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

WRL TR 2023/24, 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 Clyde 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 Clyde 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 (this report)
Shoalhaven/Crookhaven Rivers	WRL TR2023/23
Wagonga Inlet	WRL TR2023/25
Merimbula Lake	WRL TR2023/26
Pambula Lake	WRL TR2023/27

1.3 Clyde River site description

The Clyde River estuary is a coastal river in NSW, Australia, located 225 km south of Sydney. Major towns in the area include Batemans Bay and surrounding suburbs, Nelligen and Currowan. The river enters the ocean at Batemans Bay, which is a large, deep, funnel shaped embayment. There is a training wall along the southern shore where the river enters the bay, while off the northern shore there is a large, mobile sand bar. The Buckenbowra River is a major tributary and Nelligen Creek, Waterfall Creek and Cyne Mallows Creek are minor tributaries. The catchment is approximately 2,900 km^2 and the tidal extent is approximately 47 km upstream of the ocean (MHL, 1996). The tidal prism measured on a spring tide in 1996 was 20.36×10^6 m^3 at the Princes Highway bridge (MHL, 1996). The river experiences tidal amplification, with the tidal range increasing approximately 20 cm between Princess Jetty and Nelligen. The estuary has three oyster harvest areas: Moonlight, Rocky Point, and Waterfall, shown in Figure 1-1.

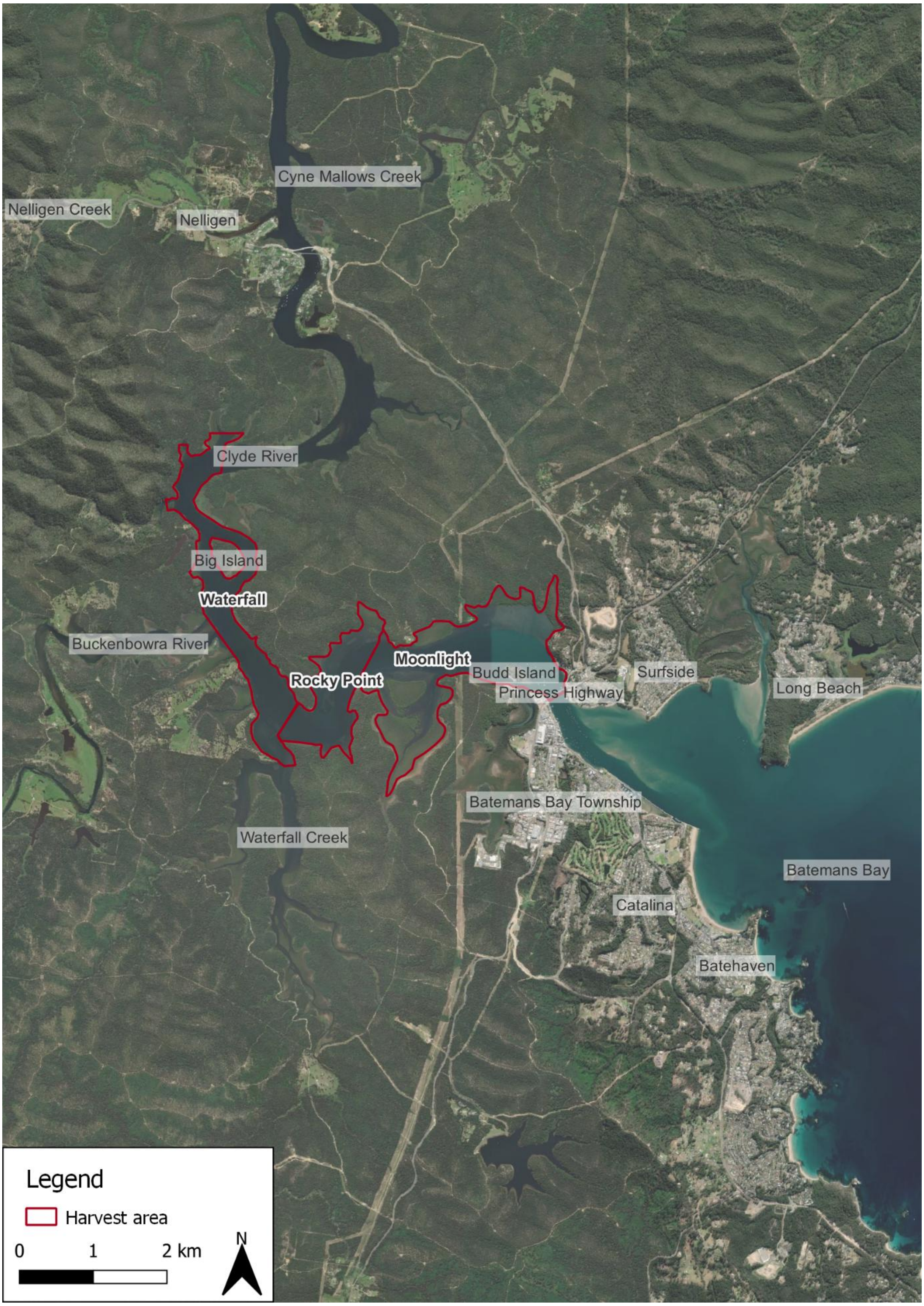

Figure 1-1 Oyster harvest areas on the Clyde River

1.4 About this report

This report includes the following sections:

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

The following appendices are included which provide additional detail:

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

2 Data collation

2.1 Preamble

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

Table 2-1 Summary of data collated for this project

Data type	Primary sources	Comments	Report section
Long term water level data	MHL (2023b) MHL (2023c)	Long term water level data available at one location in the Clyde River and at three nearby ocean tide gauges.	2.2
Tidal flow and water level	MHL (1996)	Tidal flow gauging at five locations and temporary water level gauging at an additional four locations in September to November 1996.	2.2
Catchment discharge	WaterNSW (2023)	Two long term catchment flow monitoring locations on the Clyde River and Buckenbowra 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	DPIE (2018) OEH (1995); OEH (1998); OEH (2014) NSW Spatial Services (2011) NearMap (2024)	Bathymetry primarily sourced from OEH 1998 single beam survey and 2018 NSW Marine LiDAR Topo-Bathy survey, with supplementary data from OEH 1995 single beam survey, 2011 Digital Elevation Model (DEM) and NearMap aerials.	2.5

2.2 Water level and tidal flow gauging

Manly Hydraulics Laboratory (MHL) maintain one permanent water level gauge installed on the Clyde River, one permanent ocean tide gauge on the Clyde River at Princess Jetty, and two other nearby ocean tide gauges. Further water level and flow gauging has occurred during the short-term data collection campaign run by MHL in 1996. These gauging and water level sensor locations are shown in Figure 2-1 and tabulated in Table 2-2 and Table 2-3. Water level and flow gauging locations from the 2023 field campaign (refer to Section 3) are also included in these.

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

Water level gauge	Location label	Station number	Provider	Date range	MHL report number
Princess Jetty	1	216410	MHL	1985 – present	-
Nelligen	5	216453	MHL	1994 – present	-
Ulladulla	-	216471	MHL	2008 – present	-
Jervis Bay	-	216470	MHL	1989 – present	-
Waterfall Creek Site 6	2	-	MHL	05/10/1996 – 05/11/1996	MHL792
Mays Wharf Site 8	3	-	MHL	08/10/1996 – 05/11/1996	MHL792
Buckenbowra River Site 11	4	-	MHL	25/09/1996 – 03/11/1996	MHL792
Nelligen Upstream Site 15	6	-	MHL	24/09/1996 – 27/09/1996	MHL792

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

Tidal flow gauge	Location label	Dates	Study
Highway Bridge Site 3	A	26/09/1996, 22-23/08/2023	MHL792, 2023 fieldwork
Mays Wharf Site 7	B	26/09/1996	MHL792
Buckenbowra River Site 10	C	26/09/1996	MHL792
Nelligen Upstream Site 14	D	26/09/1996	MHL792
Currowan Site 16	E	26/09/1996	MHL792
Big Island	F	23/08/2023	2023 fieldwork

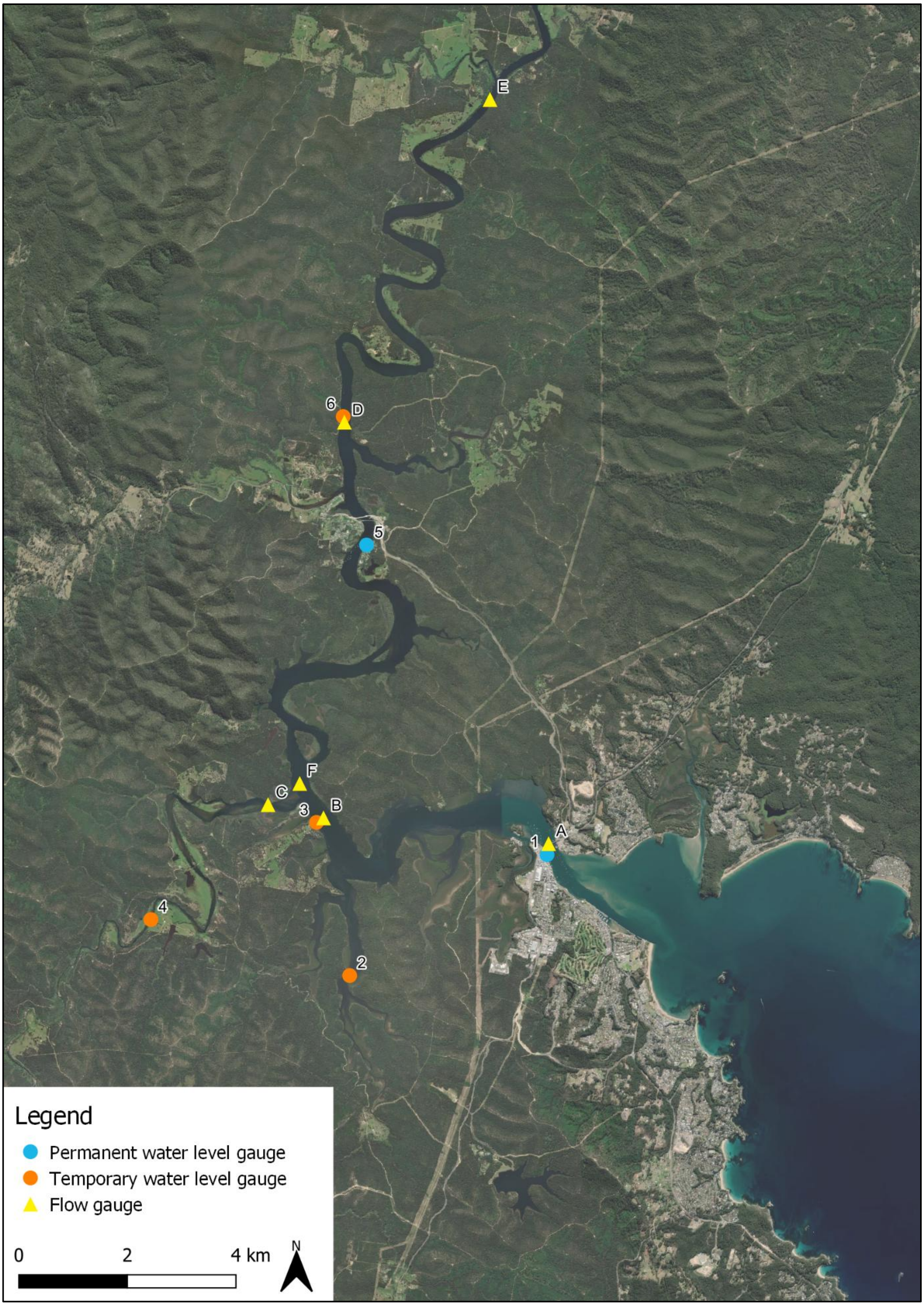

Figure 2-1 Water level and tidal flow gauging locations

2.3 Catchment inflows

Gauged catchment inflows were available from WaterNSW. When these were not at the tidal limit (the model boundary), the flows were scaled up proportional to the additional catchment area using the method in WRL TR2023/32 Section 2.4. There are three model boundary inflows into the Clyde River estuary and continuous flow gauging of discharge and water levels are available from WaterNSW (2023) at two relevant locations: Buckenbowra River (1985 to present) and Clyde River at Brooman (1960 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
Buckenbowra River	216009	1.375
Clyde River	216002	1.000

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

Table 2-5 WaterNSW gauge flow percentiles

Percentile	Buckenbowra River (216009) ML/d *(m^3/s)*	Clyde River at Brooman (216002) ML/d *(m^3/s)*
5th	0.30 *(0.00)*	4.5 *(0.05)*
20th	3.9 *(0.05)*	43 *(0.50)*
50th (median)	21 *(0.25)*	180 *(2.1)*
80th	81 *(0.94)*	1140 *(13)*
95th	619 *(7.2)*	7928 *(92)*

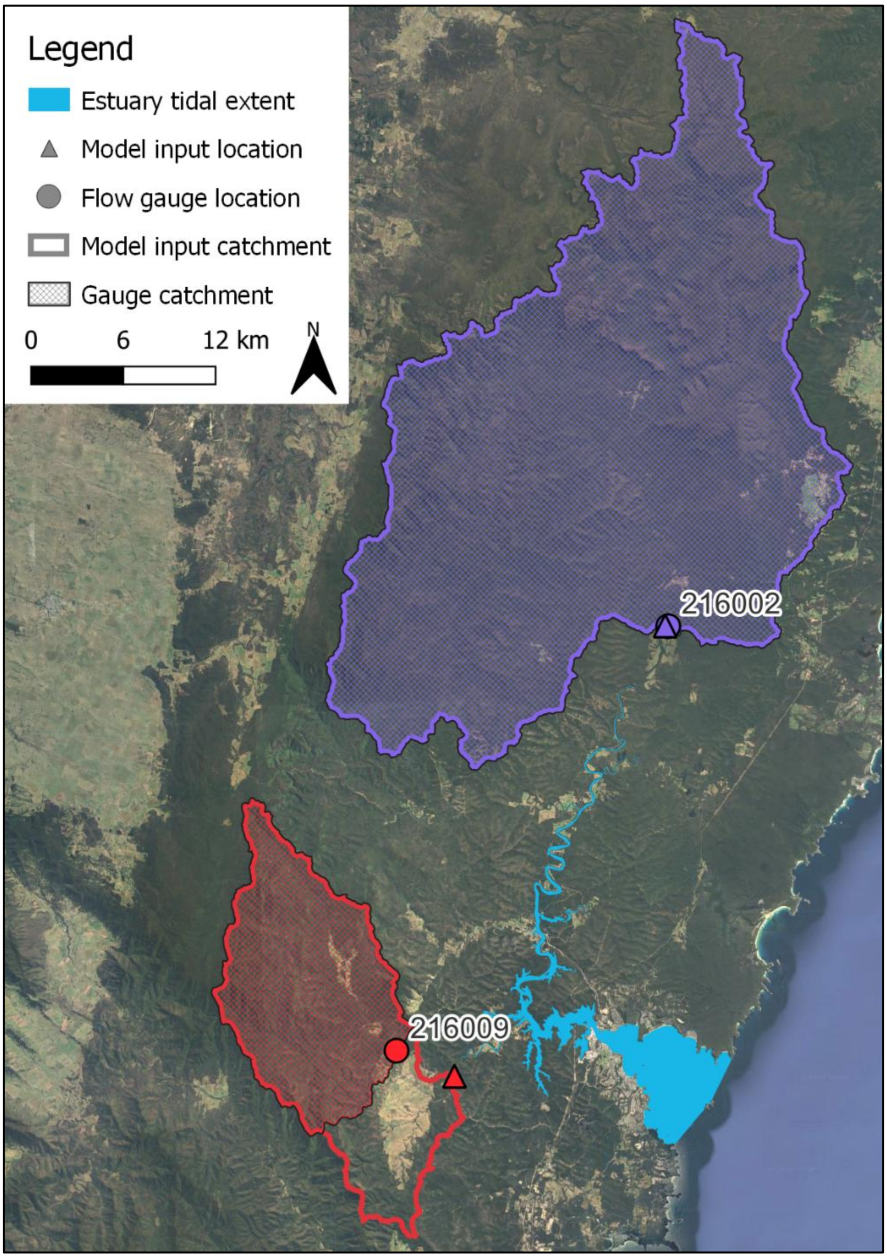

Figure 2-2 Catchment flow gauging stations*

*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

Eurobodalla Shire Council (ESC) is the agency responsible for wastewater treatment and sewage management in the catchment surrounding the Clyde River estuary. The sewerage system is comprised of a reticulation network of pipes and sewage pumping stations (SPSs), in addition to the wastewater treatment plant (WWTP) at Batemans Bay. When sewage overflows occur, ESC 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.

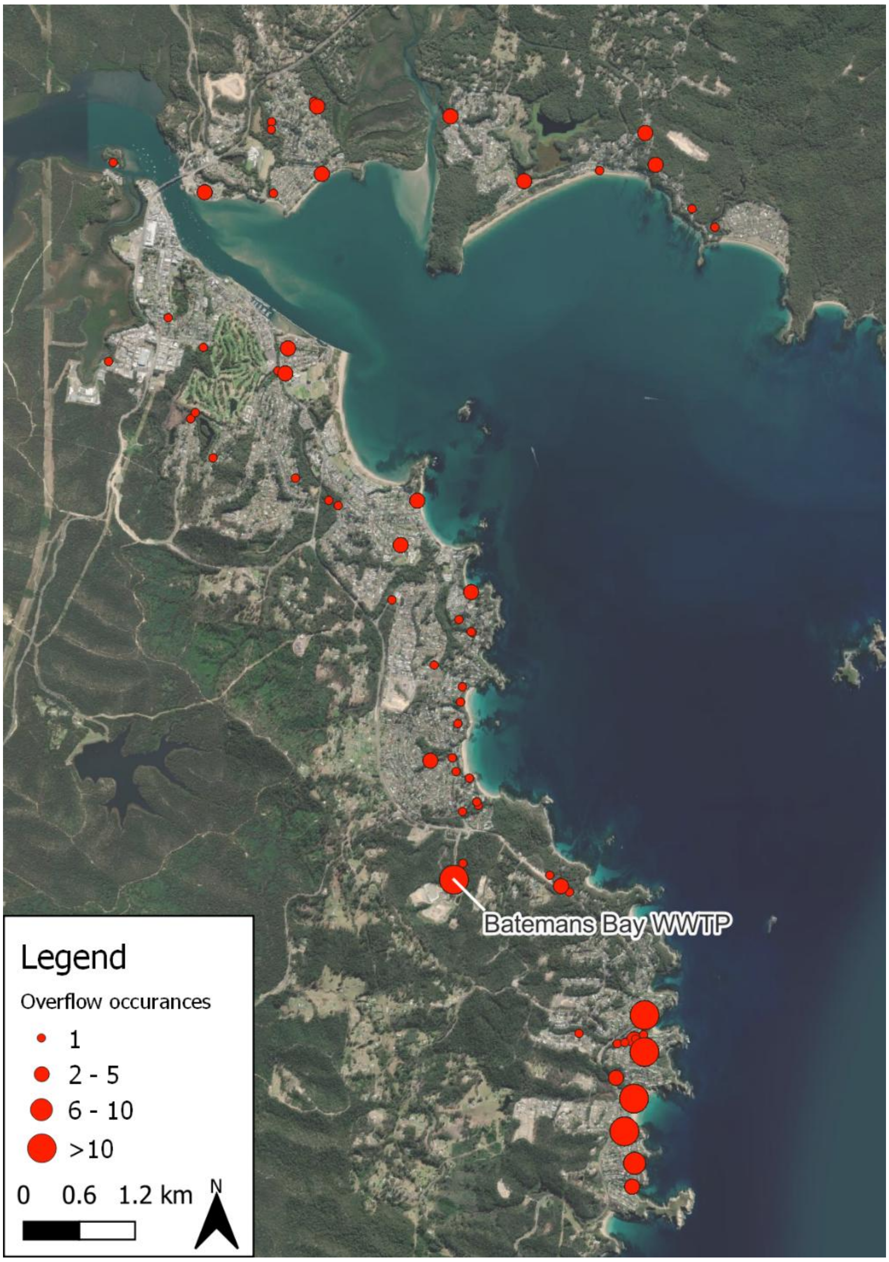

Figure 2-3 Locations of reported sewage overflows on the Clyde River

2.5 Bathymetry

Two existing bathymetry datasets were sourced for this project:

- Coastal marine LiDAR collected by the former NSW Department of Planning, Industry and Environment (DPIE, now DCCEEW) in 2018. In the Batemans Bay area, this survey covers areas from the highway bridge to approximately 2 km offshore (shown in Figure 2-4) at a resolution of 5 m. This is the most recent data and was used as the preferred bathymetry source for all regions of the mesh covered by the survey extent.
- Single beam bathymetry data collected in 1995 in Batemans Bay, 1998 in the Clyde River and 2014 on several beaches and nearshore areas. These datasets were collated and provided by the NSW Office of Environment and Heritage (OEH, now DCCEEW) and are available on the Australian Ocean Data Network (AODN) portal. The 1998 data consists of transects spaced

approximate every 250 m from the highway bridge to Nelligen, then every 500 m upstream to the tidal extent. Sparse transect data was also collected in Waterfall Creek and Buckenbowra River. The 1995 Batemans Bay data set covers the region from the highway to a line between Reef Point and Sunshine Cove. This data was converted from chart datum to AHD. The 2014 data covers areas adjacent to Wimbie Beach and Maloneys Beach. Figure 2-5 shows all bathymetry data. This data was used in regions not covered by the LiDAR data, primarily upstream of the Princes Highway Bridge.

For areas where the OEH surveys in Batemans Bay overlapped the DPIE data, bathymetry was compared refer to Figure 2-6. Differences in some areas were substantial, especially around the sand bar on the north side of the channel connecting the river to the bay. Based on aerial imagery, it is apparent that the location and shape of this sand bar is variable, however it appears to be in a state of dynamic equilibrium with no visual long-term trends. Despite this variation, a single bathymetry was used for modelled scenarios, as discussed in Section 5.4.

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 important bathymetric features. Locations where NearMap informed model bathymetry include the upstream areas of Waterfall Creek and Buckenbowra River, and other tributaries.

