# Assessing the impact of sewage overflows on oyster harvest areas: Port Stephens estuary technical summary

WRL TR 2023/22, May 2025

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

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## Project details

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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 Port Stephens 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 Port Stephens 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 |
| Hastings River | WRL TR2025/05 |
| Camden Haven River | WRL TR2023/20 |
| Wallis Lake | WRL TR2023/21 |
| Port Stephens | WRL TR2023/22 (this report) |
| 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 |

Additionally, pilot modelling was conducted in 2022 to identify data gaps and gain a better understanding of the Port Stephens system. For details on this modelling, see Harrison et al. (2022) (WRL TR2022/10).

## 1.3 Port Stephens site description

Port Stephens is a very large estuary in NSW, located 155 km north of Sydney and 40 km north of Newcastle. Major towns in the area include Nelson Bay, Salamander Bay, Tanilba Bay, Karuah and Tea Gardens. The estuary is a large, drowned river valley with tributaries including the Myall River, Tilligerry Creek and the Karuah River, as can be seen in Figure 1-1. The total estuary area is over 140 km$^2$ and the catchment area is approximately 2,900 km$^2$ (MHL, 1999). The tidal prism of the estuary was measured to be 1.68 x 10$^8$ m$^3$ on a spring tide in 1993 (MHL, 1993). The estuary consists of two similarly sized bays separated by a constriction at Soldiers Point, referred to in this report as the West Bay and the East Bay.

The Myall Lakes is a system of three large lakes 20 km to the north of Port Stephens, connected by a sinuous channel (the Myall River) to the East Bay of Port Stephens. The catchment area of Myall Lakes is approximately 780 km$^2$ (MHL, 1999). The Karuah River enters the West Bay of Port Stephens and has a catchment of 1,500 km$^2$. The tidal extent is approximately 25 km upstream of the outlet into the West Bay.

Port Stephens has 12 oyster harvest areas: Bundabah, Carrington Bay, Little Swan Bay, Swan Bay, Oyster Cove, Tilligerry Creek, Lemon Tree Passage, Cromarty Bay, Oakley Island, Corrie Island, Pindimar and Tea Gardens, as shown in Figure 1-2.

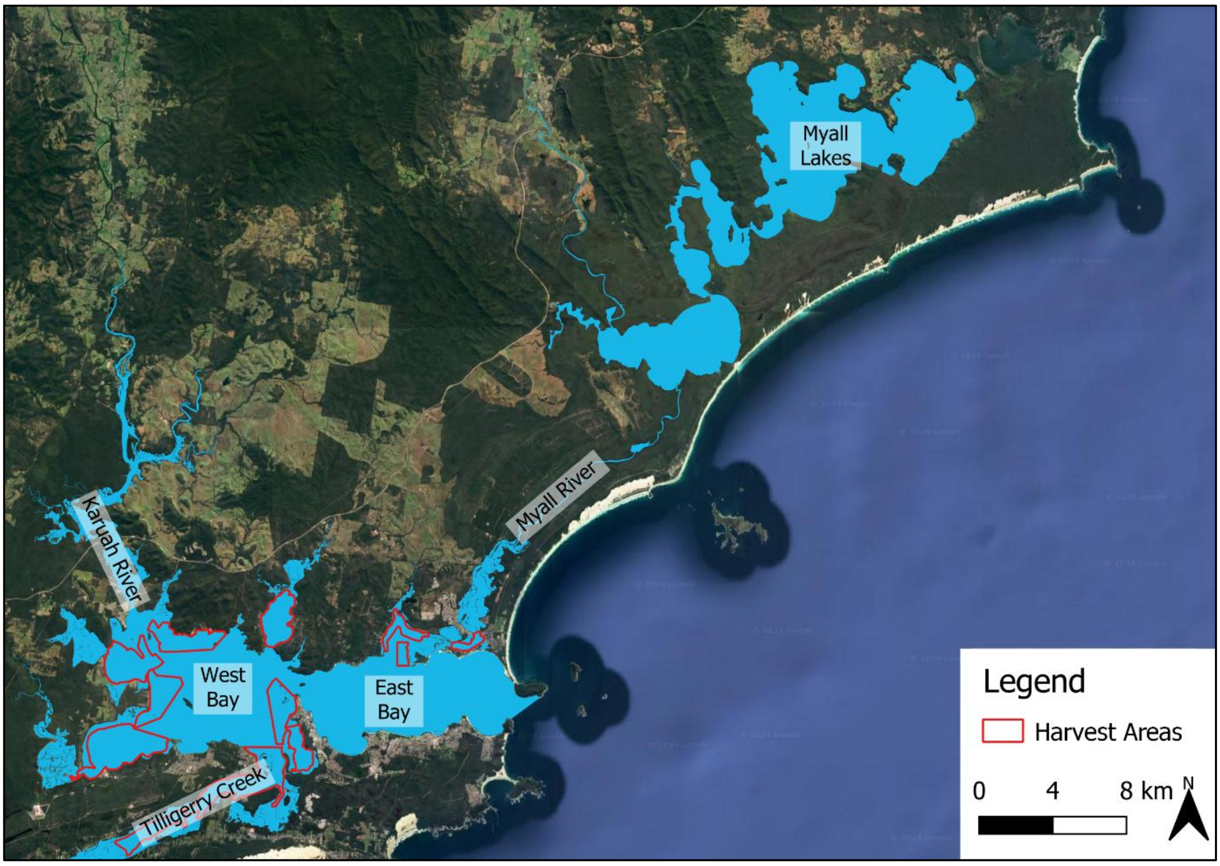


**Figure 1-1 Tributaries to Port Stephens**


**Figure 1-2 Oyster harvest areas on Port Stephens**

## 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 (2023b)<br>MHL (2023c) | Long term water level data available at five locations and one ocean tide gauge in the Port Stephens estuary. | 2.2 |
| Tidal flow and water level | MHL (1993) | Tidal flow gauging at seven locations and temporary water level gauging at an additional four locations in September 1993. | 2.2 |
| Catchment discharge | WaterNSW (2023) | One long term catchment flow monitoring locations. | 2.3 |
| Sewage overflows | NSW Food Authority<br>Hunter Water | Data on overflows including volume, duration and closure action. | 2.4 |
| Bathymetry | OEH (1969); OEH (1990); OEH (1995); OEH (2007); OEH (2009); OEH (2011); OEH (2015); OEH (2016)<br>DPIE (2018)<br>AHO (2021)<br>NSW Spatial Services (2012)<br>NAVONICS (2023)<br>NearMap (2024) | Bathymetry primarily sourced from OEH single beam surveys, 2018 NSW Marine LiDAR Topo-Bathy survey, AHO maritime charts, 2012 Digital Elevation Model (DEM), NAVONICS SonarChart and NearMap aerials. | 2.5 |

## 2.2 Water level and tidal flow gauging

Manly Hydraulics Laboratory (MHL) have five permanent water level gauges installed on Port Stephens and Myall Lakes estuary, and one ocean tide gauge at Shoal Bay, near the entrance of the estuary. This gauge was installed in 2014, and replaced a previous nearby ocean tide gauge called Port Stephens. Further water level and flow gauging has occurred during a data collection campaign run by MHL in 1993. 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 Port Stephens estuary and relevant ocean tide gauges**

| Water level gauge | Location label | Station number | Provider | Date range | MHL report number |
|---|---|---|---|---|---|
| Shoal Bay | 1 | 209474 | MHL | 2014 – present | – |
| Tea Gardens | 2 | 209480 | MHL | 2008 – present | – |
| Bombah Point | 3 (not in Figure 2-1 view) | 209475 | MHL | 2001 – present | – |
| Bulahdelah | 4 (not in Figure 2-1 view) | 209460 | MHL | 1984 – present | – |
| Mallabula Point | 5 | 209461 | MHL | 1992 – present | – |
| Karuah | 6 | 209485 | MHL | 2009 – present | – |
| Port Stephens | 7 | 209450 | MHL | 1985 – 2014 | – |
| Myall Entrance Site 4 | 8 | 2094136 | MHL | 29 – 30/09/1993 | MHL716 |
| Soldiers Point Site 7 | 9 | 2094137 | MHL | 29 – 30/09/1993 | MHL716 |
| North Arm Cove Site 13 | 10 | 2094139 | MHL | 29 – 30/09/1993 | MHL716 |
| Tilligerry Creek Site 10 | 11 | 2094138 | MHL | 29 – 30/09/1993 | MHL716 |
| Karuah River Site 16 | 12 | 2094140 | MHL | 29 – 30/09/1993 | MHL716 |
| Oakey Island | 13 | - | WRL | 16/11/2022 – 16/11/2023 | – |
| Tilligerry Creek | 14 | - | WRL | 16/11/2022 – 16/11/2023 | – |
| Swan Bay | 15 | - | WRL | 16/11/2022 – 16/08/2023 | – |
| Karuah Jetty | 16 | - | WRL | 16/11/2022 – 16/08/2023 | – |

**Table 2-3 Summary of tidal flow gauging locations on the Port Stephens estuary**

| Tidal flow gauge | Location label | Dates | Study |
|---|---|---|---|
| Entrance Site 2 | A | 18/09/1997 | MHL716, WRL 2023 fieldwork |
| Myall River Site 5 | B | 18/09/1997, 15/11/2023 | MHL716, WRL 2023 fieldwork |
| Soldiers Point Site 8 | C | 18/09/1997, 15/11/2023 | MHL716, WRL 2023 fieldwork |
| North Arm Cove Site 14 | D | 18/09/1997, 14 - 15/11/2023 | MHL716, WRL 2023 fieldwork |
| Tilligerry Creek Site 11 | E | 18/09/1997, 14/11/2023 | MHL716, WRL 2023 fieldwork |
| Karuah River Site 17 | F | 18/09/1997, 16 - 17/08/2023 | MHL716, WRL 2023 fieldwork |
| Myall River Corrie Island North | G | 15/11/2023 | WRL 2023 fieldwork |
| Myall River Corrie Island South | H | 15/11/2023 | WRL 2023 fieldwork |
| Cromartys Bay | I | 14/11/2023 | WRL 2023 fieldwork |
| Bulls Island West | J | 14/11/2023 | WRL 2023 fieldwork |
| Twelve Mile Creek | K | 16/11/2023 | WRL 2023 fieldwork |
| Karuah River North Fork | L | 16 -17/08/2023 | WRL 2023 fieldwork |
| Karuah River South Fork | M | 16 -17/08/2023 | WRL 2023 fieldwork |

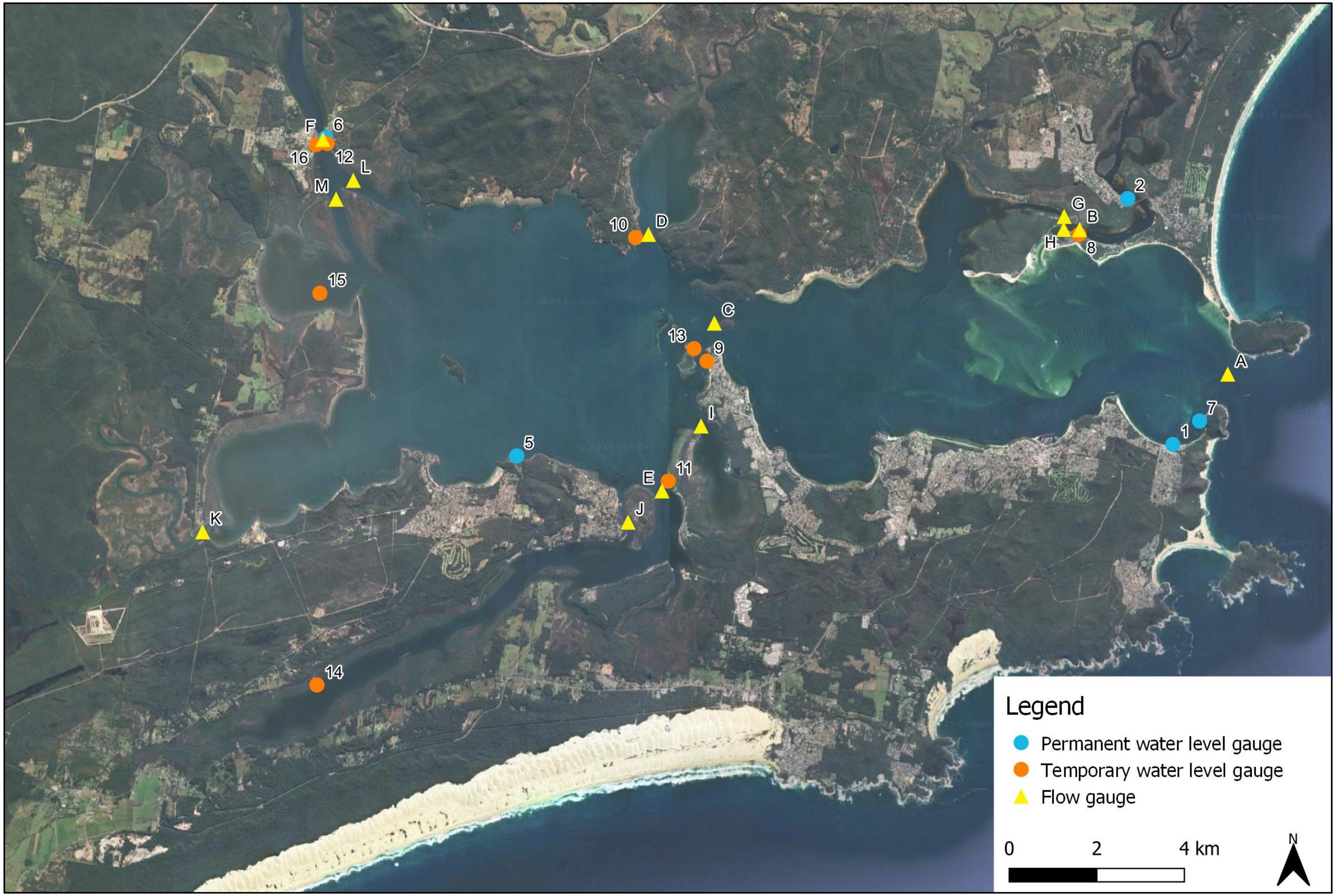


**Figure 2-1 Water level and tidal flow gauging locations**

## 2.3 Catchment inflows

Gauged catchment inflows were available from WaterNSW. There is one model boundary inflow into the Port Stephens estuary and continuous flow gauging of discharge and water levels are available from WaterNSW (2023) at one relevant location: Karuah River at Booral (1968 to present). As this gauging location was not at the tidal limit (the model boundary), the flows were scaled up proportionally to the additional catchment area using the method in WRL TR2023/32 Section 2.4. Table 2-4 lists the model boundary, the gauge used and the relevant scaling factor applied. Figure 2-2 shows the locations along with the catchment area flowing into the tidal boundary (solid line polygon) along with the associated portion of that catchment that is upstream of the gauge (hatched).

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

| Model boundary | Base WaterNSW gauge | Scaling factor |
|---|---|---|
| Karuah River | 209003 | 1.147 |

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

**Table 2-5 WaterNSW gauge flow percentiles**

| Percentile | Karuah River at Booral (209003) ML/d *($m^3/s$)* |
|---|---|
| $5^{th}$ | 0.73 *(0.01)* |
| $20^{th}$ | 23 *(0.27)* |
| $50^{th}$ (median) | 117 *(1.4)* |
| $80^{th}$ | 772 *(8.9)* |
| $95^{th}$ | 5892 *(68)* |

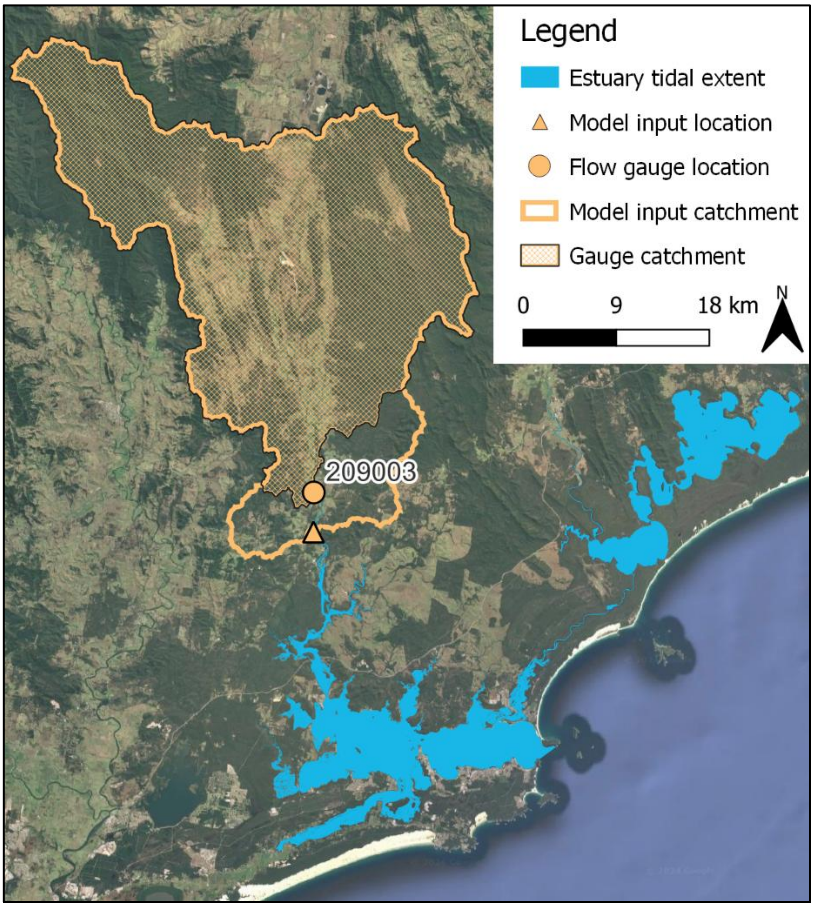


**Figure 2-2 Catchment flow gauging stations***

*Hatched areas correspond to upstream catchments of WaterNSW gauges. Outline areas correspond to model input catchment areas.

## 2.4 Sewage overflow data

The Hunter Water Corporation is the agency responsible for wastewater treatment and sewage management in the catchment surrounding the Port Stephens estuary. The sewerage system is comprised of a reticulation network of pipes and sewage pumping stations (SPS), in addition to wastewater treatment plants (WWTPs). Two WWTPs are within the catchment of Port Stephens: Karuah WWTP and Tanilba Bay WWTP.

When sewage overflows occur that may impact the estuary, Hunter Water 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 Hunter Water and is shown in Figure 2-3. More information on sewage overflows and why they occur is provided in WRL TR2023/32 Section 2.5.

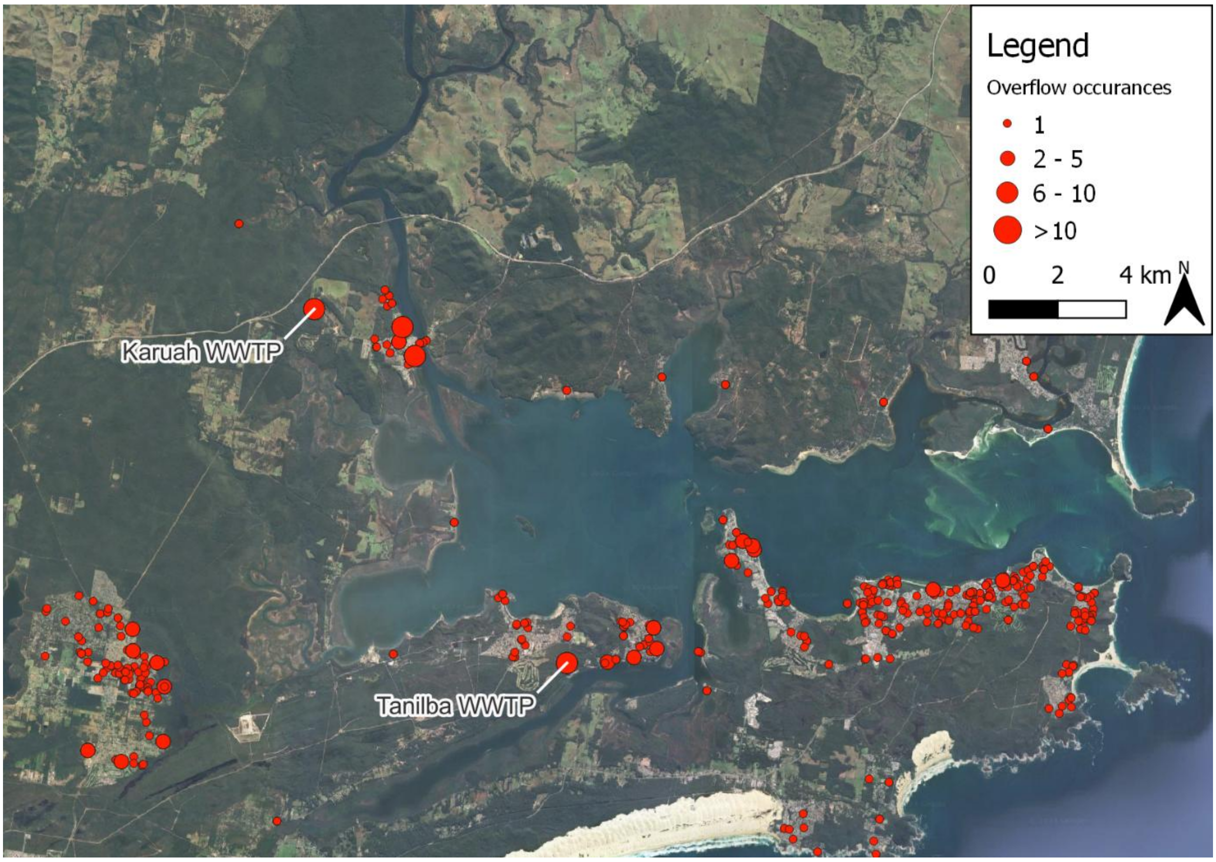


**Figure 2-3 Locations of reported sewage overflows on Port Stephens**

## 2.5 Bathymetry

Three 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 Port Stephens, this data covers shallow areas in most of Port Stephens, excluding the Karuah River and Upper Tilligerry Creek, as can be seen in Figure 2-4. The survey covers deep parts of the East Bay near the entrance, however, the survey excludes deeper sections west of Nelson Bay. This dataset was used for model bathymetry in all areas for which it was available.
- Single beam bathymetry transect data collated and provided by the NSW Office of Environment and Heritage (OEH, now DCCEEW) and available on the Australian Ocean Data Network (AODN) portal. Several OEH bathymetry datasets have been collected, mainly in the east bay. These are shown in Figure 2-5 and include:
    - 2016 – Lower Myall River
    - 2015 – Kangaroo Point
    - 2011 – Tanilba Bay
    - 2009 – Lower Myall River
    - 2007 – Port Stephens East Bay
    - 1995 – Tilligerry Creek
    - 1990 – Myall Upper
    - 1969 – Port Stephens East Bay (superseded by the 2007 survey)

This data was used in places where the 2018 LiDAR survey did not cover (mainly in the deeper parts of the East Bay).

- Depth soundings collected by the Australian Hydrographic Office (AHO) for the Port Stephens maritime chart AU433151 (2021). This dataset is comprised of point data with a spacing of 100 to 500 m and covers most of Port Stephens and offshore of the entrance. This data was used in locations the other two datasets did not cover (mainly the deeper parts of the West Bay) as can be seen in Figure 2-6.

For areas where the OEH data overlapped the DPIE LiDAR survey, the difference in bathymetry was compared, and is shown in Figure 2-7. The difference in most locations was minor (less than 50 cm), although there was some larger change, mainly representing movement of shoals in the East Bay.

Additional bathymetric, topographic, and aerial data utilised include:

- 1 x 1 m DEM LiDAR data, collected in 2012 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.
- NAVONICS SonarChart™ was utilised in locations where no other bathymetric data was available, such as the Karuah River and Myall River. Navionics crowd sources sonar data from navigation systems on boats within the waterway. As Port Stephens is a heavily boat-trafficked estuary, the data is high resolution, with significantly better coverage and detail in shallow areas than is typically captured by the AHO datasets, however, it is not quality controlled. In addition to its use in the Karuah and Myall Rivers, Navionics data was used qualitatively to assess whether model bathymetry was capturing the location and geometry of complex features not fully captured by single depth soundings such as shallow reefs, abrupt drop-offs and river confluences.
- High resolution NearMap imagery was used to qualitatively provide information on important bathymetric features, including to verify NAVIONICS data in the Karuah River.

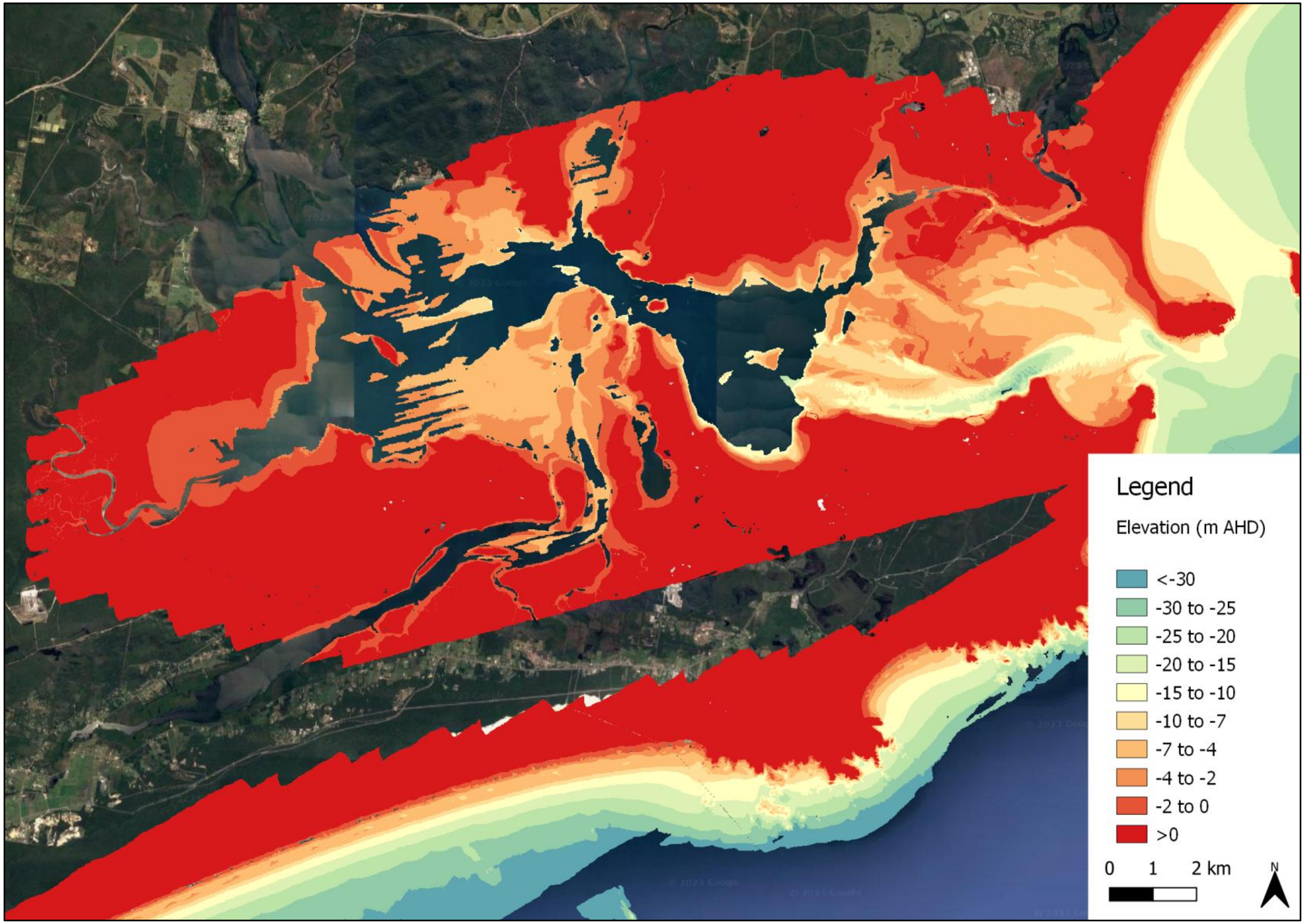


**Figure 2-4 NSW DPIE TopoBathy LiDAR bathymetry data**

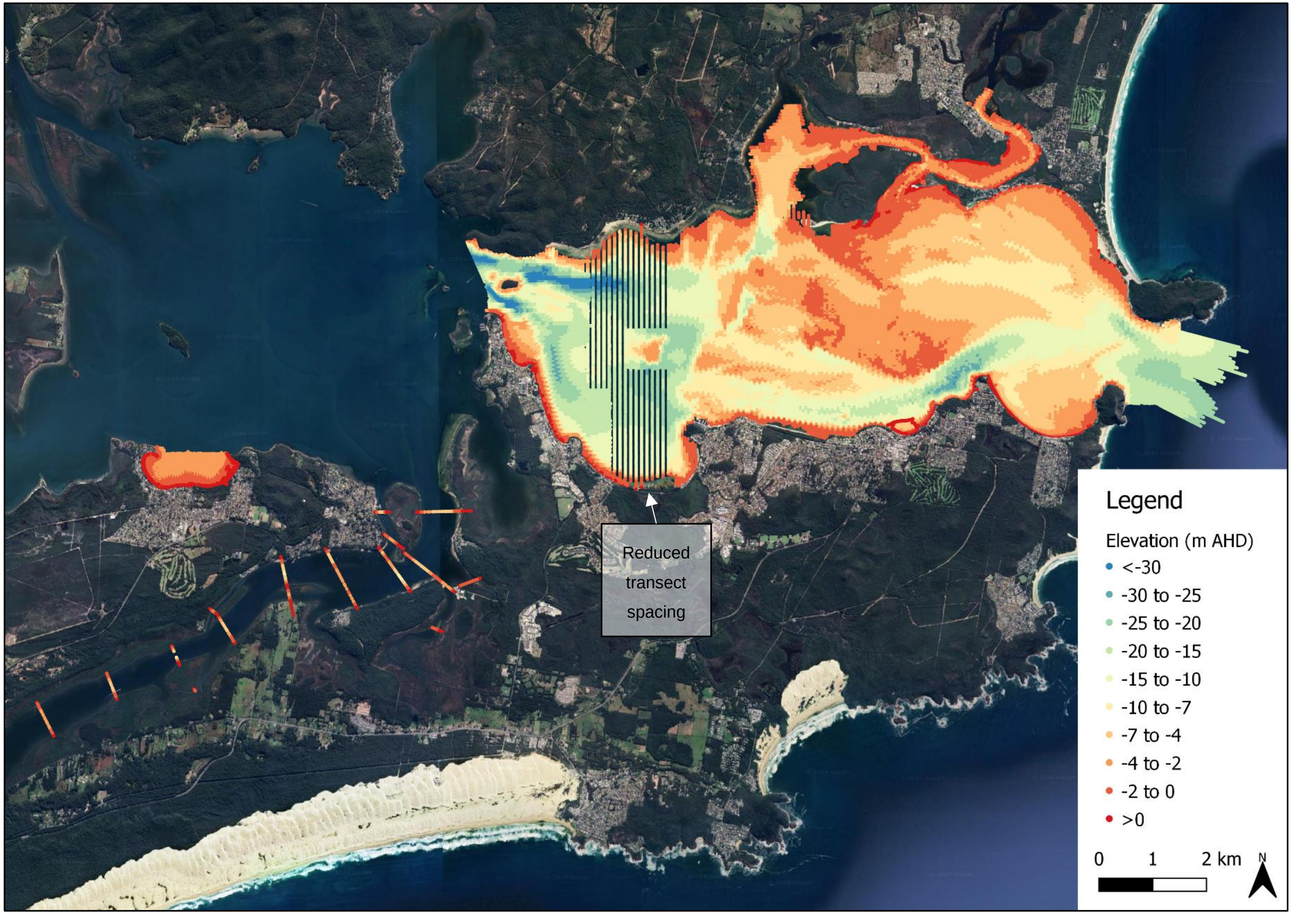


**Figure 2-5 NSW OEH single beam bathymetry data**

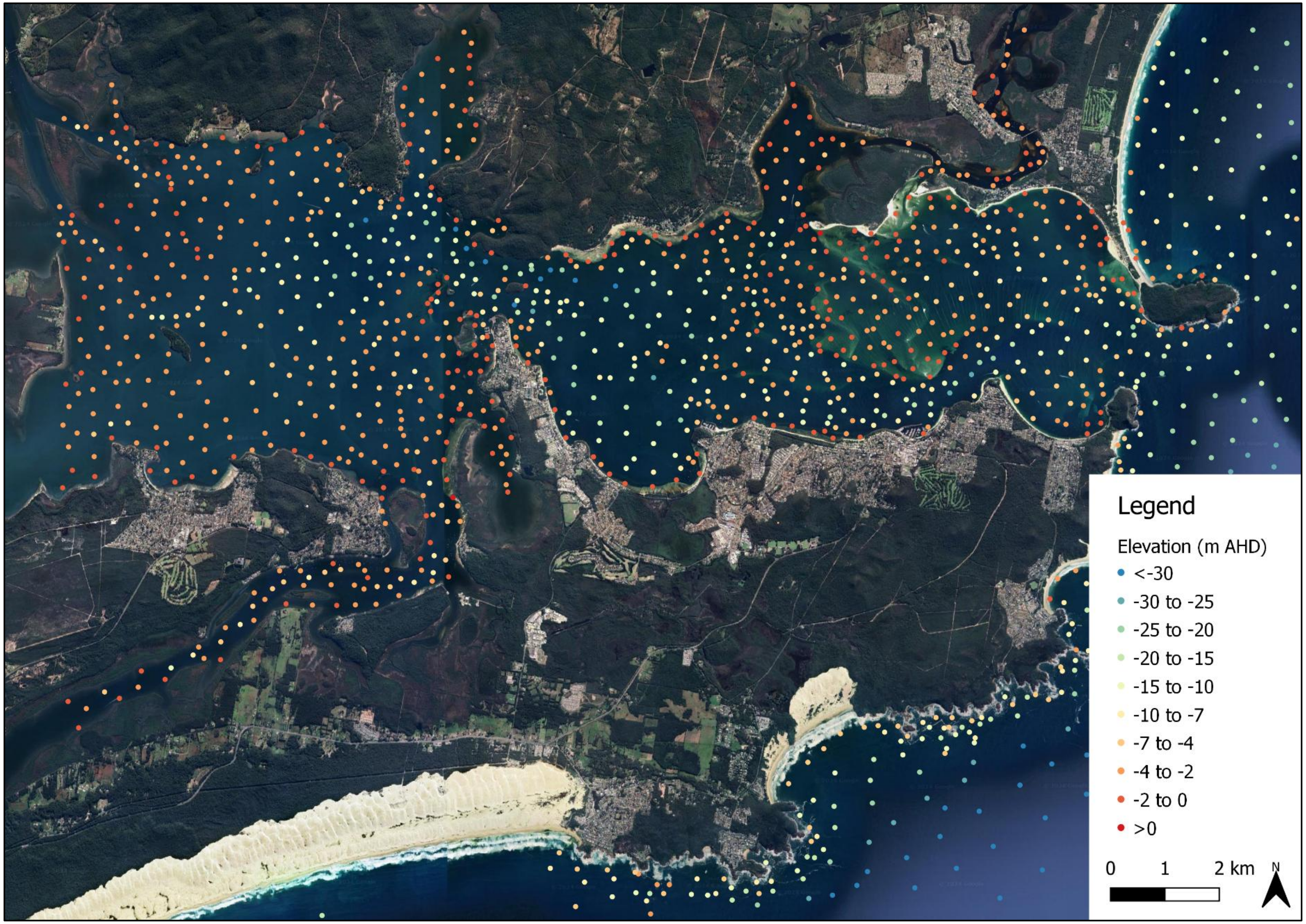


**Figure 2-6 AHO sounding bathymetry data**

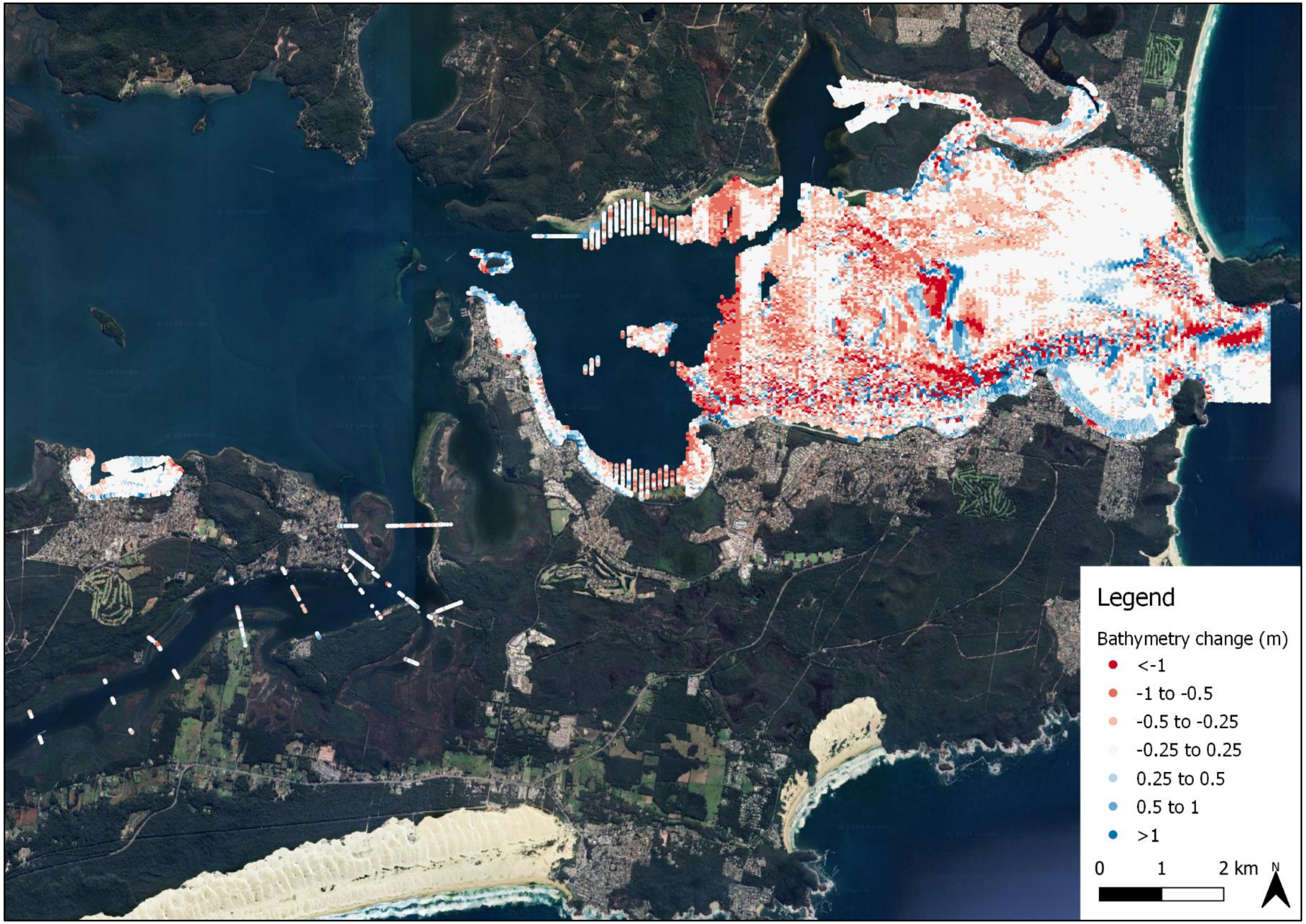


**Figure 2-7 Difference between OEH data and DPIE LiDAR data. Red corresponds to erosion and blue to accretion**

## 2.6 Existing model

Harrison et al. (2022) produced a three-dimensional RMA pilot model of the West Bay of Port Stephens. This model mesh (shown in Figure 2-8) was used as the basis for the West Bay. Mesh resolution was added, and the mesh was extended to the East Bay and Myall Lakes. The pilot modelling done by Harrison et al. (2022) also informed the fieldwork data collection campaigns discussed in Section 3.


**Figure 2-8 Pilot model mesh of the West Bay by Harrison et al. (2022)**

# 3 Field data collection

## 3.1 Preamble

Three field data collection campaigns were completed for this study: 16 November 2022 and 16 and 17 August 2023 by Yarran Doherty and Alice Harrison (supported by Hunter Water in 2023) and one on 14 to 16 November 2023 by 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
- Installation of medium-term water level gauging between the two fieldwork campaigns, in addition to collation of data from MHL water level monitoring sites
- Conductivity measurements

The November 2023 fieldwork occurred during day light savings time, however, all times in this report are given in Australian Eastern Standard Time (AEST).

## 3.2 Weather and tides

Data collection on Port Stephens was undertaken on both ebb and flood tides. Tides during field investigations ranged between approximately -0.4 to 0.4 m AHD during the first field trip and -0.6 to 0.8 m AHD during the second field trip at Shoal Bay, near the estuary entrance. The observed water levels at Shoal Bay, alongside the timing of key fieldwork components is shown in Figure 3-1 and Figure 3-2. Predicted and observed tides at the MHL ocean tide station at Shoal Bay are shown in Figure 3-3 and Figure 3-4. The increasing anomaly during both fieldwork periods can be explained by decreasing barometric pressure (MHL, 2023a).

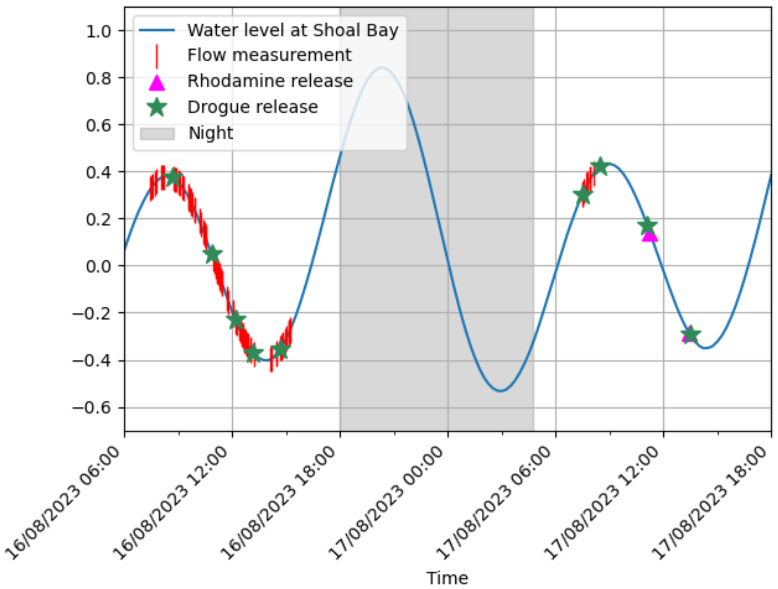


**Figure 3-1 Tides at Shoal Bay with timing of key data collection events during August fieldwork**

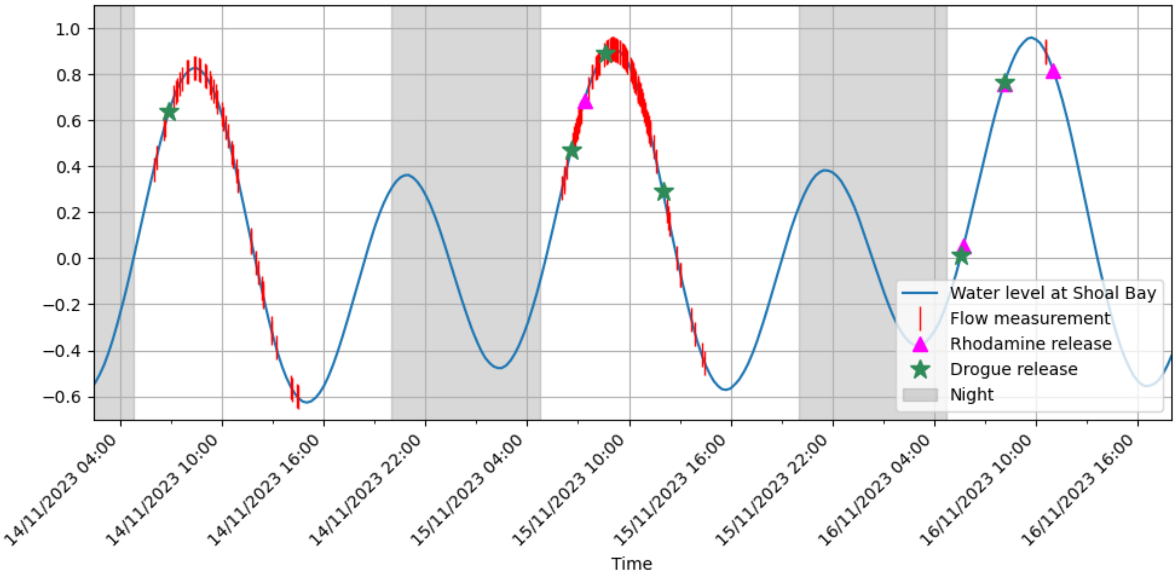


**Figure 3-2 Tides at Shoal Bay with timing of key data collection events during November fieldwork**

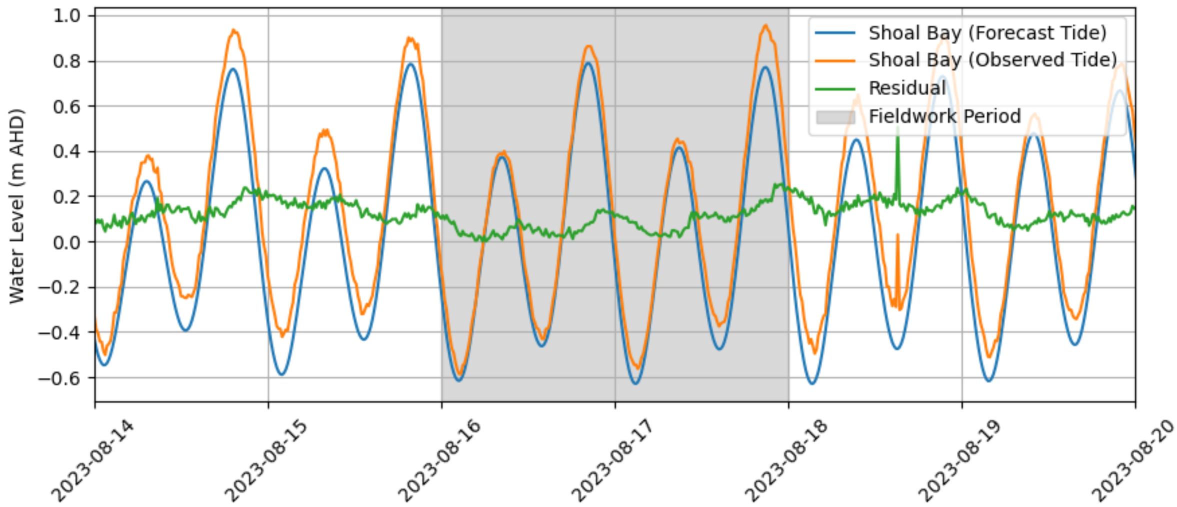


**Figure 3-3 Forecasted and observed tides at Shoal Bay for August fieldwork period**

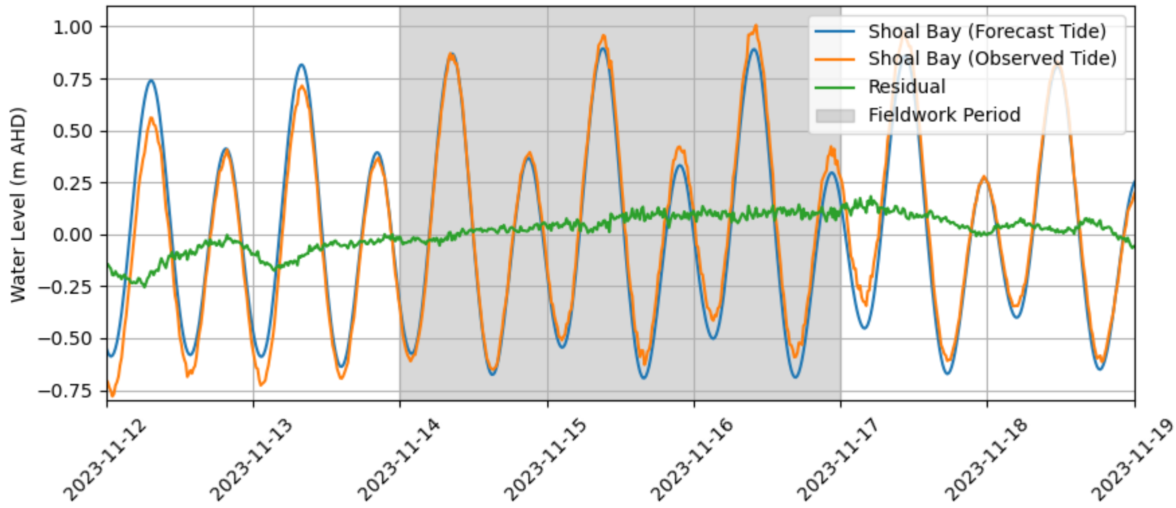


**Figure 3-4 Forecasted and observed tides at Shoal Bay for November fieldwork period**

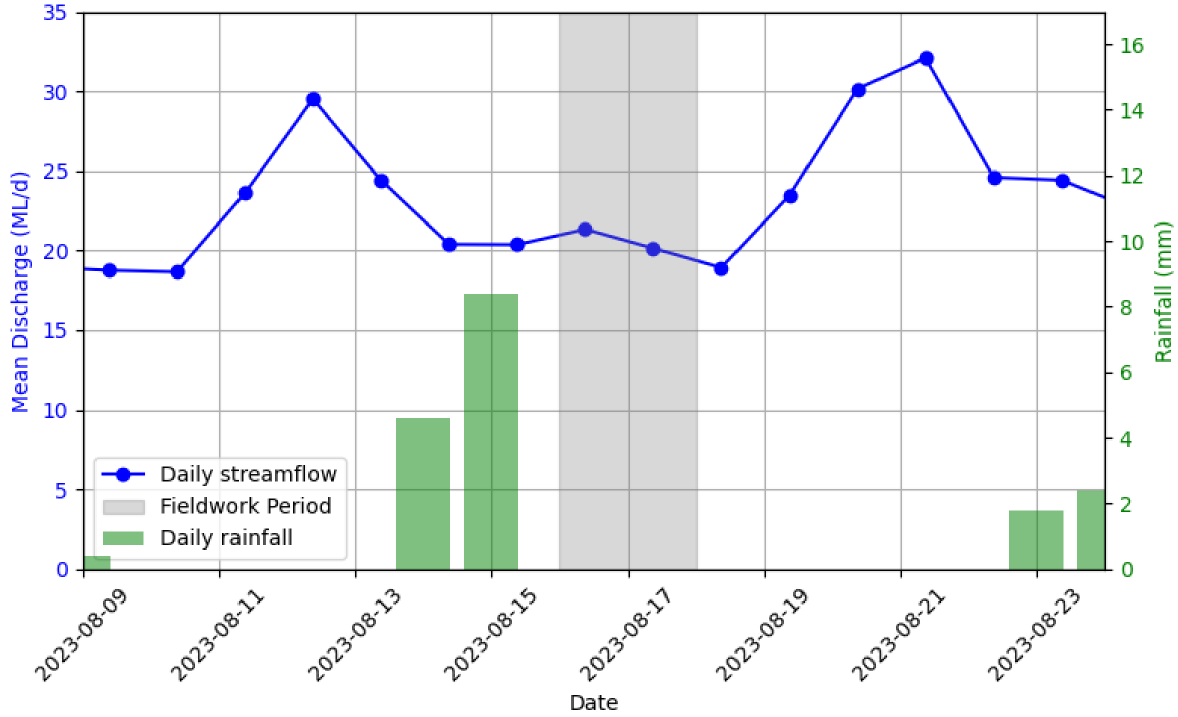


**Figure 3-5 Rainfall recorded at Williamstown RAAF and streamflow recorded at Karuah River at Booral for the period surrounding August fieldwork**

While no rainfall fell during the days of the August fieldwork, rainfall was recorded in the preceding week at Williamtown RAAF (BoM station 61078) which is located 20 km southwest of Port Stephens. Rainfall recorded at Williamstown was 5 mm on 14 August and 8 mm on 15 August 2023, as can be seen in Figure 3-5. The streamflow at Karuah was low (well below median flow) and is also shown in Figure 3-5. During the August fieldwork period, winds were negligible.

