Assessing the impact of sewage overflows on oyster harvest areas: Shoalhaven/Crookhaven River estuary technical summary

WRL TR 2023/23, 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 focused on the Shoalhaven/Crookhaven River estuary (referred to henceforth as the Shoalhaven River estuary). It provides technical details of the available data, data collection undertaken, model development and the capabilities of the predictive model.

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

Table 1-1 Summary of project reference documents

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

Table 1-2 Summary of estuary-specific reports

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

1.3 Shoalhaven River site description

The Shoalhaven estuary is a large coastal river located 115 km south of Sydney. It has a large catchment of over 7,000 km^2. The tidal extent reaches 50 km upstream and the tidal prism during a spring tide in 2005 was 19 x 10^6 m^3 (MHL, 2007). Major towns in the area include Nowra, Bomaderry and Berry. The river has two entrances, one intermittently open entrance at Shoalhaven Heads and one permanently opened and trained entrance at Crookhaven Heads, 5 km further south. The Shoalhaven and Crookhaven Rivers were connected by the construction of Berrys Canal in the early 19^{th} century. Crookhaven Heads has one training wall on the north bank and a rocky headland to the south, while Shoalhaven Heads is untrained and frequently closes due to natural sand shoaling at the entrance. Since construction, Berrys Canal has been in a state of long term erosion, and is now an efficient channel that is more than 10 m deep in some places. However, recently Thompson (2012) found rates of erosion have slowed, indicating the channel may be adjusting toward a point of dynamic equilibrium. The river has five oyster harvest areas in the lower estuary, Berrys Bay, Comerong Bay, Goodnight Island, Curleys Bay and Crookhaven, shown in Figure 1-1 and Figure 1-2.

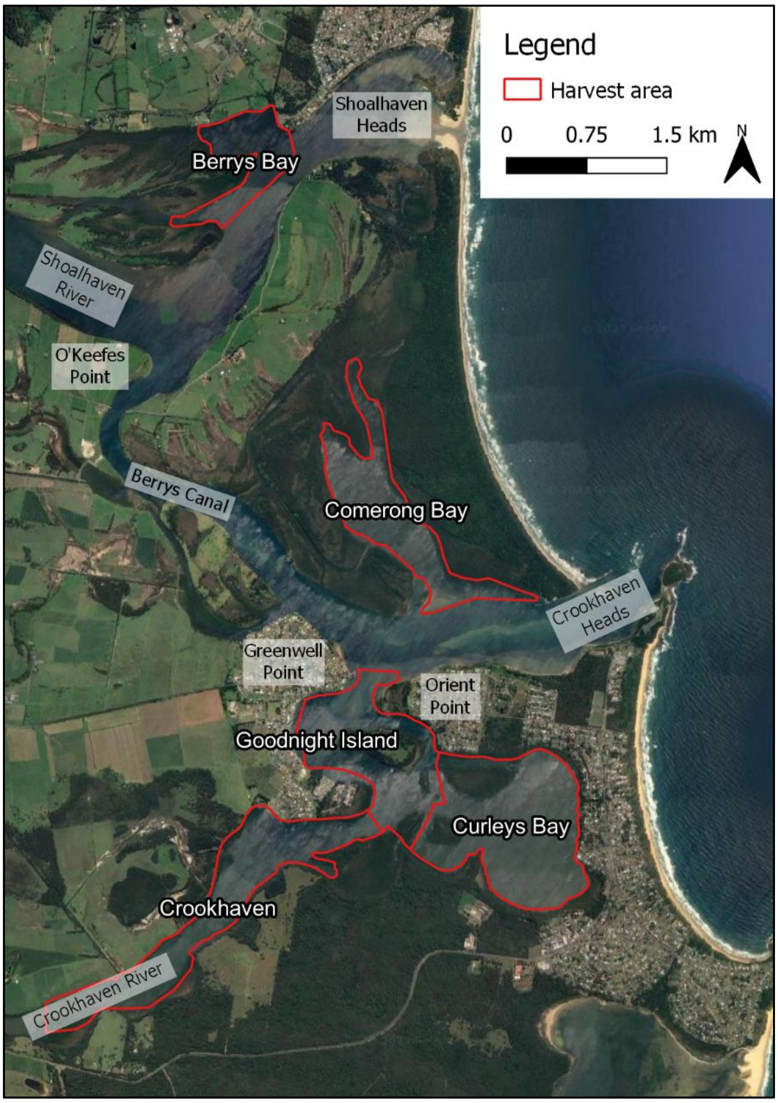

Figure 1-1 Oyster harvest areas on the Shoalhaven River

1.4 About this report

This report includes the following sections:

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

The following appendices are included which provide additional detail:

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

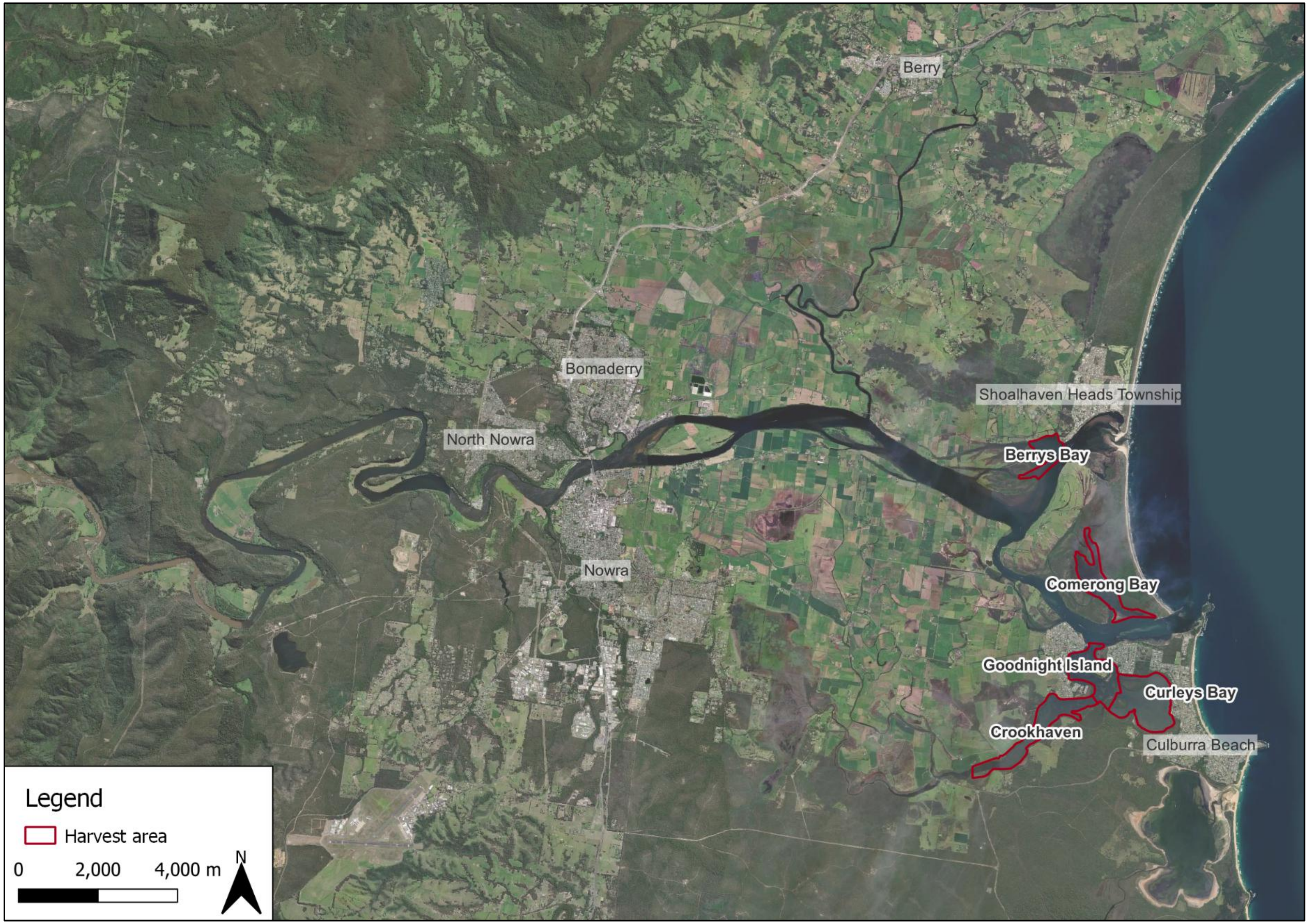

Figure 1-2 Oyster harvest areas on the Shoalhaven River with nearby towns

2 Data collation

2.1 Preamble

Table 2-1 summarises the pre-existing 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 in six locations, in the Shoalhaven River and at two nearby ocean tide gauges	2.2
Tidal flow and water level	MHL (2007)	Tidal flow gauging at seven locations, plus temporary water level gauging at seven locations in September 2005	2.2
Tidal flow and water level	MHL (1996)	Tidal flow gauging at four locations, plus water level gauging at one temporary location in August 1996	2.2
Tidal flow	MHL (1994)	Tidal flow gauging at three locations in June 1993	2.2
Catchment discharge	WaterNSW (2023)	Four long term catchment flow monitoring locations on the Shoalhaven River Broughton Creek, Bomaderry Creek and Jaspers Creek	2.3
Sewage overflows	NSW Food Authority	Data on overflows reported to EPA and NSW Food Authority including volume, duration and closure action	2.4
Bathymetry	DPIE (2018) OEH (2009) NSW Spatial Services (2011) NearMap (2024)	Bathymetry primarily sourced from OEH 2009 single beam survey, with supplementary data from 2018 NSW Marine LiDAR Topo-Bathy survey, 2011 Digital Elevation Model (DEM) and NearMap aerial images	0

2.2 Water level and tidal flow gauging

Manly Hydraulics Laboratory (MHL) maintain six permanent water level gauges installed on the Shoalhaven River, one permanent ocean tide gauge on the Shoalhaven River at Crookhaven Heads, and one other nearby ocean tide gauge at Jervis Bay. Further water level and flow gauging has occurred during the short-term data collection campaigns run by MHL in 2005, 1996 and 1993. These campaigns collected hydrodynamic data both when Shoalhaven Heads was closed (2005 and 1996) and open

(1993). Gauging and water level sensor locations are shown in Figure 2-1 and tabulated in Table 2-2 and Table 2-3.

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

Water level gauge	Location label (Figure 2-1)	Station number	Provider	Date range	MHL report number*
Crookhaven Heads	1	215408	MHL	1992 – present	-
Greenwell Point	2	215417	MHL	1988 – present	-
Hay Steet	4	215415	MHL	2002 – present	-
Shoalhaven Heads	5	215470	MHL	1991 – present	-
Terara	8	215420	MHL	2001 – present	-
Nowra Bridge	9	215411	MHL	1990 – present	-
Gradys (Decom)	16	215452	MHL	2006 – 2010	-
Gradys Caravan Park	17	215430	MHL	2010 – present	-
Jervis Bay	-	216470	MHL	1989 – present	-
Berrys Canal Site 5	3	-	MHL	2005 – 2006	MHL1450
Broughton Creek Entrance Site 20	6	-	MHL	2005 – 2006	MHL1450
Broughton Creek Upstream Site 21	7	-	MHL	2005 – 2006	MHL1450
Gypsy Point Site 12	10	-	MHL	2005 – 2006	MHL1450
Gradys Retreat Site 14	11	-	MHL	2005 – 2006	MHL1450
Crookhaven River Site 16	12	-	MHL	2005 – 2006	MHL1450
Crookhaven Creek Site 18	13	-	MHL	2005 – 2006	MHL1450
Berrys Canal Site 4	14	-	MHL	16 – 29/08/1996	MHL786
Comerong Bay	15	-	WRL	11 – 12/05/2023	-

*MHL661 – MHL(1994), MHL 786 – MHL (1996), MHL1450 – MHL(2007)

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

Tidal flow gauging	Location label (Figure 2-1)	Dates	Study*
Crookhaven Entrance Site 3	A	21/09/2005	MHL1450
Crookhaven River Site 15	B	21/09/2005	MHL1450
Berrys Canal Site 6	C	21/09/2005	MHL1450
Comerong Island Site 7	D	21/09/2005	MHL1450
Shoalhaven River Site 9	E	21/09/2005	MHL1450
Broughton Entrance Site 19	F	21/09/2005	MHL1450
Shoalhaven River Upstream Site 13	G	21/09/2005	MHL1450
Berrys Canal Site 5	C	28/08/1996	MHL786
Old Man Island Site 6	D	28/08/1996	MHL786
Shoalhaven River Upstream Site 13	G	28/08/1996	MHL786
Shoalhaven River Wharf Road Site 11	H	28/08/1996	MHL786
Berrys Canal Site 3	C	02/06/1993	MHL661
Shoalhaven River Downstream Site 2	I	02/06/1993	MHL661
Shoalhaven River Upstream Site 1	J	02/06/1993	MHL661

*MHL661 – MHL(1994), MHL 786 – MHL (1996), MHL1450 – MHL(2007)

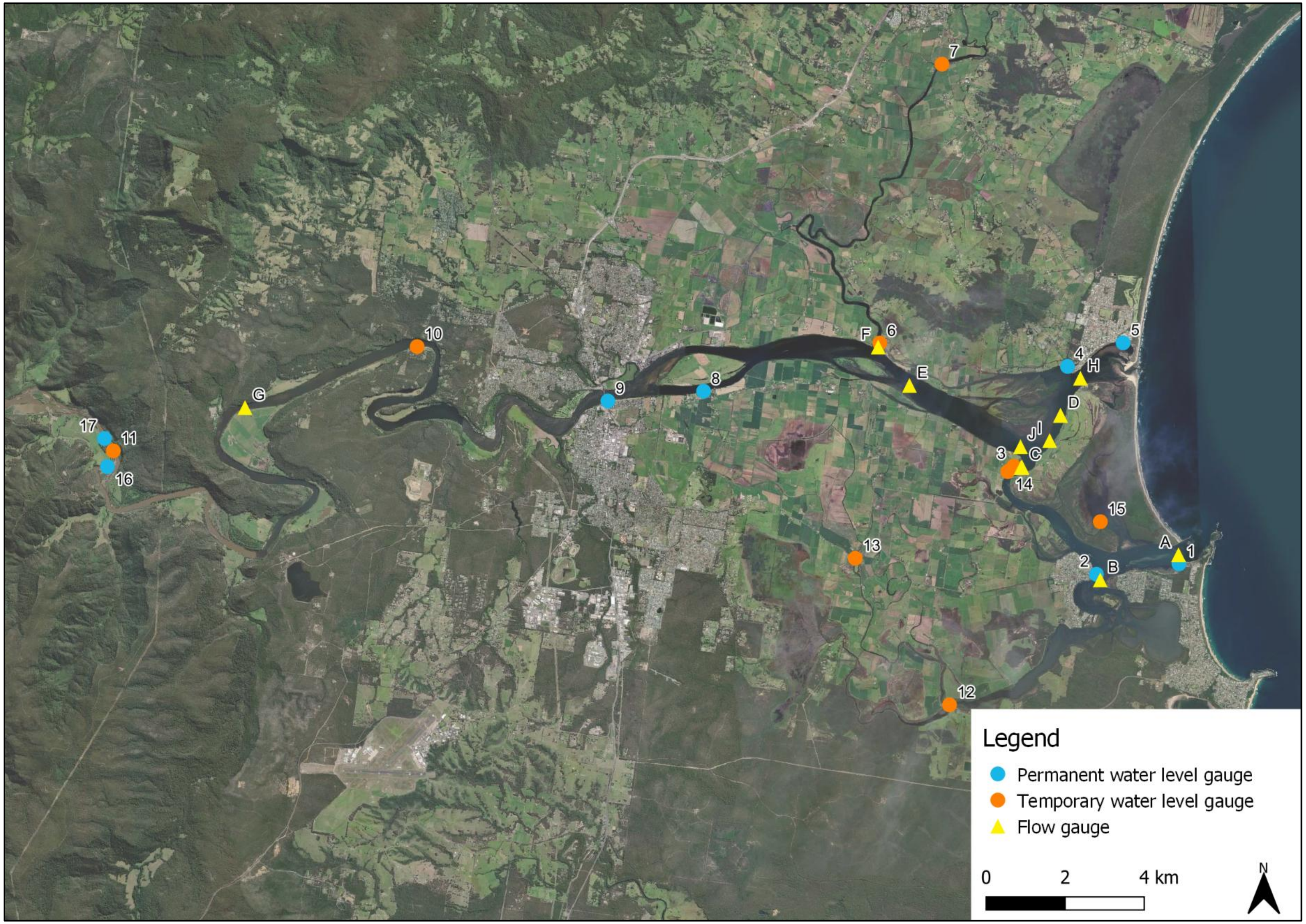

Figure 2-1 Water level and tidal flow gauging locations

2.3 Catchment inflows

Gauged catchment inflows were available from WaterNSW. When these were not at the tidal limit (the model boundary), the flows were scaled up proportional to the additional catchment area using the method in WRL TR2023/32 Section 2.4. There are three model boundary inflows into the Shoalhaven River estuary and continuous flow gauging of discharge and water levels are available from WaterNSW (2023) at four relevant locations: Shoalhaven River at Grassy Gully (1987 to present), Bomaderry Creek at Bomaderry (2003 to present), Jaspers Creek at Jasper (2011 to present) and Broughton Creek at Broughton Vale (2008 to present). Table 2-4 lists the model boundaries, the gauges used and the relevant scaling factor applied. Figure 2-2 shows the locations along with the catchment area flowing into each tidal boundary (solid line polygon) along with the associated portion of that catchment that is upstream of each gauge (hatched).

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

Model boundary	Base WaterNSW gauge	Scaling factor
Shoalhaven River	215216	1.005
Broughton Creek	215018	5.141
Jaspers Creek	215019	4.926
Bomaderry Creek	215016	1.000
Crookhaven Creek*	215016	1.925

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

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

Table 2-5 WaterNSW gauge flow percentiles

Percentile	Shoalhaven River at Grassy Gully (215216) ML/d *(m^3/s)*	Bomaderry Creek at Bomaderry (215016) ML/d *(m^3/s)*	Jaspers Creek at Jasper (215019) ML/d *(m^3/s)*	Broughton Creek at Broughton Vale (215018) ML/d *(m^3/s)*
5th	64 *(0.74)*	0.0 *(0.0)*	0.00 *(0.0)*	0.68 *(0.01)*
20th	151 *(1.8)*	1.7 *(0.02)*	1.5 *(0.02)*	3.9 *(0.05)*
50th (median)	543 *(6.3)*	6.1 *(0.07)*	3.8 *(0.04)*	13 *(0.15)*
80th	2217 *(26)*	24 *(0.28)*	14 *(0.16)*	55 *(0.63)*
95th	9661 *(112)*	115 *(1.3)*	85 *(0.98)*	289 *(3.4)*

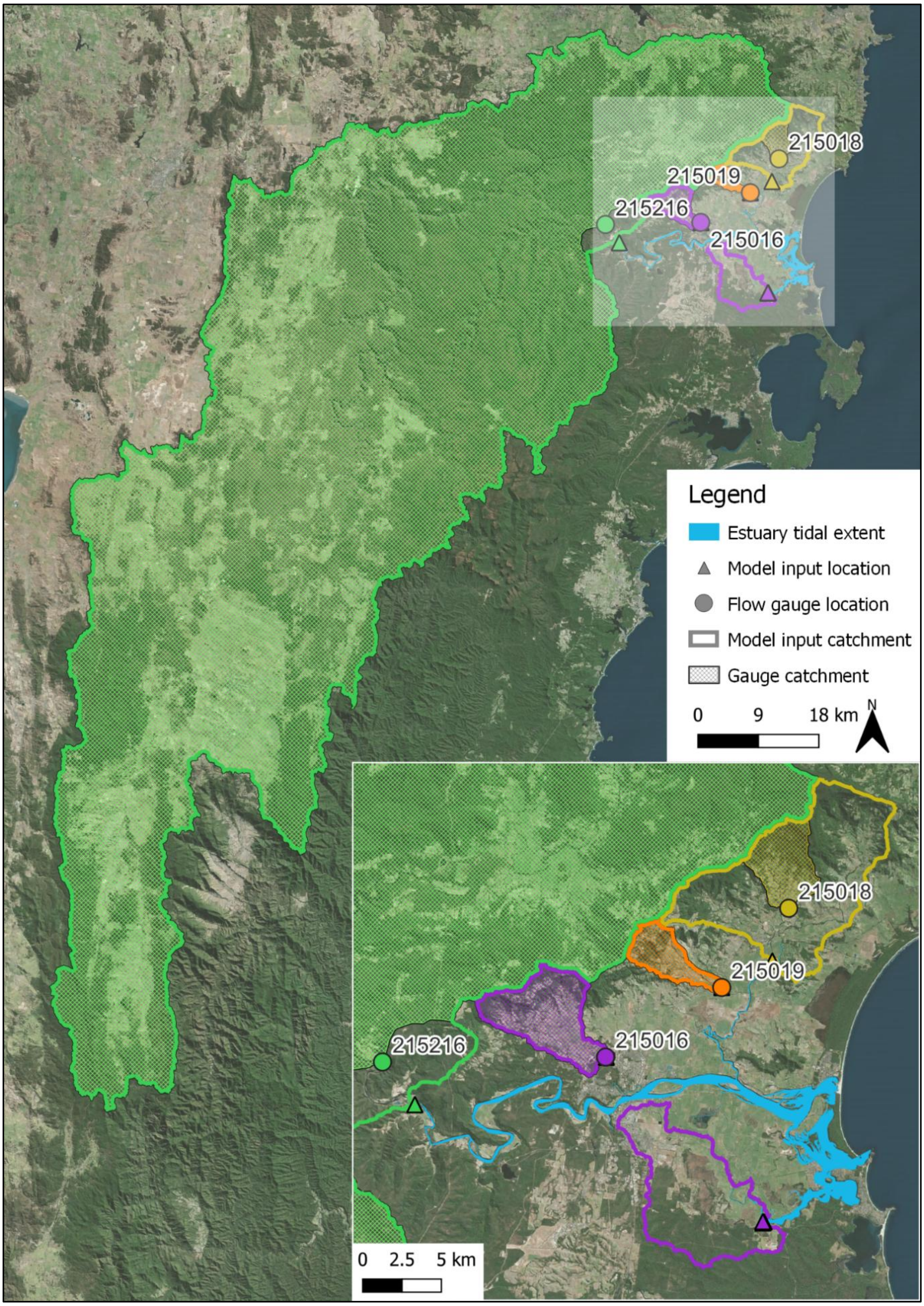

Figure 2-2 Catchment flow gauging stations*

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

2.4 Sewage overflow data

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

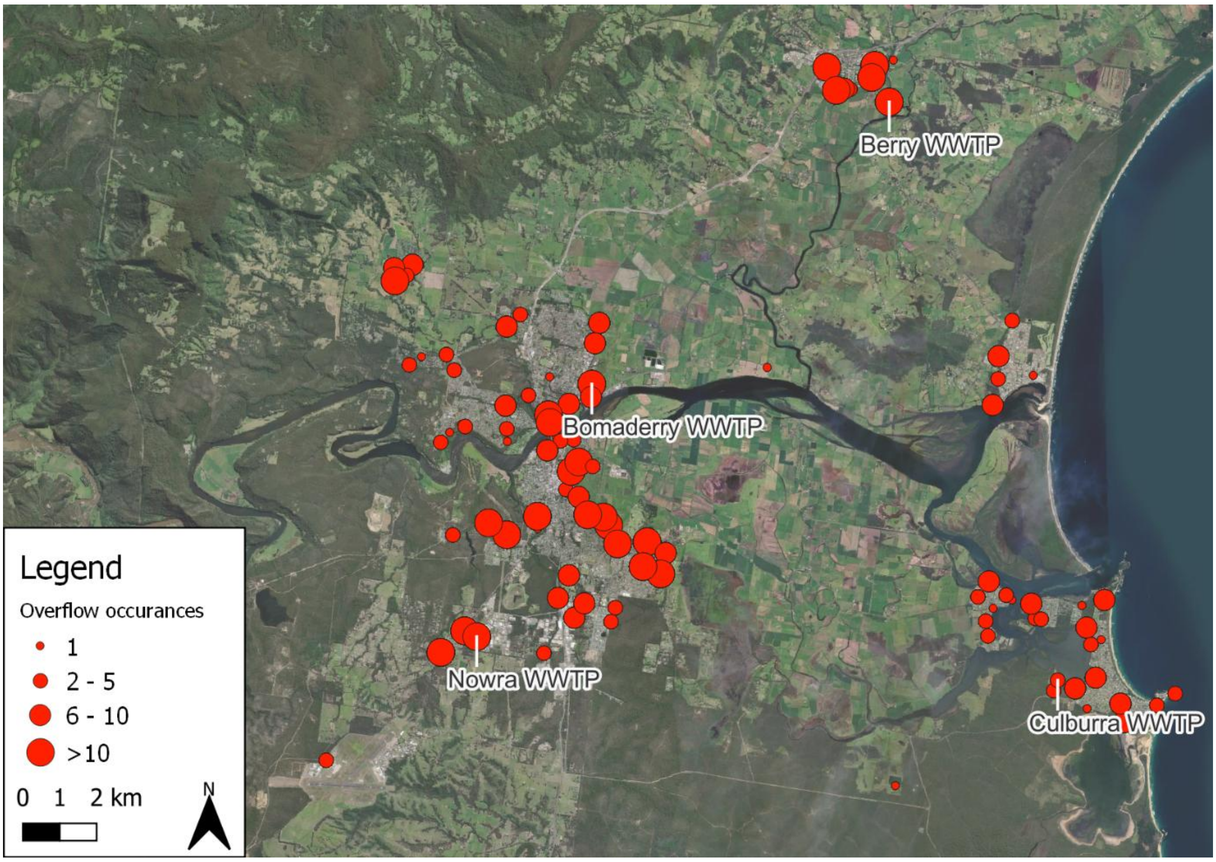

Figure 2-3 Locations of reported sewage overflows on the Shoalhaven River

2.5 Bathymetry

Two existing bathymetry datasets were sourced for this project:

- Single beam bathymetry data collected in 2006. This dataset was collated and provided by the NSW Office of Environment and Heritage (OEH, now DCCEEW) and is available on the Australian Ocean Data Network (AODN) portal. This data covers the vast majority of the model domain, with transects every 20 to 50 m from the lower estuary to the tidal extent (shown in Figure 2-4). This was the primary source of bathymetry data used in the model.
- Coastal marine LiDAR collected by the former NSW Department of Planning, Industry and Environment (DPIE, now DCCEEW) in 2018. In the Shoalhaven area, this data covers areas 1.5 to 3.5 km from the coast (shown in Figure 2-5) at a resolution of 5 m. This data was used in areas that were above the elevation of the single beam survey.

For areas where the OEH survey is overlapped the DPIE data, bathymetry was compared, refer to Figure 2-6. Differences were minor in Shoalhaven Heads and the Crookhaven River. In Berrys Canal and the Crookhaven Heads entrance, there has been movement of some shoals as well as a general trend of erosion. This is consistent with trends of erosion since the construction of Berrys Canal from tidal scour, which is documented in previous studies (AWACS, 1999; Rayner et al., 2023).

Additional bathymetric, topographic, and aerial data utilised include:

- 1 x 1 m DEM LiDAR data, collected in 2011 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 2011 survey.
- High resolution NearMap imagery was used to qualitatively provide information on small upstream tributaries.