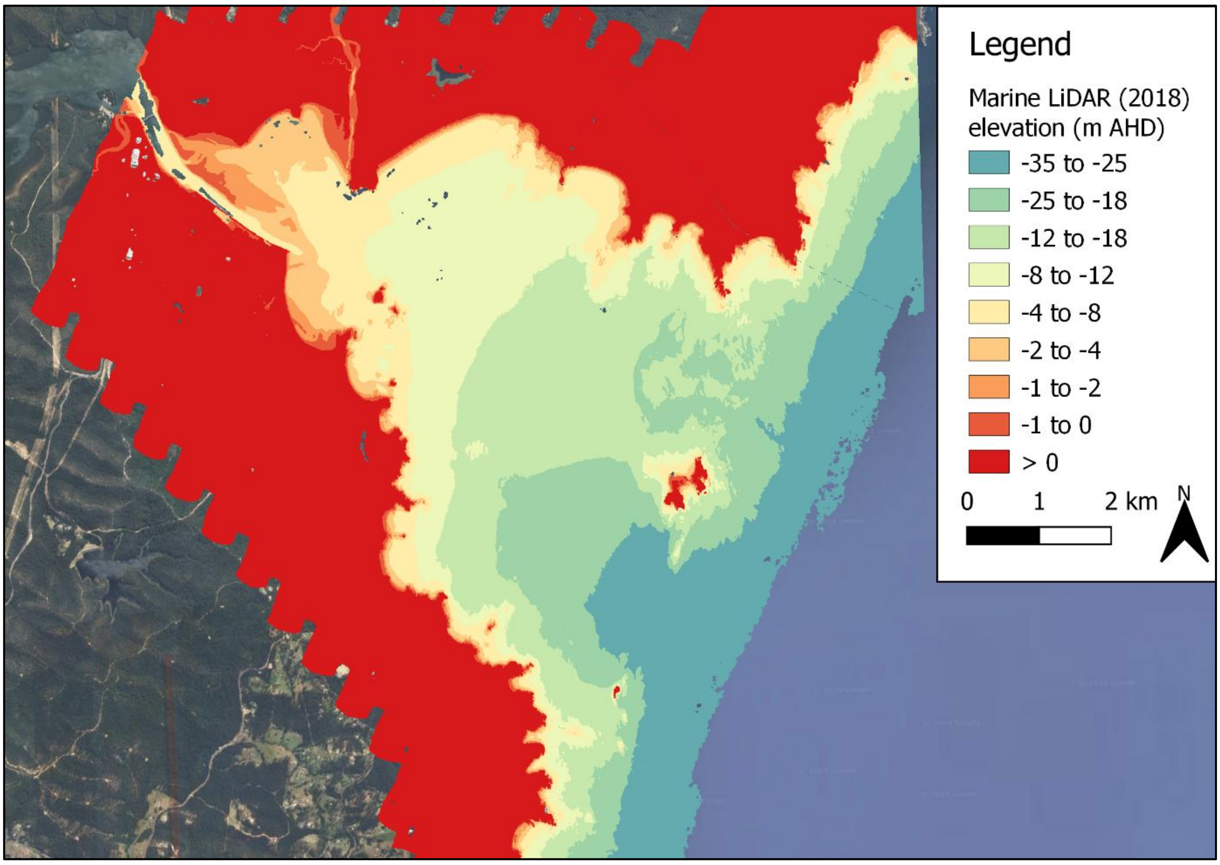

Figure 2-4 Coverage of the 2018 DPIE LiDAR survey

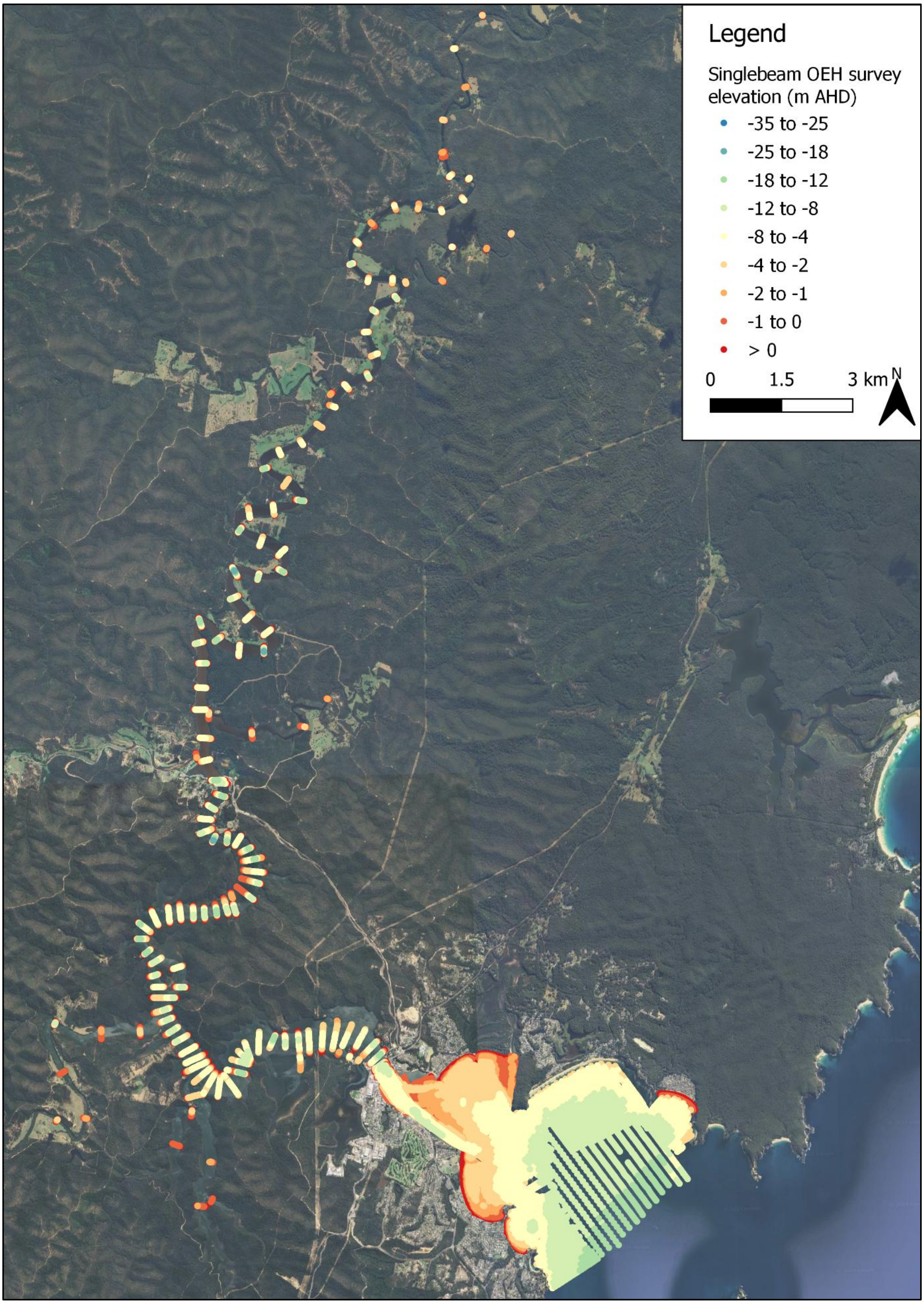

Figure 2-5 Coverage of the OEH single beam data

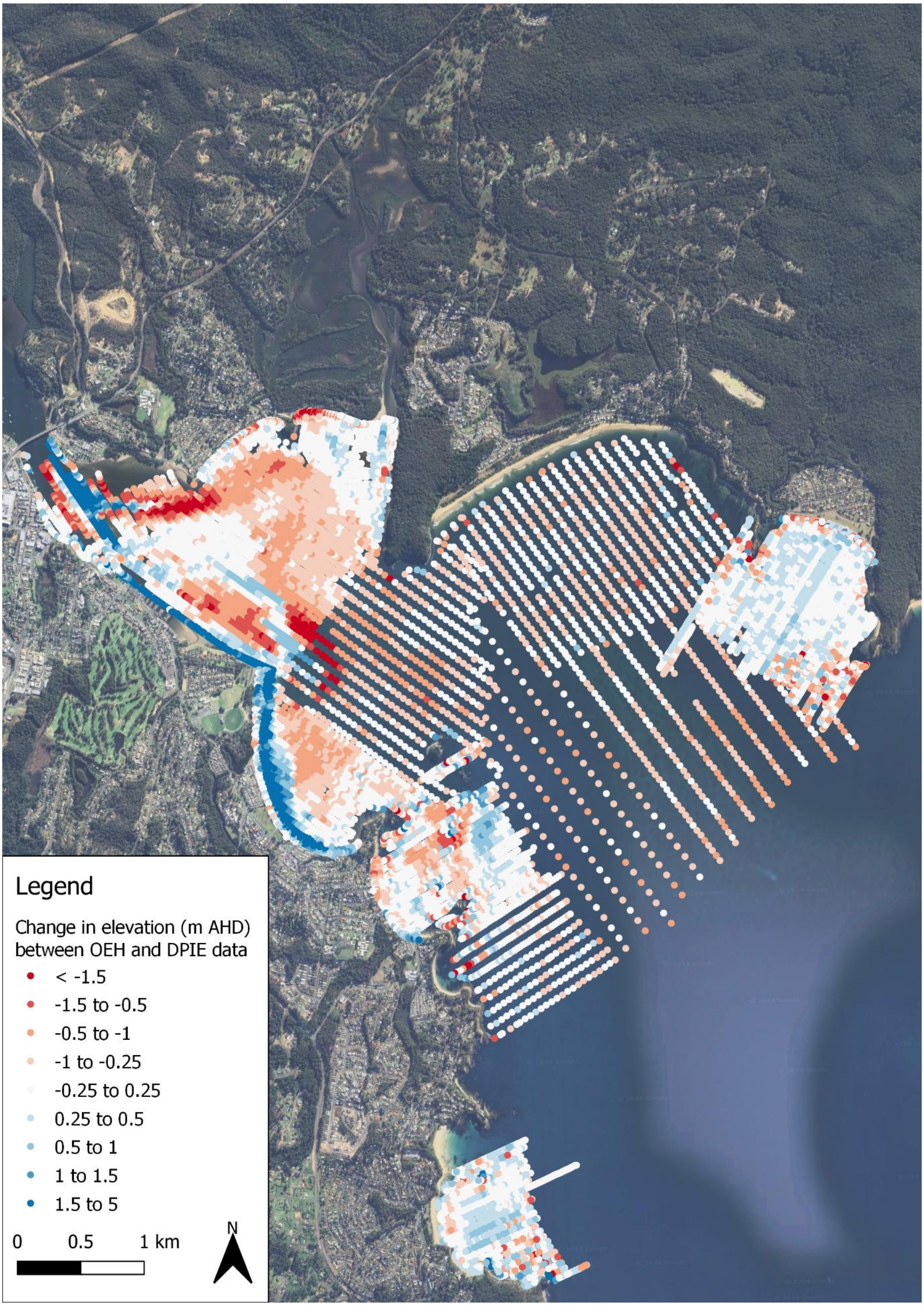

Figure 2-6 Bathymetry change between 1995 survey and 2018 marine LiDAR. Red corresponds to erosion and blue to accretion

3 Field data collection

3.1 Preamble

A data collection campaign was completed on 22 and 23 August 2023 by Margot Mason and Alice Harrison. Field data collection included:

- Monitoring of current velocities and volumetric flow using an ADCP
- Bathymetry and elevation measurements
- Monitoring of dispersion and advection using Rhodamine WT dye
- Monitoring of surface current speed and flow paths using GPS drifter drogues
- Conductivity measurements
- Collation of data from MHL water level monitoring sites

3.2 Weather and tides

Data collection on the Clyde River was undertaken on both ebb and flood tides. Tides during field investigations were similar both days, with tidal ranges between approximately -0.30 to 0.55 m AHD at Princess Jetty, where the Clyde River enters Batemans Bay. The observed water levels at Princess Jetty, 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 Jervis Bay (source of the driving tides for the model) and Princess Jetty are shown in Figure 3-2. These tides have a positive anomaly due to low pressure which increased in the early morning of 23 August 2023 (MHL, 2023a).

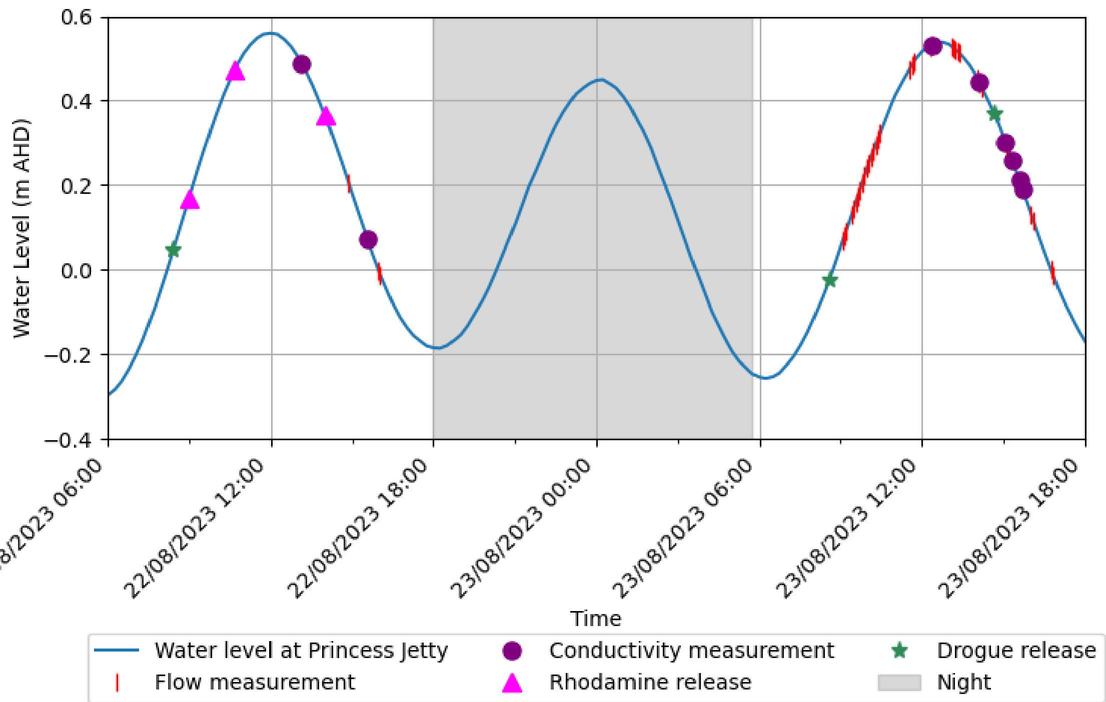

Figure 3-1 Tides at Princess Jetty with timing of key data collection events

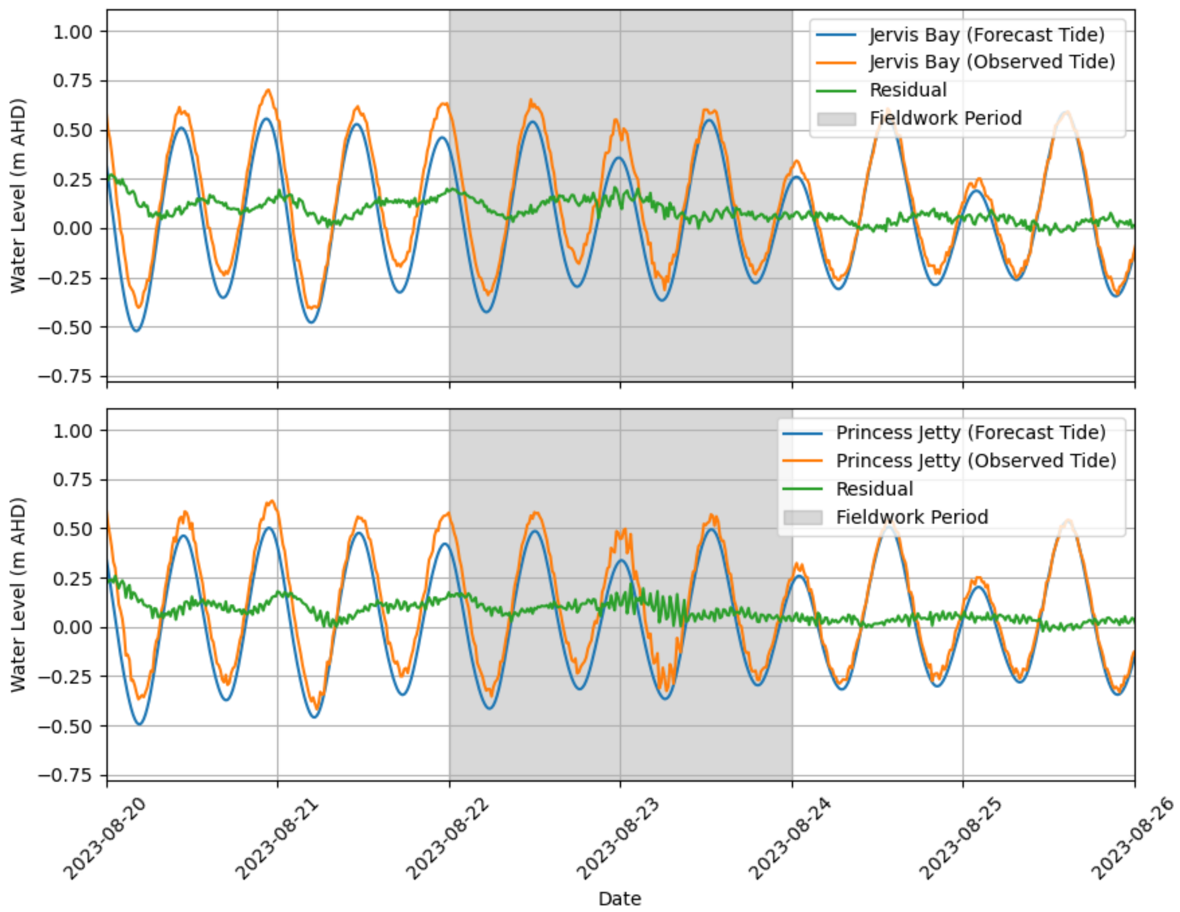

Figure 3-2 Forecasted and observed tides at Jervis Bay (upper) and Princess Jetty (lower)

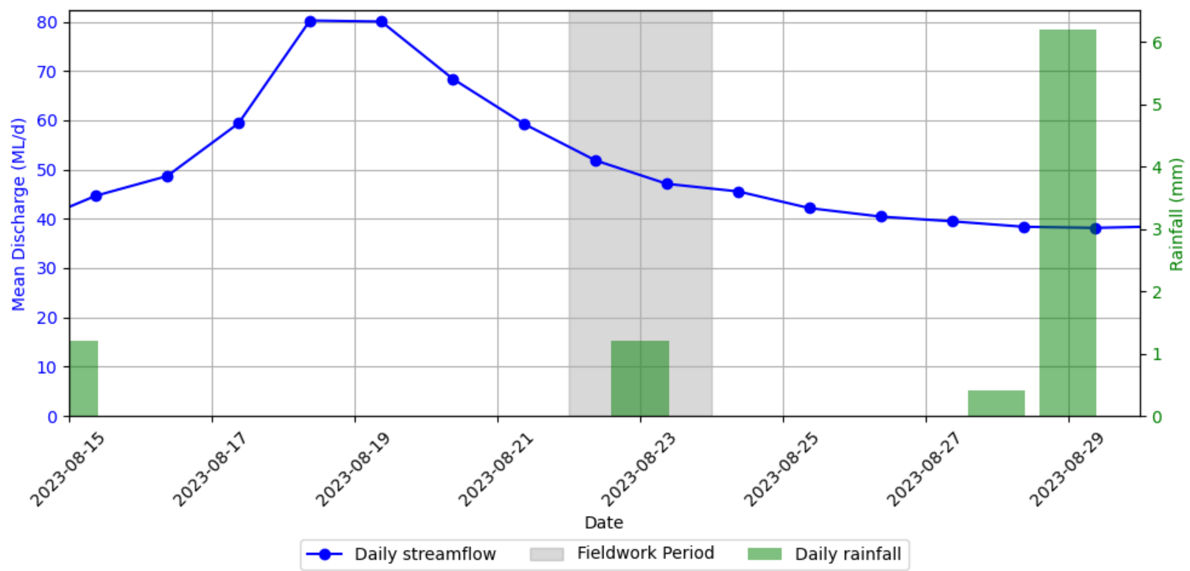

Figure 3-3 Rainfall recorded at Nelligen and streamflow recorded at Clyde River at Brooman for the period surrounding fieldwork

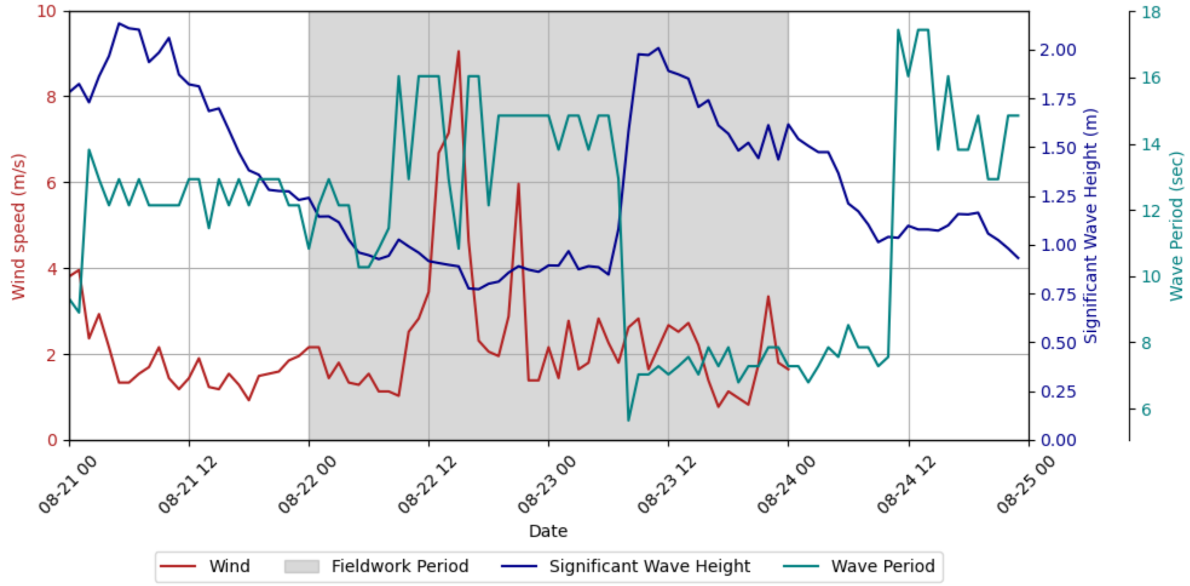

Figure 3-4 Wind recorded at Budd Island and wave data recorded at the Batemans Bay waverider buoy for the period surrounding fieldwork

While no rainfall fell during fieldwork, 1.2 mm fell after fieldwork ceased at Nelligen (BoM station 69023, refer to Figure 3-3) (BoM, 2023). Additionally, 10 mm of rainfall was recorded on 14 August and 1.2 mm on 15 August at Nelligen. As can be seen in Figure 3-3, freshwater inflows from the upstream catchments were low (below median flows at the two WaterNSW gauges in the Clyde River catchment, discussed in Section 2.3). At Budd Island the predominant wind observed was less than 10 km/h from the west on both days, with wind speeds increasing to 30 km/h for a brief period around 2pm on 22 August, as can be seen in Figure 3-4 (DPI, 2023). Swell recorded at the Batemans Bay waverider buoy operated by MHL had a significant wave height of approximately 1 m during the first day of fieldwork, which increased to 2 m on the second day, while wave period decreased, as can be seen in Figure 3-4.

3.3 Tidal flow gauging

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

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

Location	Location label*	22 August # transects	23 August # transects
Highway Bridge Site 3	A	3	27
Big Island	F	-	9

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

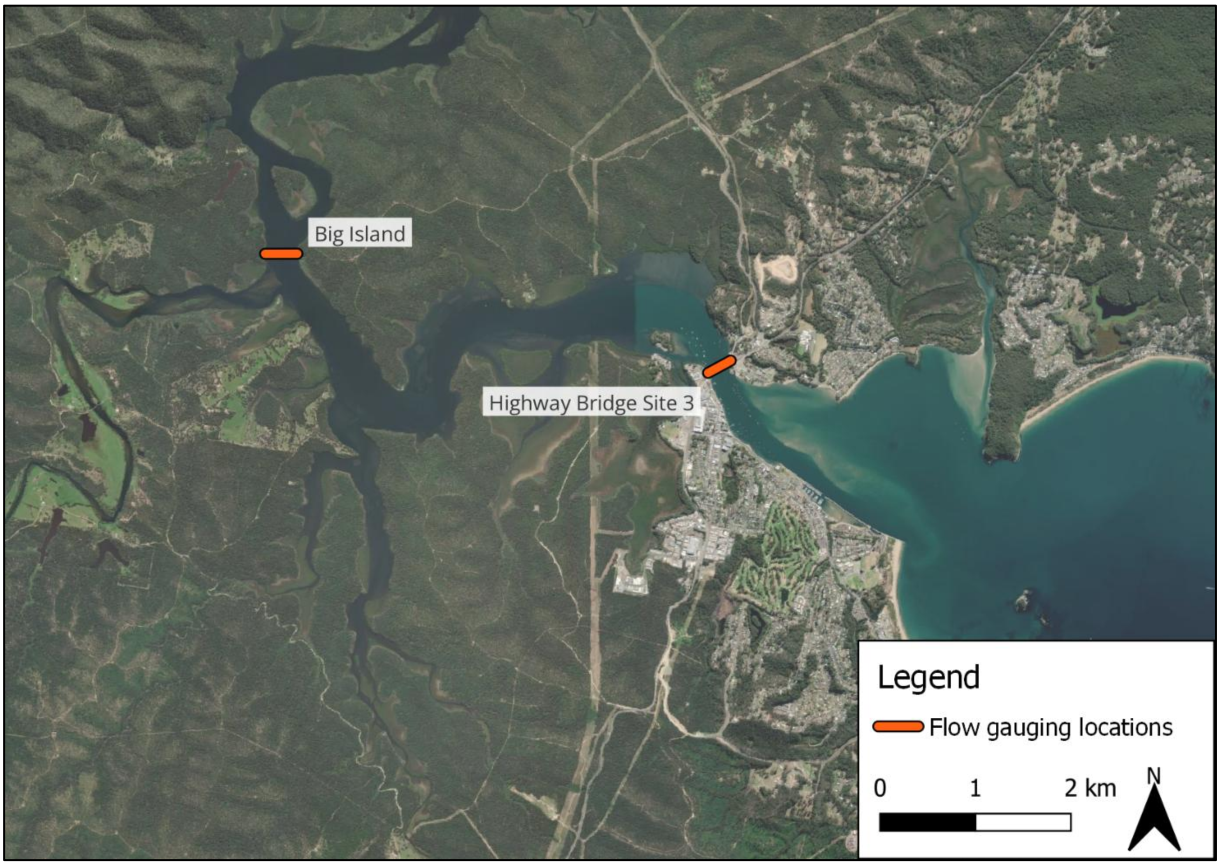

Figure 3-5 Tidal flow gauging locations from 2023 fieldwork

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 Wind driven vertical velocity distribution

Four M9 transects were taken across Batemans Bay to assess vertical velocity distribution and the effects of wind, two on 22 August 2023 and two on 23 August 2023. Wind speed during these transects was approximately 10 to 15 km/h. No visible depth varying vertical velocity distributions were detected, however, it was noted that the data was noisy due to excessive boat movement in swell, and as the boat mounted instrument does not explicitly measure the top 80 cm of the water column. Wind driven movement would be expected within the top 1 m of the water column, which is not well captured by the M9. A sample transect is presented in Appendix A4.

3.5 Bathymetry and elevation surveys

During the ADCP data collection campaign, an RTK-GPS unit collected vertical position data to an accuracy of 10 cm. By pairing depth soundings and elevation data, bathymetry was captured for all flow gauging locations (refer to WRL TR2023/32 Section 4.3 for details on methods used for bathymetric surveys). This data was collected opportunistically during other fieldwork and not targeted at particular locations. All bathymetry captured is shown in Figure 3-6, and the change between the 2018 LiDAR data and field captured bathymetry, where the two surveys overlap, is shown in Figure 3-7.

Compared with the 2018 marine LiDAR survey, the 2023 field survey bathymetry results show minor to moderate changes over the last 5 years. There was considerable swell when these measurements were taken, creating large noise in the data, so differences within 50 cm should be regarded with uncertainty. Considering this, the overall differences appear to be the movement of the bar enclosing the channel along the southern shore moving to the north, and a small amount of accretion in the area between the bar and the northern shore.