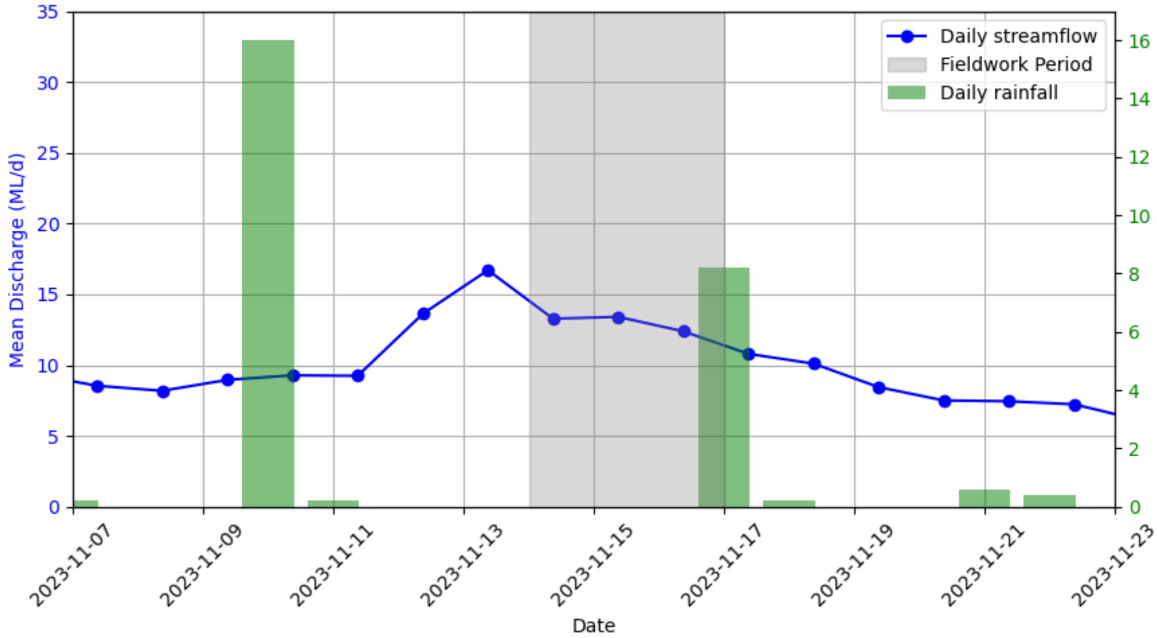


**Figure 3-6 Rainfall recorded at Williamstown RAAF and streamflow recorded at Karuah River at Booral for the period surrounding November fieldwork**

While no rainfall fell during the days of the November fieldwork, 16 mm of rainfall was recorded in the preceding week at Williamtown RAAF, as can be seen in Figure 3-6. The streamflow at Karuah was low (well below median flow) as shown in Figure 3-6. Wind speeds increasing from 5 to 20 km/h throughout the day were observed on all 3 days of the November fieldwork period, with winds from the north-east observed on 14 November and winds from the southeast observed on 15 and 16 November.

## 3.3 Tidal flow gauging

Flow was measured using a boat mounted SonTek RiverSurveyor M9 ADCP or a Workhorse 1200 kHz ADCP at 11 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 Port Stephens estuary are summarised in Table 3-1, with locations shown in Figure 3-7. For a table of tidal gauging measurements refer to Appendix A2, and for plots of tidal flows refer to Appendix B1.3 and B1.5.

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

| Location | Location label* | 16 August # transects | 17 August # transects | 14 November # transects | 15 November # transects | 16 November # transects |
|---|---|---|---|---|---|---|
| Myall River Site 5 | B | - | - | - | 17 | - |
| Soldiers Point Site 8 | C | - | - | - | 22 | - |
| North Arm Cove Site 14 | D | - | - | 2 | 11 | - |
| Tilligerry Creek Site 11 | E | - | - | 20 | - | - |
| Karuah River Site 17 | F | 41 | 4 | - | - | - |
| Myall River Corrie Island North | G | - | - | - | 17 | - |
| Myall River Corrie Island South | H | - | - | - | 12 | - |
| Cromartys Bay | I | - | - | 10 | - | - |
| Bulls Island West | J | - | - | 12 | - | - |
| Twelve Mile Creek | K | - | - | - | - | 2 |
| Karuah River North Fork | L | 15 | 2 | - | - | - |
| Karuah River South Fork | M | 18 | 2 | - | - | - |

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

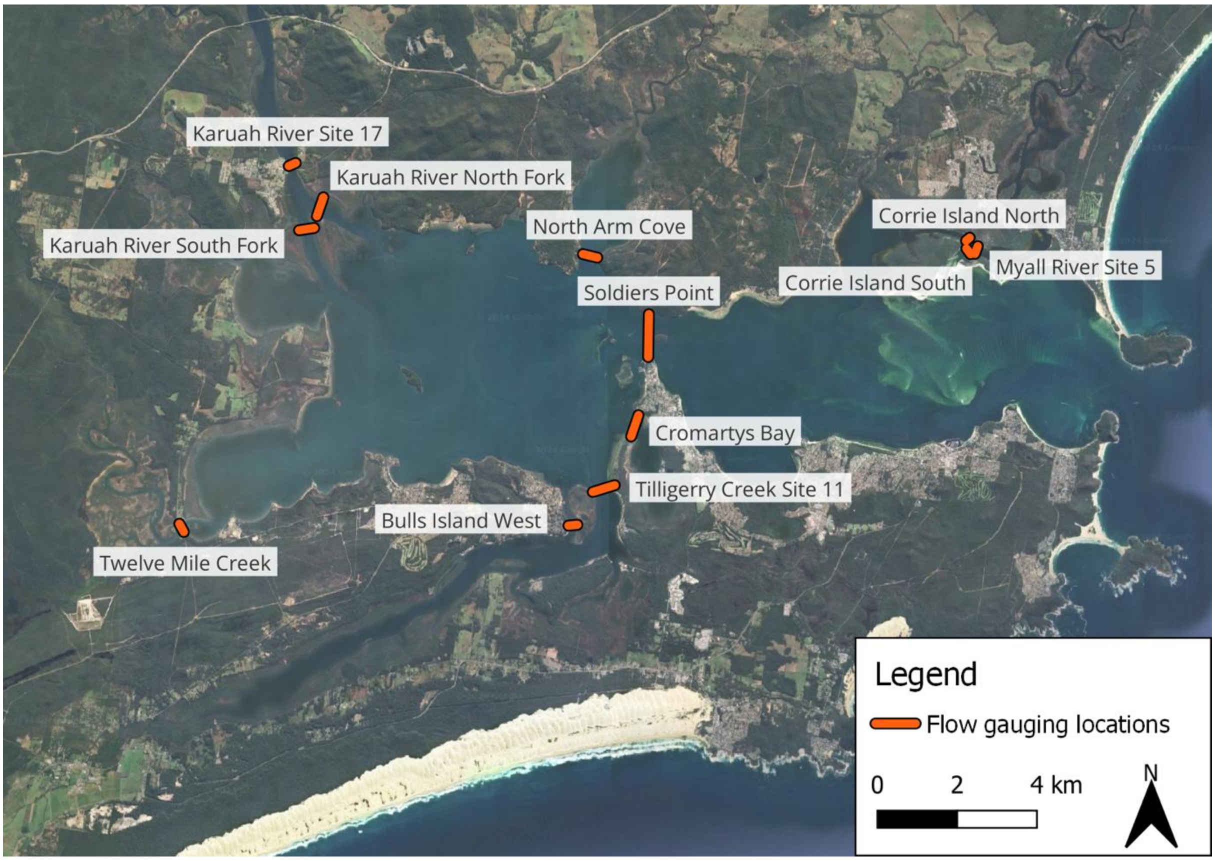


**Figure 3-7 Tidal flow gauging locations from 2023 fieldwork**

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 at gauging locations.

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. Most observations approximated depth averaged flow. Velocity depth profiles for each gauging location are presented in Appendix A4.

## 3.4 Wind driven stratification

Five M9 transects were taken across the West Bay to assess vertical stratification and the effects of wind: three on 17 August 2023 (with minimal wind) and two on 14 November 2023. Wind speed during the transects on 14 November was approximately 10 to 15 km/h from the NE. No visible stratification was detected, however, it was noted that the data was noisy due to excessive boat movement in waves, and as the boat mounted instrument does not explicitly measure the top 80 cm of the water column. Wind driven movement would be expected within the top 1 m of the water column, which is not well captured by the M9. An example transect in presented in Appendix A4.

## 3.5 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 3-8, and the change between the 2018 LiDAR data and field captured bathymetry is shown in Figure 3-9, for locations where the surveys overlapped. In most cases, bathymetry difference was minor (less than 50 cm).


**Figure 3-8 Bathymetry collected during 2023 fieldwork**


**Figure 3-9 Difference between 2018 LiDAR and 2023 fieldwork bathymetry. Red corresponds to erosion and blue to accretion**

## 3.6 Rhodamine WT dye releases

To simulate pollutant advection and dispersion in the Port Stephens estuary, six Rhodamine WT dye releases were performed during the two field campaigns (refer to WRL TR2023/32 Section 4.4 for methods). These are summarised in Table 3-2, with locations shown in Figure 3-10. The initial release concentration was 200,000,000 ppb in all instances.

**Table 3-2 Summary of dye releases**

| No. | Date | Time released | Tracked until | Volume of dye released (mL) | Location | Tide |
|---|---|---|---|---|---|---|
| 1 | 17/08/2023 | 11.16am | 12.53pm | 580 | East Bay | Ebb |
| 2 | 17/08/2023 | 1.27pm | 2:44pm | 580 | Karuah River | Ebb |
| 3 | 15/11/2023 | 7.22am | 8am | 265 | Myall River by Corrie Island | Flood |
| 4 | 16/11/2023 | 5.44am | 6.45am | 500 | Soldiers Point | Flood |
| 5 | 16/11/2023 | 8.08am | 9.03am | 500 | Tilligerry Creek | Flood |
| 6 | 16/11/2023 | 11.02am | 11.52am | 200 | East Bay | Slack high |

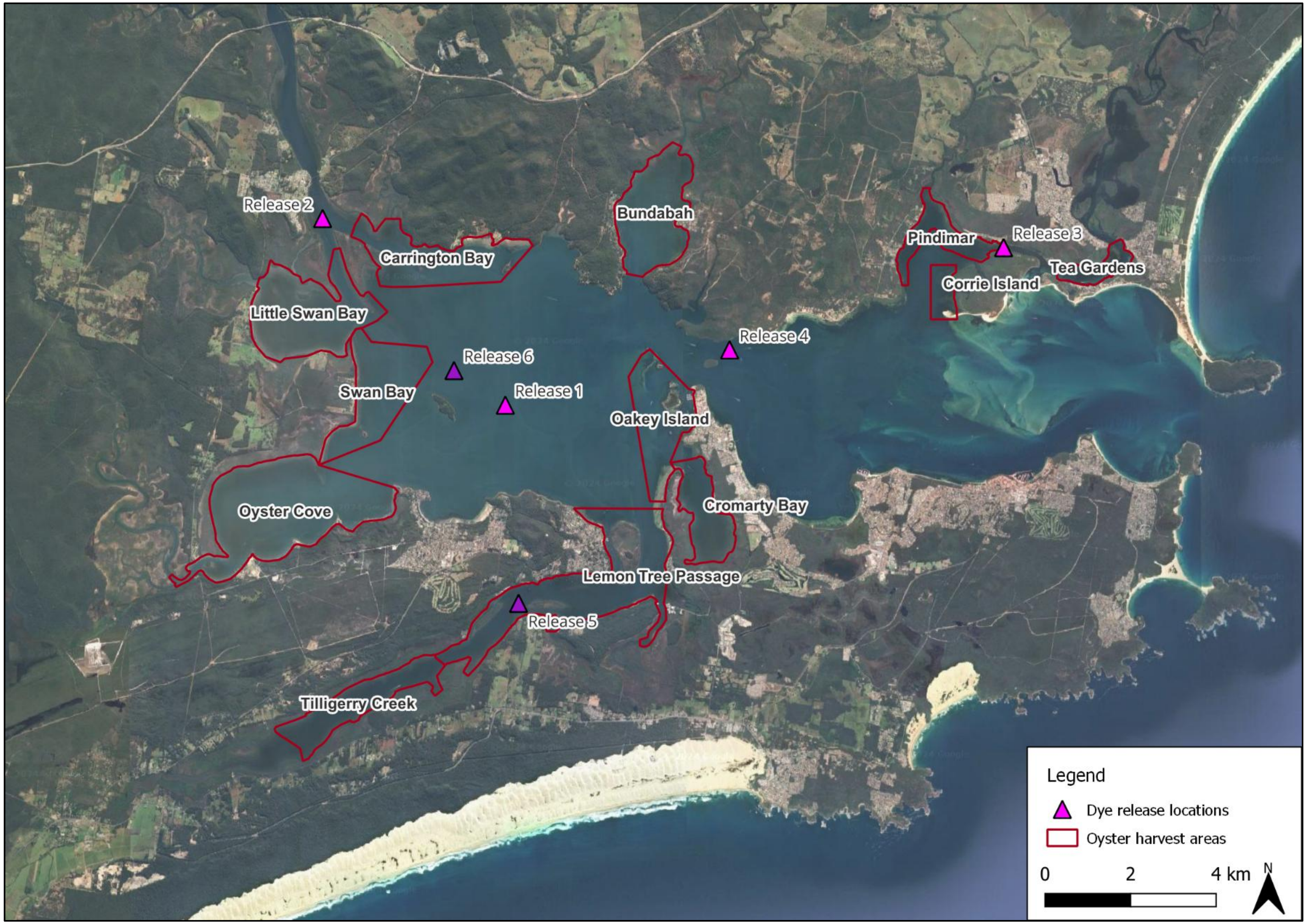


**Figure 3-10 Rhodamine WT dye release locations**

### 3.6.1 Release 1 – West Bay

Dye release 1 was completed in the East Bay in water approximately 6 m deep. This release was conducted to understand diffusion in the open bay. There was very little wind during this release, and calm water led to slow dispersion. The release occurred at 11.16am and was tracked for 1.5 hours. Figure 3-12 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

The plume moved slowly east with the outgoing tide, covering approximately 850 m in 75 minutes, at an average velocity of 11 m/min. The plume remained roughly circular through the period of tracking and dispersed slowly, reaching approximately 90 m in diameter 75 minutes after the release. Several depth profiles taken over the period of tracking show that although the peak concentrations decreased, the plume retained a similar vertical profile throughout the release, reaching to approximately 2.5 m deep with the greatest concentrations at around 1 m deep (see Figure 3-11 which plots vertical profiles on a logarithmic axis). This made surface tracking difficult at times, as the instrument was set to a depth of approximately 50 cm, which at times was above the main plume. Tracking ceased 87 minutes after the release, and the boat's motor was used to disperse the dye, which still reached concentrations of greater than 4 ppb.

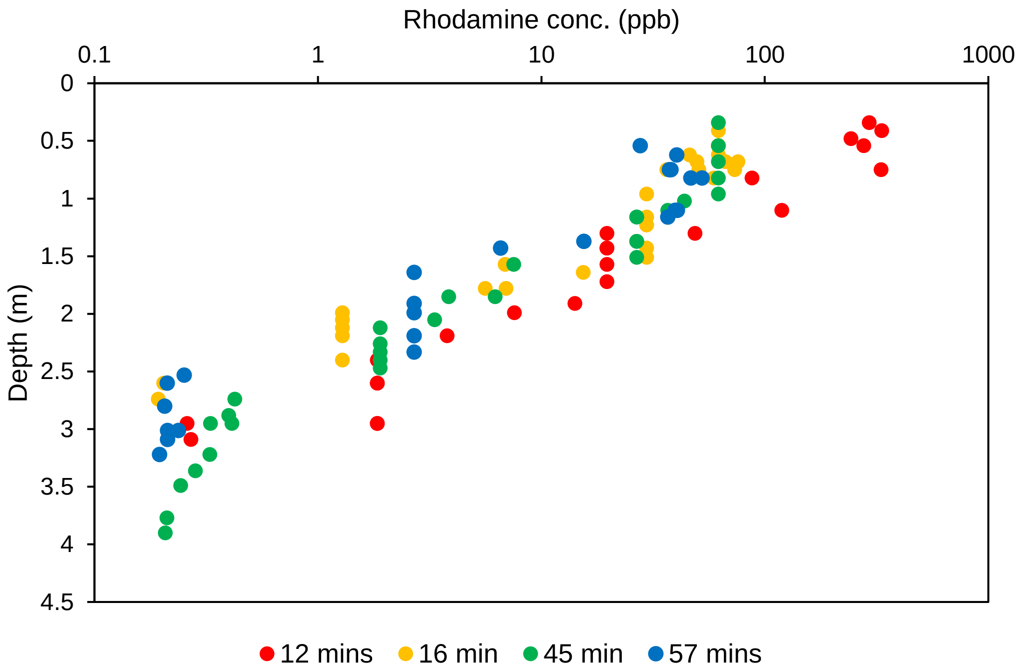


**Figure 3-11 Vertical profiles conducted during dye release 1**

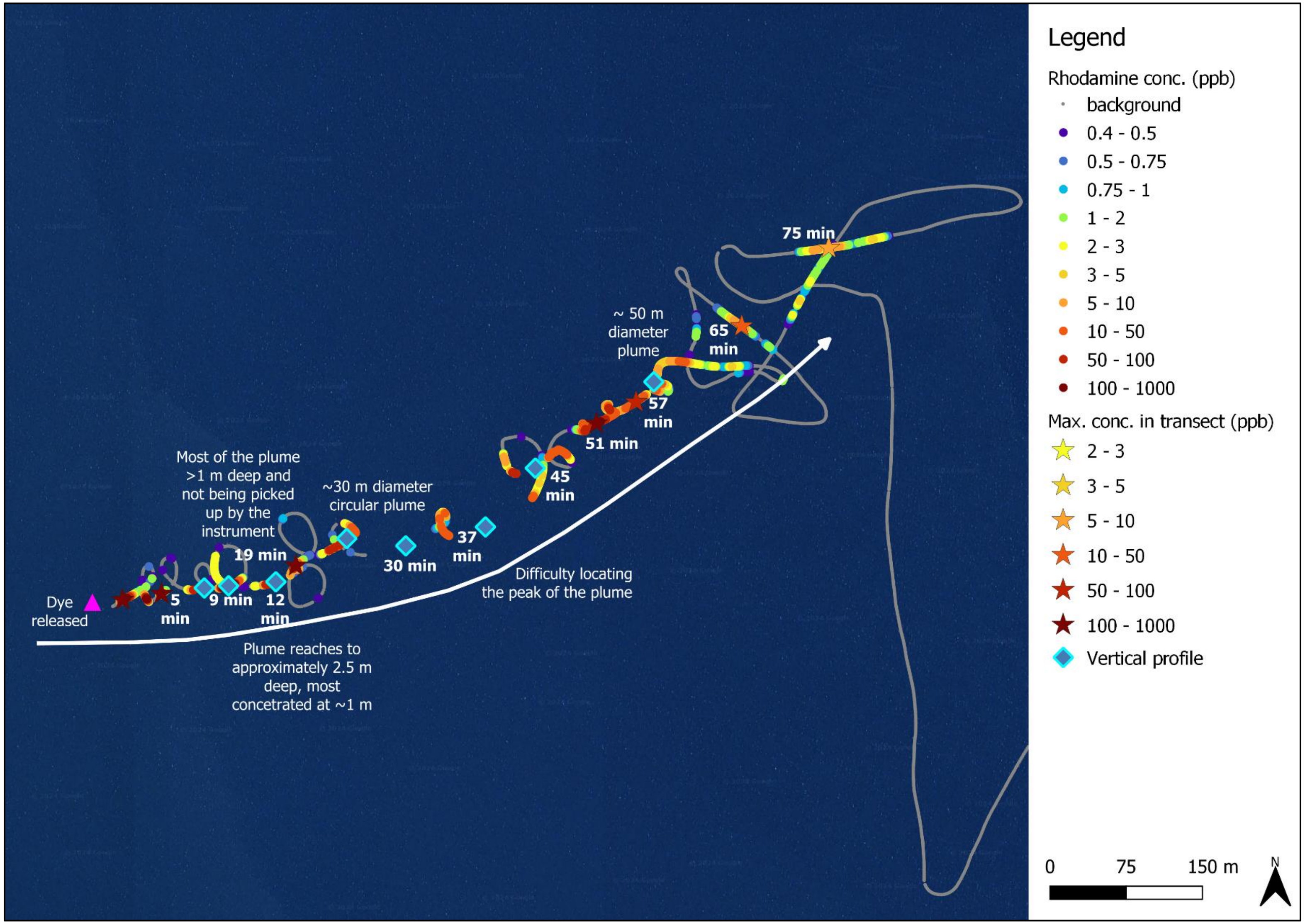


**Figure 3-12 Dye release 1 in the East Bay. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)**

### 3.6.2 Release 2 – Karuah River

Release 2 was conducted in the Karuah River to understand the transport of pollutants in this area. The release occurred at 1.27pm, on an outgoing tide, and the plume was tracked for 1.3 hours. Over this time, the plume travelled 1200 m, at an average velocity of 15 m/min. Figure 3-13 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

The plume began elongating and was approximately 10 m wide by 40 m long 10 minutes after the release. By 20 minutes the plume reached the junction created by Correebah Island, and some dye was observed going into the northern channel. This demonstrates that overflows from Karuah are unlikely to be confined to the right bank channel only. Most of the plume went into the southern channel, and tracking followed this portion. In the southern channel the plume elongated further, becoming more than 200 m long 30 minutes after release. The plume mainly stayed along the left bank despite deeper water in the centre of the channel. The plume reached all the way to the left bank, but tracking was hindered by oyster leases and shallow water. Tracking ceased at 77 minutes by which time the plume was greater than 300 m long.

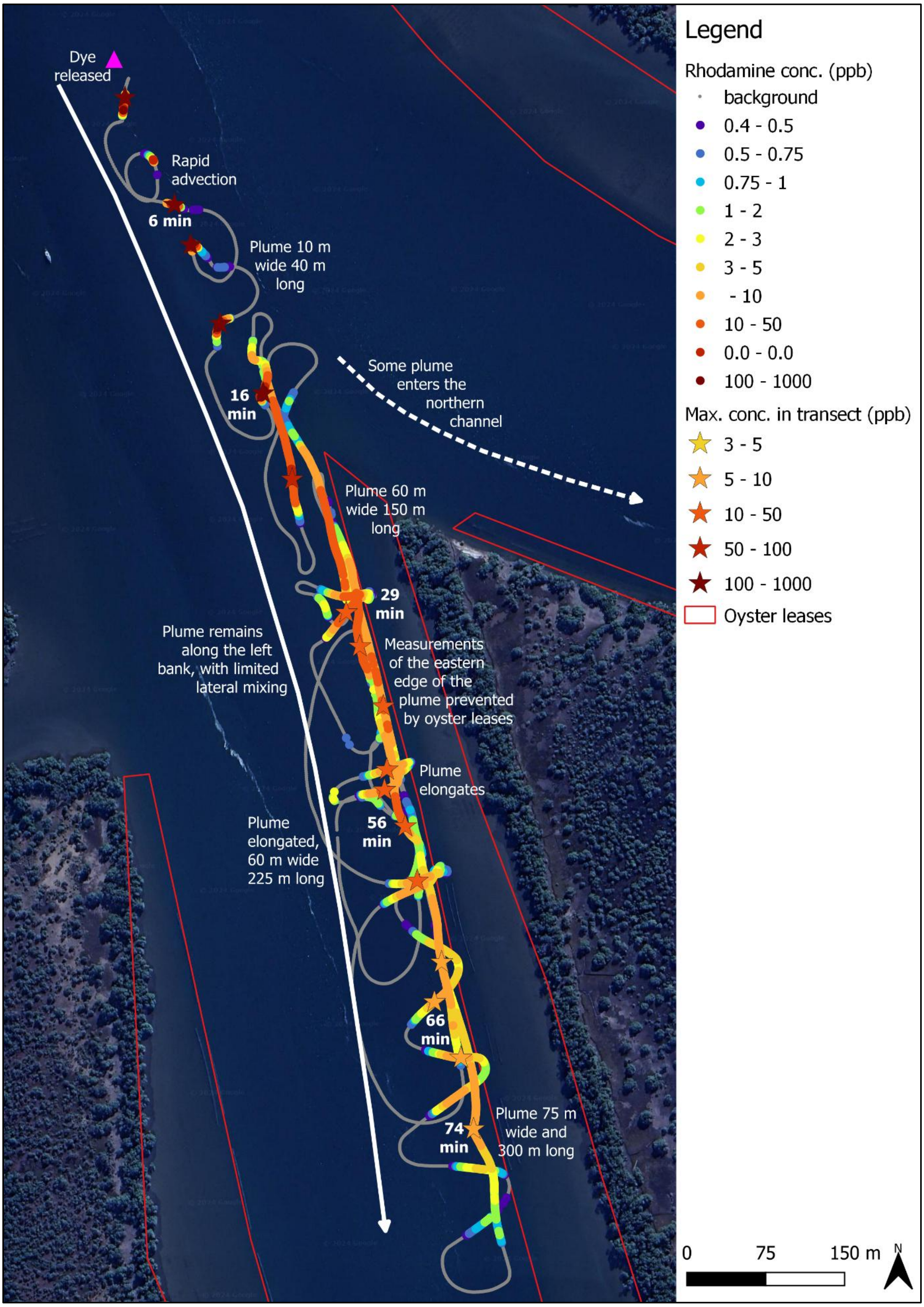


**Figure 3-13 Dye release 2 in the Karuah River. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)**

### 3.6.3 Release 3 – Myall River

Release 3 was conducted in the Myall River on the incoming tide to understand the transport of pollutants in this area. Due to the location in a small channel close to residential houses, a smaller mass of only 235 g (rather than the usual 500 g) of rhodamine dye was used. The release occurred at 7.22am on an incoming tide, and the plume was tracked for 40 minutes. The plume travelled 1280 m over 31 minutes at an average velocity of 40 m/min. Figure 3-14 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

The plume was initially disrupted by several boats passing alongside it in the first 5 minutes of dispersion. During this time the plume formed a diagonally elongated shape as it moved into the deeper part of the channel along the north bank. After around 10 minutes, the plume was greater than 200 m long and around 50 m wide. As the plume reached the junction with the channel going to the south side of Corrie Island, at around 25 minutes after release, dispersion accelerated. Tracking ceased 35 minutes after the release. The centre of mass of the plume had likely already passed the final transect.

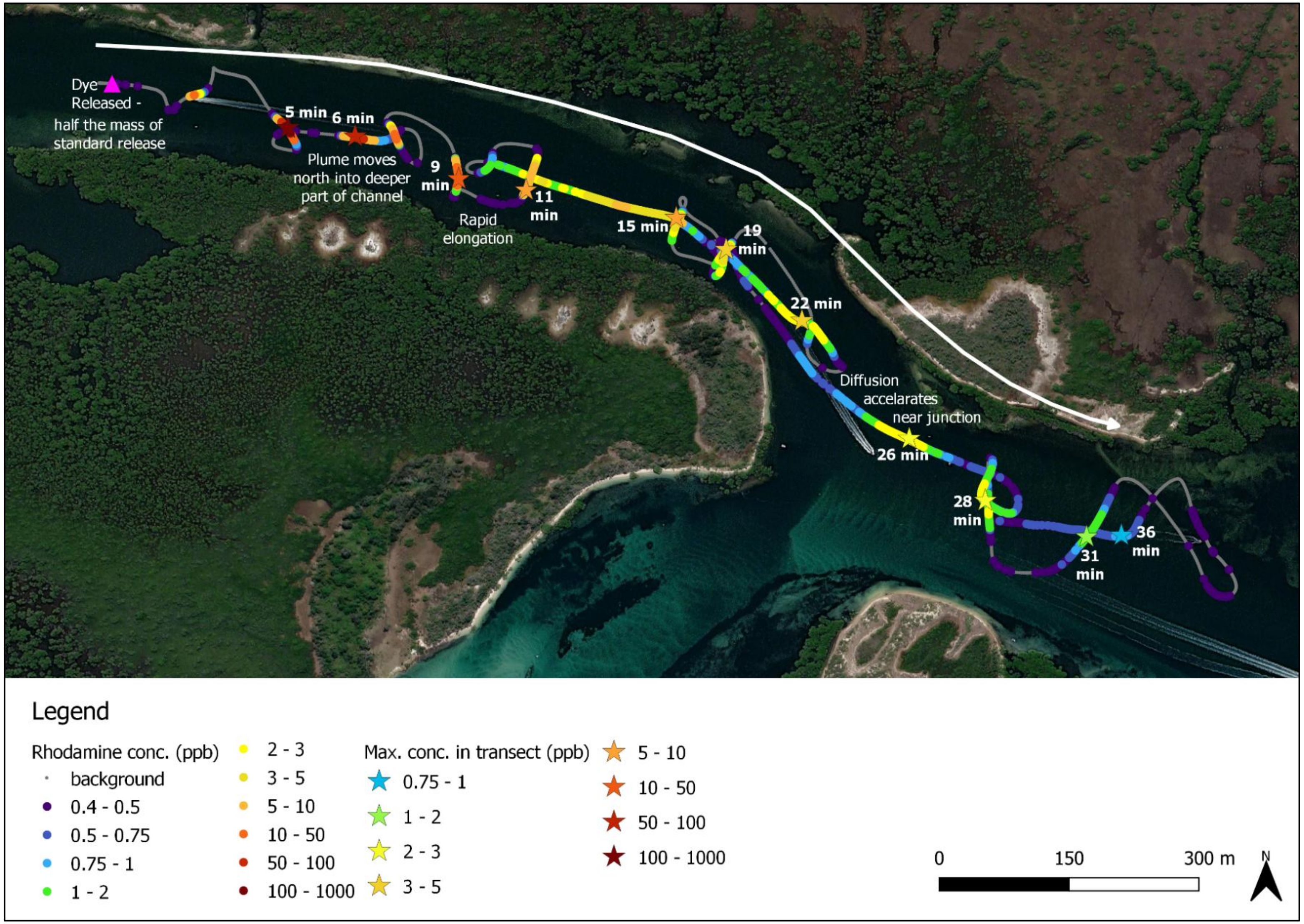


**Figure 3-14 Dye release 3 in the Myall River. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted). Note this release was approximately half of a standard release**

### 3.6.4 Release 4 – Soldiers Point

Dye release 4 was conducted by Soldiers Point to understand the transport of pollutants between the east and west bays. The release was conducted at 5.44am on the incoming tide and was tracked for 1 hour. Over this period it travelled 2 km at an average velocity of 33 m/min. Figure 3-16 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

The plume quickly mixed to a depth of 5 m, as shown in Figure 3-15, which plots vertical depth profiles on a logarithmic axis. The plume developed an elongated shape, reaching approximately 25 m wide and 50 m long by 15 minutes after release. As the plume moved into deeper water at approximately 25 minutes, it became more disparate with multiple peaks. At 35 and 45 minutes (see Figure 3-15) the plume reached to about 9 to 10 m depth and the peak concentration was at approximately 2 m depth. At around 50 minutes the plume had become wider than it was long. Tracking ceased at 60 minutes at which point the plume reached the bottom of the water column but still had a peak around 2 m deep (Figure 3-15).

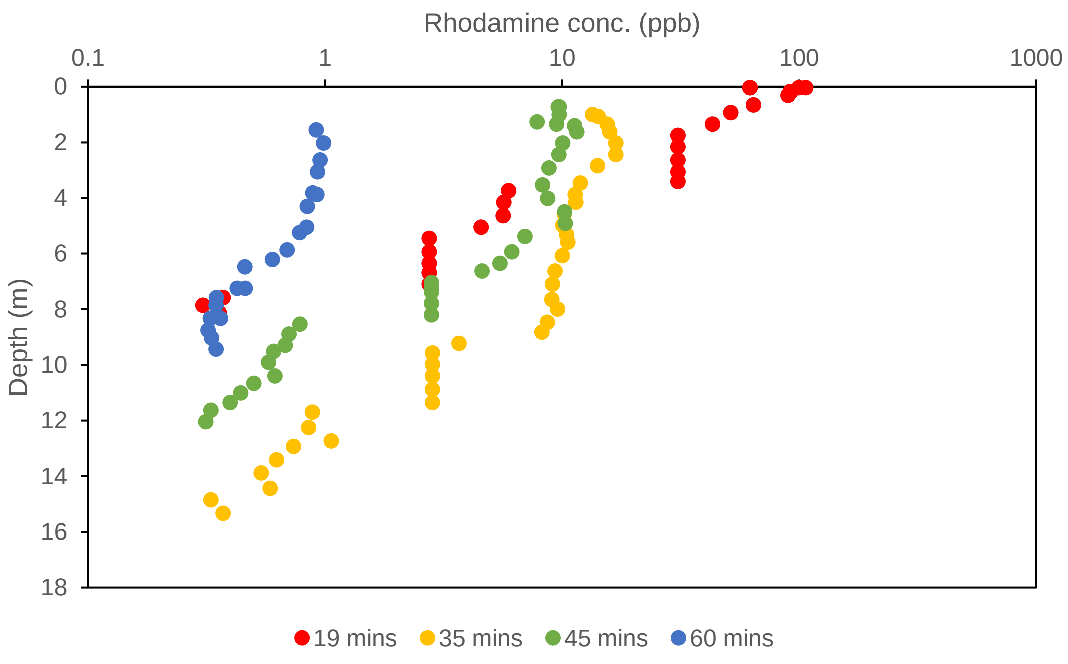


**Figure 3-15 Vertical profiles conducted during dye release 4**

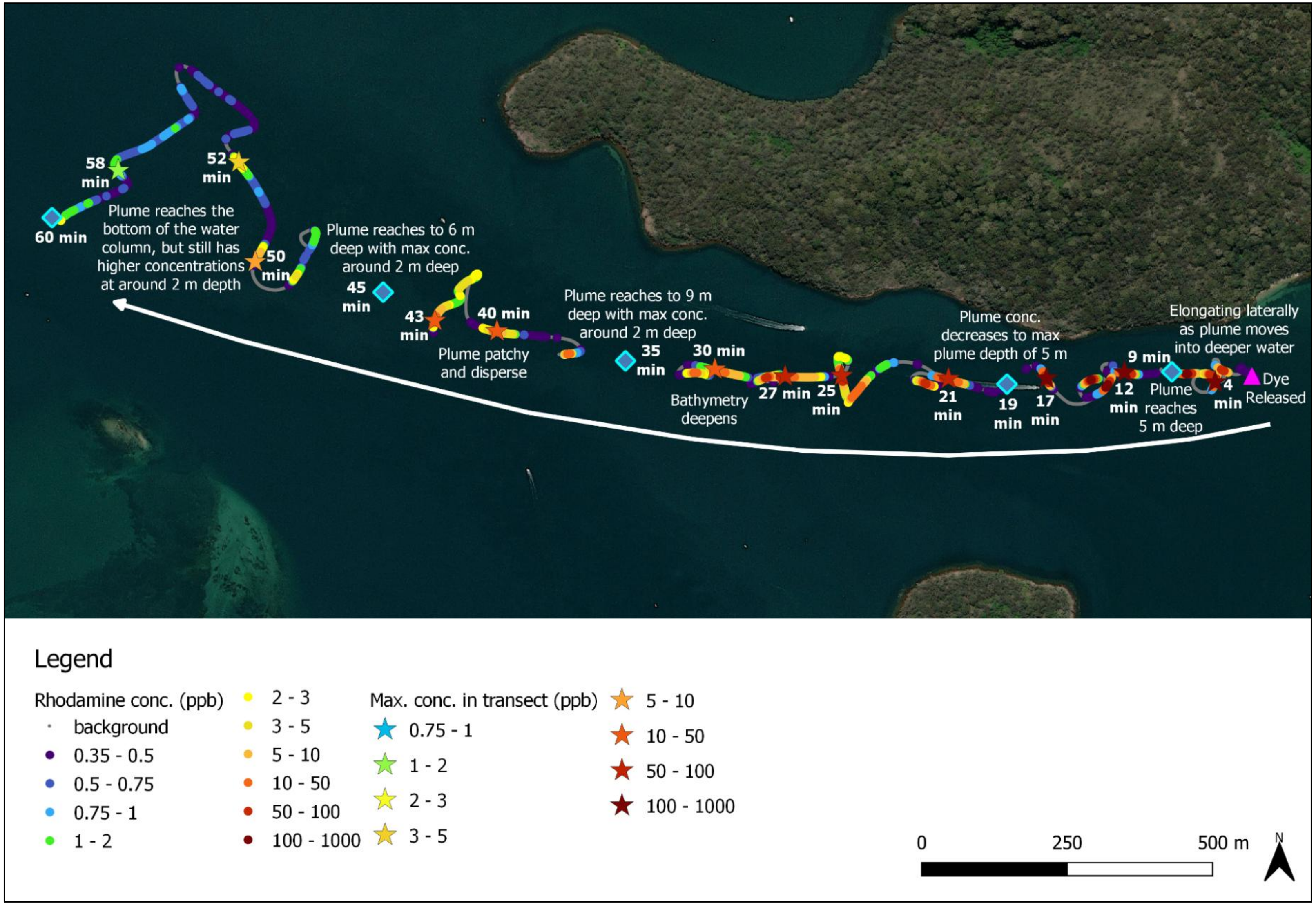


**Figure 3-16 Dye release 4 in at Soldiers Point. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)**

### 3.6.5 Release 5 – Tilligerry Creek

Dye release 5 was completed in Tilligerry Creek, in water approximately 6 m deep, in order to understand the transport of pollutants in this area. The release was completed at 8.08am on the incoming tide, and the plume was tracked for 55 minutes. Over this time it travelled 1.3 km, at an average velocity of 2 m/min. Figure 3-18 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

Although it advected upstream, the plume remained relatively circular, rather than elongated, for approximately the first 20 minutes after the release. As can be seen in Figure 3-17, which plots vertical profiles on a logarithmic axis, at 6 minutes the plume reached to approximately 4 m depth with the highest concentrations near the surface. No data was recorded between 8 and 18 minutes due to instrumentation issues. After 22 minutes, the plume was still concentrated in the upper 3 m of the water column (Figure 3-17) and was beginning to become elongated, reaching around 125 m long and 50 m wide by 28 minutes. By 41 minutes (Figure 3-17) the plume reached the bottom of the water column, with highest concentrations found at approximately 1 m deep. Tracking ceased at 53 minutes after release.

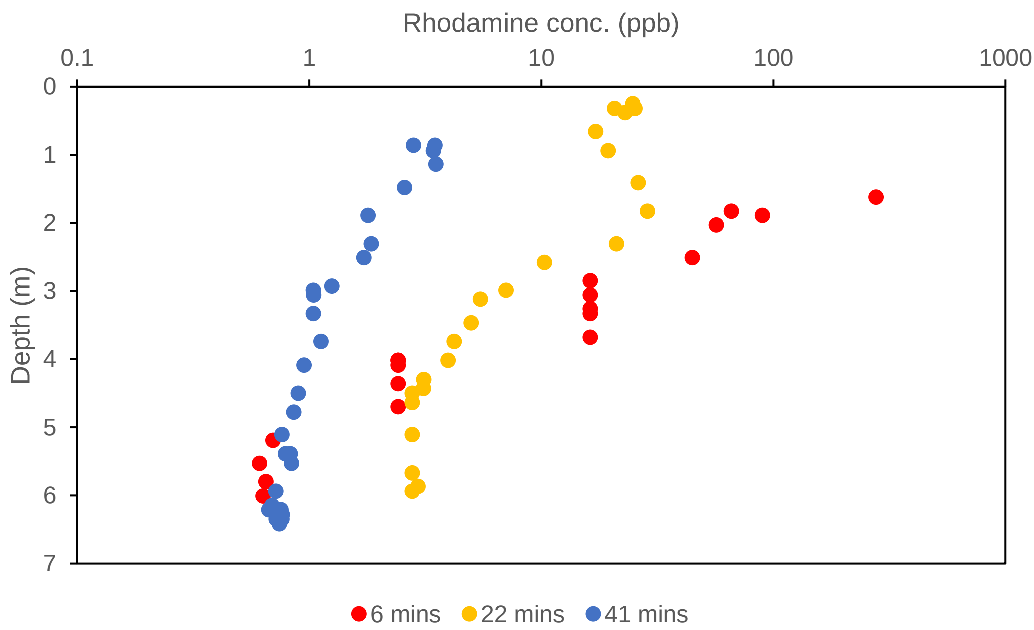


**Figure 3-17 Vertical profiles conducted during dye release 5**

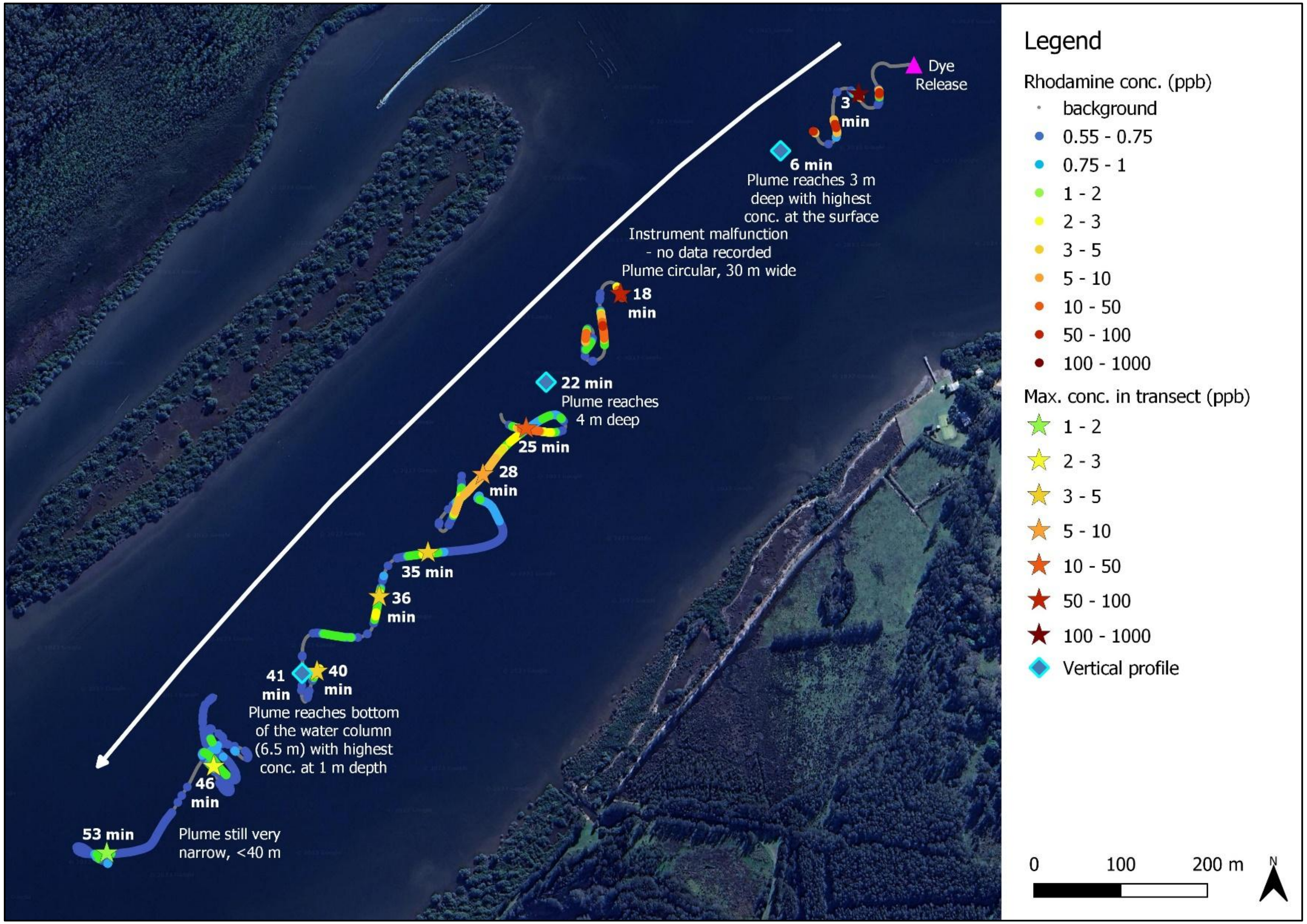


**Figure 3-18 Dye release 5 in Tilligerry Creek. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted**

### 3.6.6 Release 6 – West Bay

Dye release 6 was completed in the West Bay, near the location of dye release 1, in water approximately 6 m deep. This release was conducted to understand diffusion in the main bay under windier conditions to dye release 1. The wind was approximately 6 to 8 knots from the east. The release occurred at 11.02am and was tracked for 50 minutes. A smaller quantity of 200 g of dye was released. Figure 3-20 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

The plume initially moved west, then began moving east as the tide turned. The plume moved very slowly, covering approximately 285 m in 50 minutes, at an average velocity of 5.7 m/min. At 6 minutes after the release the plume was mainly in the top 1.5 m of the water column (Figure 3-19). By 17 minutes the plume reached to a depth of 3 to 3.5 m with maximum concentrations near the surface and maintained a similar profile for the rest of the period of tracking (see Figure 3-19). As the plume moved eastward after the change of the tide, from approximately 23 to 50 minutes, the plume remained around 80 m in circumference with peak concentrations dropping from 37 ppb at 23 minutes to 15 ppb at 50 minutes. Despite slightly windier conditions, lateral dispersion rates were similar between releases 1 and 6, although the smaller mass of release 6 makes direct comparison more difficult. However, the vertical dispersion was greater over time than in dye release 1.

