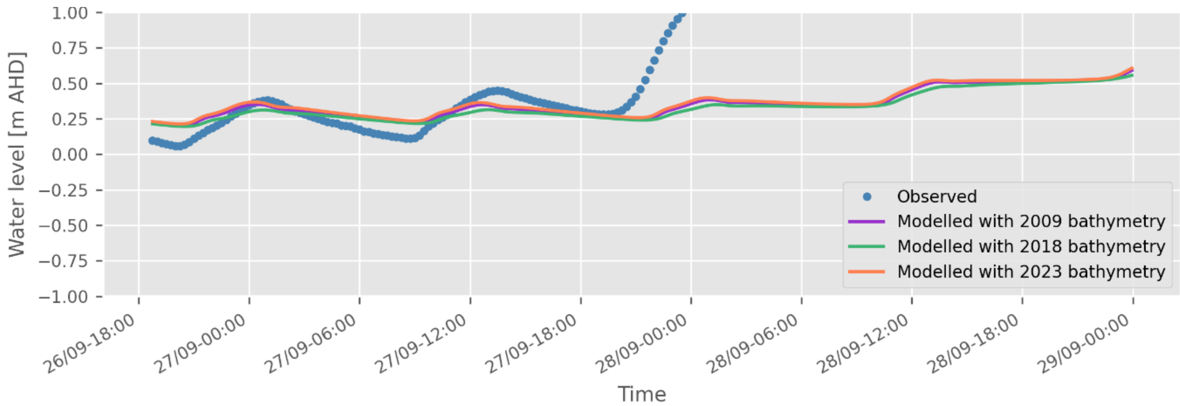

Figure 4-15 1999 water level calibration – Location 14 – Warrell Creek Upstream Site 20

The water levels in Warrell Creek have insufficient range (see Figure 4-16 for an example), a problem which is shared with other model run periods. This is likely caused by issues with the geometry in this area. However, as this was far away from overflows locations and harvest areas, it was not considered to affect the model's fitness for purpose.

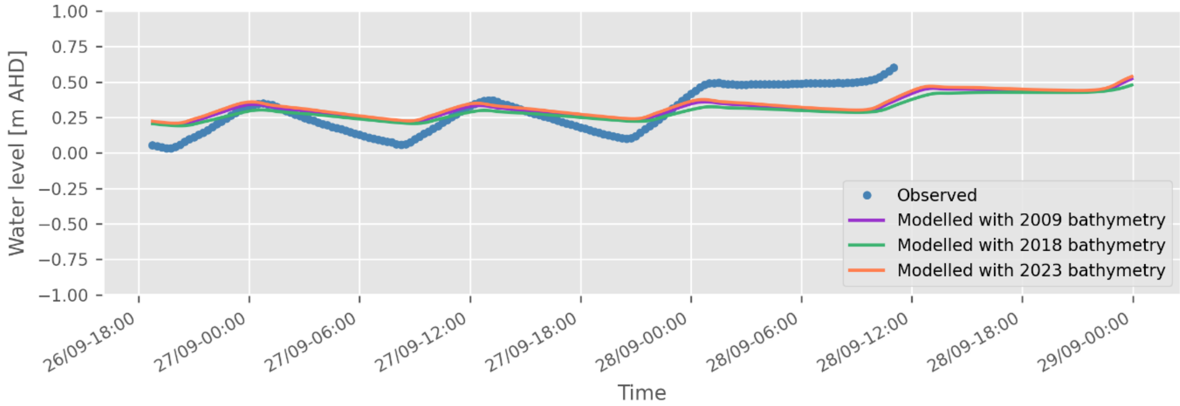

Figure 4-16 1999 water level calibration – Location 13 – Warrell Creek Highway Bridge Site 19

Similarly, The Taylors Arm and Womboyne water levels (Figure 4-14 and Figure 4-17) are higher at low tide when compared to model results, a trend which is shared in other model run periods for Bowraville (near Womboyne), although the truncated model that does not include the lower estuary achieves a much better match (Figure 4-9). This is likely due to model bathymetry missing an area of shallower bathymetry or other feature restricting low water flows. However, as flow was approximated accurately for both branches of the upper estuary (Figure 4-18 and Figure 4-19) and these locations are far from oyster harvest areas, this was deemed to have a limited impact on the usability of the model for this purpose.

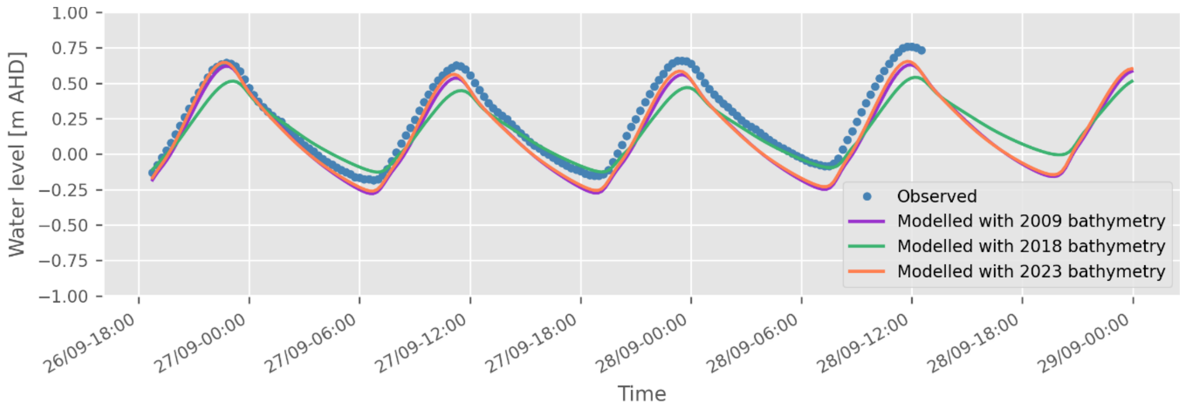

Figure 4-17 1999 water level calibration – Location 8 – Womboyne Site 13

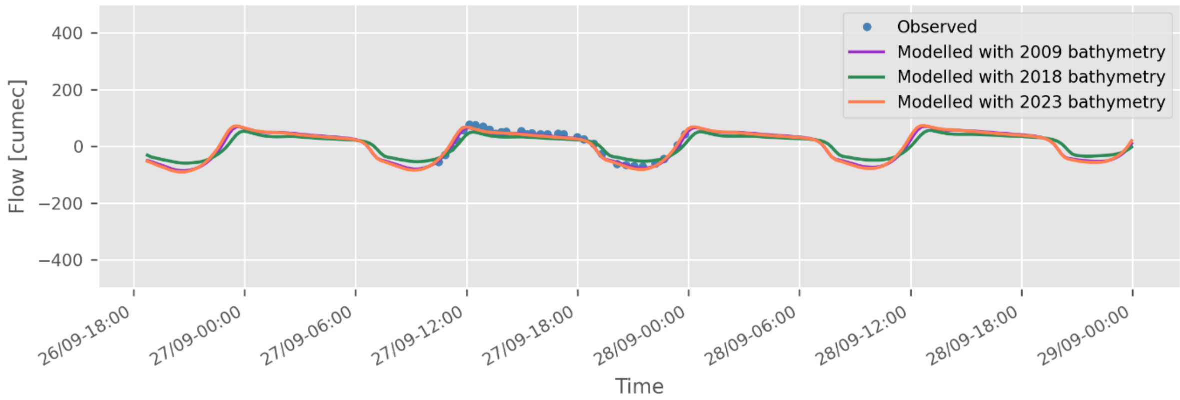

Figure 4-18 1999 tidal flow calibration – Location G – Showground Site 12

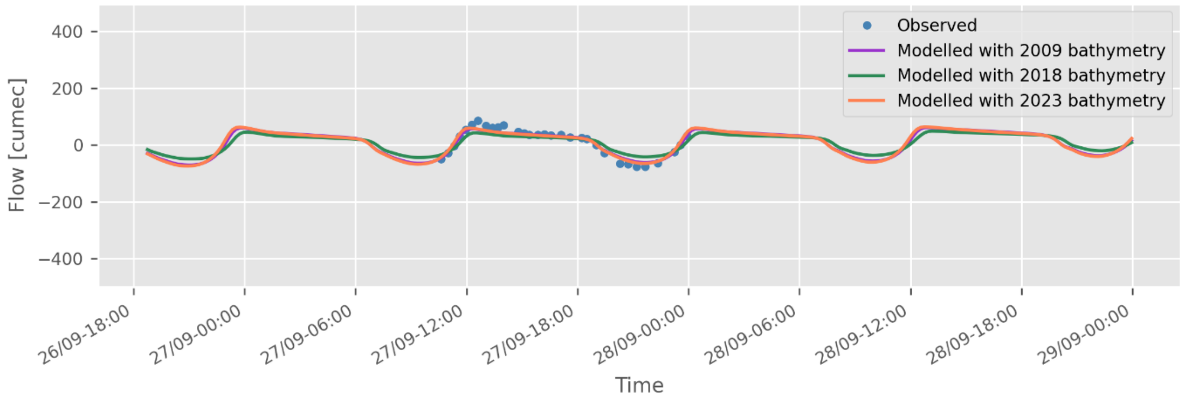

Figure 4-19 1999 tidal flow calibration – Location H – Taylors Arm Site 24

4.6.2 August 2009 verification period

For this period, water levels were only available from the four MHL long term gauges operational at the time. This model period was run to verify the 2009 (E2) bathymetry, as it was within a month of the survey date. Measured tide levels were applied at the ocean boundary and scaled measured catchment inflows were applied at the four upstream model inflow boundaries. Model results were then compared with the observed data, using the same model parameters used for the 1999 model run. Plots of all observed water level and flow compared with model results are shown in Appendix B1.5, while select results are shown below.

A good fit was achieved for Stuarts Island (Figure 4-20) and Utungun. However, low tide water levels were underestimated at Macksville and Bowraville (Figure 4-21 and Figure 4-22), similarly to the other periods. As discussed in Section 4.6.1, this is likely due to inaccurate representation of bathymetry in the upper reaches of the model, away from the oyster harvest areas.

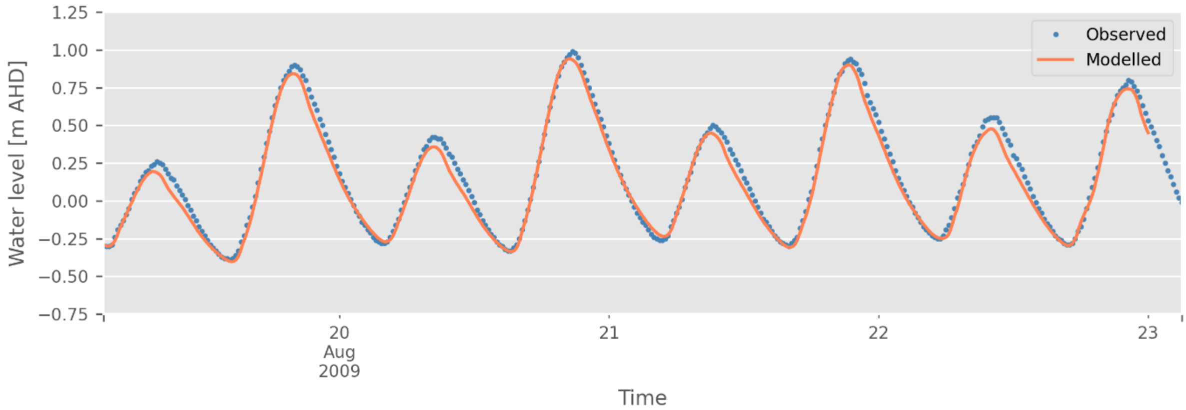

Figure 4-20 2009 water level verification – Location 3 – Stuart Island

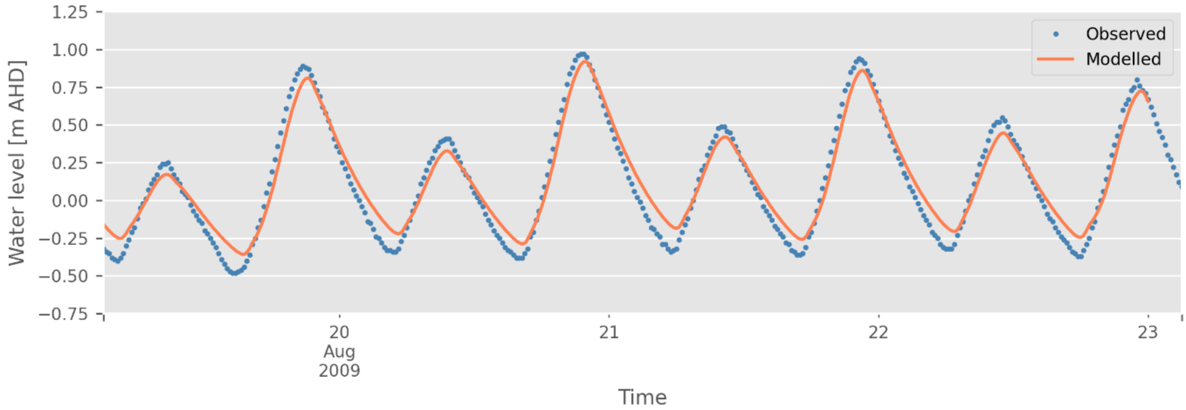

Figure 4-21 2009 water level verification – Location 7 – Macksville

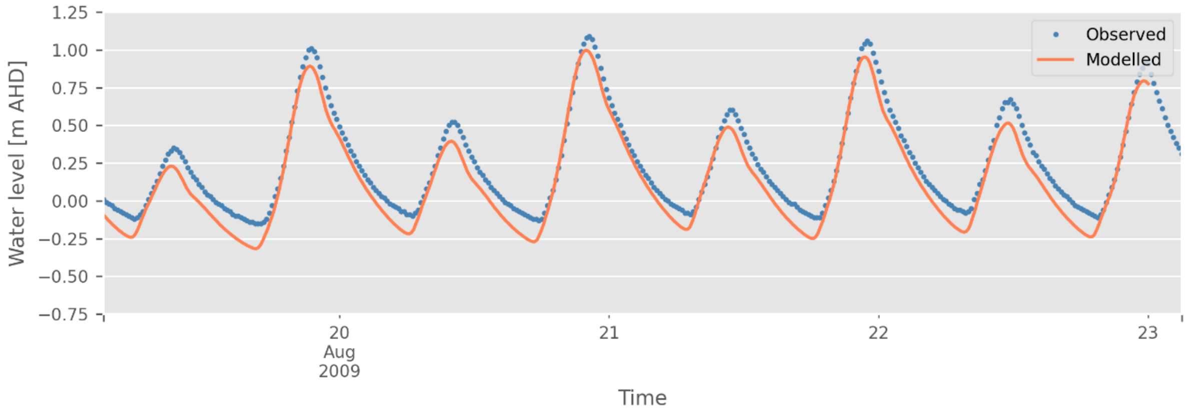

Figure 4-22 2009 water level verification – Location 9 – Bowraville

4.6.3 July 2018 verification period

For this period, water levels were only available from the five MHL long term gauges operational at the time. This model period was run to verify the 2018 (E1) bathymetry. The exact date of the 2018 DPIE bathymetry was not available, however satellite imagery shows limited changes in bathymetry over the year. Measured tide levels were applied at the ocean boundary and scaled measured catchment inflows were applied at the four upstream model inflow boundaries. Model results were then compared with the observed data, using the same model parameters used for the 1999 model run. Plots of all observed water level and flow compared with model results are shown in Appendix B1.6, while select results are shown below.

Results were similar to the 2009 period, with a relatively good fit achieved for Stuarts Island and Utungun, however, low tide water levels were underestimated at Bowraville. The fit was improved at Macksville (Figure 4-23). Water levels at Warrell Creek, not available in 2009, achieved a poor model fit as the model had insufficient tidal range (Figure 4-24), similarly to the other periods. As discussed in Section 4.6.1, this is likely due to inaccurate representation of bathymetry in the upper reaches of the model, however, was not deemed to significantly impact the model's fitness for purpose in this case.

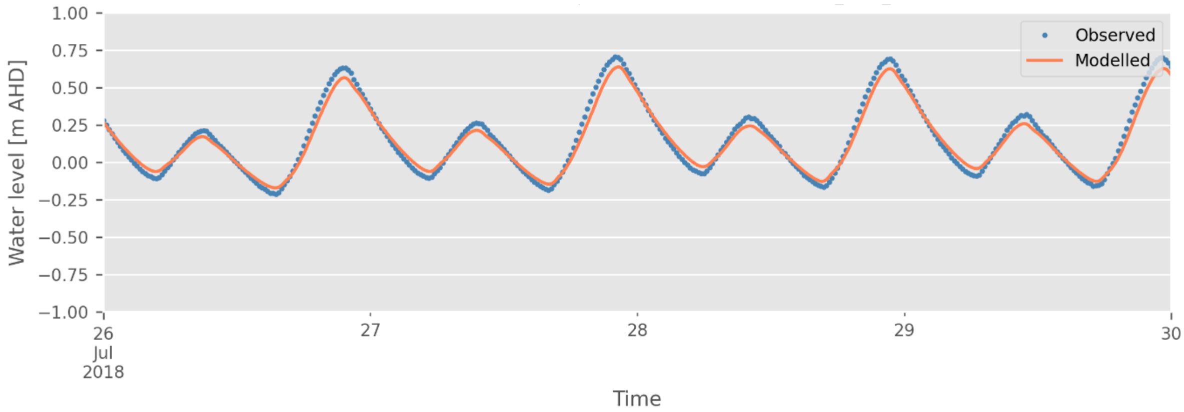

Figure 4-23 2018 water level verification – Location 7 – Macksville

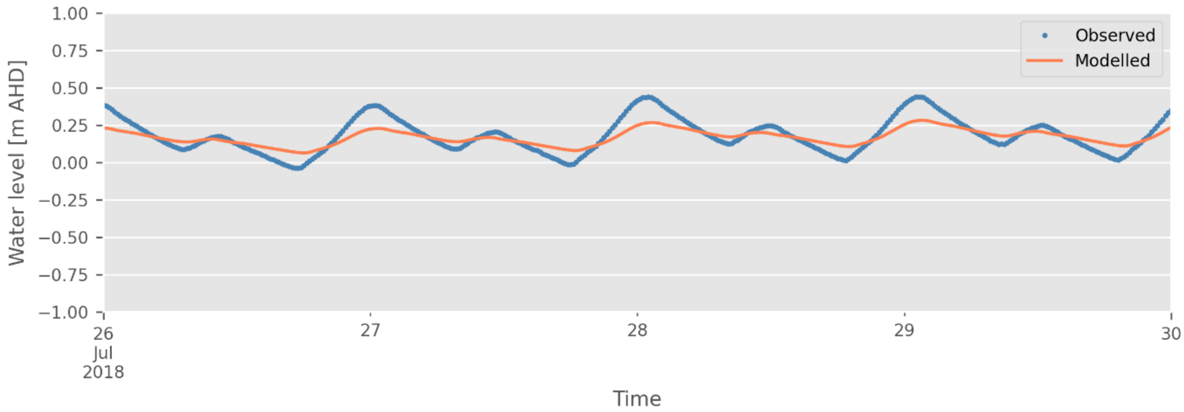

Figure 4-24 2018 water level verification – Location 15 – Warrell Creek

4.6.4 June 2023 field data verification period

The 2023 field campaign involved the collection of tidal flow gauging at six transects, and the collation of water level data at five locations from MHL (refer to Section 3) and three temporary water level gauging locations collected during the trip. Measured tide levels were applied at the ocean boundary and scaled measured catchment inflows were applied at the four upstream model inflow boundaries. Model bathymetry was based on 2009 bathymetry with variations based on field bathymetry data collected and NearMap imagery to create the 2023 bathymetry (E3). Model results were then compared with the observed data, using the same model parameters used for the 1999 model run. Plots of all observed water level and flow compared with model results are shown in Appendix B1.7 and B1.8, while select results are shown below.

A good fit was achieved for all flows (see Figure 4-25 for an example) and for all water levels except the Bowraville (Figure 4-26) and Warrell Creek (Figure 4-27) water levels, which as discussed in Section 4.6.1, there is limited bathymetric data available for and is not close to the oyster harvest areas. Thus, given the satisfactory fit to relevant parts of the model in 1999, 2009, 2018 and 2023 the model was considered fit for purpose, although the sensitivity to the system to changes in bathymetry was identified and considered highly relevant to model scenarios, as discussed further in Section 5.4.2.

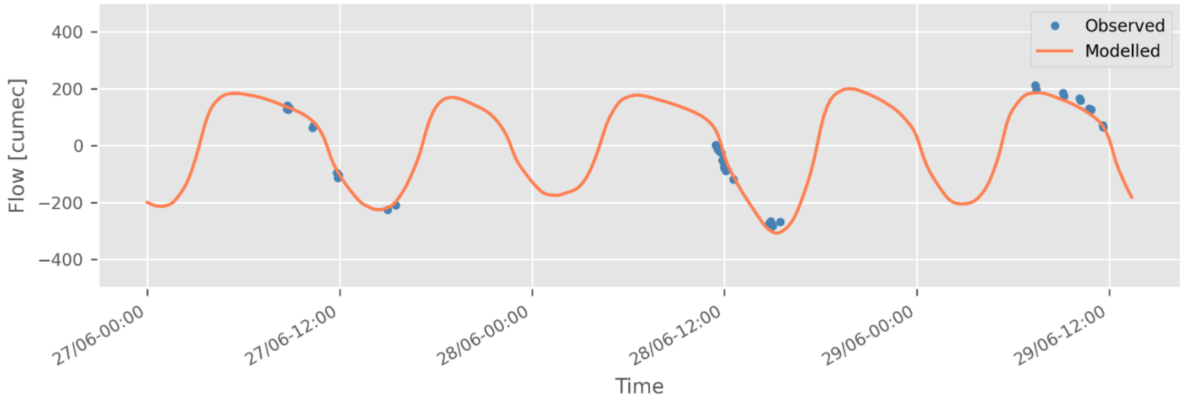

Figure 4-25 2023 tidal flow verification – Location K – Airport

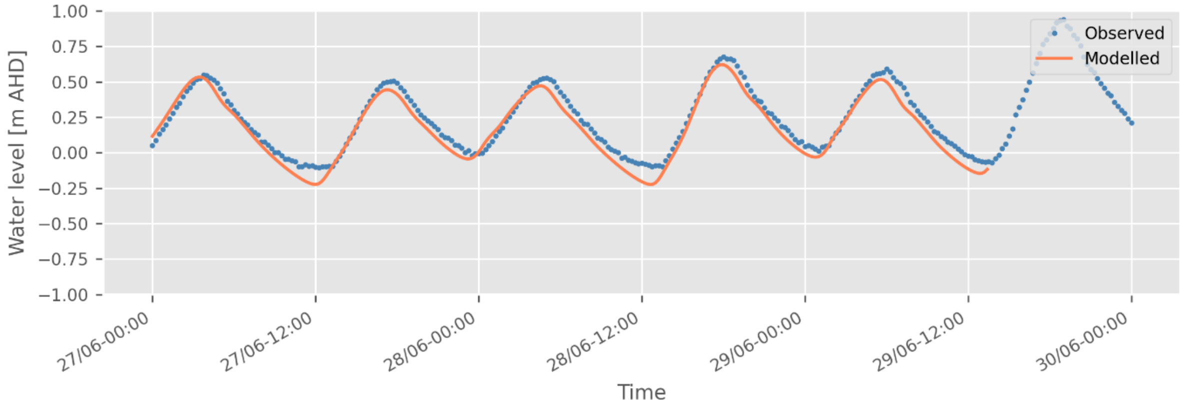

Figure 4-26 2023 water level verification – Location 9 – Bowraville Downstream

Figure 4-27 2023 water level verification – Location 15 – Warrell Creek

4.6.5 Roughness coefficients

Table 4-1 lists the roughness coefficients (Manning's n) which control the frictional losses in the final calibrated model. Most areas have a coefficient between 0.02 and 0.03, which is typical for large sandy channels. The culvert in the side channel, under the bridge connecting Stuarts Island, was a source of uncertainty in the modelling, hence multiple variations of the model were run with high and low conveyance culverts, as discussed in Section 5.4.1.

Table 4-1 Mannings n roughness coefficients of the final model

Location	Manning's n roughness coefficient
Nambucca River entrance to airport	0.025
Nambucca River upstream of airport	0.030
1D sections	0.030
Warrell Creek	0.040
Intertidal areas	0.060
Side channel culvert	0.030-0.070

4.7 Water quality model development

4.7.1 Modelling of dispersion in RMA-11

Dye dispersion experiments, discussed in Section 3.5, provided valuable information on dispersion and its simulation in modelling. In particular, they provided evidence for a sensible range of dispersion coefficients to use in the modelling. However, it was concluded that they could not be used to produce estuary specific values for dispersion. Hence, a range of dispersion values, derived from the field experiments, were used across all the estuaries. Models were run with two dispersion coefficients, 0.5 and 1.5 m^2/s, and the scenario results presented are a combination of the two to manage the uncertainty in dispersion. For further details on how these dispersion values were determined, sensitivity testing, and how model results were combined refer to WRL TR2023/32 Section 7.3, 7.4 and 8.2.3. The RMA-11 model utilised a 3 minute timestep, with results output every 12 minutes.

4.7.2 Tidal straining and vertical velocity distribution

As outlined in WRL TR2023/32 Section 7.5, tidal straining is a process leading to asymmetrical vertical velocity distributions in some estuaries. In instances of tidal straining, much higher velocities are observed at the surface than at the bed on the ebb tide, with much less velocity difference observed on the flood tide. Using the methods described in WRL TR2023/32 Section 7.5, RMA-TRK (Lagrangian model) was used to compare the travel times from field observations with drifter drogues (see Section 3.6) with modelled transport. Table 4-2 shows the difference in drogue velocity and velocity of particles released in the model at the same location and time, plus the ratio between the two.

In the Nambucca River system, depth varying vertical velocity distributions were observed on both the ebb and the flood tide, with an average ratio of drogue to modelled particle velocity being 1.1 on the flood tide and 1.9 on the ebb tide. This difference in ratio between tides is indicative of tidal straining.

