Assessing the impact of sewage overflows on oyster harvest areas: Wallis Lake estuary technical summary

WRL TR 2023/21, May 2025

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

UNSW Water Research Laboratory

UNSW Sydney

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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 Wallis Lake 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 Wallis Lake 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 TR2022/26
Camden Haven River	WRL TR2023/20
Wallis Lake	WRL TR2023/21 (this report)
Port Stephens	WRL TR2023/22
Clyde River	WRL TR2023/24
Shoalhaven/Crookhaven Rivers	WRL TR2023/23
Wagonga Inlet	WRL TR2023/25
Merimbula Lake	WRL TR2023/26
Pambula Lake	WRL TR2023/27

1.3 Wallis Lake site description

The Wallis Lake is a large coastal lake in NSW, Australia, located 225 km north of Sydney and 105 km north of Newcastle. Major towns in the area include Forster, Tuncurry, Nabiac and Coolongolook. The estuary is comprised of a large lake (approximately 73 km^2) that is fed by four main tributaries: the Wallamba, Wang Wauk, Coolongolook and Wallingat Rivers. The total catchment area of the lake is approximately 1200 km^2, of which almost half (500 km^2) drains to the Wallamba River. The tidal extent of the Wallamba River extends 31 km upstream of the estuary entrance, the Wang Wauk extends 24 km upstream, the Coolongolook extends 23 km upstream and the Wallingat extends 33 km upstream. The tidal prism of the estuary was approximately 17×10^6 m^3 on a spring tide in 1998 (MHL, 1998). The entrance to the Wallis Lake estuary was artificially trained in 1966, and has been in a state of continuing erosion since then. From 1990 to 2015, the spring tidal range has been increasing at a rate of 1.8 mm/year (Nielsen and Gordon, 2016). Management of the lake includes management of erosion and dredging in some locations as detailed in Great Lakes Council (2014).

The estuary has three oyster harvest areas: Long Island, Wallis Island and Cape Hawke, shown in Figure 1-1 and Figure 1-2.

Figure 1-1 Oyster harvest areas on Wallis Lake

Figure 1-2 Wider view of oyster harvest areas on Wallis Lake

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 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) MHL (2023c)	Long term water level data available at four locations in the Wallis Lake estuary and at two nearby ocean tide gauges.	2.2
Tidal flow and water level	MHL (1998)	Tidal flow gauging at 13 locations and temporary water level gauging at an additional 15 locations.	2.2
Tidal flow	WorleyParsons (2011)	Tidal flow gauging at five locations in October 2010.	2.2
Catchment discharge	WaterNSW (2023)	Two long term catchment flow monitoring locations on the Wang Wauk River.	2.3
Sewage overflows	NSW Food Authority	Data on overflows reported to EPA and NSW Food Authority including volume, duration and closure action.	2.4
Bathymetry	DPE (2022) DPIE (2018) DECCW (2010) OEH (1998) NSW Spatial Services (2012) NearMap (2024)	Bathymetry for various points in time sourced from various single beam surveys: in 2022, 2010 and 1998, with supplementary data from 2018 NSW Marine LiDAR Topo-Bathy survey, 2012 Digital Elevation Model (DEM) and NearMap aerials.	2.5

2.2 Water level and tidal flow gauging

Manly Hydraulics Laboratory (MHL) maintain three permanent water level gauges installed on the Wallis Lake estuary, one permanent ocean tide gauge in the estuary entrance at Forster, and one other nearby ocean tide gauge at Crowdy Head (first installed in 1986 and upgraded and moved in 2013). Further water level and flow gauging has occurred during two short-term data collection campaigns, one run by MHL in 1998 and one run by WorleyParsons in 2010. These gauging and water level sensor locations are shown in Figure 2-1 and Figure 2-2 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 Wallis Lake estuary and relevant ocean tide gauges

Water level gauge	Location label	Station number	Provider	Date range	MHL report number
Forster	1	209402	MHL	1986 – present	-
Tiona	4	209403	MHL	1985 – present	-
Pacific Palms Wharf	6	209406	MHL	2013 – present	-
Tuncurry DS	8	209401	MHL	2016 – present	-
Tuncurry (Decommissioned)	9	209402	MHL	1985 – 2016	-
Crowdy Head Harbour Fuel Wharf	-	208470	MHL	1986 – 2013	-
Crowdy Head Fishermans Wharf	-	208471	MHL	2013 – present	-
Breckenridge Channel Site 5	2		MHL	27/03/1998 – 29/03/1998	MHL927
Hells Gate Site 7	3		MHL	27/03/1998 – 29/03/1998	MHL927
Booti Island	5		MHL	31/07/1997 – 25/03/1998	MHL927
Wallamba Broadwater	7		MHL	30/07/1997 – 25/08/1998	MHL927
Wallamba River Lower Site 30	10		MHL	28/03/1998 – 28/08/1998	MHL927
Darawakh Swamp	11		MHL	26/08/1998 – 8/03/1999	MHL927
Wallamba River Mid Site 31	12		MHL	25/03/1998 – 20/05/1998	MHL927
Wallamba River Upper Site 32	13		MHL	25/03/1998 – 9/06/1998	MHL927
Little Bandicoot Is Site 11	15		MHL	26/03/1998 – 10/06/1998	MHL927
Coomba Site 16	16	-	MHL	26/03/1998 – 10/06/1998	MHL927

Water level gauge	Location label	Station number	Provider	Date range	MHL report number
Peach Tree Point	17	-	MHL	30/07/1997 – 9/03/1998	MHL927
Wallingat River Mid Site 23	18	-	MHL	26/03/1998 – 10/06/1998	MHL927
Wallingat River Upper Site 24	19	-	MHL	26/03/1998 – 10/06/1998	MHL927
Coolongolook River Site 25	20	-	MHL	25/03/1998 – 9/06/1998	MHL927
Wang Wauk River Site 26	21	-	MHL	25/03/1998 – 9/06/1998	MHL927
Breckenridge Pool	22	-	WRL 2023 fieldwork	18/09/2023 – 21/09/2023	-
Pennington Main Creek	23	-	WRL 2023 fieldwork	18/09/2023 – 21/09/2023	-
Pennington Side Creek	24	-	WRL 2023 fieldwork	18/09/2023 – 21/09/2023	-
Hells Gate	25	-	WRL 2023 fieldwork	19/09/2023 – 21/09/2023	-

Table 2-3 Summary of tidal flow gauging locations on the Wallis Lake estuary

Tidal flow gauge	Location label	Dates	Study
Entrance Site 2	A	28/03/1998, 12/10/2010, 19-21/09/2023	MHL927, WorleyParsons (2011), 2023 fieldwork
Breckenridge Entrance Site 4	B	28/03/1998, 12/10/2010, 19/09/2023	MHL927, WorleyParsons (2011), 2023 fieldwork
Marina Site 3	C	28/03/1998, 12/10/2010	MHL927
Hells Gate Site 8	D	28/03/1998, 12/10/2010, 19-21/09/2023	MHL927, WorleyParsons (2011), 2023 fieldwork
Shepherd Island Site 13	E	28/03/1998	MHL927
Lower Wallamba River Site 29	F	28/03/1998	MHL927
Wallis Island West Site 9	G	28/03/1998	MHL927
Regatta Island East Site 10	H	28/03/1998	MHL927
Coomba Site 15	I	28/03/1998	MHL927
Wallis Island South Site 14	J	28/03/1998	MHL927
Regatta Island West Site 12	K	28/03/1998	MHL927
Coolongolook Site 21	L	28/03/1998	MHL927
Coolongolook Site 22	M	28/03/1998	MHL927
WP_6	N	12/10/2010, 19-21/09/2023	WorleyParsons (2011), 2023 fieldwork
WP_7	O	12/10/2010, 21/09/2023	WorleyParsons (2011), 2023 fieldwork
Wallamba East	P	20/09/2023	2023 fieldwork
Wallamba West	Q	29/09/2023	2023 fieldwork

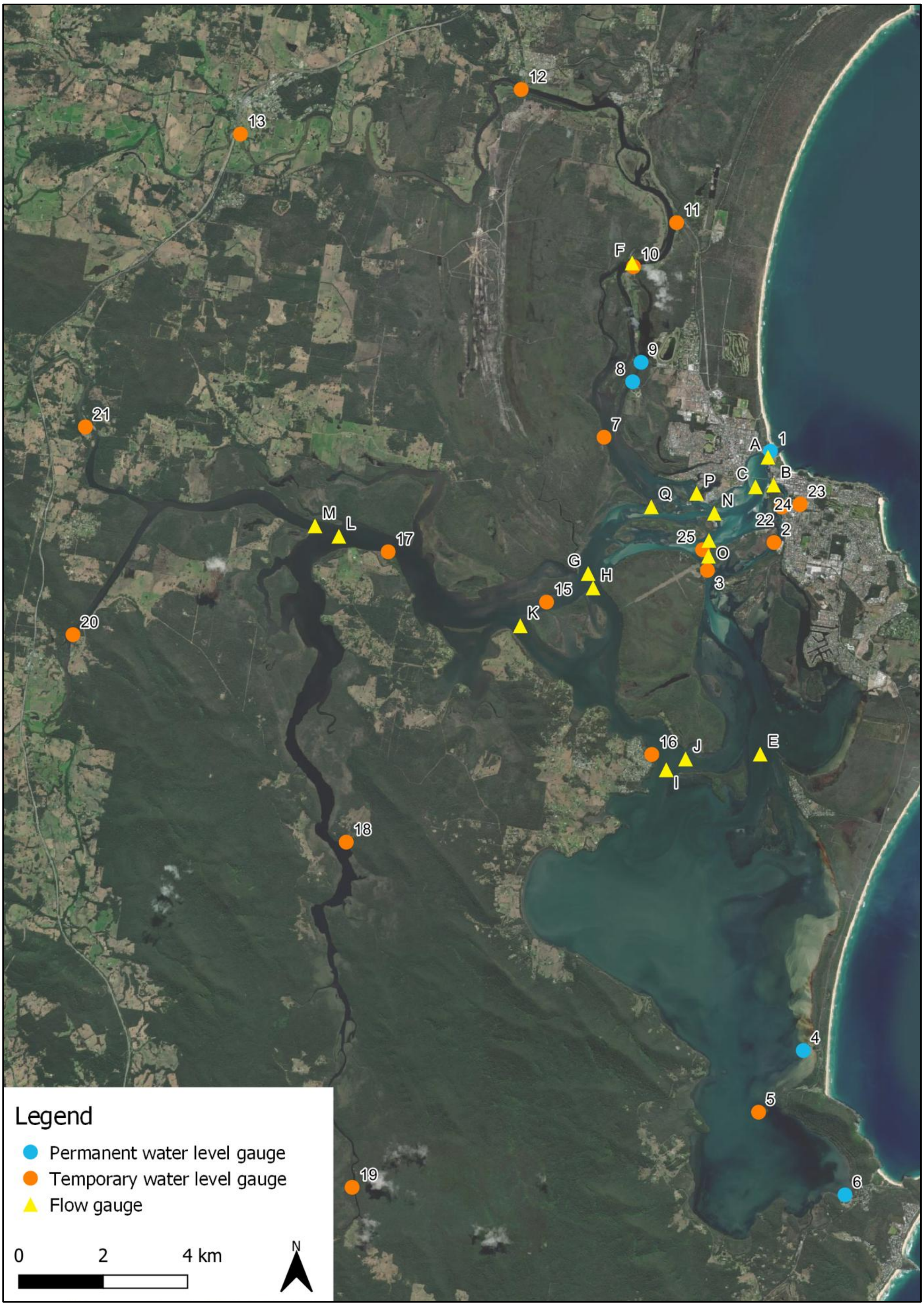

Figure 2-1 Water level and tidal flow gauging locations

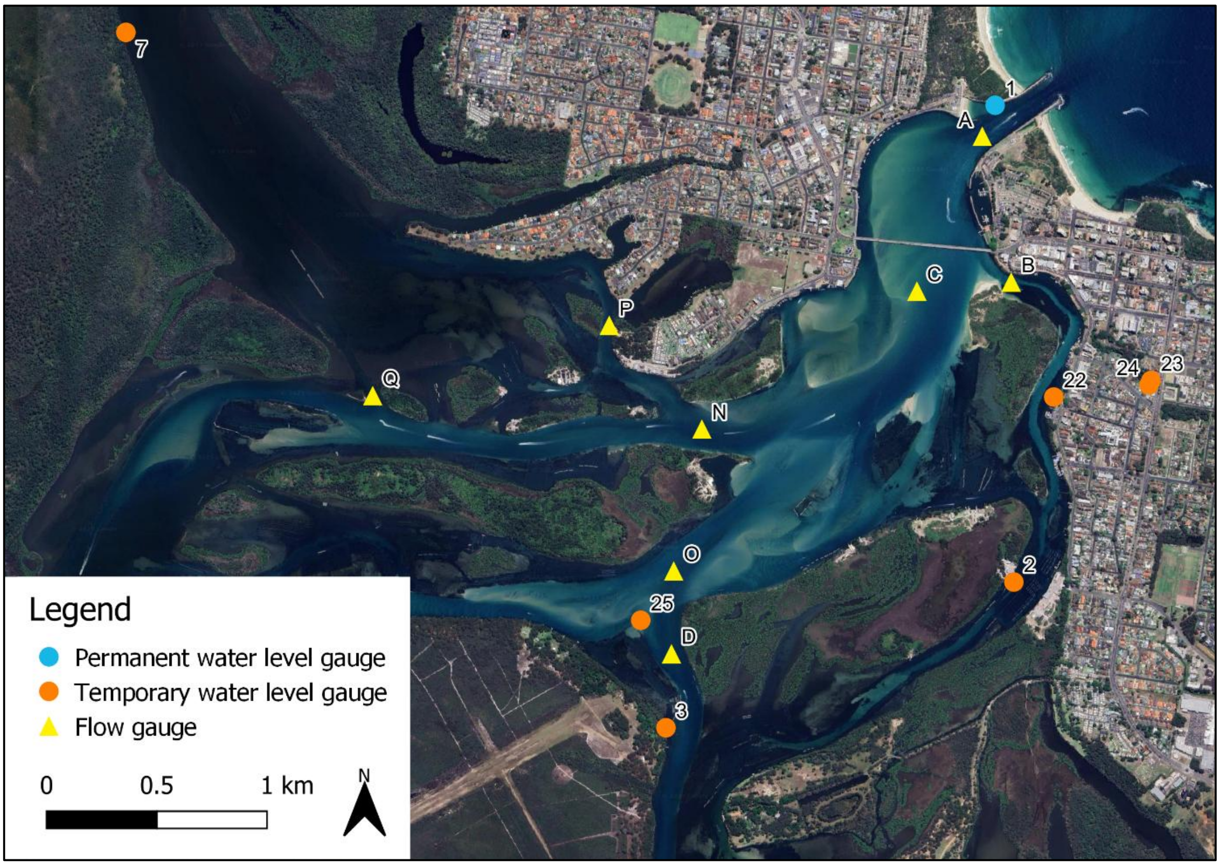

Figure 2-2 Zoomed view of water level and tidal flow gauging locations in the lower estuary

2.3 Catchment inflows

Gauged catchment inflows were available from WaterNSW. When these were not at the tidal limit (the model boundary), the flows were scaled up proportional to the additional catchment area using the method in WRL TR2023/32 Section 2.4. There are four model boundary inflows into the Wallis Lake estuary and continuous flow gauging of discharge and water levels are available from WaterNSW (2023) at one relevant location, Wang Wauk at Willina (1969 to present). Table 2-4 lists the model boundaries, the gauges used and the relevant scaling factor applied. Figure 2-3 shows the locations along with the catchment area flowing into each tidal boundary (solid line polygon) along with the associated portion of that catchment that is upstream of the gauge (hatched).

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

Model boundary	Base WaterNSW gauge	Scaling factor
Wallamba River*	209006	2.065
Wang Wauk River	209006	1.308
Coolongolook River*	209006	0.999
Wallingat River*	209006	0.332

* This catchment was ungauged so the nearby Wang Wauk River catchment was scalled and used.

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

Table 2-5 WaterNSW gauge flow percentiles

Percentile	Wang Wauk at Willina (209006) ML/d *(m^3/s)*
5^{th}	0.0 *(0.0)*
20^{th}	0.32 *(0.004)*
50^{th} (median)	3.7 *(0.04)*
80^{th}	45 *(0.52)*
95^{th}	716 *(8.3)*

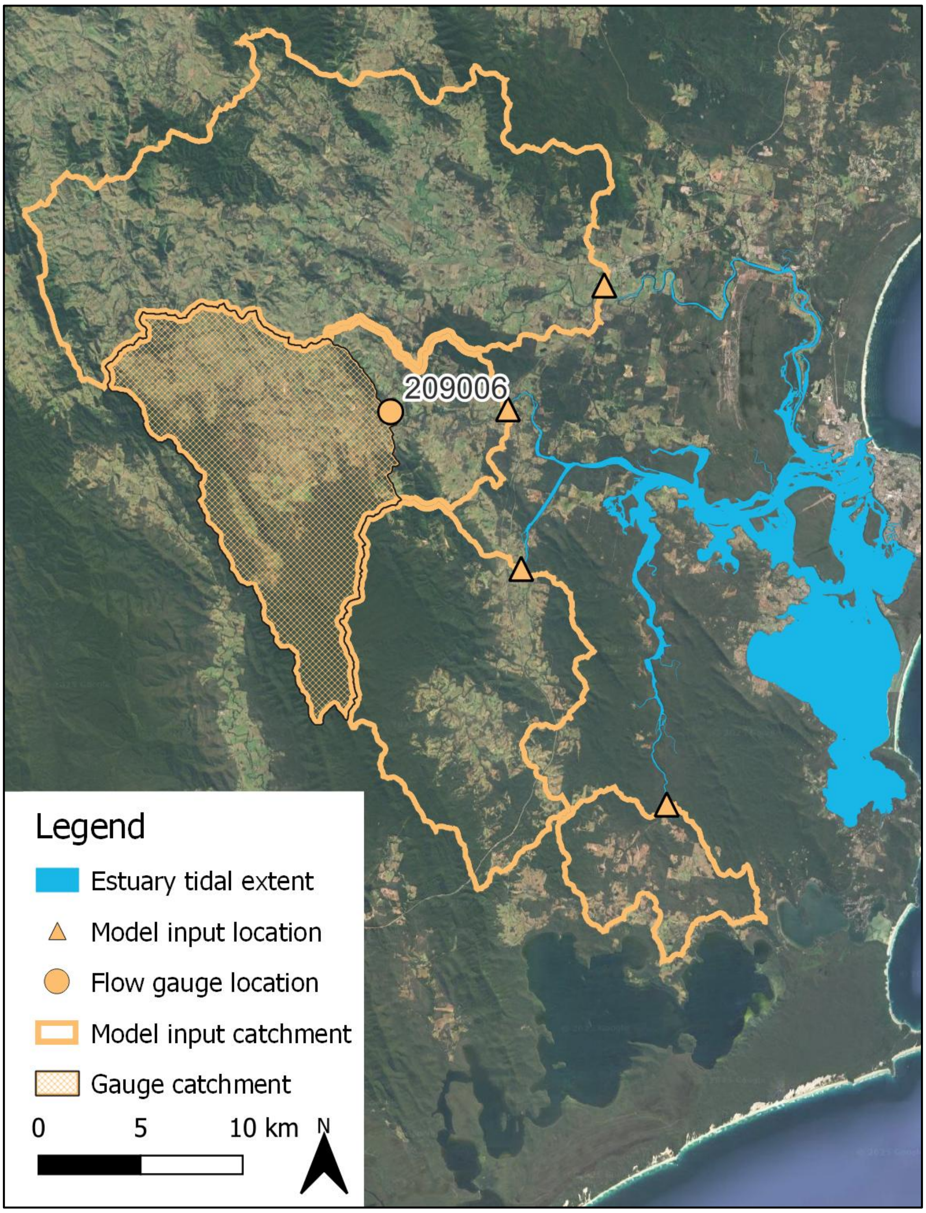

Figure 2-3 Catchment flow gauging stations*

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

2.4 Sewage overflow data

Mid Coast Council (MCC) is the agency responsible for wastewater treatment and sewage management in the catchment surrounding the Wallis Lake estuary. The sewerage system is comprised of a reticulation network of pipes and sewage pumping stations (SPS), in addition to a wastewater treatment plant (WWTP) at Forster. When sewage overflows occur, MCC is required to notify NSW Food Authority so that appropriate decisions can be made on whether harvest area closures are necessary. Information on sewage overflows between 2016 and 2023 has been provided by the NSW Food Authority and reported overflow locations are shown in Figure 2-4. More information on sewage overflows and why they occur is provided in WRL TR2023/32 Section 2.5.

Figure 2-4 Locations of reported sewage overflows on Wallis Lake

2.5 Bathymetry

Four existing bathymetry datasets were sourced for this project:

- Single beam bathymetry data collected in 2022 by the NSW Department of Planning and Environment (now DCCEEW) of the lower estuary, covering the area between the entrance and Regatta Island on the Coolongolook River, and Flat Island through Hells Gate. Breckenridge Channel is included, however the Wallamba River is not (refer to Figure 2-5). Transect spacing is 50 m, with 10 m transects near the entrance and Breckenridge Channel. This data is the most recent and was used as the primary data source for the lower estuary in the model.
- Single beam bathymetry data collected in 2010 by the NSW Department of Environment Climate Change and Water (now DCCEEW) of the lower estuary, covering the same extent as the above survey but additionally covering the Wallamba River to Muddy Creek (refer to Figure 2-6).Transect spacing is 50 m throughout. This data was used for the lower estuary bathymetry when using the 2010 calibration period.
- Single beam bathymetry data collected in 1998. This dataset was collated and provided by the NSW Office of Environment and Heritage (OEH, now DCCEEW) and is available on the Australian Ocean Data Network (AODN) portal. This data covers the entire tidal extent of the estuary, with transect spacing varying from 10 m near the entrance to 500 m in the upper reaches (refer to Figure 2-7). This data was used for all areas of the upper estuary, not covered by more recent data, and was used in the lower estuary for use during the 1998 calibration period.

- Coastal marine LiDAR collected by the NSW Department of Planning, Industry and Environment (now DCCEEW) in 2018, at a resolution of 5 m in the Wallis Lake area, this survey covers most of the lower estuary, however, excludes a large area to the north of Godwin Island, refer to Figure 2-8.

As can be seen by comparing Figure 2-5, Figure 2-6, Figure 2-7 and Figure 2-8, there is substantial variation in the location and depth of channels and sand bars in the lower estuary, in particular in the region from Hells Gate to the entrance. The dynamic nature of this estuary necessitates consideration of multiple model bathymetries. Since bathymetry data was available from around the time of each hydrodynamic data period, different model bathymetries were used for each calibration/validation period. Sensitivity analysis was done on model bathymetry change for scenario results, and is discussed in Section 5.4.

Additional 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.
- High resolution NearMap imagery was used to qualitatively provide information on important bathymetric features, including the movement of sandbars in the lower estuary over time.

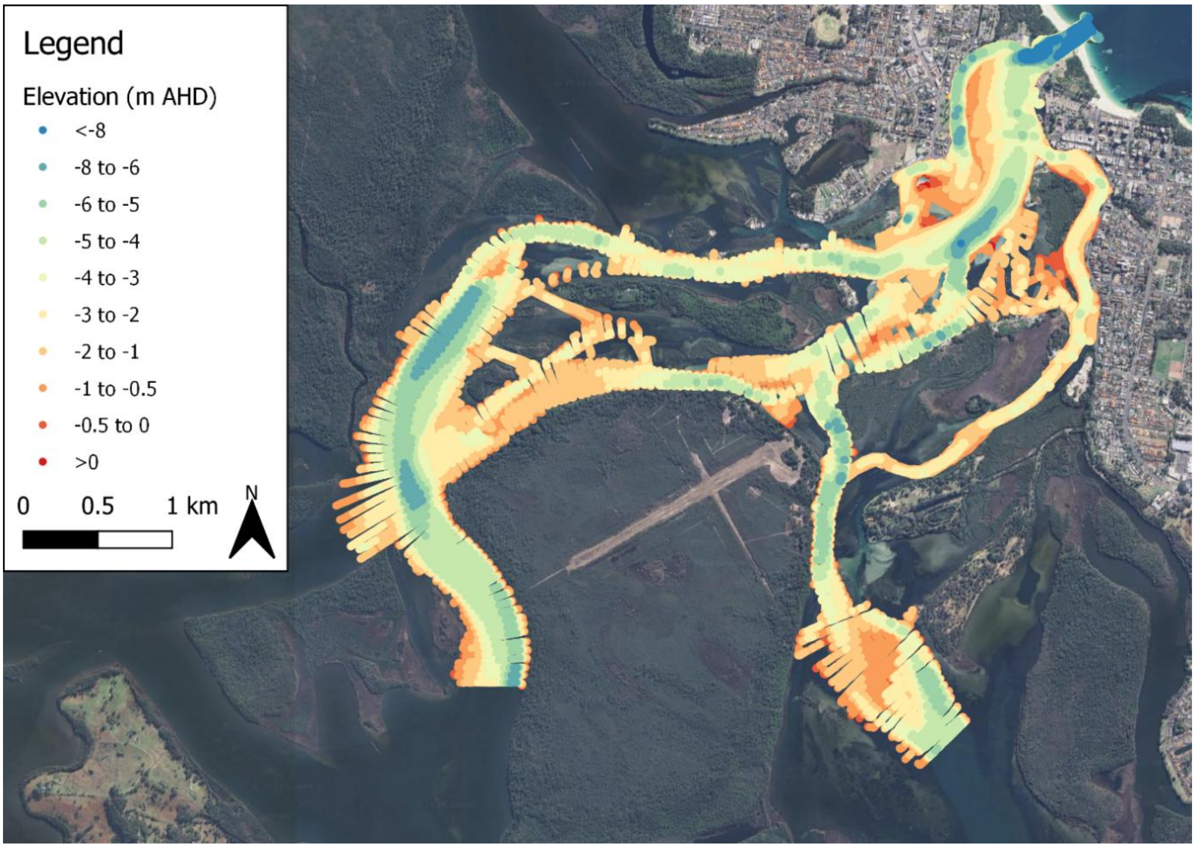

Figure 2-5 Coverage of 2022 single beam data

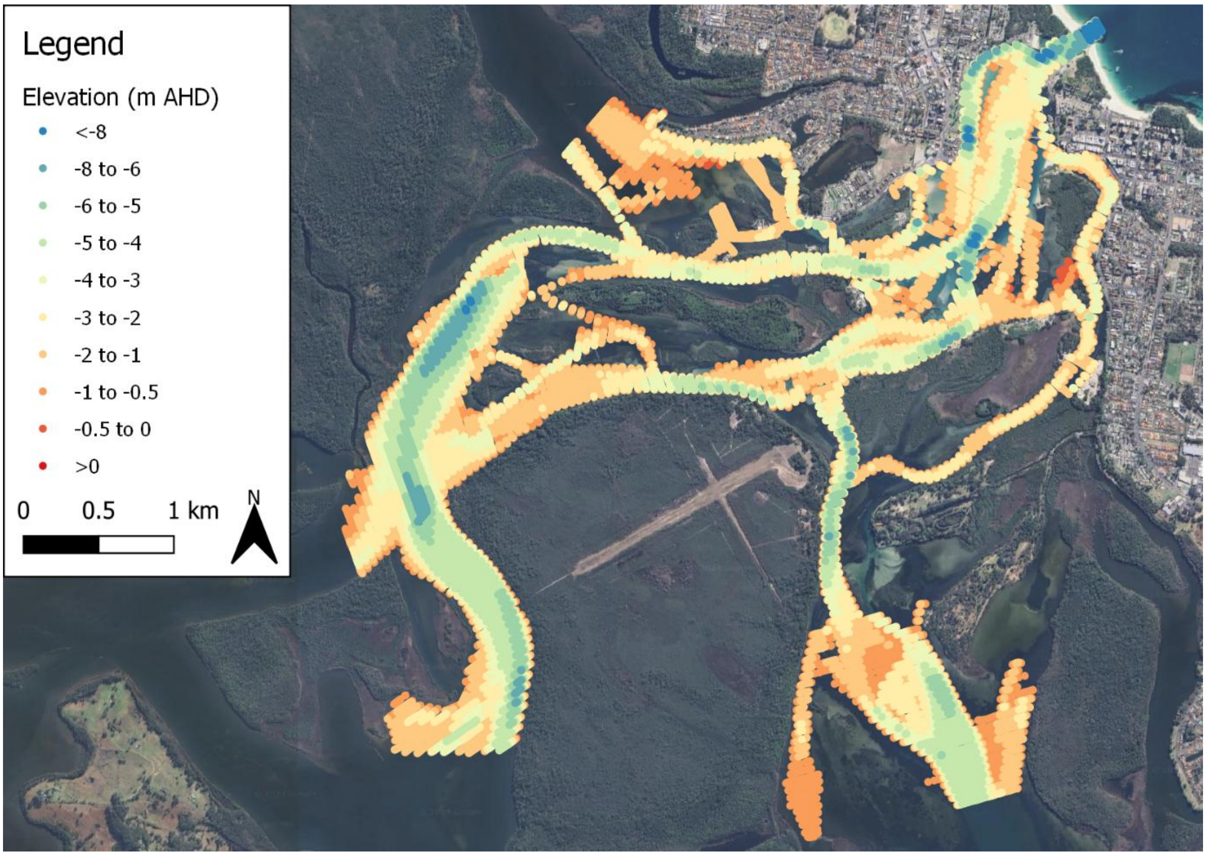

Figure 2-6 Coverage of 2010 single beam data

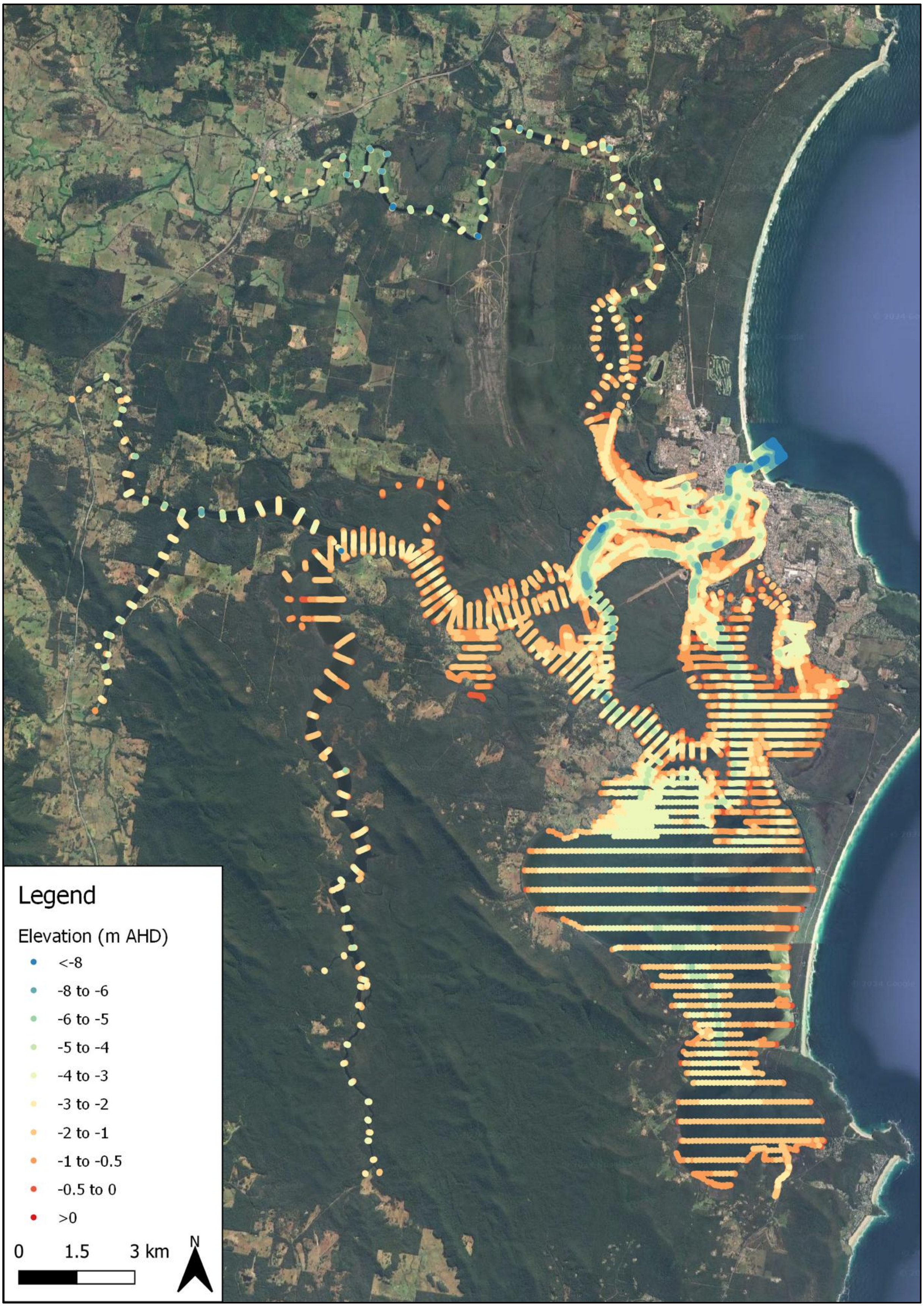

Figure 2-7 Coverage of 1998 single beam data

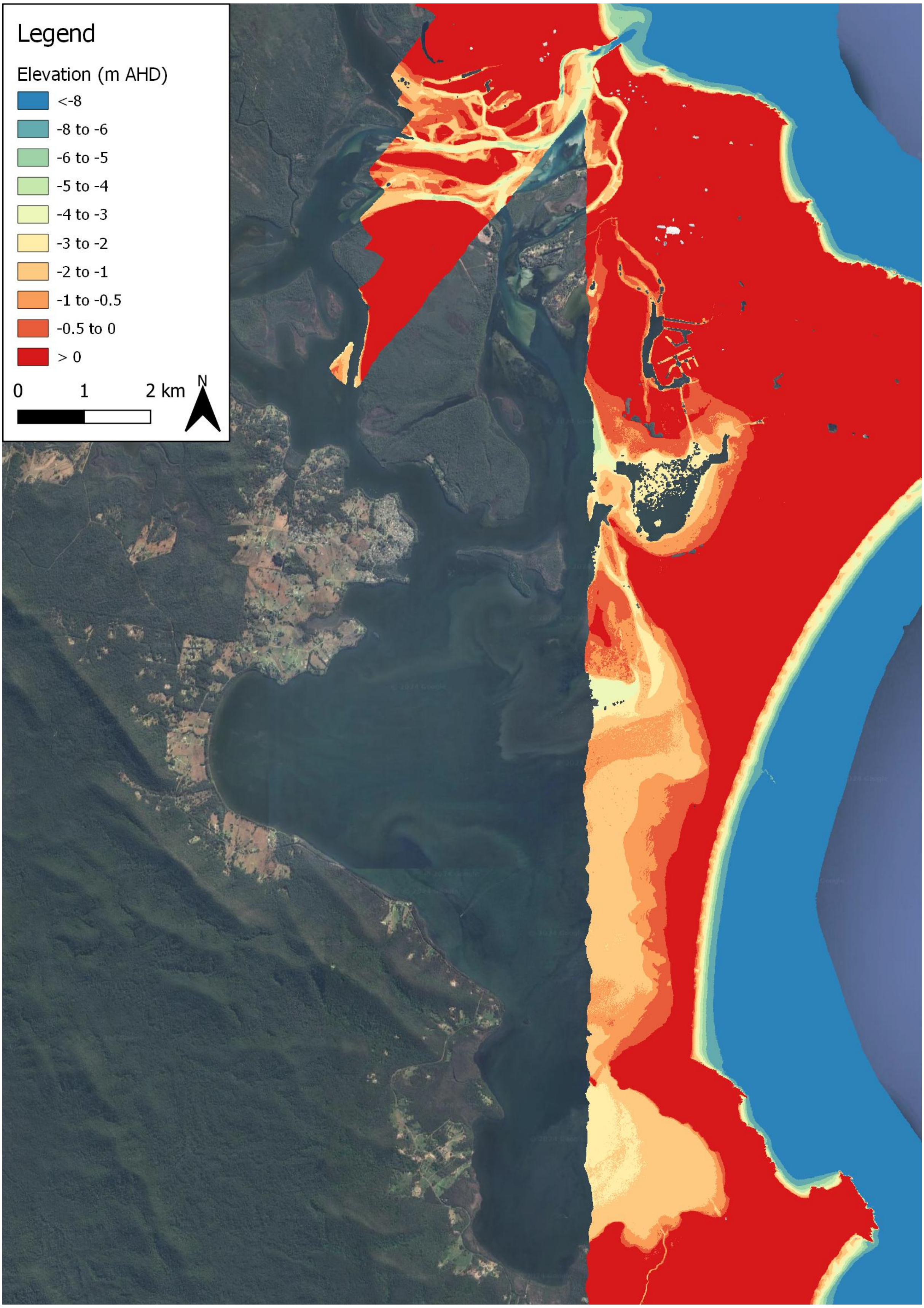

Figure 2-8 Coverage of 2018 LiDAR data

2.6 Existing model

A previous RMA model of Wallis Lake was developed by WRL and used in WRL TR2000/16 to assess viral movement in the estuary and in WRL TR2006/07 to assess the impacts of dredging (Cox, 2001; Miller et al., 2006). This model mesh (shown in Figure 2-9) was used as the basis for the mesh for this project. The mesh was retained largely without changes, however resolution was added in the lower estuary, near the overflows and the oyster harvest areas, and resolution was removed near Oaky Island, the focus for modelling in WRL TR2006/07. Bathymetry and relevant mesh geometry was also changed when creating the mesh for the 2010 and 2022 bathymetry.

