



# **NSW OCEAN AND RIVER ENTRANCE TIDAL LEVELS ANNUAL SUMMARY 2018–2019**

Report MHL2693  
November 2019

Prepared for:

NSW Department of Planning, Industry and Environment  
Climate Change and Sustainability Division

Cover photograph: Shoal Bay ocean tide gauge,  
Shoal Bay, Port Stephens, 14 December 2018  
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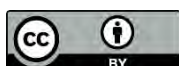
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## Document control

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# Foreword

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Manly Hydraulics Laboratory (MHL) is a business unit within the Water Group of NSW Department of Planning, Industry and Environment (DPIE)<sup>1</sup> which operates and maintains a number of ocean and river entrance tidal recording stations along the NSW coast under a service level agreement with the Climate Change and Sustainability Division<sup>2</sup> of NSW Department of Planning, Industry and Environment.

The NSW ocean tide database has been developed by MHL to support a number of Climate Change and Sustainability Division programs associated with coastal, floodplain and estuary management. These include the operations of ports and marine facilities, water level forecasts, fisheries management, determining property boundaries and developing a detailed understanding of oceanic processes. The monitoring service is available to local government and other organisations, both in Australia and overseas.

This summary has been prepared as a guide to enable ready access to the ocean tide database and the data analysis capabilities of MHL.

The standards adopted for the program are those specified by the National Permanent Committee on Tides and Mean Sea Level hosted by the Australian Hydrographic Office.

Requests for further information should be directed to:

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Other annual summaries in this series are:

- NSW Estuary and River Water Levels Annual Summary 2018–2019  
Manly Hydraulics Laboratory  
Report No. MHL2692  
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- NSW Coastal Rainfall Annual Summary 2018–2019  
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<sup>1</sup> From 1 July 2019, Manly Hydraulics Laboratory is part of the newly formed Department of Planning, Industry and Environment.

<sup>2</sup> Formerly NSW Office of Environment and Heritage (OEH).

Electronic copies of the reports in this series can be downloaded at:  
<http://www.mhl.nsw.gov.au> under the 'Publications' menu.

# Summary

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This annual summary presents ocean and river entrance tidal data captured by the automatic tide level recording stations along the coastline of NSW over the period 1 July 2018 to 30 June 2019, and catalogues all ocean and river entrance tidal data collected in NSW by MHL for the Climate Change and Sustainability Division.

The 2018–2019 data recovery rate for the 15-minute ocean tide data achieved 98.1%, which is higher than the KPI target of 95%.

This report contains:

- a brief description of the ocean and river entrance tidal measurement program
- guidelines on how to use this report
- information on how to access the database
- a description of significant events which occurred in 2018–2019
- [Appendix A](#), the annual data summaries for each site (see [Figure 1.1](#) for site locations)
- [Appendix B](#), detailing the tidal data available on line
- [Appendix C](#), detailing the historical tidal data available
- [Appendix D](#), which shows data output formats available from MHL
- [Appendix E](#), a glossary of terms
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# 1. Tidal network measurement program

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This report presents the thirty-third year of data collected by automatic ocean tide level recorders for the State of NSW. MHL provides tide data through a network of recorders and an efficient service of associated analysis routines.

The present program is based on a network of automatic ocean tide level recording stations installed at eighteen coastal and four offshore sites, and one open ocean site located on Lord Howe Island. Additional data for Norfolk Island is provided by the Bureau of Meteorology's National Tidal Unit (NTU) ([Figure 1.1](#)). The ocean tide monitoring network features distinctive systems for data capture: radar, vented pressure sensor and submersed water level pressure recorder. Previous instrumentation used to collect historical water level data for the ocean tide program included electromagnetic tide poles and solid state floatwells.

The current ocean tide monitoring systems function as follows:

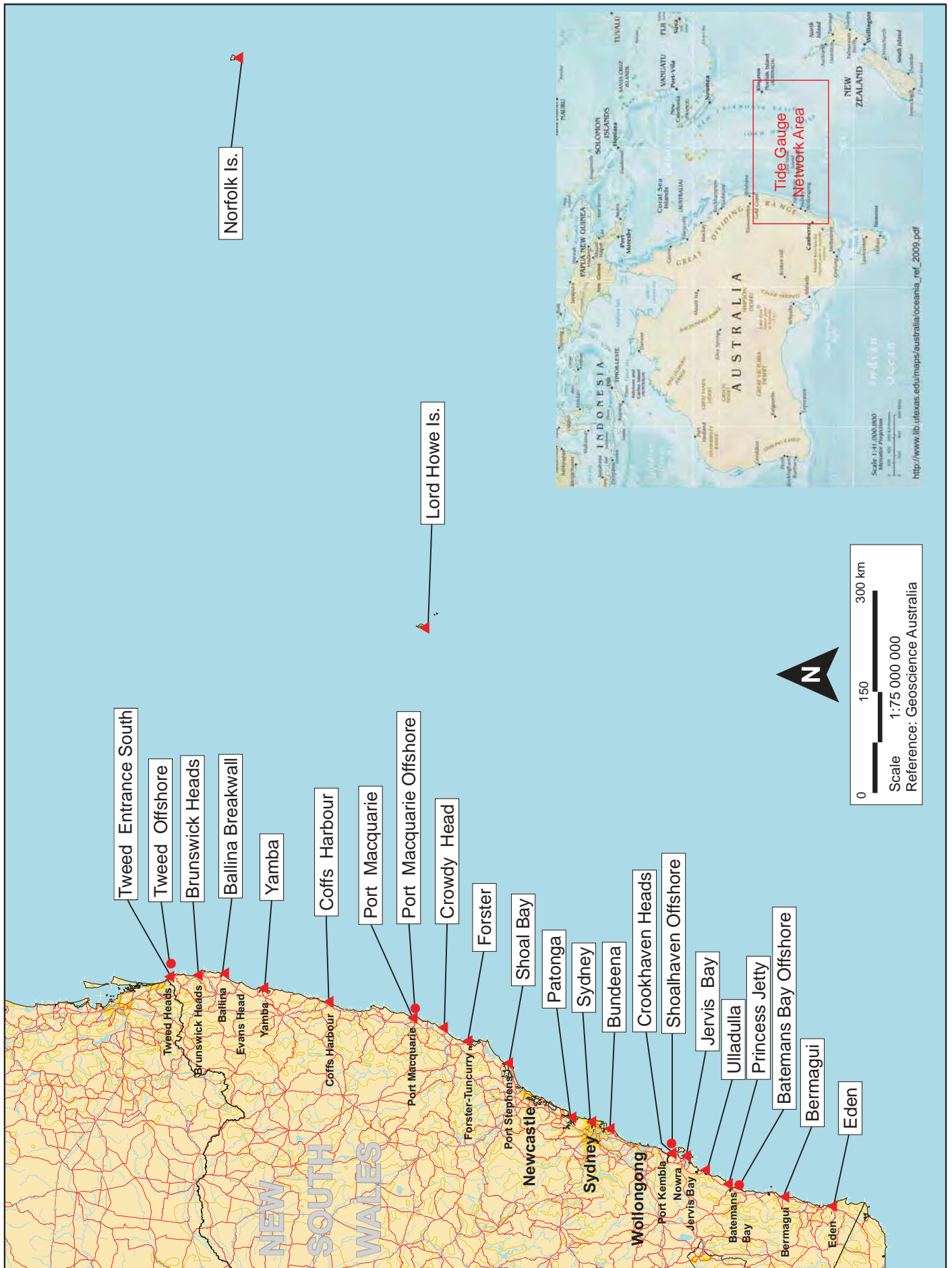
- Radar sensors: the water level is detected by radio detection and ranging technology. The data recorded is then transferred via an Internet Protocol (IP) link through a modem between the data logger and the data server. As the data is a direct measurement of the water surface, it requires no correction for barometric pressure. The system is shown in [Figure 1.2](#).
- Vented pressure sensors: the water level is determined by a vented pressure sensor and recorded on a data logger. The sensor is vented to atmospheric pressure and therefore requires no correction for barometric pressure changes. The data recorded is then transferred via an IP link through a modem between the data logger and the data server. The system is shown in [Figure 1.3](#).
- Submersed water level recorder: the water level is determined by an absolute pressure sensor sealed in a waterproof housing and mounted on the ocean bed. The data requires post-recording correction for water density and barometric pressure changes. The data is downloaded manually from the recorder to MHL's data server after recovery from the ocean bed by divers. The system is shown in [Figure 1.4](#).

Tidal data is transferred to the NSW Government Data Centre and to MHL's data server using the now upgraded internet protocol (IP) network and landline telephone (Lord Howe Island). The 15-minute tide data is available on line in tables or as plots. One-minute and some one-second data is also available on request (see [Table 4.2](#) and Appendix D, [Figure D1](#)). All data presented in this report are in Australian Eastern Standard Time (EST). Allowance for daylight saving time needs to be made by the user of the data if required.

The data is stored in a database and subject to a quality assurance process which involves several control steps to ensure data quality is maintained, as well as assignment of data quality codes. Computer programs are used to further format and analyse data. The database is backed up daily and data archived to offline storage at regular intervals.

The station locations and data summaries for 2018–2019 are presented in [Appendix A](#).

Details of current sites available in a digital format are catalogued in [Appendix B](#). [Appendix C](#) contains a list of historical data available in various formats and locations.



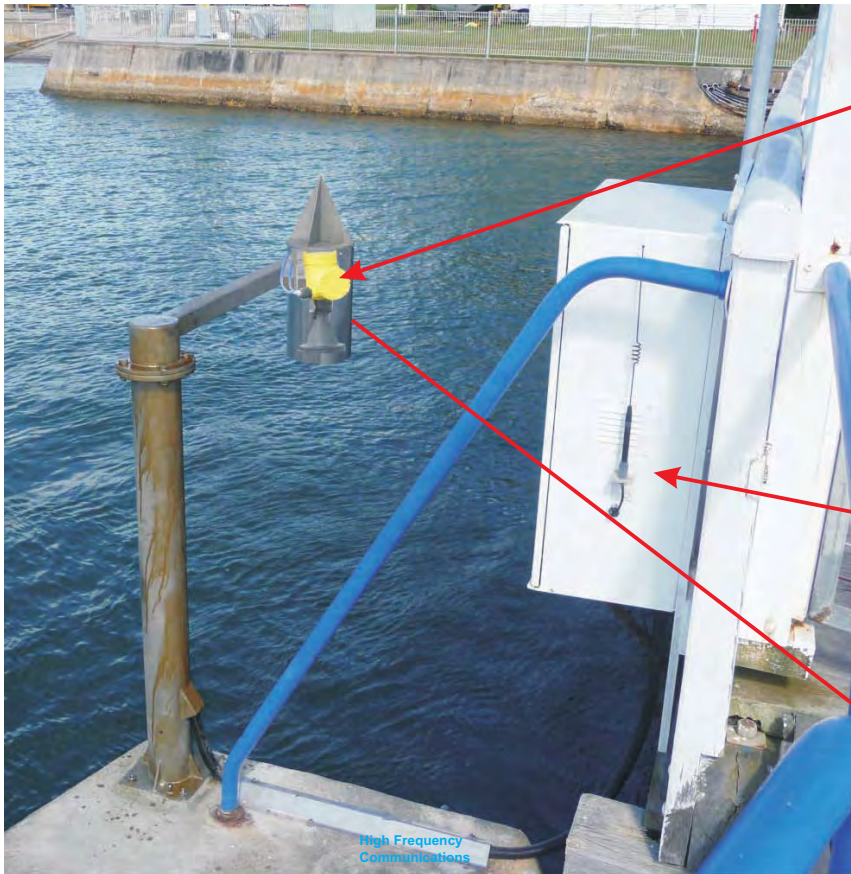
# OCEAN TIDE GAUGE NETWORK

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Figure  
1.1

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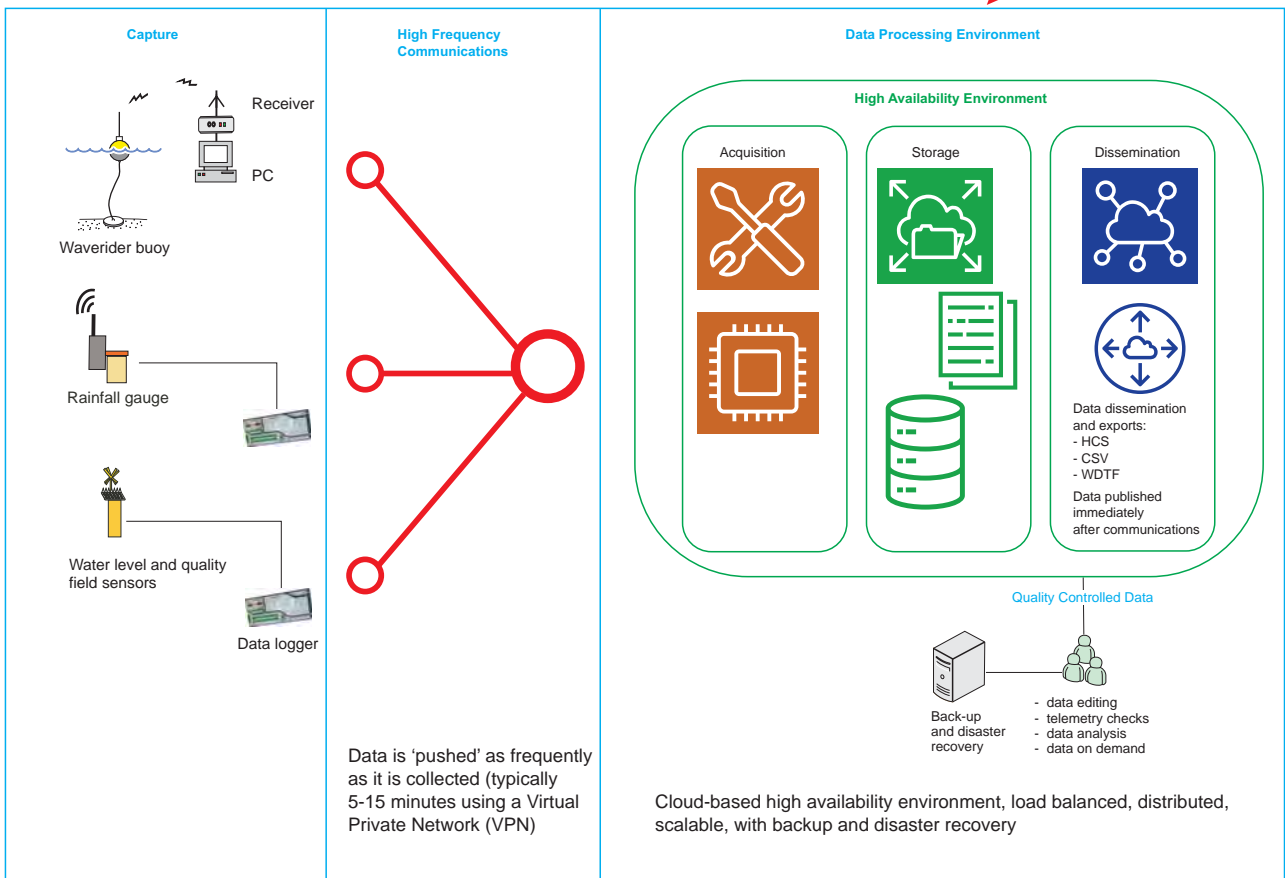


Radar inside protective housing

Enclosure containing modem, battery and data logger

DATA TRANSFER via IP (or landline)

High Frequency Communications



## RADAR SENSOR

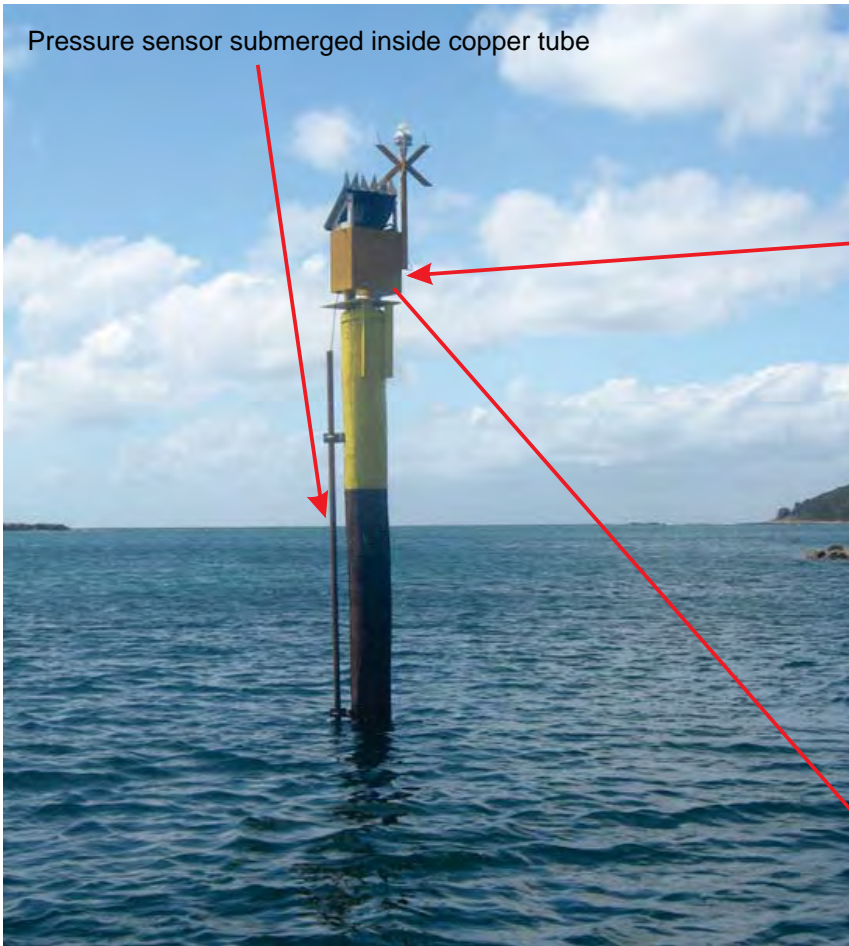
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Figure  
1.2

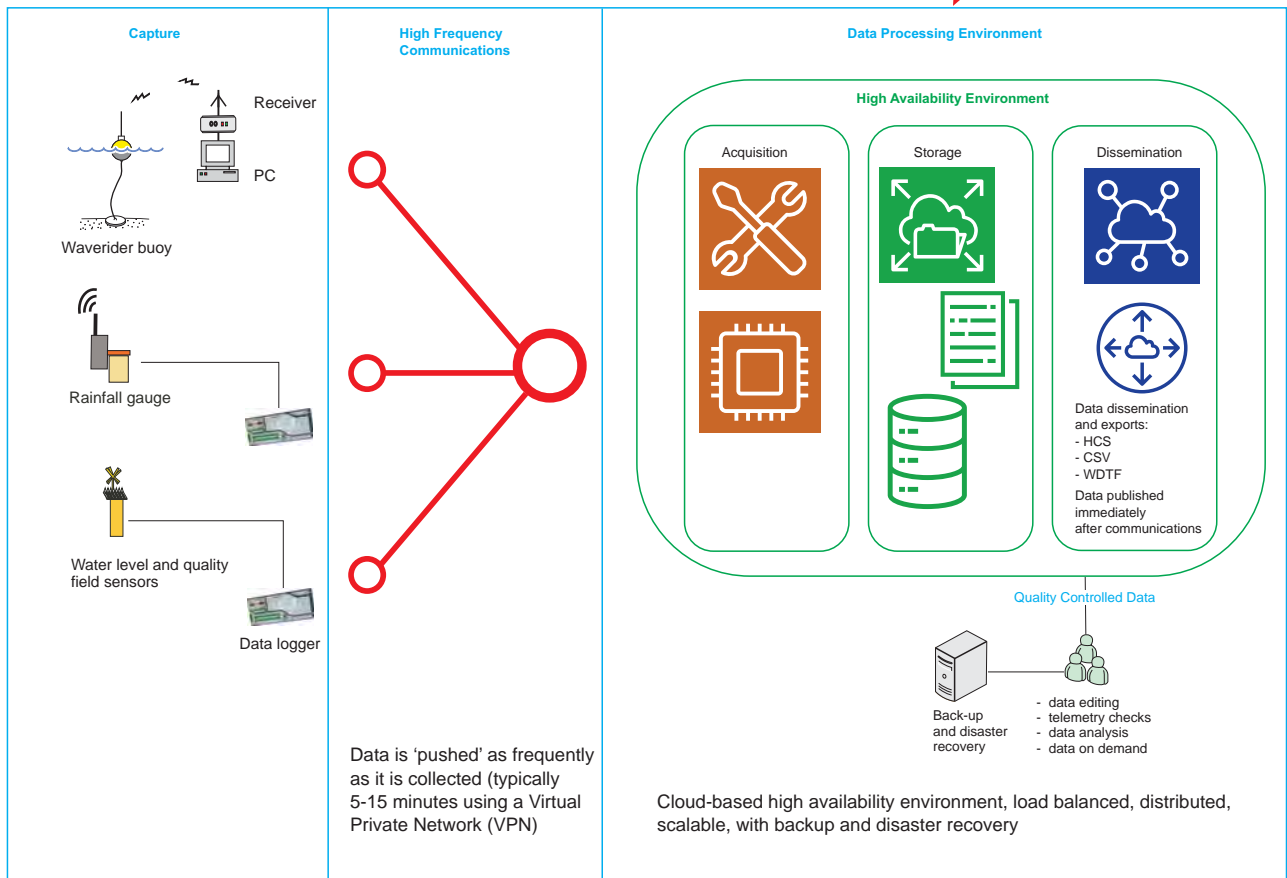
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Pressure sensor submerged inside copper tube



Enclosure containing modem, battery and data logger

DATA TRANSFER via IP modem



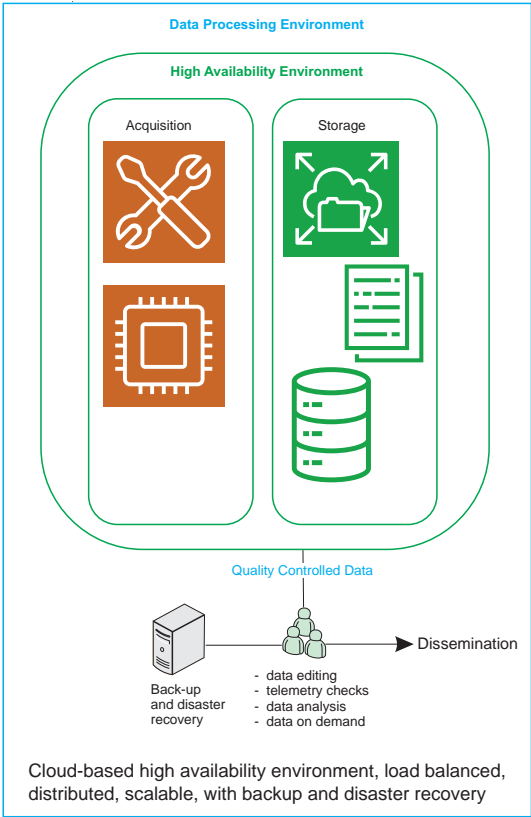
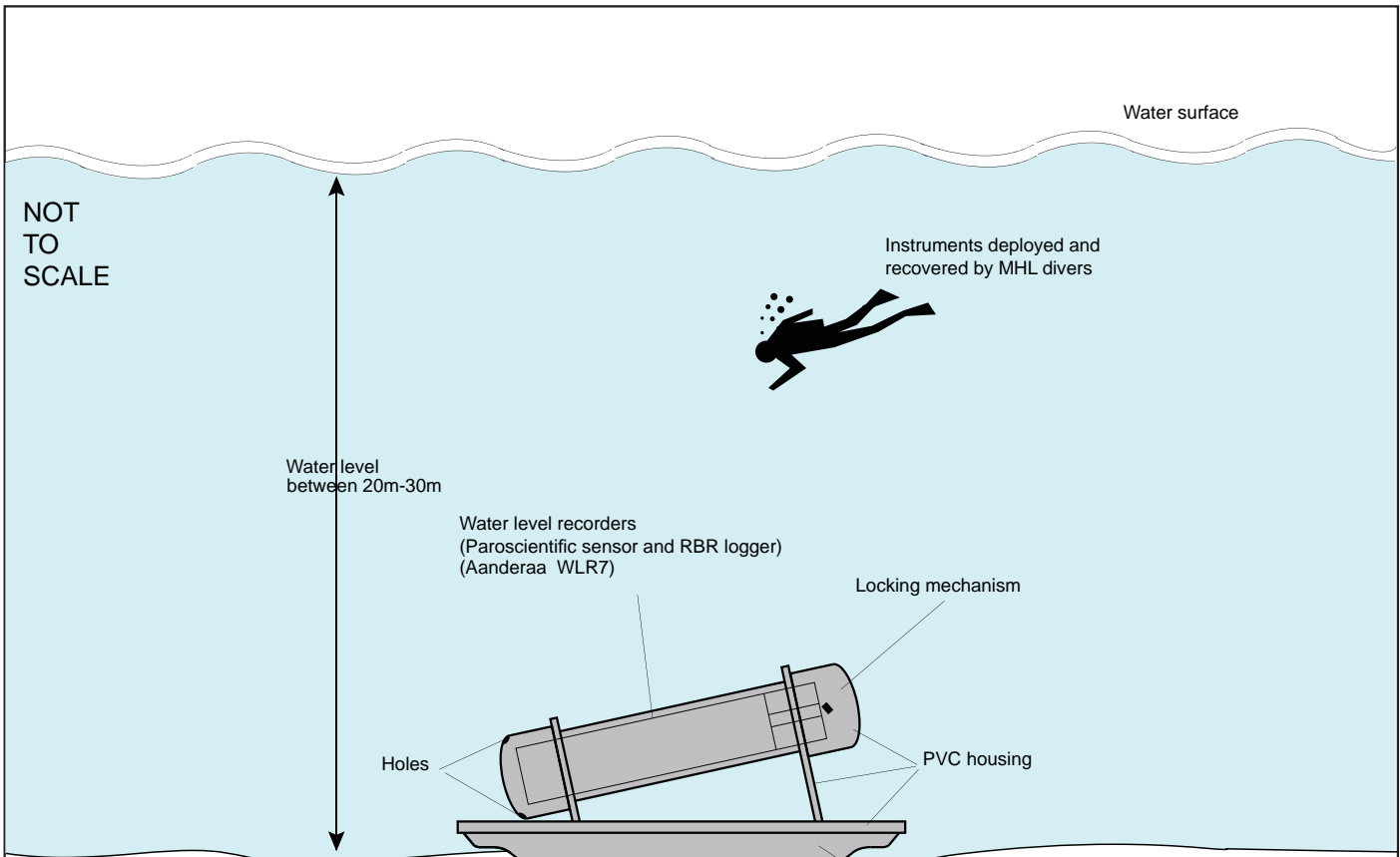
VENTED PRESSURE SENSOR

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Figure 1.3

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SUBMERSED WATER LEVEL RECORDER

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Figure  
1.4

## 2. How to use this report

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### 2.1 Using and accessing the data

This annual summary presents ocean and river entrance tidal data captured by the automatic tide level recording stations along the coastline of NSW over the period 1 July 2018 to 30 June 2019. The stations are located offshore, in bays, harbours and the entrances of major rivers.

To establish if data is available, first identify the relevant station on the ocean tide gauge network map (Figure 1.1), then refer to the relevant figure for that station. A location map of each station and a plot of the data from that station are provided in Appendix A. The plot confirms the availability of data for the fiscal year 2018–2019. For the availability of historical data which has been collected, refer to Appendices B and C.

Once a selection of data has been made the analysis and/or presentation can be obtained in a variety of formats. Appendix D shows samples of the following options – graphical plots (Figure D1), time series data (Figure D2), tidal analyses (Figure D3), tidal level ranking (Figure D4) and tidal predictions (Figure D5).

MHL provides a full on-line data access service via the Internet for its clients, and a restricted service for the general public at <http://www.mhl.nsw.gov.au>

Typically, the last seven days of data are available on line in a non-quality controlled form to aid quick access to raw data records. The on-line service for clients can provide access to all data catalogued in Appendices B and C, including tidal predictions. This data consists of tide levels and can be reviewed in graphical or numerical format shown in Appendix D.

