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

WRL TR 2023/20, May 2025

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

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1 Introduction

1.1 Project overview

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

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

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

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

1.2 Report context

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

1.3 Camden Haven River site description

The Camden Haven estuary is a coastal river in NSW, Australia, located 285 km north of Sydney and 25 km south of Port Macquarie. Major towns in the area include Laurieton, North Haven, Dunbogan, Kendall, and Kew. The estuary is comprised of two lake systems. Queens Lake to the north, which is connected to Camden Haven Inlet via Stingray Creek, and Watson Taylors Lake which drains directly through the Camden Haven River. The estuary has a catchment of approximately 720 km^2 with a waterway area of 28 km^2 (MHL, 1997). The tidal extent of the Camden Haven River is 25 km upstream of the estuary entrance. To the north, tidal influence extends 16 km inland from the ocean, passing through Queens Lake and into Herons Creek. The tidal prism of the estuary on a spring tide in 1997 was 7.6 x 10^6 m^3 (MHL, 1997). The entrance to Camden Haven Inlet was artificially trained in the early 1900s, with the breakwater at the heads last extended in 1973 (MHL, 1997). The estuary has three oyster harvest areas, Gogleys Lagoon, Stingray Creek, and Hanleys Point, shown in Figure 1-1.

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 1-1 Oyster harvest areas on the Camden Haven River

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 six locations in the Camden Haven estuary and at two nearby ocean tide gauges.	2.2
Water level data	NSW Food Authority (2023)	Single water level sensor in Gogleys Lagoon.	2.2
Tidal flow and water level	MHL (1997)	Tidal flow gauging at seven locations and temporary water level gauging at an additional four locations in August and September 1997.	2.2
Tidal flow and water level	MHL (1989)	Tidal flow gauging at three locations and temporary water level gauging at an additional four locations in August 1989.	2.2
Tidal flow and water level	MHL (1976)	Tidal flow gauging of Gogleys Lagoon at two locations and temporary water level gauging at an additional ten locations around Gogleys Lagoon in March 1976.	2.2
Catchment discharge	WaterNSW (2023)	Two long term catchment flow monitoring locations.	2.3
Sewage overflows	NSW Food Authority	Data on overflows reported to EPA and NSW Food Authority including volume, duration and closure action.	2.4
Bathymetry	DPIE (2018) OEH (1979) AHO (2021) NSW Spatial Services (2012) NAVONICS (2023) NearMap (2024)	Bathymetry primarily sourced from 2018 NSW Marine LiDAR Topo-Bathy survey with supplementary data from 1979 single beam survey, AHO maritime charts, 2012 Digital Elevation Model (DEM), NAVONICS SonarChart and NearMap aerials.	2.5

2.2 Water level and tidal flow gauging

Manly Hydraulics Laboratory (MHL) maintain six permanent water level gauges on the Camden Haven River, and two nearby ocean tide gauges. Further water level and flow gauging has occurred during four MHL short-term data collection campaigns in 1976, 1978, 1979 and 1997. The 1978 data and report (MHL250) was not available in digital form and was not considered for this study. As the 1978 study predates MHL ocean tide data collection, it has not been used for model calibration or verification, however it was used to assess the order of magnitude of tidal flows in Gogleys Lagoon where limited other data was available. NSW Food Authority maintain an additional water level sensor in Gogleys Lagoon, which is used by the oyster growers. 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 Camden Haven River and relevant ocean tide gauges

Water level gauge	Location label	Station number	Provider	Date range	MHL report number
Entrance/North Haven	1	207423	MHL	1986 – present	–
Stingray Creek/West Haven	3	207437	MHL	1986 – present	–
Hanleys Point/ Laurieton	5	207425	MHL	1990 – present	–
Logans Crossing	10	207428	MHL	1989 – present	–
Queens Lake/ Lakewood	12	207475	MHL	2001 – present	–
Watson Taylors Lake	13	207480	MHL	2001 – present	–
Port Macquarie	–	207420	MHL	1986 – present	–
Crowdy Head Harbour Fuel Wharf	–	208470	MHL	1986 – 2013	–
Crowdy Head Fishermans Wharf	–	208471	MHL	2013 – present	–
Gogleys Lagoon	14	–	NSW Food Authority *	2022 – present	–
Gogleys Lagoon Entrance	2	–	MHL	18/08/1997 – 19/09/1997	MHL887
Queens Lake	4	–	MHL	18/08/1997 – 19/09/1997	MHL887

Water level gauge	Location label	Station number	Provider	Date range	MHL report number
Watson Taylors Lake East	6	–	MHL	19/08/1997 – 19/09/1997	MHL887
Watson Taylors Lake West	7	–	MHL	19/08/1997 – 19/09/1997	MHL887
Rossglen	8	–	MHL	18/08/1997 – 19/09/1997	MHL887
Kendall	9	–	MHL	18/08/1997 – 19/09/1997	MHL887
Stewarts River Railway Bridge	11	–	MHL	19/08/1997 – 19/09/1997	MHL887
Gogleys Lagoon	– **	–	MHL	04/08/1976	MHL296
Camden Haven Estuary	– **	–	MHL	09/08/1979	MHL440

* This sensor was initially deployed as part of the 2017-2020 Food Agility CRC project: Oyster industry transformation – Building sustainability and profitability in the Australian Oyster Industry.

** Water levels from the 1976 and 1979 MHL studies are not presented in detail as these periods were not used for calibration and verification purposes due to study age and a lack of suitable ocean tide data required to run the hydrodynamic model.

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

Tidal flow gauge	Location label	Dates	Study
Entrance/North Haven	A	18/09/1997, 18-19/05/2023	MHL887, 2023 fieldwork
Stingray Creek Bridge	B	18/09/1997, 18-19/05/2023	MHL887, 2023 fieldwork
Hanleys Point Bridge/Laurieton	C	18/09/1997, 18-19/05/2023	MHL887, 2023 fieldwork
Camden Haven River Delta South	D	18/09/1997	MHL887
Camden Haven River Delta North	E	18/09/1997	MHL887
Camden Haven River	F	18/09/1997	MHL887
Stewarts River	G	18/09/1997	MHL887
Gogleys Lagoon West Entrance	H	18/05/2023	2023 fieldwork
Gogleys Lagoon	-	04/08/1976	MHL296
Camden Haven Estuary	-	09/08/1979	MHL440

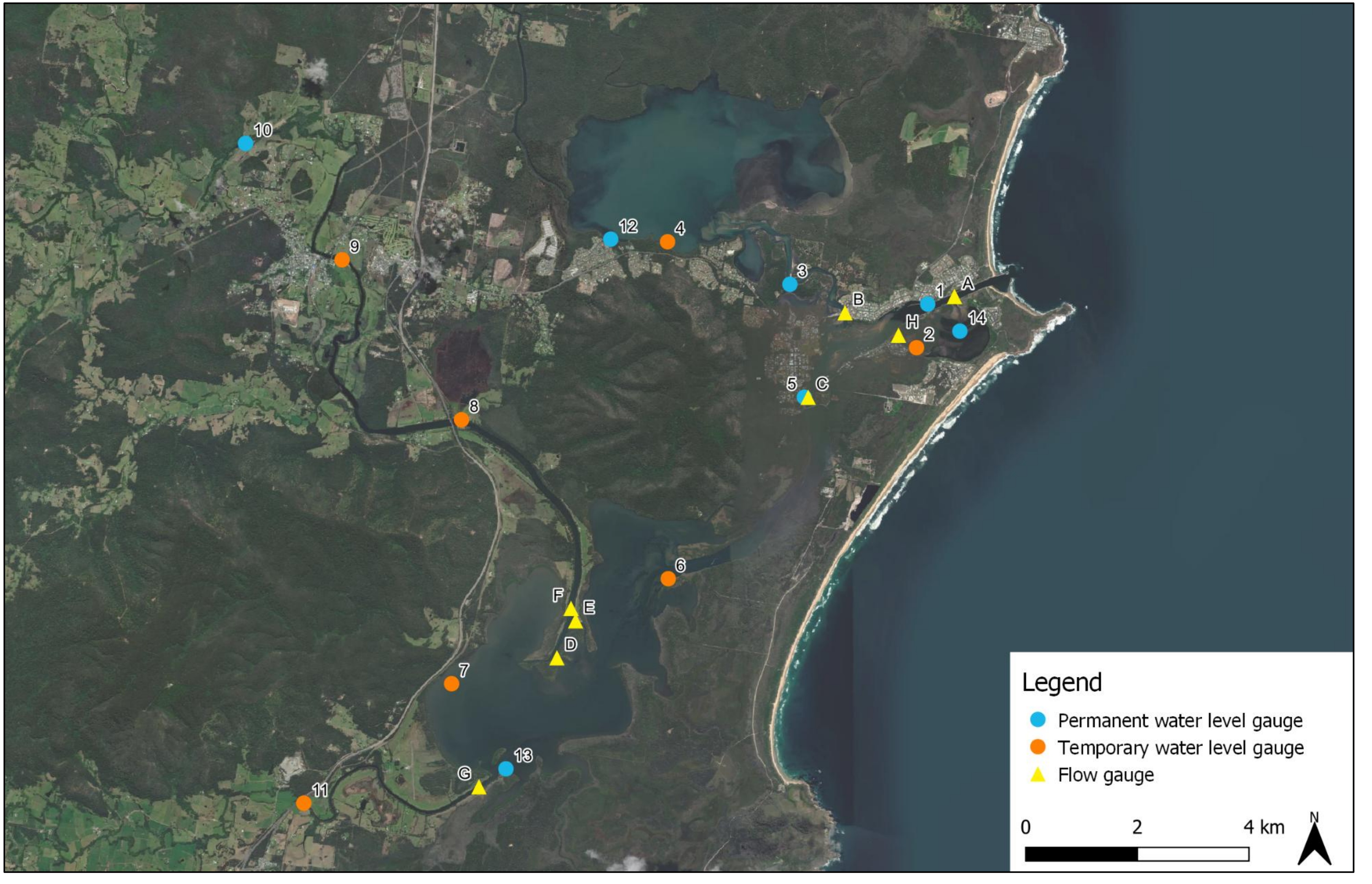

Figure 2-1 Water level and tidal flow gauging locations

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 Camden Haven estuary and continuous flow gauging of discharge and water levels are available from WaterNSW (2023) at two relevant locations: Stewarts River (1969 to present) and Camden Haven River at Kendall (1970 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
Camden Haven River	207009	1.000
Stewarts River	207008	1.544
Herons Creek*	207009	0.365

*This catchment was ungauged, so the gauge in the nearby Camden Haven River catchment was scalled and used.

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

Table 2-5 WaterNSW gauge flow percentiles

Percentile	Stewarts River (207008) ML/d *(m^3/s)*	Camden Haven River at Kendall (207009) ML/d *(m^3/s)*
5th	0.0 *(0.0)*	4.3 *(0.05)*
20th	1.7 *(0.02)*	20 *(0.23)*
50th (median)	16 *(0.19)*	79 *(0.92)*
80th	76 *(0.88)*	290 *(3.4)*
95th	447 *(5.2)*	2026 *(23)*

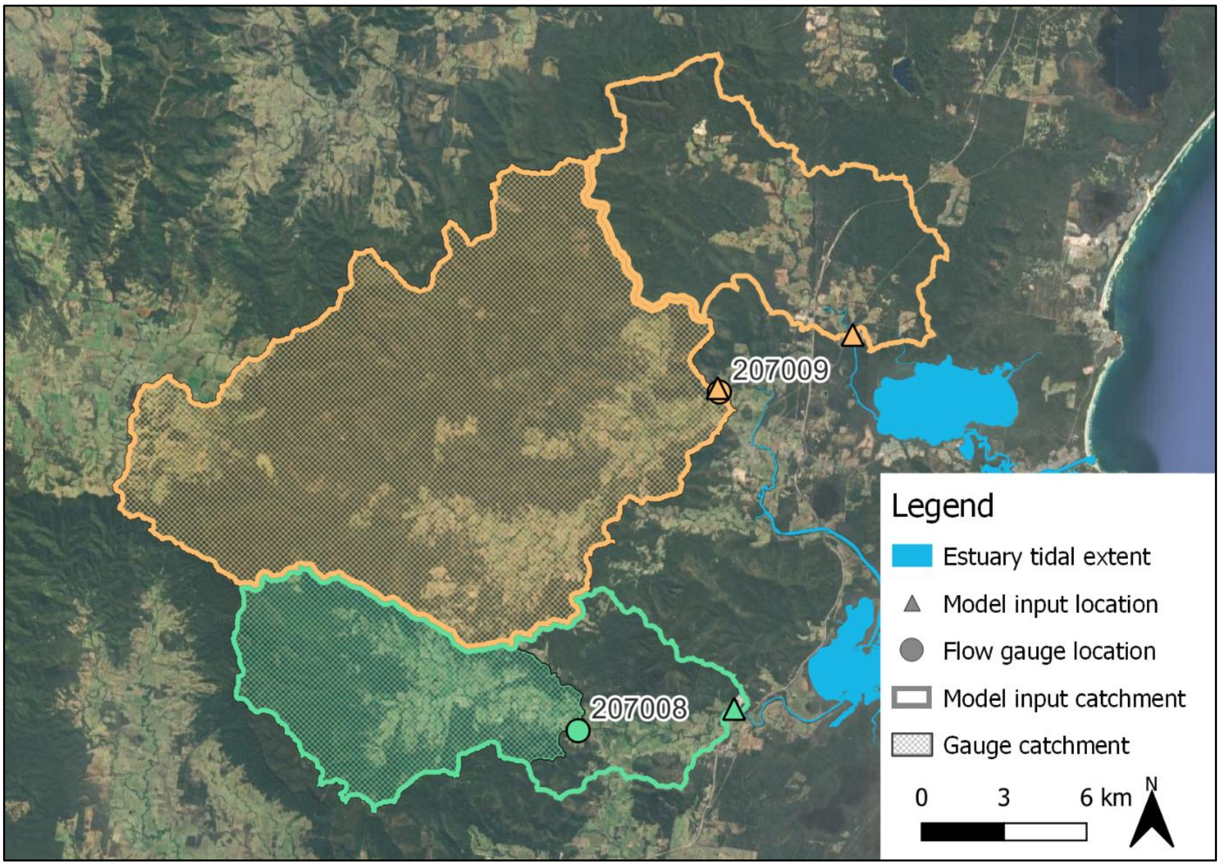

Figure 2-2 Catchment flow gauging stations*

*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

Port Macquarie Hastings Council (PMHC) is the agency responsible for wastewater treatment and sewage management in the catchment surrounding the Camden Haven estuary. The sewerage system is comprised of a reticulation network of pipes and sewage pumping stations (SPS), in addition to wastewater treatment plants (WWTPs) at Camden Haven and Herons Creek. When sewage overflows occur, PMHC 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.

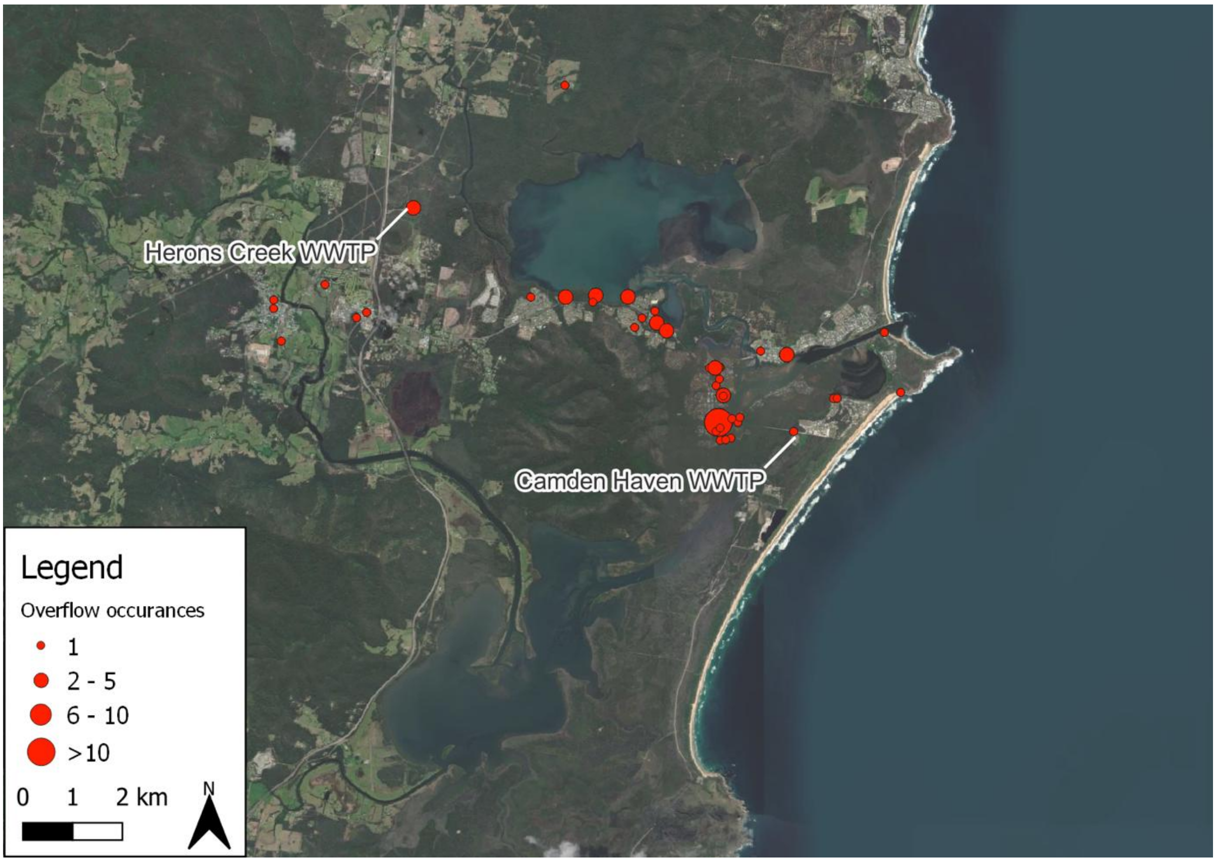

Figure 2-3 Locations of reported sewage overflows on the Camden Haven River

2.5 Bathymetry

Three existing bathymetry datasets were sourced for this project:

- Coastal marine LiDAR collected by the former NSW Department of Planning, Industry and Environment (now DCCEEW) in 2018. In the Camden Haven area, this survey covers areas 1.5 to 3 km from the coast (shown in Figure 2-4) at a resolution of 5 m. This is the most recent and detailed survey and was used as the preferred bathymetry source for all regions of the mesh covered by the survey extent. Several regions of the survey extent were noted to have no data values, particularly in deep sections of the main channel.
- Single beam bathymetry data collected in 1979. 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 was collected as a series of transects and covers Watson Taylors Lake, lower Camden Haven River, Queens Lake, Stingray Creek, and Camden Haven Inlet. Transect spacing in Camden Haven Inlet is approximately every 50 m, while spacing increases to every 150 to 300 m towards Watson Taylors Lake and Queens Lake. Transect data within the lakes is sparse (refer to
- Figure 2-5). This dataset was used in regions not covered by the marine LiDAR.
- Depth soundings collected by the Australian Hydrographic Office (AHO) for the Camden Haven Inlet maritime chart AU5JML01 (2021). This dataset is comprised of point data with a spacing of 150 to 300 m and covers Gogleys Lagoon, Camden Haven Inlet, and offshore of the entrance. Due to the sparse nature of the data and spatial overlap with the marine LiDAR survey, this data was only utilised where no other data was available.

For areas where the 2021 AHO soundings overlapped with the 2018 marine LiDAR extent, the difference in depth was minor with most readings within ± 30 cm. Compared with the 1979 single beam survey (refer to Figure 2-6), the 2018 survey showed a larger change in bathymetry. Through the lower Camden Haven Inlet, channel bathymetry deepened over the 39-year period by 0.5 to 1.5 m. Based on aerial imagery, it is apparent that the sand bars and shoals adjacent to Dunbogan and North Haven are mobile, however, they appear to be in a state of dynamic equilibrium with no visual long-term trends.

Additional bathymetric, topographic, and aerial data utilised include:

- 1 x 1 m DEM LiDAR data, collected in 2012 and available from NSW Spatial Services, was used for shallow areas inland of the extent of the 2018 LiDAR survey, provided they were above water level during the 2012 survey.
- NAVONICS SonarChart™ was utilised for qualitative verification of model bathymetry. This was primarily used to assess whether model bathymetry was capturing the location and geometry of complex features not fully captured by single depth soundings such as shallow reefs, abrupt drop-offs, and river confluences.
- High resolution NearMap imagery was used to qualitatively provide information on important bathymetric features. Locations where NearMap informed model bathymetry include the upstream delta where Stingray Creek joins Queens Lake, the delta where Camden Haven Inlet joins Watson Taylors Lake, and the edges of both lakes.

Bathymetric data in the Camden Haven River upstream of Watson Taylors Lake was also extracted from a hydrodynamic flood model of the Camden Haven River created by WorleyParsons for PMHC in 2013 (refer to Section 2.6). This bathymetry was based on cross-sections of the river surveyed by the NSW Department of Commerce in the mid-1990s. This was utilised in the upstream channels where no other data was available.