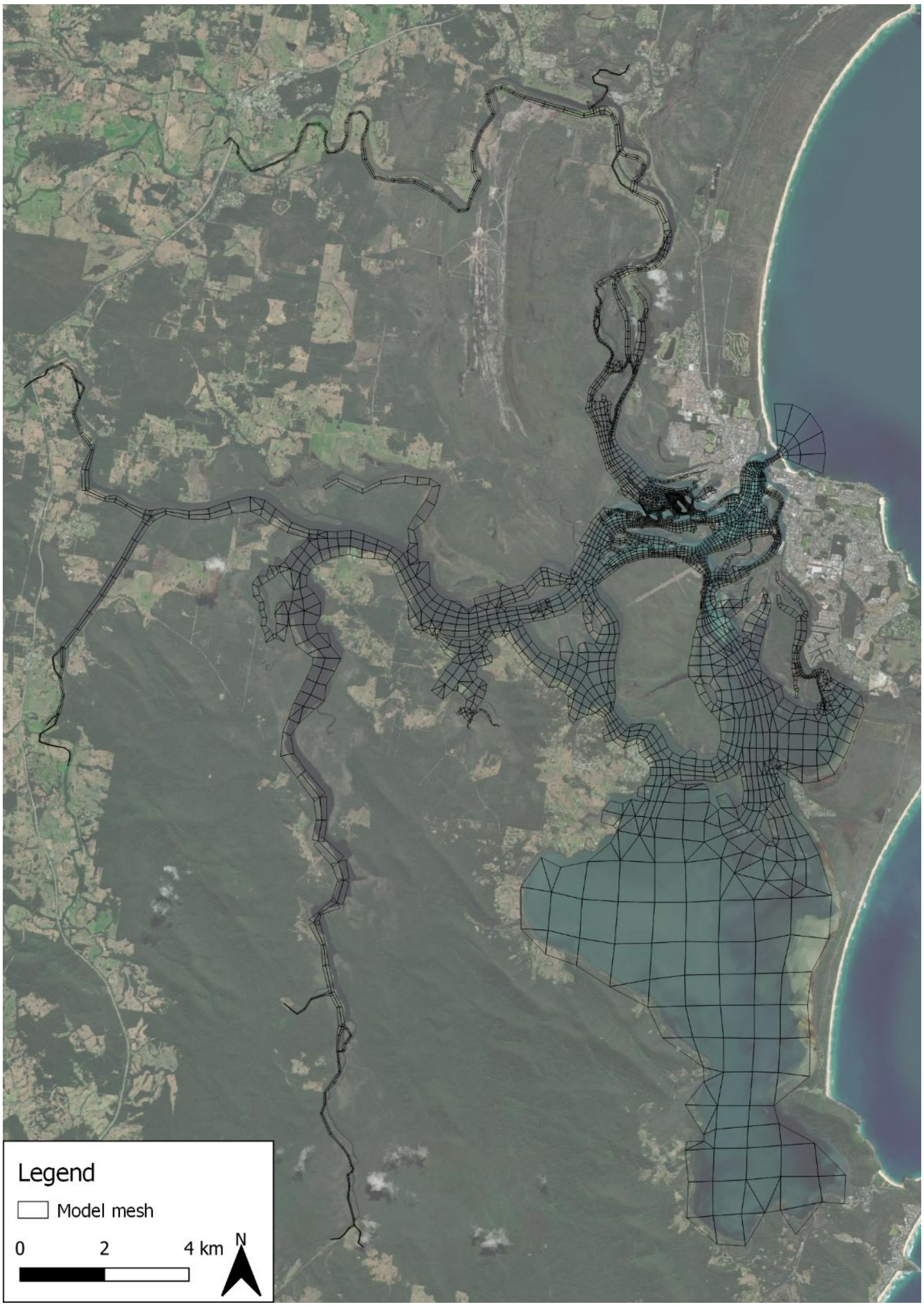

Figure 2-9 Model mesh utilised in WRL TR2006/07

3 Field data collection

3.1 Preamble

A data collection campaign was completed on 19 to 21 September 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
- Monitoring of water level data and collation of data from MHL water level monitoring sites
- Conductivity measurements

3.2 Weather and tides

Data collection on the Wallis Lake estuary was undertaken on both ebb and flood tides. Tides during field investigations were similar on both days, with tidal ranges between approximately -0.35 to 0.50 m AHD at Forster, near the estuary entrance. The observed water levels at Forster, alongside the timing of key fieldwork components is shown in Figure 3-1. Predicted and observed tides at the nearby MHL ocean tide station at Crowdy Head (the source of offshore driving tides) and Forster are shown in Figure 3-2. These observed tides had a positive anomaly during the fieldwork due to a low pressure system (MHL, 2023a). Barometric pressure was lower further south, thus the Forster gauge had a greater anomaly than Crowdy Head gauge, however the difference was not major and was not accounted for when running the model for the fieldwork period.

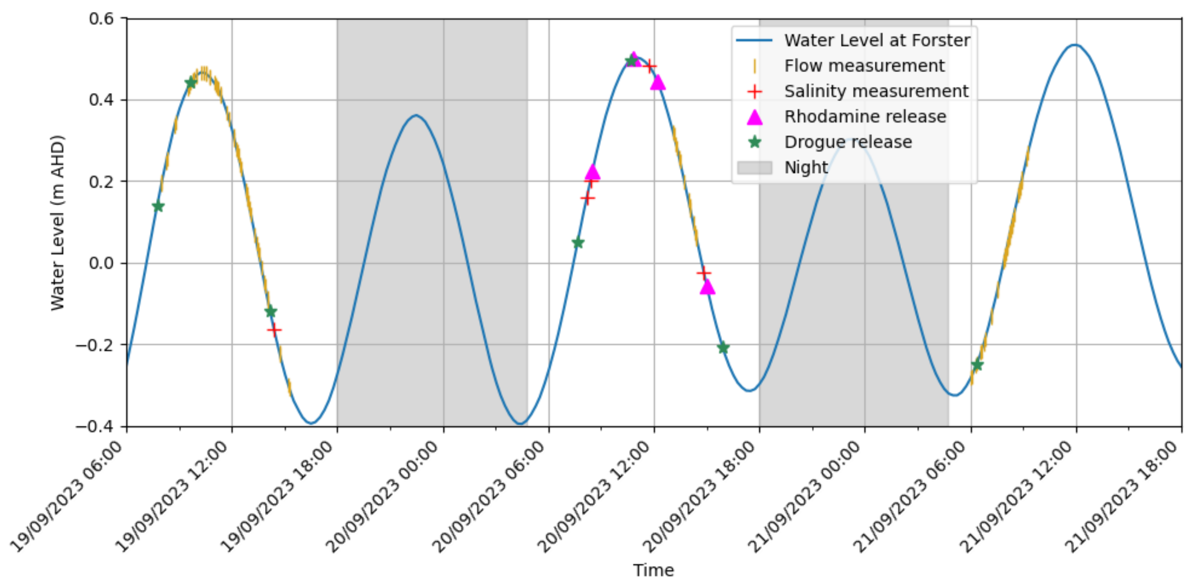

Figure 3-1 Tides at Forster with timing of key data collection events

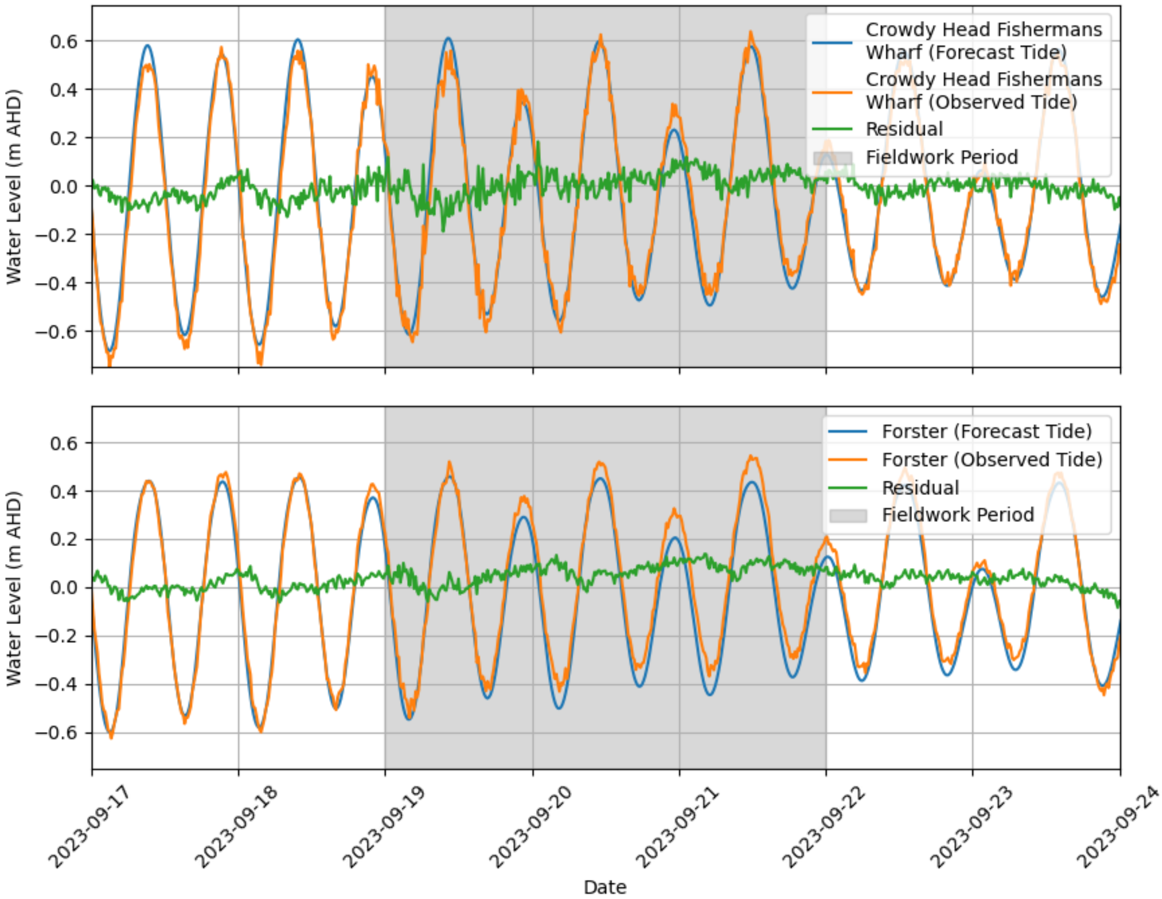

Figure 3-2 Forecasted and observed tides at Crowdy Head and Forster

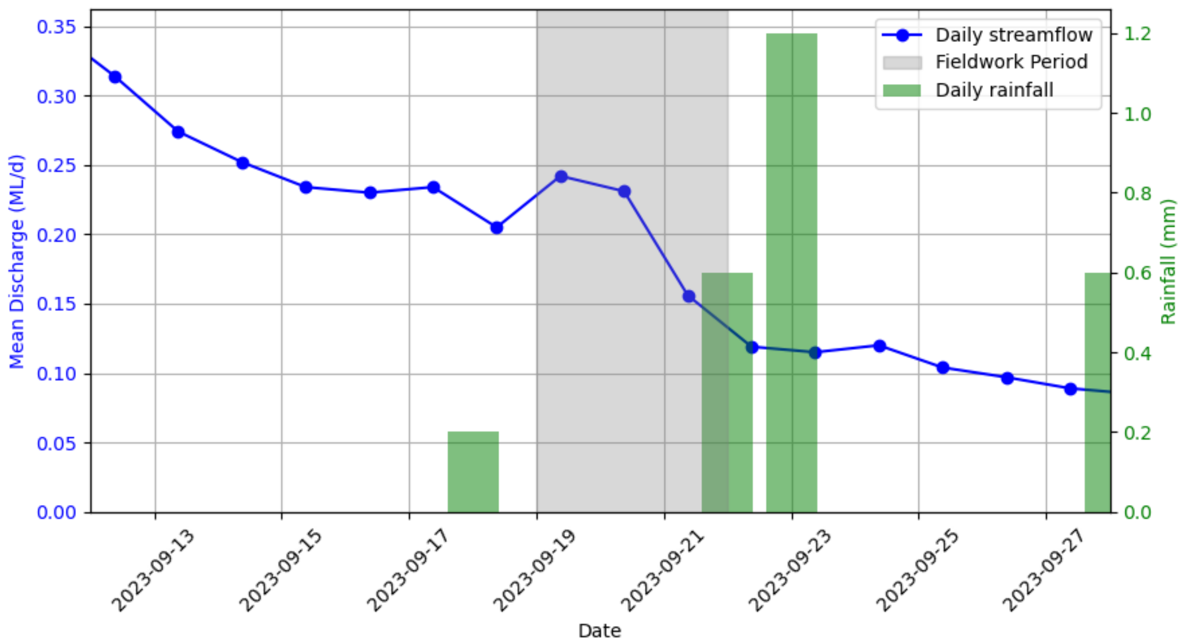

Figure 3-3 Rainfall recorded at Forster and streamflow recorded at the Wang Wauk River at Willina for the period surrounding fieldwork

No rainfall greater than 0.2 mm was observed during the fieldwork or the week preceding at Forster (BoM station 060013, refer to Figure 3-3). Freshwater inflows from the upstream Wang Wauk catchment (Figure 3-3) were low (around 20th percentile flows discussed in Section 2.3). Consistent wind speeds of 10 to 20 km/h from the east were observed in the field and at Taree (BoM station 060141) on 19 and 20 September 2023. Winds increased to 30 km/h from the south on 21 September, however all fieldwork was completed in the morning, before winds increased significantly.

3.3 Tidal flow gauging

Flow was measured using a boat mounted SonTek RiverSurveyor M9 ADCP at seven 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 Wallis Lake system are summarised in Table 3-1, with locations shown in Figure 3-4. For a table of tidal gauging measurements refer to Appendix A2, and for plots of tidal flows refer to Appendix B1.5.

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

Location	Location label*	19 September # transects	20 September # transects	21 September # transects
Entrance Site 2	A	20	-	20
Breckenridge Entrance Site 4	B	15	-	-
Hells Gate Site 8	D	6	-	8
WP 6	N	12	7	2
WP 7	O	-	-	4
Wallamba East	P	-	4	-
Wallamba West	Q	-	3	-

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

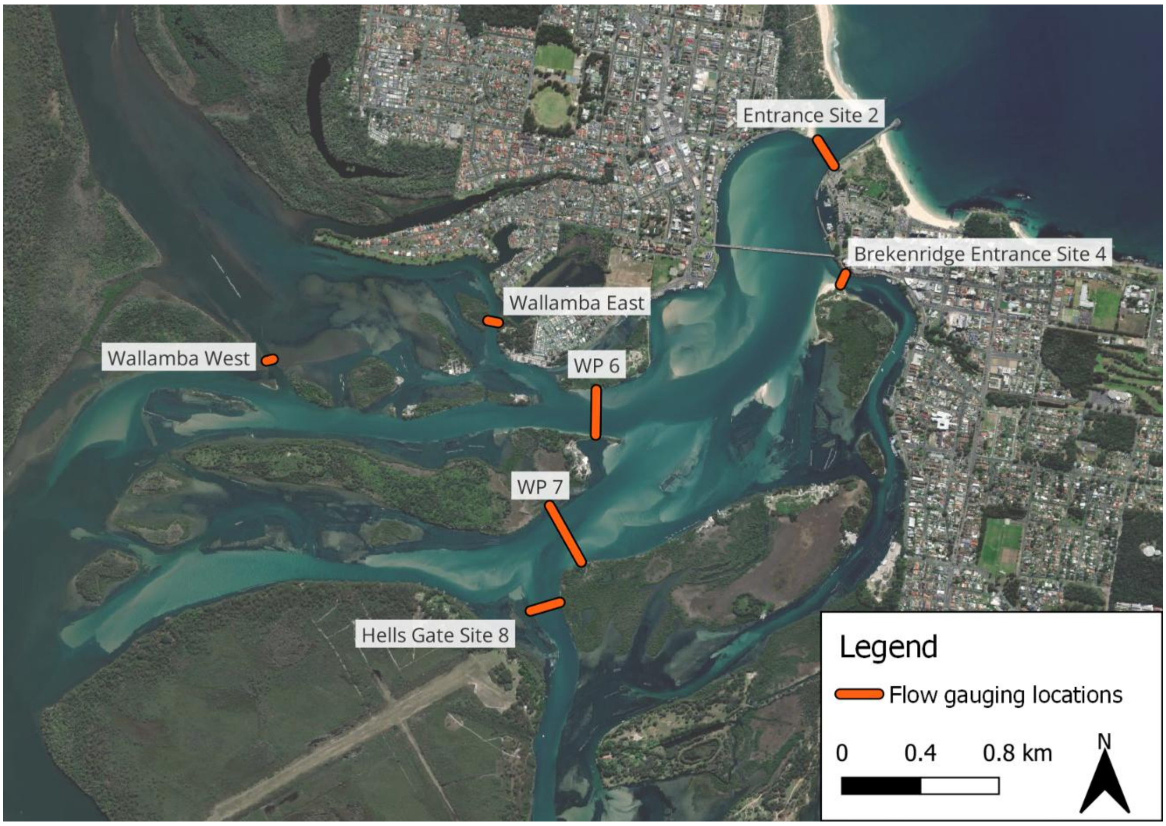

Figure 3-4 Tidal flow gauging locations from 2023 fieldwork

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

Vertical velocity distribution for incoming and outgoing flows was also assessed for each gauging transect, which is useful for assessing the validity of assumptions associated with using a two-dimensional depth averaged model. Most observations approximated depth averaged flow. Velocity depth profiles for each gauging location are presented in Appendix A4.

3.4 Bathymetry and elevation surveys

During the ADCP data collection campaign, an RTK-GPS unit collected vertical position data to an accuracy of 10 cm. By pairing depth soundings and elevation data, bathymetry was captured for all flow gauging locations (refer to WRL TR2023/32 Section 4.3 for details on methods used for bathymetric surveys). Captured data for all locations is shown in Figure 3-5. The change between the bathymetry at surveyed locations and the October 2022 bathymetry survey (refer to Figure 2-5) was not significant.

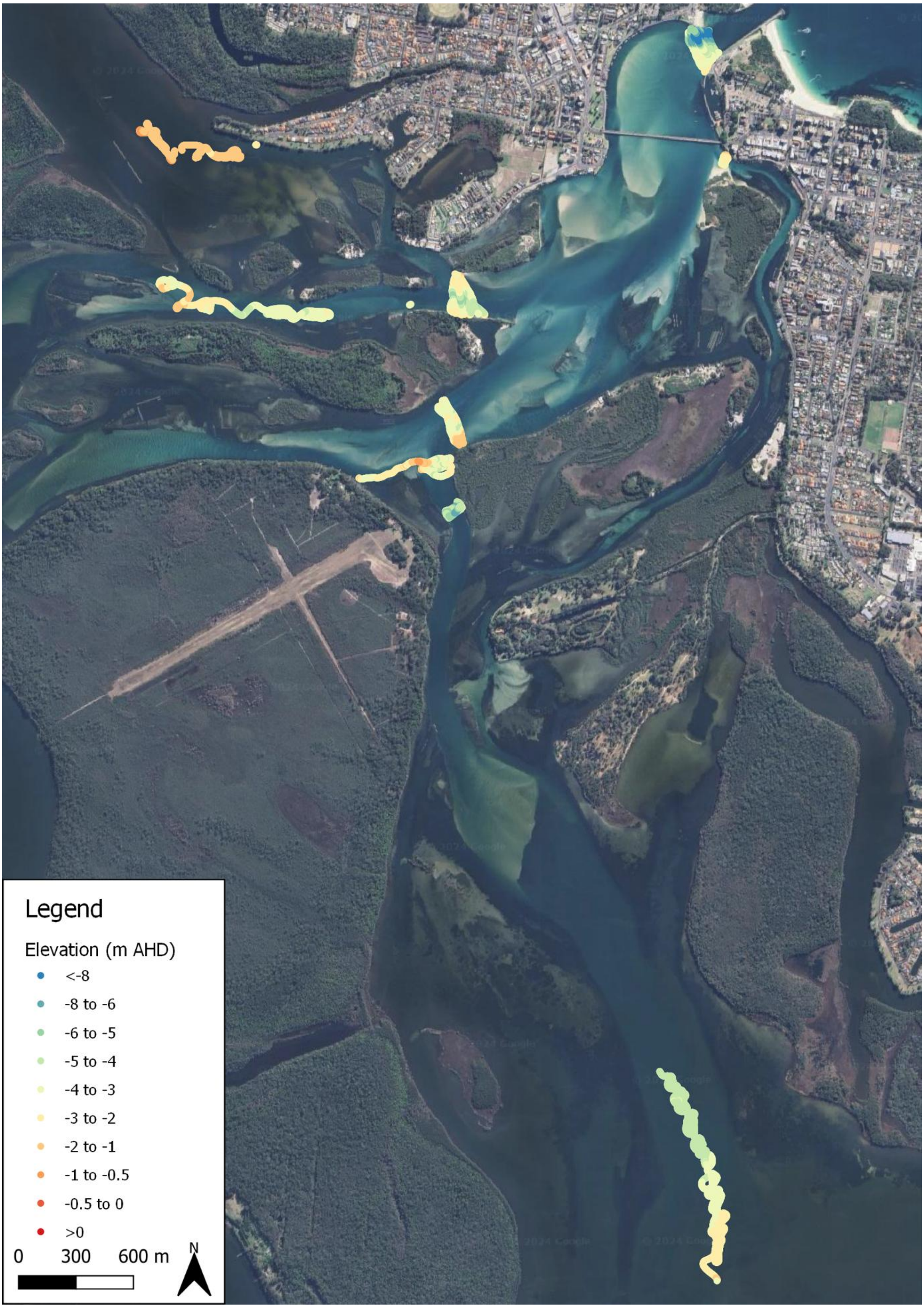

Figure 3-5 Bathymetry captured during 2023 fieldwork

3.5 Rhodamine WT dye releases

To simulate pollutant advection and dispersion in the Wallis Lake estuary, four Rhodamine WT dye releases were performed on the second day of the field campaign (refer to WRL TR2023/32 Section 4.4 for methods). These are summarised in Table 3-2, with locations shown in Figure 3-6. 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	20/09/2023	8.31am	9.45am	580	Wallis Lake near Big Island	Flood
2	20/09/2023	10.51am	11.35am	400	Wallamba River near Muddy Creek	Flood
3	20/09/2023	12.12pm	12.56pm	580	Coolongolook River near Long Island	Flood
4	20/09/2023	3.02pm	3.50pm	100	Breckenridge Channel near Goodwin Is	Ebb

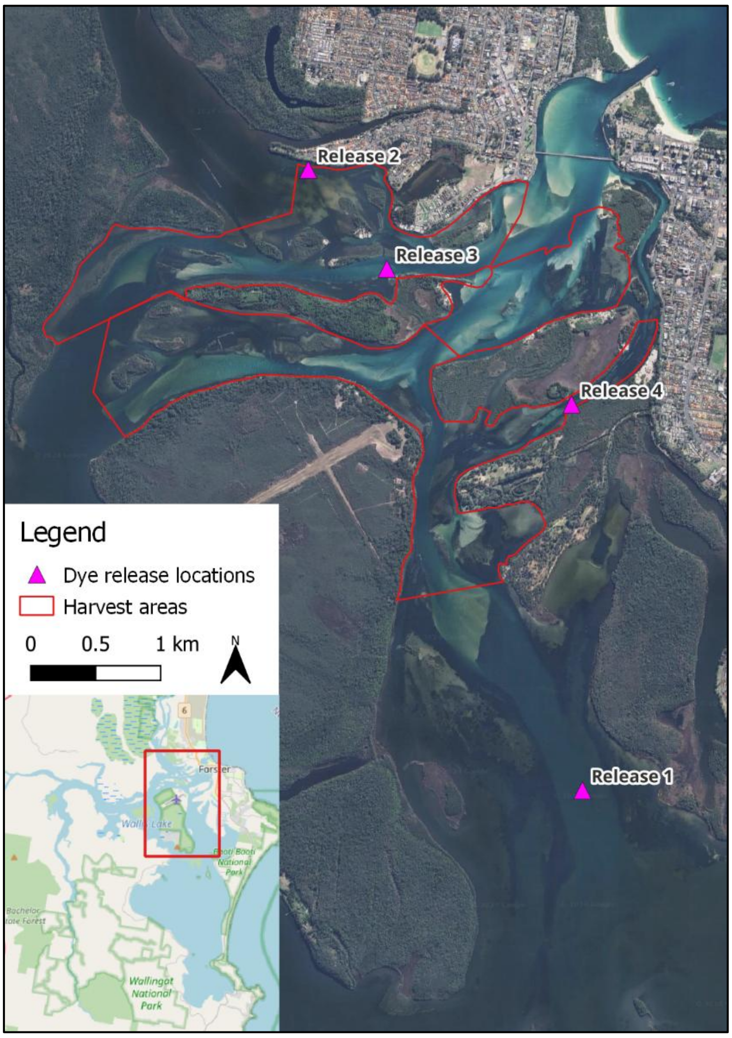

Figure 3-6 Rhodamine WT dye release locations

3.5.1 Release 1 – Wallis Lake

Dye release 1 was completed in the wide channel leading to Wallis Lake, near Big Island. This release was conducted to understand diffusion in the low velocity system of the lake. It was conducted at 8.31am, on an incoming tide. The dye release was tracked for 1 hour and 20 minutes, over which time it travelled 1.1 km, averaging 13 m/min. Figure 3-10 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

The plume moved slowly, and remained relatively circular for the first 30 minutes, before becoming increasingly elongated. Concentrations remained very high (>50 ppb) until diffusion increased when the plume began moving into shallower water, at around 60 minutes after release. Several depth profiles were taken over the course of tracking. Initially the plume decreased in concentration rapidly with depth, with the majority of the plume in the upper 2 m of the water column, see Figure 3-7 and Figure 3-8. Four depth profiles were taken along the length of the plume at 51 to 54 minutes (refer to Figure 3-8). They showed similar shapes of concentration distribution, with highest concentrations near the centre and head of the plume. After 60 minutes, when the plume began to disperse more rapidly as it moved into shallower water and began advecting faster, the plume became notably more vertically well mixed (see Figure 3-9) although concentrations were still around two times higher at the surface than at the base of the water column.

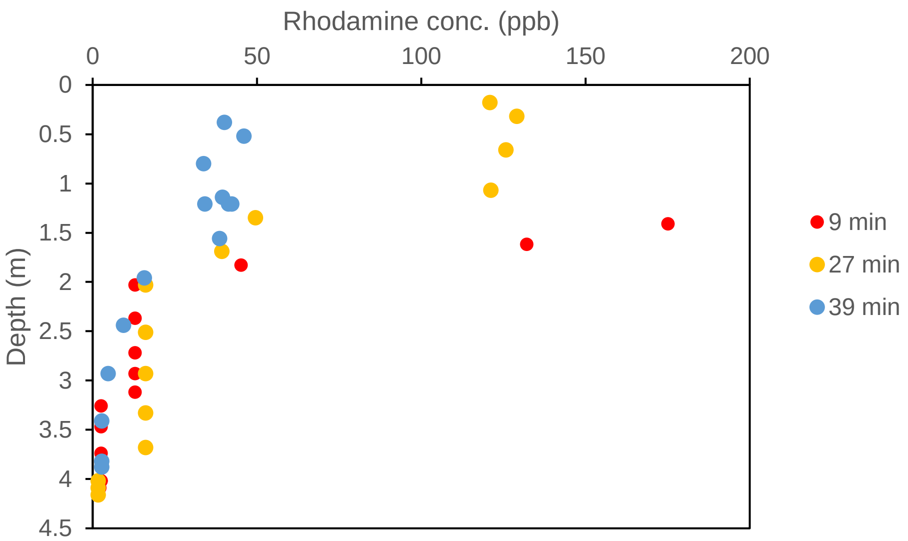

Figure 3-7 Vertical profiles conducted 9, 27 and 39 minutes after dye release 1

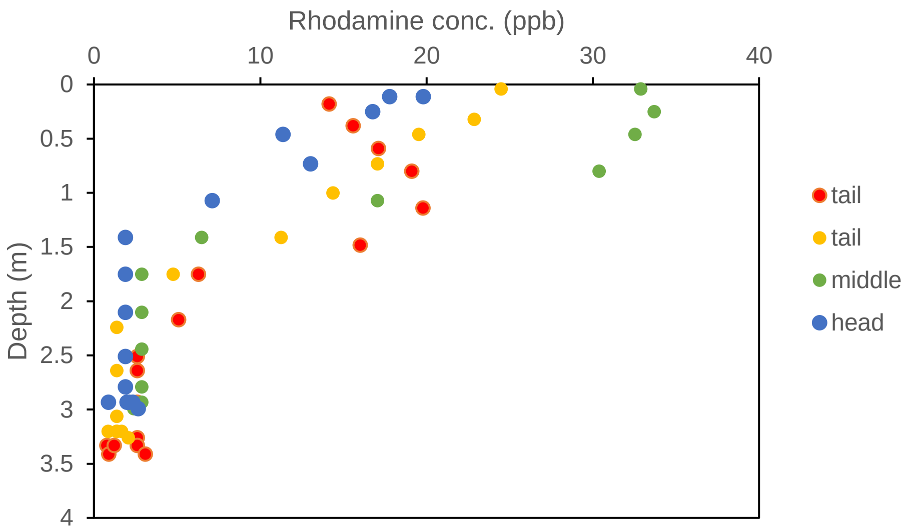

Figure 3-8 Vertical profiles conducted 51 to 53 minutes after dye release 1, in different locations along the length of the plume

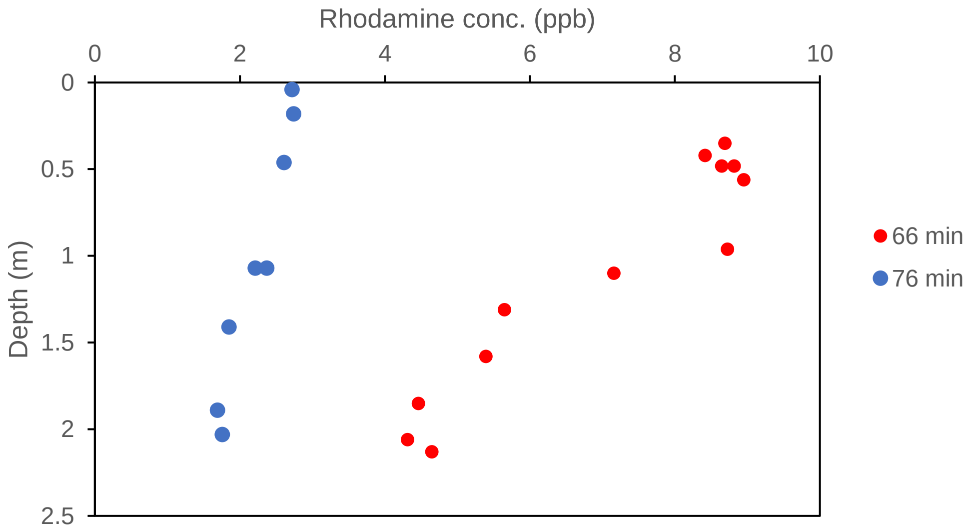

Figure 3-9 Vertical profiles conducted 66 and 76 minutes after dye release 1

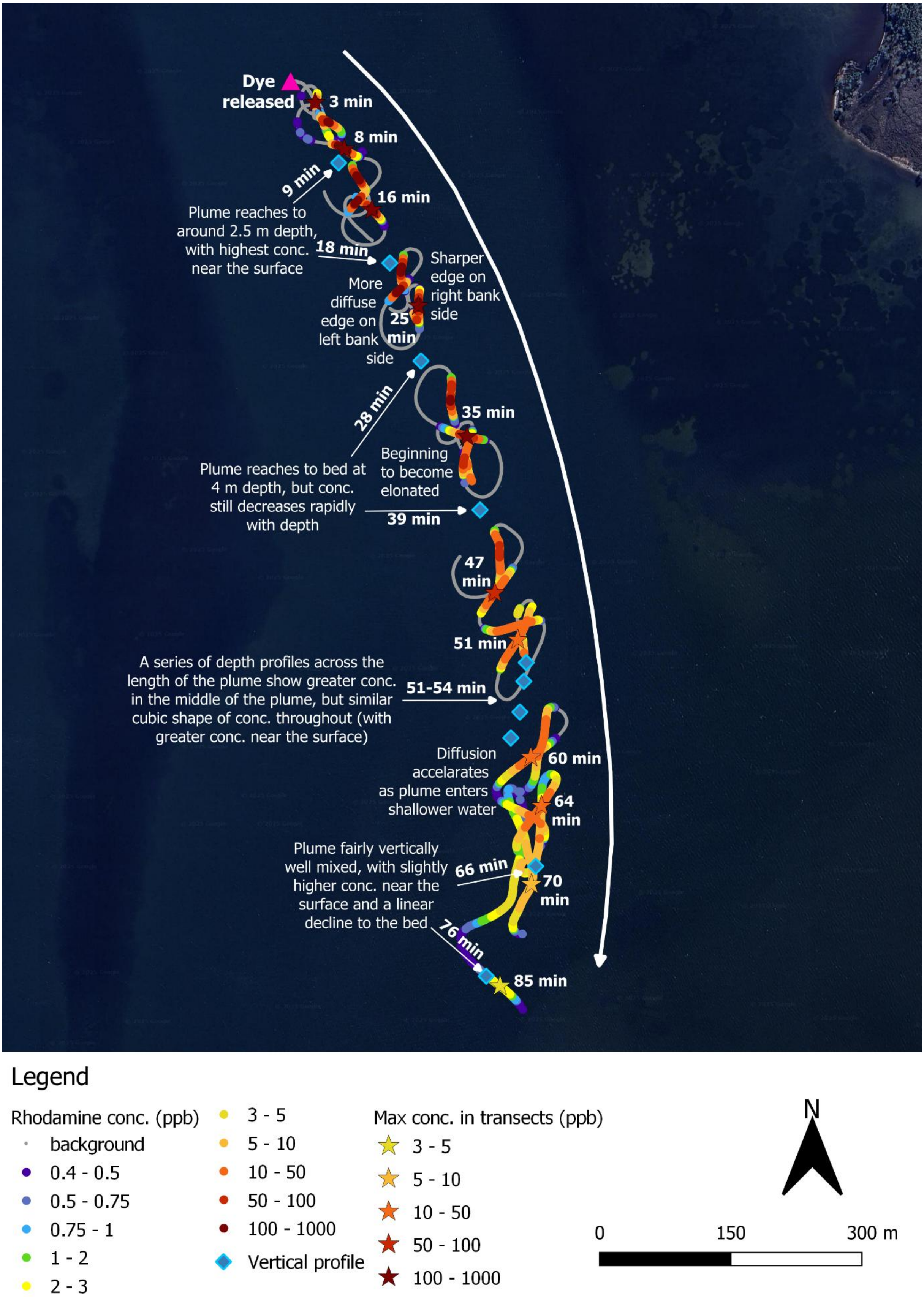

Figure 3-10 Dye release 1 in Wallis Lake. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)

3.5.2 Release 2 – Wallamba River

Dye release 2 was conducted in the Wallamba River, near Muddy Creek, to understand the transport of pollutants in this area. Due to the shallow, slow moving water and proximity to residential houses, a smaller mass of only 400 g (rather than the usual 500 or 580 g) of rhodamine was used. The release occurred at 10.51am, on an incoming tide, and the plume was tracked for 45 minutes. The plume travelled 725 m during tracking, for an average velocity of 16.5 m/min. Figure 3-12 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

The plume advected rapidly and quickly became elongated, reaching around 100 m wide by 25 m long in 12 minutes. As can be seen in Figure 3-11 the plume was vertically well mixed by 16 minutes, albeit in a water depth of just over 1 m. The plume widened to around 80 m wide as it approached the shallow oyster leases in the centre of the Wallamba River. The plume then veered towards the left bank, following the deeper channel. The shallow bathymetry and oyster leases prevented lateral transects in this area. Due to the shallow water, tracking ceased after 45 minutes, when peak concentrations were still 13 ppb.