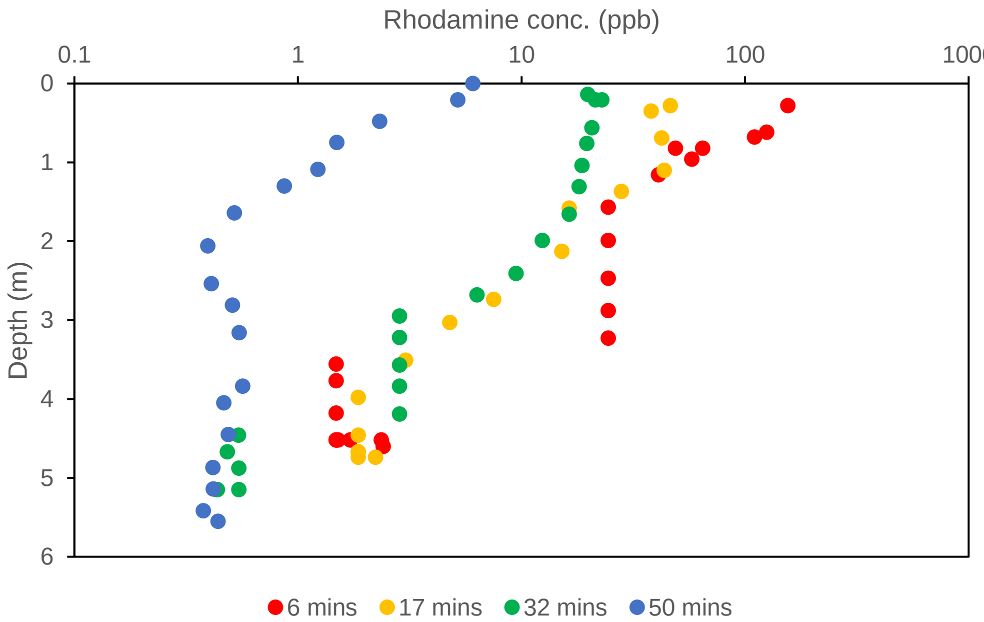


**Figure 3-19 Vertical profiles conducted during dye release 6**

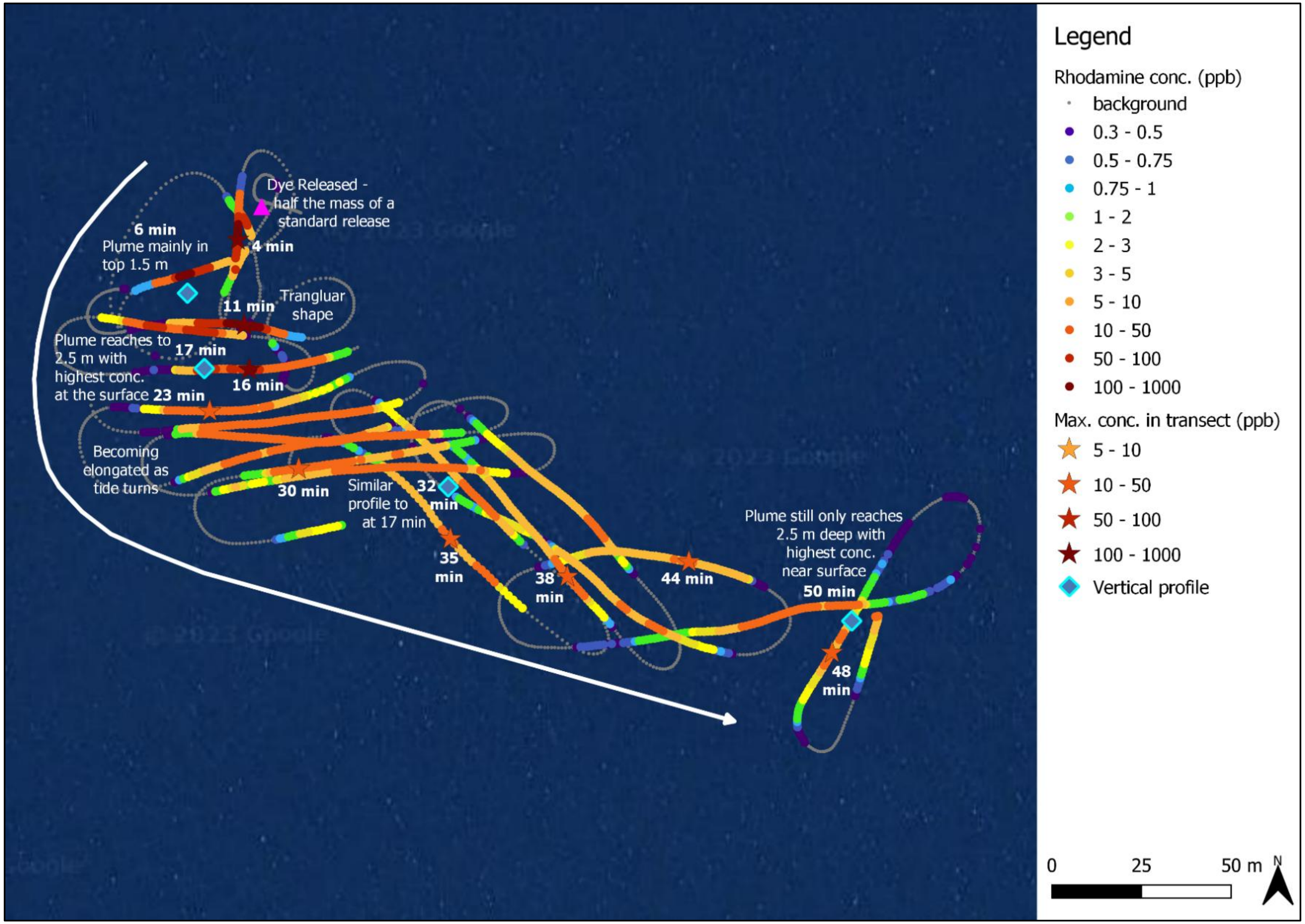


**Figure 3-20 Dye release 6 in the West Bay. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted. Note this release was approximately half the mass of a standard release**

### 3.6.7 Field derived dispersion values

Field dye experiments were used to obtain estimates of plume spreading dispersion rates in Port Stephens, 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 3-21. To allow easy comparison, concentrations for all dye releases were scaled to match an initial release volume of 500 mL before plotting.

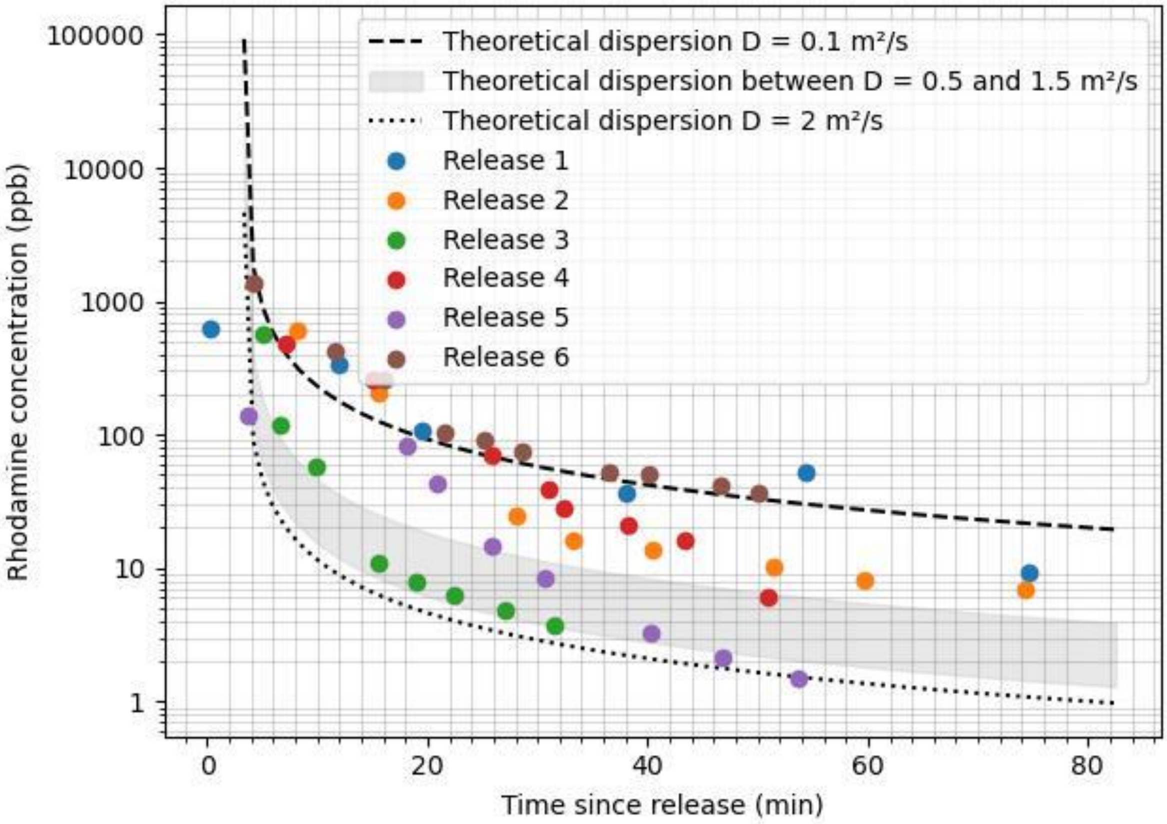


**Figure 3-21 Peak concentration of select transects plotted against theoretical dispersion**

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 $m^2/s$, which was consistent in Port Stephens. When comparing the observed peak observations to theoretical dispersion, most field dispersion values fall within D = 0.1 and 2 $m^2/s$. As discussed in Section 3.6.1 and 3.6.6, the two releases in the slow moving West Bay had low dispersion rates around 0.1 $m^2/s$, although rates may be higher in higher wind conditions.

## 3.7 GPS drifter drogue releases

To monitor surface current speeds and flow paths in the Port Stephens estuary, GPS drifter drogues were deployed at strategic locations throughout the field campaigns (refer to WRL TR2023/32 Section 4.5 for further information on drifter drogues). Drogues were released during dye releases 1, 4 and 5 to aid plume tracking, with seven additional drogue releases completed at various stages of the tide cycle. Additionally, six releases were completed outside the field campaigns by the NSW Food Authority. Table 3-3 lists details of the 16 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 |
|---|---|---|---|---|---|---|
| FA Day 1 Drop 1 | 22/05/2023 | 11.38am | Ebb | 2:35 | Karuah River | |
| FA Day 2 Drop 1 | 23/05/2023 | 11.52am | Ebb | 2:37 | Tea Gardens | |
| FA Day 3 Drop 1 | 24/05/2023 | 12.33pm | Ebb | 0:44 | Tanilba Bay | |
| FA Day 3 Drop 2 | 24/05/2023 | 1.09pm | Ebb | 1:22 | Tanilba Bay | |
| Trip 1 Day 1 Drop 1 | 16/08/2023 | 8.39am | Flood | 2:05 | Karuah River | |
| Trip 1 Day 1 Drop 2 | 16/08/2023 | 10.52am | Ebb | 1:07 | Karuah River | |
| Trip 1 Day 1 Drop 3 | 16/08/2023 | 12.11pm | Ebb | 0:59 | Karuah River | |
| Trip 1 Day 1 Drop 4 | 16/08/2023 | 1.12pm | Ebb | 1:08 | Karuah River | |
| Trip 1 Day 1 Drop 5 | 16/08/2023 | 2.37pm | Slack low | 0:45 | Karuah River | |
| Trip 1 Day 2 Drop 1 | 17/08/2023 | 7.33am | Flood | 0:44 | Karuah River | |
| Trip 1 Day 2 Drop 2 | 17/08/2023 | 8.34am | Ebb | 1:23 | West Bay | |
| Trip 1 Day 2 Drop 3 | 17/08/2023 | 11.07am | Ebb | 1:54 | West Bay | Released with dye release 1 |
| Trip 1 Day 2 Drop 4 | 17/08/2023 | 1.23pm | Ebb | 1:47 | Karuah River | |
| Trip 2 Day 1 Drop 1 | 14/11/2023 | 6.52am | Flood | 2:52 | Tilligerry Creek | |

| No. | Date | Time | Tide | Duration (h) | Location | Comments |
|---|---|---|---|---|---|---|
| Trip 2 Day 2 Drop 1 | 15/11/2023 | 6.35am | Flood | 4:46 | Corrie Island | |
| Trip 2 Day 2 Drop 2 | 15/11/2023 | 8.38am | Flood | 0:50 | Myall River | |
| Trip 2 Day 2 Drop 3 | 15/11/2023 | 12.00pm | Ebb | 2:04 | West Bay | |
| Trip 2 Day 3 Drop 1 | 16/11/2023 | 5.33am | Flood | 1:46 | Soldiers Point | Released with dye release 4 |
| Trip 2 Day 3 Drop 2 | 16/11/2023 | 8.10am | Flood | 0:53 | Tilligerry Creek | Released with dye release 5 |
| FA Day 4 Drop 1 | 27/11/2023 | 7.58am | Ebb | 1:43 | Soldiers Point | |
| FA Day 4 Drop 2 | 27/11/2023 | 10.01am | Ebb | 0:56 | Soldiers Point | |

## 3.8 Water level monitoring

To supplement the water level data available from the six long-term MHL water level gauges on Port Stephens and Myall Lakes, four medium-term water level loggers were installed at locations shown in Figure 3-22. These water level gauges were installed in November 2022 and removed at the end of the November 2023 field campaign. These were installed in locations recommended by the pilot modelling done by Harrison et al. (2022). Due to instrumentation malfunctions, no data was recorded at Karuah or Swan Bay between 16 August 2023 and 16 November 2023. Water level data can be seen in the calibration data in Appendix B1.4 and B1.6.

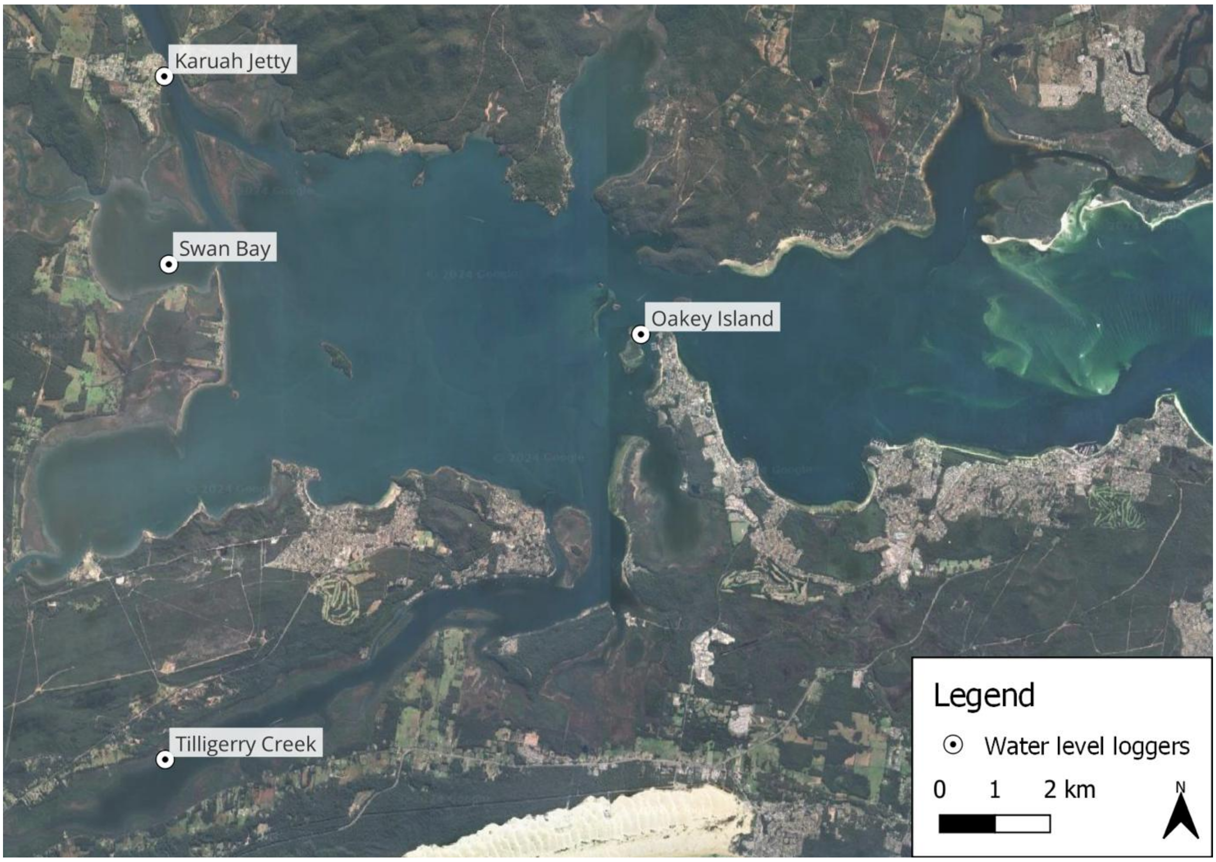


**Figure 3-22 Location of water level monitoring during 2023 fieldwork**

## 3.9 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. At all locations, salinity measured was comparable to ocean water, and no stratification was detected. Figure 3-23 shows the timing of conductivity profiles, while Figure 3-24 shows locations.

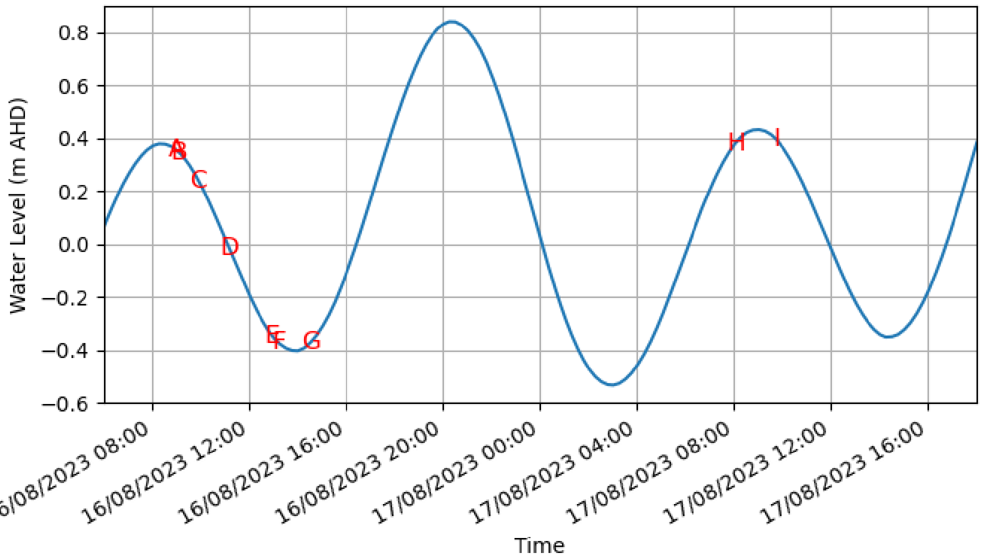


**Figure 3-23 Timing of conductivity profiles (labelled with letters) relative to the tide at Shoal Bay**

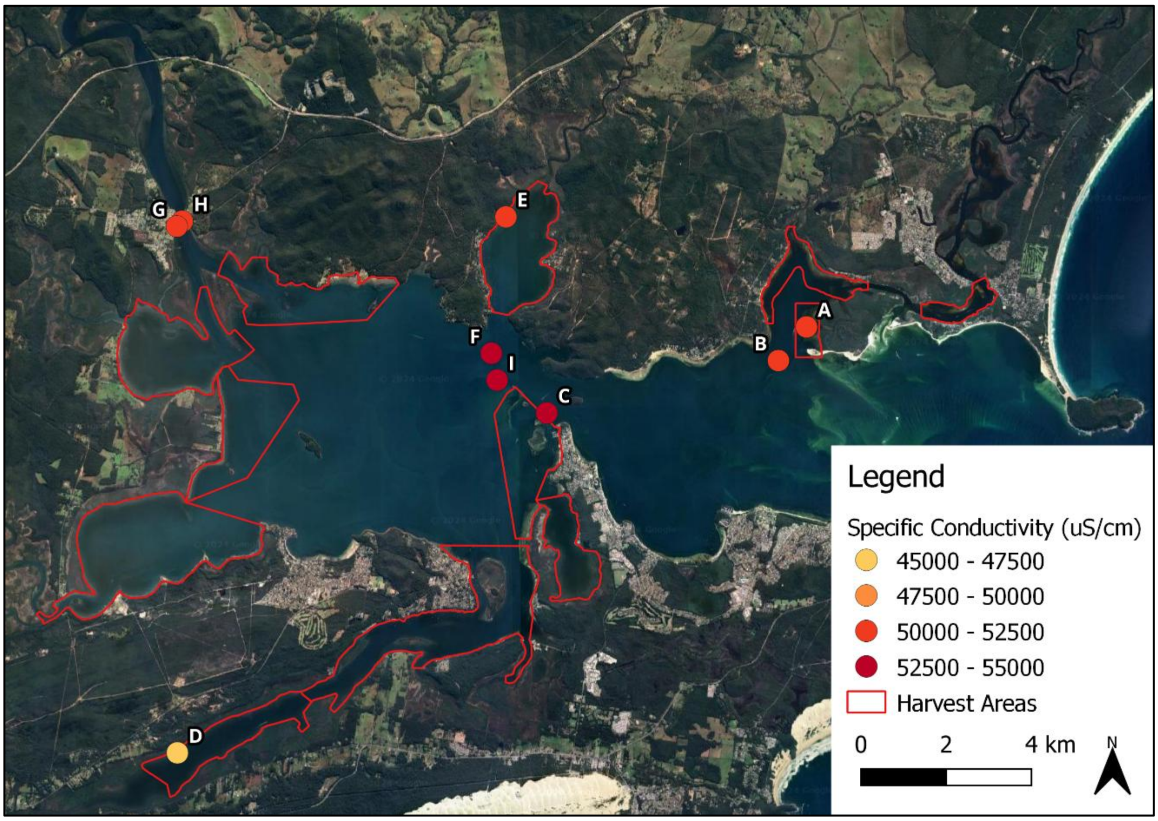


**Figure 3-24 Conductivity measurements labelled with letters corresponding to timing on Figure 3-23**

Additionally, long term conductivity measurements are available from the location of the four temporary water level loggers discussed in Section 3.8. These loggers recorded small changes in conductivity with the tide, and larger changes with fresh water events. Water was less saline and more responsive to freshwater inflows at the western loggers, and less responsive at Oakey Island. Figure 3-25 shows a sample of the data. The conductivity at all sites was near the conductivity of ocean water much of the time, including during the two fieldwork campaigns.

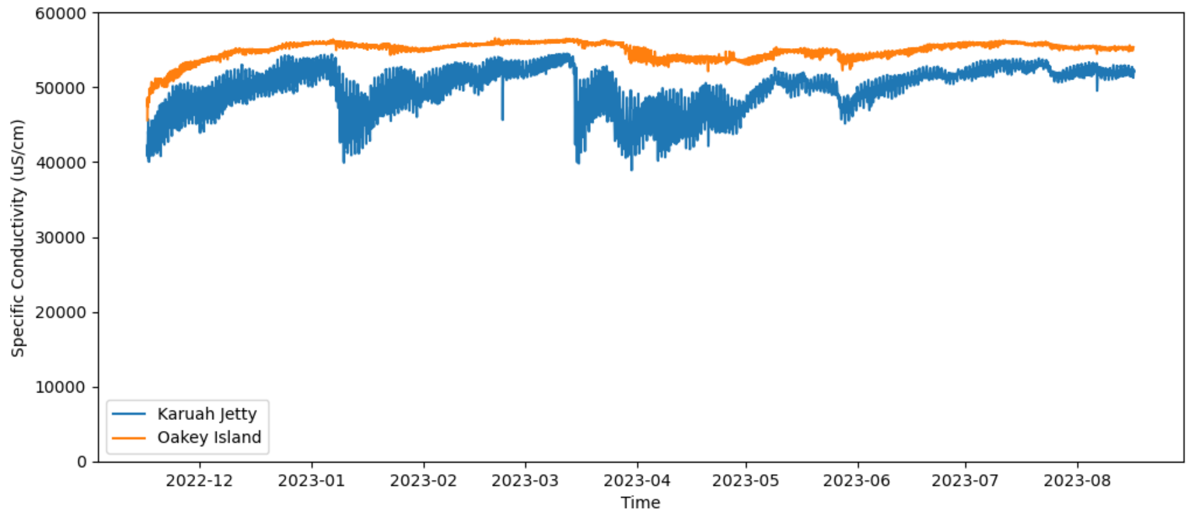


**Figure 3-25 Sample of long term conductivity measurements at two locations in Port Stephens**

# 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 1993 and the 2023 fieldwork data. 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.

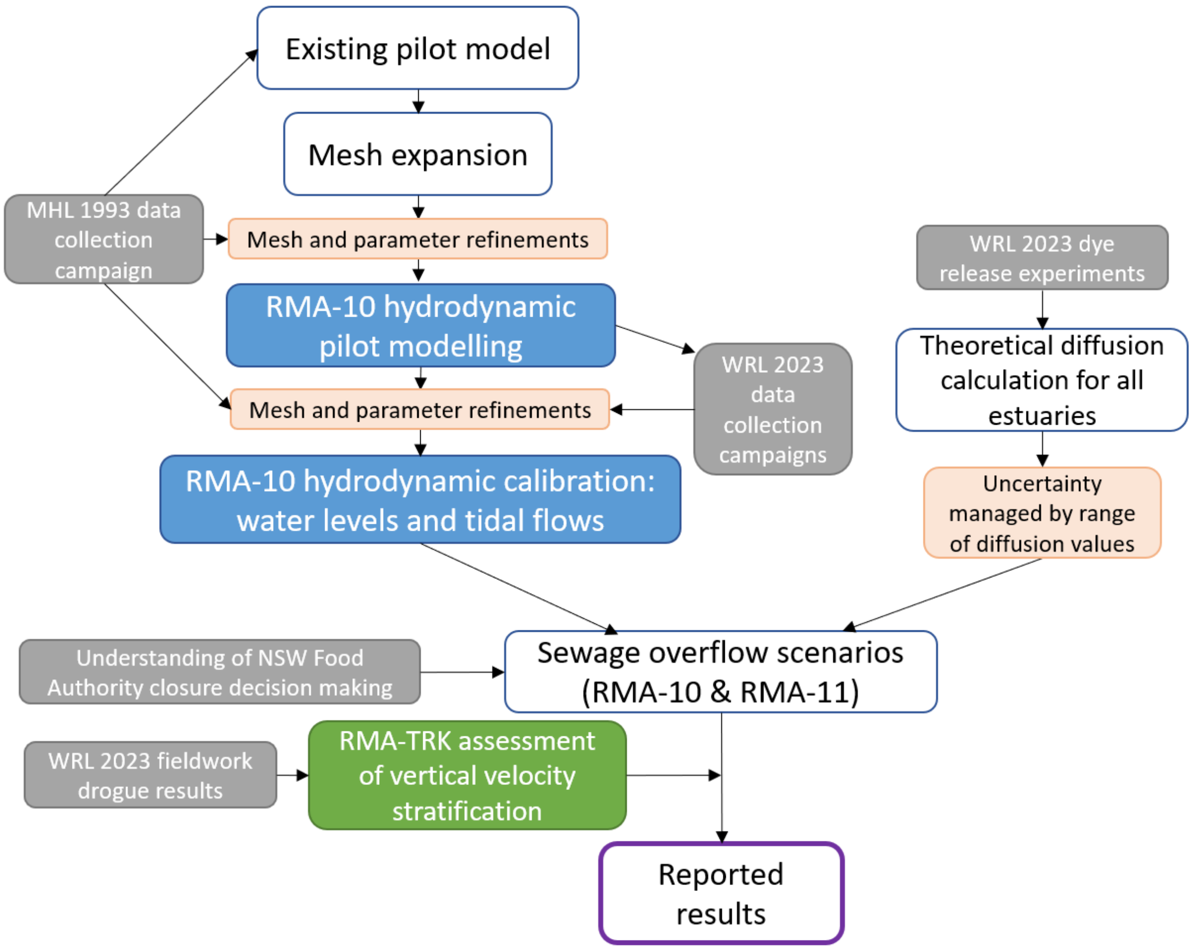


**Figure 4-1 Overview of modelling approach**

## 4.2 Model mesh development

The model domain extends from approximately 2 km offshore of the coast outside of Port Stephens, to the tidal limits of the Karuah River, Myall Lake and other tributaries (refer to Figure 4-2). The model mesh consists of approximately 12,500 nodes and 5,000 elements on the surface of the mesh varying in size from 4 $m^2$ to over 2.4 x $10^6$ $m^2$. Mesh resolution is highest around the overflow locations, with lower resolution in upstream reaches and in Myall Lakes. Lower resolution was used in Myall Lakes, which is required to model the tidal prism, but was not of significant focus for this study. Refer to WRL TR2023/32 Section 6.2.3 for a discussion of model resolution.

The Harrison et al. (2022) pilot model of Port Stephens demonstrated the impact of wind, thus three dimensional modelling was used in the bays. Approximately 2,700 elements were modelled in three dimensions, as can be seen in Figure 4-2, adding approximately 18,000 nodes in the third dimension. Two-dimensional, depth averaged modelling was chosen in shallower and more enclosed areas where advective transport is largely driven by tidal and riverine flow (not wind) whereas three-dimensional modelling was chosen in the open parts of the bays where wind driven water movement may be significant. In the three dimensional portion of the model, two layers were simulated, a 1 m deep surface layer, and a second layer extending to the bed. This vertical resolution is insufficient to resolve full vertical velocity distributions, however, tests showed it was sufficient to resolve indicative circulations caused by wind shear. A discussion on the impact of model dimensionality is provided in WRL TR2023/32 Section 6.2.2.

A second mesh with additional refinements in the East Bay and near Nelson Bay was used to simulate overflows from this location, however, to minimise run times, this mesh was not used for other scenarios.

## 4.3 Model bathymetry

Model bathymetry was based on the sources discussed in Section 2.5. The OEH datasets were primarily used in the East Bay, while AHO soundings and bathymetry from the preexisting model were used in the West Bay. The bathymetry in the Karuah and Myall Rivers, as well as Myall Lakes was based on NAVONICS (2023) SonarChart™ and NearMap imagery, as no other data was available. The DPIE 2018 LiDAR survey and NSW Spatial Services (2012) 1 m resolution DEM was used for shallow and intertidal regions, where available.

Depths near Soldiers Point were up to 35 m, however the majority of estuary was between 2 and 5 m in depth. The nodal bed elevations of the model bathymetry are shown in Figure 4-3.

Estuaries are dynamic systems and bathymetric changes through time will alter water levels, velocities, and tidal flows for the same set of boundary conditions. While change to bathymetry over time is evident in some sections of the estuary (e.g. movement of sand shoals in the East Bay), a single bathymetry was developed for this model, and used for all model runs. This was shown to result in reasonable model calibration for water levels and flow, discussed further in Section 4.6.

## 4.4 Model boundaries

The model includes one upstream catchment flow boundary, shown in Figure 4-2 and discussed in Section 2.3. A tidal elevation boundary was included in the model offshore of Port Stephens (refer to Figure 4-2). This modelled water level boundary was based on observed tidal elevation data collected by MHL at Shoal Bay (station number 209474). The nearby MHL station at Port Stephens (station number 209450) was used for periods before the Shoal Bay gauge was installed in 2014. This data was 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).

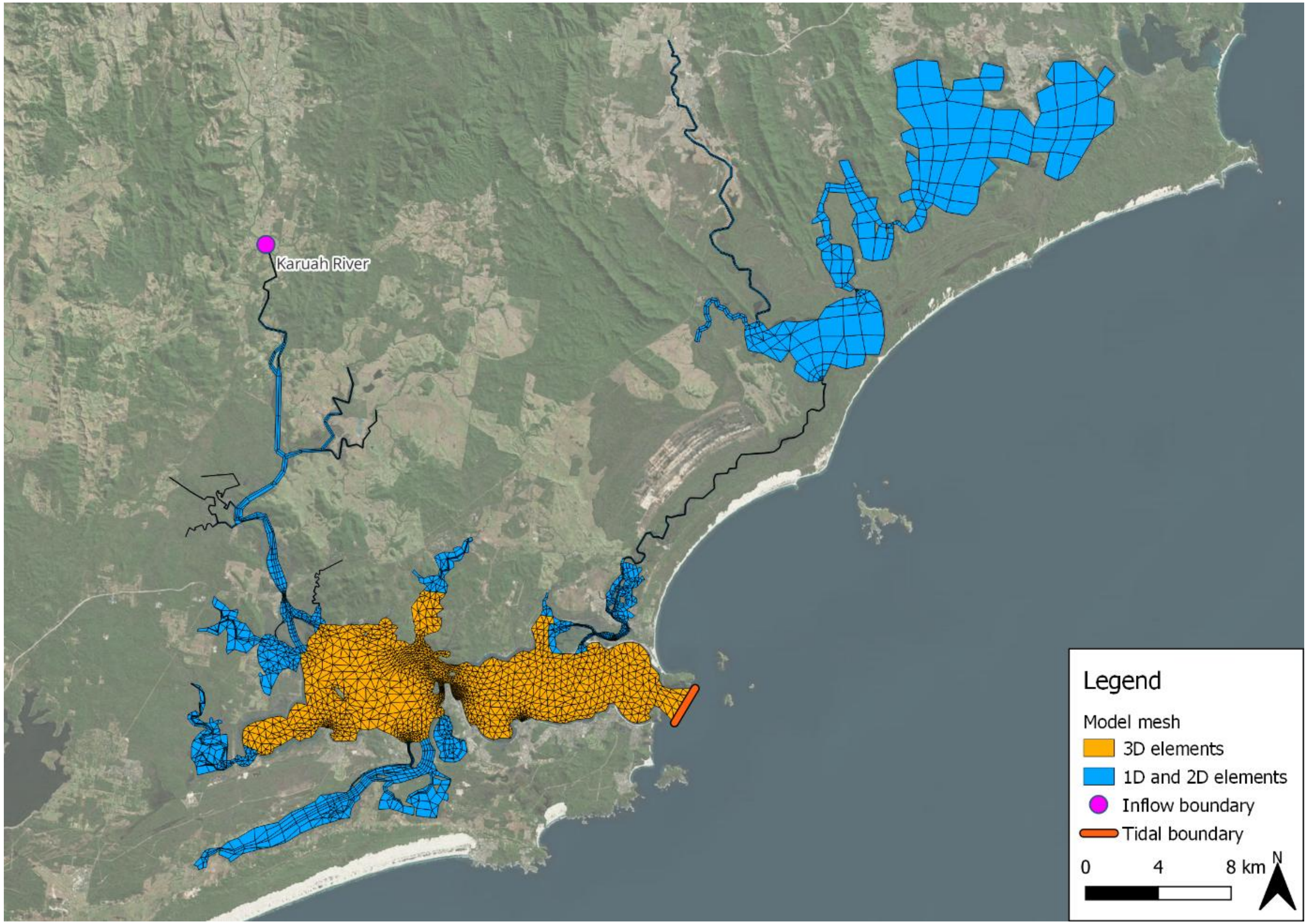


**Figure 4-2 RMA model mesh showing boundary condition locations**

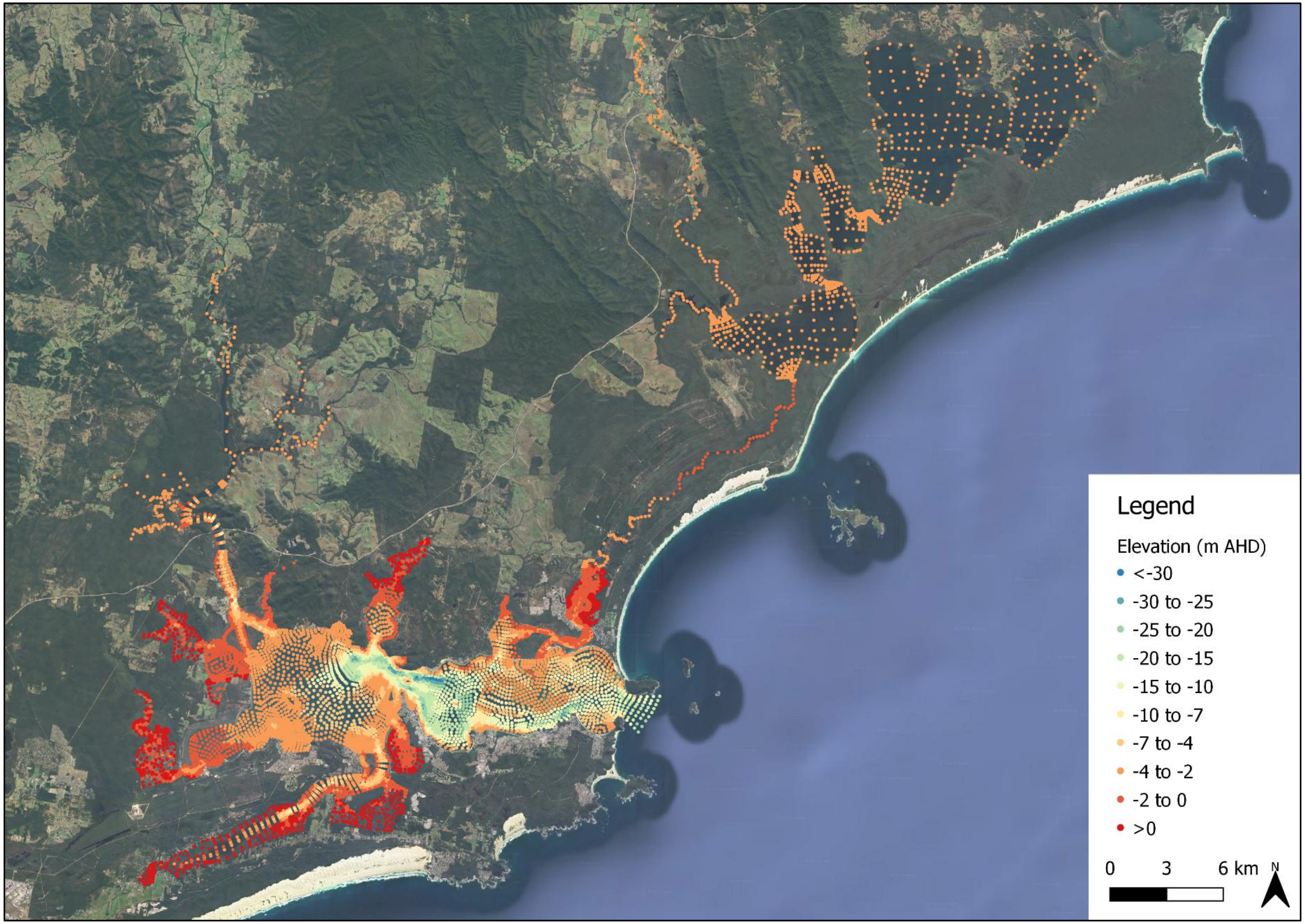


**Figure 4-3 RMA model bathymetry**

## 4.5 Pilot model

Initially, the pilot model developed by Harrison et al. (2022) of the West Bay was expanded to include the East Bay, using the existing data described in Section 1.4. 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 primary gap identified was a lack of sufficient flow data near the oyster harvest areas.

## 4.6 Hydrodynamic calibration

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. One existing set of hydrodynamic data was available for calibration purposes, collected by MHL in 1993 and described in Section 2.2. This was supplemented by data from the two 2023 fieldwork periods, which targeted key stages of the tide but was not a full tidal flow gauging. For each period, a minimum 3 day model warmup period was run.

### 4.6.1 September 1993 calibration period

During the 1993 MHL data collection campaign on Port Stephens, water level data was available at seven gauges (including four permanent gauges) and tidal flow data was available at six transects (refer to Section 2.2). The model parameters were calibrated to this period. Measured ocean tide levels from the MHL Port Stephens gauge were applied at the ocean boundary and scaled measured catchment inflows were applied at the upstream model inflow boundary. Plots of all observed water level and flow, compared with model results are shown in Appendix B1.1 and B1.2, while select results are shown below.

A good model match was achieved for all flow and water levels. The flow is slightly underestimated at the entrance and at Soldiers Point (Figure 4-4 and Figure 4-5), especially on the flood tide, but the error is minor. The match in high tide water level peaks at North Arm Cove is poor, however this appears to be due to poor data as the observed shape is unrealistic (Figure 4-6). There is a vertical offset between the modelled and observed water level data at Karuah (Figure 4-7). As the tidal amplitude was approximately correct, this may be due to a surveying issue, as the model achieved a good match during the fieldwork periods. Other water levels achieved a good match (see Figure 4-8 for an example).

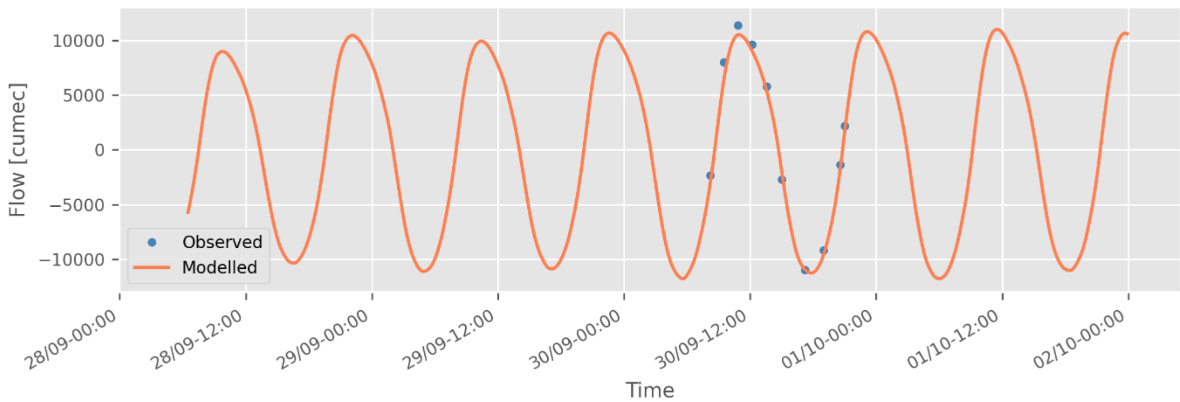


**Figure 4-4 1993 tidal flow calibration – Location A – Entrance**

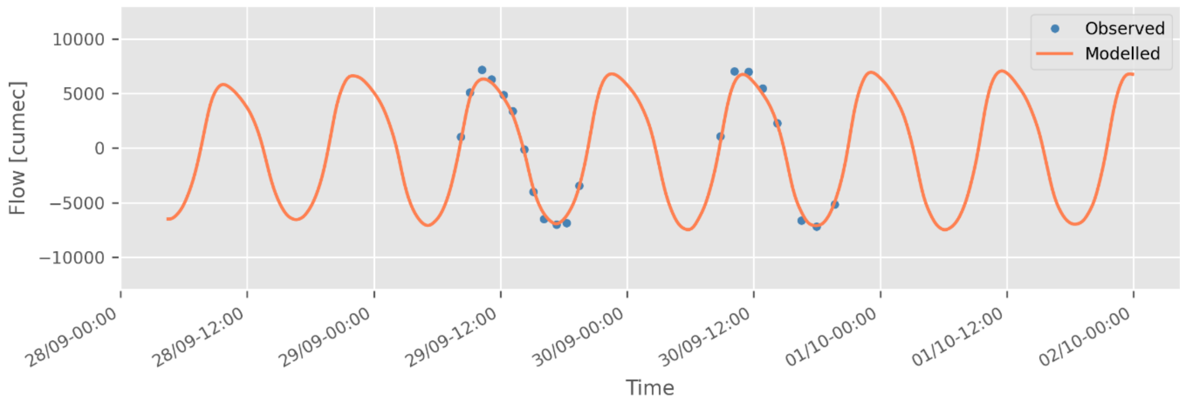


**Figure 4-5 1993 tidal flow calibration – Location C – Soldiers Point**

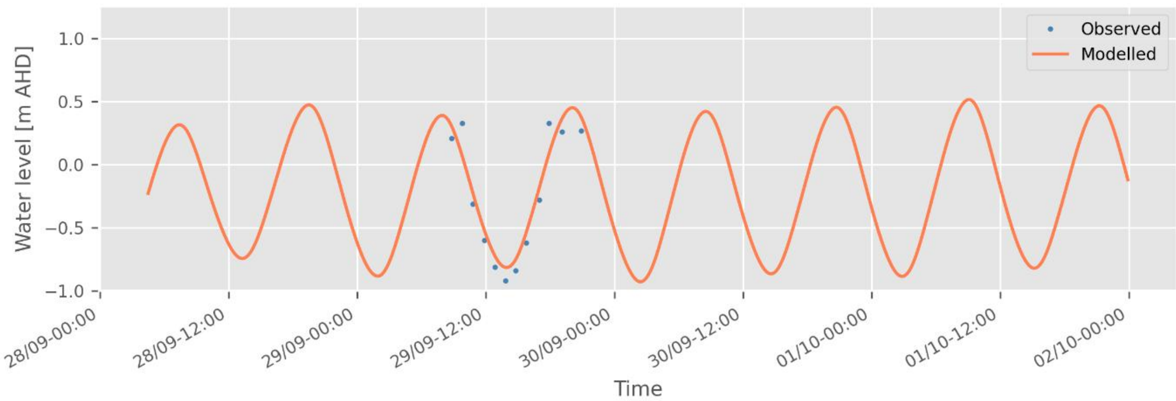


**Figure 4-6 1993 water level calibration – Location 10 – North Arm Cove**

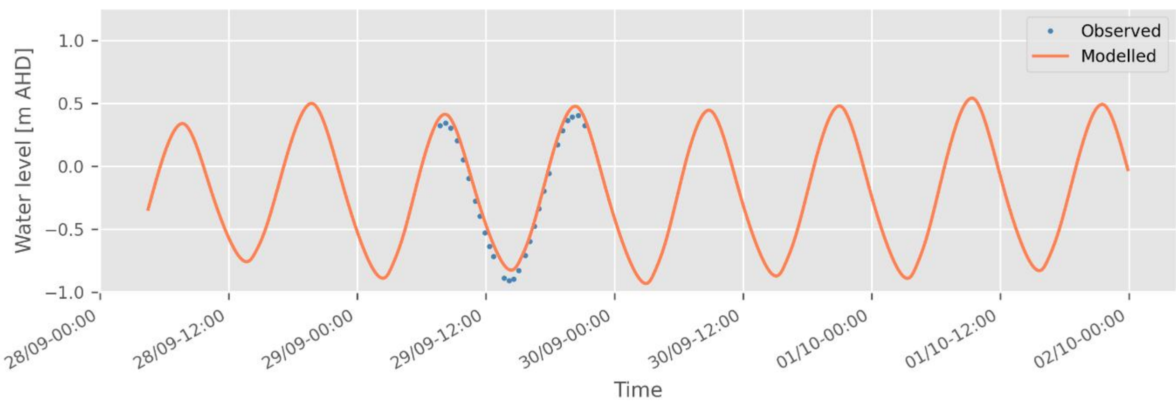


**Figure 4-7 1993 water level calibration – Location 12 – Karuah River**

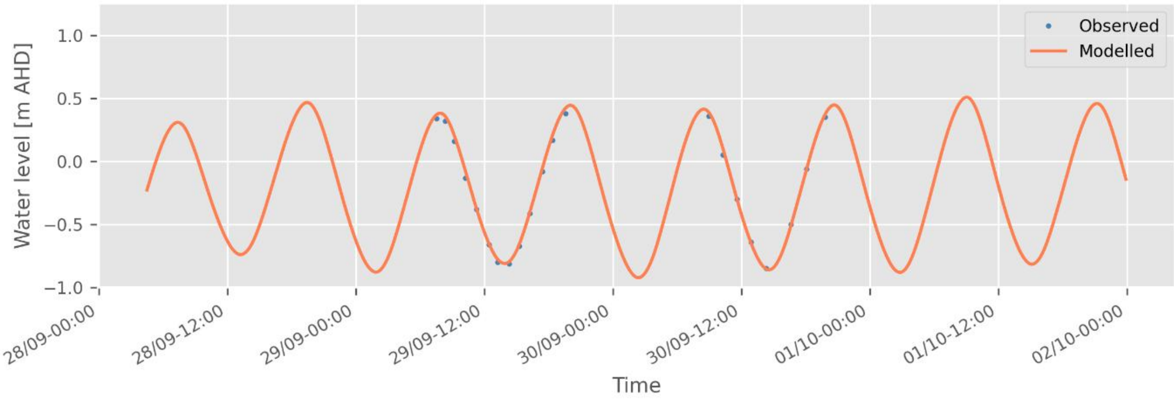


**Figure 4-8 1993 water level calibration – Location 9 – Soldiers Point**

### 4.6.2 August 2023 field data calibration period

The August 2023 field campaign involved the collection of tidal flow gauging at three transects, and the collation of water level data at six locations from MHL, plus an additional four locations from temporary water level gauges (refer to Section 3). Measured tide levels were applied at the ocean boundary and scaled measured catchment inflows were applied at the upstream model inflow boundary. Model results were then compared with the observed data, using the same model parameters used for the 1993 model run. Plots of all observed water level and flow, compared with model results are shown in Appendix B1.3 and B1.4, while select results are shown below.