Quality controlled data may be ordered via the MHL web page (<http://www.mhl.nsw.gov.au>), by emailing [data-request@mhl.nsw.gov.au](mailto:data-request@mhl.nsw.gov.au), or via customised decision support tools that can be provided on request.

### 2.2 Station location terminology

Tidal station locations can be referred to in several ways. As described in Appendix B, each station has a regional context (NSW coastal region), a catchment or port context (river catchment or port), a site context (specific locality, river port, harbour) and a specific location context (absolute location, e.g. on a specific jetty, bank of one side of the river, on a breakwater). Each context description of the location may be useful at different times, depending on what aspect of the data is being discussed. The specific latitude and longitude details of stations are distributed as part of the metadata on request. In this report, the station name, as shown in Table B1, has been used throughout the report to avoid any naming convention confusion. The only exception is where references to other work are made, in which case the naming convention of the original author(s) is retained.

## 2.3 Datums

Most ocean tide water levels are recorded in the local port datum which generally equates to Indian Spring Low Water (ISLW). An indicative adjustment of each station from Australian Height Datum (AHD) to local port datum is shown in [Table 2.1](#). Low water datums were calculated circa 1990 for MHL by NSW Public Works Survey, using range ratio method and tidal harmonic analysis over varying time periods. Converting these values to AHD should be used with caution, as AHD levels are revised from time to time and improvements to surveying techniques may provide additional refinement.

Offshore sites are not related to a datum, but are adjusted by harmonic analysis to the Mean Sea Level (MSL) of each instrument deployment. They provide valuable astronomical constituent and anomaly information. There is no AHD survey information available for Norfolk Island and Lord Howe Island. The survey information for these two stations relates to the local datum.

**Table 2.1 Summary of adjustment from AHD to local port datum**

Station	Station datum (SD)	Adjustment (SD = AHD + Adjustment)
Tweed Entrance South	Tweed River Hydro Datum	0.893
Tweed Offshore	Mean Sea Level	N/A
Brunswick Heads	Brunswick River Flood Mitigation Datum	0.024
Ballina Breakwall	Richmond River Valley Datum	0.860
Yamba	Iluka Port Datum	0.895
Coffs Harbour	Coffs Port Datum	0.882
Port Macquarie	Australian Height Datum	0.000
Port Macquarie Offshore	Mean Sea Level	N/A
Crowdy Head	Crowdy Head Datum	0.911
Forster	Forster Hydro Datum	1.061
Shoal Bay	Port Stephens Hydro Datum	0.944
Patonga	Australian Height Datum	0.000
Sydney	Zero Fort Denison	0.925
Fort Denison (Sydney Ports)	Zero Fort Denison	0.925
Bundeena	Zero Fort Denison	0.925
Crookhaven Heads	Australian Height Datum	0.000
Shoalhaven Offshore	Mean Sea Level	N/A
Jervis Bay	Chart Datum	1.070
Ulladulla	Australian Height Datum	0.000
Princess Jetty	Australian Height Datum	0.000
Batemans Bay Offshore	Mean Sea Level	N/A
Bermagui	Bermagui Local Hydro Datum	0.714
Eden	Twofold Bay Hydro Datum	0.924
Lord Howe Island	Lord Howe Island Hydro Datum	Not available
Norfolk Island	Lowest Astronomical Tide	Not available

Data for Norfolk Island since 2015 provided by Bureau of Meteorology's National Tidal Unit (NTU).

## 2.4 Tidal planes and tidal forecasts

MHL uses the Foreman (1977) method to calculate the significant tidal constituents and tidal planes from data recorded at the ocean tide sites. From these tidal planes, MHL investigated the tidal ranges at NSW ocean tide sites (MHL 2005) and concluded that there is a general trend of increasing tidal range from south to north, however, there may be local variations to this trend. Nearshore sites located in river entrances displayed total ranges lower than the closest offshore sites, suggesting that the river entrances attenuate the tide as it progresses into the estuaries. [Figure 2.1](#) shows this variation in graphical form by grouping the yearly mean ranges in geographical regions.

In 2012, a further comprehensive analysis of tidal planes was completed for 188 MHL water level stations including the ocean tide stations (MHL 2012).

It is important to recognise tidal plane and constituent variations when applying data from the ocean tide sites. Variations between sites may significantly influence investigation outcomes. For example, the difference between the sites when used as the boundary conditions for numerical hydrodynamic models may significantly influence the model results. Such variations between sites reinforce the importance of the data being used in a manner which is fit for the purpose it is intended.

A long-term forecast was produced in 2015 for each ocean tide site for the full data range of historical data and predicted to 2020. The methodology determined the average of the yearly constituent values then converted them to a single average phase and amplitude value (including  $Z_0$  or MSL). From these values a new constituent file was used to predict tidal forecasts up to 2020 (using Foreman analysis). From these forecasts the Highest Astronomical Tide and Lowest Astronomical Tide were determined for the epoch of most recent data (1995 to 2014). The values of highest astronomical tide (HAT), lowest astronomical tide (LAT) and mean sea level (MSL) were calculated to local low water datums as well as to AHD and are shown in [Table 2.2](#).

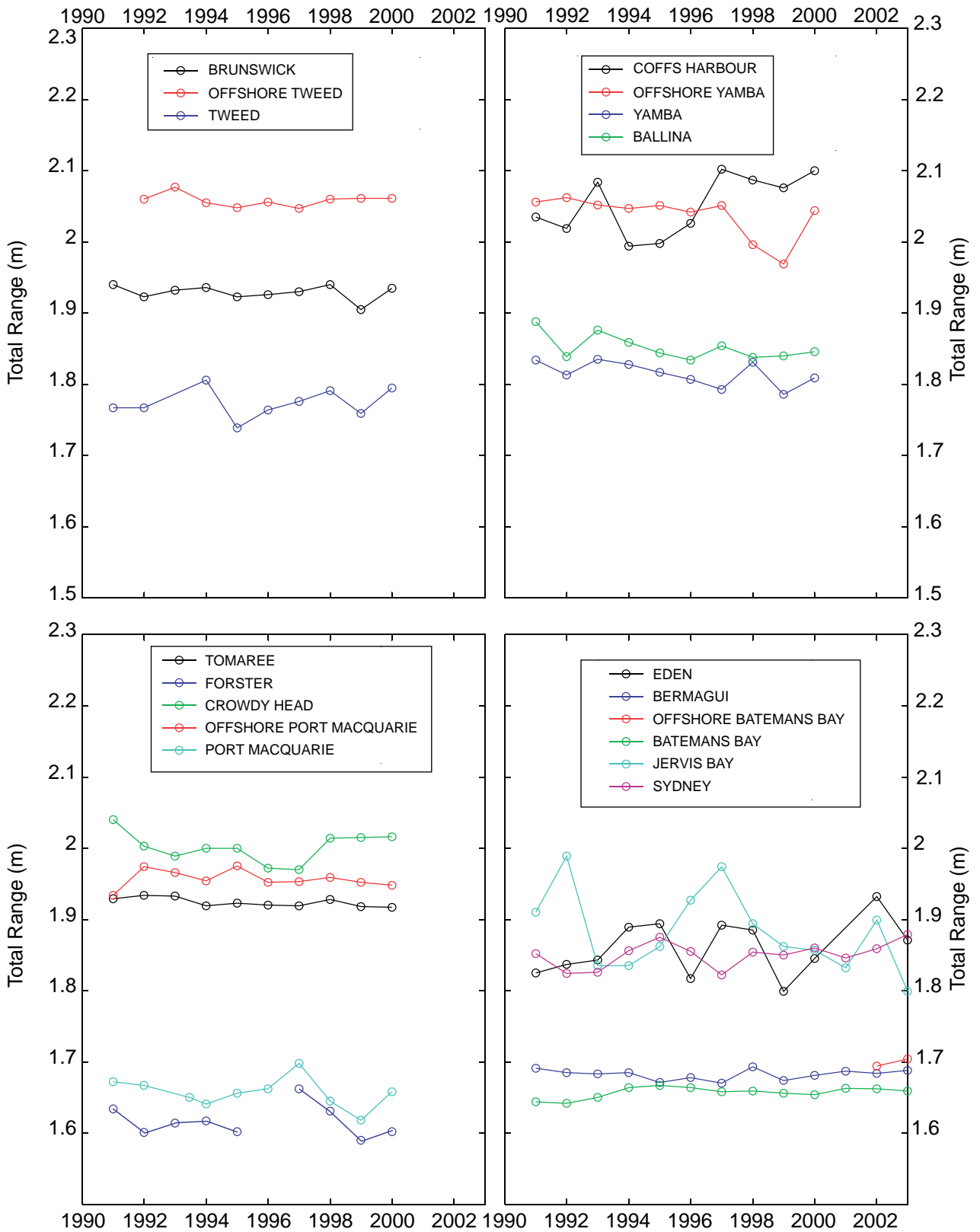
**Table 2.2 Ocean and river entrance tide HAT and LAT values**

Site	Period 1995–2014				Range (HAT-LAT)	Period 1995–2014	
	HAT <sup>^</sup>	LAT <sup>^</sup>	HAT (AHD)*	LAT (AHD)*		MSL	MSL (AHD)*
Tweed Heads	1.99	0.02	1.10	-0.87	1.97	0.93	0.04
Brunswick Heads	1.22	-0.85	1.17	-0.90	2.07	0.07	0.02
Ballina Breakwall	2.02	0.04	1.16	-0.82	1.98	0.89	0.03
Yamba	2.01	0.07	1.12	-0.83	1.94	0.95	0.05
Coffs Harbour	2.12	-0.11	1.24	-0.99	2.23	0.9	0.02
Port Macquarie	1.04	-0.74	1.04	-0.74	1.78	0.02	0.02
Crowdy Head	2.1	-0.09	1.19	-1.00	2.19	0.88	-0.03
Forster	1.93	0.17	0.87	-0.89	1.76	1.03	-0.03
Tomaree (Port Stephens)	2.08	-0.03	1.14	-0.97	2.11	0.92	-0.02
Patonga	1.16	-0.88	1.16	-0.88	2.04	0.06	0.06
Sydney	2.07	0.03	1.15	-0.90	2.04	0.96	0.03
Port Hacking	2.11	0.09	1.19	-0.84	2.02	1.00	0.08
Crookhaven Heads	1.01	-0.08	1.01	-0.08	1.09	0.03	0.03
Jervis Bay	2.19	0.10	1.12	-0.97	2.09	1.09	0.02
Ulladulla	1.20	-0.90	1.20	-0.90	2.10	0.05	0.05
Princess Jetty	1.06	-0.79	1.06	-0.79	1.85	0.06	0.06
Bermagui	1.72	-0.18	1.01	-0.89	1.90	0.69	-0.02
Eden	1.92	-0.11	1.00	-1.03	2.03	0.84	-0.08
Lord Howe Island	2.35	-0.06	n/a	n/a	2.41	1.10	n/a
Norfolk Island	1.97	0.03	n/a	n/a	1.94	0.97	n/a

\* Conversion from AHD to local port datum given in [Table 2.1](#)

<sup>^</sup> Local port datum

Data for Norfolk Island since 2015 provided by Bureau of Meteorology's National Tidal Unit (NTU).



Notes: Each offshore gauge has been grouped with the closest nearshore gauges for comparison  
 Total range defined by: tidal plane formula =  $HHWSS - ISLW$   
 or by: tidal constituent formula =  $2(M_2 + S_2 + 1.2K_1 + 1.2O_1)$   
 Forster 1996 tidal range value is not calculated due to a high proportion of poor data during that financial year.

Source: MHL 2005



TIDAL RANGE FOR GROUPED OFFSHORE AND NEARSHORE GAUGES 1990–2003

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Figure  
2.1

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### 3. Significant events 2018–2019

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The data recovery statistics are shown in [Table 3.1](#).

**Table 3.1 Data recovery July 2018 to June 2019**

Data stream	Data recovery (%)	Comments
15-minute ocean tide data	98.1	Ballina Breakwall – new conduit installed had issues of siltation build up causing delayed flushing and introducing a harmonic in the residual. Level 2 data was copied in cases but could not be imported to the 1-minute time series.
1-minute ocean tide data	97.4	
5-minute and 60-minute offshore data	99.8	Data collected for all four offshore sites with only small sections missing from Port Macquarie and Shoalhaven. Shoalhaven 60-minute data from the secondary logger had to be imported as there was a sensor failure on the primary system, increasing the value add of multiple loggers at each offshore site.

The 2020 NSW Tide Prediction Charts are available free of charge via download from the MHL public web page. The charts remain an authoritative reference for tides of the NSW coast ([Figure 3.1](#)). As for previous tide prediction publications, MHL has adopted the Sydney tide gauge as the primary reference station, and the ocean tide predictions for NSW are based on an analysis of 15–minute tide levels recorded by this primary gauge. The time difference between the primary and secondary locations in NSW was obtained when an analysis of the tide levels recorded at gauges at each of the secondary locations was conducted.

#### 3.1 Tidal anomalies

The main drivers of anomalies are barometric pressure, wind setup, coastally trapped waves, and the influence of the East Australian Current (EAC). For onshore river entrance gauges, hydrological anomalies such as floods can also occur. Storms are usually associated with large barometric pressure changes and wind setup. The types of large scale storms affecting NSW include East Coast Lows (ECL) and the effects of tropical cyclones off the Queensland coast. Furthermore, tsunamis can cause waves that show up on the onshore open ocean and onshore bay or port gauges as tidal anomalies.

The NSW Extreme Ocean Water Levels report (MHL 2018) investigated anomalies recorded on the NSW coast and considered their occurrence and forcing mechanisms.

Tidal anomalies in this report are calculated as the difference between the recorded data and the long-term epoch forecasts as discussed in [Section 2.4](#).

The anomalies recorded across the NSW coast during the reporting period are compared for a selected group of stations in Figure 3.2. The major anomalies, which are classified as greater than  $\pm 0.2$  m difference between recorded and forecast data, are identified on Figure 3.2 and documented in more detail in Figures 3.3 and 3.4. Most are driven by ECLs or large high pressure systems. Figures 3.5–3.8 show the tidal anomalies recorded at each station during the reporting period. Figure 3.9 shows the anomalies for the four offshore tide stations.

The Bureau of Meteorology (BoM) recorded two cyclones in North Queensland during the 2018–2019 reporting period:

- 29 November to 17 December 2018, Severe Tropical Cyclone Owen – Category 3 – formed over the Solomon Islands and initially only crossed over northern Queensland as a Category 1 before reorganising and strengthening in the Gulf of Carpentaria to a Category 3 with 150 km/h winds. Large rainfall totals and one death were attributed to the cyclone. This event was not observable on the NSW tide recordings.
- 07 to 22 February 2019, Tropical Cyclone Oma – Category 2 – developed as a monsoon trough off the coast of Queensland before moving into the South Pacific basin and strengthening into a Category 2 tropical cyclone. Though TC Oma never crossed over land sustained large swells impacted the coast of Queensland and northern NSW causing erosion damage, and one drowning death occurred. The resulting tidal anomalies from this event were measured on NSW gauges from Tweed Entrance South to Coffs Harbour.

## 3.2 Tsunami events

Table 3.2 lists the tsunami events in the Pacific Region for the period of time corresponding to the 2018–2019 data in this report.

**Table 3.2 Recorded earthquake events July 2018 to June 2019**

Date	Earthquake magnitude (M <sub>w</sub> )	Location	Observable on NSW tide recordings
05/08/2018	6.9	Indonesia – Bali Sea	No
19/08/2018	8.2	Fiji	No
29/08/2018	7.1	New Caledonia	No
28/09/2018	7.5	Indonesia – Sulawesi	No
05/12/2018	7.5	New Caledonia	No
14/05/2019	7.5	Papua New Guinea	No
15/06/2019	7.2	New Zealand – Kermadec Islands	No

Source: NOAA National Geophysical Data Centre Tsunami Database <http://www.ngdc.noaa.gov/hazard/tsu.shtml>

The Bureau of Meteorology and Geoscience Australia host the Joint Australian Tsunami Warning Centre (JATWC). No tsunami warnings were issued by JATWC from July 2018 to June 2019. The Bureau of Meteorology collects specific tsunami data for issuing warnings, and the data can be requested from BoM for further use.

### 3.3 King tide events

King tides occurred on 14 July 2018 and 22 January 2019. The July king tide produced a water level in Sydney of 1.21 m AHD, whilst the January king tide reached 1.08 m AHD. The highest tide of the year occurred on 4 June 2019 at 1.23 m AHD after a spring high was aided by a large south coast low pressure system highlighted in [Figure 3.4](#) which raised water level residuals along the entire NSW coast.

Ex-Tropical Cyclone Oma occurred during a spring high cycle affecting water levels. Oma stayed off the south-east Queensland coast generating larger long period swells from 21 to 25 February. The easterly direction and length of period had significant effects on the water levels in the northern rivers of NSW. In [Figure 3.10](#) an image of how this event alongside a spring tide pushed water levels up in the Brunswick and Richmond rivers with anomalies recorded over 0.5 m.

### 3.4 Meteotsunami event

The ocean tide and river entrance data are becoming increasingly valuable and, with increases in data accuracy, quality and frequency, closer inspection of the data is revealing more detailed information about features that were previously not clearly defined.

Meteotsunamis are a case in point, where the increased data quality has clarified these waves in the tidal trace, which may have previously been thought of as spikes in the data.

A basic introduction into meteotsunamis is given in MHL Report 2574 (MHL 2017).

The mid north coast barometric gauges show a step change in barometric pressure on 20 December 2018 ([Figure 3.11](#)), which is the initial energy indicator that can cause irregular water level oscillations. The plot beneath is the 15-minute residual data from the mid north coast ocean tide gauges. These all show large scale high frequency disturbance between the recorded and the predicted tide expected. The correlation and similar characteristics demonstrate it is not caused by instrument malfunction. [Figure 3.12](#) shows the sequenced synoptic charts between 19 December and 21 December 2018 (both before and during the meteotsunami) with multiple lows forming inland and intersecting a large high creating the pressure differential.

Datasets with shorter logging intervals provide greater resolution and detail of the event. Upgrades of the ocean tide program by MHL provided by Climate Change and Sustainability Division have seen data logging increase to 1-second logged data points on certain gauges. [Figure 3.13](#) is the meteotsunami event monitored at Shoal Bay on 20 December 2018 logged at the 15-minute, 1-minute and 1-second intervals. There is no averaging in the 1-second data set which allows capture of all the oscillations in the water level caused by the meteotsunami at this time step.

Effects of meteotsunamis are also felt in coastal rivers and lakes. The volume of gauges in the floodplain network across NSW can also pick up the resulting water level oscillations. The upper plot in [Figure 3.14](#) displays the Myall and Wallis Lakes estuary system for the period 12 to 27 December 2018. The effects of the meteotsunami on 20 December 2018 can be seen at the ocean entrance at Forster and 18 km upstream at Pacific Palms within Wallis Lake. The effects can also be seen at Bombah Point and Bulahdelah, which are in low tidal range areas approximately 27 km and 40 km upstream of the Port Stephens ocean entrance

respectively. The lower plot in [Figure 3.14](#) displays Lake Macquarie water levels for the period 20 to 21 December 2018, where 1-minute logging is enabled on water level gauges to detect events such as these. It is evident the barometric disturbance is oscillating throughout the lake, with gauges on the eastern and western sides being affected.

Some issues that result from these events can be inundation onto land; if the barometric event happens on a spring or king tide this can add a further tidal anomaly onto the water level. Meteotsunamis in closed ports or harbours can cause a resonance effect on the water level as the initial disturbance wave can rebound within the harbour and amplify the effect. [Figure 3.11](#) highlights this with the greatest residual spike coming within Crowdy Head boat harbour with the resonance heightened within the smaller sized harbour. This can lead to property or infrastructure damage within the harbour, however, there was none reported during the December 2018 event.



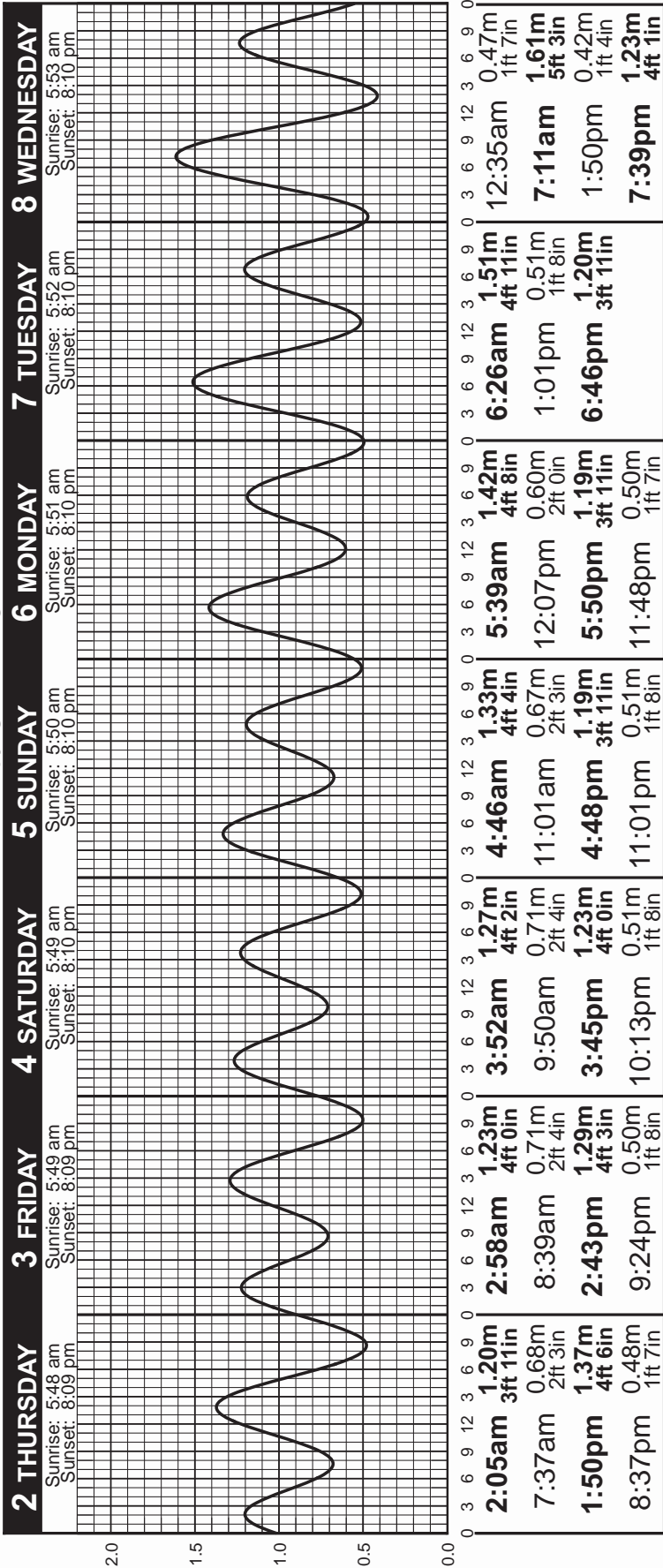
NSW TIDAL PREDICTIONS  
EXTRACT FROM 'NSW TIDE CHARTS 2020'

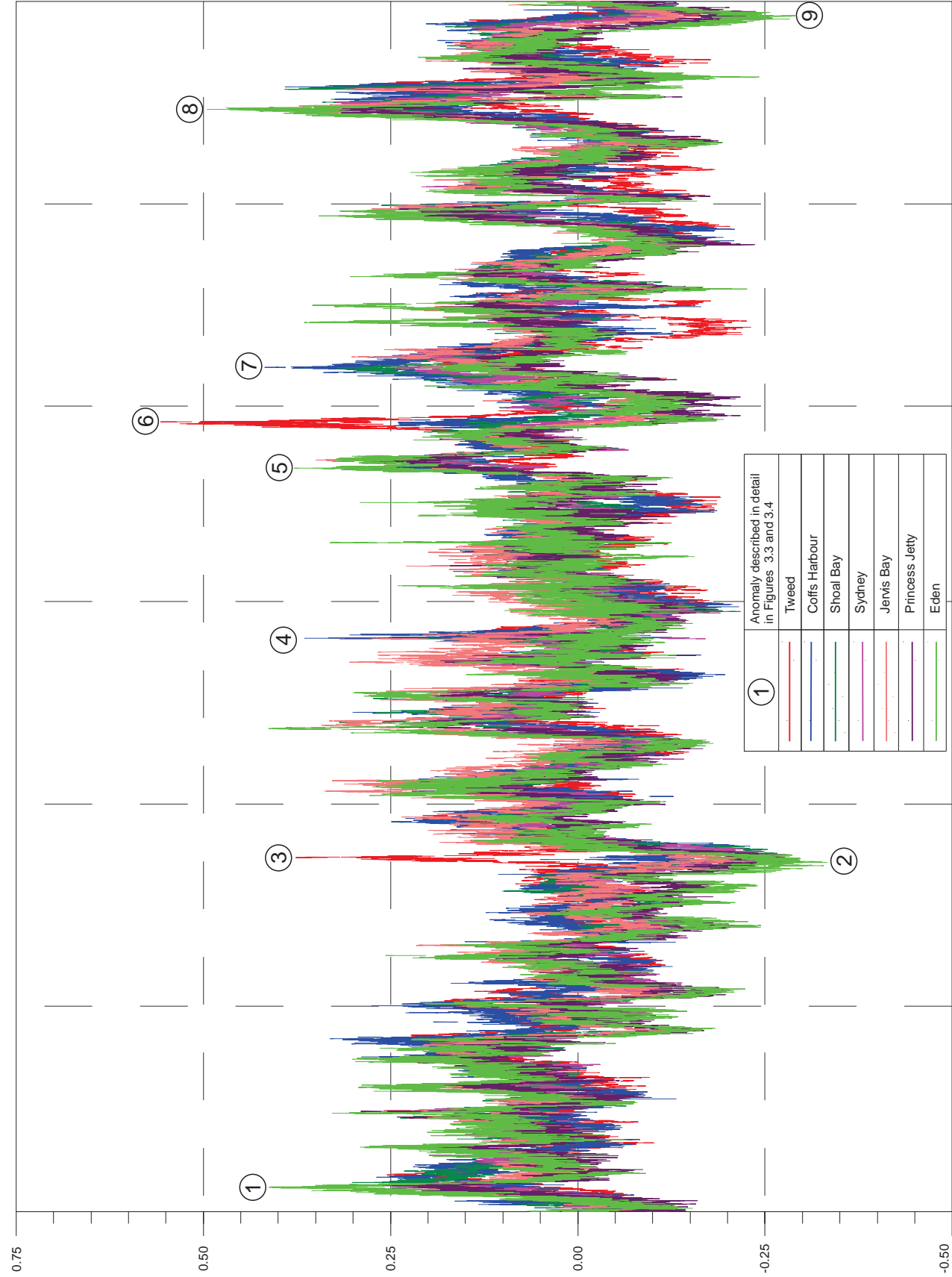
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Hydraulics  
Laboratory  
Report MHL2693  
Figure  
3.1  
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# January 2-8, 2020

Daylight Saving Time  
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1st Quarter Jan 3





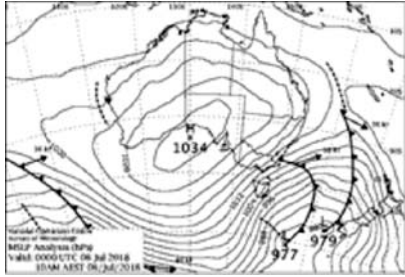
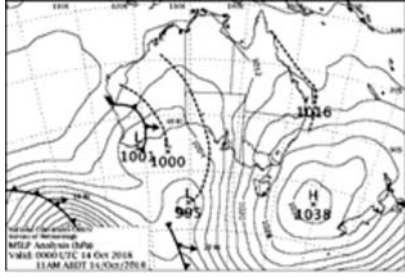
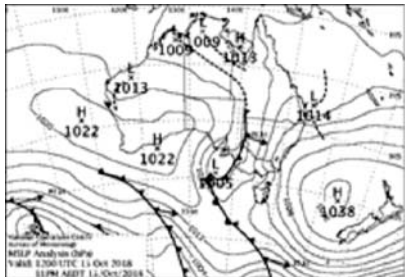
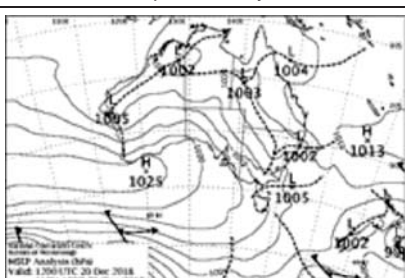
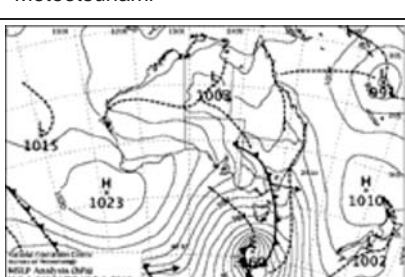
NSW TIDAL ANOMALIES PLOT 2018-2019