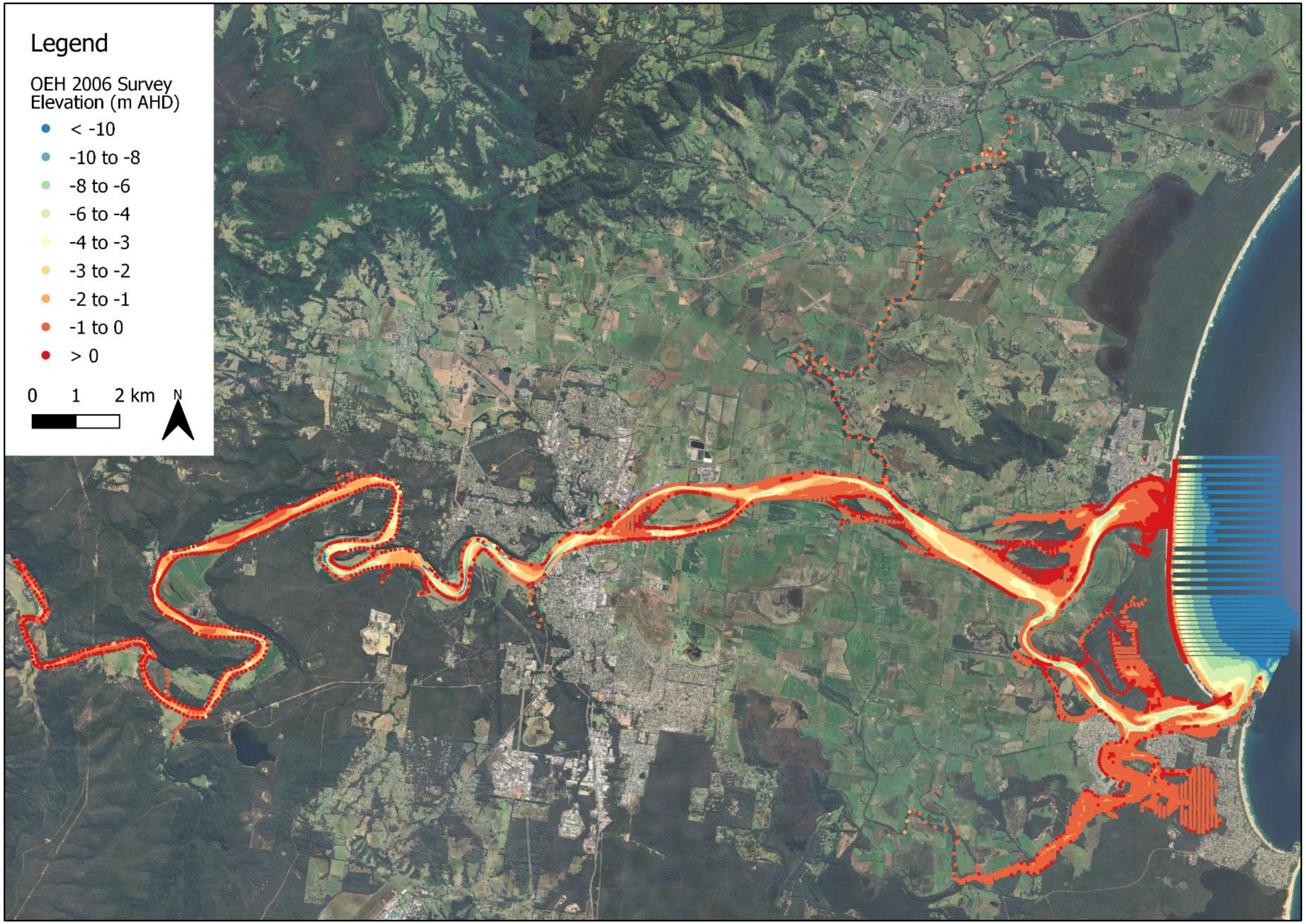

Figure 2-4 Coverage of the 2006 OEH single beam data

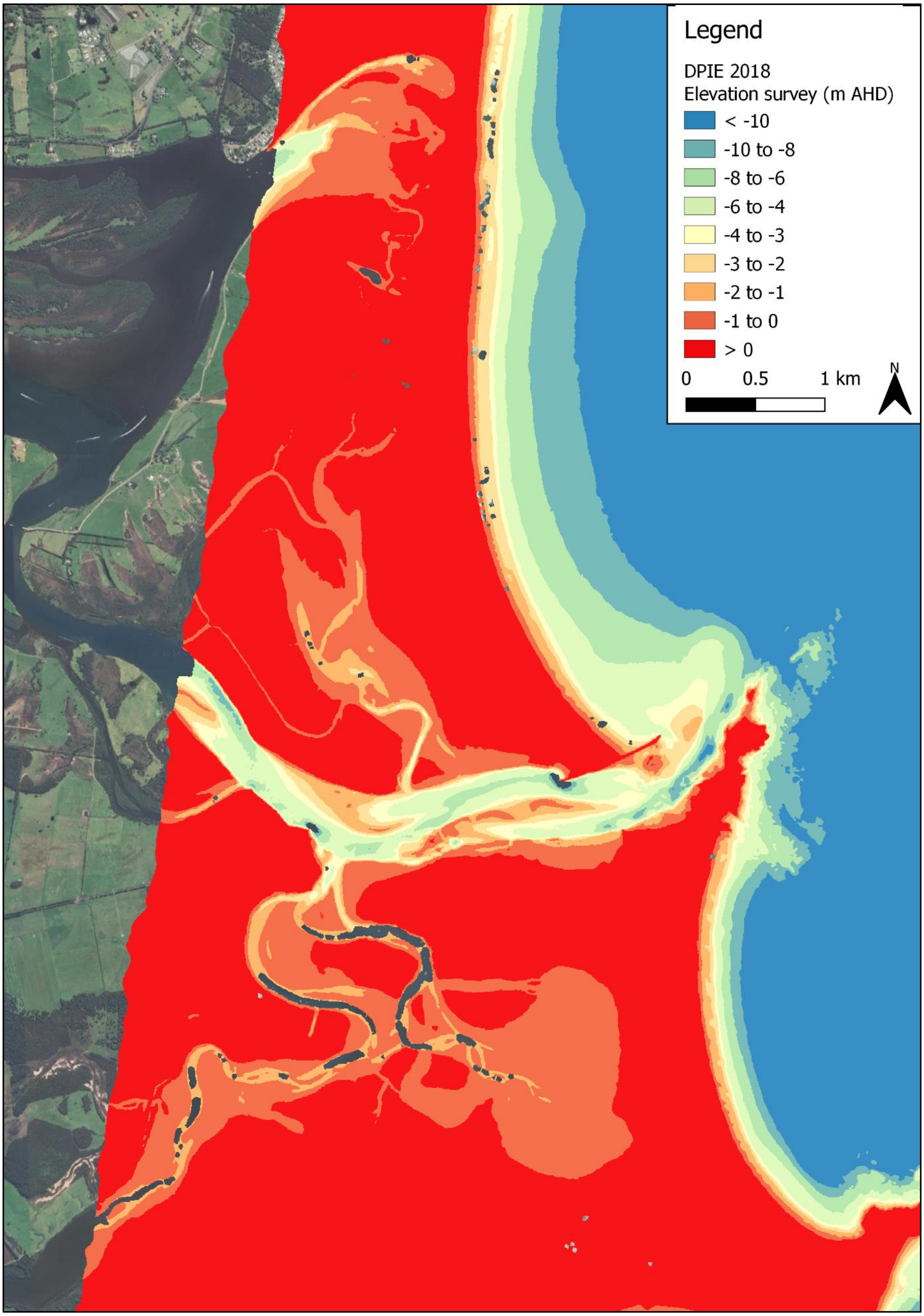

Figure 2-5 Coverage of the 2018 DPIE LiDAR survey

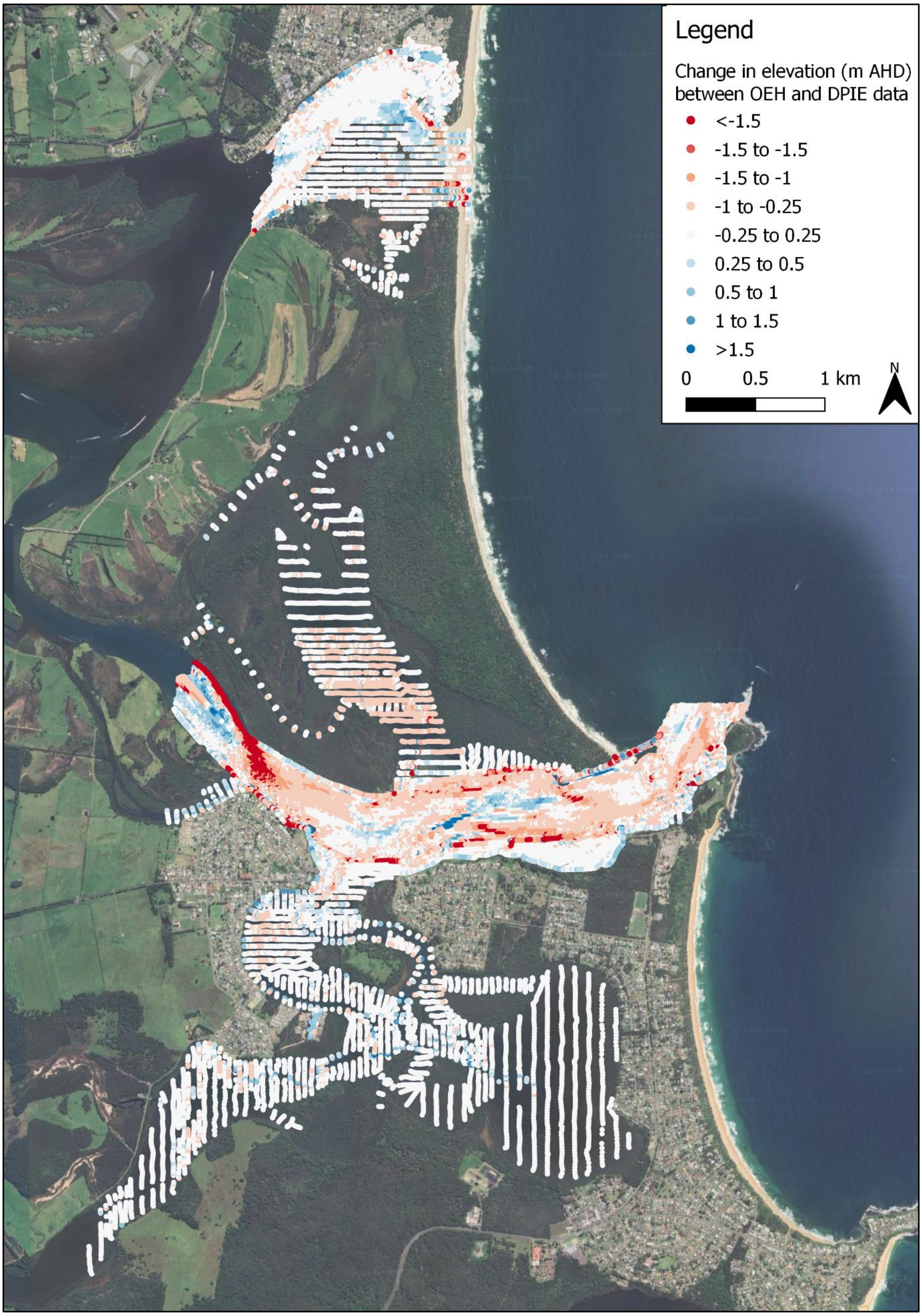

Figure 2-6 Bathymetry change between 2006 survey and 2018 marine LiDAR. Red corresponds to erosion and blue to accretion

2.6 Existing model

WRL produced an RMA hydrodynamic model of the Shoalhaven River as part of the floodplain prioritisation study (Rayner et al., 2023). This model was previously used and developed by Deiber et al. (2021) and Miller et al. (2006). Parts of this model mesh were used, with significant refinements to support the addition of the water quality component required for this project.

3 Field data collection

3.1 Preamble

A data collection campaign was completed on 11 and 12 May 2023 by Margot Mason and Alice Harrison. During this period, Shoalhaven Heads was open, however, fairly shoaled and hence did not allow much flow in and out of the heads (see Figure 3-1 for image shortly after this time). Field data collection included:

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

Figure 3-1 Shoalhaven Heads at low tide on 30 May 2023 from NearMap

3.2 Weather and tides

Data collection on the Shoalhaven River was undertaken on both ebb and flood tides. Tides during the field investigations were similar on both days, with tidal ranges between approximately -0.3 to 0.3 m AHD at Greenwell Point. The observed water levels at Greenwell Point, alongside the timing of key fieldwork components is shown in Figure 3-2. Predicted and observed tides at the nearby MHL ocean tide station at Jervis Bay (the source of the driving tides for the model) and Crookhaven Heads are shown in Figure 3-3. These tides change from a positive to negative anomaly over the week due to increasing barometric pressure (MHL, 2023a).

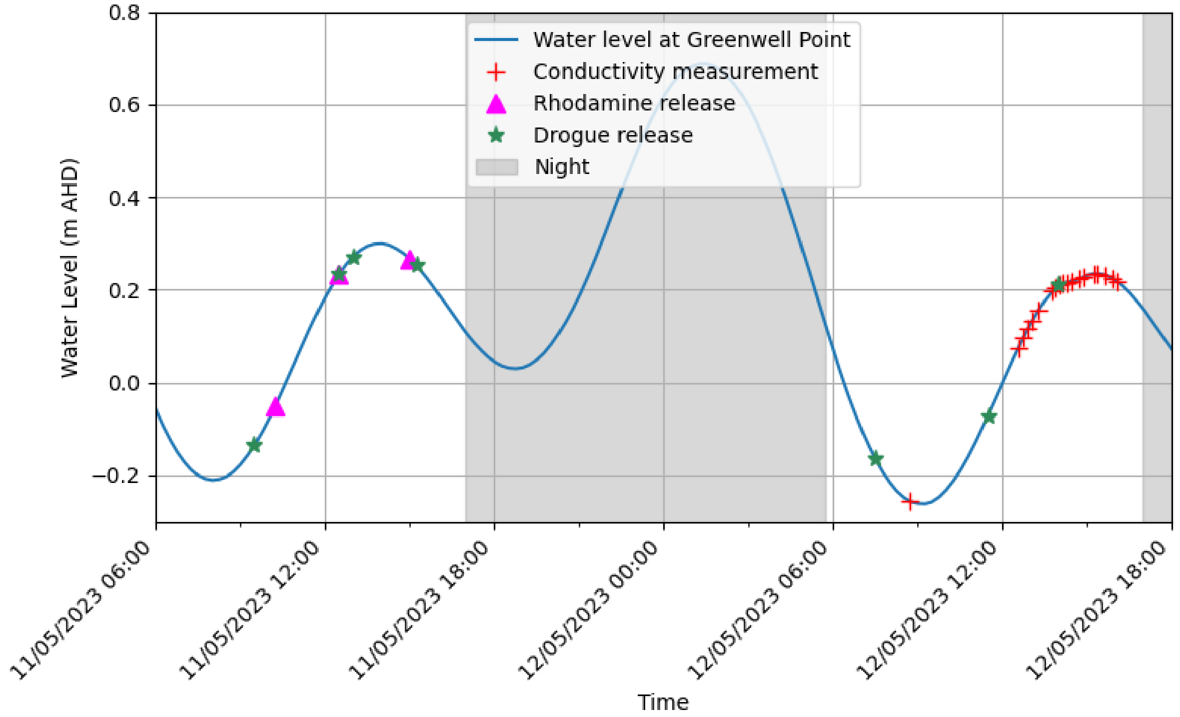

Figure 3-2 Measured tides at Greenwell Point and timing of key data collection events

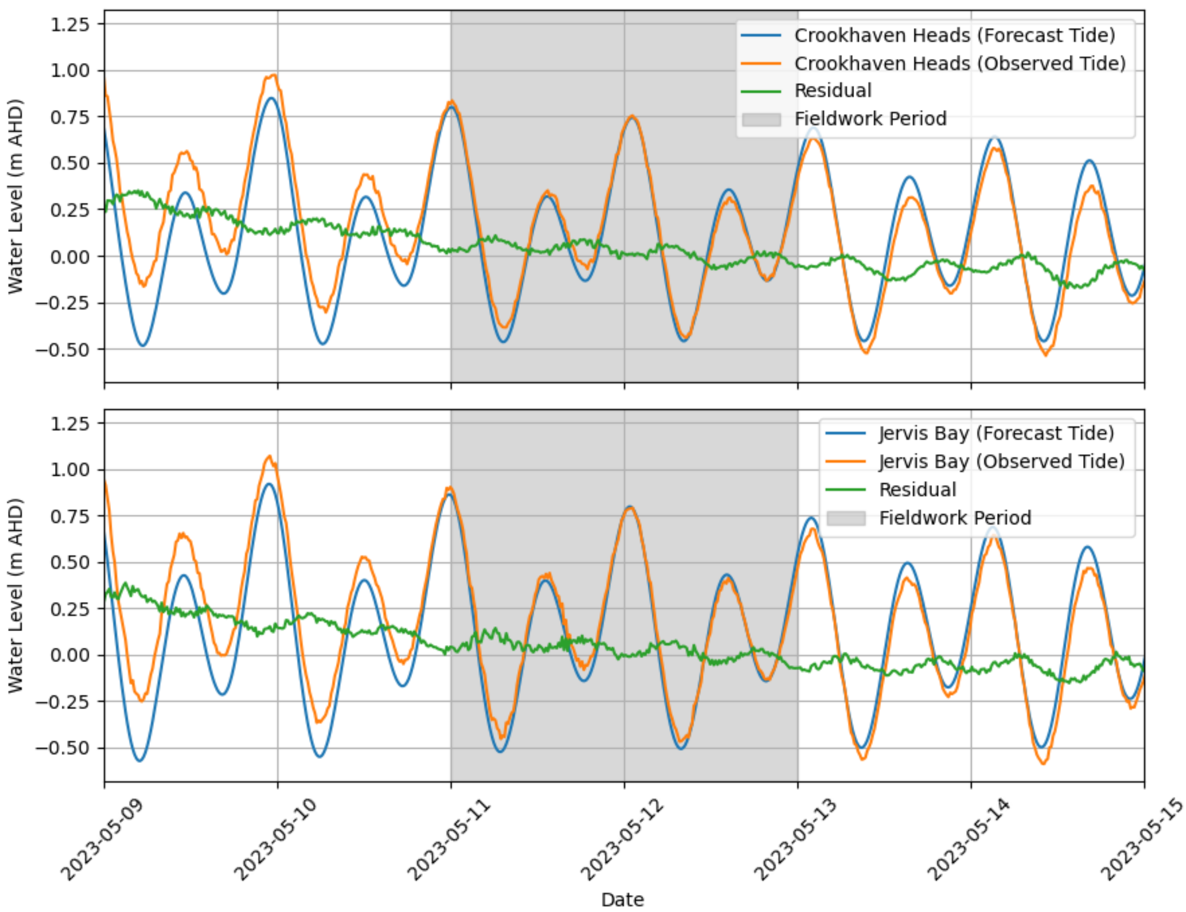

Figure 3-3 Forecast and observed tides at Crookhaven Heads (upper) and Jervis Bay (lower)

While no rain fell on the two fieldwork days, 14.8 mm of rain fell on 8 May, the only rainfall in the preceding week (BOM station 68080, refer to Figure 3-4). As can be seen in Figure 3-4, freshwater inflows from the upstream catchments were moderate (between median and 80th percentile flows at the WaterNSW gauges upstream of Shoalhaven River estuary, discussed in Section 2.3). Wind speeds were between 10 to 20 km/hr both days and swung around from the north-west in the morning to the east in the afternoon on both days.

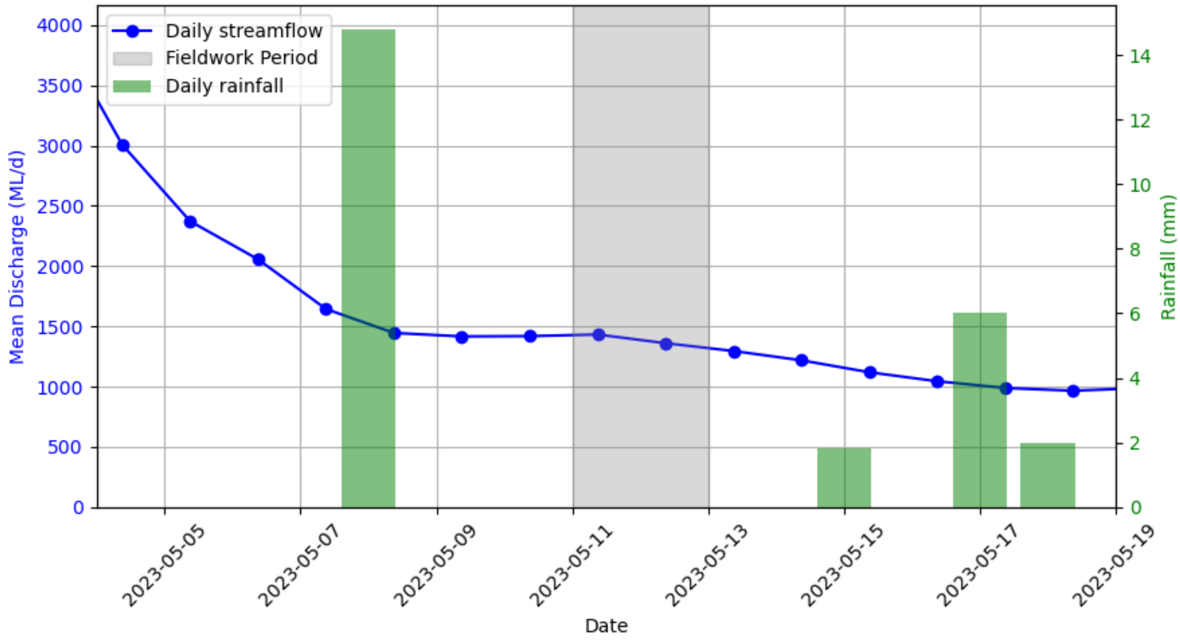

Figure 3-4 Rainfall recorded at Greenwell Point and streamflow recorded at the Shoalhaven River at Grassy Gully for the period surrounding fieldwork

3.3 Rhodamine WT dye releases

To simulate pollutant advection and dispersion in the Shoalhaven River estuary, three Rhodamine WT dye releases were performed on the first day of the field campaign (refer to WRL TR2023/32 Section 4.4 for methods). These are summarised in Table 3-1, with locations shown in Figure 3-5. The initial release concentration was 200,000,000 ppb in all instances.

Table 3-1 Summary of dye releases

No.	Date	Time released	Tracked until	Volume of dye released (mL)	Location	Tide
1	11/05/2023	10:09	11:24	500	Orient Point	Flood
2	11/05/2023	12:25	13:54	500	Berrys Canal	Flood
3	11/05/2023	15:01	16:21	500	Greenwell Point	Slack high tide

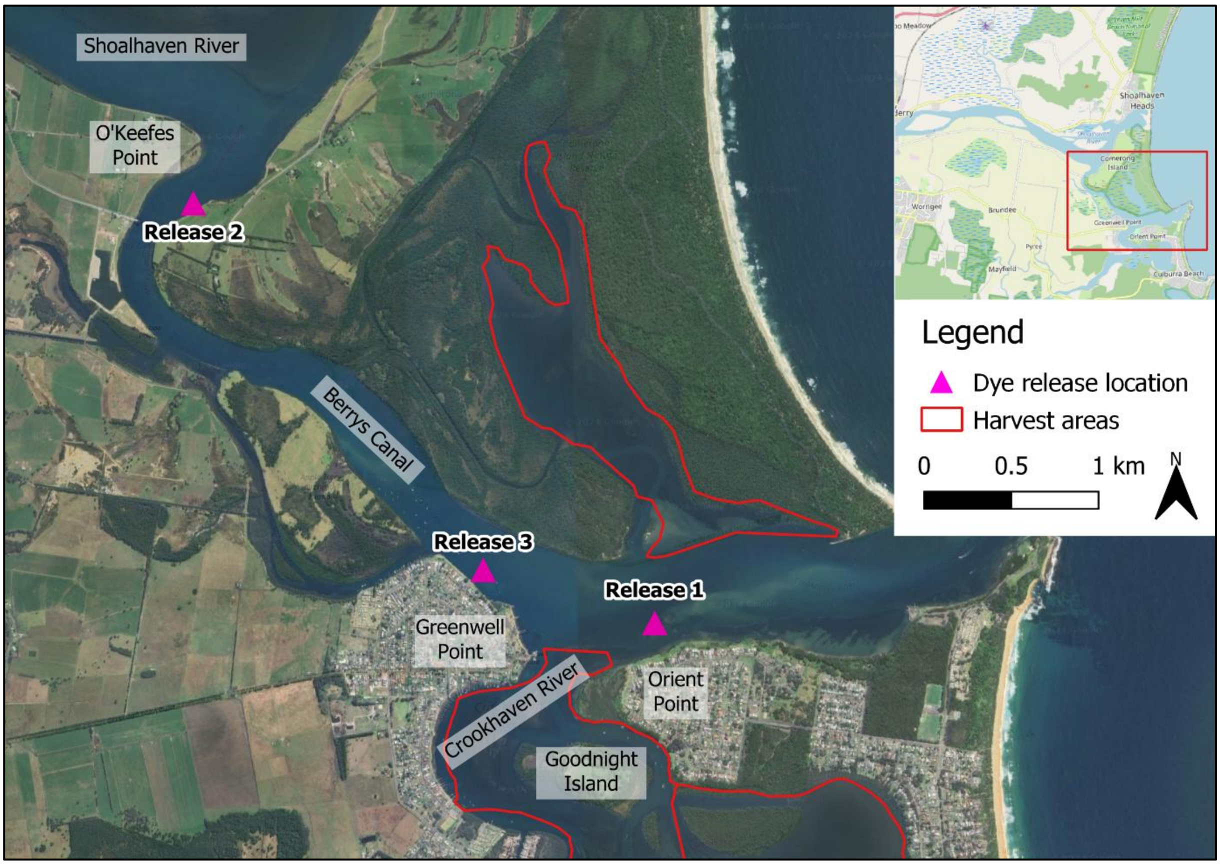

Figure 3-5 Rhodamine WT dye release locations

3.3.1 Release 1 – Orient Point

Dye release 1 was completed off Orient Point, just upstream of the large rocky reef found in the main channel to Crookhaven Heads (see Figure 3-5). This release was completed to understand the transport of pollutants from the main channel at Crookhaven Heads into the Crookhaven River. The release occurred on an incoming tide, soon after low tide. The dye was released at 10.09am, and was tracked for an hour and fifteen minutes. Figure 3-7 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

Initially, the plume moved upstream quickly, without significant lateral spreading (plume stayed within 30 to 50 m in width), however rapid decreases in peak concentrations were observed. As the plume reached the entrance to the Crookhaven River, 20 to 30 minutes after the release, significant lateral spreading occurred. A depth profile was completed here, finding most of the dye in the top metre of the water column, with some dye found down to the third metre (as can be seen in Figure 3-6, noting that concentrations below ~0.4 ppb are background concentrations). The plume was followed into the Crookhaven River, however, 35 to 40 minutes after the release, a brief search for the plume was completed in the main channel towards Berrys Canal. While the plume was not found, it is suspected that some dye still went into this channel, but was missed due to time spent in the Crookhaven River.

The plume was then tracked into the Crookhaven River, towards the Goodnight Island harvest area. In the Crookhaven River, the dye was tracked into the channel along the left bank near the Greenwell Point township. The plume was not able to be tracked into the shallow oyster leases, however, it was assumed that the plume spread significantly across the leases in this harvest area based on the observations available.

A second fixed fluorometer was located at a fixed point in shallow water at the Crookhaven River entrance. The peak concentration was observed here 50 minutes after the release, later than the boat based tracking in this area. This may be due to the shape of the plume, with the tail being more in the centre of the channel, closer to the fixed fluorometer. It was assumed that some of the dye followed the main channel (along the right bank) into Crookhaven River (shown as a dashed arrow on Figure 3-7), however no monitoring was completed in this location. Tracking was stopped 75 minutes after the release, with concentrations of around 0.8 ppb still found in the Crookhaven River near the Goodnight Island Harvest area.

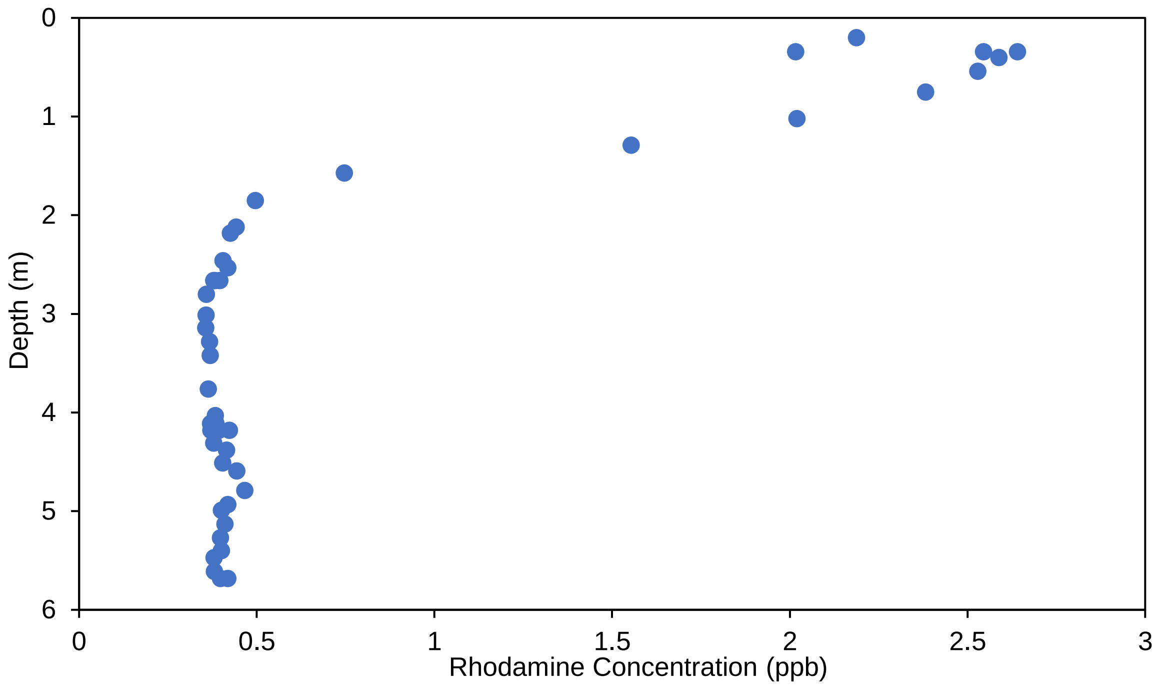

Figure 3-6 Vertical profile taken 26 minutes after dye release 1

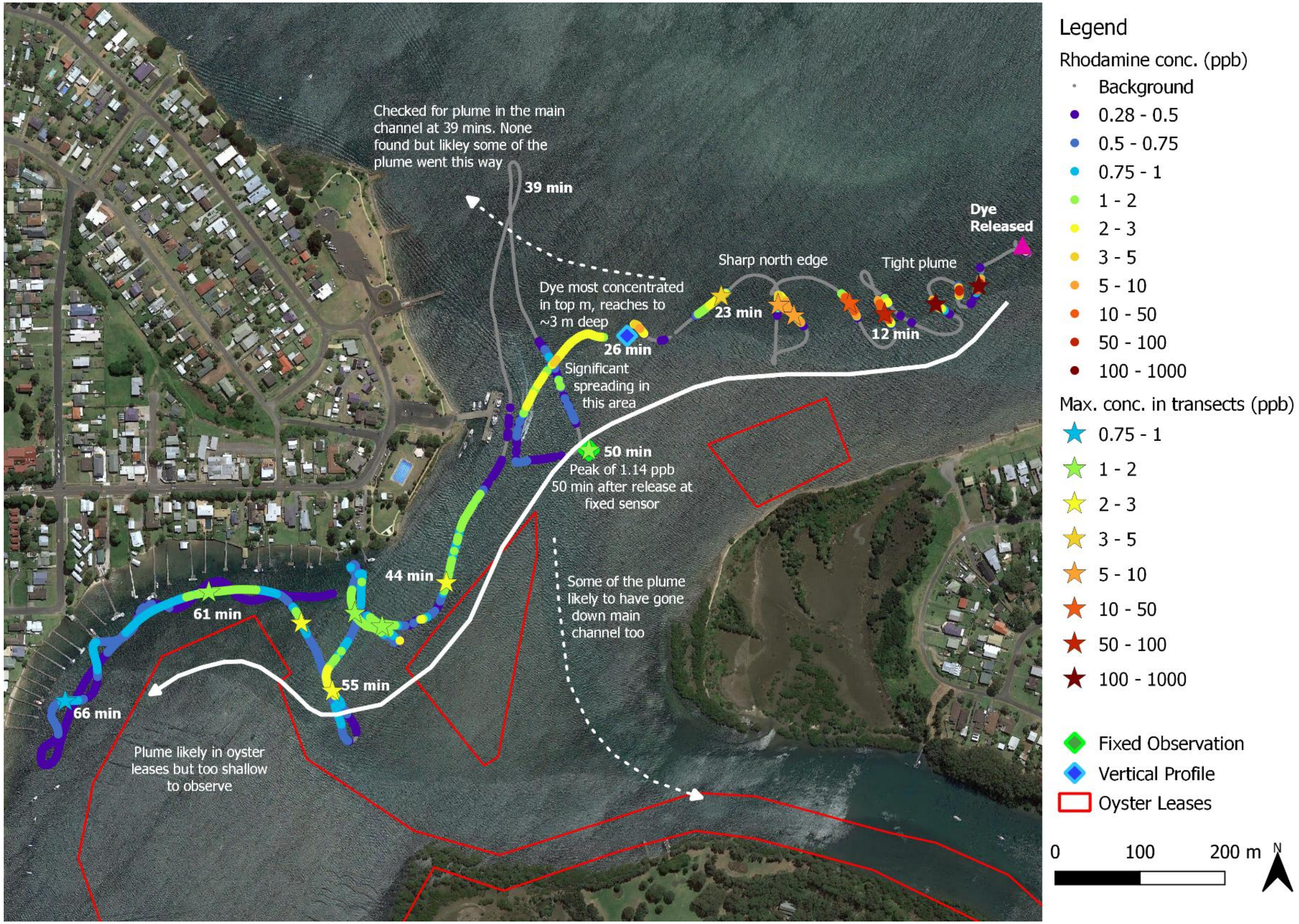

Figure 3-7 Dye release 1 at Orient Point. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)

3.3.2 Release 2 – Berrys Canal

Dye release 2 was conducted along the left bank of Berrys Canal immediately downstream of the confluence with the Shoalhaven River. This release was conducted to observe the transport of pollutants near the confluence of the Shoalhaven River, Berrys Canal, and the channel to Shoalhaven Heads. The release occurred at 12.25pm, around the time of the peak incoming tide, and dye was tracked for an hour and a half. Figure 3-10 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

The dye stayed in a relatively tight plume (<100 m wide) until reaching the Shoalhaven River, 15 to 20 minutes after the dye was released. A depth profile completed 10 minutes after the release found that similar to release 1, most of the dye was found in the top metre, however the plume persisted down to around 2 m deep (see Figure 3-8). As the plume rounded O'Keefes Point, the plume had a sharp edge along the right bank and a diffuse edge along the left bank. In the Shoalhaven River, the plume continued to dissipate as it advected downstream. From around 35 minutes until tracking ceased, the plume remained about 150 m wide. Approximately 48 minutes after the release, a vertical profile observed that the dye was spread fairly evenly through the water column indicating it had become vertically well mixed in approximately 3 m water depth (Figure 3-9). At 60 to 65 minutes, three transects were conducted in front of the plume, which then reached this location at 66 minutes, approximately 1.75 km upstream of the release location. As the plume moved further upstream, multiple peaks were observed across the channel. Tracking was ceased approximately 90 minutes after the dye release.