This field campaign targeted the Karuah River. The model achieved a good match in this area, adequately simulating flow through the river (see Figure 4-9). All water levels also achieved a good match, except for the Karuah Jetty water level (Figure 4-10) which had a vertical offset. However, as this is close to the nearby Karuah water level gauge, which achieved a good match (Figure 4-11), it is likely due to inaccuracy in surveying the elevation of the gauge.

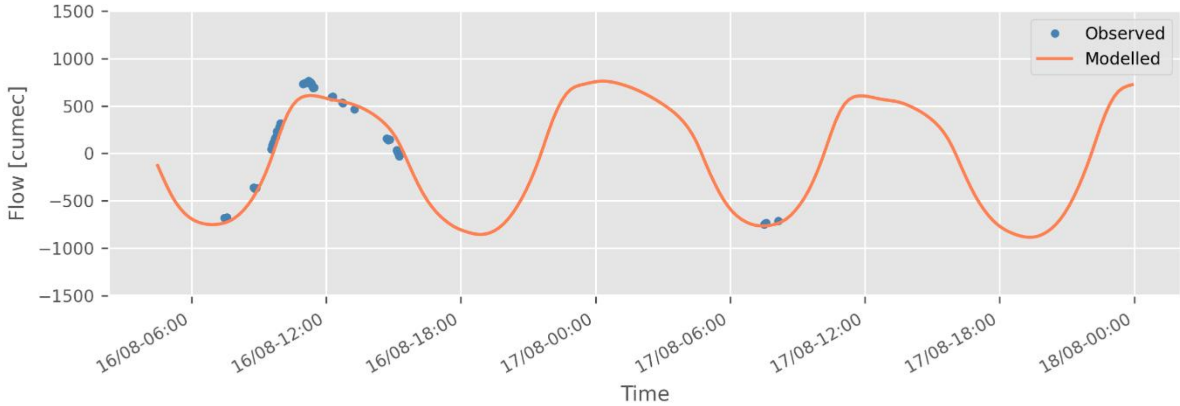


**Figure 4-9 August 2023 tidal flow verification – Location F – Karuah**

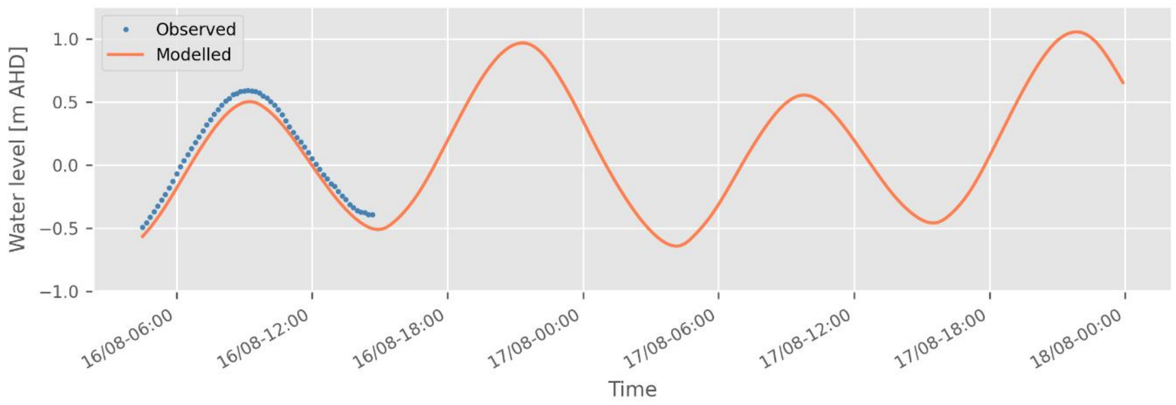


**Figure 4-10 August 2023 water level verification – Location 16 – Karuah Jetty**

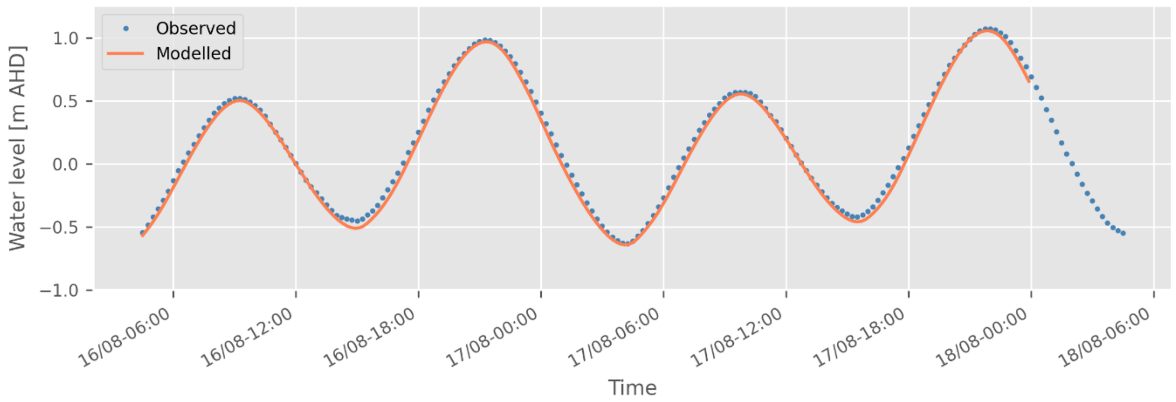


**Figure 4-11 August 2023 water level verification – Location 6 – Karuah**

### 4.6.3 November 2023 field data calibration period

The November 2023 field campaign involved the collection of tidal flow gauging at nine transects, and the collation of water level data at six locations from MHL, plus an additional two locations from temporary water level gauges (refer to Section 3). Measured tide levels were applied at the ocean boundary and scaled measured catchment inflows were applied at the upstream model inflow boundary. Model results were then compared with the observed data, using the same model parameters used for the 1993 model run. Plots of all observed water level and flow compared with model results are shown in Appendix B1.5 and B1.6, while select results are shown below.

The model achieved a good match to all water levels and flows. The peak ebb tide flow at Soldiers Point was slightly underestimated by the model (Figure 4-12), as during the 1993 period, however the error was minor. The model correctly simulates the dynamics of the Myall River channels, which transition from ebb to flood sequentially (Figure 4-13 to Figure 4-15), despite potential bathymetry changes in the channel to the south of Corrie Island.

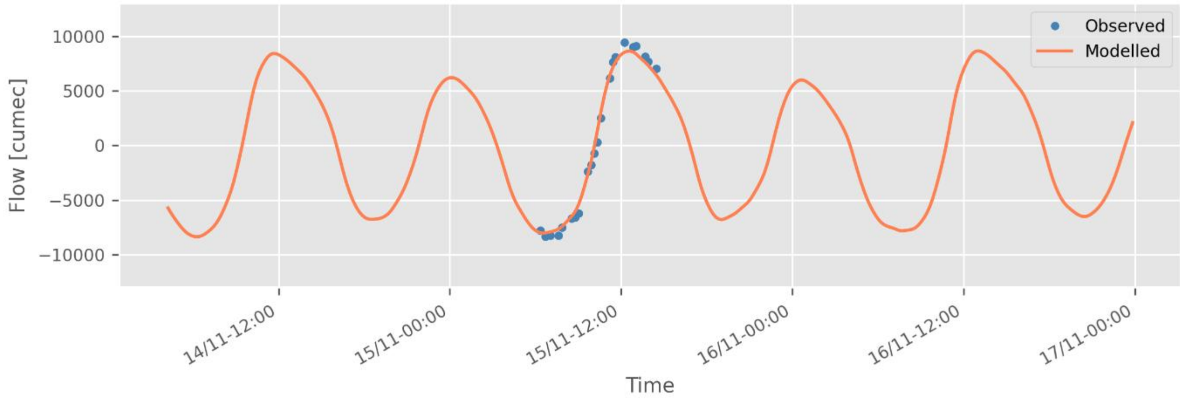


**Figure 4-12 November 2023 tidal flow verification – Location C – Soldiers Point**

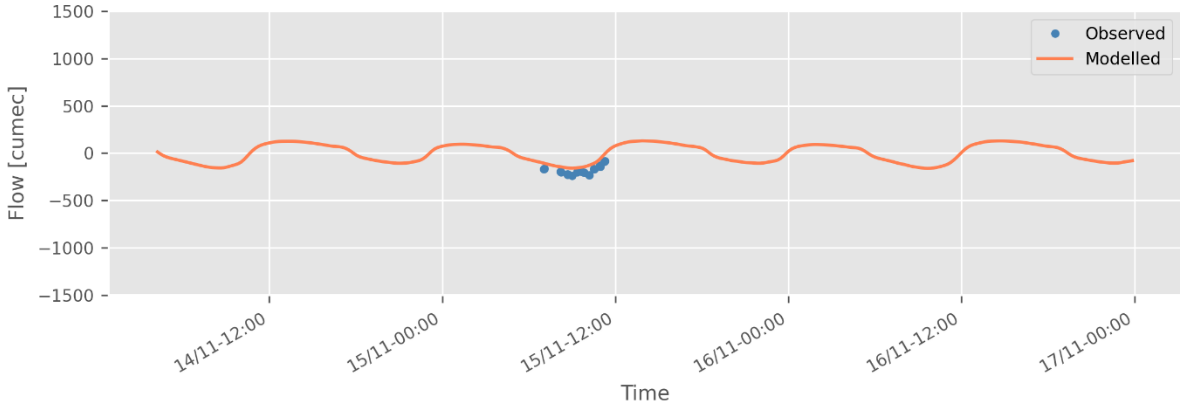


**Figure 4-13 November 2023 tidal flow verification – Location G – Myall River Corrie Island North**

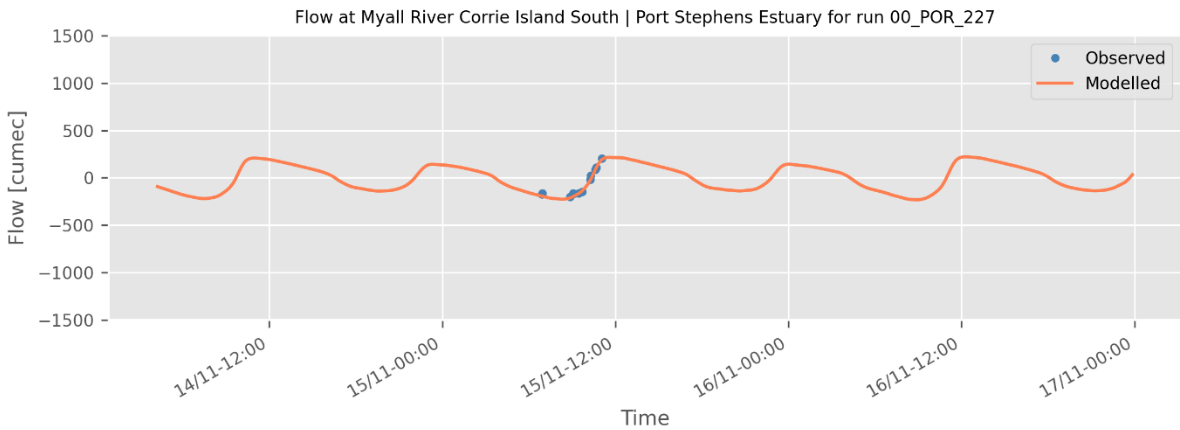


**Figure 4-14 November 2023 tidal flow verification – Location H – Myall River Corrie Island South**

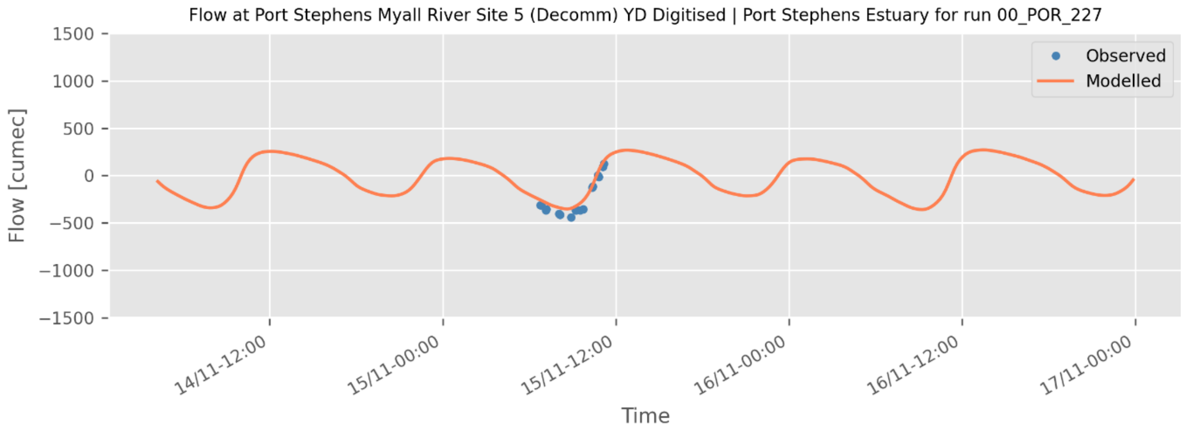


**Figure 4-15 November 2023 tidal flow verification – Location B – Myall River**

### 4.6.4 Wind

As further discussed in Section 4.8, wind is not simulated wholistically in this model. The model uses only two layers, a compromise between minimising computational time and representing the full vertical velocity profile from wind shear. Although attempts were made to measure wind shear in the field, no data was successfully collected, thus shear, as well as the circulations set up by wind, are uncalibrated and unverified. As wind scenarios are intended to be indicative simulations of patterns expected from a certain wind direction, rather than simulations of real-world scenarios (which would have wind of varying speeds and directions), this was considered appropriate. Furthermore, the shear and circulations set up were assessed using engineering judgment and appear reasonable based on knowledge of wind based circulation in bays (Sobarzo et al., 1997; Tate et al., 2000). However, if more certainty was required for wind based scenario results, further model refinement would be required.

### 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 0.035, which is typical for large sandy channels. In the three dimensional sections, the vertical eddy viscosity coefficient used was 5 $m^2/s$.

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

| Location | Manning's n roughness coefficient |
|---|---|
| 3D sections of East and West Bays | 0.035 |
| 2D sections of East and West Bays | 0.020 |
| Tilligerry Creek | 0.020 |
| Myall River | 0.035 |
| Shallow seagrass areas | 0.035 |
| Intertidal areas | 0.050 |
| Karuah River | 0.025 |
| 1D areas | 0.020 |

## 4.7 Water quality model development

### 4.7.1 Modelling of dispersion in RMA-11

Dye dispersion experiments, discussed in Section 3.6, 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, was 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 30 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 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 3.7) 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.

**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) |
|---|---|---|---|---|---|
| Trip 1 Day 1 Drop 1 | Karuah River | Ebb | 0.95 | 0.59 | 1.61 |
| Trip 1 Day 1 Drop 2 | Karuah River | Ebb | 1.33 | 0.87 | 1.53 |
| Trip 1 Day 1 Drop 3 | Karuah River | Ebb | 0.93 | 0.61 | 1.51 |
| Trip 1 Day 1 Drop 4 | Karuah River | Ebb | 0.73 | 0.49 | 1.48 |
| Trip 1 Day 2 Drop 1 | Karuah River | Flood | 1.62 | 1.28 | 1.27 |
| Trip 1 Day 2 Drop 3 | West Bay | Ebb | 0.72 | 0.53 | 1.37 |
| Trip 2 Day 1 Drop 1 | Tilligerry Creek | Flood | 0.87 | 0.62 | 1.41 |
| Trip 2 Day 2 Drop 1 | Corrie Island | Flood | 0.60 | 0.27 | 2.23 |
| Trip 2 Day 2 Drop 2 | Myall River | Flood | 2.48 | 1.30 | 1.91 |
| Trip 2 Day 2 Drop 3 | West Bay | Ebb | 1.44 | 1.11 | 1.30 |
| Trip 2 Day 3 Drop 1 | Soldiers Point | Flood | 1.75 | 1.28 | 1.37 |
| Trip 2 Day 3 Drop 2 | Tilligerry Creek | Flood | 1.24 | 0.70 | 1.78 |
| FA Day 1 Drop 1 | Karuah River | Ebb | 1.18 | 0.66 | 1.77 |
| FA Day 2 Drop 1 | Lemon Tree Passage | Ebb | 0.50 | 0.32 | 1.54 |
| FA Day 4 Drop 2 | East Bay | Ebb | 0.33 | 0.27 | 1.20 |

In the Port Stephens system, depth varying vertical velocity distributions were observed when comparing drogues to modelled particles, with ratios of an average of 1.55. However, these ratios were similar on the ebb and flood tides, thus do not indicate tidal straining (A. rather than B. on Figure 4-16).

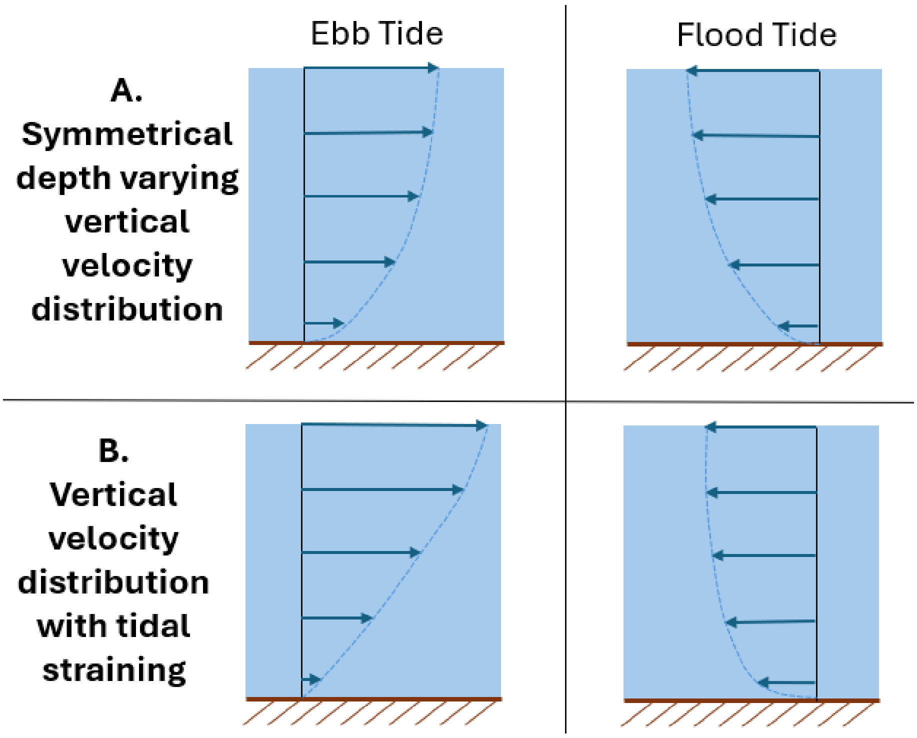


**Figure 4-16 Flow with tidally symmetrical depth varying velocity profiles and tidal straining with non-symmetrical vertical velocity profiles**

As vertical velocity distributions are tidally symmetrical, 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 is unlikely to have an effect on the reported timing of plume arrival. Hence, despite the observed vertical velocity distributions, no timing adjustments were required for this system.

### 4.7.3 Instabilities

Instabilities were identified in the water quality component of the three dimensional models, which resulted in the mass of a constituent not being conserved. These issues were most prevalent in cases where high concentrations of the overflows:

- Transitioned between two and three dimensions
- Passed over shallow areas modelled in three dimensions
- Came near the edges of the model mesh in three dimensional areas

Similar to mass conservation issues with the two dimensional models, these issues were resolved as much as possible by refining geometry and mesh resolution. Remaining instabilities were investigated, and it was ascertained that the model represented physical processes (i.e. advection and dispersion) adequately, however created or lost mass at locations where mathematical approximations are difficult to fit (e.g. in areas with very high concentrations, or near the model boundaries). These issues could be resolved by very high temporal and vertical resolution, however this was not considered computationally practical or necessary. Instead, in scenarios that lost mass, a mass correction factor was applied to adjust the final results in order to correct the total amount of mass in the system. For cases where mass was created, no adjustment was applied.

## 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 Port Stephens model include:

- Bathymetry is very uncertain in some areas of the model, mainly the Karuah River, Myall River and Myall Lakes. As these upper reaches were not the area of interest, and the tidal prism was sufficiently accurate, the model was deemed fit for purpose, however this may not be true for other use cases.
- Considering the size of the system (an order of magnitude larger than the other estuaries modelled as part of this project) there is very little flow and water level gauging data available to calibrate. Hence, the quality of model performance in some areas is highly uncertain, for example the Upper Karuah or Twelve Mile Creek. The field campaigns aimed to minimise uncertainty in areas of interest (i.e. near overflows and harvest areas), however, the areas of interest for other use cases may have insufficient hydrodynamic data.
- Due to the limited amount of preexisting hydrodynamic data for this estuary (considering its size), the 2023 field data was used as further calibration data rather than separate verification (validation) data as it was on some other estuaries. Thus, this model is not validated. This was deemed acceptable for this purpose, however, may not be for other use cases. This is discussed further in WRL TR2023/32 Section 6.4.
- The model is very low resolution in some areas (especially those which lack bathymetry data) such as the Karuah and Myall Rivers. This may be inappropriate for some model use cases.
- Port Stephens experiences bathymetry change over time, including movement of sand shoals in the East Bay, and changes to the bathymetry and shoaling of the channel to the south of Corrie Island. For this model, significant changes in bathymetry were either far from the areas of interest or, in the case of the changes to the bathymetry of the channel near Corrie Island, did not impact results significantly in sensitivity tests. However, other model use cases require reconsideration of the implications of bathymetry change, and may require bathymetry updates.
- Wind is not wholistically simulated in the model. The model was primarily constructed to indicate the general types of currents and circulation which may result from wind from a certain direction. The model uses only two layers, thus does not simulate the full vertical velocity profile expected from wind shear, and the model was also not calibrated to result in appropriate velocities resulting from wind shear, nor were the circulations resulting from wind forcing verified. Furthermore, the model does not have sufficient vertical resolution to adequately simulate three-dimensional mixing, as it was only intended to simulate the changes in advection that may be caused by wind.

# 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 Port Stephens, a total of 2,211 model scenario simulations were completed, including permutations of:

- Seven overflow locations
- Four stages of the tide
- Three catchment inflow conditions
- Five overflow volumes and durations
- Six wind directions

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

Seven locations were used to simulate overflow locations into Port Stephens. 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)
4. 300 kL overflow over 30 hours (10 kL/hr)
5. 1000 kL overflow over 100 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.

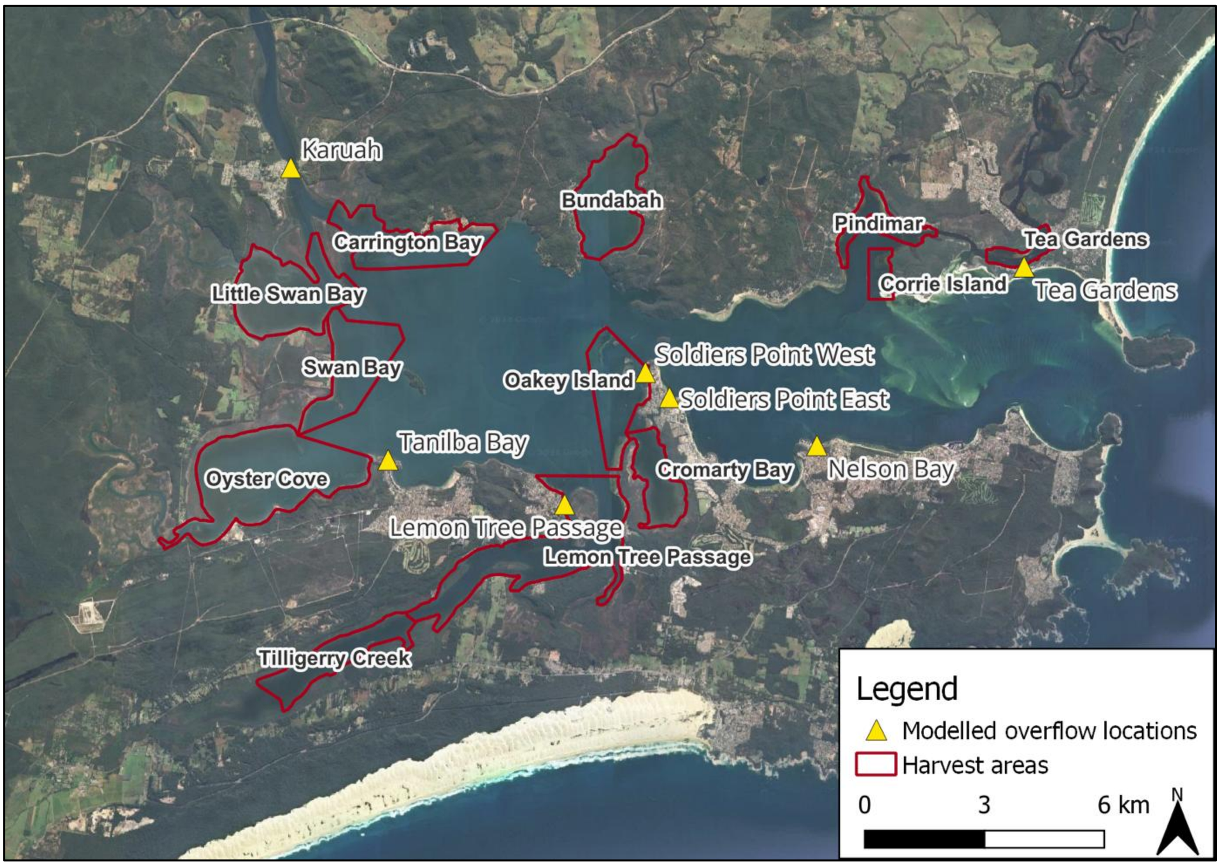


**Figure 5-1 Modelled overflow locations in the Port Stephens estuary**

## 5.3 Environmental variables

Three environmental variables were tested for Port Stephens:

1. Stage of the tide (slack low tide, slack high tide, mid ebb tide and mid flood tide)
2. Magnitude of catchment inflows (median, $80^{th}$ percentile and $95^{th}$ percentile)
3. Wind direction (No wind, north, north-east, east, south and west, at a constant wind speed of 5 m/s)

### 5.3.1 Stage of the tide

The 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 |
|---|---|---|---|
| Tea Gardens | Slack low tide | Tea Gardens (209480) | Low tide |
| Tea Gardens | Mid flood tide | Tea Gardens (209480) | Half way between low and high |
| Tea Gardens | Slack high tide | Tea Gardens (209480) | High tide |
| Tea Gardens | Mid ebb tide | Tea Gardens (209480) | Half way between high and low |
| Karuah | Slack low tide | Karuah (209485) | Low tide |
| Karuah | Mid flood tide | Karuah (209485) | Half way between low and high |
| Karuah | Slack high tide | Karuah (209485) | High tide |
| Karuah | Mid ebb tide | Karuah (209485) | Half way between high and low |
| Soldiers Point East, Soldiers Point West, Lemon Tree Passage, Tanilba Bay, Nelson Bay | Slack low tide | Mallabula Point (209461) | Low tide |
| Soldiers Point East, Soldiers Point West, Lemon Tree Passage, Tanilba Bay, Nelson Bay | Mid flood tide | Mallabula Point (209461) | Half way between low and high |
| Soldiers Point East, Soldiers Point West, Lemon Tree Passage, Tanilba Bay, Nelson Bay | Slack high tide | Mallabula Point (209461) | High tide |
| Soldiers Point East, Soldiers Point West, Lemon Tree Passage, Tanilba Bay, Nelson Bay | Mid ebb tide | Mallabula Point (209461) | Half way between high and low |

The stage of the tide is important at all overflow locations, except for Tea Gardens, for overflows of duration less than 10 hours. The effects of tide timing vary from location to location, for example, overflows at slack low tide from Karuah result in better outcomes than at slack high tide, as the plume reaches the harvest areas later, however the situation is the opposite for overflows from Soldiers Point West. For Tea Gardens, all three Myall River harvest areas are affected at high concentrations for overflows of 10 to 30 kL on all tides. However, impacts are greatest at slack high and mid ebb tide, therefore for very small overflows (less than 10 kL) tide timing may be important. For ease of use, results for different stages of the tide have been combined when the implications for harvest areas are similar, however individual scenario results can still be viewed by clicking “View sub-runs”. See WRL TR2023/32 Section 8.3.4 for more details on scenario grouping.

## 5.3.2 Catchment inflows

Catchment inflow affected all locations to some extent, especially for larger spills. In general, higher catchment inflows decreased the effects to the Karuah River harvest areas and increased the effects to the Myall River ones, as higher flows pushed overflows out of the West Bay and into the East Bay. This behaviour can be seen in Figure 5-2 and Figure 5-3. For overflows from Karuah, higher catchment inflows tend to lead to worse outcomes for all harvest areas.

For ease of use, results for different catchment inflows have been combined when the implications for harvest areas are similar, however individual scenario results can still be viewed by clicking "View sub-runs". See WRL TR2023/32 Section 8.3.4 for more details on scenario grouping.

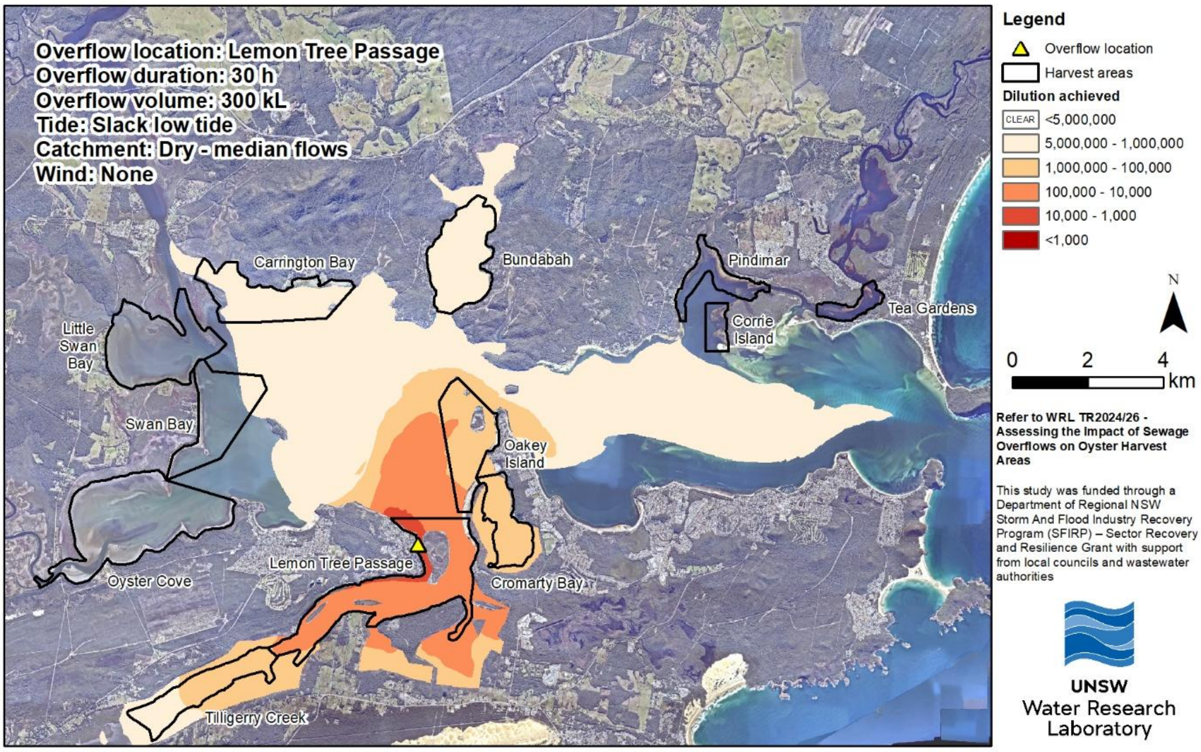


**Figure 5-2 Example of a 30 hour overflow at Lemon Tree Passage during median inflow conditions with no wind***

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

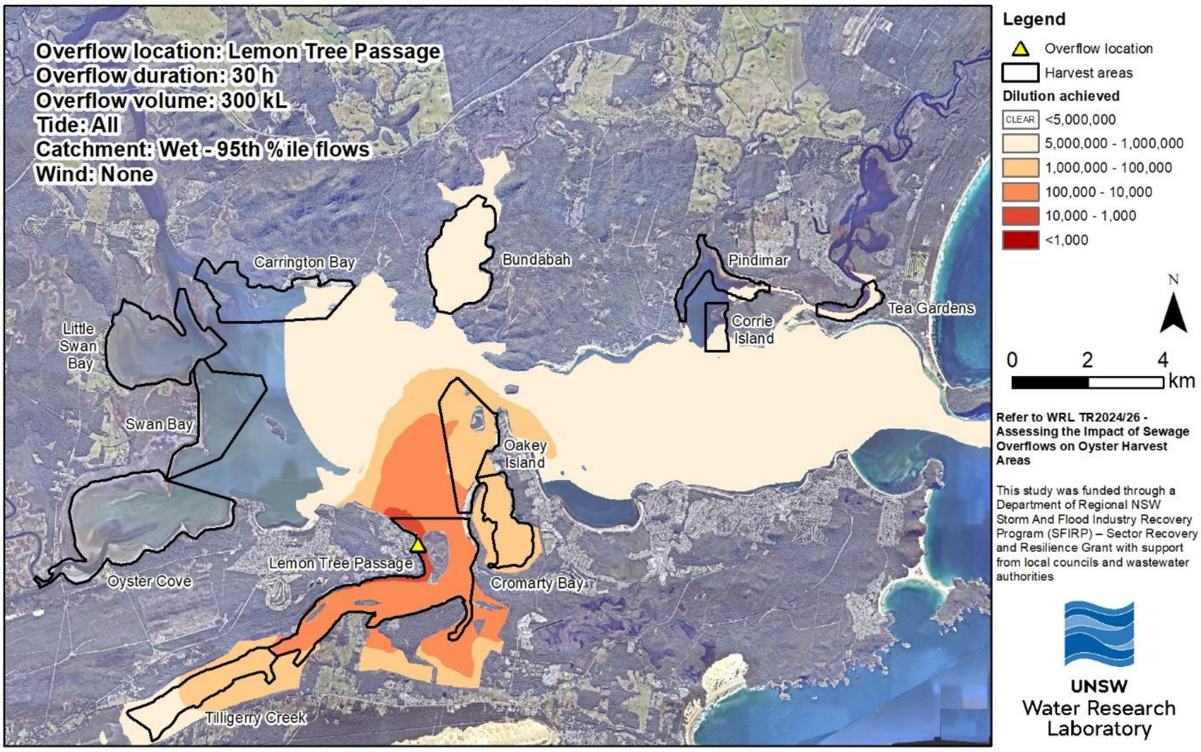


**Figure 5-3 Example of a 30 hour overflow at Lemon Tree Passage during wet (95th percentile) inflow conditions with no wind***

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

## 5.3.3 Wind

For all wind directions in these scenarios, wind has been simulated as a constant wind of 5 m/s (18 km/h) over the entire simulation period. This is not a realistic simulation of wind, which varies in direction and strength over hours and days. These scenarios are intended to provide a qualitative indication of the effects different winds may have on plume transport, rather than to simulate real world scenarios. When considering wind, multiple wind scenarios (including the no wind scenario) need to be consulted. If there is uncertainty about the implications of wind and which scenario should be used, the worst plausible case should be utilised.

Overflows from all harvest areas, especially larger overflows, are affected by wind. Wind may have unpredictable and unintuitive results, especially for overflows from Soldiers Point and Karuah. Figure 5-4, Figure 5-5, Figure 5-6 and Figure 5-7 show an example of the effects of wind. The effects of the north wind are the greatest, as a counterclockwise circulation is set up pushing the plume towards Oyster Cove and Lemon Tree Passage. In a south wind, the opposite circulation occurs, keeping the plume away from these harvest areas. In an east or west wind the impact is minimal, similar to a no wind case at this location. However, for other overflow scenarios, east and west winds have a larger impact.

For ease of use, results for different wind scenarios have been combined when the implications for harvest areas are similar, however individual scenario results can still be viewed by clicking "View sub-runs". See WRL TR2023/32 Section 8.3.4 for more details on scenario grouping. The circulations set up by wind can be unintuitive, and the effects of wind can change when other variables (especially stage of the tide) change. Therefore, it is important to consult multiple scenarios in order to ensure that the real world overflow event is being encompassed by modelled variables. If in doubt, use the worst case plausible scenario.

As discussed in Section 4.6.4, wind in this model is uncalibrated and unverified, though the hydrodynamic response to wind was considered reasonable based on engineering judgment. If it is found that many large overflows are occurring in the bay, for which wind based scenarios would affect the management outcomes, further data collection, model refinement and scenario modelling based on wind should be considered.

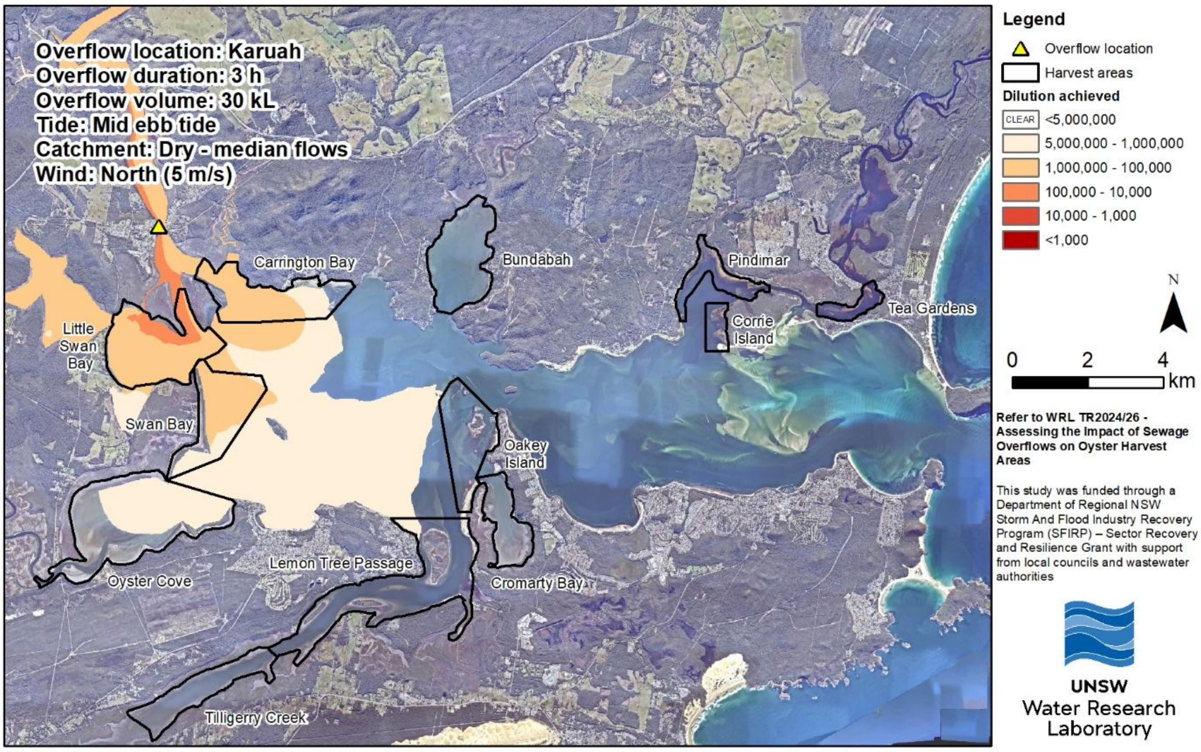


**Figure 5-4 Example of a 3 hour overflow at Karuah during median inflow conditions with North wind***

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

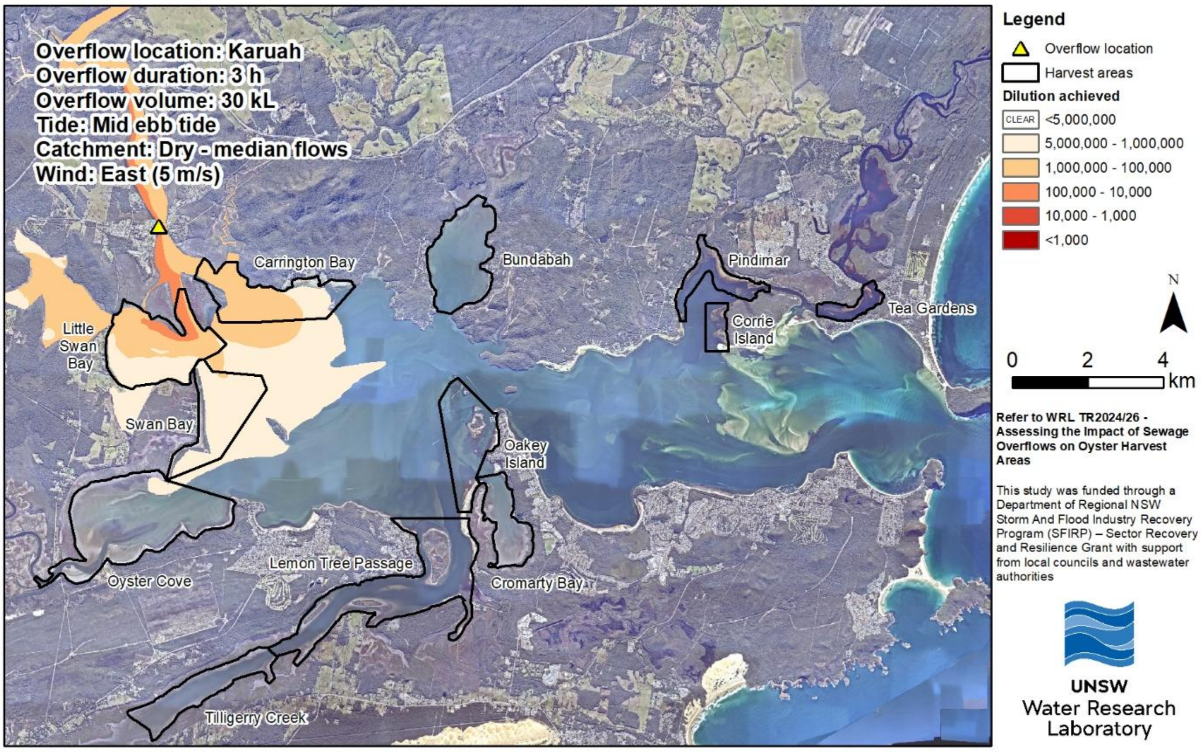


**Figure 5-5 Example of a 3 hour overflow at Karuah during median inflow conditions with east wind***

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

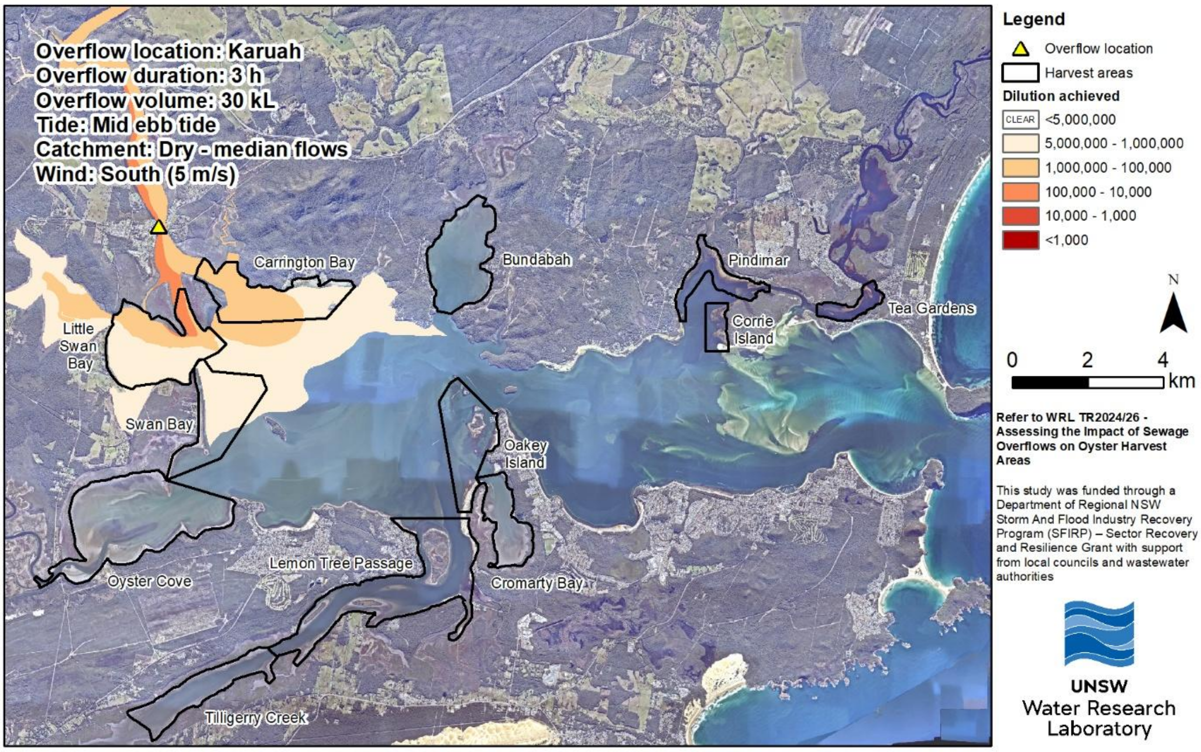


**Figure 5-6 Example of a 3 hour overflow at Karuah during median inflow conditions with South wind***

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

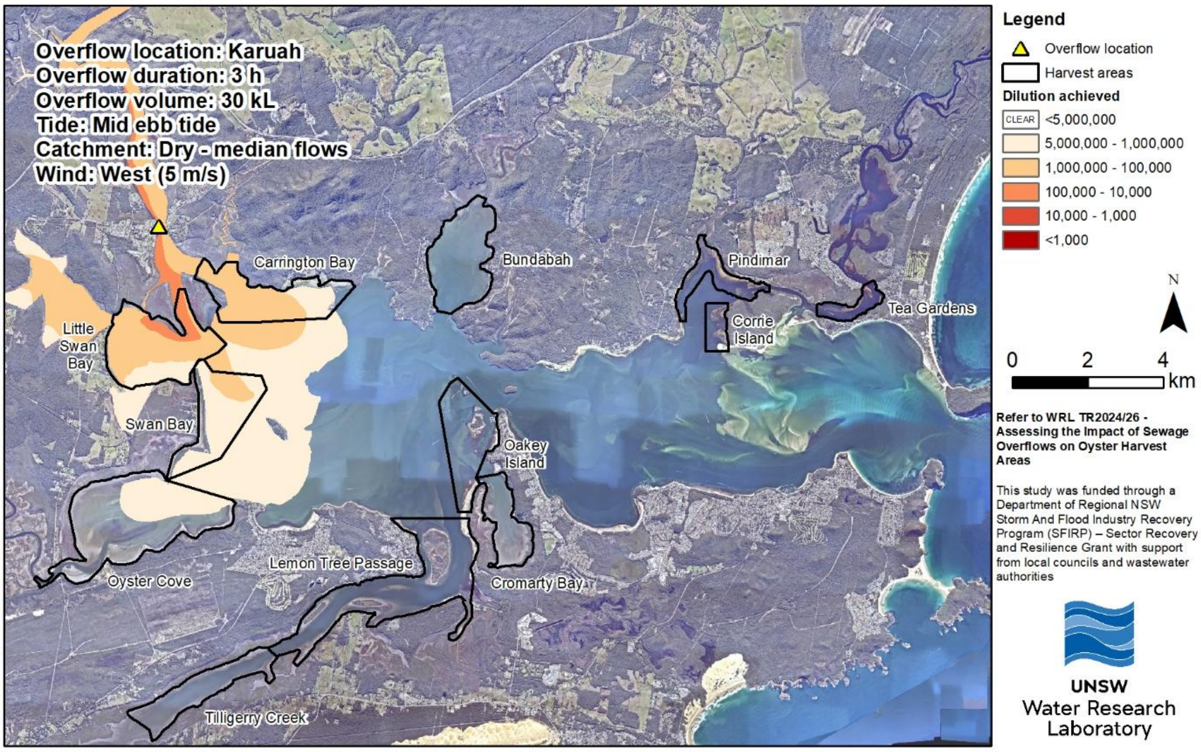


**Figure 5-7 Example of a 3 hour overflow at Karuah during median inflow conditions with West wind***

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

# 6 Conclusion

This report is focussed on the Port Stephens 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 Port Stephens estuary model. Key information included in the report relates to the integration of existing data sources, the August and November 2023 field data collection campaigns, data processing and model development. If wind is found to be significant for many management decisions on this estuary, further model refinement based on wind should be undertaken.