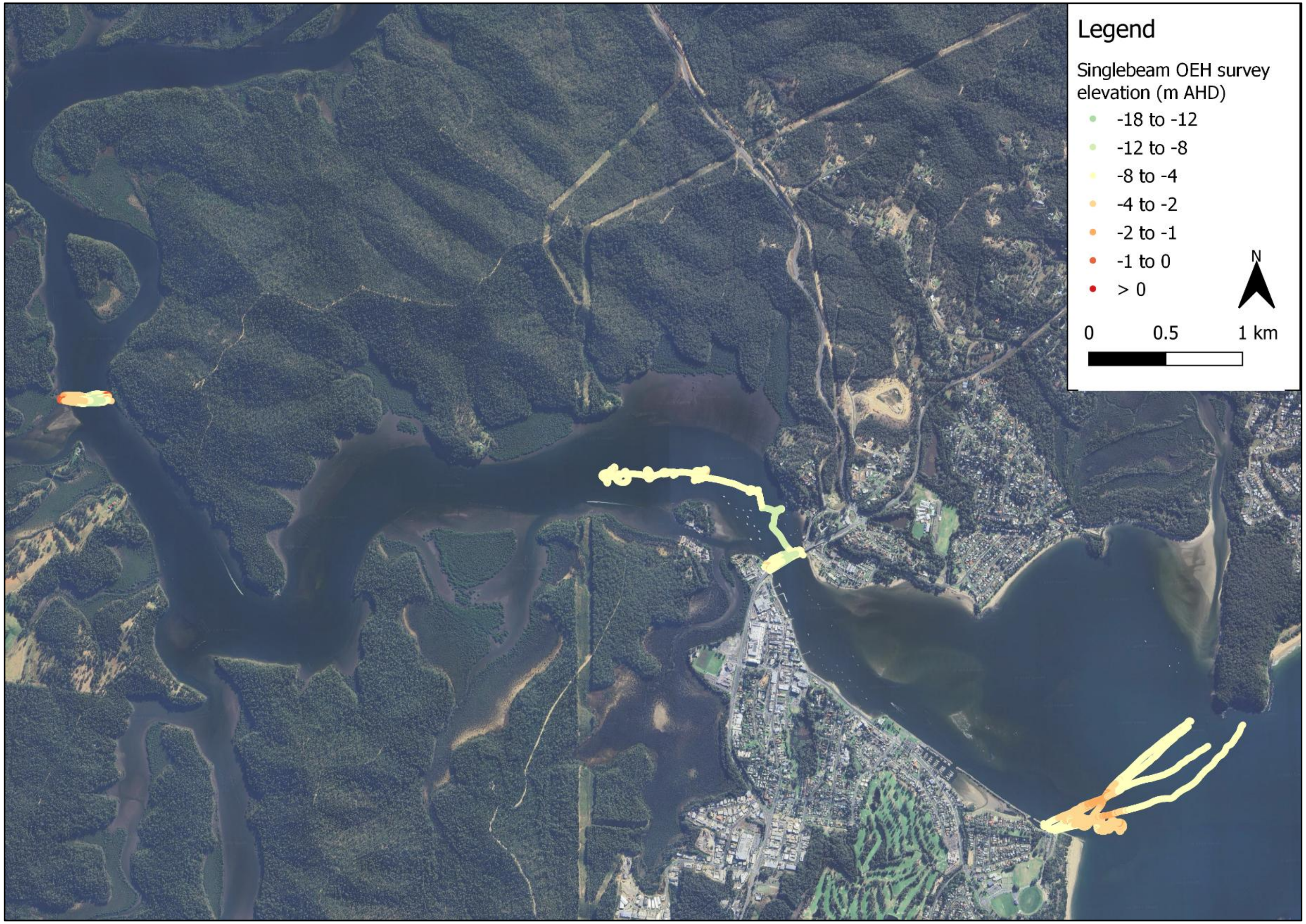

Figure 3-6 Bathymetry collected during 2023 fieldwork

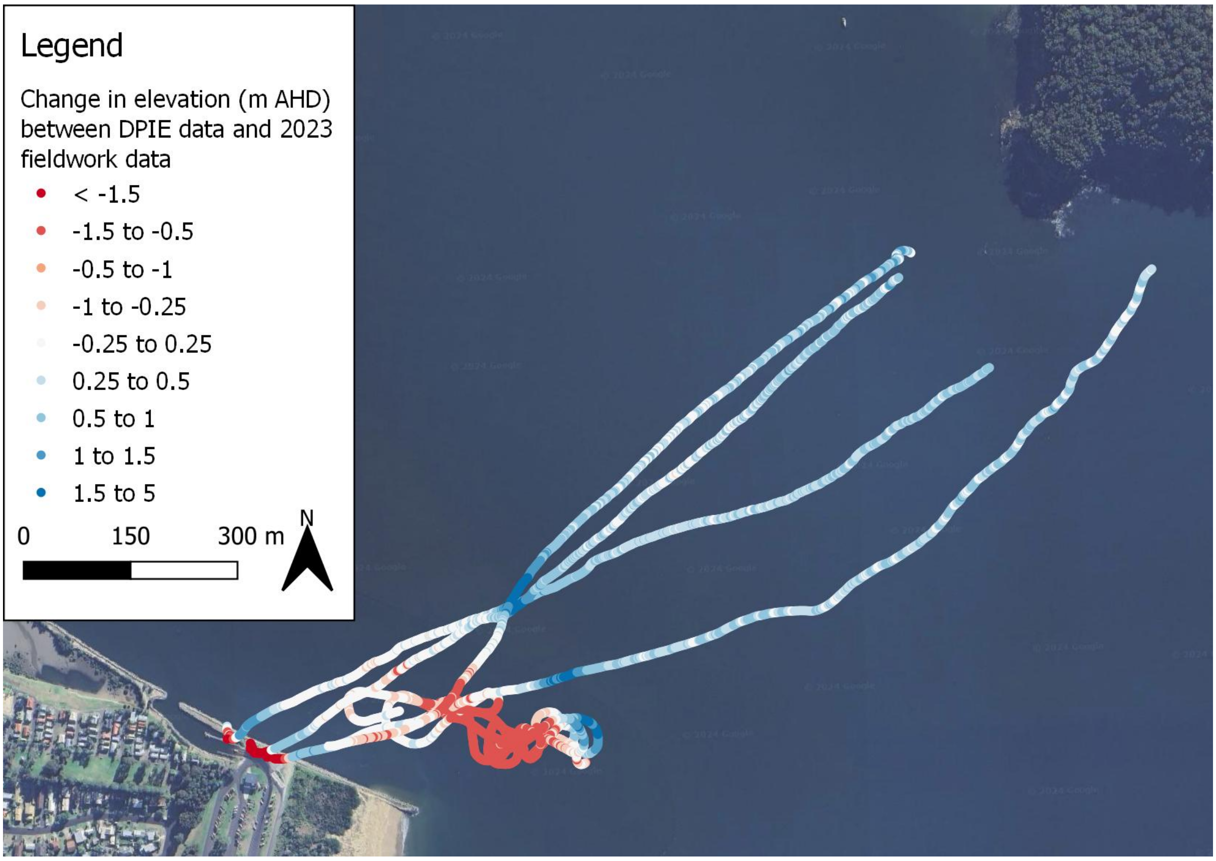

Figure 3-7 Change between 2018 LiDAR and 2023 fieldwork bathymetry. Red corresponds to erosion and blue to accretion

3.6 Rhodamine WT dye releases

To simulate pollutant advection and dispersion in the Clyde 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 3-2, with locations shown in Figure 3-8. The initial release concentration is 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	28/08/2023	9am	9.58am	500	Budd Island	Flood
2	28/08/2023	10.41am	12.01pm	500	Batemans Bay, 400 m offshore from end of navigation channel	Flood
3	28/08/2023	1.59pm	2.54pm	500	Lattas Point	Ebb

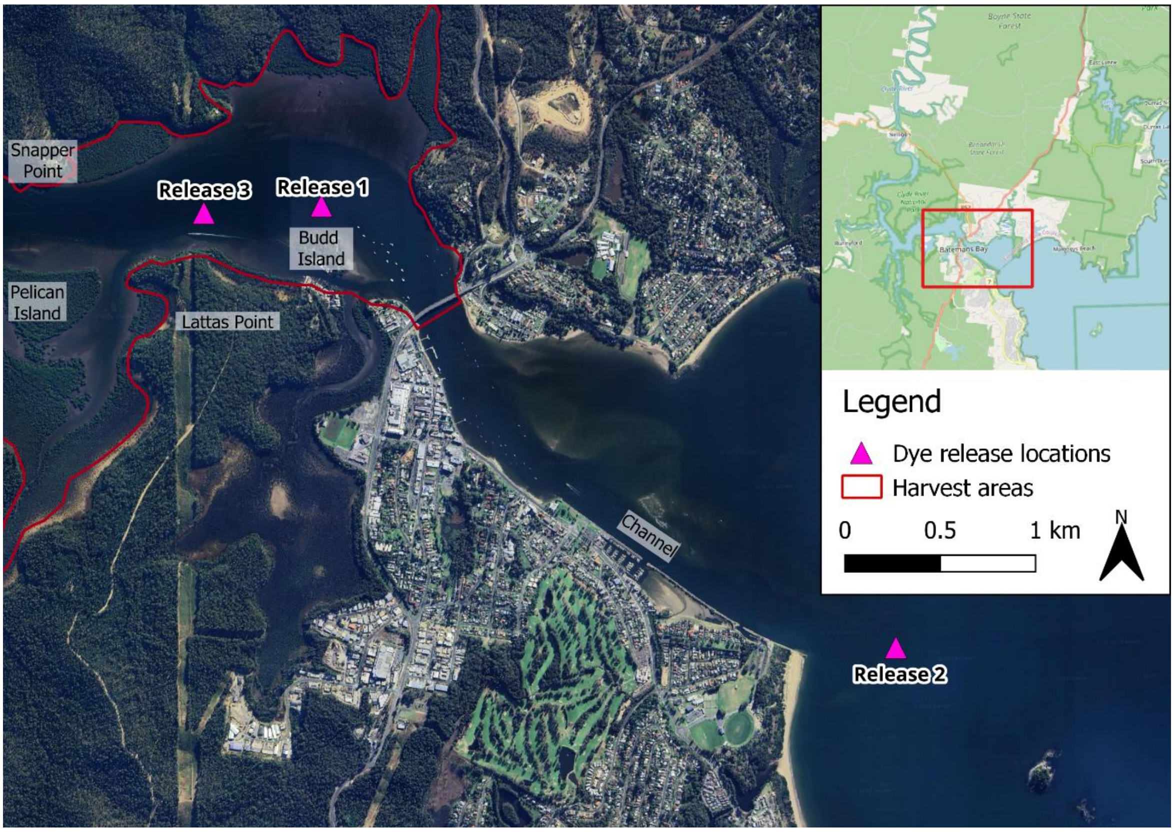

Figure 3-8 Rhodamine WT dye release locations

3.6.1 Release 1 – Budd Island

Dye release 1 was completed off Budd Island, approximately 700 m upstream of the Princes Highway bridge (see Figure 3-8). This release was completed to understand the transport of pollutants in the main channel of the Clyde River on an incoming tide. The dye was released at 9am, and was tracked for 1 hour. Figure 3-10 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

The plume advected upstream quickly and began forming an elongated shape within 3 minutes. Initially, dye was observed near the surface, however, by the time vertical profiles were taken at 13 and 16 minutes, the plume was vertically well mixed as can be seen in Figure 3-9. The plume continued to elongate as it dispersed over the next 40 minutes, however remained only 30 to 40 m wide. The plume had a much sharper boundary on the right bank, possibly as it was sheltered by slower velocities behind Lattas Point. Several transects were measured at the same location off Snapper Point. The plume was first detected at 49 minutes, and the peak passed at 54 minutes. Tracking ceased at 59 minutes. The plume was not detected at a fixed fluorometer located on the left bank downstream of Snapper Point.

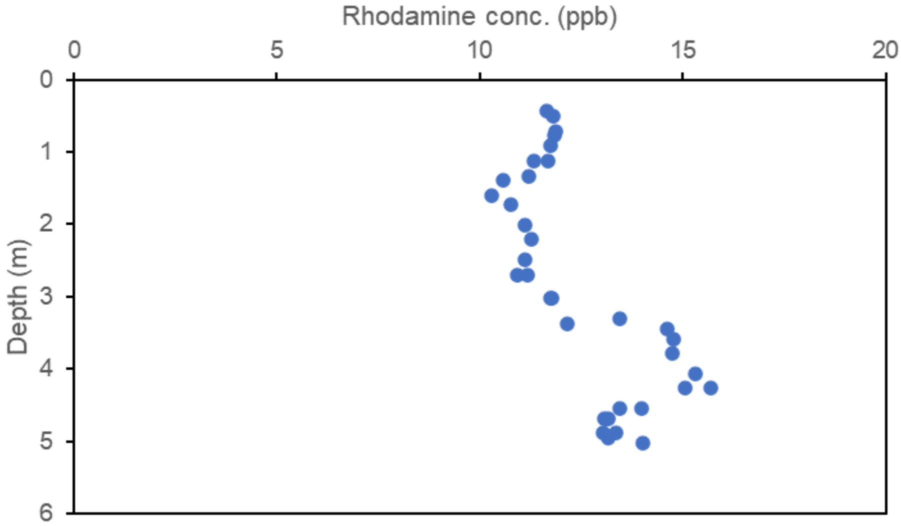

Figure 3-9 Vertical profile conducted 16 minutes after dye release 1

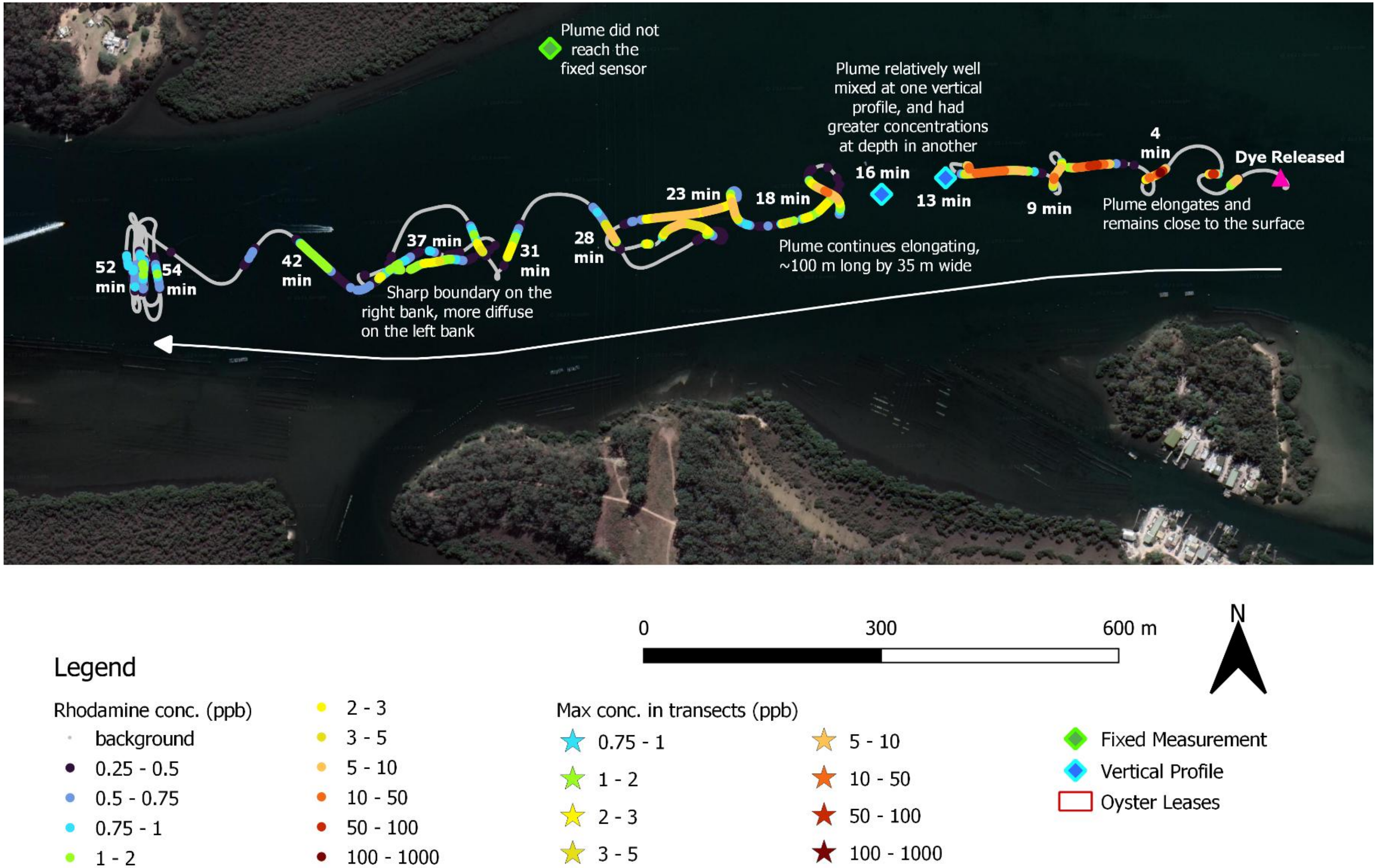

Figure 3-10 Dye release 1 off Budd Island. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)

3.6.2 Release 2 – Batemans Bay

Dye release 2 was conducted in Batemans Bay, approximately 400 m east (offshore) of the end of the navigation channel along the southwest edge of the bay. This release was conducted to observe the transport of pollutants in Batemans Bay. The release occurred at 10.41am, on an incoming tide, and dye was tracked for 1 hour and 20 minutes. Figure 3-12 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

Due to the location in the slower moving, open bay, the dye advected and dispersed much slower than the riverine releases. The plume initially remained relatively circular as it moved upstream. It began elongating as it reached and crossed over the shallower bar (approximately 2.5 to 3 m depth) at the entrance to the navigation channel, around 20 minutes after release. Six depth profiles were taken over the period of tracking and can be seen in Figure 3-11 (note the logarithmic scale). The plume initially was found predominantly only in the upper 2 m (8 minutes), however, as it crossed the bar (profiles at 29 minutes and 33 minutes) the plume reached the bottom of the water column and plume concentration decreased linearly with depth. By 76 and 79 minutes, when the plume was within the channel, slightly higher concentrations were observed at depth. Tracking ceased at 80 minutes, however, the plume was still visible after 107 minutes.

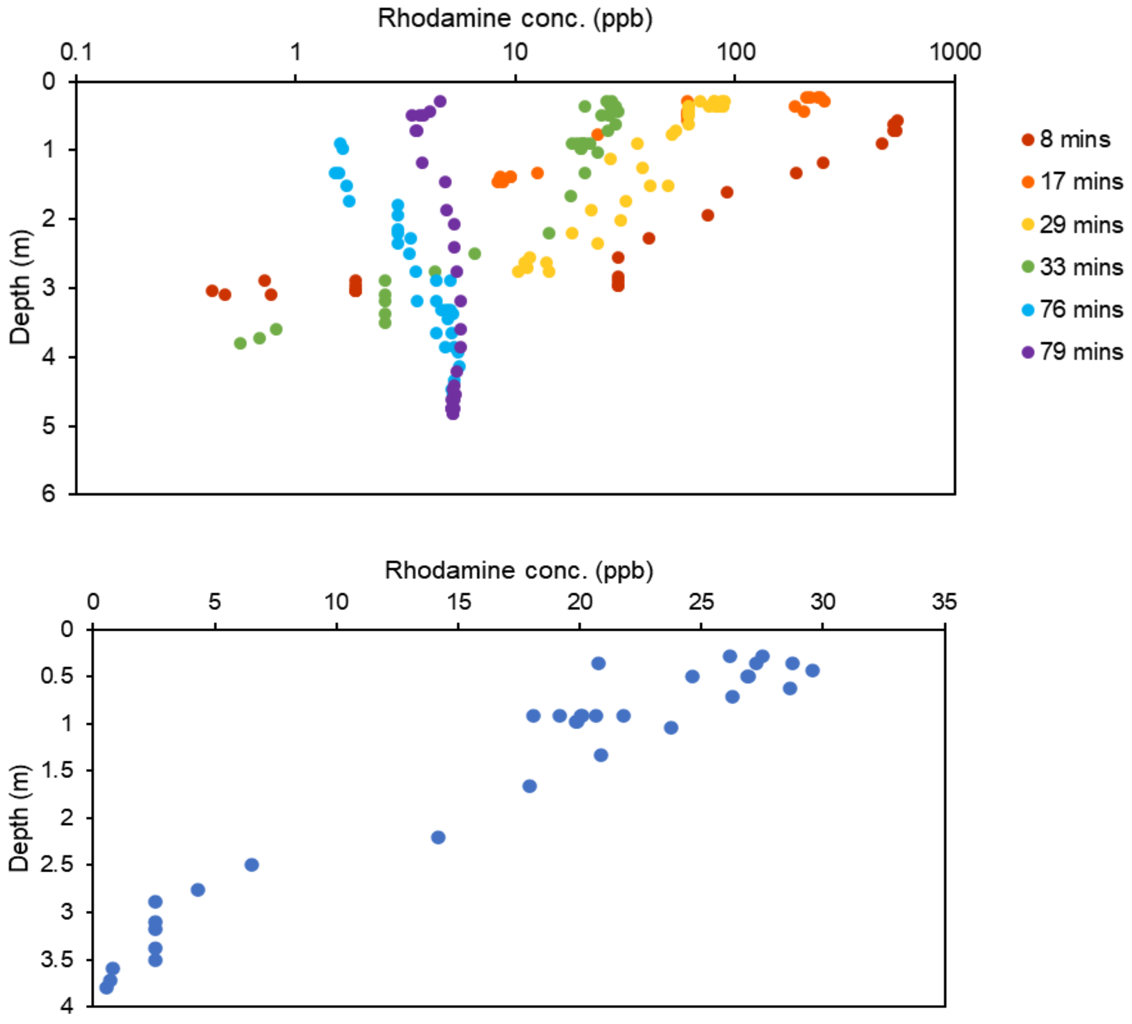

Figure 3-11 All vertical profiles conducted during dye release 2, plotted on a logarithmic scale (upper) and vertical profile conducted at 33 minutes, plotted on a linear scale (lower)

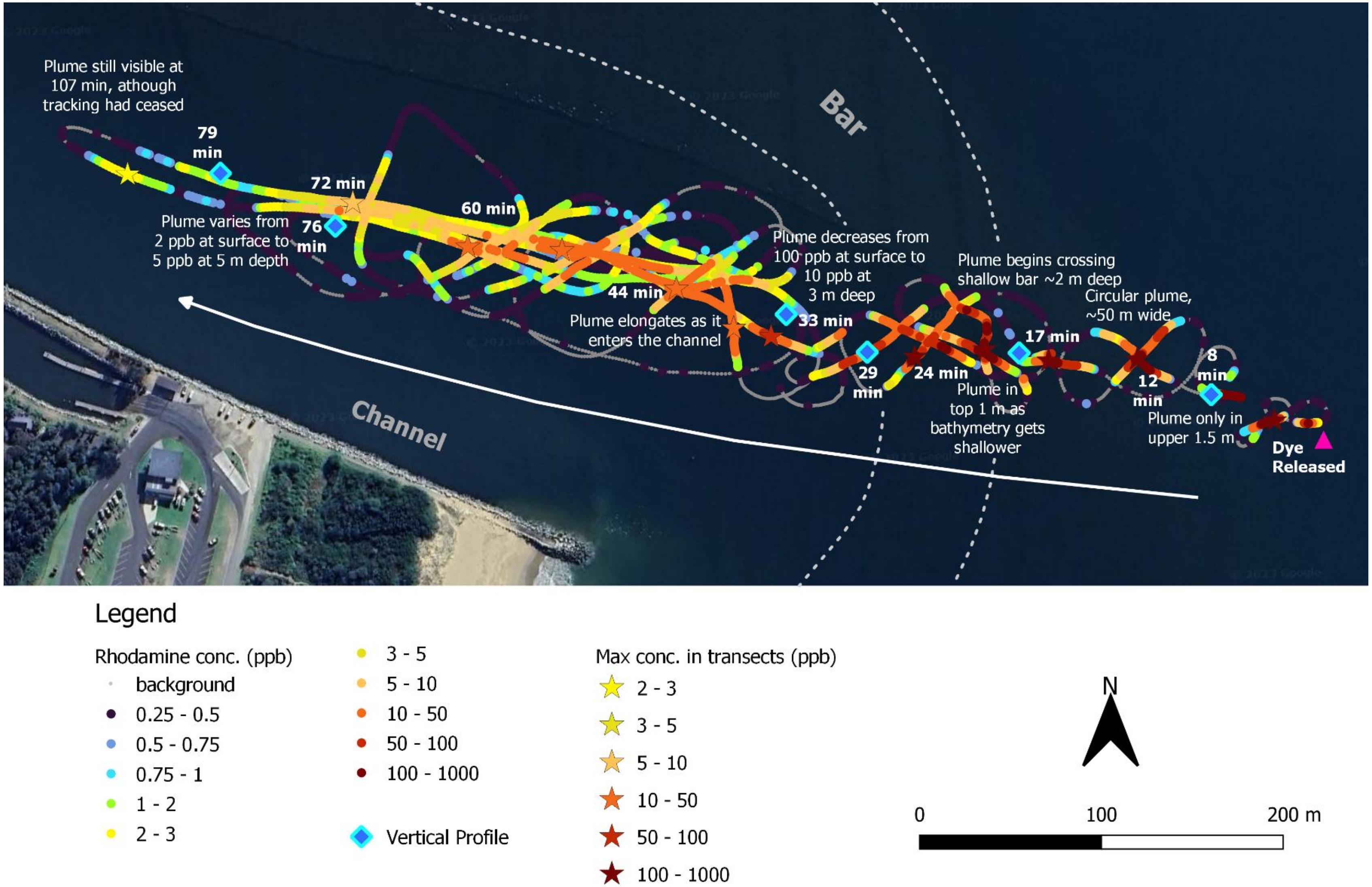

Figure 3-12 Dye release 2 in Batemans Bay. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)

3.6.3 Release 3 – Lattas Point

Dye release 3 was completed off Lattas Point, in a similar location to release 1. It was completed to understand the transport of pollutants in the main channel of the Clyde River on the outgoing tide. The dye was released at 1.59pm, and was tracked for 55 minutes. Figure 3-14 shows the observed dye concentrations over the period of monitoring, with the maximum concentration along select transects highlighted.

The dye travelled downstream in a plume that was initially round, however quickly became tadpole shaped, with a leading mass and a tail, by 5 minutes. At the three vertical profiles, shown in Figure 3-13, measured over the course of tracking (15, 19 and 35 minutes), the plume remained linearly distributed from a maximum concentration at the surface, to background concentrations at depth. By 15 minutes, the plume was no longer tadpole shaped but became increasingly elongated, reaching 400 m in length at 30 minutes. After 35 minutes, the peak of the plume was no longer tracked. The boat instead measured velocity profiles under the Princes Highway bridge, which observed that the velocity profile was vertically well mixed. A velocity profile taken under the Princes Highway bridge at 51 minutes after released, observed what was likely the tail of the plume, with a peak concentration of 0.7 ppb. The plume never reached the location of the fixed fluorometer located on shore of Budd Island.