Table 4-2 Summary of RMA-TRK velocity factors calculated from GPS drifter drogues

Drogue release	Location	Tide	Average drogue velocity (km/h)	Average model particle velocity (km/h)	Average ratio (velocity factor)
Day 1 drop 1	Goat Island	Ebb	0.89	0.47	1.88
Day 1 drop 1 (after turn of the tide)	Middle Nambucca harvest area	Flood	0.77	0.67	1.15
Day 2 drop 1	Goat Island	Ebb	1.13	0.54	2.10
Day 2 drop 2	Middle Nambucca harvest area	Ebb	0.81	0.47	1.74
Day 2 drop 3	Stuart Island	Flood	1.26	1.15	1.10
Day 3 drop 1	Goat Island	Ebb	1.16	0.63	1.85

Evidence of salinity stratification (indicating the potential for tidal straining) was also observed, although salinity profiles were not taken during the peak ebb tide (refer to Section 3.8). Moreover, depth varying vertical velocity distributions were observed at the airport flow gauging site on the ebb tide while flood tide distributions were much closer to depth averaged, as can be seen in velocity profiles in Appendix A4. Given this evidence, tidal straining was considered to be a process occurring on the Nambucca River estuary. Therefore, the methods described in WRL TR2023/32 Section 7.5 were used to adjust travel times for the upstream overflows that would be impacted by tidal straining: Bowraville WWTP and Macksville WWTP.

For the overflow locations farther downstream, due to increased mixing in the shallow, shoaled section near the entrance, salinity stratification and hence tidal straining would be minimal, however a vertical velocity distribution, such as that observed by the drogues on a flood tide would still be occurring. However, as the vertical velocity distribution would be tidally symmetrical (A. rather than B. on Figure 4-28), net movement of the plume over multiple tidal cycles would remain unaffected, as the surface is travelling faster on both ebb and flood tides. The observed distribution may still affect transport times within a single tidal cycle. However, as travel times are banded by 6 hour (tidal cycle) increments, this velocity distribution is unlikely to have an effect of the reported timing of plume arrival. Hence, despite observed vertical velocity distributions, resulting in faster transport at the surface, no timing adjustments were applied to downstream overflow locations.

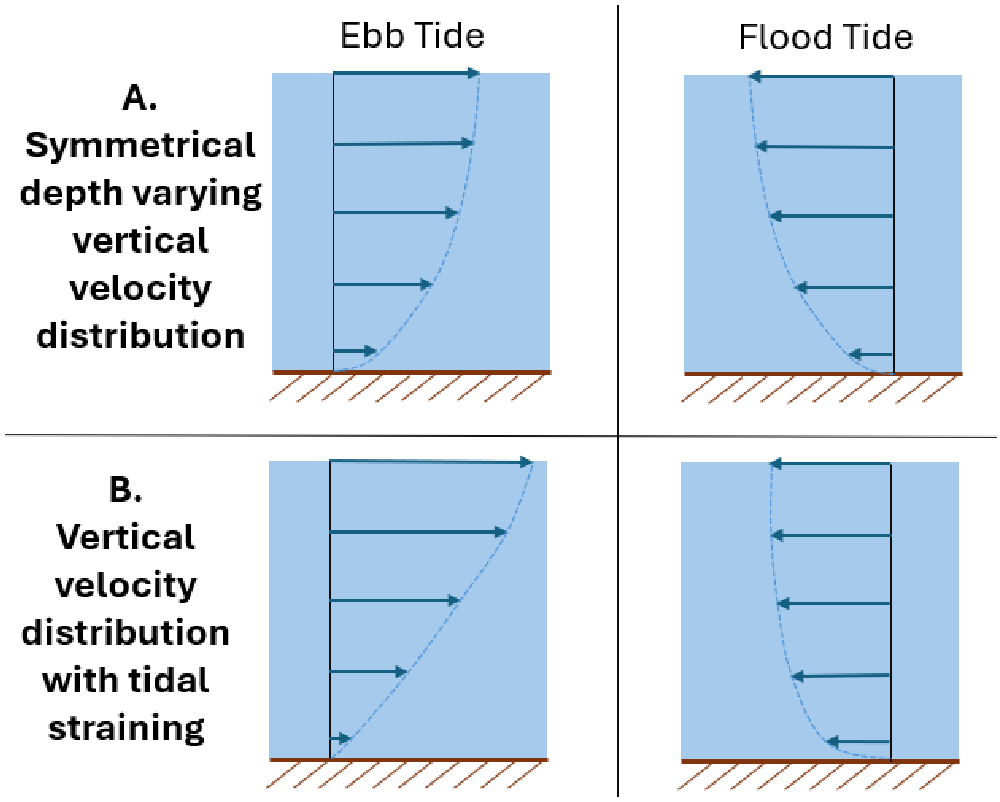

Figure 4-28 Flow with tidally symmetrical depth varying velocity profiles and tidal straining with non-symmetrical vertical velocity profiles

4.8 Limitations for future model uses

This model has been constructed and calibrated to be fit for the purpose of modelling sewage overflow transport from the modelled locations to oyster harvest areas. The model may be adapted for other uses, however the limitations must be considered. A general discussion on the limitations of applying these models to other use cases can be found in WRL TR2023/32 Section 6.6.

Limitations specific to the Nambucca model include:

- The system has a highly variable bathymetry and the hydrodynamics are sensitive to bathymetric change. Only limited bathymetric data is available, hence for any future model use case, the appropriateness of these bathymetries, the implications of future new bathymetry on model results, and the uncertainty created in calibration due to lack of appropriate bathymetry data must be considered. Sensitivity analysis to a wide range of bathymetric conditions is vital to any model use for this estuary.
- There is uncertainty in the conveyance of the culvert under the bridge connecting to Stuarts Island. As the results of this project were impacted by changes to the flow regime in this location, this was managed within this project by simulating a range of potential culvert conveyances (as discussed in 5.4.1). Future model use cases may also be impacted by this uncertainty.
- As discussed in Section 4.6, model fit to observed water levels is generally poor in Warrell Creek and the upper reaches of the Nambucca River and Taylors Arm. This was not considered to significantly impact the model's appropriateness for this purpose, as these locations were far from the area of interest in the lower estuary, however, this may impact other model use cases.

- As discussed in WRL TR2023/32 Section 6.6, the model used for this estuary does not simulate density driven currents or three dimensional processes. This is relevant in this location, where tidal straining is likely to be occurring. This was dealt with in this model by adjusting travel times from upstream overflow locations, however, other model use cases require reconsideration of the impacts of tidal straining for the relevant situation.

5 Scenario modelling

5.1 Preamble

A detailed description for the methods of scenario modelling for this project can be found in WRL TR2023/32 Section 8. For Nambucca, a total of 570 model scenario simulations were completed, including permutations of:

- Five overflow locations
- Four stages of the tide
- Three sizes of the tide
- Three catchment inflow conditions
- Three overflow volumes and duration
- Two estuary conditions (bathymetries)

Note that there were more model scenarios completed for the Nambucca River than for most other estuaries in this project. This was because of the large number of variables which had an impact on transport in the estuary. Reporting focused on the minimum dilution observed in each harvest area (during the 21 day scenario) and the time taken for the plume to reach each harvest area at 5,000,000 times dilution. Refer to WRL TR2023/32 Section 8.3 for more information. In situations where multiple scenarios gave very similar results, these scenarios were grouped for ease of use, and the worst-case results (minimum dilution and shortest travel time) were reported, as detailed in WRL TR2023/32 Section 8.3.6.

The results of all modelled scenarios have been compiled into a user-friendly HTML tool. A description of the tool and its use can be found in the User Guide (WRL TR2024/26).

5.2 Overflow locations

Five locations were used to simulate overflow locations into the Nambucca River estuary. These locations were based on historical overflow events (Section 2.4) and input from NSW Food Authority. These locations typically correspond to creek lines or infrastructure where sewage may be directed to following an overflow. The model only considers overflows from the moment they enter the estuary surface water system. Containment prior to reaching the estuary may still be effective. A judgement of whether the overflow reached the estuary should be made in consultation with local authorities to determine if the modelled scenarios need to be considered. Moreover, in situations where there is a delay between the overflow occurrence and the time it reaches the estuary, this delay and related uncertainty needs to be considered when determining which stage of the tide scenario to use. If it is uncertain which scenario timing should be used, use the possible timing which results in the worst case scenario. Modelled overflow locations are shown in Figure 5-1.

At each overflow location, three different overflow conditions were considered:

1. 10 kL overflow over 1 hour (10 kL/hr)
2. 30 kL overflow over 3 hours (10 kL/hr)
3. 100 kL overflow over 10 hours (10 kL/hr)

The rate of discharge (10 kL/hr) was kept constant between each condition. This is equivalent to a rate of approximately 3 L/s. Intermediate results can be inferred for overflows of the same duration, but a different volume. See WRL TR2023/32 Section 8.3.3 for details on how to do this. Due to the large number of model runs for this location, 3 hour (30 kL) overflows were only run for median catchment inflow conditions.

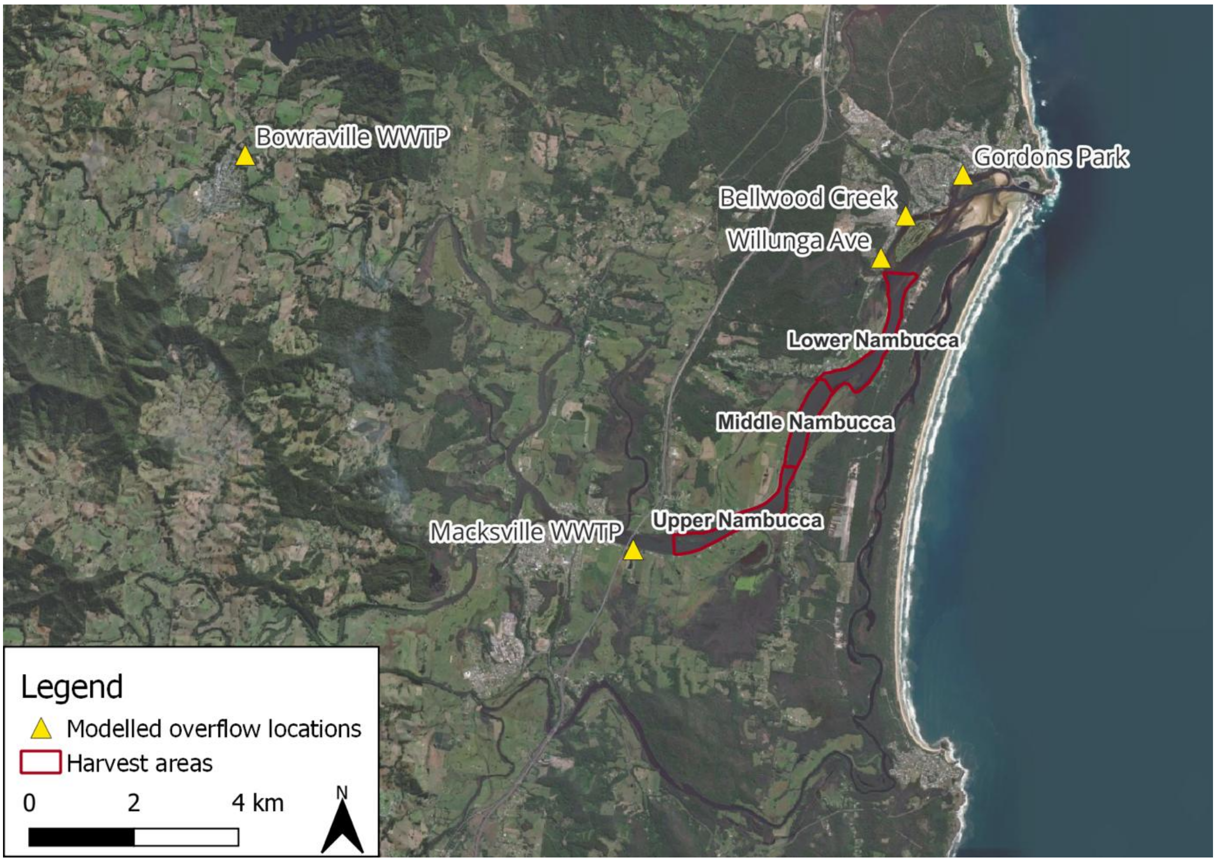

Figure 5-1 Modelled overflow locations in Nambucca River estuary

5.3 Environmental variables

Four environmental variables were tested for the Nambucca River:

1. Stage of the tide (slack low tide, slack high tide, mid ebb tide and mid flood tide)
2. Size of the tide (small, large or small then large)
3. Magnitude of catchment inflows (median, 80th percentile and 95th percentile)
4. Estuary condition or state of the entrance (E1 and E3)

5.3.1 Stage of the tide

Stage of the tide for all locations is indexed to the MHL water level gauge, via the relationship described in Table 5-1.

Table 5-1 Model stage of tide timing relative to the MHL water level gauges

Overflow location	Results scenario	MHL water level gauge	Water level at start of spill
Gordons Park, Bellwood Creek and Willunga Ave	Slack low tide	Stuarts Island Downstream (205466)	Low tide
Gordons Park, Bellwood Creek and Willunga Ave	Mid flood tide	Stuarts Island Downstream (205466)	Half way between low and high tide
Gordons Park, Bellwood Creek and Willunga Ave	Slack high tide	Stuarts Island Downstream (205466)	High tide
Gordons Park, Bellwood Creek and Willunga Ave	Mid ebb tide	Stuarts Island Downstream (205466)	Half way between high and low tide
Macksville WWTP	Slack low tide	Macksville 2 (205416A)	Low tide
Macksville WWTP	Mid flood tide	Macksville 2 (205416A)	Half way between low and high tide
Macksville WWTP	Slack high tide	Macksville 2 (205416A)	High tide
Macksville WWTP	Mid ebb tide	Macksville 2 (205416A)	Half way between high and low tide
Bowraville WWTP	Slack low tide	Bowraville Downstream (205425)	Low tide
Bowraville WWTP	Mid flood tide	Bowraville Downstream (205425)	Half way between low and high tide
Bowraville WWTP	Slack high tide	Bowraville Downstream (205425)	High tide
Bowraville WWTP	Mid ebb tide	Bowraville Downstream (205425)	Half way between high and low tide

The stage of the tide is important for overflows from all locations other than for Bowraville WWTP of durations less than 10 hours. Timing of the tide is particularly important for overflows from Gordons Park, where some overflows at slack high tide will largely leave the estuary before the turn of the tide. For ease of use, results for different stages of the tide have been combined for scenarios where the implications for harvest areas are similar. See WRL TR2023/32 Section 8.3.4 for more details on scenario grouping.

5.3.2 Size of the tide

Size of the tide was important for overflow results in some cases, thus three tide sizes were simulated. Tide sizes refer to tidal range (the difference between high and low tide water level). References to tide size are based off the size of the offshore tides driving the model, sourced from the MHL Coffs Harbour Inner Pumpout Jetty ocean tide gauge (205470). For the purpose of the modelling, three variations of tide size were modelled (shown in Figure 5-2):

- **Neap tide**: a small tide with range approximately 0.75 m, followed by other small tides, typical of tides in the neap portion of the spring-neap cycle, as shown in Figure 5-2.
- **Small spring tide**: a small tide with a range of approximately 1.25 m, followed by a larger tide of approximately 1.9 m, followed by continuing alternating small and large tides, typical of a smaller tide the spring portion of the spring-neap cycle, as shown in Figure 5-2.
- **Large spring tide**: a large tide with range approximately 1.9 m, followed by continuing alternating small and large tides, typical of a larger tide the spring portion of the spring-neap cycle, as shown in Figure 5-2.

Note that due to energy losses through the Nambucca entrance, which vary with bathymetric changes, the ocean tide (at Coffs Harbour) must be used when determining tide size for scenario usage.

Note that it is unlikely that a real-world overflow will occur on a tide with identical size to the modelled scenarios. This means that, in most cases, more than one modelled scenario will need to be considered. The tide size modelling should be treated as an indication in the differences in transport behaviour with larger and smaller tides, rather than as approximations of real-world overflows. Moreover, if the plume takes more than 6 hours to reach a harvest area, the tidal range of subsequent tides (which can be seen in Figure 5-2) should also be considered. If there is doubt about which tide size scenario to use, or the user is inexperienced, use the worst-case scenario.

The size of the tide affects overflows from near the estuary entrance (Gordons Park, Bellwood Creek and Willunga Avenue) as well as from Macksville WWTP. The size of the tide can have mixed effects, with larger tides leading to better outcomes in some cases and worse outcomes in other cases. For example, for an overflow on a low tide at Gordons Park, a large tide pushes the overflow upstream farther, leading to greater impacts on the harvest areas, as can be seen in Figure 5-3 and Figure 5-4. However, for an overflow on a high tide, a large tide makes it more likely the entire overflow can leave the estuary before the turn of the tide. Effect of the size of the tide can be complex, especially for the Bellwood Creek and Willguna Avenue overflow locations, as the hydrodynamics of the side channel are subtle. For ease of use, results for different tide sizes have been combined for scenarios where the implications for harvest areas are similar. See WRL TR2023/32 Section 8.3.4 for more details on scenario grouping.

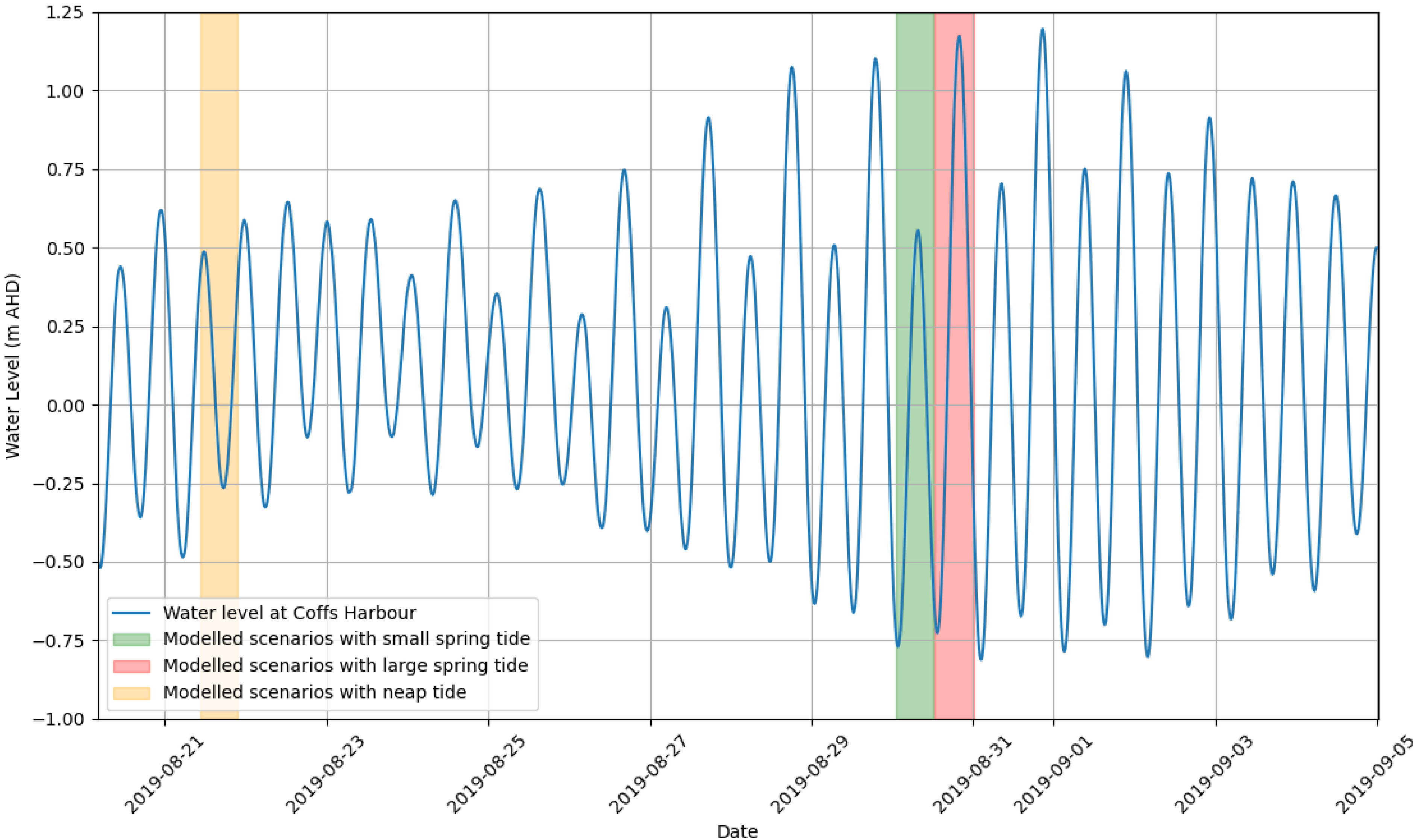

Figure 5-2 Tide sizes used in model scenarios

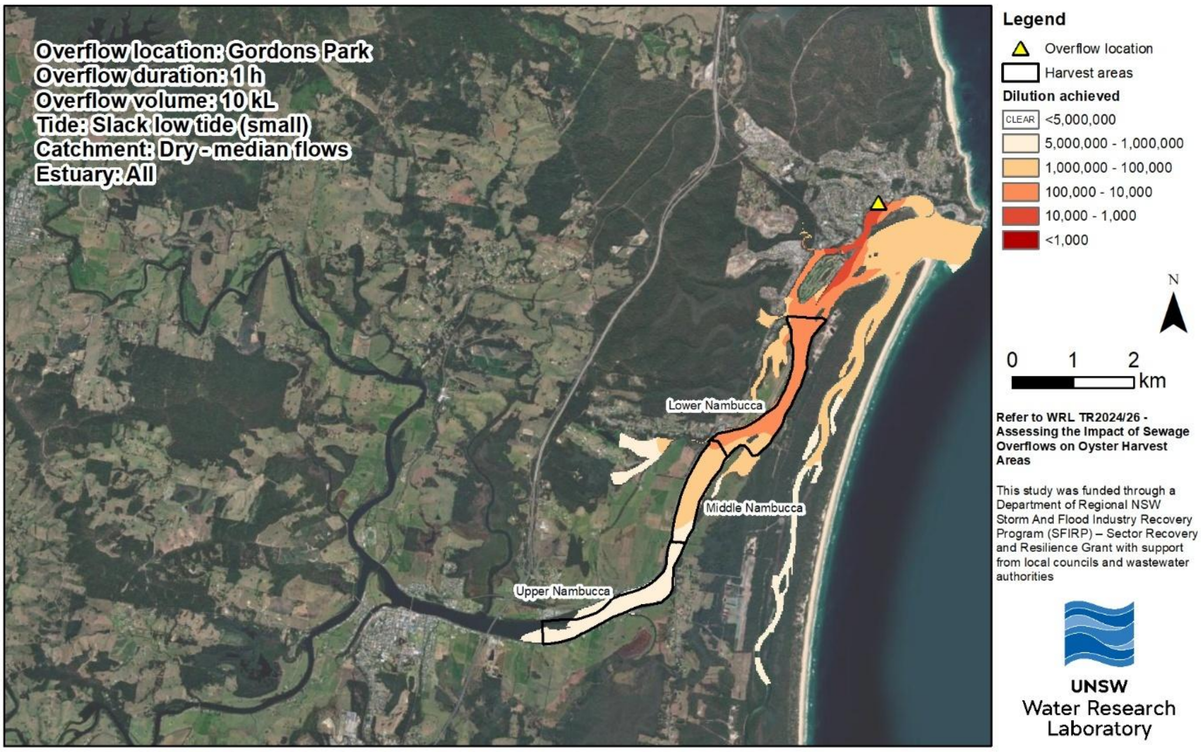

Figure 5-3 Example of a 1 hour overflow at Gordons Park on a small low tide*

*Result figures present the minimum dilution (i.e. maximum concentration) observed at each point during the entire scenario period (21 days).

Figure 5-4 Example of a 1 hour overflow at Gordons Park on a large low tide*

*Result figures present the minimum dilution (i.e. maximum concentration) observed at each point during the entire scenario period (21 days).

5.3.3 Catchment inflows

As the Nambucca River estuary is a riverine system, catchment inflows play a moderate to large role in the impacts of overflows from all locations. Higher flows minimise the impacts from downstream overflows (as the intrusion of the plume upstream is less) and make upstream overflows reach the harvest areas sooner and at higher concentrations.

5.3.4 Estuary condition

Two different estuary entrance bathymetries, E1, simulating a more closed entrance condition, based on bathymetry data from 2018 and E3, simulating a more open entrance condition, based on the bathymetry in 2023. These bathymetries do not represent the full range of possible bathymetry and there are difficulties associated in determining whether a given model bathymetry is a suitable simulation of different real-world bathymetries. The uncertainties surrounding the estuary condition are further discussed in Section 5.4.2. For these reasons, all estuary conditions are grouped in the results, including in situations where the implications for harvest areas are substantially different. This is different to other instances of grouping. See WRL TR2023/32 Section 8.3.4 for more details on scenario grouping.

In other words, the results show the worst case (lowest dilution and shortest time of arrival) across the two model results. Due to the uncertainty surrounding determining entrance conditions, it is recommended that the grouped scenarios reported are used to make decisions, rather than consideration of individual estuary condition results. However, for experienced model users, results for different estuary conditions can still be viewed by clicking ‘View sub-runs’.

Estuary condition plays a moderate to small role on the impacts of overflows from all locations. E3 results in a larger tidal prism (total flow through the entrance) than E1, which has a similar effect to the tide being larger. Additionally, as the E1 state has a single channel, running along the northern training wall, while the E3 state has a second southern channel as well, the estuary conditions also effects flow paths through the side channel. Hence, the fate of overflows from the three overflow locations in the side channel are impacted by changes in estuary condition. In general, the E3 state leads to worse outcomes than the E1 state for overflows from Bowraville, as the greater tidal prism leads to more movement on each tide, as can be seen in Figure 5-5 and Figure 5-6. The effect on the other four overflow locations is much more variable. Figure 5-7 and Figure 5-8 show an example of a scenario which is most impacted by estuary condition.