This report should be read in conjunction with WRL TR2023/32 which provides details on the technical methods used across each of the 11 study estuaries (including Port Stephens) 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).

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# 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 3.6.1.

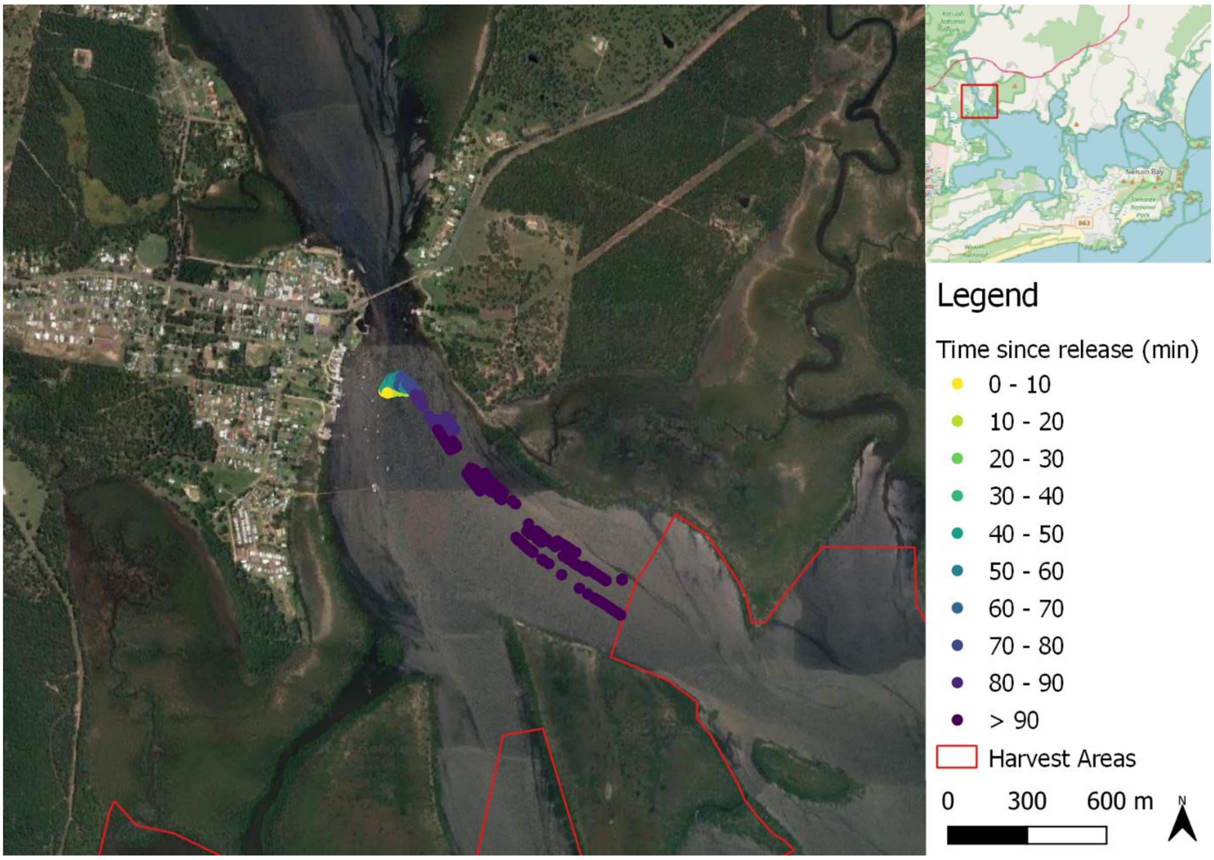


**Figure A-1 GPS drifter drogue release Trip 1 Day 1 Drop 1 – Karuah River – ebb tide**

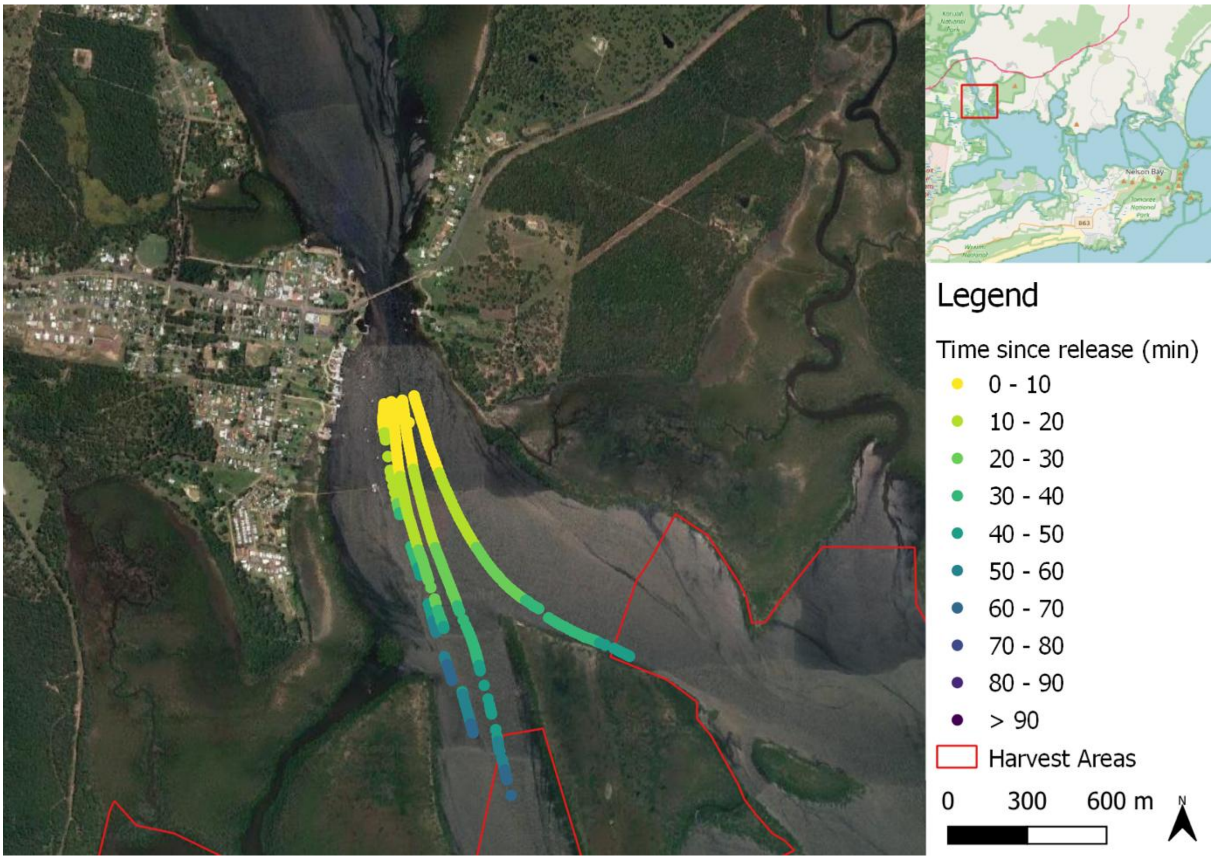


**Figure A-2 GPS drifter drogue release Trip 1 Day 1 Drop 2 – Karuah River – ebb tide**

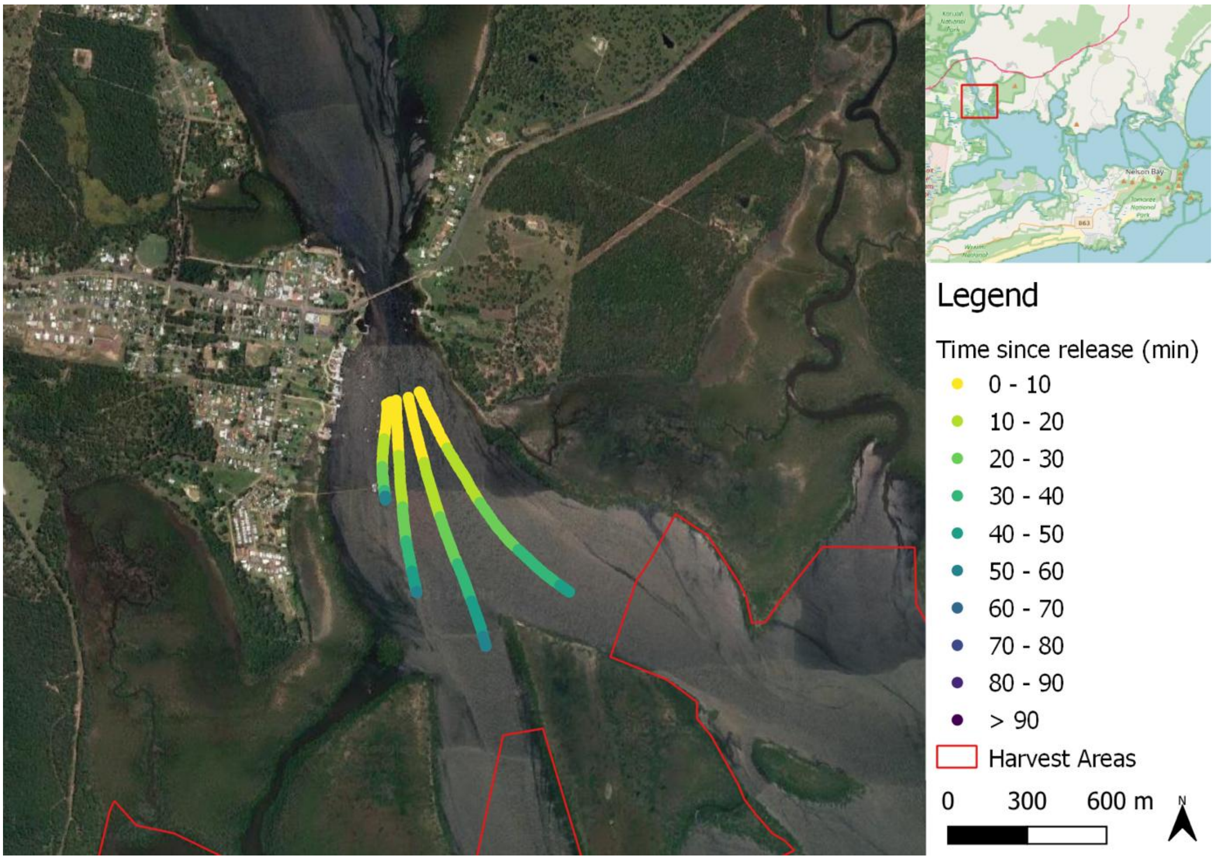


**Figure A-3 GPS drifter drogue release Trip 1 Day 1 Drop 3 – Karuah River – ebb tide**

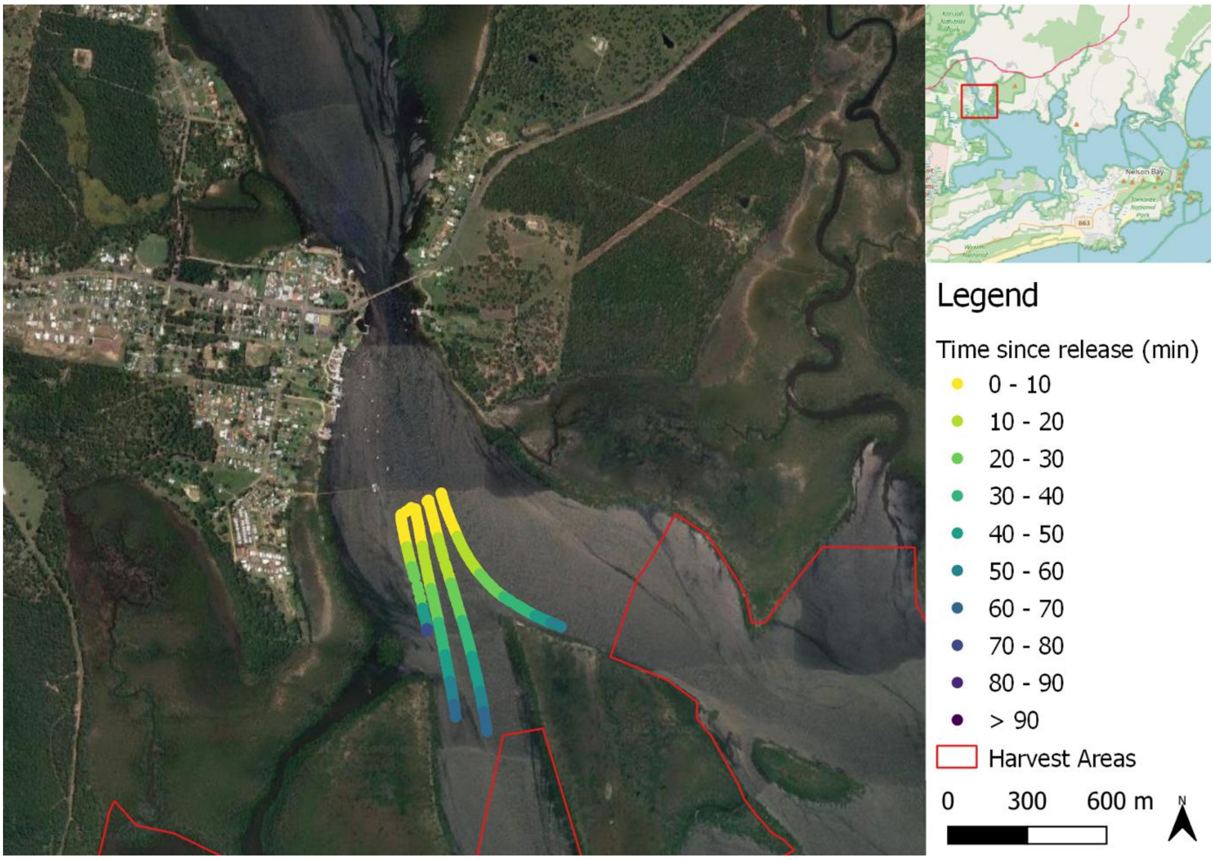


**Figure A-4 GPS drifter drogue release Trip 1 Day 1 Drop 4 – Karuah River – ebb tide**

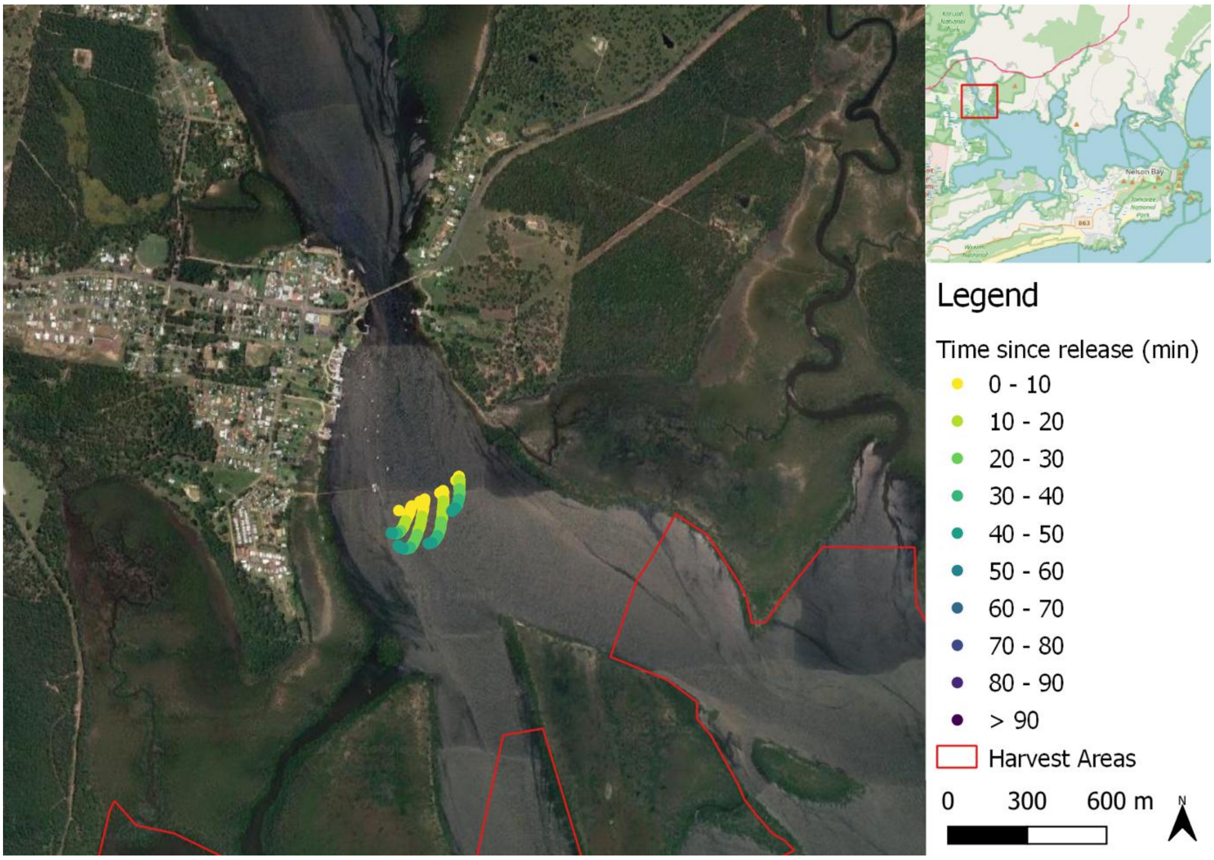


**Figure A-5 GPS drifter drogue release Trip 1 Day 1 Drop 5 – Karuah River – slack low**

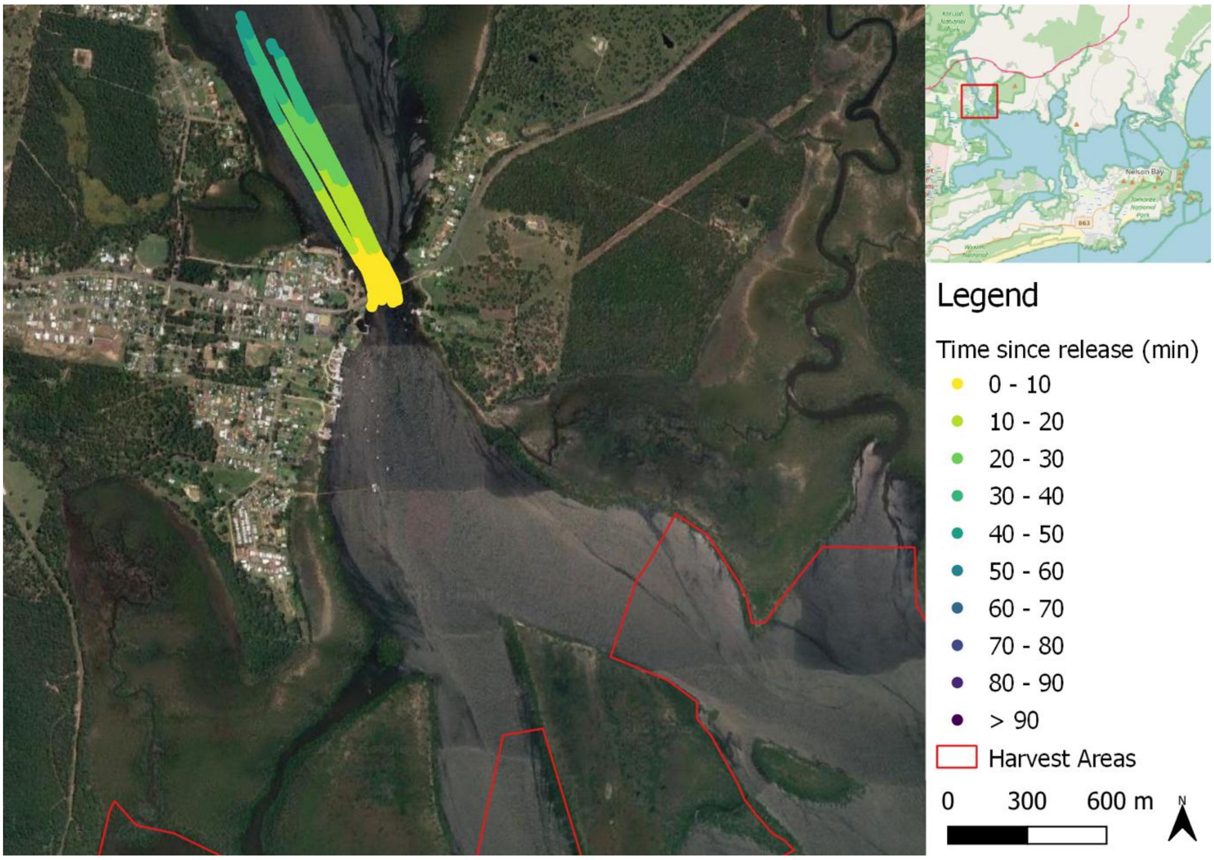


**Figure A-6 GPS drifter drogue release Trip 1 Day 2 Drop 1 – Karuah River – flood tide**

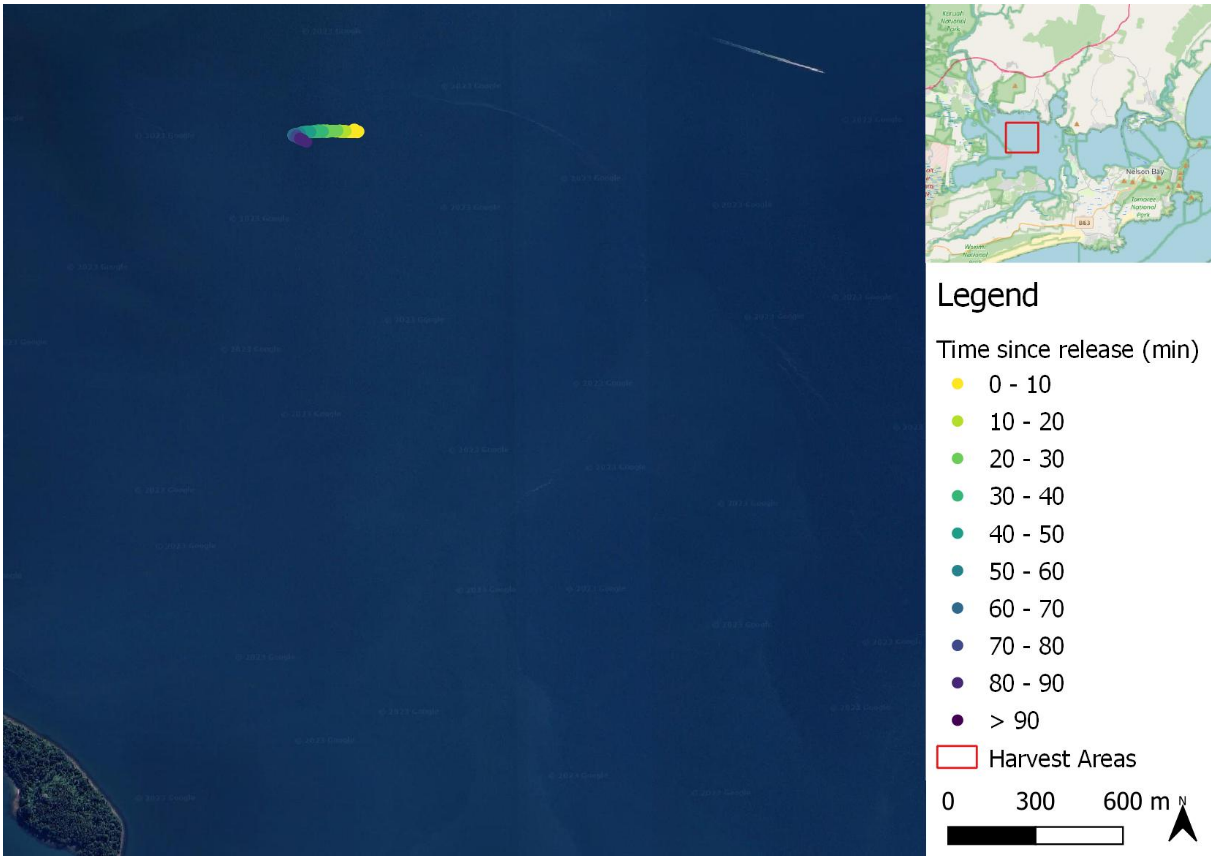


**Figure A-7 GPS drifter drogue release Trip 1 Day 2 Drop 2 – West Bay – slack high**

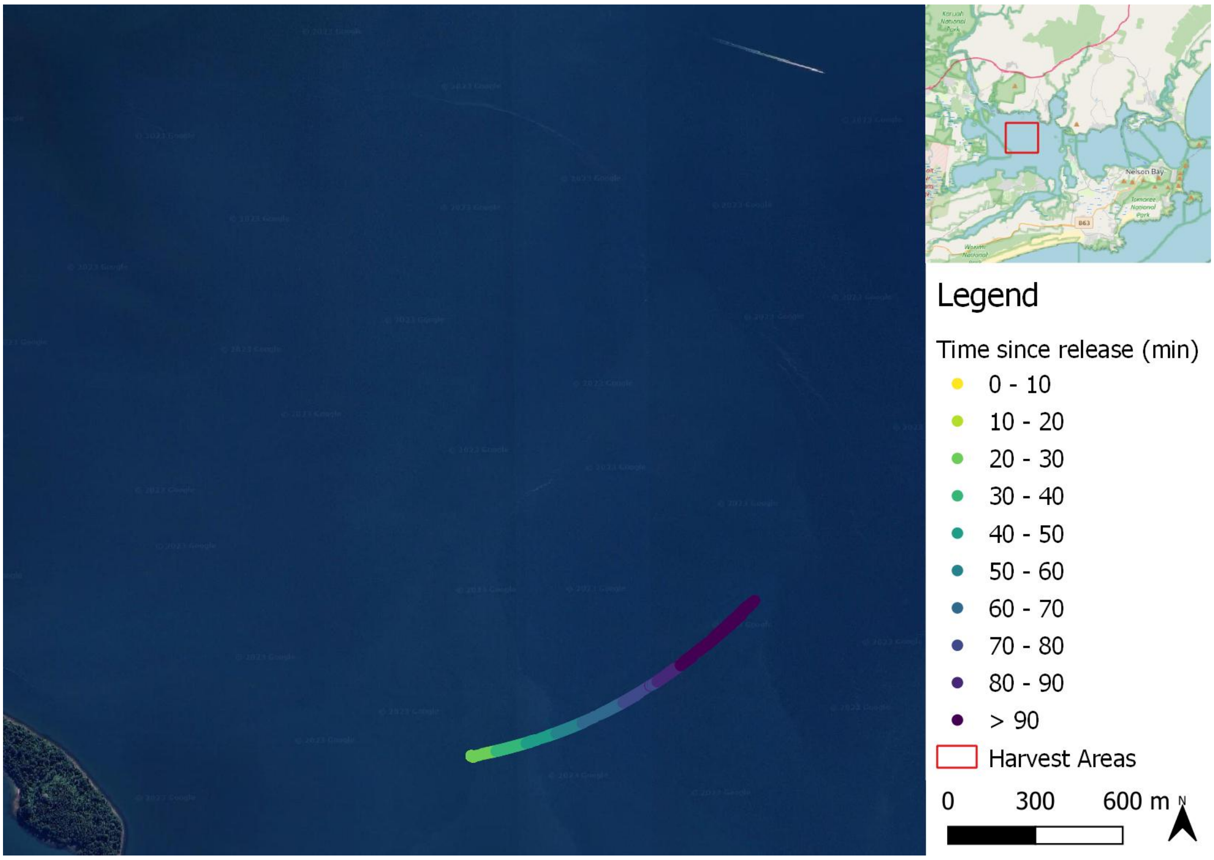


**Figure A-8 GPS drifter drogue release Trip 1 Day 2 Drop 3 – West Bay– ebb tide**

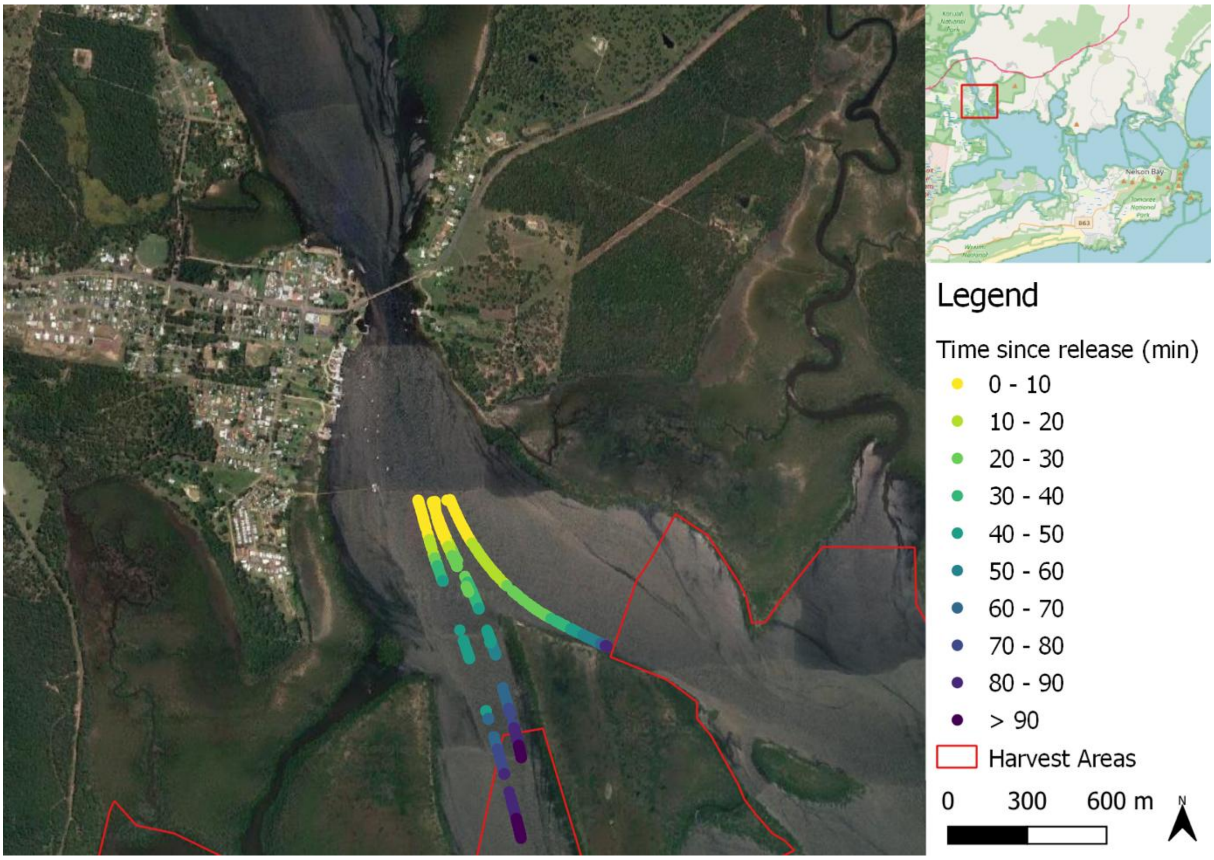


**Figure A-9 GPS drifter drogue release Trip 1 Day 2 Drop 4 – Karuah River – ebb tide**

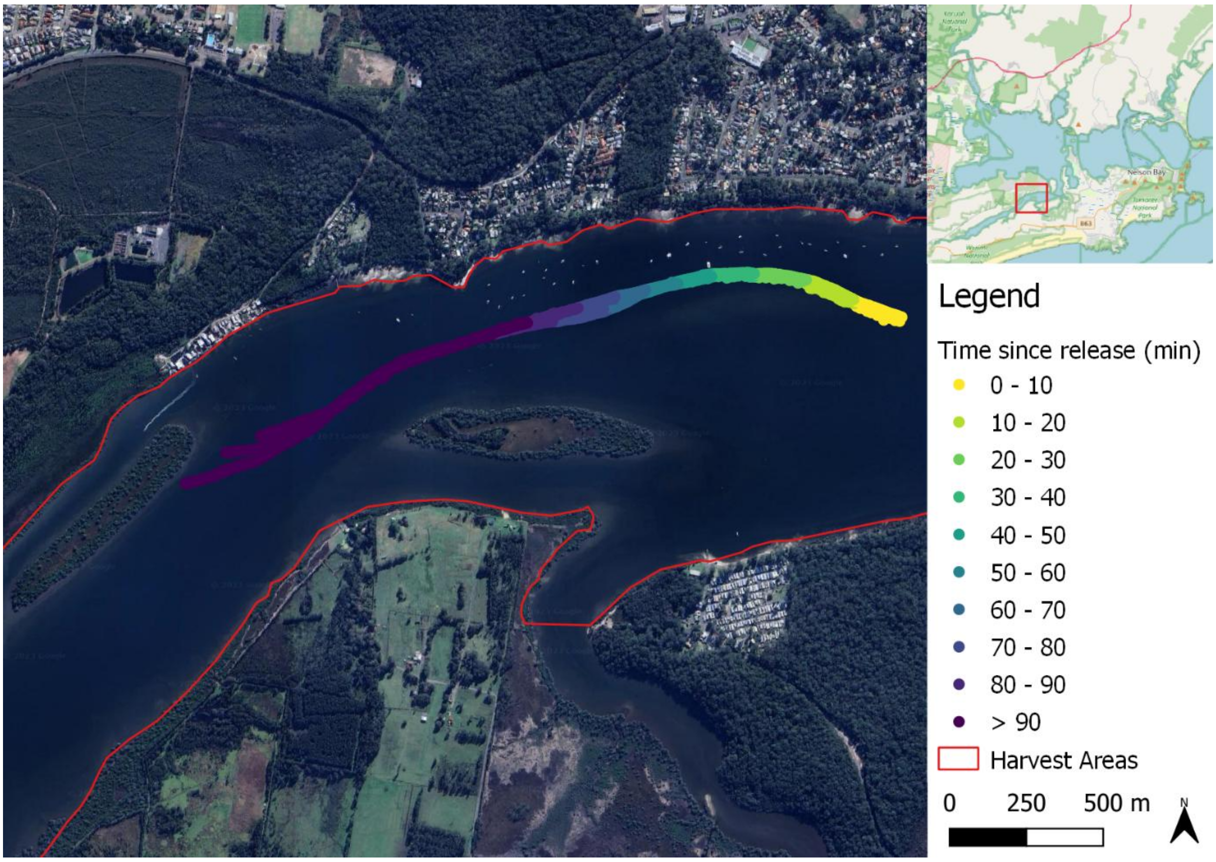


**Figure A-10 GPS drifter drogue release Trip 2 Day 1 Drop 1 – Tilligerry Creek – flood tide**

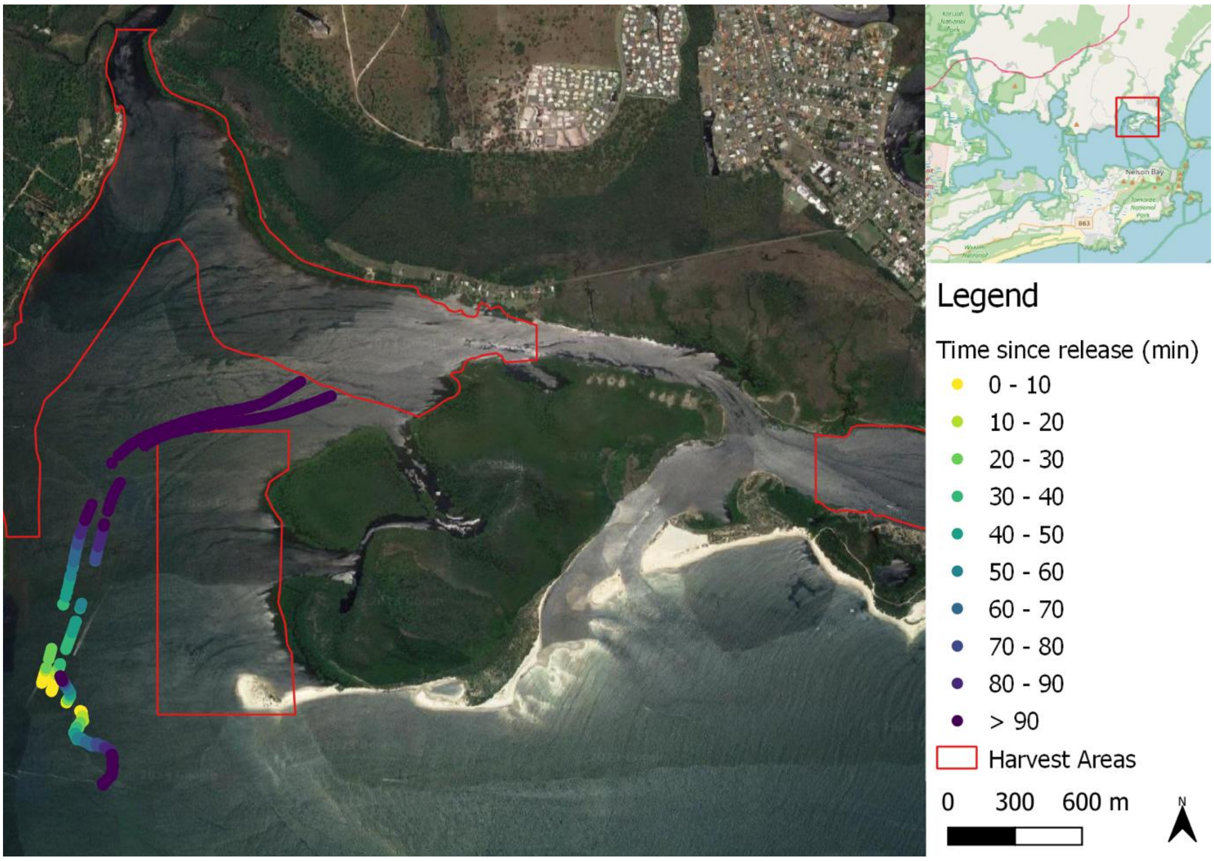


**Figure A-11 GPS drifter drogue release Trip 2 Day 2 Drop 1 – Myall River – flood tide**

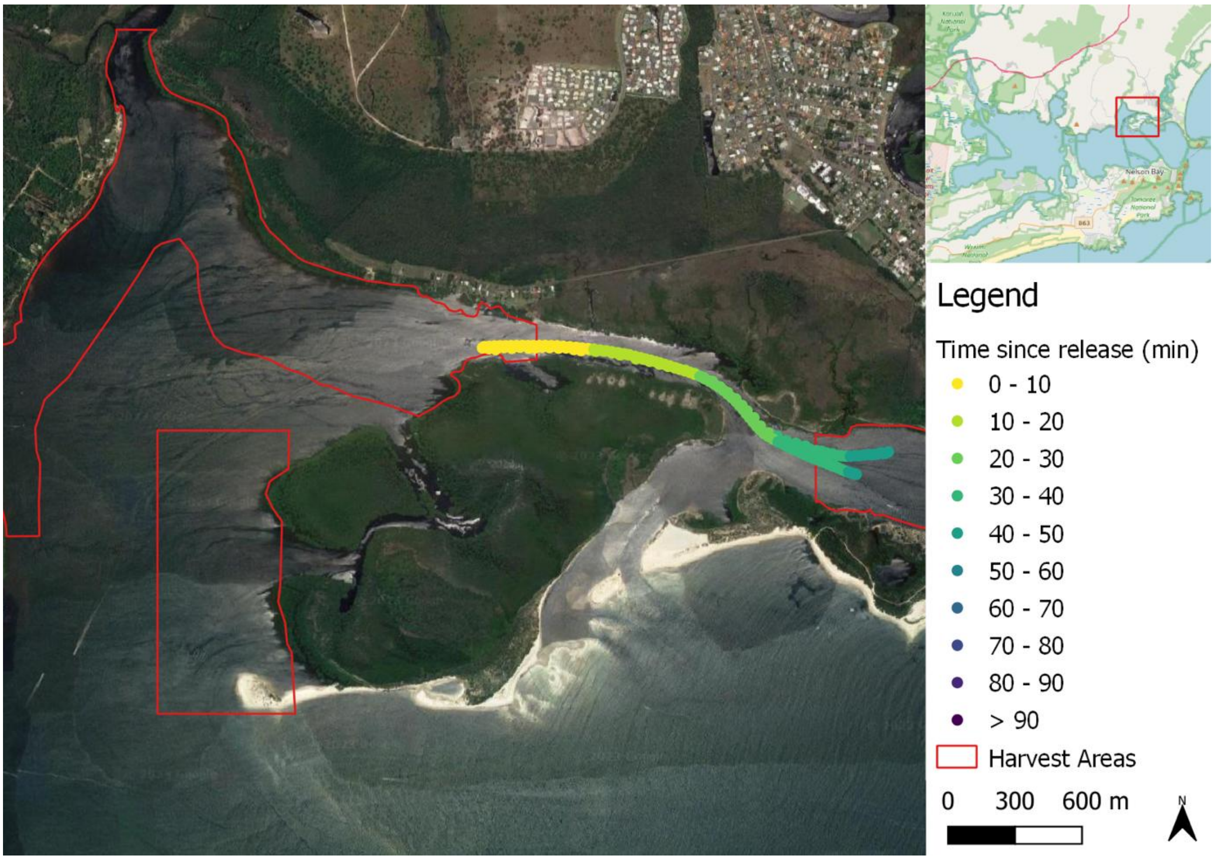


**Figure A-12 GPS drifter drogue release Trip 2 Day 2 Drop 2 – Myall River – flood tide**

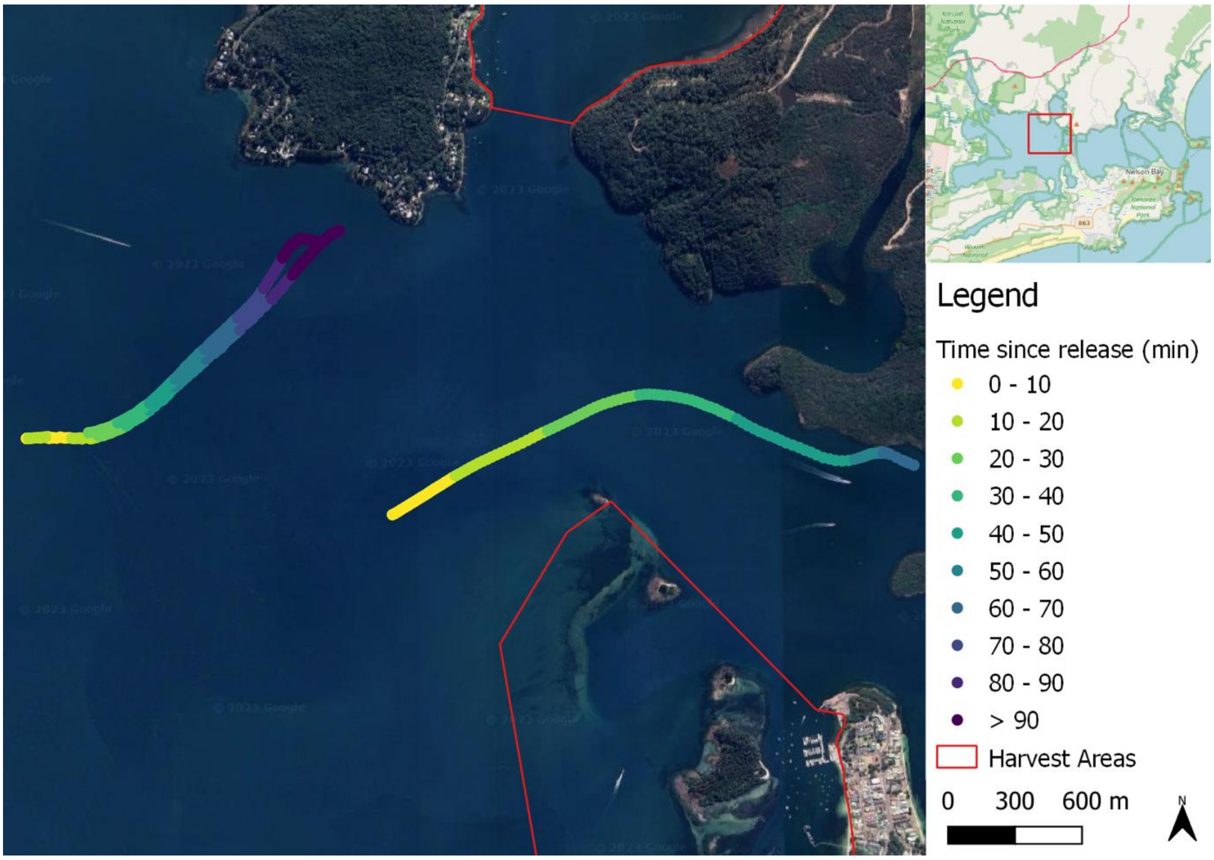


**Figure A-13 GPS drifter drogue release Trip 2 Day 2 Drop 3 – West Bay – ebb tide**

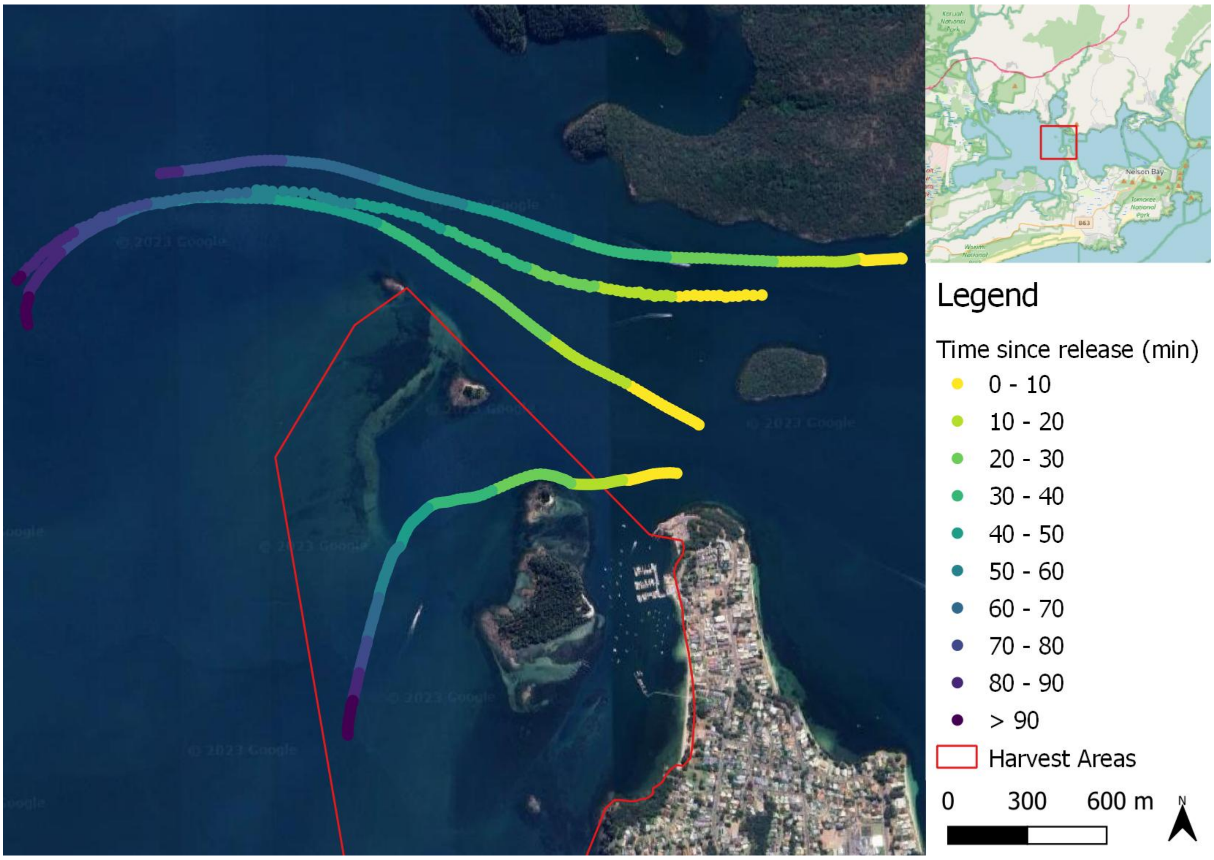


**Figure A-14 GPS drifter drogue release Trip 2 Day 3 Drop 1 – Soldiers Point – flood tide**

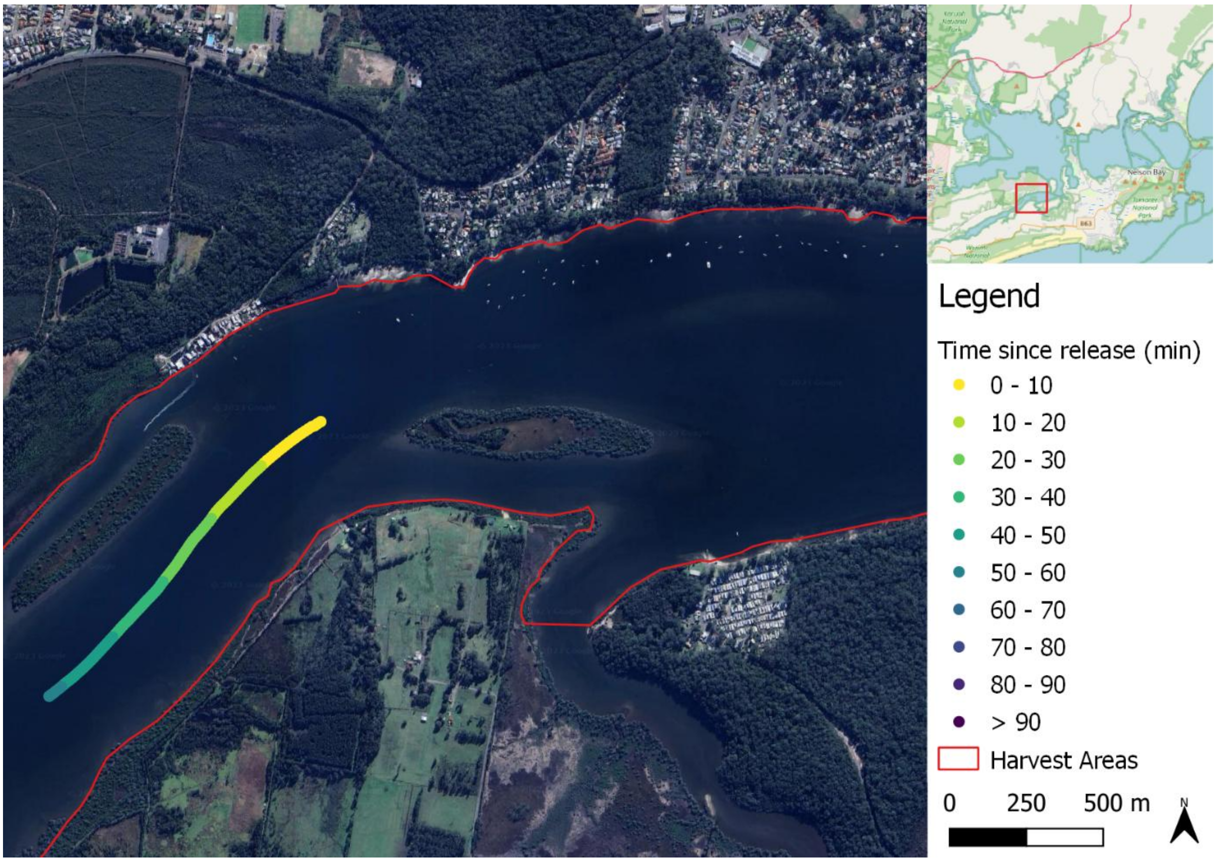


**Figure A-15 GPS drifter drogue release Trip 2 Day 3 Drop 2 – Tilligerry Creek – flood tide**

## A2 Tidal flow gauging

The below figures summarise tidal flow gauging results from the 2023 field campaign. For more information, refer to Section 3.3. All times are in AEST.