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Figure  
3.2

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Event Number (see Figure 3.2)	Event Period	BoM Weather Map*	Peak Anomaly	Sites where Anomaly > +/- 0.2m
1	7–10 July 2018	 <p>South coast low pressure system</p>	Site Eden Date 8/7/2018 Time 0715 Peak Value 0.415	Crowdy Head, Forster, Shoal Bay, Princess Jetty, Bermagui, Eden
2	12–19 October 2018	 <p>Large high pressure system</p>	Site Bundeena Date 15/10/2018 Time 1430 Peak Value -0.347	Yamba, Coffs Harbour, Crowdy Head, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Ulladulla, Princess Jetty, Bermagui, Eden
3	15–16 October 2018	 <p>Localised low pressure system</p>	Site Tweed Heads Date 15/10/2018 Time 2115 Peak Value 0.348	Tweed Heads, Brunswick Heads
4	20 December 2018	 <p>Metetsunami</p>	Site Crowdy Head Date 20/12/2018 Time 2015 Peak Value 0.384	Port Macquarie, Crowdy Head, Shoal Bay, Patonga, Sydney, Bundeena, Jervis Bay, Ulladulla
5	12–16 May 2018	 <p>South coast low pressure system</p>	Site Bermagui Date 12/2/2019 Time 1200 Peak Value 0.354	Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden



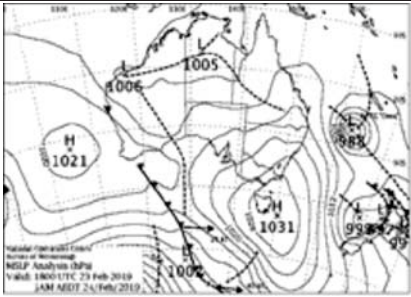
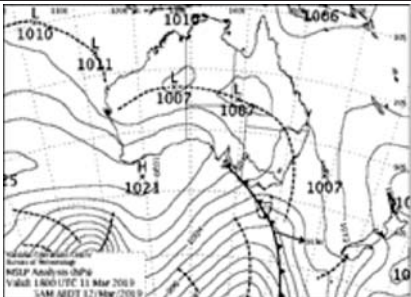
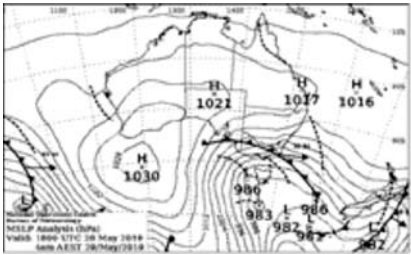
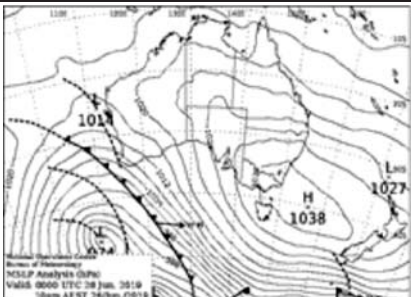
TIDAL ANOMALIES JULY 2018–JUNE 2019

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Hydraulics  
Laboratory

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Figure  
3.3

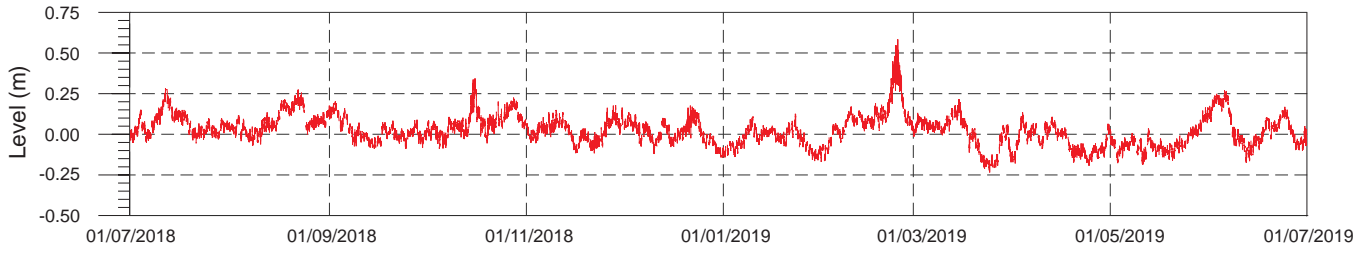
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Event Number (see Figure 3.2)	Event Period	BoM Weather Map*	Peak Anomaly	Sites where Anomaly > +/- 0.2m
6	21–25 February 2019	 <p>Ex-Tropical Cyclone Oma</p>	Site Brunswick Heads Date 23/2/2019 Time 1515 Peak Value 0.680	Tweed Heads, Brunswick Heads, Yamba
7	10–14 March 2019	 <p>East Coast Low</p>	Site Coffs Harbour Date 12/3/2019 Time 1415 Peak Value 0.418	Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay
8	27 May–7 June 2019	 <p>South coast low pressure system</p>	Site Eden Date 29/5/2019 Time 1030 Peak Value 0.501	Tweed Heads, Brunswick Heads, Yamba, Ballina, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
9	25–27 June 2019	 <p>Large high pressure system</p>	Site Eden Date 26/6/2019 Time 1400 Peak Value -0.295	Ulladulla, Princess Jetty, Bermagui, Eden

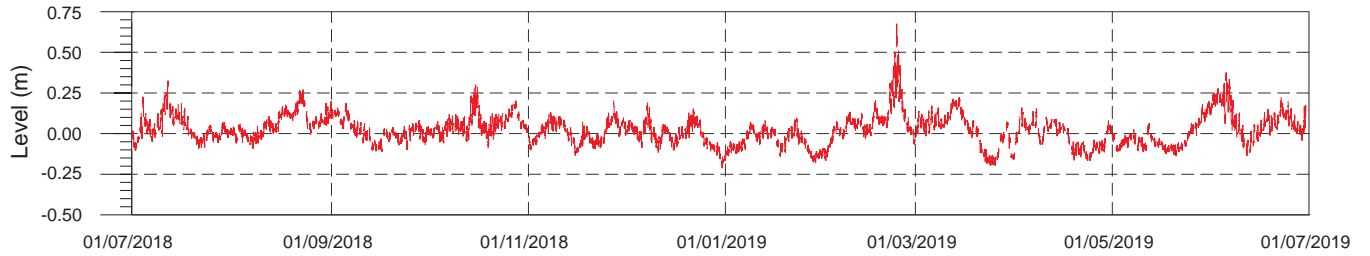
\*Weather map images courtesy BoM © [Copyright](#) Commonwealth of Australia, Bureau of Meteorology



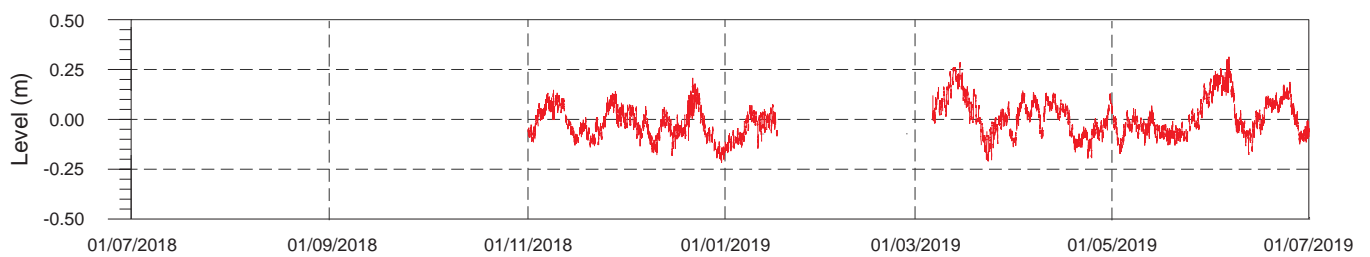
Tweed Entrance South



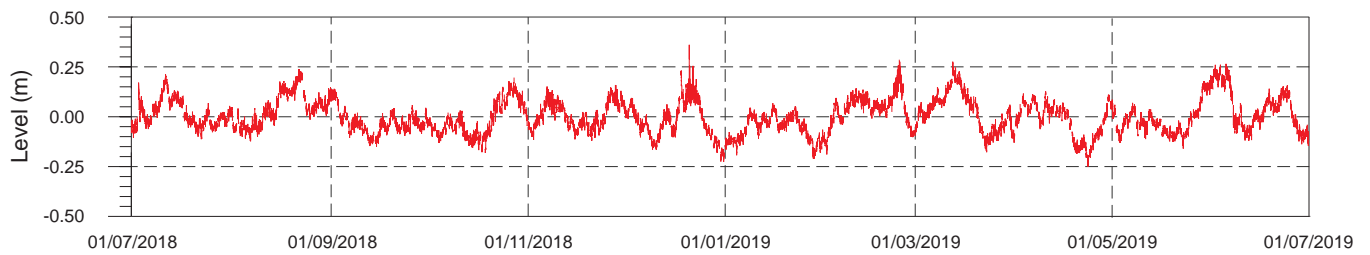
Brunswick Heads



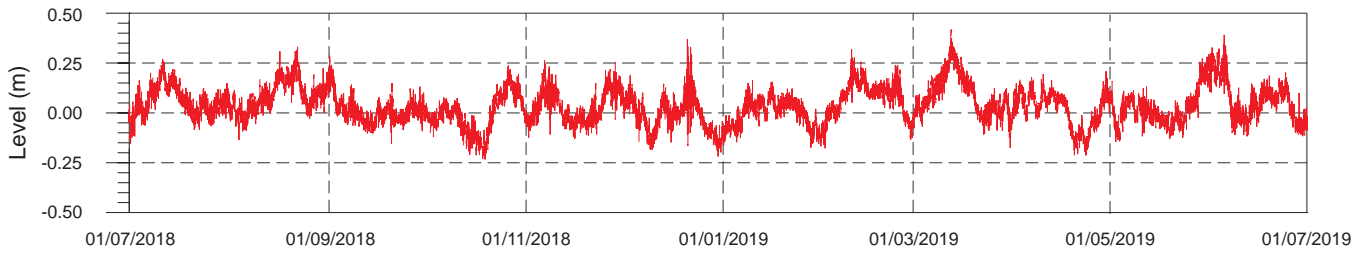
Ballina Breakwall



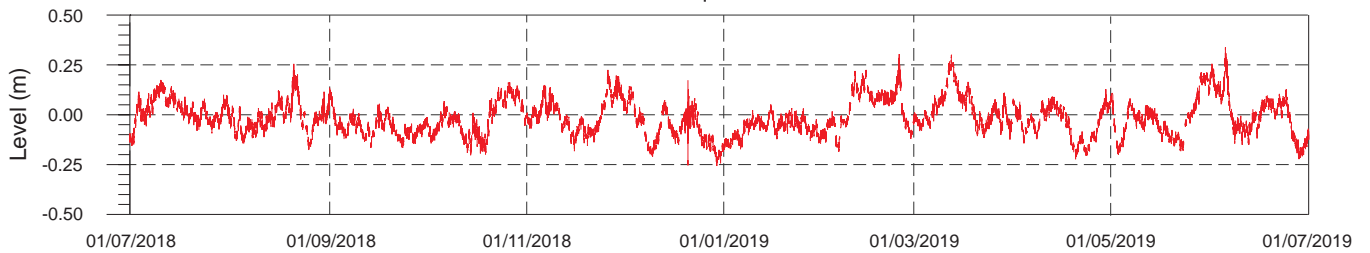
Yamba



Coffs Harbour



Port Macquarie



TIDAL ANOMALIES 2018–2019  
TWEED ENTRANCE SOUTH TO PORT MACQUARIE

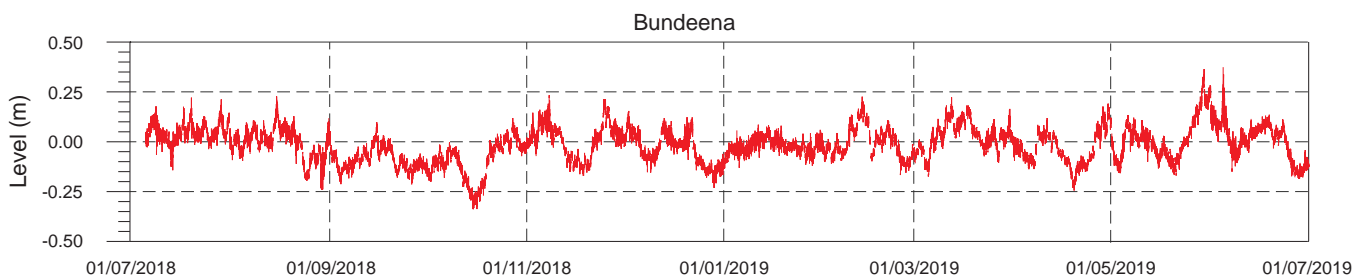
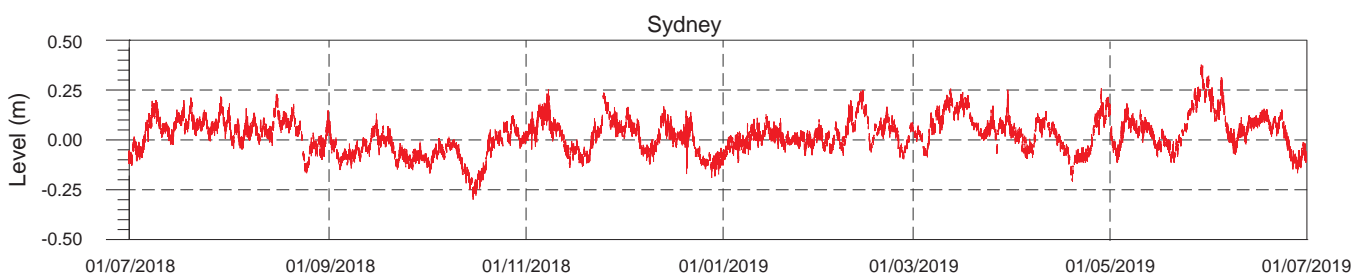
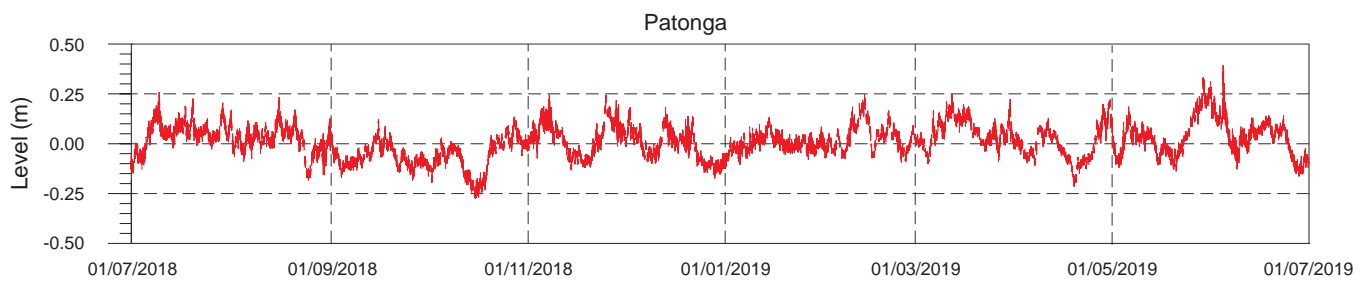
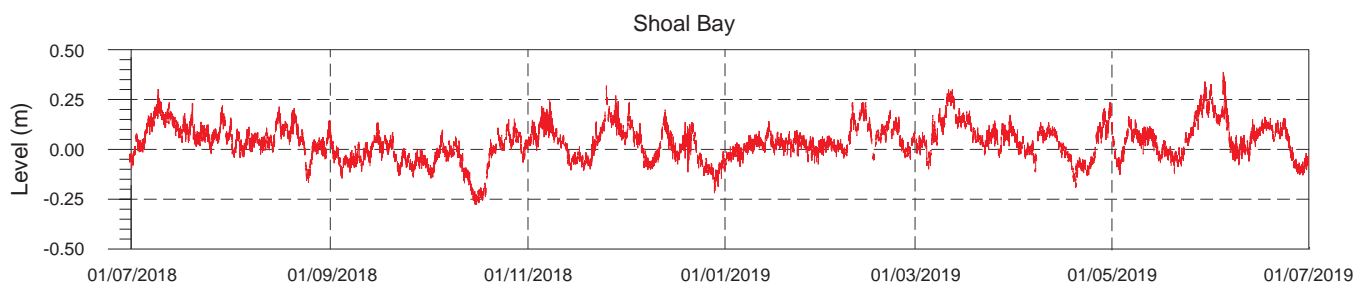
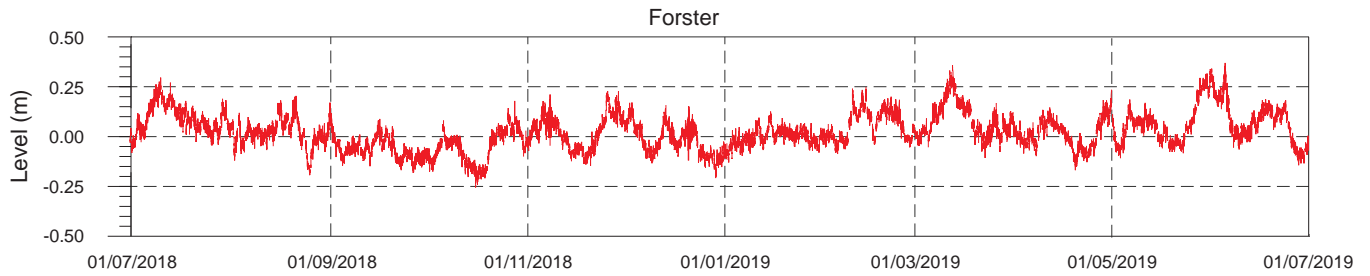
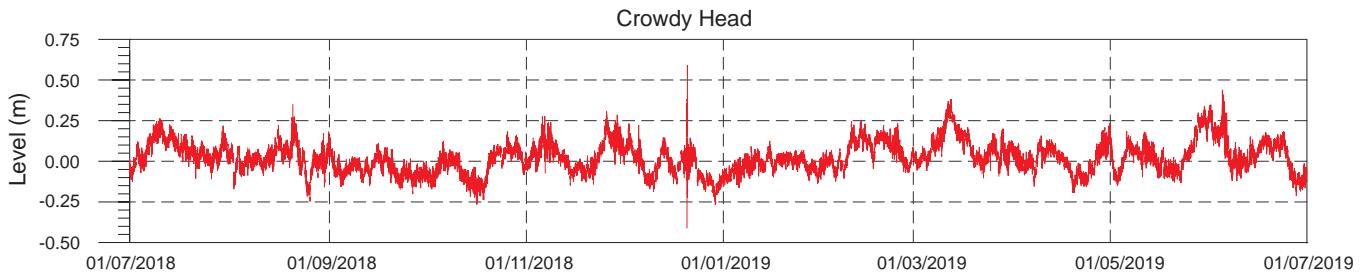
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Figure

3.5

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TIDAL ANOMALIES 2018–2019  
CROWDY HEAD TO BUNDEENA

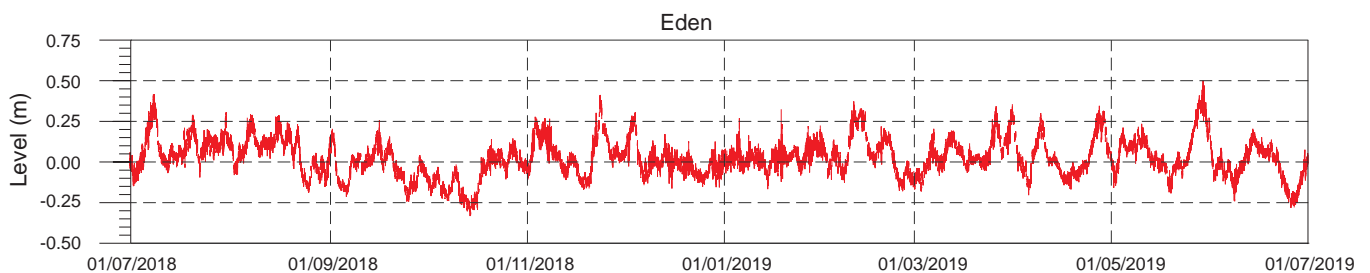
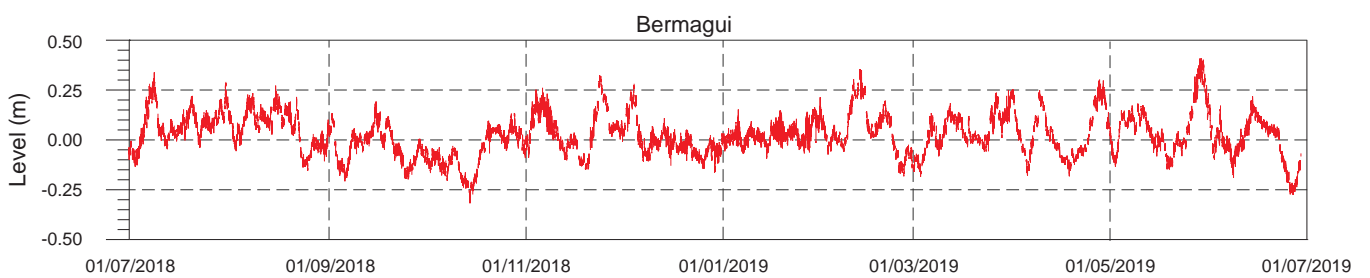
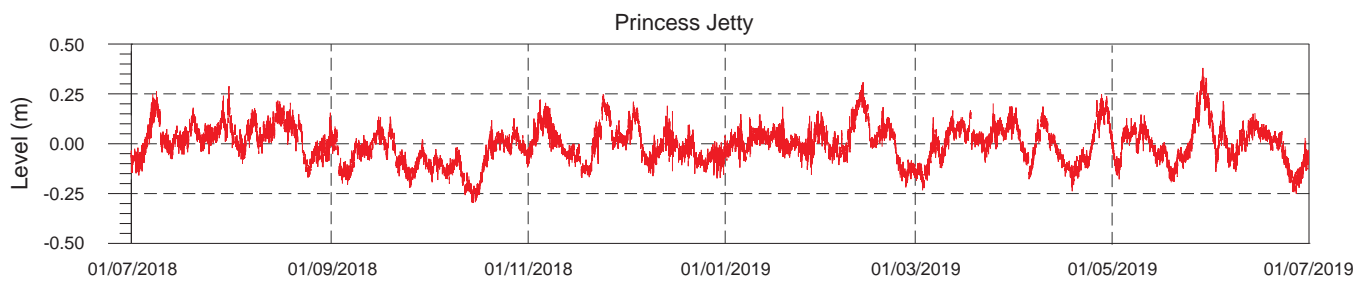
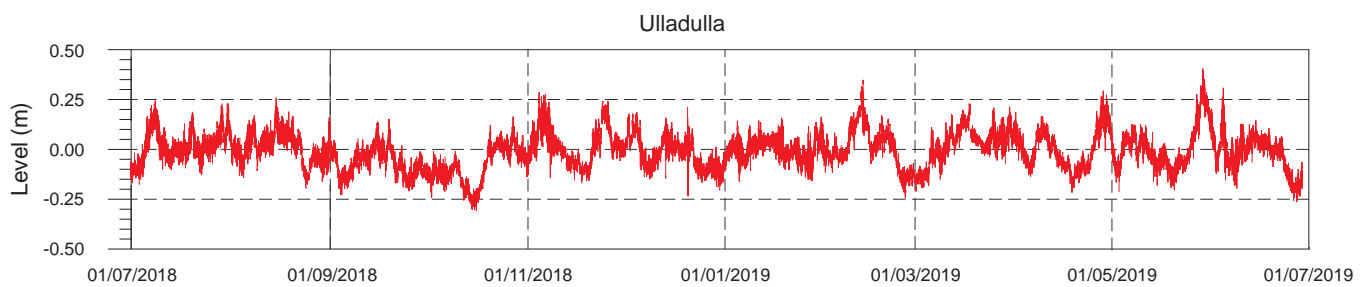
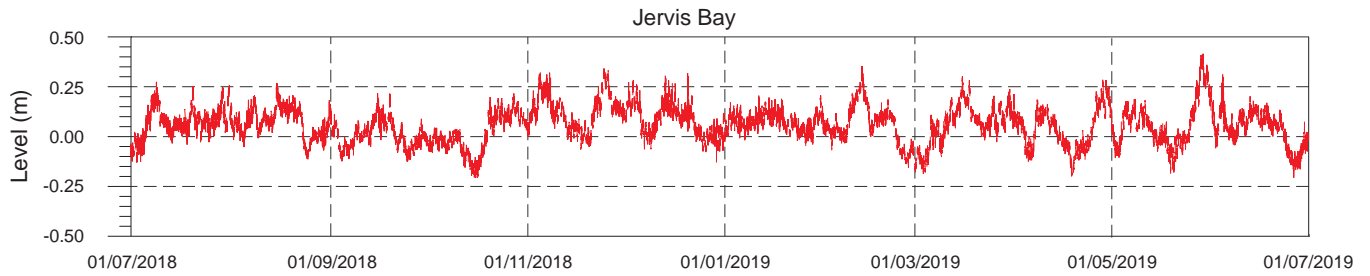
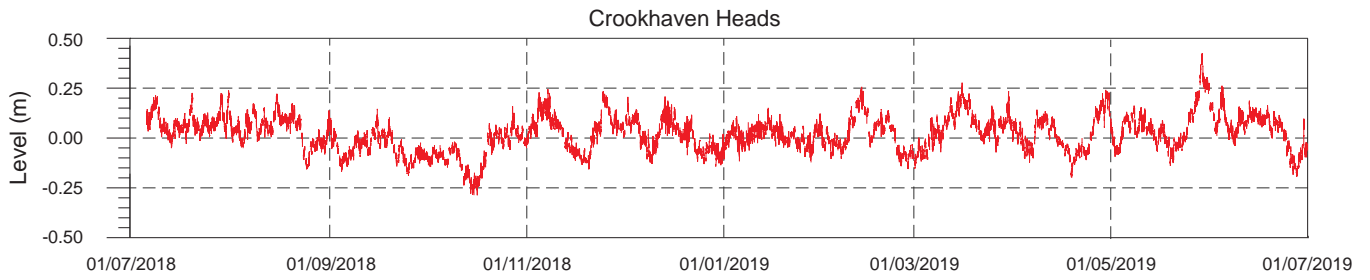
Manly  
Hydraulics  
Laboratory

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Figure

3.6

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TIDAL ANOMALIES 2018–2019  
CROOKHAVEN HEADS TO EDEN