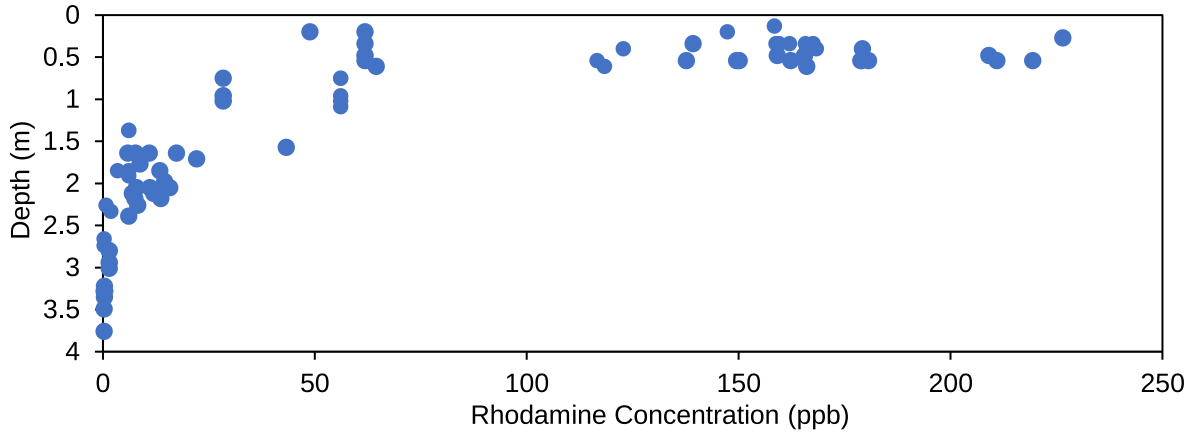

Figure 3-8 Vertical profile conducted 10 minutes after dye release 2

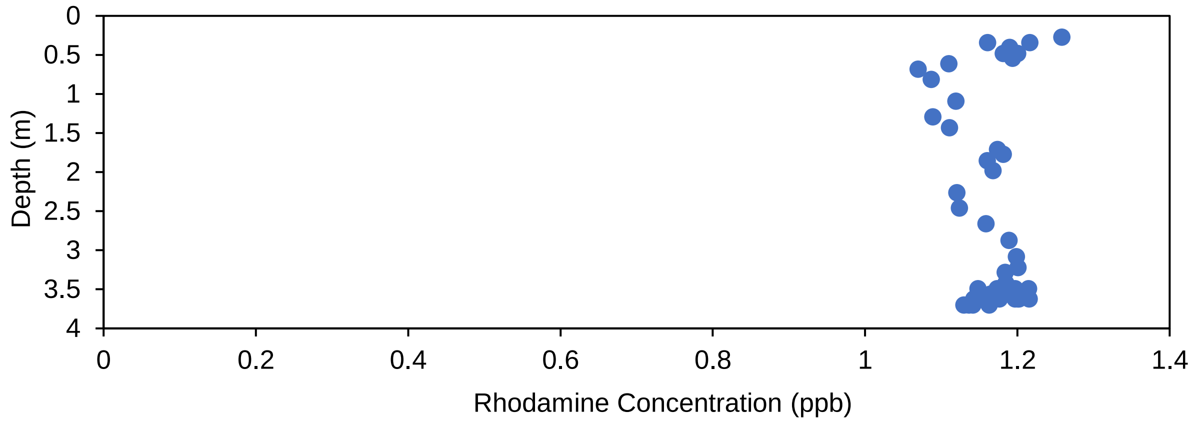

Figure 3-9 Vertical profile conducted 48 minutes after dye release 2

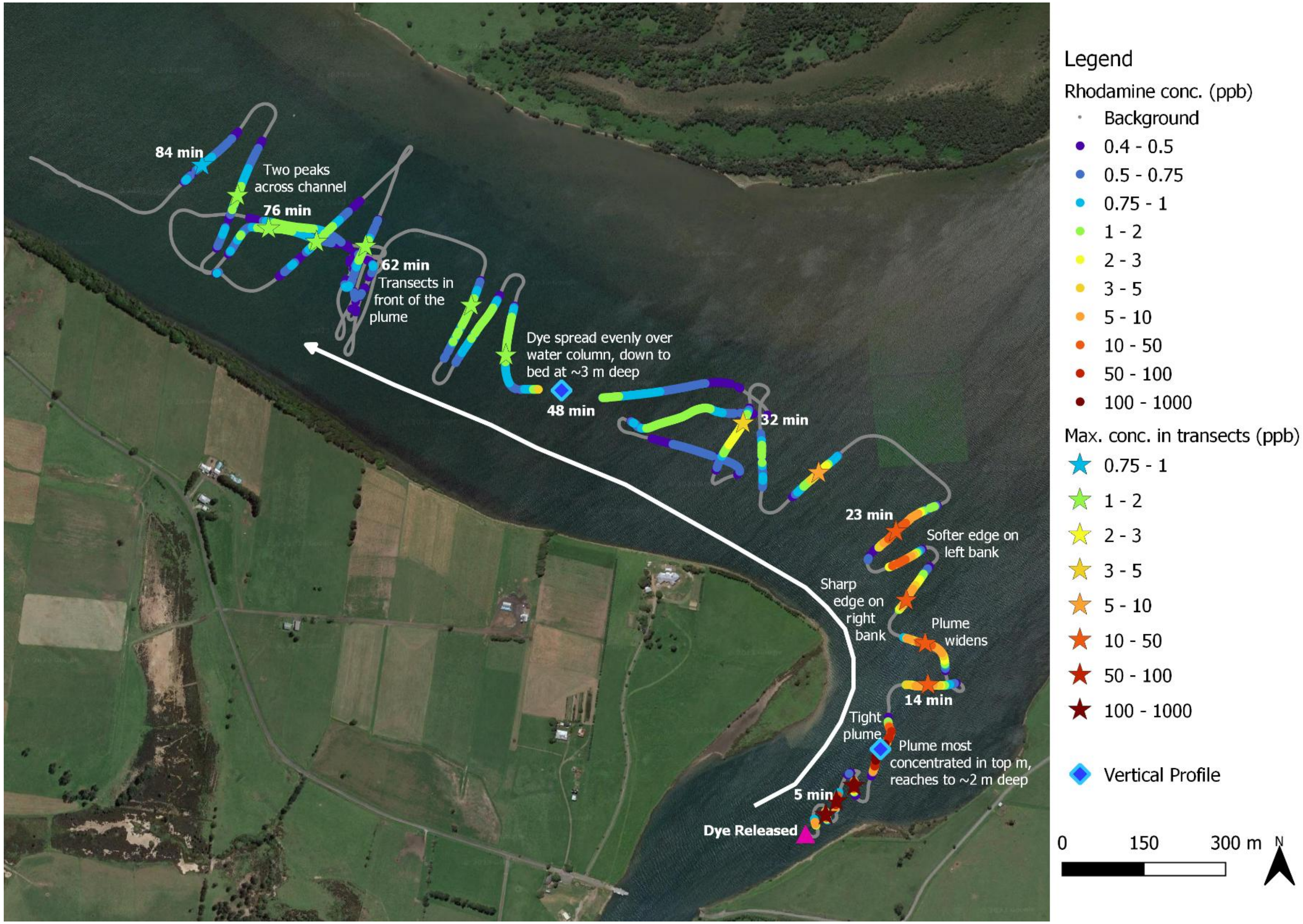

Figure 3-10 Dye release 2 in Berrys Canal. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)

3.3.3 Release 3 – Greenwell Point

Dye release 3 was completed off Greenwell Point, in Berrys Canal, immediately upstream of the entrance to the Crookhaven River near slack tide. This release was conducted to determine the transport of pollutants around Crookhaven River and Comerong Bay from Berrys Canal. The dye was released at 3.01pm, with the tide still incoming. Around 30 minutes after the release, the tide changed and the release was then carried downstream. Figure 3-11 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

The dye travelled upstream for around 15 minutes before slack tide. This release advected and diffused slower than the first two releases, due to the slow moving currents. Concentrations of above 100 ppb were observed up to 24 minutes after the release. Over the change of the tide, which occurred approximately 20 to 40 minutes after the release, the plume remained largely in the same area, in a roughly circular shape, with a diameter of approximately 50 m and peak concentrations of around 50 ppb. Vertical profiles conducted 14 and 37 minutes after the release found that dye was concentrated in the upper 1.5 m of the water column. As the tide began to flow out, the plume moved towards the northern (left) bank, where water was shallower. As the dye moved downstream the plume elongated and peak concentrations decreased more rapidly. The northern side of the plume maintained a sharp edge until it reached the left bank at around 70 minutes after the release. On the southern side of the plume, secondary peaks occurred, and the boundary was much more diffuse. Tracking ceased at 80 minutes after the release.

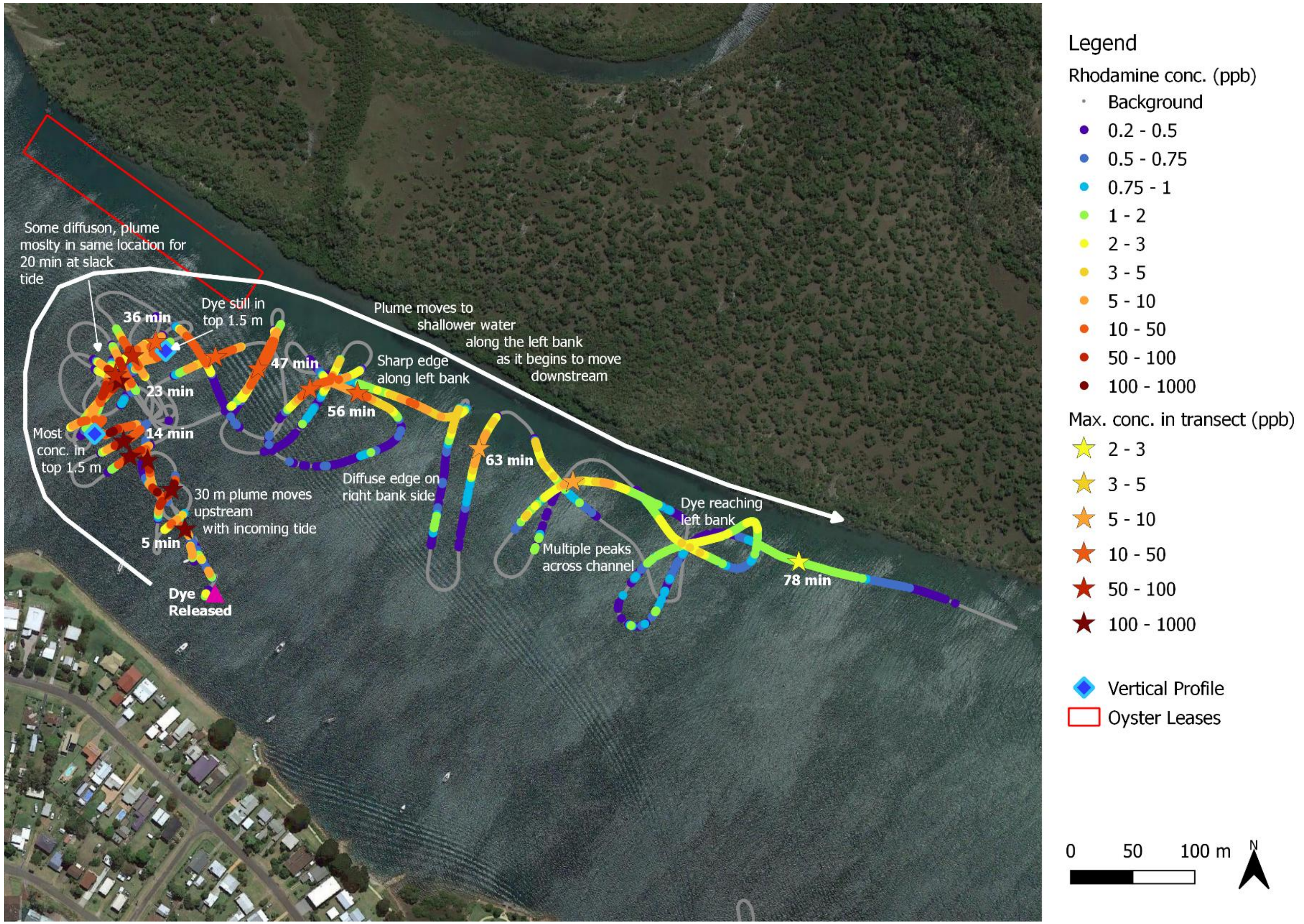

Figure 3-11 Dye release 3 of Greenwell Point. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)

3.3.4 Field derived dispersion values

Field dye experiments were used to obtain estimates of plume spreading dispersion rates in the Shoalhaven River 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 3-12.

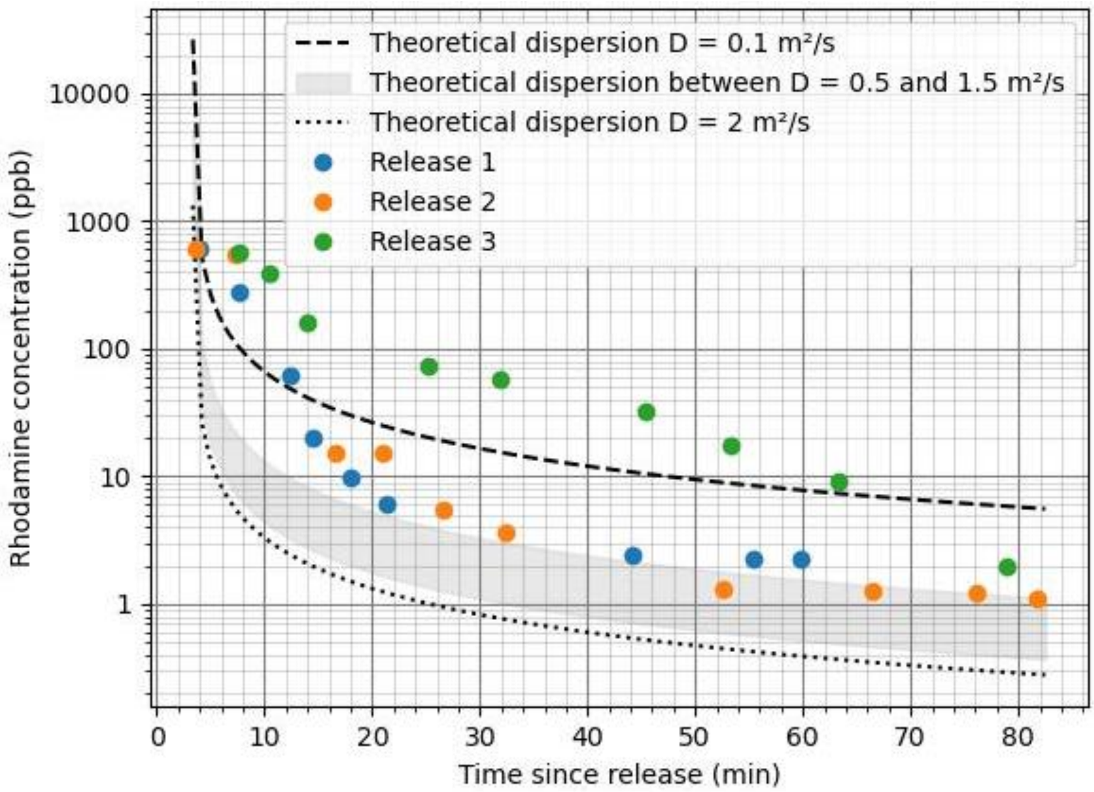

Figure 3-12 Peak concentration of select transects plotted against theoretical dispersion

Measurements of field dispersion across the state for this project showed dispersion was spatially and temporally variable typically between D = 0.1 and 2 m^2/s, with the most common range being 0.5 to 1.5 m^2/s. For the Shoalhaven River, when comparing the observed peak observations to theoretical dispersion, field dispersion values for release 1 and 2 are around 0.5 m^2/s. For release 3, the low dispersion values of <0.1 m^2/s early in the experiment may be attributed to the slow movement and low turbulence conditions during slack tide (refer to Section 3.3.3). Dispersion rates increased as the tide began to ebb, and the plume began to move faster.

These dispersion values were generally lower than in other estuaries measured in this project. However, due to the high levels of variability and uncertainty in dispersion (demonstrated by the fieldwork), a standardised approach was used in modelling dispersion across all estuaries as discussed in WRL TR2023/32 Section 7.4.6. The results of dye dispersion across all estuaries can be found in WRL TR2023/32 Section 7.3.

3.4 GPS drifter drogue releases

To monitor surface current speeds and flow paths in the Shoalhaven River 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). Drogues were released during dye releases 2 and 3 to aid plume tracking, and four additional drogue releases and retrievals were completed at various stages of the tide (refer to Table 3-2 for details of each drogue release). The GPS locations of the drogues, along with the time since release for the releases that were not in conjunction with dye are shown in Appendix A1, and a brief discussion regarding the observations is provided in this section.

Table 3-2 Summary of drogue releases

Release number	Date	Time	Tide	Duration (h:mm)	Location	Comments
Day 1 Drop 1	11/05/2023	9.34am	Flood	2:15	Crookhaven Heads	-
Day 1 Drop 2	11/05/2023	12.29pm	Flood	1:25	Berrys Canal	Released in conjunction with dye release 2
Day 1 Drop 3	11/05/2023	3.03pm	Slack high	1:32	Greenwell Point	Released in conjunction with dye release 3
Day 2 Drop 1	12/05/2023	7.32am	Ebb	3:41	Shoalhaven River	-
Day 2 Drop 2	12/05/2023	11.28am	Flood	1:14	Crookhaven Heads	-
Day 2 Drop 3	12/05/2023	1.55pm	Flood	1:04	Crookhaven Heads	-

Drogues were released near Crookhaven Heads on an incoming tide on multiple occasions. When released upstream of Crookhaven Heads, drogues went into Comerong Bay, Berrys Canal and the Crookhaven River, depending on the location in the channel and the period in the tidal cycle. Figure 3-13 shows the path of drogues from the three releases in this location, highlighting that minor differences in initial location change the destination of the drogue. This demonstrates the capacity for spreading of pollutants across the multiple channels in the lower Shoalhaven River system. It is also suspected that transport is more likely into Comerong Bay and Crookhaven River in the earlier part of the incoming tide, while transport is more likely into Berrys Canal later, as the tide changes slightly later in Berrys Canal. More details of these drogue releases can be found in Appendix A1.

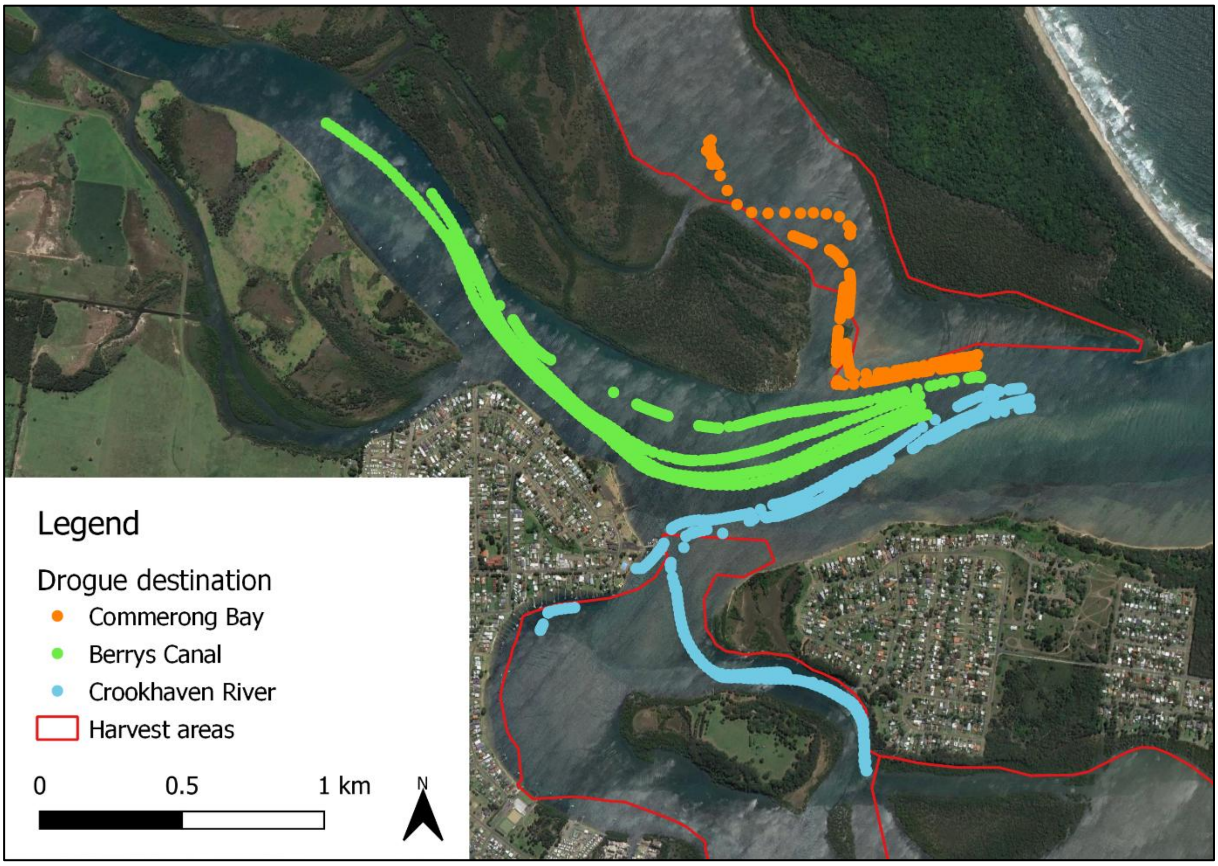

Figure 3-13 All Crookhaven Heads drogue drops, coloured by final destination

At some locations, oranges were used as manual drogues on the second day of data collection (12/05/23). The oranges were labelled, and three to seven oranges were dropped at a location, which was recorded with GPS. The time and coordinates of the oranges were recorded at future points. Results of two drops at the Shoalhaven Heads (Figure A-5) showed movement towards the heads on an incoming tide in the main bay, and no movement in the northern channel to the heads. This movement indicates that most of the tidal prism filling the area around Berrys Bay and Shoalhaven Heads is coming through Crookhaven Heads via Berrys Canal, rather than through Shoalhaven Heads.

In the Crookhaven River, two separate drops occurred (Figure A-6). Seven oranges placed in the main channel stayed relatively close together (approximately 60 m) despite travelling around 1 km over an hour. This may indicate lower dispersion in the Crookhaven River, which is subjected to lower velocities than the larger Shoalhaven River system.

3.5 Water level monitoring

To supplement the water level data available from the five long term MHL water level gauges on the Shoalhaven River estuary, one water level logger was installed during the 2023 fieldwork, in Comerong Bay (refer to Figure 3-14). The plots of the water level data can be seen alongside the model results in Appendix B1.7.

Figure 3-14 Location of water level monitoring during 2023 fieldwork

3.6 Conductivity measurements

Conductivity profiles were taken during the fieldwork campaign with a Sontek EXO3, as detailed in WRL TR2023/32 Section 4.7. Conductivity profiles were recorded in various locations on the second day of field monitoring, mainly on the incoming tide. These profiles provide insight into whether there is density stratification throughout the water column (water increases in density throughout the water column). Salinity stratification (distinguished as a difference of more than 10,000 µS/cm across the water column) was observed in Berrys Canal as the tide peaked and started to flow out, however, it was not observed on the rising tide. The lowest salinity observed was near Shoalhaven Heads, which indicates that it has a lesser exchange with the main river on an incoming tide. Figure 3-15 shows the timing of conductivity profiles, while Figure 3-17 shows locations and Figure 3-16 plots some sample profiles for both stratified and unstratified locations.

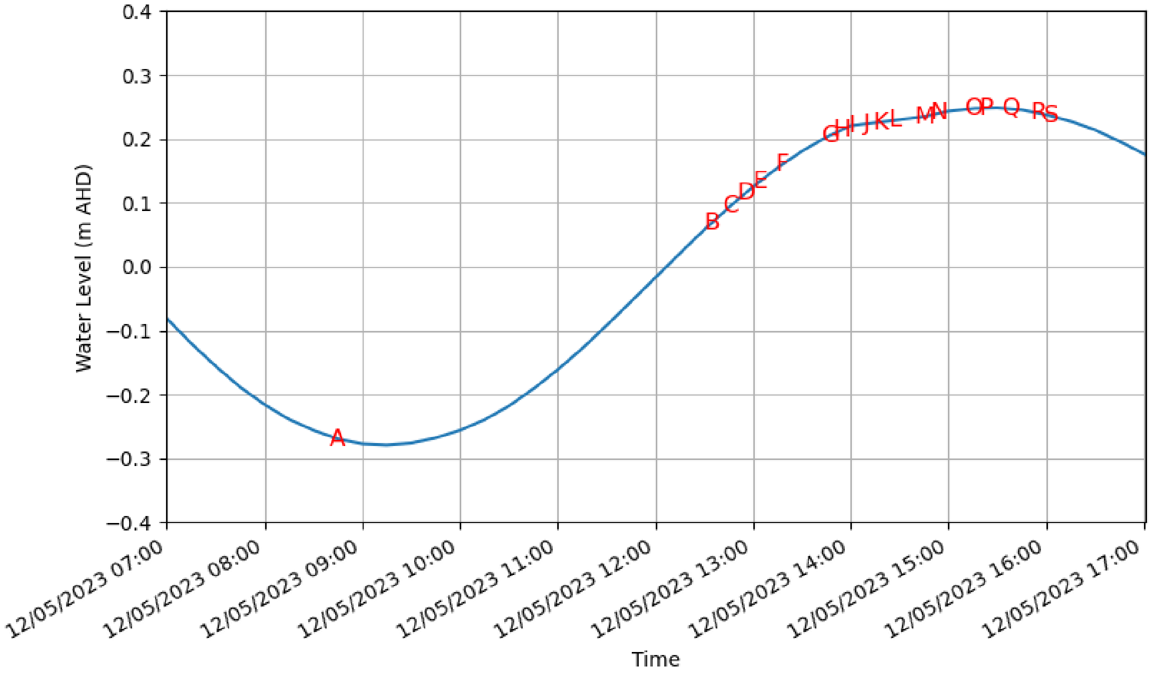

Figure 3-15 Timing of conductivity profiles (labelled with letters) relative to the tide at Greenwell Point

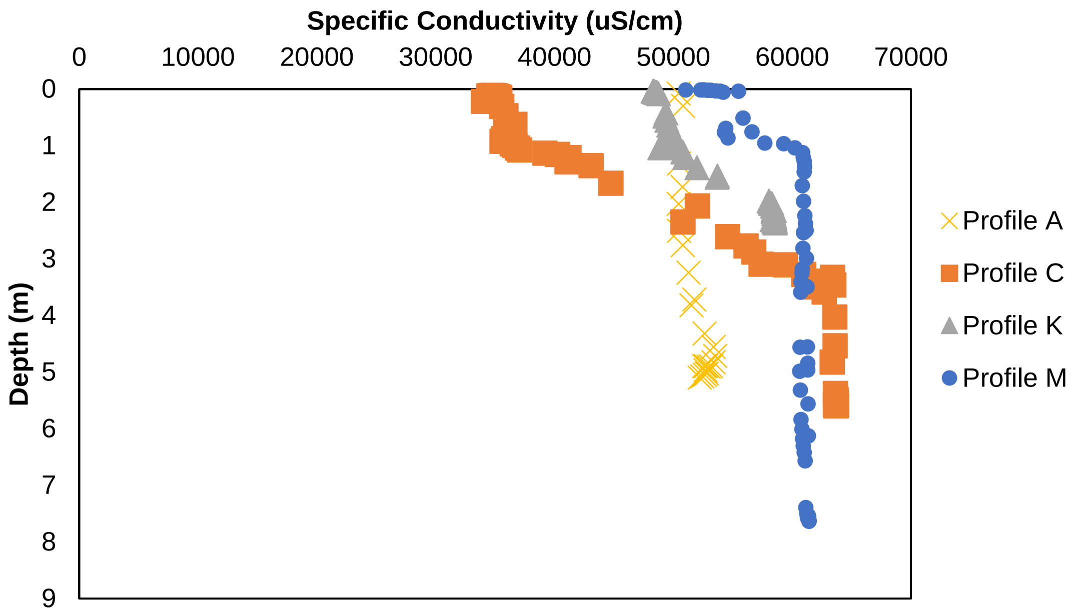

Figure 3-16 Conductivity profiles at select locations labelled with letters corresponding to timing on Figure 3-15

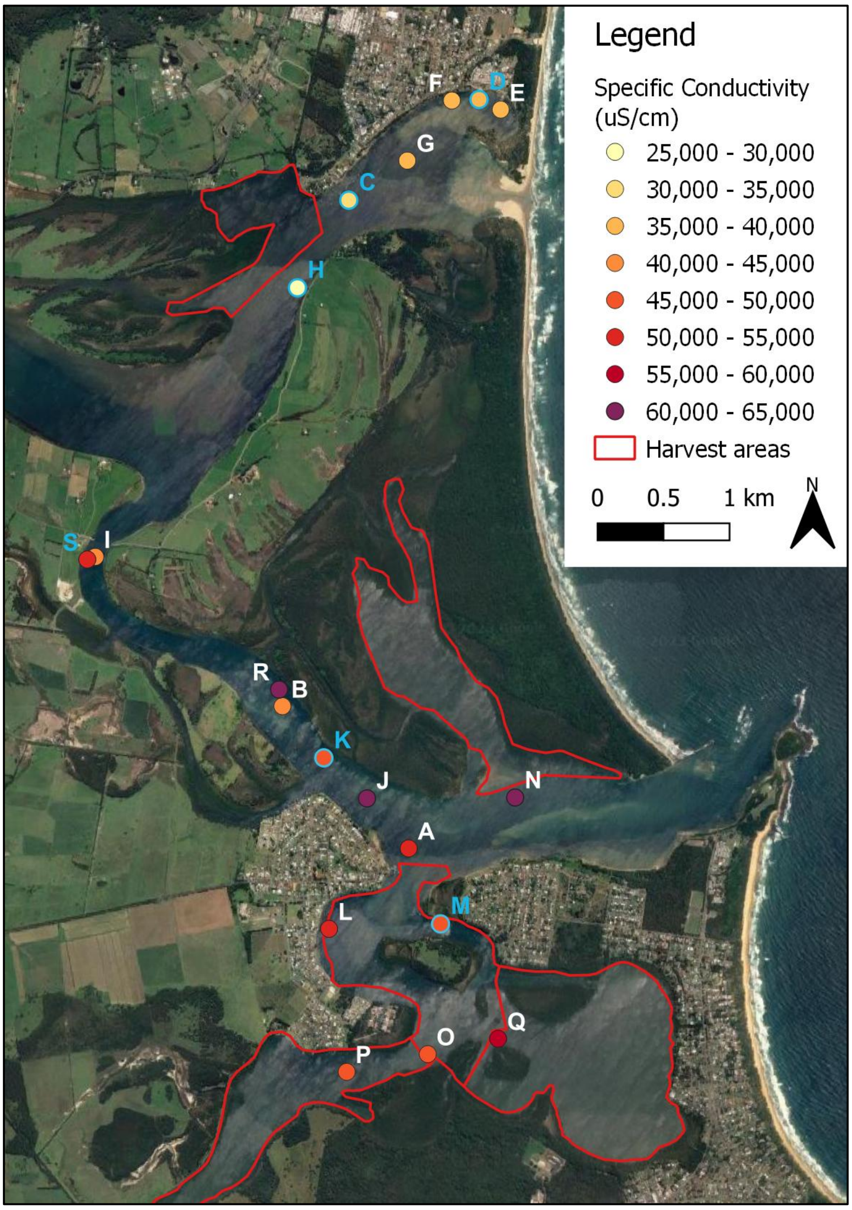

Figure 3-17 Conductivity measurements labelled with letters corresponding to timing on Figure 3-15. Letters in blue show locations which had stratification of at least 10,000 uS/cm, while colour shows surface conductivity (for stratified locations) or average conductivity for unstratified sites

4 Model development

4.1 Preamble

The model used for this project consists of both a hydrodynamic and a water quality model. Initially, a hydrodynamic pilot model was developed which identified data gaps to be targeted during field data collection. After incorporating new data from the field, the hydrodynamic model was iteratively refined through calibration and validation based on the MHL data collection campaigns in 1993, 1996 and 2005, as well as field data collected for this project in 2023. The hydrodynamic model was then used as an input for the water quality model. This model was informed by dye release experiments and was then used to run sewage overflow scenarios. A schematic of this process can be seen in Figure 4-1. For a detailed overview of the model development used for the broader project, refer to WRL TR2023/32 Sections 6 and 7.