**Table A-1 Soldiers Point Site 8 2023 tidal flow gauging**

| No. | Date | Time | Flow ($m^3/s$) * |
|---|---|---|---|
| 1 | 15/11/2023 | 6:21:00 | -7781 |
| 2 | 15/11/2023 | 6:41:00 | -8342 |
| 3 | 15/11/2023 | 7:04:00 | -8249 |
| 4 | 15/11/2023 | 7:36:00 | -8275 |
| 5 | 15/11/2023 | 7:51:00 | -7498 |
| 6 | 15/11/2023 | 8:32:00 | -6698 |
| 7 | 15/11/2023 | 8:47:00 | -6608 |
| 8 | 15/11/2023 | 9:01:00 | -6220 |
| 9 | 15/11/2023 | 9:40:00 | -2391 |
| 10 | 15/11/2023 | 9:54:00 | -1779 |
| 11 | 15/11/2023 | 10:07:00 | -716 |
| 12 | 15/11/2023 | 10:21:00 | 302 |
| 13 | 15/11/2023 | 10:34:00 | 2492 |
| 14 | 15/11/2023 | 11:12:00 | 6152 |
| 15 | 15/11/2023 | 11:26:00 | 7652 |
| 16 | 15/11/2023 | 11:37:00 | 8108 |
| 17 | 15/11/2023 | 12:14:00 | 9434 |
| 18 | 15/11/2023 | 12:50:00 | 9040 |
| 19 | 15/11/2023 | 13:03:00 | 9124 |
| 20 | 15/11/2023 | 13:41:00 | 8149 |
| 21 | 15/11/2023 | 13:55:00 | 7696 |
| 22 | 15/11/2023 | 14:29:00 | 7039 |

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

**Table A-2 Myall River Site 5 2023 tidal flow gauging**

| No. | Date | Time | Flow ($m^3/s$) * |
|---|---|---|---|
| 1 | 15/11/2023 | 7:08:32 | -368 |
| 2 | 15/11/2023 | 7:11:36 | -354 |
| 3 | 15/11/2023 | 6:46:24 | -314 |
| 4 | 15/11/2023 | 6:49:01 | -315 |
| 5 | 15/11/2023 | 8:04:06 | -402 |
| 6 | 15/11/2023 | 8:06:35 | -413 |
| 7 | 15/11/2023 | 8:52:52 | -439 |
| 8 | 15/11/2023 | 9:11:40 | -364 |
| 9 | 15/11/2023 | 9:14:31 | -366 |
| 10 | 15/11/2023 | 9:30:40 | -367 |
| 11 | 15/11/2023 | 9:44:14 | -357 |
| 12 | 15/11/2023 | 10:21:53 | -124 |
| 13 | 15/11/2023 | 10:24:45 | -115 |
| 14 | 15/11/2023 | 10:45:34 | -1 |
| 15 | 15/11/2023 | 10:48:30 | -12 |
| 16 | 15/11/2023 | 11:06:03 | 94 |
| 17 | 15/11/2023 | 11:09:03 | 124 |

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

**Table A-3 Myall River Corrie Island North 2023 tidal flow gauging**

| No. | Date | Time | Flow ($m^3/s$) * |
|---|---|---|---|
| 1 | 15/11/2023 | 7:01:43 | -170 |
| 2 | 15/11/2023 | 7:03:24 | -161 |
| 3 | 15/11/2023 | 8:12:31 | -196 |
| 4 | 15/11/2023 | 8:14:23 | -200 |
| 5 | 15/11/2023 | 8:40:08 | -228 |
| 6 | 15/11/2023 | 8:41:49 | -224 |
| 7 | 15/11/2023 | 8:59:30 | -238 |
| 8 | 15/11/2023 | 9:21:12 | -200 |
| 9 | 15/11/2023 | 9:36:38 | -198 |
| 10 | 15/11/2023 | 9:50:17 | -208 |
| 11 | 15/11/2023 | 10:10:08 | -231 |
| 12 | 15/11/2023 | 10:30:52 | -170 |
| 13 | 15/11/2023 | 10:32:53 | -169 |
| 14 | 15/11/2023 | 10:54:13 | -134 |
| 15 | 15/11/2023 | 10:58:04 | -144 |
| 16 | 15/11/2023 | 11:14:43 | -88 |
| 17 | 15/11/2023 | 11:16:16 | -82 |

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

**Table A-4 Myall River Corrie Island North 2023 tidal flow gauging**

| No. | Date | Time | Flow ($m^3/s$) * |
|---|---|---|---|
| 1 | 15/11/2023 | 6:54:02 | -172 |
| 2 | 15/11/2023 | 6:56:51 | -161 |
| 3 | 15/11/2023 | 8:52:09 | -203 |
| 4 | 15/11/2023 | 9:03:44 | -164 |
| 5 | 15/11/2023 | 9:06:00 | -171 |
| 6 | 15/11/2023 | 9:27:03 | -162 |
| 7 | 15/11/2023 | 9:41:02 | -148 |
| 8 | 15/11/2023 | 10:14:22 | -18 |
| 9 | 15/11/2023 | 10:17:24 | 23 |
| 10 | 15/11/2023 | 10:37:18 | 89 |
| 11 | 15/11/2023 | 10:39:40 | 109 |
| 12 | 15/11/2023 | 11:04:06 | 203 |

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

**Table A-5 North Arm Cove Site 14 2023 tidal flow gauging**

| No. | Date | Time | Flow ($m^3/s$) * |
|---|---|---|---|
| 1 | 14/11/2023 | 12:53:44 | 379 |
| 2 | 14/11/2023 | 12:57:58 | 384 |
| 3 | 15/11/2023 | 6:04:52 | -426 |
| 4 | 15/11/2023 | 6:09:07 | -469 |
| 5 | 15/11/2023 | 6:12:43 | -477 |
| 6 | 15/11/2023 | 7:51:00 | -380 |
| 7 | 15/11/2023 | 8:06:00 | -378 |
| 8 | 15/11/2023 | 10:34:00 | 283 |
| 9 | 15/11/2023 | 10:45:00 | 278 |
| 10 | 15/11/2023 | 12:20:00 | 450 |
| 11 | 15/11/2023 | 12:24:00 | 489 |
| 12 | 15/11/2023 | 13:03:00 | 428 |
| 13 | 15/11/2023 | 14:18:00 | 465 |

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

**Table A-6 Cromartys Bay 2023 tidal flow gauging**

| No. | Date | Time | Flow ($m^3/s$) * |
|---|---|---|---|
| 1 | 14/11/2023 | 7:09:41 | -184 |
| 2 | 14/11/2023 | 7:16:04 | -168 |
| 3 | 14/11/2023 | 7:20:02 | -191 |
| 4 | 14/11/2023 | 8:21:03 | -146 |
| 5 | 14/11/2023 | 8:25:15 | -121 |
| 6 | 14/11/2023 | 9:59:35 | 165 |
| 7 | 14/11/2023 | 10:04:02 | 174 |
| 8 | 14/11/2023 | 12:19:46 | 155 |
| 9 | 14/11/2023 | 12:23:04 | 176 |
| 10 | 14/11/2023 | 12:26:17 | 165 |

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

### Table A-7 Tilligerry Creek Site 11 2023 tidal flow gauging

| No. | Date | Time | Flow ($m^3/s$) * |
|---|---|---|---|
| 1 | 14/11/2023 | 5:58:33 | -1080 |
| 2 | 14/11/2023 | 6:08:38 | -1027 |
| 3 | 14/11/2023 | 7:30:25 | -991 |
| 4 | 14/11/2023 | 7:38:21 | -943 |
| 5 | 14/11/2023 | 8:36:33 | -730 |
| 6 | 14/11/2023 | 8:42:51 | -642 |
| 7 | 14/11/2023 | 9:16:39 | -312 |
| 8 | 14/11/2023 | 9:23:53 | -165 |
| 9 | 14/11/2023 | 9:29:56 | -135 |
| 10 | 14/11/2023 | 9:37:49 | 48 |
| 11 | 14/11/2023 | 9:44:17 | 159 |
| 12 | 14/11/2023 | 10:12:30 | 748 |
| 13 | 14/11/2023 | 10:20:12 | 938 |
| 14 | 14/11/2023 | 10:50:34 | 1270 |
| 15 | 14/11/2023 | 10:57:28 | 1321 |
| 16 | 14/11/2023 | 12:00:10 | 1065 |
| 17 | 14/11/2023 | 12:07:16 | 1000 |
| 18 | 14/11/2023 | 13:11:23 | 1021 |
| 19 | 14/11/2023 | 14:03:21 | 744 |
| 20 | 14/11/2023 | 14:08:43 | 734 |

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

**Table A-8 Bulls Island West 2023 tidal flow gauging**

| No. | Date | Time | Flow ($m^3/s$) * |
|---|---|---|---|
| 1 | 14/11/2023 | 6:35:01 | -115 |
| 2 | 14/11/2023 | 6:38:34 | -123 |
| 3 | 14/11/2023 | 7:57:12 | -104 |
| 4 | 14/11/2023 | 8:00:09 | -110 |
| 5 | 14/11/2023 | 8:59:27 | -28 |
| 6 | 14/11/2023 | 9:02:06 | -32 |
| 7 | 14/11/2023 | 10:35:56 | 208 |
| 8 | 14/11/2023 | 10:38:32 | 196 |
| 9 | 14/11/2023 | 11:42:13 | 142 |
| 10 | 14/11/2023 | 11:44:50 | 132 |
| 11 | 14/11/2023 | 14:24:49 | 46 |
| 12 | 14/11/2023 | 14:27:19 | 42 |

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

**Table A-9 Karuah River Site 17 2023 tidal flow gauging**

| No. | Date | Time | Flow ($m^3/s$) * |
|---|---|---|---|
| 1 | 16/08/2023 | 7:28:22 | -679 |
| 2 | 16/08/2023 | 7:31:40 | -684 |
| 3 | 16/08/2023 | 7:34:31 | -673 |
| 4 | 16/08/2023 | 8:46:27 | -362 |
| 5 | 16/08/2023 | 8:49:22 | -373 |
| 6 | 16/08/2023 | 8:52:21 | -366 |
| 7 | 16/08/2023 | 9:33:07 | 45 |
| 8 | 16/08/2023 | 9:36:07 | 87 |
| 9 | 16/08/2023 | 9:39:07 | 114 |
| 10 | 16/08/2023 | 9:42:14 | 155 |
| 11 | 16/08/2023 | 9:45:17 | 170 |
| 12 | 16/08/2023 | 9:48:22 | 231 |
| 13 | 16/08/2023 | 9:54:43 | 280 |
| 14 | 16/08/2023 | 9:57:38 | 316 |
| 15 | 16/08/2023 | 10:57:51 | 733 |
| 16 | 16/08/2023 | 11:01:03 | 738 |
| 17 | 16/08/2023 | 11:04:26 | 745 |
| 18 | 16/08/2023 | 11:07:01 | 741 |
| 19 | 16/08/2023 | 11:10:09 | 744 |
| 20 | 16/08/2023 | 11:12:34 | 762 |
| 21 | 16/08/2023 | 11:14:57 | 745 |
| 22 | 16/08/2023 | 11:17:54 | 748 |
| 23 | 16/08/2023 | 11:20:32 | 734 |
| 24 | 16/08/2023 | 11:22:43 | 710 |
| 25 | 16/08/2023 | 11:25:11 | 690 |
| 26 | 16/08/2023 | 11:27:51 | 697 |

| No. | Date | Time | Flow ($m^3/s$) * |
|---|---|---|---|
| 27 | 16/08/2023 | 12:14:58 | 595 |
| 28 | 16/08/2023 | 12:17:08 | 600 |
| 29 | 16/08/2023 | 12:43:02 | 536 |
| 30 | 16/08/2023 | 12:45:00 | 532 |
| 31 | 16/08/2023 | 13:15:32 | 466 |
| 32 | 16/08/2023 | 14:42:13 | 156 |
| 33 | 16/08/2023 | 14:44:08 | 151 |
| 34 | 16/08/2023 | 14:46:20 | 140 |
| 35 | 16/08/2023 | 14:48:27 | 146 |
| 36 | 16/08/2023 | 14:50:25 | 148 |
| 37 | 16/08/2023 | 15:08:43 | 31 |
| 38 | 16/08/2023 | 15:10:26 | 15 |
| 39 | 16/08/2023 | 15:12:07 | 10 |
| 40 | 16/08/2023 | 15:14:04 | -22 |
| 41 | 16/08/2023 | 15:15:53 | -28 |
| 42 | 17/08/2023 | 7:30:36 | -751 |
| 43 | 17/08/2023 | 7:32:58 | -738 |
| 44 | 17/08/2023 | 7:35:44 | -733 |
| 45 | 17/08/2023 | 8:08:14 | -714 |

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

**Table A-10 Karuah River North Fork 2023 tidal flow gauging**

| No. | Date | Time | Flow ($m^3/s$) * |
|---|---|---|---|
| 1 | 16/08/2023 | 7:43:28 | -419 |
| 2 | 16/08/2023 | 7:48:49 | -414 |
| 3 | 16/08/2023 | 9:01:51 | -147 |
| 4 | 16/08/2023 | 9:05:54 | -119 |
| 5 | 16/08/2023 | 10:10:21 | 310 |
| 6 | 16/08/2023 | 10:15:17 | 353 |
| 7 | 16/08/2023 | 11:44:19 | 483 |
| 8 | 16/08/2023 | 11:48:08 | 458 |
| 9 | 16/08/2023 | 12:23:57 | 407 |
| 10 | 16/08/2023 | 12:27:17 | 411 |
| 11 | 16/08/2023 | 12:51:12 | 341 |
| 12 | 16/08/2023 | 12:54:12 | 361 |
| 13 | 16/08/2023 | 14:07:58 | 209 |
| 14 | 16/08/2023 | 14:11:49 | 185 |
| 15 | 16/08/2023 | 14:57:01 | 54 |
| 16 | 17/08/2023 | 7:45:47 | -495 |
| 17 | 17/08/2023 | 7:48:55 | -485 |

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

**Table A-11 Karuah River South Fork 2023 tidal flow gauging**

| No. | Date | Time | Flow ($m^3/s$) * |
|---|---|---|---|
| 1 | 16/08/2023 | 8:03:16 | -280 |
| 2 | 16/08/2023 | 8:07:18 | -264 |
| 3 | 16/08/2023 | 8:11:18 | -265 |
| 4 | 16/08/2023 | 9:14:37 | -98 |
| 5 | 16/08/2023 | 9:19:22 | -73 |
| 6 | 16/08/2023 | 10:25:40 | 212 |
| 7 | 16/08/2023 | 10:28:34 | 224 |
| 8 | 16/08/2023 | 10:31:37 | 233 |
| 9 | 16/08/2023 | 10:34:54 | 244 |
| 10 | 16/08/2023 | 12:02:22 | 255 |
| 11 | 16/08/2023 | 12:05:06 | 261 |
| 12 | 16/08/2023 | 12:34:21 | 205 |
| 13 | 16/08/2023 | 12:36:37 | 216 |
| 14 | 16/08/2023 | 13:01:02 | 176 |
| 15 | 16/08/2023 | 13:03:22 | 181 |
| 16 | 16/08/2023 | 14:27:52 | 100 |
| 17 | 16/08/2023 | 14:30:57 | 86 |
| 18 | 16/08/2023 | 15:02:47 | 26 |
| 19 | 17/08/2023 | 7:55:15 | -314 |
| 20 | 17/08/2023 | 7:57:48 | -298 |

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

**Table A-12 Twelve Mile Creek 2023 tidal flow gauging**

| No. | Date | Time | Flow ($m^3/s$) * |
|---|---|---|---|
| 1 | 16/11/2023 | 10:33:53 | -223 |
| 2 | 16/11/2023 | 10:36:24 | -229 |

* 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 3.3. Note that all measurements are at a different stage of the tidal cycle so the magnitude of flow will vary. The primary purpose is to illustrate flow distribution across the channel. Profiles taken at Soldiers Point and North Arm Cove were collected with the RiverPro ADCP and are not displayed due to a different data format.

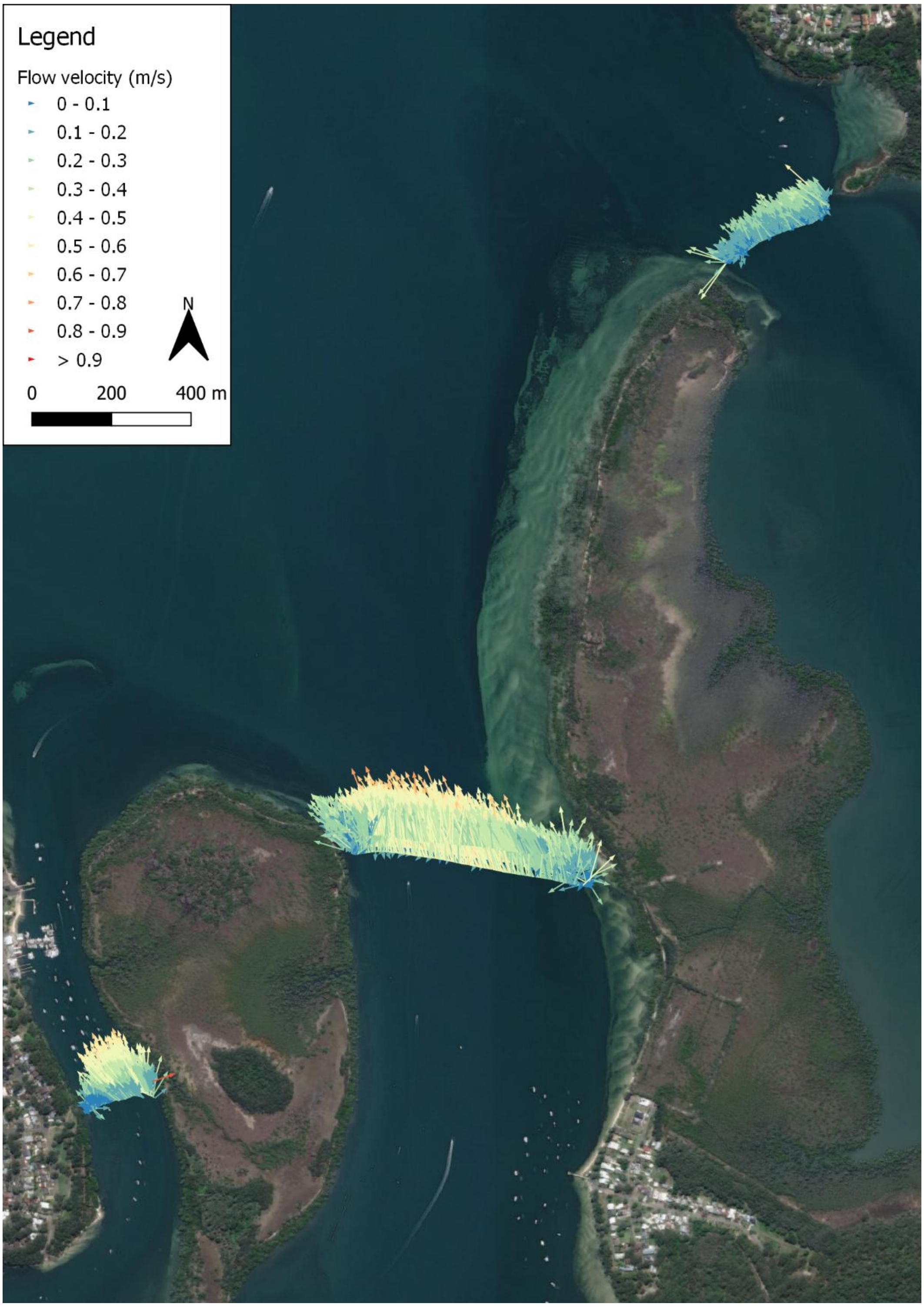


**Figure A-16 Ebb tide channel flow distribution Tilligerry Creek and Cromartys Bay**

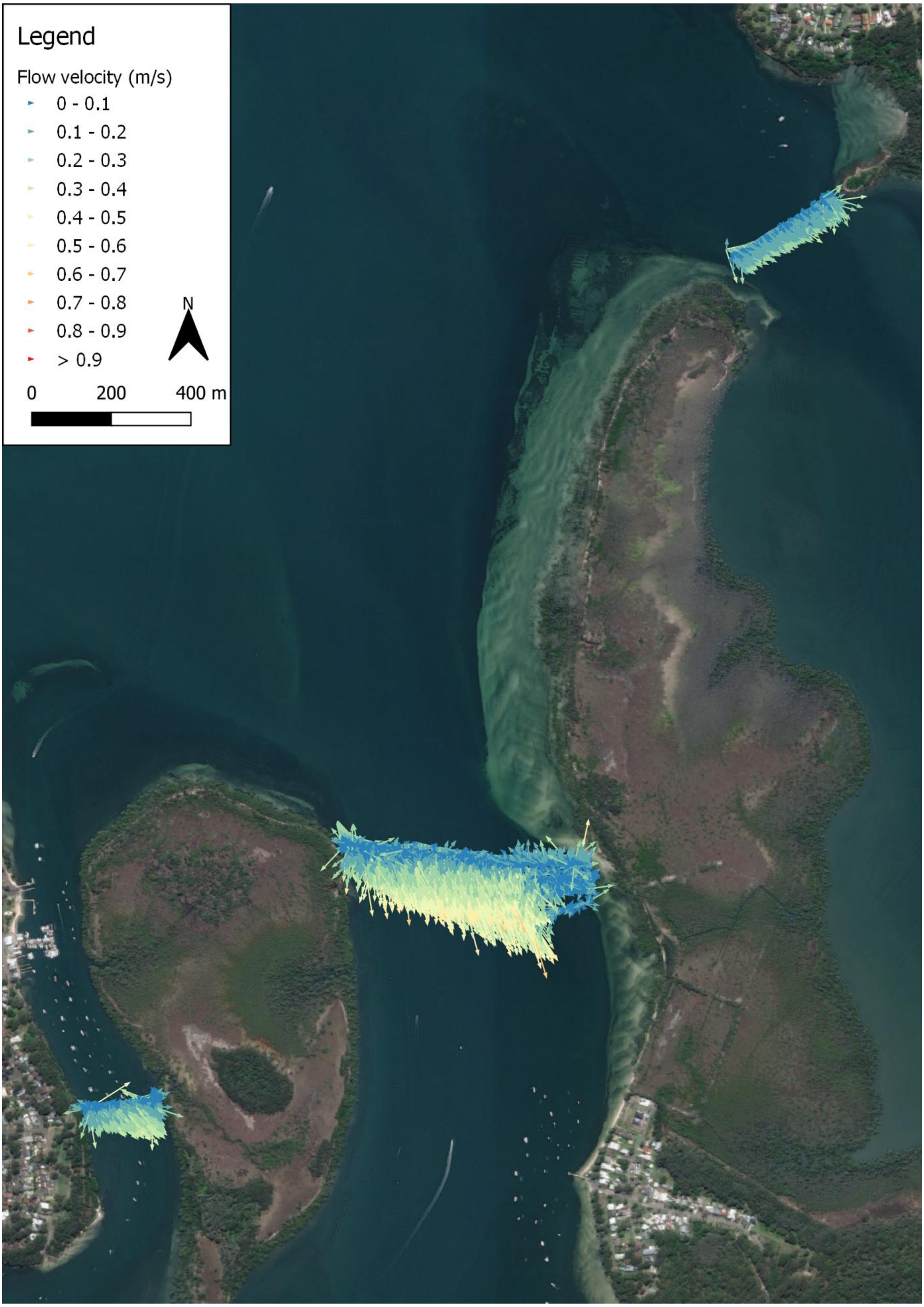


**Figure A-17 Flood tide channel flow distribution Tilligerry Creek and Cromartys Bay**

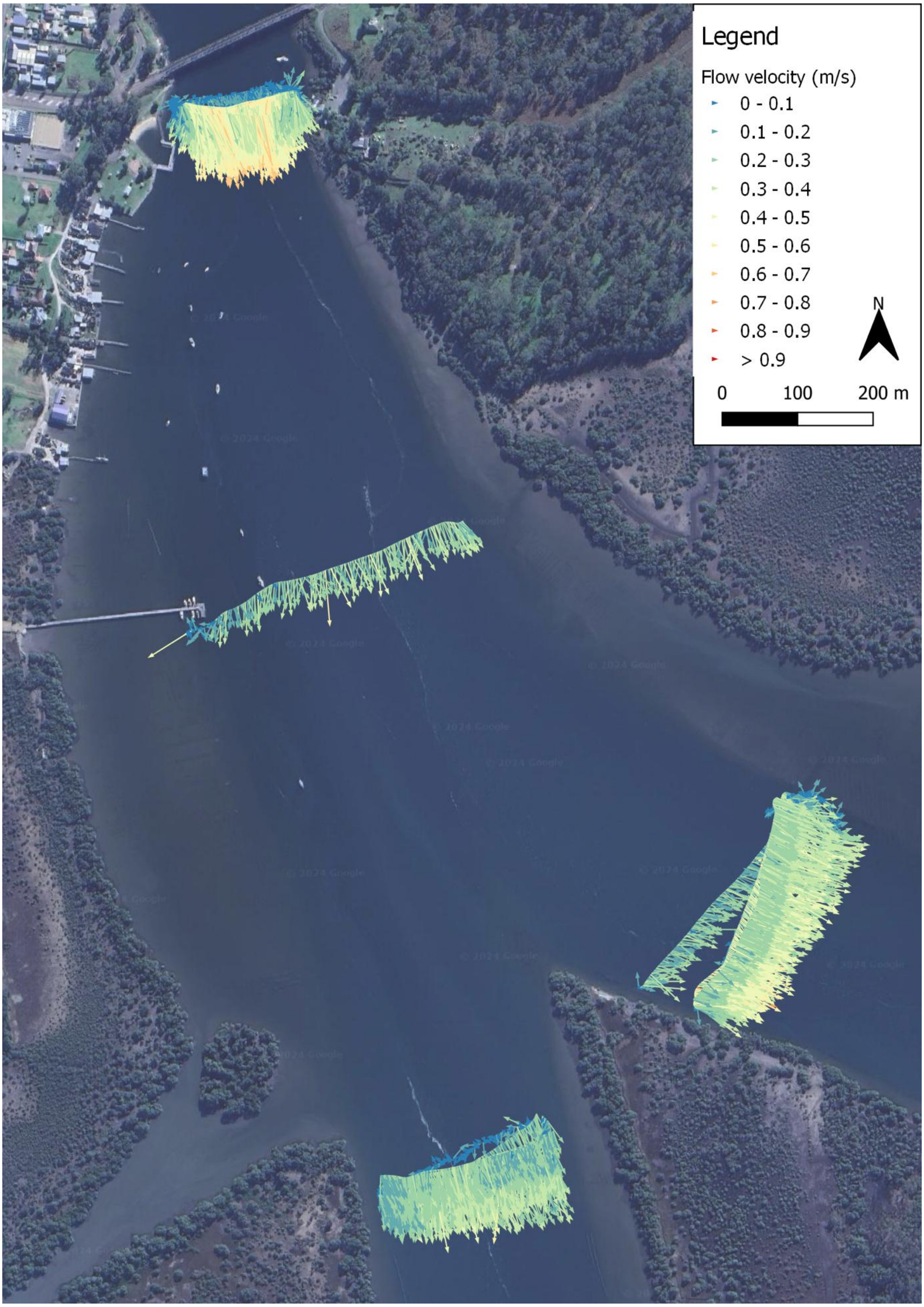


**Figure A-18 Ebb tide channel flow distribution at Karuah**

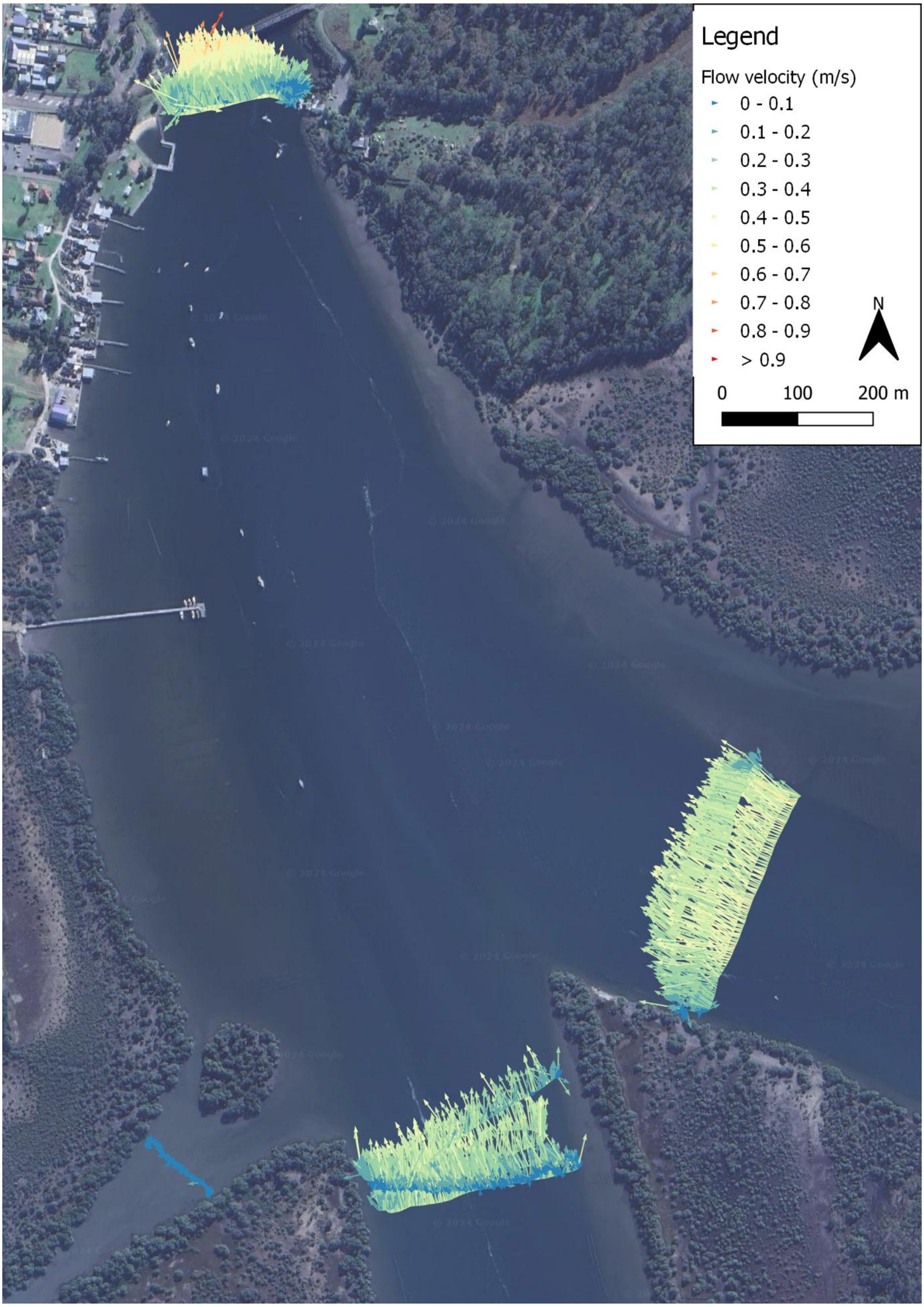


**Figure A-19 Flood tide channel flow distribution at Karuah**

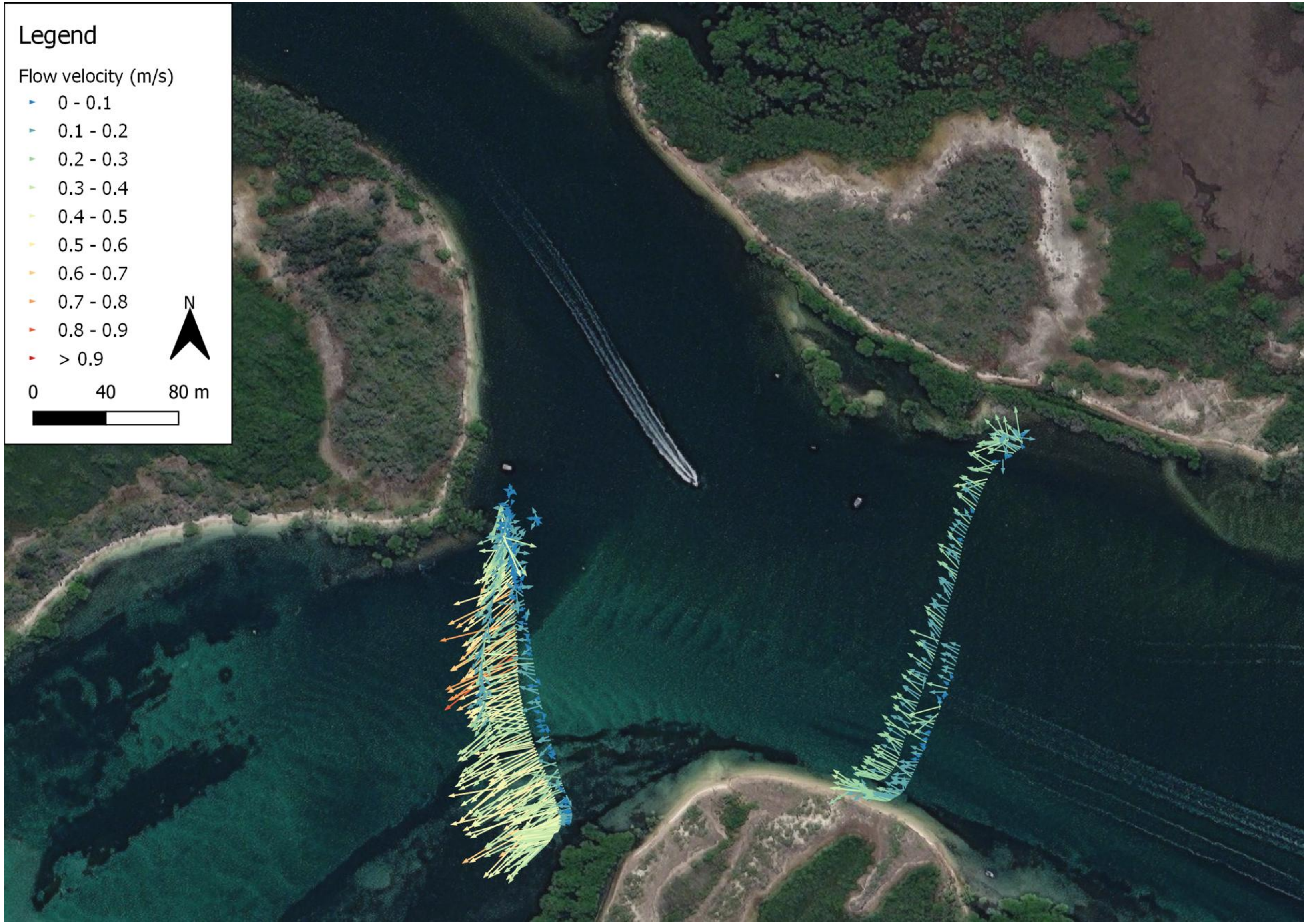


**Figure A-20 Ebb tide channel flow distribution at Myall River**


**Figure A-21 Transitional channel flow distribution at Myall River**

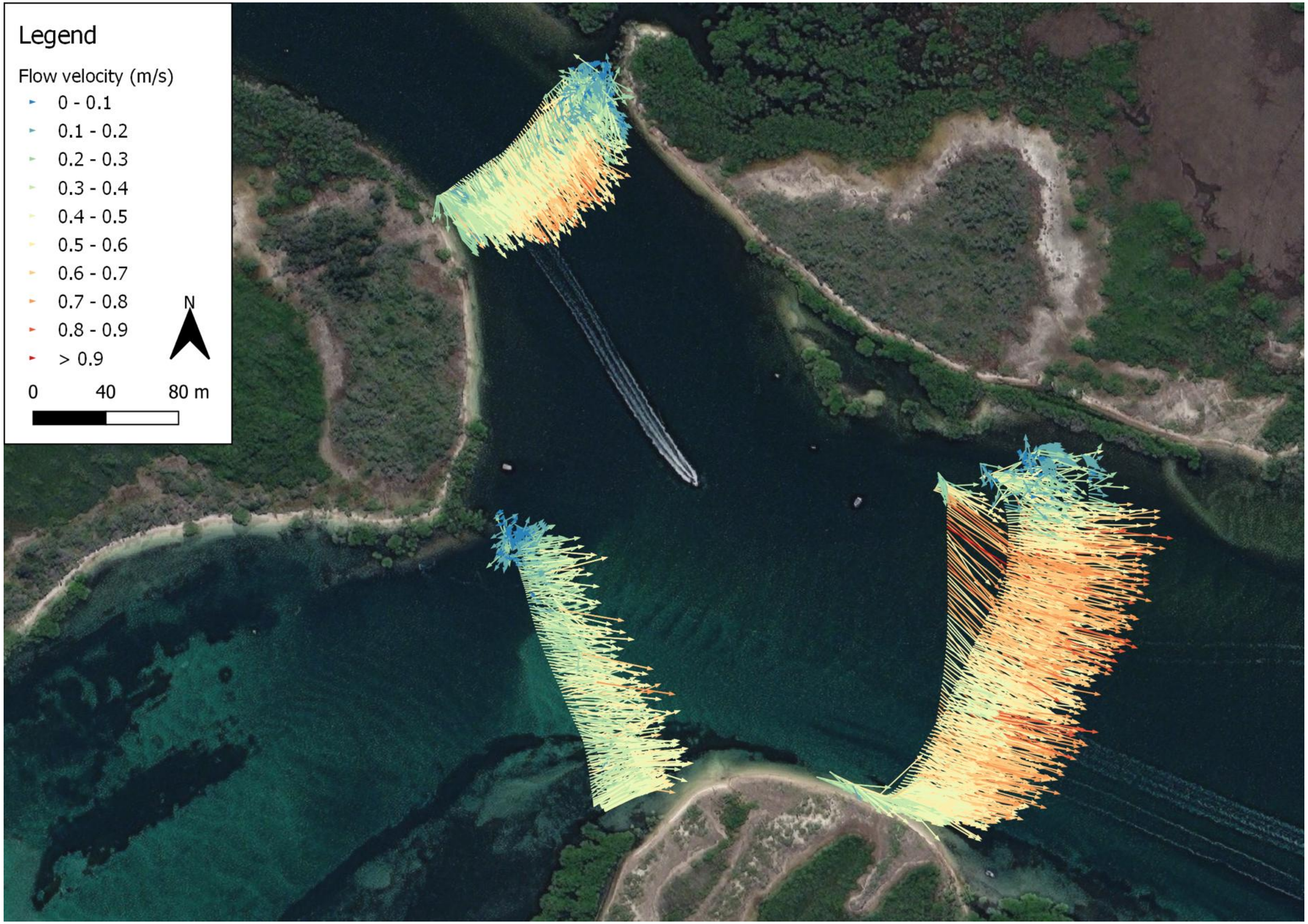


**Figure A-22 Flood tide channel flow distribution at Myall River**

# 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 stratification was 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.