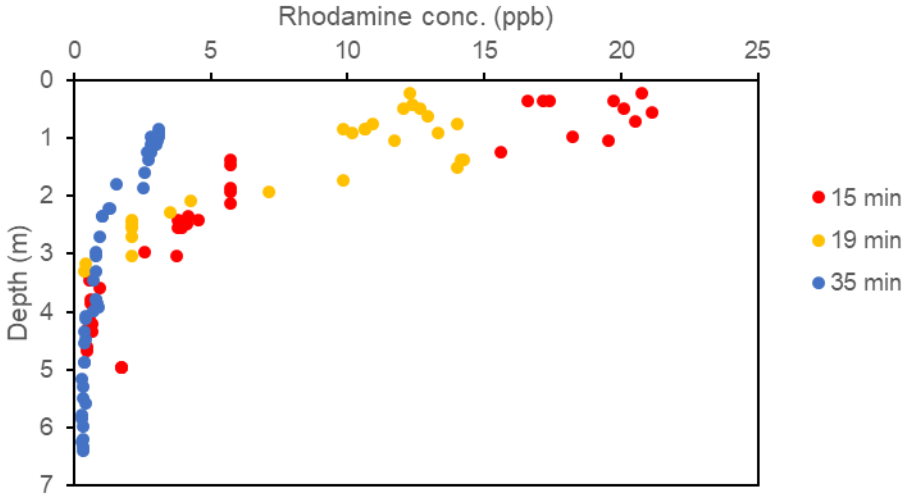

Figure 3-13 Vertical profiles conducted 15, 19 and 35 minutes after dye release 3

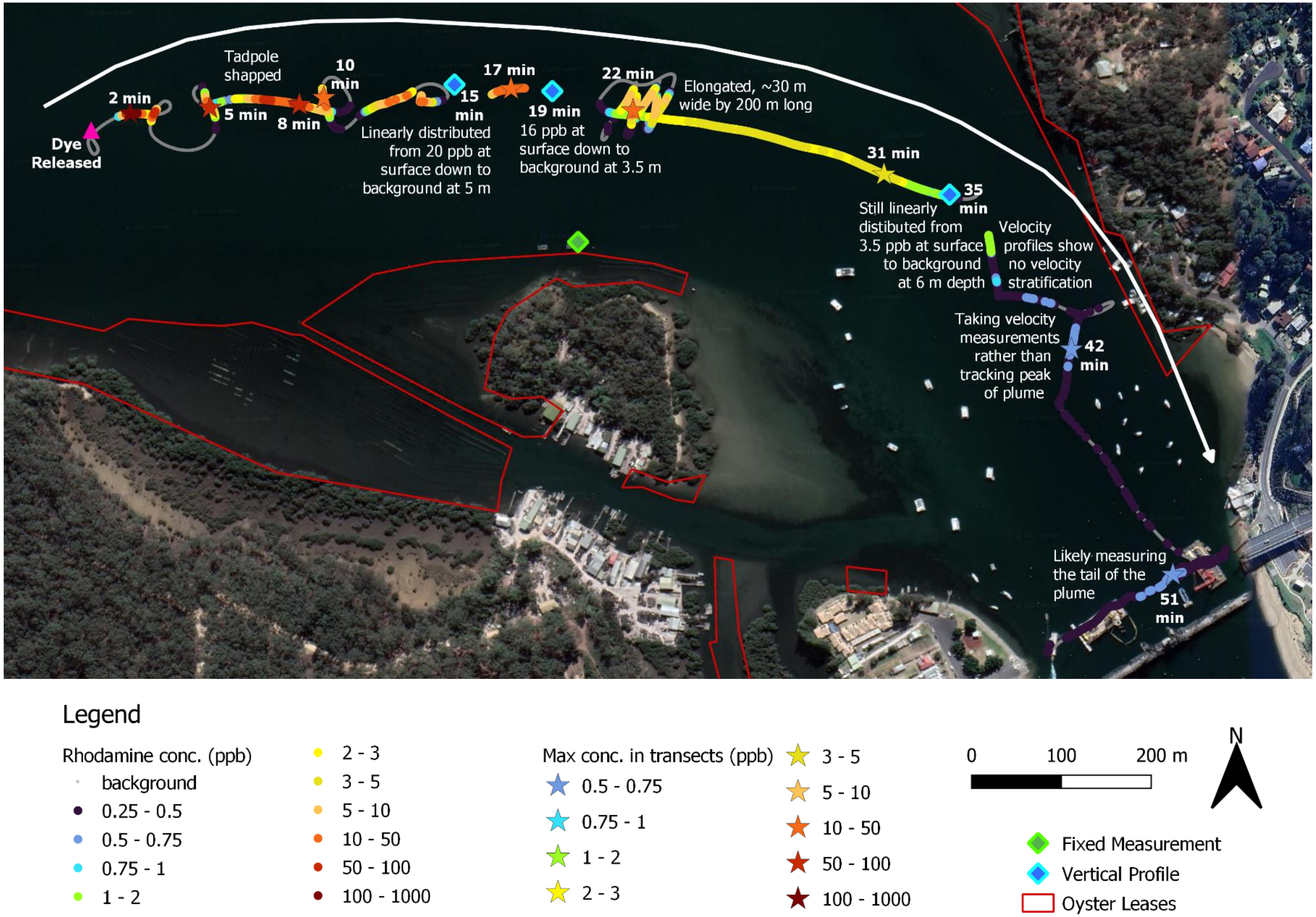

Figure 3-14 Dye release 3 off Lattas Point. All observed concentrations (circles) and maximum concentration observed in select transects (stars, with time of observation highlighted)

3.6.4 Field derived dispersion values

Field dye experiments were used to obtain estimates of plume spreading dispersion rates in the Clyde 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 3-15.

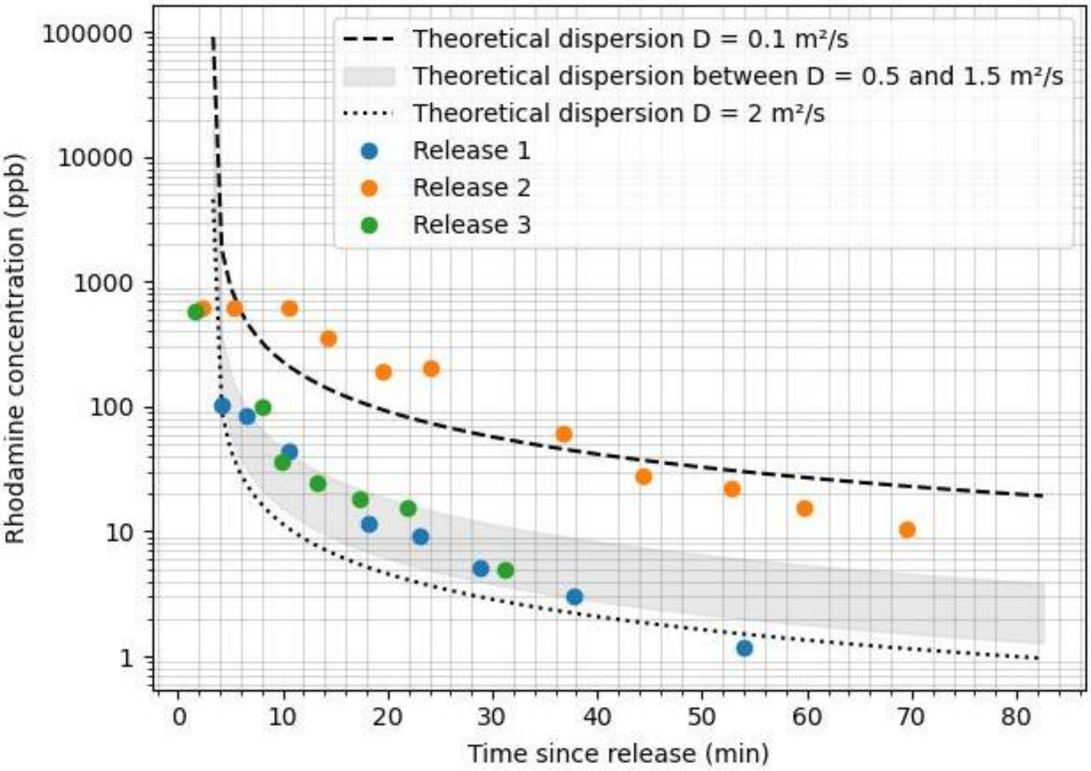

Figure 3-15 Peak concentration of select transects plotted against theoretical dispersion

Measurements of field dispersion across the state for this project showed dispersion was spatially and temporally variable typically between D = 0.1 and 2 m^2/s, with the most common range being 0.5 to 1.5 m^2/s, which was consistent in the Clyde (Figure 3-15). When comparing the observed peak observations to theoretical dispersion, most field dispersion values fall within D = 0.1 and 2 m^2/s, with dye releases 1 and 3 largely within D = 0.5 to 1.5 m^2/s. For release 2, the low dispersion values of <0.1 m^2/s in the first portion of the experiment may be attributed to the slow movement and low turbulence conditions in the open bay during low wind conditions (refer to Section 3.6.2). Dispersion rates increased as the plume entered the channel along the southern shore and began moving faster. The results of dye dispersion across all estuaries can be found in WRL TR2023/32 Section 7.3.

3.7 GPS drifter drogue releases

To monitor surface current speeds and flow paths in the Clyde 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 in the morning of both days of fieldwork. On the first day, all four drogues were released under the Princes Highway bridge. On the second day, two drogues were dropped in Batemans Bay, approximately 500 m beyond the end of the training wall along the southern shore, and two were released in the channel alongside the training wall. The drogues travelled up the river on the incoming tide, then travelled downstream after the turn of the tide around midday. Most drogues became snagged in oyster leases on the outgoing tide, and hence tracking duration varies. An additional, shorter release on the outgoing tide was completed on the second day. Table 3-3 shows the details of each drogue release while 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
1	22/09/2023	8.25am	Flood to Ebb	5:40	Princes Highway bridge
2	23/09/2023	8.30am	Flood to Ebb	6:30	Batemans Bay
3	23/09/2023	2.39pm	Ebb	1:20	Clyde River near Pelican Island

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. Figure 3-16 shows the timing of conductivity measurements while Figure 3-17 shows the locations and results of conductivity measurements. No stratification was noticed in any conductivity profiles.

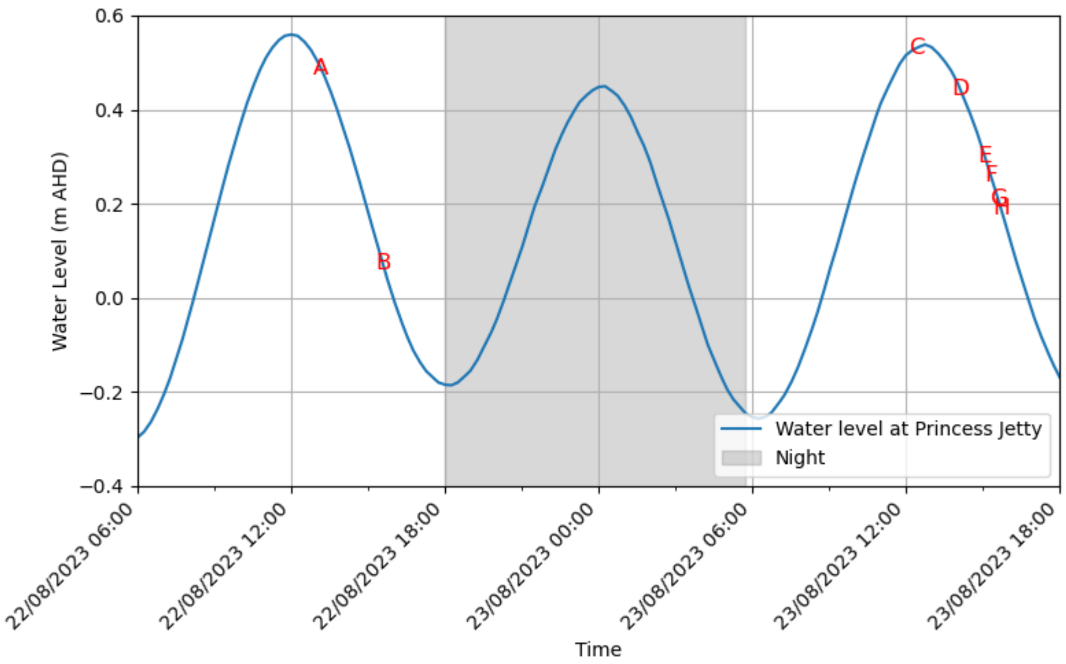

Figure 3-16 Timing of conductivity measurements. Red letters denote each conductivity profile and correspond to letters on the map in Figure 3-17

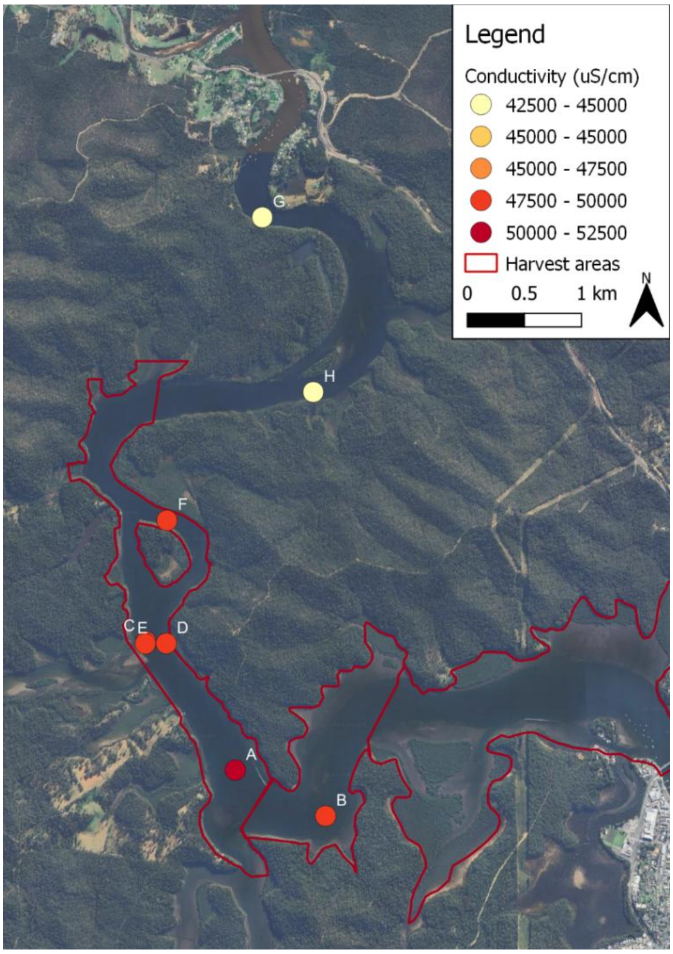

Figure 3-17 Locations of conductivity profiles

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 1996 MHL data collection campaign, and verification based on field data collected for this project in 2023. The hydrodynamic model was then used as an input for the water quality model. This model was informed by dye release experiments and was then used to run sewage overflow scenarios. A schematic of this process can be seen in Figure 4-1. For a detailed overview of the model development used for the broader project, refer to WRL TR2023/32 Sections 6 and 7.

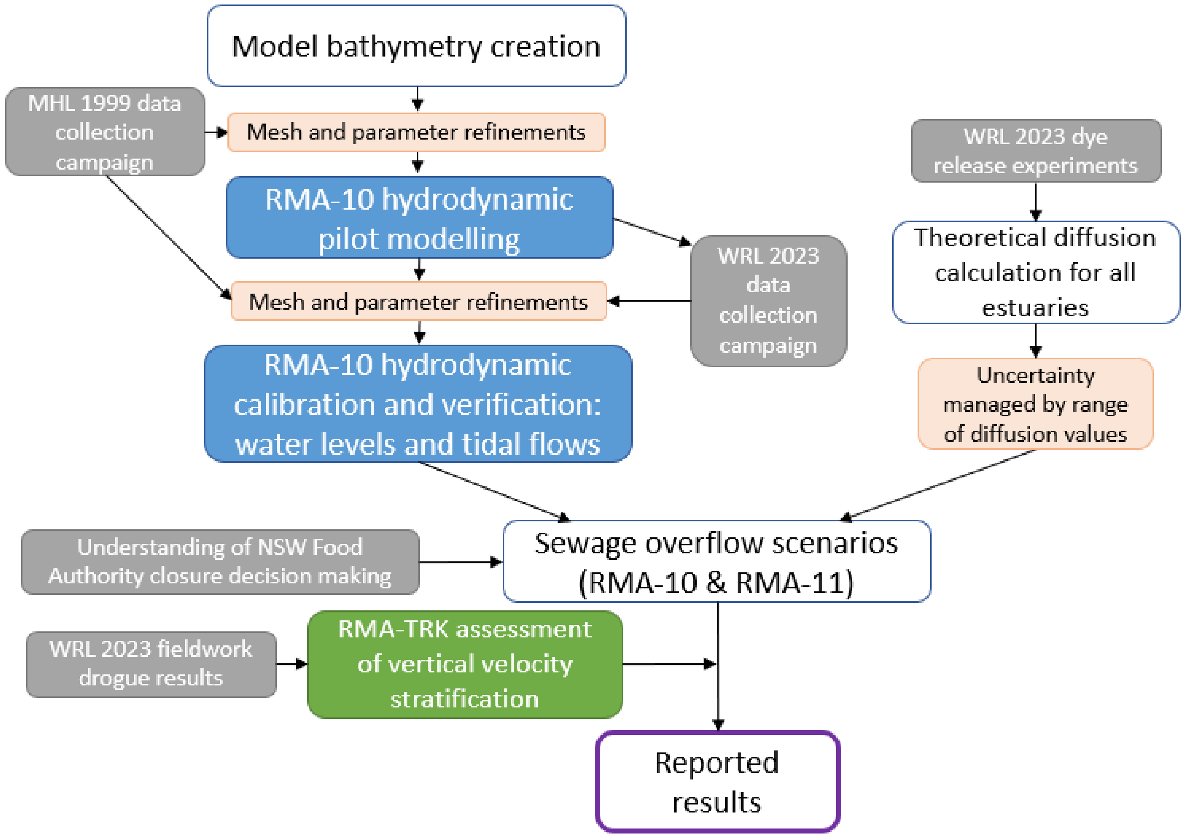

Figure 4-1 Overview of modelling approach

4.2 Model mesh development

The model domain extends from approximately 2.5 km offshore of the coast outside of Batemans Bay, to the tidal limits of the Clyde River estuary and its major tributaries (refer to Figure 4-2). The model mesh consists of approximately 15,000 nodes and 5,800 elements on the surface of the mesh varying in size from 4 m^2 to over 810,000 m^2. About 1,950 of these elements were modelled in three dimensions, as can be seen in Figure 4-2 adding approximately 10,000 nodes in the third dimension. Two-dimensional, depth averaged modelling was chosen in shallower and more enclosed areas where advective transport is largely driven by tidal and riverine flow (not wind) whereas three-dimensional modelling was chosen in the open parts of the bay where wind driven water movement may be significant. In the three dimensional portion of the model, two layers were simulated: a 1 m deep surface layer, and a second layer extending to the bed. This vertical resolution is insufficient to resolve full vertical velocity distributions, however, tests showed it was sufficient to resolve indicative circulations caused by wind shear. A discussion on the impact of model dimensionality is provided in WRL TR2023/32 Section 6.2.2.

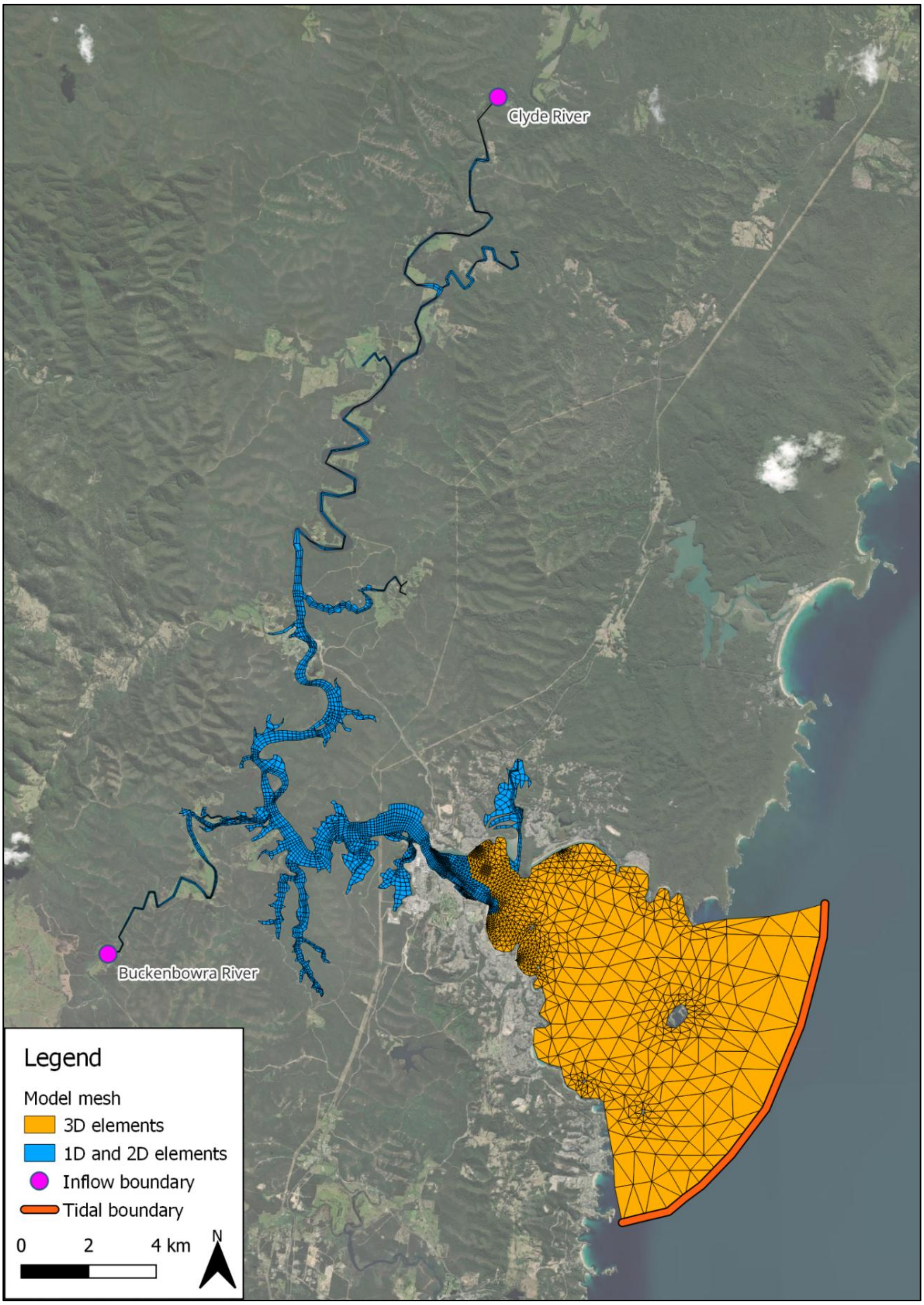

Figure 4-2 RMA model mesh showing boundary condition locations

Mesh resolution is highest around the overflow locations, the entrance channel and the bar, with lower resolution upstream and in the main part of the bay. Refer to WRL TR2023/32 Section 6.2.3 for a discussion of model resolution.

4.3 Model bathymetry

Model bathymetry was based on the sources discussed in Section 2.5 and with a general preference of the most recent available data. This was typically the 2018 DPIE coastal marine LiDAR topo-bathy survey for the lower estuary, which covers the majority of Batemans Bay. The 1998 OEH single-beam survey was utilised in areas upstream of the Princes Highway bridge, not covered by the LiDAR survey. The NSW Spatial Services (2011) 1 m resolution DEM was used for shallow intertidal regions. The nodal bed elevations of the model bathymetry are shown in Figure 4-3.

Estuaries are dynamic systems and bathymetric changes through time will alter water levels, velocities, and tidal flows for the same set of boundary conditions. The Clyde River estuary has a partially trained entrance, which largely prevents significant short-term changes in the entrance conditions like those seen at some untrained entrances in NSW. While changes to bathymetry over time are still evident, mainly around the sand bar on the untrained northern side of the entrance channel, a single bathymetry was developed for this model and used for all model runs. This was shown to result in reasonable model calibration and verification for water levels and flow across the main channel, discussed further in Section 4.6. Sensitivity to bathymetry was also tested, the results of which are presented and their implications discussed in Section 5.4.

4.4 Model boundaries

The model includes two upstream catchment flow boundaries, shown in Figure 4-2 and discussed in Section 2.3. A tidal elevation boundary was included in the model offshore of Batemans Bay (refer to Figure 4-2). This modelled water level boundary was based off observed tidal elevation data collected by MHL at Ulladulla (station number 216471), or from Jervis Bay (station number 216470) for models run prior to the installation of the tide gauge in Ulladulla in 2008. 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 1.4. For more details on pilot modelling and its purpose refer to WRL TR2023/32 Section 3. This initial modelling was used to identify data gaps to be targeted during fieldwork, such as supplementary flow data and information on wind driven vertical velocity distributions.

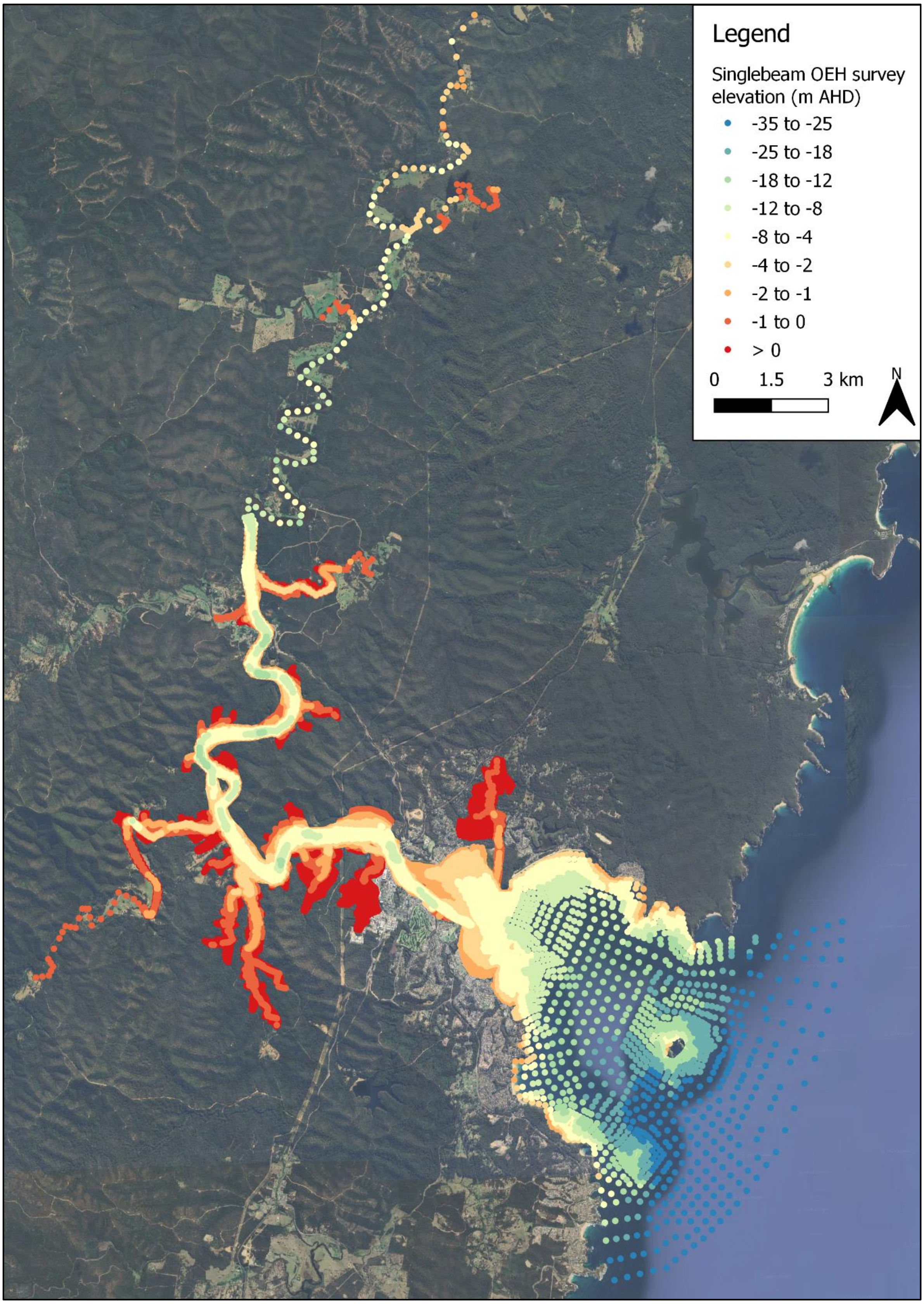

Figure 4-3 RMA model bathymetry

4.6 Hydrodynamic calibration and verification

Hydrodynamic calibration should be based on flow, velocities and water levels at several locations throughout the estuary. For more details on calibration and how models were determined to be fit for purpose refer to WRL TR2023/32 Section 6.4. One set of preexisting hydrodynamic calibration data was available for calibration and verification purposes, collected by MHL in 1996 and described in Section 2.2. The 2023 data collection campaign period was then used to verify the model (refer to Section 3). Both calibration and verification also considered MHL's long term water level gauges available at two locations in the Clyde River estuary (see Section 2.2). For each period, a minimum 3 day model warmup period was run.