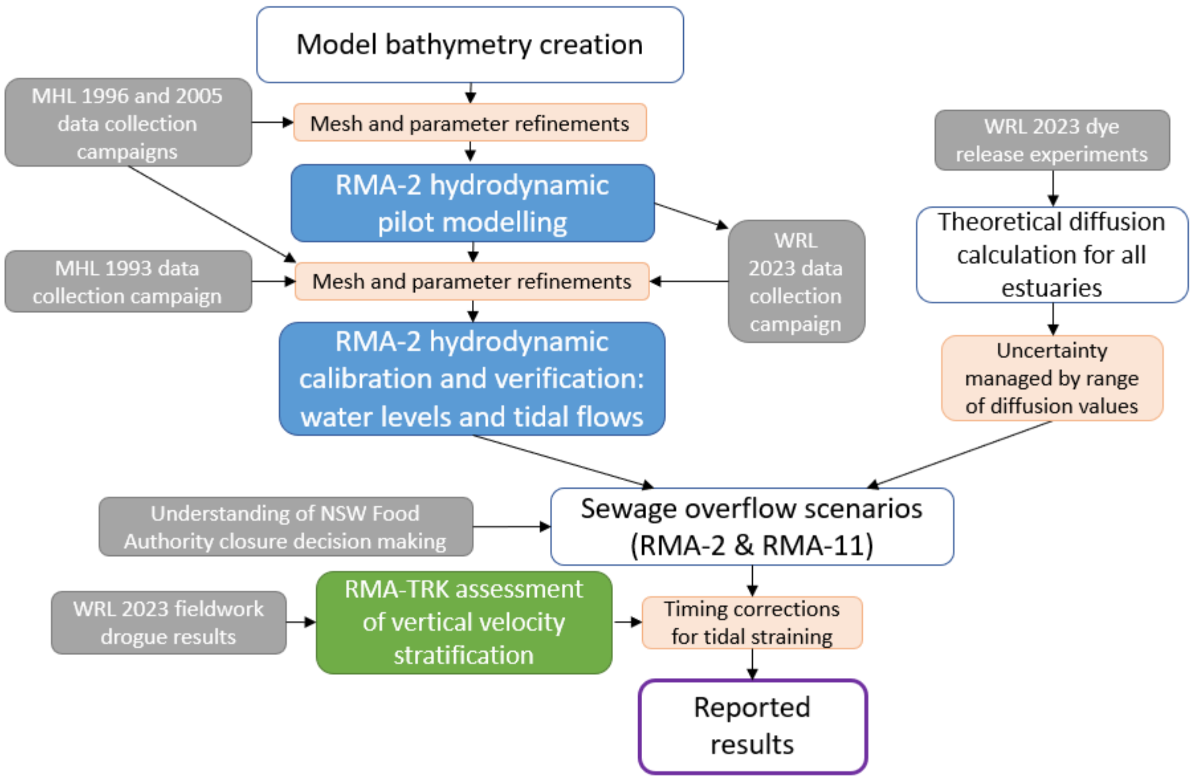

Figure 4-1 Overview of modelling approach

4.2 Model mesh development

The model domain extends from approximately 500 m offshore of the ocean entrance of the Shoalhaven River, to the tidal limits of the estuary and its major tributaries. Two meshes were used, one with Shoalhaven Heads closed, and another with an open channel and second tidal boundary at Shoalhaven Heads, see Figure 4-2 and Figure 4-3. The model mesh consists of over 15,000 elements, varying in size from 2 to over 40,000 m^2. The majority of the model has been developed in 2D (two-dimensions), however the Shoalhaven River upstream of Nowra, Broughton Creek, the upper reaches of the Crookhaven River, and several other small tributaries were modelled in 1D (one-dimension). A discussion on the impact of model dimensionality is provided in WRL TR2023/32 Section 6.2.2. Mesh resolution is highest around the overflow locations, harvest areas and entrance channel, with lower resolution upstream. Refer to WRL TR2023/32 Section 6.2.3 for a discussion of model resolution.

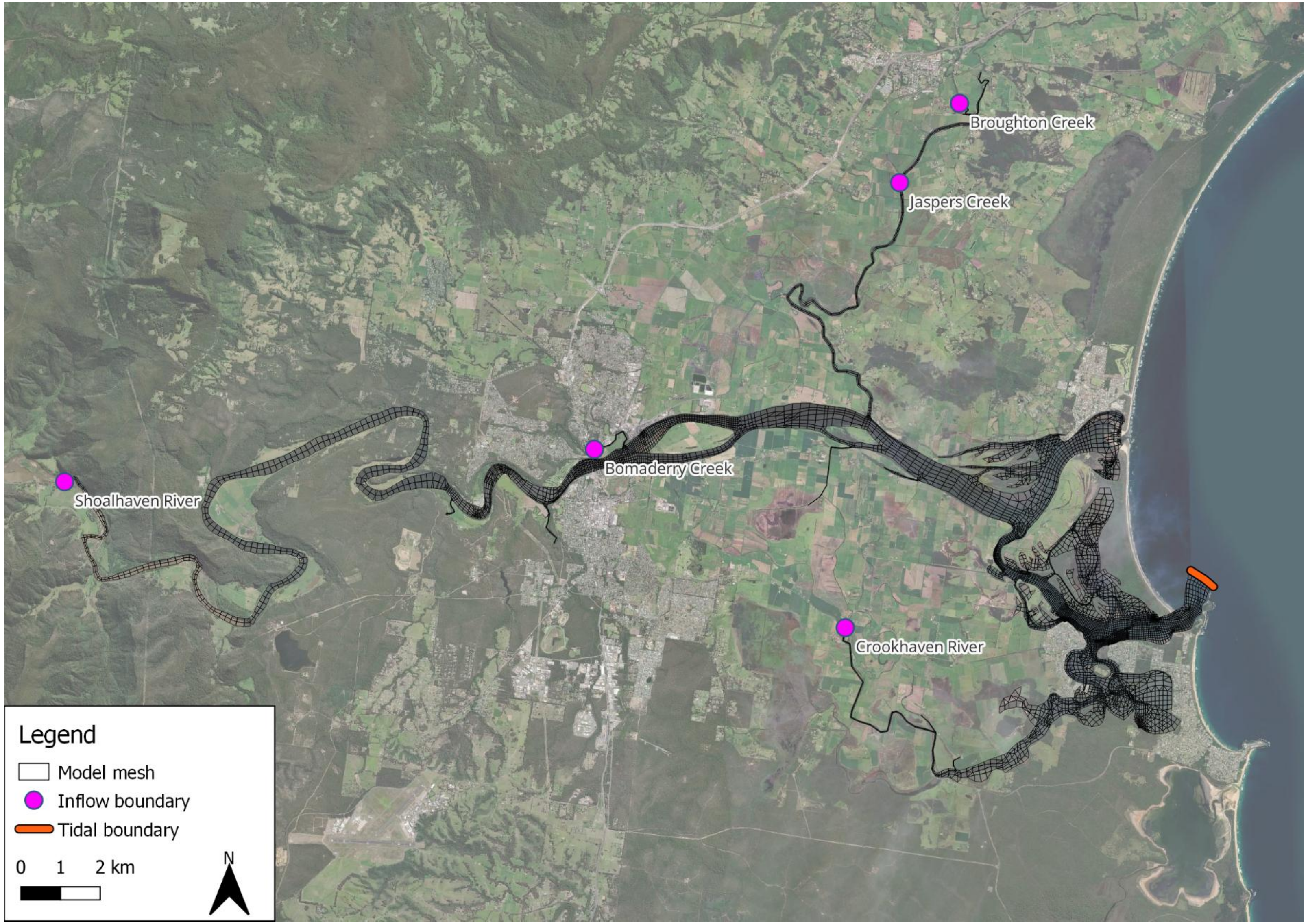

Figure 4-2 RMA model mesh with Shoalhaven Heads closed showing boundary condition locations

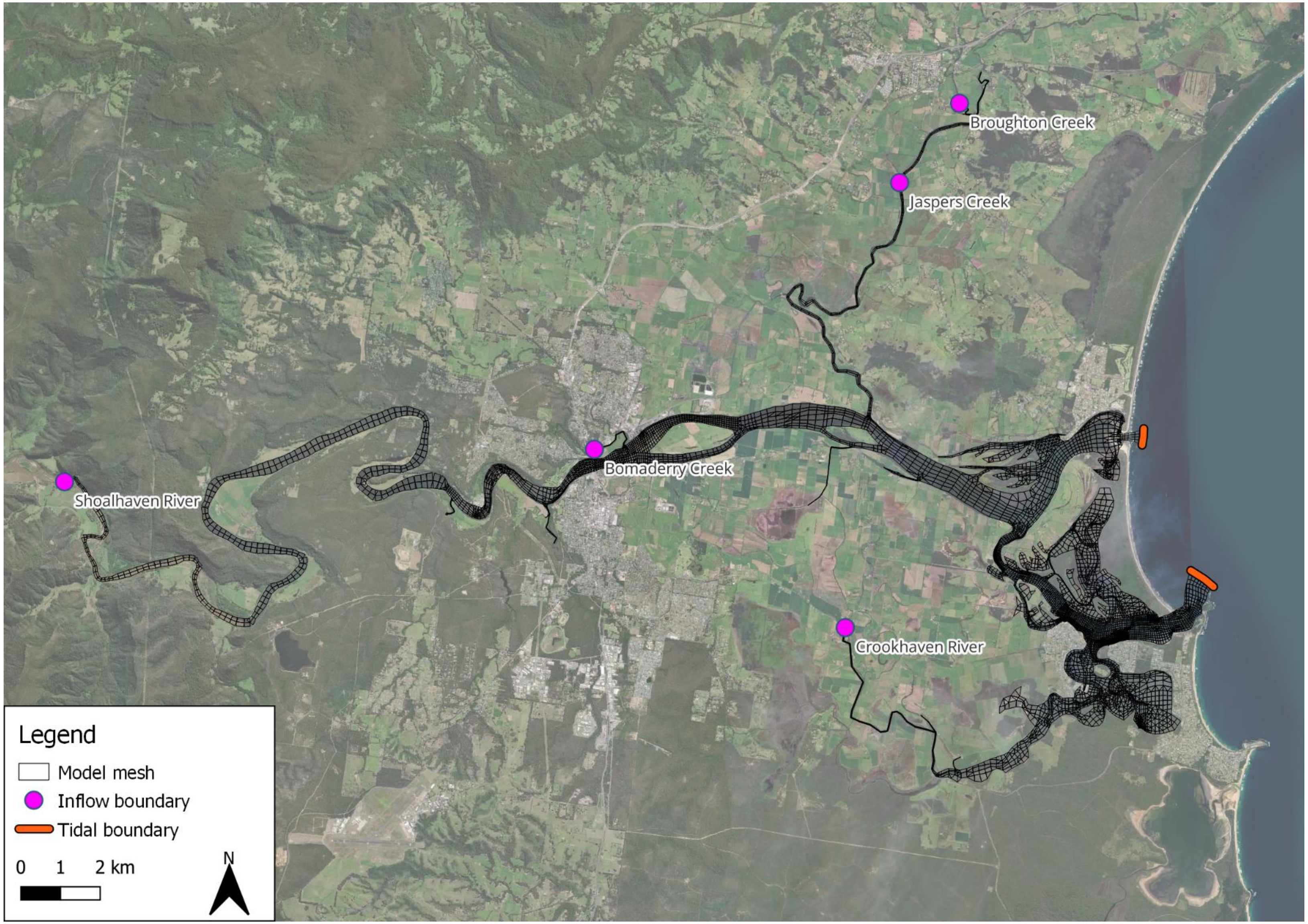

Figure 4-3 RMA model mesh with Shoalhaven Heads open showing boundary condition locations

4.3 Model bathymetry

Model bathymetry was based on the sources discussed in Section 0 and utilised point bed elevation data collected by NSW OEH in 2006. For shallower areas not covered by the OEH survey, 5 m marine LiDAR data collected by NSW DPIE in 2018 was used where available (Shoalhaven Heads, Comerong Bay, and most of Crookhaven Creek). In shallow areas not covered by the marine LiDAR, the 2011 1 m terrestrial LiDAR available from NSW Spatial Services was used, excluding areas below water level in the survey. The model bathymetry and nodal bed elevations is shown in Figure 4-5. The river reaches depths of greater than -15 m AHD around bends, however the majority of the river is around -6 to -3 m AHD. In all three sources of bathymetric data, the Shoalhaven Heads were closed, hence, for the model mesh with Shoalhaven Heads open, a mesh with a channel at a depth of -1.5 m AHD and 175 m wide was constructed based on aerial imagery, as can be seen in Figure 4-4.

The one dimensional sections of the model were modelled as trapeziums with the top width as river width and side slope and depth chosen to best match the flow area at mid tide, calculated from surveyed cross sections available from the OEH survey.

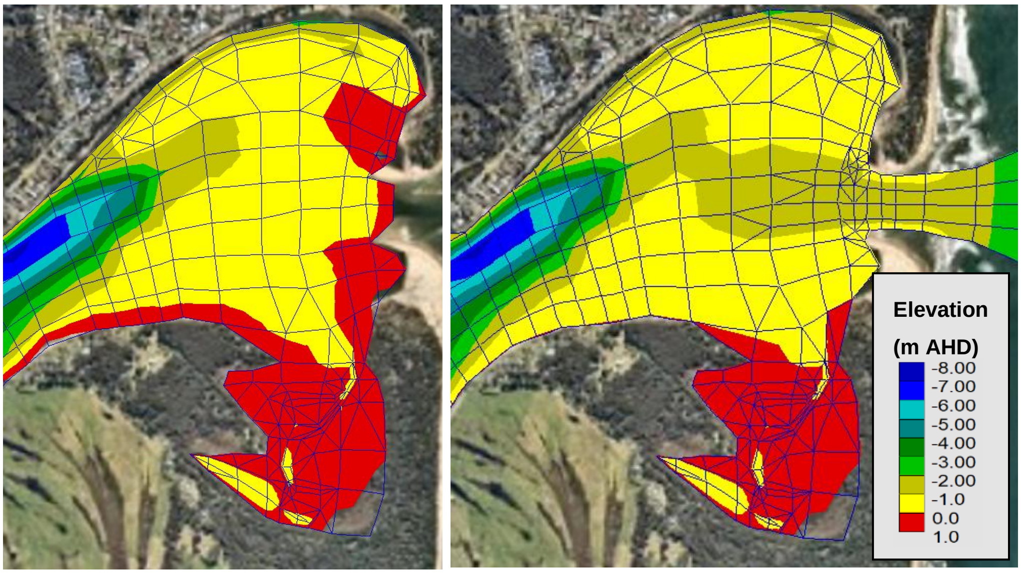

Figure 4-4 RMA model mesh with Shoalhaven Heads closed (left) and open (right)

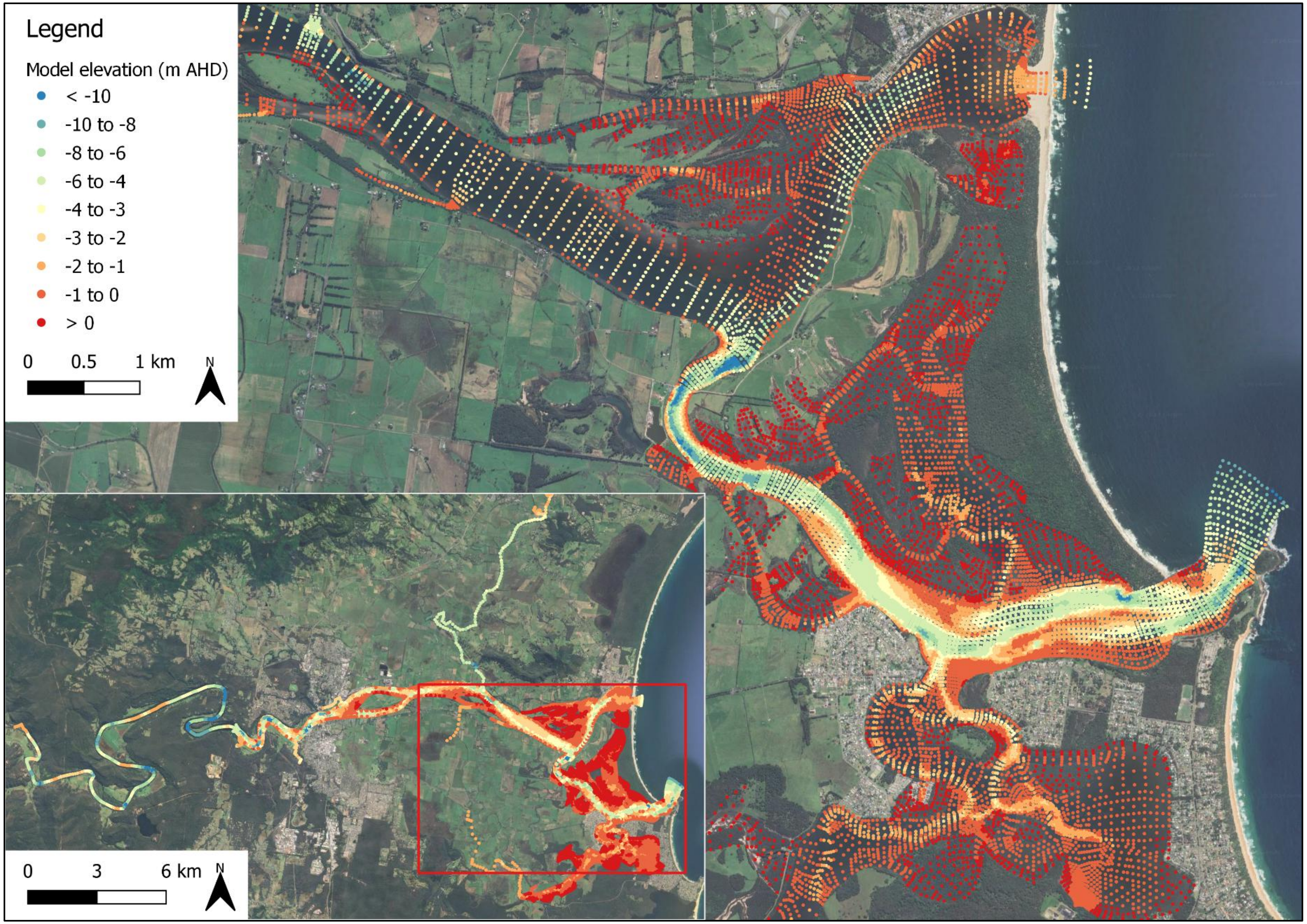

Figure 4-5 RMA model bathymetry for mesh with Shoalhaven Heads open

4.4 Model boundaries

The model includes five 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 Crookhaven Heads (and offshore of Shoalhaven Heads if this entrance is open) (refer to Figure 4-3 and Figure 4-4). This modelled water level boundary was based on observed tidal elevation data collected by MHL at Jervis Bay (station number 216470). This data was then smoothed to remove signal noise to increase model stability. For modelling water quality scenarios, all boundaries (upstream and ocean) were set to a constant constituent concentration of zero (e.g. no pollutant inflows from these boundaries).

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, including limited data in Comerong Bay in regards to tidal lags.

4.6 Hydrodynamic calibration and verification

Hydrodynamic calibration should be based on flow, velocities and water levels at several locations throughout the estuary. For more details on calibration and how the models were determined to be fit for purpose refer to WRL TR2023/32 Section 6.4. Three main sets of pre-existing hydrodynamic calibration data were available for calibration and validation purposes, collected by MHL in 2005, 1996 and 1993 and described in Section 2.2. Additionally, long term water level gauges managed by MHL were available at seven locations in the Shoalhaven (see Section 2.2), which were used to verify the model for other periods, including the field collection period. For each period, a minimum 3 day model warmup period was run. Throughout this section, positive flow is associated with flow from upstream to downstream (an ebb tide).

4.6.1 September 2005 calibration period – closed condition

During the 2005 MHL data collection campaign on the Shoalhaven River (MHL, 2007), data is available from 13 water level gauges (including several permanent gauges). In addition to water level gauge data available from August 2005 into April 2006, tidal flow data was collected at seven sites on 21 September 2005. The model was primarily calibrated to this period, as the available data was most extensive and the 2006 OEH bathymetry survey was close to this period. Measured tide levels at Jervis Bay were applied at the ocean boundary and scaled, measured catchment inflows were applied at the five upstream model inflow boundaries. Plots of all observed water levels and flows compared with model results are shown in Appendix B1.1 and B1.2, while select results are shown in Figure 4-6 to Figure 4-8.

A good model match was achieved for flow and water levels downstream of Terara (see Figure 4-6 and Figure 4-7 for examples), while the modelled water level tended to exhibit smaller tidal range than the observed levels from Terara upstream (see Figure 4-8 for an example). However, as this location is far from the oyster harvest areas, this calibration was deemed fit for purpose for this study.

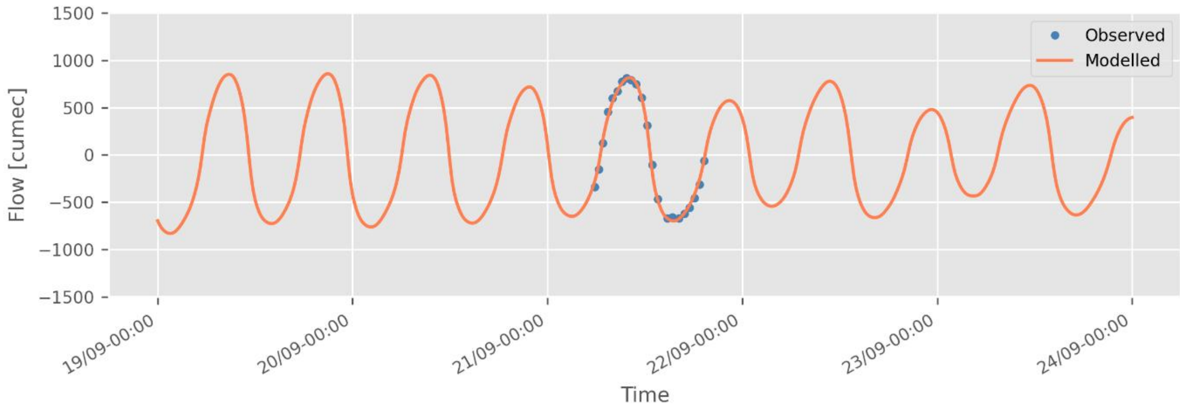

Figure 4-6 2005 tidal flow calibration – Location C – Berrys Canal

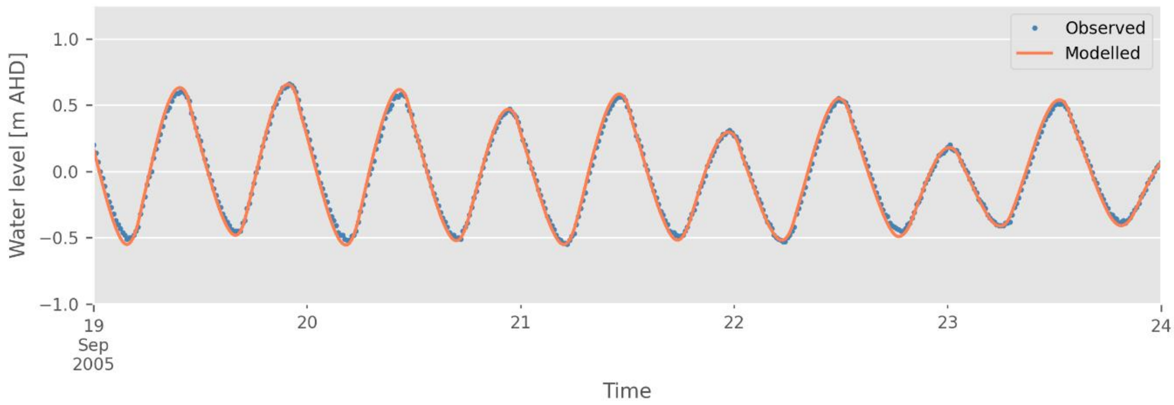

Figure 4-7 2005 water level calibration – Location 2 – Greenwell Point

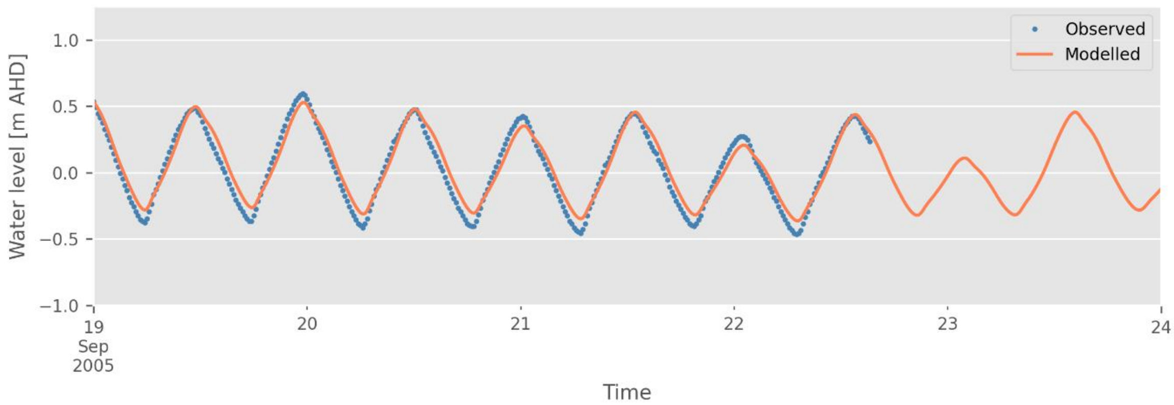

Figure 4-8 2005 water level calibration – Location 8 – Terara

4.6.2 August 1996 validation period – closed condition

The 1996 MHL Shoalhaven data collection campaign was targeted to assess the river during a time when the heads were closed (MHL, 1996). During this campaign, tidal flow data was collected at three sites on 28 August 1996 and water level data was available for the period from four long term gauges. The model mesh calibrated to the 2005 data period (with Shoalhaven Heads closed) was applied to the 1996 data period. Measured tide levels at Jervis Bay were applied at the ocean boundary and scaled, measured catchment inflows were applied at the five upstream model inflow boundaries. Plots of all observed water levels and flows compared with model results are shown in Appendix B1.3 and B1.4, while select results are shown in Figure 4-9.

The fit of the model to both water levels and flows is satisfactory however, it is noticeably worse than in the 2005 calibration period, which was likely due to bathymetric changes between the 1996 period and the 2006 OEH bathymetry survey, which was used for the model. Specifically, the observed data includes greater losses between Crookhaven Heads and Greenwell Point than the model, resulting in an overestimation of tidal range (see Figure 4-9). This is likely due to increased scouring of the channel in the 10 years since the 1996 data collection program, consistent with the trend of long term erosion in Berrys Canal. However, because of the satisfactory fit of the model with Shoalhaven Heads open for both the calibration and validation periods, the model was deemed fit for purpose. However, longer term changes to the model may need to be considered if scour continues to occur through Berrys Canal and Crookhaven Heads. Thompson (2012) indicates that this scour is lessening but ongoing.