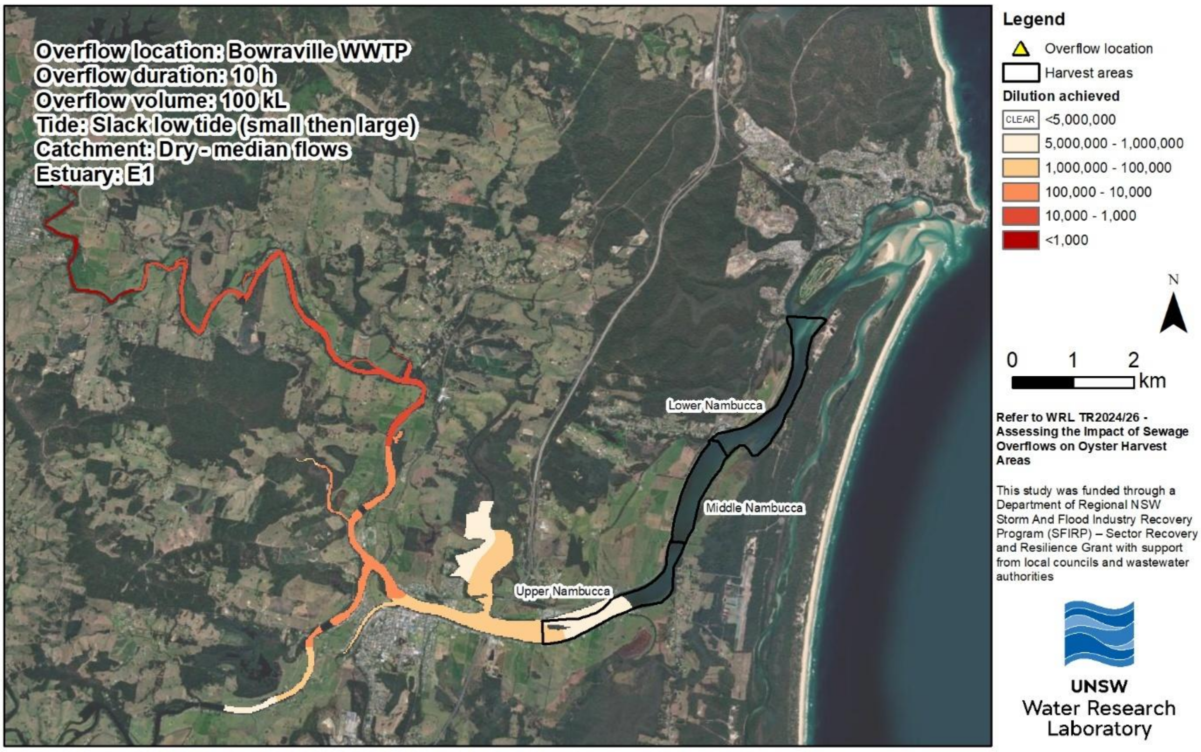

Figure 5-5 Example of a 10 hour overflow at Bowraville WWTP in median flow conditions for estuary condition E1*

*Result figures present the minimum dilution (i.e. maximum concentration) observed at each point during the entire scenario period (21 days).

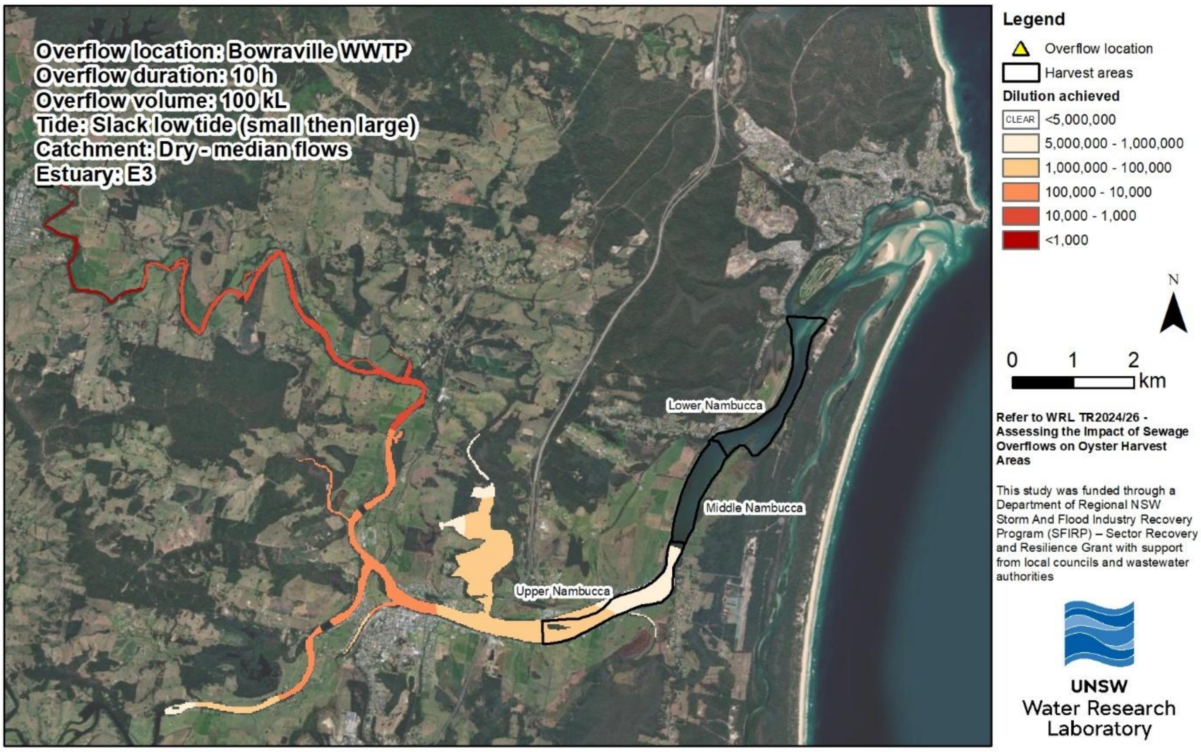

Figure 5-6 Example of a 10 hour overflow at Bowraville WWTP in median flow conditions for estuary condition E3*

*Result figures present the minimum dilution (i.e. maximum concentration) observed at each point during the entire scenario period (21 days).

Figure 5-7 Example of a 3 hour overflow at Gordons Park on a mid flood tide for estuary condition E1*

*Result figures present the minimum dilution (i.e. maximum concentration) observed at each point during the entire scenario period (21 days).

Figure 5-8 Example of a 3 hour overflow at Gordons Park on a mid flood tide for estuary condition E3*

*Result figures present the minimum dilution (i.e. maximum concentration) observed at each point during the entire scenario period (21 days).

5.4 Sensitivity analysis

5.4.1 Side channel culvert

There was found to be significant uncertainty associated with the conveyance through the culvert under the bridge connecting to Stuarts Island, shown in Figure 5-9 and Figure 5-10. Although dimensions of the culvert were known, there was substantial turbulence (leading to energy losses) observed at the culvert. A large eddy viscosity was used in the model to capture some of these energy losses and ensured model stability. A larger eddy viscosity will reduce turbulence but increase losses in the model. However, there was no flow data available to calibrate or validate. Sensitivity analysis showed the conveyance through this culvert can play a substantial role in the transport of plumes from Bellwood Creek and Willguna Avenue.

To account for this uncertainty and associated sensitivity, multiple model iterations with different culvert conveyances were run and incorporated into a single result. In all cases, the reported model results present the worst case result (lowest dilution and shortest arrival time), as is described in WRL TR2023/32 Section 8.2.3. The conveyance of the culvert was increased by increasing the width, while it was decreased by increasing the friction and eddy viscosity. Table 5-2 shows the parameters used.

Figure 5-9 Culvert under bridge to Stuarts Island

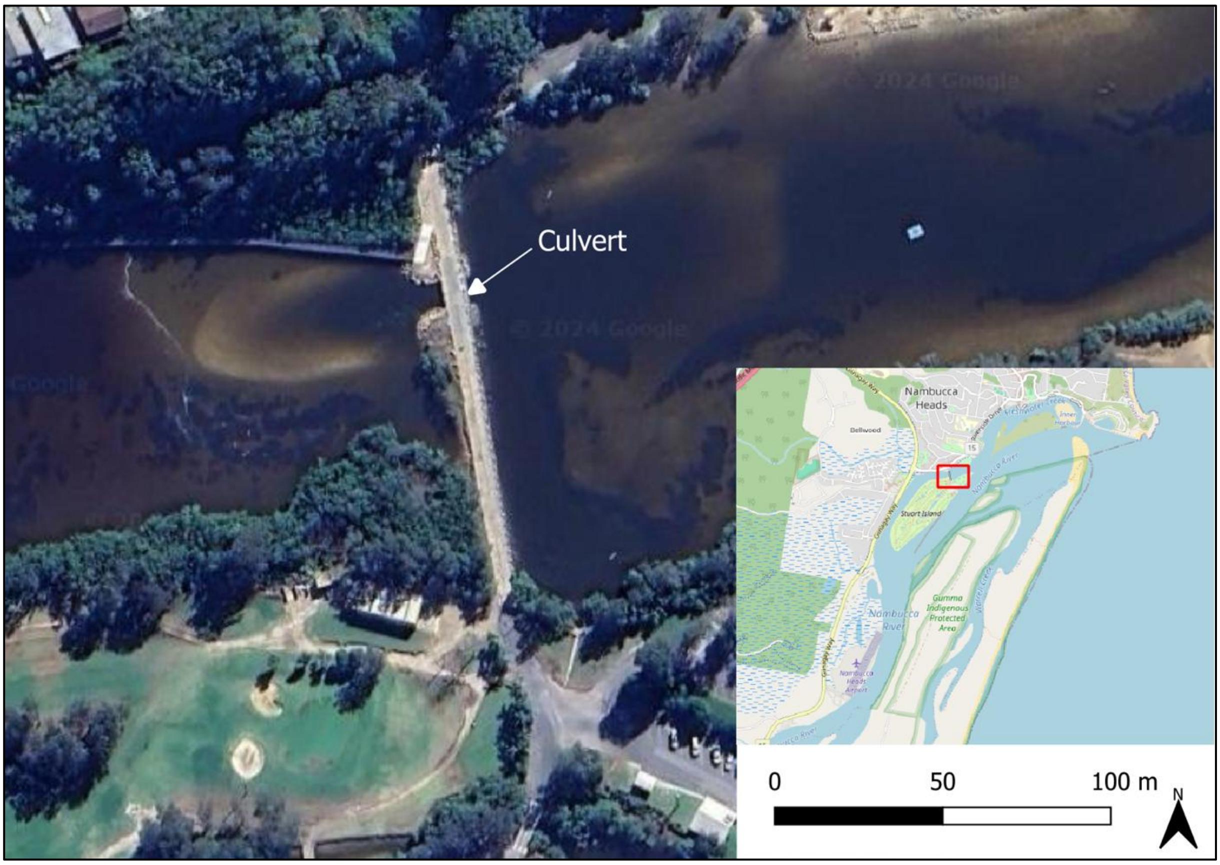

Figure 5-10 Map showing culvert under bridge to Stuarts Island

Table 5-2 Parameters used to model scenarios with different culvert conveyances

Culvert conveyance	Friction (Manning's n)	Eddy viscosity	Width (m)
High	0.03	3	10
Mid	0.03	3	7
Low	0.07	8	7

5.4.2 Entrance bathymetry

The Nambucca River shows significant and complex variations in bathymetry. The variations involve widening and deepening of the entrance, the formation and shifting of secondary channels, and sandbar movement up to 2 km upstream. This can have complex effects on both the tidal prism (the amount of flow entering and leaving the estuary in a tidal cycle) and flow paths, especially around the islands at the entrance and the side channel where the Gordons Park, Bellwood Creek and Willguna Avenue overflows are located. Figure 5-11 shows examples of the diversity of entrance conditions experienced over 4 years. As three sources of entrance bathymetry were available for this project, three estuary bathymetries were developed, as discussed in Section 4.3. Coincidentally, the available bathymetries appear to cover diverse bathymetries, from a relatively open state based on the 2023 bathymetry, with a large southern breakout channel (E3) to a more closed state, based on the 2018 bathymetry, with a single channel located next to the northern training wall (E1). E2, based on the 2009 bathymetry, and was found to have scenario results which were between E1 and E3, hence, to limit model runs, a full range of scenarios were not simulated for E2. Moreover, a more open (than the E3) bathymetry was tested by removing the shoal adjacent to the training wall, and deepening the channels, and this was found to not substantially affect results compared to E3.

However, these bathymetries (E1 and E3) do not necessarily capture the range of extremes possible, and moreover do not capture the diversity of intermediate options and sandbar arrangements which may affect flow paths, especially for the overflows located in the side channel. For example, as can be seen in Figure 4-7, the flow paths upstream of the entrance were substantially different in 1999, reflected in the difficulty calibrating to this period. Moreover, it can be difficult to determine if a model estuary condition is applicable to a real-world estuary bathymetry, even using high resolution aerial imagery, as depths are difficult to determine and subtle changes (for example, an upstream bar) can have large impacts. For these reasons, results for all estuary conditions have been grouped, via the methods described in WRL TR2023/32 Section 8.3.4 and the worst case results reported in the results tables. This is different than other instances of grouping, where only scenarios that gave very similar results were grouped. Due to the uncertainty surrounding determining entrance conditions, it is strongly recommended that the grouped scenarios reported are used to make decisions. However, for experienced model users, results for different estuary conditions can still be viewed by clicking ‘View sub-runs’, and the effects of different estuary conditions have been discussed in this report.

Future changes in bathymetry should be monitored, and if bathymetry departs significantly from the bathymetries tested in this model the model may require updated bathymetry and further sensitivity analysis.

Figure 5-11 Examples of different Nambucca entrance states (4/10/2024, 9/4/2024, 6/7/2023, 19/11/2022, 8/6/2022 and 4/7/2021) from NearMap imagery

6 Conclusion

This report is focussed on the Nambucca River estuary produced for the study "Assessing the impact of sewage overflows on oyster harvest areas in NSW". The purpose of this report was to provide technical and estuary specific information on the process and data sources used to create the Nambucca River estuary model. Key information included in the report relates to the integration of existing data sources, the June 2023 field data collection campaign, data processing, model development, and model verification.

This report should be read in conjunction with the WRL TR2023/32 which provides details on the technical methods used across each of the 11 study estuaries (including Nambucca) and discussions on modelling limitations including model parameter sensitivity and pollutant dispersion. Results of the scenario modelling is available in the accompanying tool, which is documented in the User Guide (WRL TR2024/26).

7 References

DPIE 2018. NSW Marine LiDAR Topo-Bathy 2018 Geotif. Department of Planning, Industry and the Environment.

MHL 1999. NAMBUCCA RIVER ESTUARY TIDAL DATA COLLECTION August-September 1999.

MHL. 2023a. *NSW Ocean Tide Data Collection Program* [Online]. Manly Hydraulics Laboratory. Available: https://www.mhl.nsw.gov.au/Data-OceanTide [Accessed 2023].

MHL. 2023b. *NSW Water Level Data Collection Program* [Online]. Manly Hydraulics Laboratory. Available: https://www.mhl.nsw.gov.au/Data-Level [Accessed 2023].

NearMap. 2024. *NearMap MapBrowser* [Online]. Available: https://apps.nearmap.com/maps/ [Accessed 2024].

NSW Spatial Services 2009. 2km x 2km Grid 1 metre Resolution Digital Elevation Model. Department of Finance, Services and Innovation.

NSW Spatial Services 2016. 2km x 2km Grid 1 metre Resolution Digital Elevation Model. Department of Finance, Services and Innovation.

OEH 2009. NSW Office of Environment and Heritage (OEH) Single-beam Bathymetry and Coastal Topography Surveys.

WaterNSW. 2023. *Continuous water monitoring network* [Online]. Available: https://realtimedata.waternsw.com.au/water.stm [Accessed 2023].

Appendix A Field data collection

A1 Drifter drogue experiments

The below figures summarise the behaviour of the four drifter drogue experiments. For more information on these deployments, refer to Section 3.5.1.

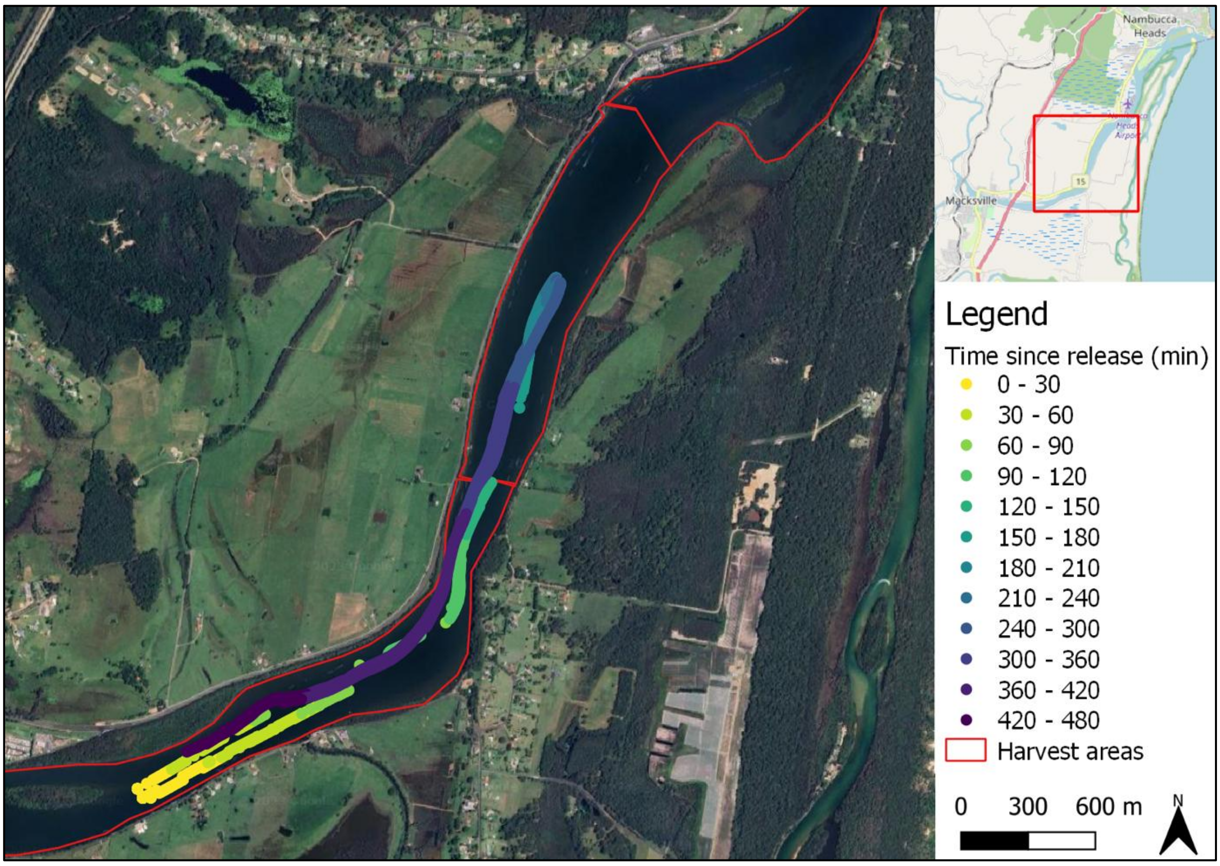

Figure A-1 GPS drifter drogue release day 1 drop 1 – Goat Island – outgoing to incoming tide

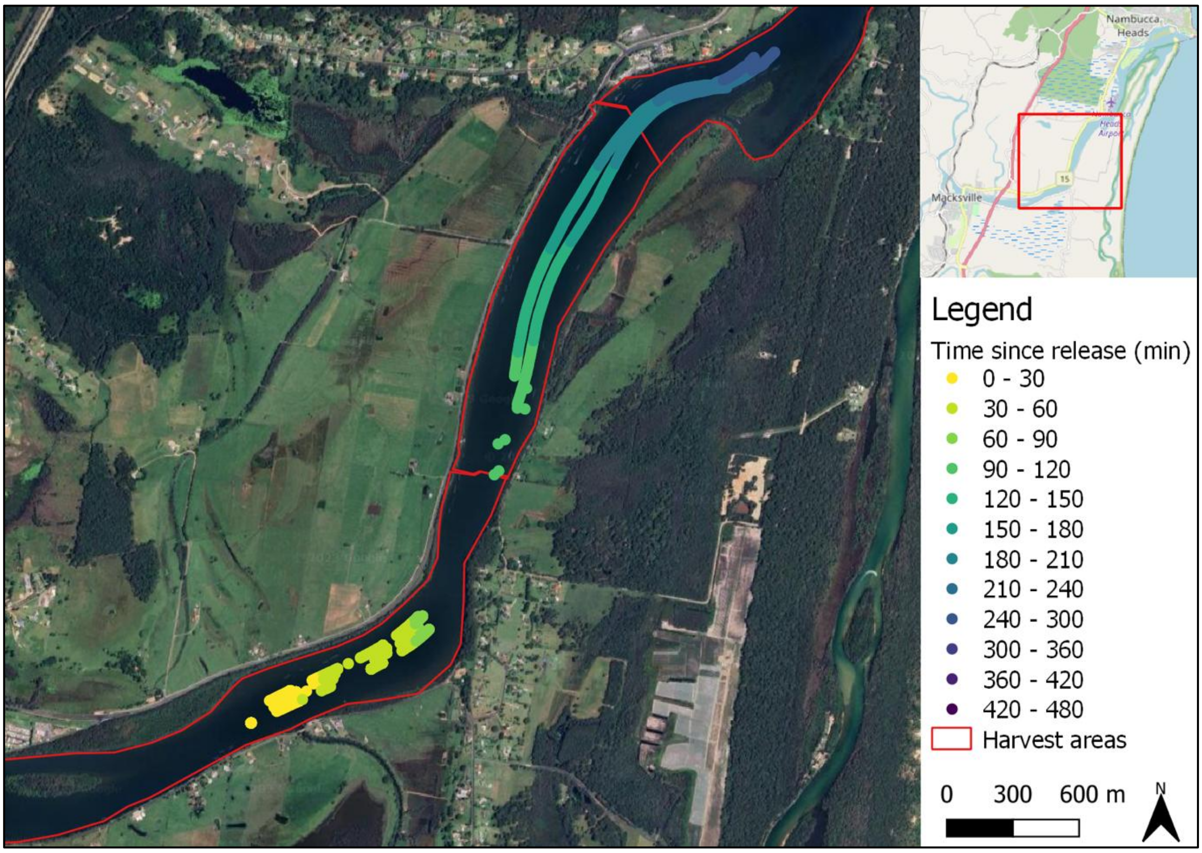

Figure A-2 GPS drifter drogue release day 2 drop 1 – Goat Island – outgoing tide

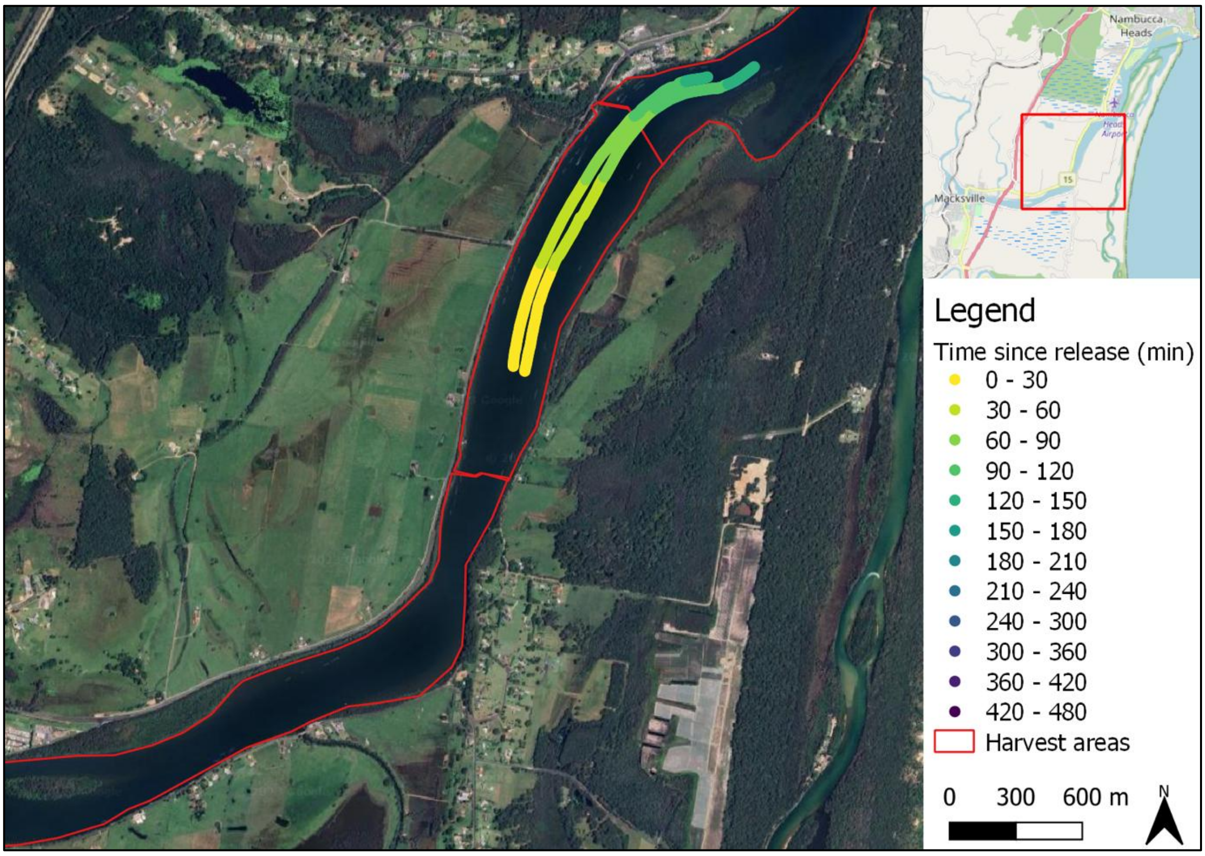

Figure A-3 GPS drifter drogue release day 2 drop 2 – Middle Nambucca – outgoing tide

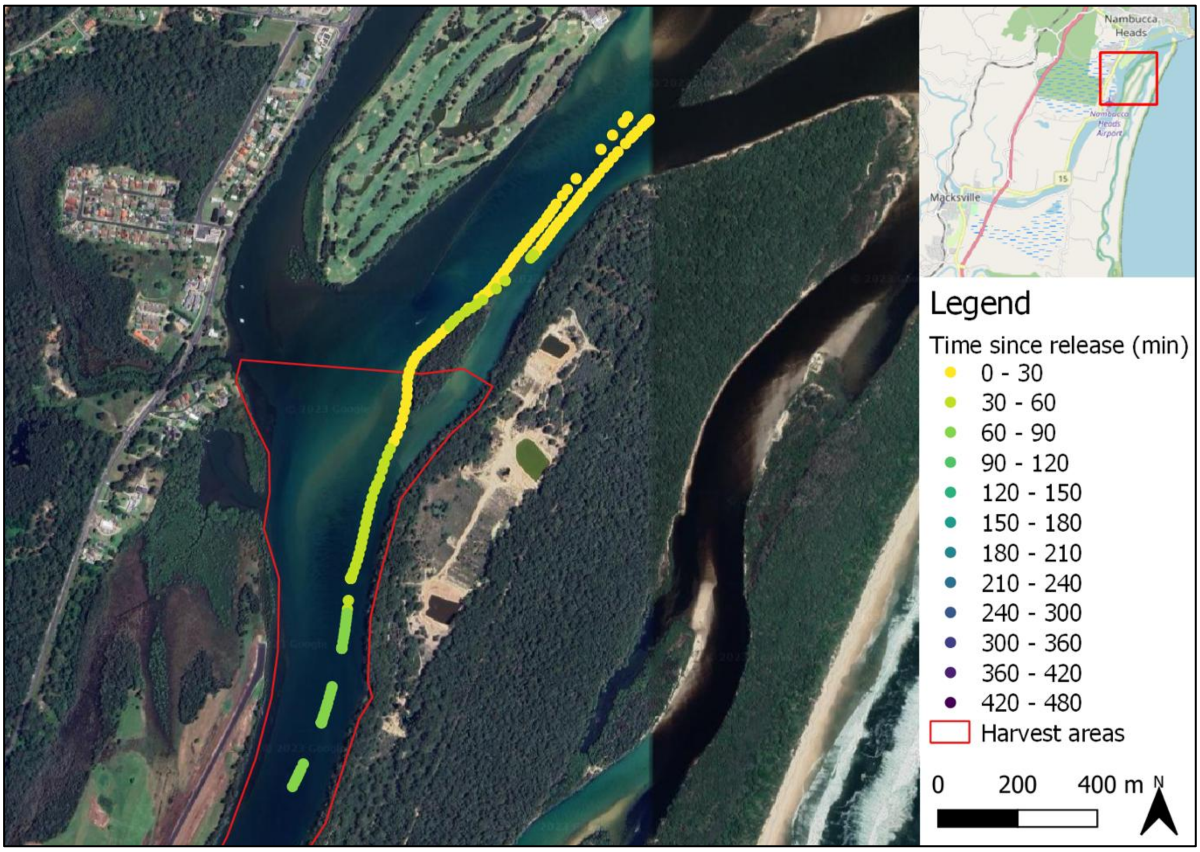

Figure A-4 GPS drifter drogue release day 2 drop 3 – Stuart Island – incoming tide