4.6.1 September 1996 calibration period

During the 1996 MHL data collection campaign on the Clyde River estuary, water level data was available at six gauges (including two permanent gauges) and tidal flow data was available at five transects (refer to Section 2.2). The model parameters were calibrated to this period. Measured tide levels at Jervis Bay were applied at the ocean boundary (as the Ulladulla gauge was not yet operational) and scaled measured catchment inflows were applied at the two upstream model inflow boundaries. As two of the water level gauges were not operational when tidal flow gauging was occurring, two calibration periods were run, one in September (when flow gauging occurred) and one in November when the two additional tidal gauges were operational. 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, and the tidal amplification occurring in the system was captured. Observed water levels at Princess Jetty and other lower estuary gauges have a smaller tidal range and high tide peaks lag behind what is simulated in the model (see Figure 4-4). This indicates that losses in Batemans Bay, especially over the bar and through the channel, are being underestimated. This is possibly due to bathymetry differences between the time of the1996 data collection campaign and the 2018 LiDAR survey, however errors were minor. Flow is overestimated by the model on the flood tide at several locations, notably at Mays Wharf (Figure 4-5). However, the model achieved an appropriate fit with observed data, particularly at the Princes Highway Bridge (Figure 4-6) that connects Batemans Bay and the Clyde River. Thus, and given the 2023 verification period results, the model was deemed fit for purpose for this study, which is to predict the direction and spread of pollutants throughout the estuary.

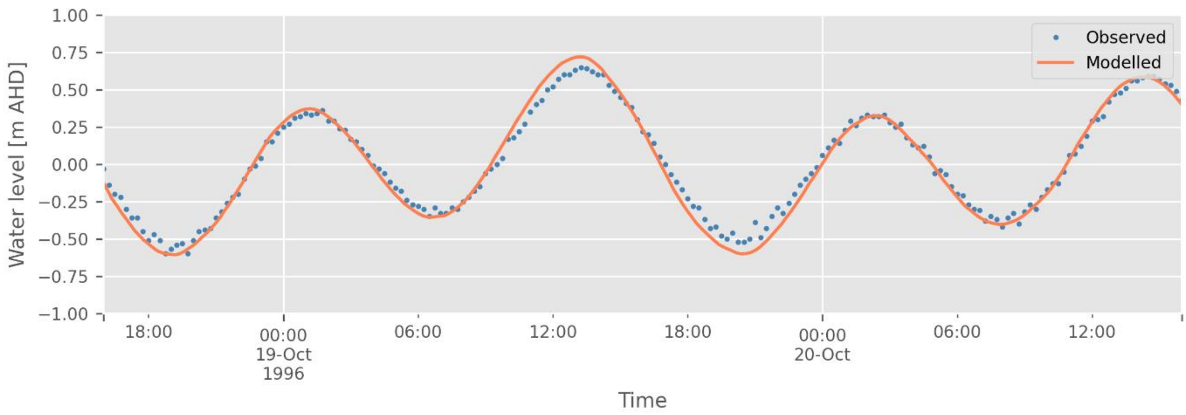

Figure 4-4 1996 water level calibration – Location 1 – Princess Jetty (September period, upper and October period, lower)

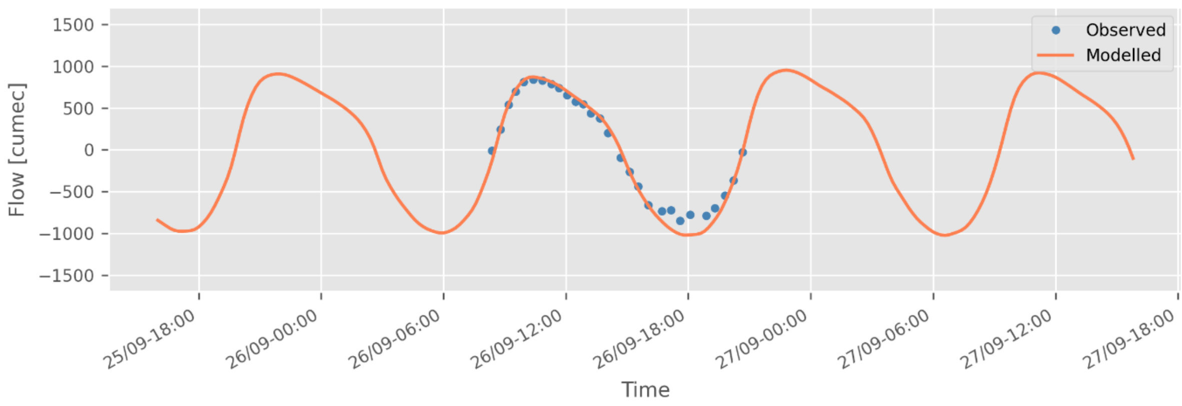

Figure 4-5 1996 tidal flow calibration – Location B – Mays Wharf Site 7

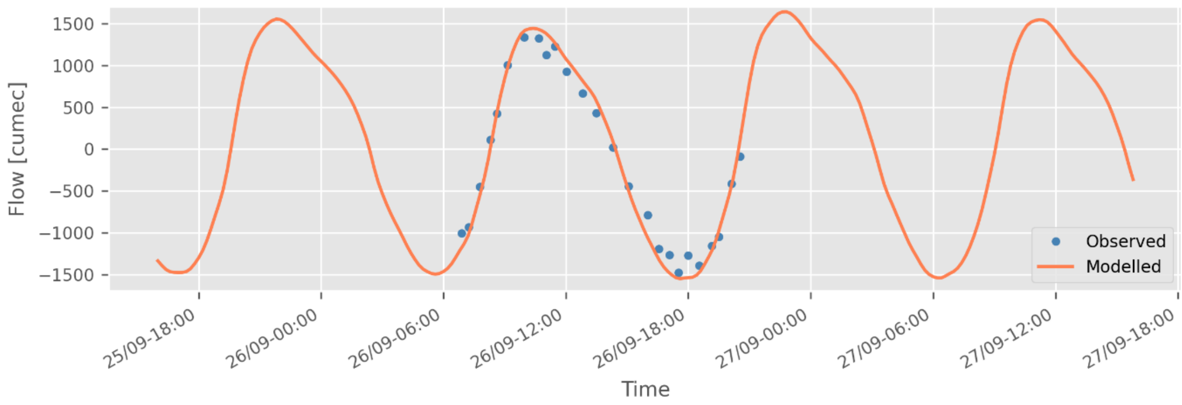

Figure 4-6 1996 tidal flow calibration – Location A – Princes Highway Bridge Site 3

4.6.2 August 2023 field data verification period

The 2023 field campaign involved the collection of tidal flow gauging at two transects, and the collation of water level data at two locations from MHL (refer to Section 3). Measured tide levels at Ulladulla were applied at the ocean boundary and scaled measured catchment inflows were applied at the two upstream model inflow boundaries. Model results were then compared with the observed data, using the same model parameters used for the 1997 model run. Plots of all observed water level and flow compared with model results are shown in Appendix B1.3 and B1.4, while select results are shown below.

Water level and flow results from the 2023 verification were consistent with the 1996 calibration period for all locations (see Figure 4-7 and Figure 4-8 for examples). This provides confidence that the model is fit for purpose for simulating present day sewage overflow scenarios. The similarly appropriate model fit in the 1996 and 2023 period in the lower estuary and around the key areas of interest demonstrates the capacity of the model to represent hydrodynamic behaviour despite small changes in observed bathymetry.

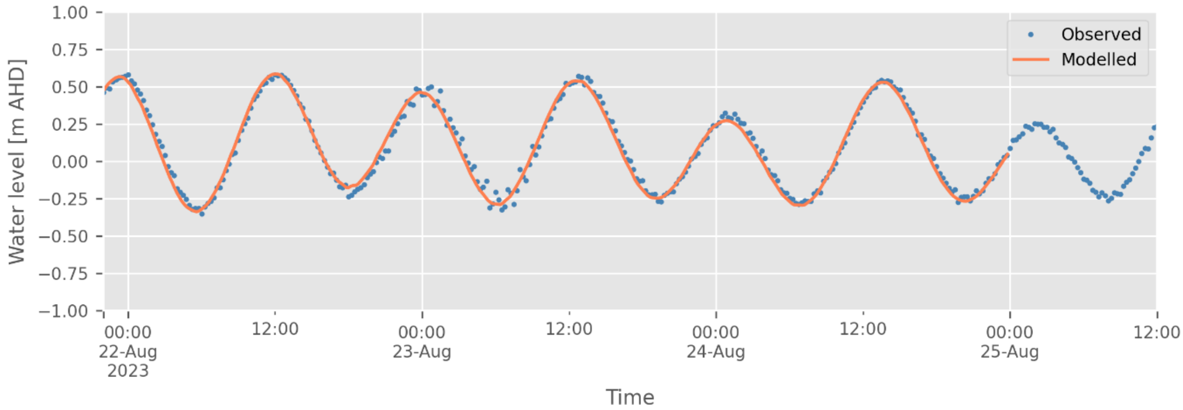

Figure 4-7 2023 water level verification – Location 1 – Princess Jetty

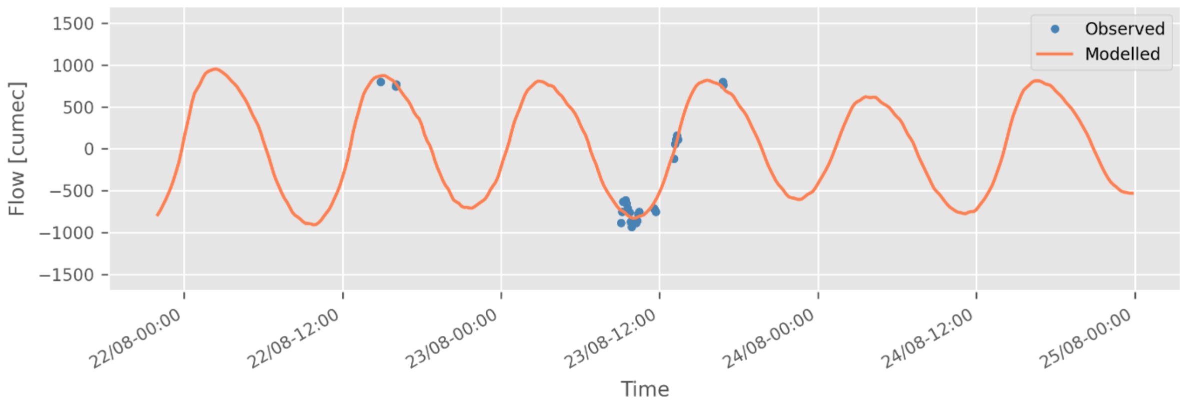

Figure 4-8 2023 tidal flow verification – Location A – Highway Bridge Site 3

4.6.3 Wind

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

4.6.4 Roughness coefficients

A roughness coefficients (Manning's n) of 0.025 was applied to the entire model domain, which is in the standard range for large sandy channels. In the three dimensional sections, the vertical eddy viscosity coefficient used was 5 m^2/s.

4.7 Water quality model development

4.7.1 Modelling of dispersion in RMA-11

Dye dispersion experiments, discussed in Section 3.6, provided valuable information on dispersion and its simulation in modelling. In particular, they provided evidence for a sensible range of dispersion coefficients to use in the modelling. However, it was concluded that they could not be used to produce estuary specific values for dispersion. Hence, a range of dispersion values, derived from the field experiments, was used across all the estuaries. Models were run with two dispersion coefficients, 0.5 and 1.5 m^2/s, and the scenario results presented are a combination of the two to manage the uncertainty in dispersion. For further details on how these dispersion values were determined, sensitivity testing, and how model results were combined refer to WRL TR2023/32 Section 7.3, 7.4 and 8.2.3.

The RMA-11 model utilised a 3 minute timestep, with results output every timestep. 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 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 3.7) with modelled transport. Table 4-1 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 Clyde River system, some depth varying vertical velocity distributions were observed when comparing drogues to modelled particles, with ratios of an average of 1.4. However, this ratio was similar on the ebb and flood tides, thus does not indicate tidal straining, and net plume transport over multiple tides would remain the same.

Table 4-1 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)
1	Princes Highway Bridge	Flood	1.42	1.08	1.32
1b	Rocky Point	Ebb	0.85	0.55	1.53
2	Batemans Bay	Flood	1.51	1.06	1.42
3	Pelican Island	Ebb	1.27	0.93	1.38

In the Clyde River system, although it is a riverine system over which a substantial salinity gradient exists (refer to Section 3.8 and DPI (2023)) no evidence of tidal straining was observed during fieldwork:

- A moderate vertical velocity distribution was observed in ADCP transects both the flood and ebb tide (refer to Appendix A4)
- No salinity stratification was observed, including on the ebb tide (refer to Section 3.8)
- The ratios of observed drifter to modelled drifter drogues velocities (Table 4-1) do indicate a vertical velocity distribution, however, are similar on ebb and flood tides
- Modelled rhodamine dye releases matched observed rhodamine advection timing on both flood and ebb tides

The process of tidal straining may still occur in this estuary, yet was not observed during this fieldwork as most observations occurred in the relatively saline lower estuary. However, as no modelled overflow locations are upstream of the harvest areas, any tidal straining would have minimal impact on outcomes, hence tidal straining was not considered in this model.

If tidal straining is not considered, vertical velocity distributions would be symmetrical (A. rather than B. on Figure 4-9). If 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 observed vertical velocity distributions, no timing adjustments were required for this system.

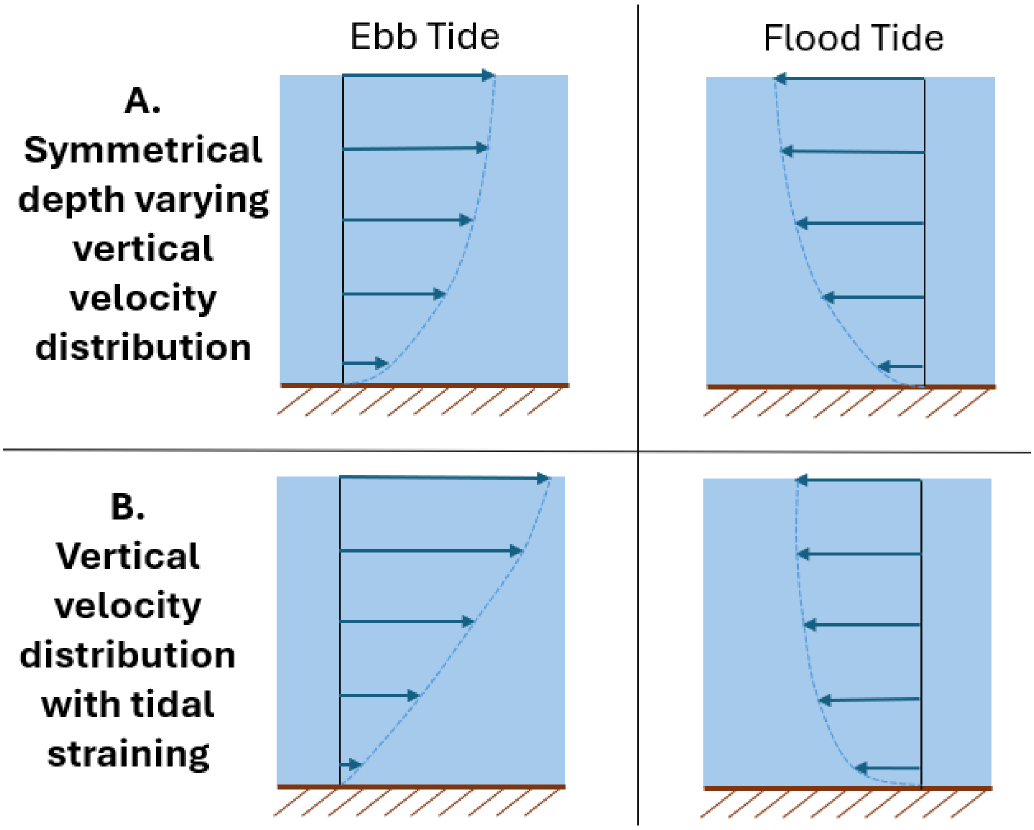

Figure 4-9 Flow with tidally symmetrical depth varying velocity profiles and tidal straining with non-symmetrical vertical velocity profiles

4.7.3 Instabilities

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

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

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

4.8 Limitations for future model uses

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

Limitations specific to the Clyde River model include:

- 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, this may not be true for other use cases and multiple bathymetries or/and updated bathymetry may be required.
- Calibration data in the upper estuary is sparse and calibration is poor. This was not prioritised in the construction of this model, as the results were primarily dependent on whether overflows were transported into the entrance channel, thus focus was mainly given to measuring and calibrating the flow through the entrance. This means less confidence should be placed on the upstream processes without further data collection for verification.
- Wind is not wholistically simulated in the model. The model was primarily constructed to indicate the general types of currents and circulation which may result from wind from a certain direction. The model uses only two layers, thus does not simulate the full vertical velocity profile expected from wind shear, and the model was also not calibrated to velocities resulting from wind shear, nor were the circulations resulting from wind forcing verified. Furthermore, the model does not have sufficient vertical resolution to adequately simulate three-dimensional mixing, as it was only intended to simulate the changes in advection that may be caused by wind.
- The model does not simulate density driven processes, which are likely to result in tidal straining in some situations in the Clyde River. As is discussed in Section 4.7.2, this was not considered as a potential impact on results from this model, as all overflows come from downstream of the harvest areas, however, could be important for other model use cases.

5 Scenario modelling

5.1 Preamble

Detailed description for the methods of scenario modelling for this project can be found in WRL TR2023/32, Section 8. For the Clyde River, a total of 1,080 model scenario simulations were completed, including permutations of:

- Six overflow locations
- Four stages of the tide
- Three catchment inflow conditions
- Three overflow volumes and duration
- Six wind conditions

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

This is especially relevant for overflows at, or near, the Joes Creek location. Joes Creek is an intermittently closed and open lake or lagoon (ICOLL) system with an entrance that is at times open to Batemans Bay (usually after a larger rain event) and at times closed, as shown in Figure 5-2. If the entrance is closed, for the 21 days following an overflow into the creek, there will be no threat to oyster harvesting at this location.

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.

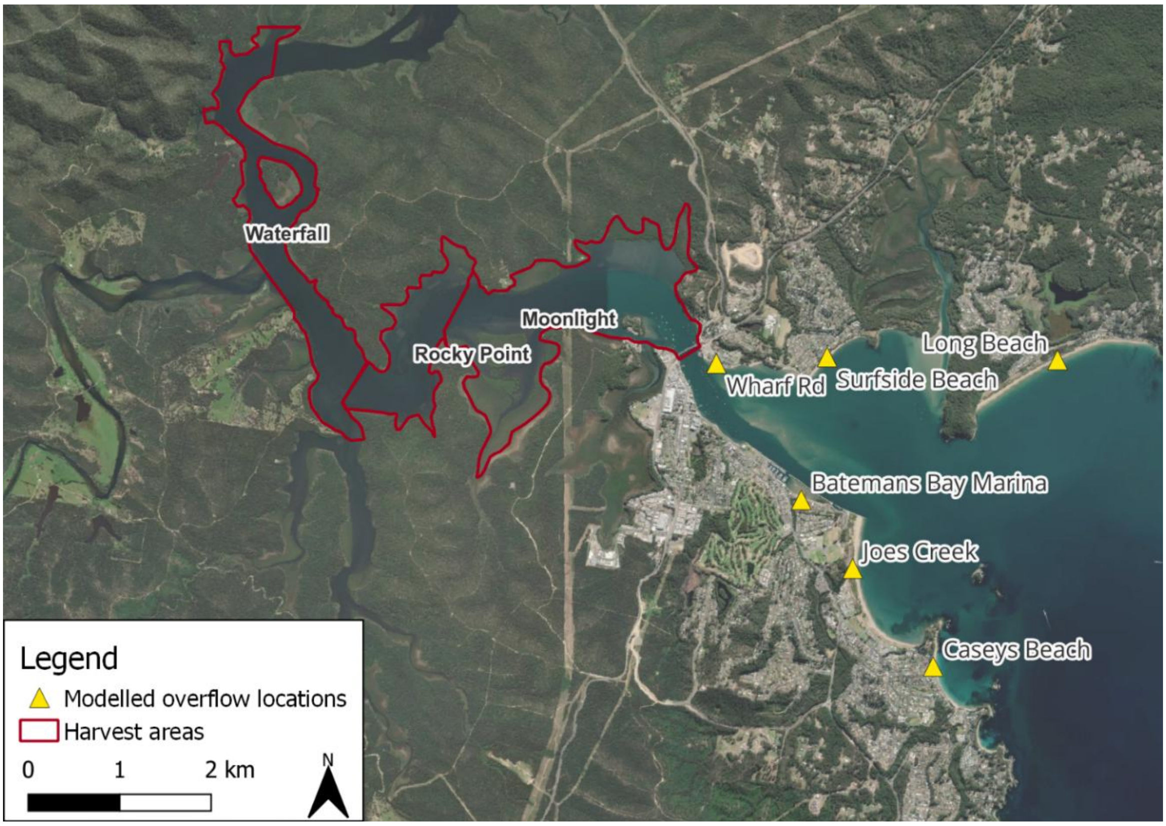

Figure 5-1 Modelled overflow locations in Clyde River estuary

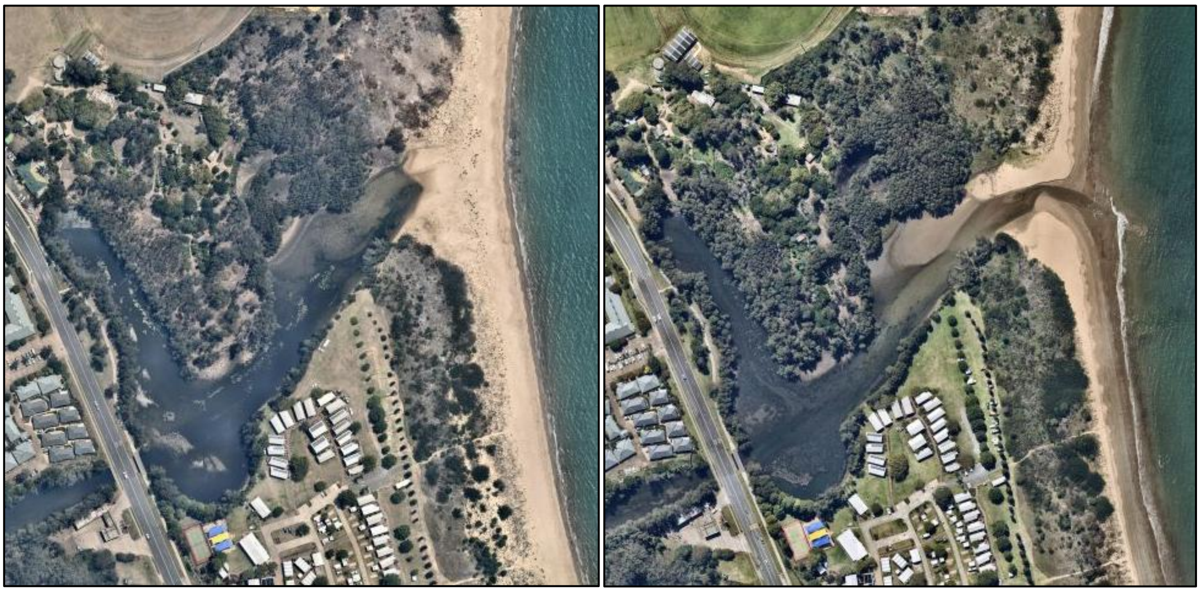

Figure 5-2 Aerial imagery of Joes Creek entrance open (left) and closed (right) from NearMap (2024)

5.3 Environmental variables

Three environmental variables were tested for the Clyde River:

1. Stage of the tide (slack low tide, slack high tide, mid ebb tide and mid flood tide)
2. Wind direction (No wind, North, North east, East, South and West, at a constant wind speed of 5 m/s)
3. Magnitude of catchment inflows (median, 80th percentile and 95th percentile)

Each overflow location had differing effects from these three variables, and which variable/s were most important for controlling plume transport varied. Western overflows (Wharf Road, Surfside and Batemans Bay Marina) were primarily influenced by tide, while eastern overflows (Long Beach, Joes Creek and Caseys Beach) were more influenced by wind.

5.3.1 Stage of the tide

The stage of the tide for all locations is indexed to the MHL Princess Jetty ocean tide gauge, via the relationship described in Table 5-1.

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

Overflow location	Results scenario	MHL water level gauge	Water level at start of spill
All	Slack low tide	Princess Jetty (216410)	Low tide
All	Mid flood tide	Princess Jetty (216410)	Half way between low and high
All	Slack high tide	Princess Jetty (216410)	High tide
All	Mid ebb tide	Princess Jetty (216410)	Half way between high and low

Results for Joes Creek were affected by stage of the tide. However, as overflows at this location would be delayed in the ICOLL system, predicting the time an overflow enters Batemans Bay (and hence is represented by the modelled scenario) would be very difficult, and is not simulated in this modelling. Hence, tides for all runs from this location were grouped, via the methods described in WRL TR2023/32 Section 8.3.4. The individual scenario result can still be viewed by clicking “View sub runs”. This has been left as an option in case this overflow location is used as a proxy for other, nearby overflows which flow directly into Batemans Bay. However, it is not recommended that these are used for overflows from Joes Creek.