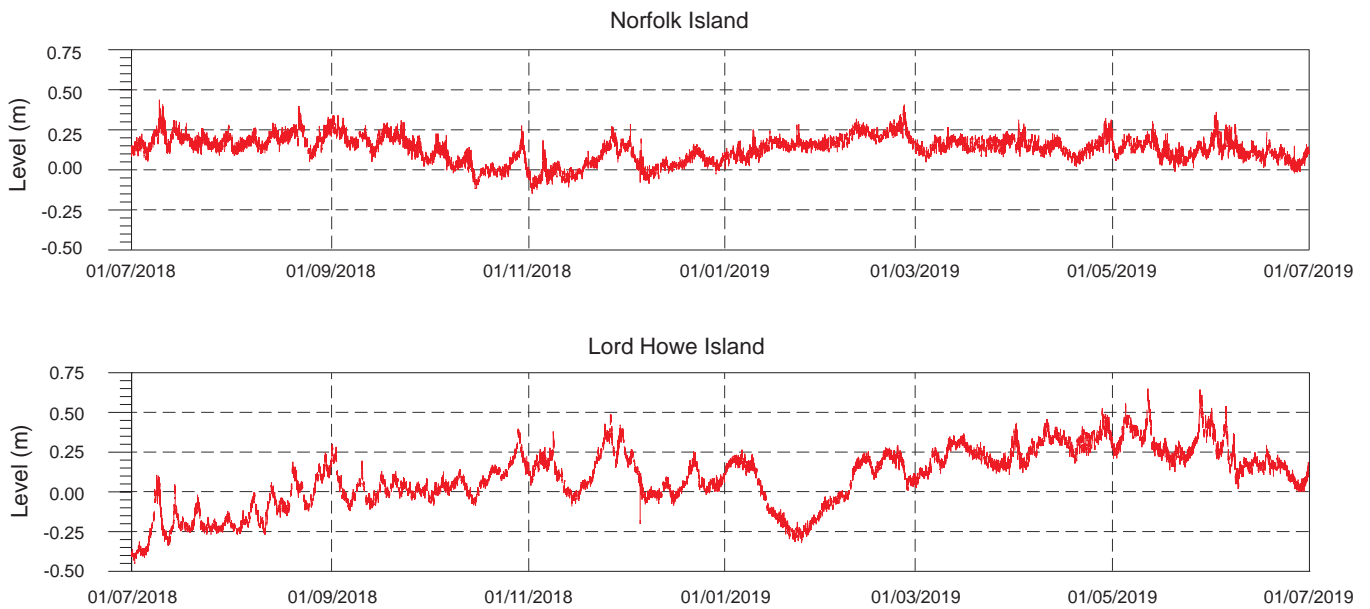
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Figure

3.7

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Data for Norfolk Island provided by Bureau of Meteorology's National Tidal Unit (NTU)



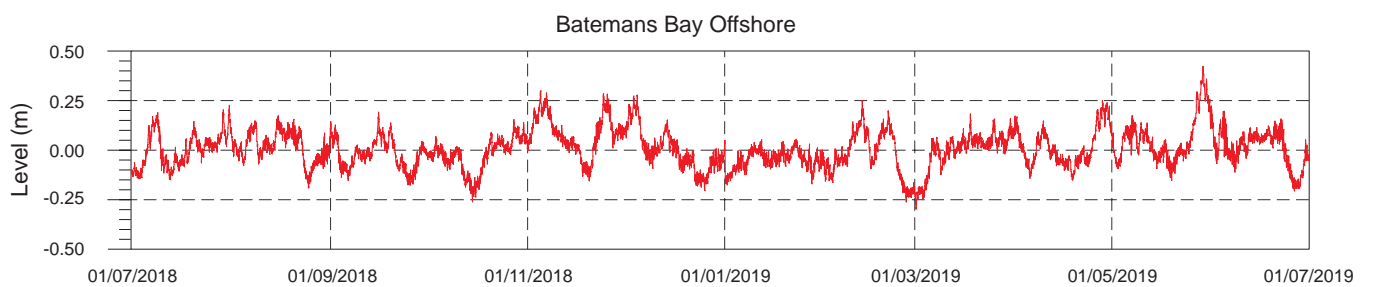
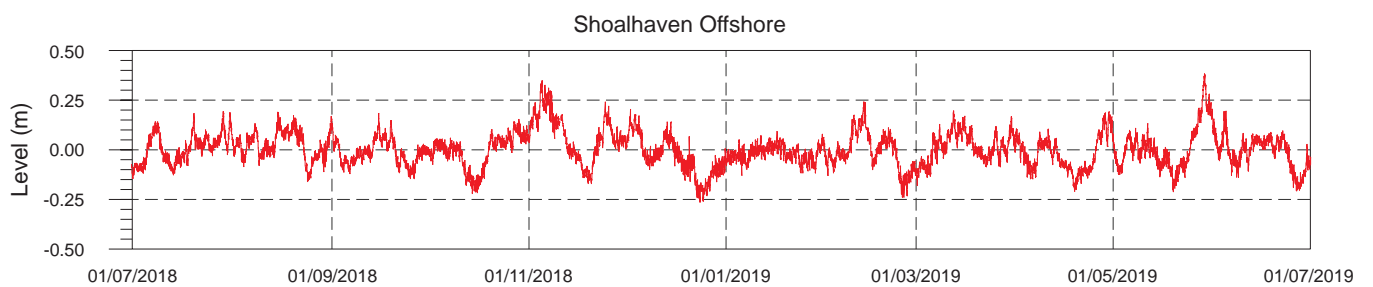
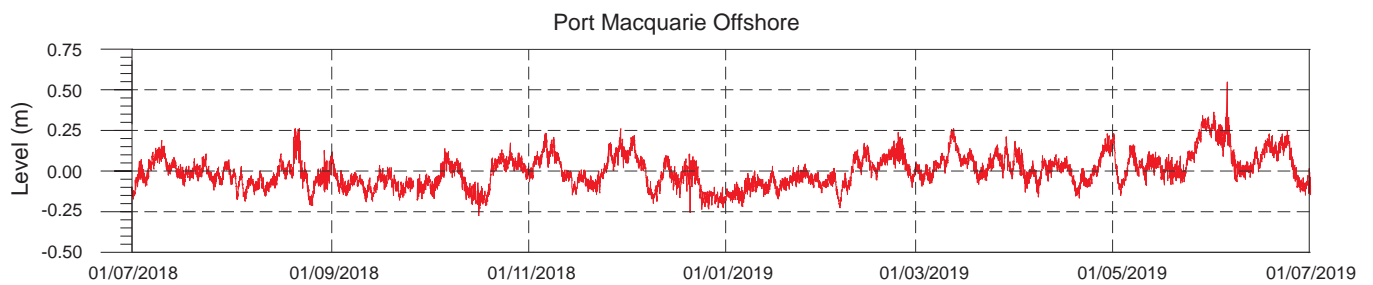
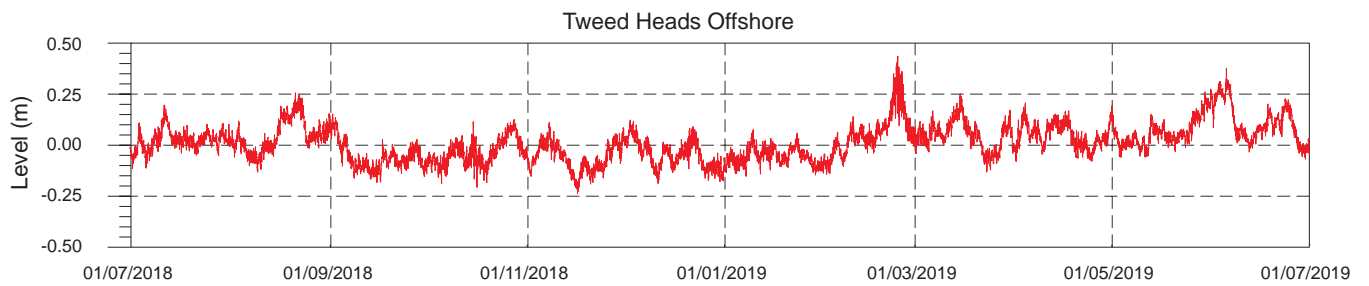
TIDAL ANOMALIES 2018–2019  
NORFOLK ISLAND AND LORD HOWE ISLAND

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Figure  
3.8

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TIDAL ANOMALIES 2018–2019  
OFFSHORE TIDE GAUGES

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Laboratory

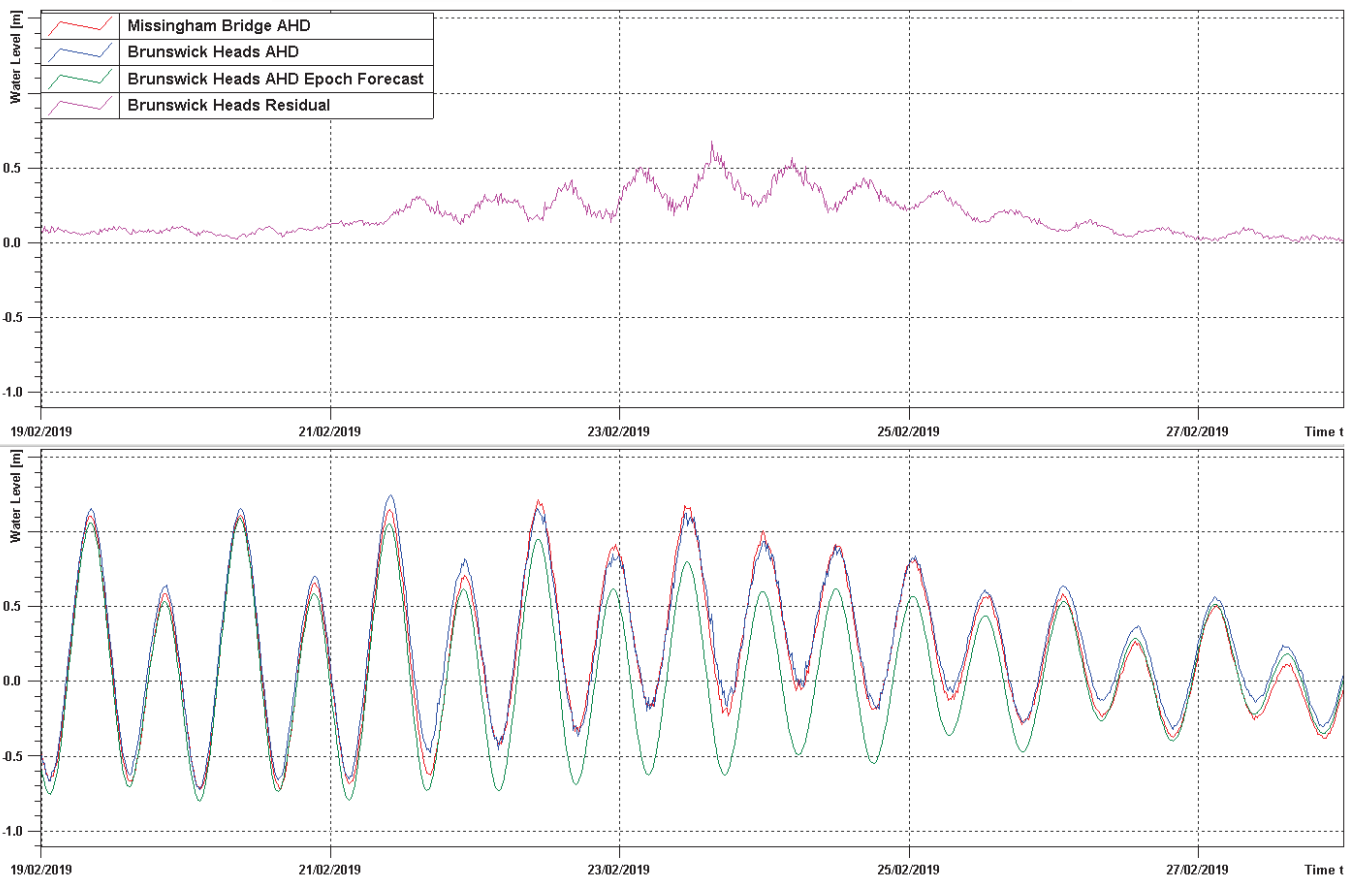
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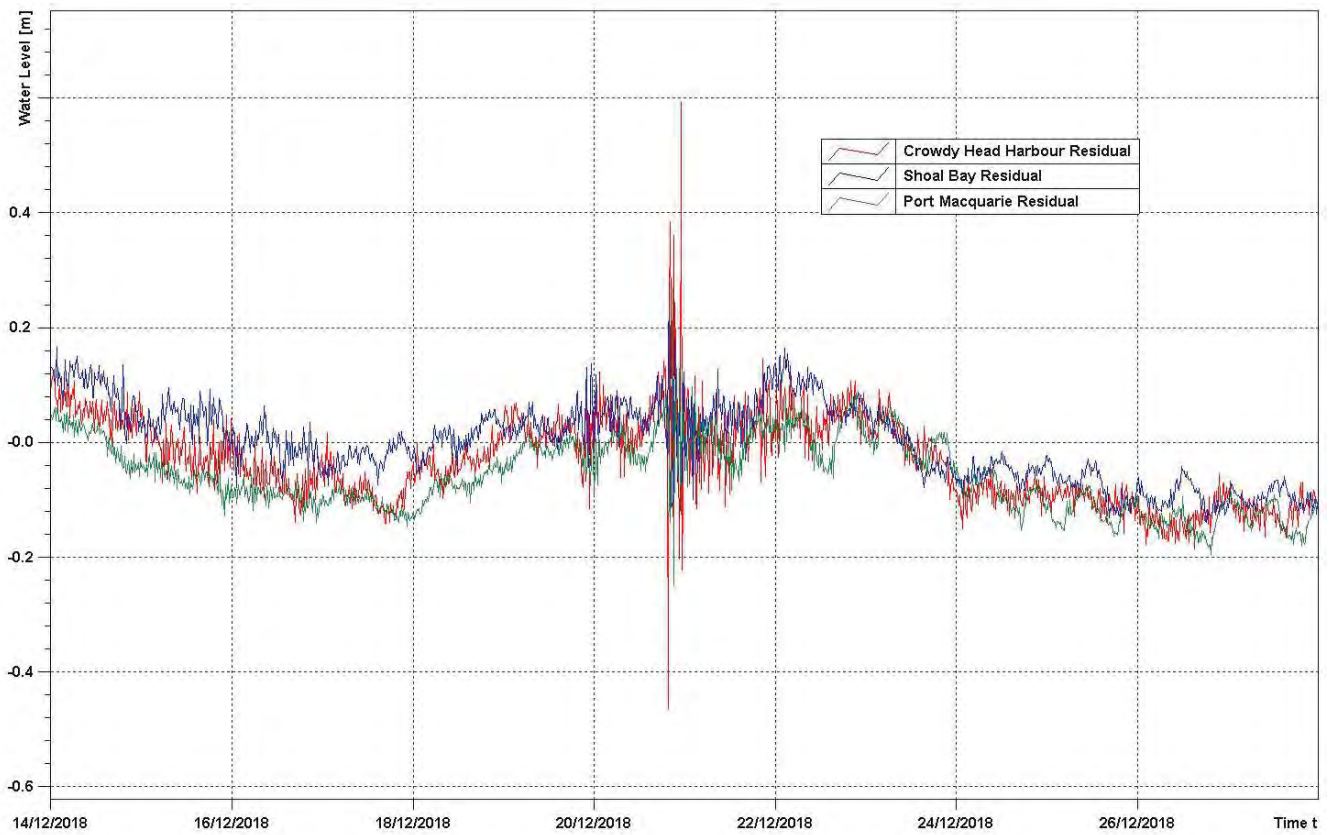
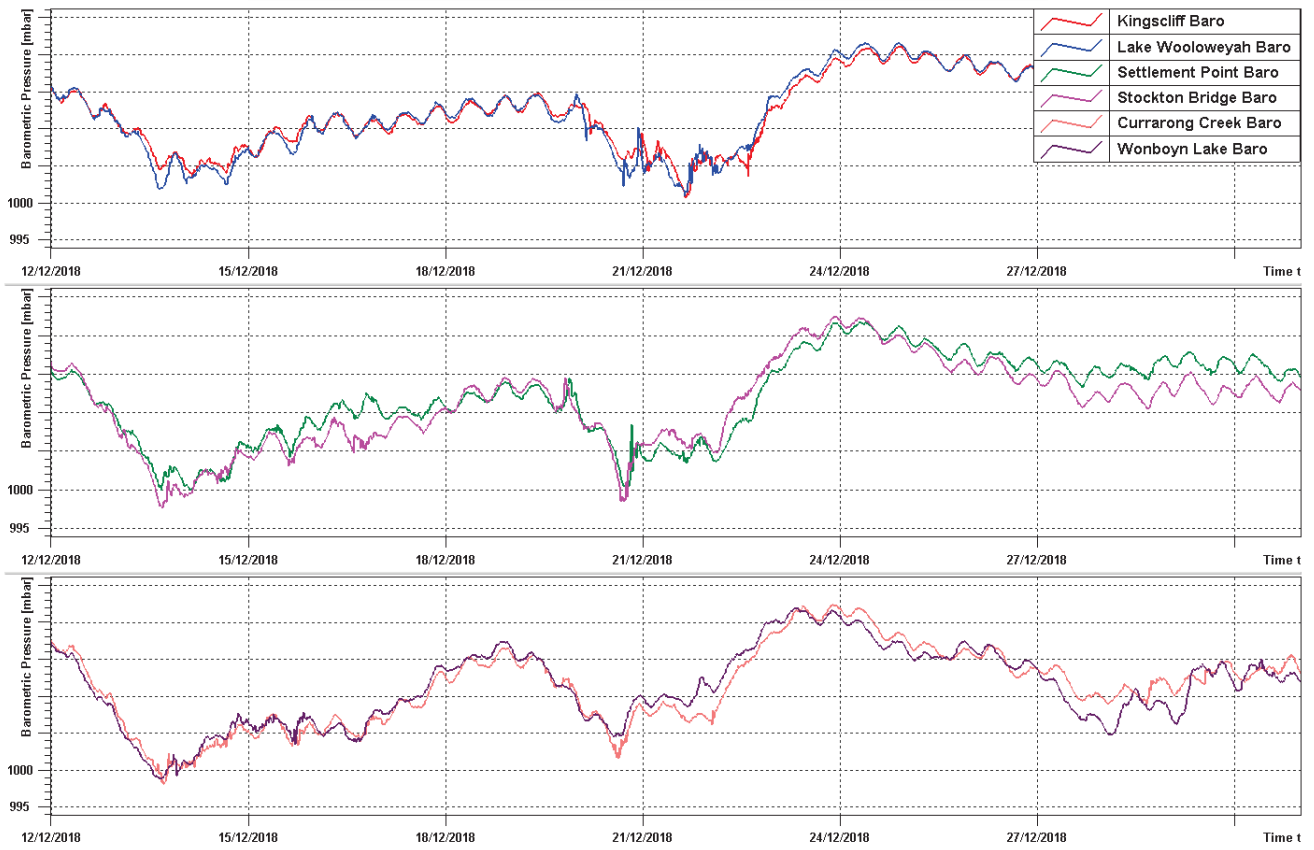
Figure  
3.9

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Riverview Park, Ballina looking east at high tide 22 February 2019  
 Source: Rick Beddoes, Facebook





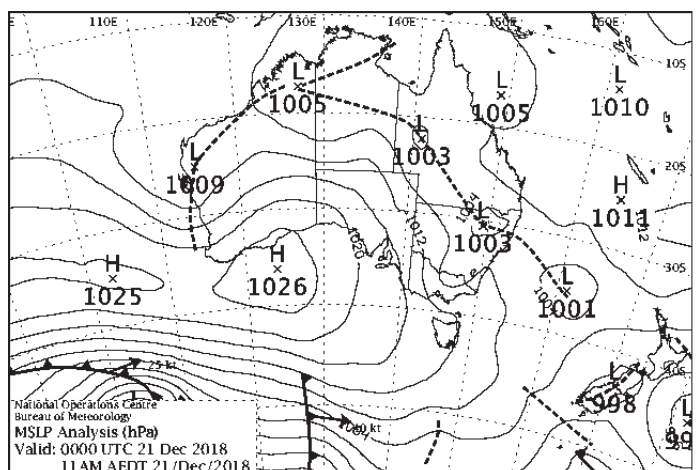
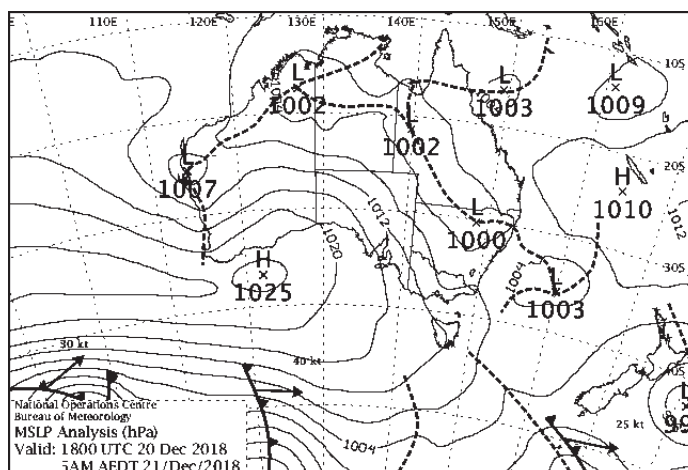
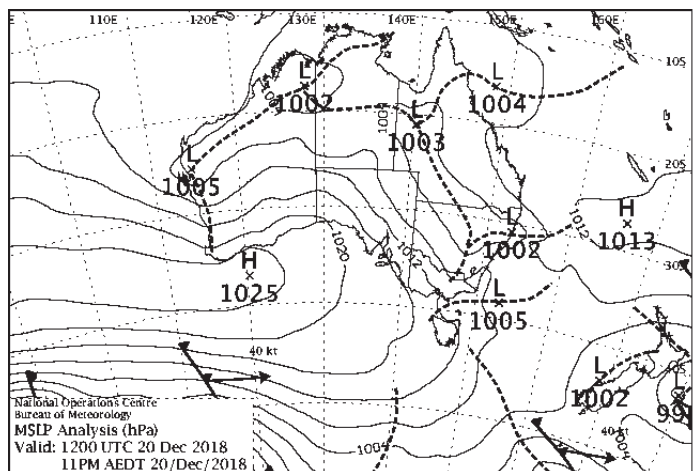
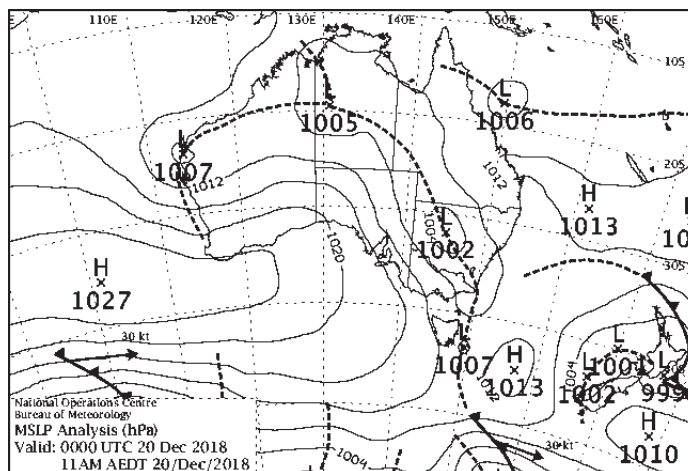
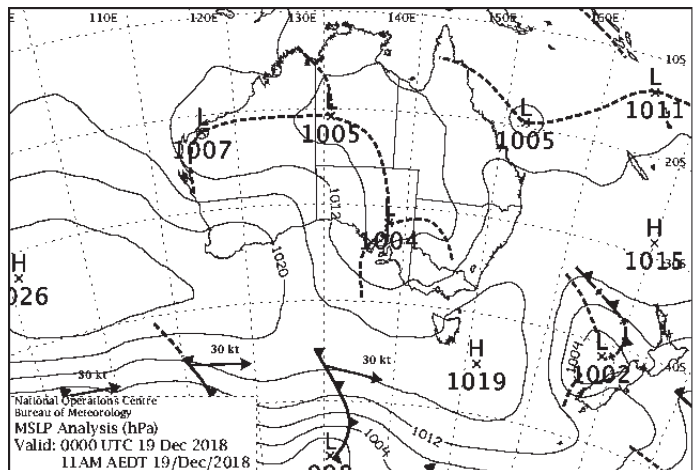
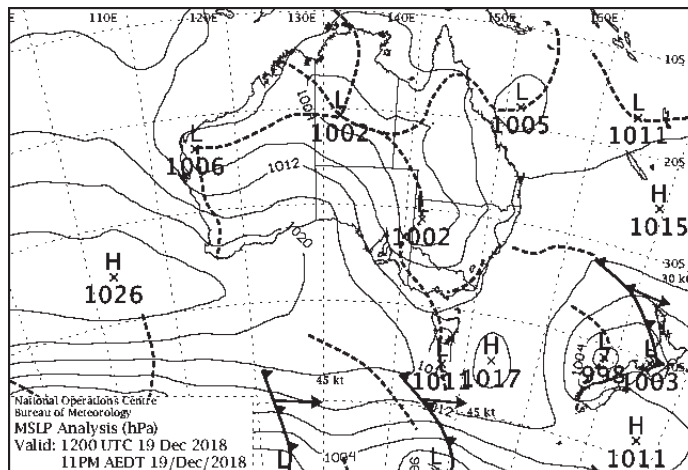
IDENTIFYING DECEMBER 2018  
METEOTSUNAMI EVENT  
ON NSW COAST

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Hydraulics  
Laboratory

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Figure  
3.11

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Source: Weather map images courtesy BoM © Commonwealth of Australia, Bureau of Meteorology)



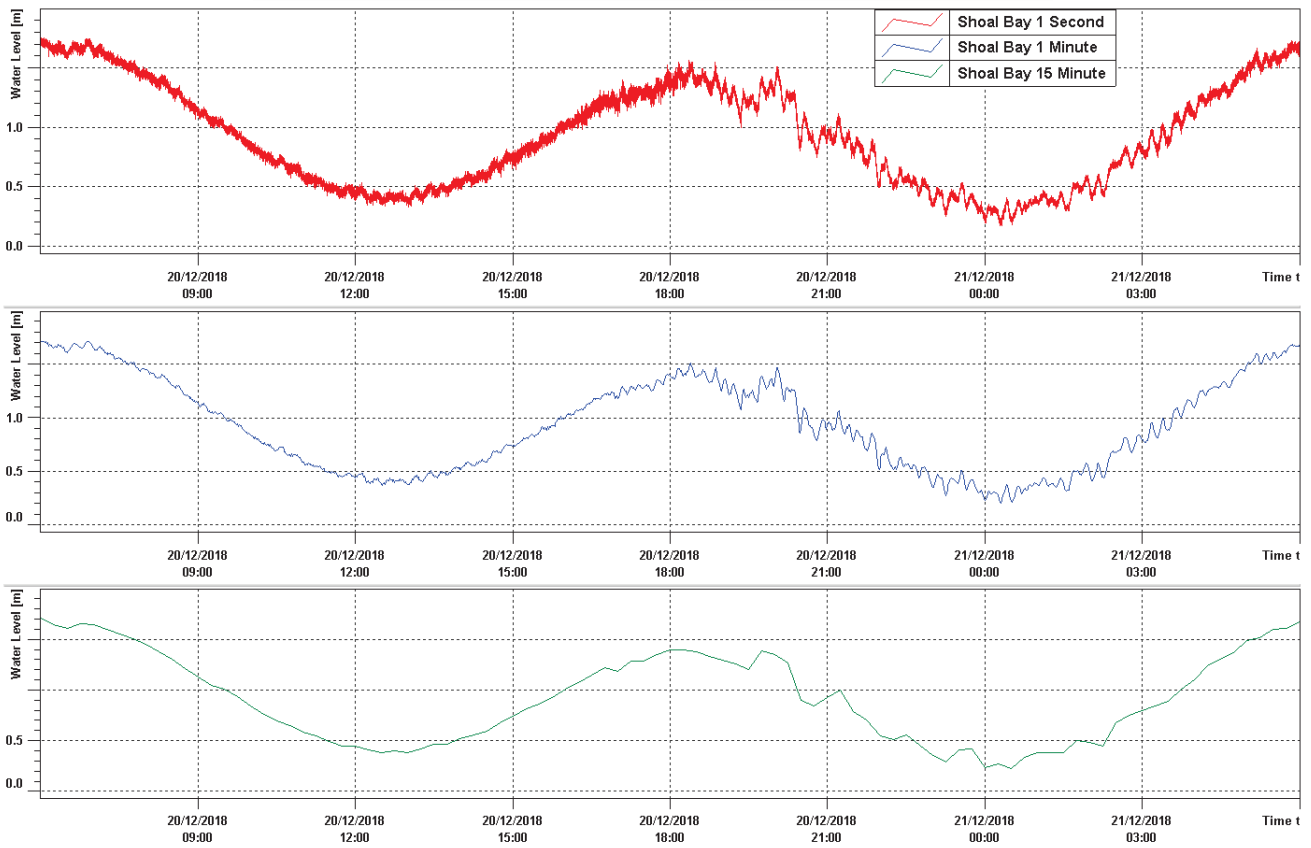
DECEMBER 2018 SYNOPTIC MAPS  
FOR MID NORTH COAST METEETSUNAMI EVENT

Manly  
Hydraulics  
Laboratory

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Figure  
3.12

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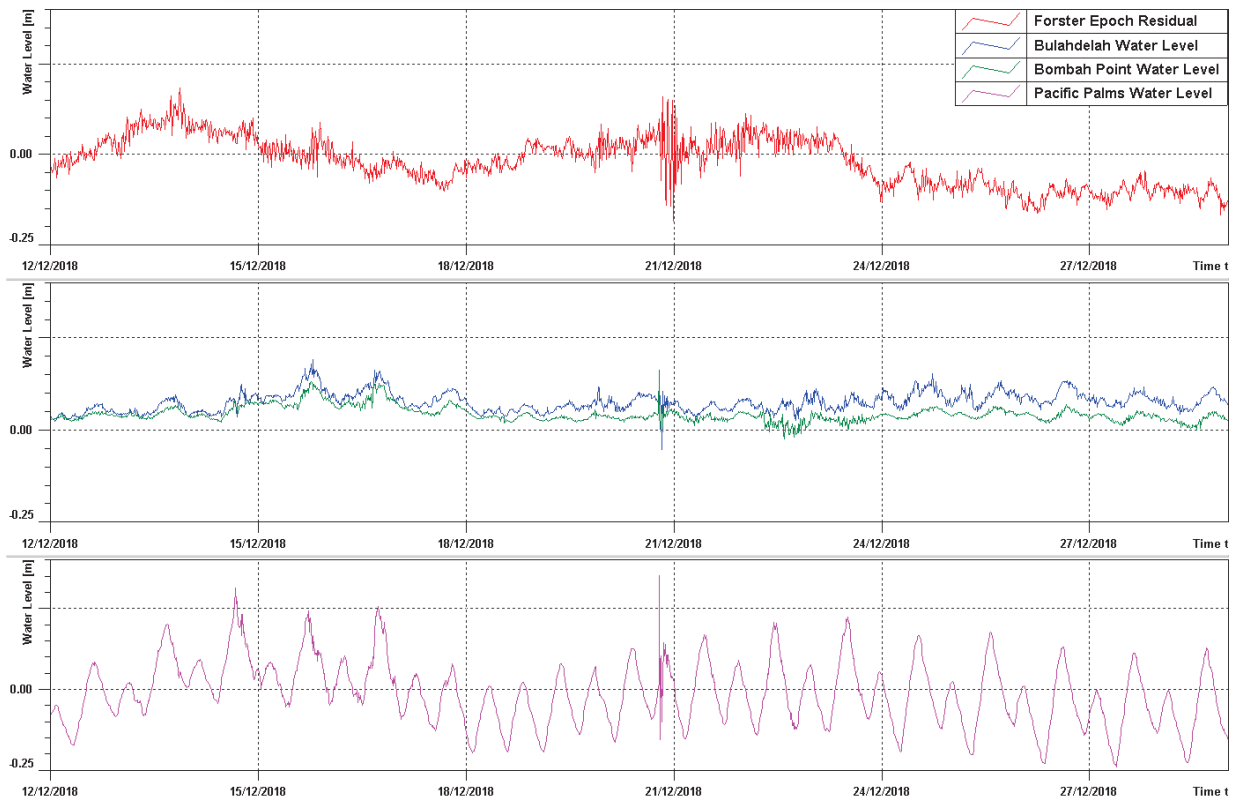
SHOAL BAY OCEAN TIDE GAUGE DATA LOGGING INTERVALS  
DURING DECEMBER 2018 METEOTSUNAIM