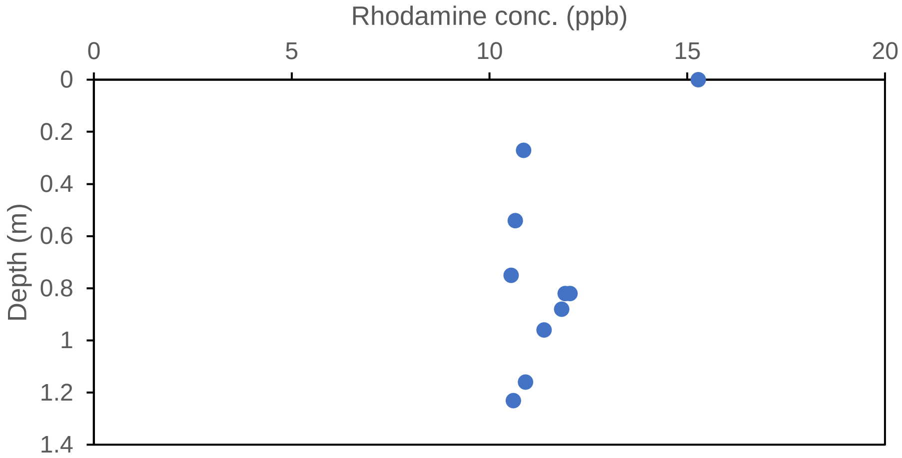

Figure 3-11 Vertical profile conducted 16 minutes after dye release 2

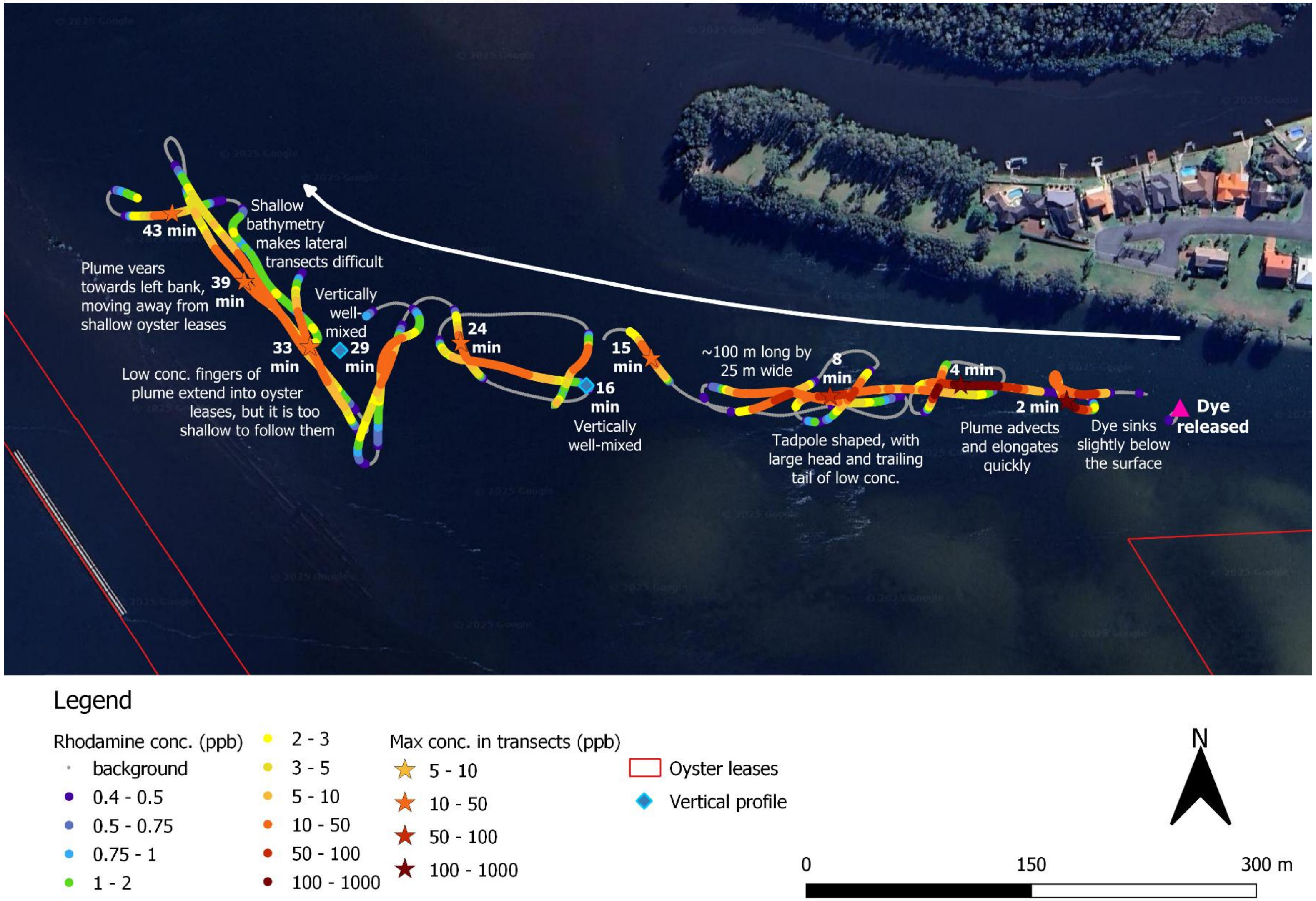

Figure 3-12 Dye release 2 in the Wallamba River. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted). Note this release was 80% of the mass of a standard release

3.5.3 Release 3 – Coolongolook River

Dye release 3 was completed in the Coolongolook River near Long Island, to understand transport and diffusion in the high velocity environment of the main channels. The release was conducted at 12.12pm, on the incoming tide, and was tracked for 45 minutes. In this time, it travelled 1.7 km, for an average velocity of 37 m/min. Figure 3-14 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

Similar to dye release 2, the plume travelled quickly and became elongated. As can be seen in Figure 3-13, the dye was vertically well mixed through the 4 m water column by 8 minutes after release. By 15 minutes, the plume was approximately 100 m long by 30 m wide. After 25 to 30 minutes, the channel began to split in two, going around the oyster leases surrounding Corstorphine Island. The plume split, with a small amount going into the shallower channel south of the island and the majority going in the deeper channel to the north of the island. The plume continued to elongate as it went past the island, and the tail of the plume travelled through the oyster leases, where it could not be tracked. Tracking ceased after 45 minutes, at which point the plume still reached concentrations greater than 3.5 ppb. This dye release experienced the fastest rates of dispersion out of the four dye releases in the Wallis Lake estuary.

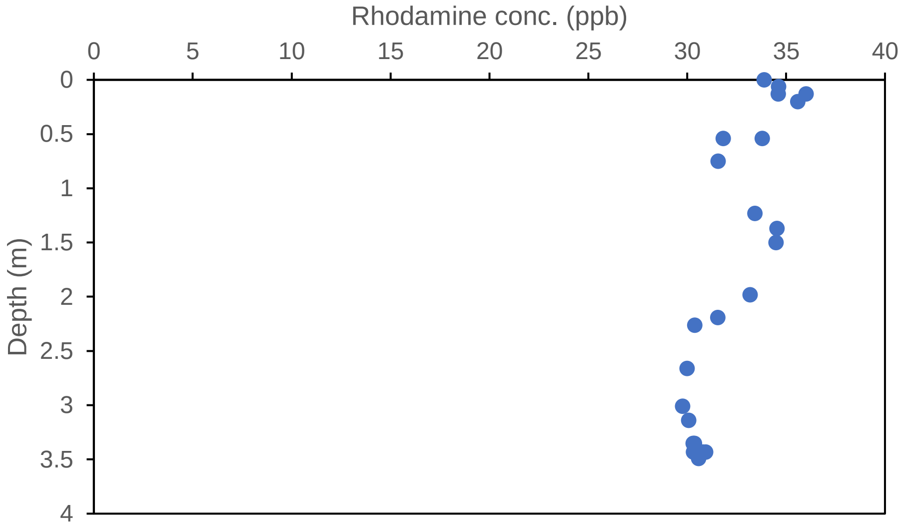

Figure 3-13 Vertical profile conducted 8 minutes after dye release 3

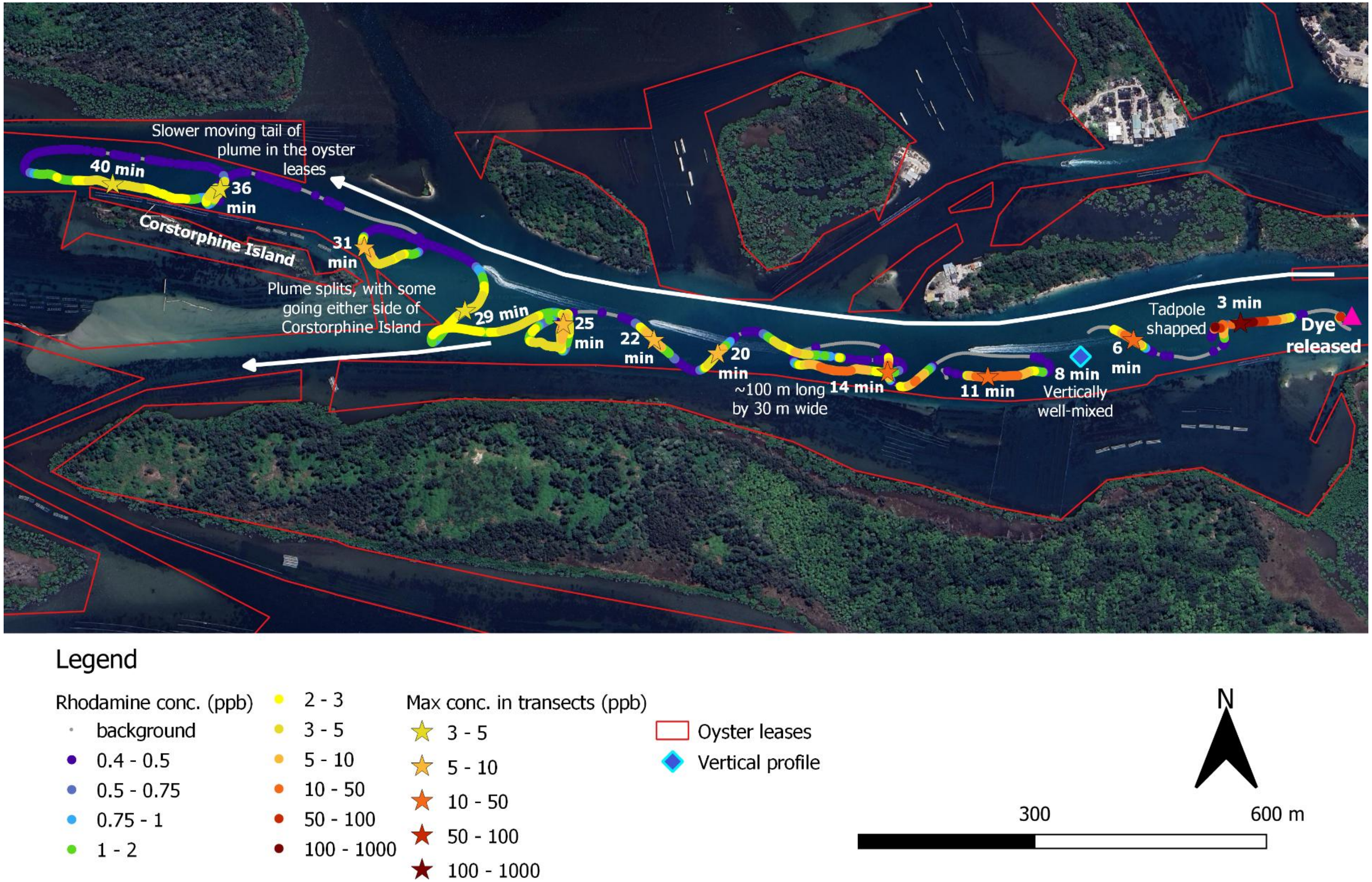

Figure 3-14 Dye release 3 in the Coolongolook River. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)

3.5.4 Release 4 – Breckenridge Channel

Dye release 4 was completed in the Breckenridge Channel near Godwin Island, to understand transport and diffusion in this smaller channel. As this was a highly trafficked location that was close to urbanised foreshore and shallow, slow moving water, a much smaller mass of only 100 g (rather than the usual 500 or 580 g) of rhodamine was used. The release was conducted at 3.02pm on the outgoing tide, and was tracked for 45 minutes. The average velocity of the plume was 17 m/min. During this release, there were NE winds of around 20 km/h. Although the channel was small enough to prevent large fetch waves from generating, the water was choppier than in the other releases. Figure 3-14 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

Similar to dye releases 2 and 3, the plume became quickly elongated and vertically well mixed. Figure 3-15 shows the plume was vertically well mixed by 11 minutes after release. The plume had a very long, low concentration tail and was around 200 m long by 30 minutes. This may be due to the opposing wind slowing the transport of the dye near the surface of the plume. Due to the oyster leases on each side of the channel, the lateral edges of the plume could not be located after around 20 minutes, however it was noted that the plume spread well into the leases on both sides of the channel, although the most concentrated part of the plume remained in the channel. Tracking ceased at 3.50pm, at which point the plume still reached concentrations greater than 1.5 ppb.

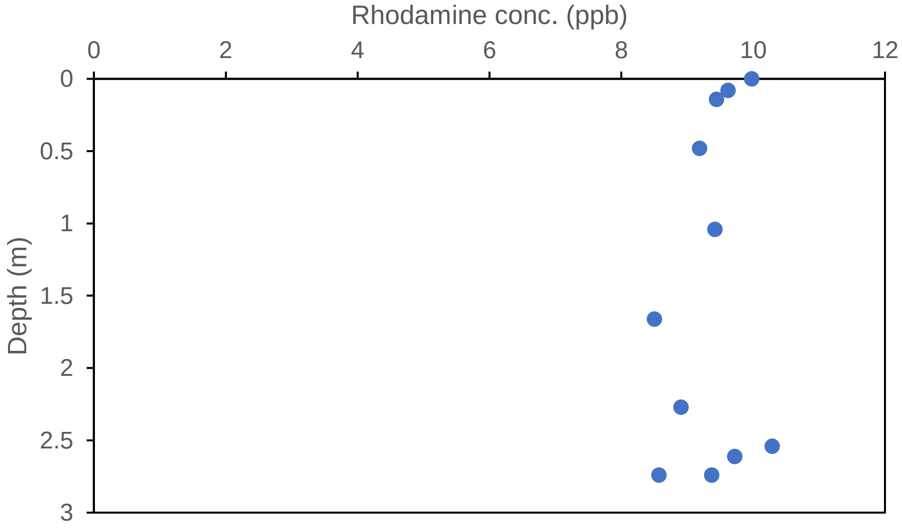

Figure 3-15 Vertical profile conducted 11 minutes after dye release 4

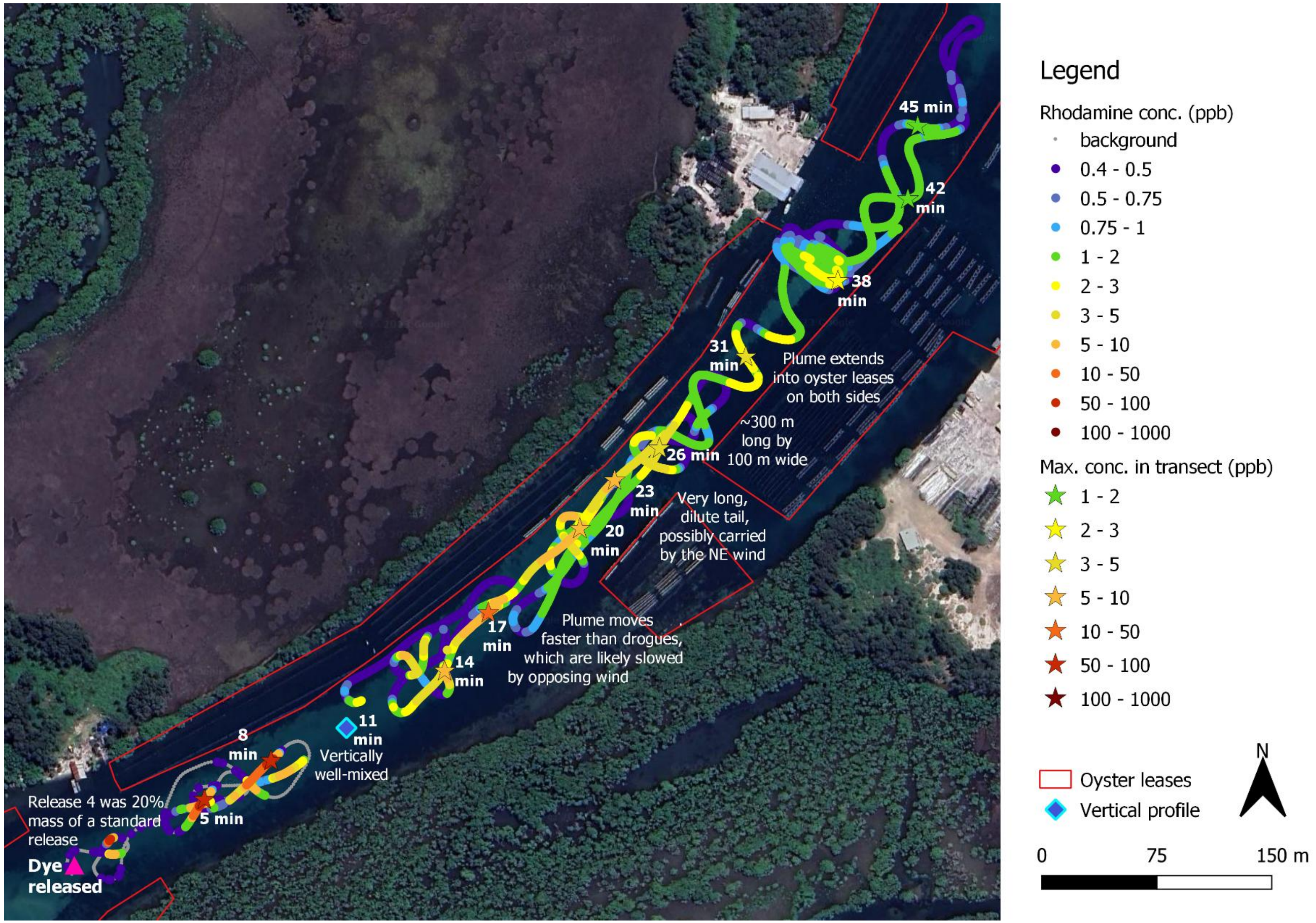

Figure 3-16 Dye release 4 in the Breckenridge Channel. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted). Note this release was 20% of the mass of a standard release

3.5.5 Field derived dispersion values

Field dye experiments were used to obtain estimates of plume spreading dispersion rates in the Wallis Lake estuary, 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 3-17. To allow easy comparison, concentrations for all dye releases were scaled to match an initial release volume of 500 mL before plotting.

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 a slightly higher dispersion than was observed in some locations in Wallis Lake (Figure 3-17). When comparing the observed peak observations to theoretical dispersion, most field dispersion values fall within D = 0.1 and 1.5 m^2/s. For release 1, the very low dispersion values of < 0.1 m^2/s in the first half of the release are due to the low velocities in a slow moving channel near the lake (refer to Section 3.5.1). The results of dye dispersion across all estuaries can be found in WRL TR2023/32 Section 7.3.

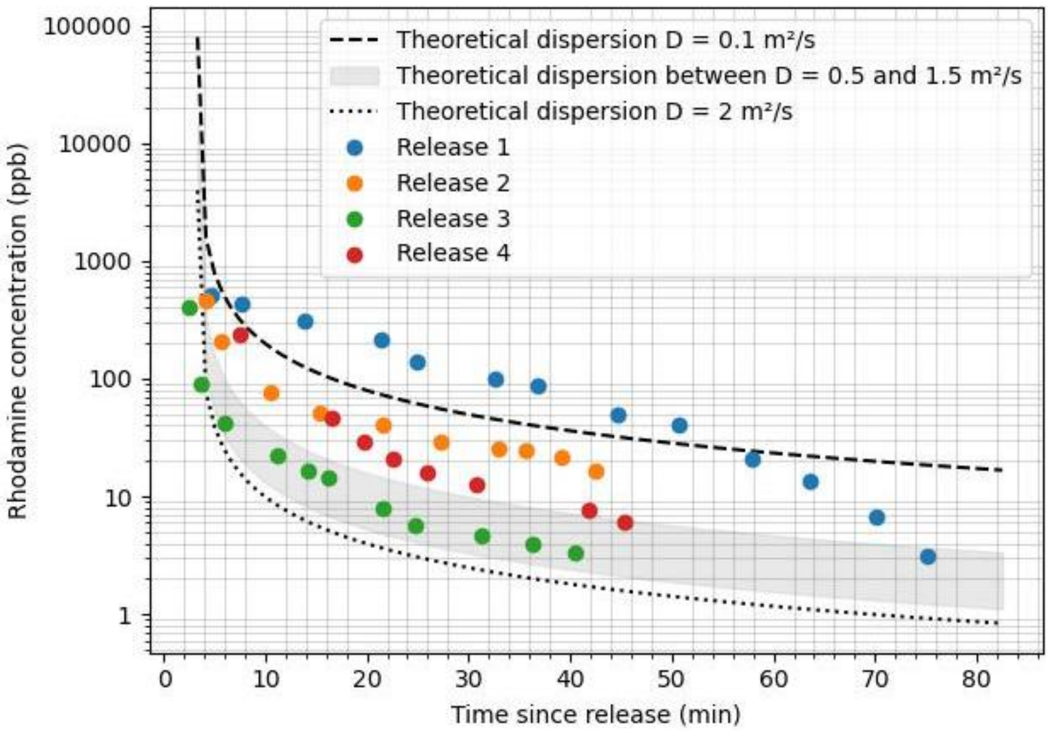

Figure 3-17 Peak concentration of select transects plotted against theoretical dispersion

3.6 GPS drifter drogue releases

To monitor surface current speeds and flow paths in the Wallis Lake estuary, GPS drifter drogues were deployed at strategic locations throughout the field campaign (refer to WRL TR2023/32 Section 4.5 for further information on drifter drogues). Table 3-3 tabulates the seven drogue releases conducted on the Wallis Lake estuary. 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
D1D1	19/09/2023	7.44am	Flood	1:16	Forster – Tuncurry Bridge	-
D1D2	19/09/2023	9.36am	Flood	0:55	Godwin Island	-
D1D4	19/09/2023	2.12pm	Ebb	0:28	WP 6	-
D2D1	20/09/2023	7.40am	Flood	2:23	Forster – Tuncurry Bridge	Near dye release 2
D2D2	20/09/2023	10.40am	Flood	0:58	Wallamba East	-
D2D3	20/09/2023	2.55pm	Ebb	0:58	Breckenridge Channel near Godwin Island	With dye release 4
D3D1	21/09/2023	6.22am	Ebb	0:34	WP 6	-

Five releases occurred in the main channel, three on the flood tide and two on the ebb tide. In all cases on the flood tide, the drogues travelled towards or through Hells Gate. Two additional releases occurred in side channels, one near Native Dog Island, at the location of the Wallamba West tidal flow gauging transect. These drogues were near, but not following, dye release 2. Another release occurred in Breckenridge Channel, in conjunction with dye release 4. In this case, drogues first lagged behind, and then caught up with the plume, likely due to the effects of the opposing wind.

3.7 Water level monitoring

To supplement the water level data available from the five long term MHL water level gauges on the Wallis Lake estuary, four water level loggers were installed during the 2023 fieldwork. One logger was installed at Hells Gate, one was installed in Breckenridge Channel and two were installed in Pennington Creek, the location of an artificial wetland designed to treat stormwater, where sewage overflows would flow before entering Breckenridge Channel. Locations are shown in Figure 3-18. Both water level loggers in Pennington Creek were installed upstream of gates separating the creek from the artificial wetland and detected only very small variations in water level with the changing tide. Thus, this location was not considered tidally connected to the estuary. The water level data recorded at the other two locations can be seen in the calibration data in Appendix B1.6.

Figure 3-18 Location of water level monitoring during 2023 fieldwork

3.8 Conductivity measurements

To measure saline intrusion, conductivity profiles were taken during the fieldwork campaign with a Sontek EXO3, as detailed in WRL TR2023/32 Section 4.7. At all locations, conductivity measured was high (specific conductivity > 52,000 µS/cm), comparable to ocean water, and no vertical stratification was detected.

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 1998 (MHL, 1998), the WorleyParsons 2010 campaign (WorleyParsons, 2011), 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.

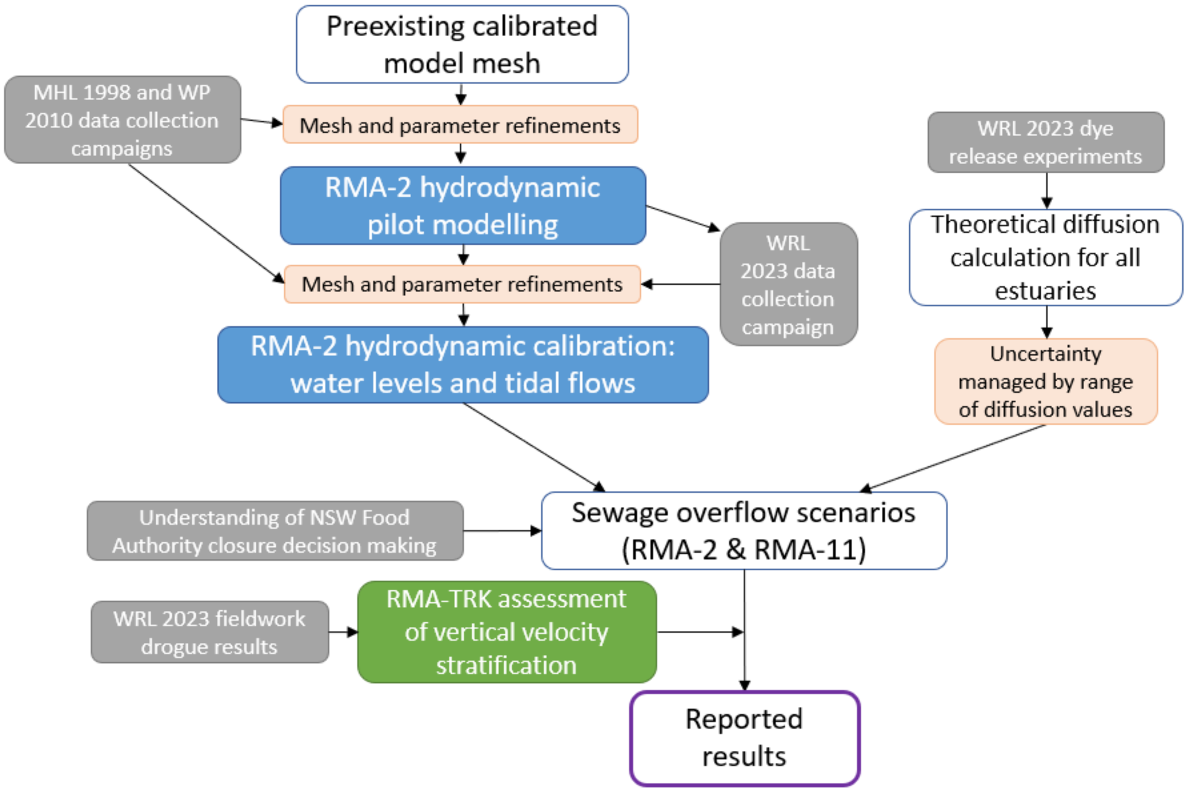

Figure 4-1 Overview of modelling approach

4.2 Model mesh development

The model domain extends from approximately 500 m offshore of the ocean entrance at Forster, to the tidal limits of the estuary and its major tributaries (refer to Figure 4-3). The model mesh consists of over 15,000 nodes and 5,000 two dimensional elements varying in size from 4 m^2 to over 850,000 m^2. A two-dimensional, depth averaged model mesh was chosen for Wallis Lake, where in the lower channelised section of the estuary (the area of interest) advective transport is largely driven by tidal and riverine flow (not wind). A discussion on the impact of model dimensionality is provided in WRL TR2023/32 Section 6.2.2. Note that wind would be an important driver of transport in the open section of the lake, however, that is not the focus of this study.

Mesh resolution is highest in the lower estuary, near both the overflow locations and oyster harvest areas, with lower resolution in the lake and upstream reaches. Refer to WRL TR2023/32 Section 6.2.3 for a discussion of model resolution.

4.3 Model bathymetry

Due to the bathymetric changes over time in Wallis Lake (variable movement of sand bars and channels, as well as long term erosion), three model bathymetries were constructed. This was necessary as a model cannot be calibrated to observations within the estuary using external boundary conditions, without having the bathymetry representing the conditions during the calibration data collection. The creation of multiple bathymetries was possible due to the availability of multiple high quality bathymetric surveys of the lower estuary, discussed in Section 2.5. The bathymetry of the upper reaches of the Wallamba, Wang Wauk, Coolongolook and Wallingat Rivers, as well as the bathymetry in Wallis Lake, was based on the 1998 bathymetry survey in all model iterations, however, the bathymetry of the lower estuary was reconstructed to represent the data available in 1998, 2010 and 2022. This primarily included changes to:

- Coolongolook River downstream of Regatta Island
- The channels flowing into Wallis Lake
- Wallamba River to Muddy Creek
- Breckenridge Channel

These three bathymetries were used for calibration with the 1998, 2010 and 2023 data, respectively. For model scenarios, the 2022 bathymetry was used as this was the most recent bathymetry. As the 2023 fieldwork bathymetry aligned with the 2022 bathymetry, no changes were made to the model bathymetry after field data collection. However, sensitivity to bathymetric changes was assessed (refer to Section 5.4) and updated bathymetry may be necessary if the model is to remain appropriate in the long term.

The estuary reaches depths greater than -10 m AHD in the entrance channel, however the majority of estuary channels are around -4 to -1 m AHD. The nodal bed elevations of the 2022 model bathymetry used for scenarios are shown in Figure 4-2.

4.4 Model boundaries

The model includes four upstream catchment flow boundaries, shown in Figure 4-3 and discussed in Section 2.3. A tidal elevation boundary was included in the model offshore of the Wallis Lake estuary entrance (refer to Figure 4-3). This modelled water level boundary was based off observed tidal elevation data collected by MHL at Crowdy Head (station number 208470 prior to 2013, and 208471 from 2013). This data was then smoothed, removing 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).

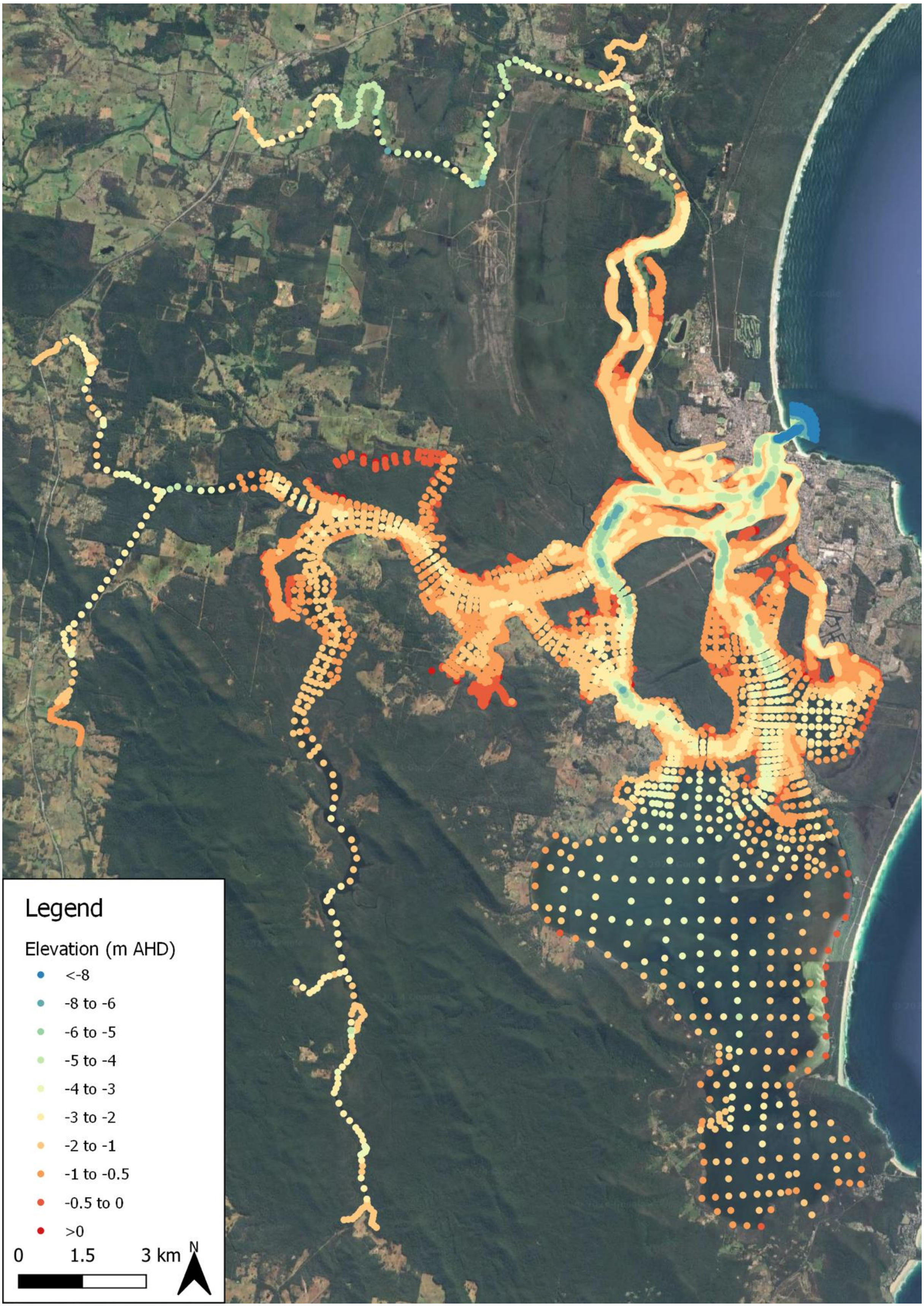

Figure 4-2 RMA model bathymetry used for scenarios, based on 2022 bathymetry

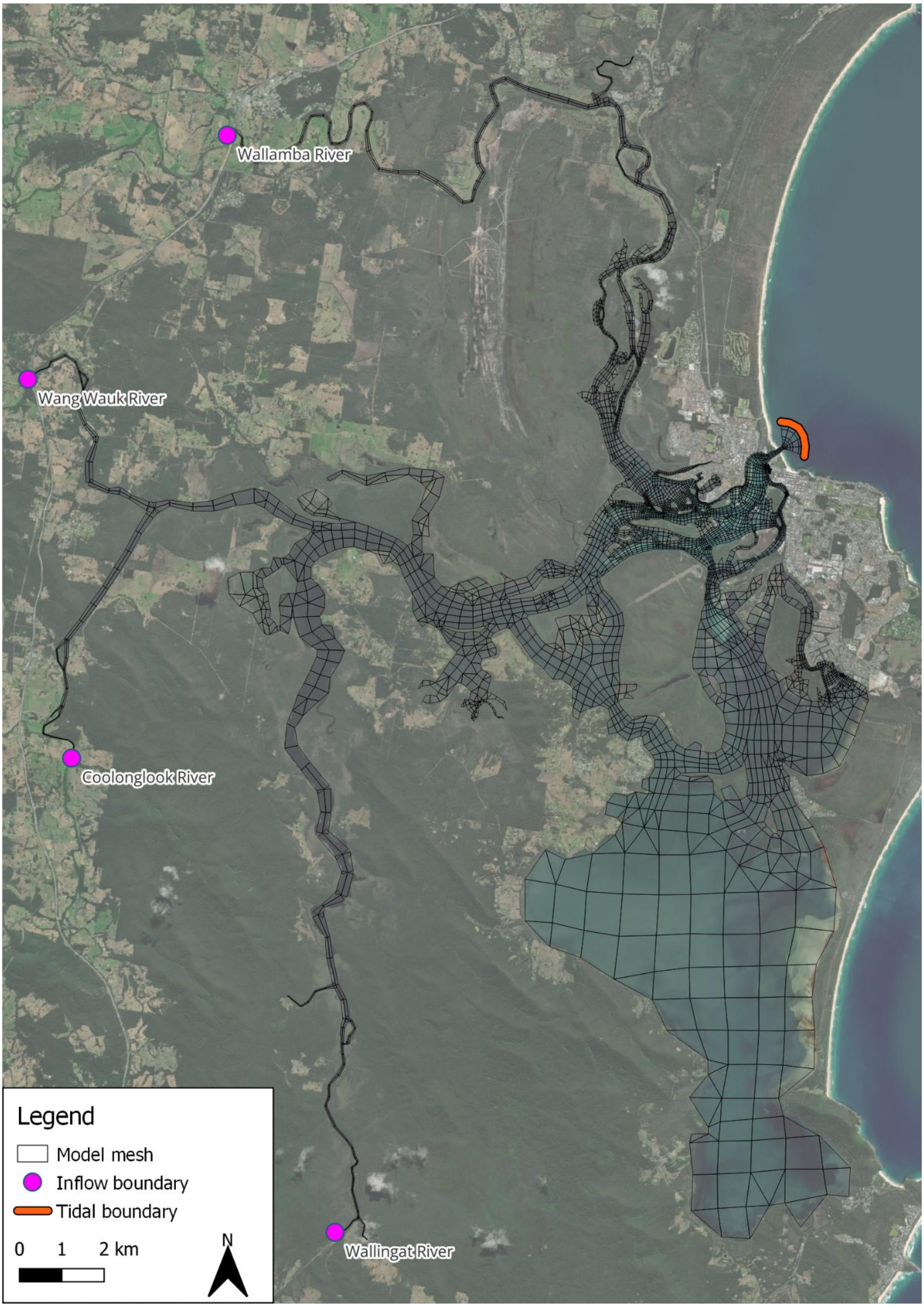

Figure 4-3 RMA model mesh showing boundary condition locations

4.5 Pilot model

Initially, a hydrodynamic pilot model was developed using the existing data described in Section 2. For more details on pilot modelling and its purpose refer to WRL TR2023/32 Section 3. This initial modelling was used to identify data gaps to be targeted during fieldwork. Data gaps identified included lower estuary flow gauging with recent bathymetric conditions, especially around Breckenridge Channel and Cockatoo Island. There was poor performance for the pilot model during the 2010 period at flow gauging location WP 6 (see Figure 3-4), and no gauging at this location for the 1998 period, so this transect was a focus of data collection.

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. Two existing sets of hydrodynamic data were available for calibration purposes. These were collected by MHL (1998) and WorleyParson (2010) and are described in Section 2.2. These were supplemented by data from the 2023 fieldwork period, which targeted key stages of the tide but was not a full tidal flow gauging. Due to changes in the bathymetry and the subsequent impacts on the hydrodynamics of the system, a different model bathymetry was used for each calibration period, using the 1998, 2010 and 2022 bathymetry surveys, respectively. However, the model parameterisation (e.g. Mannings roughness and eddy viscosity) was consistent between the models. For each period, a minimum 3 day model warmup period was run.

4.6.1 March 1998 calibration period

During the 1998 MHL data collection campaign on the Wallis Lake estuary, water level data was available at 18 gauges (including three permanent gauges) and tidal flow data was available at 13 transects (refer to Section 2.2). Measured tide levels at Crowdy Head were applied at the ocean boundary, and scaled measured catchment inflows were applied at the four upstream model inflow boundaries. 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 most flow and water levels. Flow through the entrance and marina sites (Figure 4-4 and Figure 4-5) is slightly underestimated, however flow magnitude and shape of flow at all other locations in the lower estuary is well matched (see Figure 4-6 for an example). Due to the issues noticed measuring flow at this location during the fieldwork, as well as inconsistencies evident in the 2010 data, the gauging at the entrance was considered less reliable for all calibration periods, and the model fit at other locations was prioritised. Modelled water levels achieved a very good match to measured levels in the lower estuary (see Figure 4-7 for example), although there are small timing offsets at some of the upstream gauging locations (see Figure 4-8 for an example).