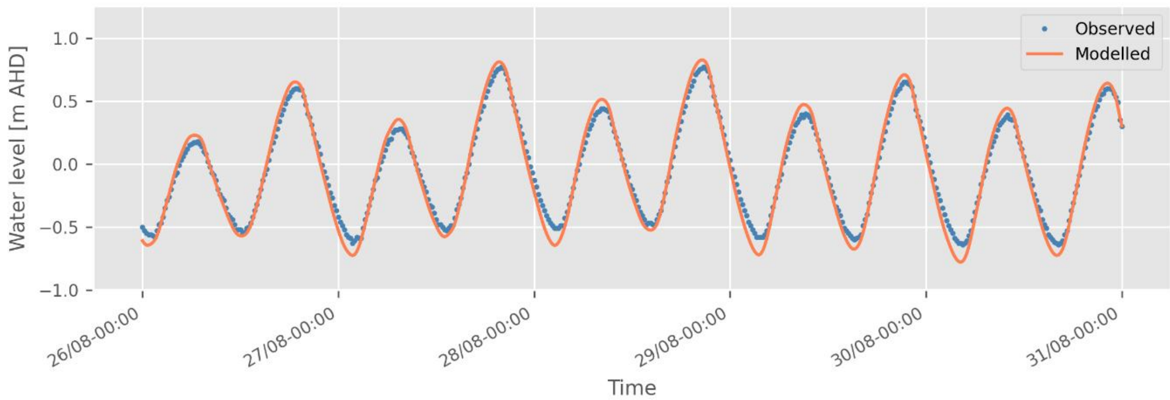

Figure 4-9 1996 water level calibration – Location 2 – Greenwell Point

4.6.3 June 1993 calibration period – open condition

The 1993 MHL Shoalhaven data collection campaign occurred when the Shoalhaven Heads were open and involved measurement of tidal flow data at three sites on 2 June 1993 (MHL, 1994). There is also water level data available from long term gauges at Crookhaven and Shoalhaven Heads for this period. The model mesh calibrated to the 2005 data period was edited to include a second entrance to the estuary at Shoalhaven Heads (see Figure 4-4 and Figure 4-3). As no bathymetry was available for this period, the depth and width of the Shoalhaven entrance were approximated based on aerial imagery with the entrance open. Measured tide levels at Jervis Bay were applied at the ocean boundary and scaled, measured catchment inflows were applied at the five upstream model inflow boundaries. Plots of all observed water levels and flows compared with model results are shown in Appendix B1.5 and B1.6, while select results are shown in Figure 4-10 to Figure 4-12.

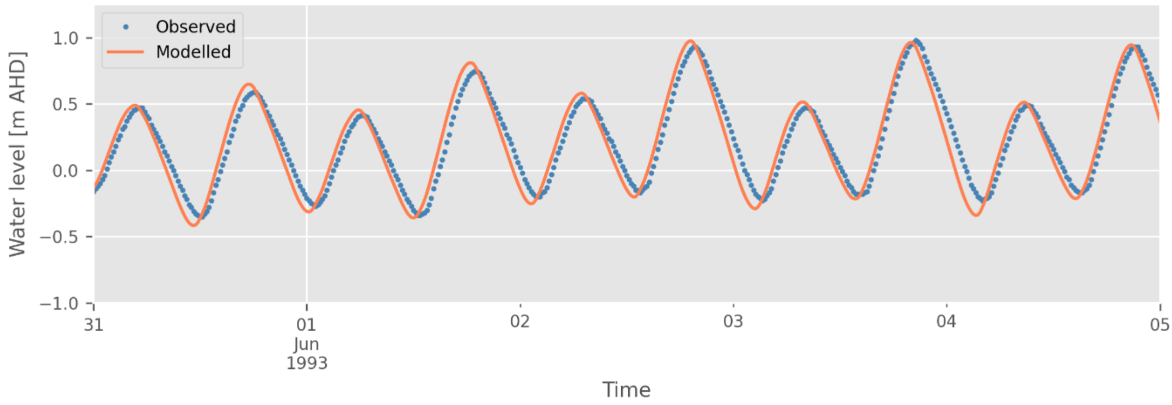

Figure 4-10 1993 water level verification – Location 5 – Shoalhaven Heads

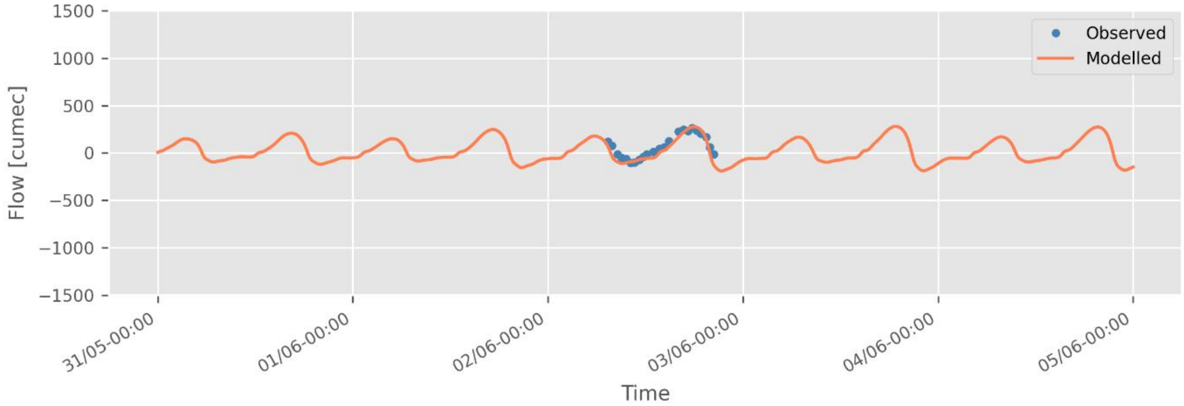

Figure 4-11 1993 tidal flow verification – Location I – Shoalhaven River Downstream (Old Man Island)

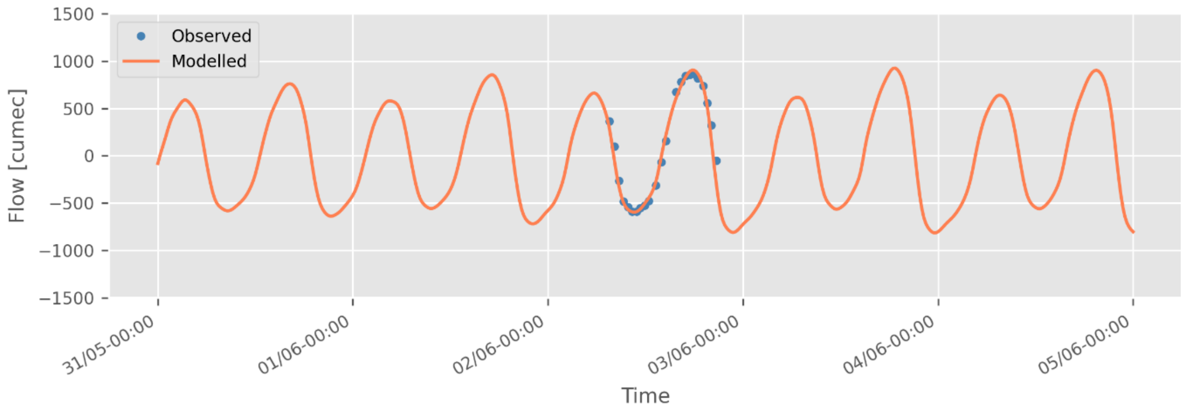

Figure 4-12 1993 tidal flow verification – Location J – Shoalhaven River

The observed water levels at Shoalhaven Heads appears to drain slower than the model simulates, resulting in modelled water levels with a greater range and a small phase offset compared to observed levels at Shoalhaven Heads, as well as a mismatch in shape for the flow at Location I (Figure 4-10 and Figure 4-11). This is likely due to inaccuracies of the modelled entrance at Shoalhaven Heads due to a lack of bathymetry data. For the purpose of this model, the primary aim of the alternative model bathymetry is to demonstrate the difference in behaviour near Berrys Bay when the heads are open, which will be more pronounced when the entrance is more efficient. Considering that the entrance is highly changeable and unlikely to exactly match the 1993 conditions in the future, and the flow in Berrys Canal and the Shoalhaven River were well matched (see Figure 4-12). Therefore this model, which approximated behaviour with the heads open, was deemed sufficient.

4.6.4 May 2023 field data verification period

During the 2023 field data collection period (11 and 12 May 2023) water level data was available at seven long term water level stations and one temporary station installed in Comerong Bay. Measured tidal levels were applied at the ocean boundary condition, and median catchment inflows were scaled as per Section 2.3 and applied at the five upstream model inflow boundaries. The state of Shoalhaven Heads was approximated by setting the depth of the entrance to Shoalhaven Heads to -0.5 m AHD (rather than -1.5 m used in the fully open model for the 1993 period). This approximated the observed, partially open condition of the heads at the time of data collection. Plots of all observed water level and flow compared with model results are shown in Appendix B1.7, while select results are shown in Figure 4-13.

The fit for all locations was satisfactory, including the gauge installed at Comerong Bay (shown in Figure 4-13) demonstrating the model's capacity to replicate present day water level conditions across the estuary.

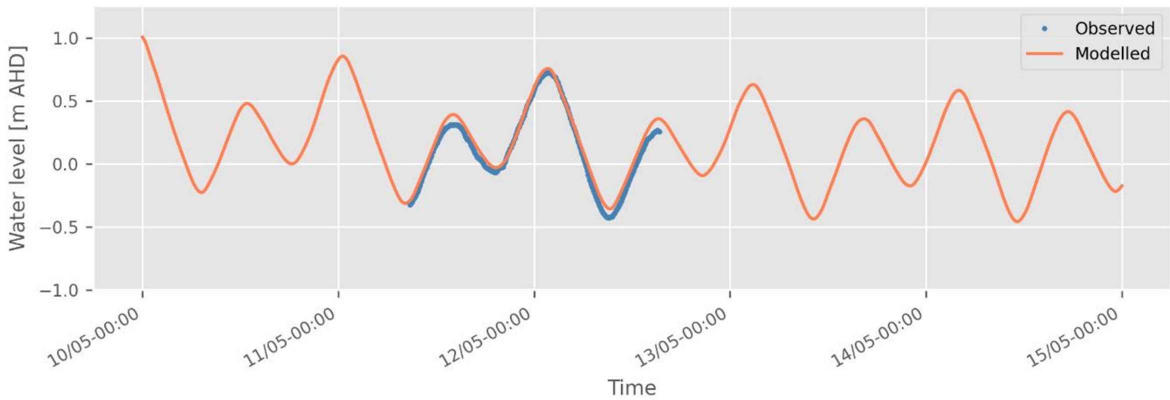

Figure 4-13 2023 water level validation – Location 15 – Comerong Bay

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.

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

Location	Manning's n roughness coefficient
Crookhaven Heads	0.030
Shoalhaven Heads	0.025
Berrys Canal to Regatta Creek	0.022
Shoalhaven River upstream of Regatta Creek	0.020
Seagrass areas and oyster leases	0.030
Intertidal areas	0.063
Crookhaven Creek	0.053
Channels in Crookhaven, Berrys Bay and Comerong Bay	0.025

4.7 Water quality model development

4.7.1 Modelling of dispersion in RMA-11

Dye dispersion experiments, discussed in Section 3.3, provided valuable information on dispersion and its simulation in modelling. In particular, they provided evidence for a reasonable range of dispersion coefficients to use in the modelling. However, it was concluded that they could not be used to produce estuary-specific values for dispersion. Hence, a range of dispersion values, derived from the field experiments, was used across all the estuaries. Models were run with two dispersion coefficients, 0.5 and 1.5 m^2/s, and the scenario results presented are a combination of the two to manage the uncertainty in dispersion. For further details on how these dispersion values were determined, sensitivity testing, and how model results were combined refer to WRL TR2023/32 Section 7.3, 7.4 and 8.2.3. The RMA-11 model utilised a 3 minute timestep, with results output every 12 minutes.

4.7.2 Tidal straining and vertical velocity distribution

As outlined in WRL TR2023/32 Section 7.5, tidal straining is a process leading to asymmetrical vertical velocity distributions in some estuaries. In instances of tidal straining, much higher velocities are observed at the surface than at the bed on the ebb tide, with much less velocity difference observed on the flood tide. Using the methods described in WRL TR2023/32 Section 7.5, RMA-TRK (Lagrangian model) was used to compare the travel times from field observations with drifter drogues (see Section 3.4) 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 Shoalhaven River system, depth varying vertical velocity distributions were observed on both the ebb and the flood tide, with an average ratio of drogue to modelled particle velocity being 1.3 on the flood tide and 1.7 on the ebb tide, although it should be noted there were only two releases on the ebb tide.

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

Drogue release	Location	Tide	Average drogue velocity (km/hr)	Average model particle velocity (km/hr)	Average ratio (velocity factor)
Day 1 drop 1	Crookhaven Heads	Flood	1.1	0.9	1.2
Day 1 drop 2	Berrys Canal	Flood	1.5	1.2	1.2
Day 1 drop 3	Berrys Canal	Ebb	2.0	1.2	1.6
Day 2 drop 1	Shoalhaven River	Ebb	2.5	1.5	1.7
Day 2 drop 2	Crookhaven Heads	Flood	1.8	1.3	1.3
Day 2 drop 3	Crookhaven Heads	Flood	2.1	1.6	1.4
Day 2 oranges	Crookhaven River	Flood	1.5	1.0	1.6

While the differential between the flood and ebb tide velocity factors was smaller than those observed in other riverine systems, tidal straining was considered to be a process likely to be occurring on the Shoalhaven River estuary for the following reasons:

- The Shoalhaven River estuary is a riverine system over which a substantial salinity gradient has been shown to exist (refer to Section 3.6 and Miller et al., (2006))
- There was evidence of salinity stratification during fieldwork
- Small, but measurable, differential vertical velocity distributions on the ebb and flood tides were observed from drogues

Therefore, the methods described in WRL TR2023/32 Section 7.5 were used to adjust travel times for the upstream overflows that would be impacted by tidal straining: Bomaderry WWTP and Berry WWTP.

For the overflow locations further downstream, salinity stratification and hence tidal straining would be minimal, however a vertical velocity distribution, such as that observed by the drogues on a flood tide would still be occurring. Despite this, as the vertical velocity distribution would be tidally symmetrical (A. rather than B. on Figure 4-14), net movement of the plume over multiple tidal cycles would remain unaffected, as the surface is travelling faster on both ebb and flood tides. The observed distribution may still affect transport times within a single tidal cycle. However, as travel times are banded by 6 hour (tidal cycle) increments, this velocity distribution is unlikely to have an effect on the reported timing of plume arrival. Hence, despite observed vertical velocity distributions resulting in faster transport at the surface, no timing adjustments were applied to downstream overflow locations.

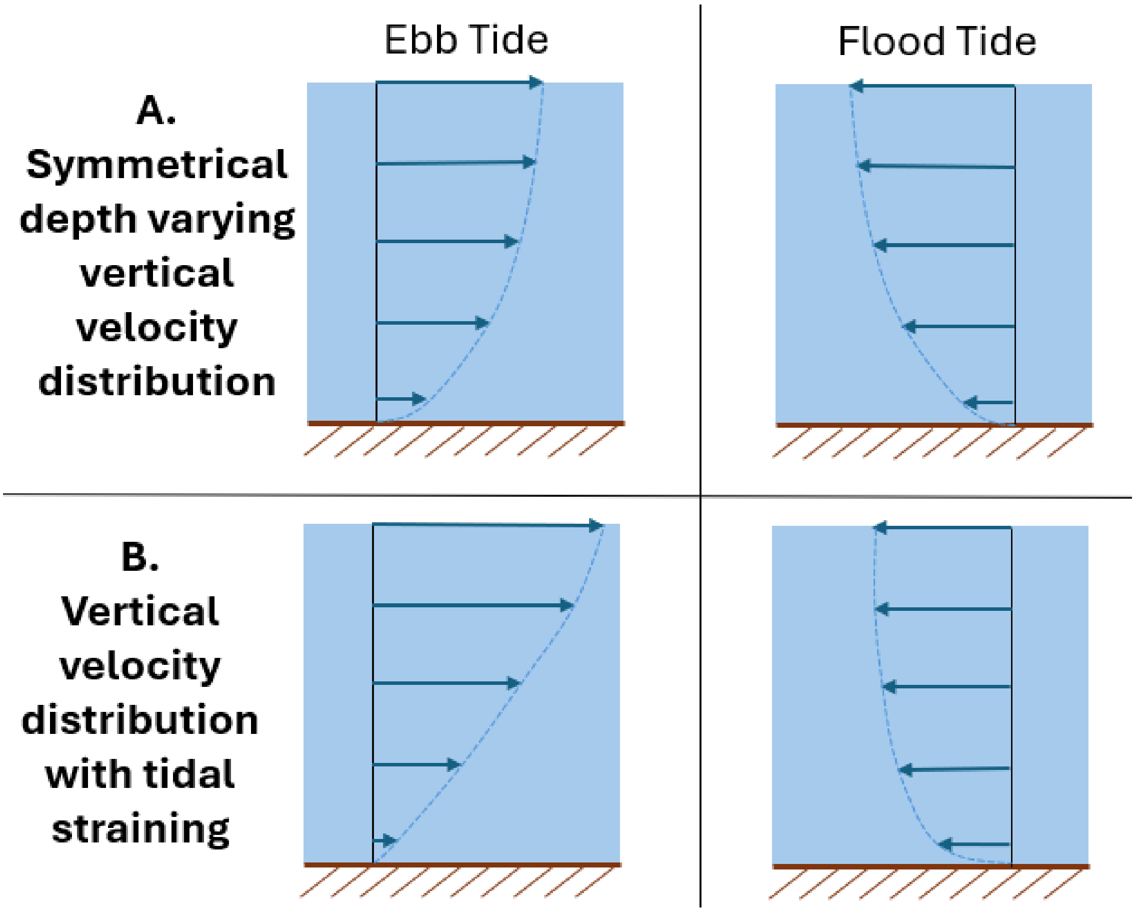

Figure 4-14 Flow with tidally symmetrical depth varying velocity profiles and tidal straining with non-symmetrical vertical velocity profiles

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 Shoalhaven River estuary model include:

- As discussed in WRL TR2023/32 Section 6.6, the model used for this estuary does not simulate density driven currents or three-dimensional processes. This is relevant in this location, where tidal straining is likely to be occurring. This was dealt with in this model by adjusting travel times from upstream overflow locations, however other model use cases require reconsideration of the impacts of tidal straining for the relevant situation.
- Berrys Canal is in a state of long term erosion, which may necessitate updates for this model to continue to be fit for purpose into the future, or for other model uses.
- The Shoalhaven Heads entrance is highly dynamic. While two model bathymetries have been included in this model, this does not account for dynamic scour which may be required for other purposes.

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 the Shoalhaven River estuary, a total of 720 model scenario simulations were completed, including permutations of:

- Six overflow locations
- Four stages of the tide
- Three catchment inflow conditions
- Three overflow volumes and durations
- Two estuary conditions (Shoalhaven Heads open/closed)

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

Six locations were used to simulate overflows into the Shoalhaven River estuary. These locations were based on historical overflow events (Section 2.4) and input from NSW Food Authority. These locations typically correspond to creek lines or infrastructure where sewage may be directed to, following an overflow. 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 a real-world overflow reached the estuary should be made in consultation with local authorities, to determine if the modelled scenarios need to be consulted. 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, WRL recommends using the possible timing which results in the worst case scenario.

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 apply this approach.

Figure 5-1 Modelled overflow locations in the Shoalhaven River estuary

5.3 Environmental variables

Three environmental variables were tested for the Shoalhaven River:

1. Stage of the tide (slack low tide, slack high tide, mid ebb tide and mid flood tide)
2. Estuary condition (Shoalhaven Heads open or closed)
3. Magnitude of catchment inflows (median, 80^{th} percentile and 95^{th} percentile)

Each overflow location had differing effects from these three variables, described in the following sub-sections.

5.3.1 Stage of the tide

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

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

Overflow location	Results scenario	MHL water level gauge	Water level at start of spill
Culburra WWTP, Orient Point, Greenwell Point	Slack high tide	Greenwell Point (215417)	High tide
Culburra WWTP, Orient Point, Greenwell Point	Slack low tide	Greenwell Point (215417)	Low tide
Culburra WWTP, Orient Point, Greenwell Point	Mid ebb tide	Greenwell Point (215417)	Half way between high and low
Culburra WWTP, Orient Point, Greenwell Point	Mid flood tide	Greenwell Point (215417)	Half way between low and high
Hay Street	Slack high tide	Hay Street (215415)	High tide
Hay Street	Slack low tide	Hay Street (215415)	Low tide
Hay Street	Mid ebb tide	Hay Street (215415)	Half way between high and low
Hay Street	Mid flood tide	Hay Street (215415)	Half way between low and high
Bomaderry WWTP, Berry WWTP	Slack high tide	Nowra Bridge (215411)	High tide
Bomaderry WWTP, Berry WWTP	Slack low tide	Nowra Bridge (215411)	Low tide
Bomaderry WWTP, Berry WWTP	Mid ebb tide	Nowra Bridge (215411)	Half way between high and low
Bomaderry WWTP, Berry WWTP	Mid flood tide	Nowra Bridge (215411)	Half way between low and high

The stage of the tide affected overflows from all locations, with the greatest effect observed at the overflow locations closest to the estuary entrance (Orient and Greenwell Points) where it is possible for a spill at high tide to entirely leave the model domain in one tide. Model results show some differences between spills at different stages of the tide at Berry WWTP for high catchment inflow conditions. However, due to greater uncertainty in the hydrodynamics of Broughton Creek, due to tidal straining and limited bathymetry data, these runs were grouped to exclude the influence of the tide from the decision making. See WRL TR2023/32 Section 8.3.4 for more details on scenario grouping.

5.3.2 Estuary condition

Estuary condition for the Shoalhaven estuary refers to the state of Shoalhaven Heads. Shoalhaven Heads is the historic outlet of the Shoalhaven River, however, since the construction of Berrys Canal in the 19th century, most of the flow goes through Crookhaven Heads. Shoalhaven Heads remains an untrained entrance, which tends to accrete sand and close during periods of low catchment flows. The entrance then regains connection to the ocean during larger flood events. This impacts the way water moves around the lower estuary.

To simulate this morphodynamical change, two model bathymetries were run, one with Shoalhaven Heads open (i.e. connected to the ocean) and one with Shoalhaven Heads closed. In the bathymetry with the heads open, the channel is -1.5 m AHD and 180 m wide (similar to the width in the image in the upper right of Figure 5-2). A decision maker referring to these scenarios needs to consider whether Shoalhaven Heads are in an open or closed state to choose which model scenario to use. This can be done by consulting local community members, local government, or aerial photography. Note that the state of the heads can change quickly and aerial photography may not be accurate if there has been recent morphodynamical change. Figure 5-2 shows sample aerial photography of the Shoalhaven Heads during the last 15 years, highlighting that the entrance of the heads is highly variable. In many cases, the heads are in an open state, but with a narrow and shallow channel. In this case, the transport of overflows would lie somewhere in between the open and closed case. If there is any doubt about the state of the heads, or the entrance is in an intermediate state, then the worst case scenario should be used.

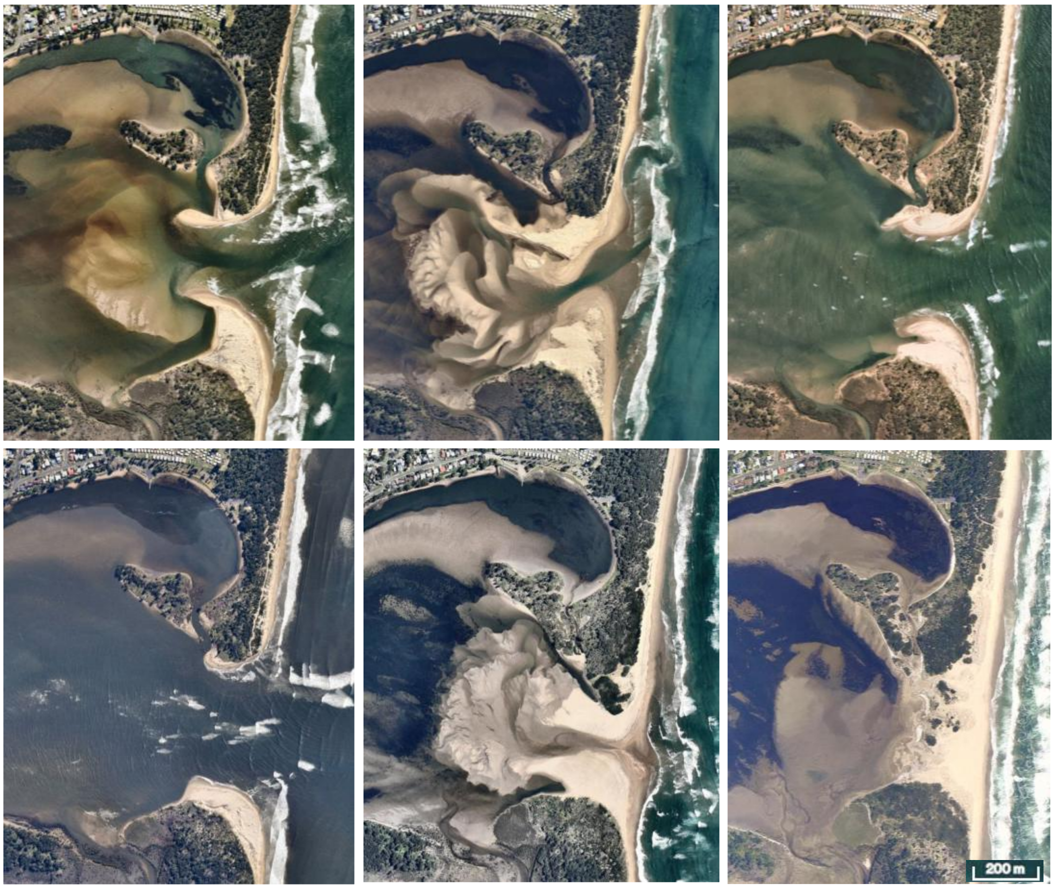

Figure 5-2 Shoalhaven Heads from Nearmap imagery. Dates from upper left in a clockwise direction: 30/6/2022, 19/5/2021, 7/9/2020, 6/8/2020, 4/3/2016, 12/11/2010

The state of Shoalhaven Heads only has significant effects on the outcomes for Berrys Bay harvest area and for overflows from Hay Street. In general, Berrys Bay harvest area is more vulnerable when Shoalhaven Heads are closed. Conversely, other harvest areas are more likely to be hit at high concentrations by overflow from Hay Street when Shoalhaven Heads are open. This is because flow in and out of the Shoalhaven Heads embayment is much greater when the heads are open. Therefore the plume is much more mobile from this location when the heads are open, even if more flushing occurs. Outcomes for many locations and scenarios were not affected by the state of Shoalhaven Heads, and results for these scenarios were grouped. See WRL TR2023/32 Section 8.3.4 for more details on scenario grouping.

5.3.3 Catchment inflows

For this riverine system, catchment inflows can have a major influence on pollutant transport, especially from upstream overflow locations. Catchment inflows had the greatest effect on overflows from Berry and Bomaderry WWTP, and made overflows reach the harvest areas faster and at greater concentrations. In general, the faster plume transport had a much greater effect on the added dilution from greater floodwaters, therefore downstream harvest areas are typically more vulnerable during high catchment inflows. See WRL TR2023/32 Section 8.3.4 for more details on scenario grouping.

As overflows for Berry WWTP are highly dependent on catchment inflows, particular care should be taken in assessing which model scenario results to use for this location. Instead of using the Shoalhaven River gauge to assess catchment inflows, the Broughton Creek at Broughton Vale (WaterNSW gauge number 215018) should be used. It should also be noted that this catchment only gauges a small proportion (approximately 20%) of the model inflow boundary catchment. As such, there is sizable further catchment flowing into the creek downstream of the tidal extent, which is not accounted for in this model. To account for this, rainfall records from the BoM station in Berry (068003) should be consulted, as well as other nearby rain gauges, to assess whether rain has fallen within the Broughton Creek catchment but not within the gauged portion. If there is any doubt, the worst case plausible scenario should be used. Due to these uncertainties, if there are many overflows from Berry WWTP requiring decisions based on catchment inflows, improvements to the model to simulate catchment inflows in a more robust way should be considered.

6 Conclusion

This report is focused on the Shoalhaven River estuary and was produced for the extensive study titled "Assessing the impact of sewage overflows on oyster harvest areas in NSW". The purpose of this report is to provide technical and estuary-specific information regarding the process and data sources used to create the Shoalhaven estuary model. Key information included in the report relates to the integration of existing data sources, WRL's May 2023 field data collection campaign, data processing, model development and model verification.

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 the Shoalhaven River) and discussions on modelling limitations including model parameter sensitivity and pollutant dispersion. Results of the scenario modelling is available in the accompanying tool, which is documented in the User Guide (WRL TR2024/26).

7 References

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Appendix A Field data collection

A1 Drifter drogue experiments

The following figures summarise the four drifter drogue experiments. For more information on these deployments, refer to Section 3.4.