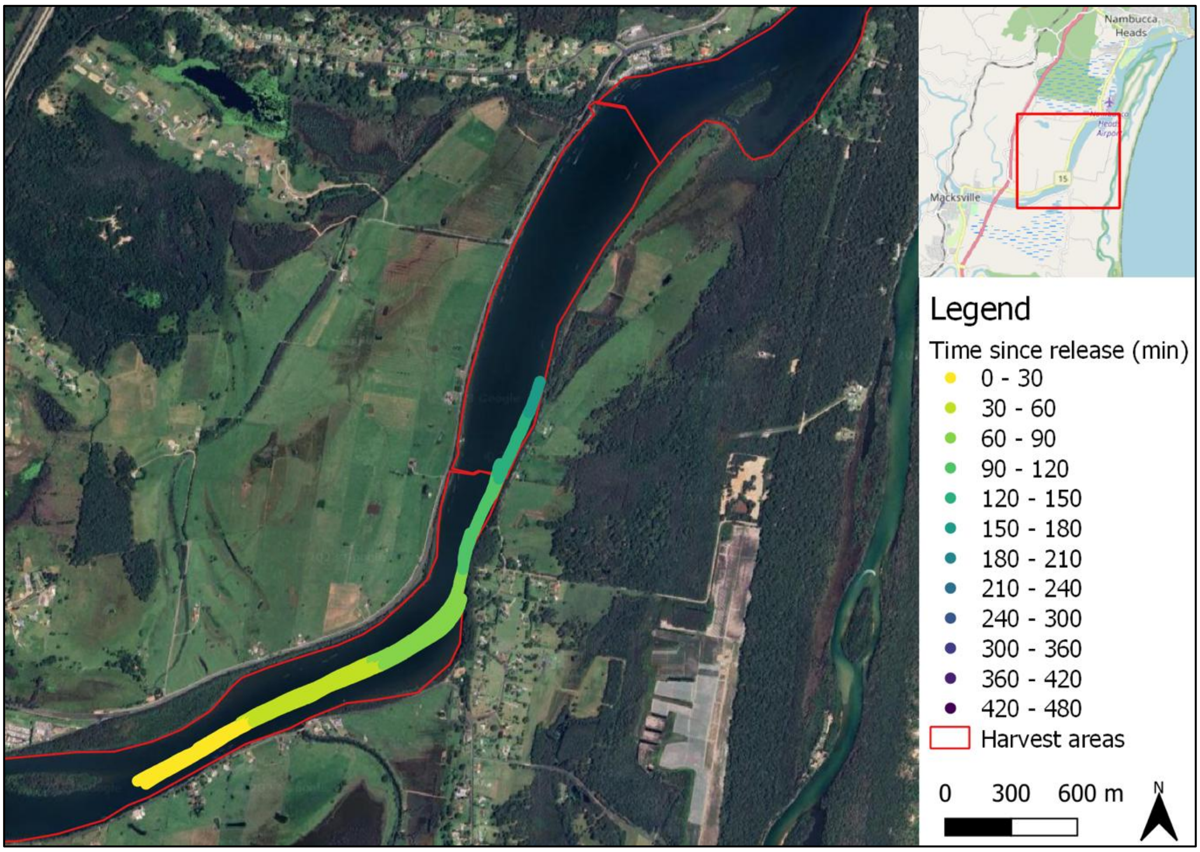

Figure A-5 GPS drifter drogue release day 3 drop 1 – Goat Island – outgoing tide

A2 Tidal flow gauging

The below figures summarise tidal flow gauging results from the 2023 field campaign. For more information, refer to Section 3.

Table A-1 Side Channel Main Entrance Site 3 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	27/06/2023	14:25:50	-35
2	27/06/2023	14:29:59	-32
3	29/06/2023	8:22:42	33

* Flow sign relative to upstream river flow direction. Outgoing ebb flows are positive, while incoming flood flows are negative.

Table A-2 Stuarts Island Site 5 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	27/06/2023	13:28:22	-112
2	27/06/2023	14:32:39	-131
3	29/06/2023	8:11:29	113
4	29/06/2023	8:30:27	114
5	29/06/2023	9:29:01	90
6	29/06/2023	9:33:40	95

* Flow sign relative to upstream river flow direction. Outgoing ebb flows are positive, while incoming flood flows are negative.

Table A-3 Warrell Point Site 6 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	27/06/2023	9:34:09	30
2	27/06/2023	9:36:55	30
3	27/06/2023	13:05:26	-93
4	27/06/2023	13:08:24	-95
5	29/06/2023	8:37:01	80
6	29/06/2023	8:39:37	85
7	29/06/2023	9:37:40	68

No.	Date	Time	Flow (m^3/s) *
8	29/06/2023	9:40:09	69
9	29/06/2023	10:34:35	51
10	29/06/2023	10:36:34	46

* Flow sign relative to upstream river flow direction. Outgoing ebb flows are positive, while incoming flood flows are negative.

Table A-4 Breakwater Main Channel 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	27/06/2023	8:08:49	151
2	27/06/2023	8:14:51	165
3	27/06/2023	9:18:45	113
4	27/06/2023	9:22:53	123
5	27/06/2023	9:46:32	100
6	27/06/2023	9:52:05	88
7	27/06/2023	9:55:05	95
8	27/06/2023	12:53:18	-209
9	27/06/2023	12:57:20	-213
10	27/06/2023	13:14:31	-248
11	27/06/2023	13:18:49	-250
12	27/06/2023	13:36:37	-266
13	27/06/2023	13:41:12	-273
14	27/06/2023	13:50:05	-281
15	27/06/2023	13:57:40	-271
16	27/06/2023	14:01:37	-282
17	27/06/2023	14:05:41	-271
18	27/06/2023	14:09:29	-274
19	27/06/2023	14:41:36	-251
20	27/06/2023	14:45:26	-269

No.	Date	Time	Flow (m^3/s) *
21	27/06/2023	15:39:41	-181
22	29/06/2023	8:00:27	219
23	29/06/2023	8:04:15	211
24	29/06/2023	8:45:33	207
25	29/06/2023	8:49:47	197
26	29/06/2023	9:17:26	194
27	29/06/2023	9:22:04	189
28	29/06/2023	9:50:01	172
29	29/06/2023	10:22:48	149
30	29/06/2023	10:26:39	141
31	29/06/2023	11:15:03	101
32	29/06/2023	11:18:52	94
33	29/06/2023	11:46:20	49
34	29/06/2023	11:50:27	54
35	29/06/2023	11:55:01	45
36	29/06/2023	11:58:52	34
37	29/06/2023	12:02:37	22
38	29/06/2023	12:06:23	9
39	29/06/2023	12:10:44	-14
40	29/06/2023	12:14:33	-34

* Flow sign relative to upstream river flow direction. Outgoing ebb flows are positive, while incoming flood flows are negative.

Table A-5 Breakwater Island 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	27/06/2023	8:24:31	126
2	27/06/2023	8:26:59	131
3	27/06/2023	10:03:10	69
4	27/06/2023	10:06:31	70
5	27/06/2023	12:44:43	-156
6	27/06/2023	12:47:36	-173
7	29/06/2023	7:32:27	185
8	29/06/2023	7:34:34	200
9	29/06/2023	7:52:24	191
10	29/06/2023	7:55:14	192
11	29/06/2023	8:57:16	180
12	29/06/2023	8:59:42	171
13	29/06/2023	9:56:37	152
14	29/06/2023	9:59:26	143
15	29/06/2023	10:02:37	149
16	29/06/2023	11:25:37	69
17	29/06/2023	11:28:13	73

* Flow sign relative to upstream river flow direction. Outgoing ebb flows are positive, while incoming flood flows are negative.

Table A-6 Airport 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	27/06/2023	8:41:25	128
2	27/06/2023	8:44:20	141
3	27/06/2023	8:47:34	127
4	27/06/2023	8:51:06	132
5	27/06/2023	10:18:20	63
6	27/06/2023	10:22:06	70
7	27/06/2023	11:48:54	-96
8	27/06/2023	11:52:30	-114
9	27/06/2023	11:56:15	-105
10	27/06/2023	14:59:15	-225
11	27/06/2023	15:29:32	-209
12	28/06/2023	11:27:09	3
13	28/06/2023	11:31:04	-5
14	28/06/2023	11:34:06	-14
15	28/06/2023	11:37:13	-12
16	28/06/2023	11:40:42	-18
17	28/06/2023	11:44:02	-22
18	28/06/2023	11:47:26	-24
19	28/06/2023	11:50:43	-51
20	28/06/2023	11:54:28	-56
21	28/06/2023	11:57:52	-75
22	28/06/2023	12:01:30	-82
23	28/06/2023	12:04:34	-89
24	28/06/2023	12:32:50	-119
25	28/06/2023	14:46:17	-274
26	28/06/2023	14:49:19	-280

No.	Date	Time	Flow (m^3/s) *
27	28/06/2023	14:52:13	-266
28	28/06/2023	14:54:40	-277
29	28/06/2023	14:57:28	-276
30	28/06/2023	15:00:16	-282
31	28/06/2023	15:27:52	-268
32	29/06/2023	7:22:58	212
33	29/06/2023	7:25:59	198
34	29/06/2023	9:06:34	185
35	29/06/2023	9:10:01	174
36	29/06/2023	10:09:02	166
37	29/06/2023	10:12:48	158
38	29/06/2023	10:45:00	131
39	29/06/2023	10:48:21	123
40	29/06/2023	10:52:11	126
41	29/06/2023	11:35:01	71
42	29/06/2023	11:38:10	64

* Flow sign relative to upstream river flow direction. Outgoing ebb flows are positive, while incoming flood flows are negative.

A3 Cross-channel velocity distribution

The below figures summarise velocity distribution results from the 2023 field campaign. For more information, refer to Section 3. The transects displayed are the peak ebb and flood tide measurements taken at each location, the timing of which can be seen in Section A2. The primary purpose is to illustrate flow distribution across the channel.

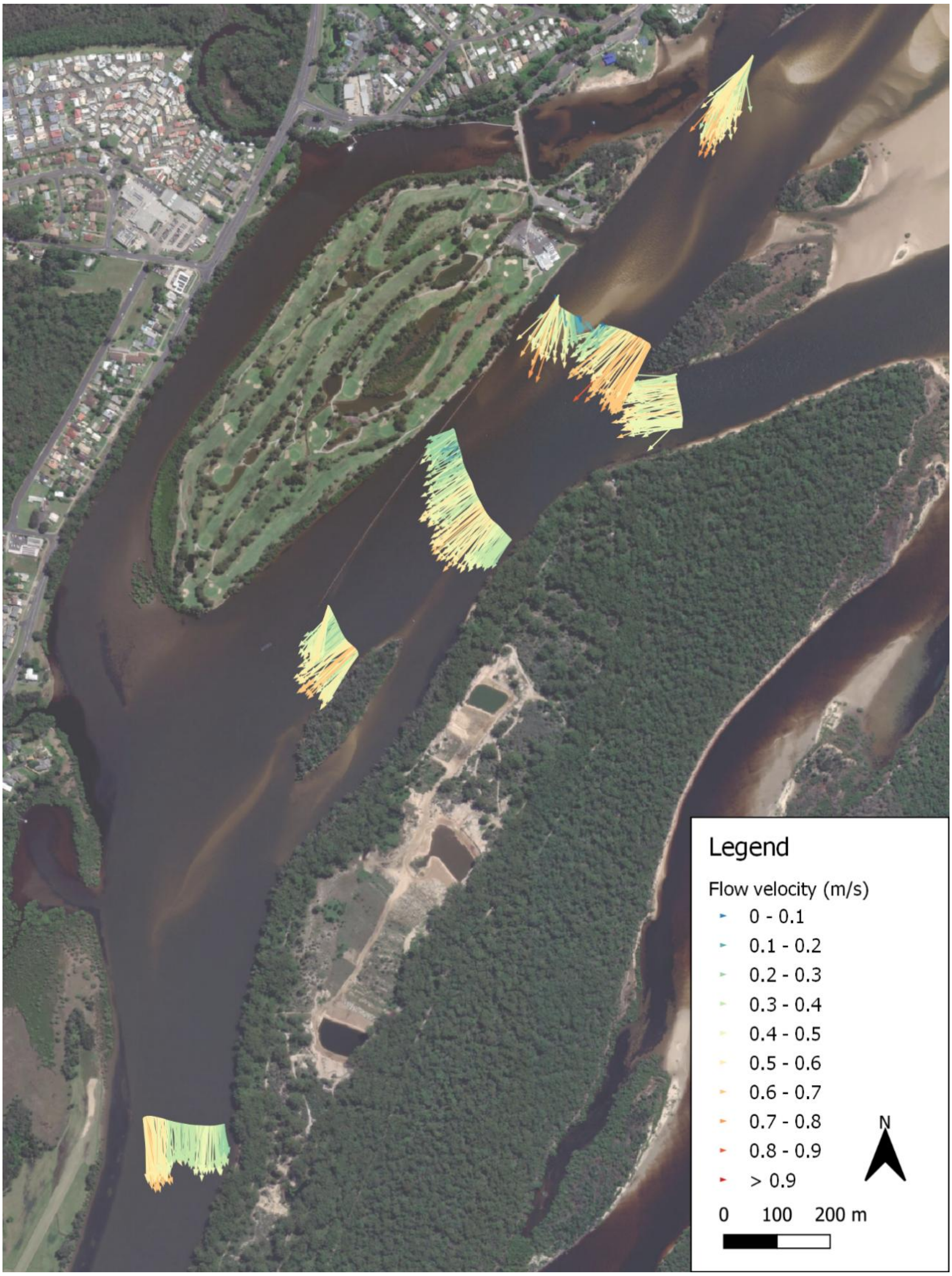

Figure A-6 Flood tide channel flow distribution

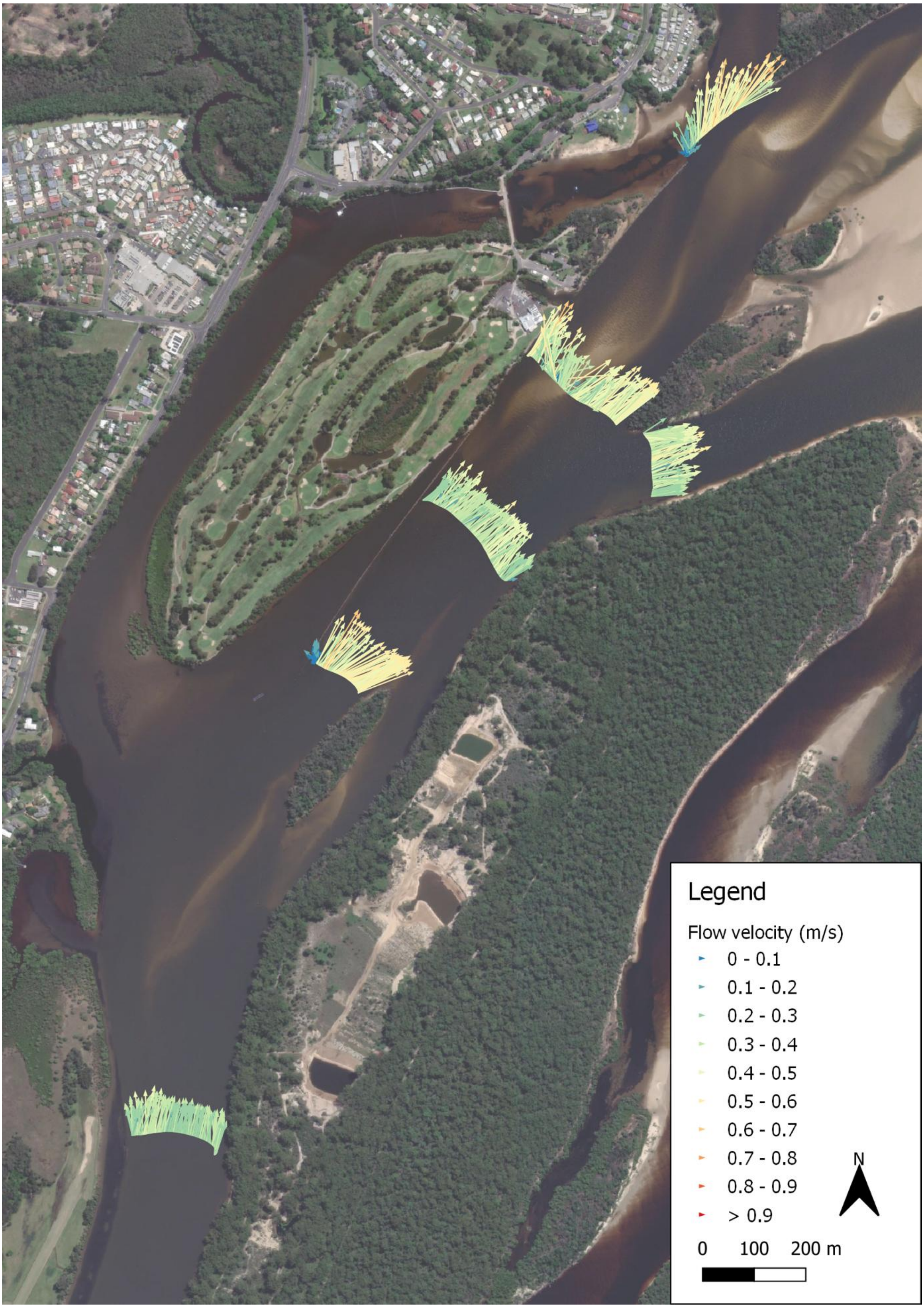

Figure A-7 Ebb tide channel flow distribution

A4 Vertical velocity distributions

The following figures show the vertical distribution of horizontal speed for select transects measured during the 2023 field campaign. This was used to help assess whether vertical velocity distributions were significant. For more information, refer to Section 3.3 and 4.7.2. Bathymetry sometimes varies between ebb and flood transects because transects were not always taken at the exact same location due to boat manoeuvrability limitations. Transects were usually taken within a 50 m reach in which flow would be equivalent.

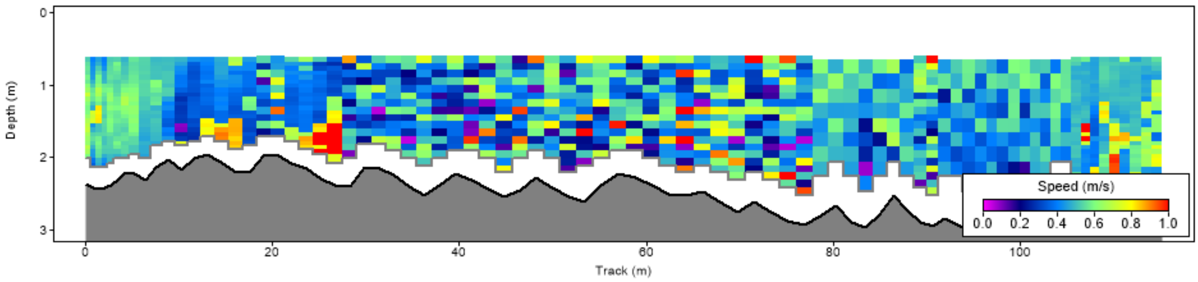

Figure A-8 Vertical velocity distribution – Side Channel Main Entrance Site 3 – Flood tide – (2023/06/27 14:29:59)

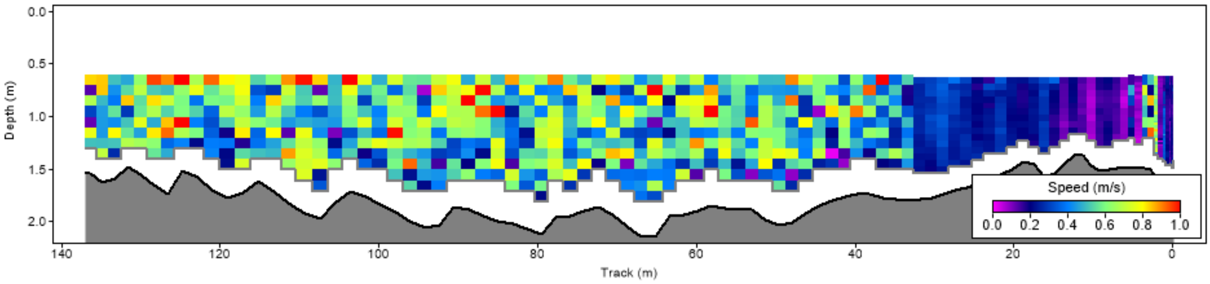

Figure A-9 Vertical velocity distribution – Side Channel Main Entrance Site 3 – Ebb tide – (2023/06/29 08:22:42)

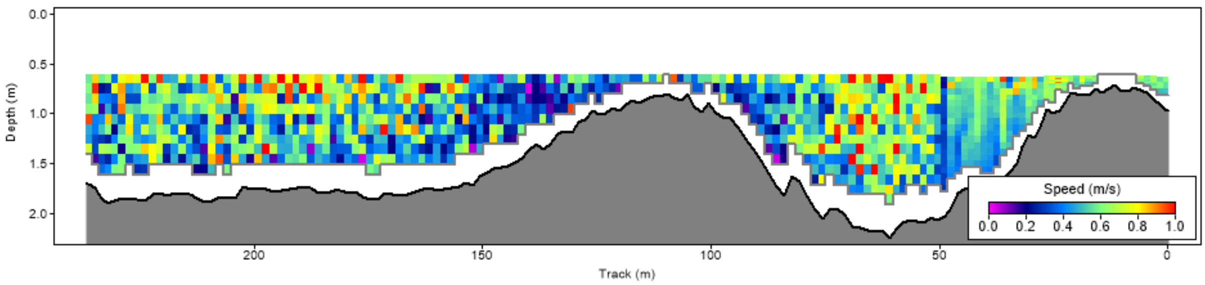

Figure A-10 Vertical velocity distribution – Stuarts Island Site 5 – Flood tide - (2023/06/27 14:32:39)

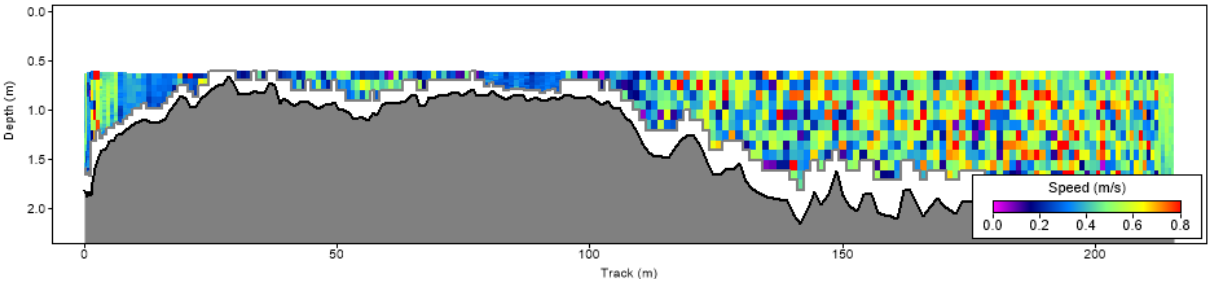

Figure A-11 Vertical velocity distribution – Stuarts Island Site 5 – Ebb tide – (2023/06/29 08:30:27)

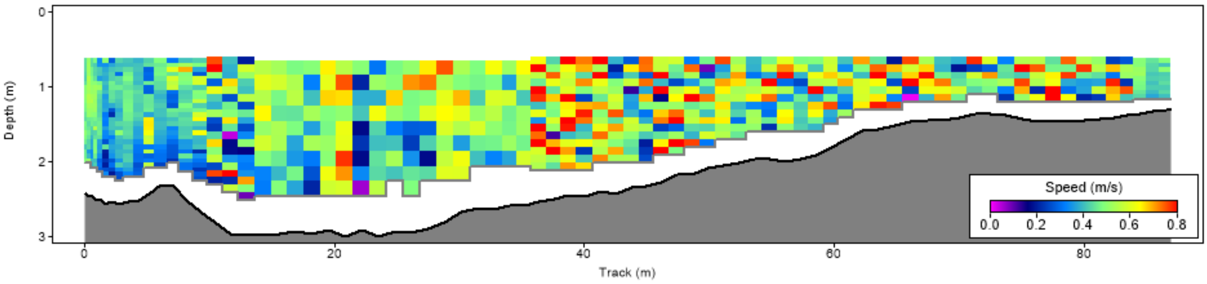

Figure A-12 Vertical velocity distribution – Warrell Point Site 6 – Flood tide - (2023/06/27 13:08:24)

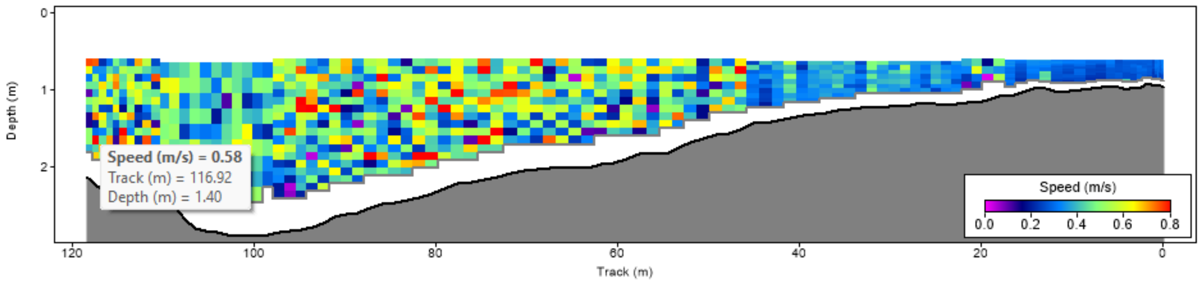

Figure A-13 Vertical velocity distribution – Warrell Point Site 6 – Ebb tide – (2023/06/29 08:39:37)