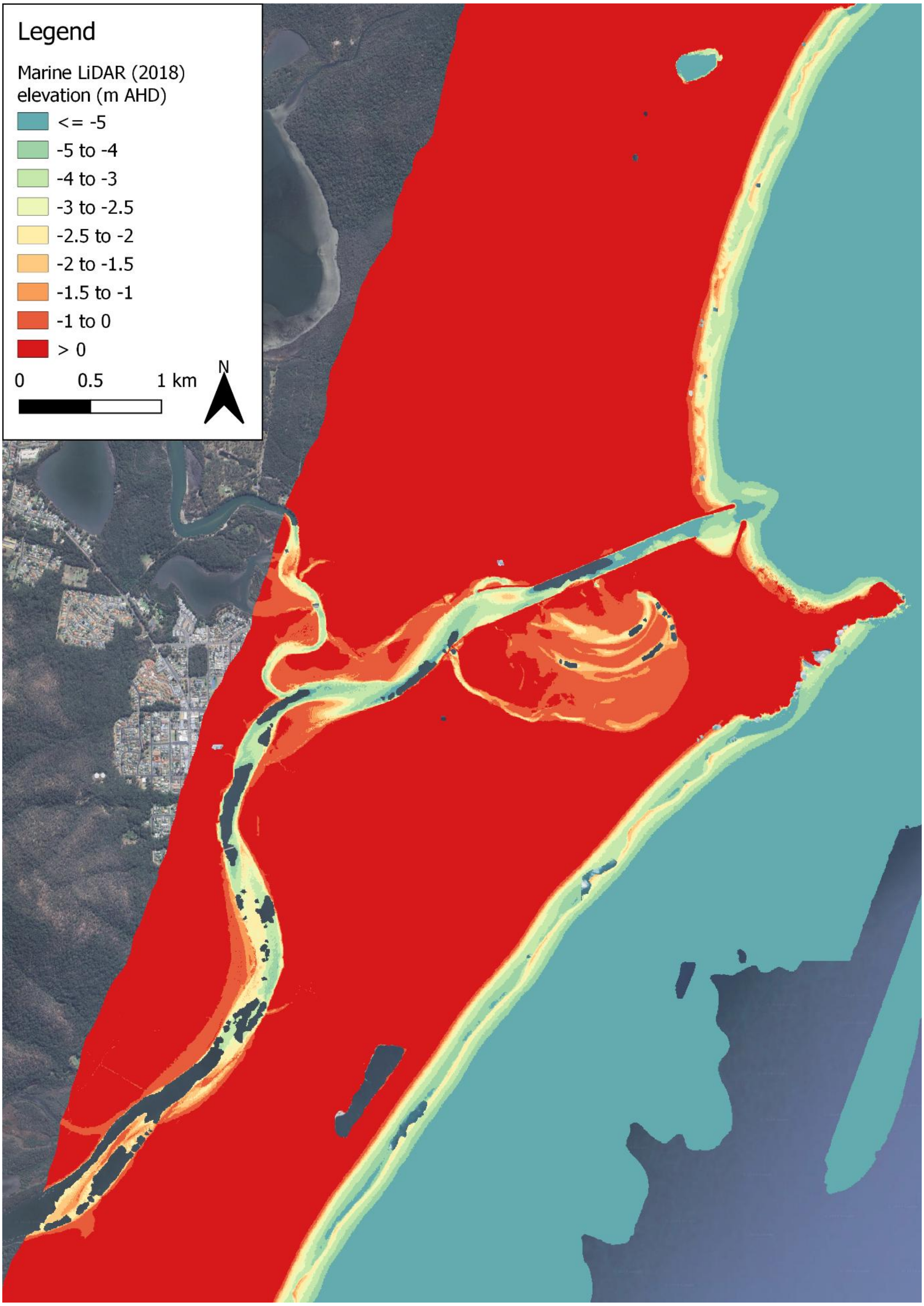

Figure 2-4 Coverage of 2018 LiDAR survey data

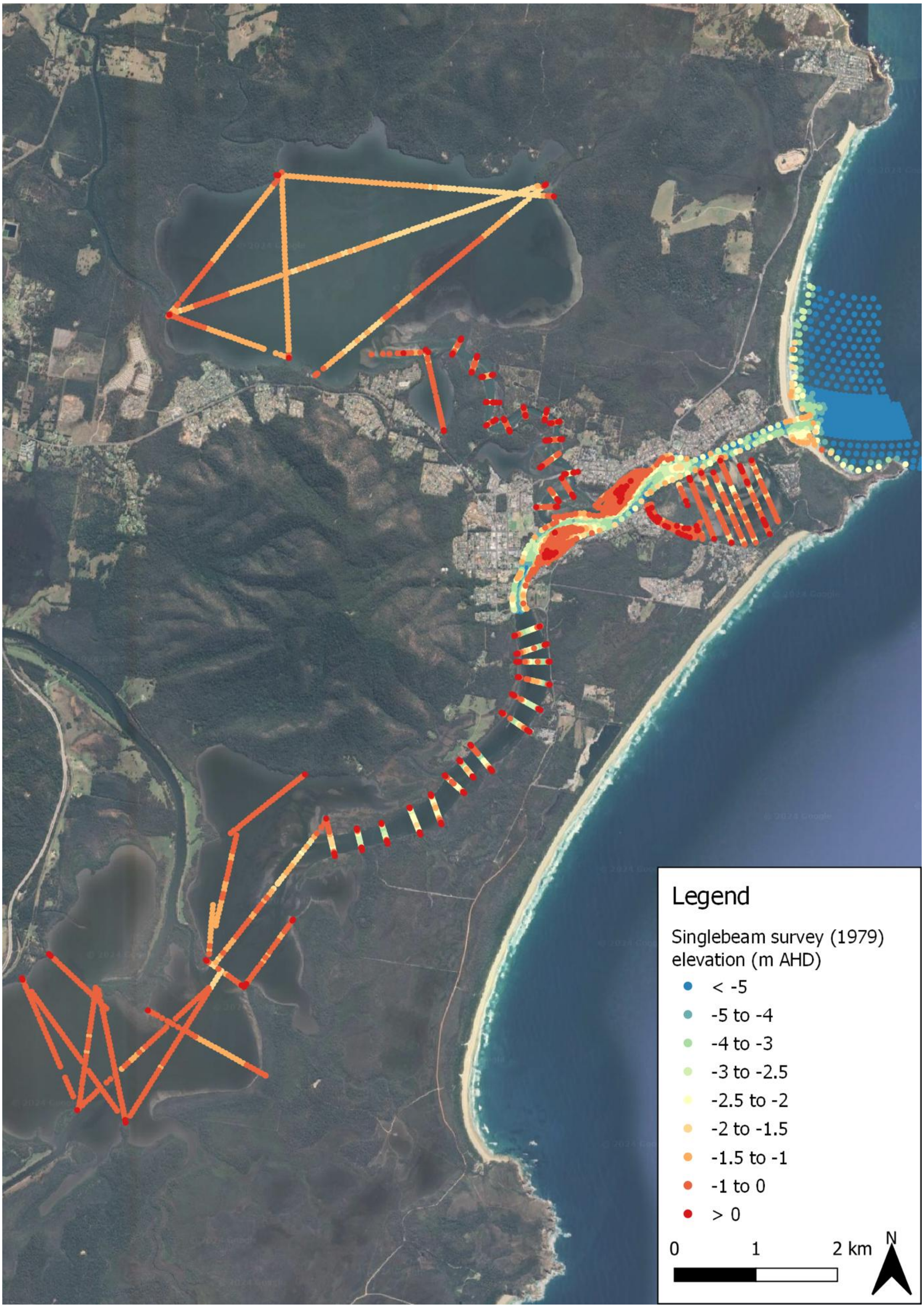

Figure 2-5 Coverage of 1979 single beam data

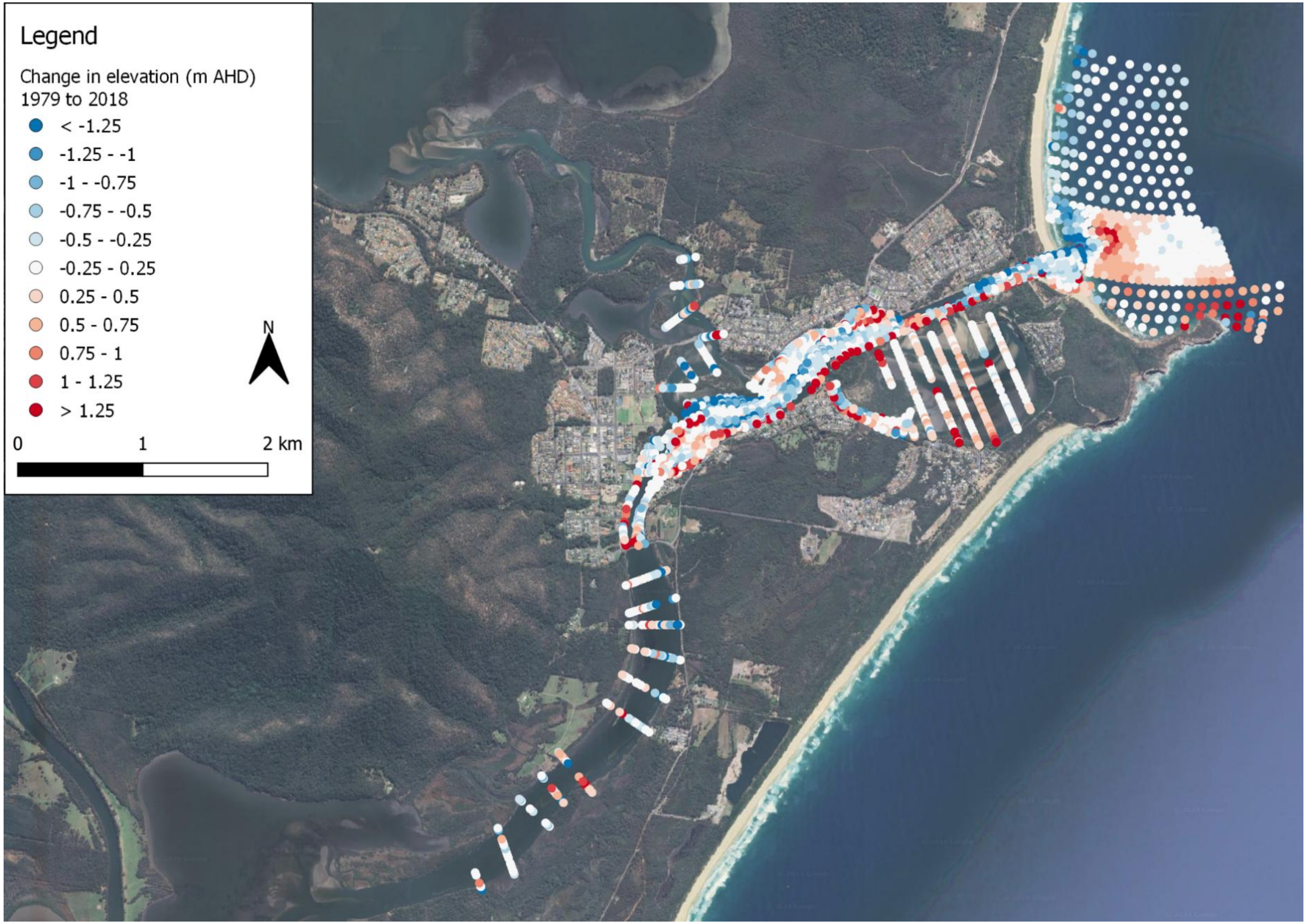

Figure 2-6 Bathymetry change between 1979 survey and 2018 marine LiDAR. Blue represents erosion and red represents accretion

2.6 Existing model

WorleyParsons (2013) produced an RMA-2 hydrodynamic model of the Camden Haven River and lakes system for PMHC as part of a flood study assessment, which was provided for this study. This model mesh was used in the initial model development. However, the WorleyParsons (2013) focussed on overland flooding, while this current study is limited to in-bank estuary dynamics. Therefore, substantial changes and refinements were made, including removal of all overbank flood storage regions and refinement of the in-channel geometry.

3 Field data collection

3.1 Preamble

A data collection campaign was completed on 18 and 19 May 2023 by Yarran Doherty and Brett Miller. Field data collection included:

- Monitoring of current velocities and volumetric flow using an ADCP
- Monitoring of dispersion and advection using Rhodamine WT dye
- Monitoring of surface current speed and flow paths using GPS drifter drogues
- Collation of data from MHL water level monitoring sites
- Observations of Gogleys Lagoon eastern and western entrances

3.2 Weather and tides

Data collection on the Camden Haven River was undertaken on both ebb and flood tides. Tides during field investigations were similar both days, with tidal ranges between approximately -0.35 to 0.80 m AHD at North Haven, near the estuary entrance. The observed water levels at North Haven, alongside the timing of key fieldwork components is shown in Figure 3-1. Predicted and observed tides at the nearby MHL ocean tide station at Crowdy Head are shown in Figure 3-2. These tides had a residual close to 0, however a the slight positive anomaly on 17 to 19 May can be explained by low pressure (MHL, 2023a).

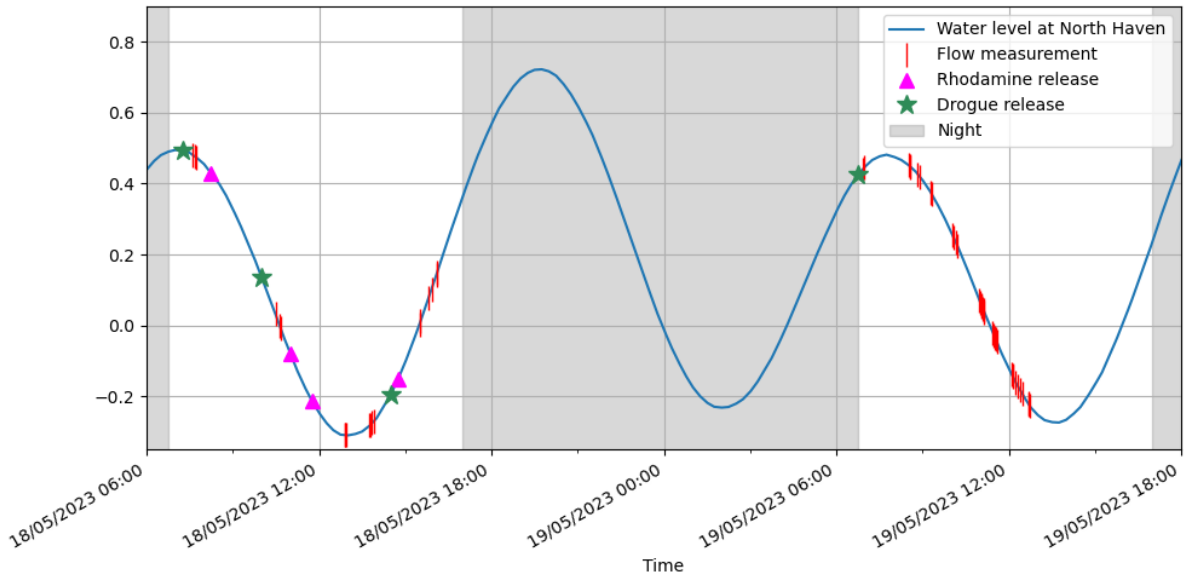

Figure 3-1 Tides at North Haven with timing of key data collection events

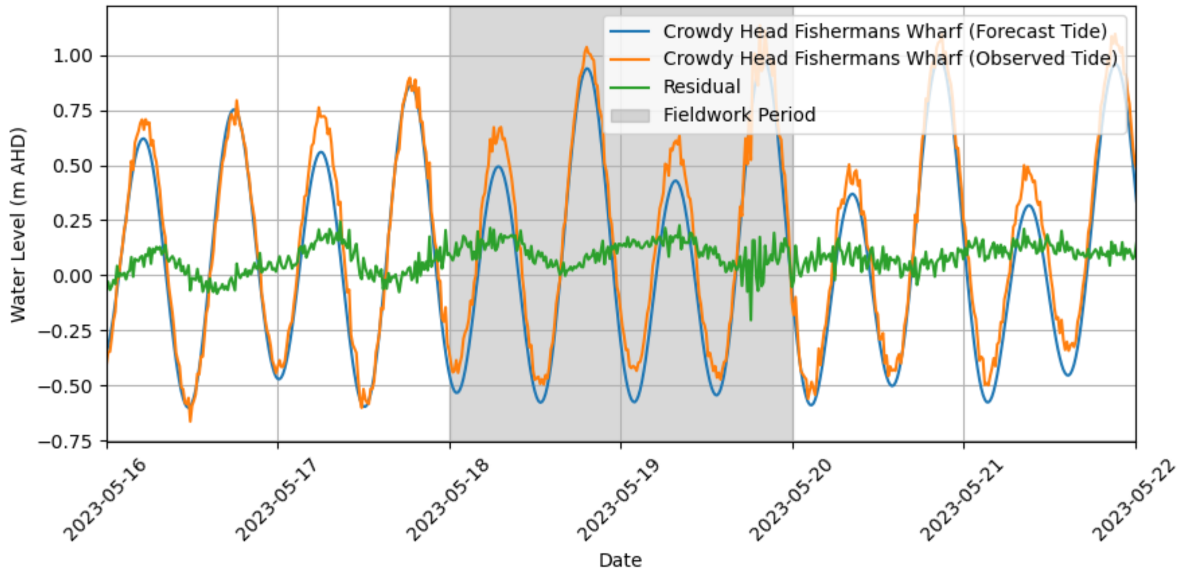

Figure 3-2 Forecasted and observed tides at Crowdy Head

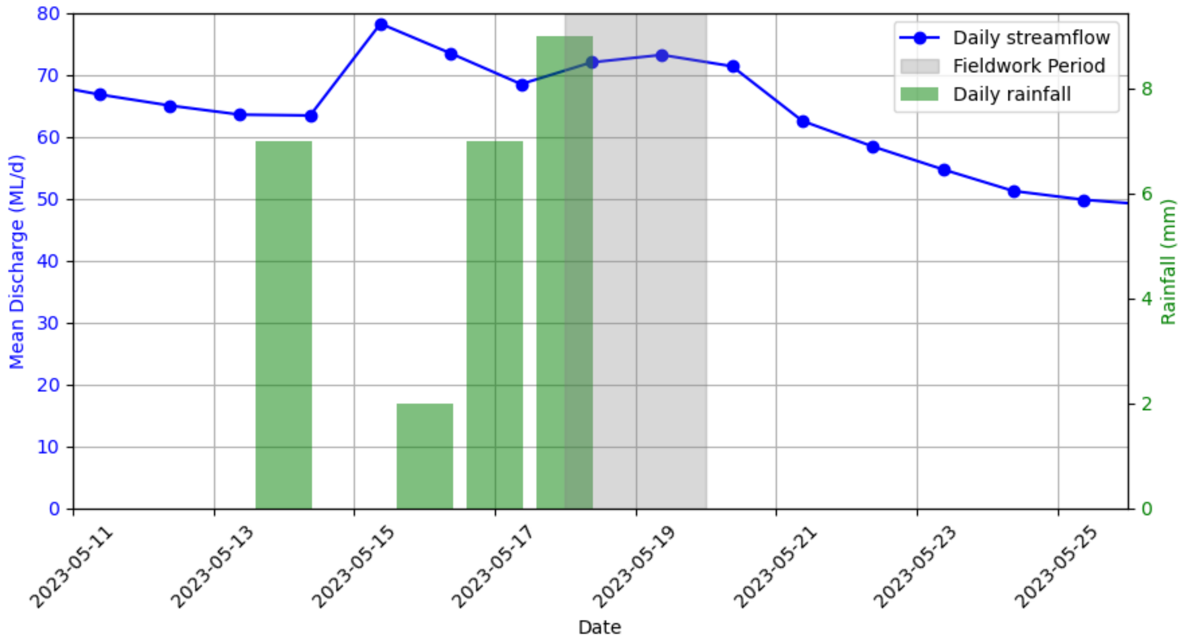

Figure 3-3 Rainfall recorded at Comboyne and streamflow recorded at Camden Haven River at Kendall for the period surrounding fieldwork

While no rainfall was observed in the field during fieldwork, as shown in Figure 3-3 rainfall was recorded in the preceding week at Comboyne (BoM station 60161) which is located 25 km west of North Haven and partially within the Camden Haven River catchment (BoM, 2023). As can be seen in Figure 3-3, freshwater inflows from the upstream catchments were low (well below median flows at the two WaterNSW gauges upstream of Camden Haven estuary, discussed in Section 2.3). Consistent wind speeds of 10 to 20 km/h from the SW were observed in the field and at Port Macquarie Airport (BoM station 060139) on both field days.

3.3 Tidal flow gauging

Flow was measured using a boat mounted SonTek RiverSurveyor M9 ADCP at four targeted locations across a range of ebb and flood tidal stages. More information on methods used for tidal gauging can be found in WRL TR2023/32 Section 4.2. Flow measurements in the Camden Haven estuary are summarised in Table 3-1, with locations shown in Figure 3-4. For a table of tidal gauging measurements refer to Appendix A2, and for plots of tidal flows refer to Appendix B1.3. A greater number of transects were taken measuring flow in Gogleys Lagoon as this is known to be an important oyster harvest area and limited existing data was available at this location.

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

Location	Location label*	18 May 2023 # transects	19 May 2023 # transects
Entrance	A	3	-
North Haven	A	4	8
Gogleys Lagoon Entrance	H	7	21
Stingray Creek	B	5	-
Hanleys Point	C	-	6

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

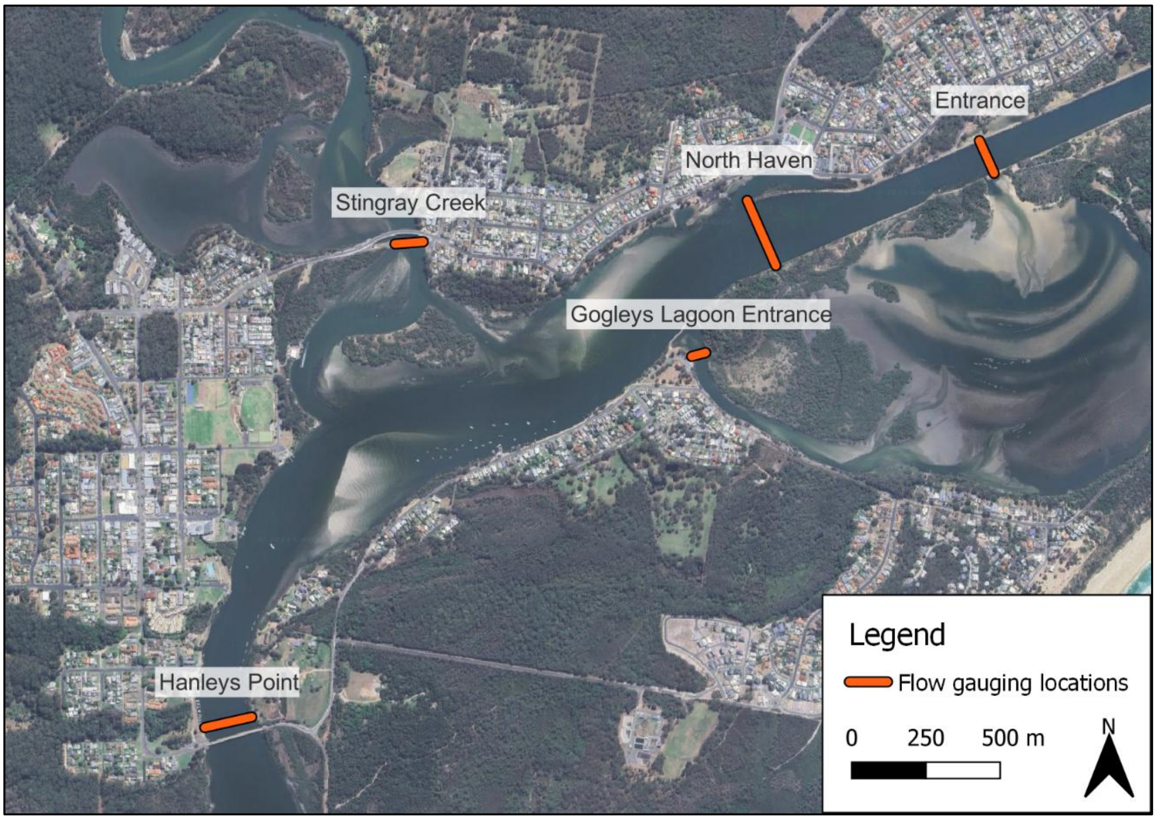

Figure 3-4 Tidal flow gauging locations from 2023 fieldwork

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

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

3.4 Bathymetry and elevation surveys

During the ADCP data collection campaign, an RTK-GPS unit collected vertical position data to an accuracy of 10 cm. By pairing depth soundings and elevation data, bathymetry was captured for all flow gauging locations (refer to WRL TR2023/32 Section 4.3 for details on methods used for bathymetric surveys). In addition to gauging sites, additional bathymetry was collected at the western entrance to Gogleys Lagoon to gather depth information where gaps in the existing bathymetry datasets (outlined in Section 2.5) had been identified. Bathymetry data for all locations is shown in Figure 3-5, and change between the 2018 LiDAR data and field captured bathymetry is shown in Figure 3-6.

Figure 3-5 Bathymetry collected during 2023 fieldwork

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

Compared with the 2018 marine LiDAR survey, the 2023 field survey bathymetry results show minor to moderate changes over the last 5 years. This includes:

- Adjacent to Hanleys Point Bridge, channel deepening of up to 1 m was observed on the mid-to-eastern side of the channel. Due to large gaps in the LiDAR data at this location, it is not apparent if this is due to the realignment of the channel, or loss of sediment from the system.
- At Stingray Creek Bridge, no major changes were observed except from a minor shift in the southern sand bar edge location.
- Across the main channel at North Haven, widening of the sand bar on the northern bank resulted in minor changes to the channel bathymetry, typically within 30 cm.
- Changes in Gogleys Lagoon were minor. Note that the apparent deepening at Gogleys Lagoon western entrance is due to improved data resolution in the 2023 survey, not a change in entrance morphology.

3.5 Rhodamine WT dye releases

To simulate pollutant advection and dispersion in the Camden Haven estuary, four 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 3-7. The initial release concentration was 200,000,000 ppb in all instances.

Table 3-2 Summary of dye releases

No.	Date	Time released	Tracked until	Volume of dye released (mL)	Location	Tide
1	18/05/2023	8.08am	9.01am	500	North Haven	Flood
2	18/05/2023	11.01am	11.36am	500	Hanleys Point Bridge	Ebb
3	18/05/2023	11.38am	12.14pm	500	Camden Haven Marine Rescue	Ebb
4	18/05/2023	2.38pm	3.27pm	500	Stingray Creek	Ebb

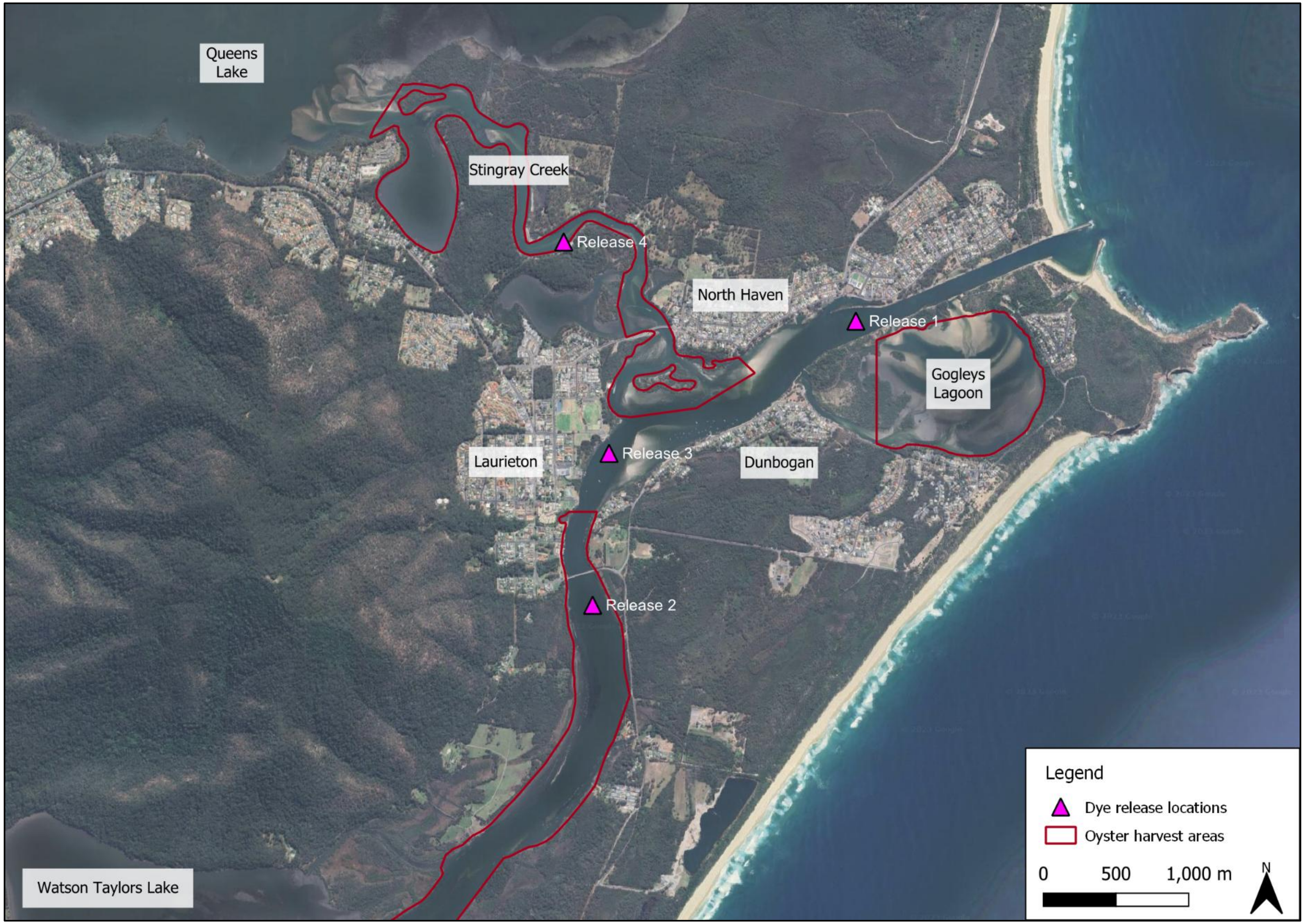

Figure 3-7 Rhodamine WT dye release locations

3.5.1 Release 1 – North Haven

Dye release 1 was started mid-channel of the Camden Haven Inlet entrance off North Haven, approximately 500 m downstream of North Haven Public Baths (refer to Figure 3-7 and Figure 3-9). This release was completed to understand the transport of pollutants from the Camden Haven entrance towards Gogleys Lagoon and Laurieton, and to determine pollutant dispersion rates. The release occurred on an incoming tide, approximately 1 hour after peak inflow. The dye was released at 8.08am and tracked until 9.01am. Figure 3-9 shows the observed dye concentrations over the period of monitoring, with the maximum plume concentration along select transects highlighted.