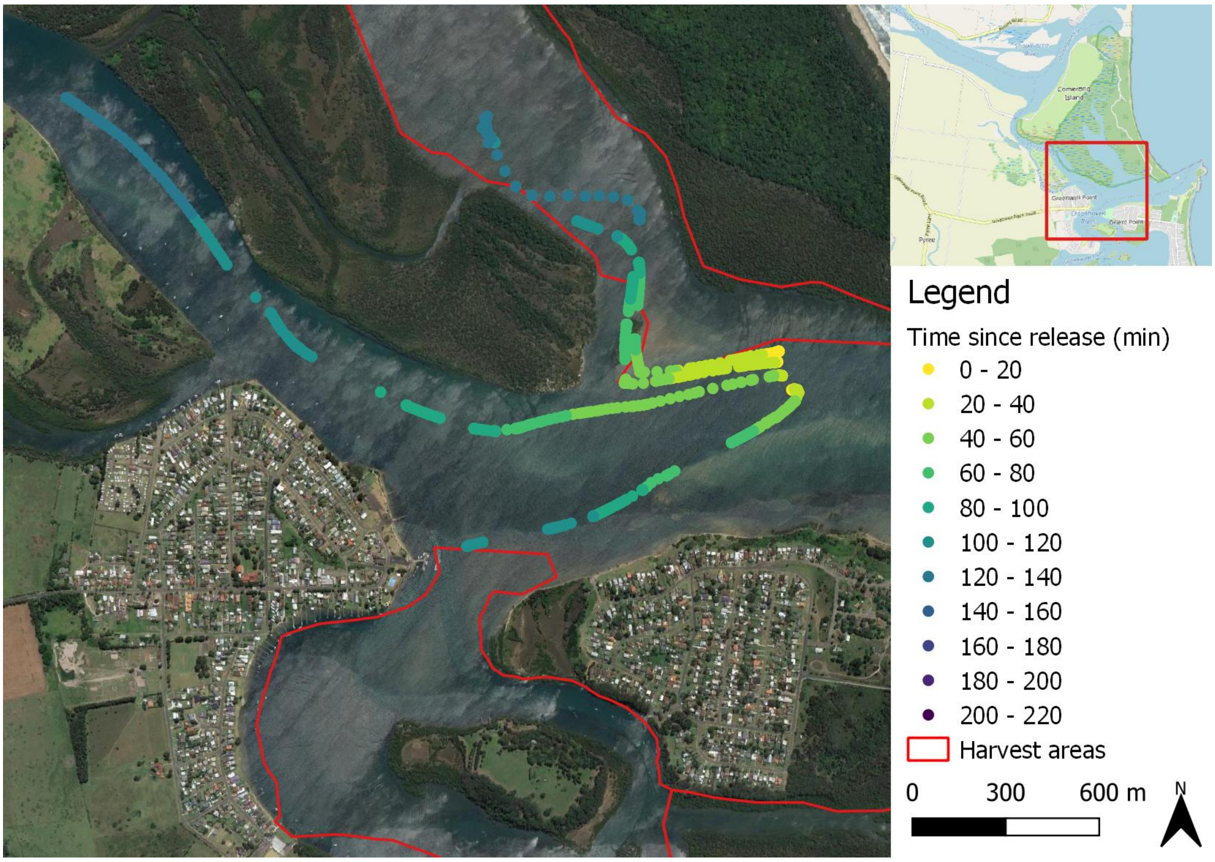

Figure A-1 Drogue day 1 drop 1 – incoming tide

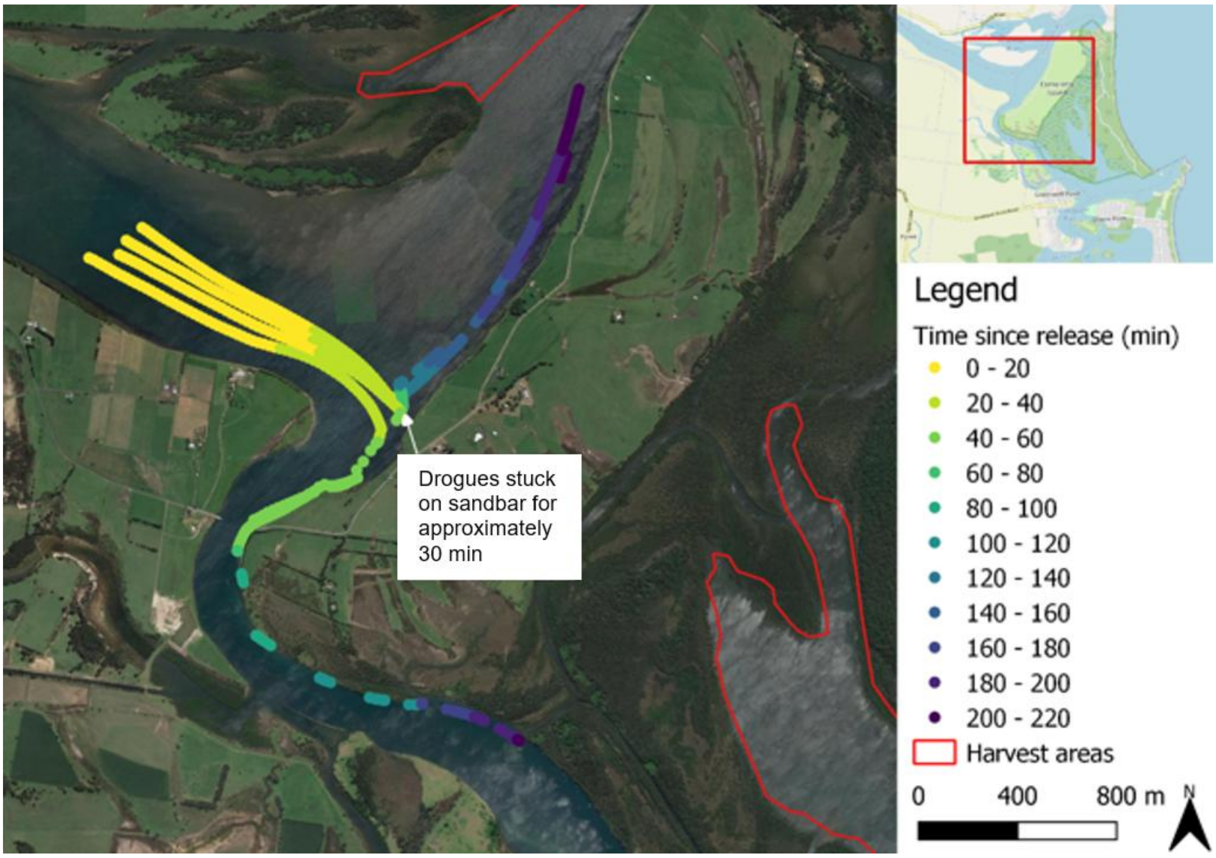

Figure A-2 Drogue day 2 drop 1 – outgoing tide

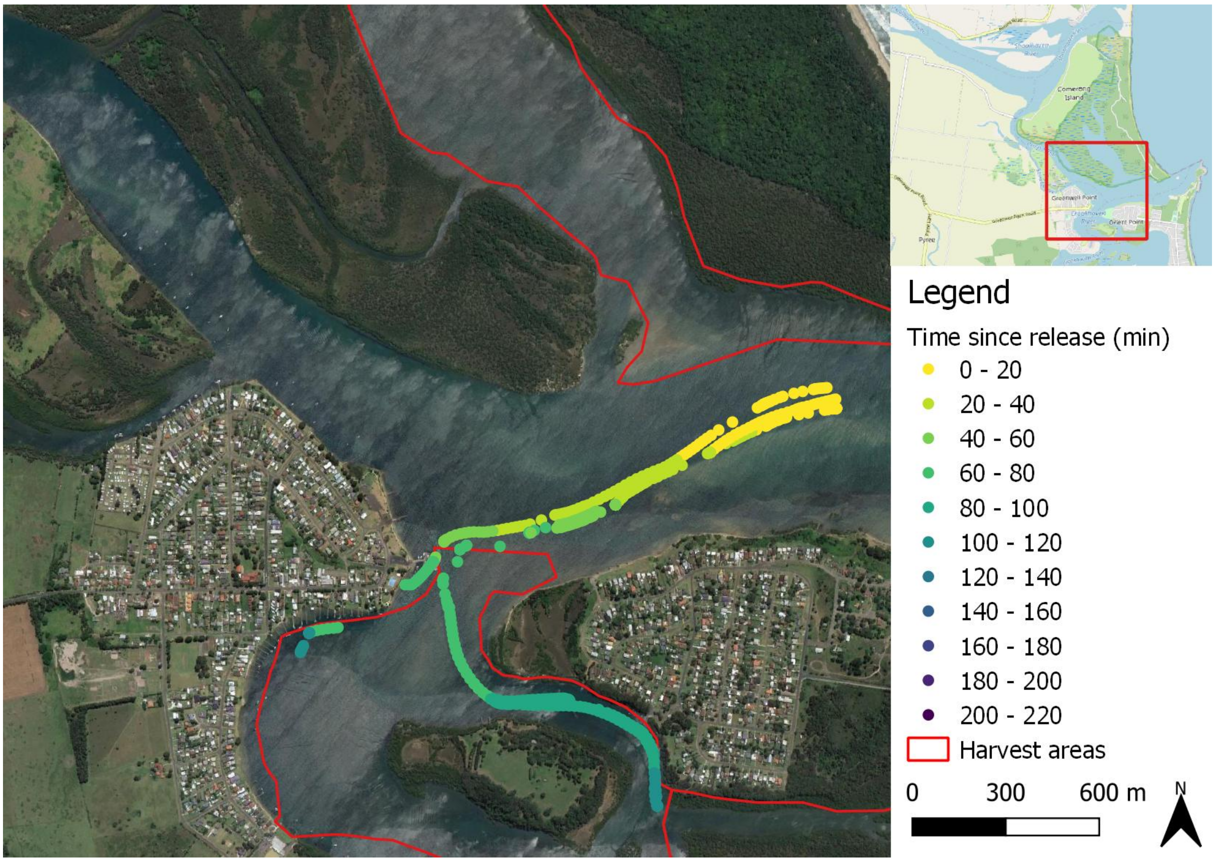

Figure A-3 Drogue day 2 drop 2 – incoming tide

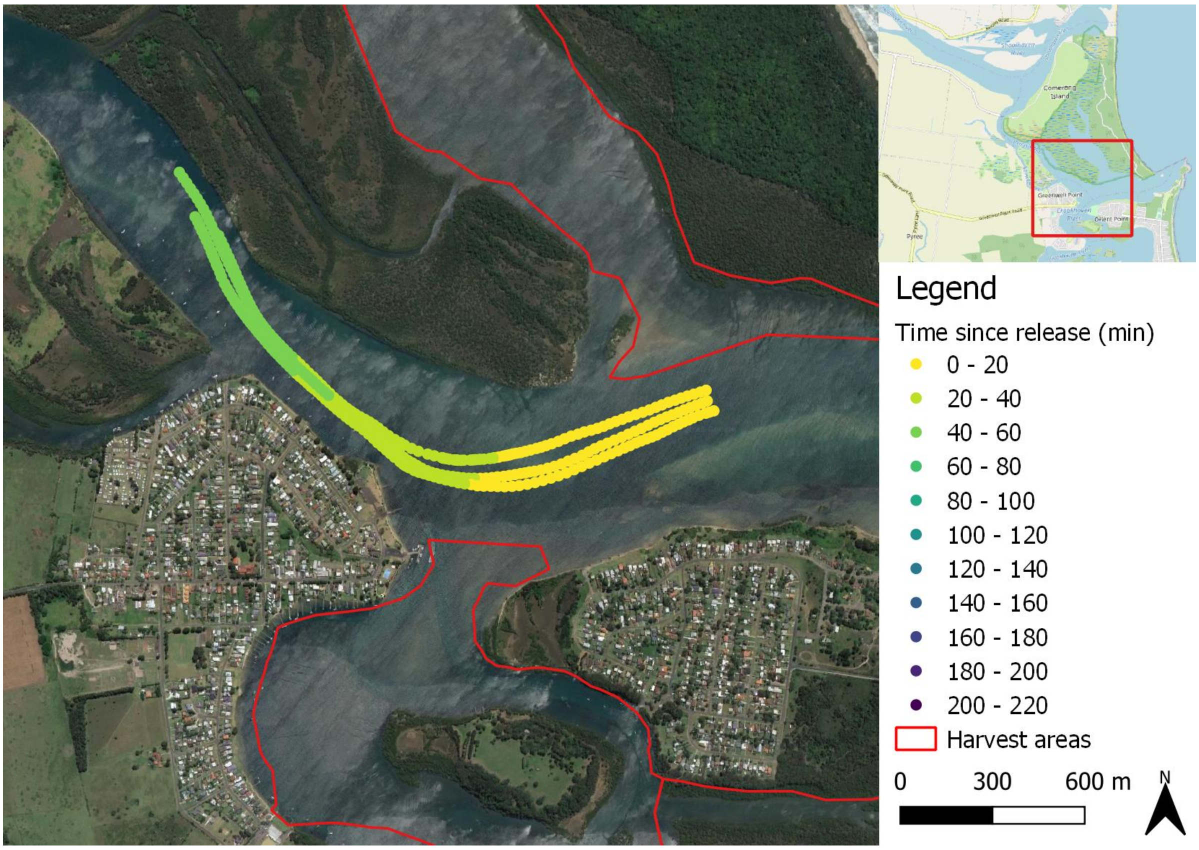

Figure A-4 Drogue day 2 drop 3 – incoming tide

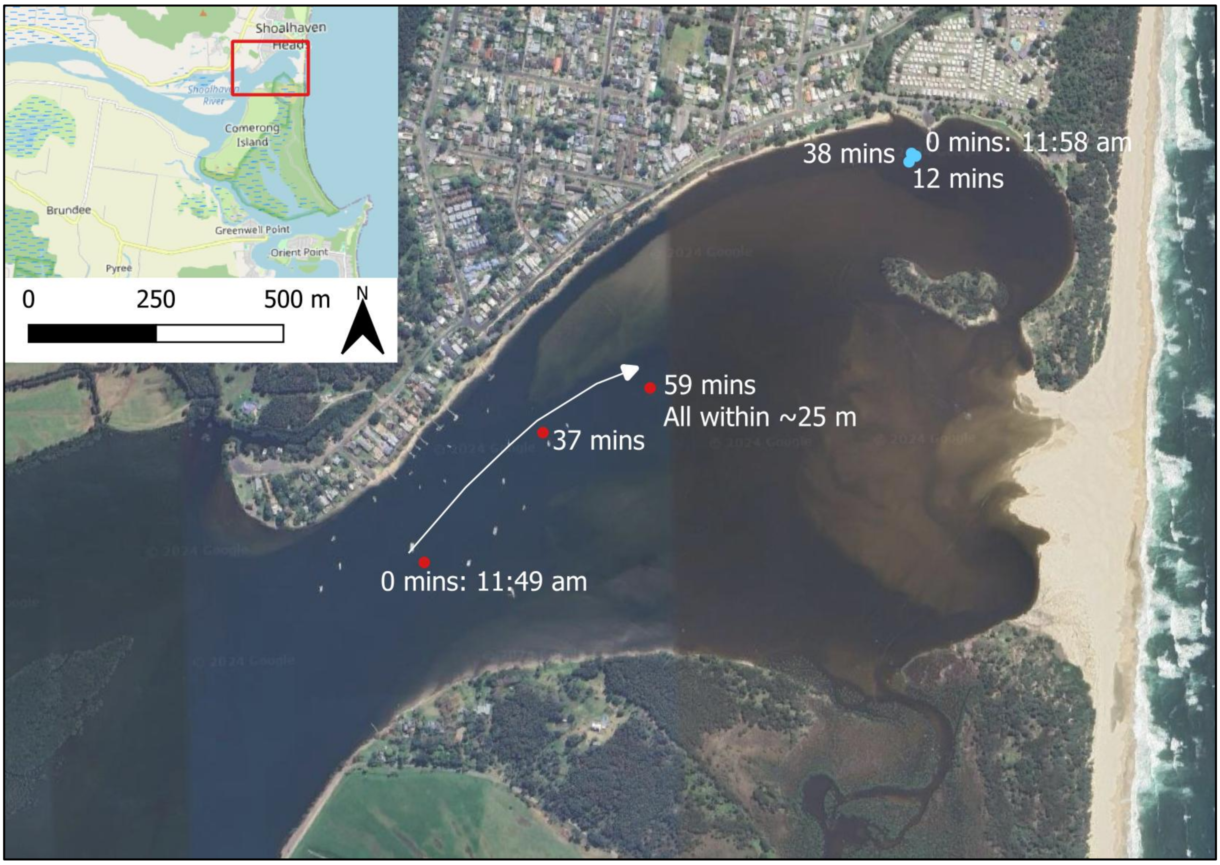

Figure A-5 Manual drogue drops in Shoalhaven Heads on the incoming tide of 12/05/23

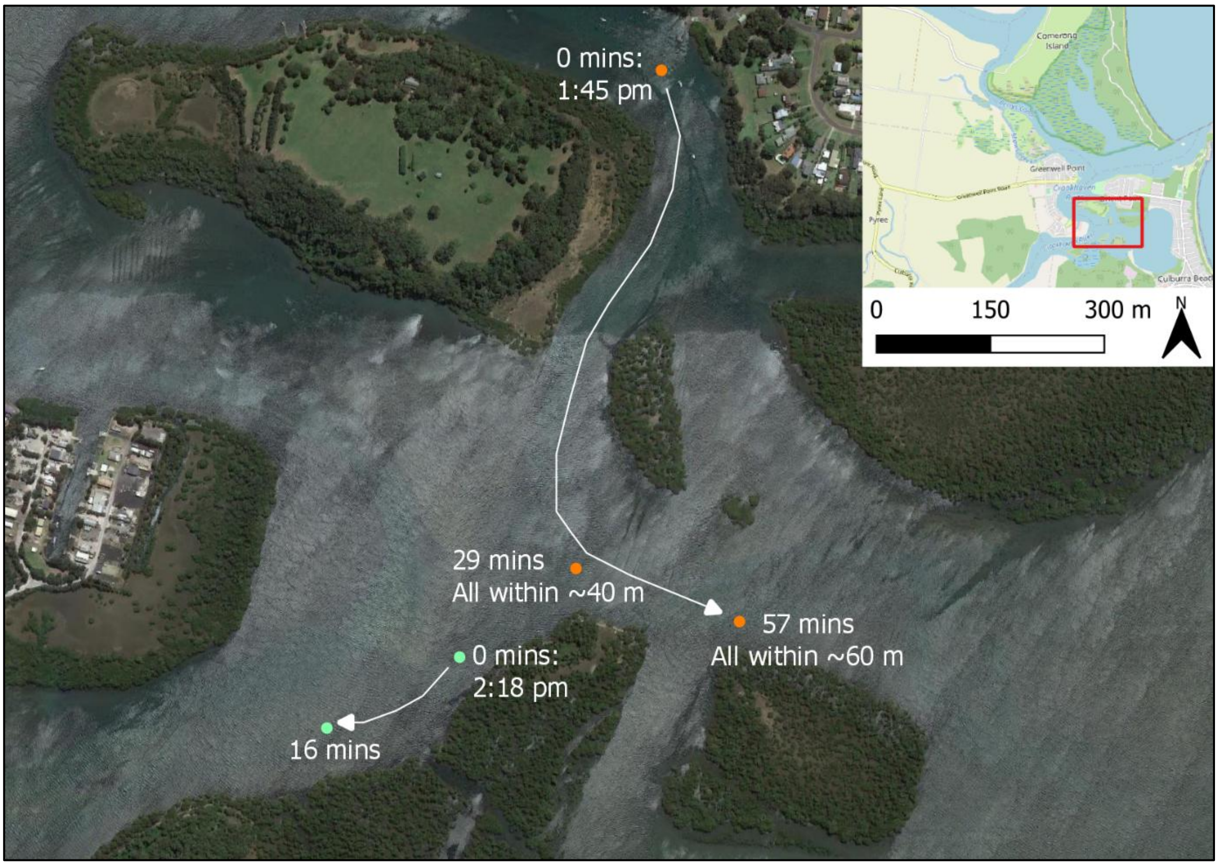

Figure A-6 Manual drogue drops in the Crookhaven River on the incoming tide of 12/05/23

Appendix B Model calibration

B1 Hydrodynamic calibration and verification results

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

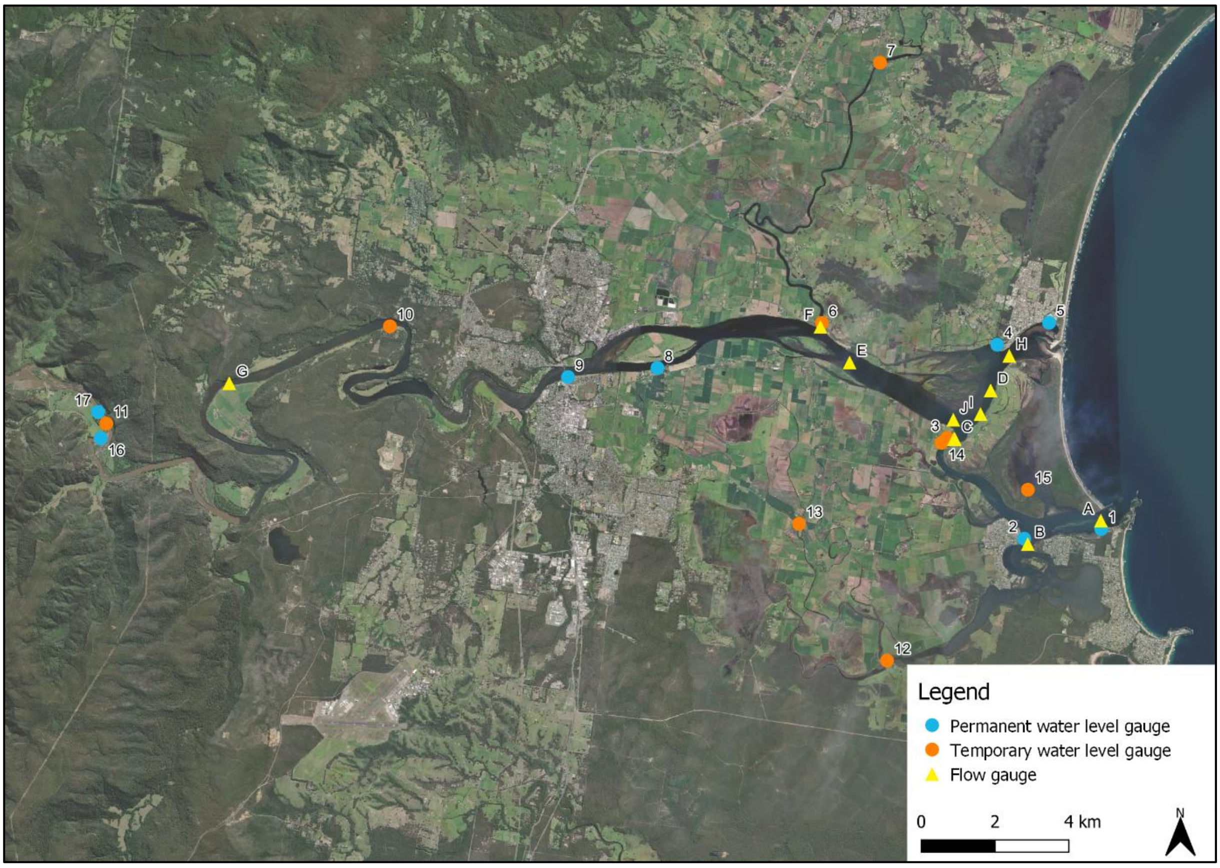

Figure B-1 Water level and tidal flow gauging locations

B1.1 Tidal flow gauging calibration – 2005 (Shoalhaven Heads closed)

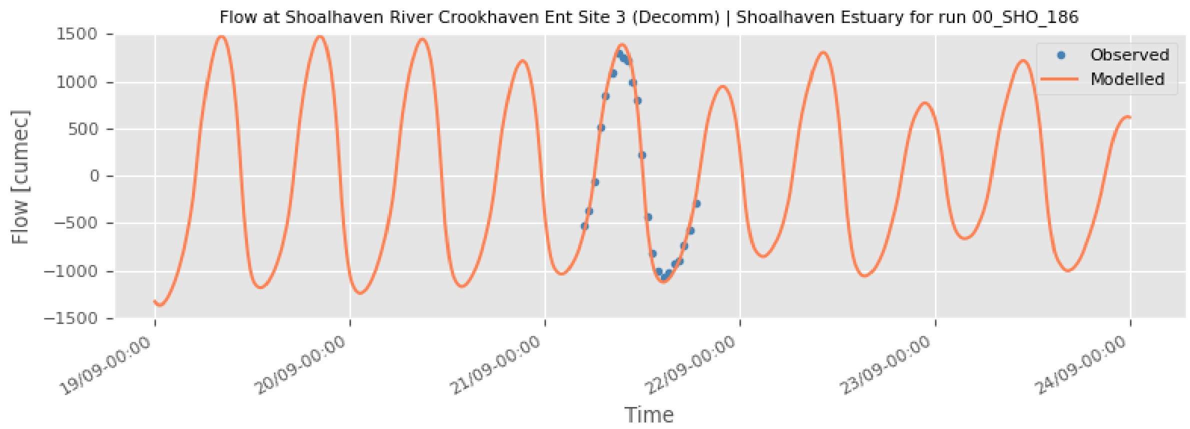

Figure B-2 2005 tidal flow calibration – Location A – Crookhaven River Entrance

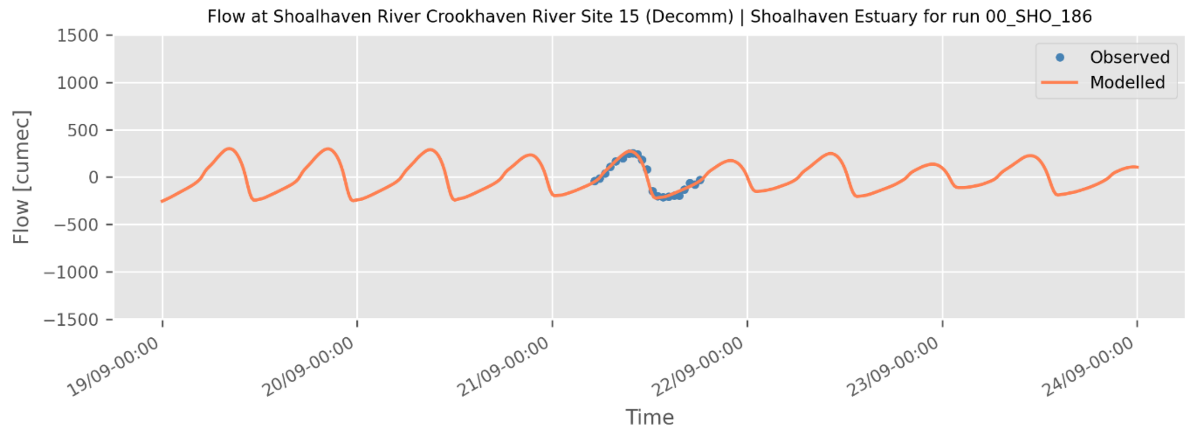

Figure B-3 2005 tidal flow calibration – Location B – Crookhaven River Site 15

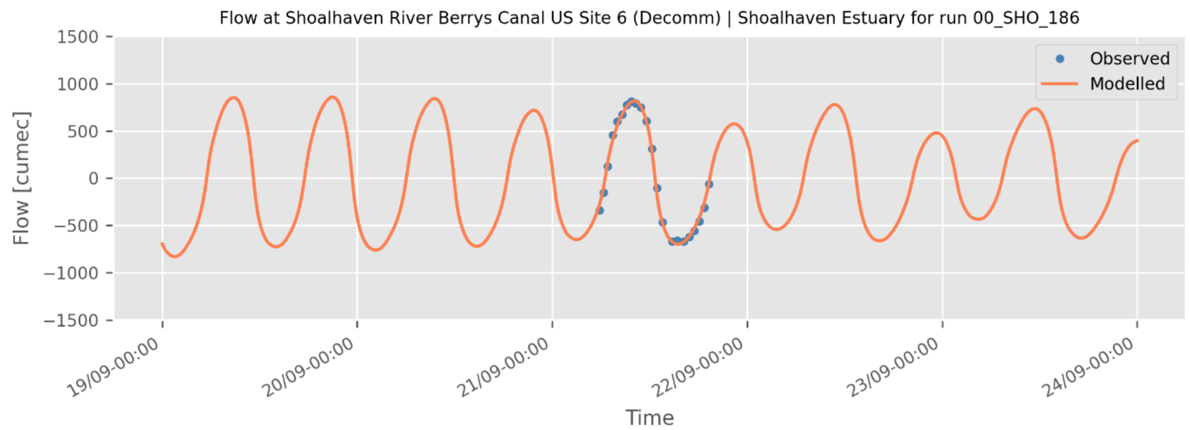

Figure B-4 2005 tidal flow calibration – Location C – Berrys Canal

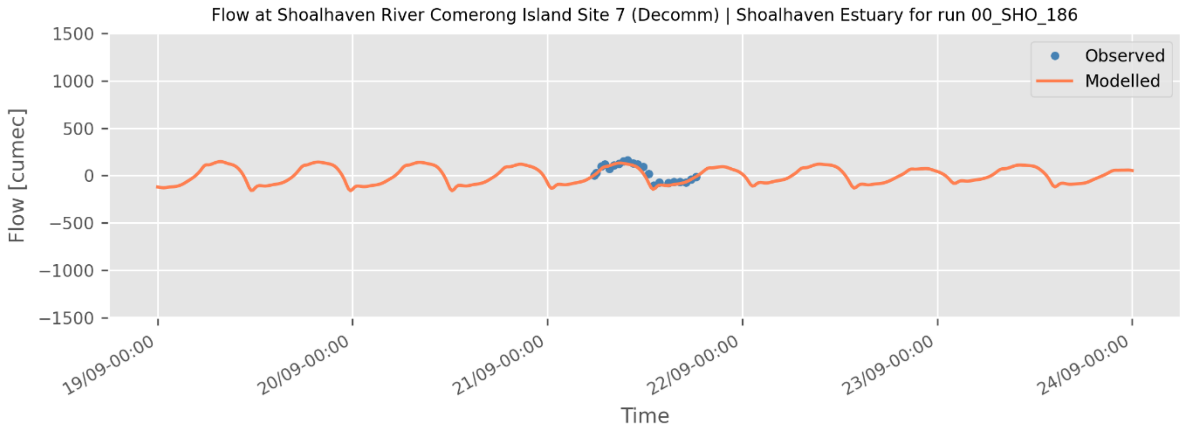

Figure B-5 2005 tidal flow calibration – Location D – Comerong Island (Old Man Island)