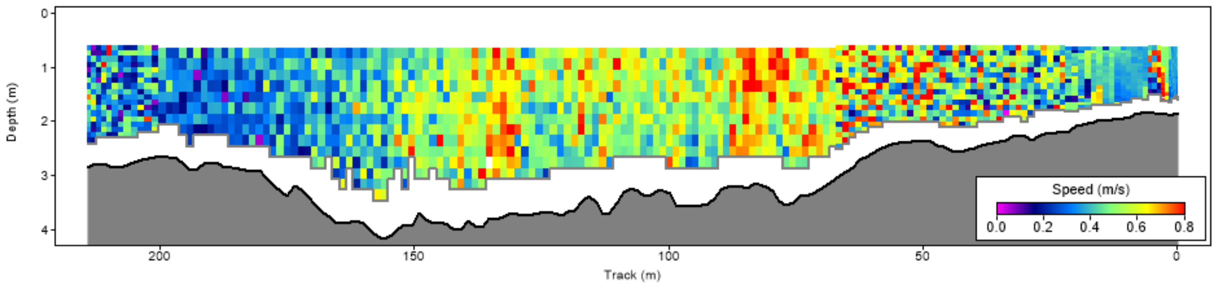

Figure A-14 Vertical velocity distribution – Breakwater Main Channel – Flood tide - (2023/06/27 13:50:05)

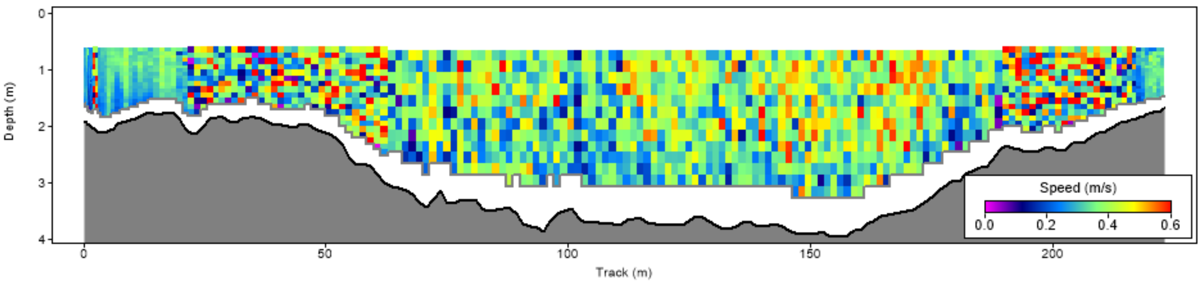

Figure A-15 Vertical velocity distribution – Breakwater Main Channel – Ebb tide – (2023/06/29 08:04:15)

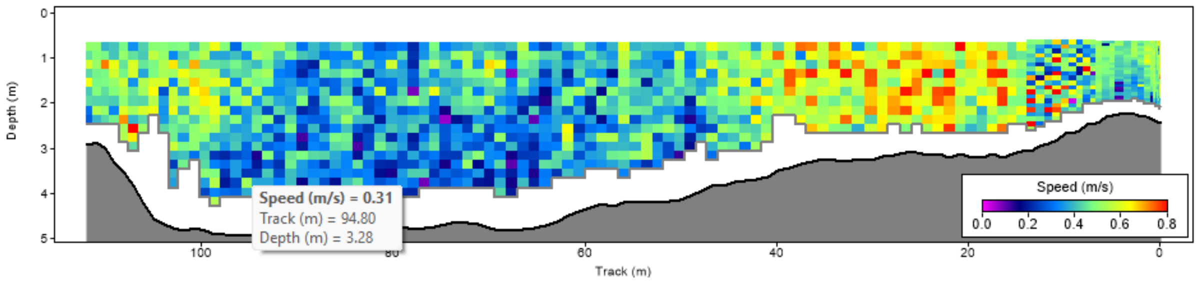

Figure A-16 Vertical velocity distribution – Breakwater Island – Flood tide – (2023/06/27 12:47:36)

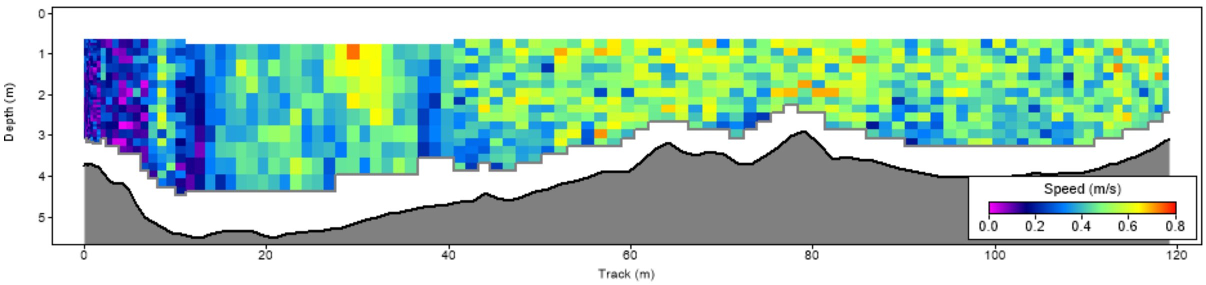

Figure A-17 Vertical velocity distribution – Breakwater Island – Ebb tide – (2023/06/29 07:55:14)

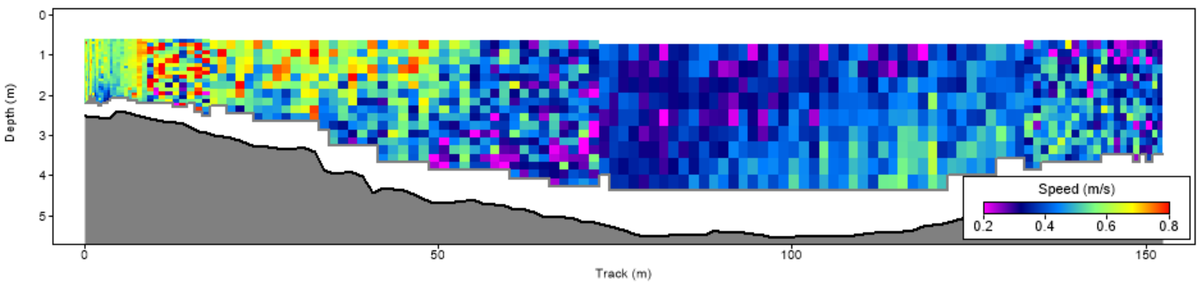

Figure A-18 Vertical velocity distribution – Airport – Flood tide - (2023/06/28 15:00:16)

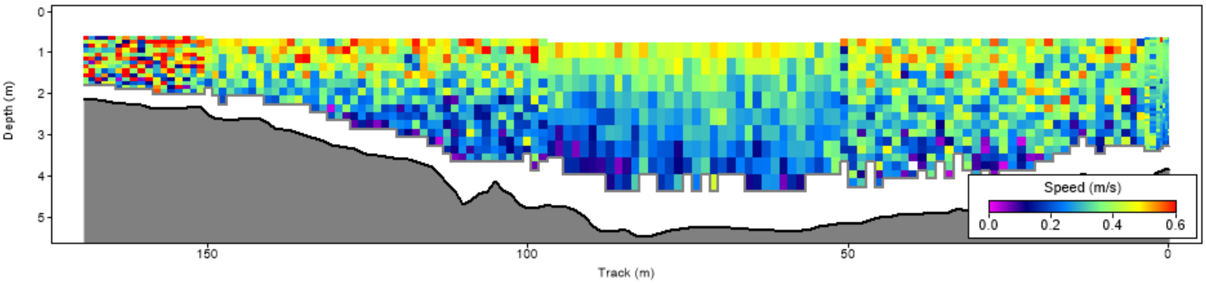

Figure A-19 Vertical velocity distribution – Airport – Ebb tide – (2023/06/29 07:22:58)

Appendix B Model calibration

B1 Hydrodynamic calibration and verification results

The below figures summarise results from the Nambucca hydrodynamic calibration and verification process. For more information, refer to Section 4.6.

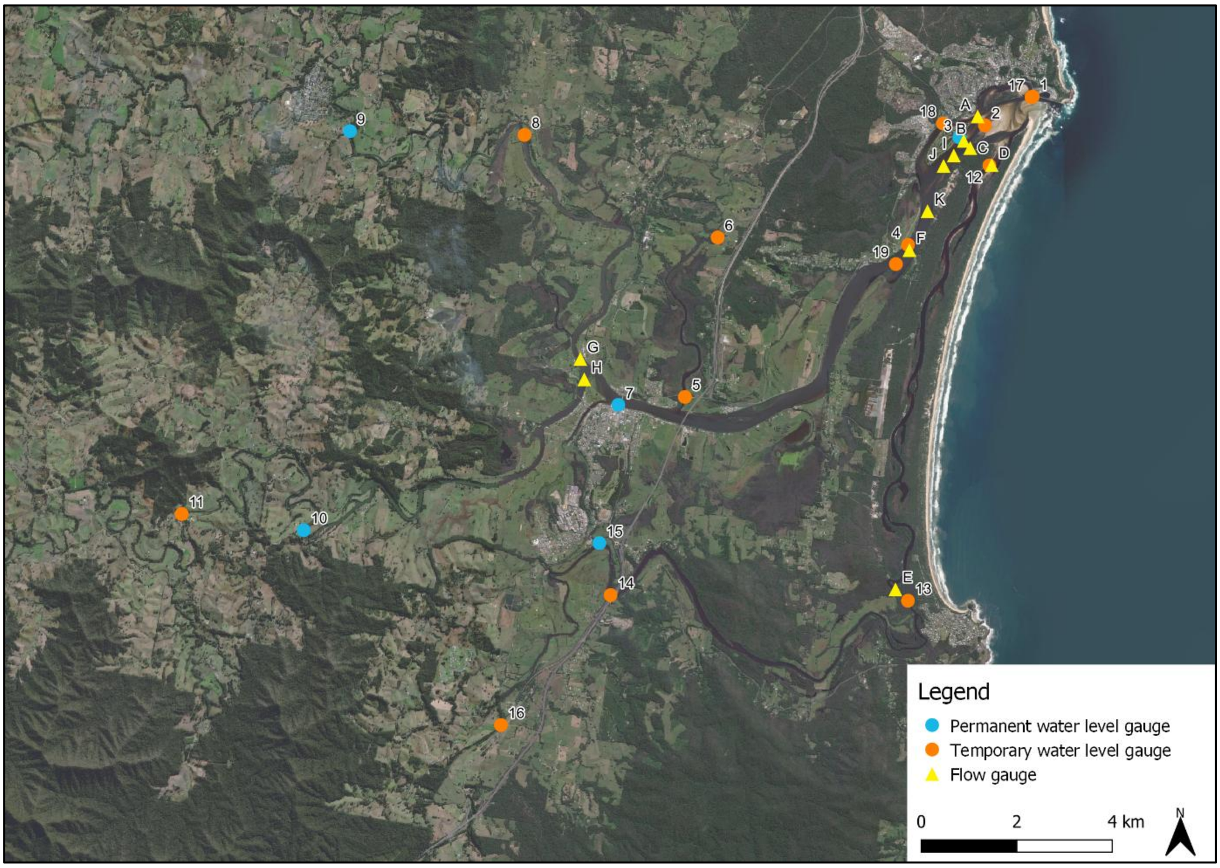

Figure B-1 Water level and tidal flow gauging locations

B1.1 Tidal flow gauging calibration – 1999

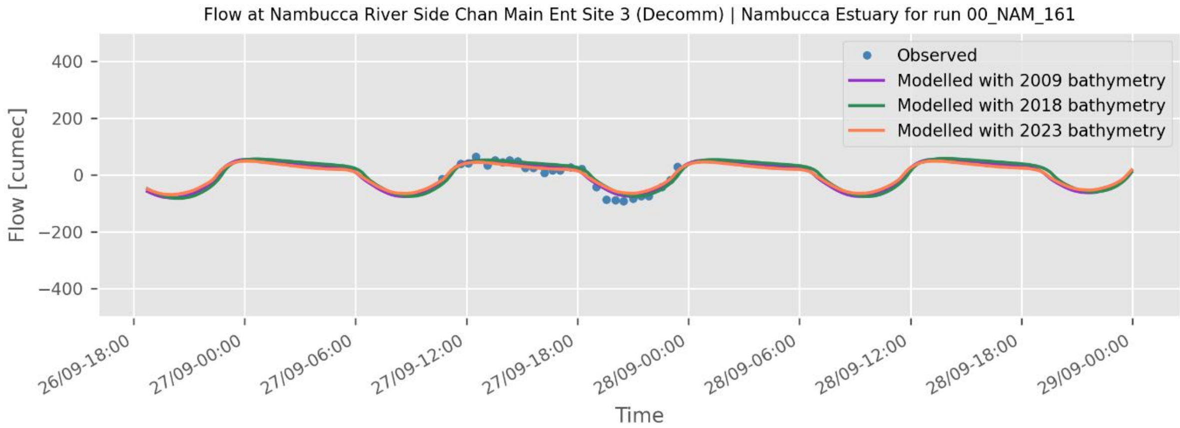

Figure B-2 1999 tidal flow calibration – Location A – Side Channel Main Entrance Site 3

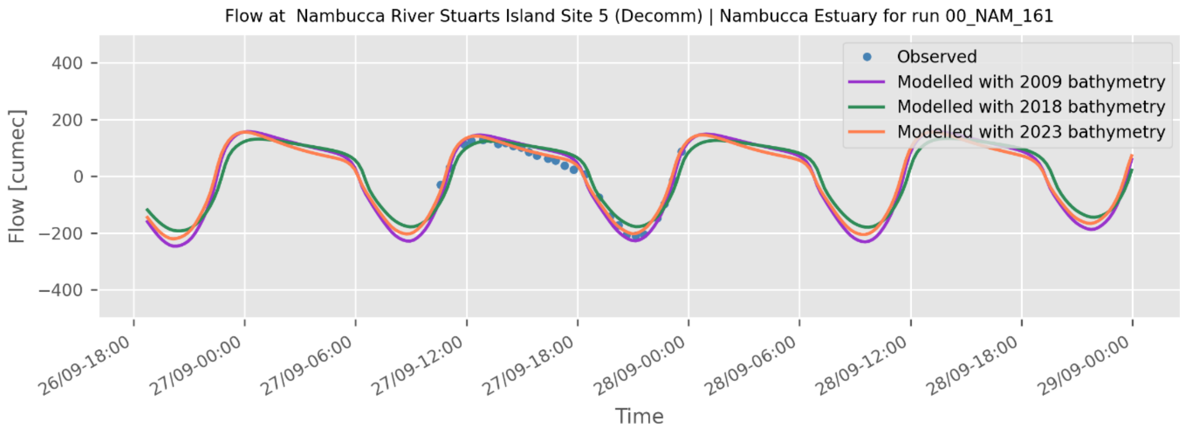

Figure B-3 1999 tidal flow calibration – Location B – Stuarts Island Site 5

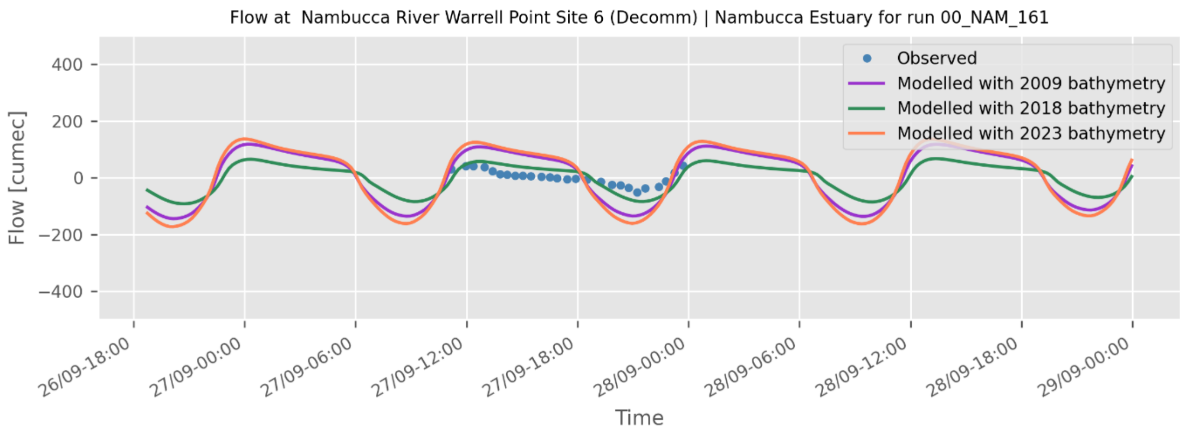

Figure B-4 1999 tidal flow calibration – Location C – Warrell Point Site 6

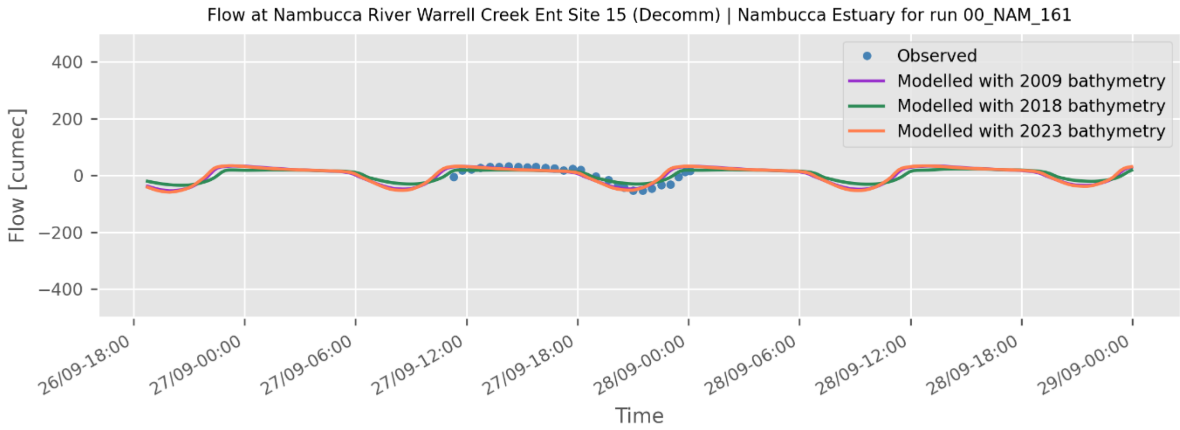

Figure B-5 1999 tidal flow calibration – Location D – Warrell Creek Entrance Site 15

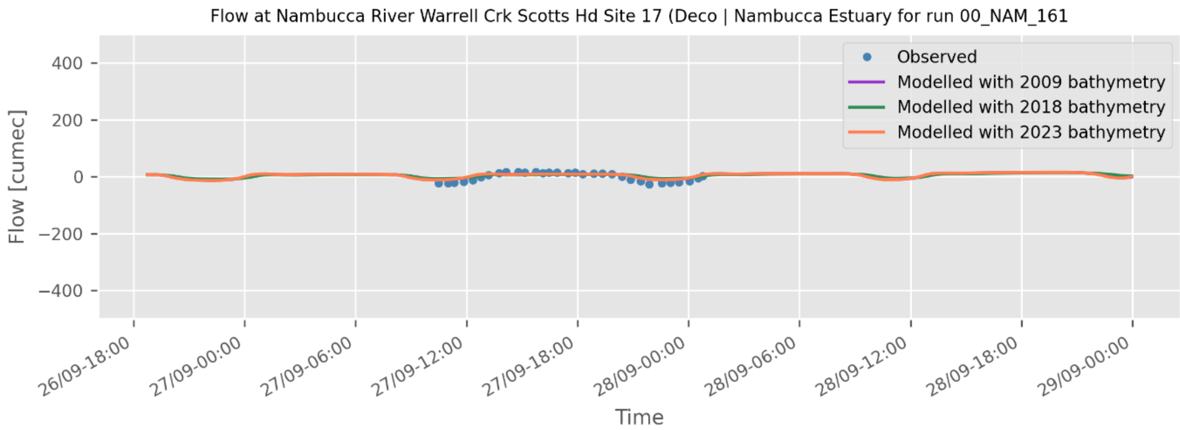

Figure B-6 1999 tidal flow calibration – Location E – Warrell Creek Scotts Head Site 17