Initially the plume moved upstream quickly towards Laurieton without significant lateral spreading (plume stayed within 30 to 40 m in width), however rapid decreases in peak concentrations were observed (refer to Figure 3-8). As the plume continued upstream, significant longitudinal spreading was observed and after 20 minutes (offshore of the entrance to Gogleys Lagoon), the visible plume was approximately 200 x 50 m. As the plume had not spread to the southern bank by this point, no obvious dye was noted entering Gogleys Lagoon. Past Gogleys Lagoon entrance, the plume continued spreading and by 30 minutes measured 280 x 55 m.

Figure 3-8 North Haven Dye release after 5 minutes

After 40 minutes as the plume continued offshore of Dunbogan, further spreading and mixing were observed, and the plume became less visually distinguishable. As the plume entered the yacht mooring areas surrounding Dunbogan Boat Shed and Marina (50 minutes), the plume was noted to have spread across the majority of the main channel and plume dimensions of >300 x 70 m were observed. The plume was followed for another 10 minutes as the plume continued past Dunbogan Boat Shed, however the plume became difficult to distinguish as flows in the main channel were approaching slack tide.

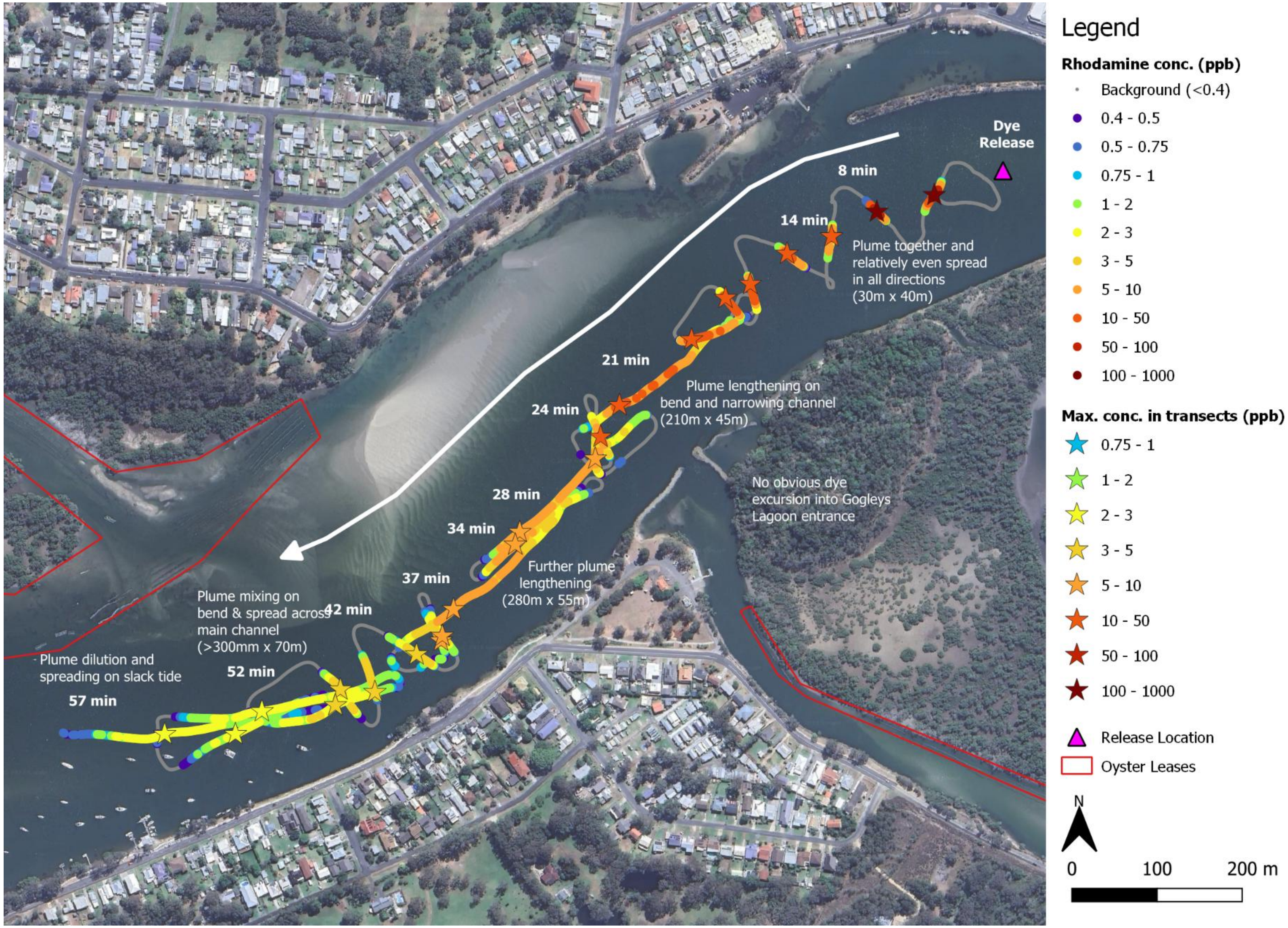

Figure 3-9 Dye release 1 at North Haven. All observed concentrations (circles) and maximum concentration observed in select transects (stars)

3.5.2 Release 2 – Hanleys Point Bridge

Dye release 2 was conducted mid-channel in the Camden Haven Inlet approximately 230 m upstream of the Hanleys Point Bridge to the south of Laurieton (refer to Figure 3-7, Figure 3-10 and Figure 3-12). The aim of this release was to observe the velocity and dispersion behaviours of an overflow event from Laurieton on an outgoing tide. The release was timed to roughly coincide with the peak tidal outflow and was tracked from 11.01am to 11.35am. Figure 3-12 shows the observed dye concentrations over the period of monitoring, with the maximum plume concentration along select transects highlighted.

Figure 3-10 Dye release 2 after 3 minutes

Upon release, the plume spread rapidly in the longitudinal direction and after 3 minutes measured 30 x 10 m, and 60 x 20 m after 6 minutes. As the front edge of the plume passed the bridge (9 minutes after release) additional mixing was observed as the plume was dispersed by pylon eddies and vortices (Figure 3-11). This mixing resulted in additional dilution and elongation of the plume (140 x 20 m after 14 minutes).

Figure 3-11 Dye release 2 mixing around bridge pylons 9 minutes after release

As the plume passed offshore of Laurieton Swimming Pool (26 minutes after release), an abrupt shallowing of the channel bathymetry resulted in significant dilution arising from three-dimensional mixing. Following this mixing event, the plume spread across the width and depth of the channel and no longer had a visually discernible edge. The plume was followed for 250 m further downstream until tracking was ceased 37 minutes after the initial release.

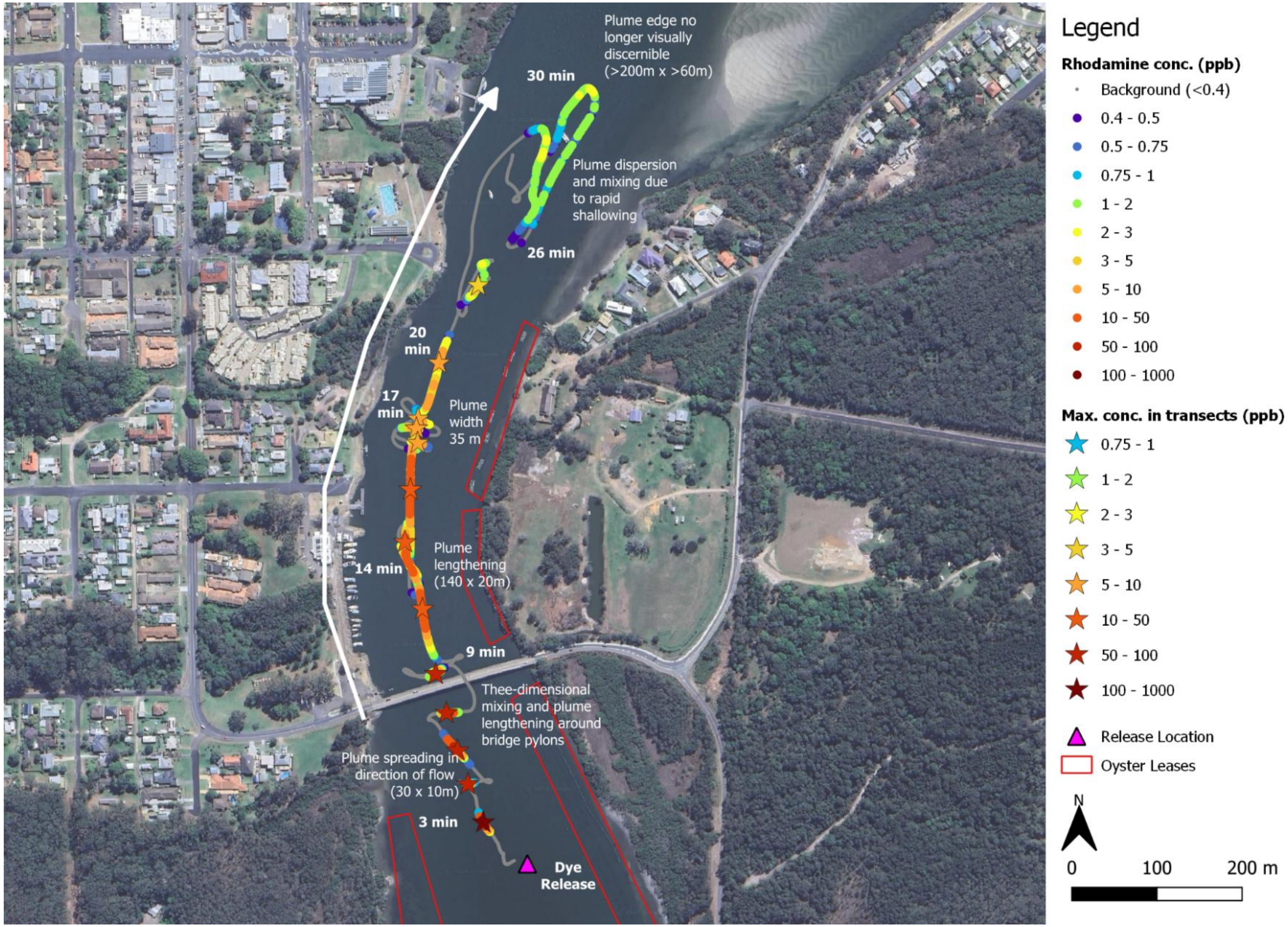

Figure 3-12 Dye release 2 at Hanleys Point Bridge. All observed concentrations (circles) and maximum concentration observed in select transects (stars)

3.5.3 Release 3 – Camden Haven Marine Rescue

Dye release 3 was completed mid-channel in Camden Haven Inlet approximately 100 m upstream of Camden Haven Marine Rescue (refer to Figure 3-7 and Figure 3-14). Due to the rapid dispersion from release 2 and associated difficulties in tracking the plume past Laurieton Swimming Pool, release 3 was performed as a continuation of release 2. Dye was released at 11.38am, 5 minutes after the tail edge of release 2 had passed. Outflow in the channel was still close to peak tidal outflow. Figure 3-14 shows the observed dye concentrations over the period of monitoring, with the maximum plume concentration along select transects highlighted. Tracking commenced with a slight delay after release, at 11.43am, explaining the gap observed in Figure 3-14.

Similar to release 2, longitudinal spreading was greater than lateral spreading and after 7 minutes, the plume was approximately 50 x 30 m (refer to Figure 3-13). As the plume reached the inside bend of the shallow bar at Camden Point, the plume spread longitudinally before mixing and diluting at the convergence with Stingray Creek. Immediately downstream of this junction, the plume had spread to cover the main deep channel width and measured 80 x 110 m. Offshore of Dunbogan Marina, the plume visually began to disperse and the plume edge was no longer clearly distinguishable. The plume was tracked in a dispersed state covering the main channel width for another 750 m downstream to the entrance of Gogleys Lagoon until recordings were stopped at 12.14pm.

Figure 3-13 Dye release 3 prior to mixing with Stingray Creek after 10 minutes

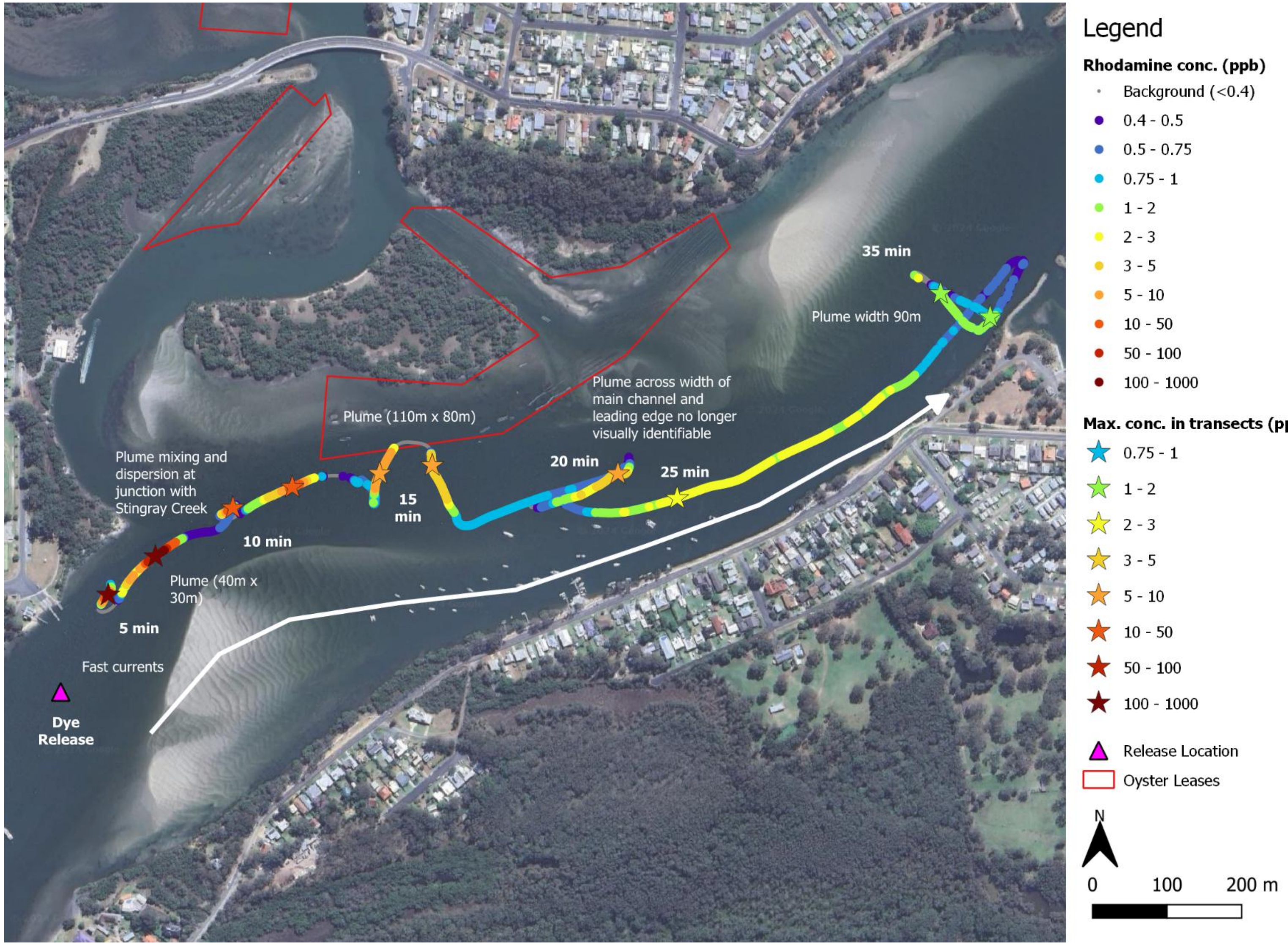

Figure 3-14 Dye release 3 near Camden Haven Marine Rescue. All observed concentrations (circles) and maximum concentration observed in select transects (stars)

3.5.4 Release 4 – Stingray Creek

Dye release 4 was performed in Stingray Creek approximately 250 m downstream of Henry Kendall Reserve picnic area (refer to Figure 3-7 and Figure 3-16). This release was completed to understand the behaviour and rates of transport of pollutant plumes in Stingray Creek. The release occurred on an outgoing tide, approximately 1.5 hours before slack tide. The dye was released at 2.38pm and was tracked for 50 minutes. Figure 3-16 shows the observed dye concentrations over the period of monitoring, with the maximum plume concentration along select transects highlighted.

After the initial dye release, significant longitudinal spreading was observed and at 4 minutes, the plume measured approximately 30 x 4 m (Figure 3-15). As the plume moved downstream, flow transitioned across the channel from the right bank to left bank resulting in significant spreading. After the plume had rounded the first bend and reached the straight (14 minutes), the plume visually covered two thirds of the channel width with dimensions of 35 x 100 m. Around the second bend, further mixing increased dilution and the plume edge was no longer visually discernible.

Figure 3-15 Dye release 4 spreading as flow transitions from right bank to left bank

Approximately 450 m upstream of the Laurieton to North Haven bridge and 25 minutes after the initial dye release, a shallow sand bar impeded boat navigation. The plume was visually observed to spread and dilute over this shallow area, and low concentrations were observed in the main channel and immediately downstream of the sand bar. Recordings were stopped at this point at 3.28pm.

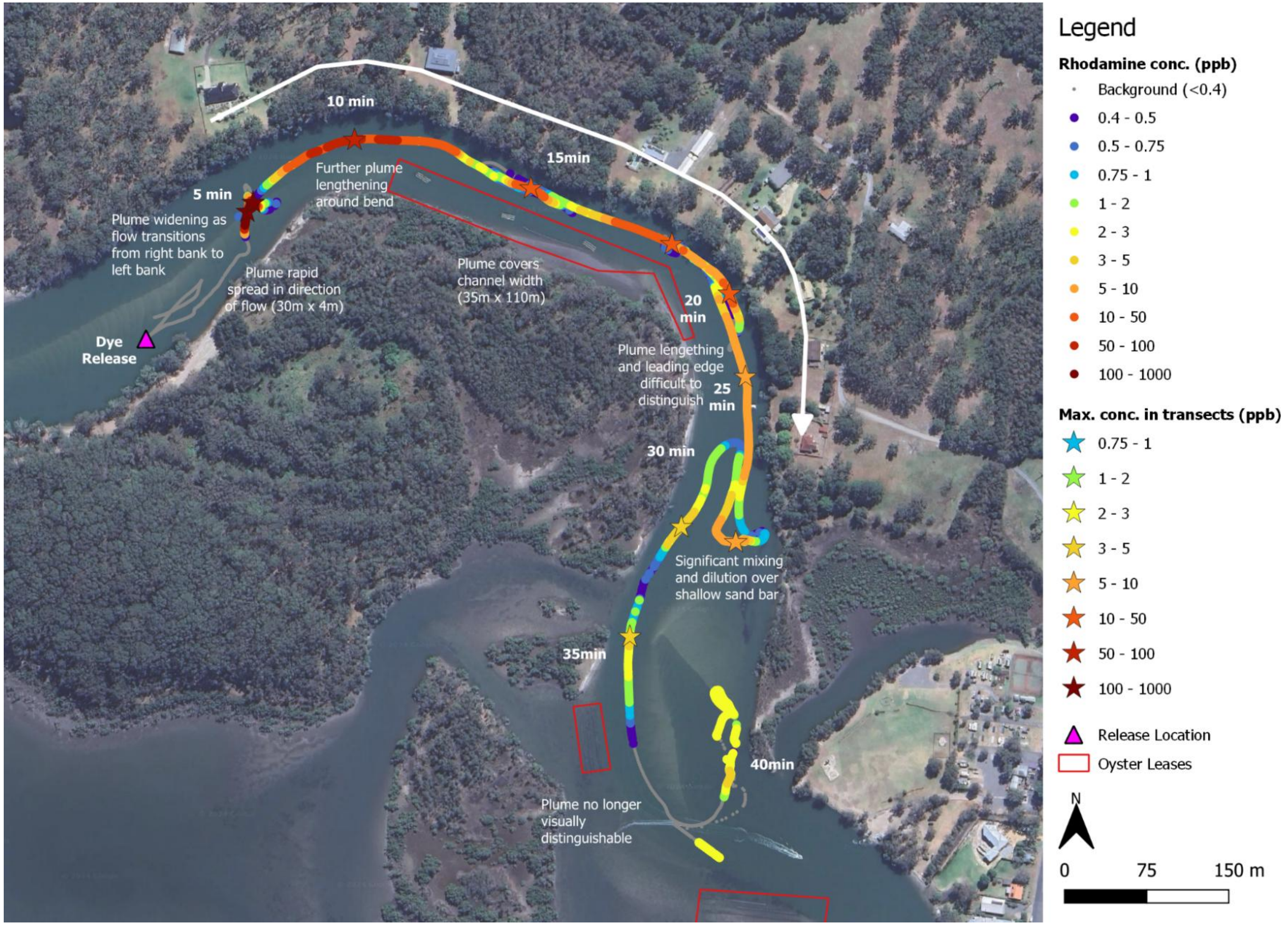

Figure 3-16 Dye release 4 in Stingray Creek. All observed concentrations (circles) and maximum concentration observed in select transects (stars)

3.5.5 Field derived dispersion values

Field dye experiments were used to obtain estimates of plume spreading dispersion rates in the Camden Haven River, using the methods described in WRL TR2023/32 Section 7.3. During each dye release, transects were taken across the plume to capture the plume width and peak concentration at a point in time. From the set of all transects, a subset of representative peak concentrations was compared to theoretical estimates of maximum plume concentrations over time. This is shown in Figure 3-17.

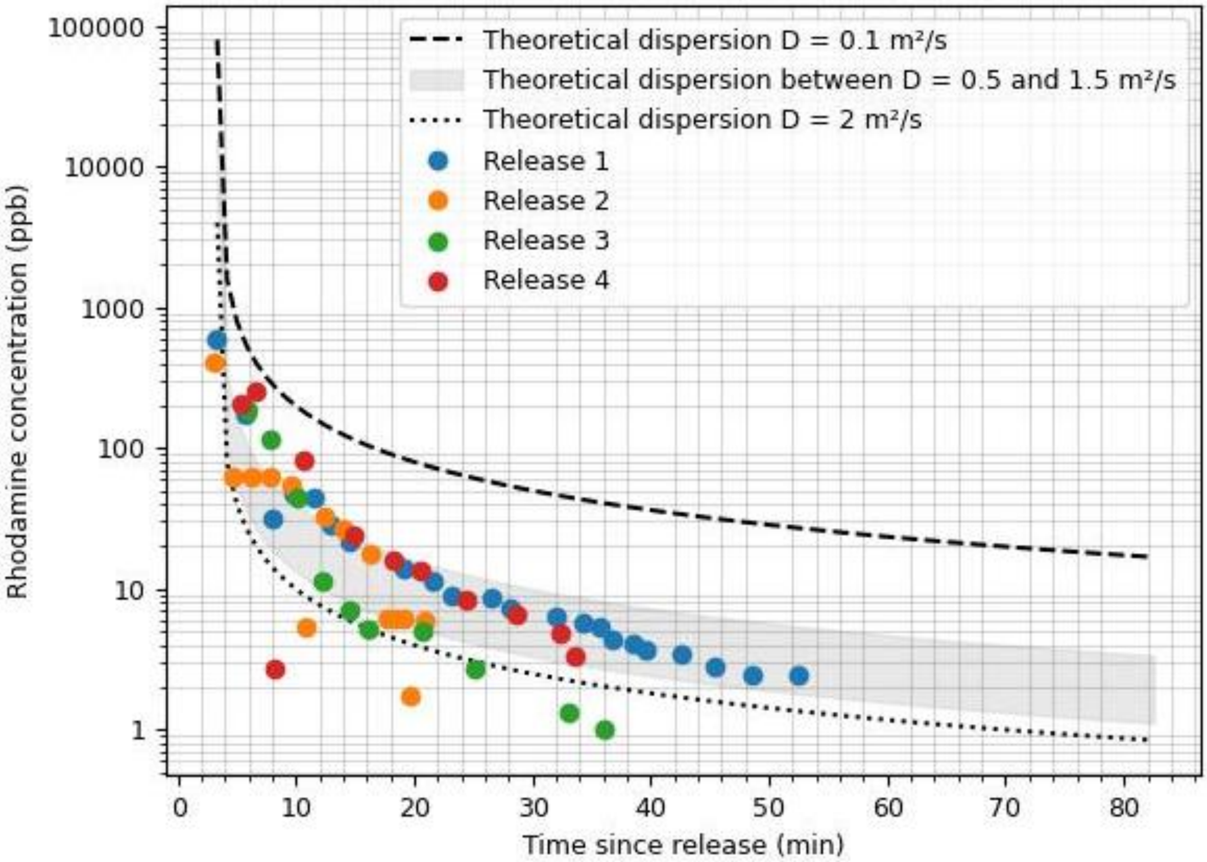

Figure 3-17 Peak concentration of select transects plotted against theoretical dispersion

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 Camden Haven. 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 release 1, 2 and 4 largely within D = 0.5 to 1.5 m^2/s. For release 3, the high dispersion values of >2 m^2/s may be attributed to the rapid mixing of the plume shortly after release as the plume reached the junction with Stingray Creek (refer to Section 3.5.3).

3.6 GPS drifter drogue releases

To monitor surface current speeds and flow paths in the Camden Haven 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 1 and 4 to aid plume tracking, with two additional drogue releases completed at various stages of the tide cycle (refer to Table 3-3). The GPS tracks for the drogue releases are shown in Appendix A1. A brief discussion of the observations is provided in this section.

Table 3-3 Summary of drogue releases

No.	Date	Time	Tide	Duration (h)	Location	Comments
1	18/05/2023	7.22am	Flood	1:02	North Haven	Released with dye drop 1
2	18/05/2023	10.05am	Ebb	2:30	Stingray Creek	-
3	18/05/2023	2.32pm	Ebb	0:48	Stingray Creek	Released with dye drop 4
4	19/05/2023	6.42am	Flood	3:12	North Haven	-

Drogues were released near the Camden Haven entrance on an incoming time on both field days. On the first day, drogues were released on the northern half of the entrance channel. While two drogues were caught on the north bank sand bar, the remaining two drogues entered the mouth of Stingray Creek. On the second day, drogues were released closer to the centre of the channel and further towards the mouth. In this instance, only one drogue entered Stingray Creek, while the remaining three travelled up the Camden Haven River. During the dye releases (drogue drops 1 and 3), it was noted that the drogues were a reasonable proxy for the advection and longitudinal dispersion of dye in the river.