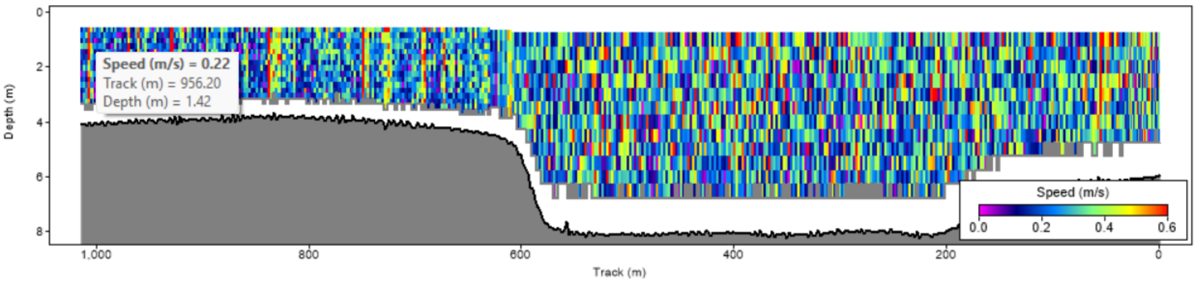


**Figure A-23 Vertical velocity distribution – East Bay – outgoing flow – (2023/11/14 13:34:42)**

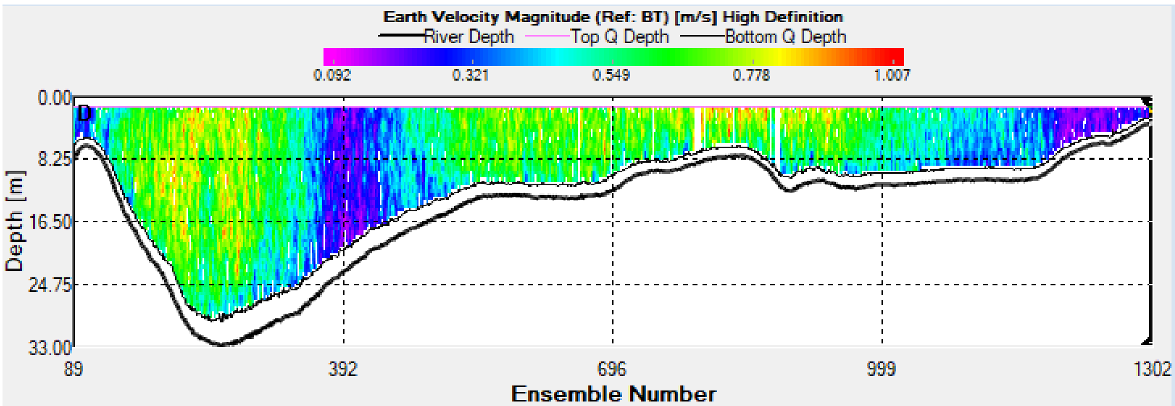


**Figure A-24 Vertical velocity distribution – Soldiers Point– incoming flow – (2023/11/15 08:35:00)**

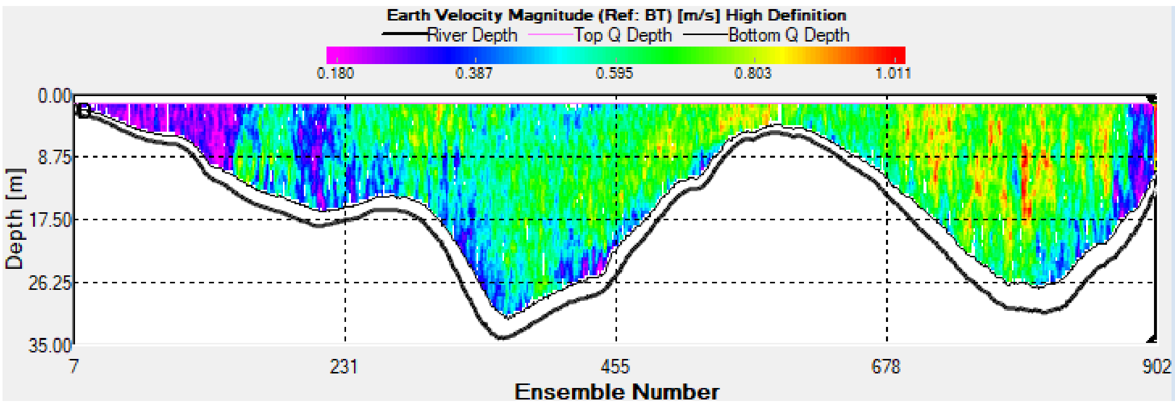


**Figure A-25 Vertical velocity distribution – Soldiers Point– outgoing flow – (2023/11/15 12:14:00)**

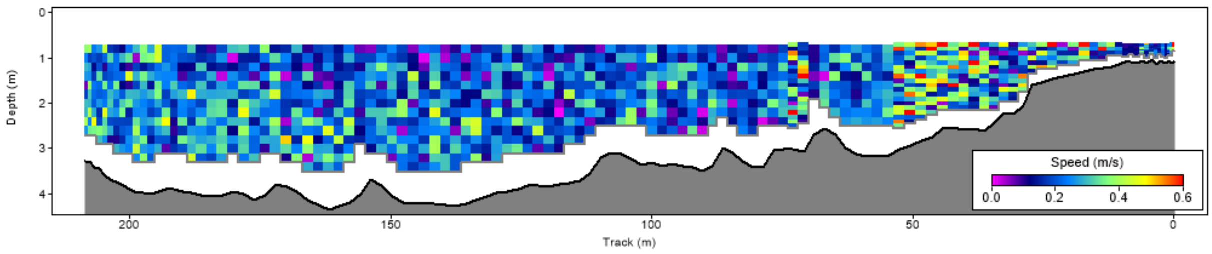


**Figure A-26 Vertical velocity distribution – Myall River Site 5 – outgoing flow – (2023/11/15 11:09:03)**

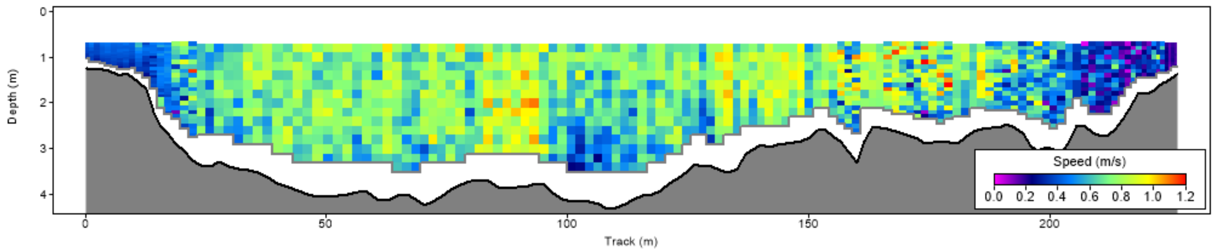


**Figure A-27 Vertical velocity distribution – Myall River Site 5 – incoming flow – (2023/11/15 08:52:52)**

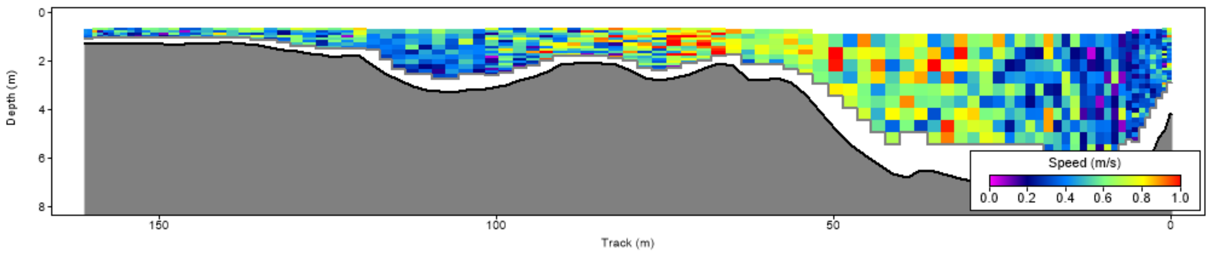


**Figure A-28 Vertical velocity distribution – Myall River Corrie Island North – outgoing flow – (2023/11/15 11:04:06)**

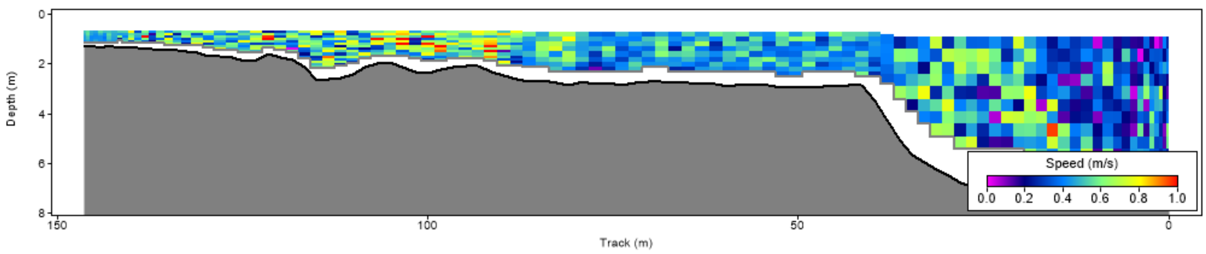


**Figure A-29 Vertical velocity distribution – Myall River Corrie Island North – incoming flow – (2023/11/15 08:52:09)**

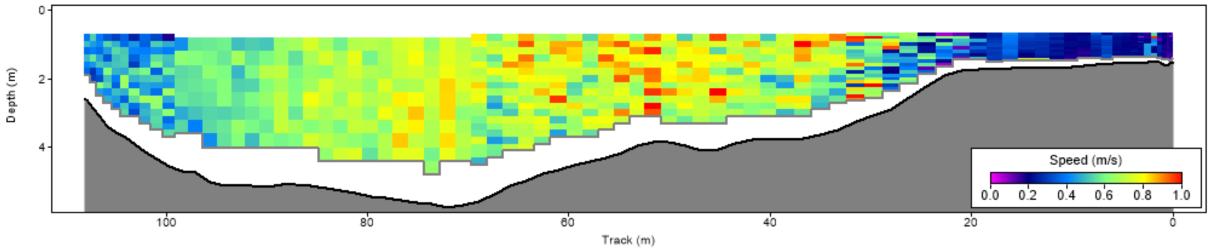


**Figure A-30 Vertical velocity distribution – Myall River Corrie Island South – incoming flow – (2023/11/15 08:59:30)**

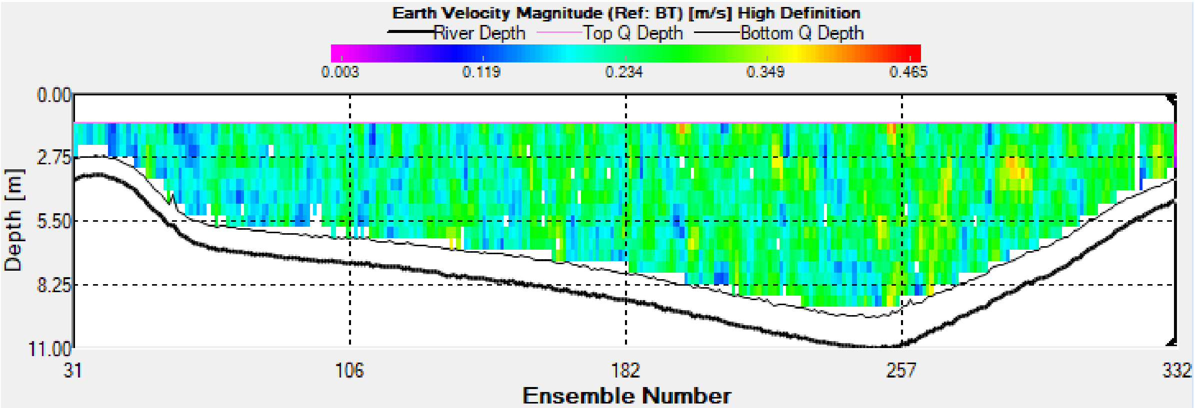


**Figure A-31 Vertical velocity distribution – North Arm Cove – incoming flow – (2023/11/15 07:51:00)**

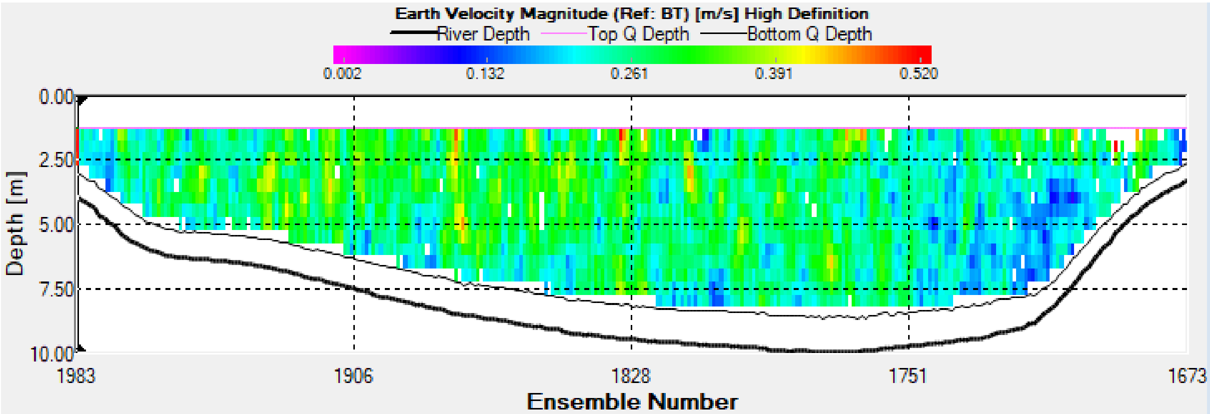


**Figure A-32 Vertical velocity distribution – North Arm Cove – outgoing flow – (2023/11/15 12:24:00)**

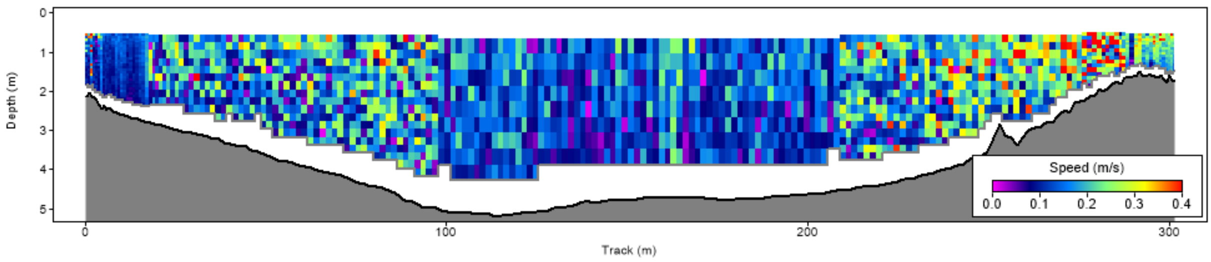


**Figure A-33 Vertical velocity distribution – Cromartys Bay – outgoing flow – (2023/11/14 09:59:35)**

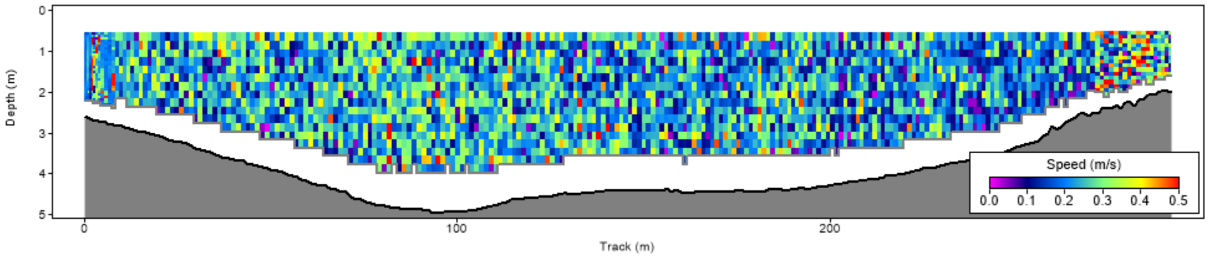


**Figure A-34 Vertical velocity distribution – Cromartys Bay – incoming flow – (2023/11/14 07:09:41)**

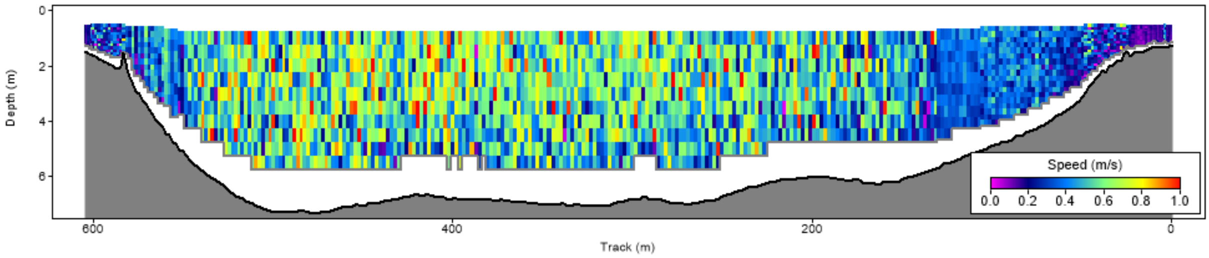


**Figure A-35 Vertical velocity distribution – Tilligerry Creek – outgoing flow – (2023/11/14 10:57:28)**

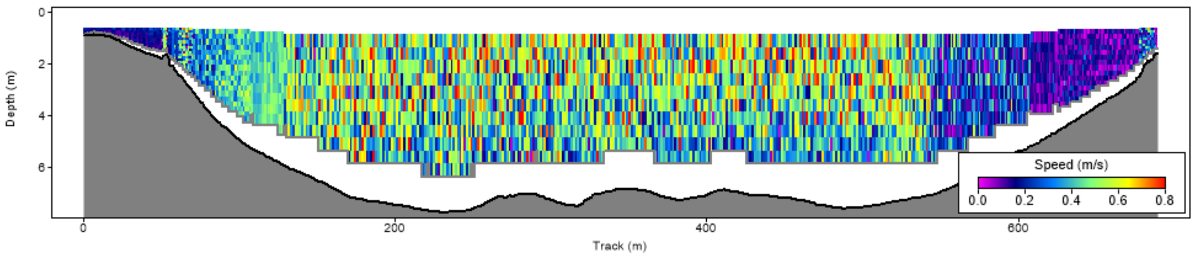


**Figure A-36 Vertical velocity distribution – Tilligerry Creek – incoming flow – (2023/11/14 05:58:33)**

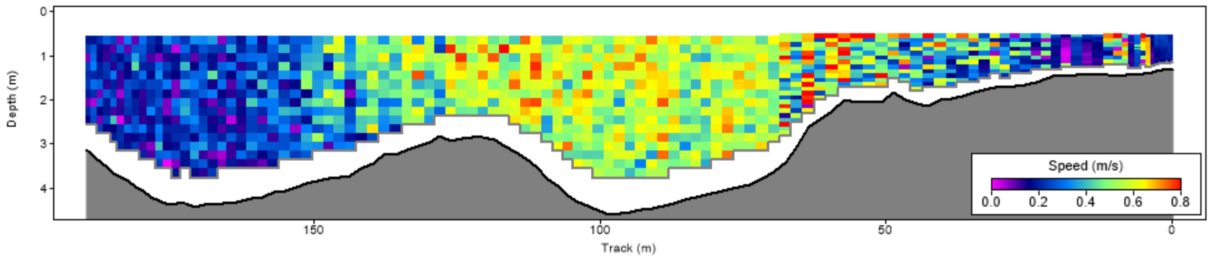


**Figure A-37 Vertical velocity distribution – Bulls Island West – outgoing flow – (2023/11/14 10:35:56)**

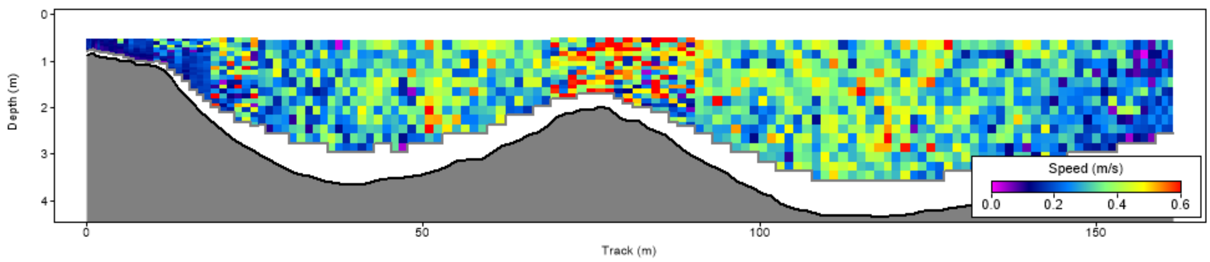


**Figure A-38 Vertical velocity distribution – Bulls Island West – incoming flow – (2023/11/14 06:41:26)**

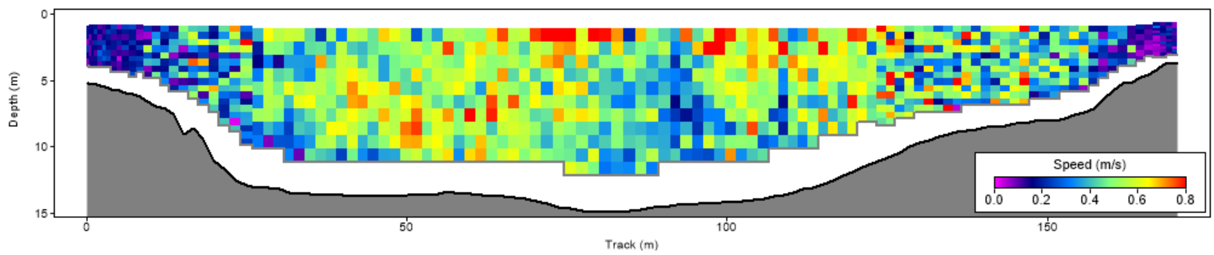


**Figure A-39 Vertical velocity distribution – Karuah River Site 17– outgoing flow – (2023/08/16 11:12:34)**

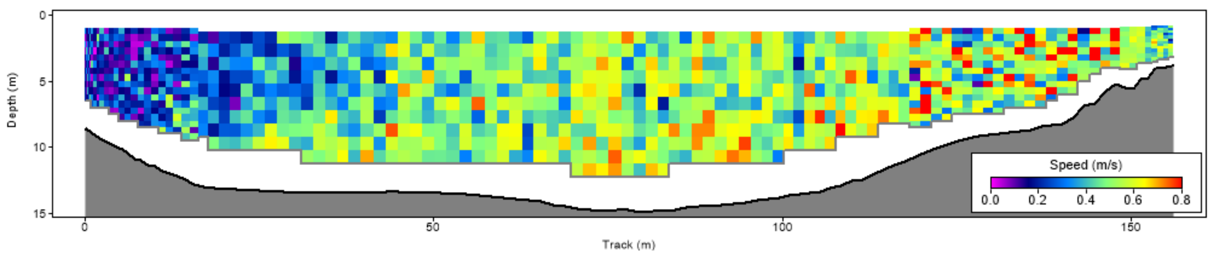


**Figure A-40 Vertical velocity distribution – Karuah River Site 17– incoming flow – (2023/08/17 07:30:36)**

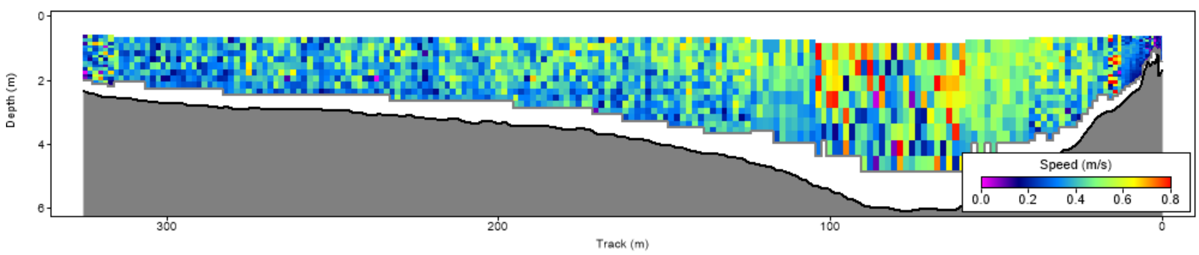


**Figure A-41 Vertical velocity distribution – Karuah River North Fork – outgoing flow – (2023/08/16 11:44:19)**

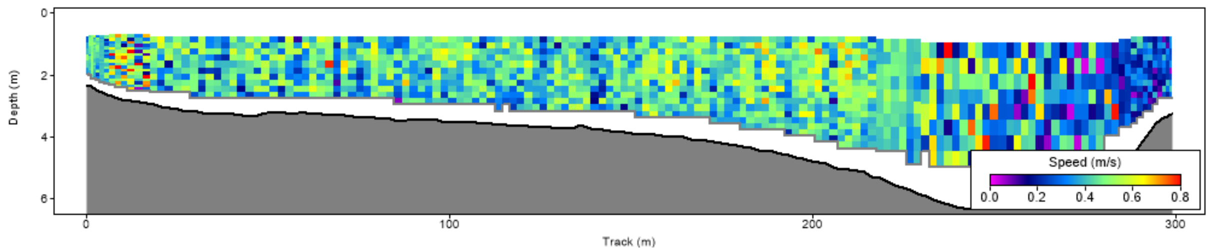


**Figure A-42 Vertical velocity distribution – Karuah River North Fork – incoming flow – (2023/08/17 07:45:47)**

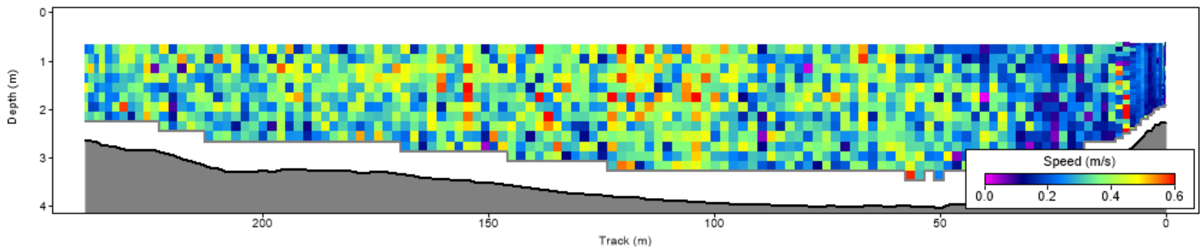


**Figure A-43 Vertical velocity distribution – Karuah River South Fork– outgoing flow – (2023/08/16 12:05:06)**

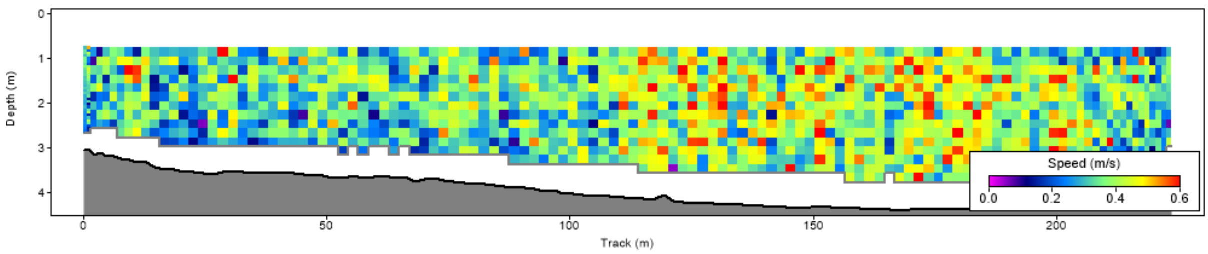


**Figure A-44 Vertical velocity distribution – Karuah River South Fork– incoming flow – (2023/08/17 07:55:15)**

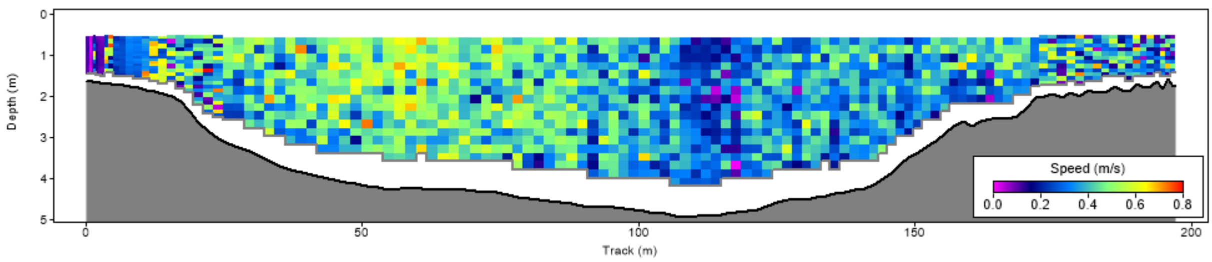


**Figure A-45 Vertical velocity distribution – Twelve Mile Creek – incoming flow – (2023/11/15 10:36:24)**

# Appendix B Model calibration

## B1 Hydrodynamic calibration results

The below figures summarise results from the Port Stephens hydrodynamic calibration and verification process. For more information, refer to Section 4.5. Note the y-axis for flow at the Entrance and Soldiers Point locations is different to all other locations.