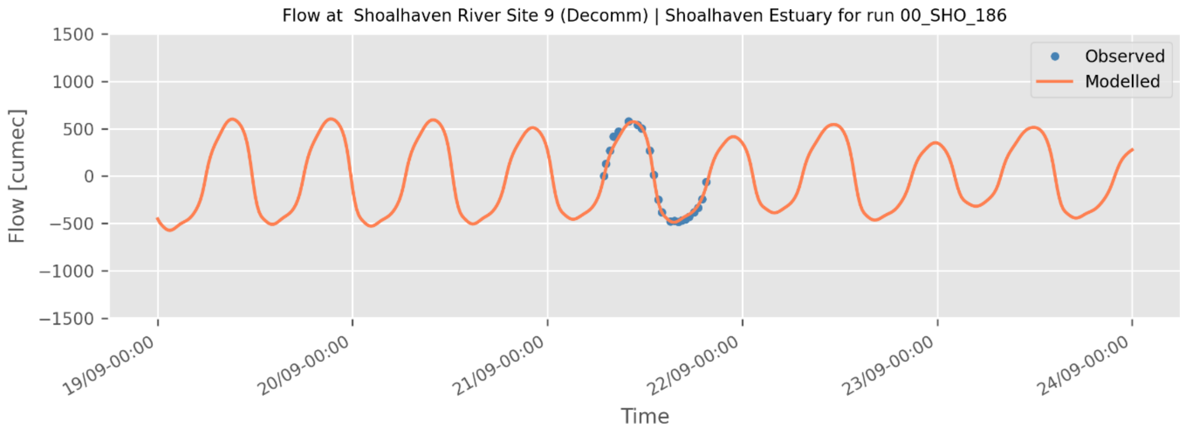

Figure B-6 2005 tidal flow calibration – Location E – Shoalhaven River

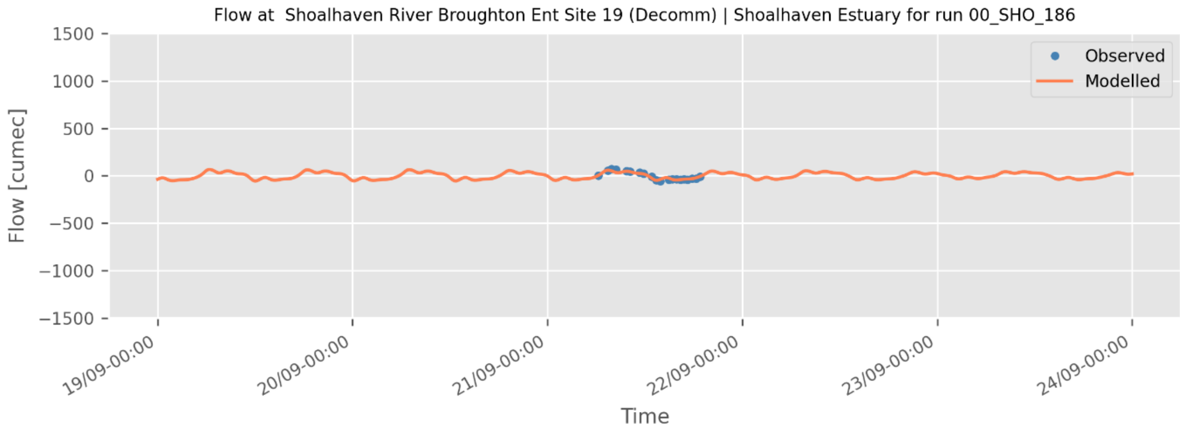

Figure B-7 2005 tidal flow calibration – Location F – Broughton Creek Entrance

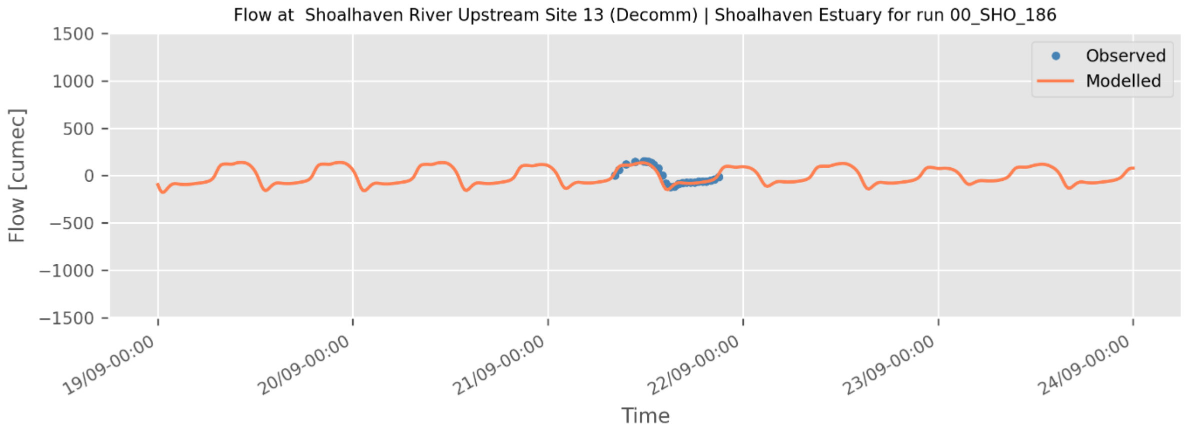

Figure B-8 2005 tidal flow calibration – Location G – Shoalhaven River Upstream

B1.2 Water level calibration – 2005 (Shoalhaven Heads closed)

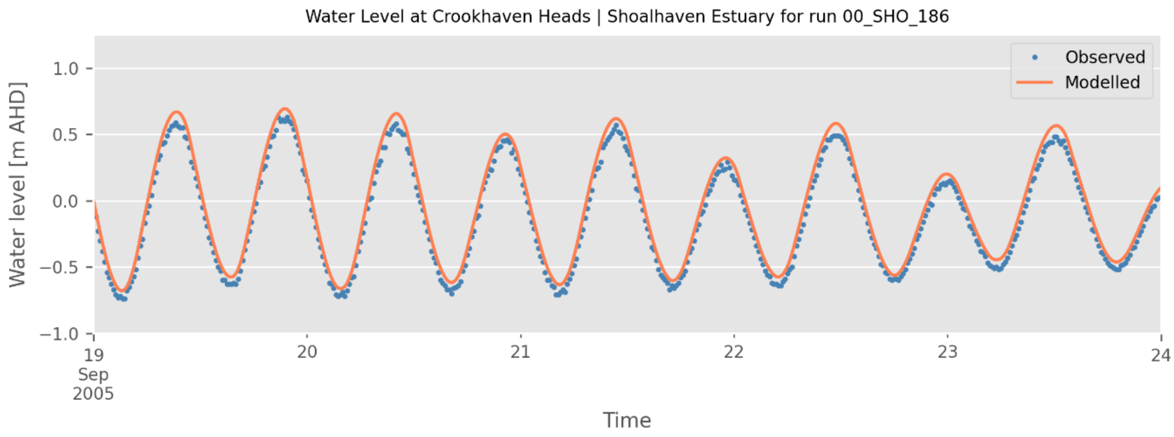

Figure B-9 2005 water level calibration – Location 1 – Crookhaven Heads

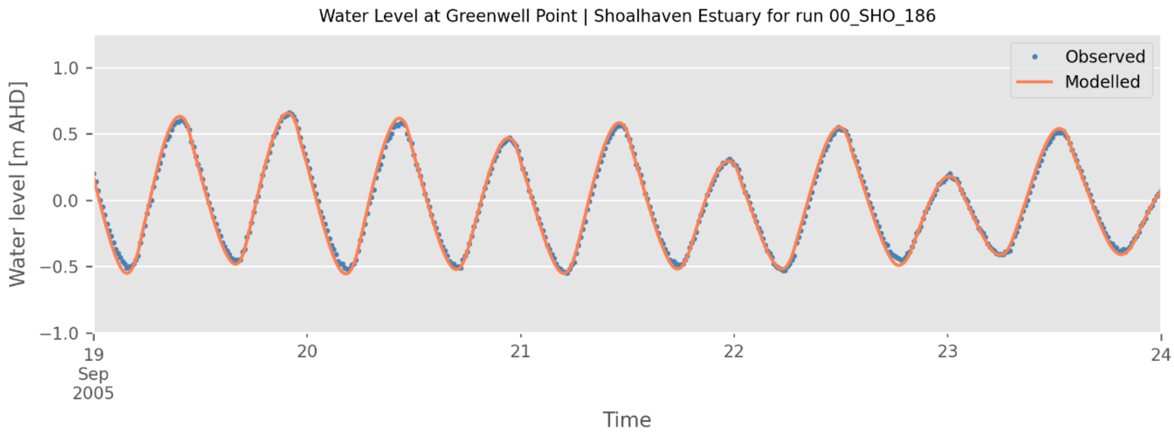

Figure B-10 2005 water level calibration – Location 2 – Greenwell Point

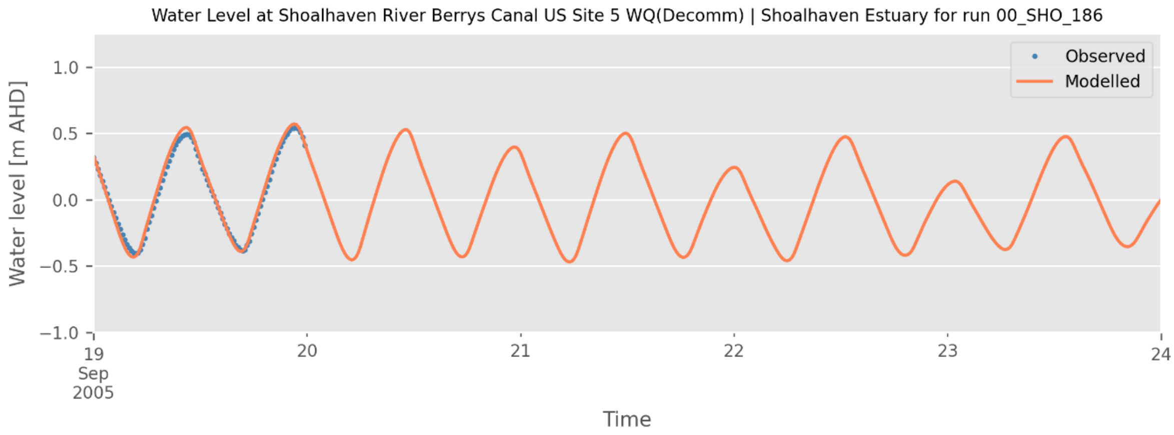

Figure B-11 2005 water level calibration – Location 3 – Berrys Canal

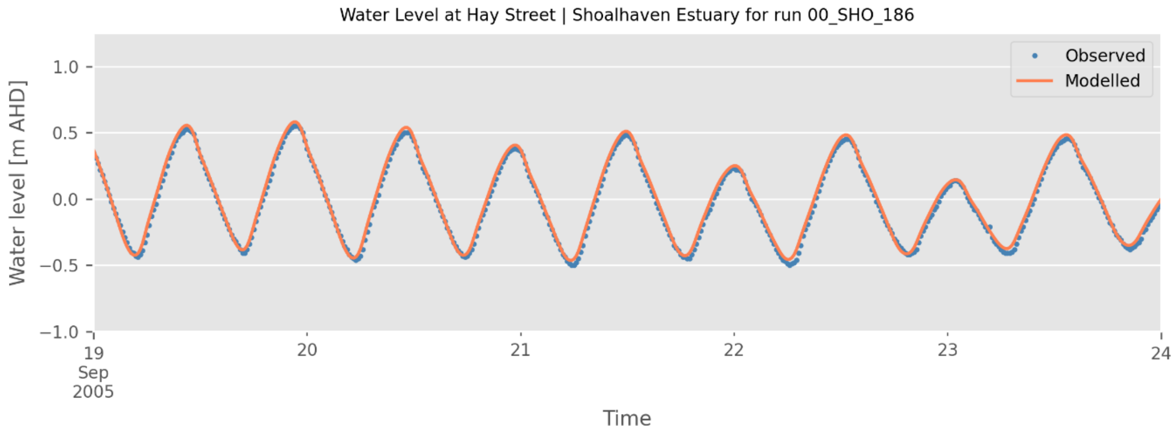

Figure B-12 2005 water level calibration – Location 4 – Hay Street

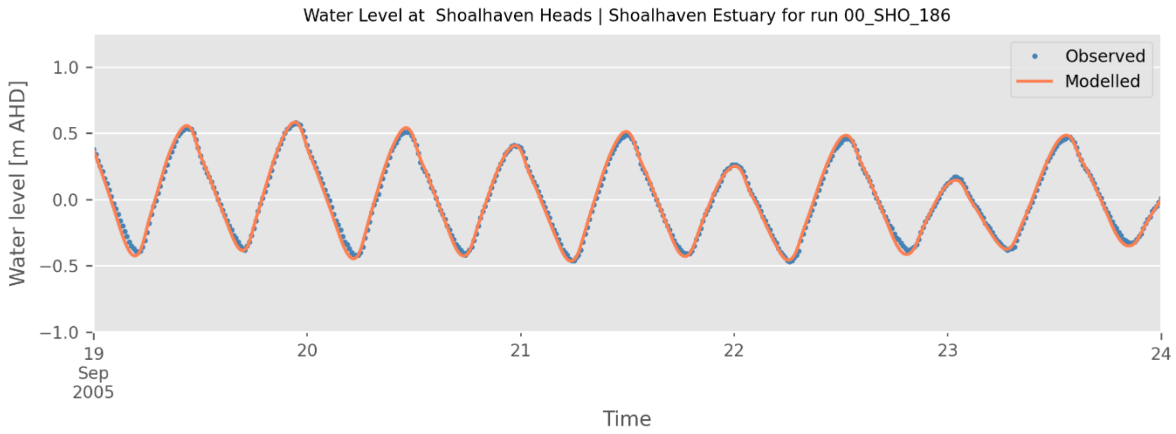

Figure B-13 2005 water level calibration – Location 5 – Shoalhaven Heads

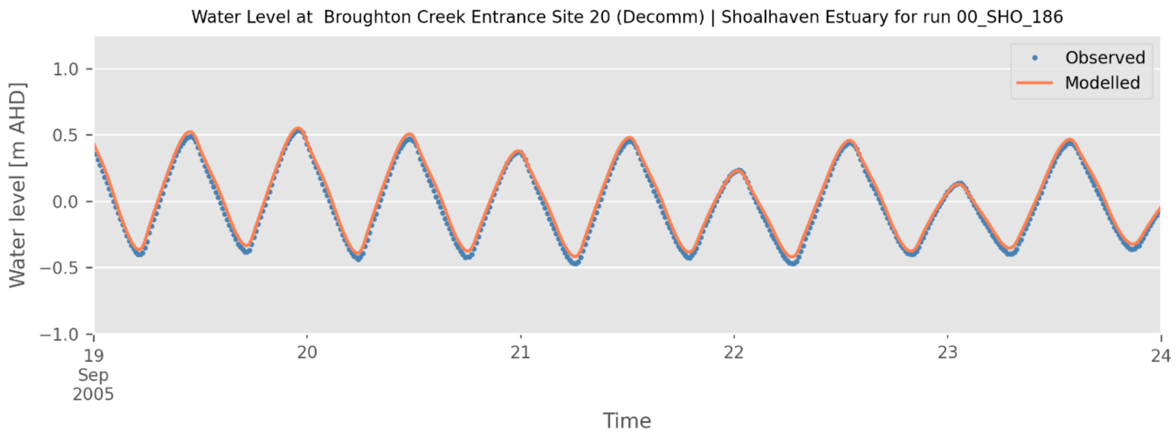

Figure B-14 2005 water level calibration – Location 6 – Broughton Creek Entrance

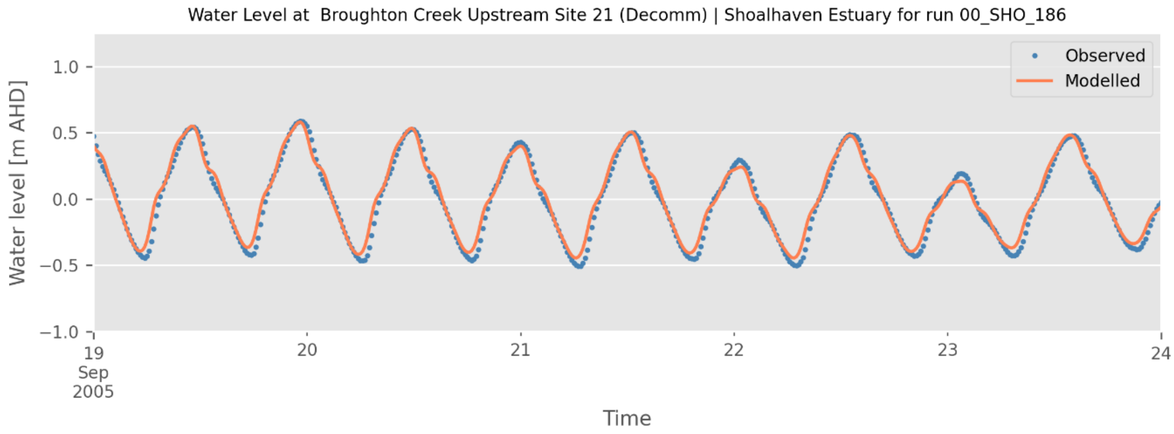

Figure B-15 2005 water level calibration – Location 7 – Broughton Creek Upstream

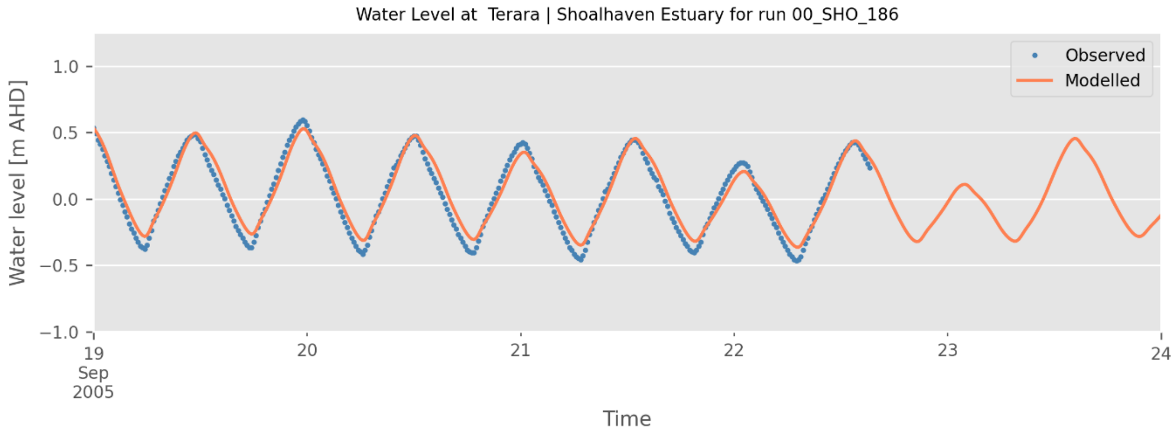

Figure B-16 2005 water level calibration – Location 8 – Terara

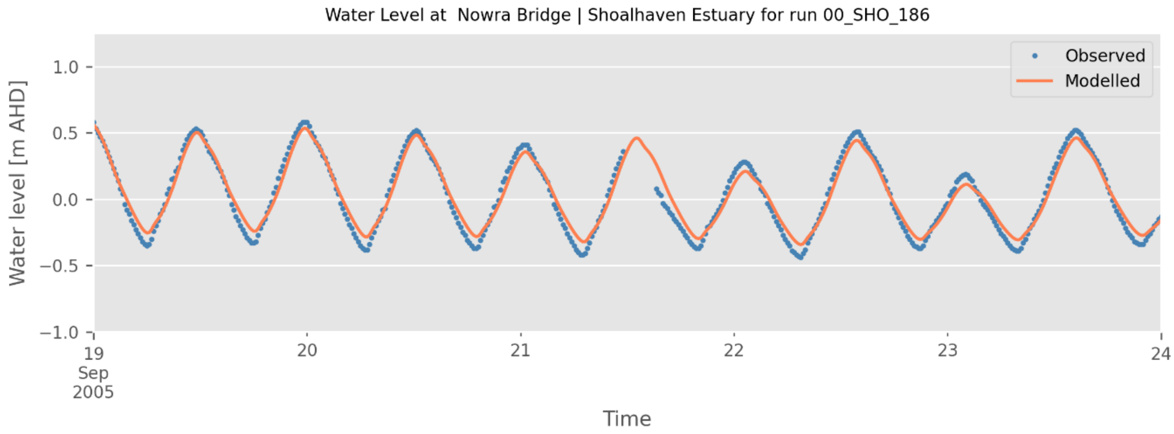

Figure B-17 2005 water level calibration – Location 9 – Nowra Bridge

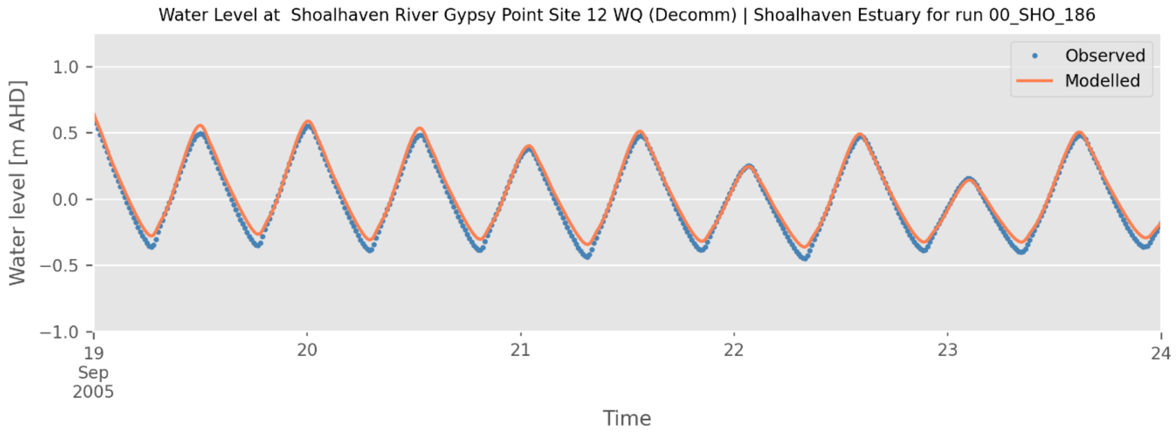

Figure B-18 2005 water level calibration – Location 10 – Gypsy Point

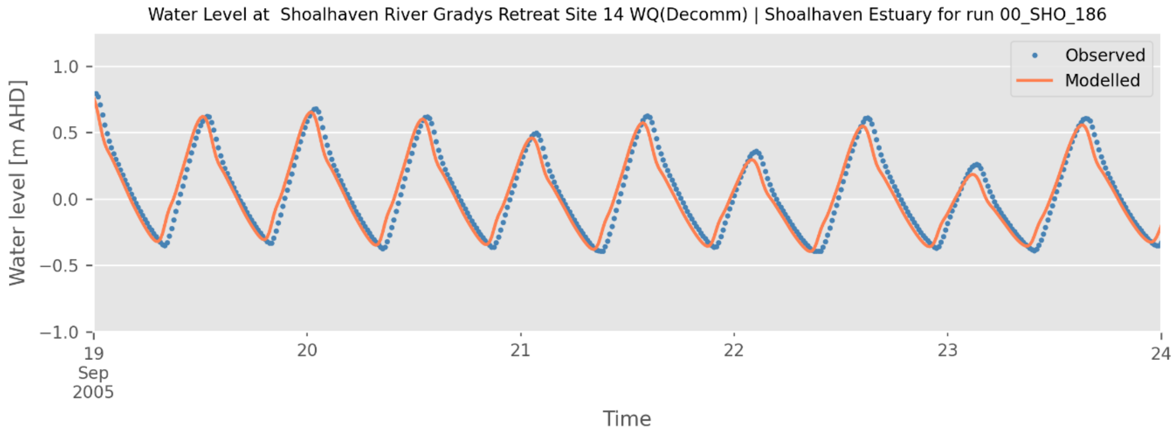

Figure B-19 2005 water level calibration – Location 11 – Gradys Caravan Park

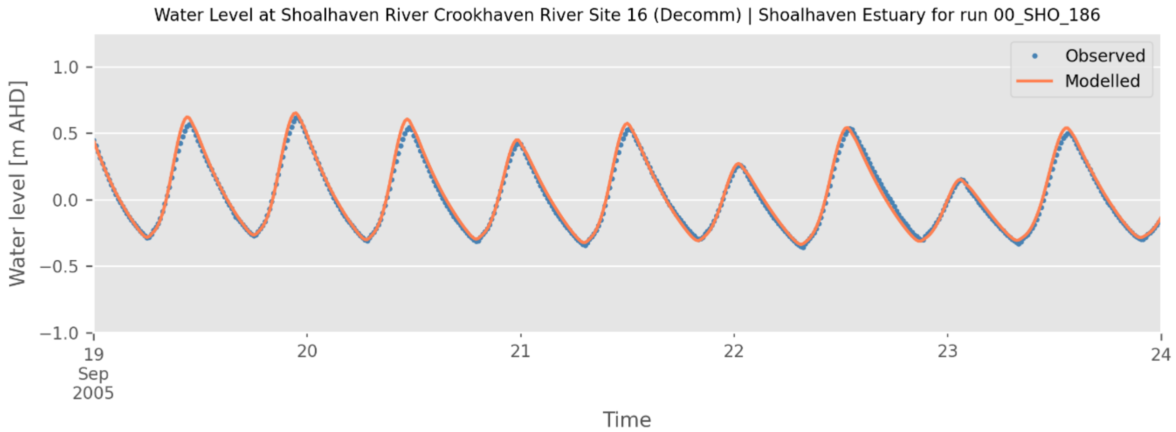

Figure B-20 2005 water level calibration – Location 12 – Crookhaven River

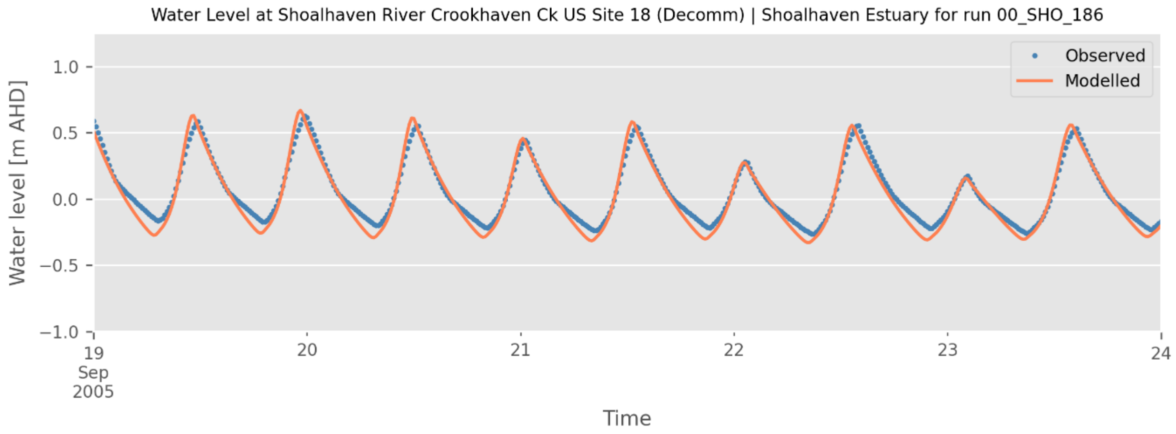

Figure B-21 2005 water level calibration – Location 13 Crookhaven Creek

B1.3 Tidal flow gauging validation – 1996 (Shoalhaven Heads closed)

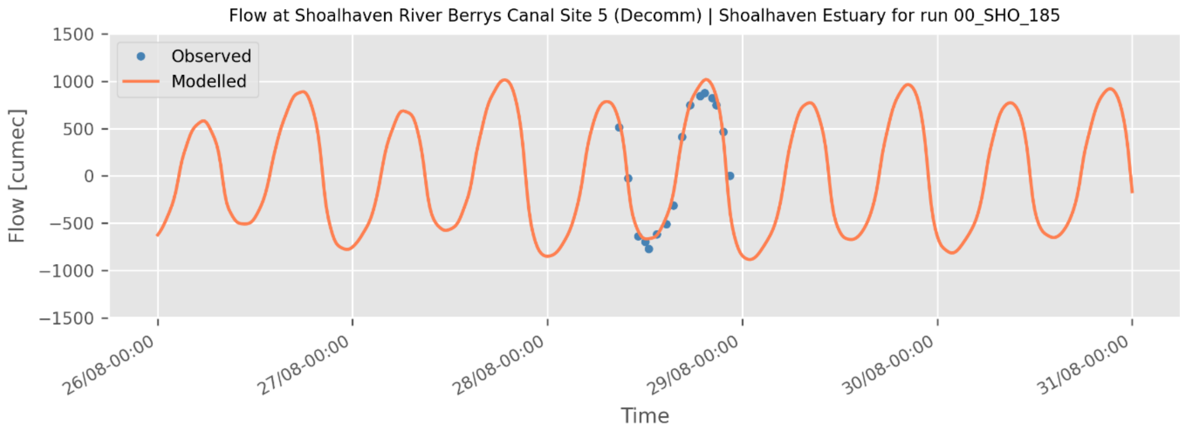

Figure B-22 1996 tidal flow calibration – Location G – Berrys Canal

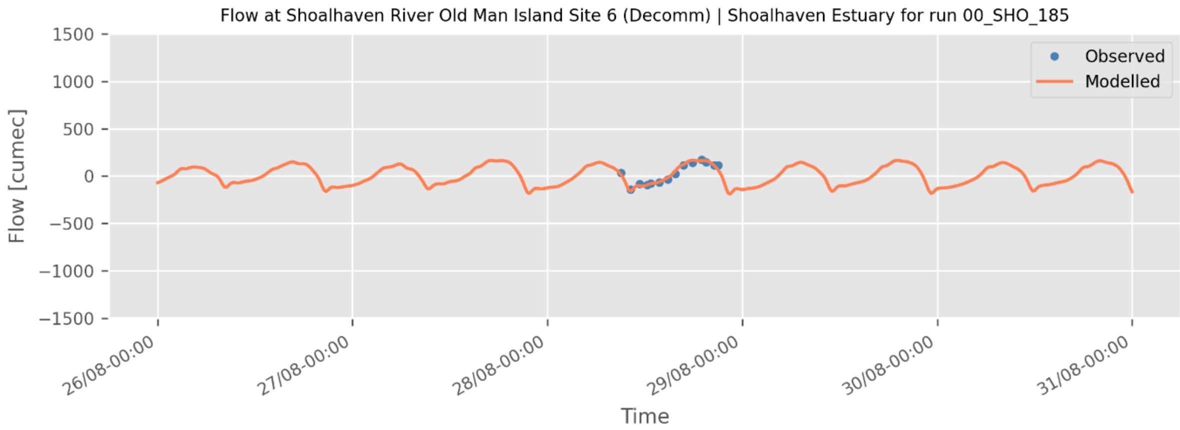

Figure B-23 1996 tidal flow calibration – Location D – Old Man Island

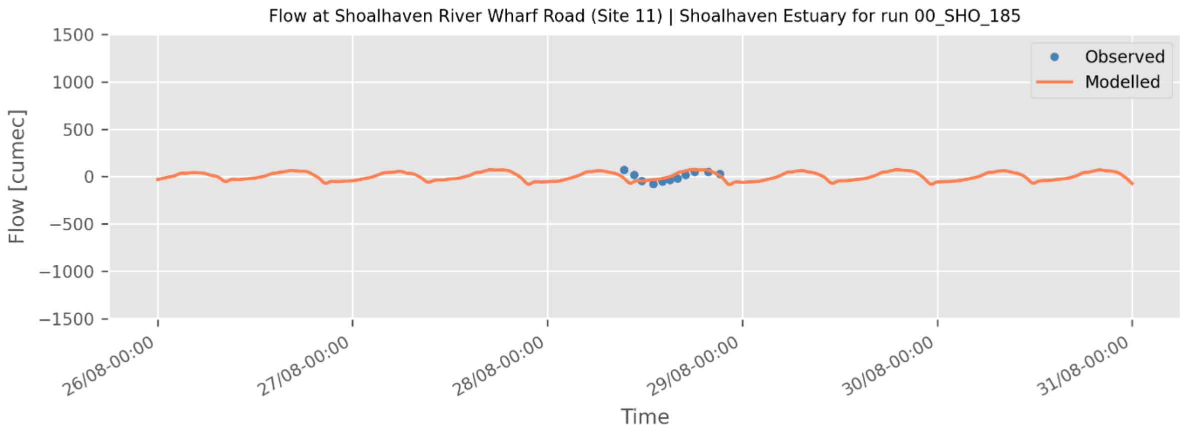

Figure B-24 1996 tidal flow calibration – Location H – Shoalhaven River Wharf Road

B1.4 Water level validation – 1996 (Shoalhaven Heads closed)