3.7 Observations of Gogleys Lagoon and southern training wall

Located adjacent to the southern wall of the Camden Haven entrance channel, Gogleys Lagoon is an important feature and potential trap for sewage overflow effluent heading towards the heads. As previous surveys were either outdated, or lacked the resolution and accuracy to capture the geometry of important hydrodynamic features, surveys were undertaken to capture important features of the:

- Western entrance channel (see Section 3.4 for bathymetry survey)
- Training wall elevation at breaches identified in MHL report 296 (refer to Section 1)
- Eastern entrance channel weir

The Gogleys Lagoon entrance training walls are submerged at high tide. To determine an approximate crest height, water level at the North Haven MHL gauge was checked during a time when the crest was partially submerged (refer to Figure 3-18) and found to be at an approximate elevation of 0.3 to 0.4 m AHD. This method was utilised again to determine the elevation of the entrance wall breaches.

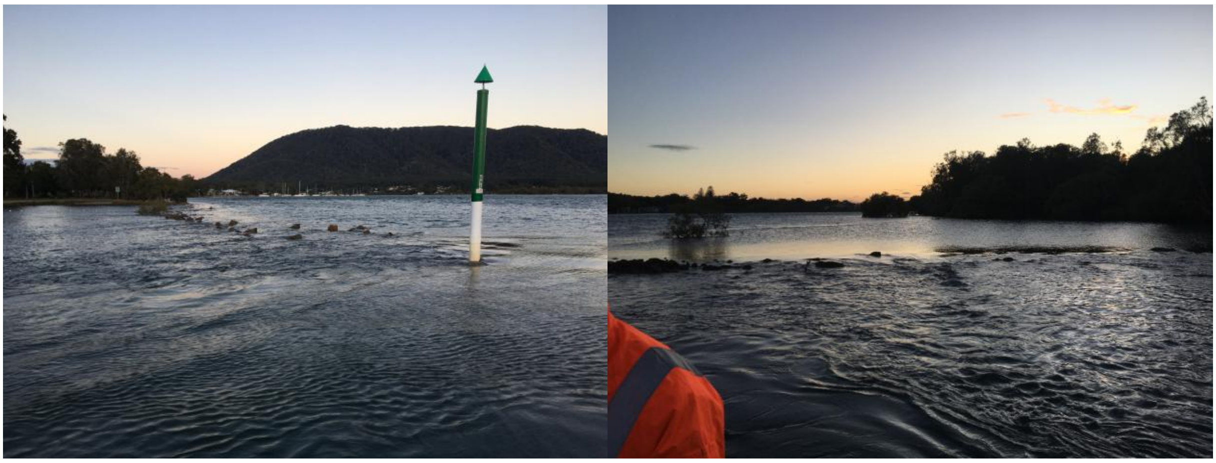

Figure 3-18 Partially submerged Gogleys Lagoon entrance wall crest

The eastern entrance weir to Gogleys Lagoon was observed on several occasions during the field campaign. In the middle of the entrance channel the weir is around low tide level and due to fast velocities it was unable to be surveyed using the ADCP or RTK-GPS. The weir was only observed during mid-tides (refer to Figure 3-19), so an estimation of water depth was made by observing the water level from the North Haven water level gauge. The estimate of the crest elevation at this location is between -0.3 to -0.6 m AHD. The weir is comprised of large rock armour units with diameters ranging from 50 cm to 1 m and as a result, the weir is porous and allows some flow even when the crest is exposed.

Figure 3-19 Gogleys Lagoon eastern entrance weir at mid tide

Figure 3-20 Gogleys Lagoon western entrance at mid tide

The western entrance to Gogleys Lagoon is a deeper channel, approximately -3.5 m AHD, and the bathymetry of this entrance was thoroughly surveyed, as discussed in Section 3.4. The western entrance at mid tide is shown in Figure 3-20.

During some periods of outgoing ebb flow in the main channel, flows were observed still entering Gogleys Lagoon via the eastern and western entrances. As the flow into Gogleys Lagoon is via these two small entrances, water levels in the lagoon are attenuated and tidal peaks lag behind the main channel. This indicates that inflow into Gogleys Lagoon can occur even during outgoing tides.

4 Model development

4.1 Preamble

The model used for this project consists of both a hydrodynamic and a water quality model. Initially, a hydrodynamic pilot model was developed which identified data gaps to be targeted during field data collection. After incorporating new data from the field, the hydrodynamic model was iteratively refined through calibration based on the MHL data collection campaign in 1997, 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.

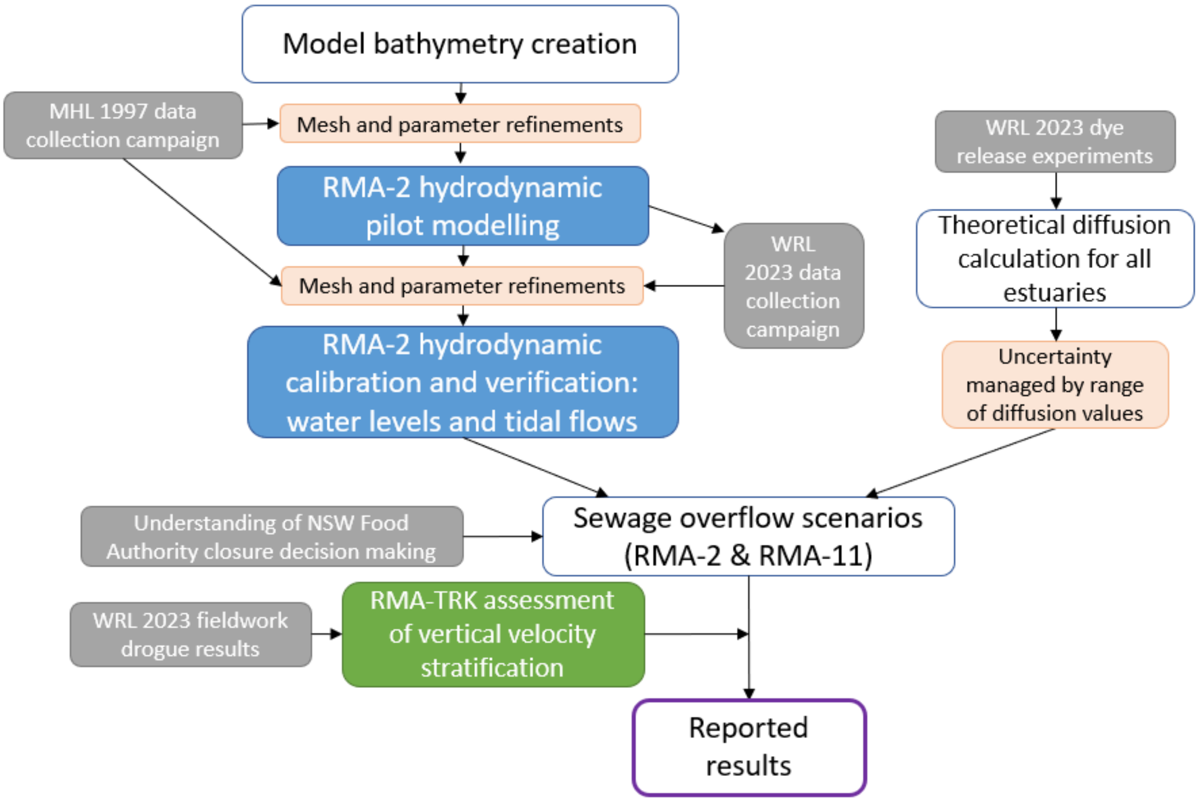

Figure 4-1 Overview of modelling approach

4.2 Model mesh development

The model domain extends from approximately 1 km offshore of the ocean entrance of the Camden Haven Inlet, to the tidal limits of the estuary and its major tributaries (refer to Figure 4-2). The model mesh consists of over 28,000 nodes and 10,000 two dimensional elements varying in size from 4 m^2 to over 35,000 m^2. A two-dimensional, depth averaged model mesh was chosen for Camden Haven, where advective transport is largely driven by tidal and riverine flow (not wind), near-depth averaged vertical velocity profiles were observed. A discussion on the impact of model dimensionality is provided in WRL TR2023/32 Section 6.2.2.

Mesh resolution is highest in Camden Haven Inlet and Gogleys Lagoon, near both the overflow locations and oyster harvest areas, with lower resolution in the two lake systems. Refer to WRL TR2023/32 Section 6.2.3 for a discussion of model resolution. The semi-submerged breakwaters along the edge of Gogleys Lagoon have been modelled as submerged breakwaters in RMA, meaning no marshing occurs through these elements.

4.3 Model bathymetry

Model bathymetry was based on the sources discussed in Section 2.5 with a general preference of the most recent data. This was primarily the 2018 DPIE coastal marine LiDAR topo-bathy survey for the lower estuary, which covers the majority of the oyster harvest areas and sewage overflow locations. Minor changes were included based on field data collected by WRL. NAVONICS (2023) SonarChart™ and NearMap imagery were used to visually verify sand bar bathymetry and channel edge locations in conjunction with the field data collection.

For most regions outside of the LiDAR extent, the AHO (2021) soundings were used and the OEH (1979) single beam survey data was used where no other data was available. Bathymetry in the upper modelled section of the Camden Haven River was extracted from the 2013 Worley Parsons flood model mesh (refer to Section 2.6). The NSW Spatial Services (2012) 1 m resolution DEM was used for shallow intertidal regions.

Depths in the entrance channel were up to 14 m, however the majority of estuary channels were between 2 and 5 m in depth. The nodal bed elevations of the model bathymetry are shown in Figure 4-3.

Estuaries are dynamic systems and bathymetric changes through time will alter water levels, velocities, and tidal flows for the same set of boundary conditions. The Camden Haven estuary has a trained river entrance, which prevents significant short-term changes in the entrance conditions. While change to bathymetry over time is evident in some fast moving sections of the estuary (e.g. movement of sand shoals, or deepening of the 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.

4.4 Model boundaries

The model includes three 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 the Camden Haven Inlet heads (refer to Figure 4-2). This modelled water level boundary was based on observed tidal elevation data collected by MHL at Crowdy Head (station number 208470 prior to 2013, and 208471 from 2013). This data was then smoothed to remove signal noise to increase model stability. For modelling water quality scenarios, all boundaries (upstream and ocean) were set to a constant constituent concentration of zero (e.g. no pollutant inflows from these boundaries).

Figure 4-2 RMA model mesh showing boundary condition locations

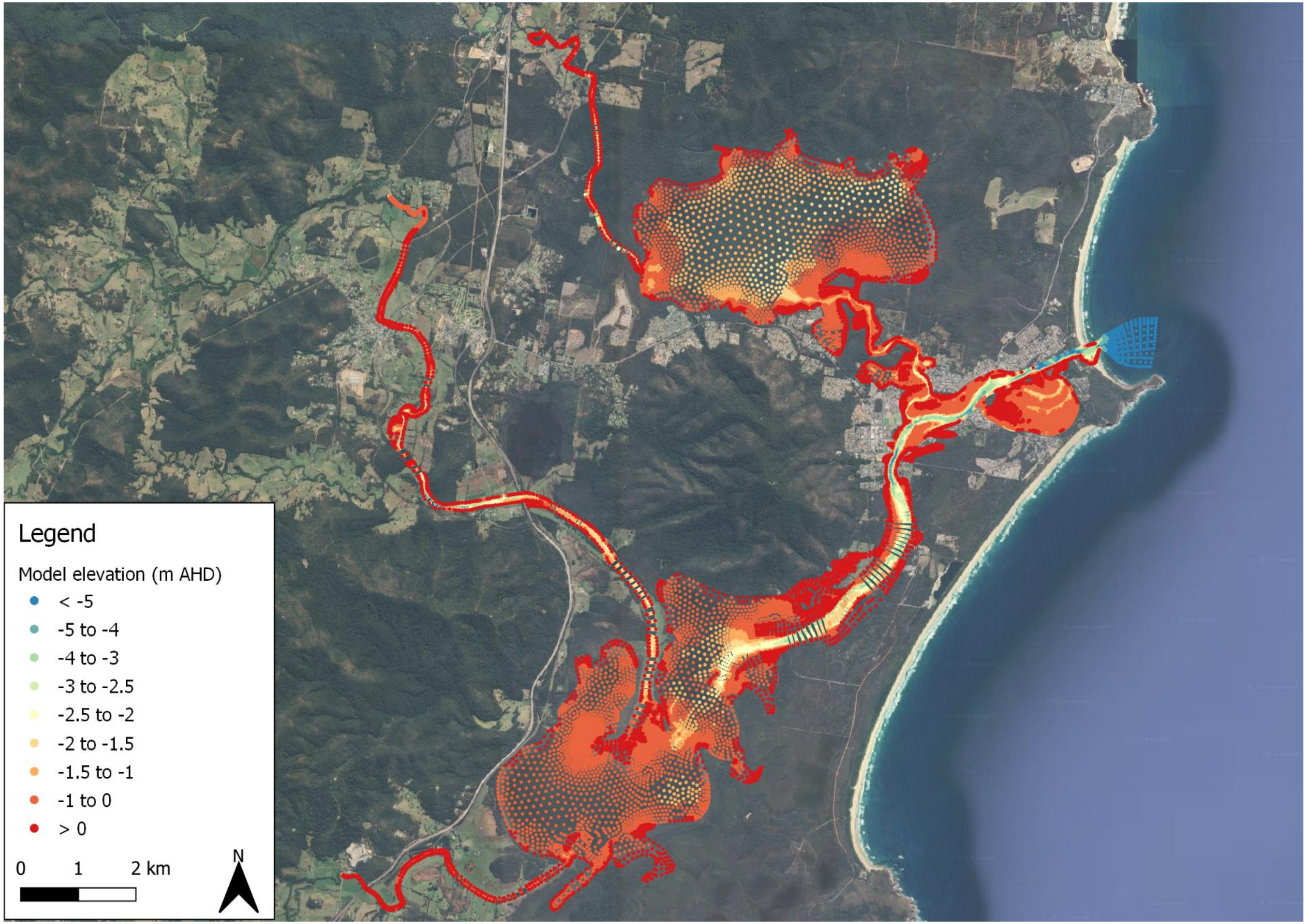

Figure 4-3 RMA model bathymetry

4.5 Pilot model

Initially, a hydrodynamic pilot model was developed using the existing data described in Section 2. For more details on pilot modelling and its purpose refer to WRL TR2023/32 Section 3. This initial modelling was used to identify data gaps to be targeted during fieldwork. The primary gap identified was bathymetry and flow at the entrance to Gogleys Lagoon. The model was updated to reflect this new bathymetry data, and the results presented below incorporate these updates.

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. Multiple sets of hydrodynamic data collected by MHL was available for calibration and verification purposes. Due to potential changes in the bathymetry and hydrodynamics of the system since the 1970s, the 1997 study was used as the primary calibration dataset for the hydrodynamic model. The 2023 WRL data collection campaign period was then used to verify the model (refer to Section 3). Both calibration and verification also considered MHL long term water level gauges available at six locations in the Camden Haven estuary (see Section 2.2). Data from the 1976 MHL study was compared to model results with a similar tidal range to verify flow in and out of Gogleys Lagoon. For each period, a minimum 3-day model warmup period was run.

4.6.1 August and September 1997 calibration period

During the 1997 MHL data collection campaign on the Camden Haven estuary, water level data was available at 11 gauges (including four permanent gauges) and tidal flow data was available at seven transects (refer to Section 2.2). The model parameters were calibrated to this period. Measured tide levels were applied at the ocean boundary. Complete catchment inflow data was not available from WaterNSW for this period, thus (based on rainfall records) median catchment inflows were applied at the three upstream model inflow boundaries as constant flows. Plots of all observed water level and flow compared with model results are shown in Appendix B1.1 and B1.2, while select results are shown below.

A good model match was achieved for all flow and water levels downstream of Watson Taylors Lake (in the area where harvest areas and overflows are located) including in Stingray Creek and Queens Lake (see Figure 4-4, Figure 4-5 and Figure 4-6 for examples). The modelled water level was attenuated and offset from observed water levels in Watson Taylors Lake (see Figure 4-7) and in the upper Camden Haven River, however all oyster harvest areas are located downstream of this lake system. Water levels at Logans Crossing (Figure 4-8) indicate that there is an important bathymetric feature which controls water levels in this area, which is not captured by the model. However, given that this is not close to the areas of interest for this study, this feature is not considered of importance for this study.

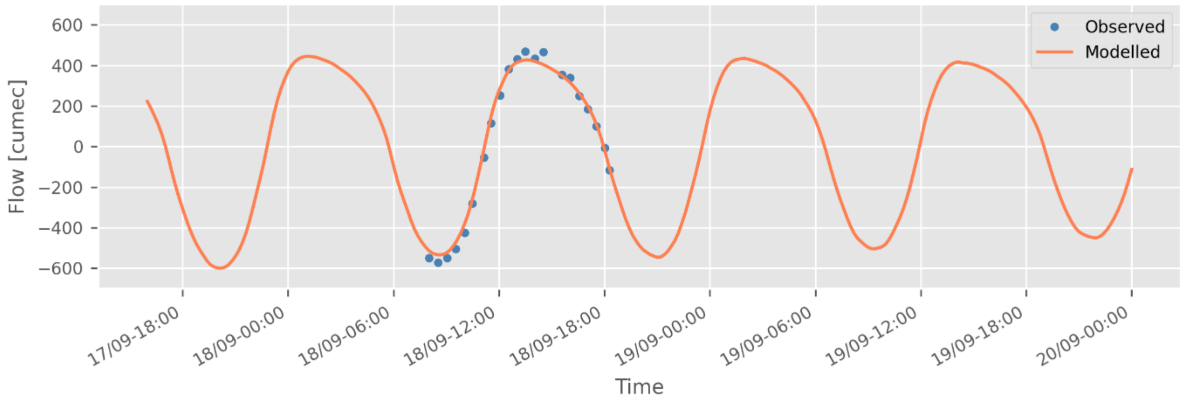

Figure 4-4 1997 tidal flow calibration – Location A – Entrance/North Haven

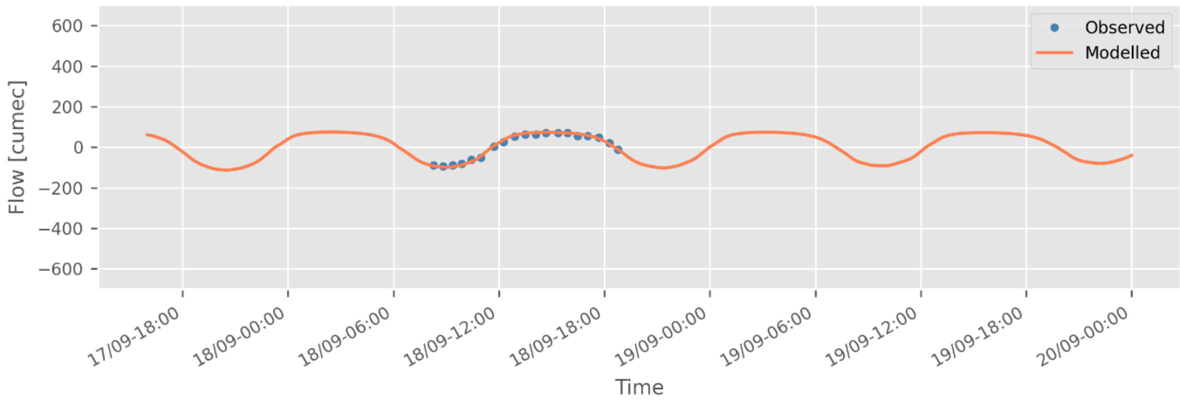

Figure 4-5 1997 tidal flow calibration – Location B – Stingray Creek Bridge

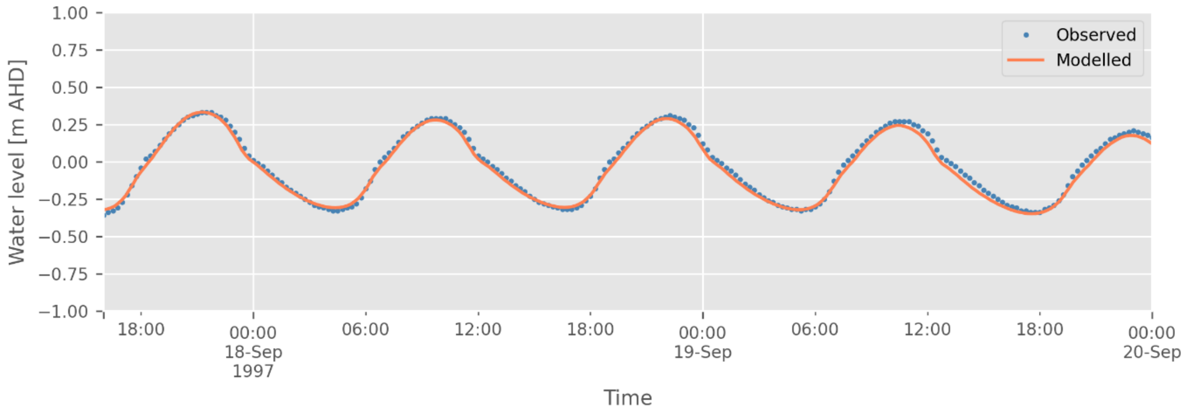

Figure 4-6 1997 water level calibration – Location 3 – Stingray Creek/West Haven

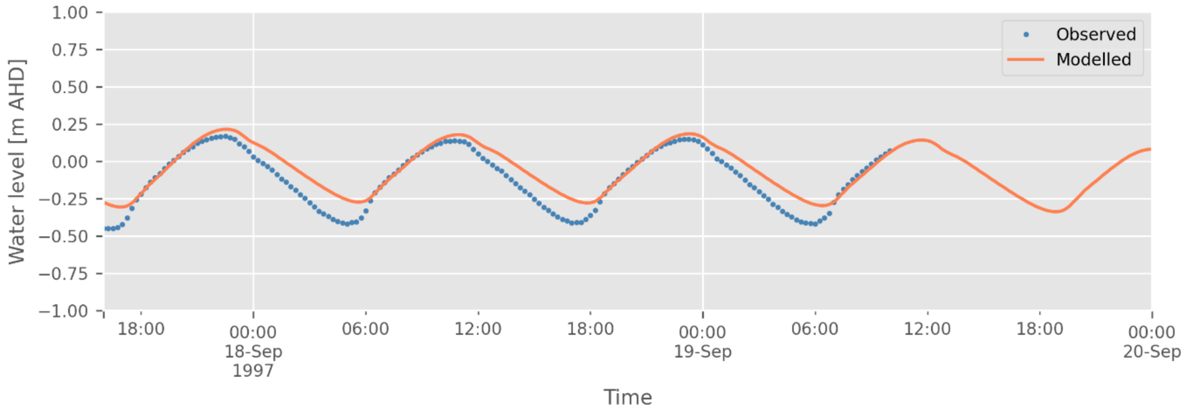

Figure 4-7 1997 water level calibration – Location 6 – Watson Taylors Lake East

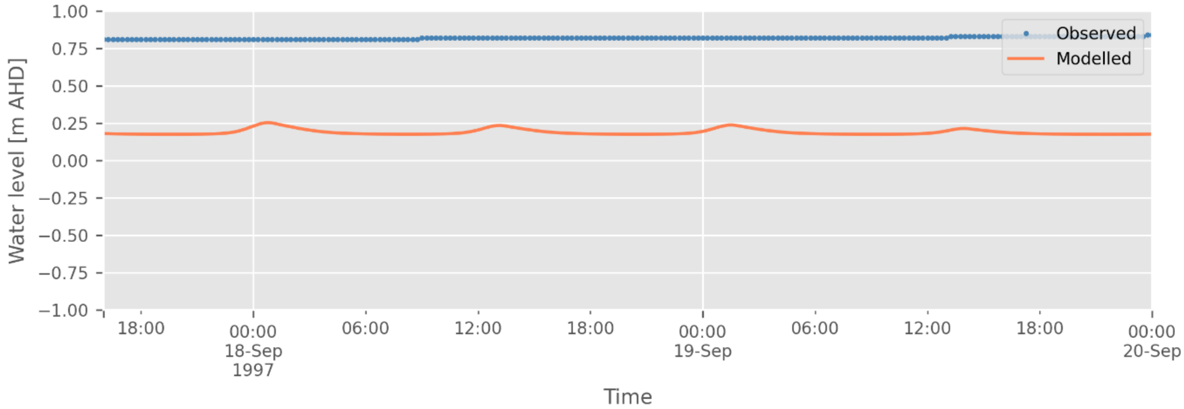

Figure 4-8 1997 water level calibration – Location 10 – Logans Crossing

4.6.2 May 2023 field data verification period

The 2023 field campaign involved the collection of tidal flow gauging at four transects, and the collation of water level data at seven locations from MHL (refer to Section 3). Measured tide levels were applied at the ocean boundary and scaled measured catchment inflows were applied at the three 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 or improved compared to the results from the 1997 calibration period for all locations. In particular, there was a significant improvement in model performance in Watson Taylors Lake (Figure 4-9). Additional water level and flow data was also available for Gogleys Lagoon for this period, which was well represented by the model (see Figure 4-10 and Figure 4-11). This provides confidence that the model is fit for purpose for simulating present day sewage overflow scenarios. The consistency of the results from the 1997 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.