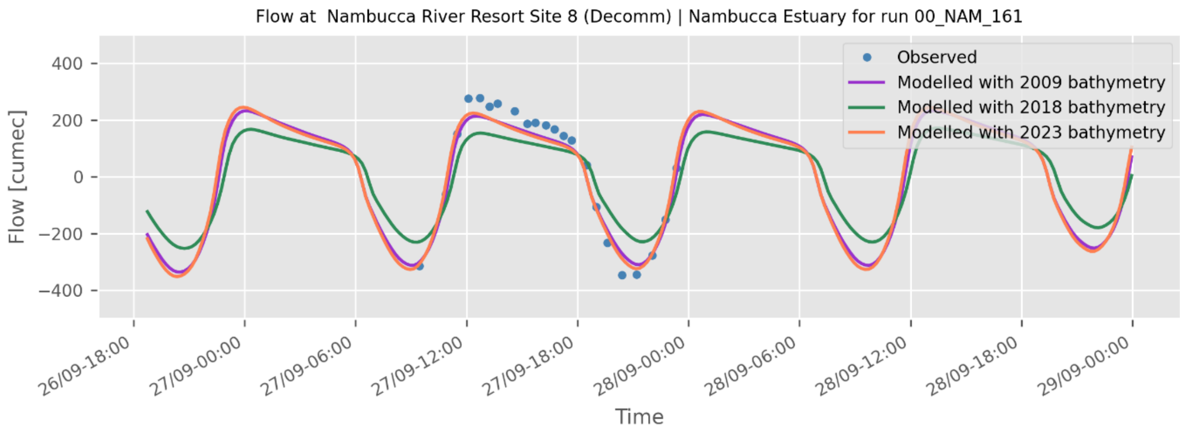

Figure B-7 1999 tidal flow calibration – Location F – Resort Site 8

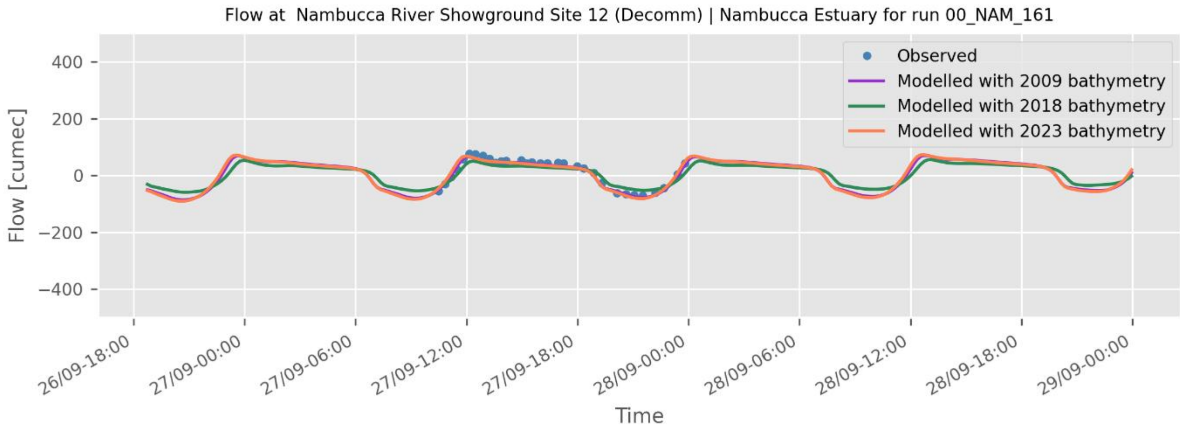

Figure B-8 1999 tidal flow calibration – Location G – Showground Site 12

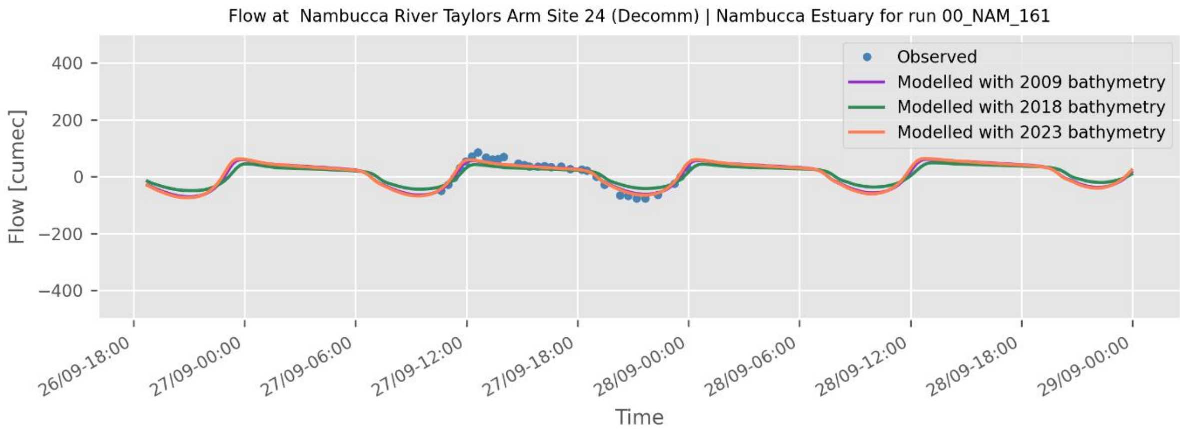

Figure B-9 1999 tidal flow calibration – Location H – Taylors Arm Site 24

B1.2 Water level calibration – 1999

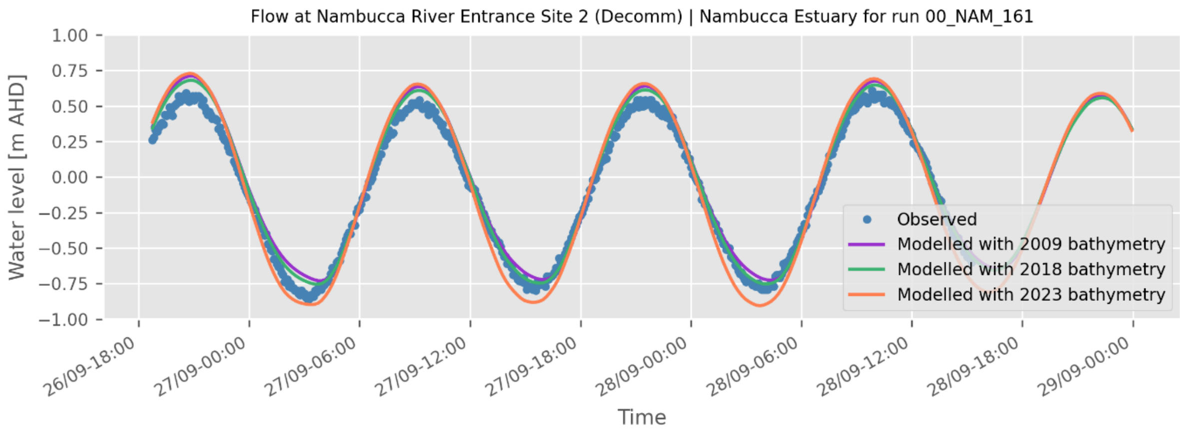

Figure B-10 1999 water level calibration – Location 1 – Entrance Site 2

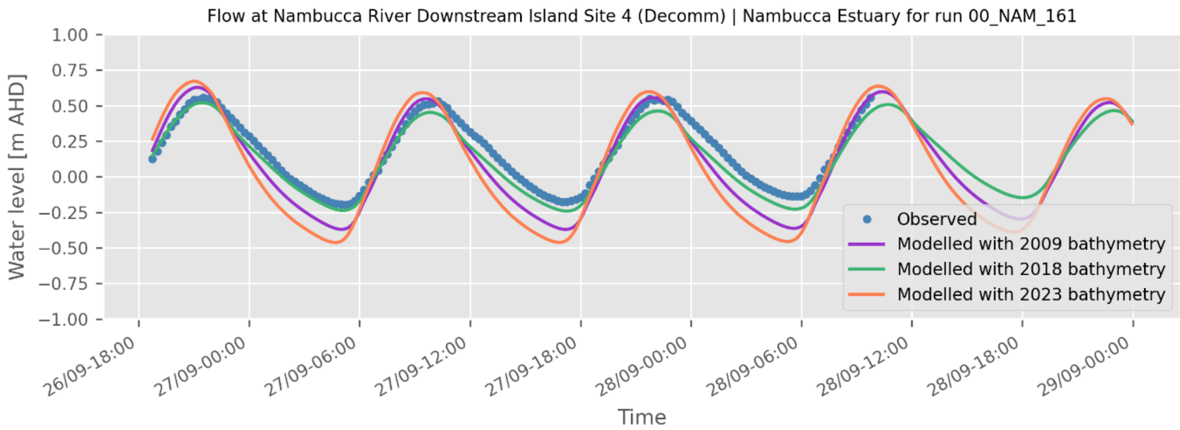

Figure B-11 1999 water level calibration – Location 2 – Downstream Island Site 4

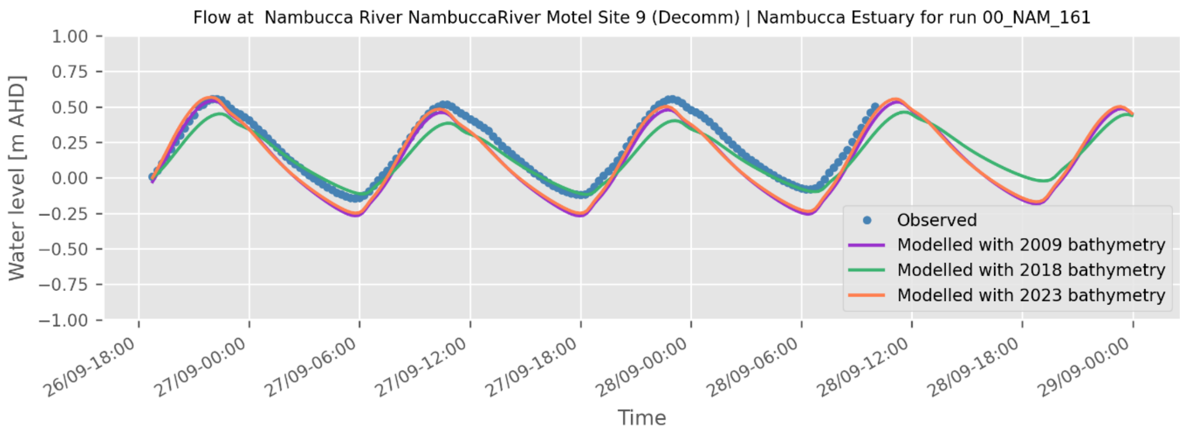

Figure B-12 1999 water level calibration – Location 4 – Motel Site 9

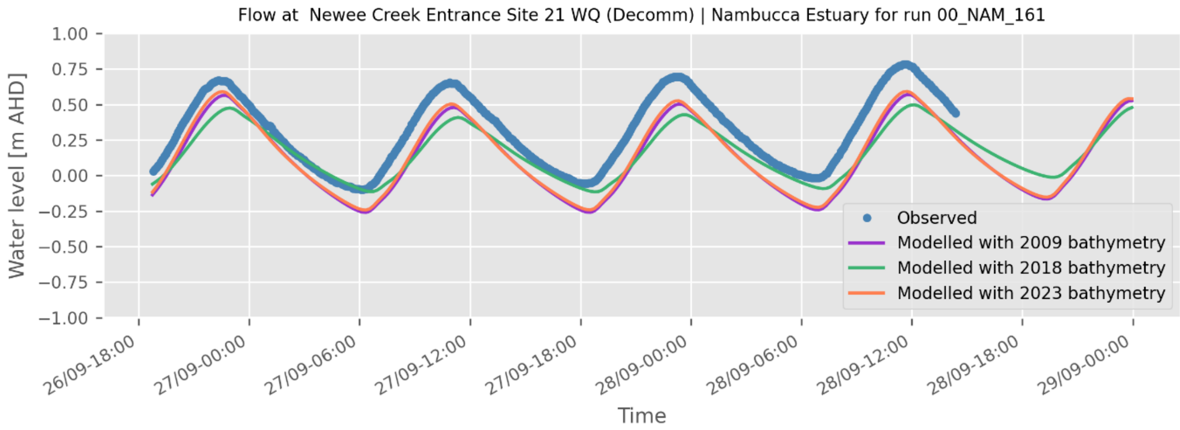

Figure B-13 1999 water level calibration – Location 5 – Newee Creek Entrance Site 21

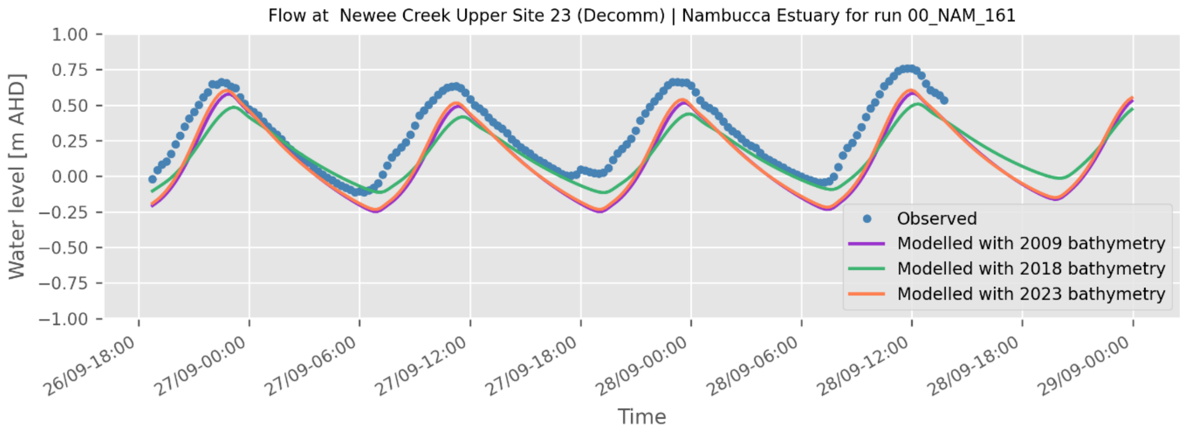

Figure B-14 1999 water level calibration – Location 6 – Newee Creek Upper Site 23

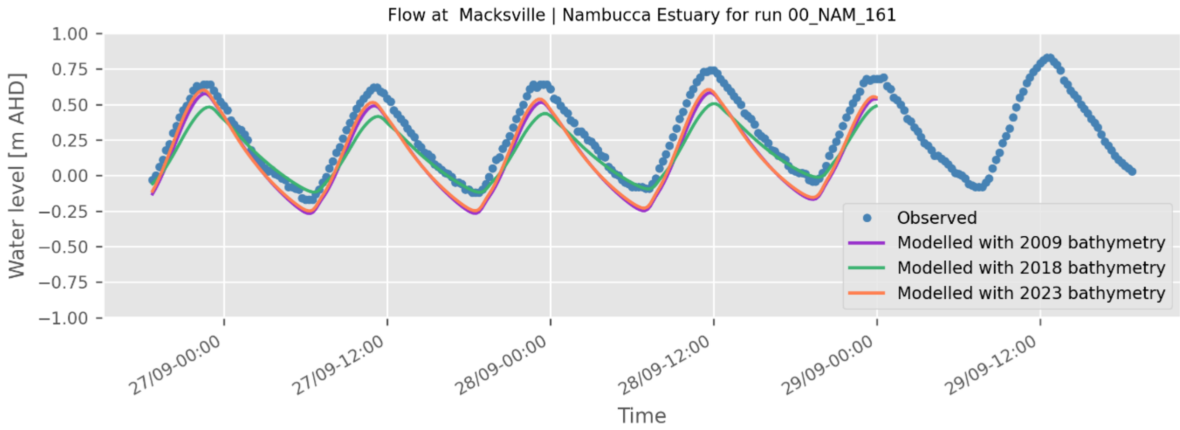

Figure B-15 1999 water level calibration – Location 7 – Macksville

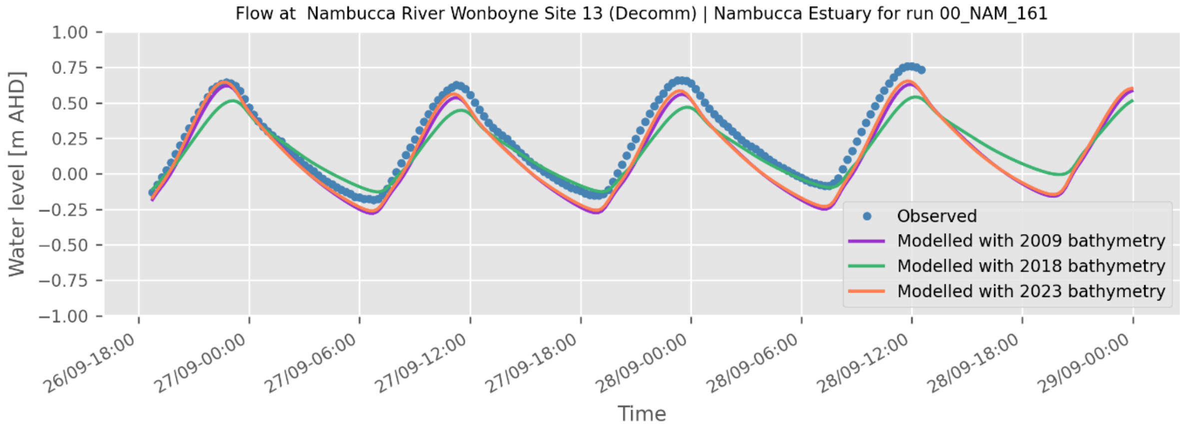

Figure B-16 1999 water level calibration – Location 8 – Womboyne Site 13

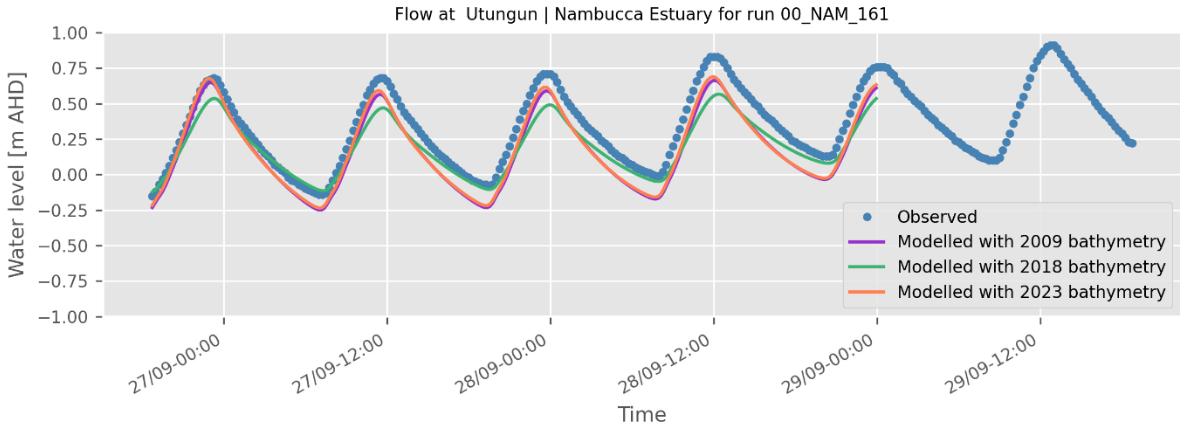

Figure B-17 1999 water level calibration – Location 10 – Utungun

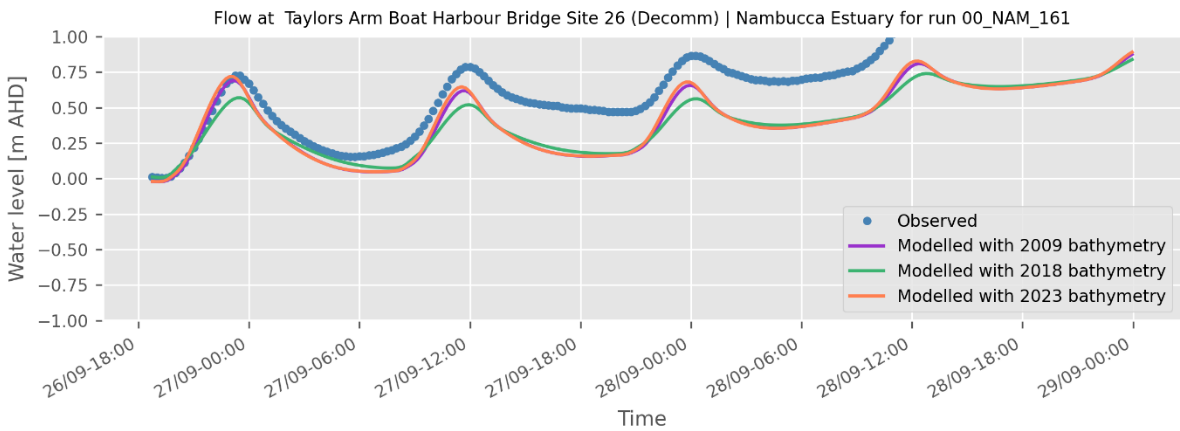

Figure B-18 1999 water level calibration – Location 11 – Taylors Arm Boat Harbour Bridge Site 26

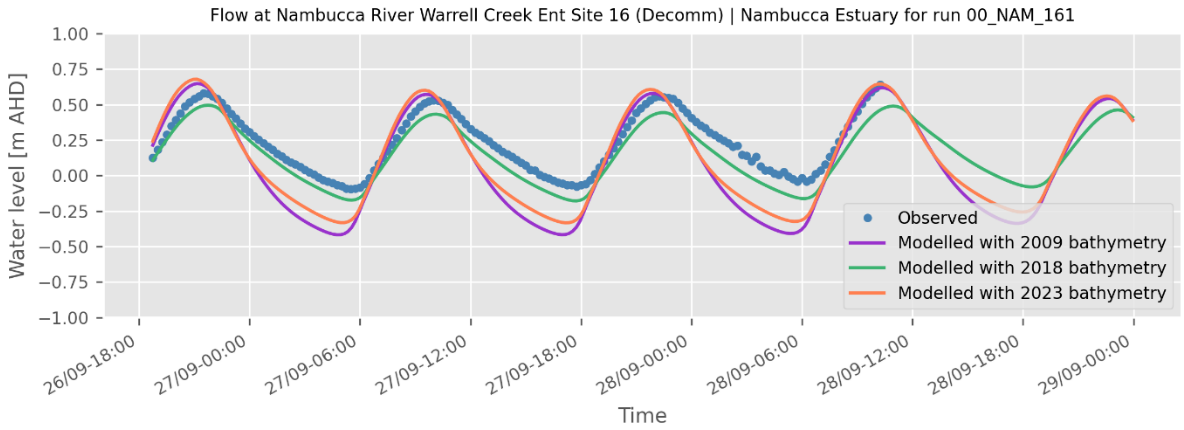

Figure B-19 1999 water level calibration – Location 12 – Warrell Creek Entrance Site 16

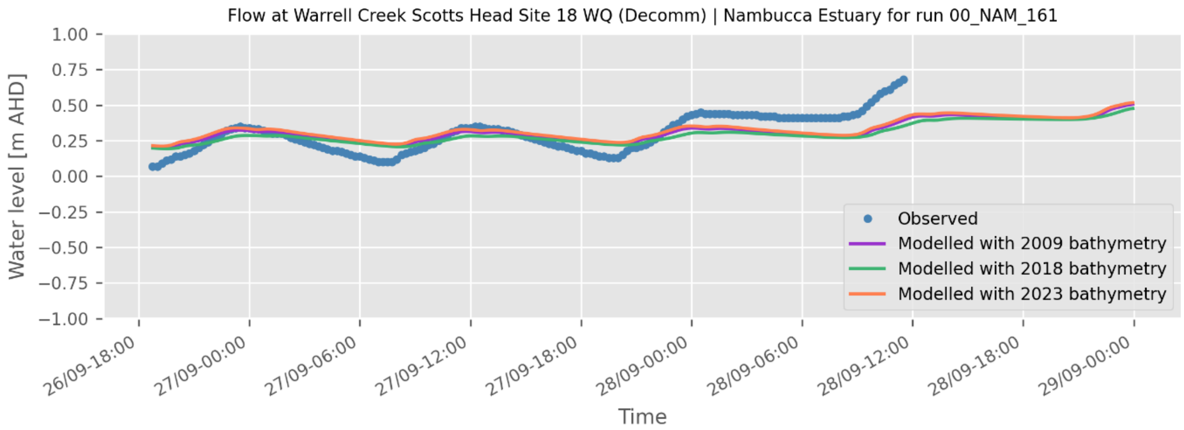

Figure B-20 1999 water level calibration – Location 13 – Warrell Creek Scotts Head Site 18

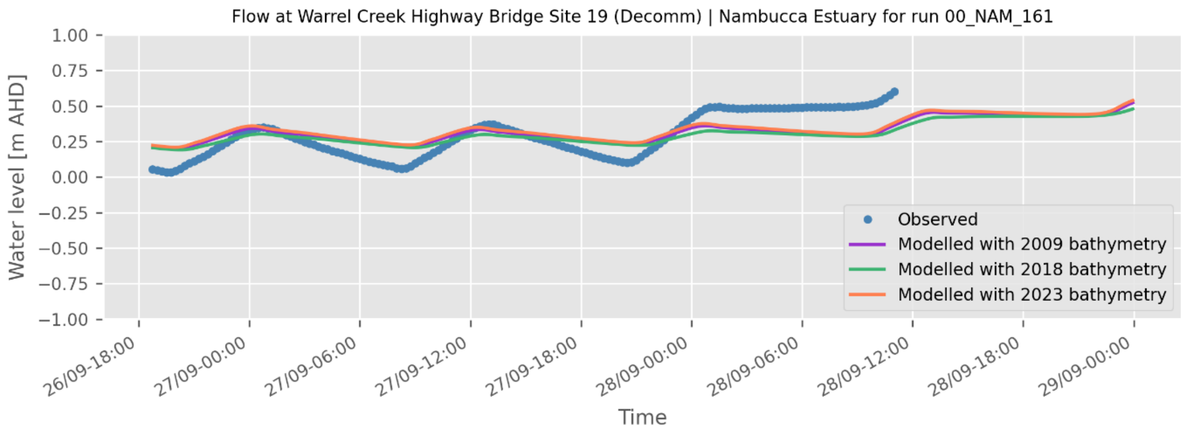

Figure B-21 1999 water level calibration – Location 13 – Warrell Creek Highway Bridge Site 19

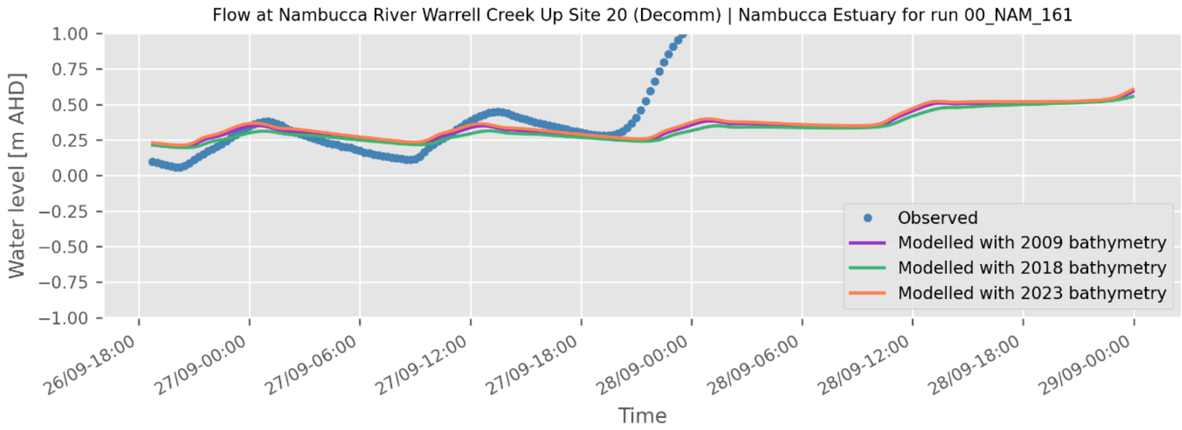

Figure B-22 1999 water level calibration – Location 14 – Warrell Creek Upstream Site 20

B1.3 Tidal flow gauging calibration – 1999 (cropped mesh)

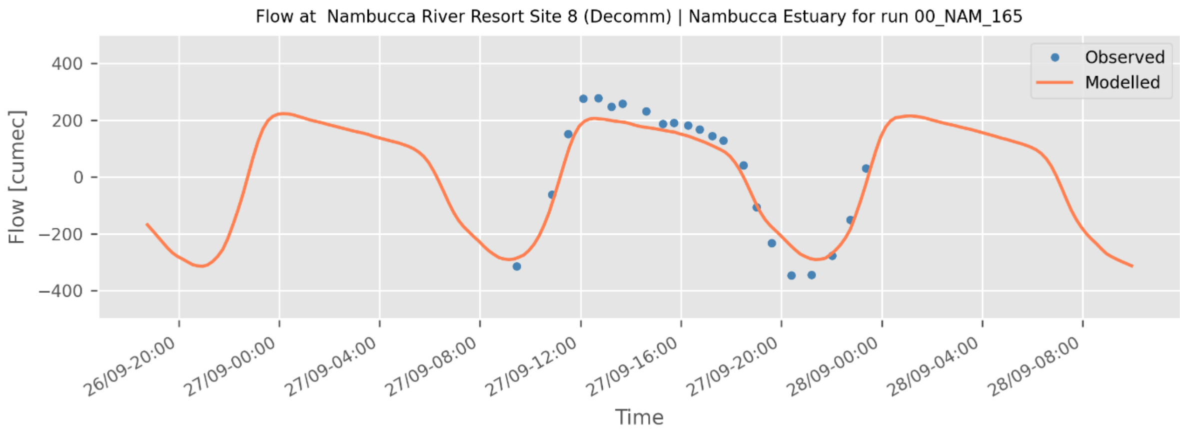

Figure B-23 1999 tidal flow calibration (using mesh cropped at Resort Site 8) – Location F – Resort Site 8

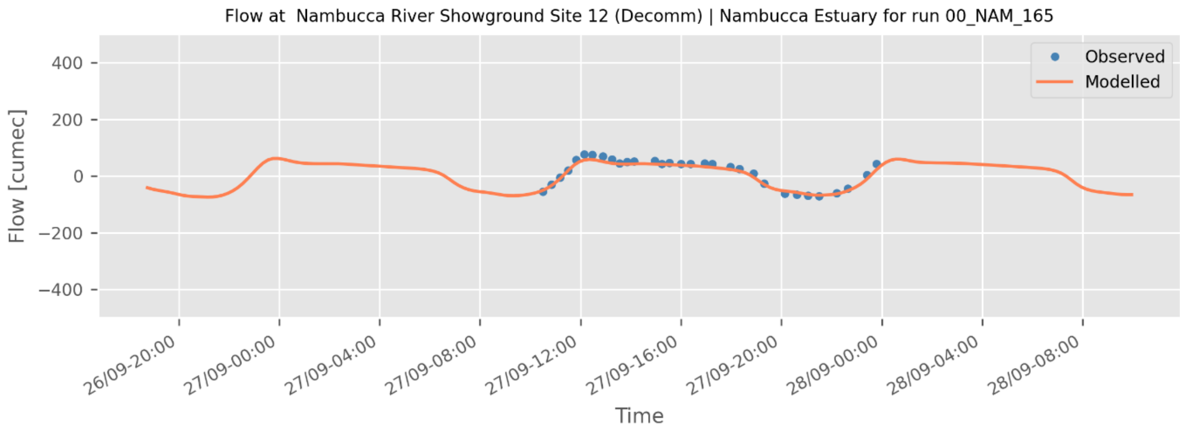

Figure B-24 1999 tidal flow calibration (using mesh cropped at Resort Site 8) – Location G – Showground Site 12

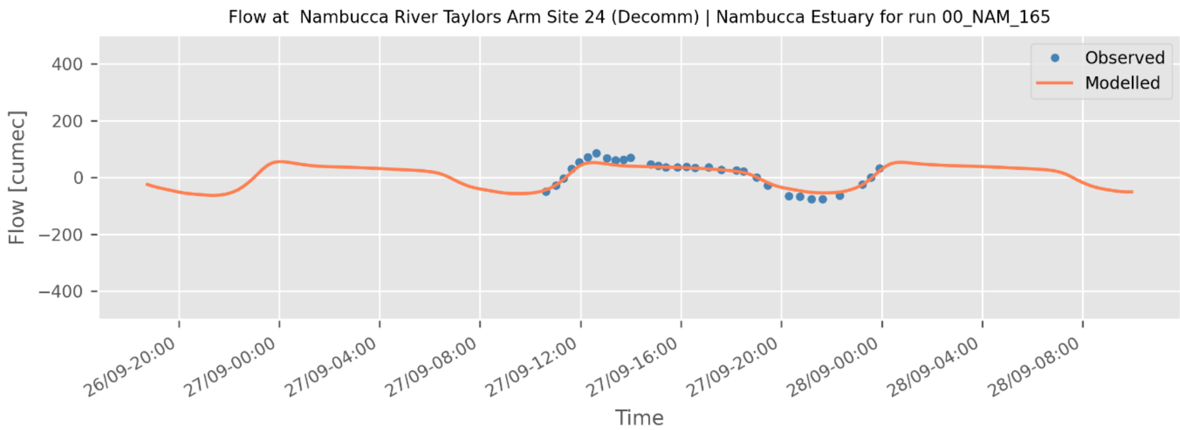

Figure B-25 1999 tidal flow calibration (using mesh cropped at Resort Site 8) – Location H – Taylors Arm Site 24