5.3.2 Wind

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

Overflows from Joes Creek and Caseys Beach (on the southern side of Batemans Bay) generally reached the harvest areas at lower concentrations (i.e. were safer) during northern and northeastern winds (which set up a counterclockwise circulation in the bay) while overflows from Long Beach (on the northern side of Batemans Bay) were generally safer during southern and western winds which set up a clockwise circulation. See Figure 5-3 and Figure 5-4 for an example of the effects of wind.

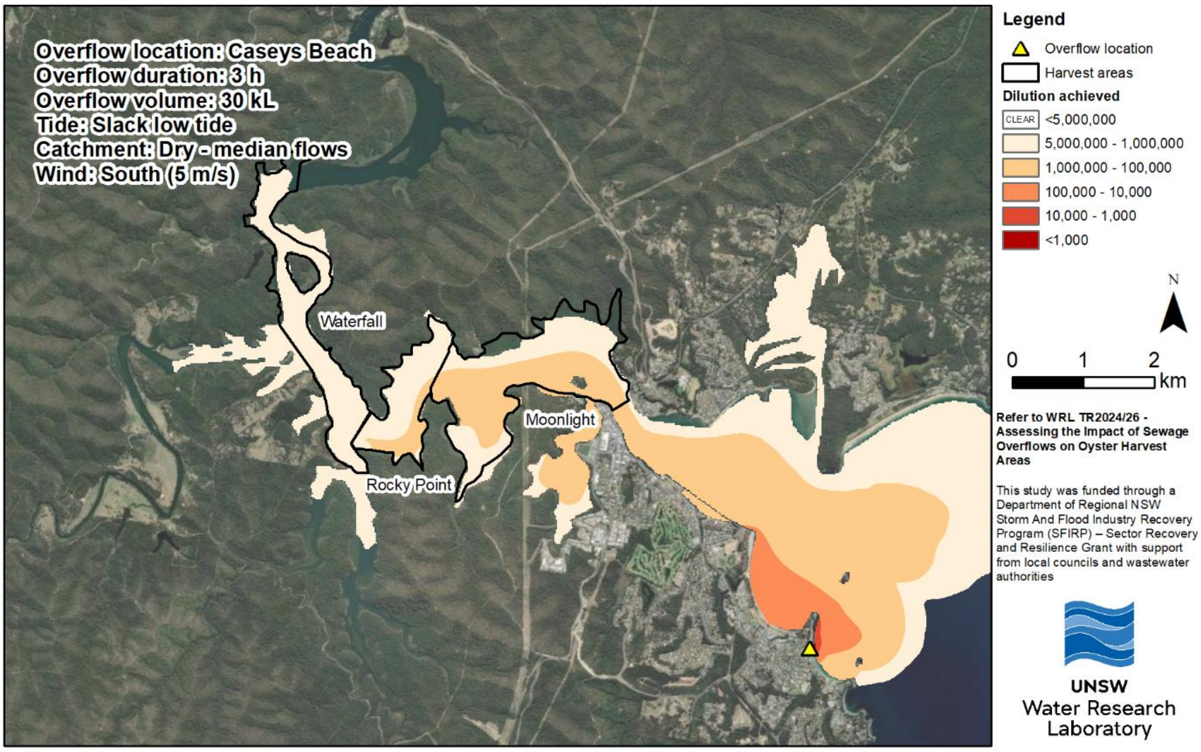

Figure 5-3 Example of a 3 hour overflow at Caseys Beach on a slack low tide with a south wind*

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

Figure 5-4 Example of a 3 hour overflow at Caseys Beach on a slack low tide with a north wind*

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

As discussed in Section 4.6.3, wind in this model is uncalibrated and unverified, though the hydrodynamic response to wind was considered reasonable based on engineering judgment. If it is found that many large overflows are occurring in the bay, for which wind based scenarios would affect the management outcomes, further data collection, model refinement and scenario modelling based on wind should be considered.

5.3.3 Catchment inflows

Catchment inflows influenced the extent of plume incursion upstream, however, it was not generally a major influence. For context, the total catchment inflows (from all three upstream boundaries into the model, shown in Figure 4-2) for the 95th percentile flow is approximately 92 m^3/s, less than 10% of the peak tidal flows through the Princes Highway Bridge site, which highlights the relative importance of tidal flows in transport and dilution of overflows in this estuary. In most cases, the median and 80th percentile flows resulted in very similar outcomes for the three harvest areas. In some cases, 95th percentile catchment inflows significantly changed outcomes. For ease of use, results for different catchment inflows have been combined for many scenarios (when the implications for harvest areas are identical). See WRL TR2023/32 Section 8.3.4 for more details on scenario grouping.

5.4 Sensitivity to bathymetric changes

As noted previously, Batemans Bay has a mobile sandy bar that creates the north west boundary of the channel leading from the river into the bay (while the southern side is trained). As can be seen in Figure 5-5 and Figure 5-6, this bar moves and changes shape with time. Notable changes include:

- Width of the channel
- Depth of the bar, especially where it encloses the end of the channel
- Location and depth of break out channels along the bar

Changes in the bathymetry can also be seen between the 1995 and 2018 bathymetric surveys in Figure 2-6 and between the 2018 and 2023 surveys in Figure 3-7.

To test the sensitivity of the model to changing bathymetry, 1 hour, no wind, median catchment inflow scenarios were run for four stages of the tide using the 1995 bathymetry. As can be seen by comparing the 2018 image in Figure 5-5 to Figure 5-6, or in the bathymetry comparison in Figure 2-6, the main differences are that in 1995 a narrower, longer breakout channel along the north shore was present, forming a second shallow bar off Surfside, and in 2018 the southern portion of the channel was wider, but with a higher elevation bar enclosing the terminus of the channel. With the 1995 bathymetry, overflows from the Marina, Joes Creek, Caseys Beach and Long Beach generally reached the harvest areas at higher concentrations, likely due to greater conveyance through the main channel caused by the lower bar. Table 5-2, Figure 5-7 and Figure 5-8 show an example of this. Although there was a more pronounced breakout channel in 1995, since the bathymetry offshore of Surfside was in general deeper and more efficient in 2018, overflows from Surfside reached the harvest areas at lower concentrations when run with the 1995 bathymetry, as can be seen in Table 5-3, Figure 5-9 and Figure 5-10. The 1995 bathymetry also effected overflows from Wharf Road, however implications were mixed, resulting in higher concentrations for some stages of the tide and lower concentrations for others.

Figure 5-5 NearMap imagery of the bar in Batemans Bay from 01/01/2012 (upper left), 15/07/2018 (year of DPIE LiDAR data, upper right), 16/05/2022 (lower left) and 10/03/2023 (year of fieldwork, lower right) (NearMap, 2024)

Figure 5-6 Aerial Imagery taken 21/01/1997, similar to the 1995 OEH bathymetric survey (NSW Spatial Services, 2024)

Table 5-2 Bathymetric sensitivity results for a 1 hour overflow from Caseys Beach on a mid ebb tide with no wind

Bathymetry	Minimum dilution achieved in Waterfall	Hours for plume to reach Waterfall	Minimum dilution achieved in Rocky Point	Hours for plume to reach Rocky Point	Minimum dilution achieved in Moonlight	Hours for plume to reach Moonlight
2018	>5,000,000	-	>5,000,000	-	1,800,000	<6 h
1995	>5,000,000	-	3,400,000	24 – 48 h	820,000	<6 h

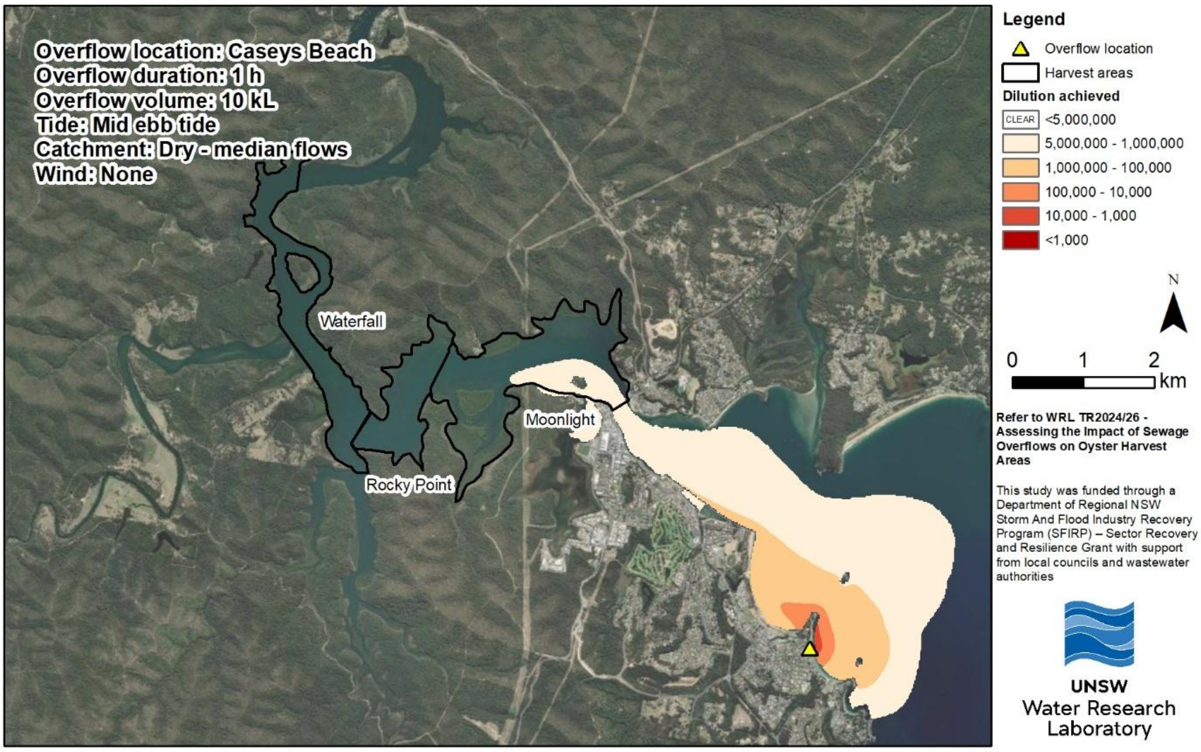

Figure 5-7 Results of model with 2018 bathymetry for 1 hour overflow from Caseys Beach on a mid-ebb tide with no wind*

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

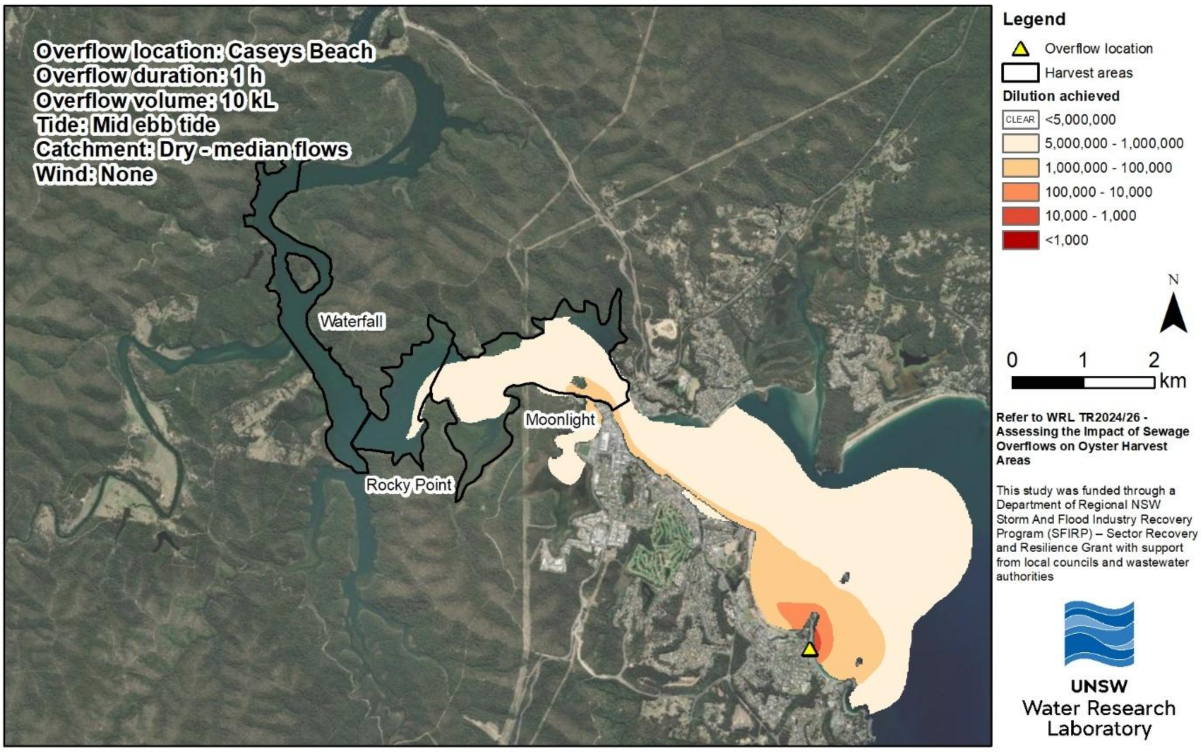

Figure 5-8 Results of model with 1995 bathymetry for 1 hour overflow from Caseys Beach on a mid-ebb tide with no wind*

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

Table 5-3 Bathymetric sensitivity results for a 1 hour overflow from Surfside on a slack low tide with no wind

Bathymetry	Minimum dilution achieved in Waterfall	Hours for plume to reach Waterfall	Minimum dilution achieved in Rocky Point	Hours for plume to reach Rocky Point	Minimum dilution achieved in Moonlight	Hours for plume to reach Moonlight
2018	230,000	<6 h	100,000	<6 h	14,000	<6 h
1995	340,000	<6 h	130,000	<6 h	24,000	<6 h

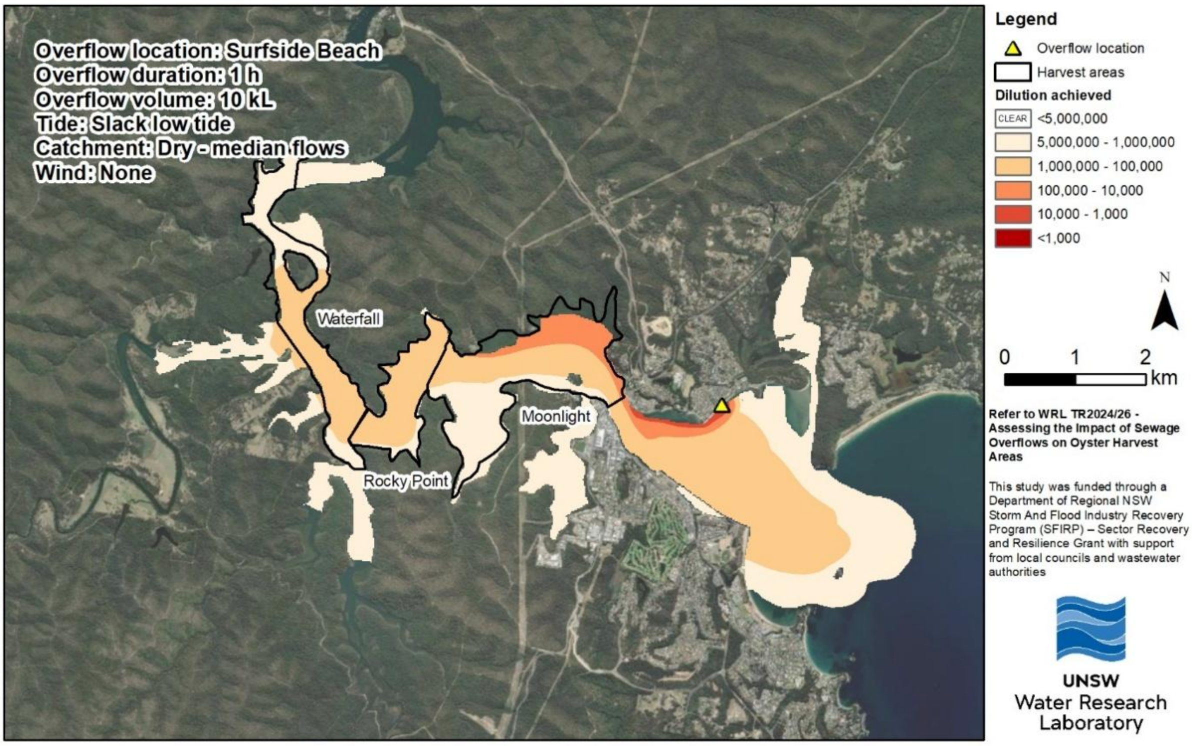

Figure 5-9 Results of model with 2018 bathymetry for 1 hour overflow from Surfside on a mid-ebb tide with no wind*

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

Figure 5-10 Results of model with 1995 bathymetry for 1 hour overflow from Surfside on a mid-ebb tide with no wind*

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

This sensitivity analysis indicates that, although outcomes are similar between bathymetries, bathymetry change of the bar does affect the results of overflows, especially in cases where the edge of the plume is near a harvest area boundary such as those presented above. Nevertheless, the impacts on the results were deemed to be relatively minor, and unlikely to change the management decisions after an overflow. Bathymetry changes appear to be driven mainly by events (such as floods) which have a short term impact on the bar. The model scenarios only consider a single bathymetry, based on the 2018 LiDAR survey. From available NearMap imagery, this bathymetry seems generally representative of the bathymetry from 2018 to 2024, however it may not be adequate to represent the bathymetry in more extreme variations, such as that in 2012 (which has a large breakout channel in the middle of the sand bar) as can be seen in Figure 5-5.

Monitoring of areal imagery through NearMap and other sources can be used to detect large bathymetric changes that may substantially affect transport. Some changes, such as formation of a breakout channel, may be more visible than others, such as elevation change in the bar encircling the terminus of the channel. Moreover, changes in bathymetry may have unintuitive results. Therefore, 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.

6 Conclusion

This report is focussed on the Clyde River estuary produced for the study “Assessing the impact of sewage overflows on oyster harvest areas in NSW”. The purpose of this report was to provide technical and estuary specific information on the process and data sources used to create the Clyde River estuary model. Key information included in the report relates to the integration of existing data sources, the August 2023 field data collection campaign, data processing, model development, and model verification. If wind is found to be significant for many management decisions on this estuary, further model refinement based on wind should be undertaken.

This report should be read in conjunction with WRL TR2023/32 which provides details on the technical methods used across each of the 11 study estuaries (including the Clyde) 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 below figures summarise the behaviour of the four drifter drogue experiments. For more information on these deployments, refer to Section 3.7.

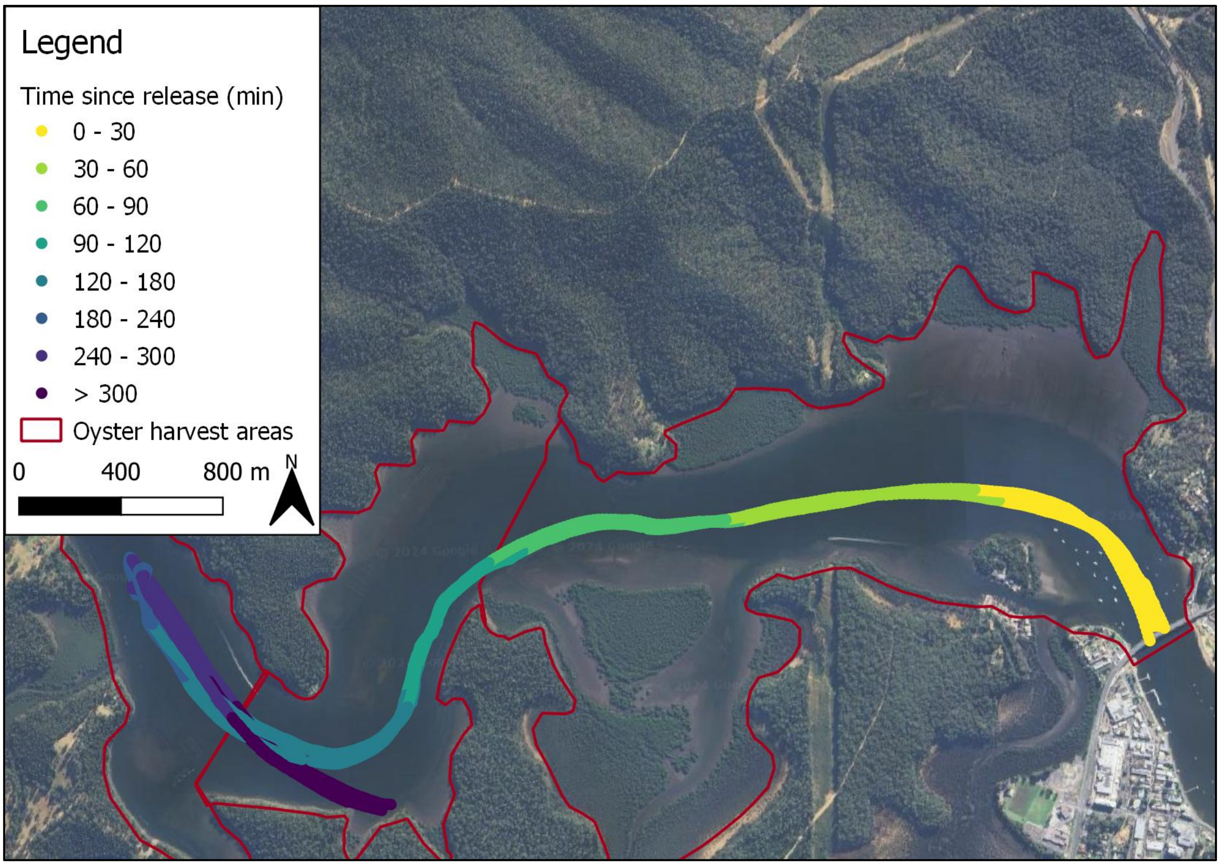


Figure A-1 GPS drifter drogue release 1 – Princes Highway

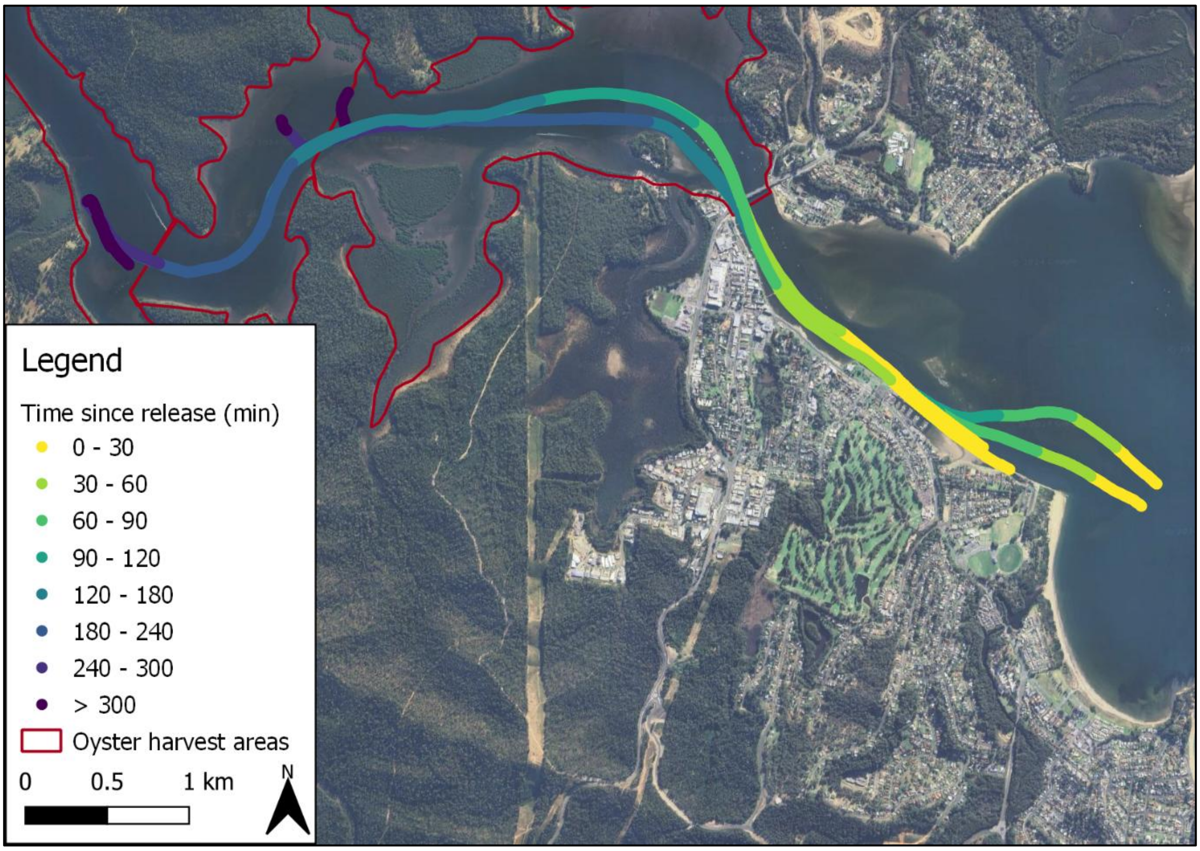


Figure A-2 GPS drifter drogue release 2 – Batemans Bay

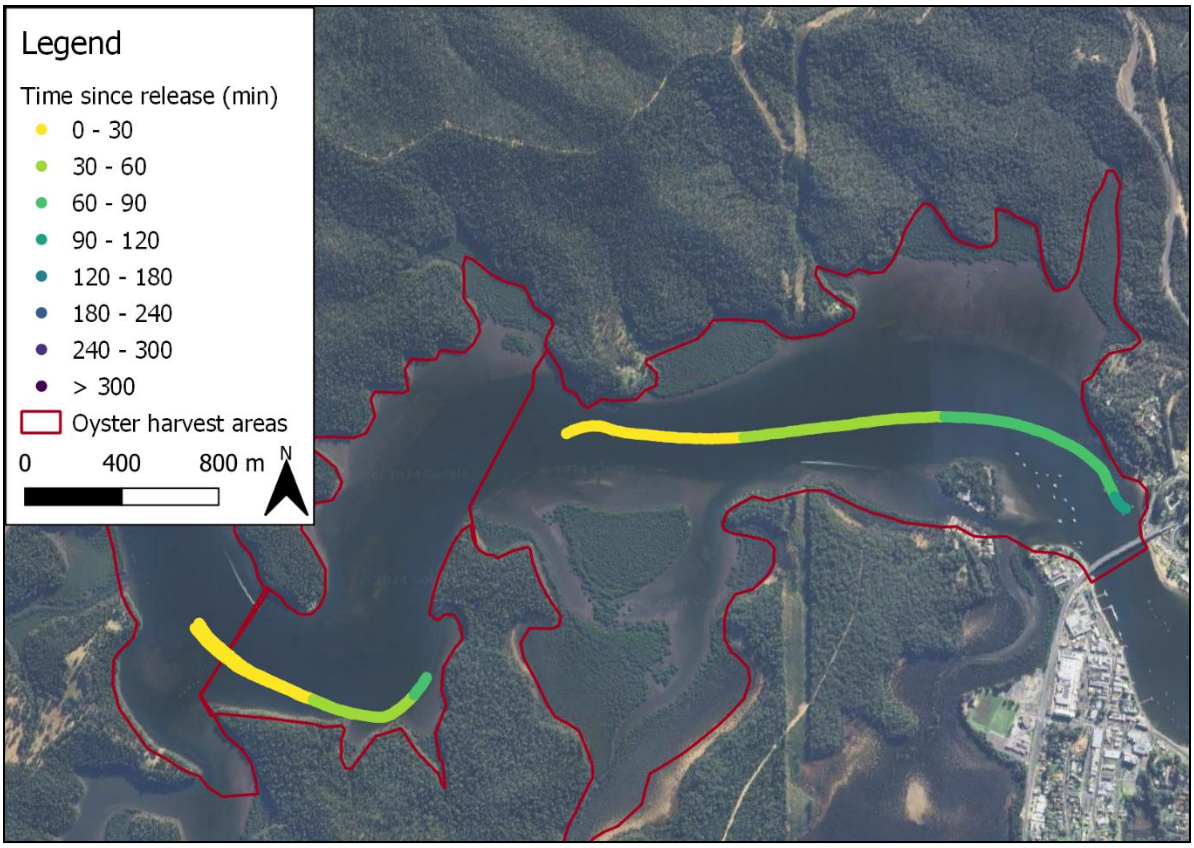


Figure A-3 GPS drifter drogue release 3 – Pelican Island

A2 Tidal flow gauging

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

Table A-1 Princes Highway Bridge Site 3 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	22/08/2023	16:00:28	748
2	22/08/2023	16:03:59	768
3	23/08/2023	9:05:39	-884
4	23/08/2023	9:09:23	-754
5	23/08/2023	9:13:15	-634
6	23/08/2023	9:25:02	-616
7	23/08/2023	9:29:13	-657
8	23/08/2023	9:34:14	-713
9	23/08/2023	9:38:26	-746
10	23/08/2023	9:43:45	-757
11	23/08/2023	9:48:20	-873
12	23/08/2023	9:54:04	-936
13	23/08/2023	9:59:00	-899
14	23/08/2023	10:03:51	-868
15	23/08/2023	10:08:28	-866
16	23/08/2023	10:13:14	-886
17	23/08/2023	10:18:23	-863
18	23/08/2023	10:22:55	-777
19	23/08/2023	10:27:01	-755
20	23/08/2023	11:33:29	-714
21	23/08/2023	11:38:43	-730
22	23/08/2023	11:42:52	-751