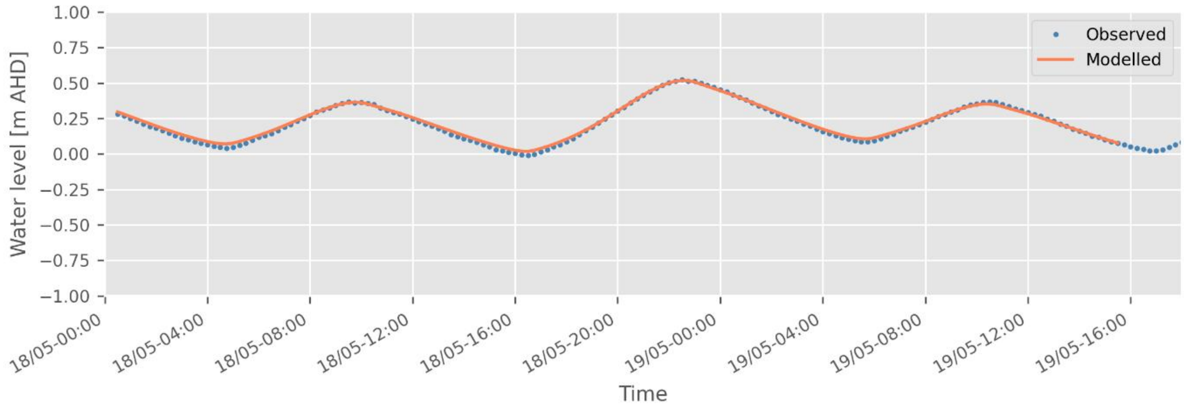

Figure 4-9 2023 water level verification – Location 13 – Watson Taylors Lake

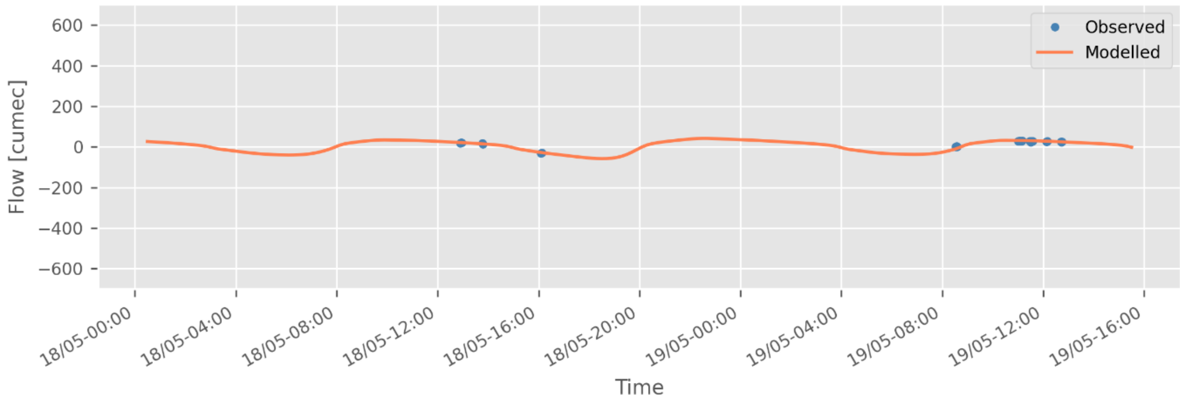

Figure 4-10 2023 tidal flow verification – Location H – Gogleys Lagoon West Entrance

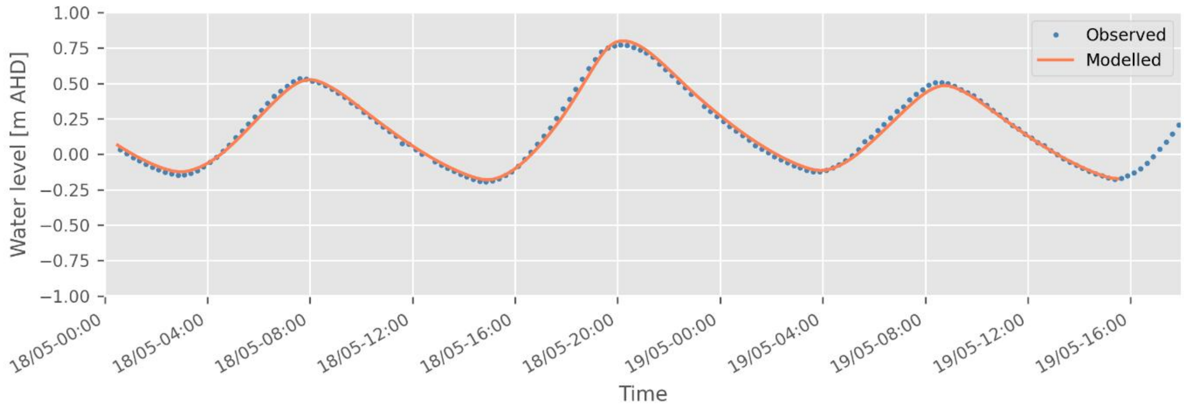

Figure 4-11 2023 water level verification – Location 14 – Gogleys Lagoon

4.6.3 Gogleys Lagoon 1976 data

Described in Section 2.2, inflows into Gogleys Lagoon via the eastern weir entrance and the primary western entrance were measured by MHL in 1976. While observed offshore tides are not available for this period, MHL flows were compared against model flows from the 2023 model run on a day with a similar tidal range. The flood/ebb cycle starting midday on 17 May 2023 was used for flow comparison. The results are shown in Appendix B1.5.

While the tides were not identical, this exercise provides insight into whether the model is capturing the correct order of magnitude of flow in and out of Gogleys Lagoon. The above results show reasonable agreement between the modelled and measured peak flows in and out of Gogleys Lagoon relative to total inflow. The main western entrance modelled flows are within 1 m^3/s of the measured flows. The smaller eastern entrance is conveying more flow than observed by MHL, however the magnitude of this flow is significantly smaller than the eastern entrance. This demonstrates that the model is simulating the correct order of magnitude of flow in and out of Gogleys Lagoon.

4.6.4 Roughness coefficients

Table 4-1 lists the roughness coefficients (Manning's n) which control the frictional losses in the final calibrated model. Most areas have a coefficient between 0.02 and 0.03, which is typical for large sandy channels. The rip rap entrances to Gogleys Lagoon have a higher frictional coefficient to account for the large amount of friction created by the rock.

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

Location	Manning's n roughness coefficient
Camden Haven River entrance to Gogleys Lagoon	0.029
Camden Haven River from Gogleys Lagoon to Hanley Point Bridge	0.020
Camden Haven River from Hanley Point Bridge to Watson Taylors Lake	0.025
Stingray Creek	0.020
Gogleys Lagoon main entrances	0.030
Rip rap entrances to Gogleys Lagoon	0.060
Intertidal areas	0.050
Lakes and all other areas	0.025

4.7 Water quality model development

4.7.1 Modelling of dispersion in RMA-11

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

A single dispersion coefficient of 4 m^2/s was used in the lakes to capture potential dispersion from wind driven mixing. The RMA-11 model utilised a 3 minute timestep, with results output every 6 minutes.

4.7.2 Tidal straining and vertical velocity distribution

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

In the Camden Haven system, ratios were close to one, indicating that vertical velocity profiles in the system were close to depth averaged (consistent with observations from the tidal flow gauging). Hence no timing adjustments were required for this system.

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

Drogue release	Location	Tide	Average drogue velocity (km/h)	Average model particle velocity (km/h)	Average ratio (velocity factor)
1	North Haven	Flood	1.73	1.70	1.02
2	Hanleys Point Bridge	Ebb	1.30	1.30	1.00
3	Camden Haven Marine Rescue	Ebb	1.94	1.98	0.98
4	Stingray Creek	Flood	1.87	1.73	1.09

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 Camden Haven model include:

- Less focus was placed on model calibration in the Camden Haven River upstream of Watson Taylors Lake. As discussed in Section 4.6.1, flow in this location is not a major influence on transport from the modelled overflow locations, hence the model was deemed fit for purpose, however this may not be true for other use cases.
- Bathymetry is very uncertain in the upper estuary. As this was not the area of interest, and the tidal prism was sufficiently accurate, the model was deemed fit for purpose, however this may not be true for other use cases.

- The lake transport processes are likely to be driven by wind, not captured in this model. Uncertainty about the lake transport processes are dealt with in the model by having a higher diffusion coefficient of 4 m^2/s in the lake, however future modelling purposes may wish to simulate lake transport processes explicitly through the addition of wind as an input.

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 Camden Haven, a total of 81 model scenario simulations were completed, including permutations of:

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

Reporting focused on the minimum dilution observed in each harvest area (during the 21 day scenario) and the time taken for the plume to reach each harvest area at 5,000,000 times dilution. Refer to WRL TR2023/32 Section 8.3 for more information. In situations where multiple scenarios gave very similar results, these scenarios were grouped for ease of use, and the worst case results (minimum dilution and shortest travel time) were reported, as detailed in WRL TR2023/32 Section 8.3.6.

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

5.2 Overflow locations

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

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

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

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

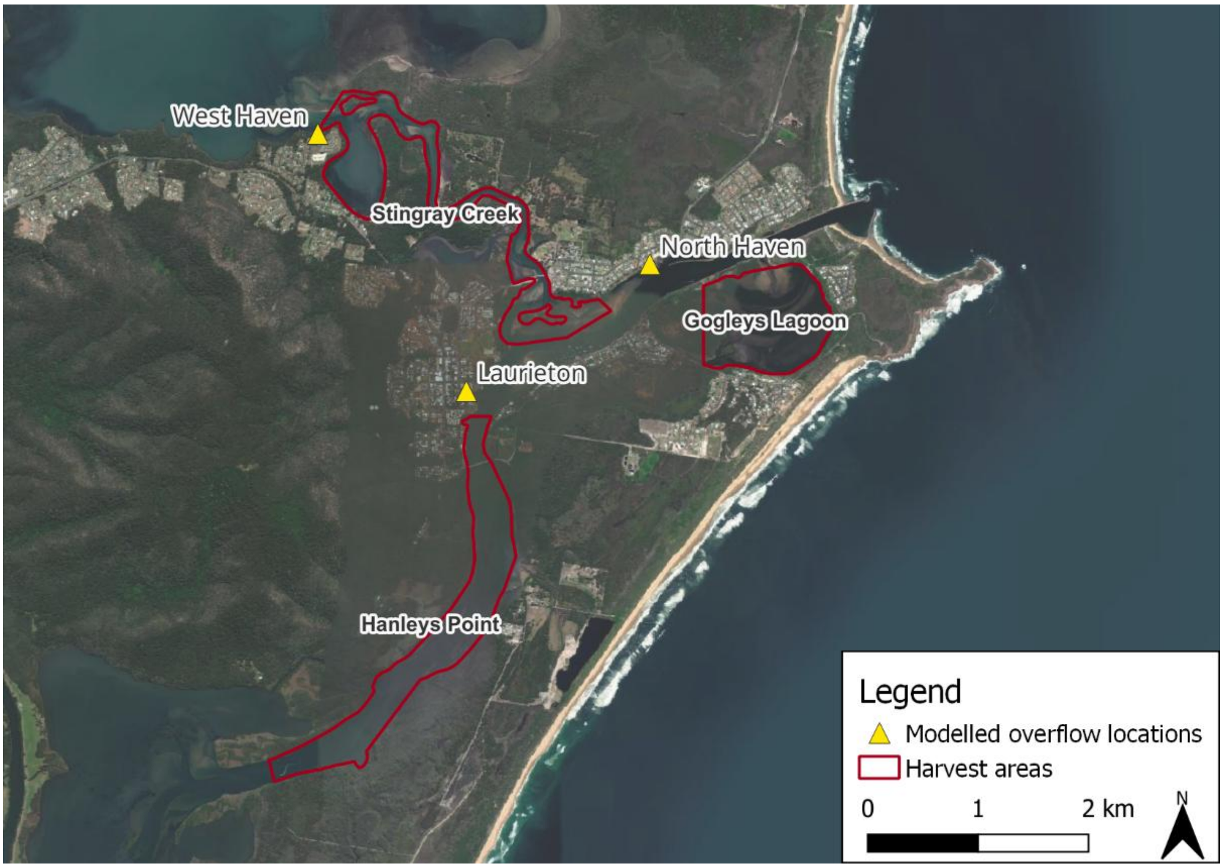

Figure 5-1 Modelled overflow locations in Camden Haven estuary

5.3 Environmental variables

Two environmental variables were tested for Camden Haven:

1. Stage of the tide (slack low tide, slack high tide, mid ebb tide and mid flood tide)
2. Magnitude of catchment inflows (median, 80th percentile and 95th percentile)

5.3.1 Stage of the tide

Stage of the tide for all locations is indexed to the MHL water level gauge, via the relationship described in Table 5-1. Because of the nature of a lake system, slack tides do not correspond to the highest and lowest water levels, and instead lag behind. Table 5-1 specifies the appropriate lags.

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
West Haven	Slack low tide	West Haven (207437)	30 mins after low tide
West Haven	Mid flood tide	West Haven (207437)	1 hr 30 mins before high tide
West Haven	Slack high tide	West Haven (207437)	1 hr after high tide
West Haven	Mid ebb tide	West Haven (207437)	3 hr before low tide
Laurieton	Slack low tide	Laurieton (207425)	30 mins after low tide
Laurieton	Mid flood tide	Laurieton (207425)	1 hr 45 mins before high tide
Laurieton	Slack high tide	Laurieton (207425)	1 hr after high tide
Laurieton	Mid ebb tide	Laurieton (207425)	3 hr 30 mins before low tide
North Haven	Slack low tide	North Haven (207423)	1 hr 15 mins after low tide
North Haven	Mid flood tide	North Haven (207423)	1 hr 30 mins before high tide
North Haven	Slack high tide	North Haven (207423)	30 mins after high tide
North Haven	Mid ebb tide	North Haven (207423)	3 hr before low tide

The stage of the tide is important at all overflow locations and is important for all overflows of duration less than 10 hours. Timing of the tide is particularly important for 1-hour overflows from North Haven and Laurieton, where overflows at slack high tide (the beginning of the outgoing tide) will largely leave the estuary before the turn of the tide. This highlights the need for accurate reporting of the timing and duration of overflows from these locations.

5.3.2 Catchment inflows

While catchment inflow did influence plume behaviour in the broader estuary, it did not significantly influence the minimum dilution (maximum concentration) that was observed in each harvest area from each of the three overflow locations in most cases. 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 40 m^3/s, less than 10% of the peak tidal flows through the entrance, which highlights the relative importance of tidal flows in transport and dilution of overflows in this estuary.

An example of a 1-hour overflow from Laurieton on a slack low tide during median catchment inflows is shown in Figure 5-2 and 95th percentile catchment inflows is shown in Figure 5-3. As the majority of the catchment for the Camden Haven system comes from the north-west in Watson Taylor Lake, higher catchment inflows limit plume transport into the western lake. This pushes more of the mass of the plume into the main channel and up Stringray Creek. However, the minimum dilution and travel time into all three harvest areas remained very similar. For ease of use, results for different catchment inflow have been combined for most scenarios (when the implications for harvest areas are similar). See WRL TR2023/32 Section 8.3.4 for more details on scenario grouping.

Figure 5-2 Example of a 1-hour overflow at Laurieton during median inflow conditions*

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

Figure 5-3 Example of a 1-hour overflow at Laurieton during wet (95th percentile) inflow conditions*

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

6 Conclusion

This report is focussed on the Camden Haven 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 Camden Haven River estuary model. Key information included in the report relates to the integration of existing data sources, the 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 Camden Haven) and discussions on modelling limitations including model parameter sensitivity and pollutant dispersion. Results of the scenario modelling is available in the accompanying tool, which is documented in the User Guide (WRL TR2024/26).

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Appendix A Field data collection

A1 Drifter drogue experiments

The below figures summarise the behaviour of the four drifter drogue experiments. For more information on these deployments, refer to Section 3.5.5.

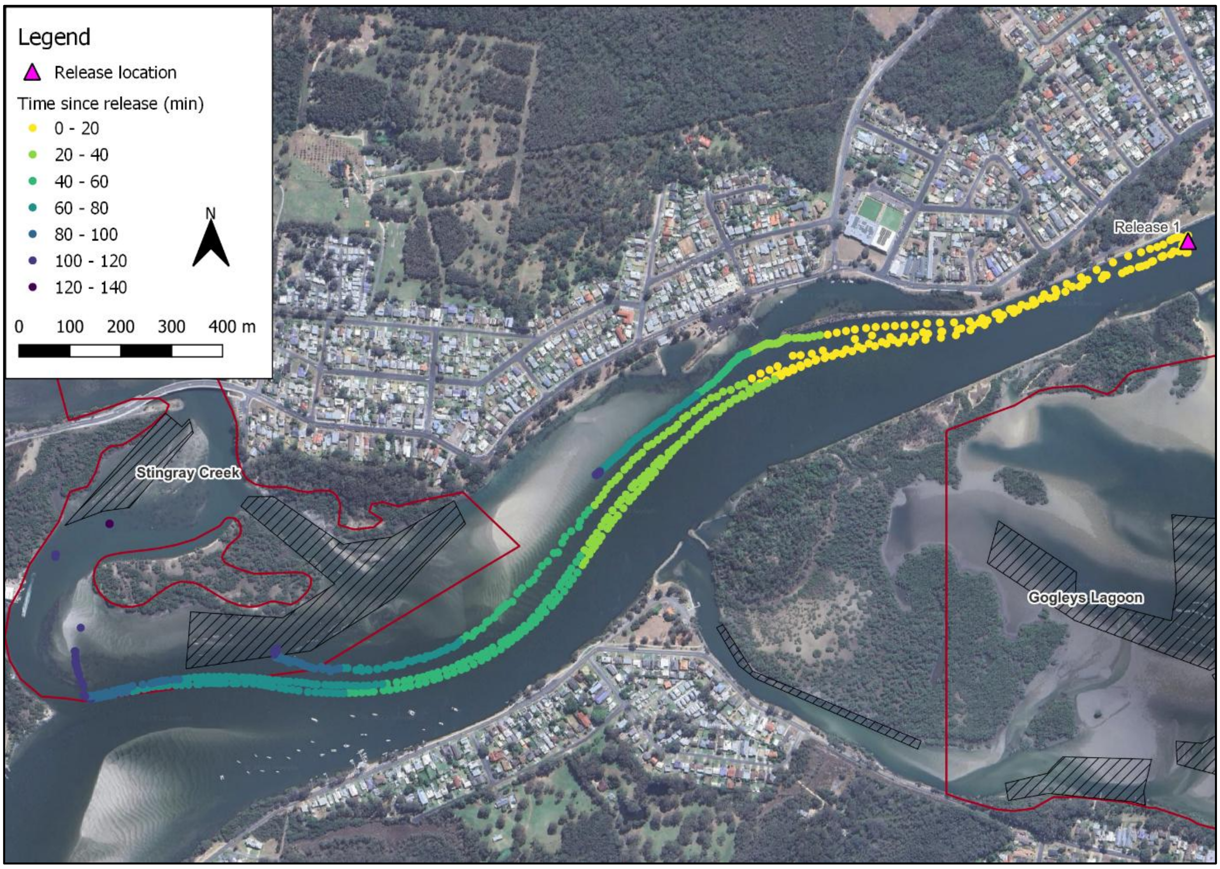

Figure A-1 GPS drifter drogue release 1 – North Haven – incoming tide

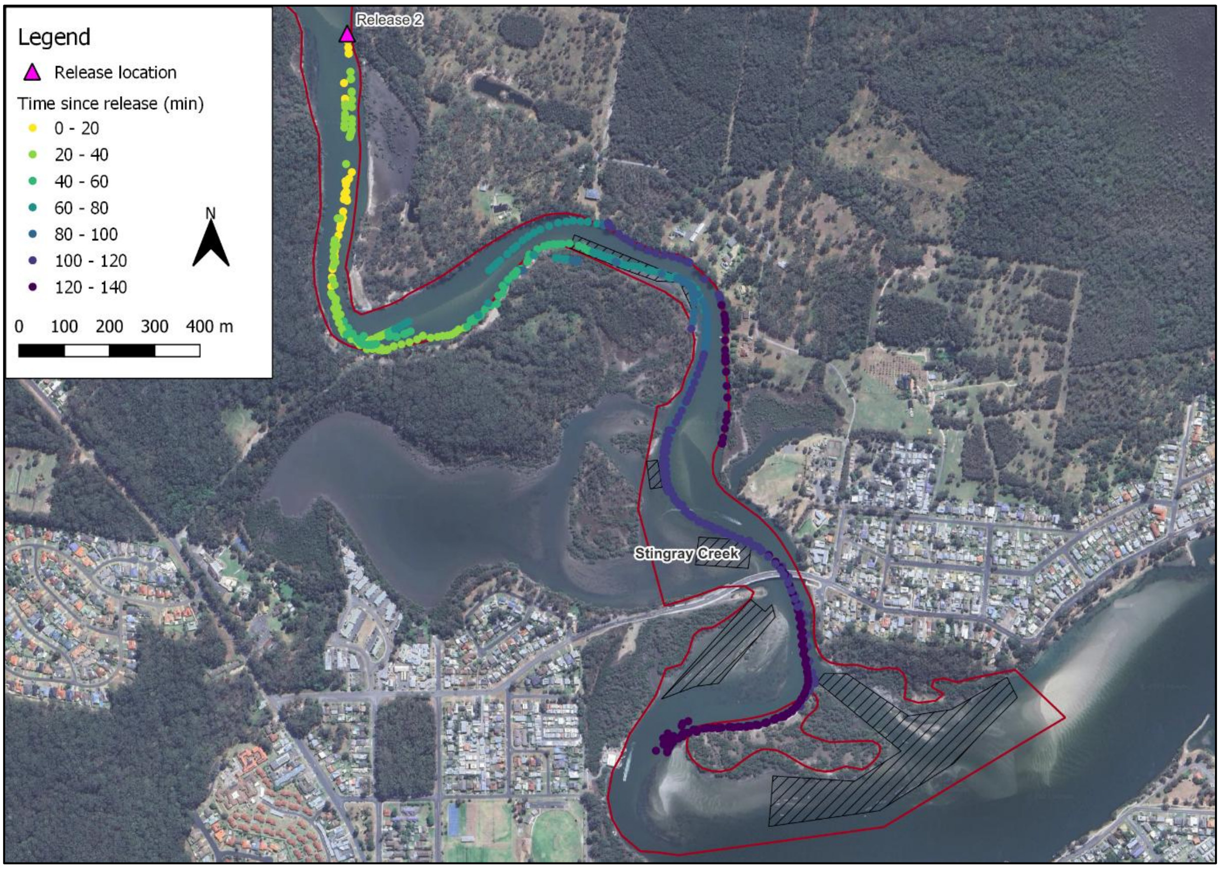

Figure A-2 GPS drifter drogue release 2 – Stingray Creek – outgoing tide

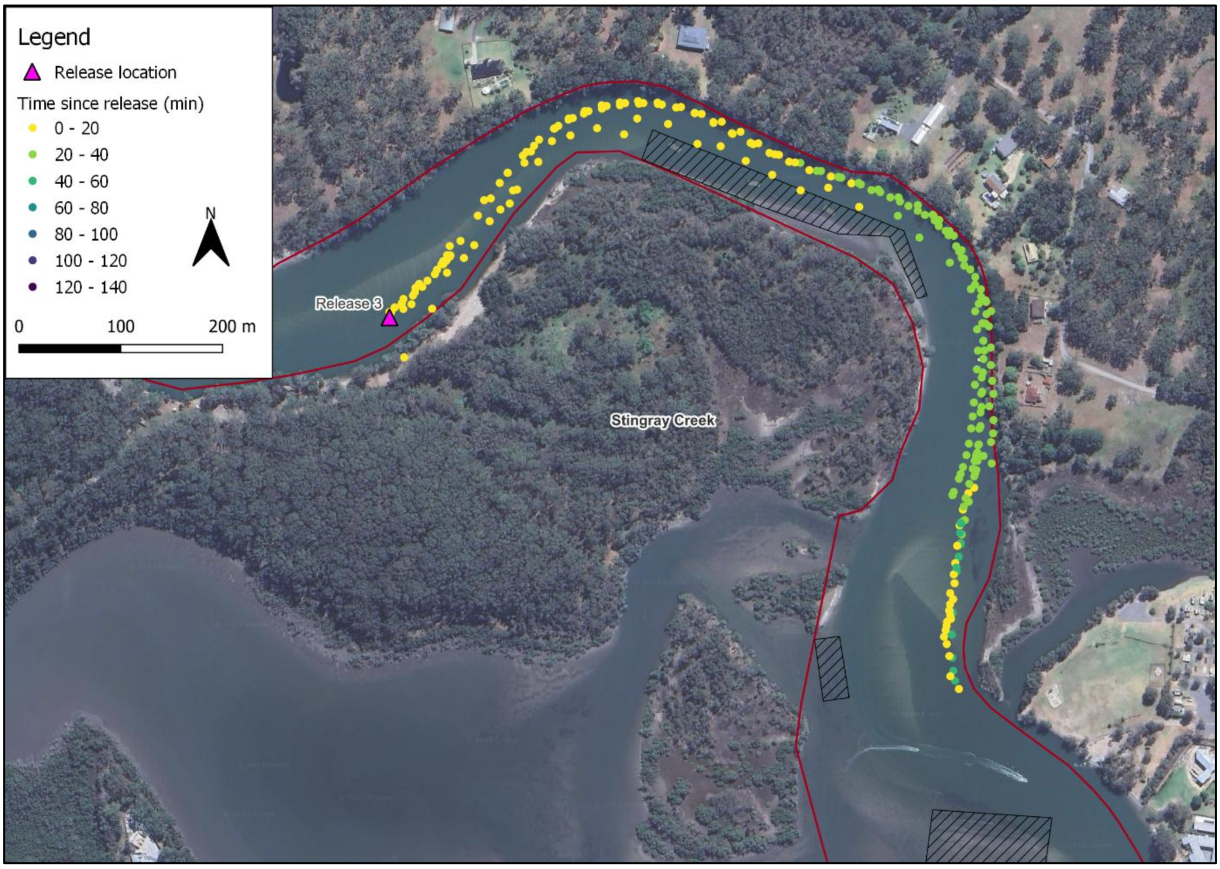

Figure A-3 GPS drifter drogue release 3 – Stingray Creek – outgoing tide

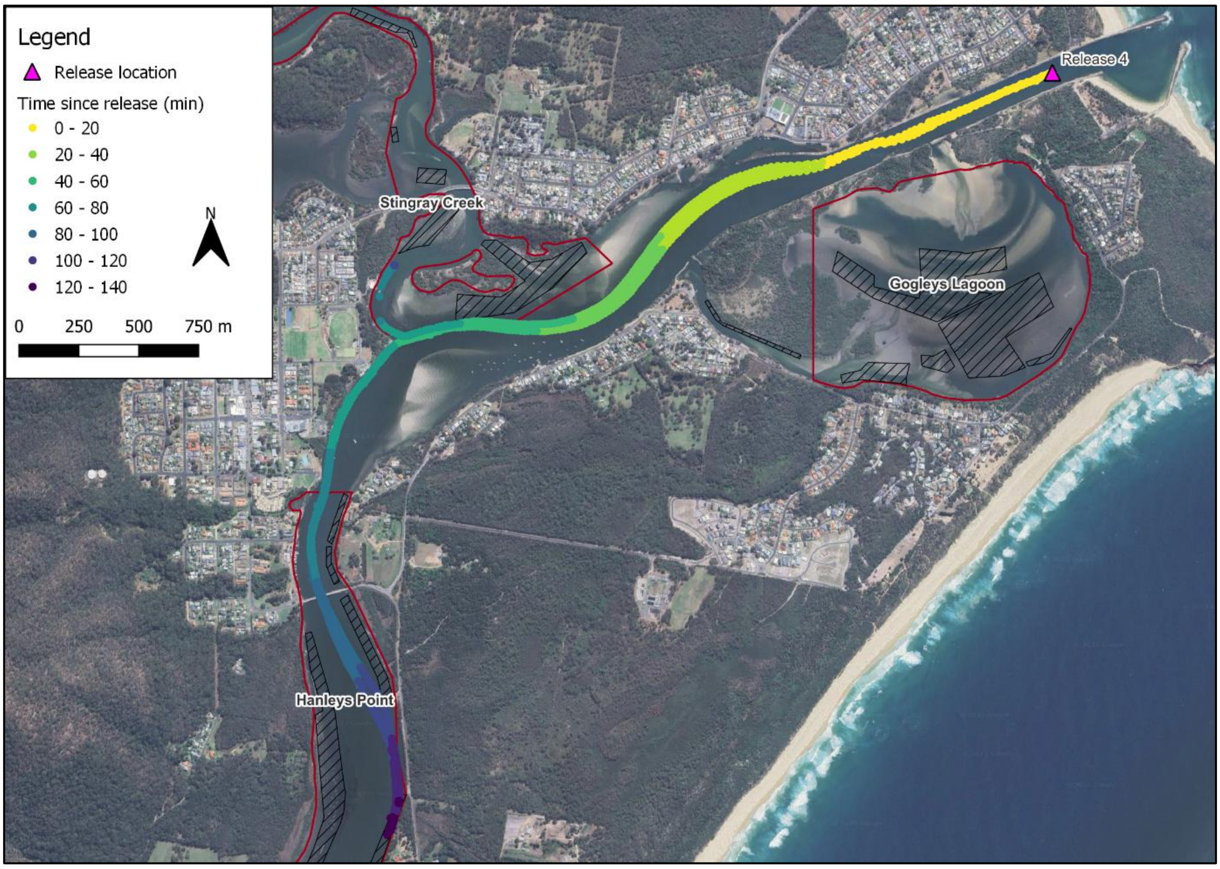

Figure A-4 GPS drifter drogue release 4 – North Haven – incoming tide

A2 Tidal flow gauging

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

Table A-1 North Haven 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	17/05/2019	7:37:58	-412
2	17/05/2019	7:40:45	-413
3	17/05/2019	7:43:39	-410
4	17/05/2019	13:51:51	371
5	17/05/2019	13:55:14	366
6	17/05/2019	15:49:37	-51
7	17/05/2019	15:55:53	-149
8	18/05/2019	6:55:42	-501
9	18/05/2019	6:58:33	-455
10	18/05/2019	8:50:41	-318
11	18/05/2019	8:55:23	-297
12	18/05/2019	12:15:31	459
13	18/05/2019	12:19:30	445
14	18/05/2019	12:24:49	414
15	18/05/2019	12:28:31	432