B1.4 Water level calibration – 1999 (cropped mesh)

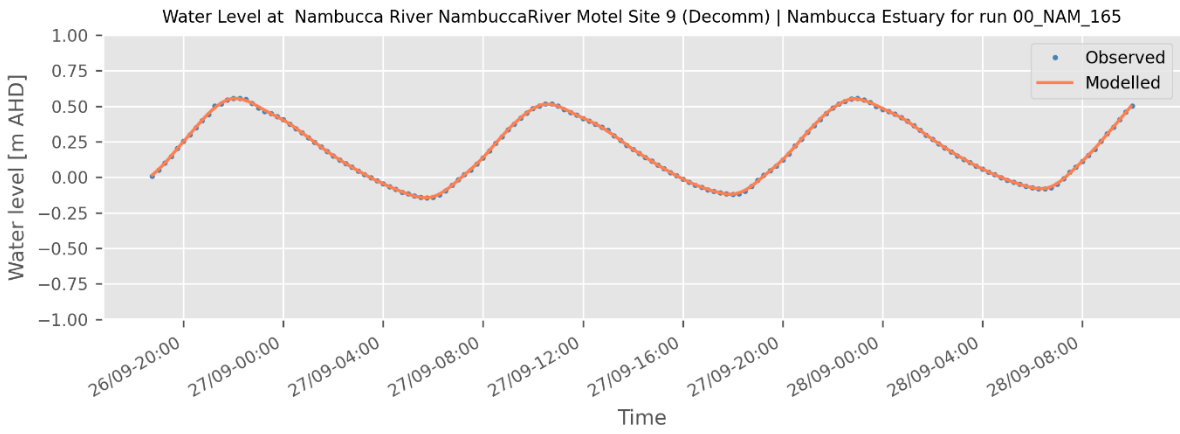

Figure B-26 1999 water level calibration (using mesh cropped at Resort Site 8) – Location 4 – Motel Site 9

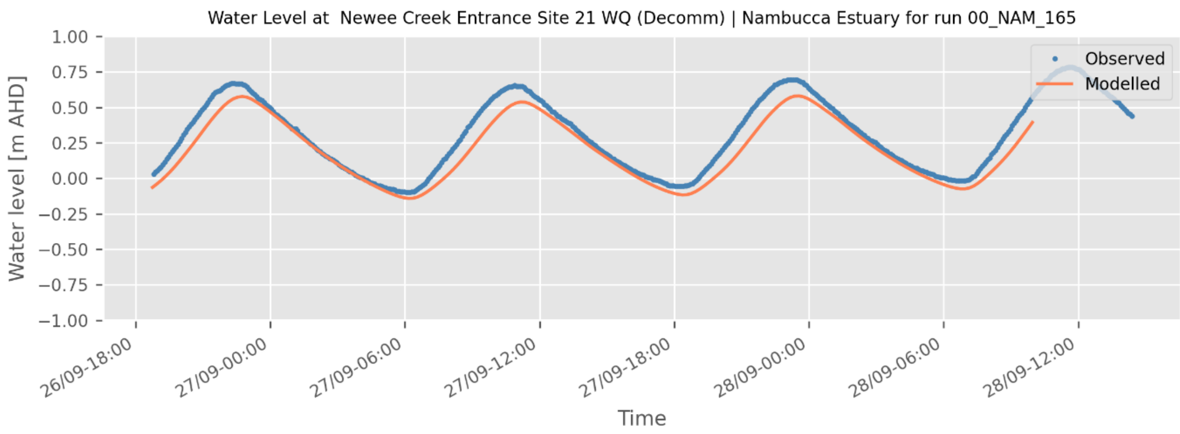

Figure B-27 1999 water level calibration (using mesh cropped at Resort Site 8) – Location 5 – Newee Creek Entrance Site 21

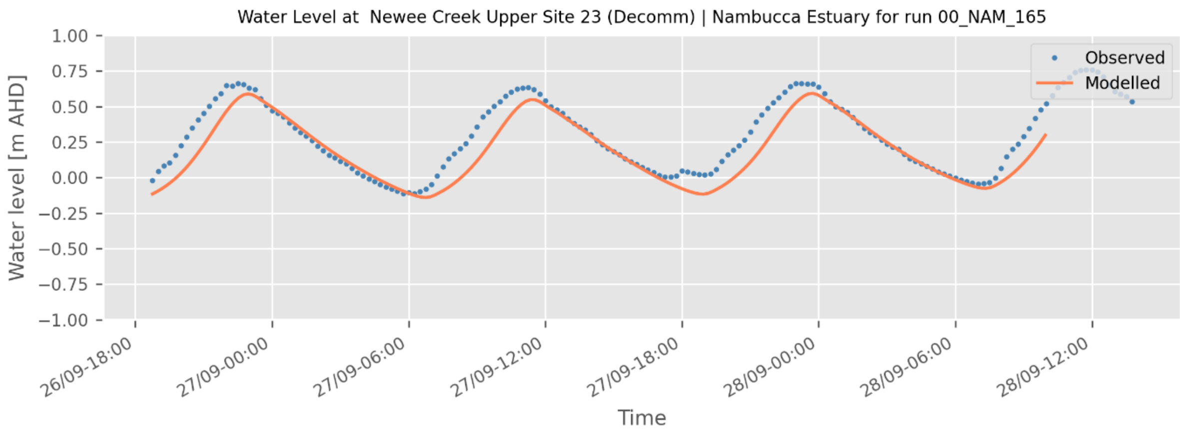

Figure B-28 1999 water level calibration (using mesh cropped at Resort Site 8) – Location 6 – Newee Creek Upper Site 23

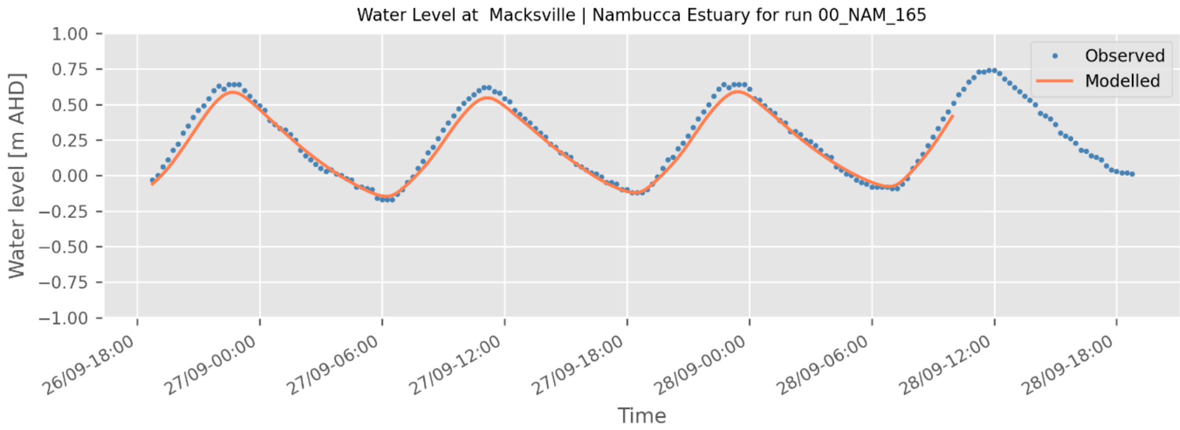

Figure B-29 1999 water level calibration (using mesh cropped at Resort Site 8) – Location 7 – Macksville

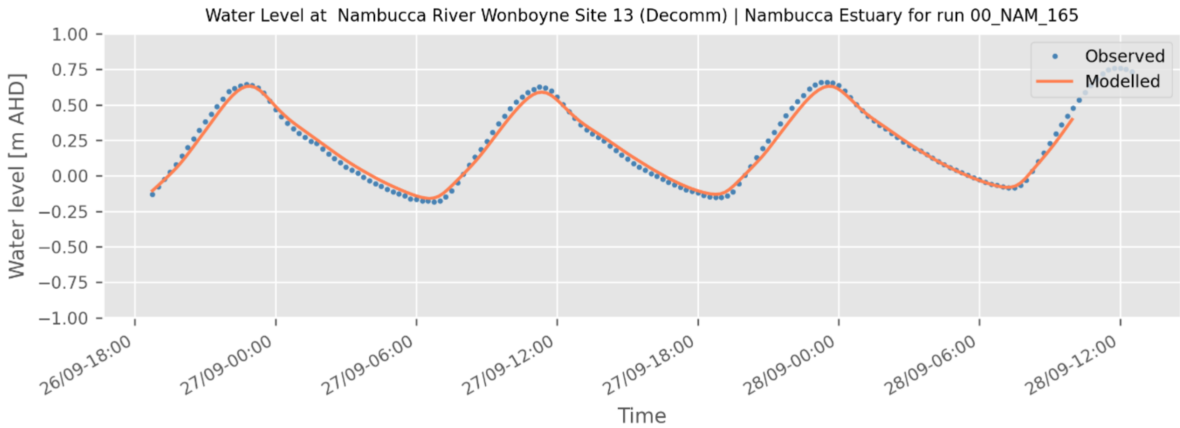

Figure B-30 1999 water level calibration (using mesh cropped at Resort Site 8) – Location 8 – Womboyne Site 13

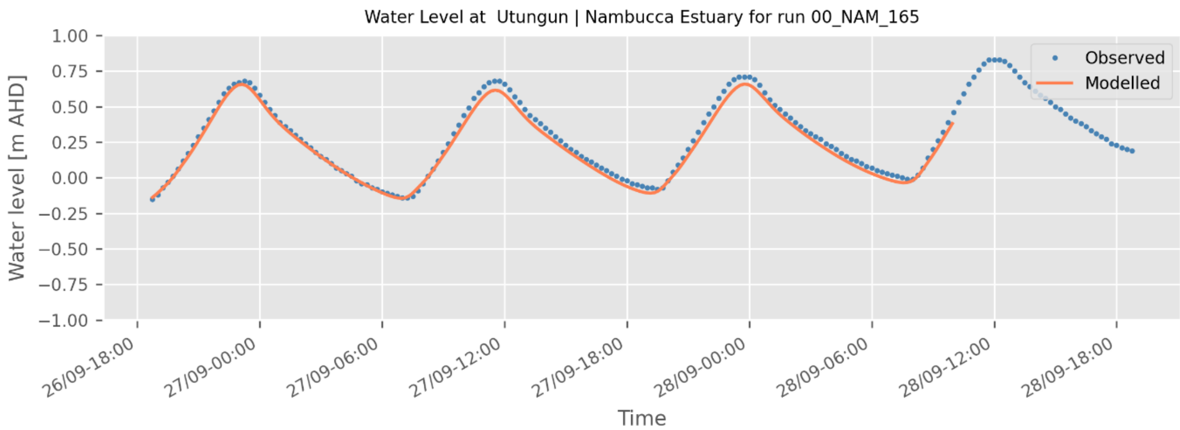

Figure B-31 1999 water level calibration (using mesh cropped at Resort Site 8) – Location 10 – Utungun

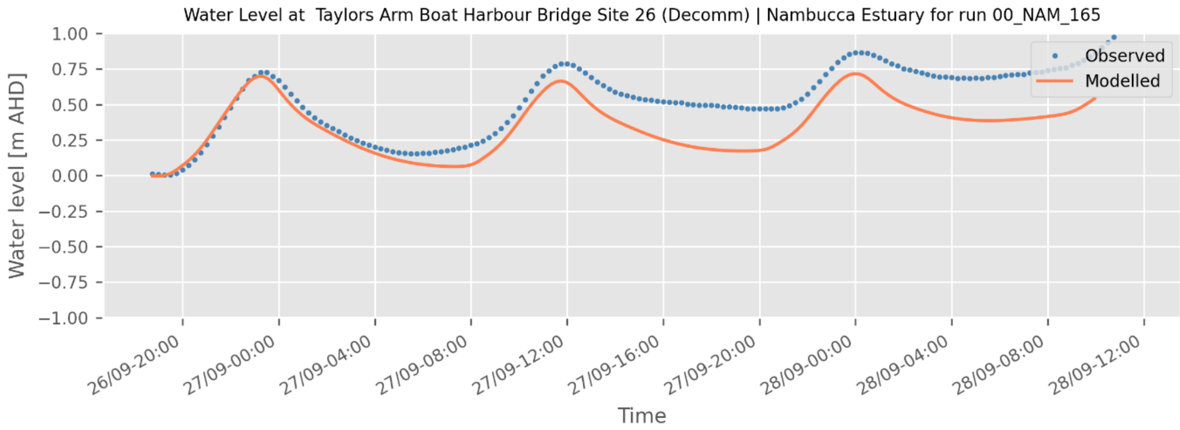

Figure B-32 1999 water level calibration (using mesh cropped at Resort Site 8) – Location 11 – Taylors Arm Boat Harbour Bridge Site 26