No.	Date	Time	Flow (m^3/s) *
23	23/08/2023	13:06:39	-117
24	23/08/2023	13:11:12	57
25	23/08/2023	13:14:57	112
26	23/08/2023	13:19:33	157
27	23/08/2023	13:23:37	111
28	23/08/2023	16:46:54	802
29	23/08/2023	16:51:07	762

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

Table A-2 Big Island 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	23/08/2023	12:19:44	-307
2	23/08/2023	12:23:54	-305
3	23/08/2023	14:03:13	111
4	23/08/2023	14:08:34	175
5	23/08/2023	14:13:18	170
6	23/08/2023	15:08:41	411
7	23/08/2023	15:14:09	459
8	23/08/2023	16:02:16	462
9	23/08/2023	16:07:25	471

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

A3 Cross-channel velocity distribution

The below figures summarise velocity distribution results from the 2023 field campaign. For more information, refer to Section 3.3. Note that all measurements are at a different stage of the tidal cycle so the magnitude of flow will vary. The primary purpose is to illustrate flow distribution across the channel.

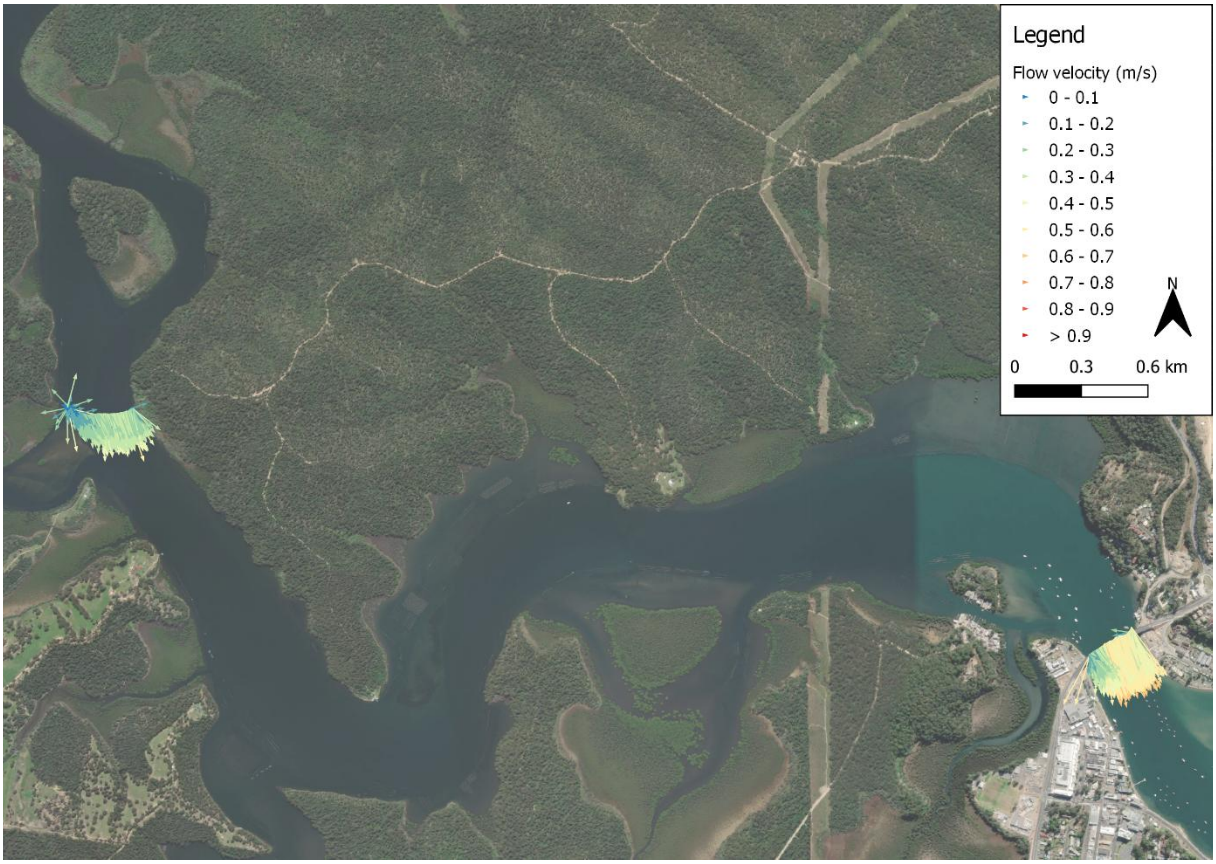


Figure A-4 Ebb tide channel flow distribution

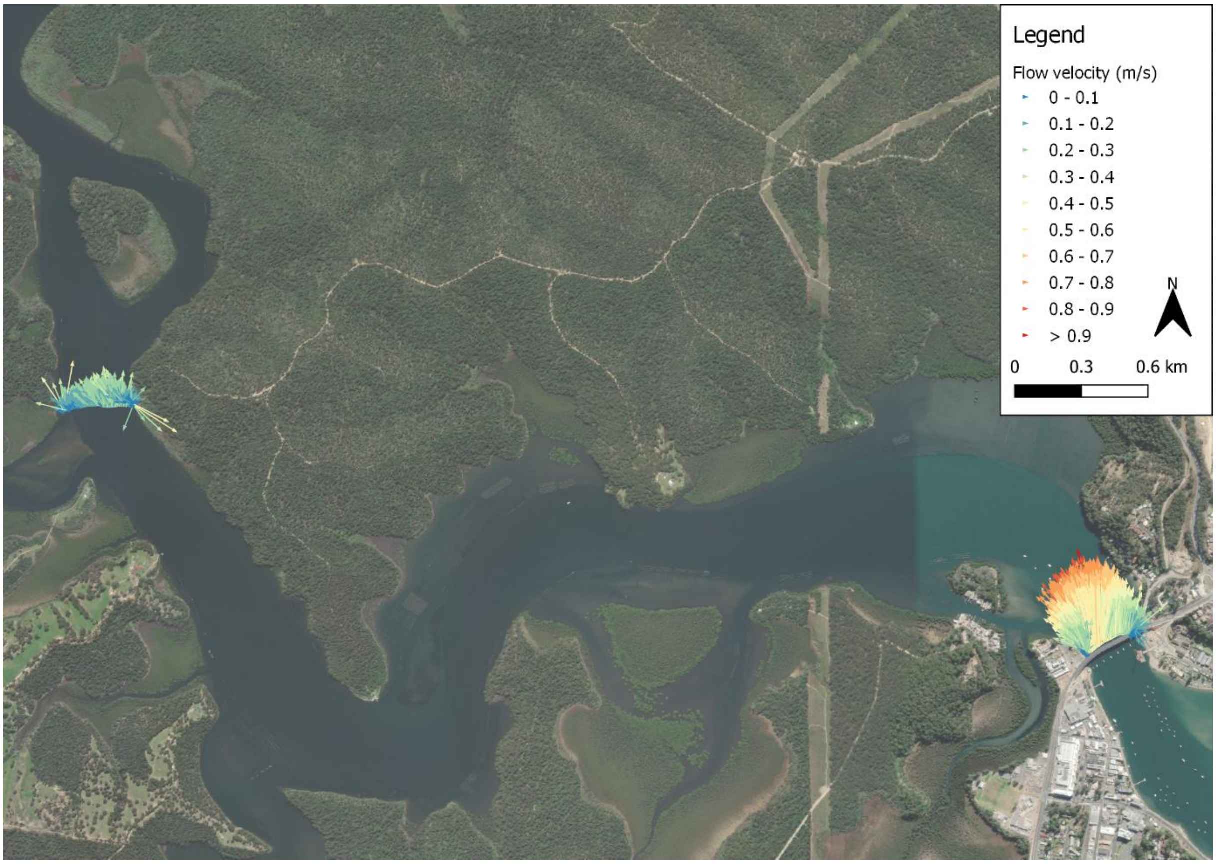


Figure A-5 Flood tide channel flow distribution

A4 Vertical velocity distributions

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

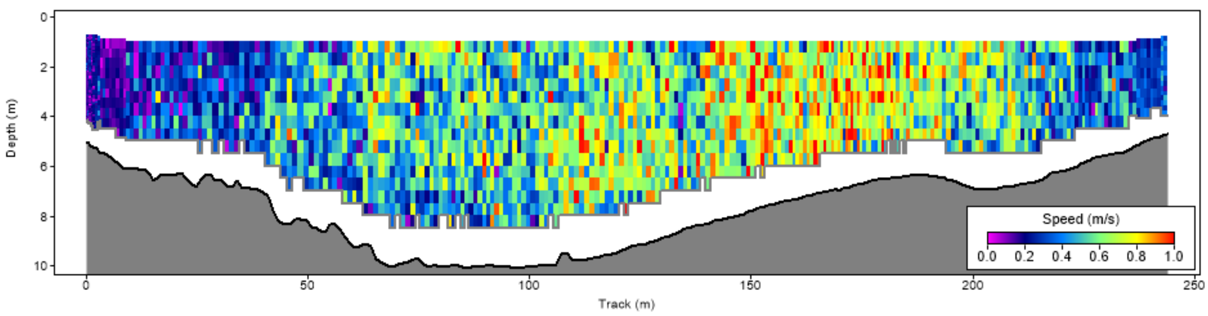


Figure A-6 Vertical velocity distribution – Princes Highway Bridge Site 3 – Flood tide – (2023/08/23 10:03:51)

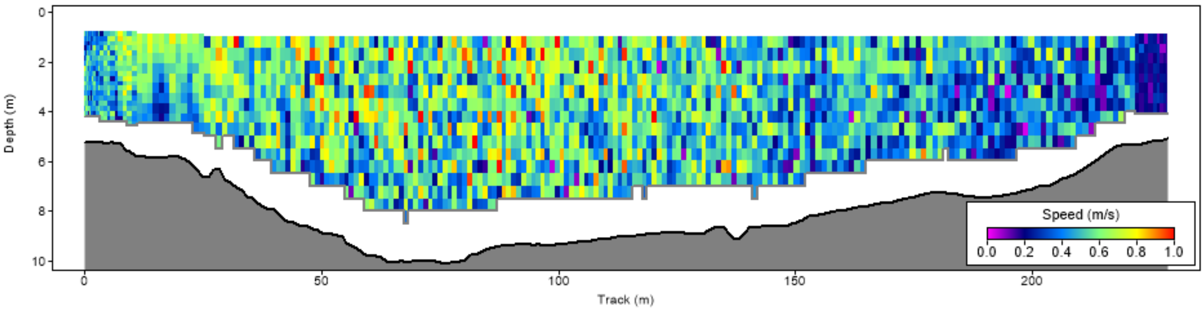


Figure A-7 Vertical velocity distribution – Princes Highway Bridge Site 3 – Ebb tide – (2023/08/23 16:46:54)

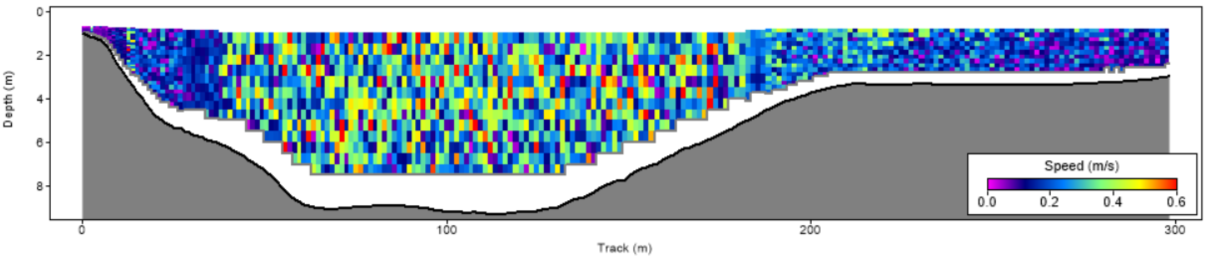


Figure A-8 Vertical velocity distribution – Big Island – Flood tide – (2023/08/23 12:19:44)

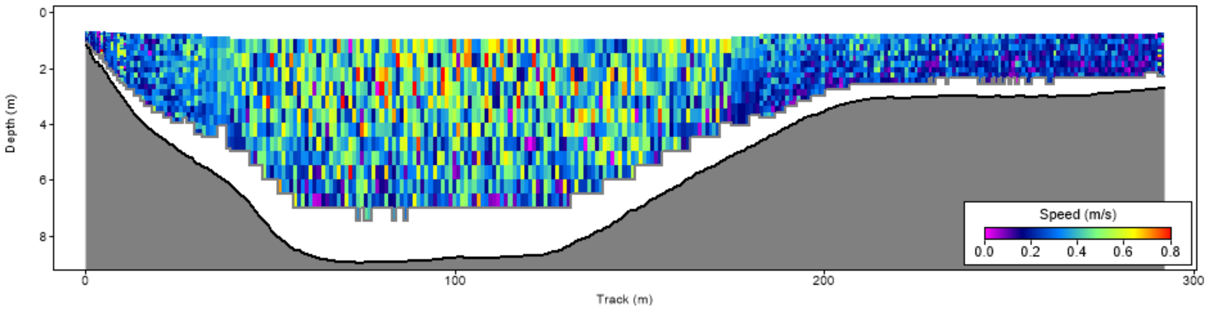


Figure A-9 Vertical velocity distribution – Big Island – Ebb tide – (2023/08/23 16:02:16)

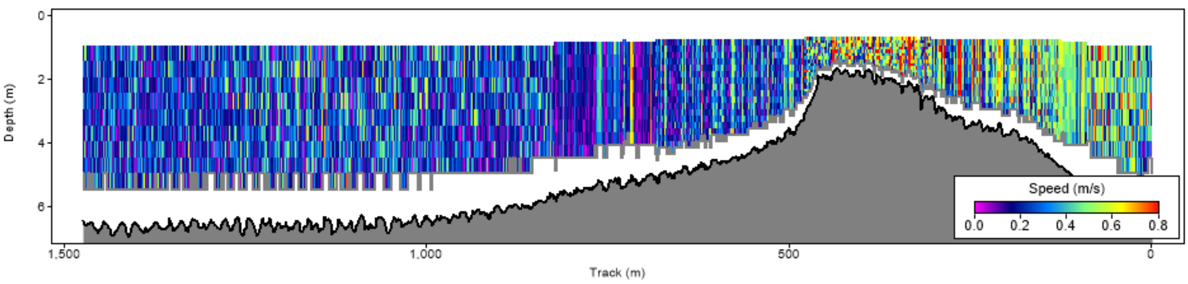


Figure A-10 Vertical velocity distribution – Batemans Bay transect – (2023/08/22 16:30:31)

Appendix B Model calibration

B1 Hydrodynamic calibration and verification results

The below figures summarise results from the Clyde River hydrodynamic calibration and verification process. For more information, refer to Section4.6.

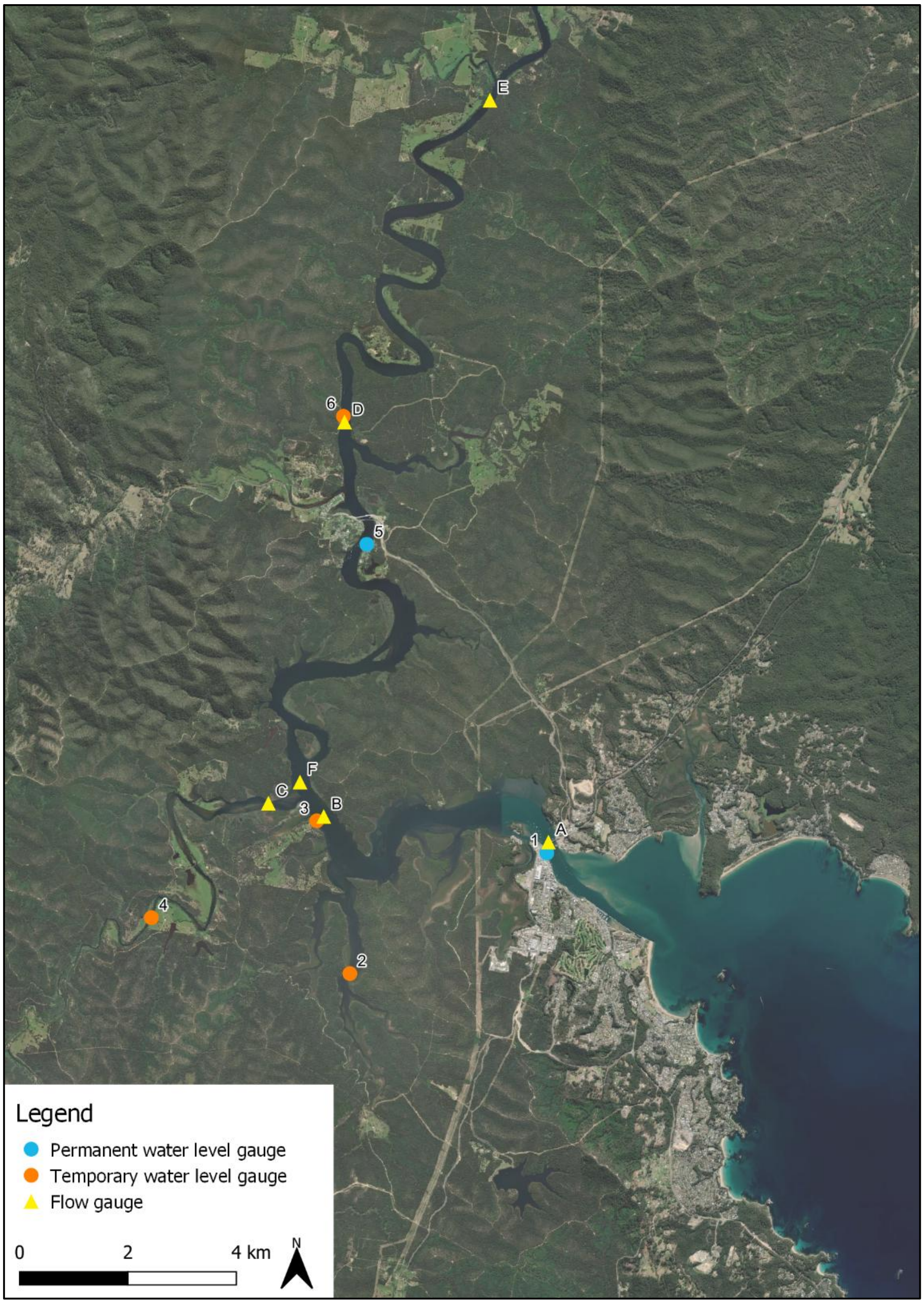


Figure B-1 Water level and tidal flow gauging locations

B1.1 Tidal flow gauging calibration – 1996

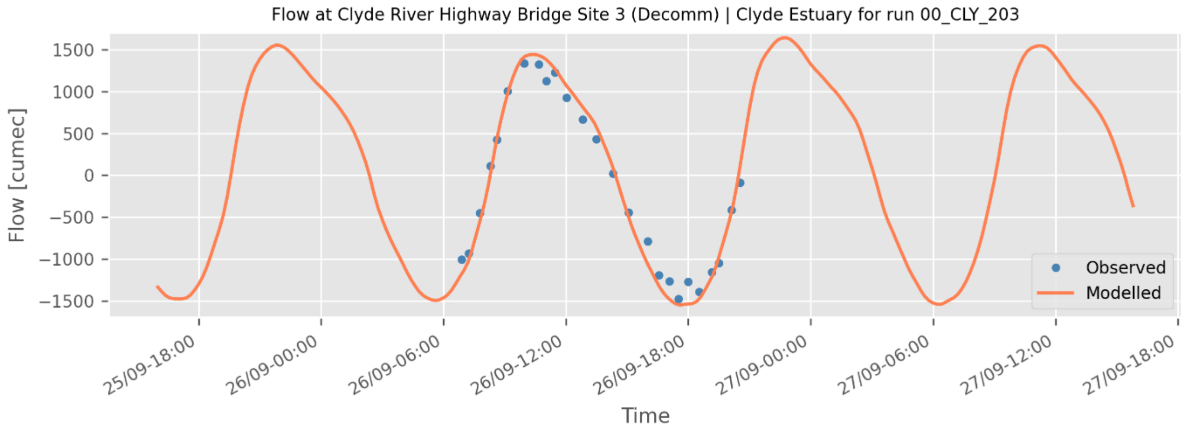


Figure B-2 1996 tidal flow calibration – Location A – Princes Highway Bridge Site 3