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

Table A-2 Gogleys Lagoon Entrance 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	18/05/2023	12:53:02	18
2	18/05/2023	12:54:51	20
3	18/05/2023	12:57:36	20
4	18/05/2023	13:46:01	17
5	18/05/2023	13:47:39	14
6	18/05/2023	16:05:56	-32
7	18/05/2023	16:07:53	-28
8	19/05/2023	8:31:58	2
9	19/05/2023	8:33:54	3
10	19/05/2023	8:35:26	2
11	19/05/2023	10:59:59	29
12	19/05/2023	11:01:38	29
13	19/05/2023	11:03:11	30
14	19/05/2023	11:04:47	29
15	19/05/2023	11:06:14	29
16	19/05/2023	11:07:49	28
17	19/05/2023	11:09:14	30
18	19/05/2023	11:27:59	27
19	19/05/2023	11:29:40	24
20	19/05/2023	11:31:33	27
21	19/05/2023	11:33:23	28
22	19/05/2023	11:35:00	28
23	19/05/2023	12:06:49	26
24	19/05/2023	12:08:15	26
25	19/05/2023	12:09:45	27
26	19/05/2023	12:41:18	25

No.	Date	Time	Flow (m^3/s) *
27	19/05/2023	12:42:44	24
28	19/05/2023	12:44:13	26

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

Table A-3 Hanleys Point Bridge 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	19/05/2023	9:17:33	-185
2	19/05/2023	9:19:50	-174
3	19/05/2023	10:02:28	-56
4	19/05/2023	10:05:11	-36
5	19/05/2023	10:10:13	-22
6	19/05/2023	10:13:09	18

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

Table A-4 Stingray Creek Bridge 2023 tidal flow gauging

No.	Date	Time	Flow (m^3/s) *
1	18/05/2023	10:29:11	66
2	18/05/2023	10:38:16	78
3	18/05/2023	10:40:19	81
4	18/05/2023	15:30:25	46
5	18/05/2023	15:32:21	44

* 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-5 Incoming channel flow distribution at North Haven

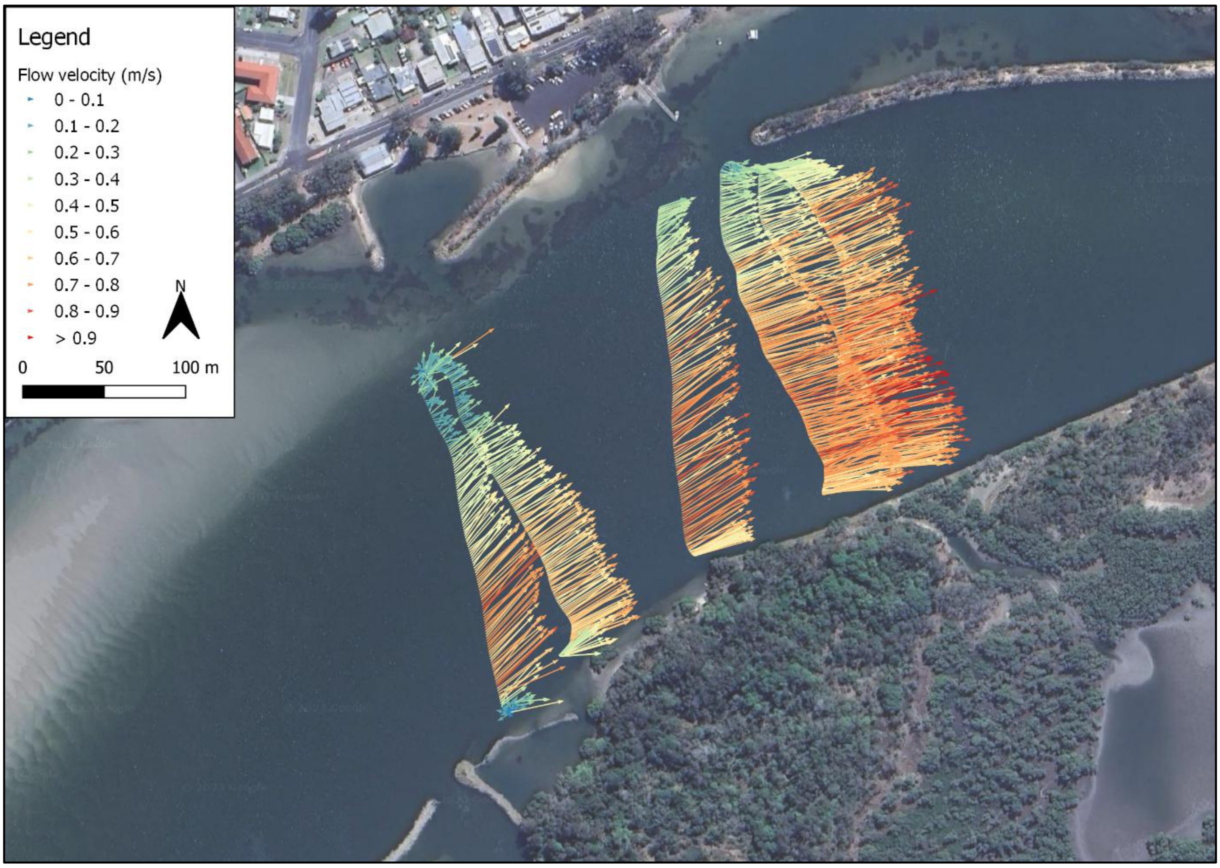

Figure A-6 Outgoing channel flow distribution at North Haven

Figure A-7 Outgoing channel flow distribution at Stingray Creek

Figure A-8 Incoming channel flow distribution at Gogleys Lagoon entrance

Figure A-9 Outgoing channel flow distribution at Gogleys Lagoon entrance

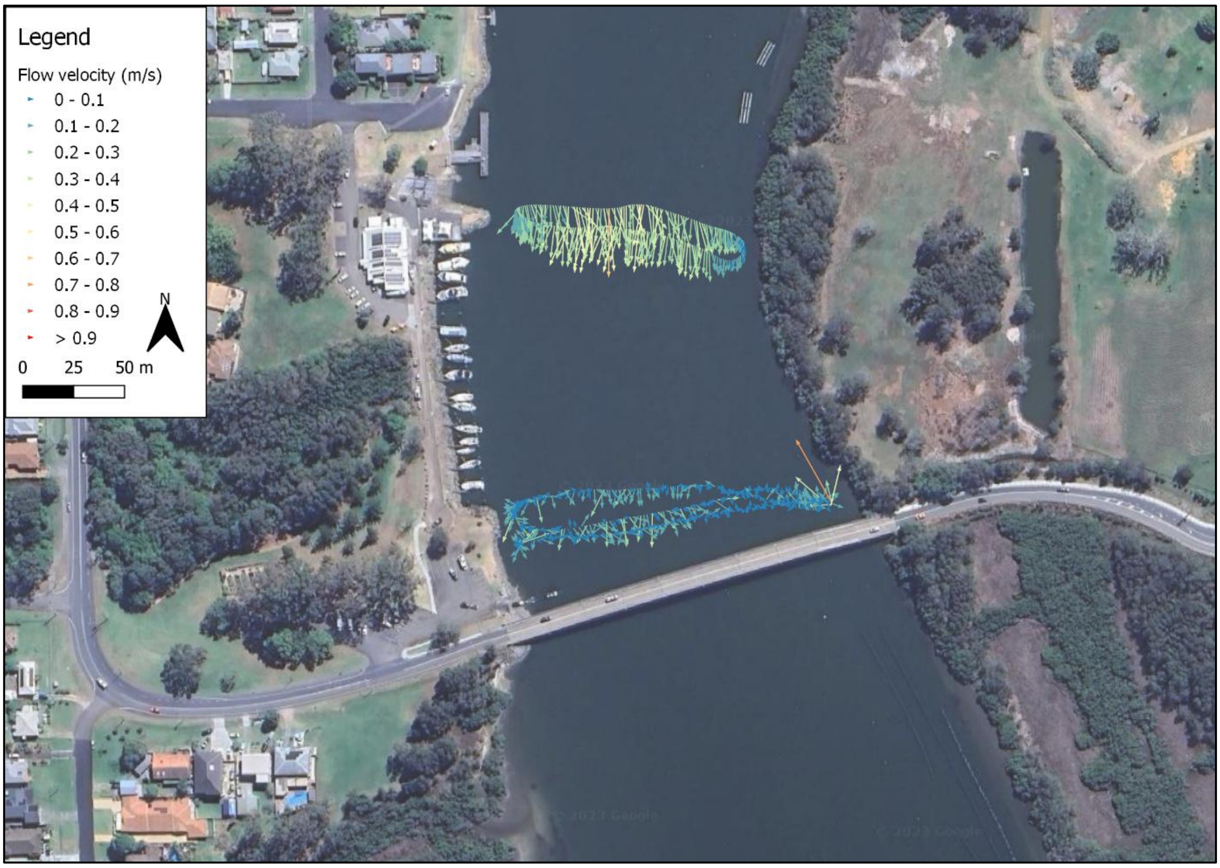

Figure A-10 Incoming channel flow distribution at Laurieton

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.

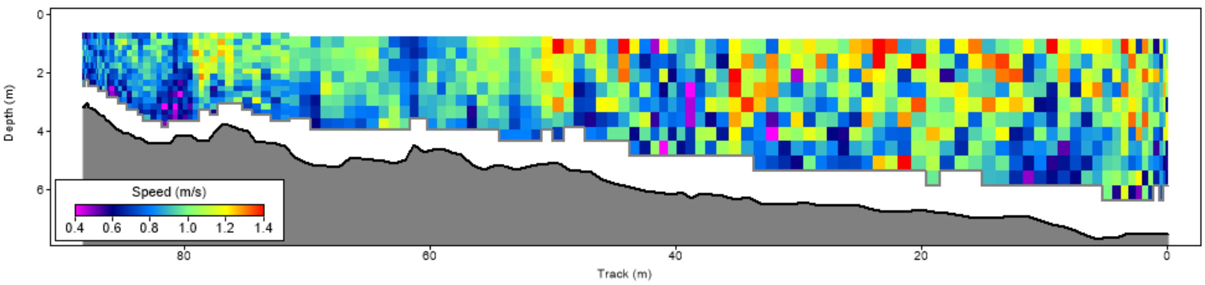

Figure A-11 Vertical velocity distribution – main entrance near heads – incoming flow – (2023/05/19 06:58:33)

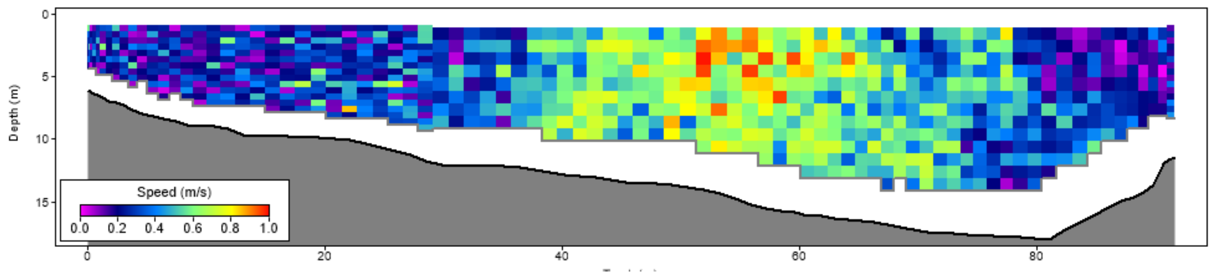

Figure A-12 Vertical velocity distribution – main entrance at North Haven – incoming flow – (2023/05/18 07:43:39)

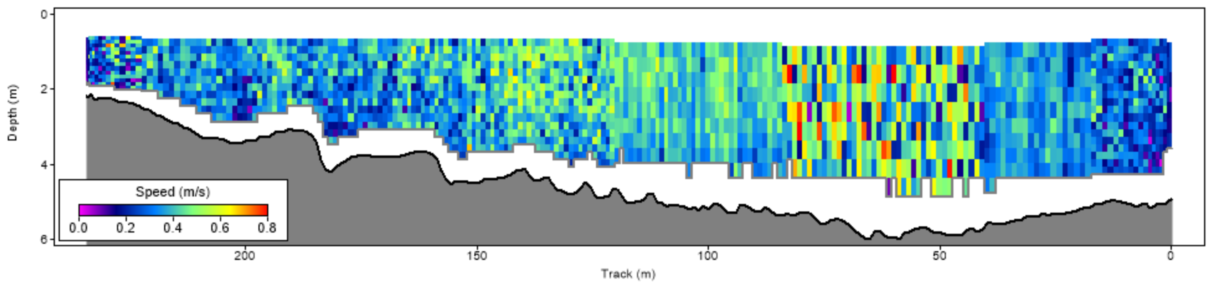

Figure A-13 Vertical velocity distribution – main entrance at Gogleys Lagoon Western Entrance – incoming flow – (2023/05/19 08:50:41)

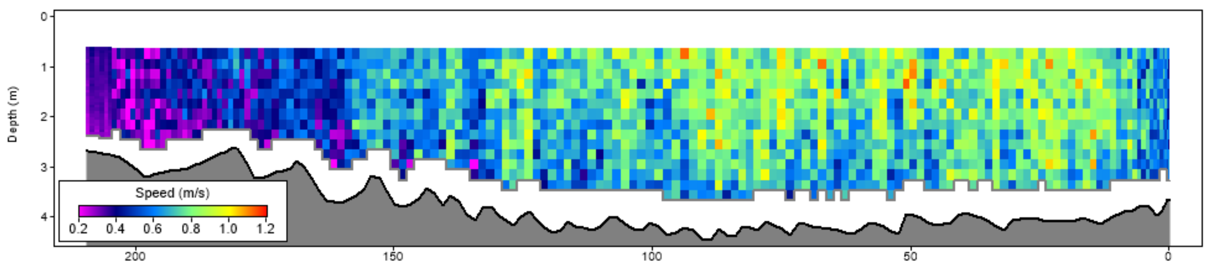

Figure A-14 Vertical velocity distribution – main entrance at Gogleys Lagoon Western Entrance – outgoing flow – (2023/05/19 12:15:31)

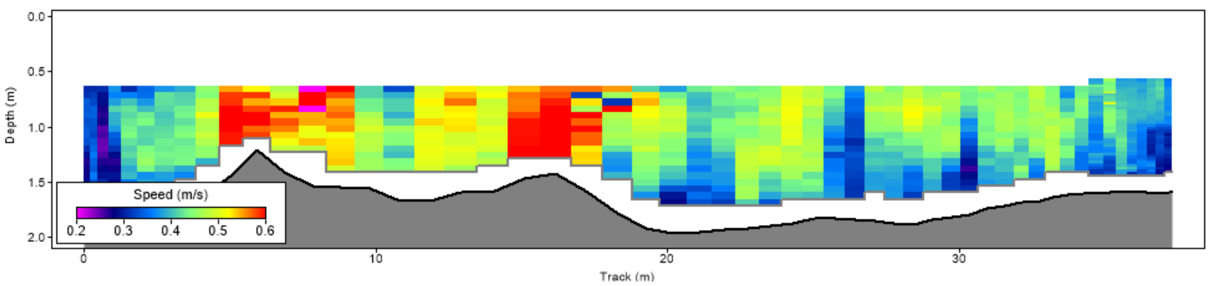

Figure A-15 Vertical velocity distribution – Gogleys Lagoon Western Entrance – outgoing flow – (2023/05/19 11:01:38)

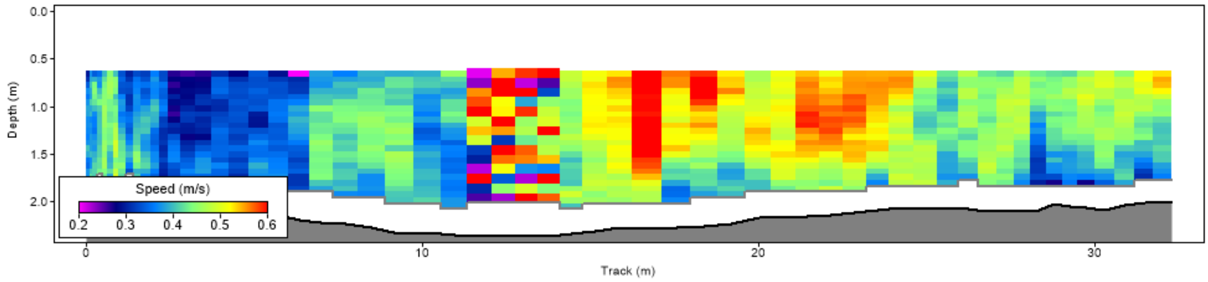

Figure A-16 Vertical velocity distribution – Gogleys Lagoon Western Entrance – outgoing flow – (2023/05/18 16:07:53)

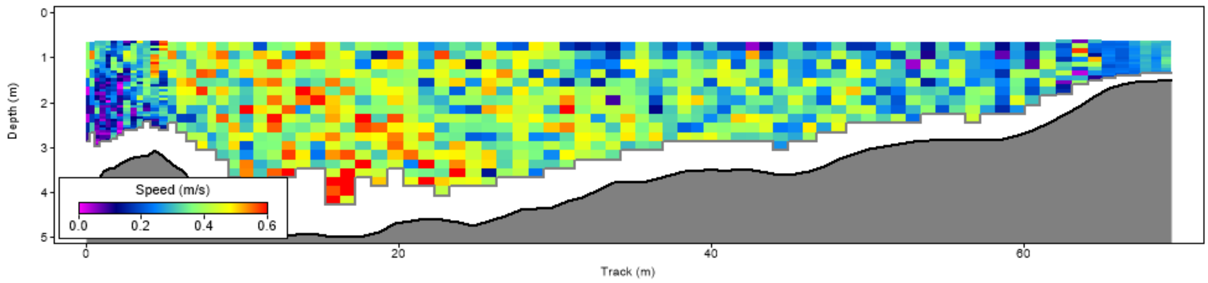

Figure A-17 Vertical velocity distribution – Stingray Creek – outgoing flow – (2023/05/18 10:38:16)

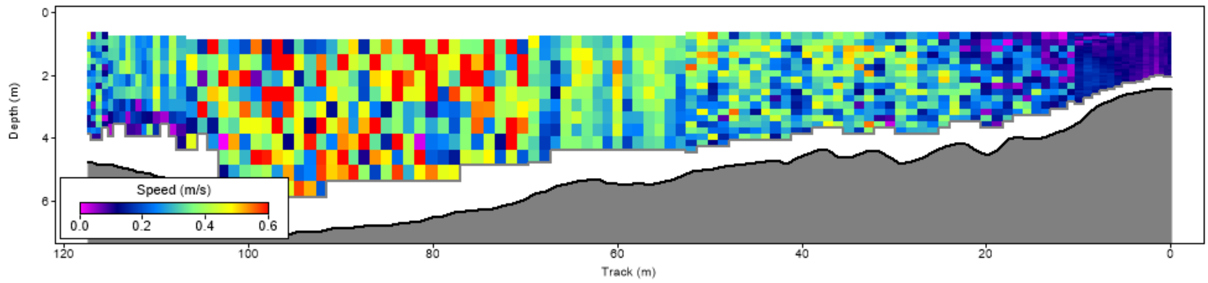

Figure A-18 Vertical velocity distribution – Hanleys Point Bridge – outgoing flow – (2023/05/19 09:19:50)

Appendix B Model calibration

B1 Hydrodynamic calibration and verification results

The below figures summarise results from the Camden Haven hydrodynamic calibration and verification process. For more information, refer to Section 4.5.