B1.5 Water level verification – 2009

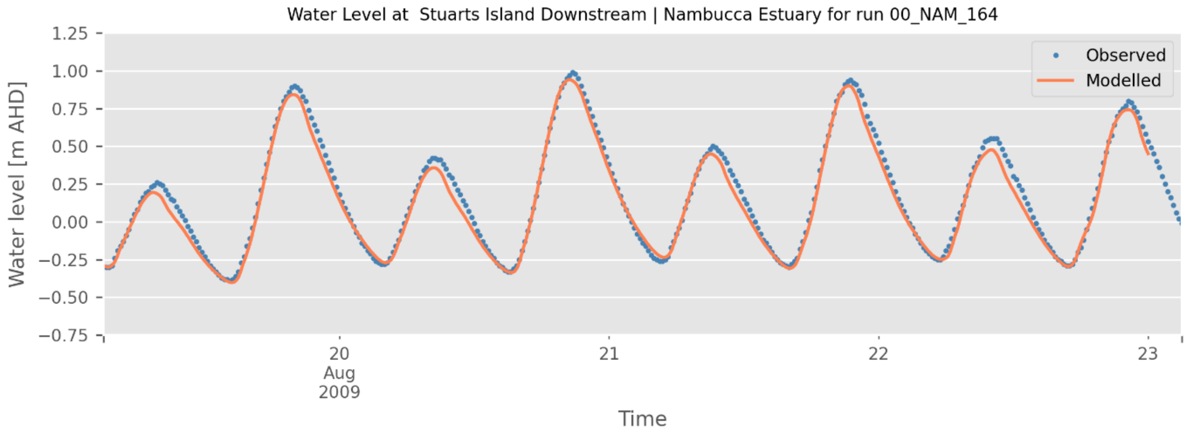

Figure B-33 2009 water level verification – Location 3 – Stuart Island

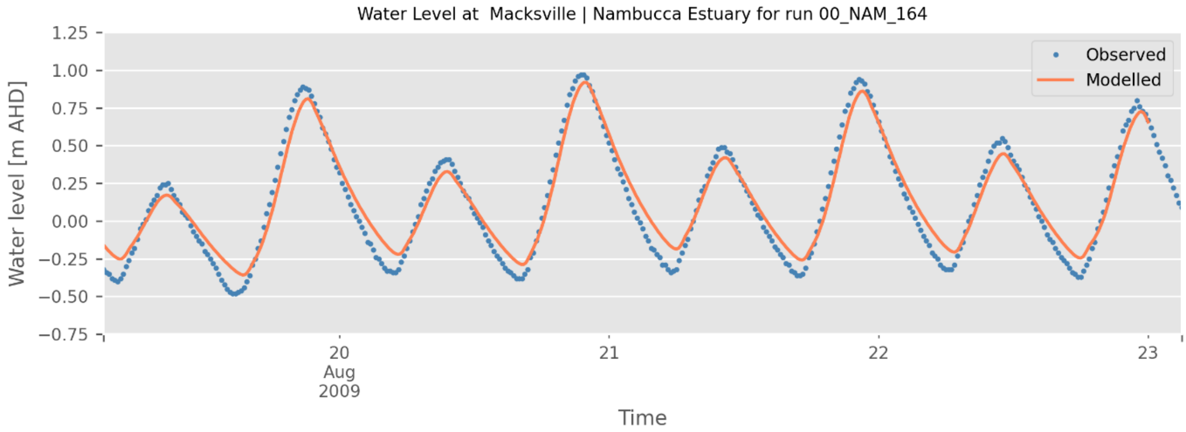

Figure B-34 2009 water level verification – Location 7 – Macksville

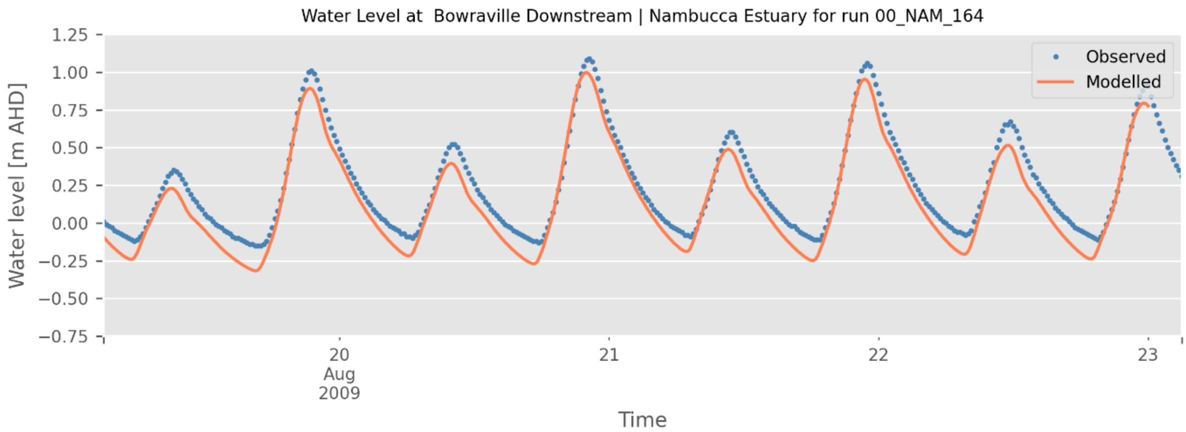

Figure B-35 2009 water level verification – Location 9 – Bowraville

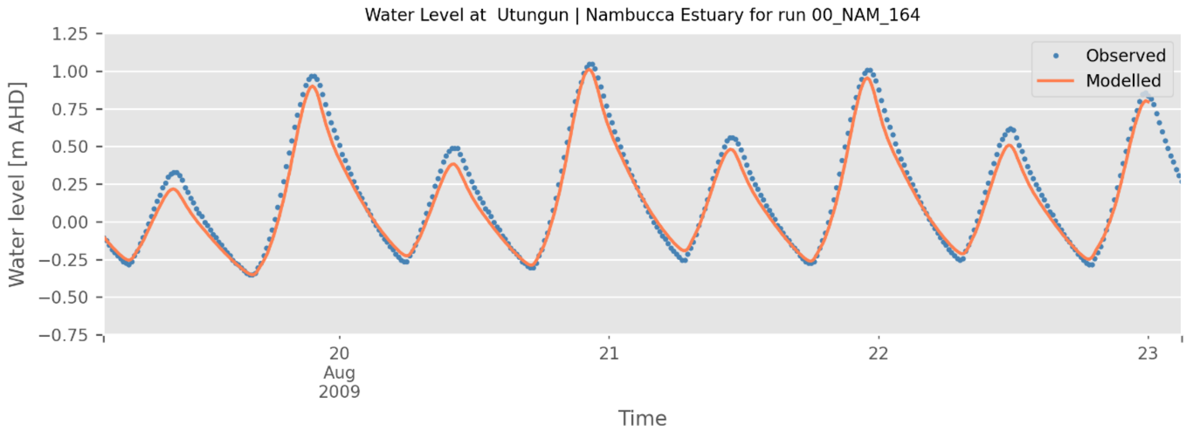

Figure B-36 2009 water level verification – Location 10 – Utungun

B1.6 Water level verification – 2018

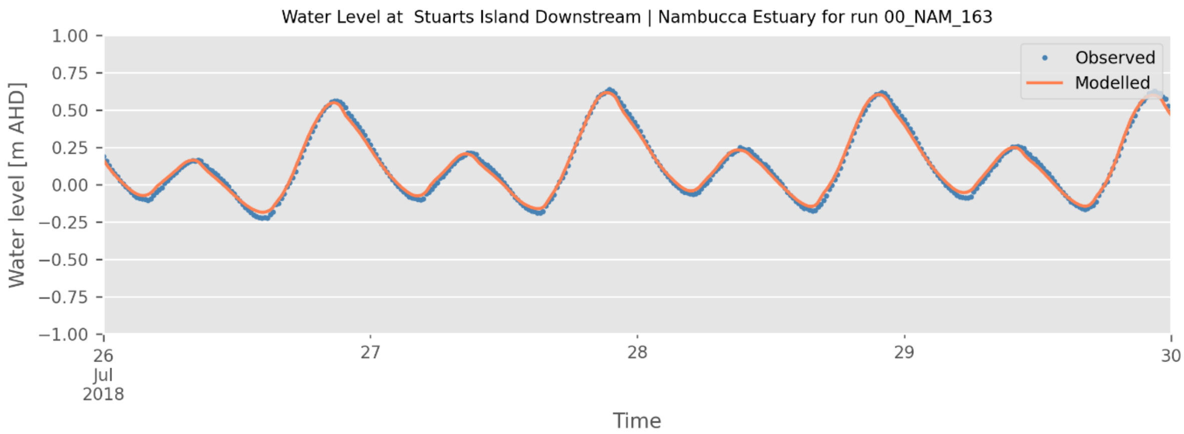

Figure B-37 2018 water level verification – Location 3 – Stuart Island

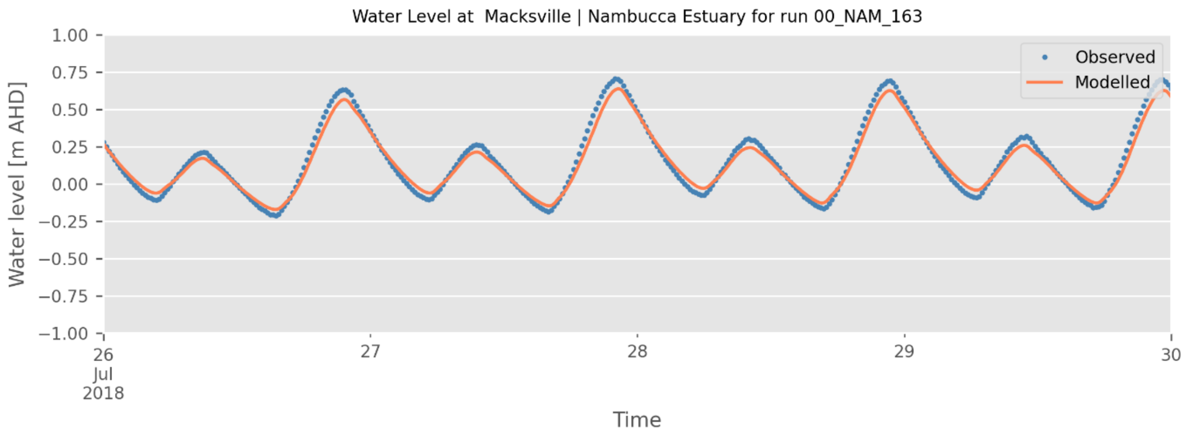

Figure B-38 2018 water level verification – Location 7 – Macksville

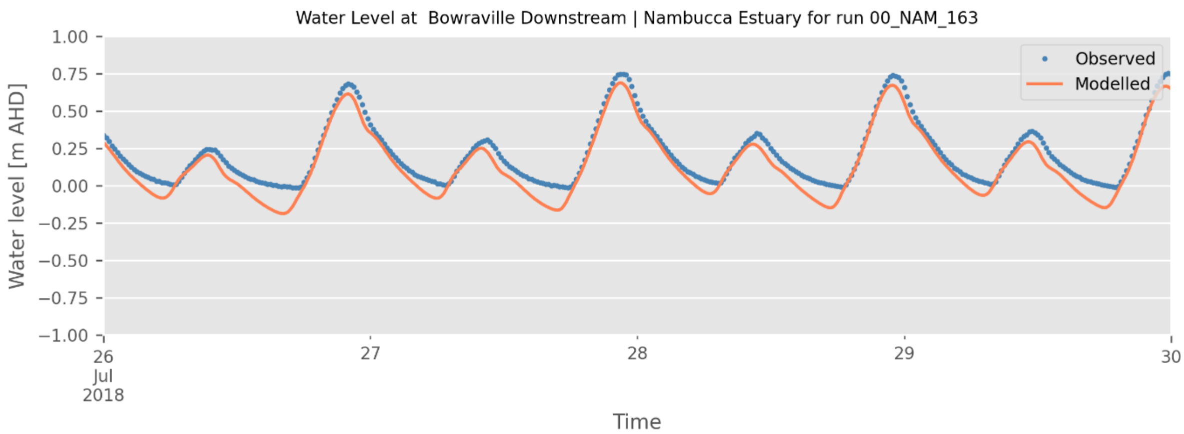

Figure B-39 2018 water level verification – Location 9 – Bowraville Downstream

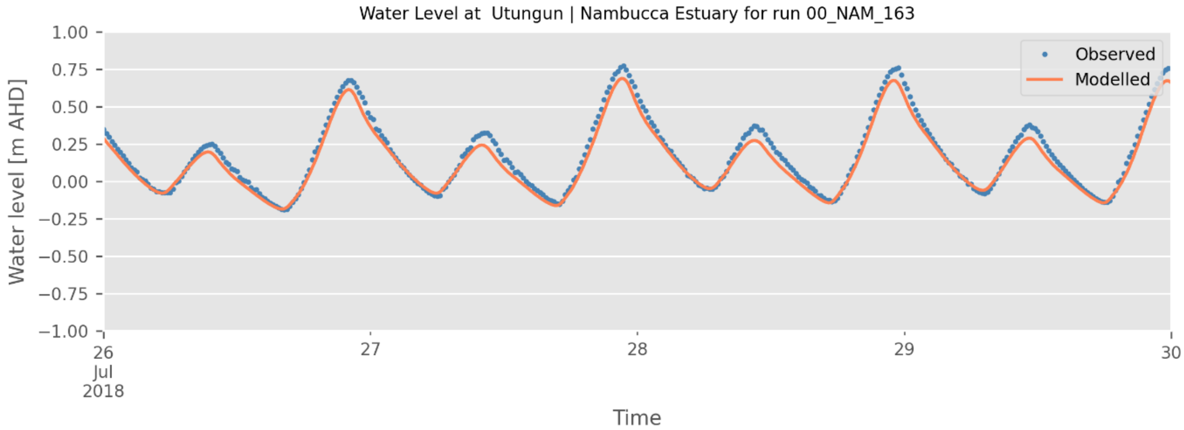

Figure B-40 2018 water level verification – Location 10 – Utungun

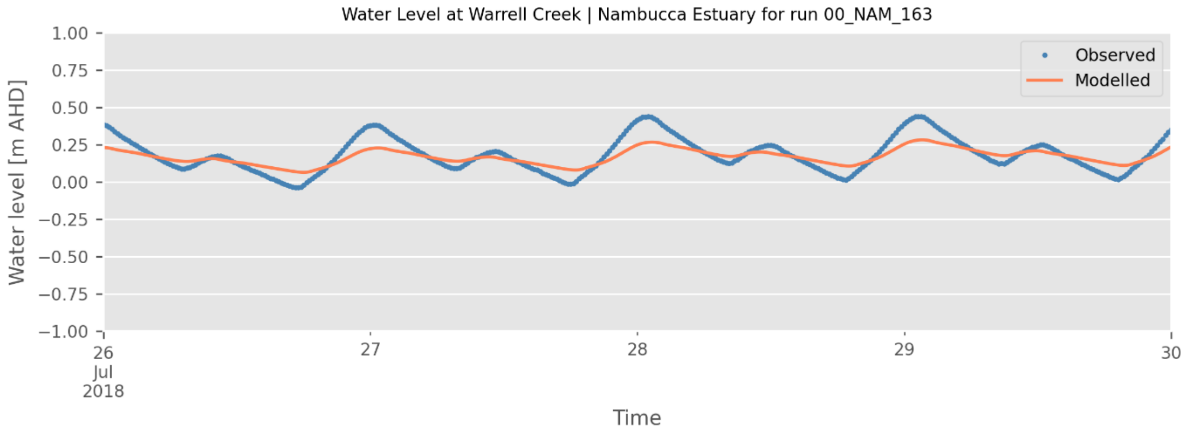

Figure B-41 2018 water level verification – Location 15 – Warrell Creek

B1.7 Tidal flow gauging verification – 2023

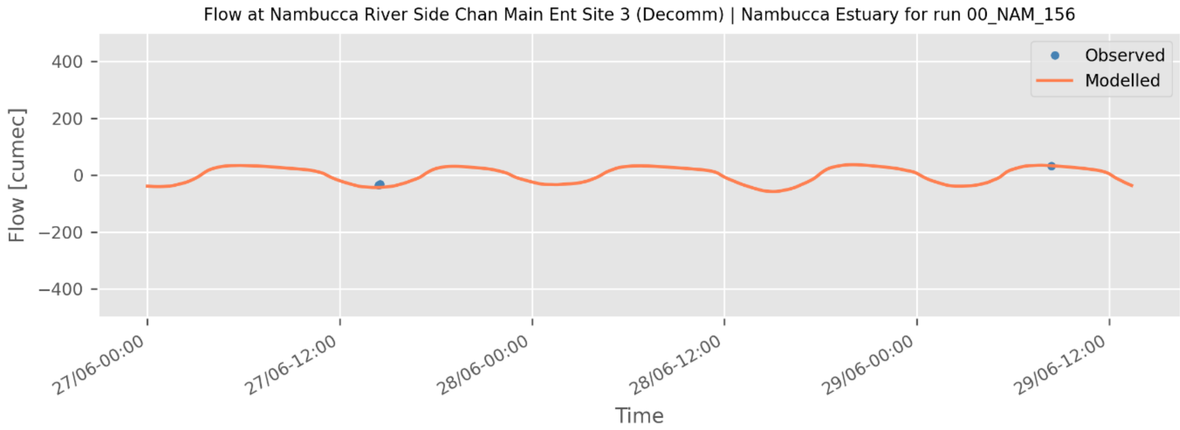

Figure B-42 2023 tidal flow verification – Location A – Side Channel Main Entrance Site 3

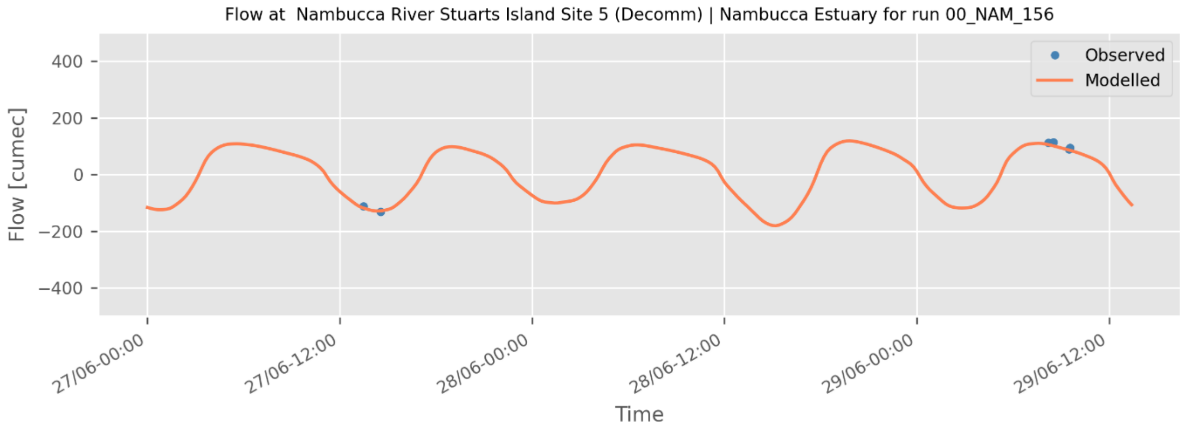

Figure B-43 2023 tidal flow verification – Location B – Stuarts Island Site 5

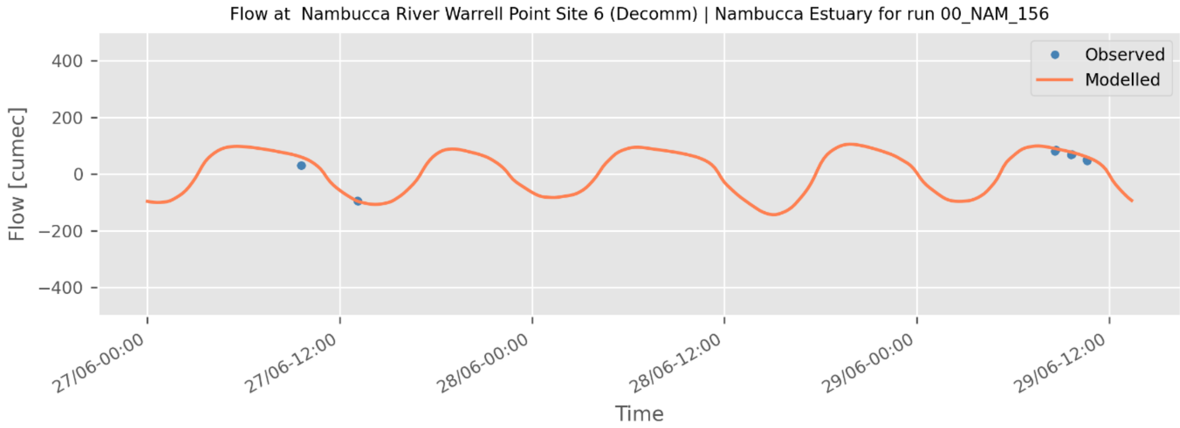

Figure B-44 2023 tidal flow verification – Location C – Warrell Point Site 6

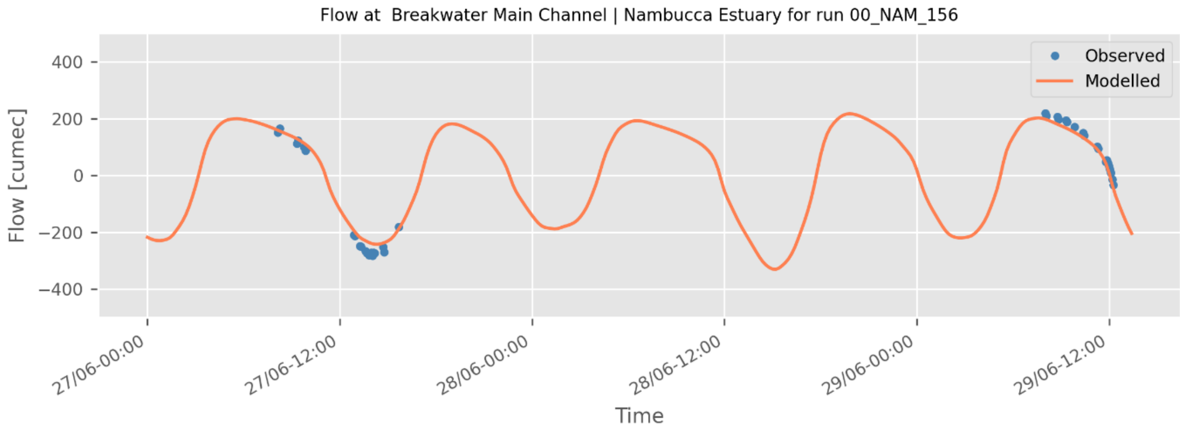

Figure B-45 2023 tidal flow verification – Location I – Breakwater Main Channel

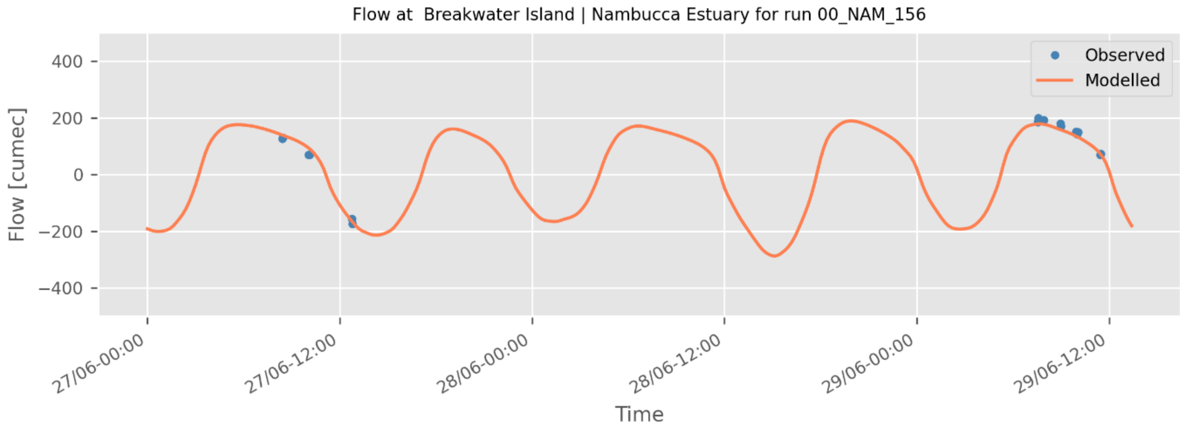

Figure B-46 2023 tidal flow verification – Location J – Breakwater Island

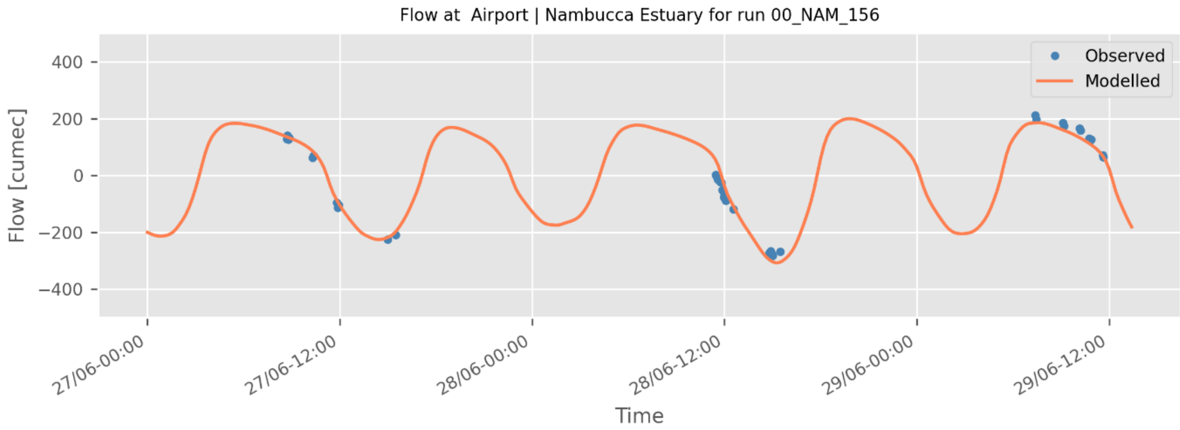

Figure B-47 2023 tidal flow verification – Location K – Airport

B1.8 Water level verification – 2023

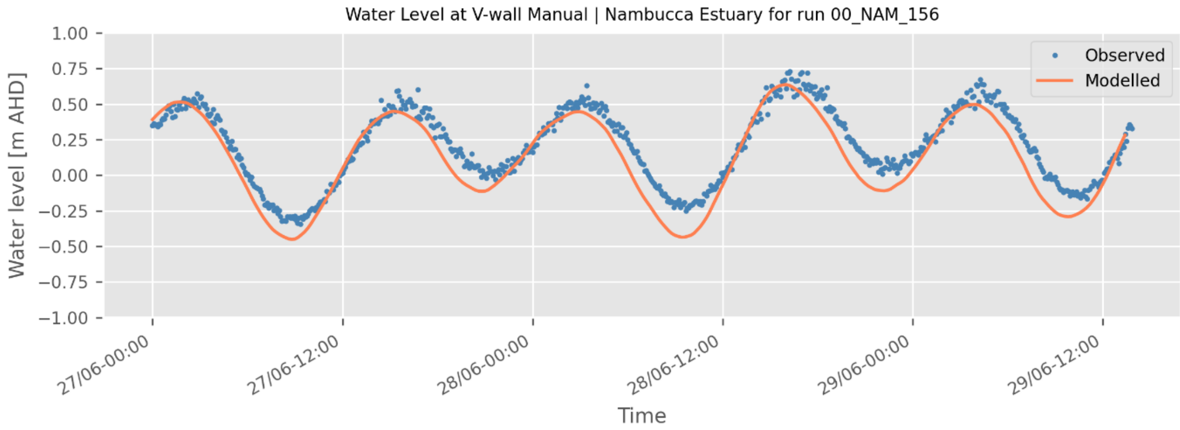

Figure B-48 2023 water level verification – Location 17 – V-wall

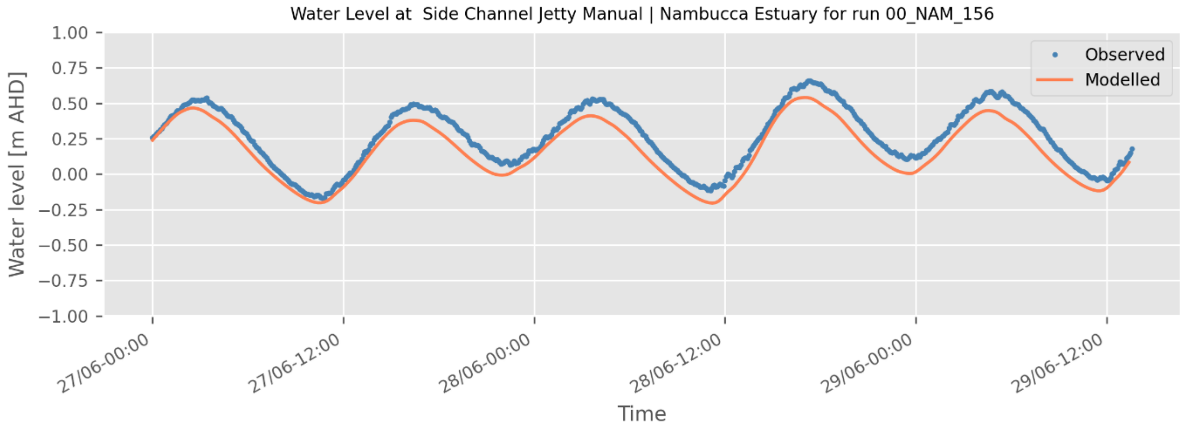

Figure B-49 2023 water level verification – Location 18 – Side Channel Jetty

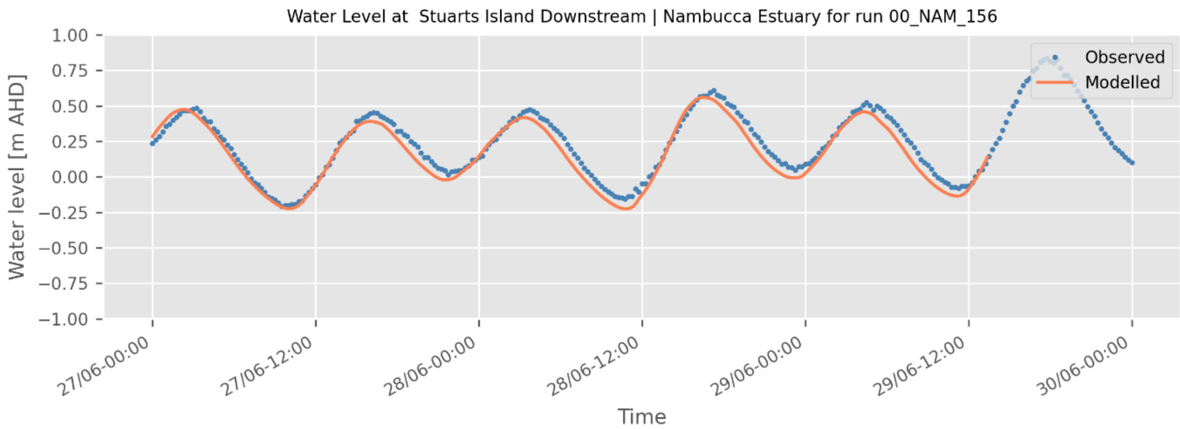

Figure B-50 2023 water level verification – Location 3 – Stuart Island

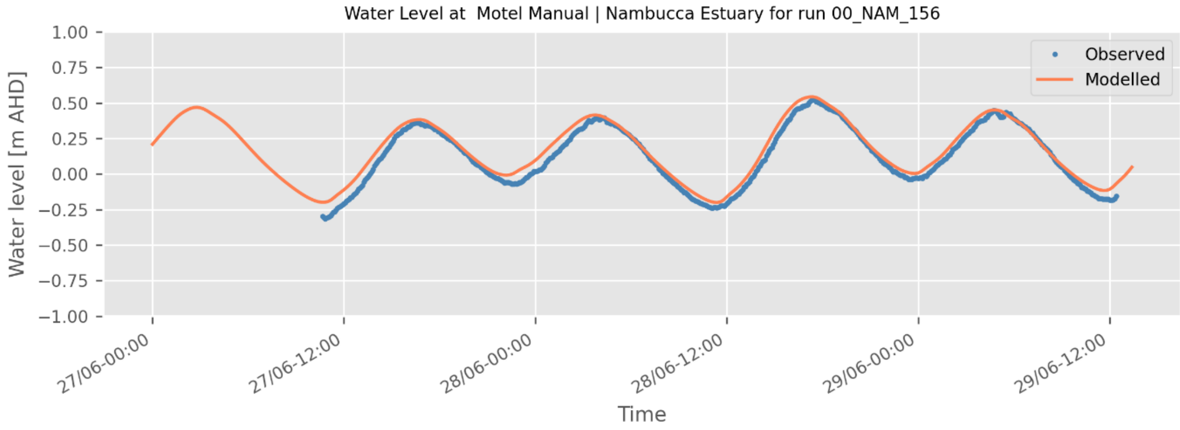

Figure B-51 2023 water level verification – Location 19 – Motel

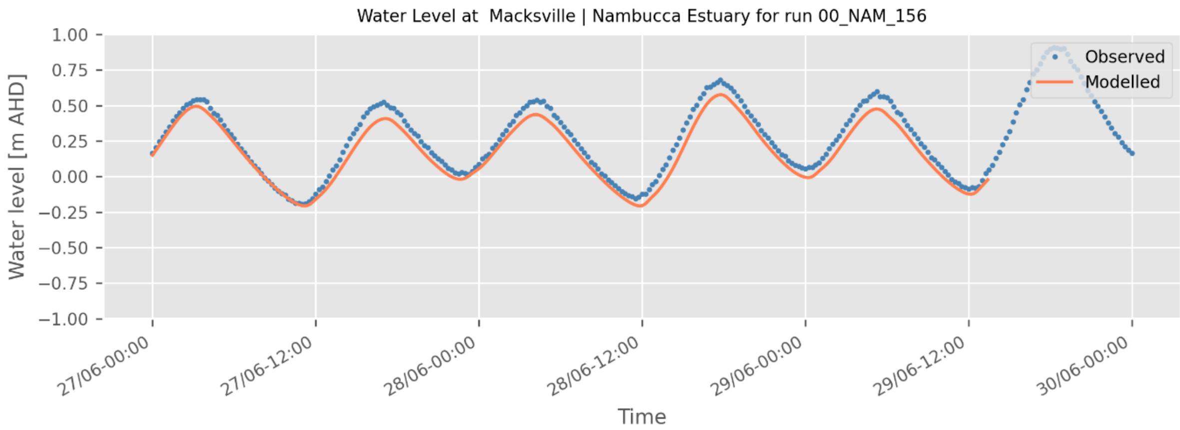

Figure B-52 2023 water level verification – Location 7 – Macksville

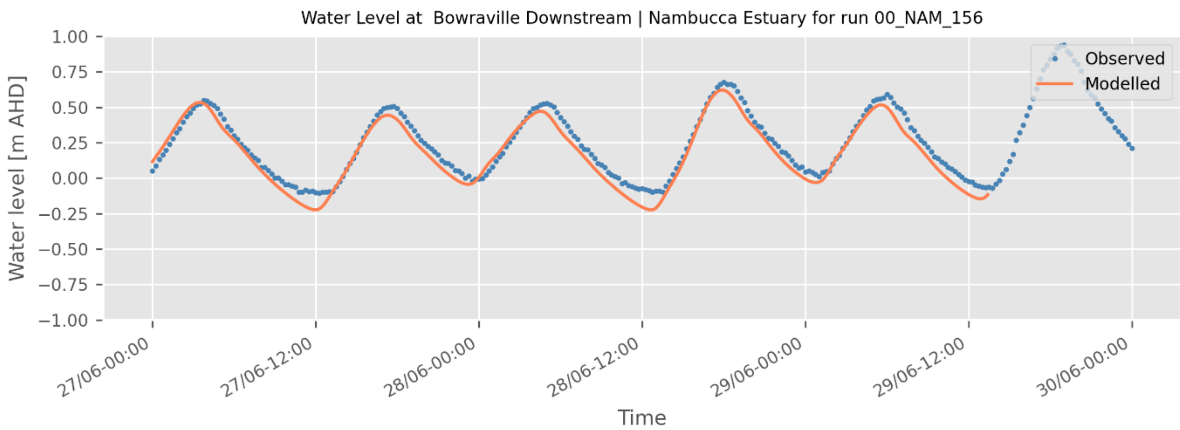

Figure B-53 2023 water level verification – Location 9 – Bowraville Downstream

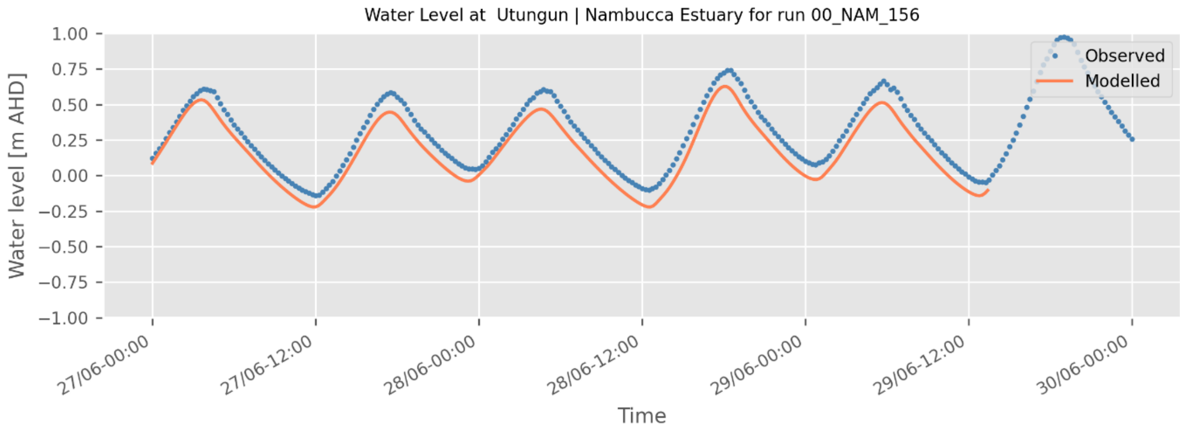

Figure B-54 2023 water level verification – Location 10 – Utungun

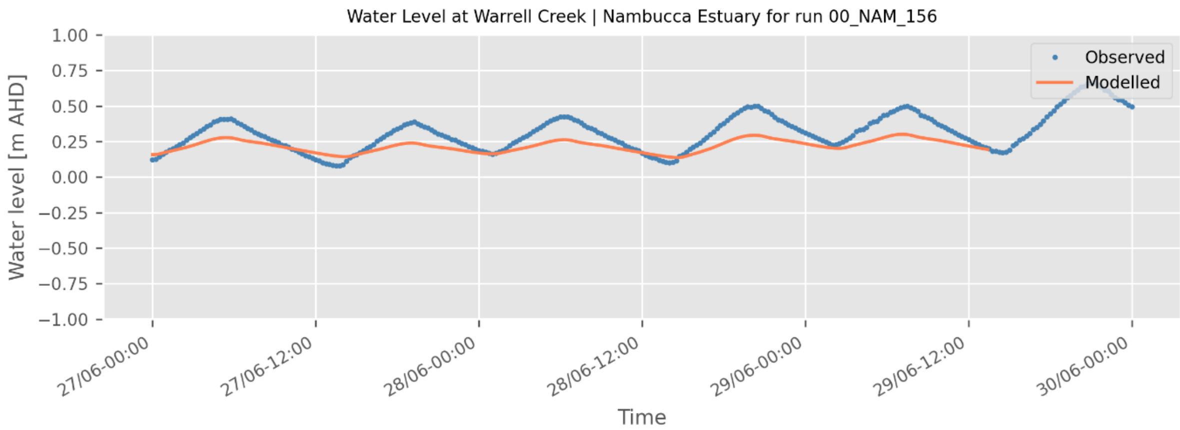

Figure B-55 2023 water level verification – Location 15 – Warrell Creek