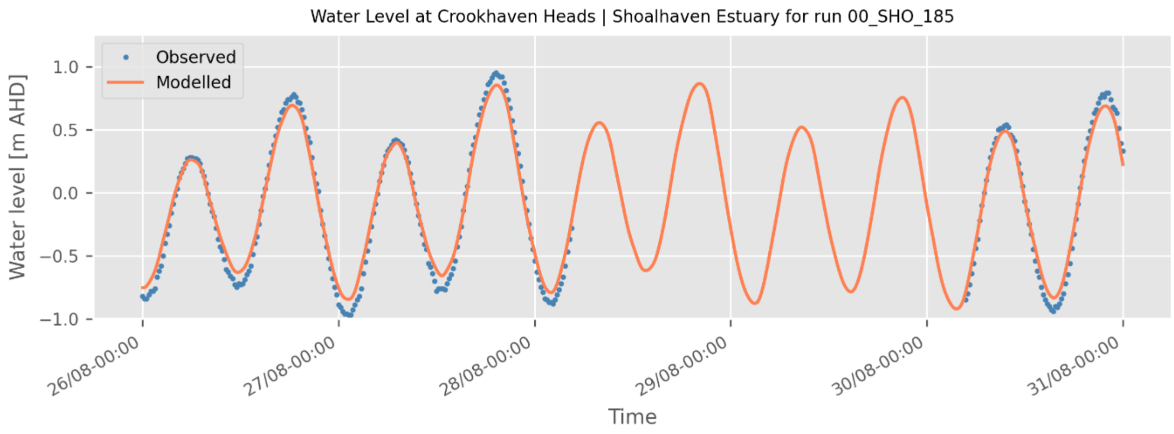

Figure B-25 1996 water level calibration – Location 1 – Crookhaven Heads

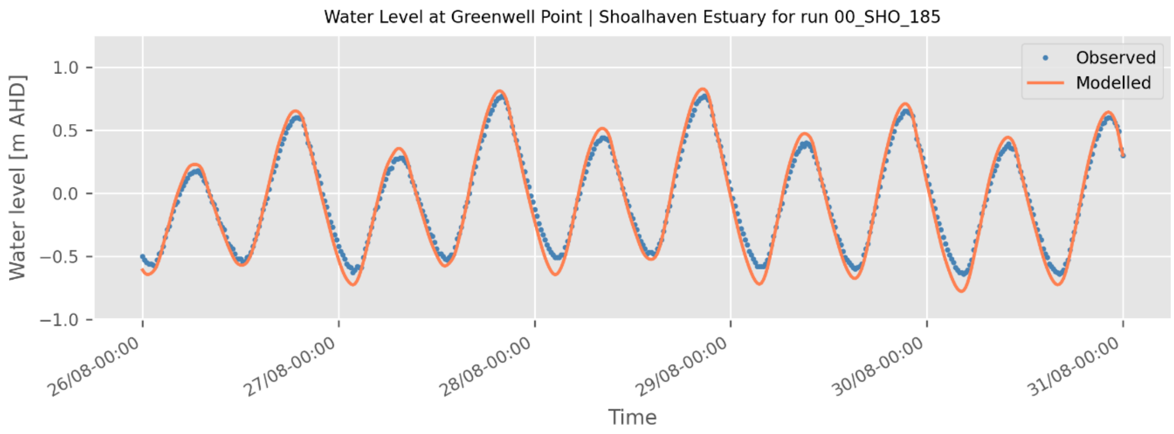

Figure B-26 1996 water level calibration – Location 2 – Greenwell Point

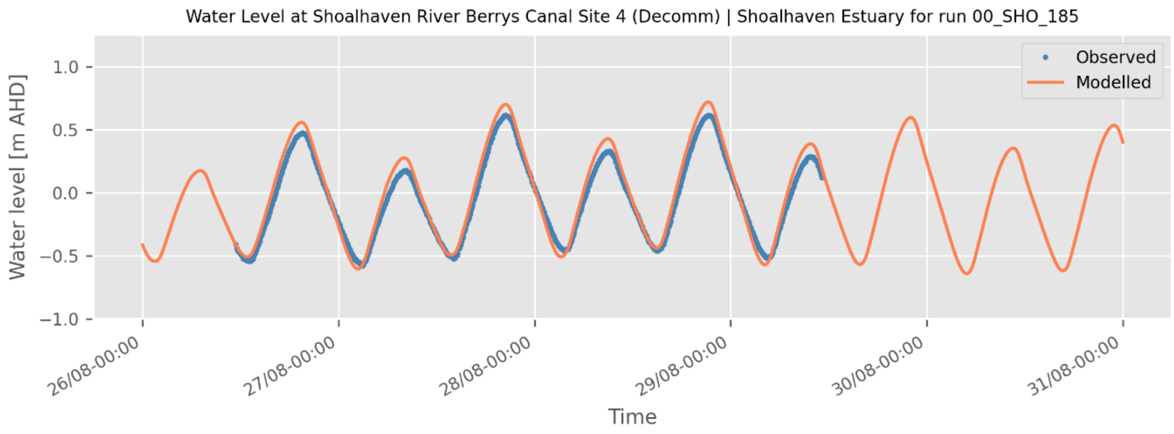

Figure B-27 1996 water level calibration – Location 14 – Berrys Canal Site 4

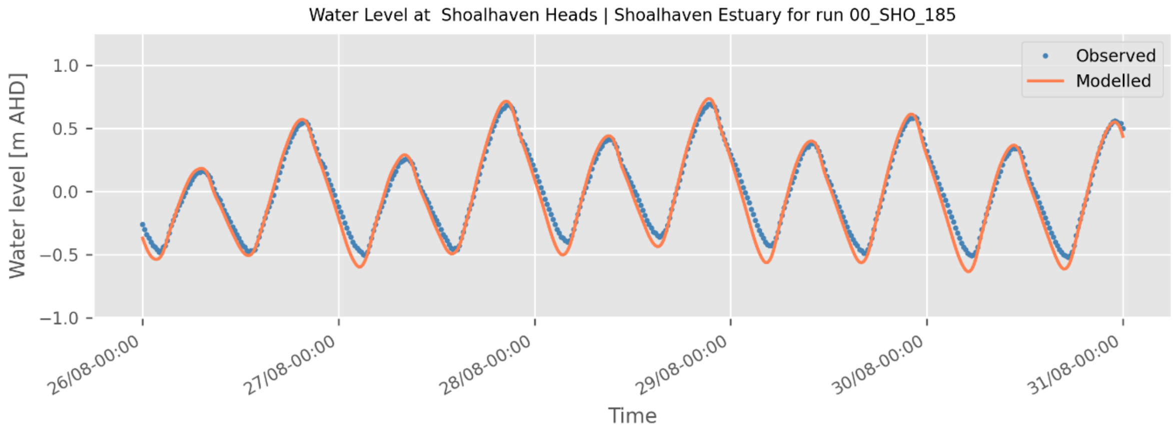

Figure B-28 1996 water level calibration – Location 5 – Shoalhaven Heads

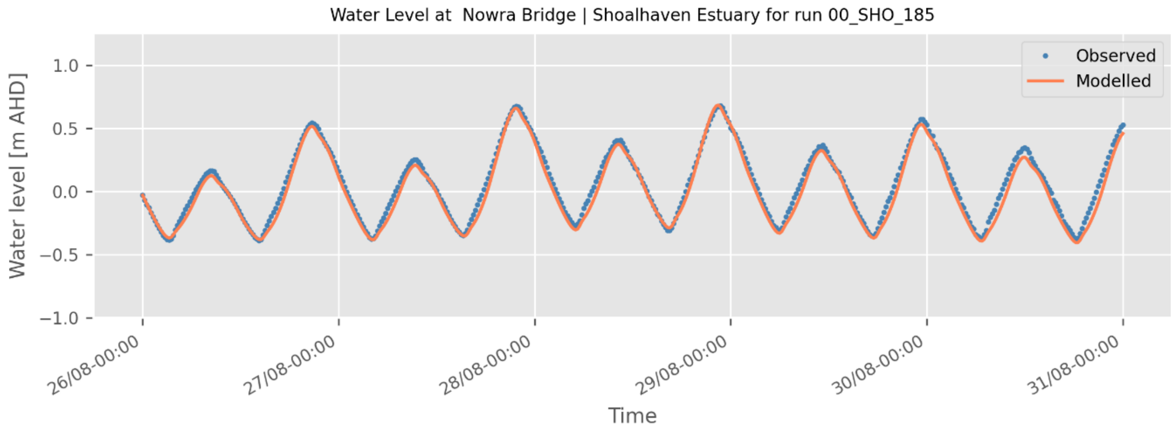

Figure B-29 1996 water level calibration – Location 9 – Nowra Bridge

B1.5 Tidal flow gauging calibration – 1993 (Shoalhaven Heads closed)

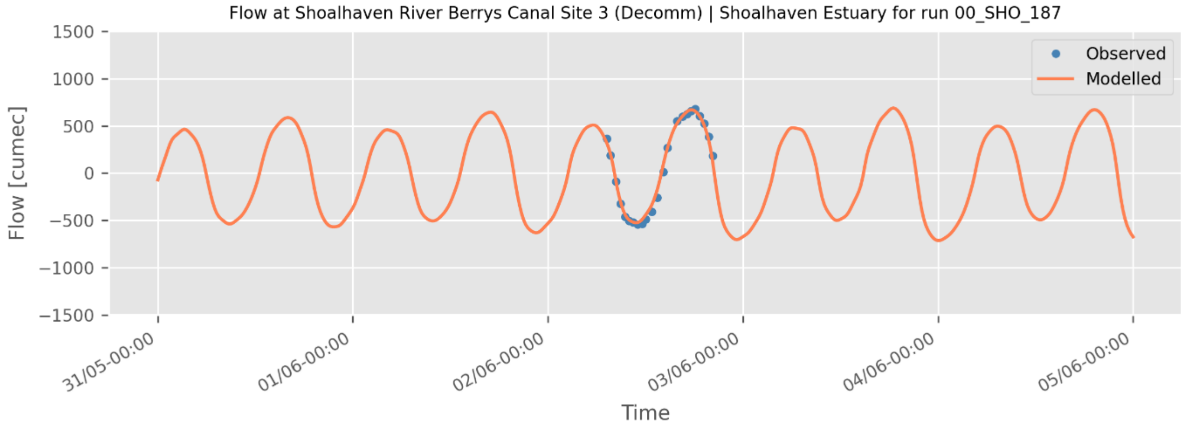

Figure B-30 1993 tidal flow verification – Location C – Berrys Canal

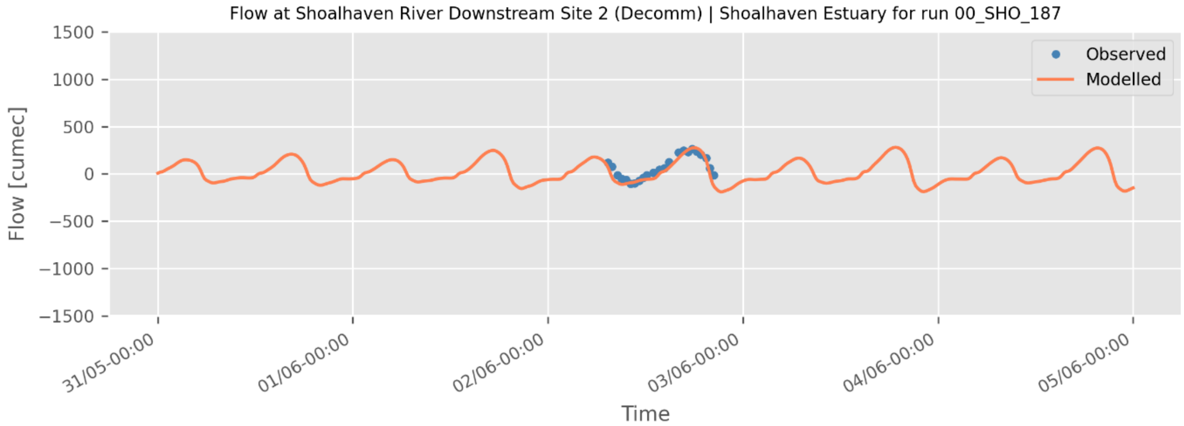

Figure B-31 1993 tidal flow verification – Location I – Shoalhaven River Downstream (Old Man Island)

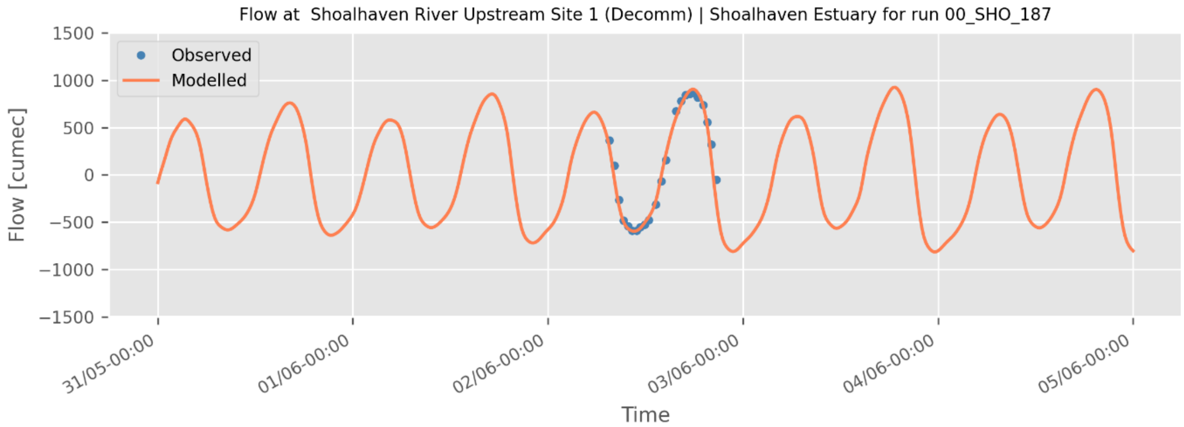

Figure B-32 1993 tidal flow verification – Location J – Shoalhaven River

B1.6 Water level calibration – 1993 (Shoalhaven Heads closed)

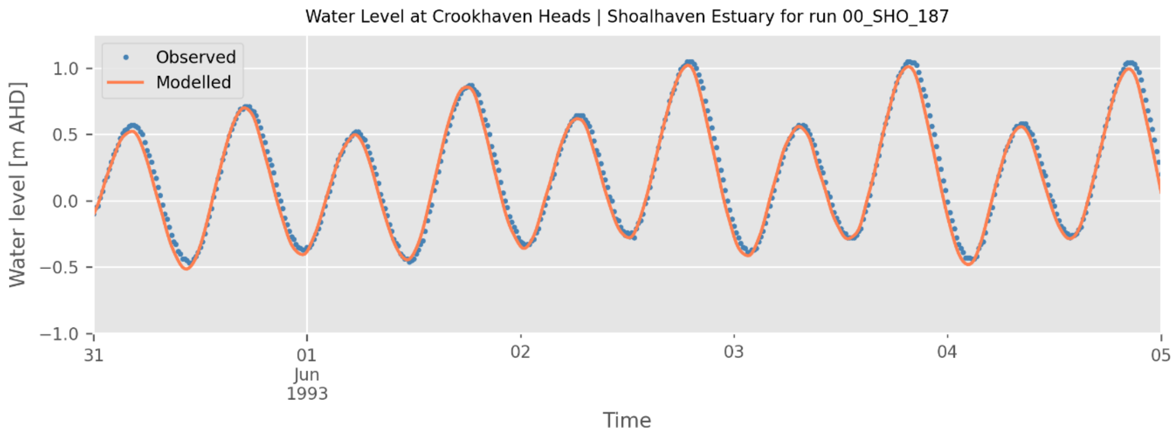

Figure B-33 1993 water level verification – Location 2 – Greenwell Point

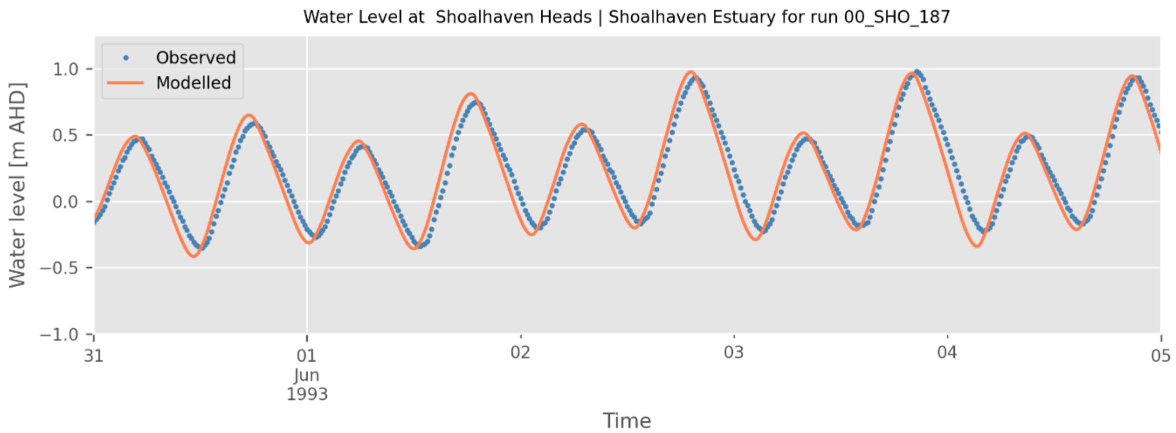

Figure B-34 1993 water level verification – Location 5 – Shoalhaven Heads

B1.7 Water level verification – 2023 (Shoalhaven heads partially open)

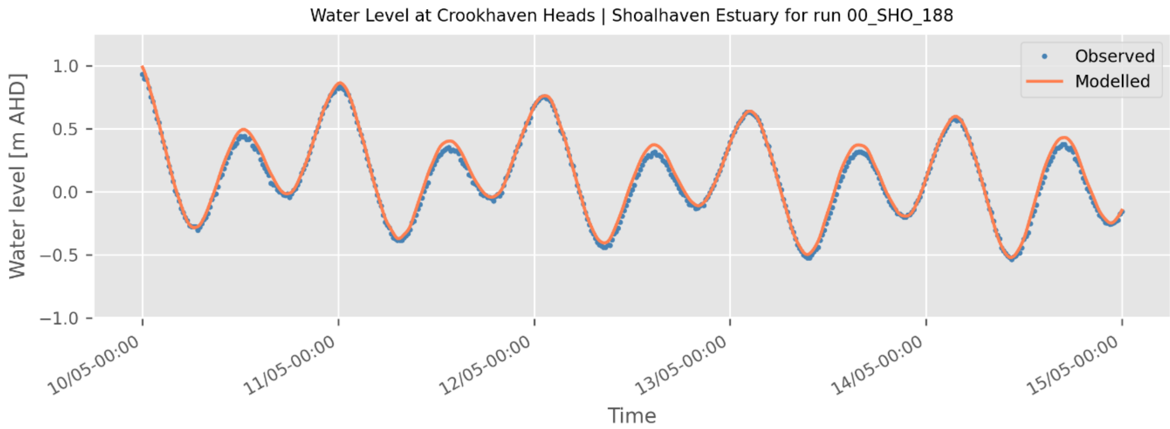

Figure B-35 2023 water level validation – Location 1 – Crookhaven Heads

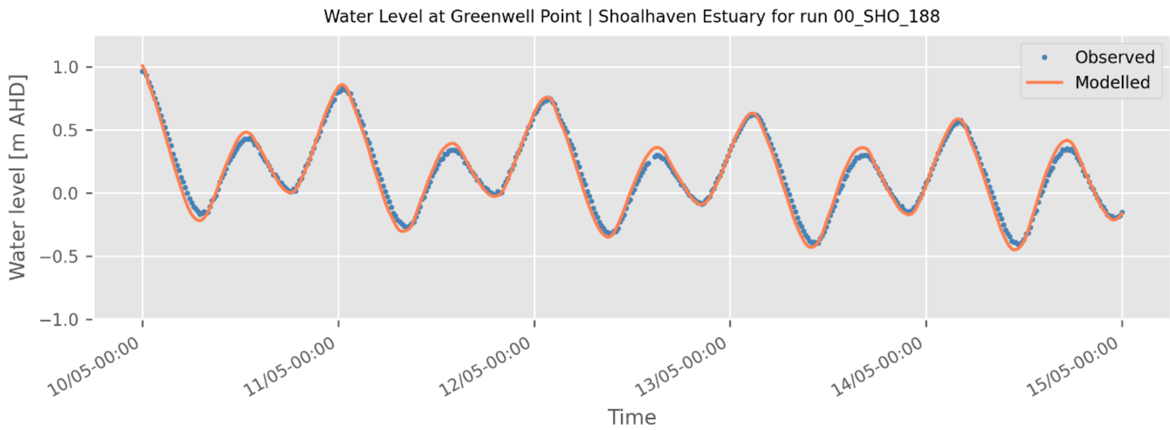

Figure B-36 2023 water level validation – Location 2 – Greenwell Point

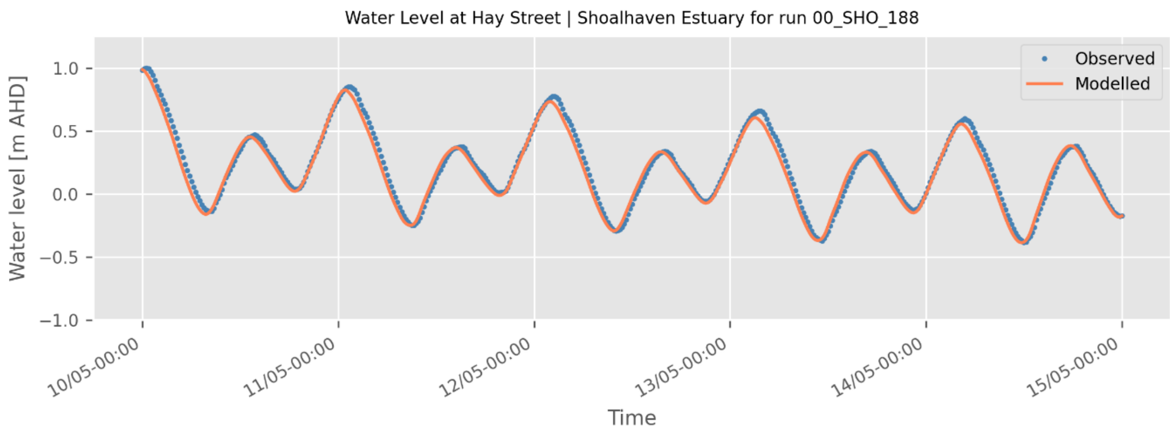

Figure B-37 2023 water level validation – Location 4 – Hay Street

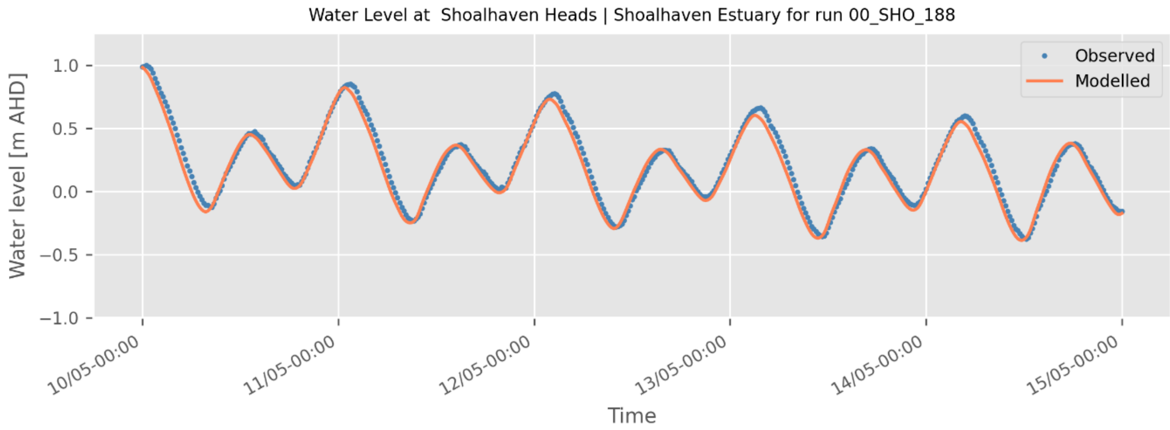

Figure B-38 2023 water level validation – Location 5 – Shoalhaven Heads

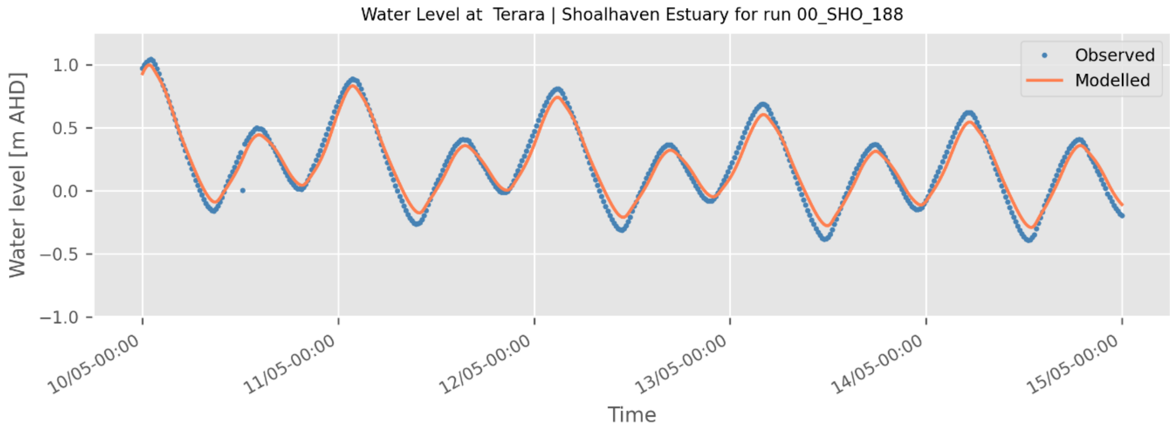

Figure B-39 2023 water level validation – Location 8 – Terara

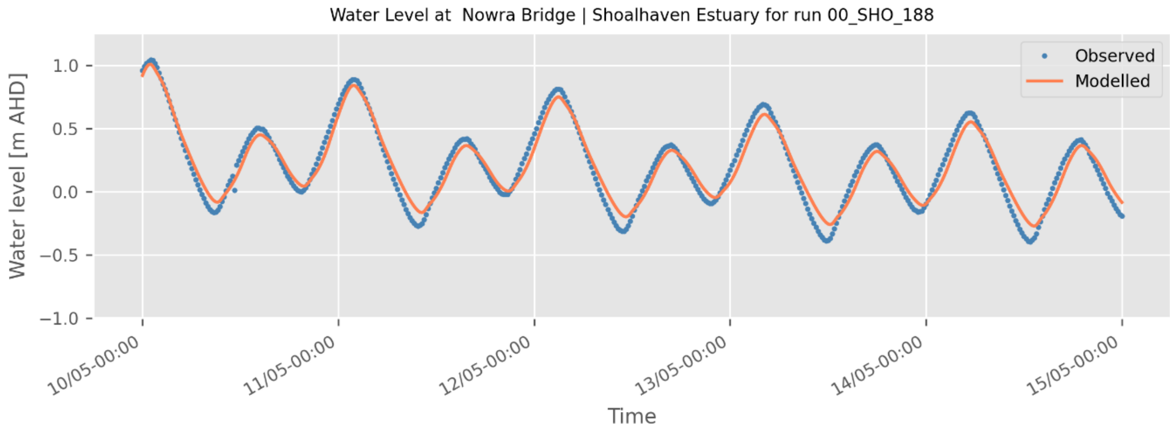

Figure B-40 2023 water level validation – Location 9 – Nowra Bridge

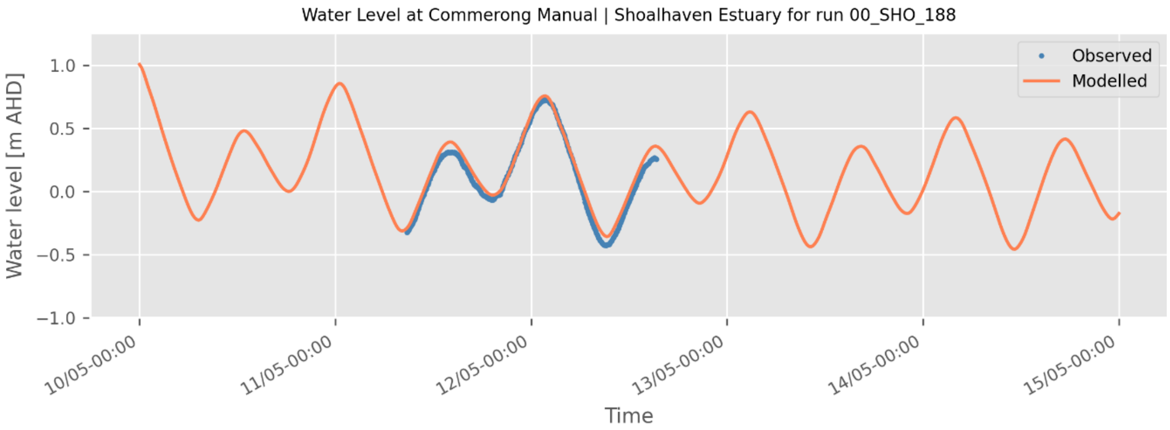

Figure B-41 2023 water level validation – Location 15 – Comerong Bay

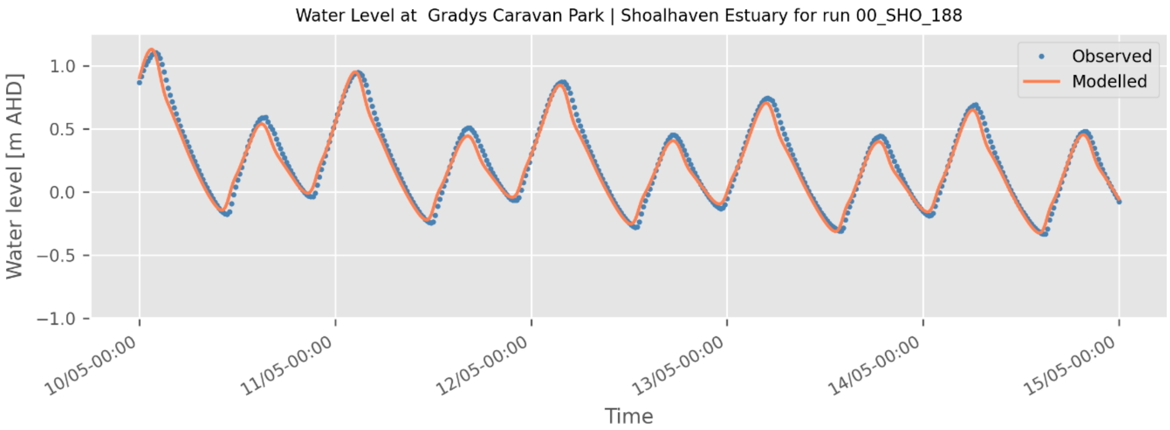

Figure B-42 2023 water level validation – Location 16 – Gradys Caravan Park