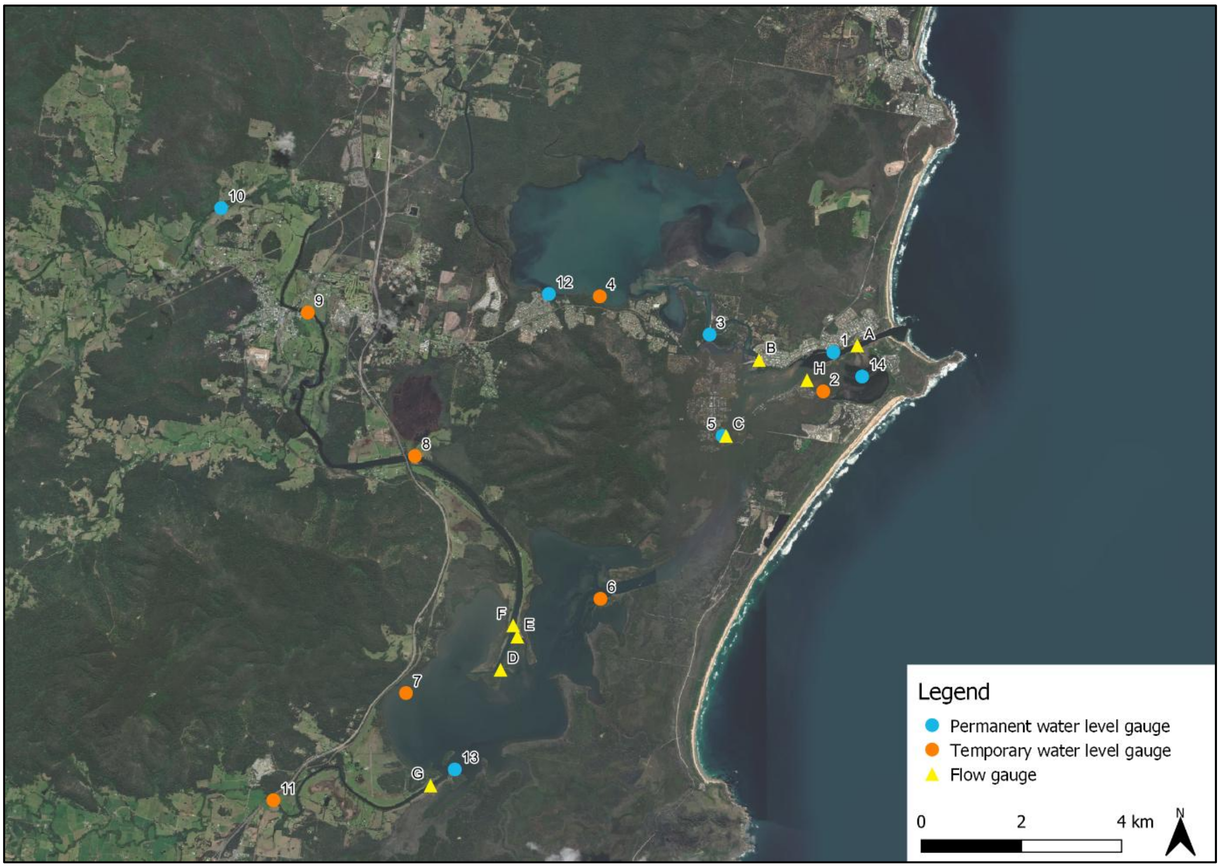

Figure B-1 Water level and tidal flow gauging locations

B1.1 Tidal flow gauging calibration – 1997

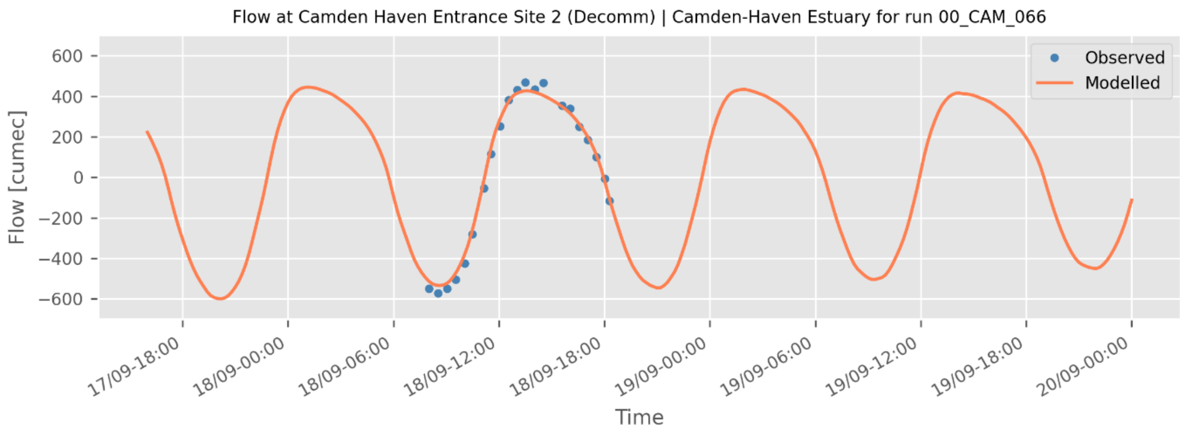

Figure B-2 1997 tidal flow calibration – Location A – Entrance/North Haven

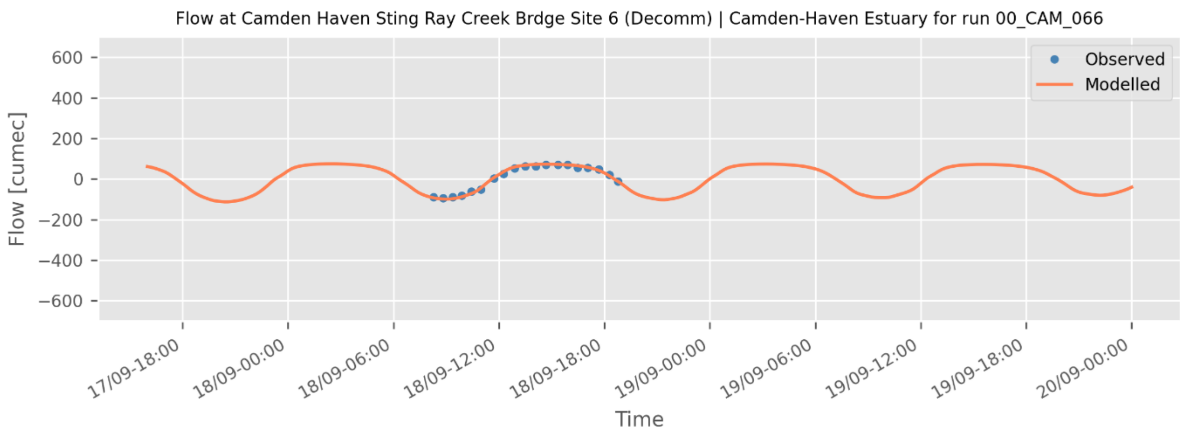

Figure B-3 1997 tidal flow calibration – Location B – Stingray Creek Bridge

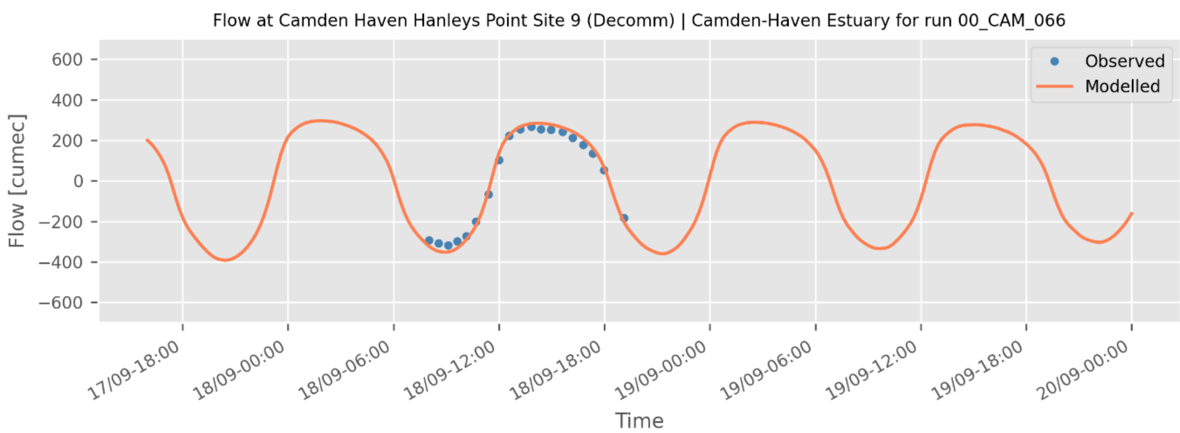

Figure B-4 1997 tidal flow calibration – Location C – Hanleys Point Bridge/Laurieton

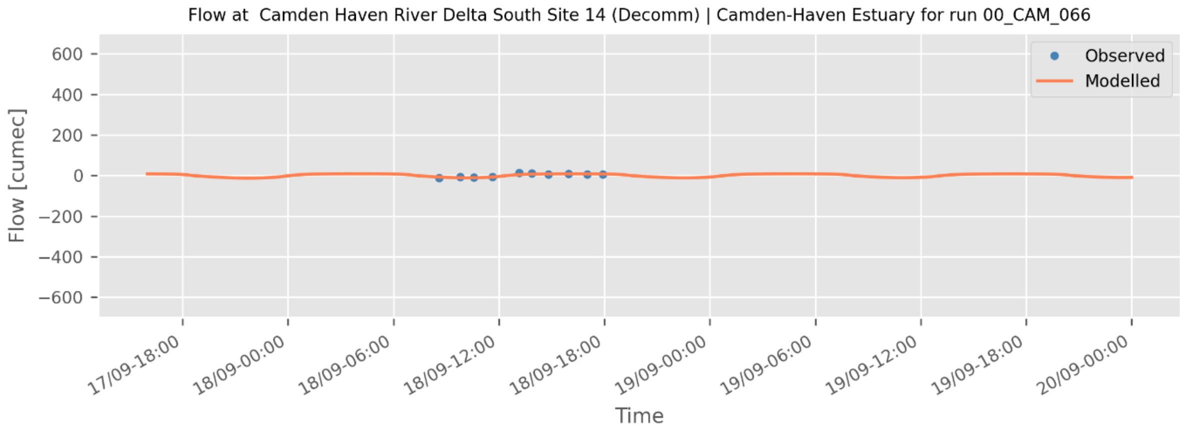

Figure B-5 1997 tidal flow calibration – Location D – Camden Haven River Delta South

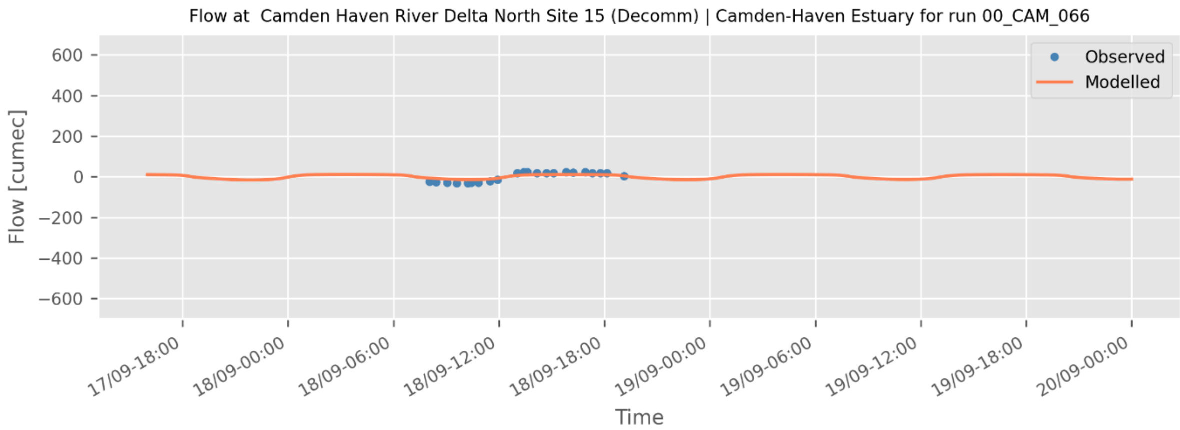

Figure B-6 1997 tidal flow calibration – Location E – Camden Haven River Delta North

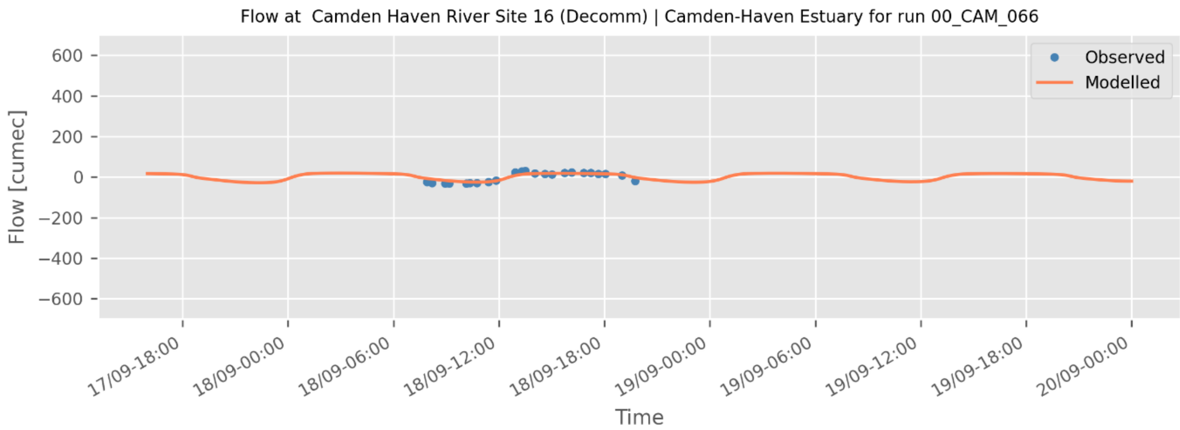

Figure B-7 1997 tidal flow calibration – Location F – Camden Haven River

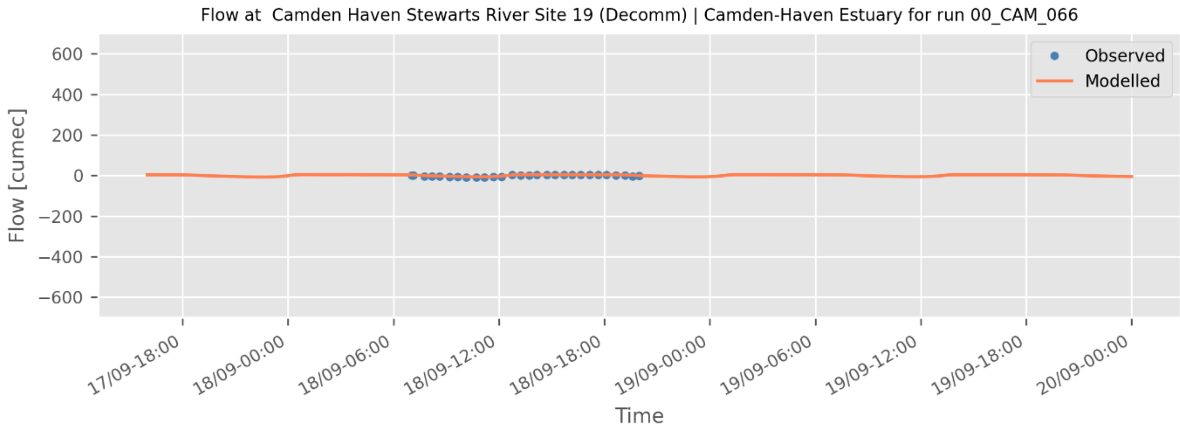

Figure B-8 1997 tidal flow calibration – Location G – Stewarts River

B1.2 Water level calibration – 1997

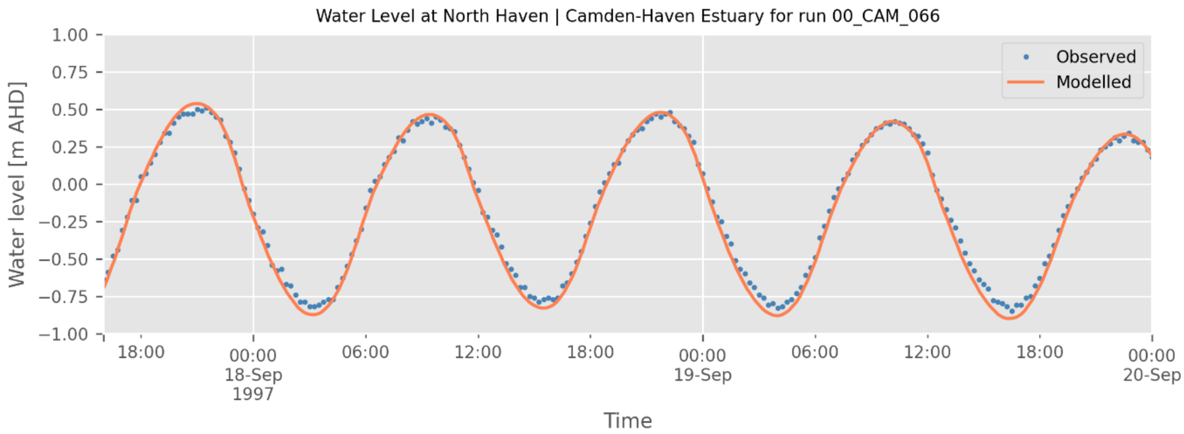

Figure B-9 1997 water level calibration – Location 1 – Entrance/North Haven

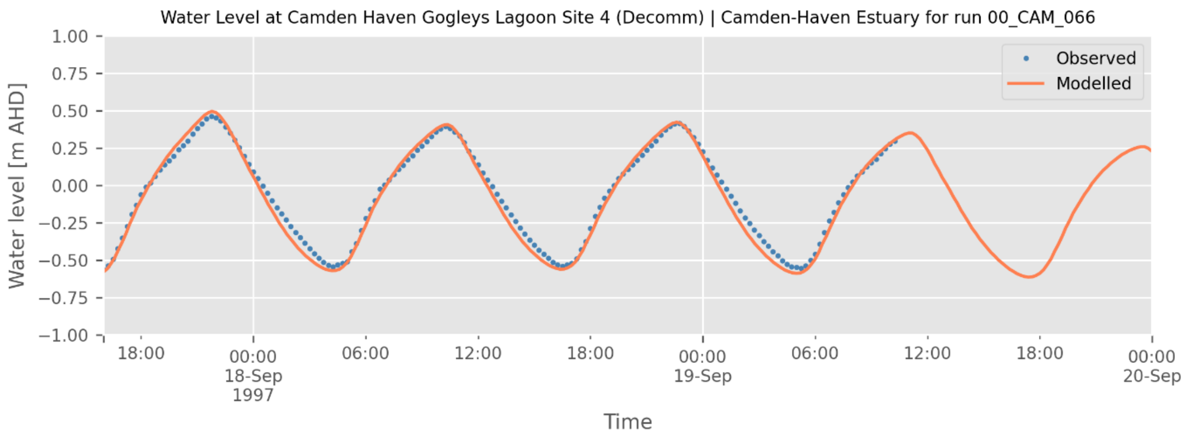

Figure B-10 1997 water level calibration – Location 2 – Gogleys Lagoon Entrance

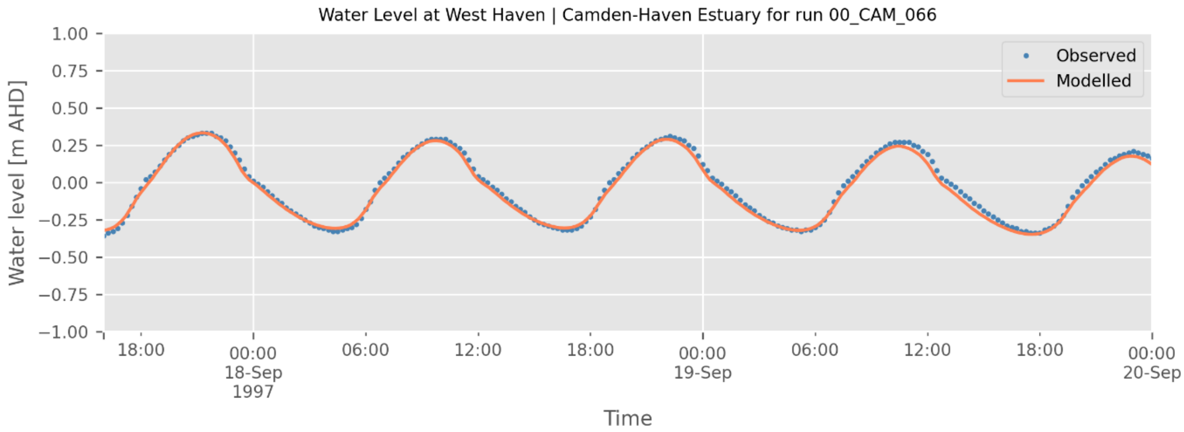

Figure B-11 1997 water level calibration – Location 3 – Stingray Creek/West Haven