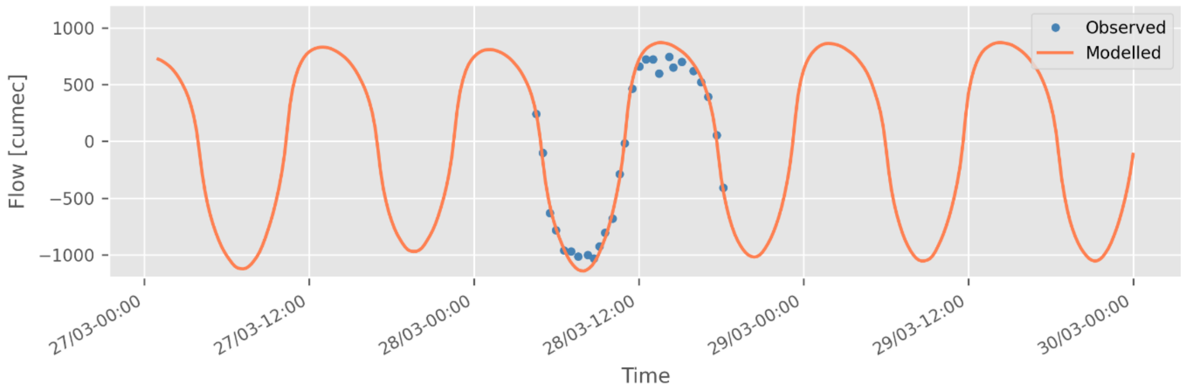

Figure 4-4 1998 tidal flow calibration – Location A – Entrance Site 2

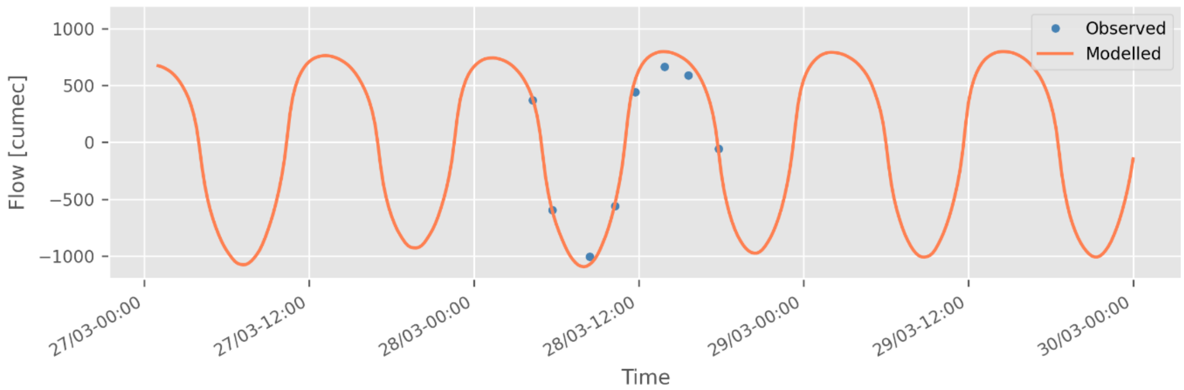

Figure 4-5 1998 tidal flow calibration – Location C – Marina Site 3

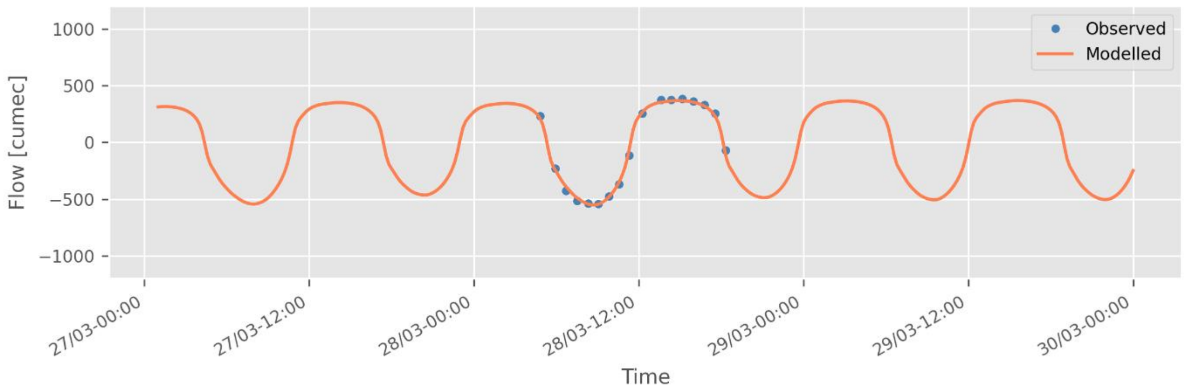

Figure 4-6 1998 tidal flow calibration – Location G – Wallis Island West Site 9

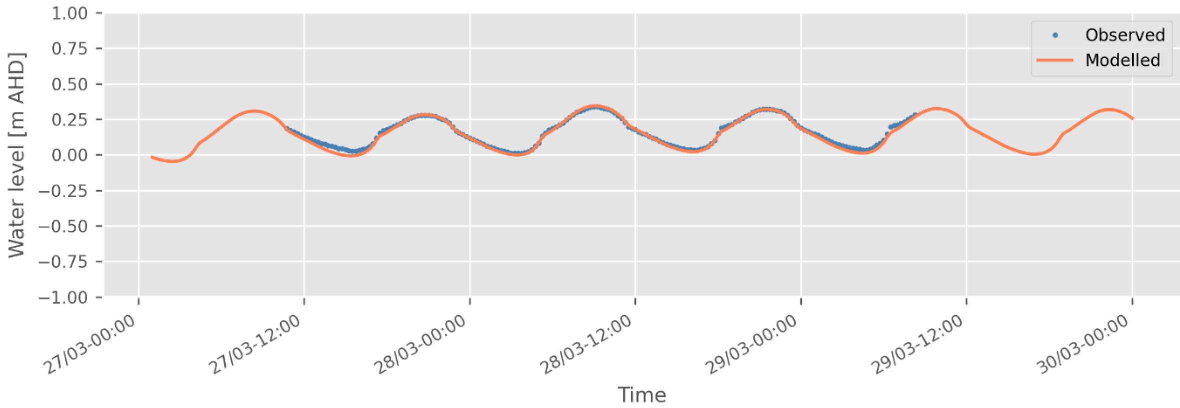

Figure 4-7 1998 water level calibration – Location 3 – Hells Gate Site 7

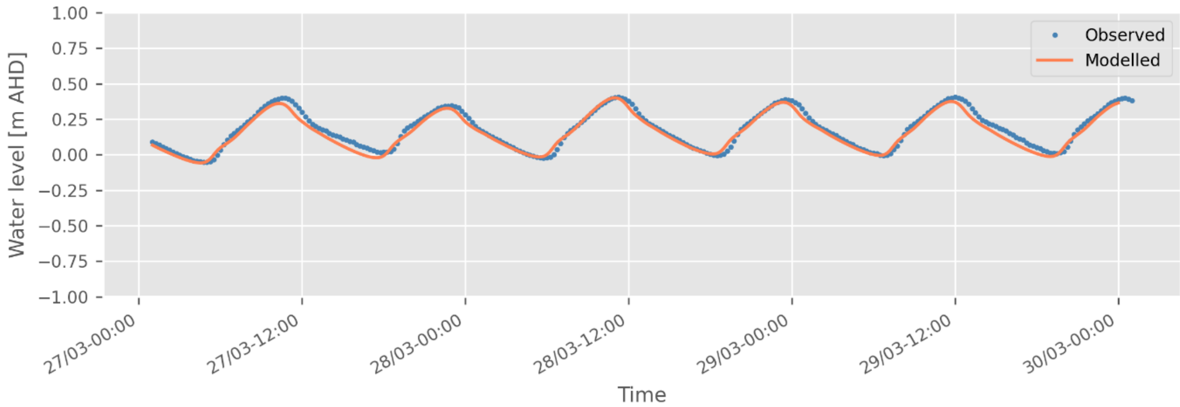

Figure 4-8 1998 water level calibration – Location 13 – Wallamba River Upper Site 32

4.6.2 October 2010 calibration period

During the 2010 data collection campaign on the Wallis Lake estuary, water level data was available at three permanent gauges and tidal flow data was available at six transects (refer to Section 2.2). Measured tide levels at Crowdy Head were applied at the ocean boundary, and scaled measured catchment inflows were applied at the four upstream model inflow boundaries. 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.

A similarly good model match was achieved to the 1998 calibration period. Although flow through the entrance was of an appropriate magnitude (Figure 4-9) the flow at the marina site was underestimated (Figure 4-10), however, the observed flow through the marina site was larger than the flow at the entrance, which should not be possible. Hence, this data was considered less reliable and the model fit at other locations was prioritised. The flow at WP 6 (Figure 4-11) was underestimated, an issue that was shared in the 2023 calibration period, and in the WorleyParsons (2011) model.

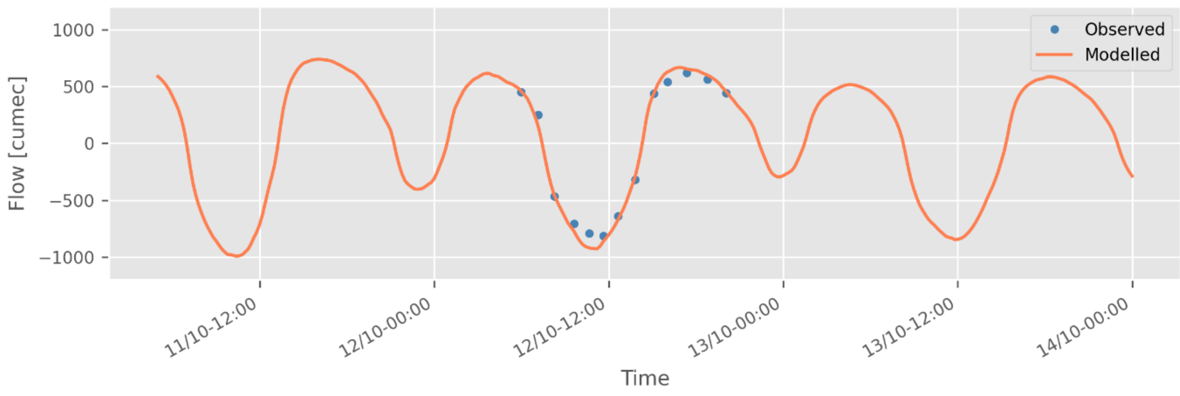

Figure 4-9 2010 tidal flow calibration – Location A – Entrance Site 2

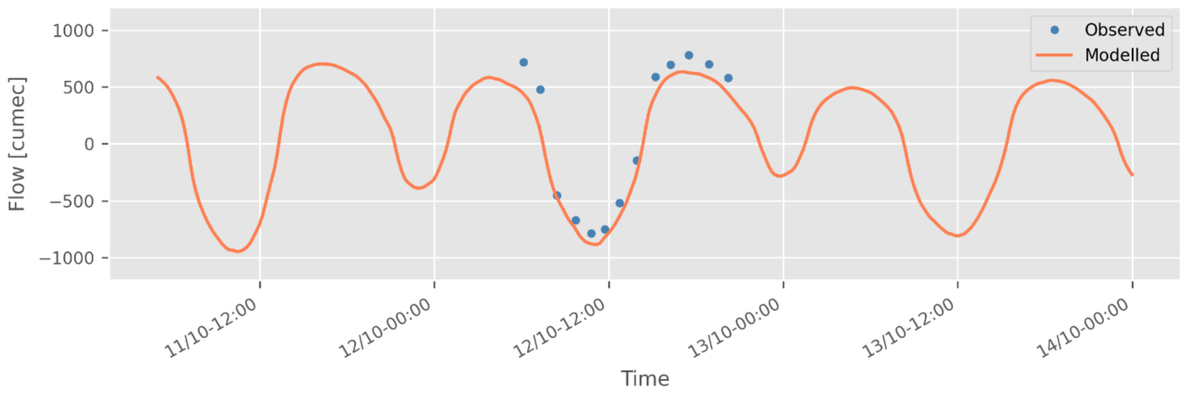

Figure 4-10 2010 tidal flow calibration – Location C – Marina Site 3

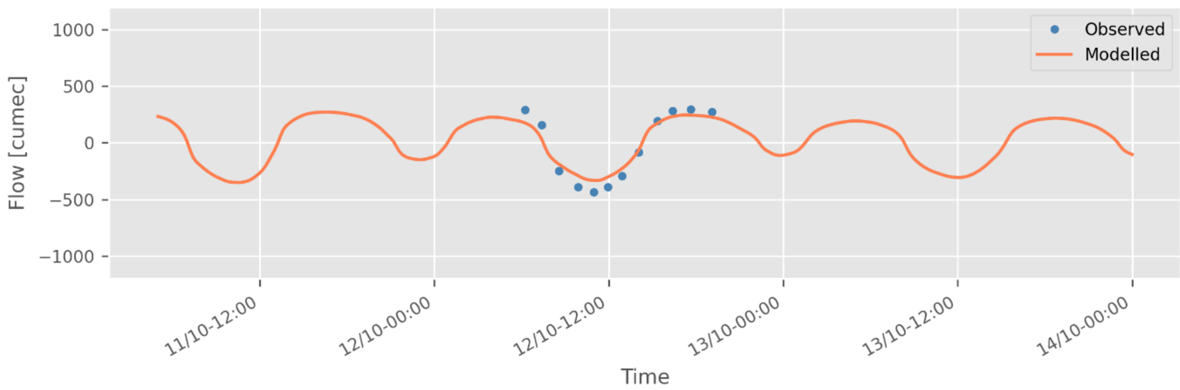

Figure 4-11 2010 tidal flow calibration – Location N – WP 6

4.6.3 September 2023 field data calibration period

The 2023 field campaign involved the collection of tidal flow gauging at seven transects, and the collation of water level data at three locations from MHL and two water level locations gauged during fieldwork (refer to Section 3). Measured tide levels at Crowdy Head were applied at the ocean boundary and scaled measured catchment inflows were applied at the four upstream model inflow boundaries. Plots of all observed water level and flow compared with model results are shown in Appendix B-16 and B-18, while select results are shown below.

A similar fit was achieved for flow gauges to the 2010 calibration period. Flow at the entrance (Figure 4-12) was underestimated, however, due to the high currents and the shape of the channel, meaning much of the flow was through a deep channel on the left bank, close to the training wall, measuring at this site was difficult and the data was noisy, hence, this data was considered less reliable and the model fit at other locations was prioritised. Similar to the 2010 period and the WorleyParsons (2011) model, flow at WP 6 was slightly underestimated (Figure 4-13). No bathymetric explanation for this issue could be determined, however, it was concluded that the flow through this channel would have minimal impact on overflows from the scenario locations, thus the model was still considered fit for purpose. The water levels at all locations were underestimated, though the range and shape of the water level profiles achieved a good match. The vertical offset in water levels in the lower estuary (see Figure 4-14 for an example) is likely due to the low pressure during the fieldwork. This caused a relatively large anomaly at Forster, however affected the Crowdy Heads gauge (the source of the driving tides for the model) less. This can be seen in Figure 3-2. The gauge at Pacific Palms Wharf (Figure 4-15) showed a similar offset before 21 September 2023, however, the observed water level then dropped on 21 September, likely due to the strong southerly winds creating set up on the north side of the lake, reducing water levels near the gauge. This would not be simulated in the model as wind is not included. Hence, considering the model had an appropriate fit to the measured data for the three calibration periods in areas of interest, the model was considered fit for purpose.

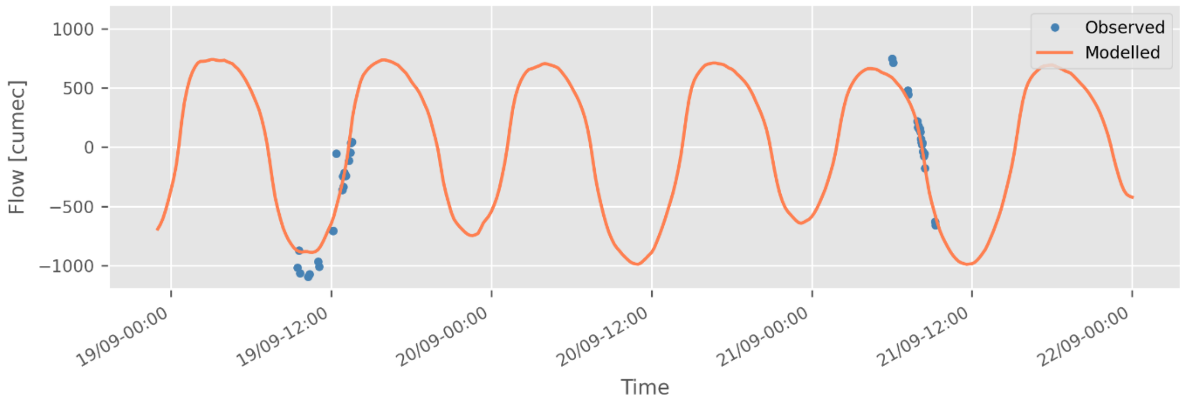

Figure 4-12 2023 tidal flow calibration – Location A – Entrance Site 2

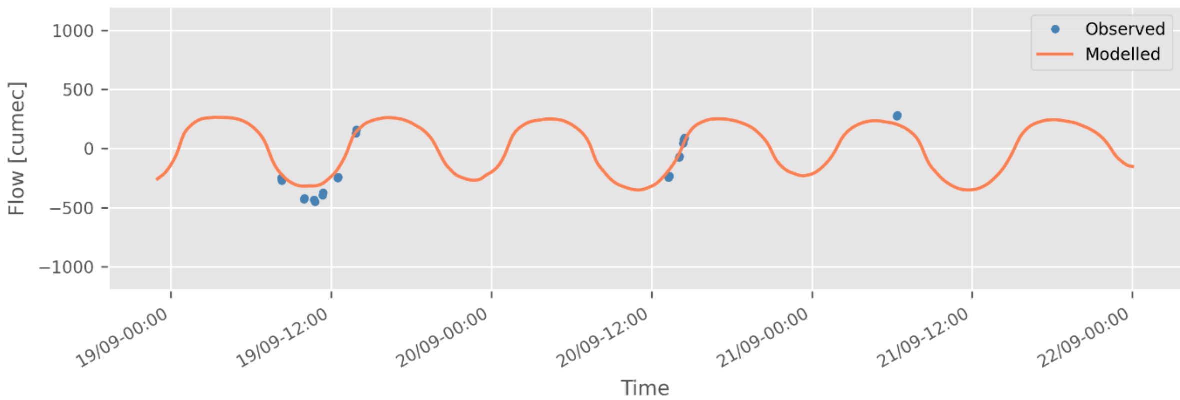

Figure 4-13 2023 tidal flow calibration – Location N – WP 6

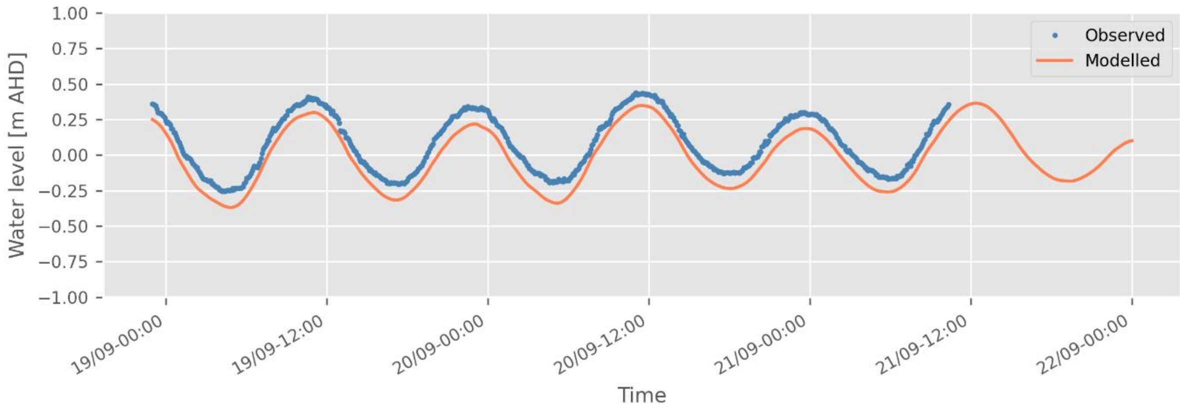

Figure 4-14 2023 water level calibration – Location 22 – Breckenridge Pool

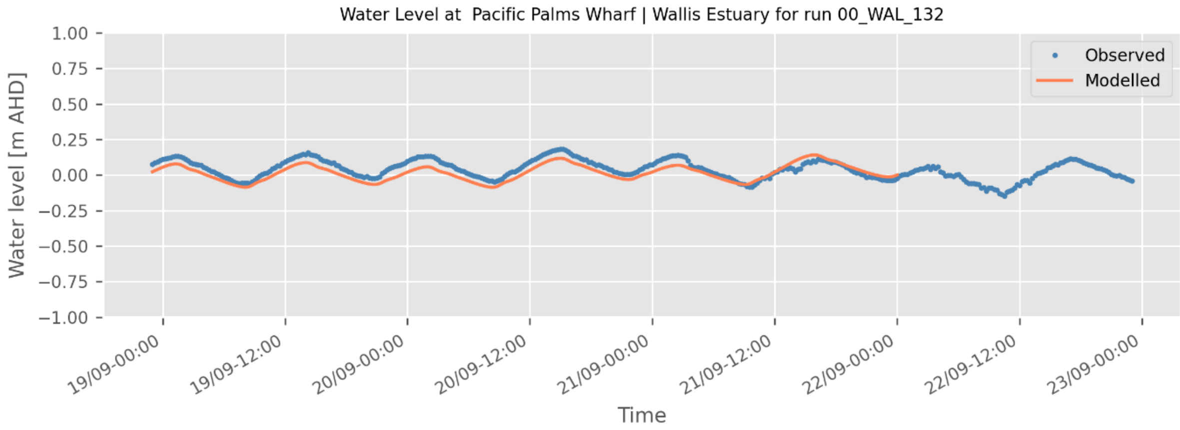

Figure 4-15 2023 water level calibration – Location 6 – Pacific Palms Wharf

4.6.4 Comparison to previous models

The model achieved a very similar fit to the existing models (WRL TR2000/16 and WorleyParsons, 2011) for most locations. Notably, for the Hells Gate location, which is adjacent to two oyster harvest areas, the model achieved a better fit for water level than the 2000 WRL model (Figure B-17) and for flow than the WorleyParsons model (Figure B-35).

4.6.5 Roughness coefficients

Table 4-1 lists the roughness coefficients (Manning's n) which control the frictional losses in the calibrated model. Most areas have a coefficient between 0.025 and 0.035, which is in the normal range for large sandy channels, and similar to the coefficient of 0.035 used throughout the entire model domain of the WRL TR2000/16 model. The Manning's n used in the entrance channel is 0.05, which is very high for a sandy channel, however, a high roughness was needed to accurately simulate the losses through a fast moving narrow constriction.

Table 4-1 Manning's n roughness coefficients of the final model

Location	Manning's n roughness coefficient
Entrance	0.050
Coolongolook River from entrance to Cockatoo Island	0.031
Coolongolook River from Cockatoo Island to Regatta Island	0.035
Hells Gate channel	0.025
Seagrass areas and oyster leases	0.035
Intertidal areas	0.045
All other areas	0.030

4.7 Water quality model development

4.7.1 Modelling of dispersion in RMA-11

Dye dispersion experiments, discussed in Section 3.5, provided valuable information on dispersion and its simulation in modelling. In particular, they provided evidence for a sensible range of dispersion coefficients to use in the modelling. However, it was concluded that they could not be used to produce estuary specific values for dispersion. Hence, a range of dispersion values, derived from the field experiments, was used across all the estuaries. Models were run with two dispersion coefficients, 0.5 and 1.5 m^2/s in the channels, 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.

A single dispersion coefficient of 4 m^2/s was used in the lake, to capture potential dispersion from wind driven mixing. The RMA-11 model utilised a 3 minute timestep, with results output every 6 minutes. High temporal resolution was required in this system due to the high velocities which result in rapid plume movement through the channels.

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 3.6) with modelled transport. Table 4-2 shows the difference in drogue velocity and velocity of particles released in the model at the same location and time, plus the ratio between the two.

In the Wallis Lake system, depth varying vertical velocity distributions were observed when comparing drogues to modelled particles, with ratios of an average of 1.37. 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).

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)
D1D1	Forster – Tuncurry Bridge	Flood	1.82	1.38	1.33
D1D2	Godwin Island	Flood	2.84	2.12	1.33
D1D4	WP 6	Ebb	2.19	1.68	1.30
D2D1	Forster – Tuncurry Bridge	Flood	2.02	1.50	1.35
D2D2	Wallamba West	Ebb	1.59	1.00	1.59
D2D3	Breckenridge Channel near Godwin Island	Ebb	0.81	0.81	1.00
D3D1	WP 6	Ebb	2.68	1.58	1.69

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.

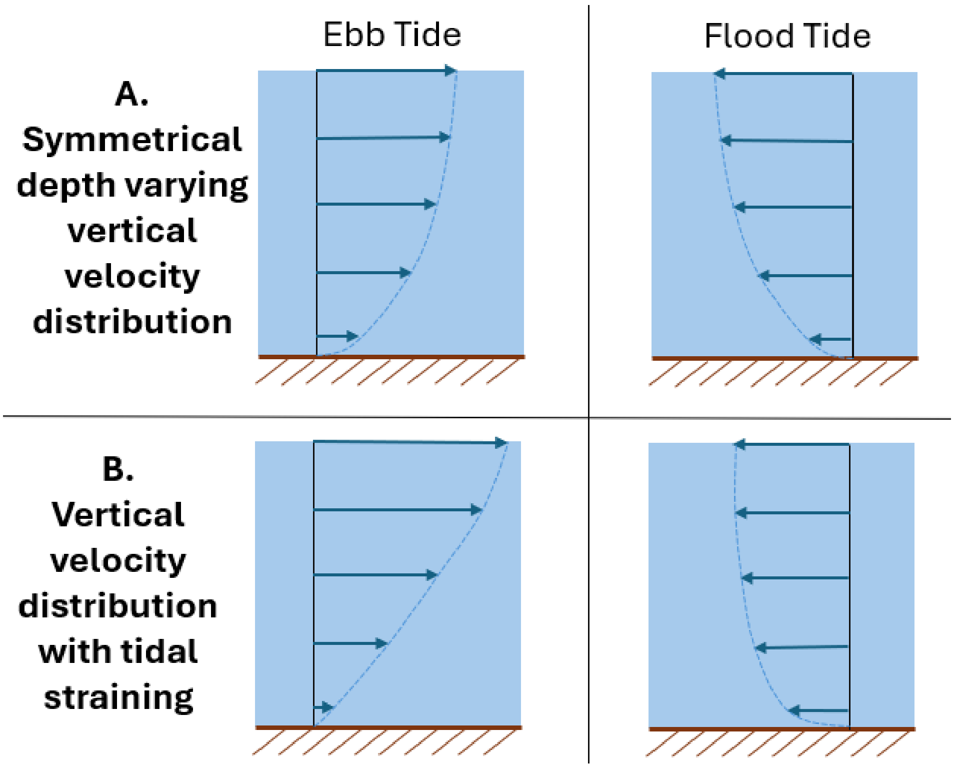

Figure 4-16 Flow with tidally symmetrical depth varying velocity profiles and tidal straining with non-symmetrical vertical velocity profiles

4.8 Limitations for future model uses

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

Limitations specific to the Wallis Lake model include:

- Underestimation of flow at WP 6. As discussed in Section 4.6.3, flow in this location is not a major influence on transport from the modelled overflow locations, hence the model was deemed fit for purpose, however this may not be true for other use cases.
- Bathymetric changes are common in this system. Sensitivity of the modelled overflow results was assessed and is discussed in Section 5.4. Although sensitivity to bathymetry was considered low for this use case due to the relative location of the oyster harvest areas and overflows, this may not be true for other use cases and multiple bathymetries or/and updated bathymetry may be required.
- There is also a long term trend of increasing channel efficiency, as a result of instillation of the training walls, leading to increased tidal ranges in the lake (Nielsen and Gordon, 2016). Due to the satisfactory fit to calibration periods over a wide range of time, this was not deemed to be significant for the models current purpose, however, may affect future use cases and updated bathymetries may be required.

- The transport processes in Wallis Lake are likely to be driven by wind, not captured in this model. Uncertainty about the lake transport processes for the Pipers Bay location (in wide channels leading to the main lake) are dealt with by having a higher diffusion coefficient of 4 m^2/s in the lake and surrounding large channels, however, future modelling purposes may wish to simulate lake transport processes explicitly through the addition of wind as an input.
- Losses through the entrance are not well simulated, as reflected by the large Manning's n through the entrance of 0.05. This indicates that energy loss processes are not being appropriately simulated by the model. In this situation, adding frictional losses achieved the effects of creating losses to accurately approximate the tidal prism of the system, however, this approach may not be appropriate for use cases where the entrance dynamics are of greater concern, such as informing dredging.
- Due to the limited amount of preexisting hydrodynamic data for this estuary, 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.

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 Wallis Lake, a total of 144 model scenario simulations were completed, including permutations of:

- Four overflow locations
- Four stages of the tide
- Two tide sizes
- Two catchment inflow conditions
- Three overflow volumes and duration

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

Four locations were used to simulate overflow locations into the Wallis Lake estuary. These locations were based on historical overflow events (Section 2.4) and input from NSW Food Authority. These locations typically correspond to creek lines or infrastructure where sewage may be directed to following an overflow. Modelled overflow locations are shown in Figure 5-1. 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.

This is especially relevant for overflows at or near the Breckenridge Channel location. This location corresponds to the outlet of Pennington Creek, a creek with an artificial wetland system designed to divert and treat stormwater rather than it entering the estuary. This system is shown in Figure 5-2 and is designed to divert flow from upstream into the artificial wetland adjacent to Pennington Creek, as long as upstream water levels remain below the level of the high water floodgates connecting to the main creek. This system should prevent sewage overflows entering upstream from reaching the estuary, unless there is a malfunction or the capacity is exceeded in a large rain event, in which case the system is designed to flow into the main creek. When a spill is reported in this area, local authorities should be consulted to determine if the overflow would or would not have reached the estuary.
At each overflow location, three different overflow conditions were considered:

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

The rate of discharge (10 kL/hr) was kept constant between each condition. This is equivalent to a rate of approximately 3 L/s. Intermediate results can be inferred for overflows of the same duration, but a different volume. See WRL TR2023/32 Section 8.3.3 for details on how to do this.

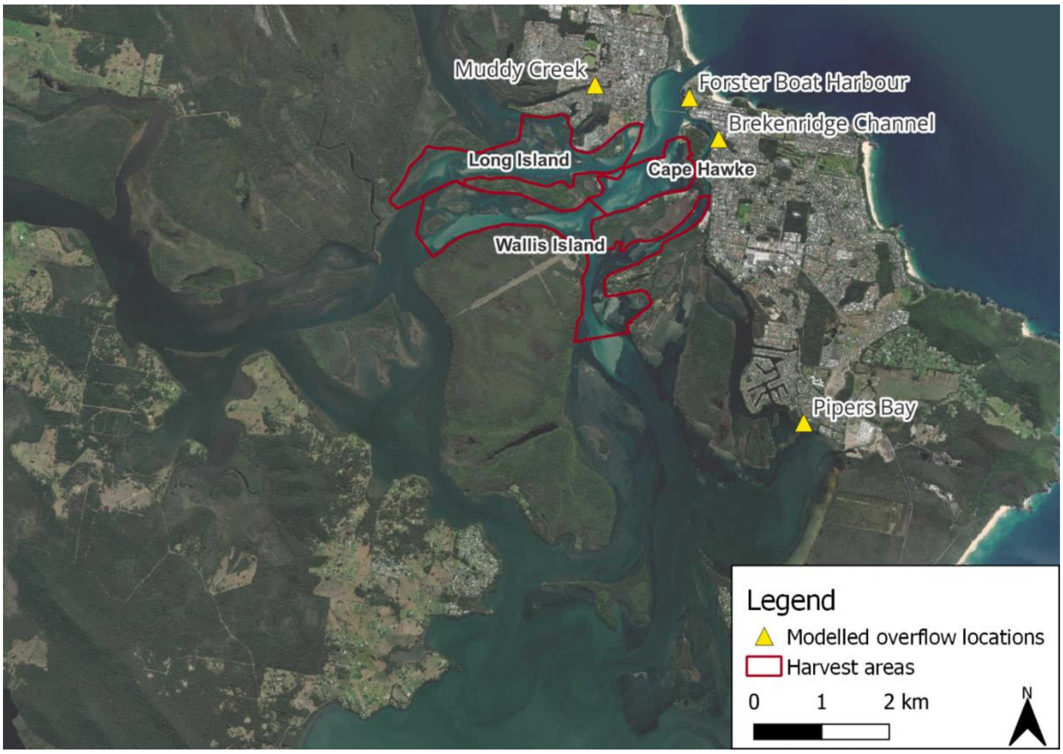

Figure 5-1 Modelled overflow locations in Wallis Lake estuary

Figure 5-2 Areal imagery of Pennington Creek artificial wetland system from Nearmap

5.3 Environmental variables

Three environmental variables were tested for Wallis Lake:

1. Stage of the tide (slack low tide, slack high tide, mid ebb tide and mid flood tide)
2. Size of the tide (small or large)
3. Magnitude of catchment inflows (median and 95th percentile)

5.3.1 Stage of the tide

Stage of the tide for all locations is indexed to the MHL Forster ocean tide gauge, via the relationship described in Table 5-1. Because of the nature of a lake system, slack tides do not correspond to the highest and lowest water levels at the entrance. Instead, these correspond to mid flood and ebb tide.

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
All	Slack low tide	Forster (209402)	Half way between low and high
All	Mid flood tide	Forster (209402)	High tide
All	Slack high tide	Forster (209402)	Half way between high and low
All	Mid ebb tide	Forster (209402)	Low tide

The stage of the tide is important for the Breckenridge Channel and Forster Boat Harbour overflow locations for overflows of duration less than 10 hours. Timing of the tide is particularly important for 1 hour overflows from the Breckenridge Channel, where overflows at slack high tide (the beginning of the outgoing tide) will largely leave the estuary before the turn of the tide. This highlights the need for accurate reporting of the timing and duration of overflows from these locations. The stage of the tide has some impact on timing for overflows from Pipers Bay, and has no impact on overflows from Muddy Creek.

5.3.2 Size of the tide

Size of the tide was important for overflow results in some cases, thus two tide sizes were simulated. Tide sizes refer to tidal range (the difference between high and low tide water level). References to tide size are based off the size of the offshore tides driving the model, sourced from the MHL Crowdy Head Fishermans Wharf ocean tide gauge (208471). For the purpose of the modelling:

- A large tide had a range of 1.75 m, as shown Figure 5-3
- A small tide had a range of approximately 0.75 m, as shown in Figure 5-3

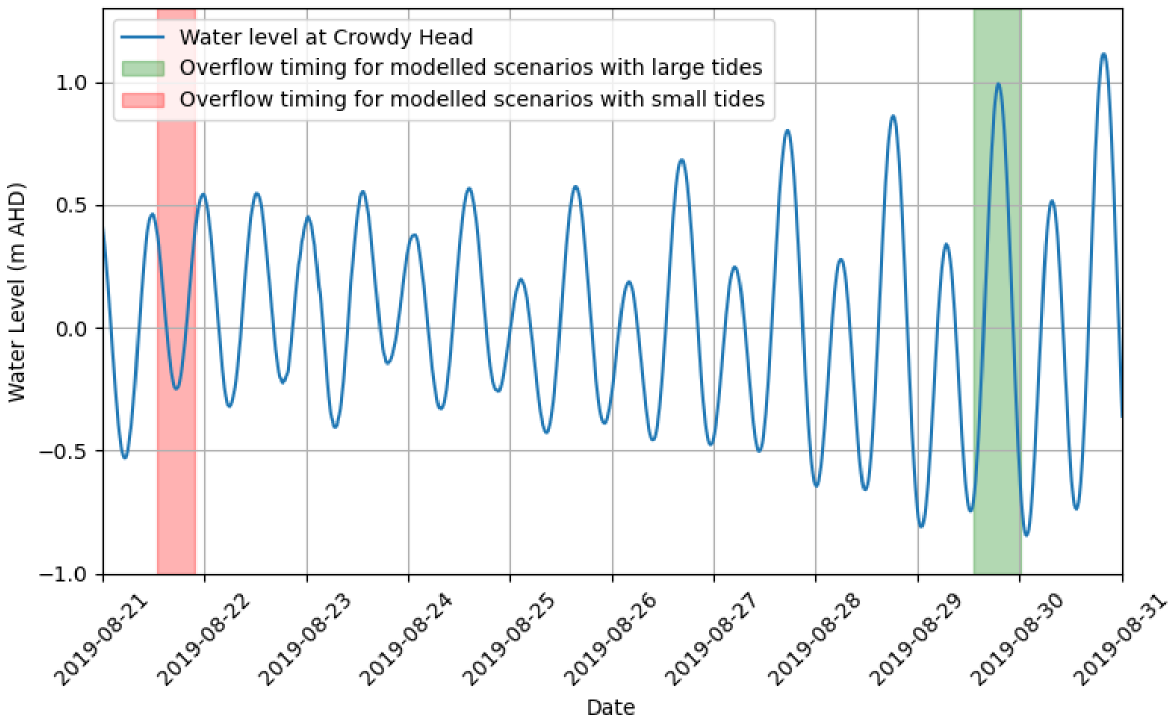

Figure 5-3 Small and large tide sizes used in modelling

Due to the hydrodynamics of the lake system, there are large tidal lags (which result in mid ebb tide occurring when water levels at Crowdy Head are at low tide, for example). Thus, it can be difficult to determine what tidal range at Crowdy Head corresponds with a given tidal prism size within Wallis Lake. Given this, and the fact that an overflow will usually occur on an intermediate tide, it was determined that for ease of use, tide size should be combined for all scenarios.

Scenario results differentiated by tide size can still be viewed in sub-runs, however, it is not recommended that users use this for decision making unless they are familiar with the hydrodynamics of lake systems. See WRL TR2023/32 Section 8.3.4 for more details on scenario grouping in the results.