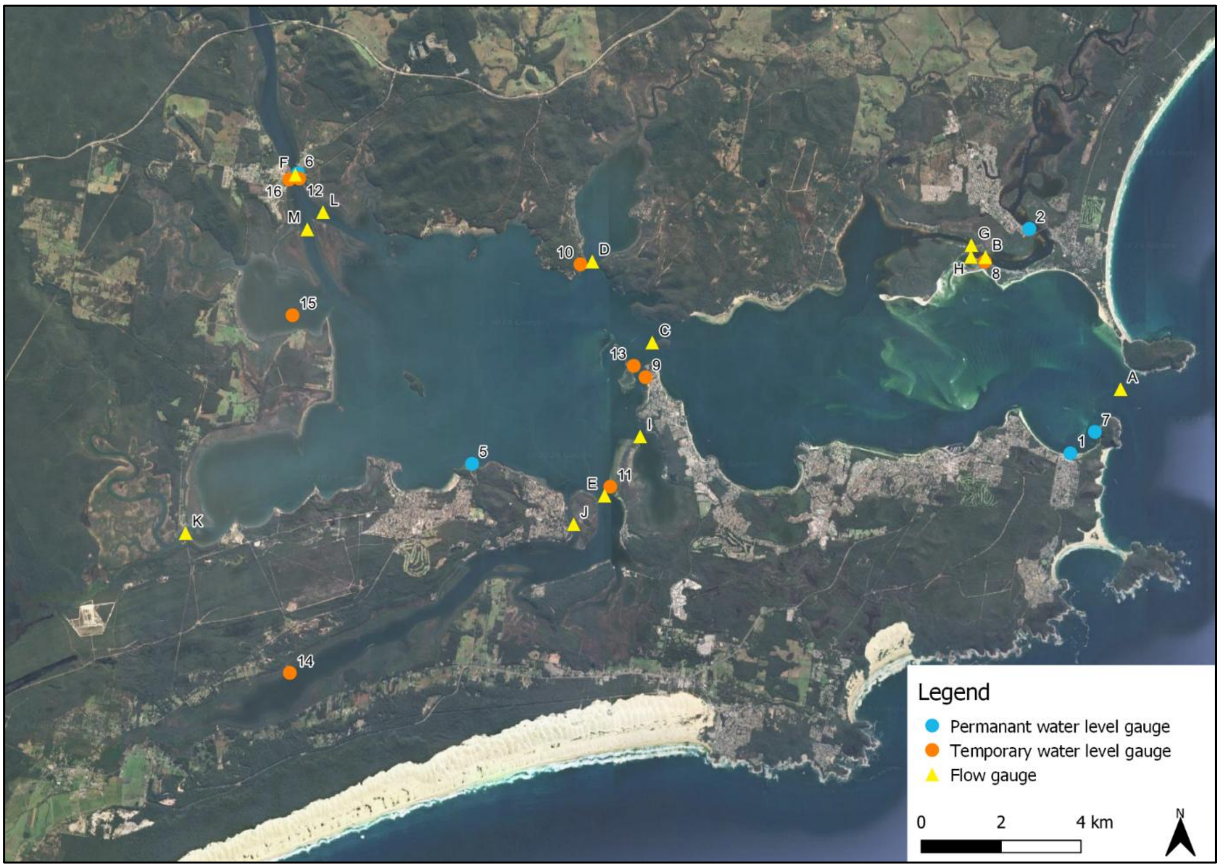


**Figure B-1 Water level and tidal flow gauging locations**

## B1.1 Tidal flow gauging calibration – 1993

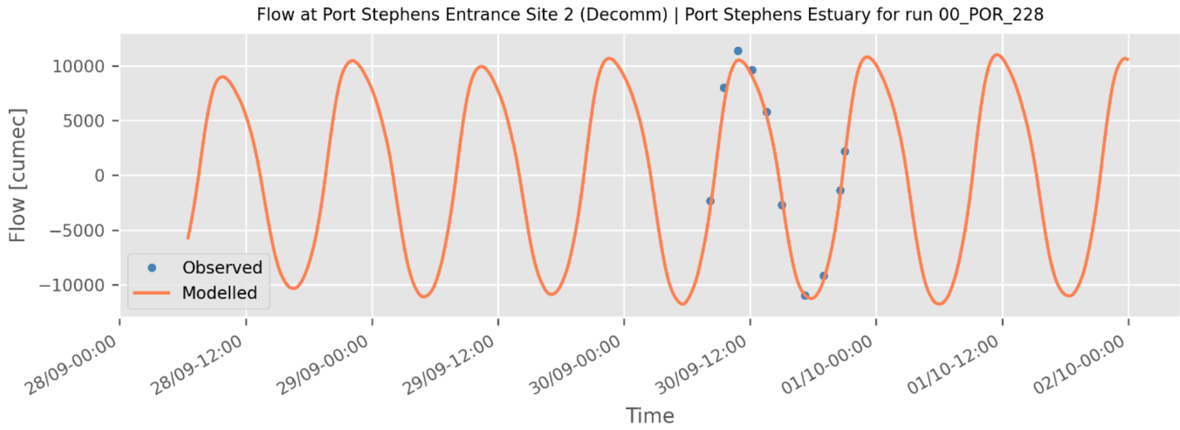


**Figure B-2 1993 tidal flow calibration – Location A – Entrance**

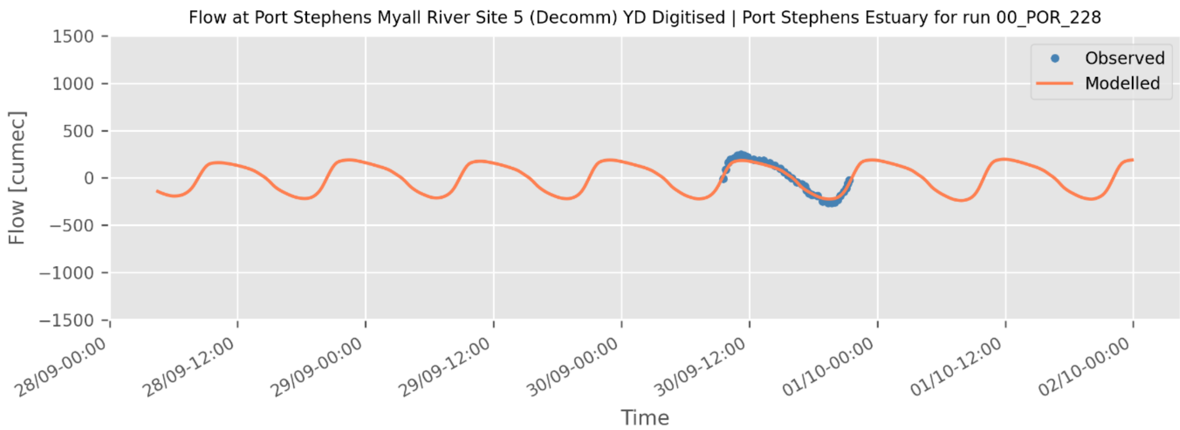


**Figure B-3 1993 tidal flow calibration – Location B – Myall River**

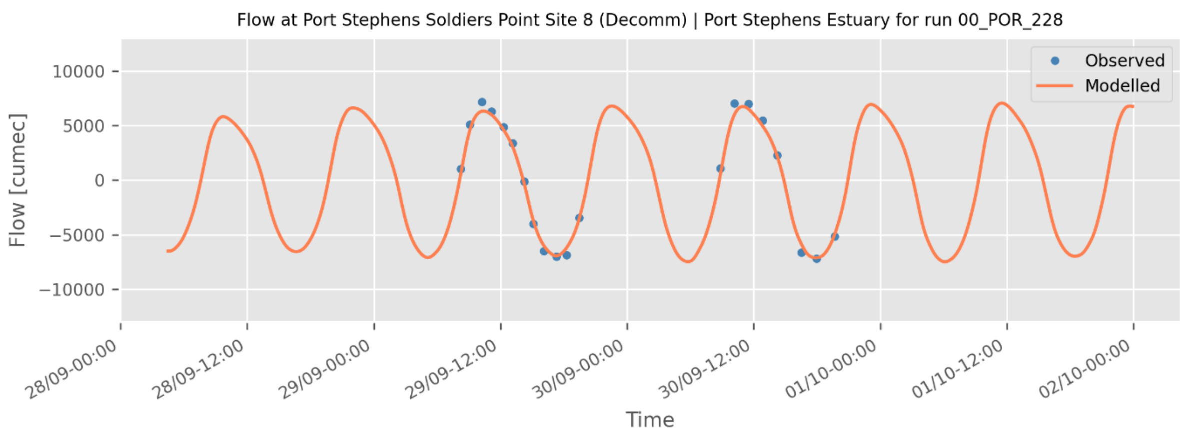


**Figure B-4 1993 tidal flow calibration – Location C – Soldiers Point**

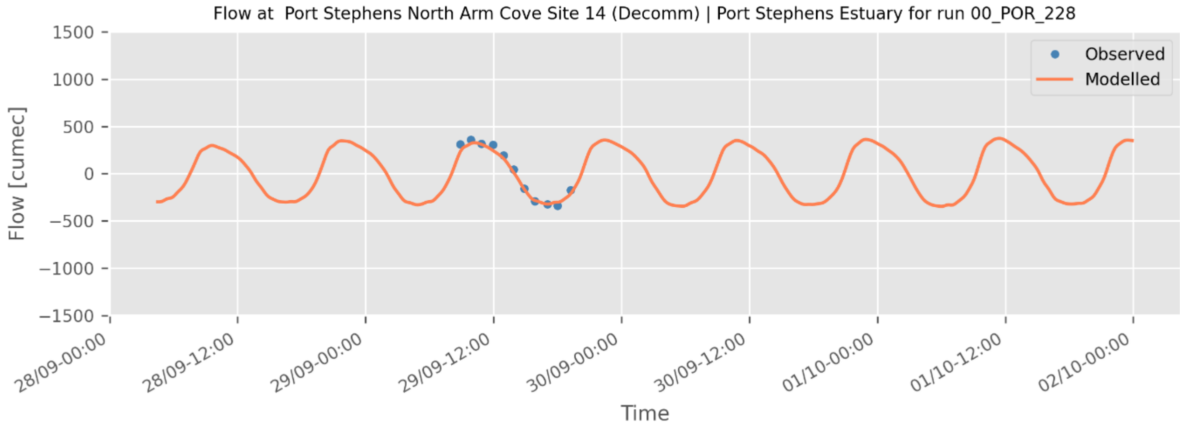


**Figure B-5 1993 tidal flow calibration – Location D – North Arm Cove**

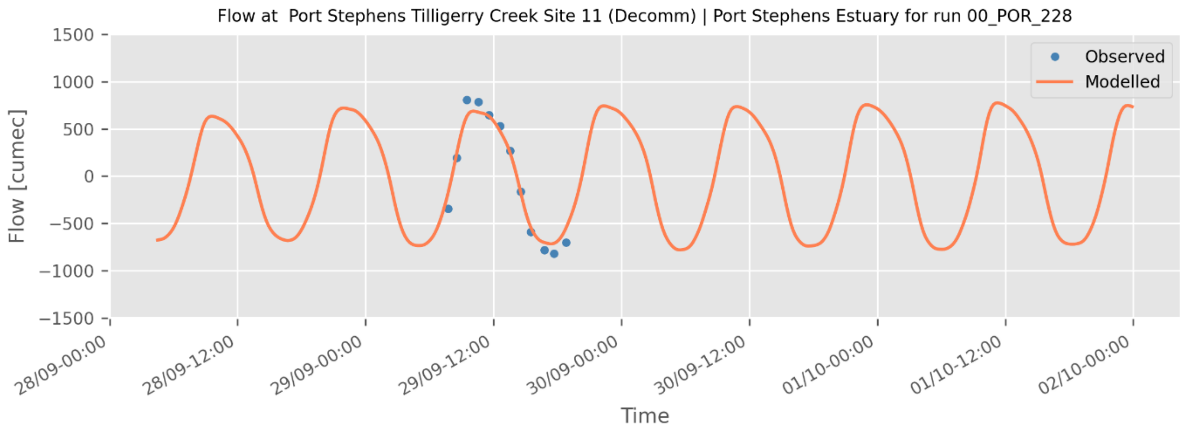


**Figure B-6 1993 tidal flow calibration – Location E – Tilligerry Creek**

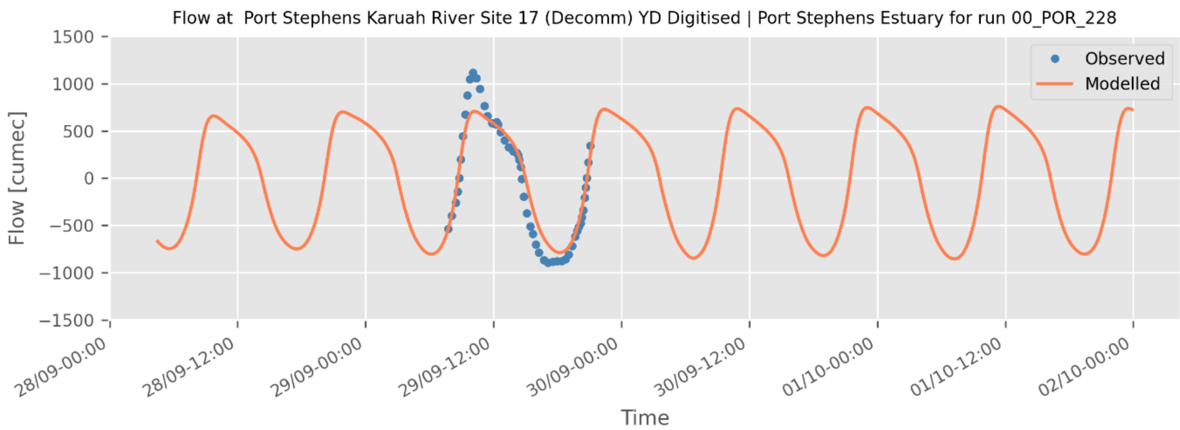


**Figure B-7 1993 tidal flow calibration – Location F – Karuah**

## B1.2 Water level calibration – 1993

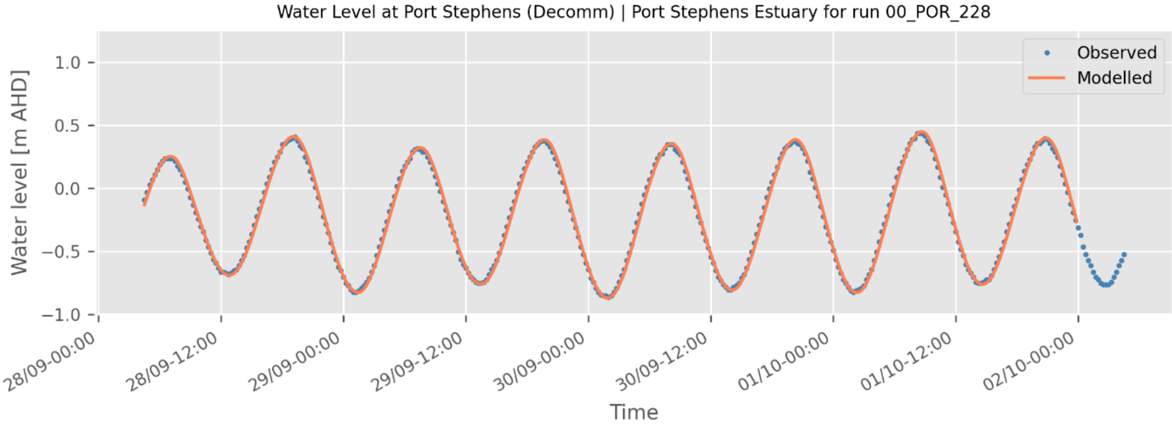


**Figure B-8 1993 water level calibration – Location 7 – Port Stephens**

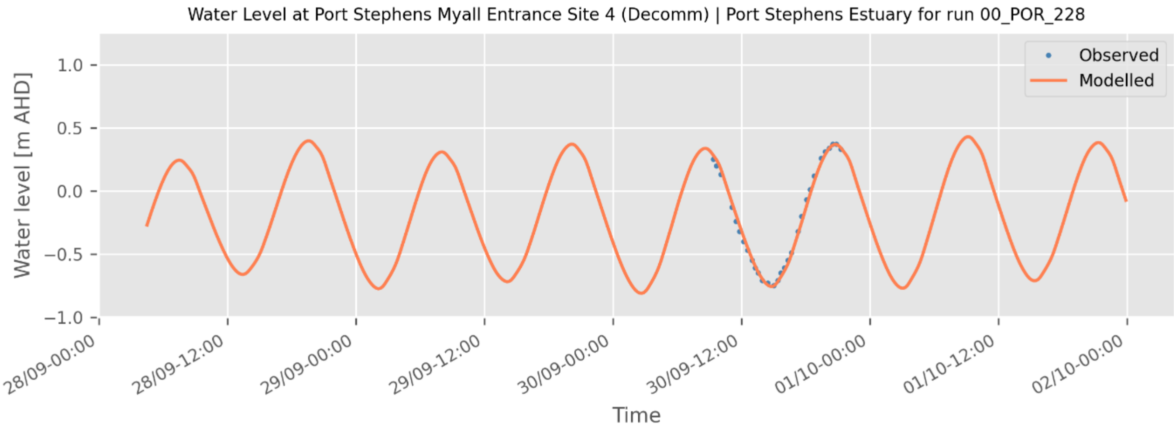


**Figure B-9 1993 water level calibration – Location 8 – Myall Entrance**

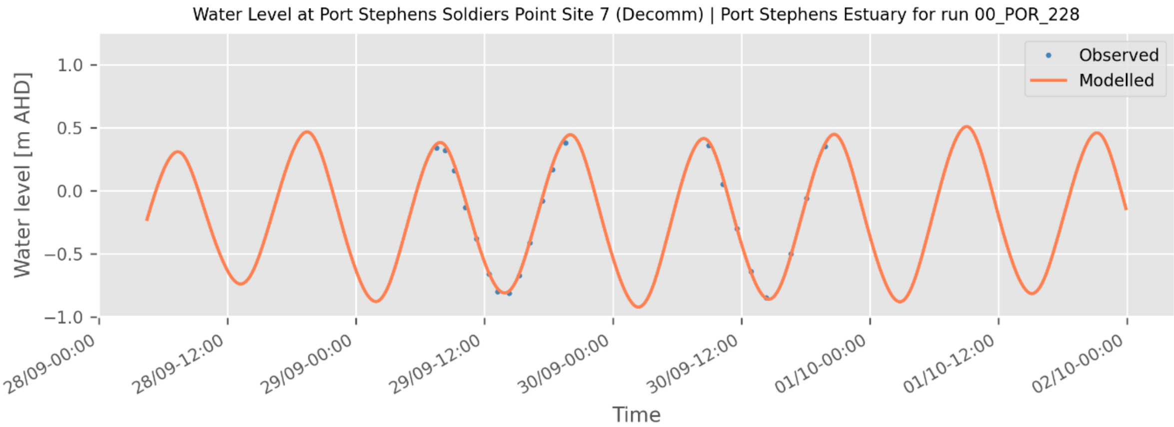


**Figure B-10 1993 water level calibration – Location 9 – Soldiers Point**

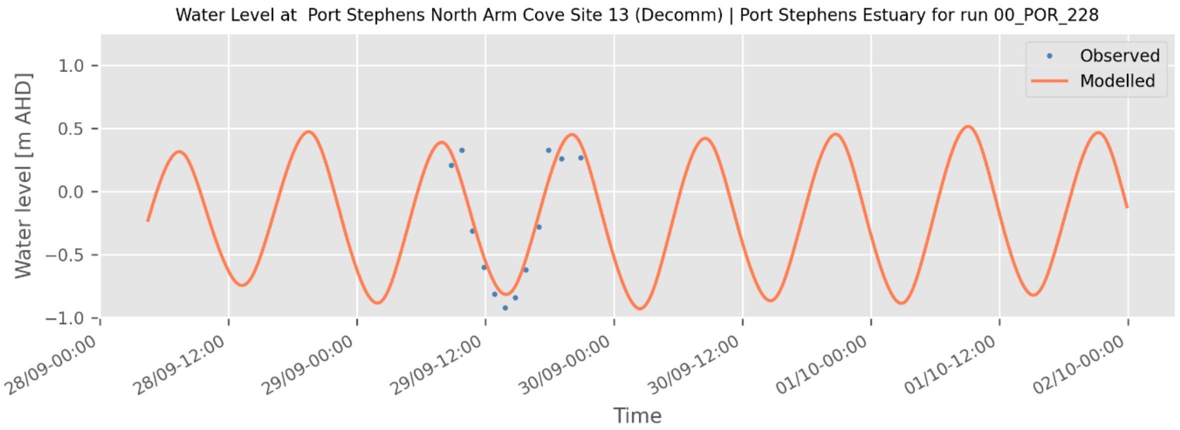


**Figure B-11 1993 water level calibration – Location 10 – North Arm Cove**

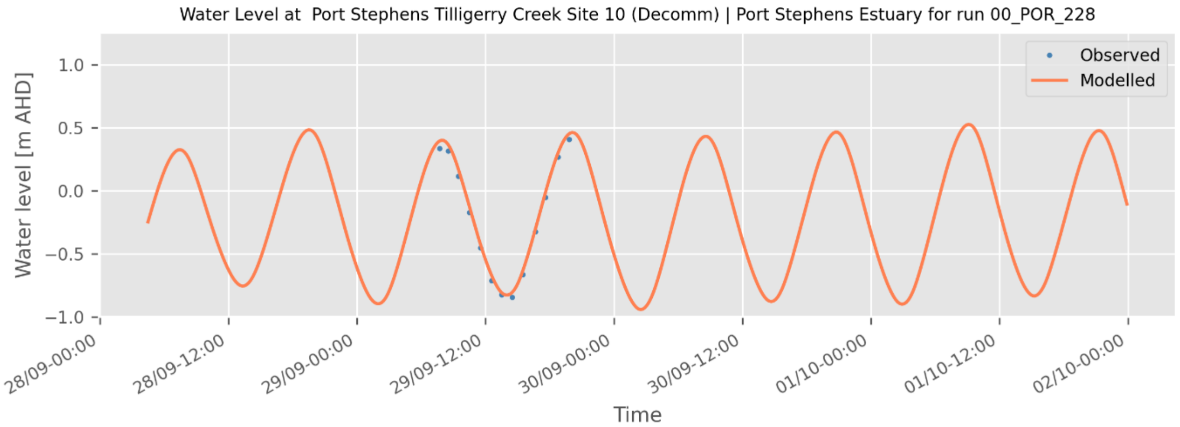


**Figure B-12 1993 water level calibration – Location 11 – Tilligerry Creek**

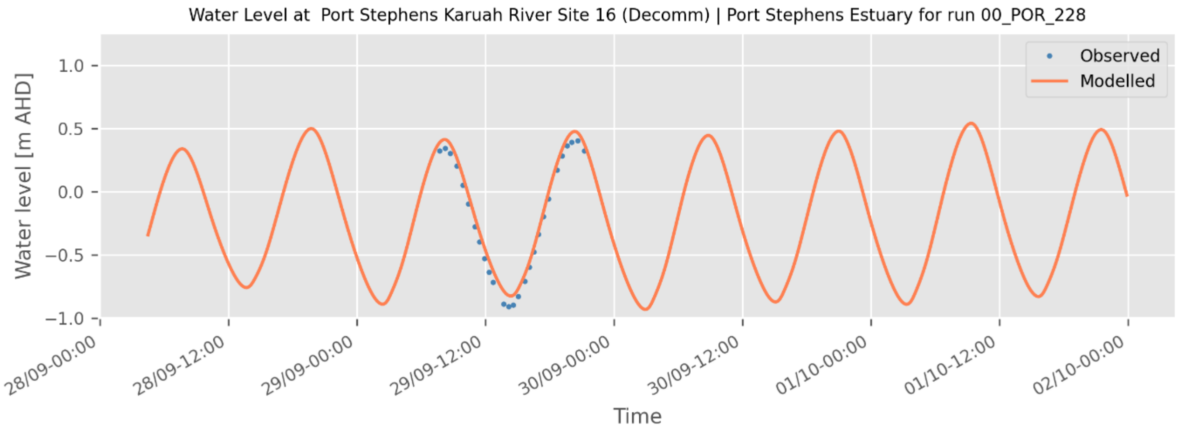


**Figure B-13 1993 water level calibration – Location 12 – Karuah River**

## B1.3 Tidal flow gauging verification – August 2023

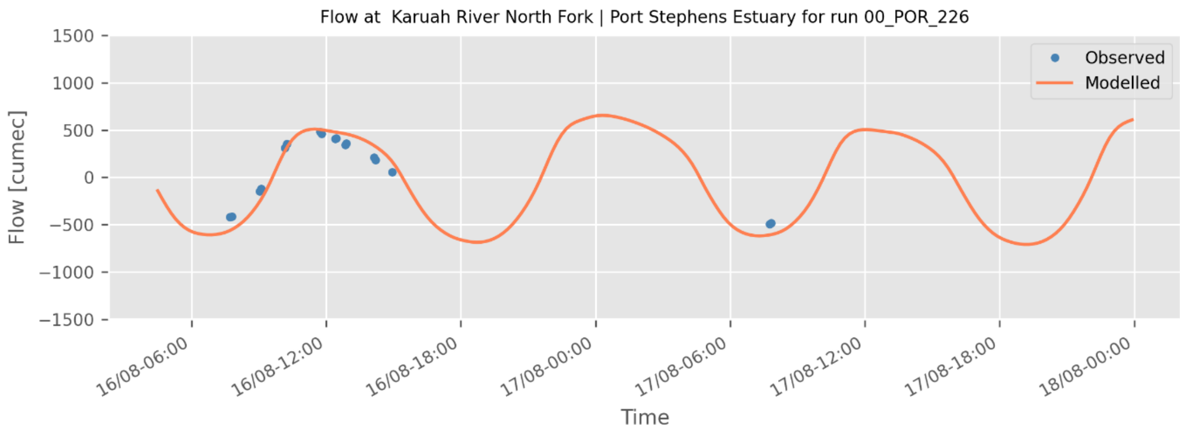


**Figure B-14 August 2023 tidal flow verification – Location L – Karuah River North Fork**

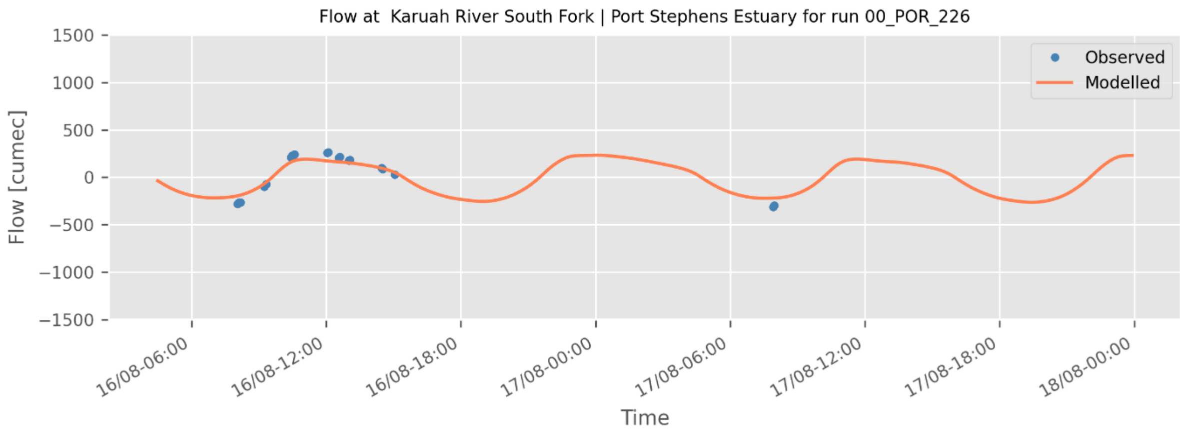


**Figure B-15 August 2023 tidal flow verification – Location M – Karuah River South Fork**

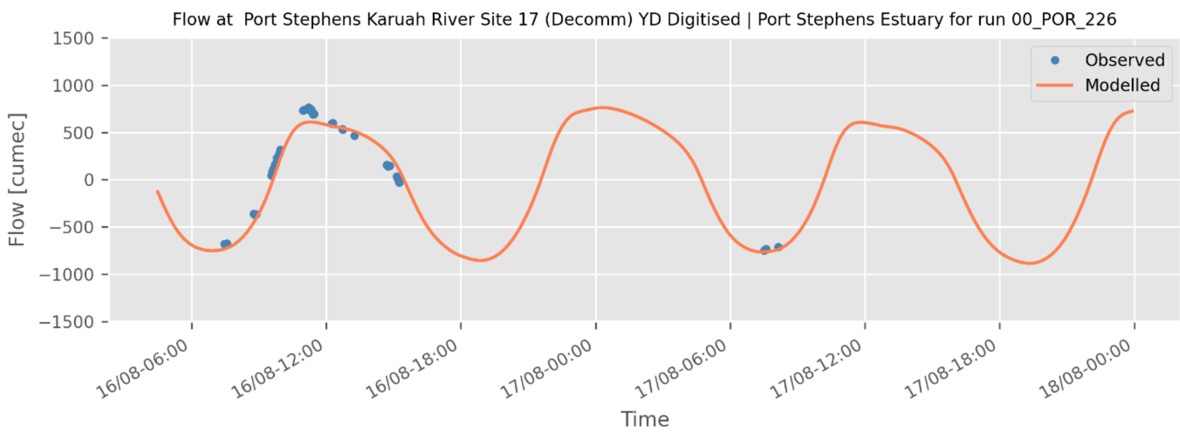


**Figure B-16 August 2023 tidal flow verification – Location F – Karuah**

## B1.4 Water level verification – August 2023

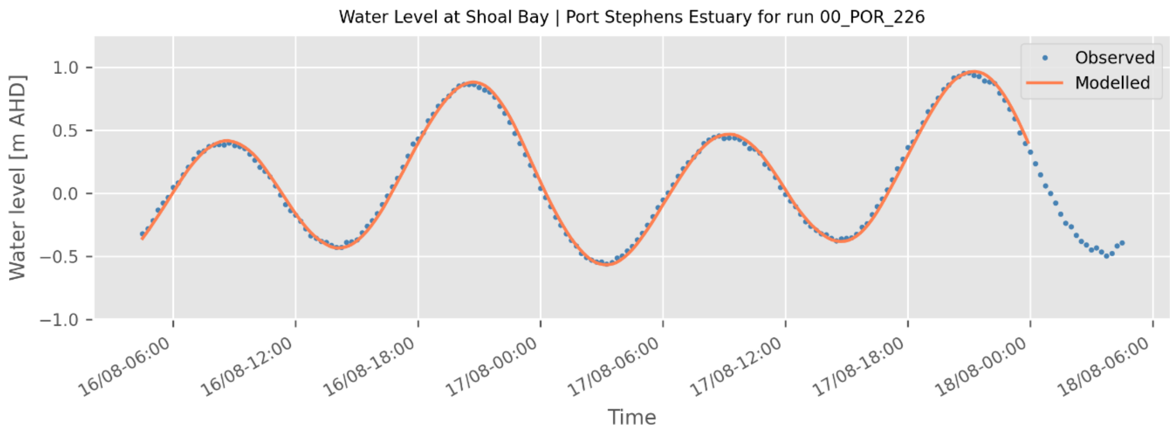


**Figure B-17 August 2023 water level verification – Location 1 – Shoal Bay**

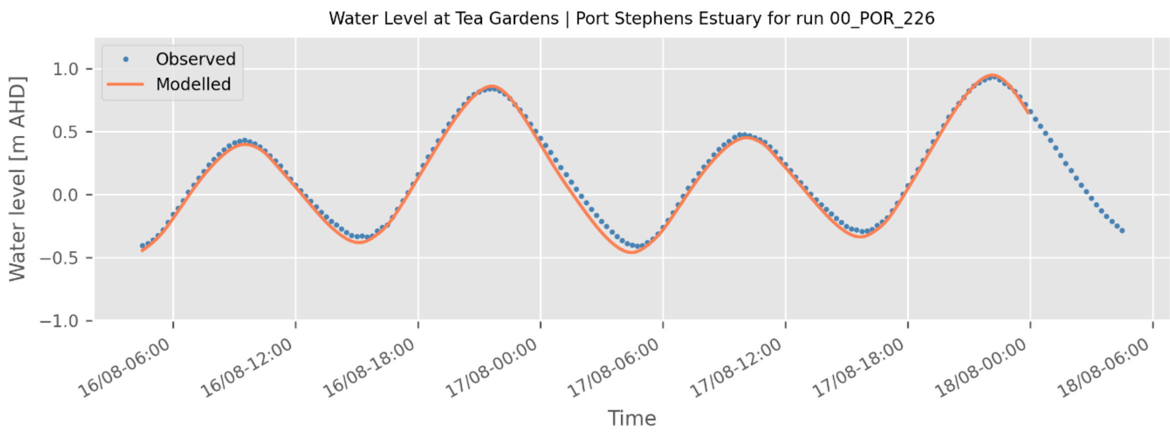


**Figure B-18 August 2023 water level verification – Location 2 – Tea Gardens**

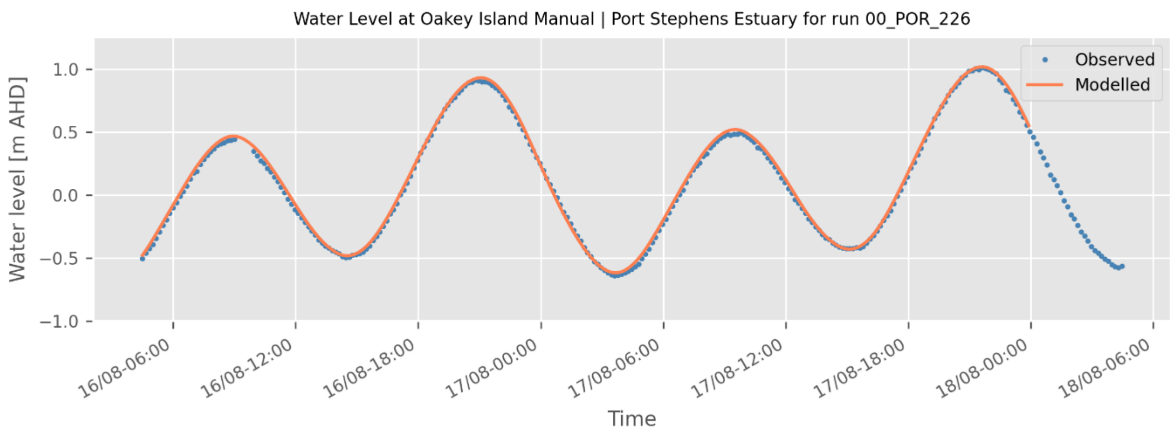


**Figure B-19 August 2023 water level verification – Location 13 – Oakey Island**

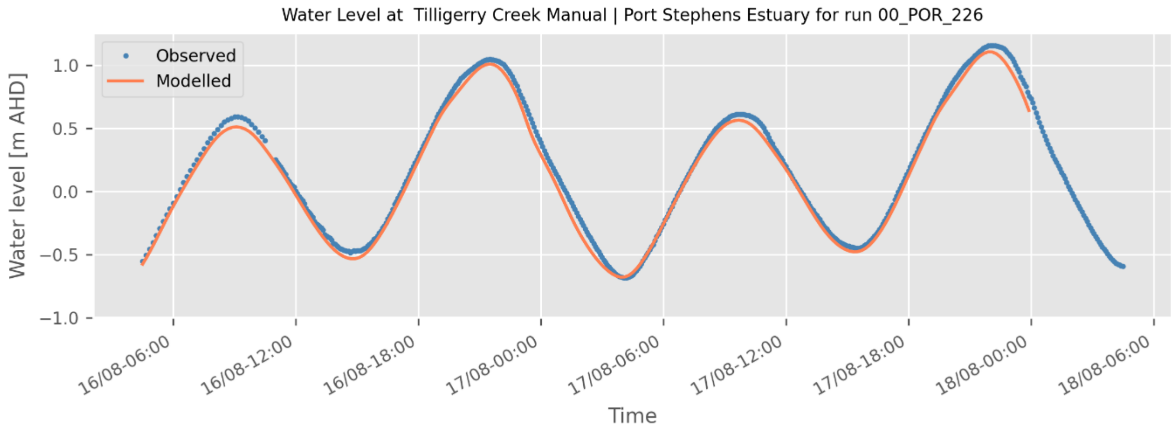


**Figure B-20 August 2023 water level verification – Location 11 – Tilligerry Creek**

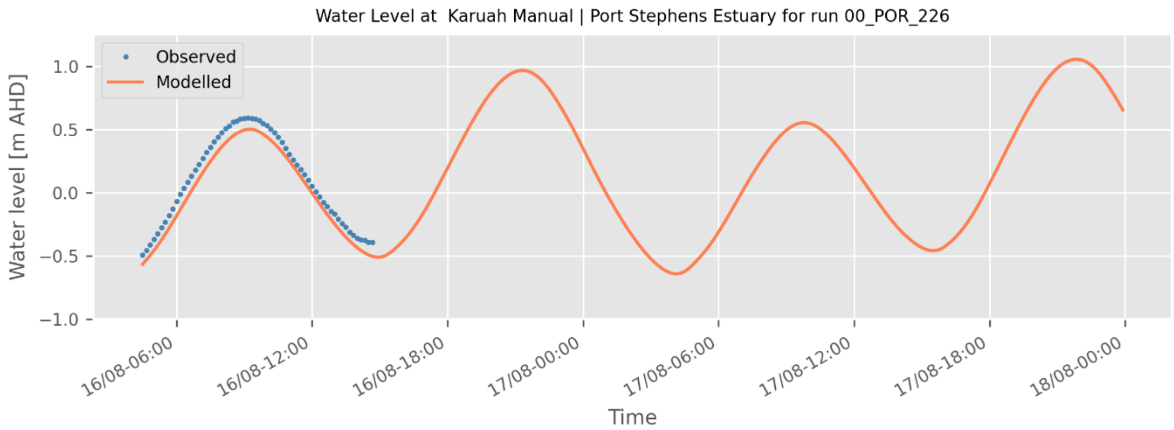


**Figure B-21 August 2023 water level verification – Location 16 – Karuah Jetty**

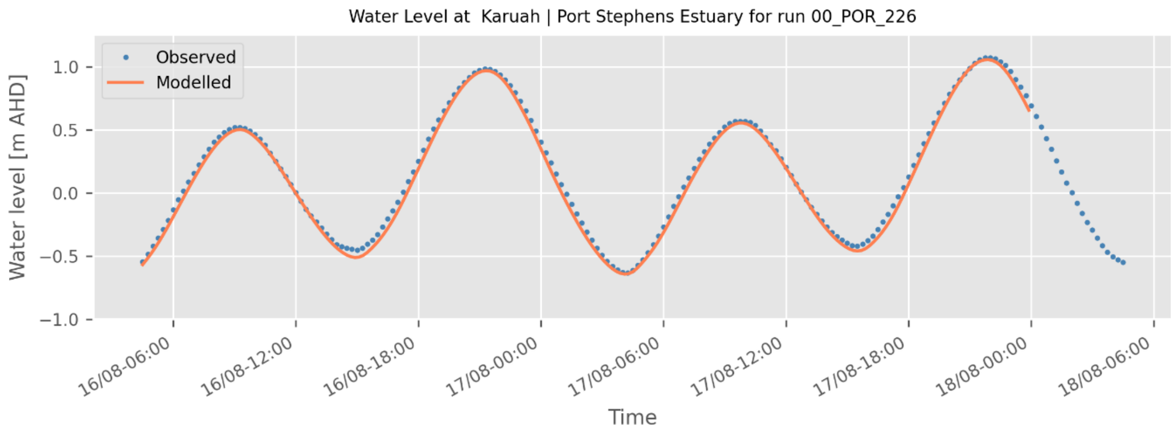


**Figure B-22 August 2023 water level verification – Location 6 – Karuah**

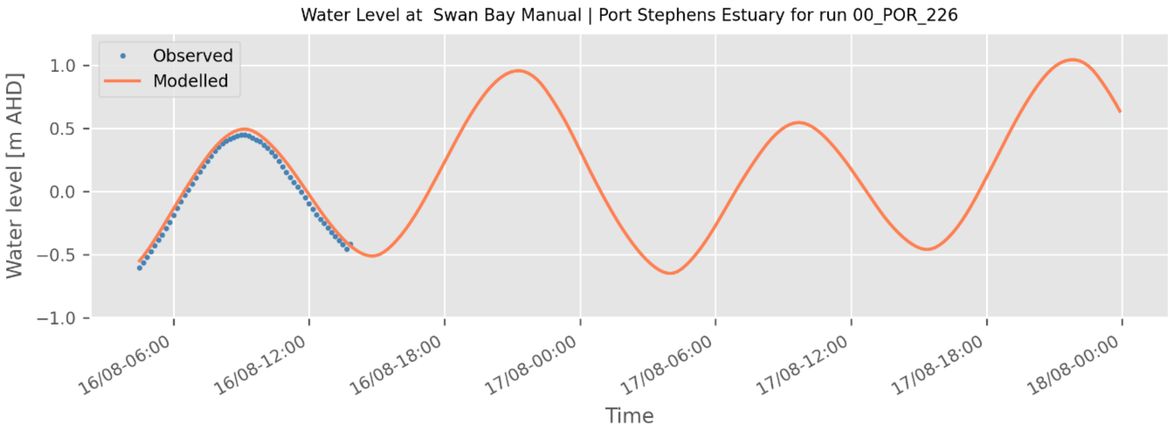


**Figure B-23 August 2023 water level verification – Location 15 – Swan Bay**

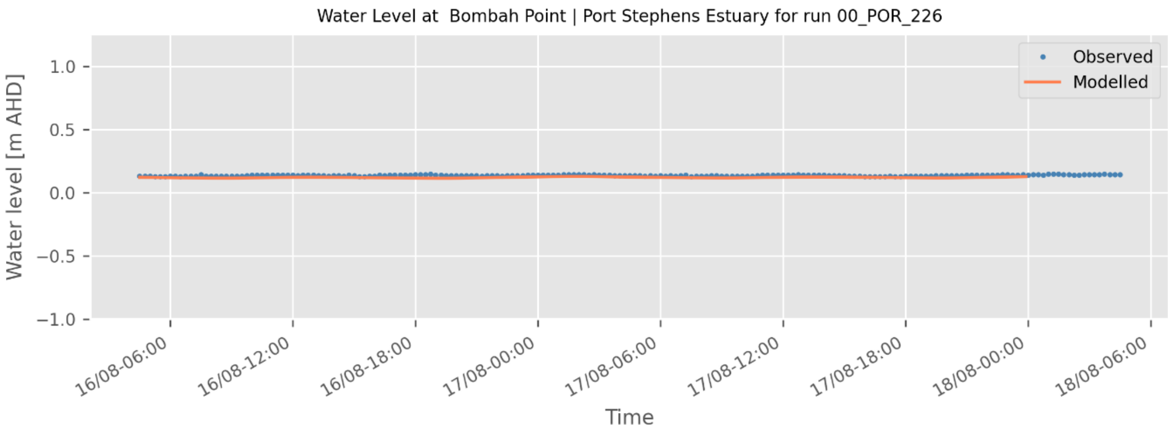


**Figure B-24 August 2023 water level verification – Location 4 – Bombah Point**

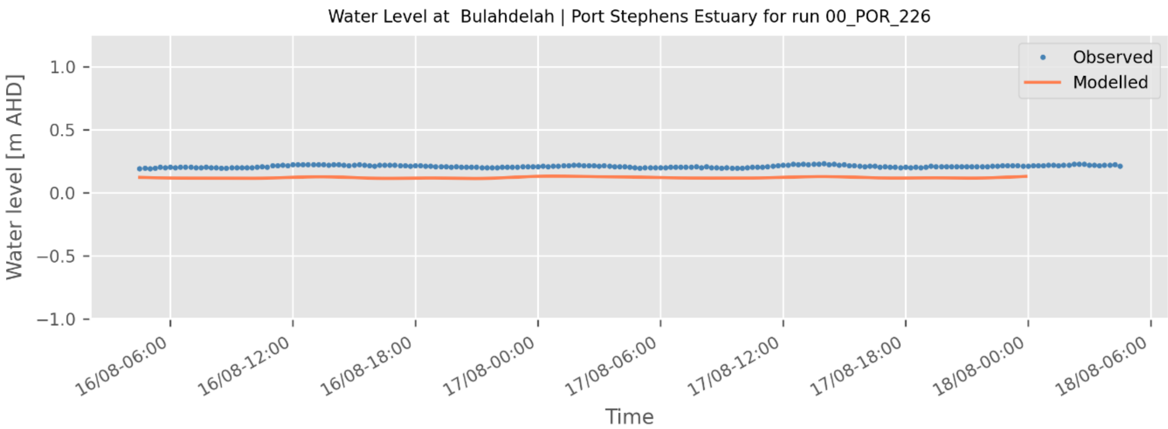


**Figure B-25 August 2023 water level verification – Location 5 – Bulahdelah**

## B1.5 Tidal flow gauging verification – November 2023

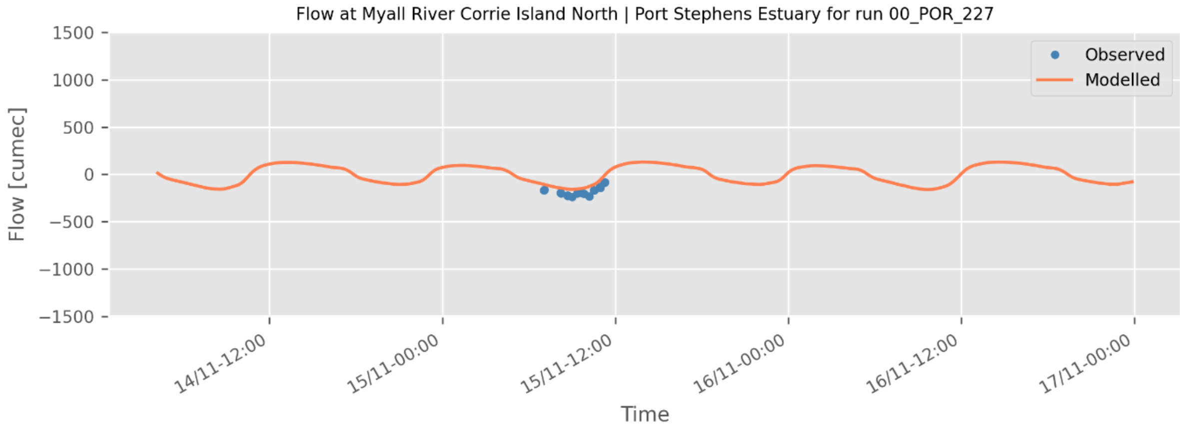


**Figure B-26 November 2023 tidal flow verification – Location G – Myall River Corrie Island North**

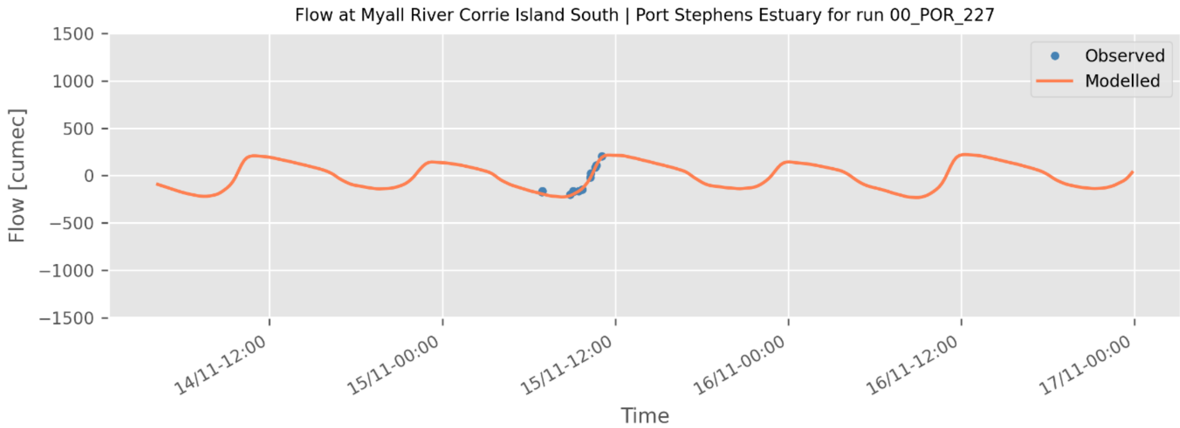


**Figure B-27 November 2023 tidal flow verification – Location H – Myall River Corrie Island South**

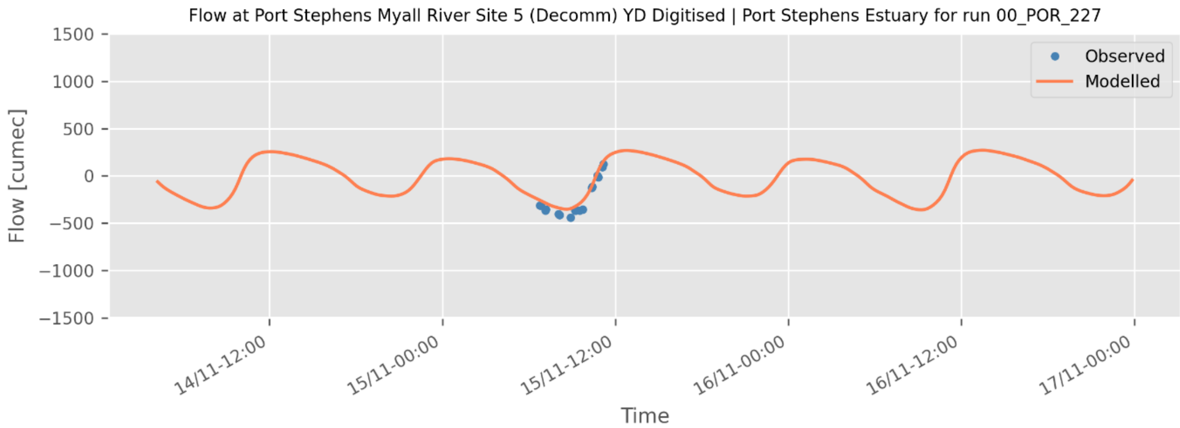


**Figure B-28 November 2023 tidal flow verification – Location B – Myall River**

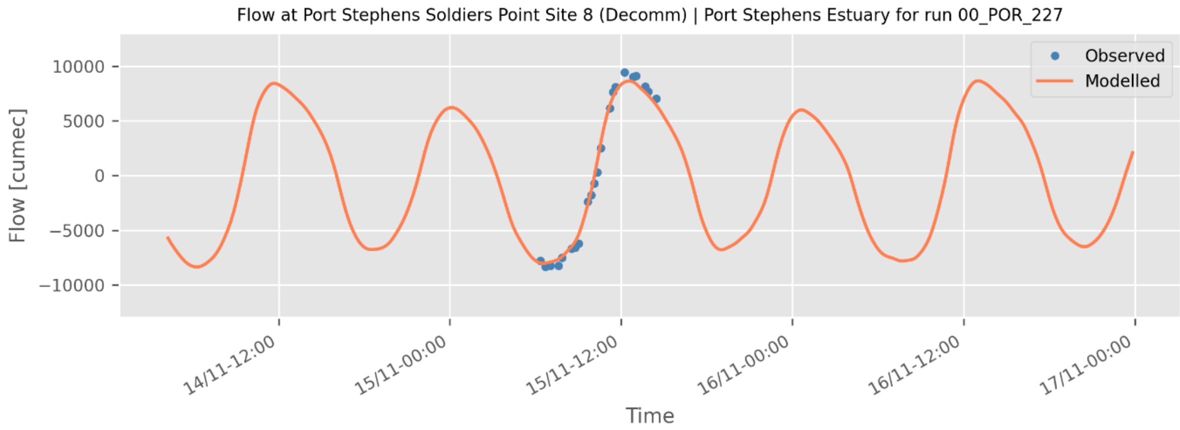


**Figure B-29 November 2023 tidal flow verification – Location C – Soldiers Point**

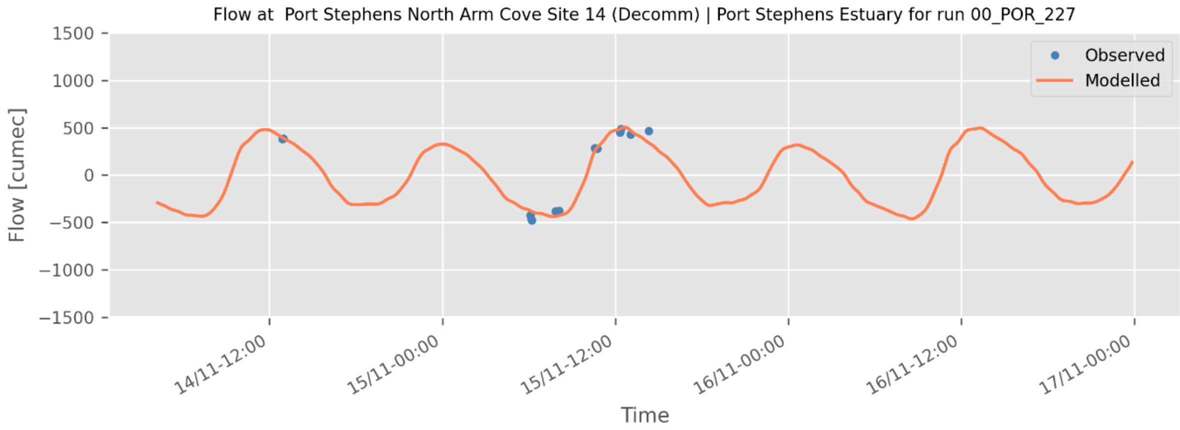


**Figure B-30 November 2023 tidal flow verification – Location D – North Arm Cove**

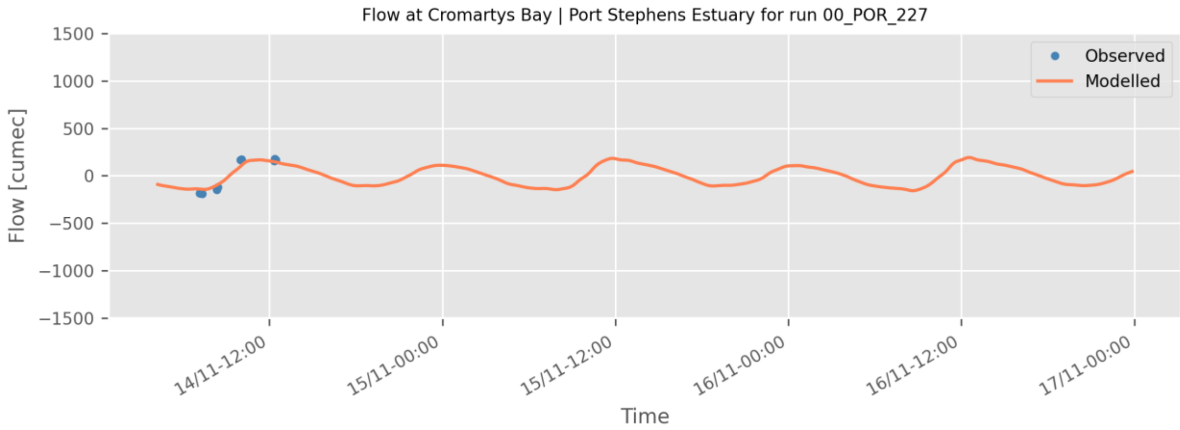


**Figure B-31 November 2023 tidal flow verification – Location I – Cromartys Bay**

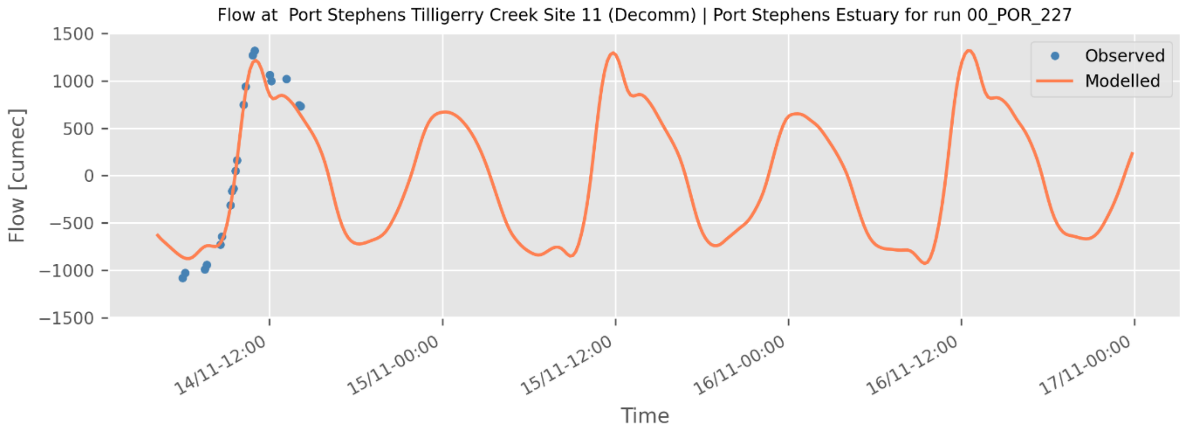


**Figure B-32 November 2023 tidal flow verification – Location E – Tilligerry Creek**

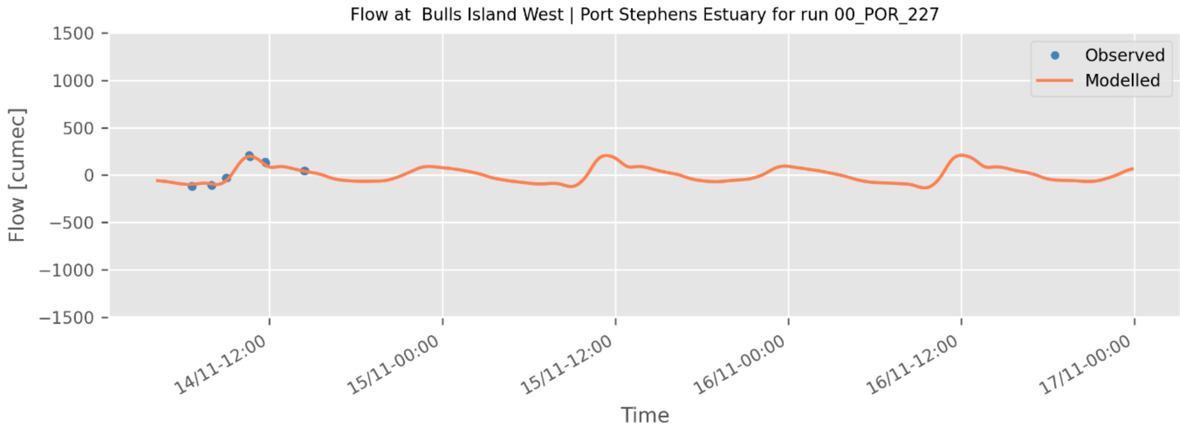


**Figure B-33 November 2023 tidal flow verification – Location J – Bulls Island West**

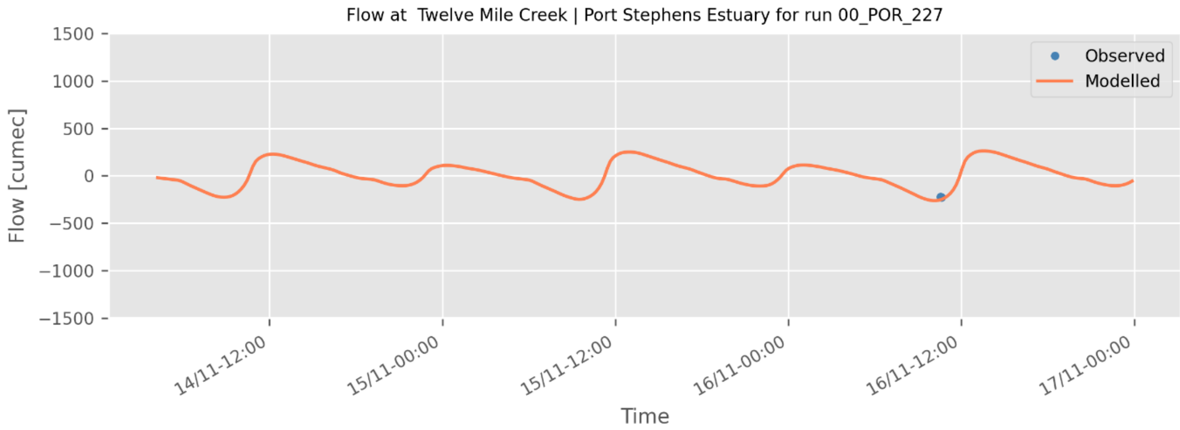


**Figure B-34 November 2023 tidal flow verification – Location K – Twelve Mile Creek**

## B1.6 Water level verification – November 2023

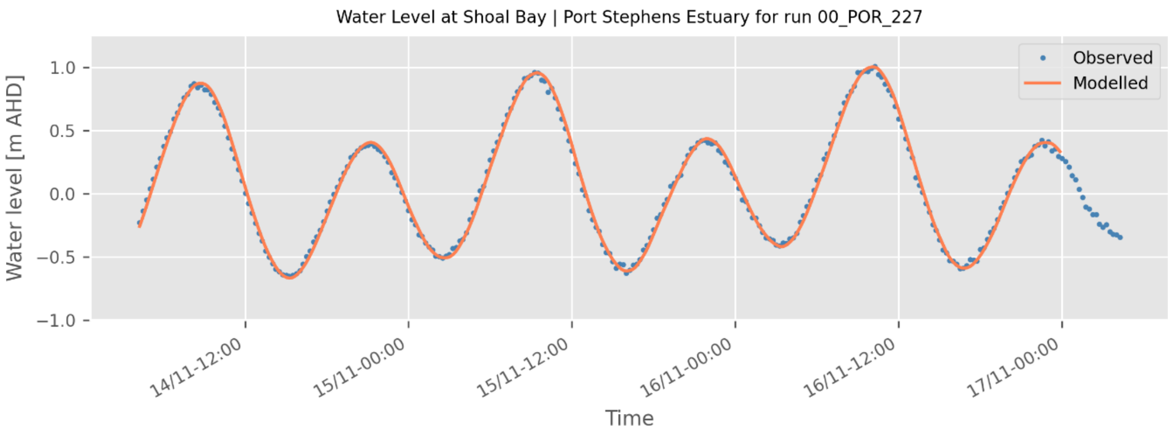


**Figure B-35 November 2023 water level verification – Location 1 – Shoal Bay**

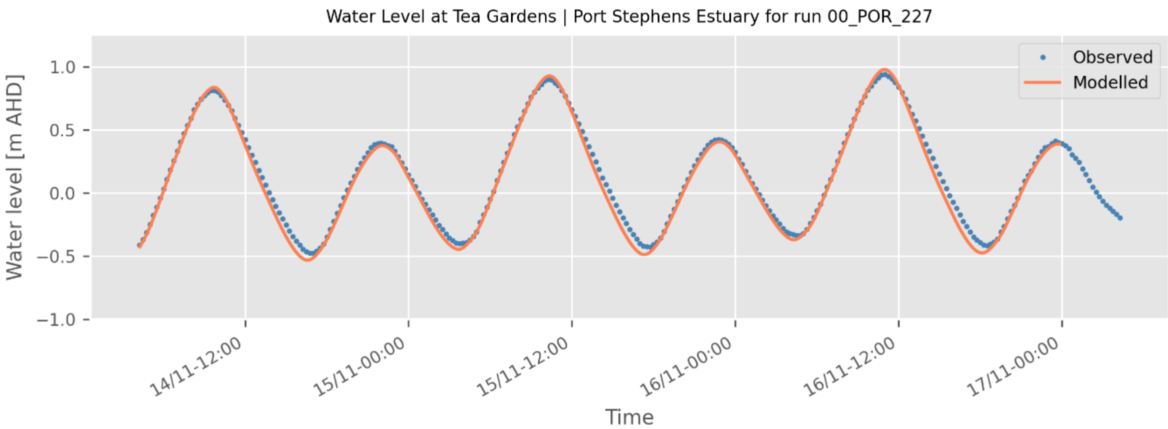


**Figure B-36 November 2023 water level verification – Location 2 – Tea Gardens**

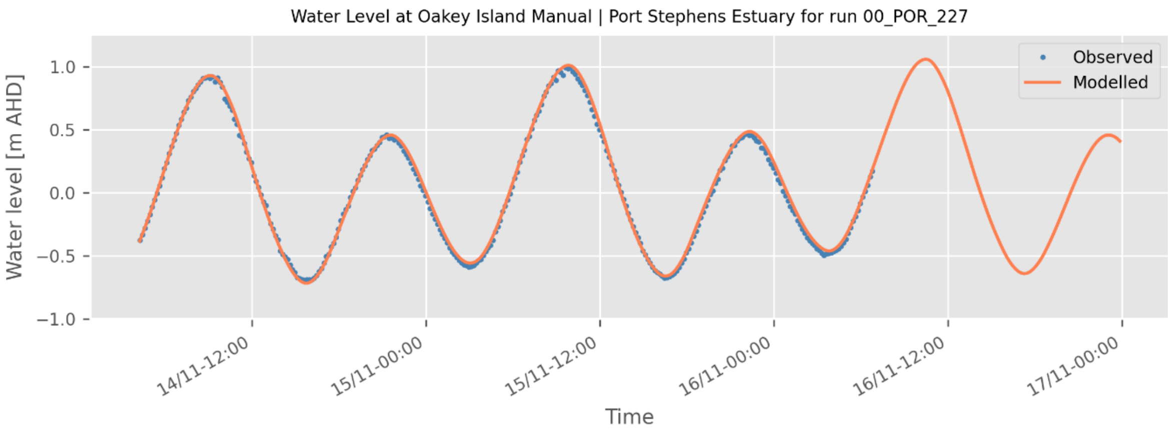


**Figure B-37 November 2023 water level verification – Location 13 – Oakey Island**

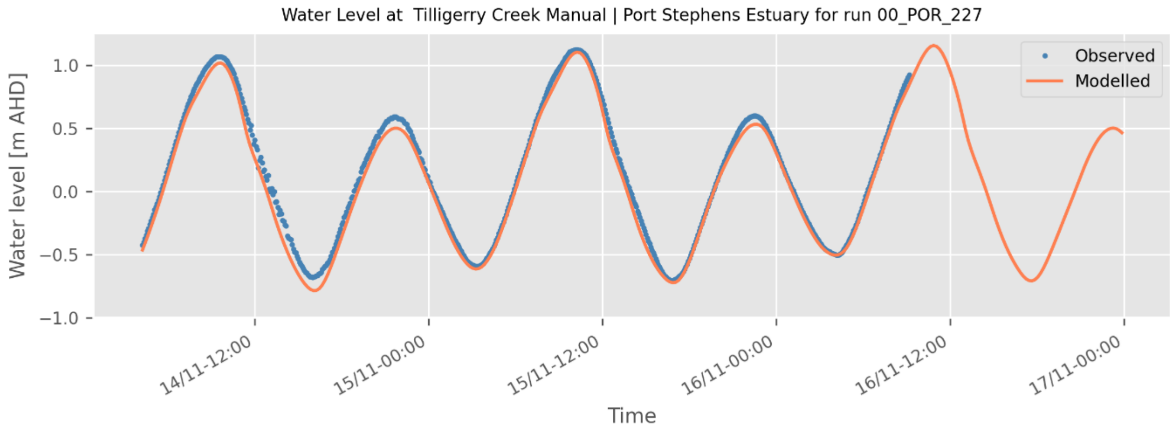


**Figure B-38 November 2023 water level verification – Location 11 – Tilligerry Creek**

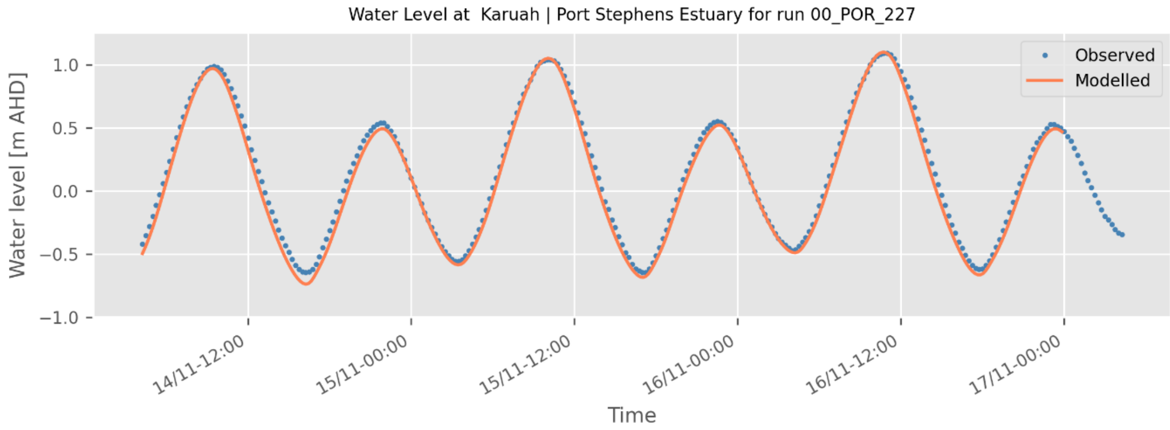


**Figure B-39 November 2023 water level verification – Location 6 – Karuah**

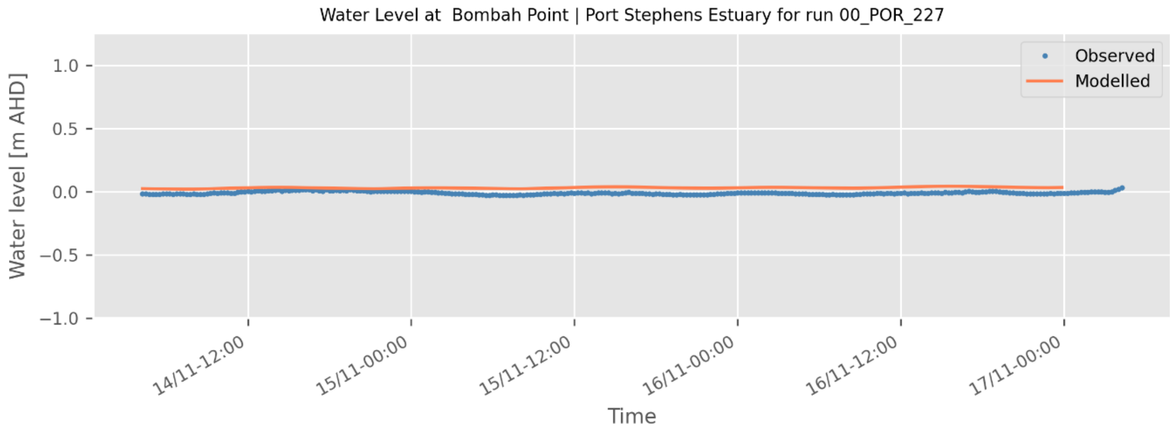


**Figure B-40 November 2023 water level verification – Location 4 – Bombah Point**

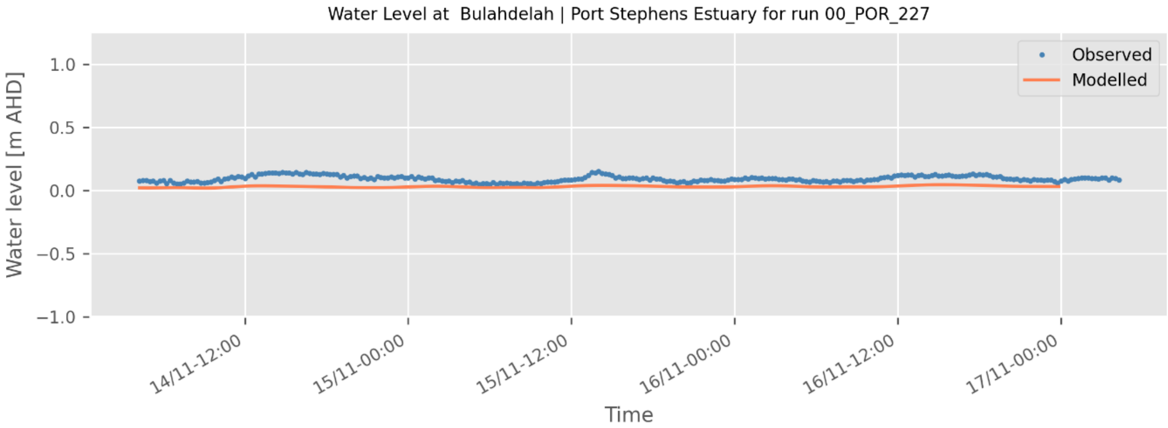


**Figure B-41 November 2023 water level verification – Location 5 – Bulahdelah**