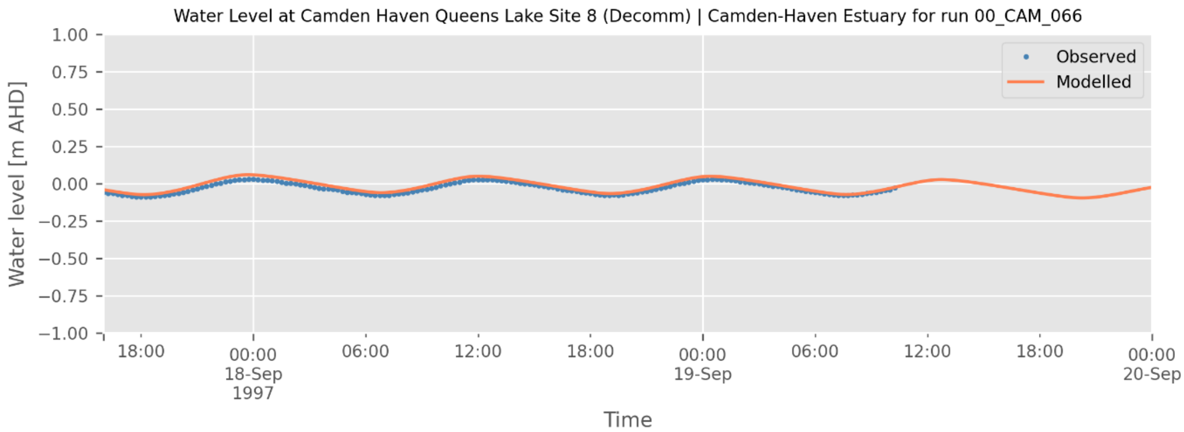

Figure B-12 1997 water level calibration – Location 4 – Queens Lake

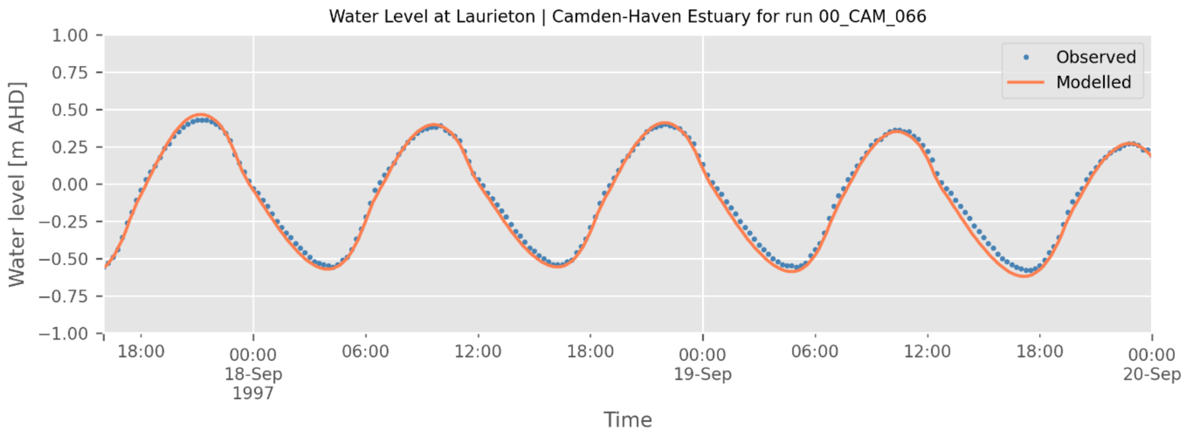

Figure B-13 1997 water level calibration – Location 5 – Hanleys Point/Laurieton

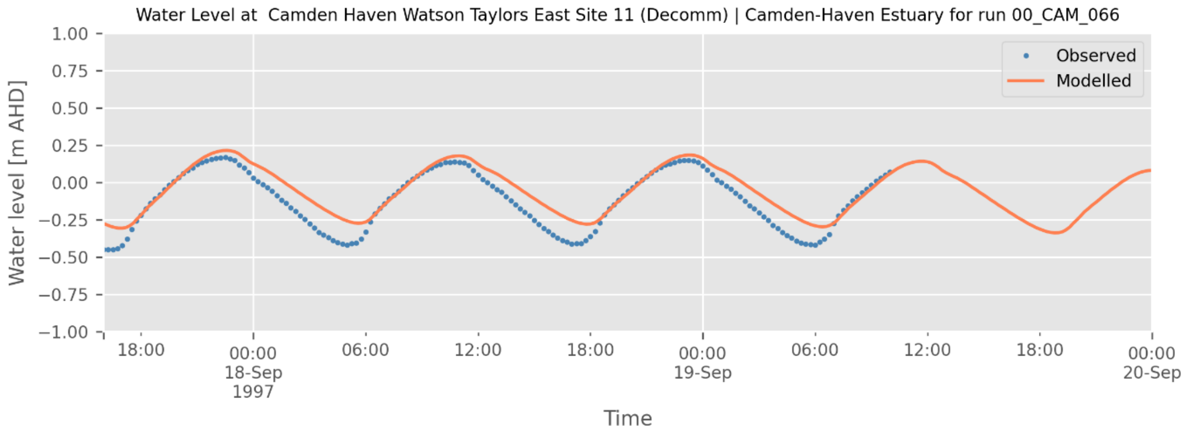

Figure B-14 1997 water level calibration – Location 6 – Watson Taylors Lake East

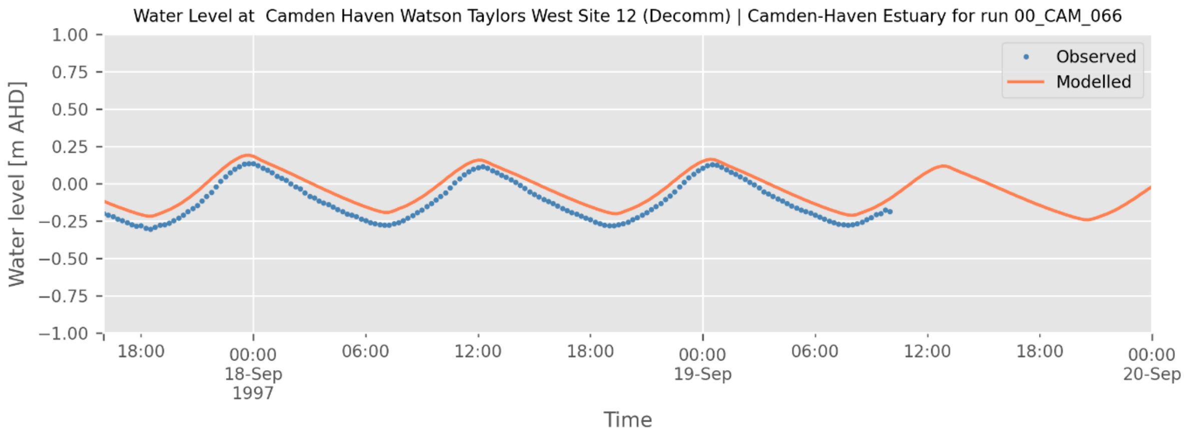

Figure B-15 1997 water level calibration – Location 7 – Watson Taylors Lake West

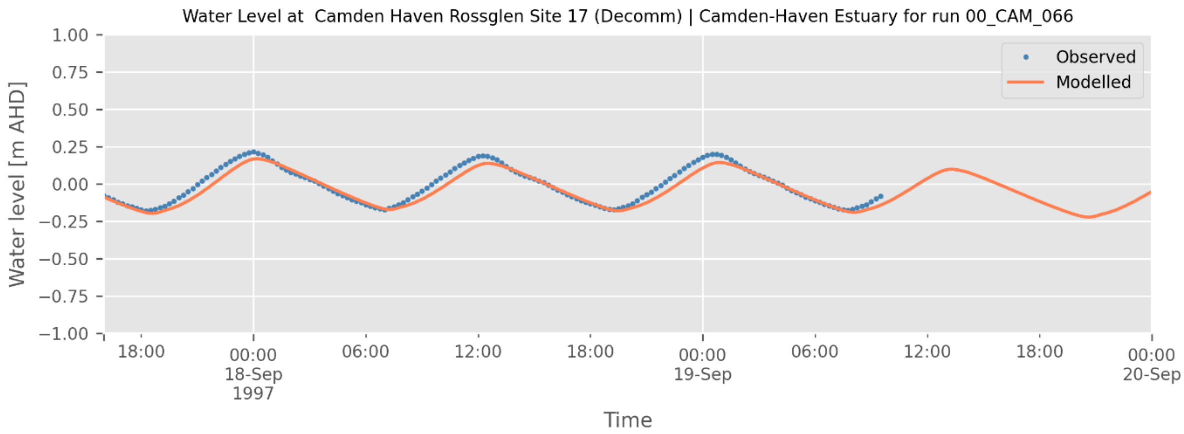

Figure B-16 1997 water level calibration – Location 8 – Rossglen

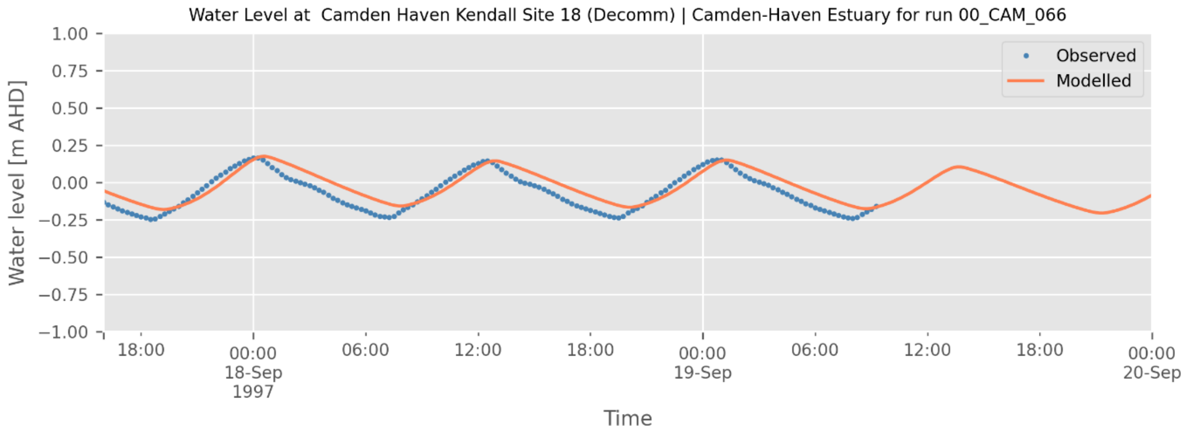

Figure B-17 1997 water level calibration – Location 9 – Kendall

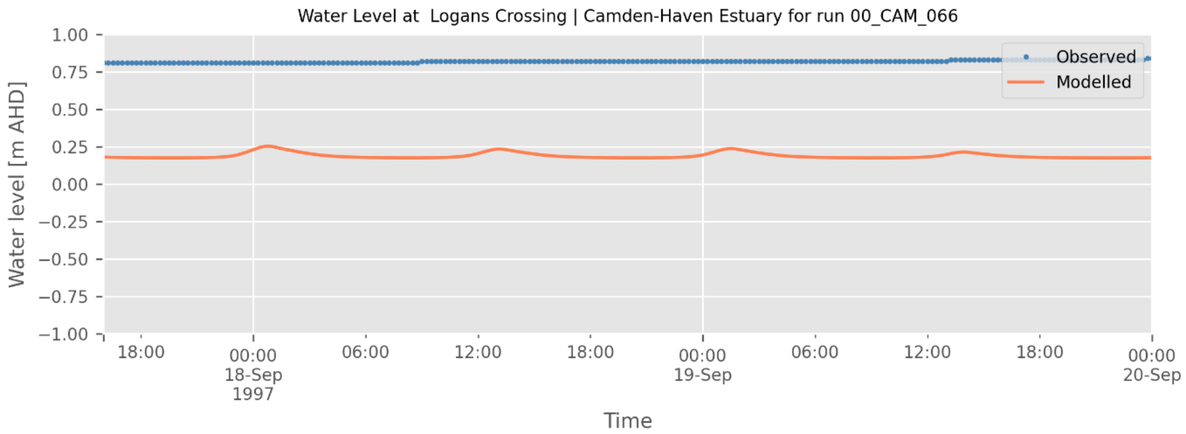

Figure B-18 1997 water level calibration – Location 10 – Logans Crossing

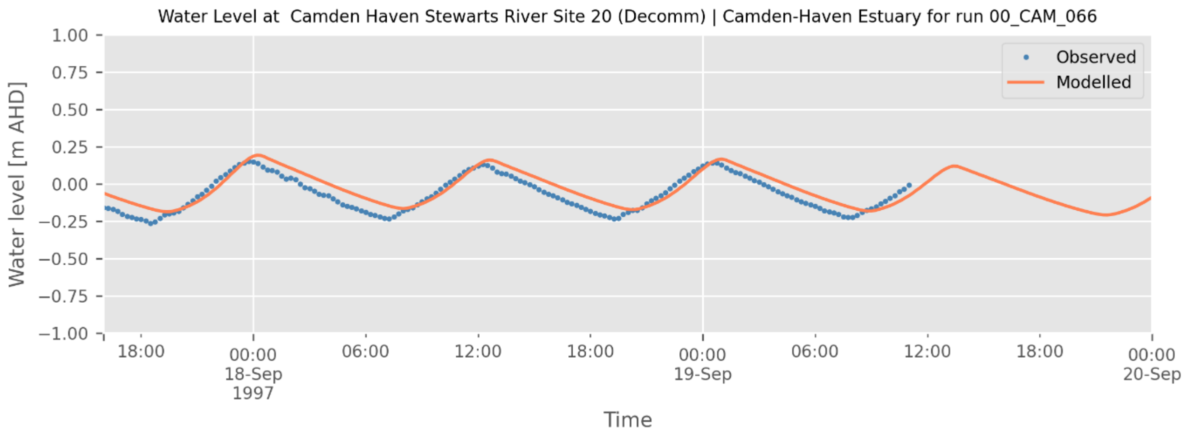

Figure B-19 1997 water level calibration – Location 11 – Stewarts River Railway Bridge

B1.3 Tidal flow gauging verification – 2023

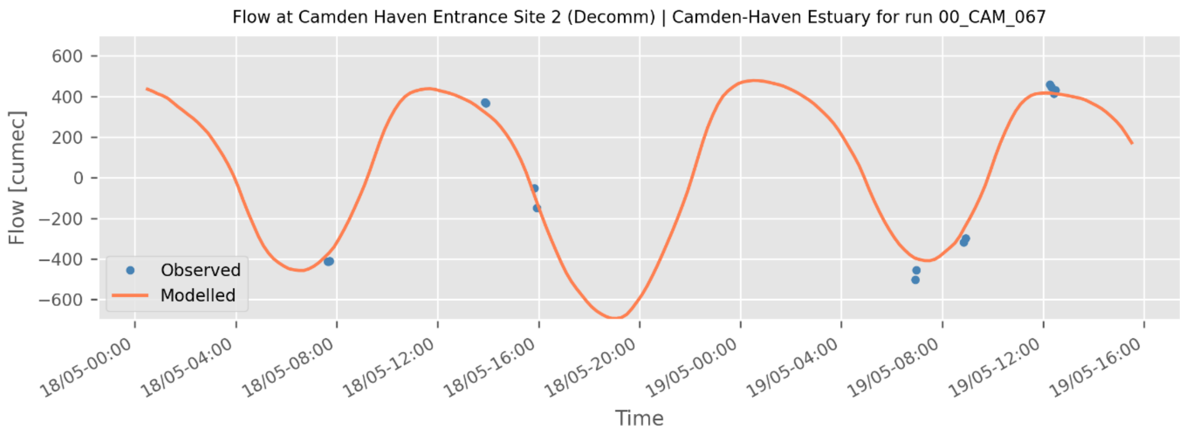

Figure B-20 2023 tidal flow verification – Location A – Entrance/North Haven

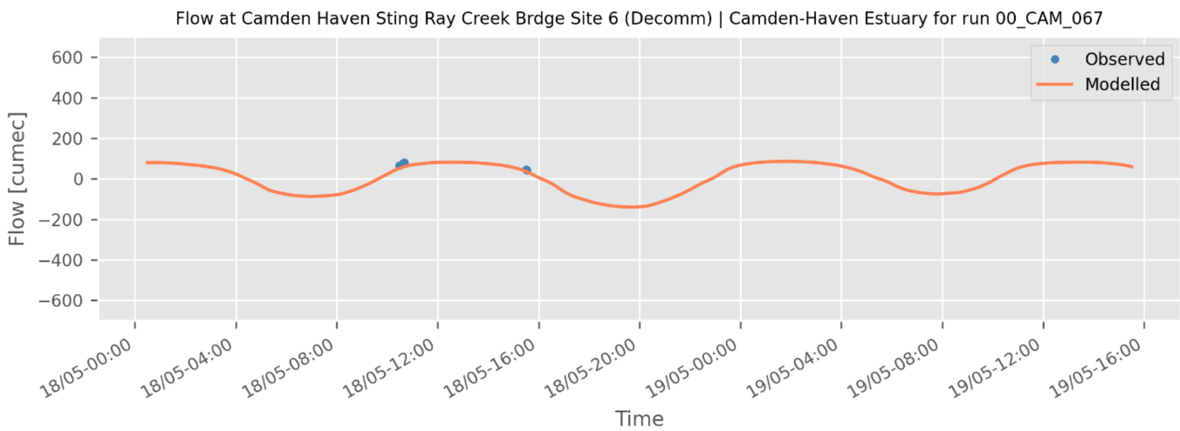

Figure B-21 2023 tidal flow verification – Location B – Stingray Creek Bridge

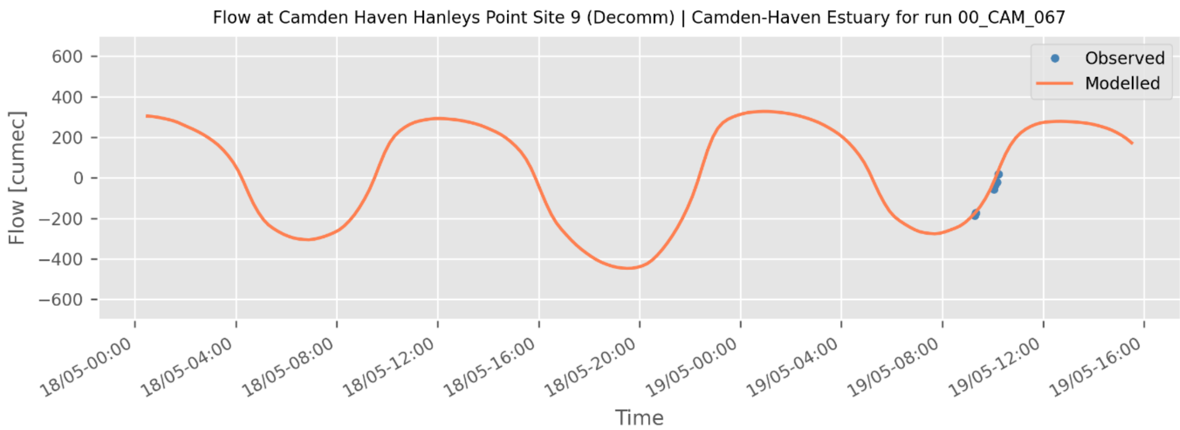

Figure B-22 2023 tidal flow verification – Location C – Hanleys Point Bridge/Laurieton

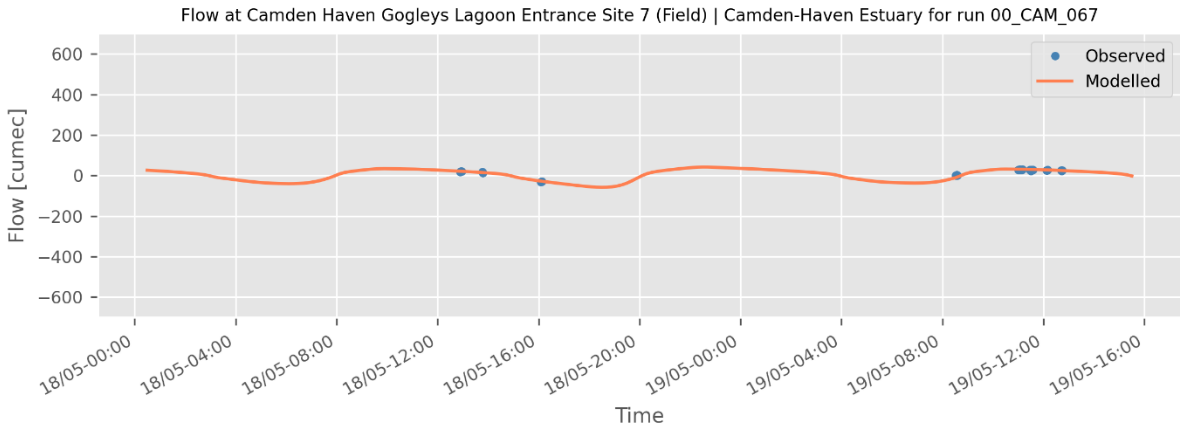

Figure B-23 2023 tidal flow verification – Location H – Gogleys Lagoon West Entrance

B1.4 Water level verification – 2023

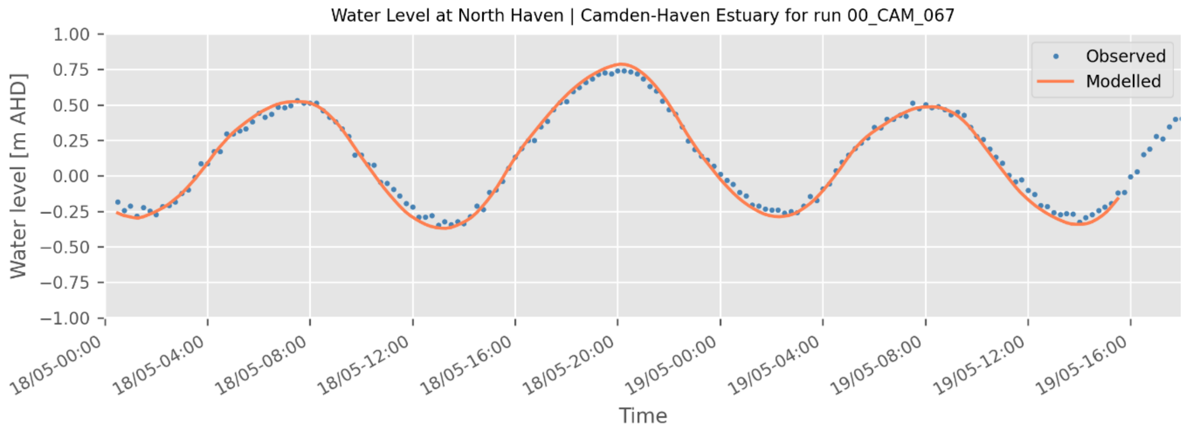

Figure B-24 2023 water level verification – Location 1 – North Haven

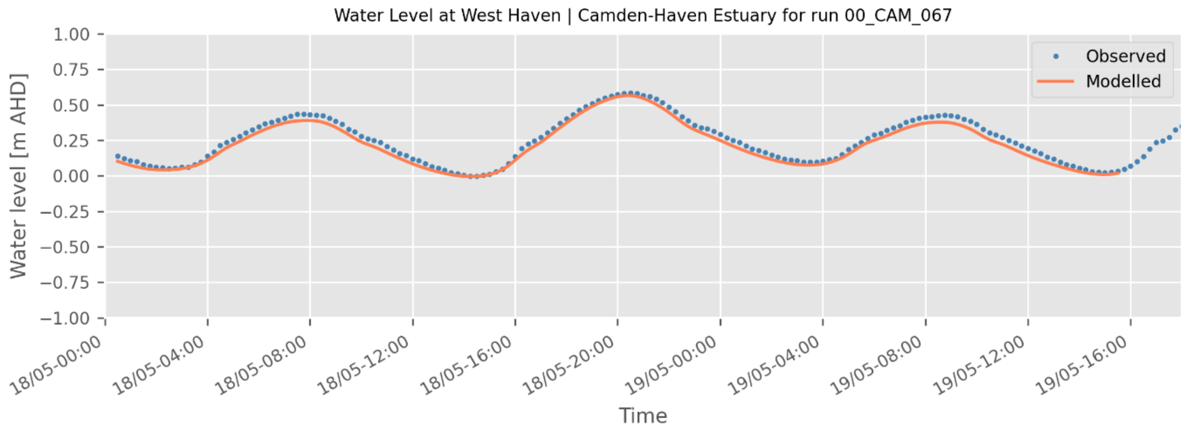

Figure B-25 2023 water level verification – Location 3 – Stingray Creek/West Haven

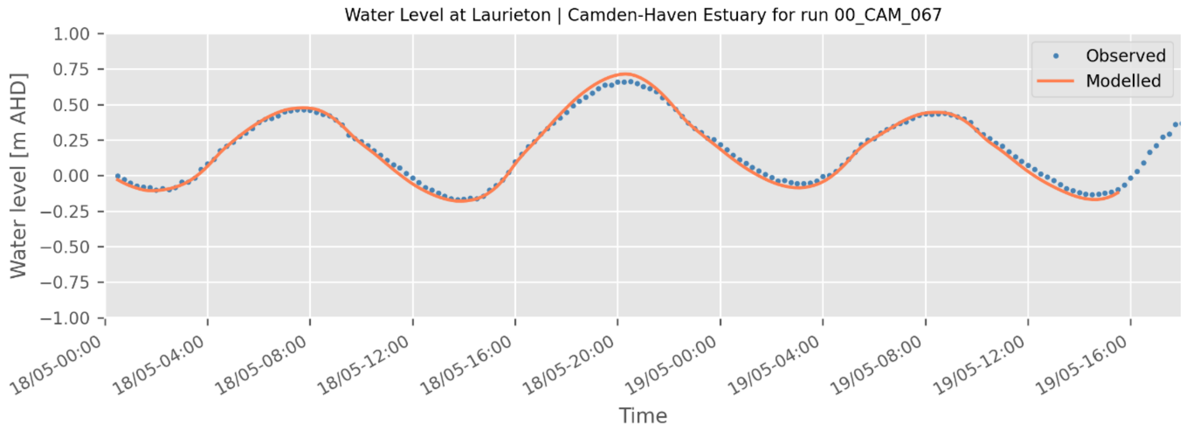

Figure B-26 2023 water level verification – Location 5 – Hanleys Point/Laurieton

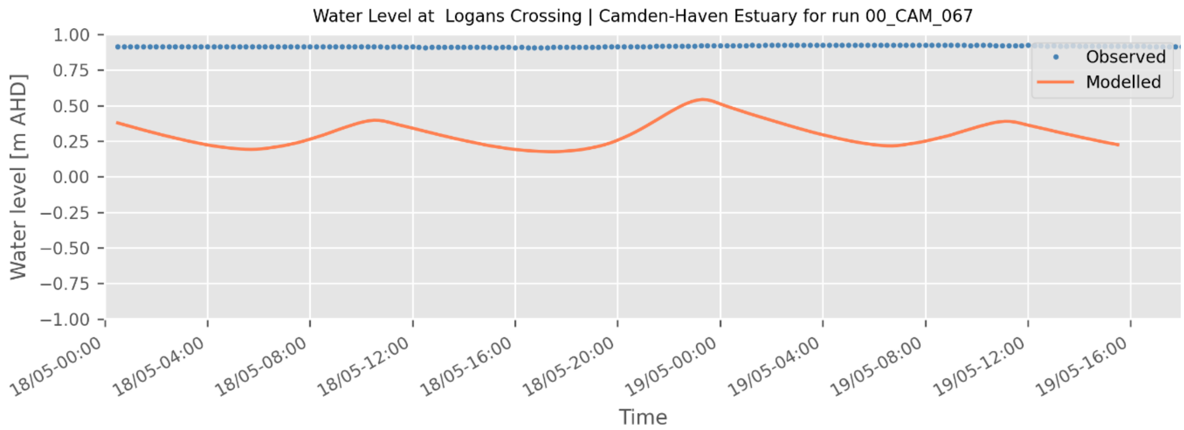

Figure B-27 2023 water level verification – Location 10 – Logans Crossing

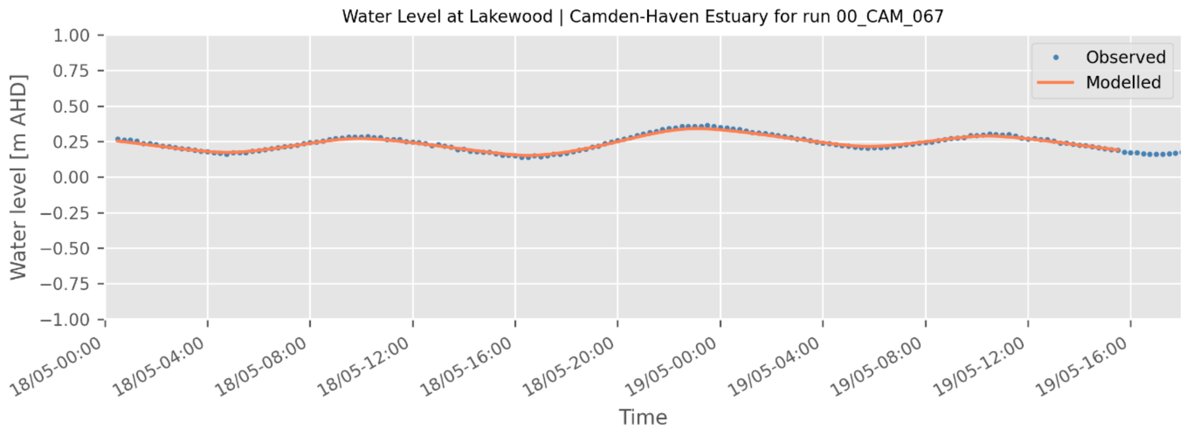

Figure B-28 2023 water level verification – Location 12 – Queens Lake/Lakewood

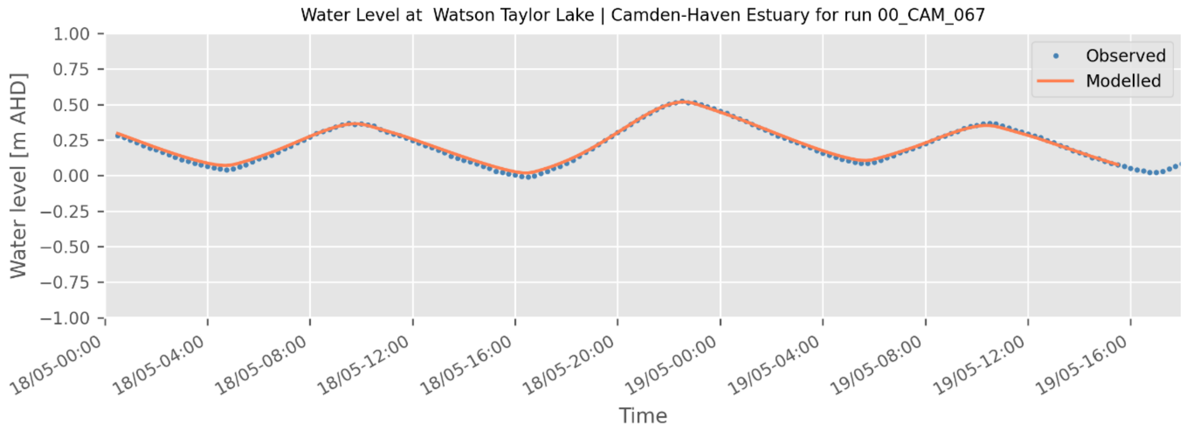

Figure B-29 2023 water level verification – Location 13 – Watson Taylors Lake

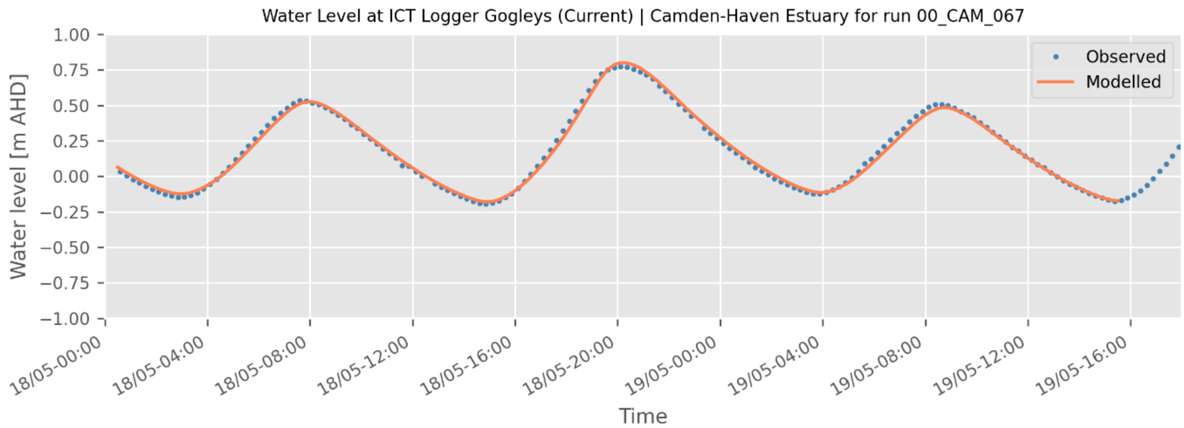

Figure B-30 2023 water level verification – Location 14 – Gogleys Lagoon

B1.5 Gogleys Lagoon inflow verification – 2023/1976

Table B-1 Gogleys Lagoon flow verification

	1976 MHL measurements	2023 model results	Difference
North Haven low water level (m AHD)	-0.48	-0.44	0.04
North Haven high water level (m AHD)	0.63	0.68	0.05
North Haven low water level (m AHD)	-0.3	-0.3	0
North Haven flood water level range (m)	1.11	1.12	0.01
North Haven ebb water level range (m)	0.93	0.98	0.05
Flood peak flow western entrance (m^3/s)	52	53	1
Ebb peak flow western entrance (m^3/s)	39	39	0
Flood peak flow eastern entrance (m^3/s)	11	15.5	4.5
Ebb peak flow eastern entrance (m^3/s)	6	10	4