5.3.3 Catchment inflows

Catchment inflow had negligible effect on plume transport, thus a full suite of catchment inflow conditions was not simulated. The 95th percentile flow scenarios were only run for 3 hour overflows. For context, the total catchment inflows (from all three upstream boundaries into the model, shown in Figure 4-3) for the 95th percentile flow is approximately 40 m^3/s, less than 4% of the peak tidal flows through the entrance, which highlights the relative importance of tidal flows in transport and dilution of overflows in this estuary. For ease of use, results for different catchment inflow have been combined when multiple catchment inflow scenarios were run, and in cases where only the median case was run, the scenario has been labelled to apply to all catchment inflow conditions (sub-runs are not available in this case). See WRL TR2023/32 Section 8.3.4 for more details on scenario grouping.

5.4 Sensitivity to bathymetric changes

As noted previously, the bathymetry in the lower estuary is variable, with several mobile sandbars. Changes in bathymetry can be seen in Figure 2-5, Figure 2-6, Figure 2-7 and Figure 2-8. These changes affect the quantity and timing of flow being directed into the various channels around the lower estuary. To test the sensitivity of the model to changing bathymetry, 1 hour median catchment inflow scenarios were run for four stages of a large tide using the 1998, 2010 and 2022 bathymetry. Outcomes were largely the same for all harvest areas in all scenarios, with the minimum dilution in all harvest areas falling within the same bands of dilution for concentrations >5,000,000, 5,000,000 to 1,000,000 and <1,000,000. An example of the largest change can be seen in Figure 5-4, Figure 5-5 and Table 5-2. Although the shape of the plume changes, the impact on harvest areas is largely unchanged. Thus, a single bathymetry was deemed acceptable for modelling overflows from the chosen locations. However, conservatism should be applied in cases where the plume is near a harvest area boundary or a decision is uncertain, as bathymetry change may affect results.

Table 5-2 Bathymetric sensitivity results for a 1 hour overflow from Forster Boat Harbour on a mid ebb tide

Bathymetry	Minimum dilution achieved in Wallis Island	Hours for plume to reach Wallis Island	Minimum dilution achieved in Long Island	Hours for plume to reach Long Island	Minimum dilution achieved in Cape Hawke	Hours for plume to reach Cape Hawke
2022	150,000	<6 h	760,000	<6 h	170,000	<6 h
2010	96,000	<6 h	760,000	<6 h	100,000	<6 h
1998	100,000	<6 h	870,000	<6 h	110,000	<6 h

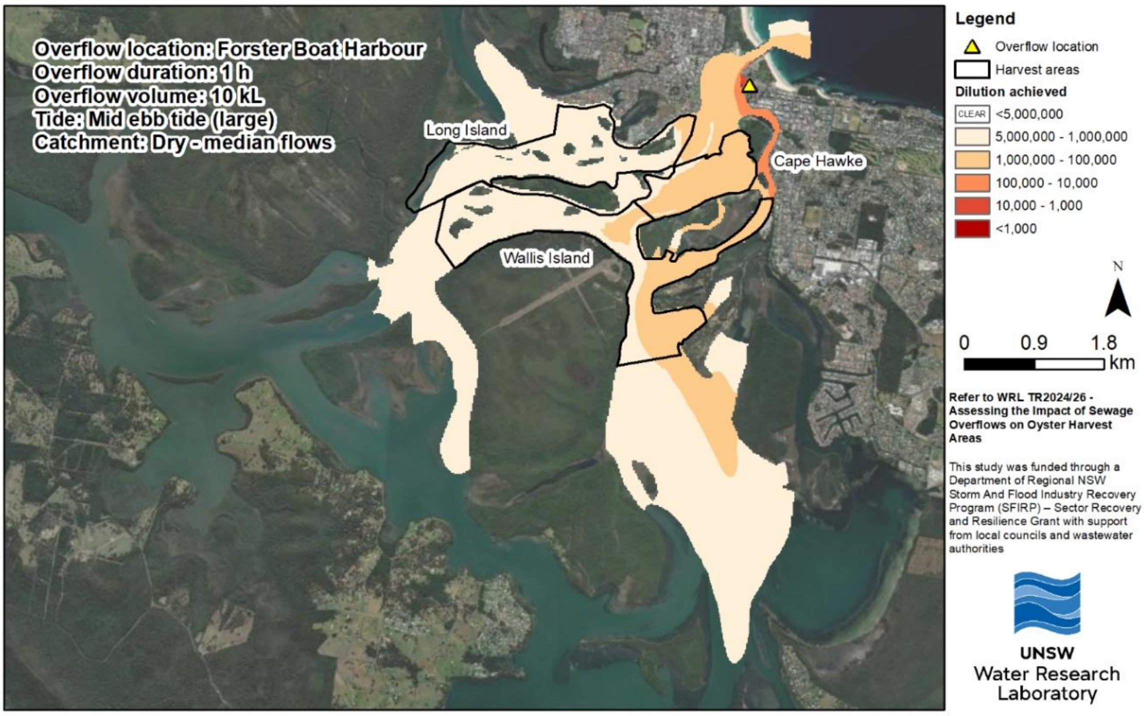

Figure 5-4 Results of model with 2010 bathymetry for 1 hour overflow from Forster Boat Harbour on a mid ebb tide*

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

Figure 5-5 Results of model with 2022 bathymetry for 1 hour overflow from Forster Boat Harbour on a mid ebb tide*

*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 Wallis Lake 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 Wallis Lake estuary model. Key information included in the report relates to the integration of existing data sources, the September 2023 field data collection campaign, data processing and model development.

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 Wallis Lake) 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.

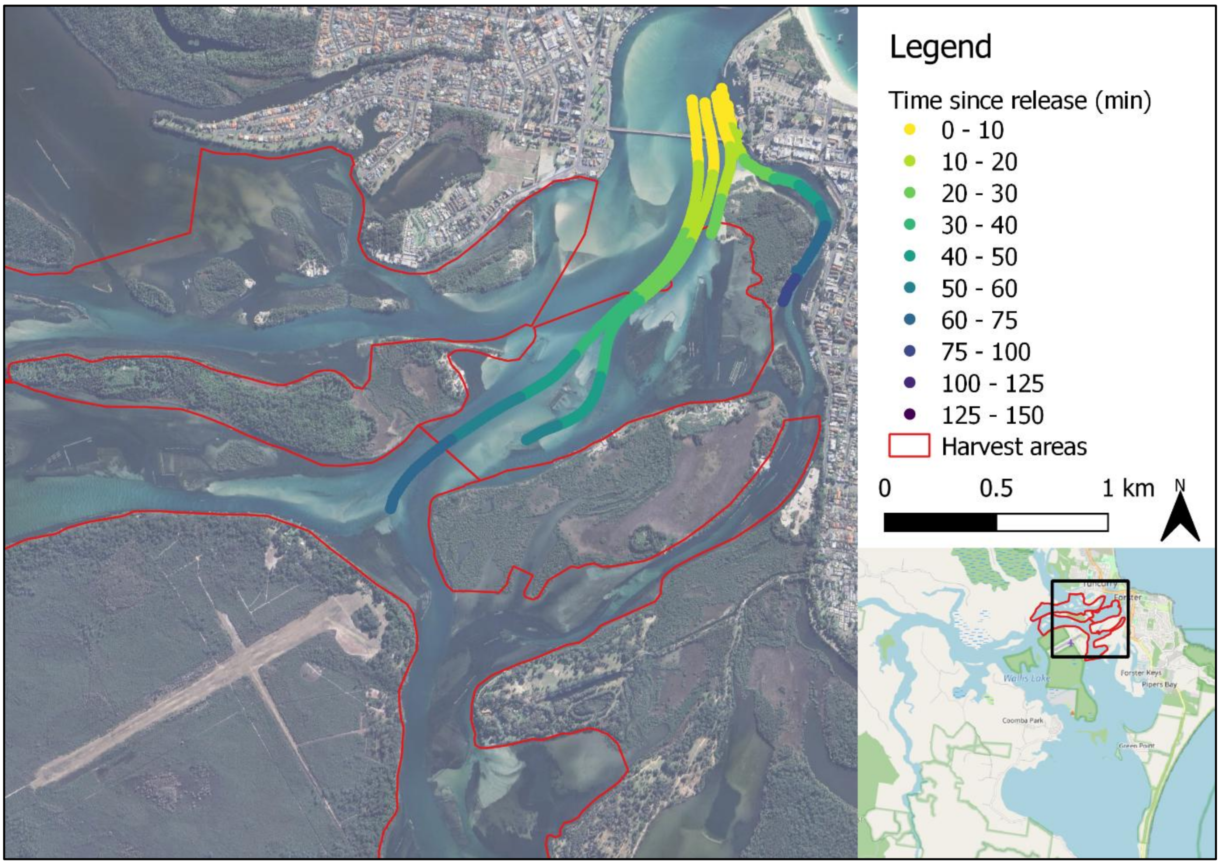

Figure A-1 GPS drifter drogue release D1D1 – Forster-Tuncurry Bridge – incoming tide

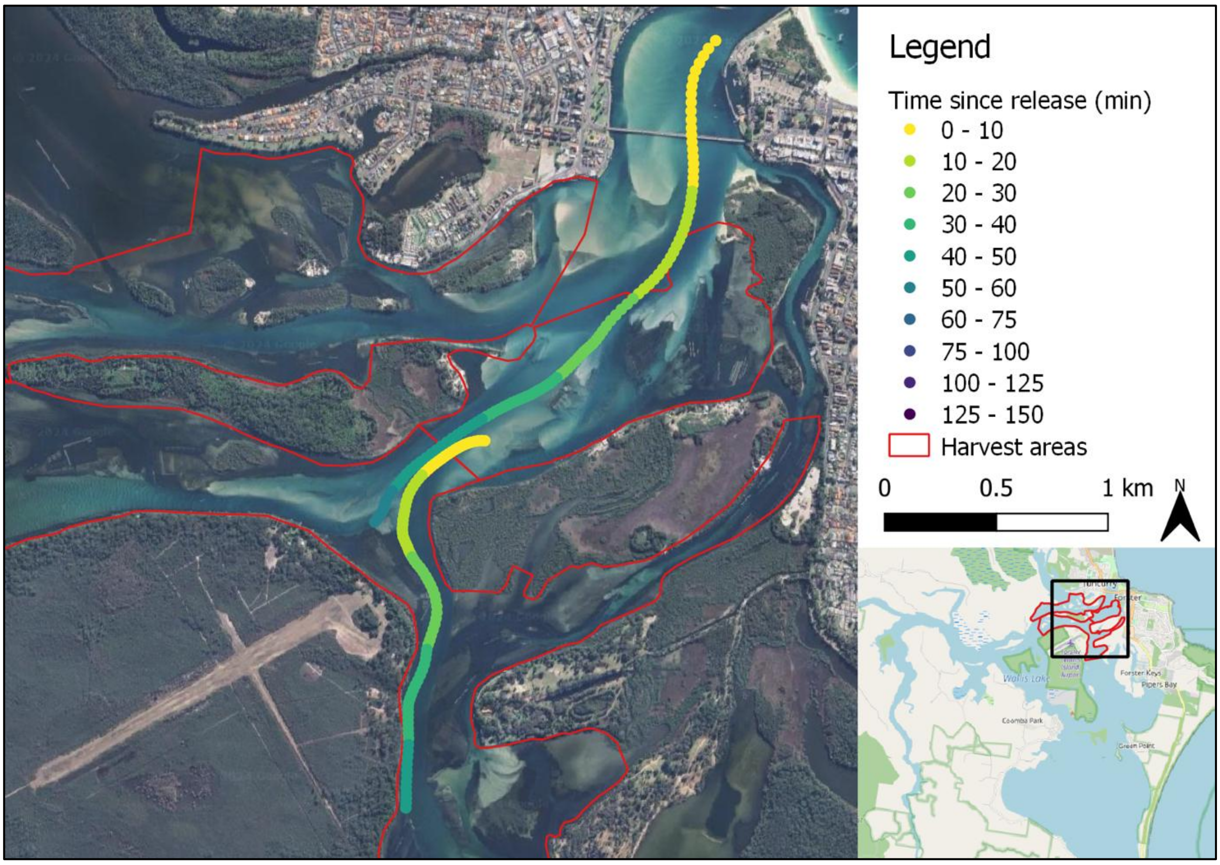

Figure A-2 GPS drifter drogue release D1D2 – Godwin Island – incoming tide

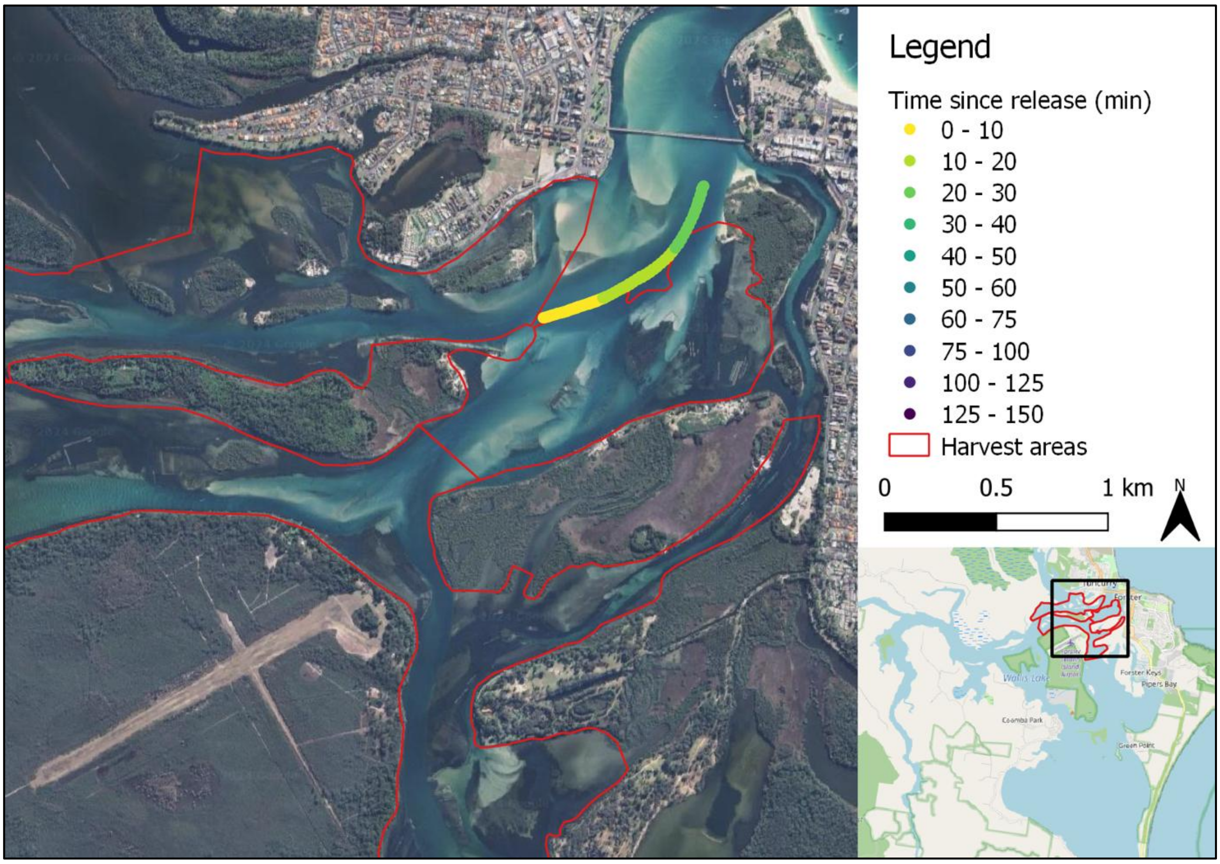

Figure A-3 GPS drifter drogue release D1D4 – WP 6 – outgoing tide

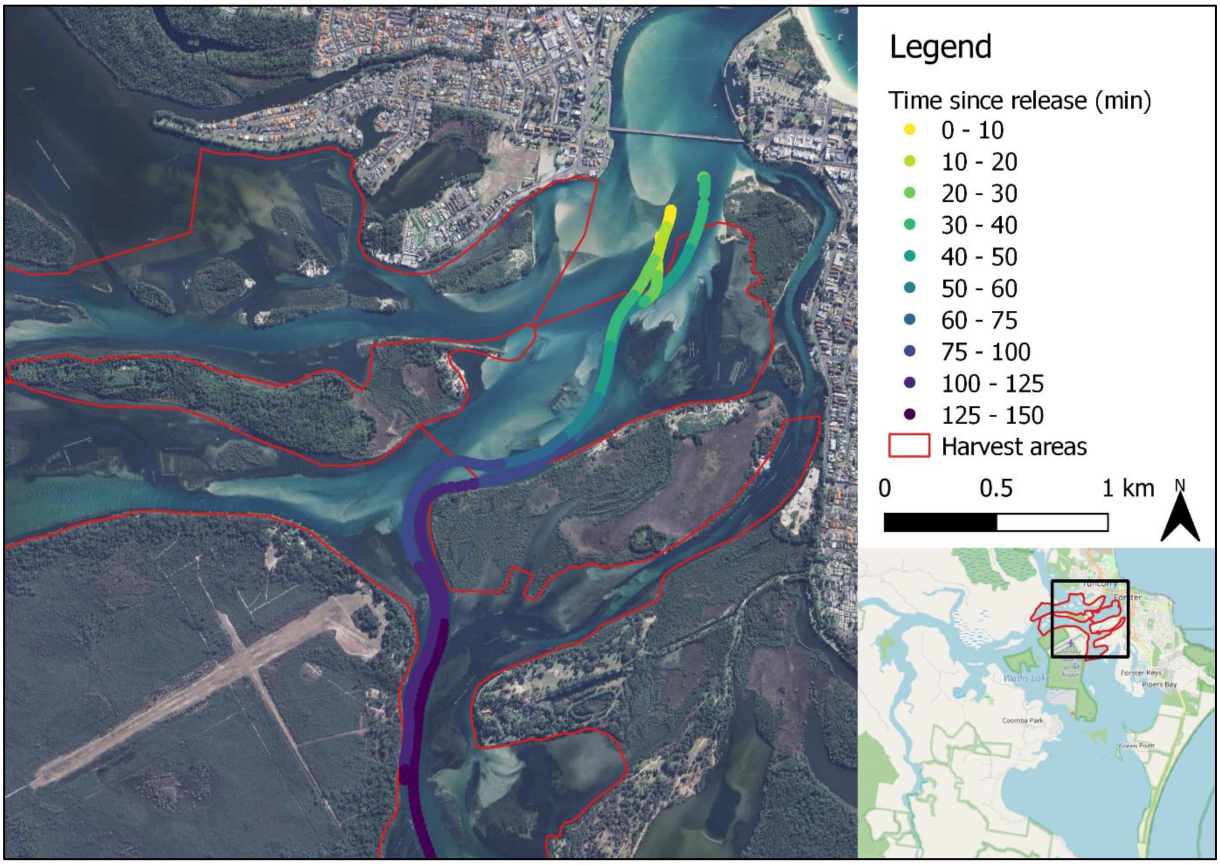

Figure A-4 GPS drifter drogue release D2D1 – Forster-Tuncurry Bridge – incoming tide

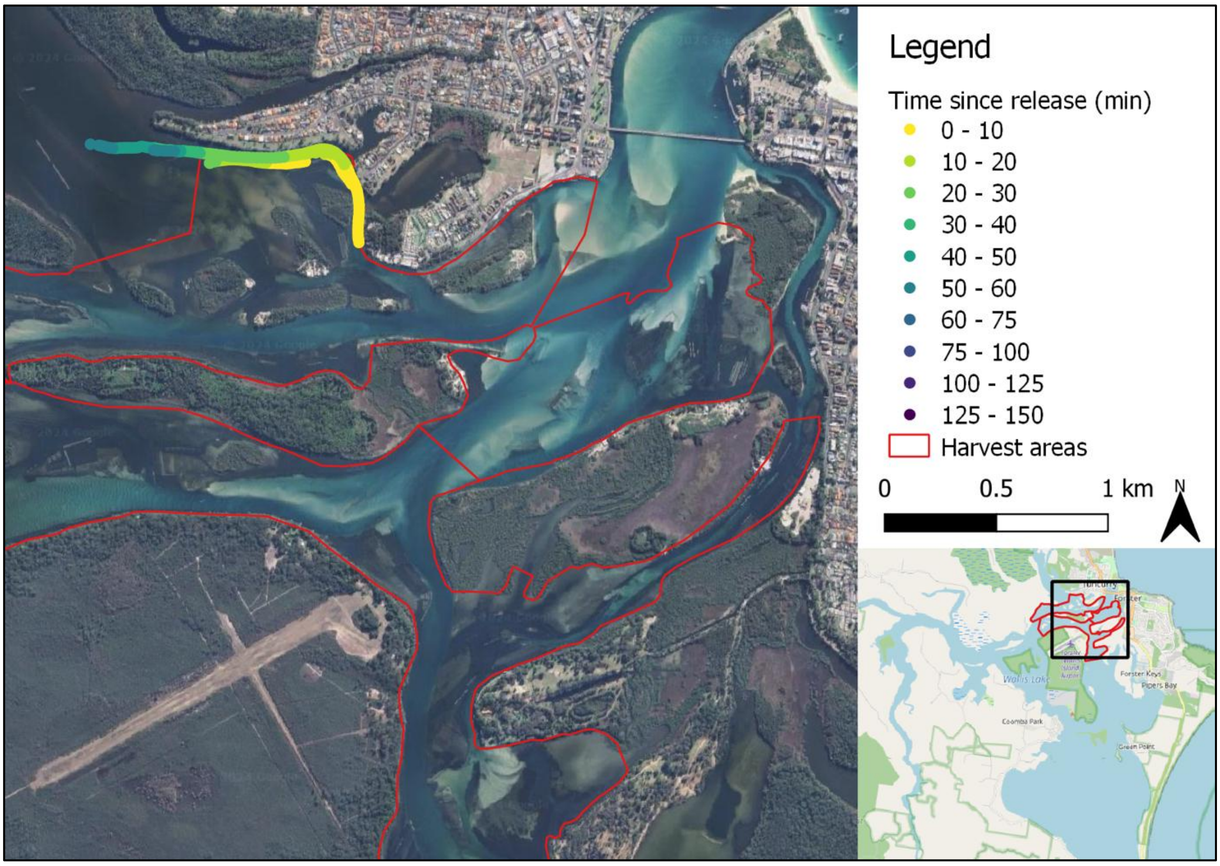

Figure A-5 GPS drifter drogue release D2D2 – Wallamba East – incoming tide

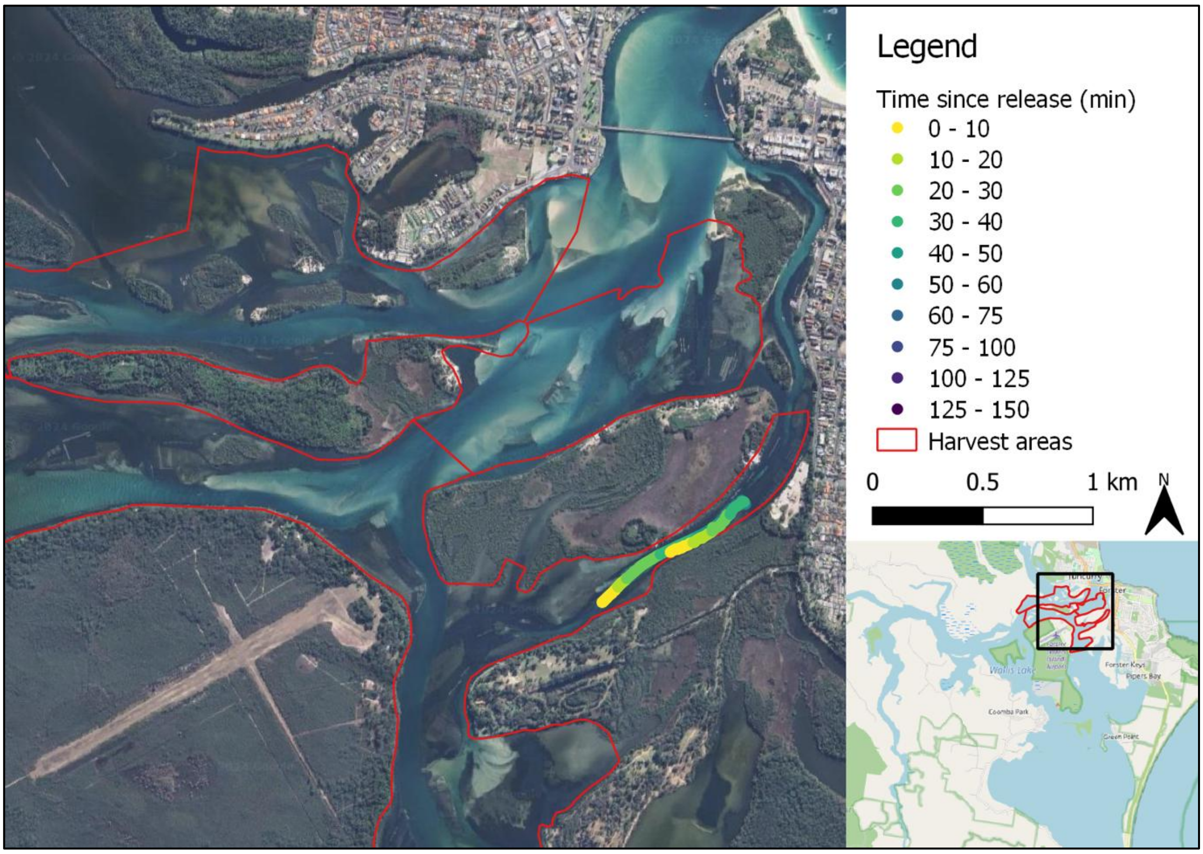

Figure A-6 GPS drifter drogue release D2D3 – Breckenridge Channel near Godwin Island – outgoing tide

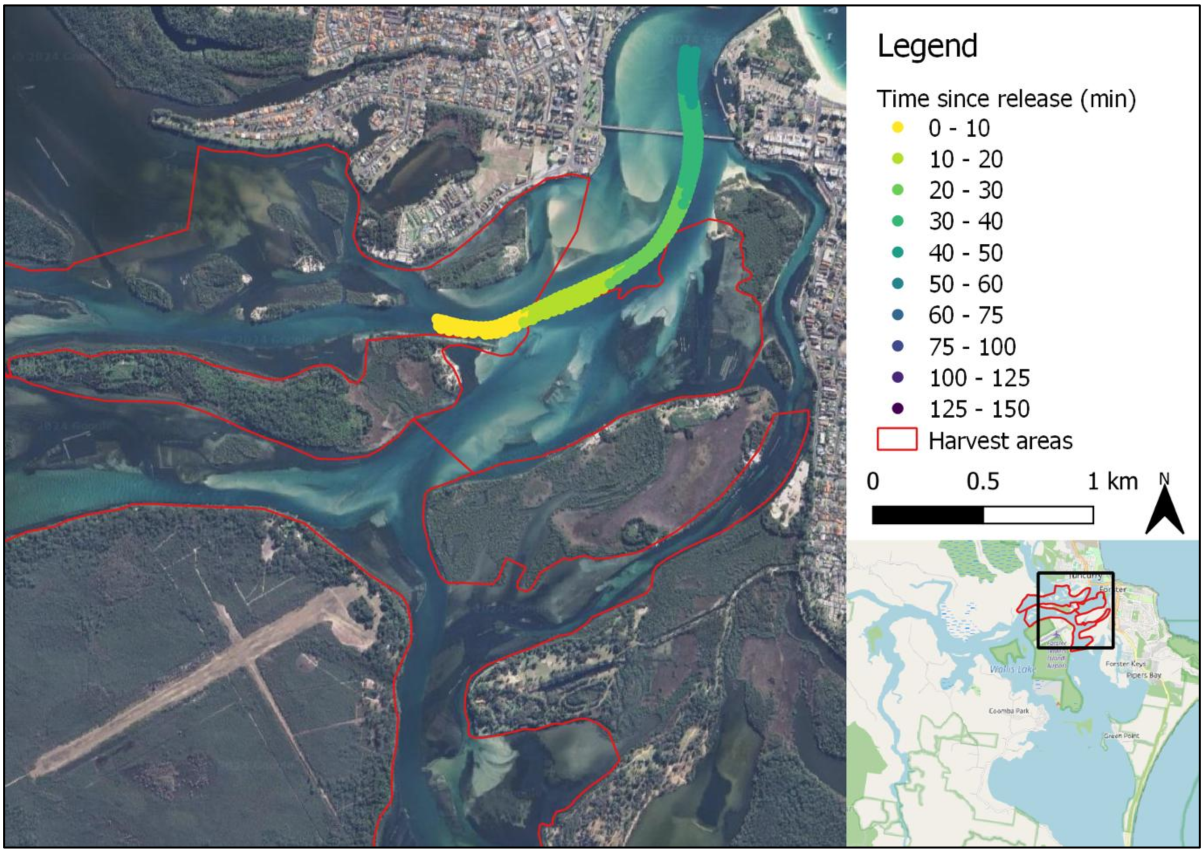

Figure A-7 GPS drifter drogue release D3D1 – WP 6 – outgoing tide

A2 Tidal flow gauging

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

Table A-1 Entrance Site 2 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	19/09/2023	9:29:07	-1018
2	19/09/2023	9:34:21	-872
3	19/09/2023	9:40:08	-1067
4	19/09/2023	10:16:08	-1097
5	19/09/2023	10:23:19	-1073
6	19/09/2023	11:00:02	-965
7	19/09/2023	11:04:38	-1008
8	19/09/2023	12:06:48	-706
9	19/09/2023	12:09:52	-707
10	19/09/2023	12:48:54	-361
11	19/09/2023	12:51:44	-248
12	19/09/2023	12:54:53	-334
13	19/09/2023	12:57:43	-217
14	19/09/2023	13:01:16	-240
15	19/09/2023	13:05:07	-242
16	19/09/2023	13:19:07	-114
17	19/09/2023	12:22:10	-56
18	19/09/2023	13:25:51	-46
19	19/09/2023	13:29:15	36
20	19/09/2023	13:32:47	43
21	21/09/2023	6:01:42	747
22	21/09/2023	6:04:35	713

No.	Date	Time	Flow (m^3/s) *
23	21/09/2023	7:10:24	478
24	21/09/2023	7:12:55	443
25	21/09/2023	7:54:14	220
26	21/09/2023	7:56:51	168
27	21/09/2023	7:59:22	182
28	21/09/2023	8:01:45	154
29	21/09/2023	8:04:38	153
30	21/09/2023	8:06:55	129
31	21/09/2023	8:10:04	69
32	21/09/2023	8:12:26	38
33	21/09/2023	8:15:16	23
34	21/09/2023	8:17:31	34
35	21/09/2023	8:20:19	-39
36	21/09/2023	8:22:39	-75
37	21/09/2023	8:25:04	-52
38	21/09/2023	8:29:10	-176
39	21/09/2023	9:12:59	-632
40	21/09/2023	9:16:53	-660

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

Table A-2 Breckenridge Entrance Site 4 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	19/09/2023	7:59:49	-27
2	19/09/2023	8:01:20	-31
3	19/09/2023	9:47:50	-54
4	19/09/2023	9:49:24	-53
5	19/09/2023	10:30:54	-80
6	19/09/2023	10:32:55	-79
7	19/09/2023	11:11:52	-54
8	19/09/2023	11:13:25	-57
9	19/09/2023	12:17:38	-32
10	19/09/2023	12:19:10	-31
11	19/09/2023	13:41:33	16
12	19/09/2023	14:42:13	33
13	19/09/2023	14:44:30	34
14	19/09/2023	15:13:14	40
15	19/09/2023	15:16:43	41

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

Table A-3 WP 6 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	19/09/2023	8:15:03	-252
2	19/09/2023	8:18:39	-270
3	19/09/2023	9:57:42	-429
4	19/09/2023	10:00:42	-422
5	19/09/2023	10:43:13	-434
6	19/09/2023	10:46:13	-451
7	19/09/2023	11:20:44	-394
8	19/09/2023	11:23:46	-372
9	19/09/2023	12:29:26	-252
10	19/09/2023	12:32:03	-241
11	19/09/2023	13:50:49	131
12	19/09/2023	13:53:48	158
13	20/09/2023	13:16:01	-248
14	20/09/2023	13:19:01	-235
15	20/09/2023	14:02:52	-76
16	20/09/2023	14:05:45	-66
17	20/09/2023	14:21:06	45
18	20/09/2023	14:24:15	74
19	20/09/2023	14:26:52	89
20	21/09/2023	6:20:28	276
21	21/09/2023	6:23:33	285

Table A-4 WP 7 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	21/09/2023	6:46:39	340
2	21/09/2023	6:50:28	331
3	21/09/2023	8:54:47	-171
4	21/09/2023	8:57:43	-211

Table A-5 Hells Gate Site 8 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	19/09/2023	8:44:13	-246
2	19/09/2023	8:47:39	-251
3	19/09/2023	11:44:02	-303
4	19/09/2023	11:50:00	-301
5	19/09/2023	14:01:55	112
6	19/09/2023	14:04:13	129
7	21/09/2023	6:36:07	212
8	21/09/2023	6:38:36	210
9	21/09/2023	7:32:18	164
10	21/09/2023	7:34:27	163
11	21/09/2023	8:44:29	-24
12	21/09/2023	8:46:13	-57
13	21/09/2023	8:47:50	-43
14	21/09/2023	8:49:35	-53

Table A-6 Wallamba East 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	20/09/2023	13:26:58	-29
2	20/09/2023	13:29:17	-29
3	20/09/2023	13:44:00	-22
4	20/09/2023	14:14:16	5

Table A-7 Wallamba West 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	20/09/2023	13:06:00	19
2	20/09/2023	13:08:18	19
3	20/09/2023	13:58:06	28

A3 Cross-channel velocity distribution

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

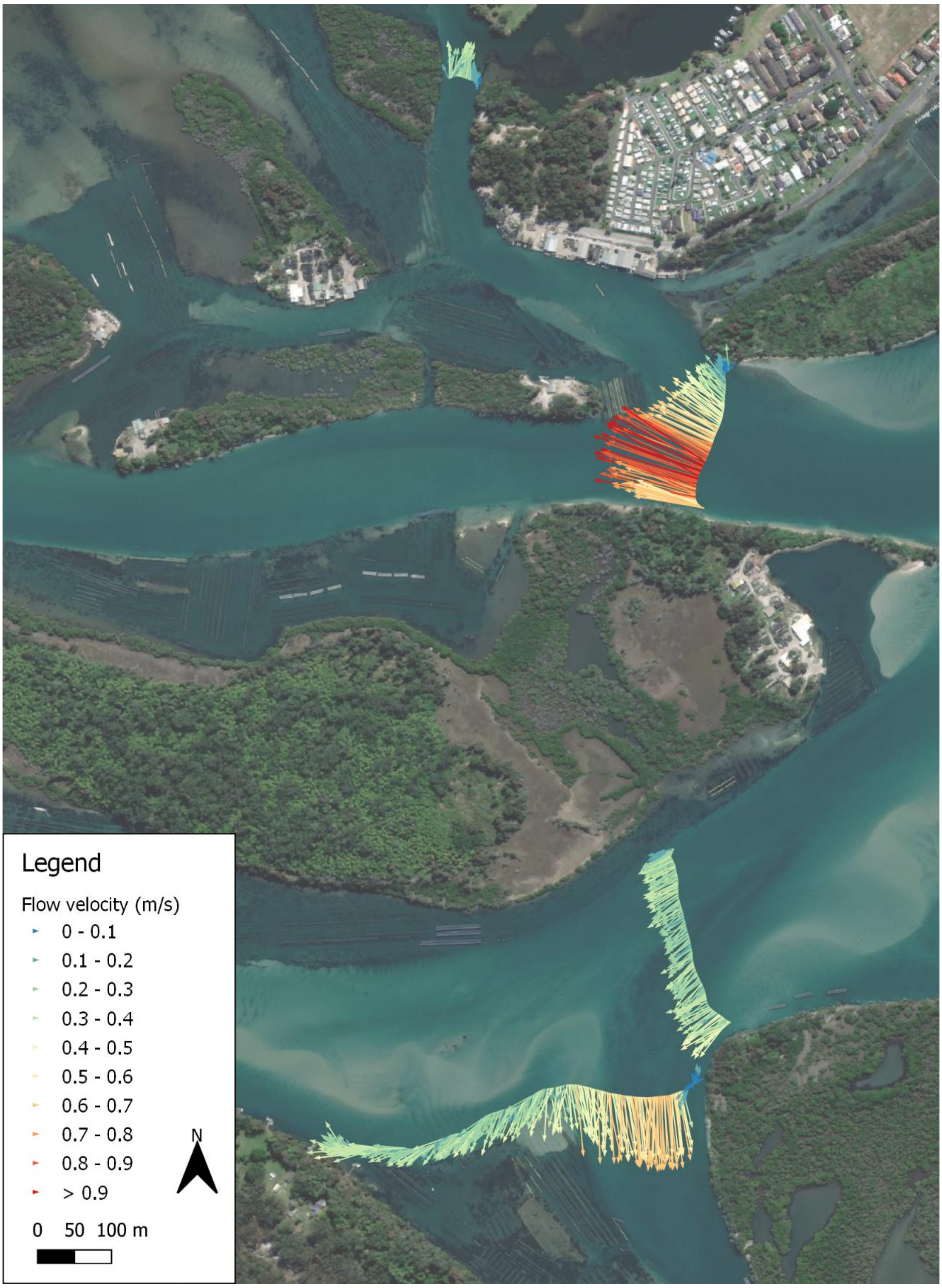

Figure A-8 Flood tide channel flow distribution at Wallamba East, WP 6, WP 7 and Hells Gate