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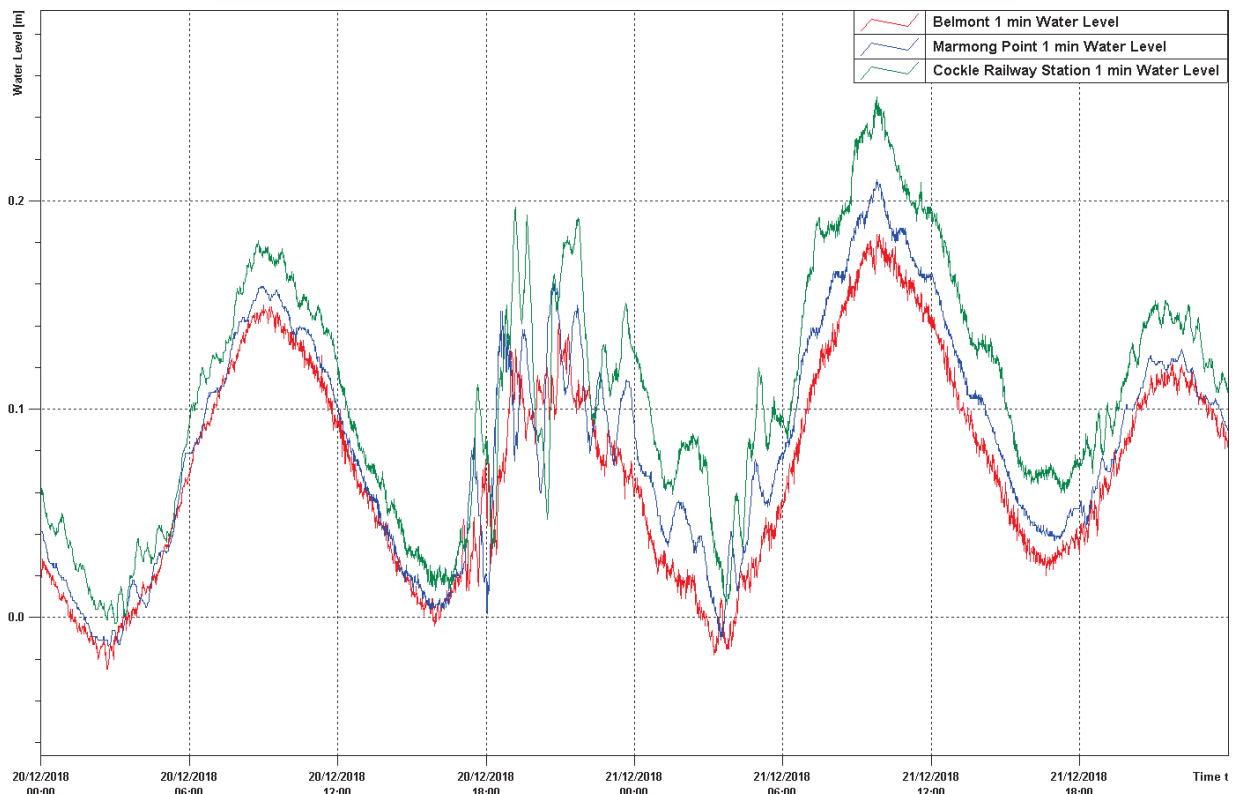
Report MHL2693

Figure  
3.13

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Great Lakes estuary system water levels 12-27 December 2018



Lake Macquarie water levels 20-21 December 2018



MID COAST ESTUARY WATER LEVELS  
DURING DECEMBER 2018 METEOTSUNAMI

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
3.14

DRAWING 2693-03-14.cdr

## 4. Program developments 2018–2019

### 4.1 Classification of stations

An increasing interest in sea level rise, tsunami and storm surge data has led to the adoption of a classification of each of the stations based on the type of data they represent from their recording location. As the ocean tide and river entrance program collects data from a variety of recording locations, from offshore sites to sites inside the entrances of rivers and inside ports, this classification of sites highlights to users the possible variability of data, based on recording location.

The classifications in order from river entrance to offshore are:

- Onshore river entrance – stations that are located within a river a short distance upstream of the entrance usually maintained open by training walls. Typically these locations do not provide good representation of ocean water levels because they show a reduction of tidal range between 0.1 and 0.2 m compared to ocean tide, and may be affected by entrance conditions and floods.
- Onshore bay or port – bank or pole-mounted sensor located in an embayment or harbour. Effective at measuring the ocean water levels where there is no influence by floods. Can be influenced by harbour motions (i.e. seiches).
- Onshore open ocean – jetty or bank-mounted sensor located in an open ocean location. Effective at measuring the ocean water levels, but may have problems if located in the surf zone. Lord Howe Island is currently the only operating station in this category.
- Offshore open ocean – bottom-mounted sensors that are located between 2 and 5 km offshore of the coast generally in about 25 m depth of water. Very effective at measuring ocean water level but the datum cannot be accurately determined.

The classification indicates sites that are similar in their location and gives an indication to the end data user to assist selection of the site location type that would be most representative for the required analysis. Table 4.1 lists the classification of each of the stations in the program.

**Table 4.1 Ocean and river entrance tide site classification**

Station	Classification	Classification code
Tweed Entrance South	Onshore River Entrance	OR
Tweed Offshore	Offshore Open Ocean	O
Brunswick Heads	Onshore River Entrance	OR
Ballina Breakwall	Onshore River Entrance	OR
Yamba	Onshore River Entrance	OR
Coffs Harbour	Onshore Bay or Port	OB
Port Macquarie	Onshore River Entrance	OR
Port Macquarie Offshore	Offshore Open Ocean	O
Crowdy Head	Onshore Bay or Port	OB
Forster	Onshore River Entrance	OR
Shoal Bay	Onshore Bay or Port	OB
Patonga	Onshore Bay or Port	OB

Station	Classification	Classification code
Sydney	Onshore Bay or Port	OB
Bundeena	Onshore Bay or Port	OB
Crookhaven Heads	Onshore River Entrance	OR
Shoalhaven Offshore	Offshore Open Ocean	O
Jervis Bay	Onshore Bay or Port	OB
Ulladulla	Onshore Bay or Port	OB
Princess Jetty	Onshore River Entrance	OR
Batemans Bay Offshore	Offshore Open Ocean	O
Bermagui	Onshore River Entrance	OR
Eden	Onshore Bay or Port	OB
Norfolk Island	Onshore Open Ocean	OO
Lord Howe Island	Onshore Open Ocean	OO

## 4.2 Program improvements/changes

Further improvements and changes to the network have continued in 2018– 2019. Major changes are summarised below.

- A vertical seabed diving marker for the Shoalhaven and Batemans Bay offshore instrument locations was laid. All four offshore sites now have a vertical landmark with documented GPS coordinates to facilitate locating the sites in the future by dive teams.
- A new RBR logger has been purchased and tested before first initial deployment in the 2019–20 financial year. This is a combined and more compact alternative to current RBR loggers and Paros sensors which are larger in size and come in separate pieces connected by a cord.
- Aanderaa sensors are being refurbished with in-house designed loggers. With digital storage unit (DSU) loggers becoming obsolete and unsupported we have identified that Aanderaa quartz sensors are generally reliable for one-year deployments at a ~25 m depth and are a useful backup instrument.
- 95% of all ocean tide stations have now been upgraded to high frequency 4G IP data transfers (with data available in near real-time, every 15 minutes). This improved communications network provides faster data transfer between the logger and MHL's website after each point is logged.
- New loggers have been purchased and one installed at Patonga which allows for faster communication between field computer and logger during station visits, as well as an inbuilt SD card reading system for improved reliability of 1-second data logging.

Table 4.2 shows the status of the sites as of June 2019.

**Table 4.2 MHL tidal logging and sensing system status 1/7/2018–30/6/2019**

Station	Latitude	Longitude	Site classification <sup>1</sup>	Primary loggers <sup>2</sup>	Secondary loggers <sup>2</sup>	Primary sensors	Secondary sensors	Station	
								Sampling	Logging
Tweed Entrance South	-28.1706	153.5512	OR	4 Com	-	Radar	Vented pressure	120 samples averaged 1 minute either side of the quarter hour and 60 samples averaged 30 seconds either side of each minute and 9 sites logging at 1 second to onsite data storage card (Tweed Entrance South, Coffs Harbour, Port Macquarie, Lord Howe Island, Shoal Bay, Patonga, Sydney, Princess Jetty and Eden)	15 minutes on the quarter hour and 1 minute on the minute
Brunswick Heads	-28.5370	153.5528	OR	2 Com	-	Vented pressure	Vented pressure		
Ballina Breakwall	-28.8754	153.5844	OR	4 Com	-	Vented pressure	Vented pressure		
Yamba	-29.4290	153.3621	OR	2 Com	-	Radar	Vented pressure		
Coffs Harbour	-30.3029	153.1461	OB	4 Com	-	Radar	Vented pressure		
Port Macquarie	-31.4268	152.9111	OR	4 Com	-	Radar	Vented pressure		
Crowdy Head	-31.8387	152.7500	OB	2 Com	-	Radar	Vented pressure		
Forster	-32.1740	152.5082	OR	2 Com	-	Vented pressure	Vented pressure		
Shoal Bay	-32.7197	152.1757	OB	4 Com	-	Radar	Vented pressure		
Patonga	-33.5510	151.2746	OB	4 Com	-	Radar	Vented pressure		
Sydney	-33.8255	151.2585	OB	4 Com	-	Radar	n/a		
Sydney Backup	-33.8263	151.2572	OB	2 Com	-	Vented pressure	Vented pressure		
Bundeena	-34.0827	151.1509	OB	2 Com	-	Radar	n/a		
Crookhaven Heads	-34.9053	150.7594	OR	2 Com	-	Vented pressure	Vented pressure		
Jervis Bay	-35.1220	150.7074	OB	2 Com	-	Radar	Vented pressure		
Ulladulla	-35.3577	150.4765	OB	2 Com	-	Vented pressure	Vented pressure		
Princess Jetty	-35.7038	150.1778	OR	4 Com	-	Radar	Vented pressure		
Bermagui	-36.4263	150.0715	OR	2 Com	-	Vented pressure	Vented pressure		
Eden	-37.0712	149.9083	OB	4 Com	-	Radar	Vented pressure		
Lord Howe Island	-31.5236	159.0581	OO	4 Com	-	Radar	Vented pressure		
Tweed Offshore	-28.1811	153.5940	O	RBR Virtuoso	WLR7	Submersible Paroscientific Pressure Sensor and RBR Logger	Aanderaa submersible Pressure (only at 2 of the 4 sites per deployment year)	Integrated over 40 seconds	RBR 5 minutes Aanderaa 60 minutes
Port Macquarie Offshore	-31.4519	152.9455	O	RBR Virtuoso	WLR7				
Shoalhaven Offshore	-34.9165	150.7863	O	RBR Virtuoso	WLR7				
Batemans Bay Offshore	-35.7794	150.2533	O	RBR Virtuoso	WLR7				

<sup>1</sup> Classification: OR = Onshore River entrance, OB = Onshore Bay or Port, OO = Onshore Open Ocean, O = Offshore Open Ocean

<sup>2</sup> Loggers: 2 Com/4 Com = Indicating number of communication ports on the multi-channel programmable logger as per MHL Report 2546 (MHL 2019), RBR Virtuoso = RBR Ltd (Kanata, Canada), WLR7 = Aanderaa Data Instruments (Bergen, Norway)

### 4.3 Program plans 2019–2020

MHL is continuing to upgrade the ocean tide program to adopt best practice in data collection, maximise the efficiency of maintaining the program, increase data accuracy and capture, improve data resolution and increase the value of the data collected. The planned 2019–2020 program upgrades include:

- recalculation of the new epoch tidal forecasts for future tidal predictions noting MHL's current method may be updated based on the findings of the yet-to-be released *Tidal methodologies report* (MHL Report 2156)
- updating surveys for ocean tide sites and inclusion of more reference marks to better align with NTC standards
- relocation of Princess Jetty gauge due to highway bridge upgrade
- radar installation at Ulladulla boat harbour
- an offshore tide metadata and site location report referencing the location landmarks and creating a more transparent contingency plan for future dive teams.

## 5. References

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Foreman, MGG 1977, *Manual for tidal heights analysis and prediction*, Pac. Mar. Sci. Rep. 77-10, Inst. of Ocean Sciences, Patricia Bay, Sidney, B.C., 58pp (2004 revision).

MHL 2005, *Investigation into Tidal Planes Compilation – NSW Tidal Planes Data Compilation Stage 3*, MHL Report 1269, November 2005.

MHL 2012, *OEH NSW Tidal Planes Analysis 1990 – 2010 Harmonic Analysis*, MHL Report 2053, October 2012.

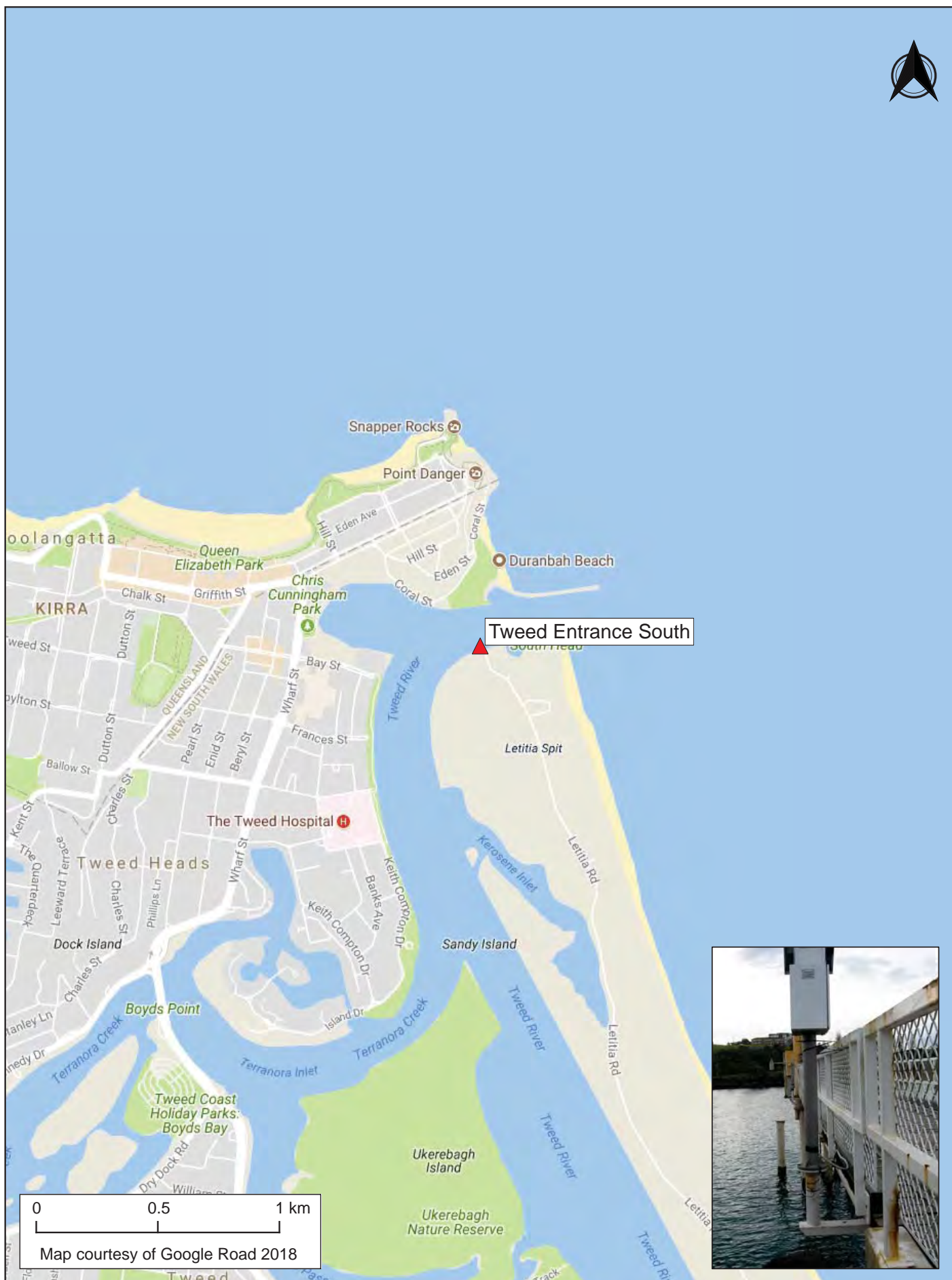
MHL 2017, *NSW Ocean and River Entrance Tidal Levels Annual Summary*, MHL Report 2574, December 2017.

MHL 2018, *NSW Extreme Ocean Water Levels*, MHL Report 2236, December 2018.

MHL 2019, *Review of NSW OEH Automatic Water Level Recorder Network*, MHL Report 2546, March 2019.

# Appendix A Annual data site summaries

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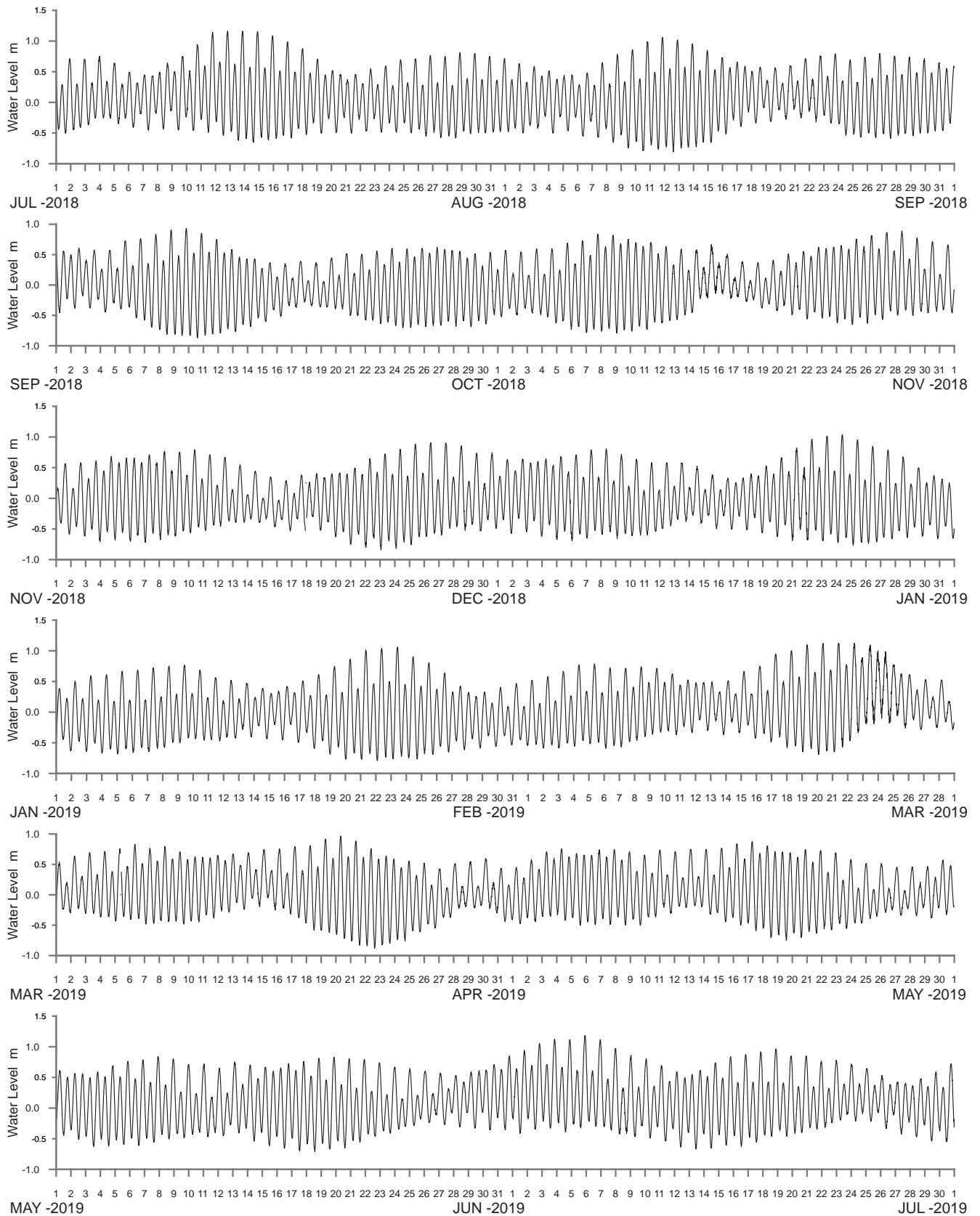
### TWEED ENTRANCE SOUTH STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A1

DRAWING 2693-A1.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



TWEED ENTRANCE SOUTH DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

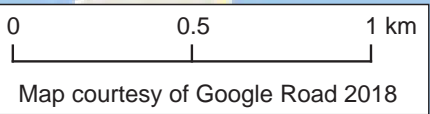
Report MHL2693

Figure  
A2

DRAWING 2693-A2.cdr



Tweed Heads Offshore ▲



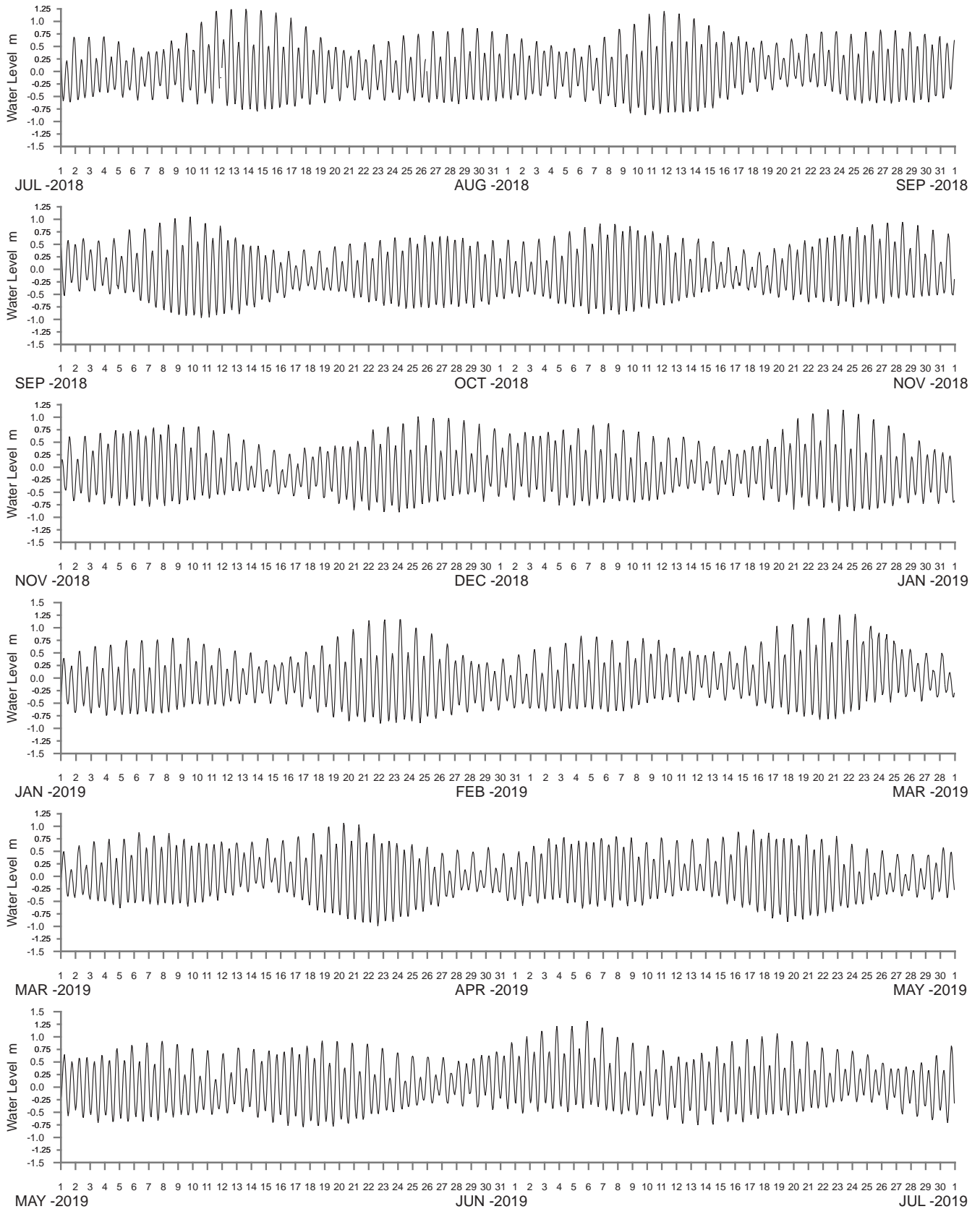
### TWEED HEADS OFFSHORE STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A3