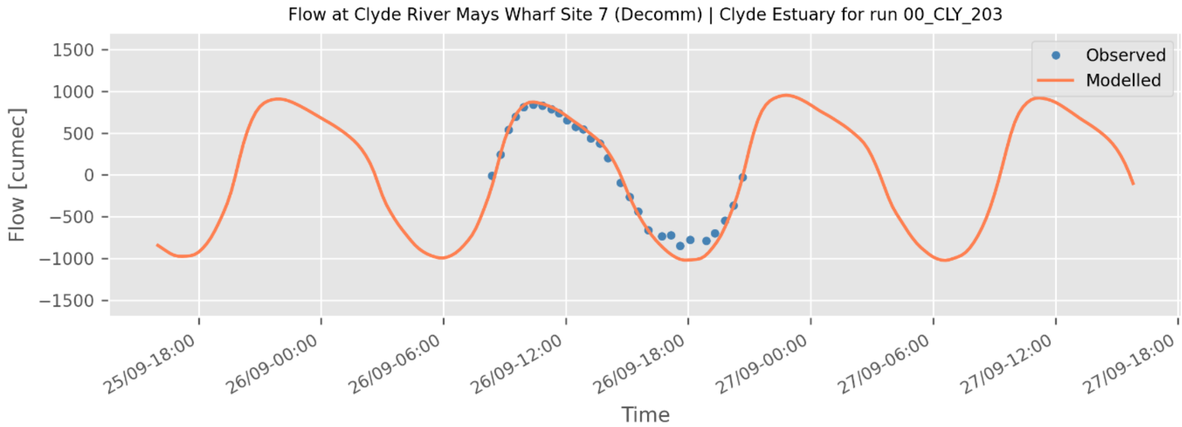


Figure B-3 1996 tidal flow calibration – Location B – Mays Wharf Site 7

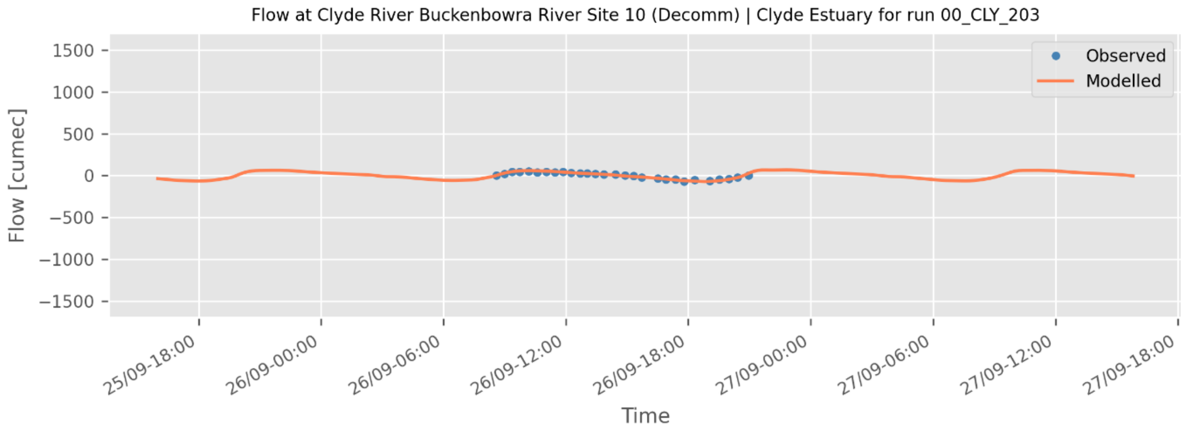


Figure B-4 1996 tidal flow calibration – Location C – Buckenbowra River Site 10

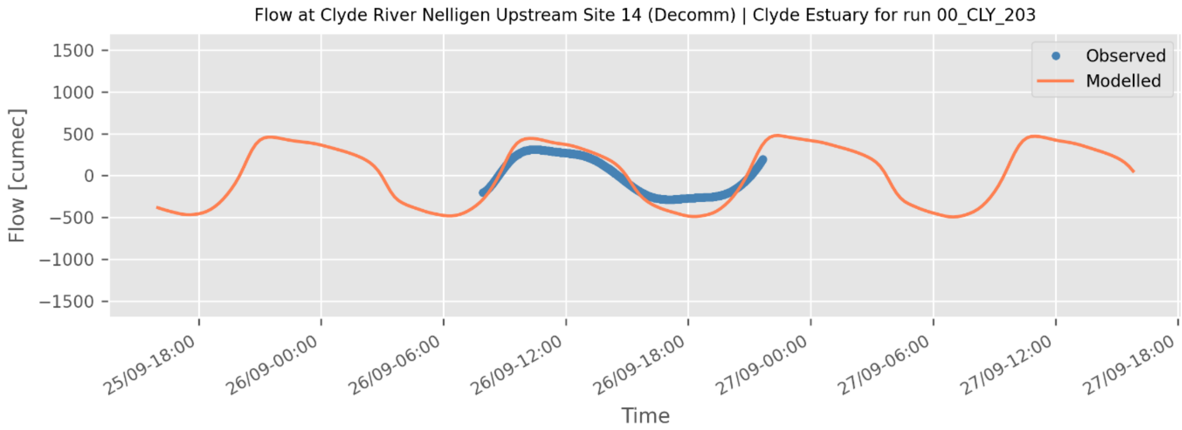


Figure B-5 1996 tidal flow calibration – Location D – Nelligen Upstream Site 14

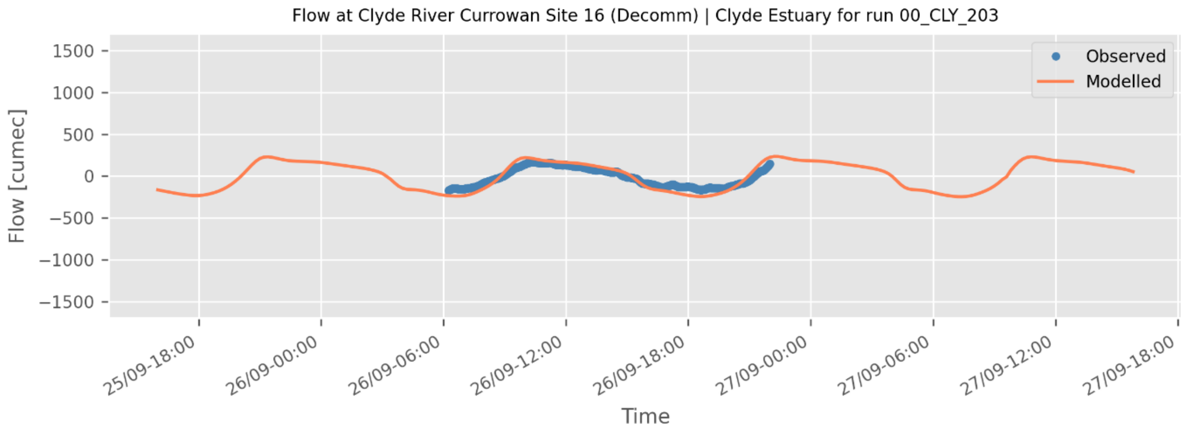
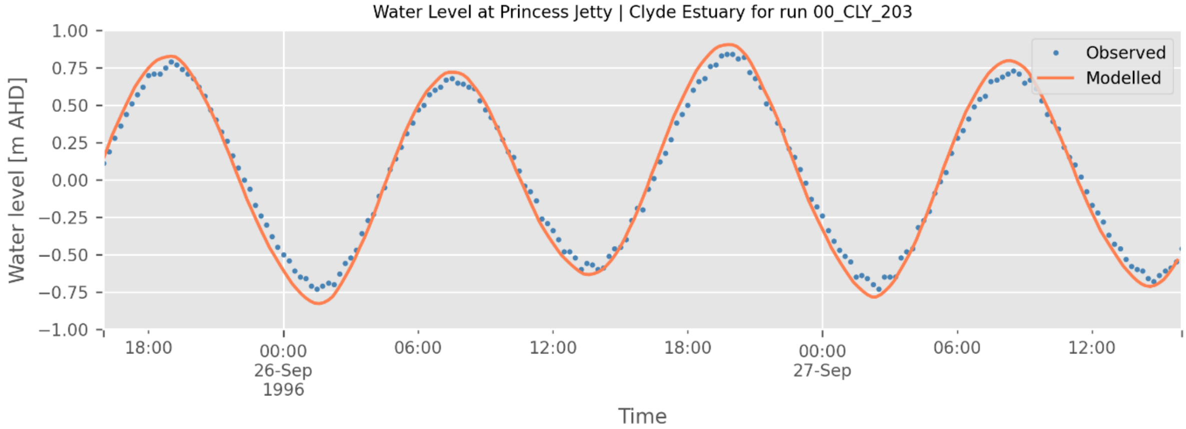


Figure B-6 1996 tidal flow calibration – Location E – Currowan Site 16

B1.2 Water level calibration – 1996



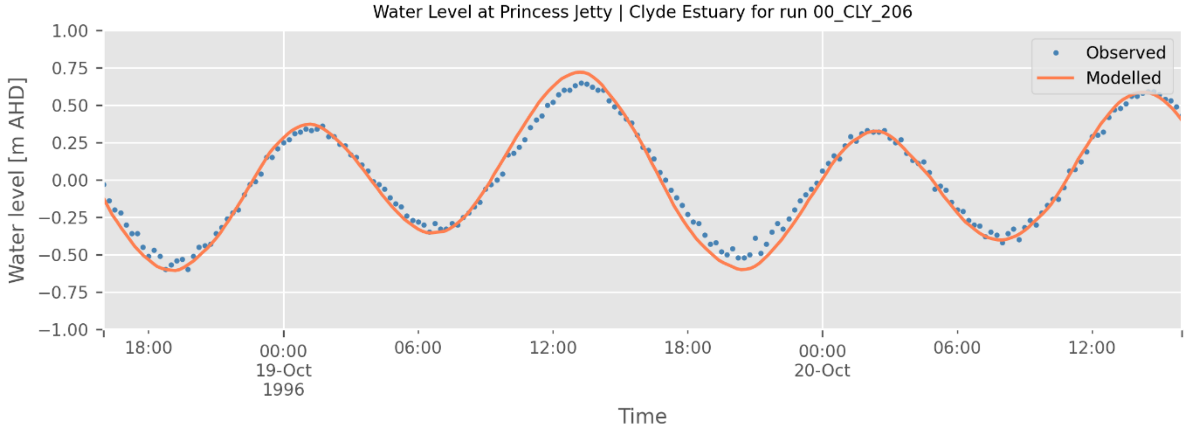


Figure B-7 1996 water level calibration – Location 1 – Princess Jetty (September period, upper and October period, lower)

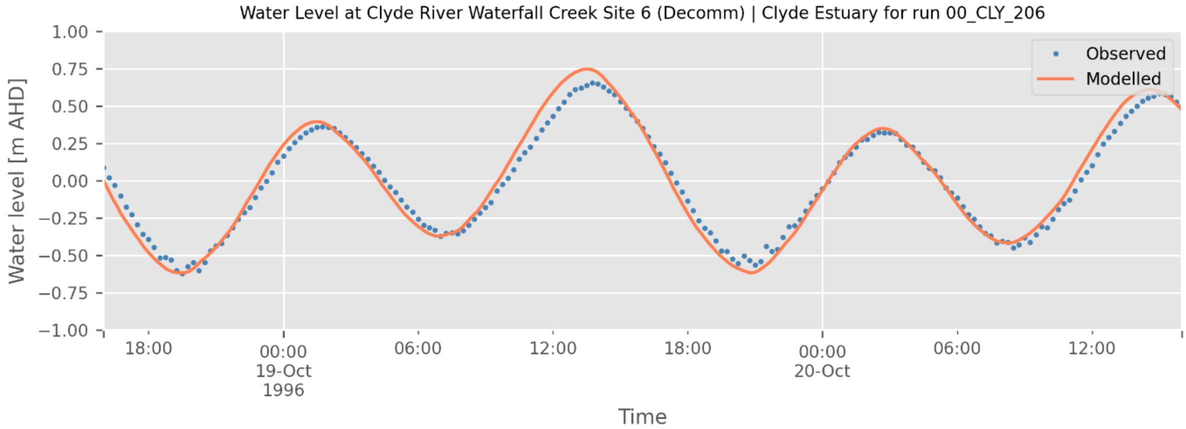


Figure B-8 1996 water level calibration – Location 2 – Waterfall Creek Site 6 (October period)

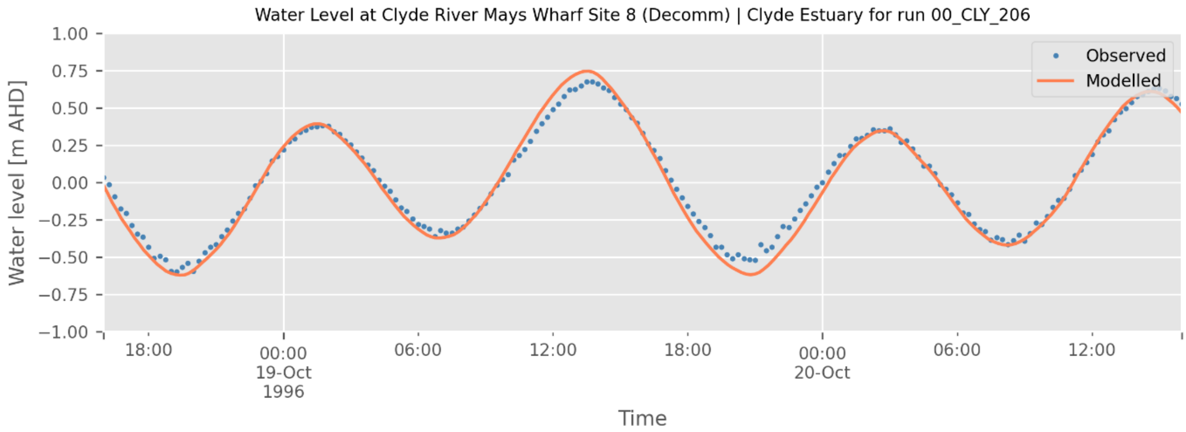


Figure B-9 1996 water level calibration – Location 3 – Mays Wharf Site 8 (October period)

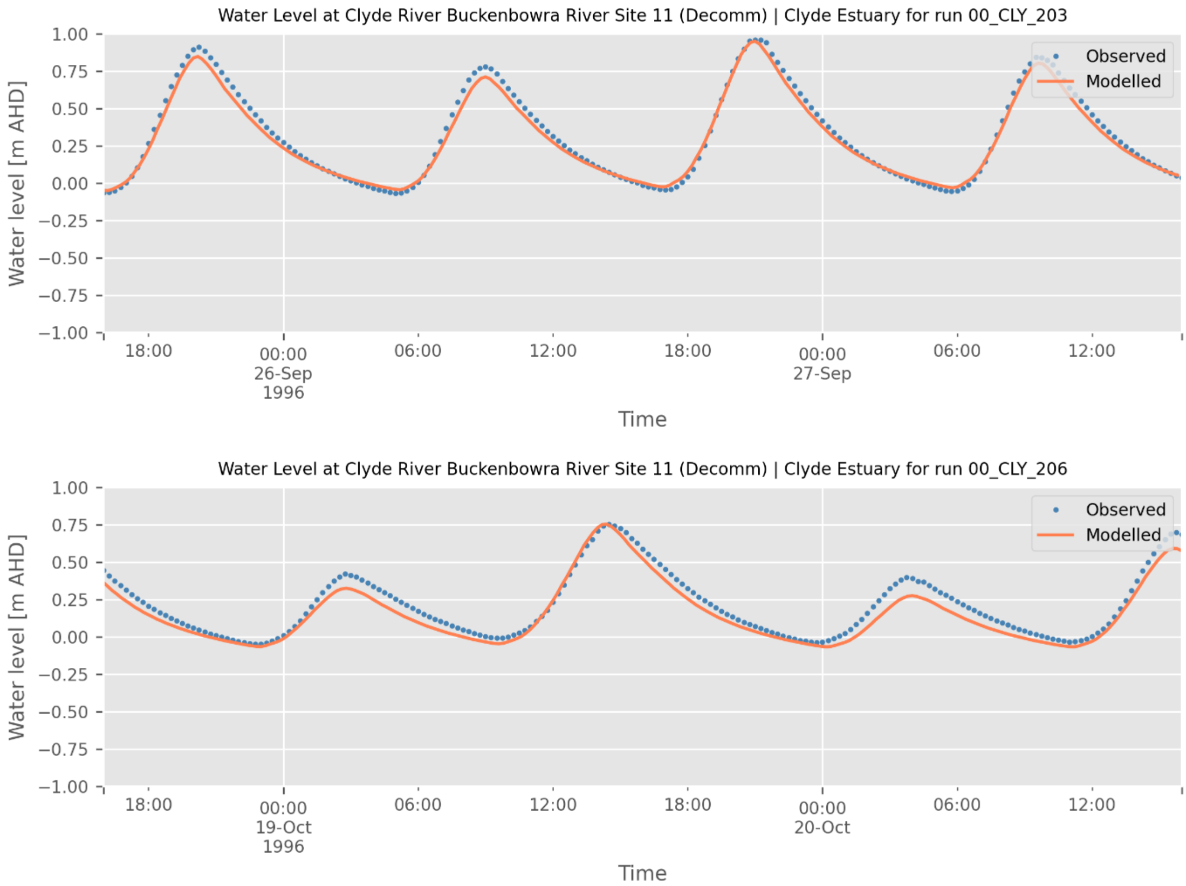


Figure B-10 1996 water level calibration – Location 4 – Buckenbowra River Site 11 (September period, upper and October period, lower)

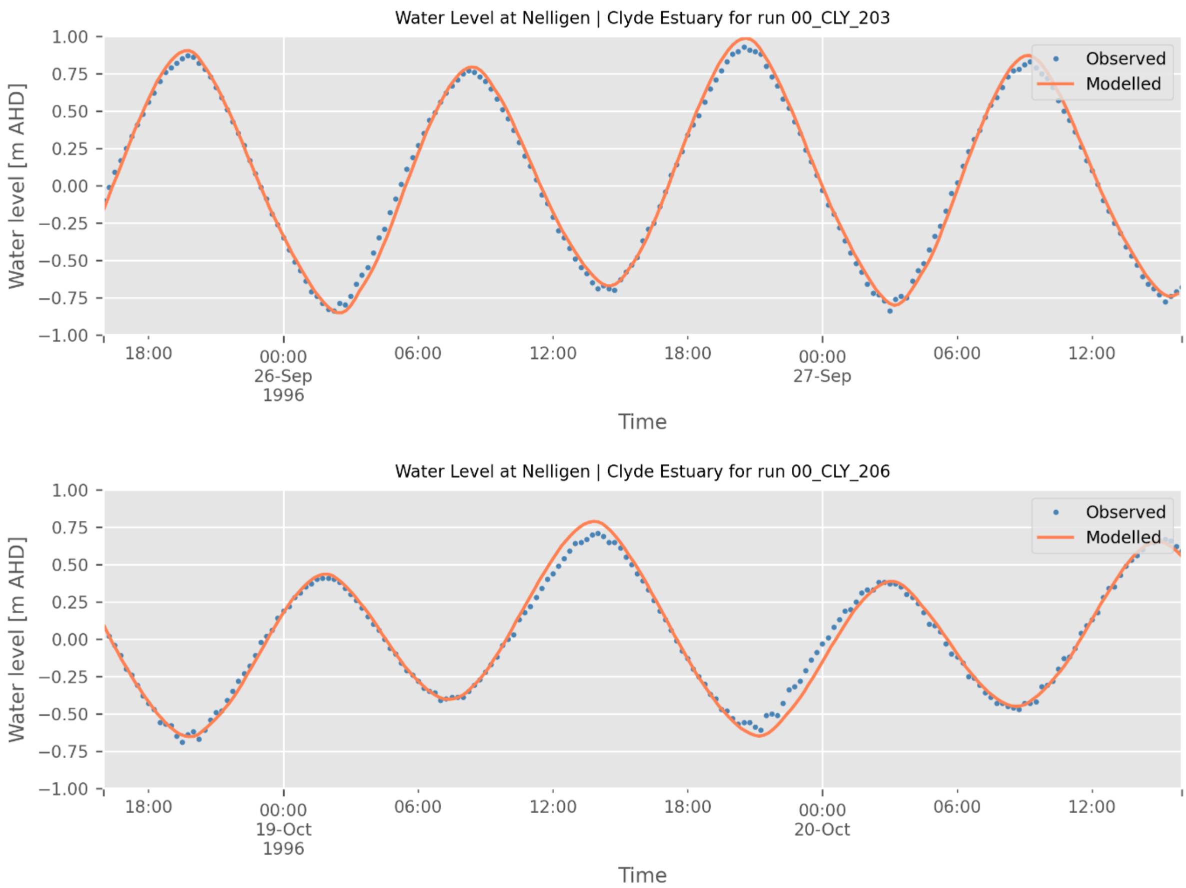


Figure B-11 1996 water level calibration – Location 5 – Nelligen (September period, upper and October period, lower)

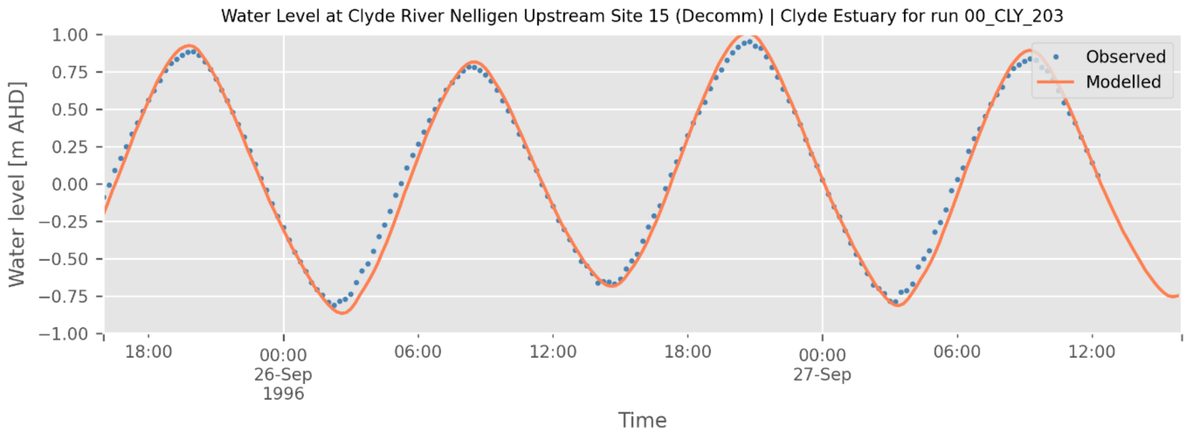


Figure B-12 1996 water level calibration – Location 6 – Nelligen Upstream Site 15 (September period)

B1.3 Tidal flow gauging verification – 2023

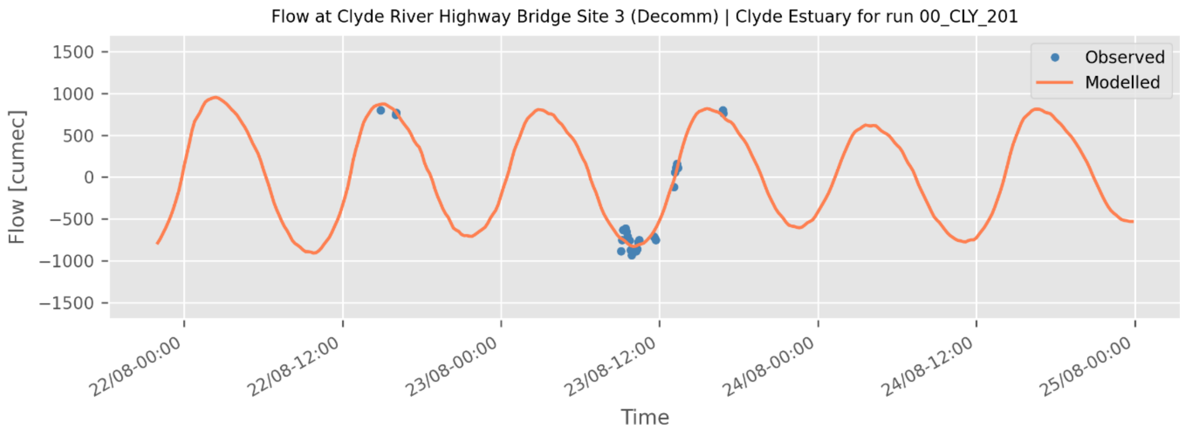


Figure B-13 2023 tidal flow verification – Location A – Highway Bridge Site 3

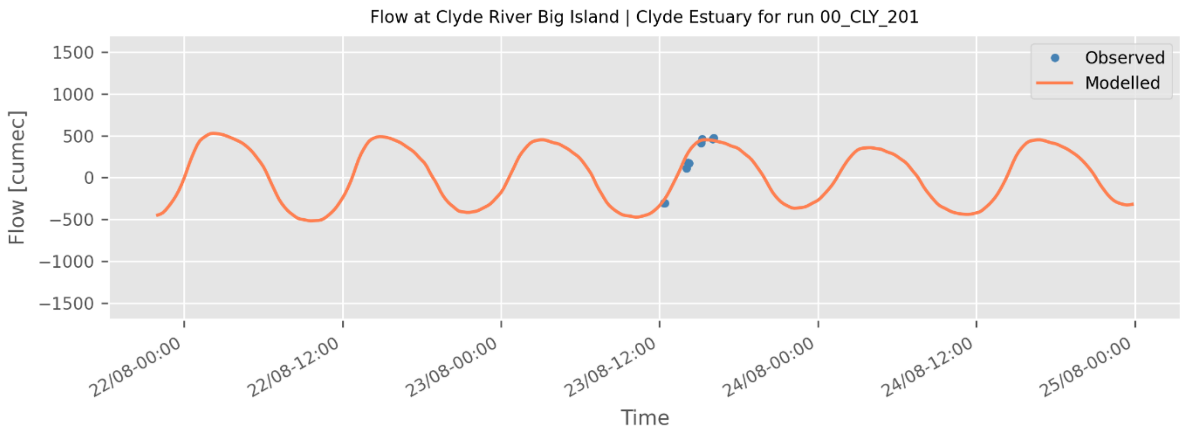


Figure B-14 2023 tidal flow verification – Location F – Big Island

B1.4 Water level verification – 2023

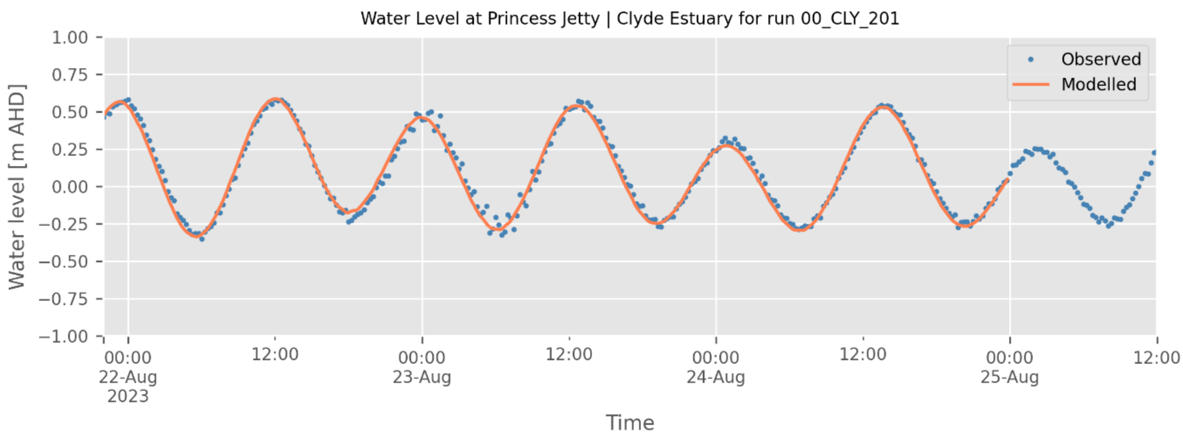


Figure B-15 2023 water level verification – Location 1 – Princess Jetty

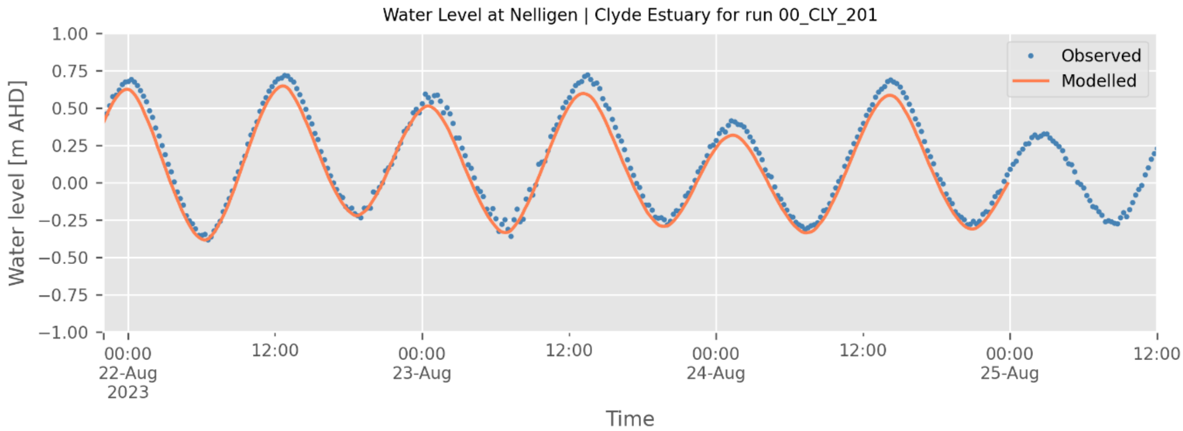


Figure B-16 2023 water level verification – Location 5 – Nelligen