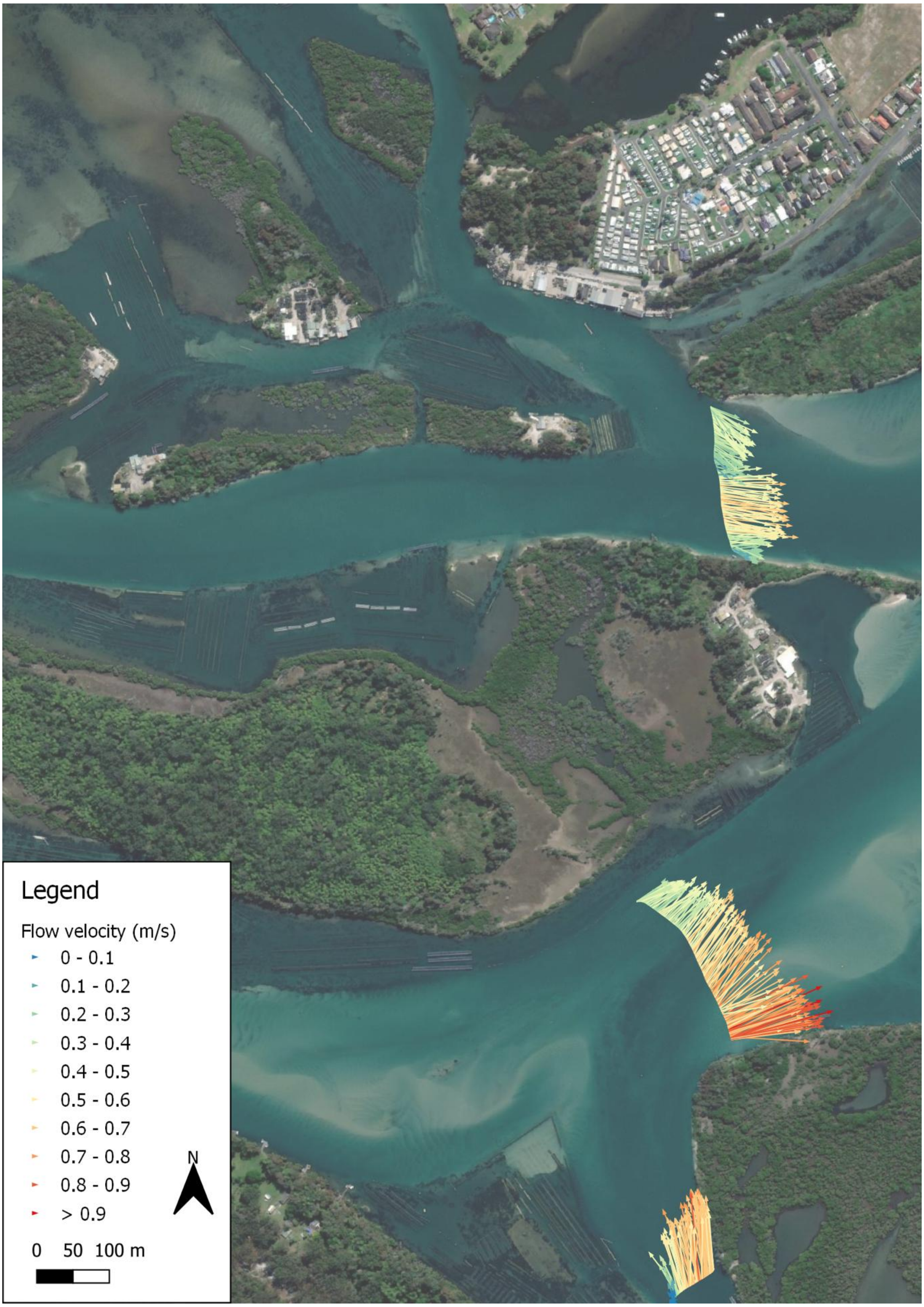

Figure A-9 Ebb tide channel flow distribution at WP 6, WP 7 and Hells Gate

Figure A-10 Ebb tide channel flow distribution at Entrance and Breckenridge

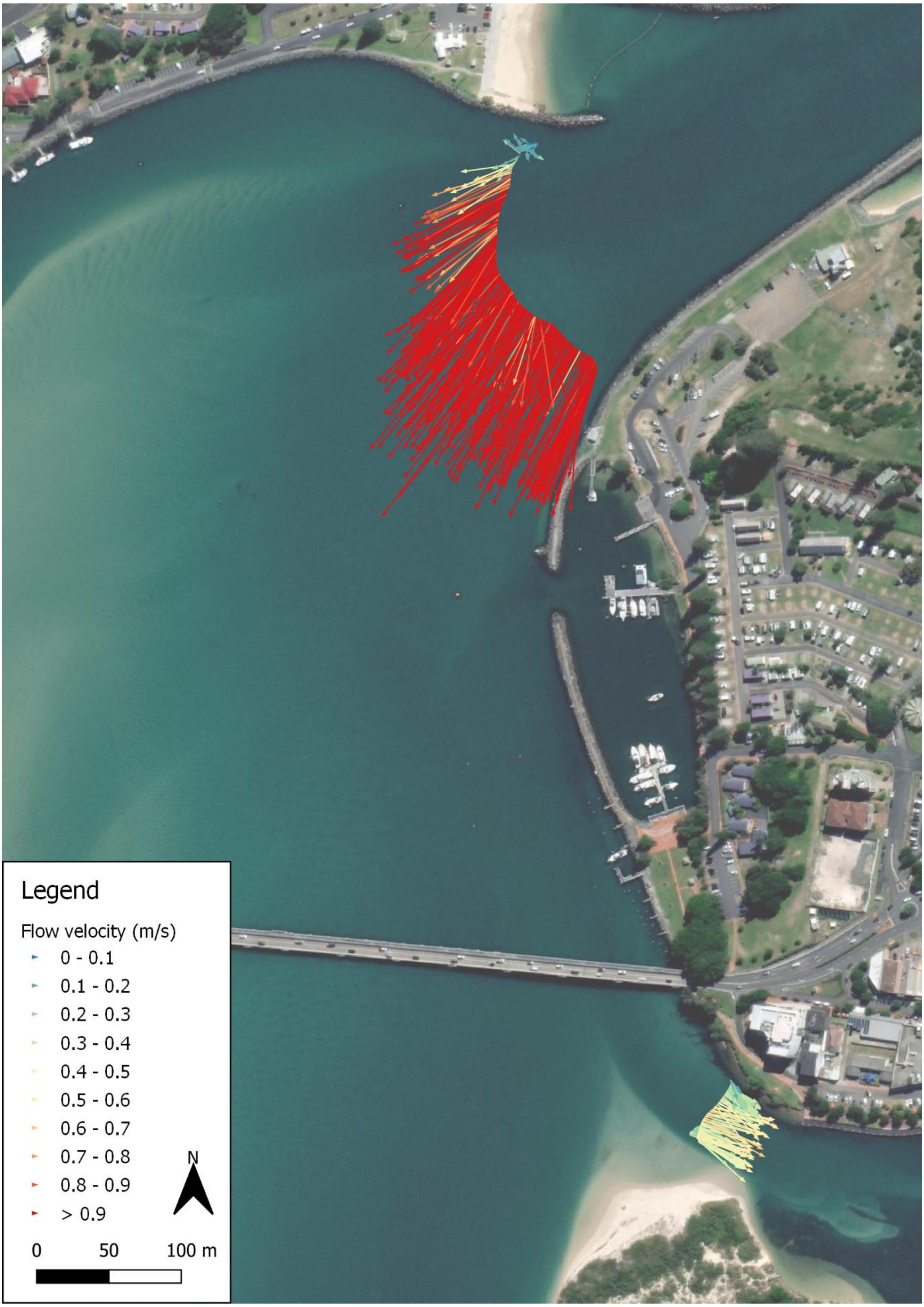

Figure A-11 Flood tide channel flow distribution at Entrance and Breckenridge

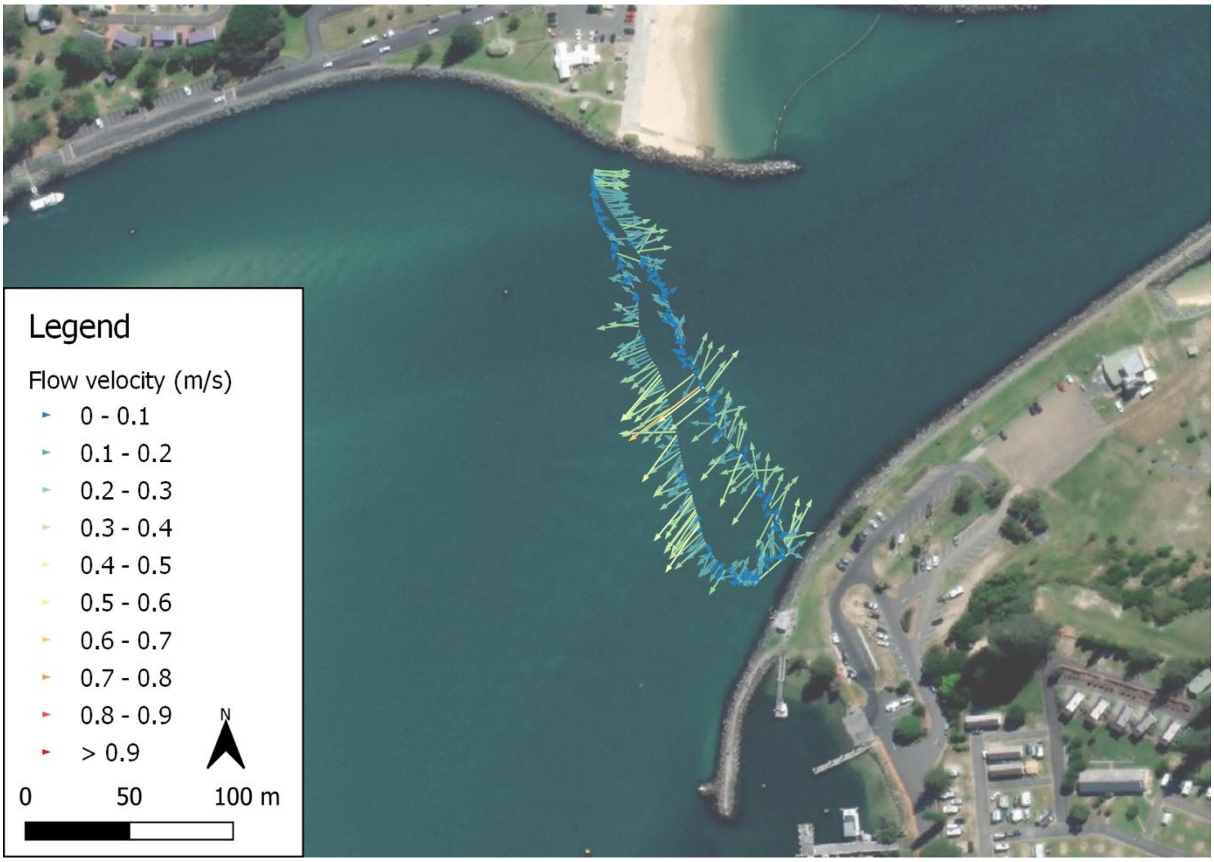

Figure A-12 Transitional flow at Entrance

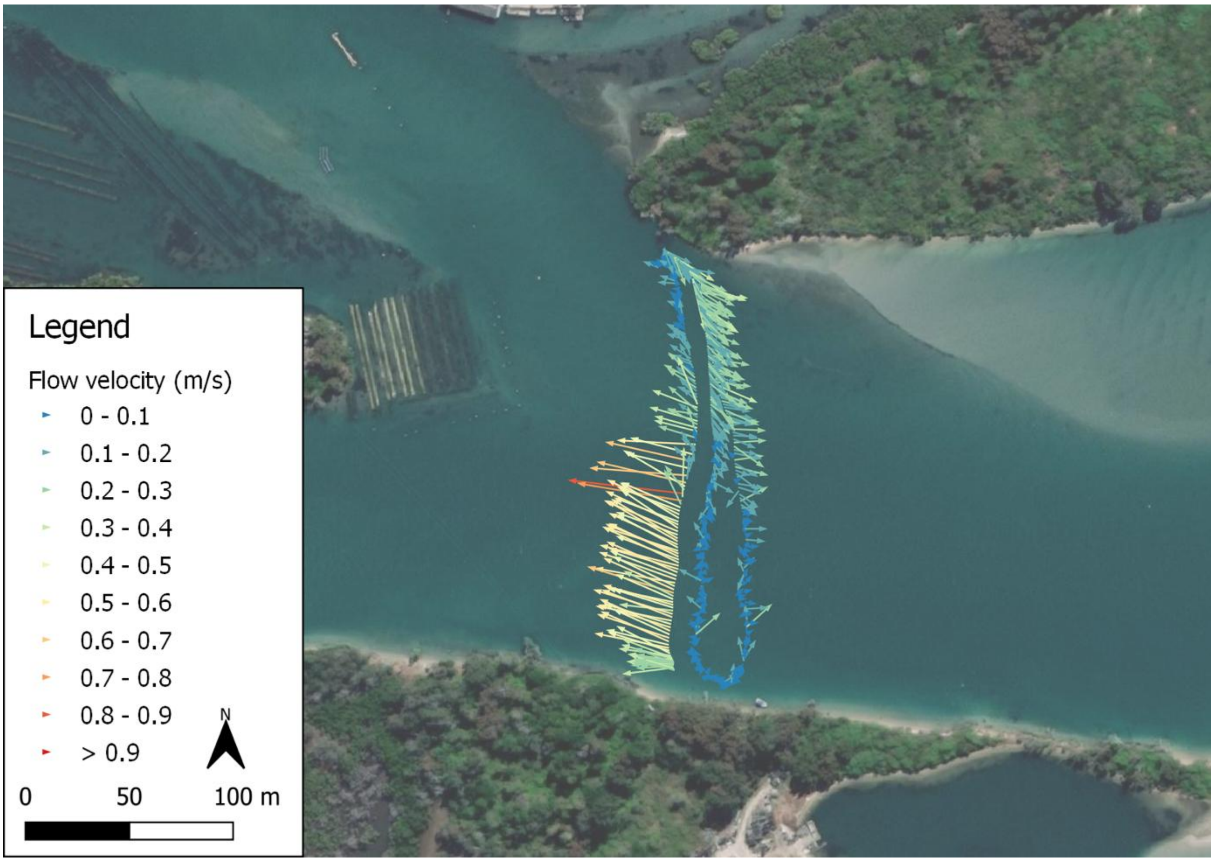

Figure A-13 Transitional flow at WP 6

A4 Vertical velocity distributions

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

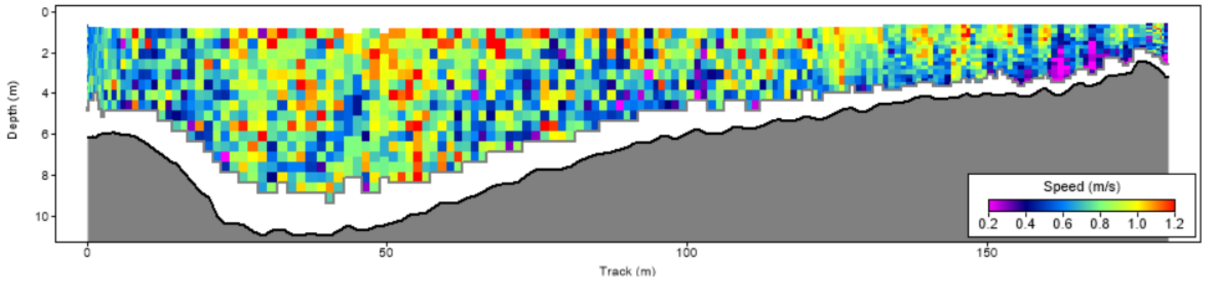

Figure A-14 Vertical velocity distribution – Entrance – Ebb tide – (2023/09/21 06:07:50)

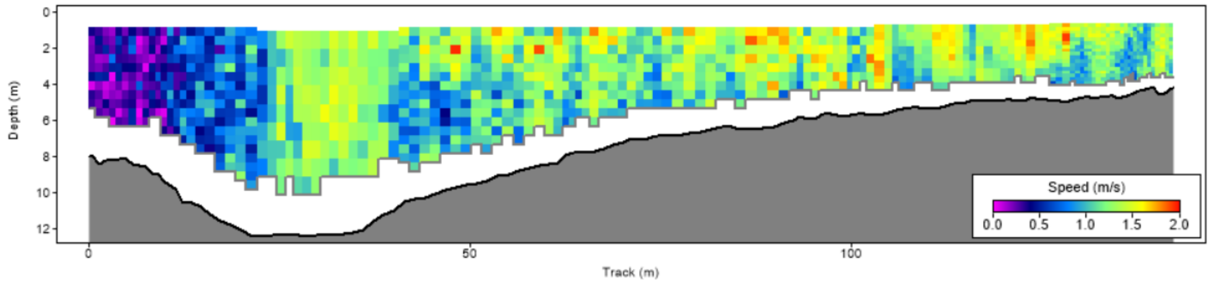

Figure A-15 Vertical velocity distribution – Entrance – Flood tide – (2023/09/19 10:26:09)

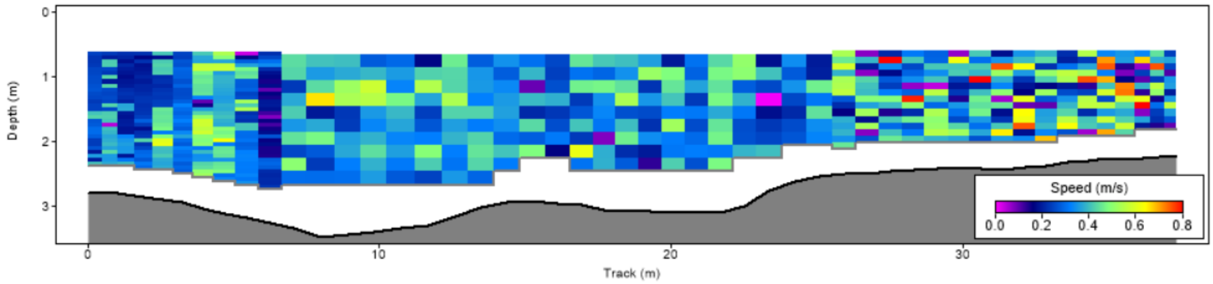

Figure A-16 Vertical velocity distribution – Breckenridge Channel – Ebb tide – (2023/09/19 14:45:46)

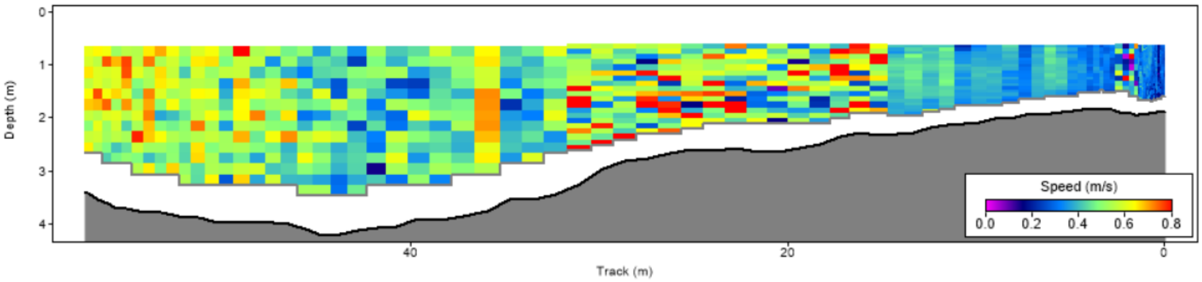

Figure A-17 Vertical velocity distribution – Breckenridge Channel – Flood tide – (2023/09/19 10:32:50)

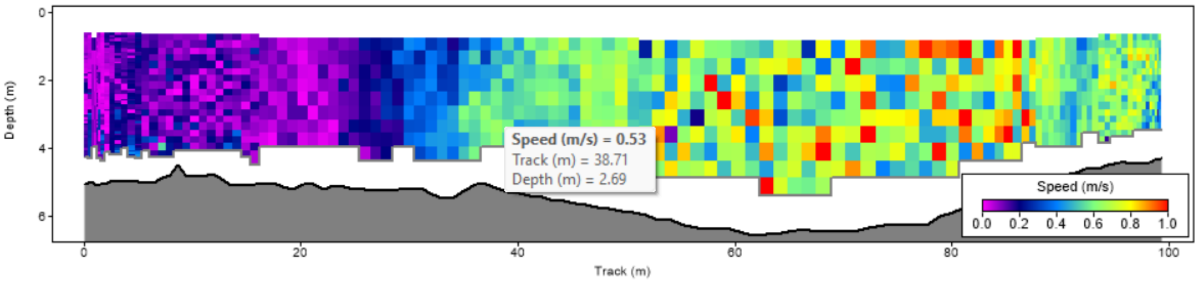

Figure A-18 Vertical velocity distribution – Hells Gate – Ebb tide – (2023/09/21 06:41:01)

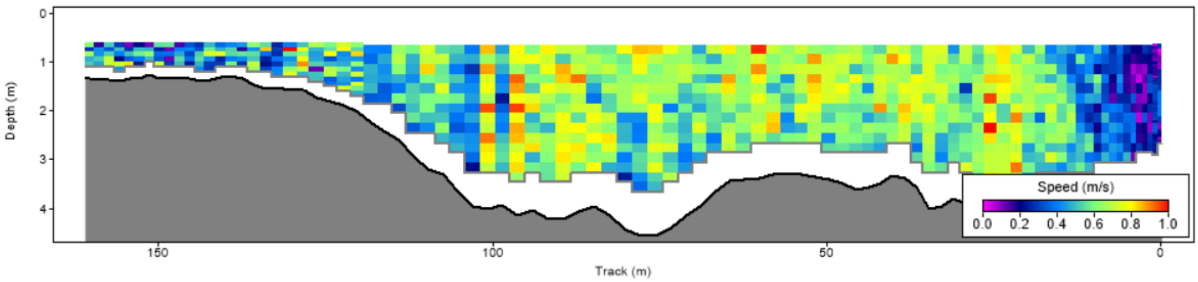

Figure A-19 Vertical velocity distribution – Hells Gate – Flood tide – (2023/09/19 11:51:54)

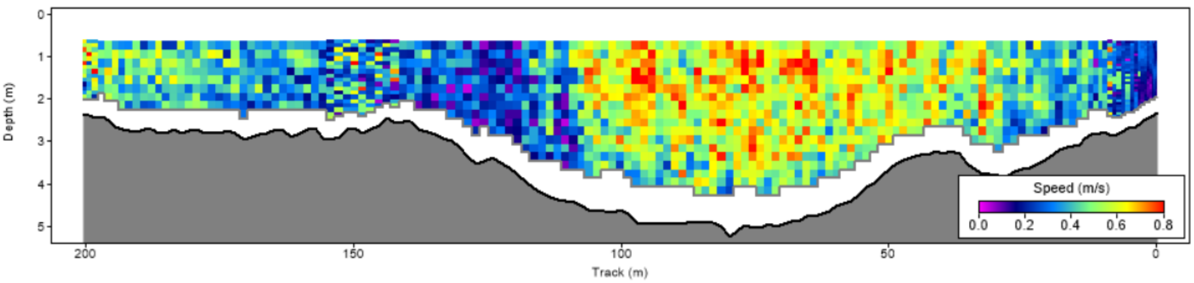

Figure A-20 Vertical velocity distribution – WP 6 – Ebb tide – (2023/09/21 06:23:30)

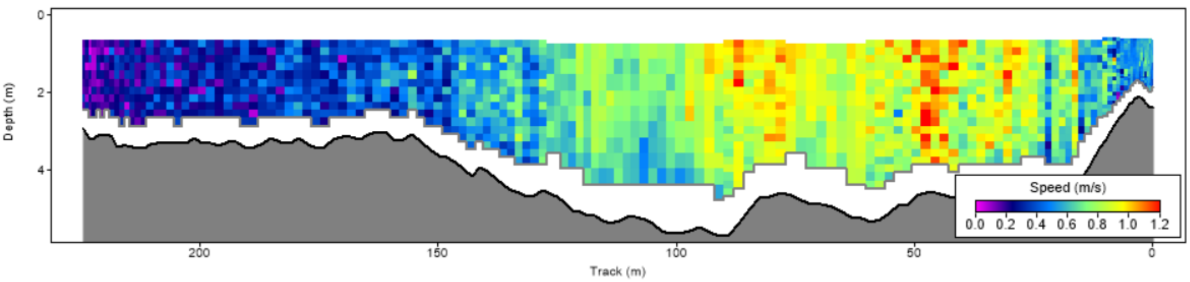

Figure A-21 Vertical velocity distribution – WP 6 – Flood tide – (2023/09/19 10:00:39)

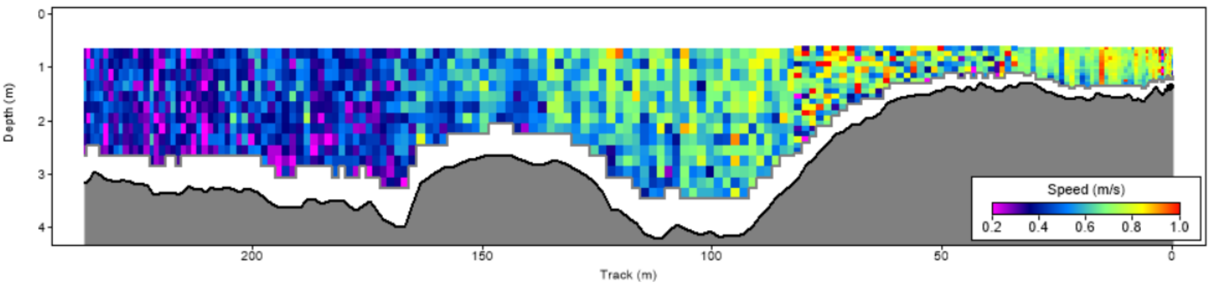

Figure A-22 Vertical velocity distribution – WP 7 – Ebb tide – (2023/09/21 06:50:24)

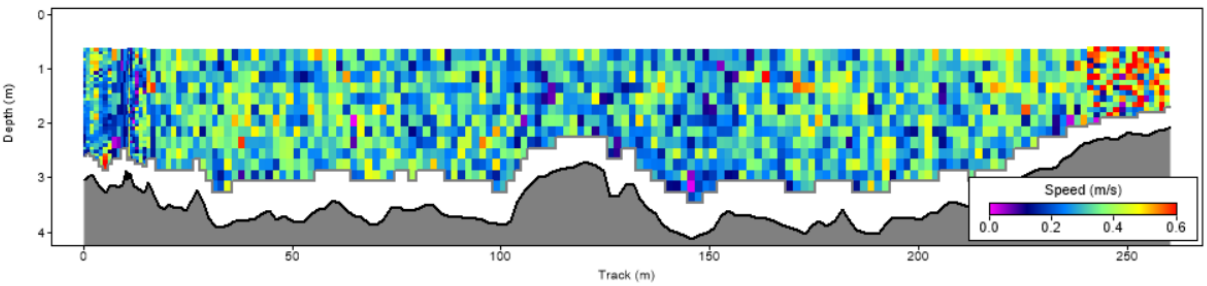

Figure A-23 Vertical velocity distribution – WP 7 – Flood tide – (2023/09/21 09:01:03)

Appendix B Model calibration

B1 Hydrodynamic calibration results

The below figures summarise results from the Wallis Lake estuary hydrodynamic calibration process. For more information, refer to Section 4.5.

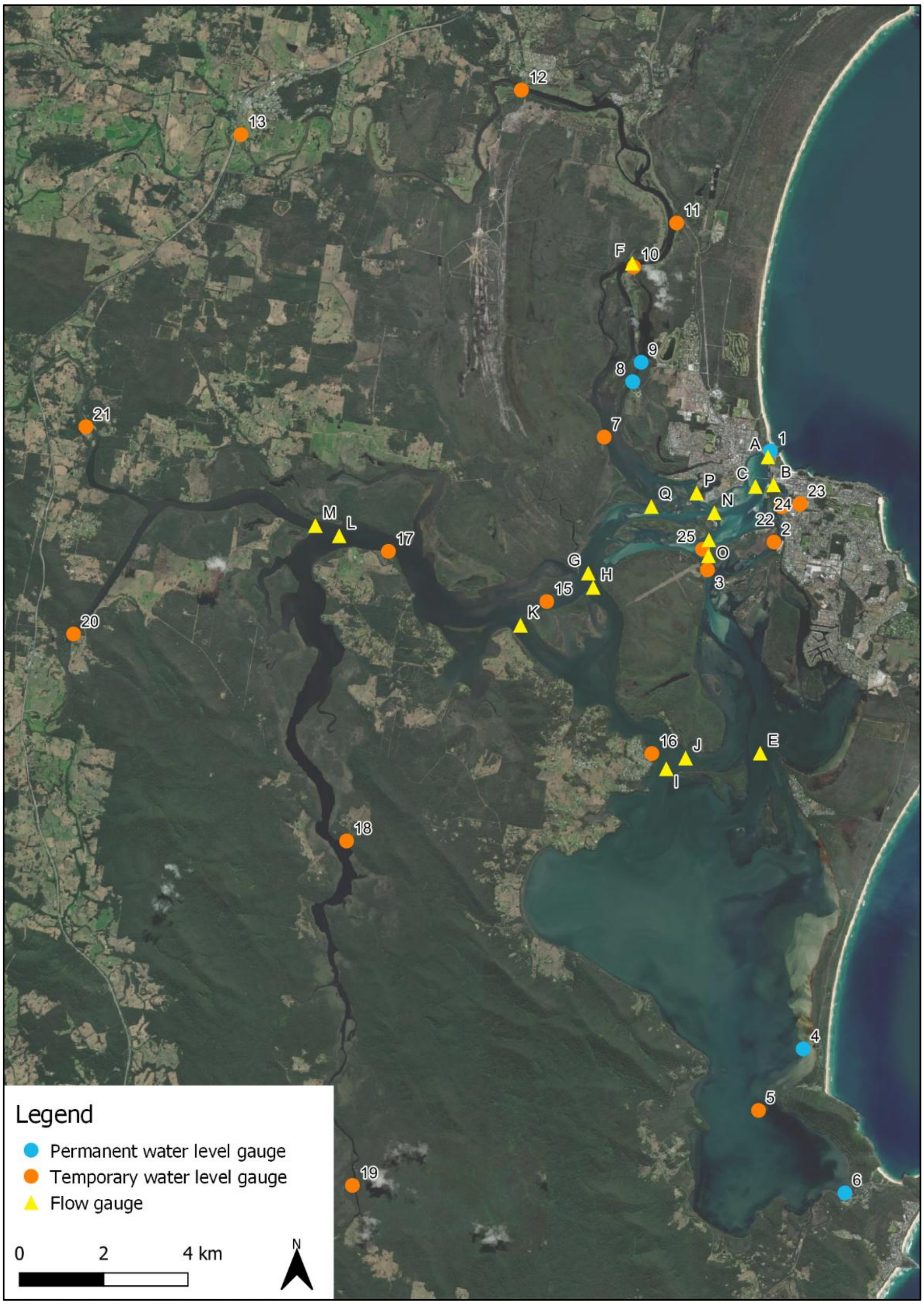

Figure B-1 Water level and tidal flow gauging locations

B1.1 Tidal flow gauging calibration – 1998

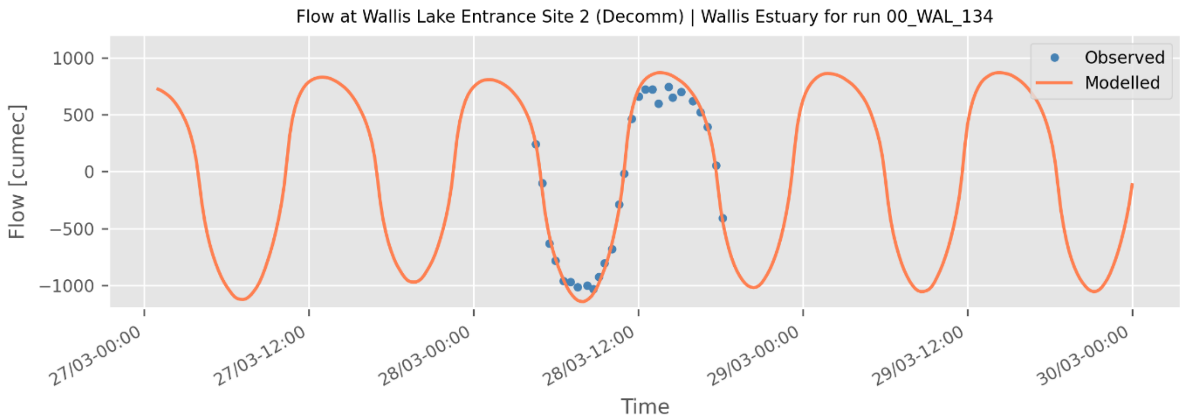

Figure B-2 1998 tidal flow calibration – Location A – Entrance Site 2

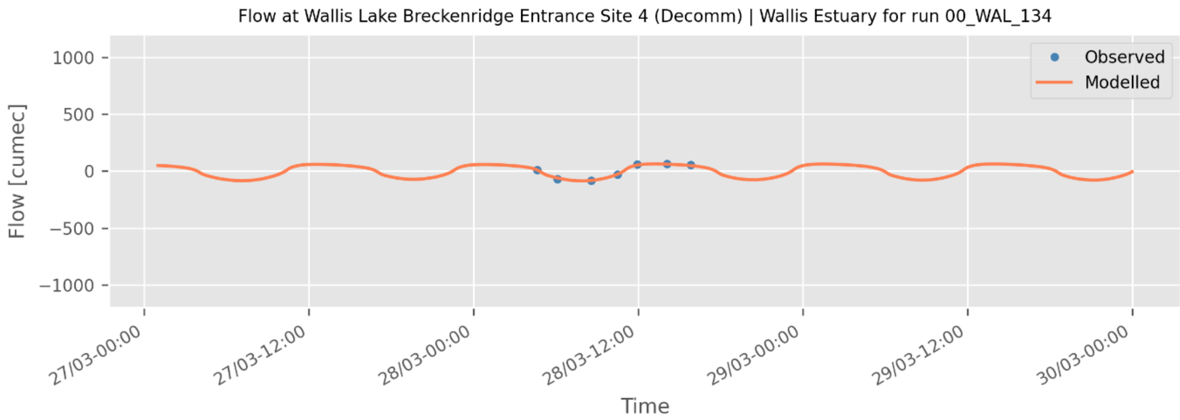

Figure B-3 1998 tidal flow calibration – Location B – Breckenridge Channel Site 4

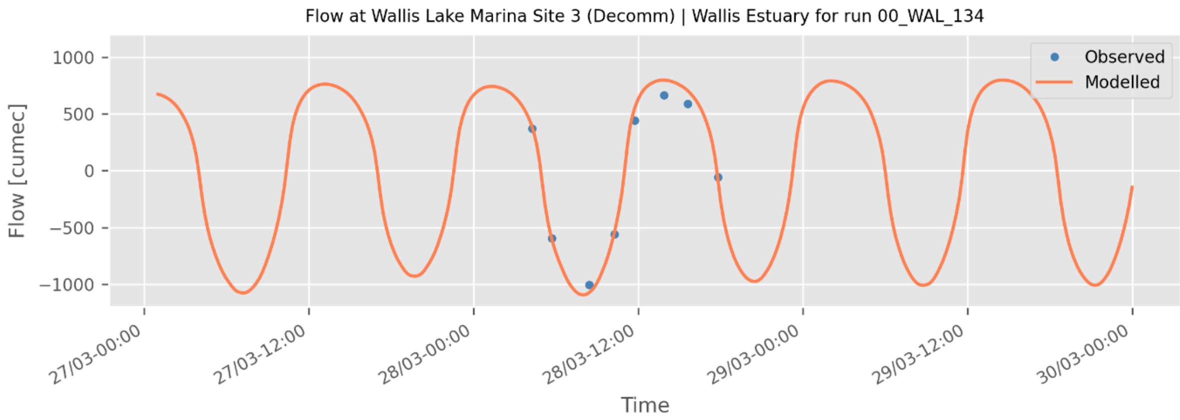

Figure B-4 1998 tidal flow calibration – Location C – Marina Site 3

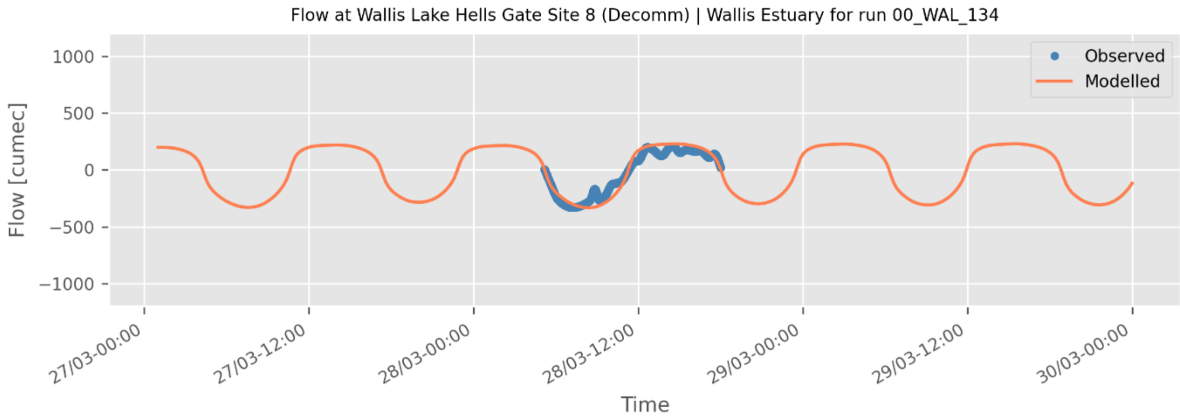

Figure B-5 1998 tidal flow calibration – Location D – Hells Gate Site 8

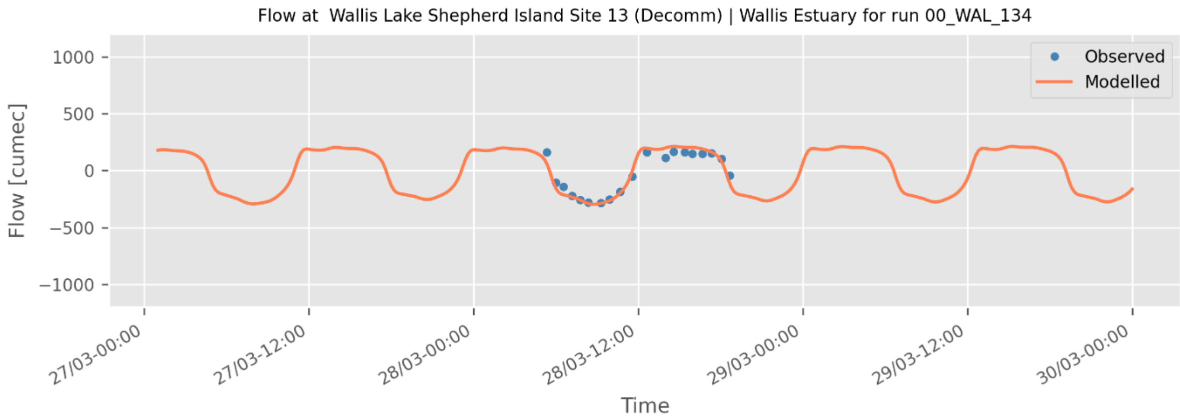

Figure B-6 1998 tidal flow calibration – Location E – Shepherd Island Site 13

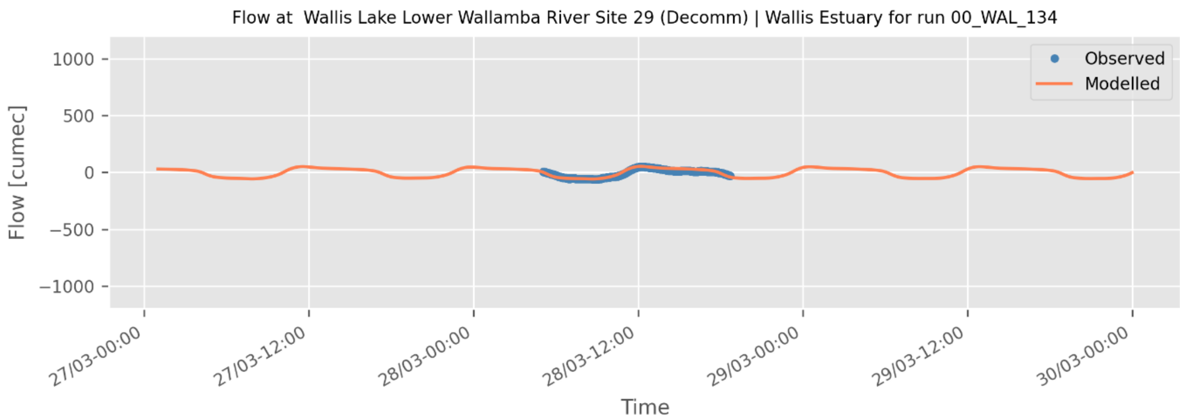

Figure B-7 1998 tidal flow calibration – Location F – Lower Wallamba River Site 29