DRAWING 2693-A3.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS



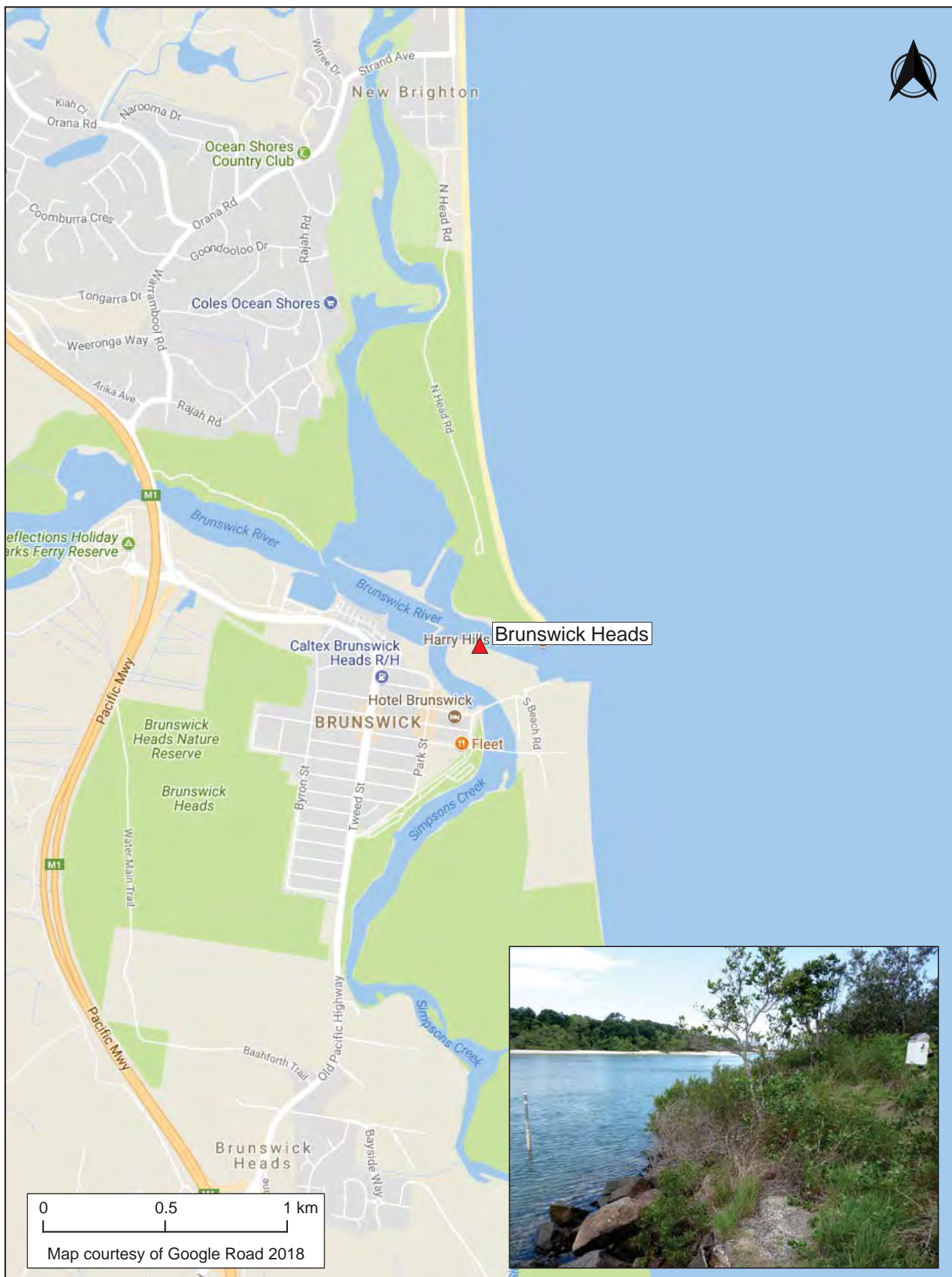
TWEED HEADS OFFSHORE DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A4

DRAWING 2693-A4.cdr



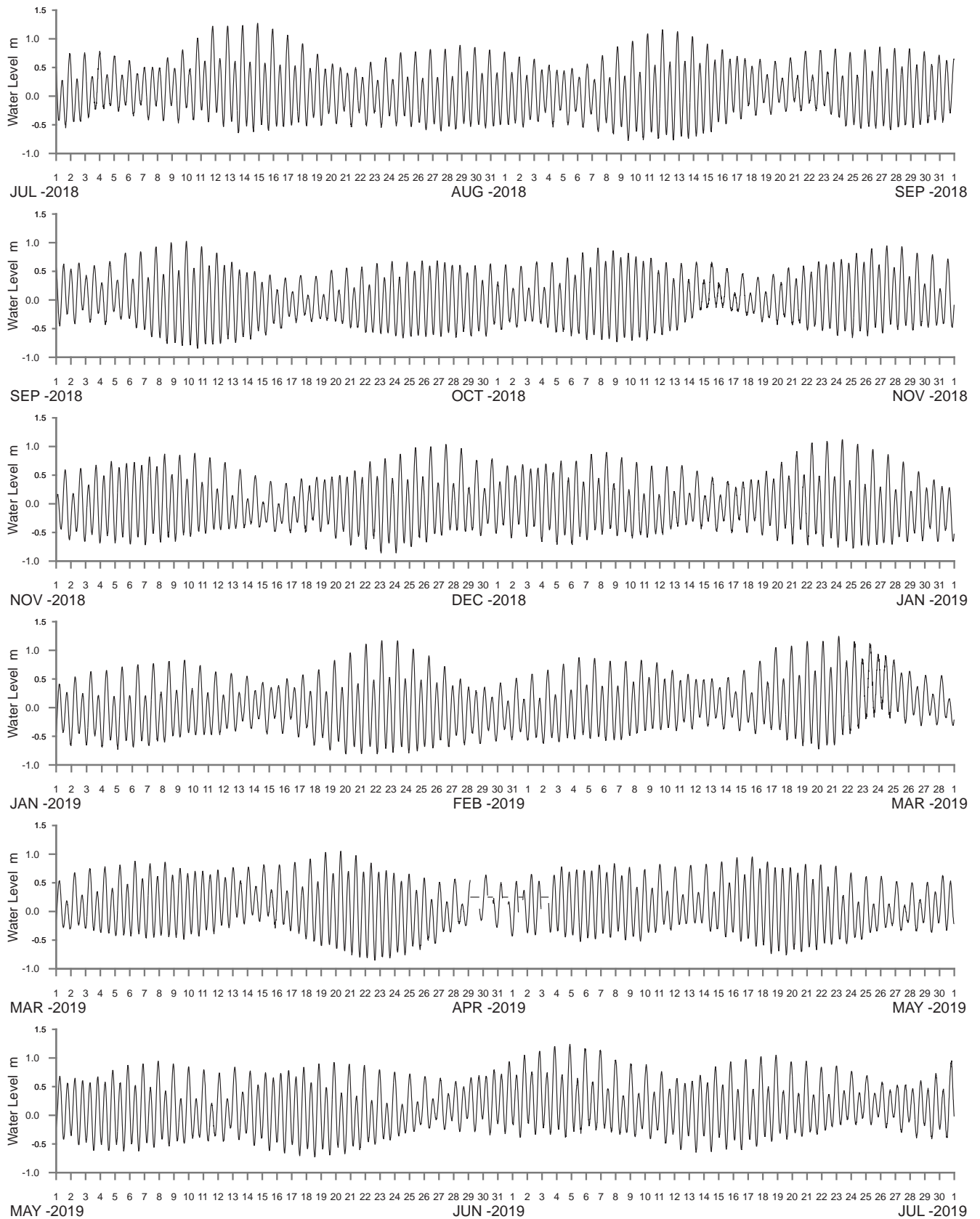
# BRUNSWICK HEADS STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A5

DRAWING 2693-A5.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



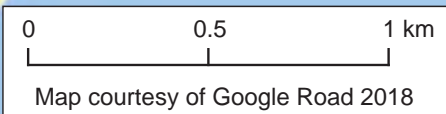
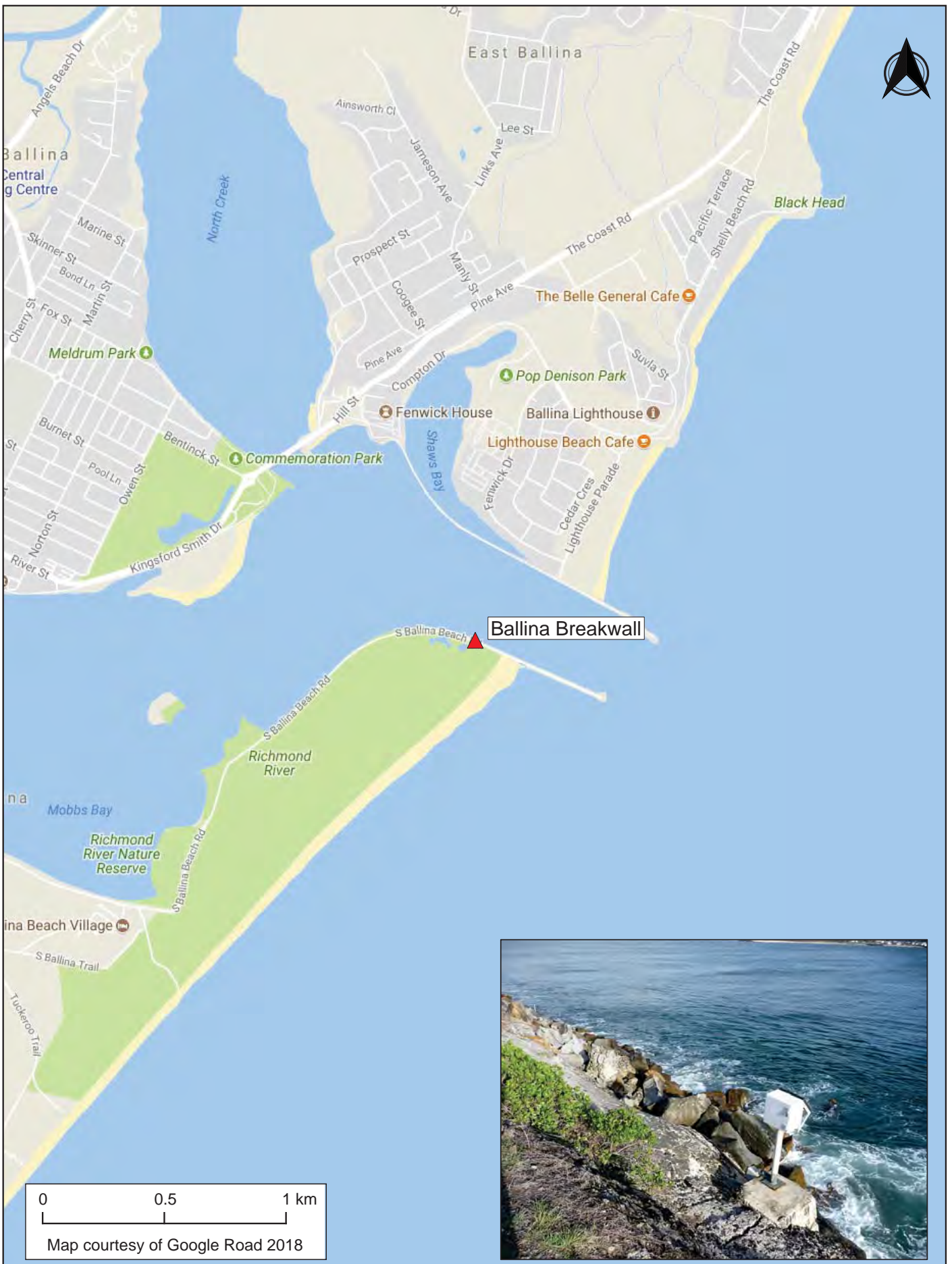
BRUNSWICK HEADS DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A6

DRAWING 2693-A6.cdr



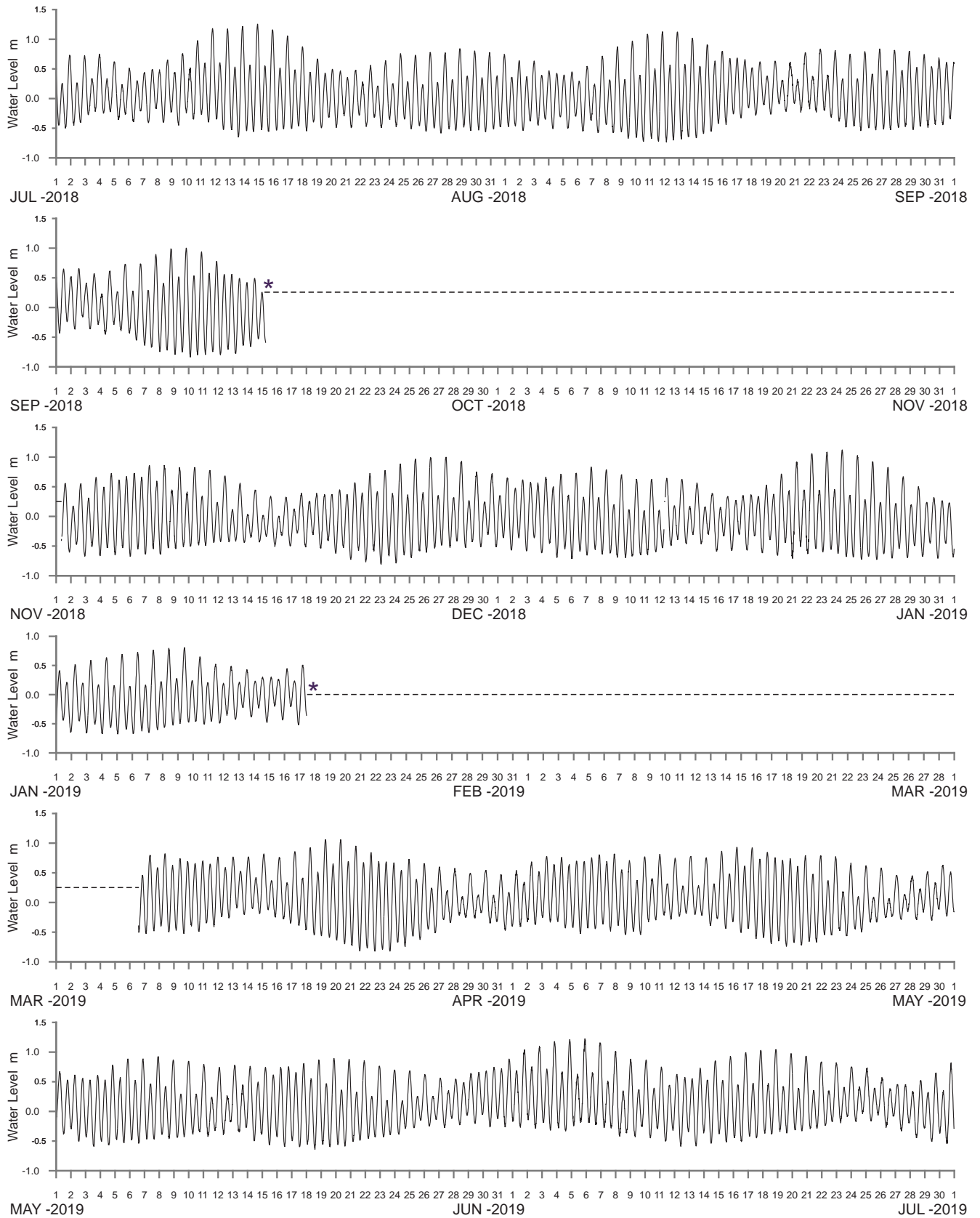
**BALLINA BREAKWALL  
STATION LOCATION**

**Manly  
Hydraulics  
Laboratory**

Report MHL2693

Figure  
A7

DRAWING 2693-A7.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS

\* Flushing issues due to siltation



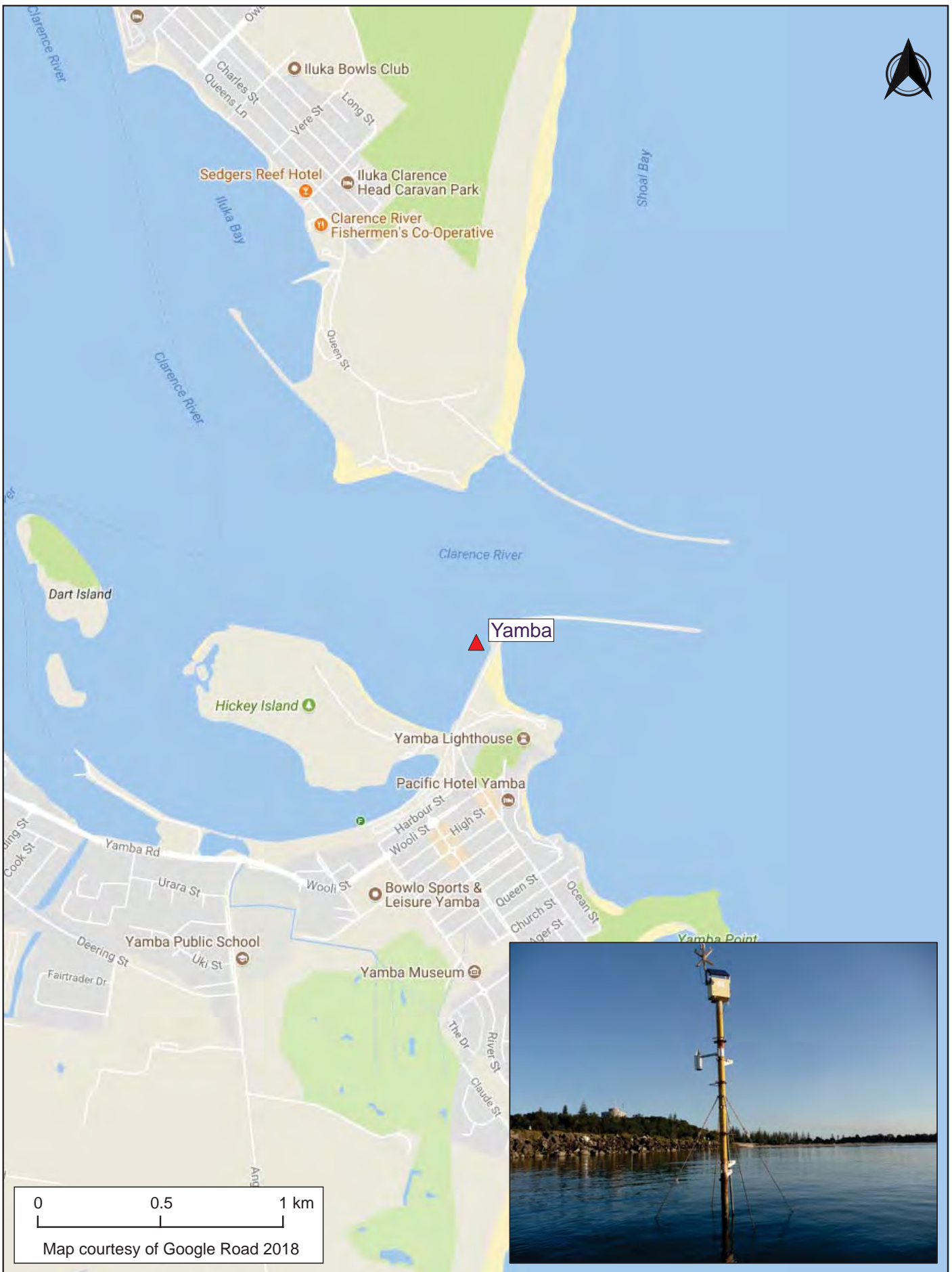
BALLINA BREAKWALL DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A8

DRAWING 2693-A8.cdr



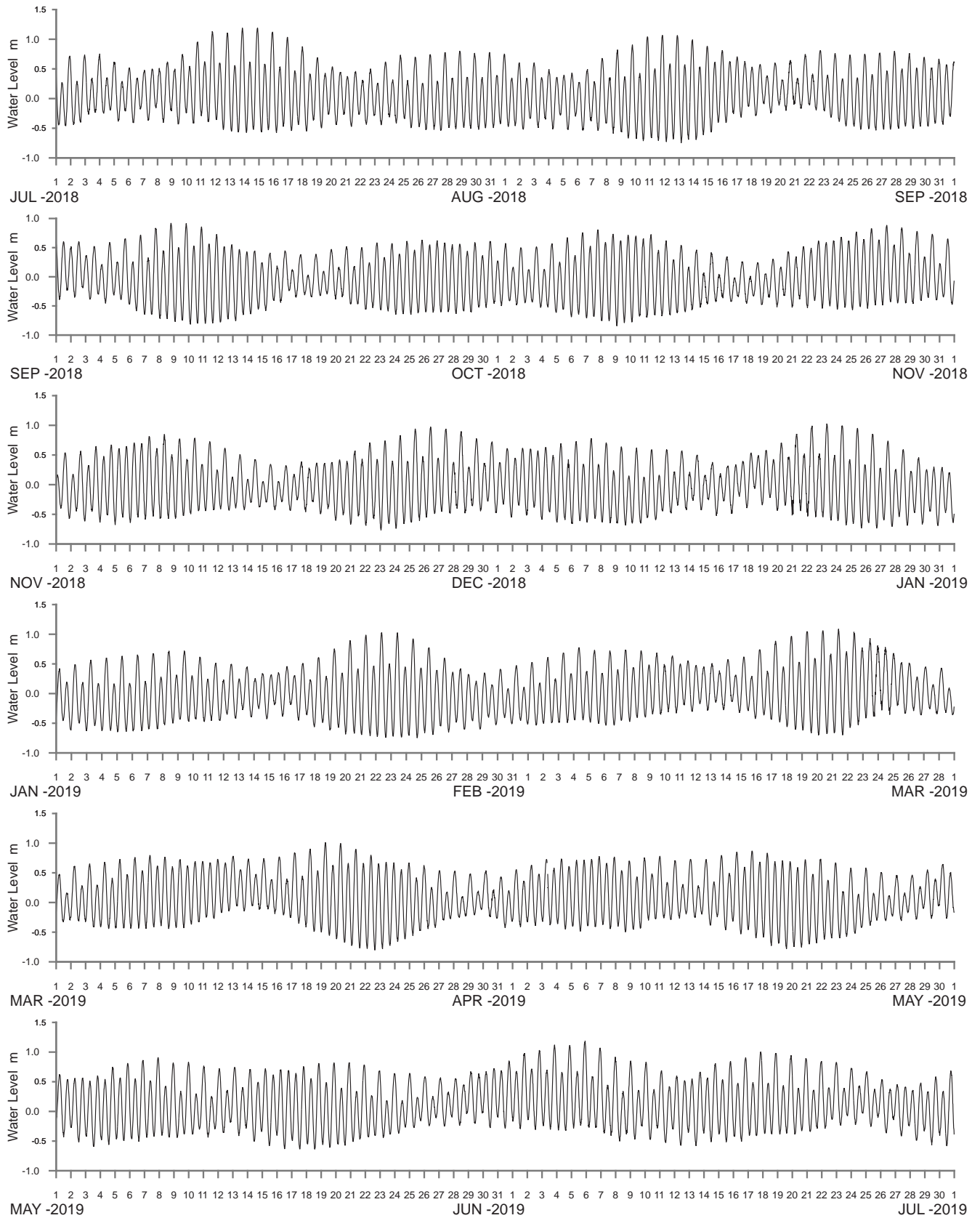
### YAMBA STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A9

DRAWING 2693-A9.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



YAMBA DATA SUMMARY  
2018–2019

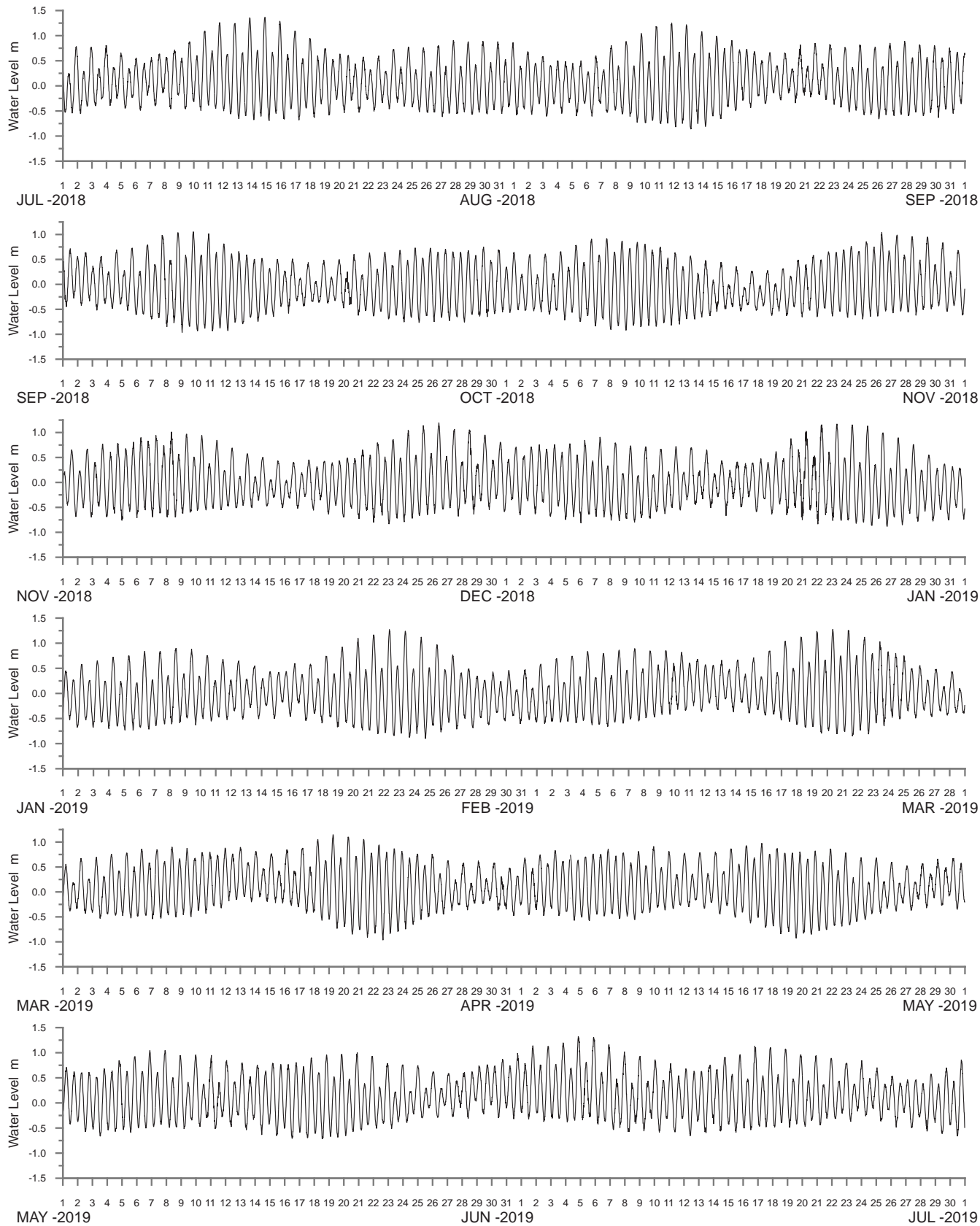
Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A10