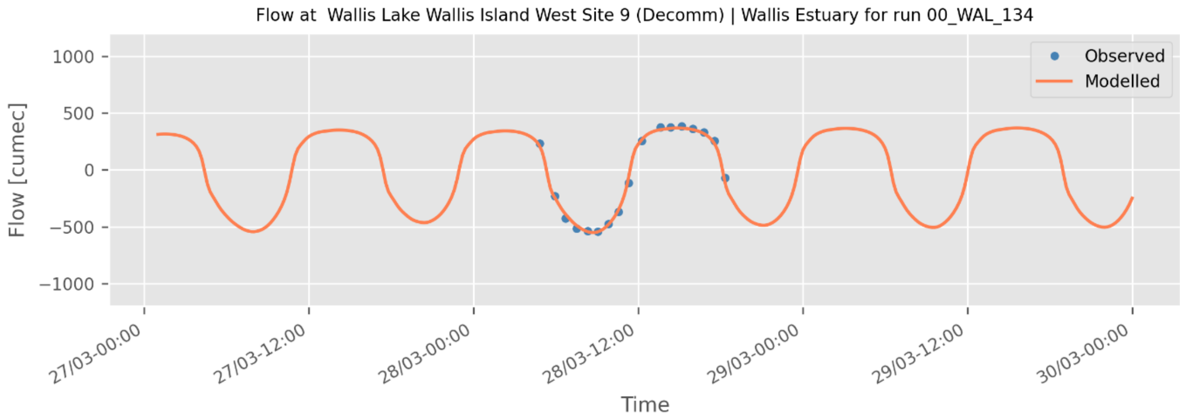

Figure B-8 1998 tidal flow calibration – Location G – Wallis Island West Site 9

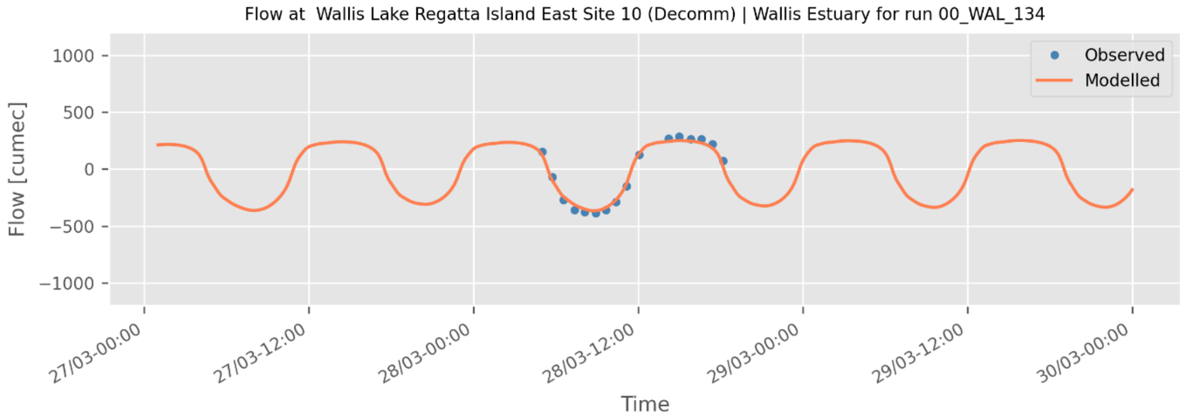

Figure B-9 1998 tidal flow calibration – Location H – Regatta Island East Site 10

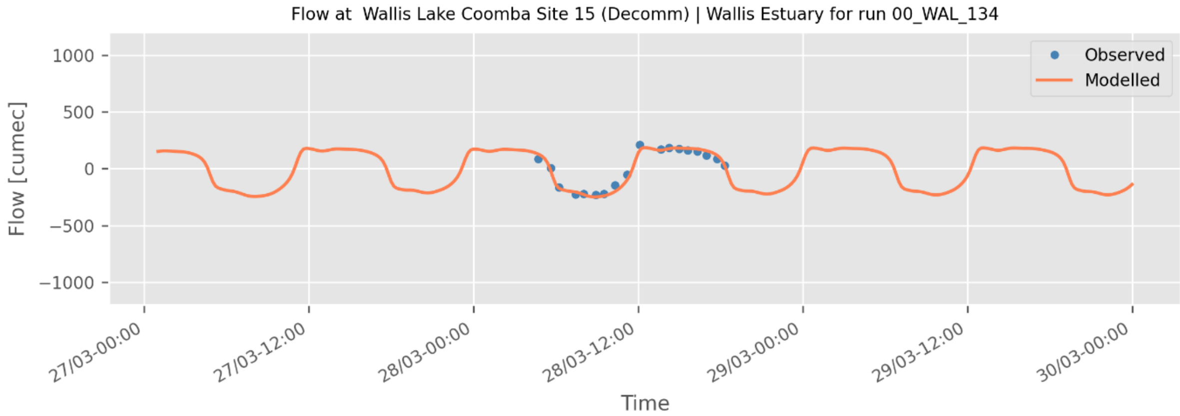

Figure B-10 1998 tidal flow calibration – Location I – Coomba Site 15

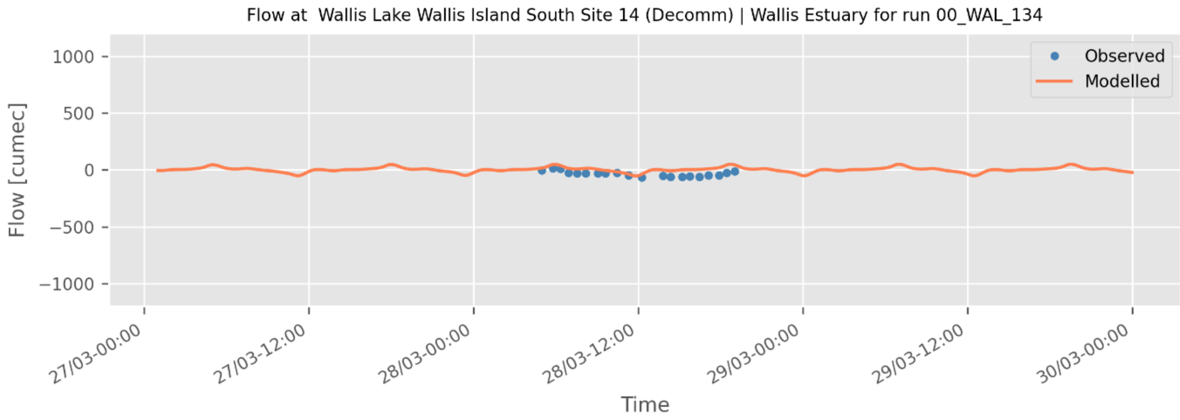

Figure B-11 1998 tidal flow calibration – Location J – Wallis Island South Site 14

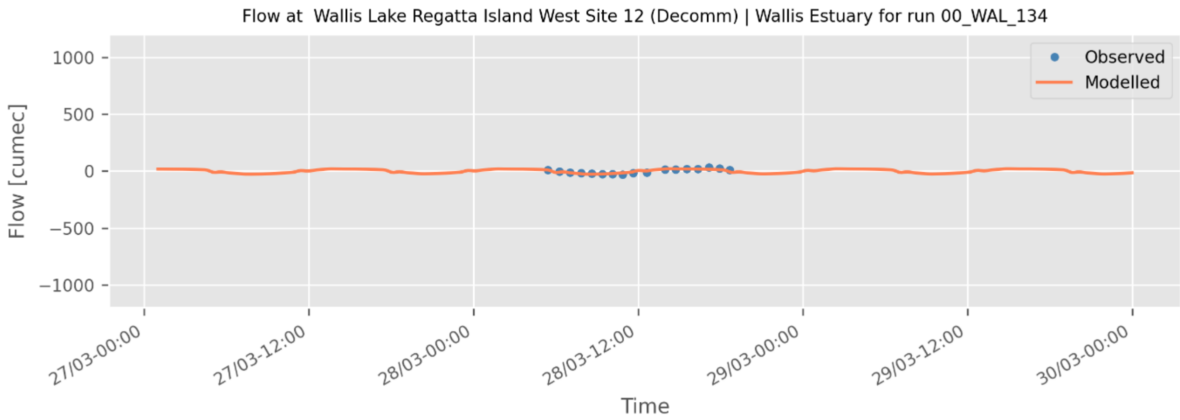

Figure B-12 1998 tidal flow calibration – Location K – Regatta Island West Site 12

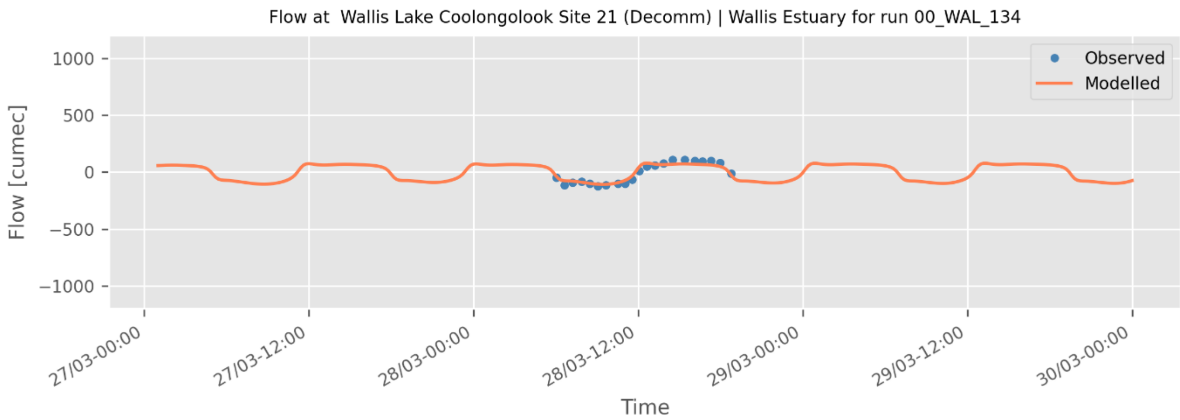

Figure B-13 1998 tidal flow calibration – Location L – Coolongolook Site 21

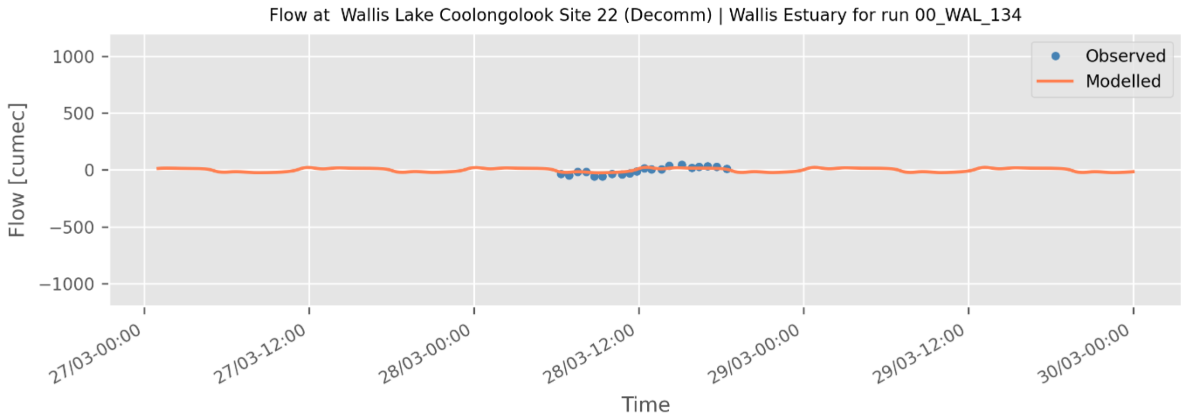

Figure B-14 1998 tidal flow calibration – Location M – Coolongolook Site 22

B1.2 Water level calibration – 1998

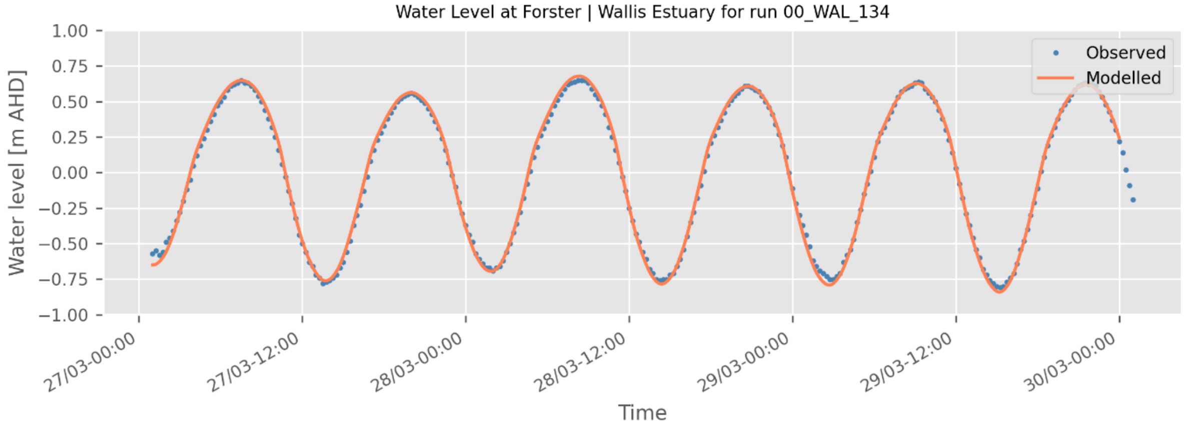

Figure B-15 1998 water level calibration – Location 1 – Forster

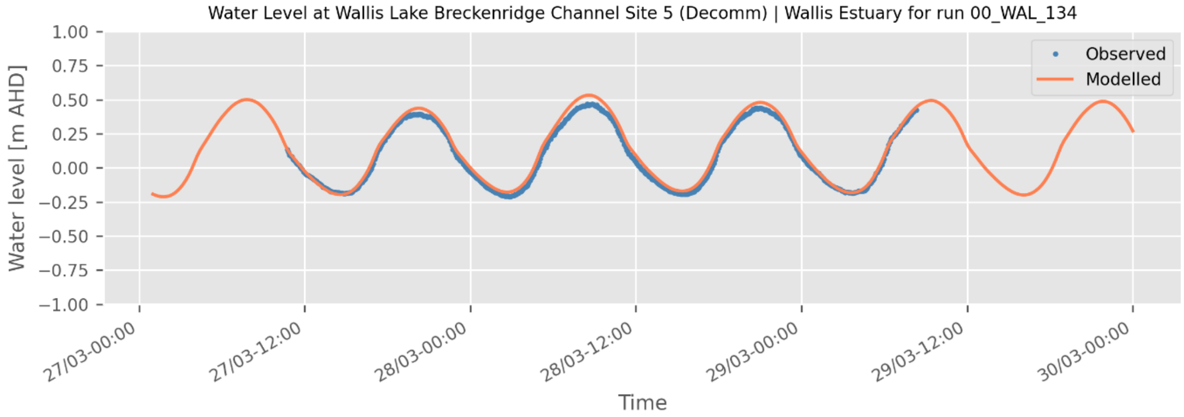

Figure B-16 1998 water level calibration – Location 2 – Breckenridge Channel Site 5

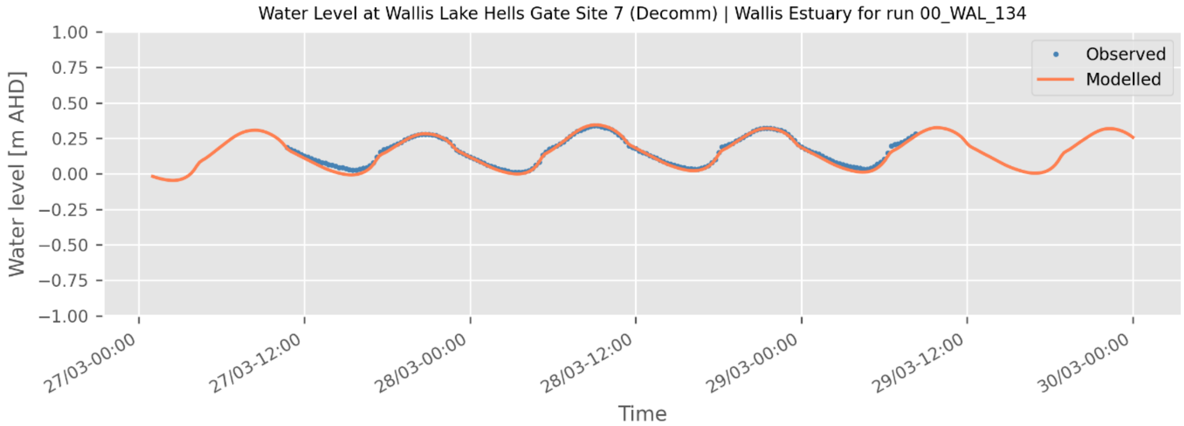

Figure B-17 1998 water level calibration – Location 3 – Hells Gate Site 7

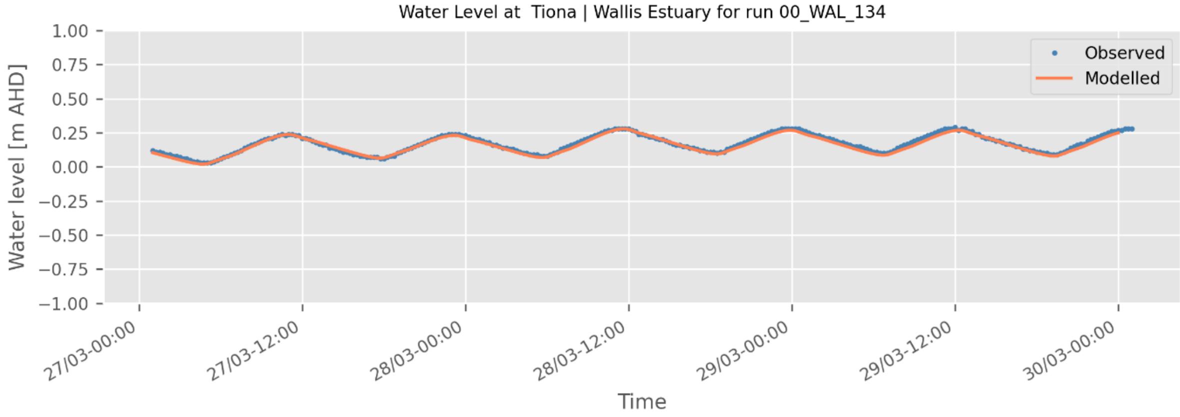

Figure B-18 1998 water level calibration – Location 4 – Tiona

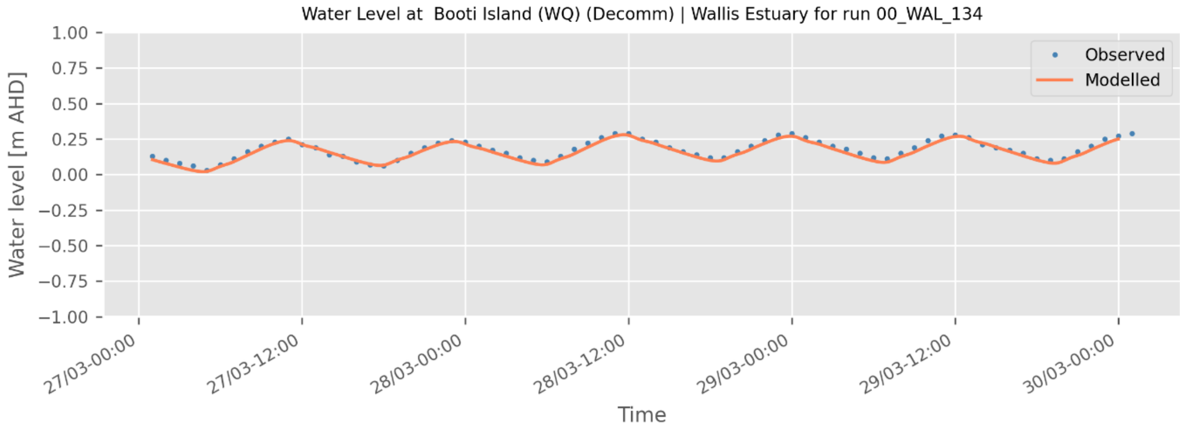

Figure B-19 1998 water level calibration – Location 5 – Booti Island

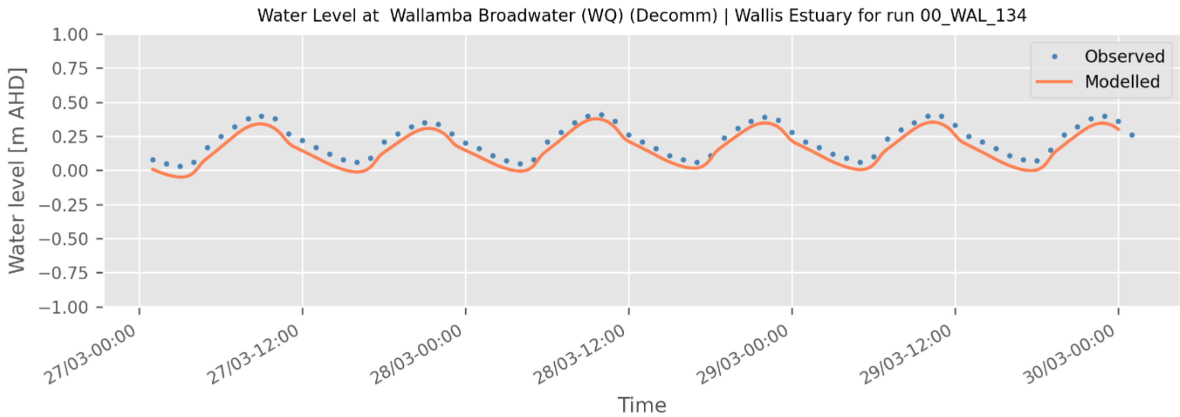

Figure B-20 1998 water level calibration – Location 7 – Wallamba Broadwater

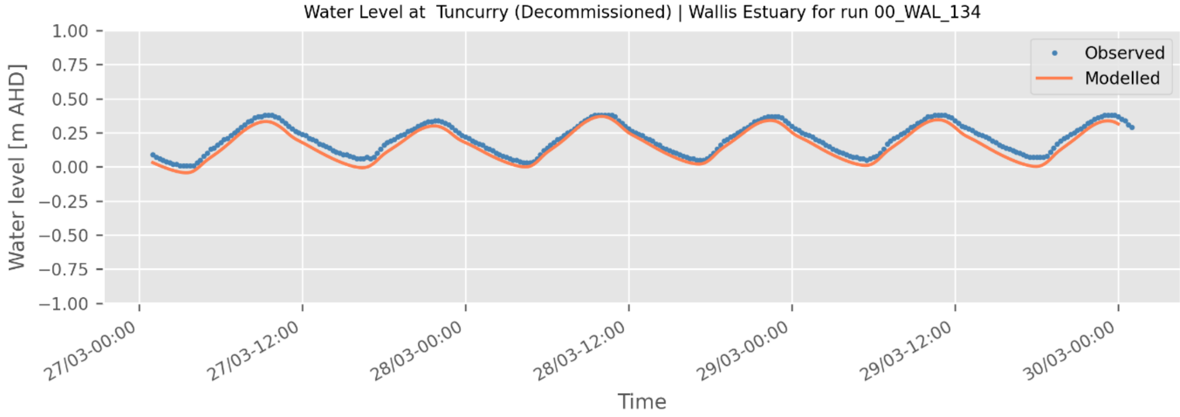

Figure B-21 1998 water level calibration – Location 9 – Tuncurry (decommissioned)

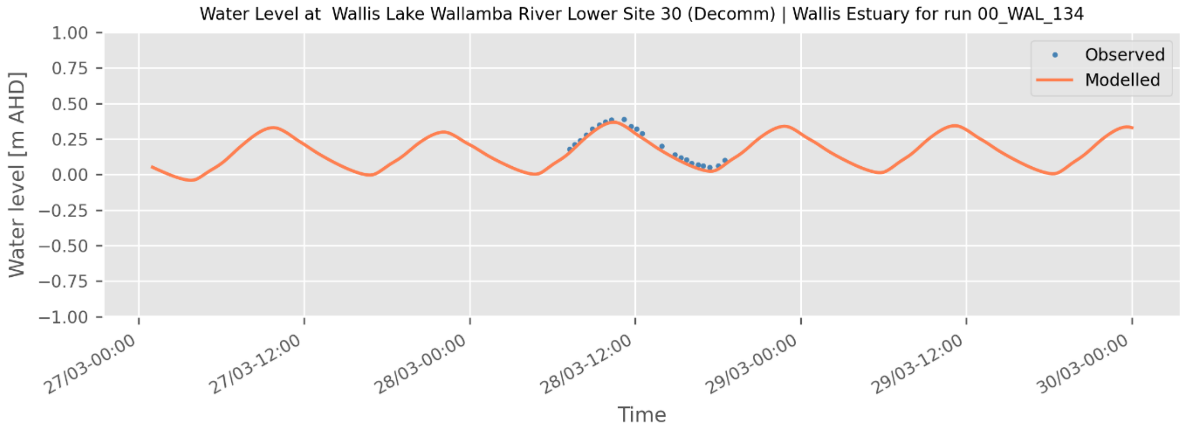

Figure B-22 1998 water level calibration – Location 10 – Wallamba River Lower Site 30

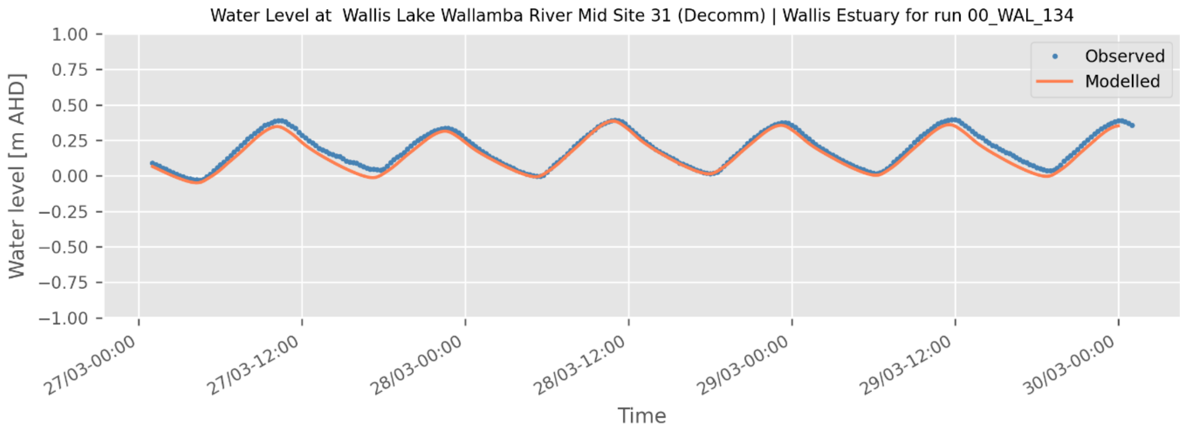

Figure B-23 1998 water level calibration – Location 12 – Wallamba River Mid Site 31

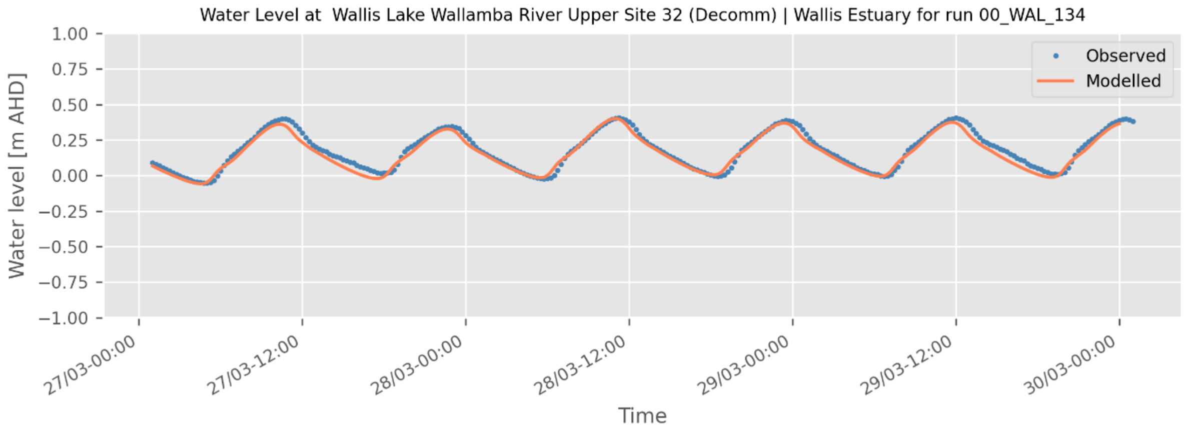

Figure B-24 1998 water level calibration – Location 13 – Wallamba River Upper Site 32

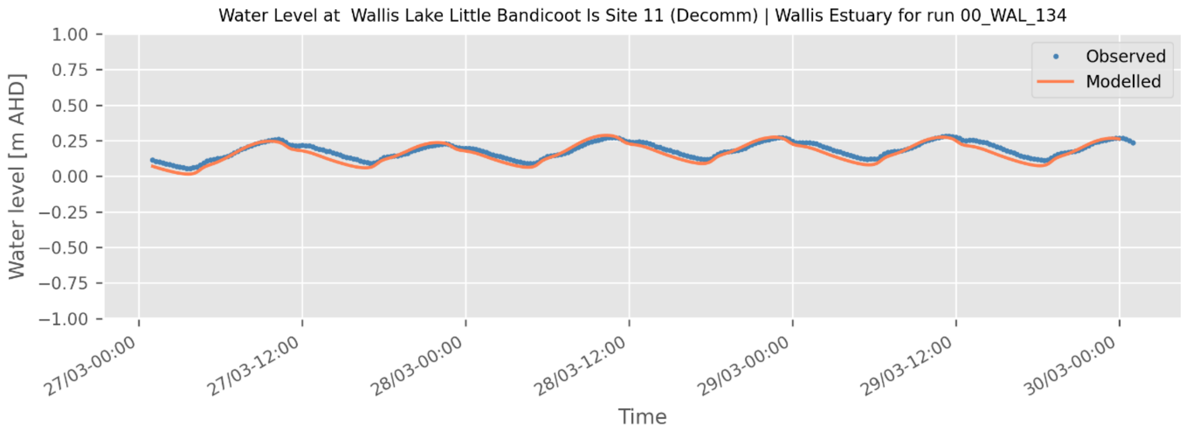

Figure B-25 1998 water level calibration – Location 15 – Little Bandicoot Island Site 11

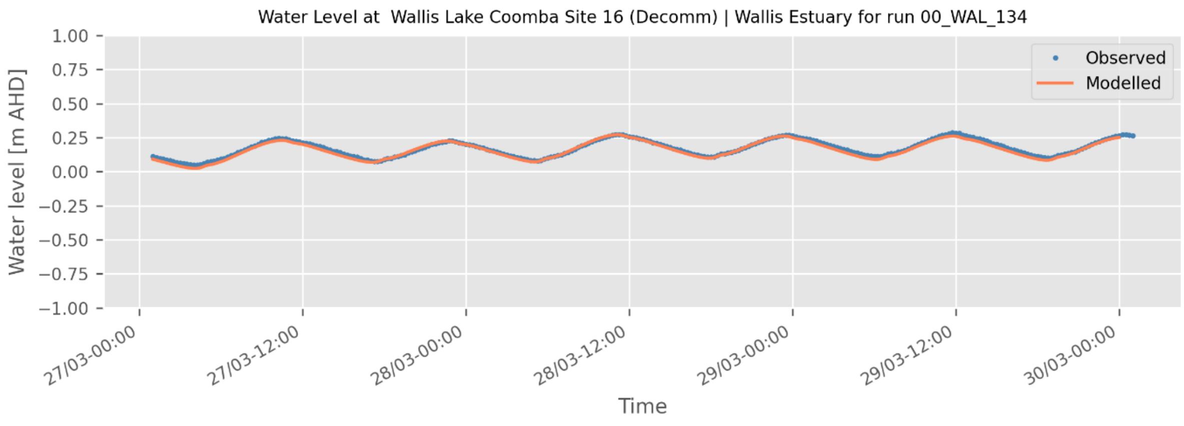

Figure B-26 1998 water level calibration – Location 16 – Coomba Site 16

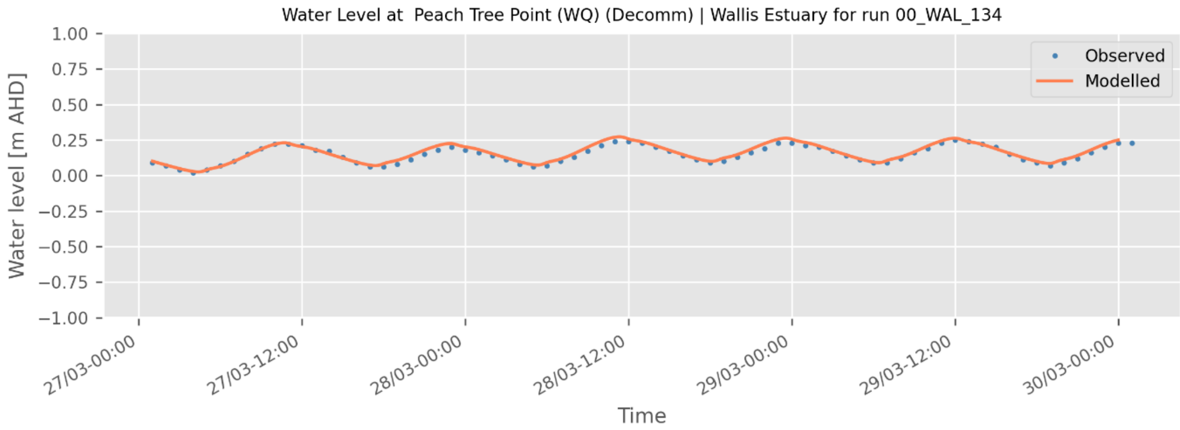

Figure B-27 1998 water level calibration – Location 17 – Peach Tree Point

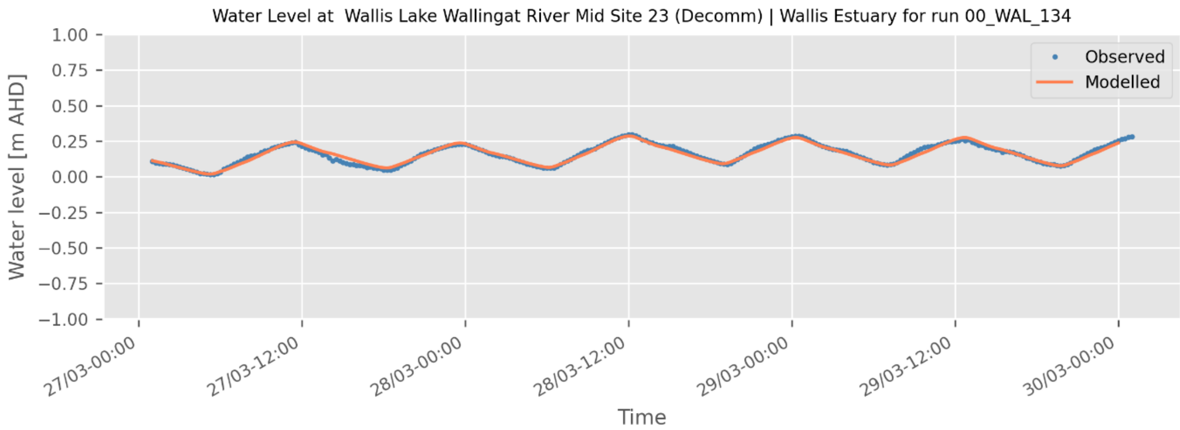

Figure B-28 1998 water level calibration – Location 18 – Wallingat River Mid Site 23