DRAWING 2693-A10.cdr





WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS

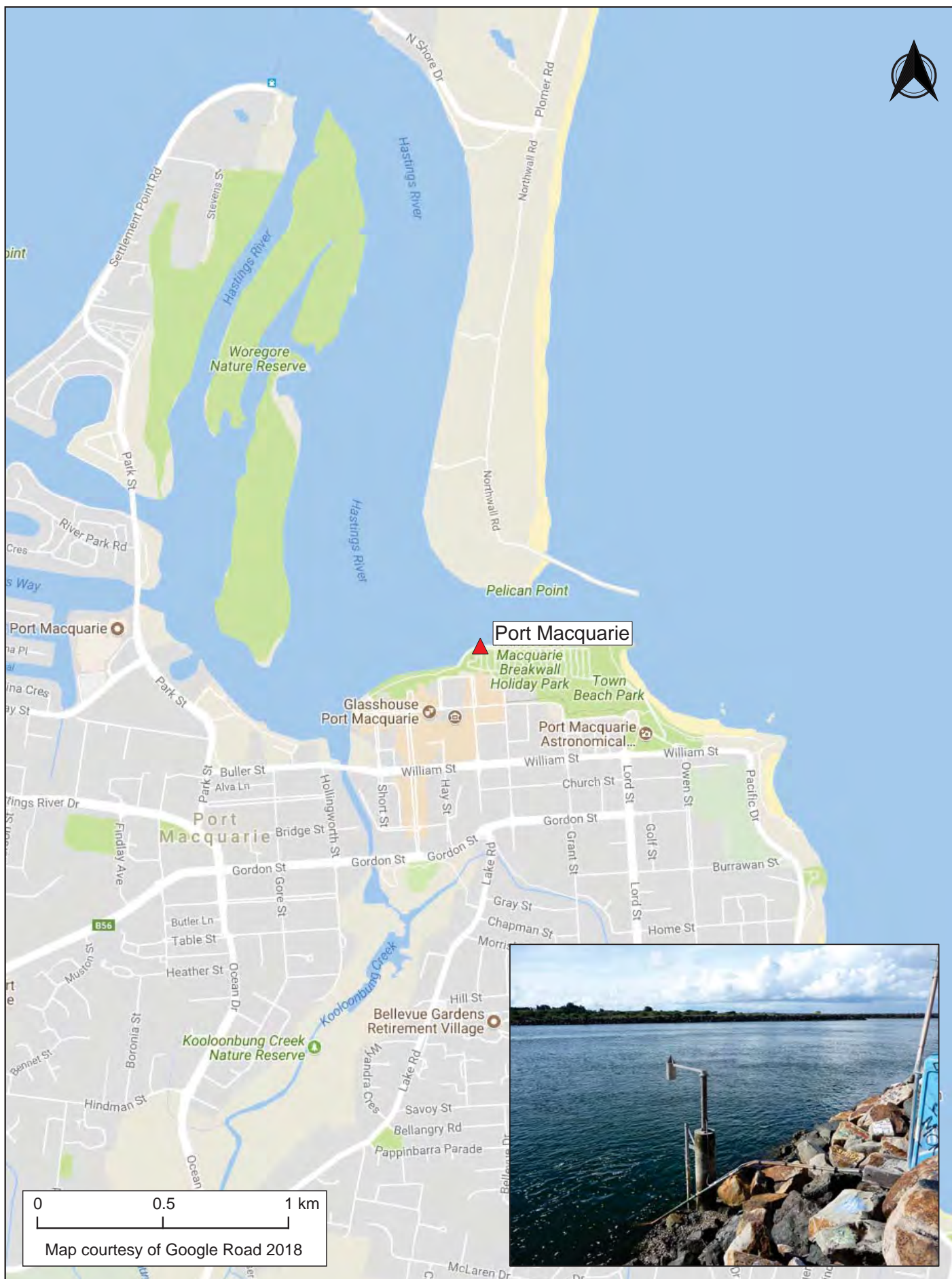


COFFS HARBOUR DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693  
Figure  
A12

DRAWING 2693-A12.cdr



0 0.5 1 km  
Map courtesy of Google Road 2018



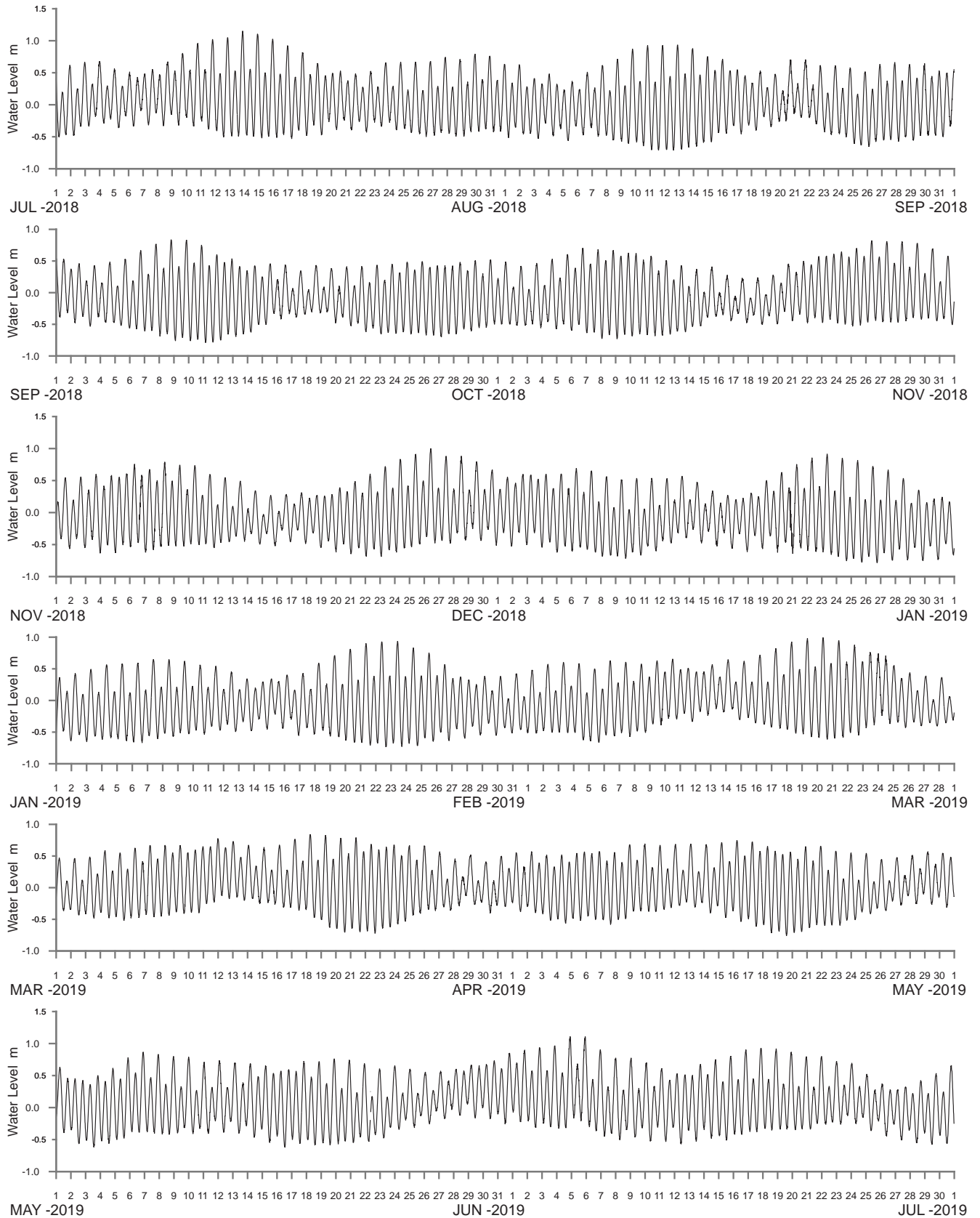
### PORT MACQUARIE STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A13

DRAWING 2693-A13.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



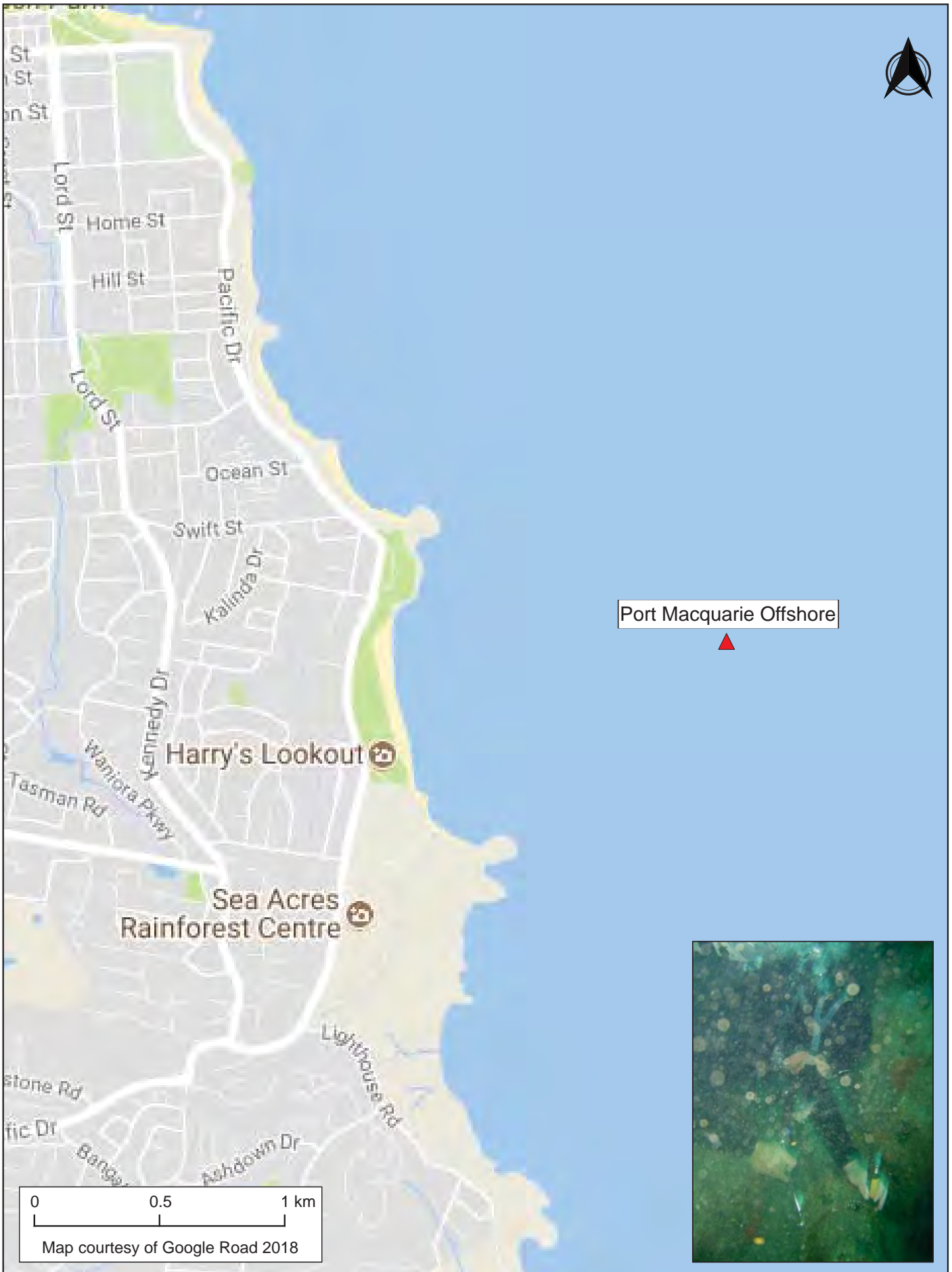
PORT MACQUARIE DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A14

DRAWING 2693-A14.cdr



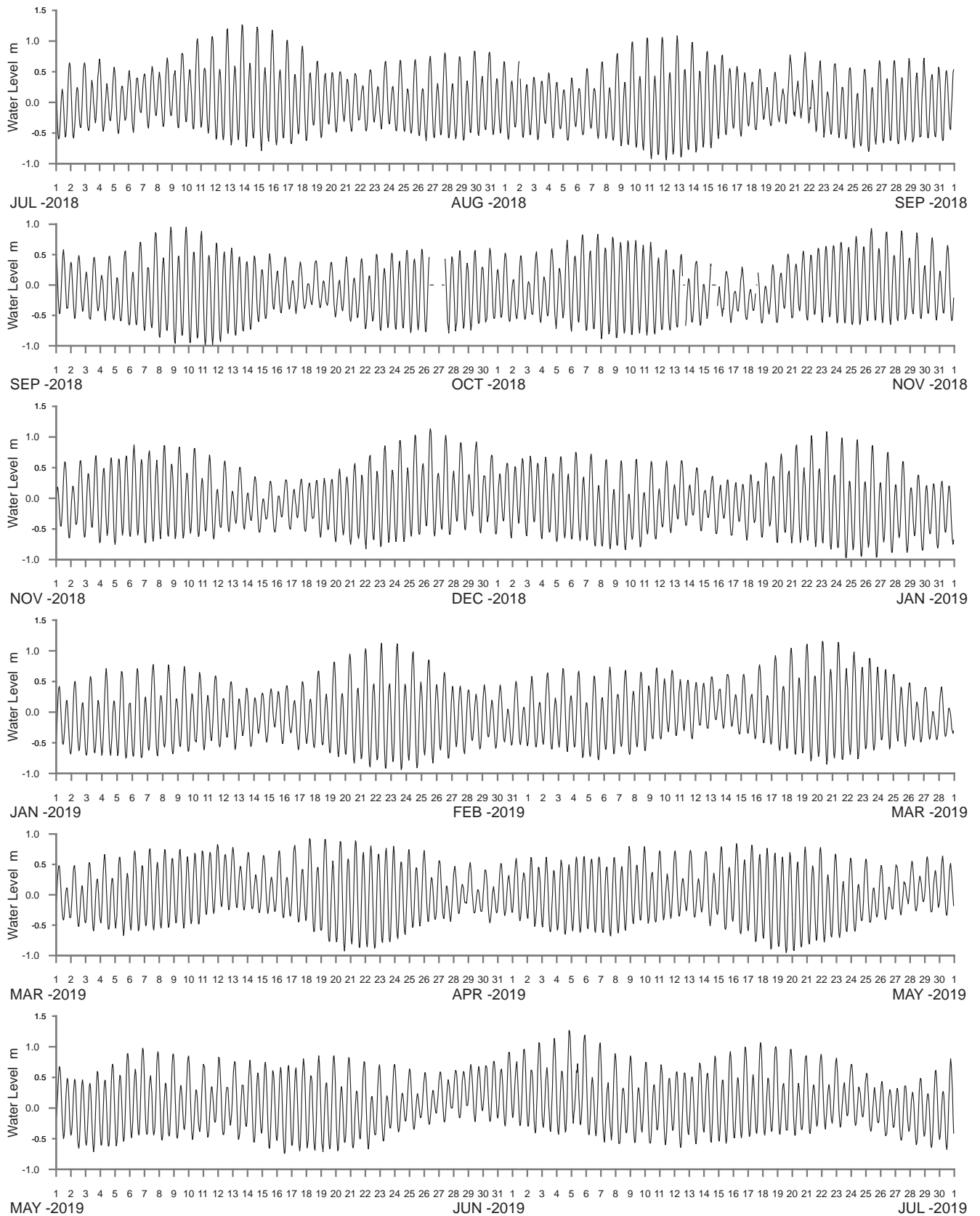
PORT MACQUARIE OFFSHORE  
STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A15

DRAWING 2693-A15.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS



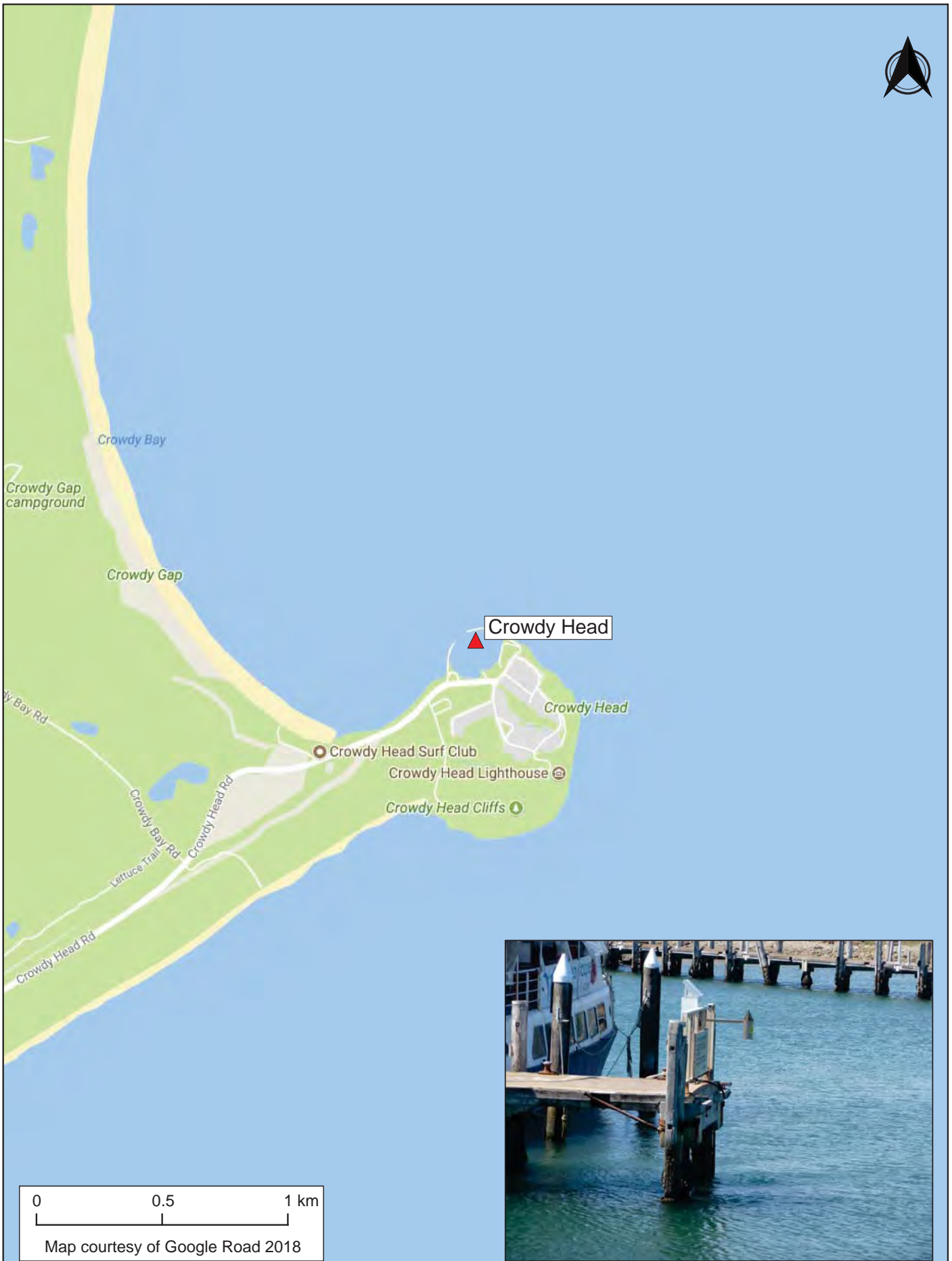
PORT MACQUARIE OFFSHORE DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A16

DRAWING 2693-A16.cdr



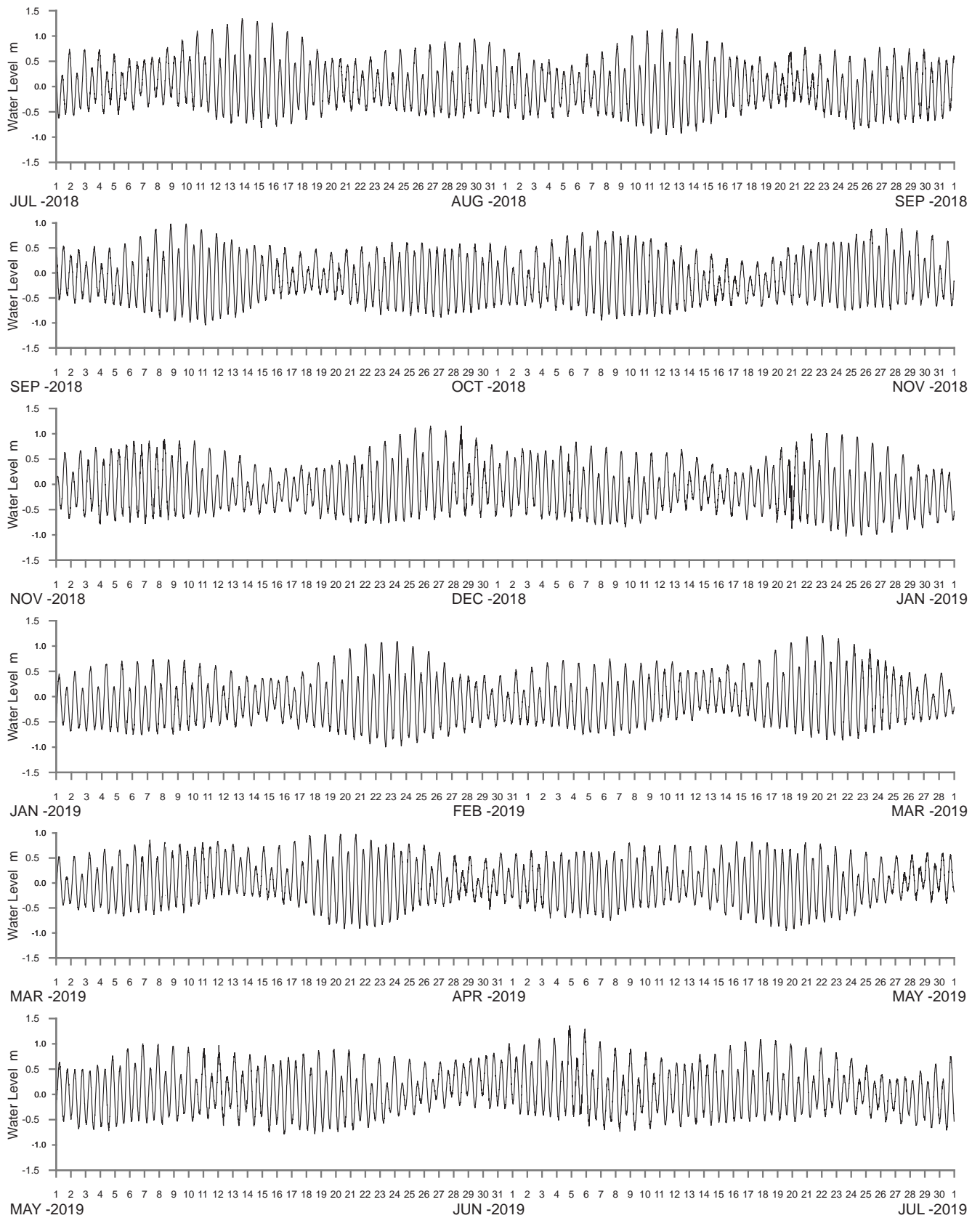
### CROWDY HEAD STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A17

DRAWING 2693-A17.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



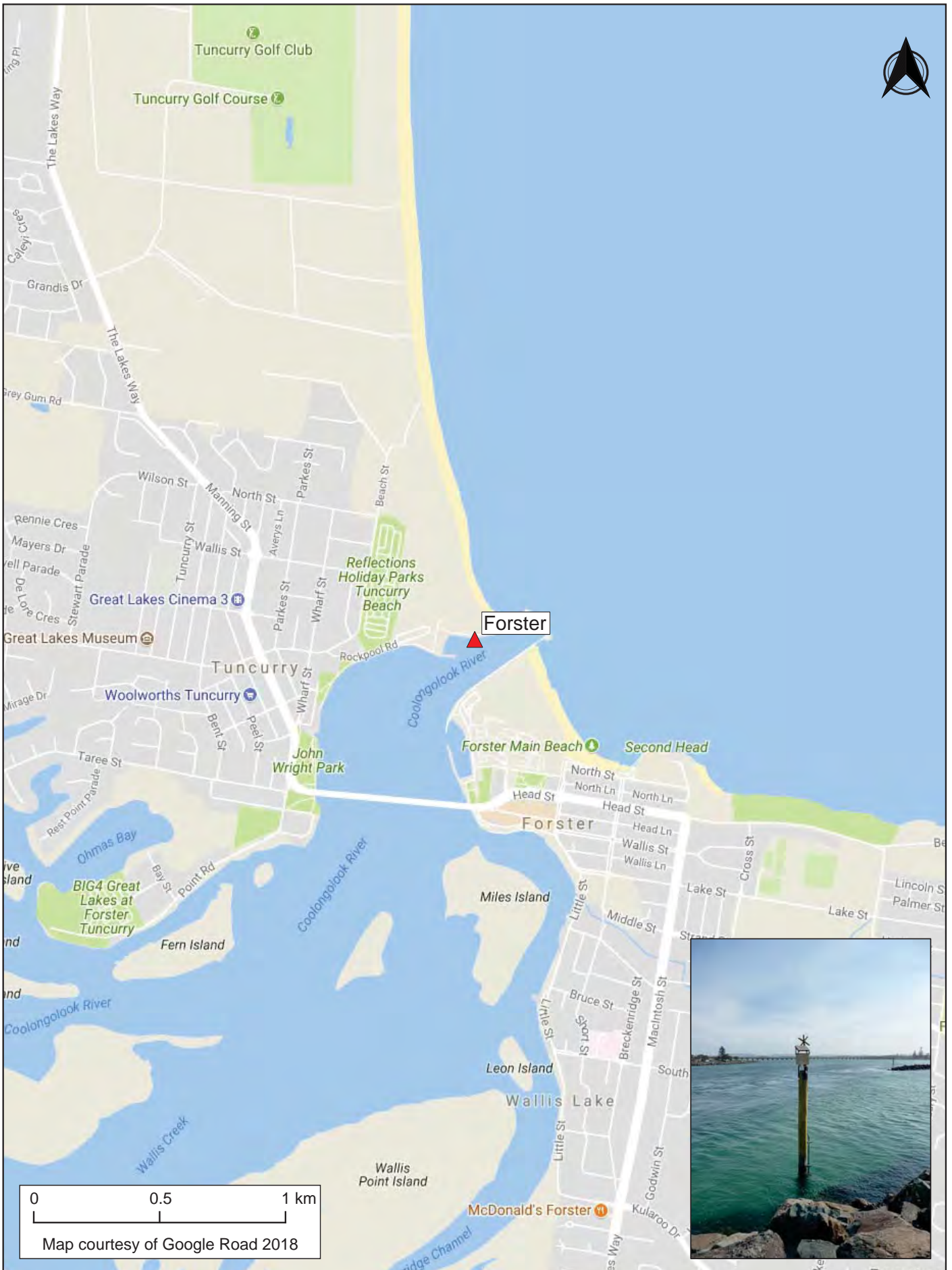
CROWDY HEAD DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A18

DRAWING 2693-A18.cdr



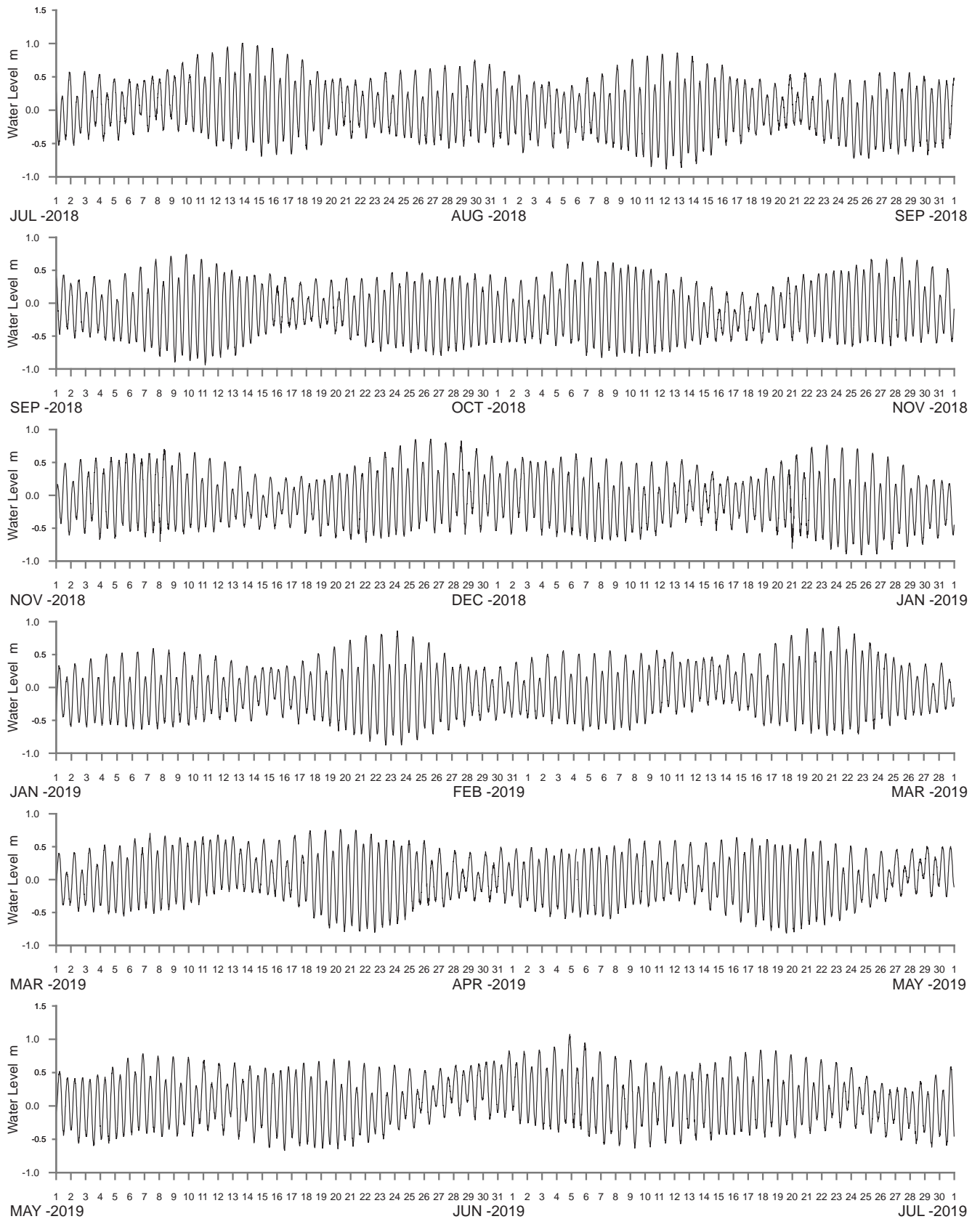
### FORSTER STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A19