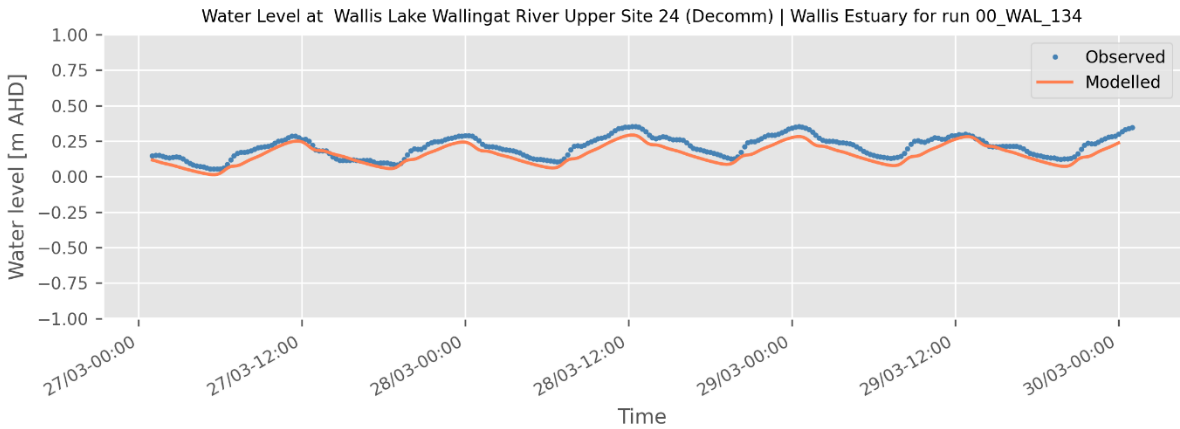

Figure B-29 1998 water level calibration – Location 19 – Wallingat River Upper Site 24

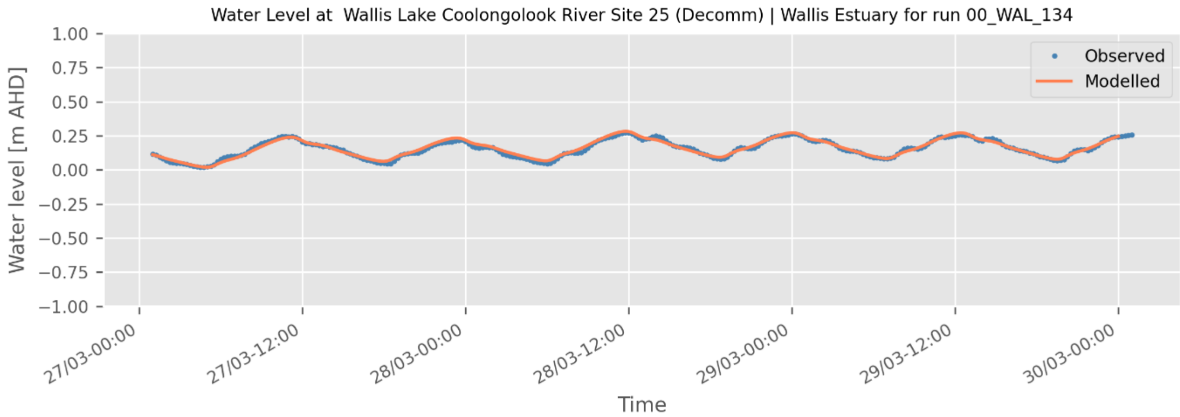

Figure B-30 1998 water level calibration – Location 20 – Coolongolook River Site 25

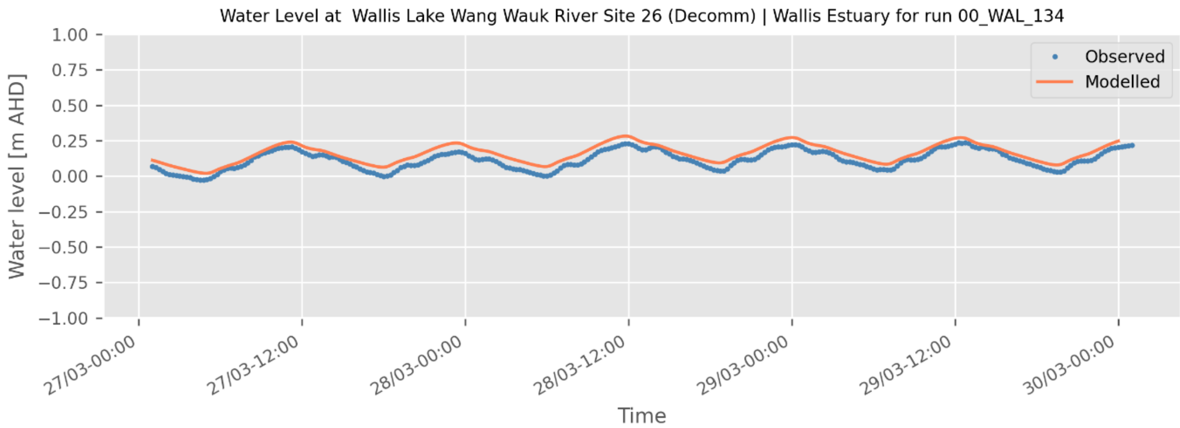

Figure B-31 1998 water level calibration – Location 21 – Wang Wauk River Site 26

B1.3 Tidal flow gauging calibration – 2010

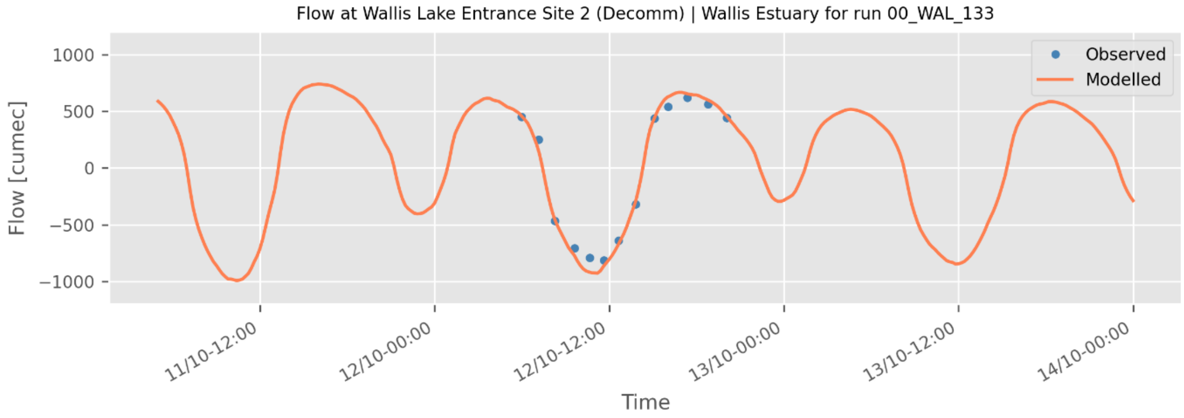

Figure B-32 2010 tidal flow calibration – Location A – Entrance Site 2

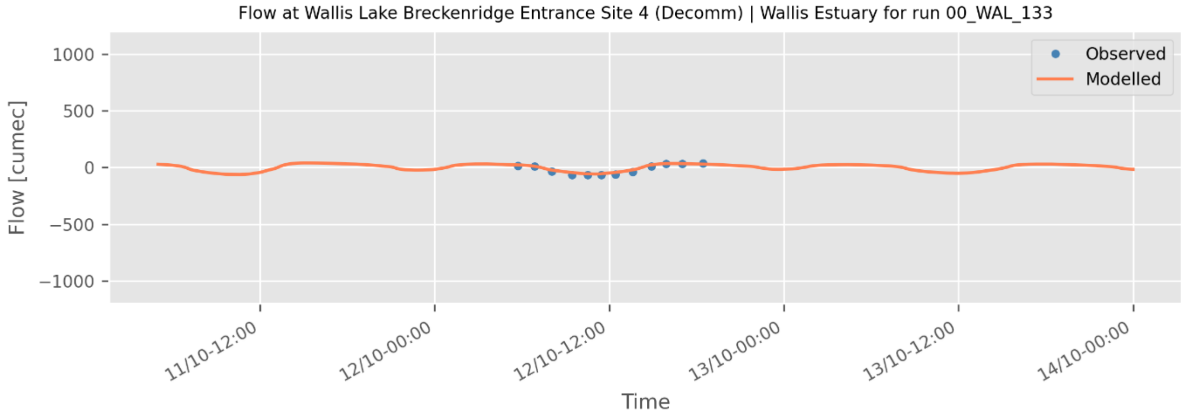

Figure B-33 2010 tidal flow calibration – Location B – Breckenridge Channel Site 4

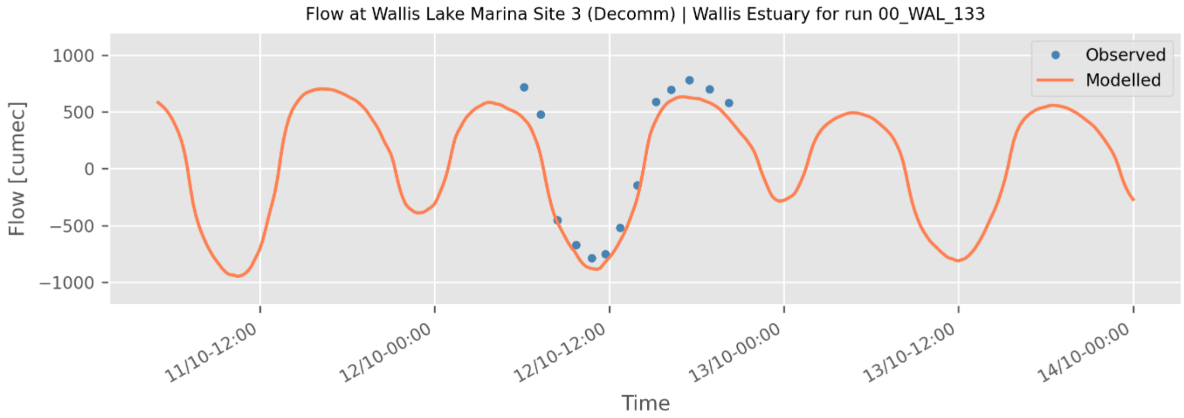

Figure B-34 2010 tidal flow calibration – Location C – Marina Site 3

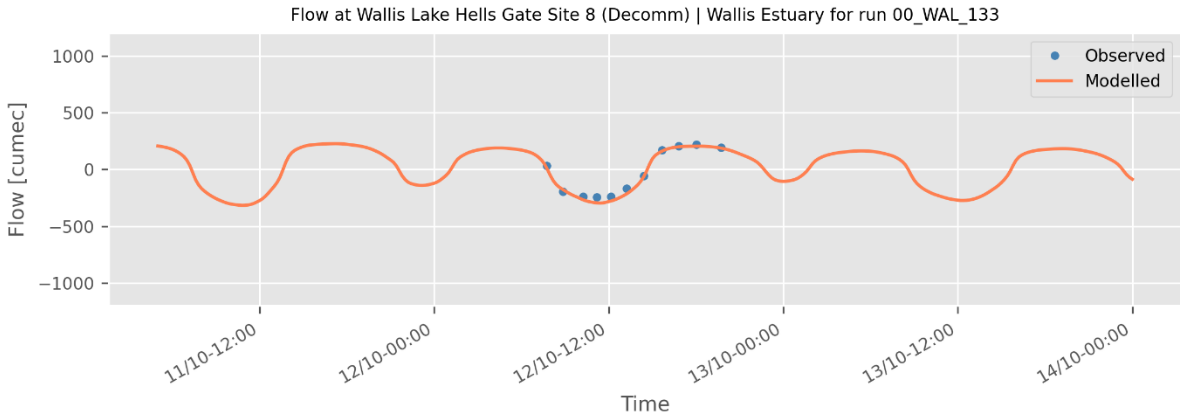

Figure B-35 2010 tidal flow calibration – Location D – Hells Gate Site 8

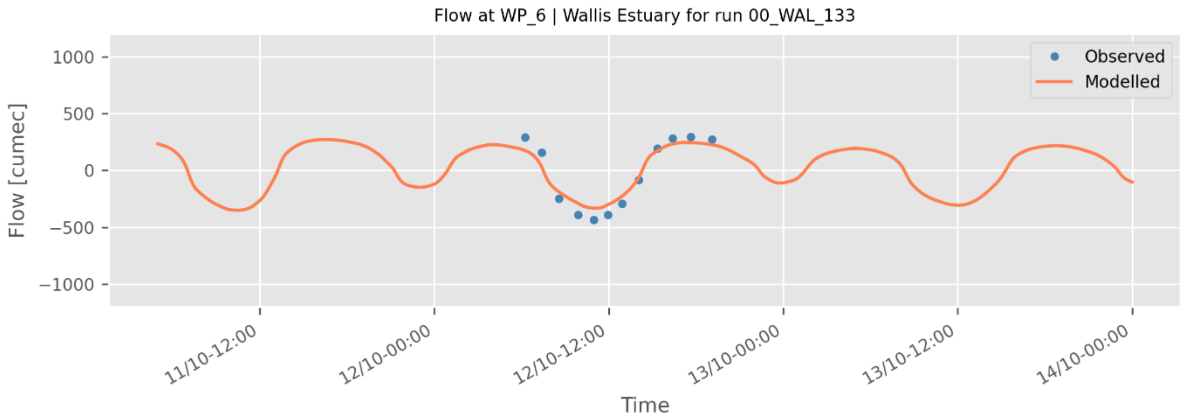

Figure B-36 2010 tidal flow calibration – Location N – WP 6

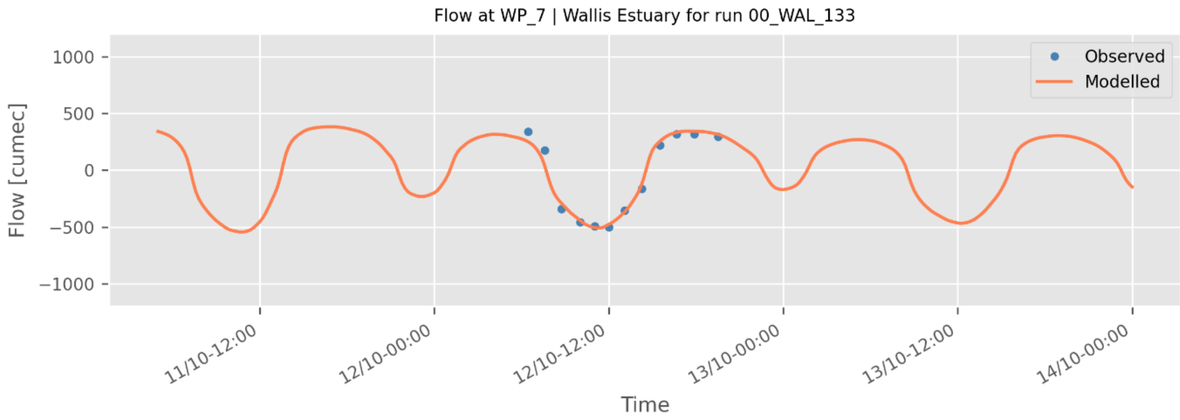

Figure B-37 2010 tidal flow calibration – Location O – WP 7

B1.4 Water level calibration – 2010

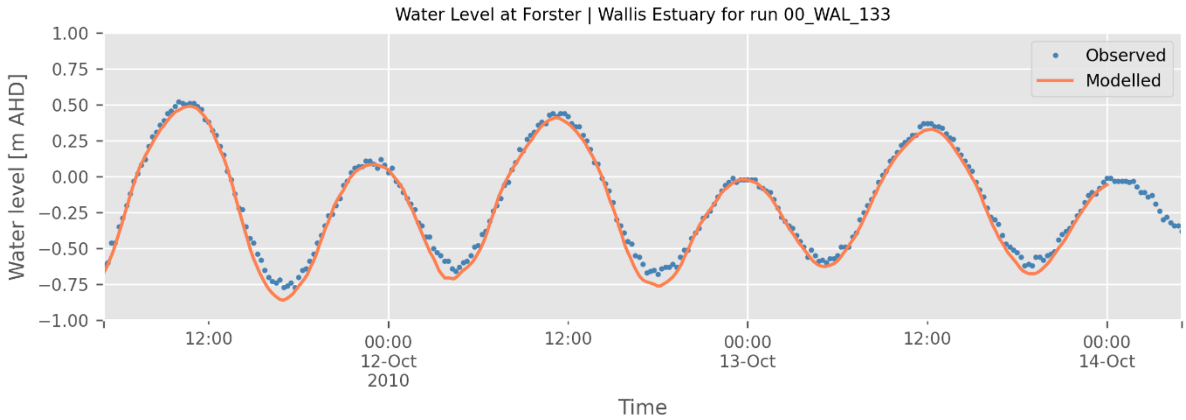

Figure B-38 2010 water level calibration – Location 1 – Forster

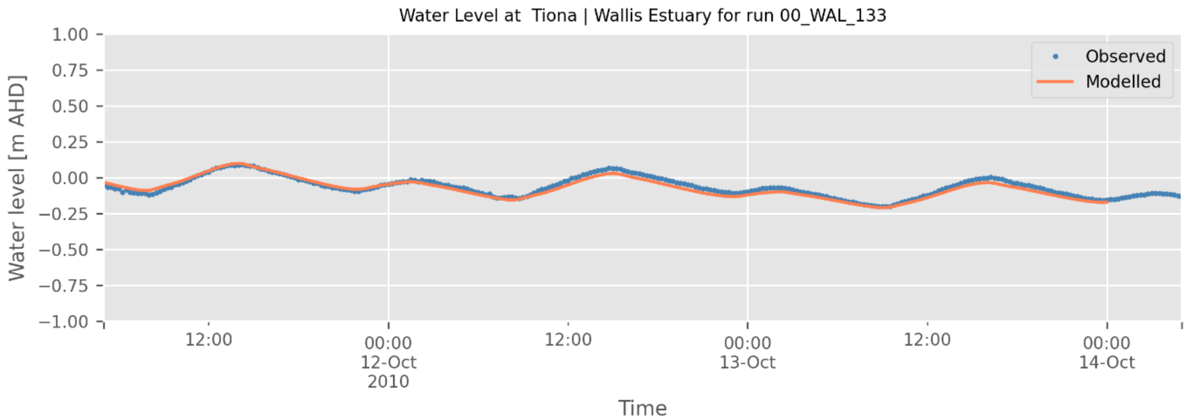

Figure B-39 2010 water level calibration – Location 4 – Tiona

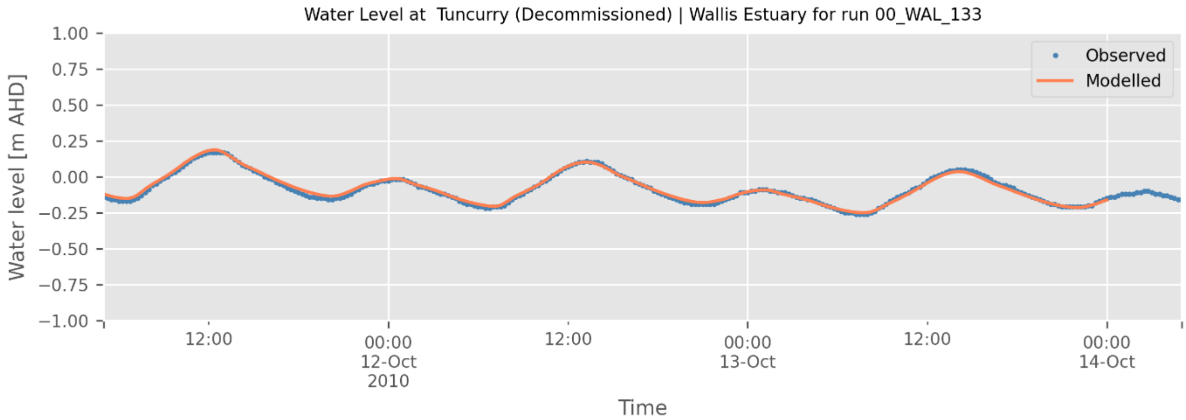

Figure B-40 2010 water level calibration – Location 9 – Tuncurry (Decommissioned)

B1.5 Tidal flow gauging calibration – 2023

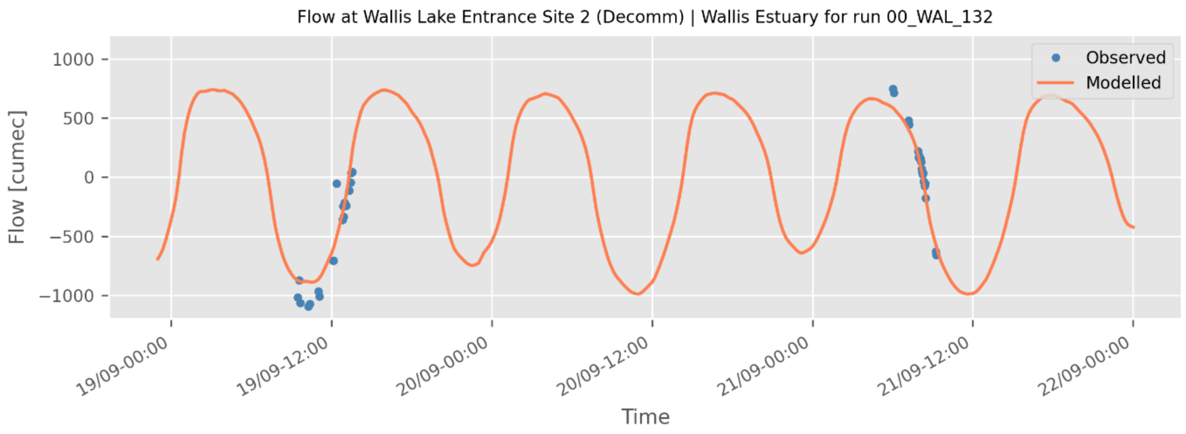

Figure B-41 2023 tidal flow calibration – Location A – Entrance Site 2

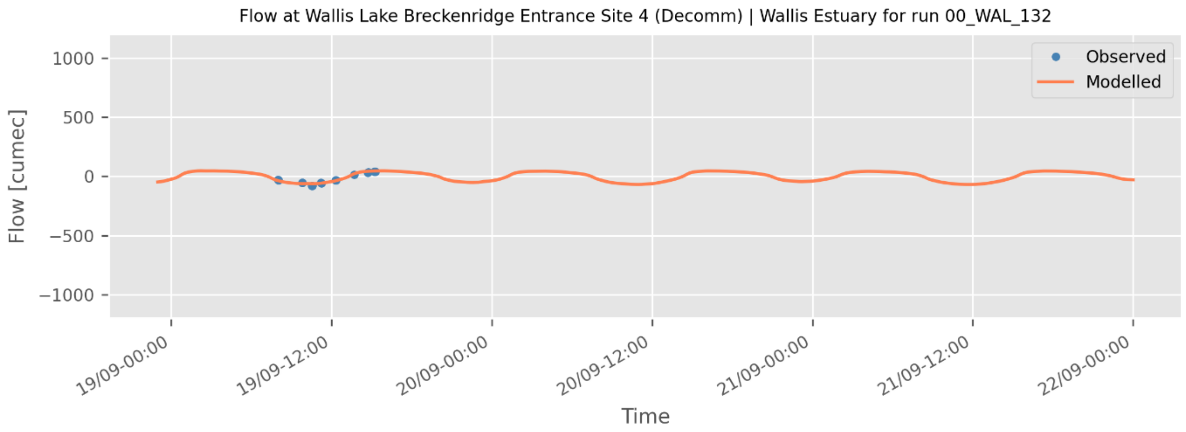

Figure B-42 2023 tidal flow calibration – Location B – Breckenridge Channel Site 4

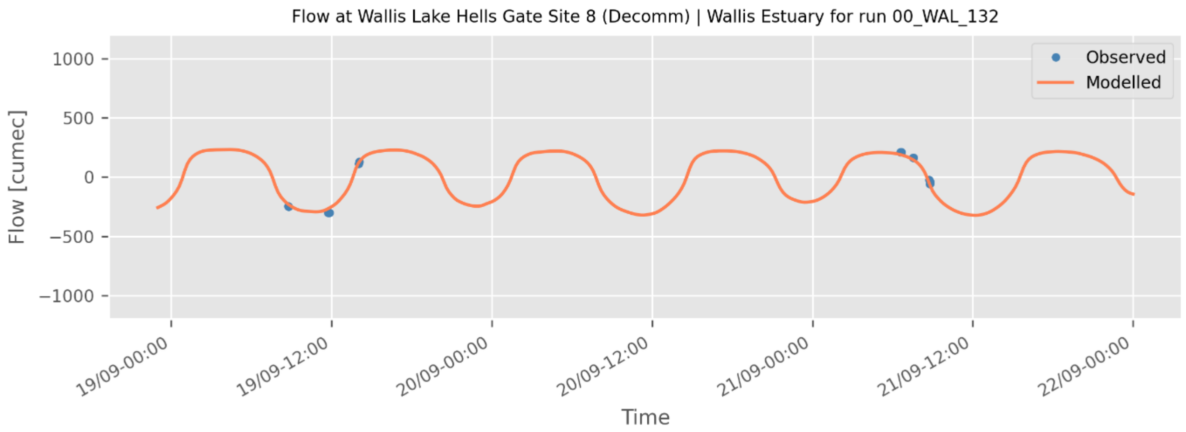

Figure B-43 2023 tidal flow calibration – Location D – Hells Gate Site 8

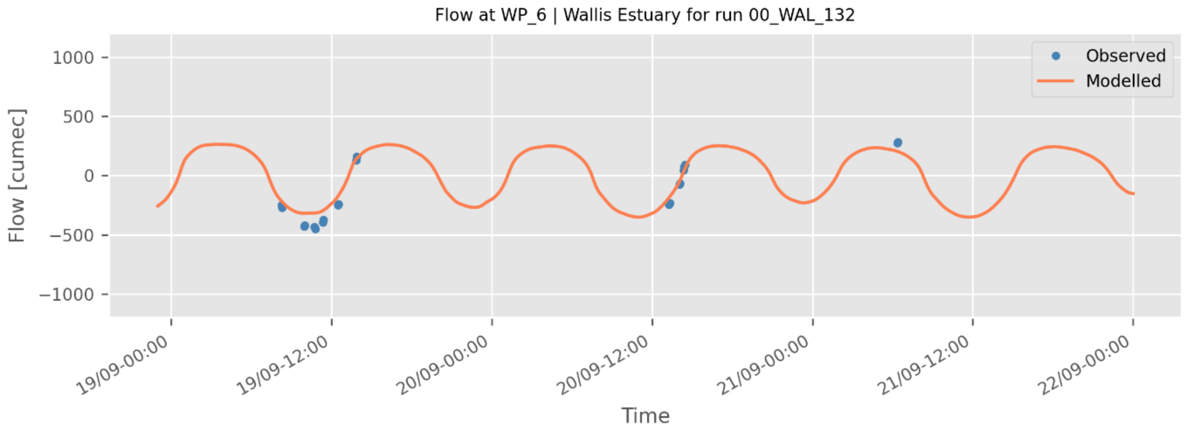

Figure B-44 2023 tidal flow calibration – Location N – WP 6

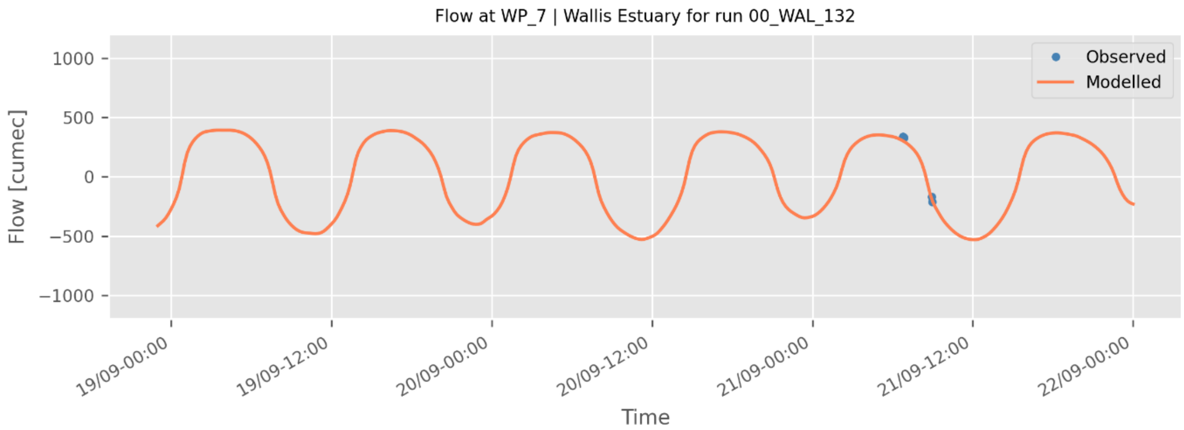

Figure B-45 2023 tidal flow calibration – Location O – WP 7

B1.6 Water level calibration – 2023

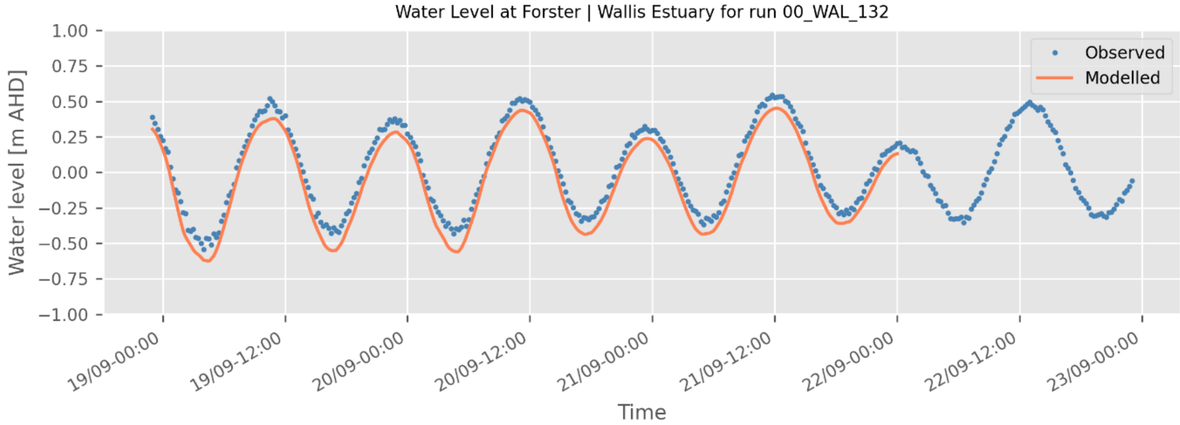

Figure B-46 2023 water level calibration – Location 1 – Forster

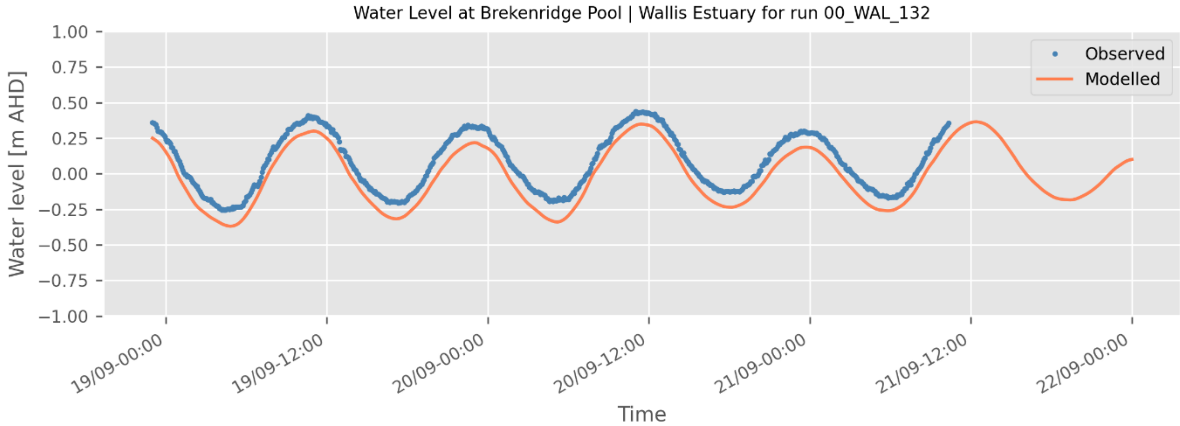

Figure B-47 2023 water level calibration – Location 22 – Breckenridge Pool

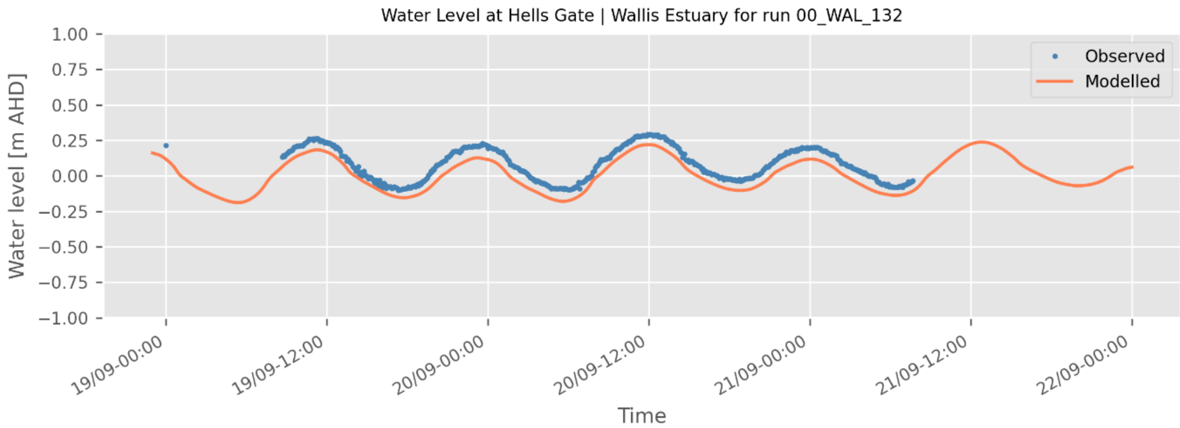

Figure B-48 2023 water level calibration – Location 25 – Hells Gate

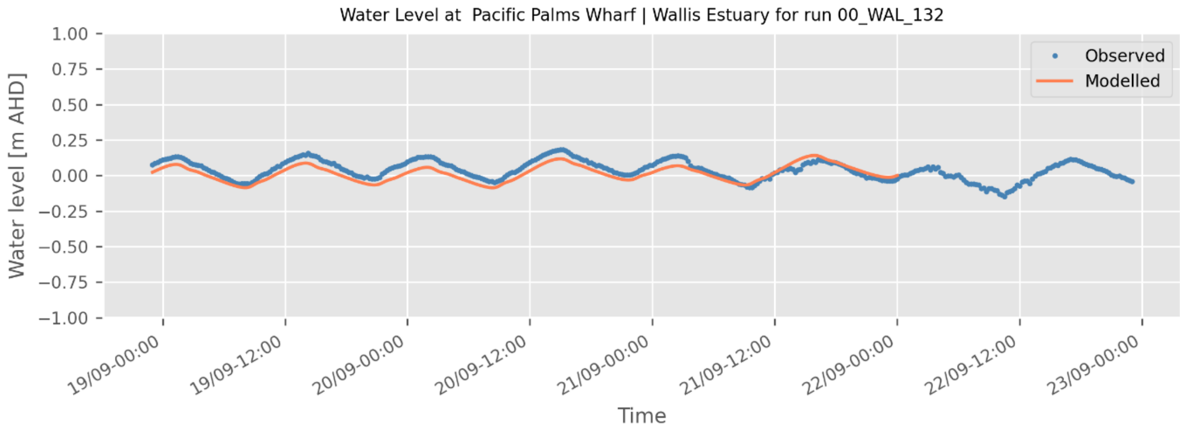

Figure B-49 2023 water level calibration – Location 6 – Pacific Palms Wharf

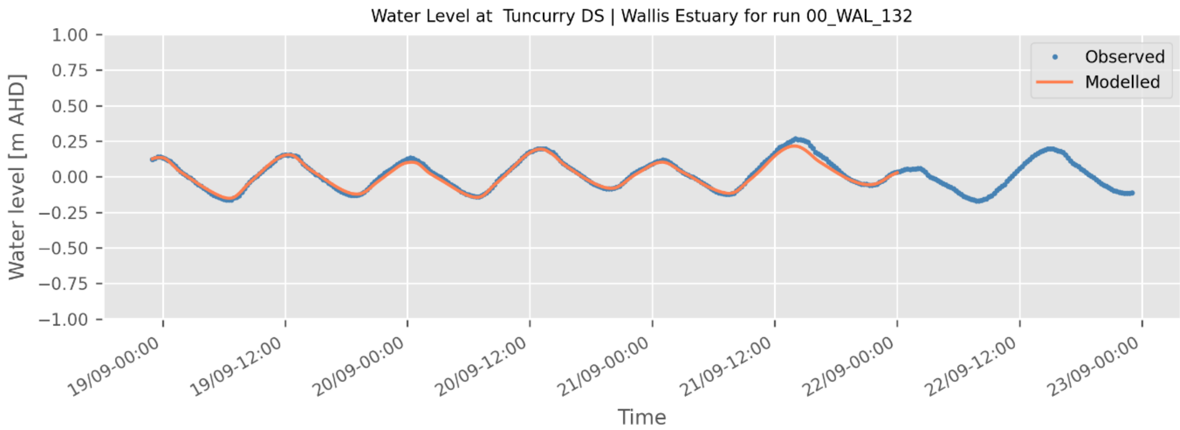

Figure B-50 2023 water level calibration – Location 8 – Tuncurry DS