DRAWING 2693-A19.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



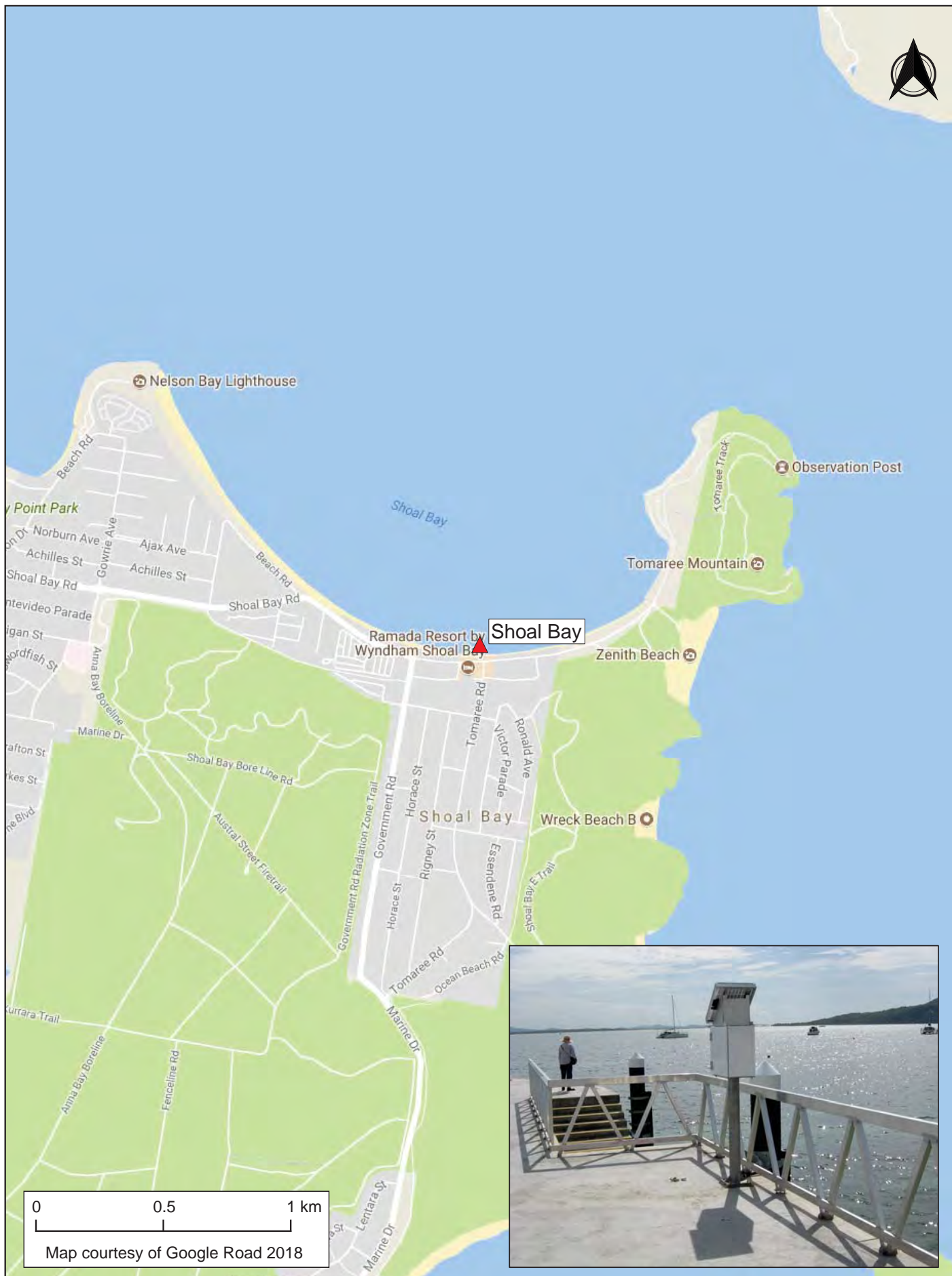
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2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A20

DRAWING 2693-A20.cdr



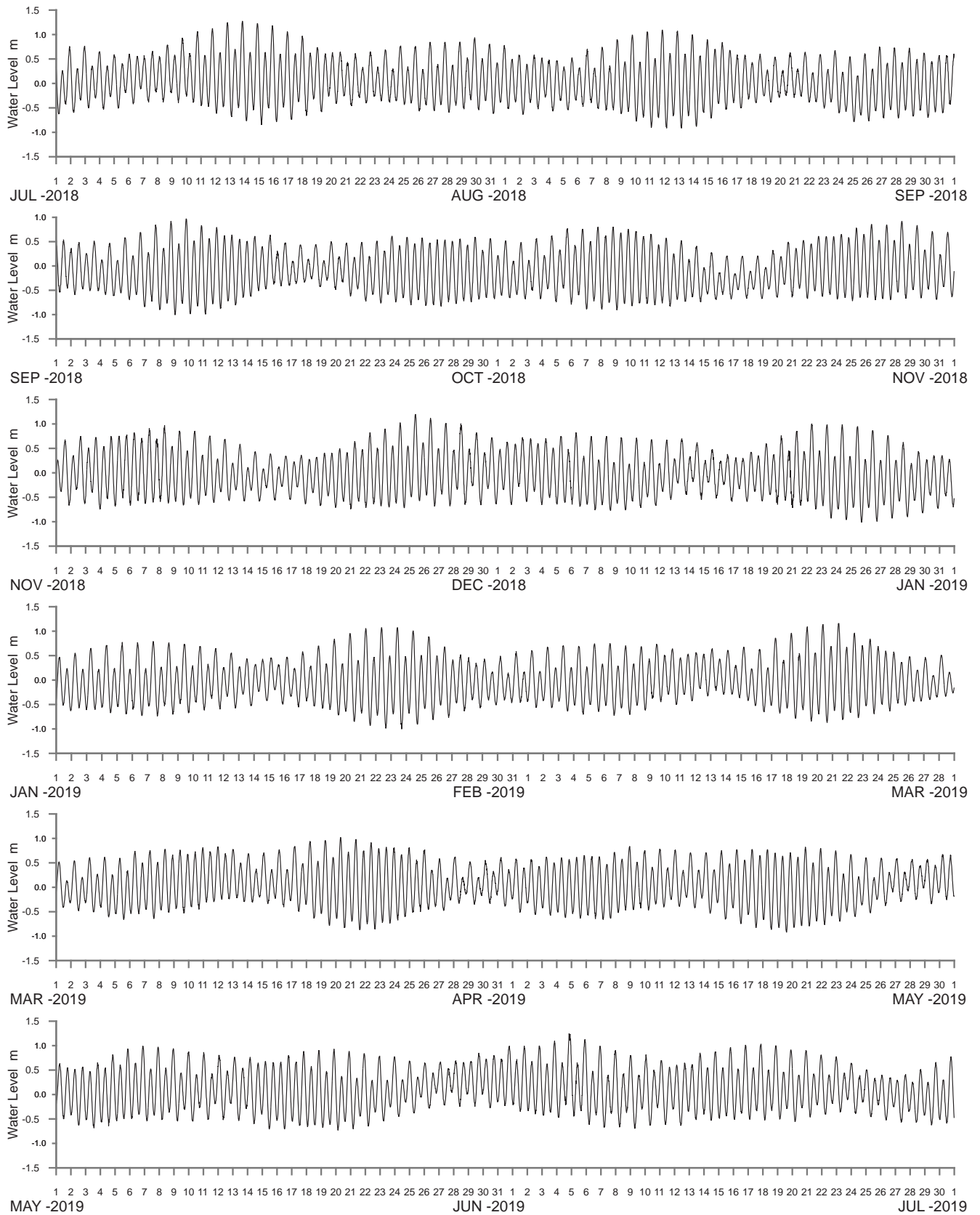
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 Map courtesy of Google Road 2018



SHOAL BAY  
 STATION LOCATION

Manly  
 Hydraulics  
 Laboratory

Report MHL2693  
 Figure  
 A21



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



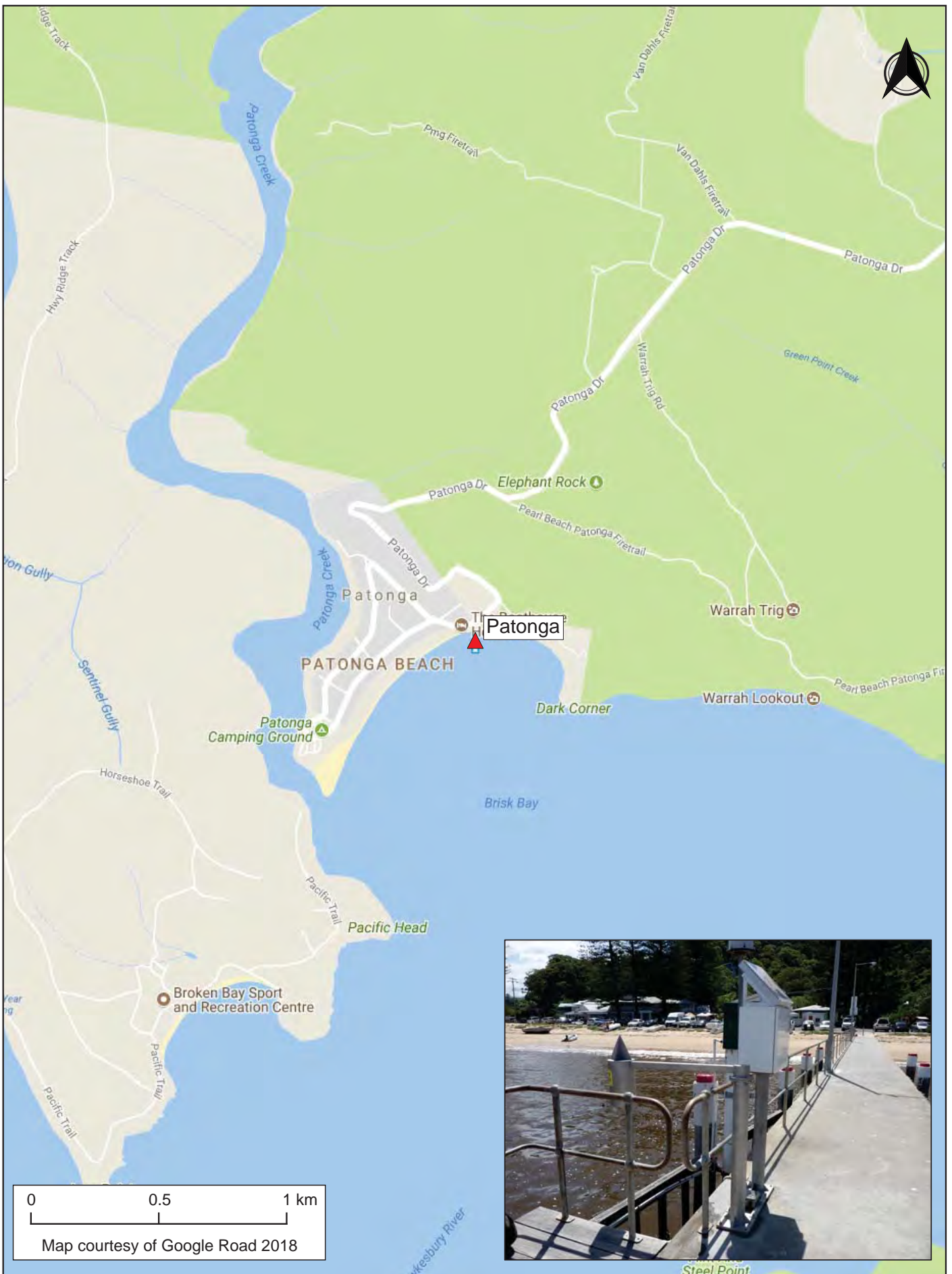
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2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

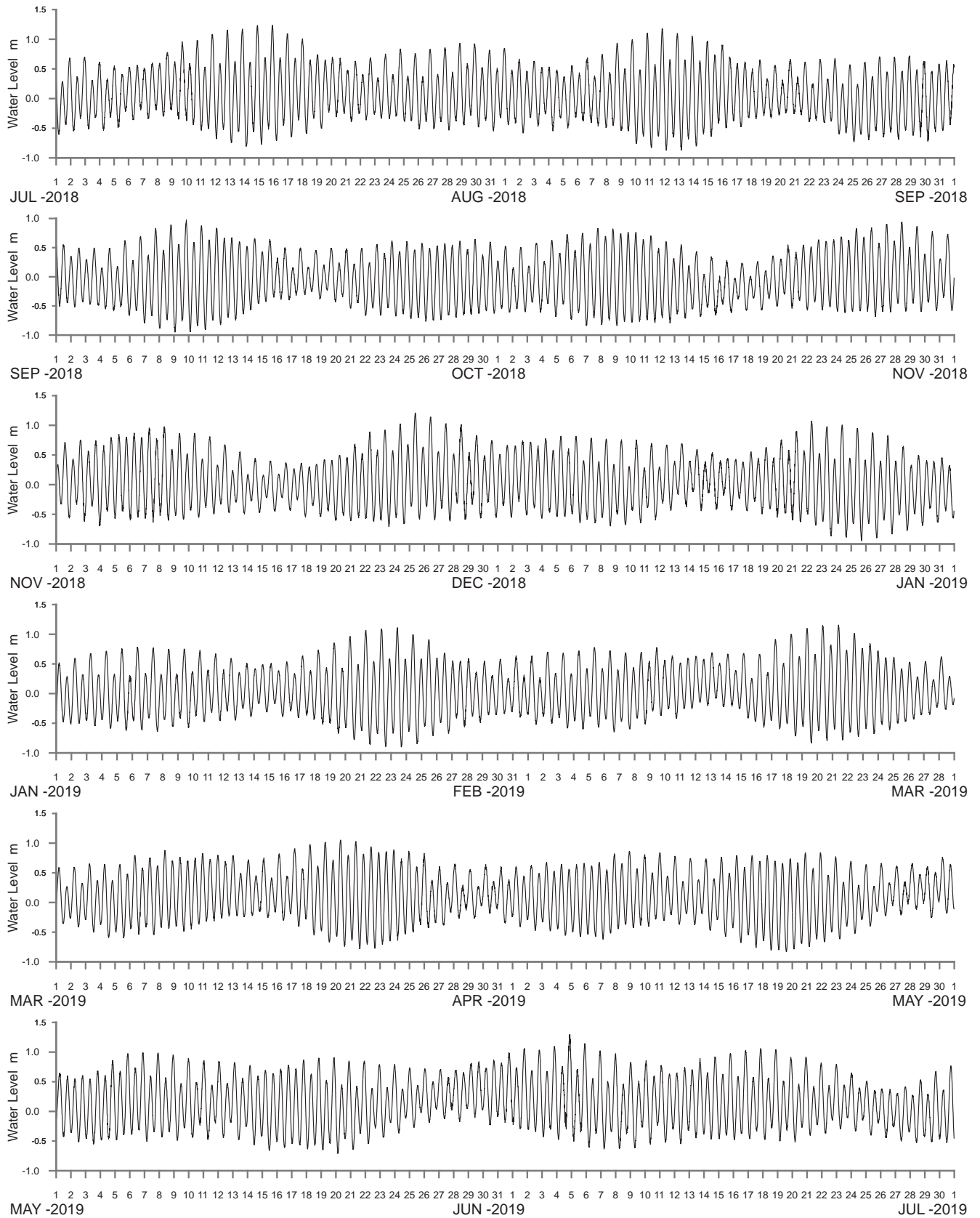
Figure  
A22

DRAWING 2693-A22.cdr



PATONGA  
STATION LOCATION

Manly  
Hydraulics  
Laboratory  
Report MHL2693  
Figure  
A23  
DRAWING 2693-A23.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



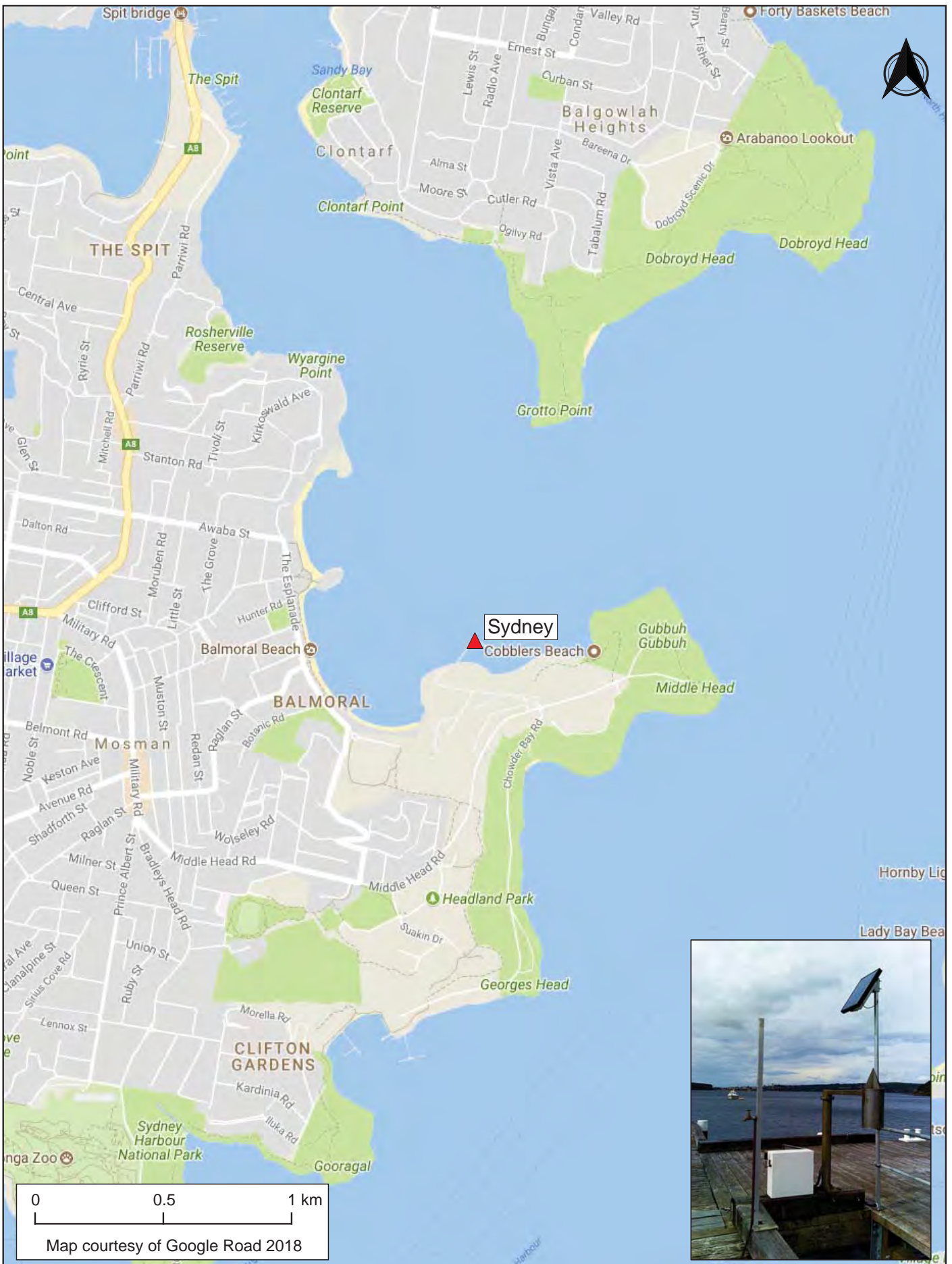
PATONGA DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A24

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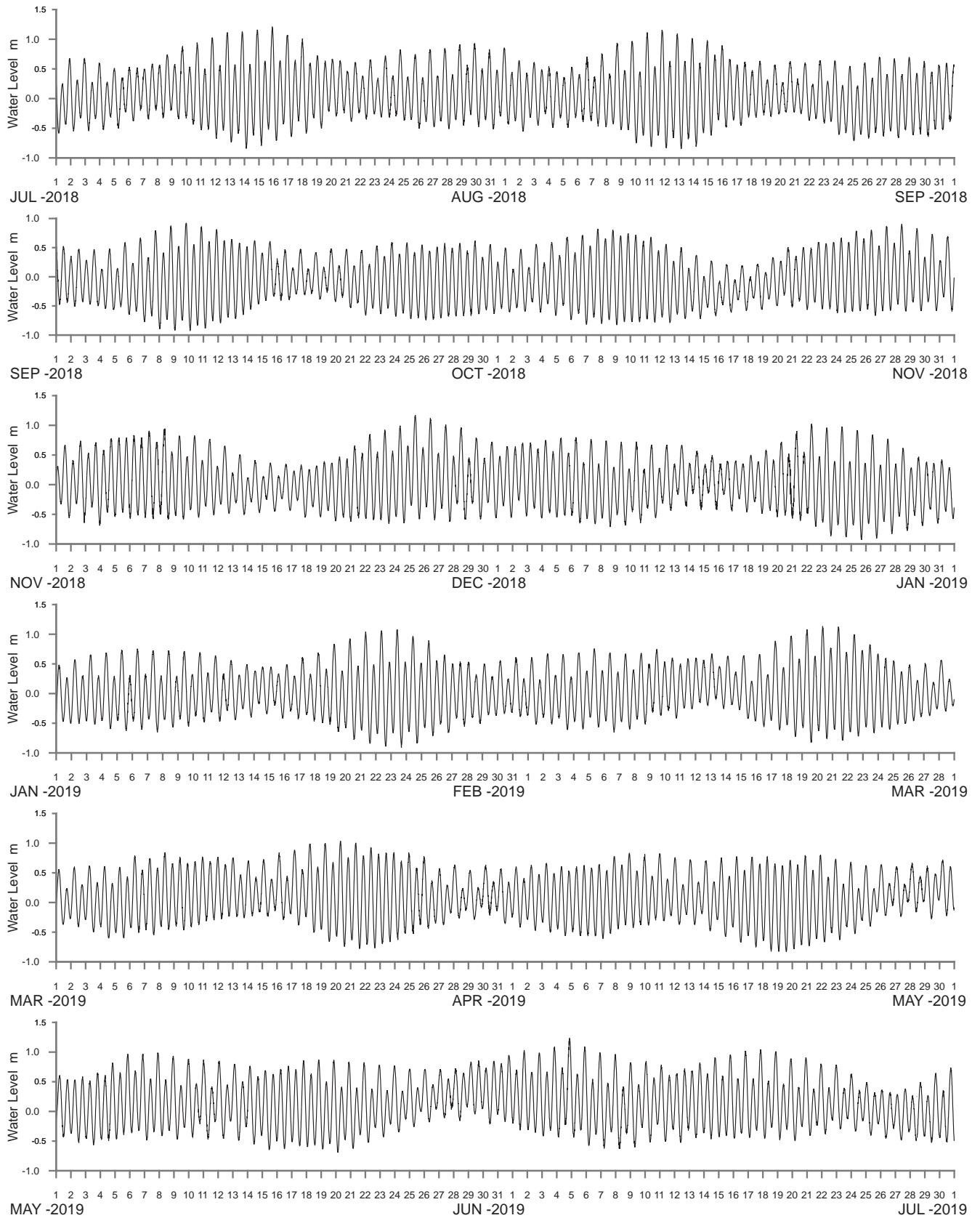
SYDNEY  
STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A25

DRAWING 2693-A25.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



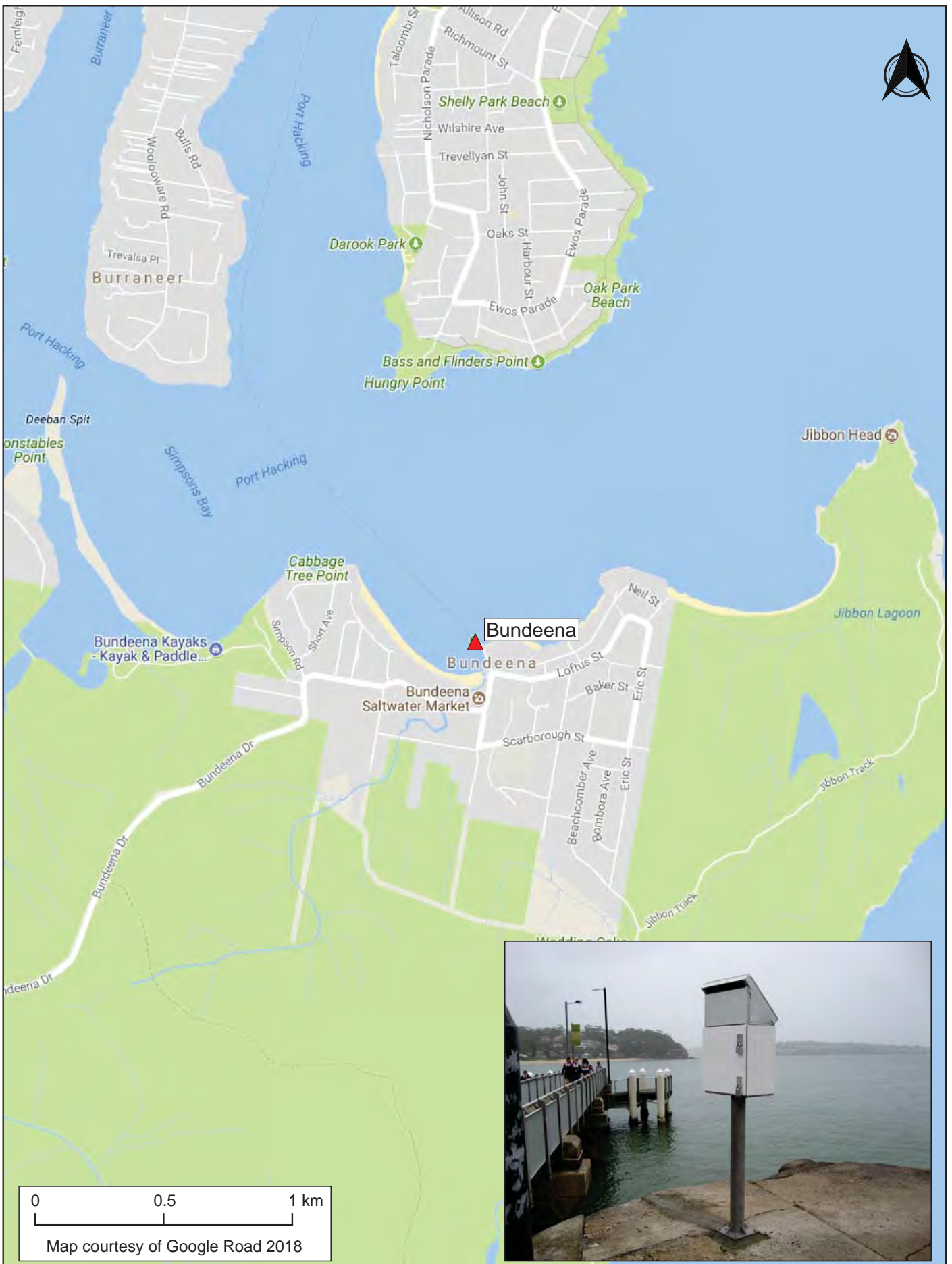
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2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A26

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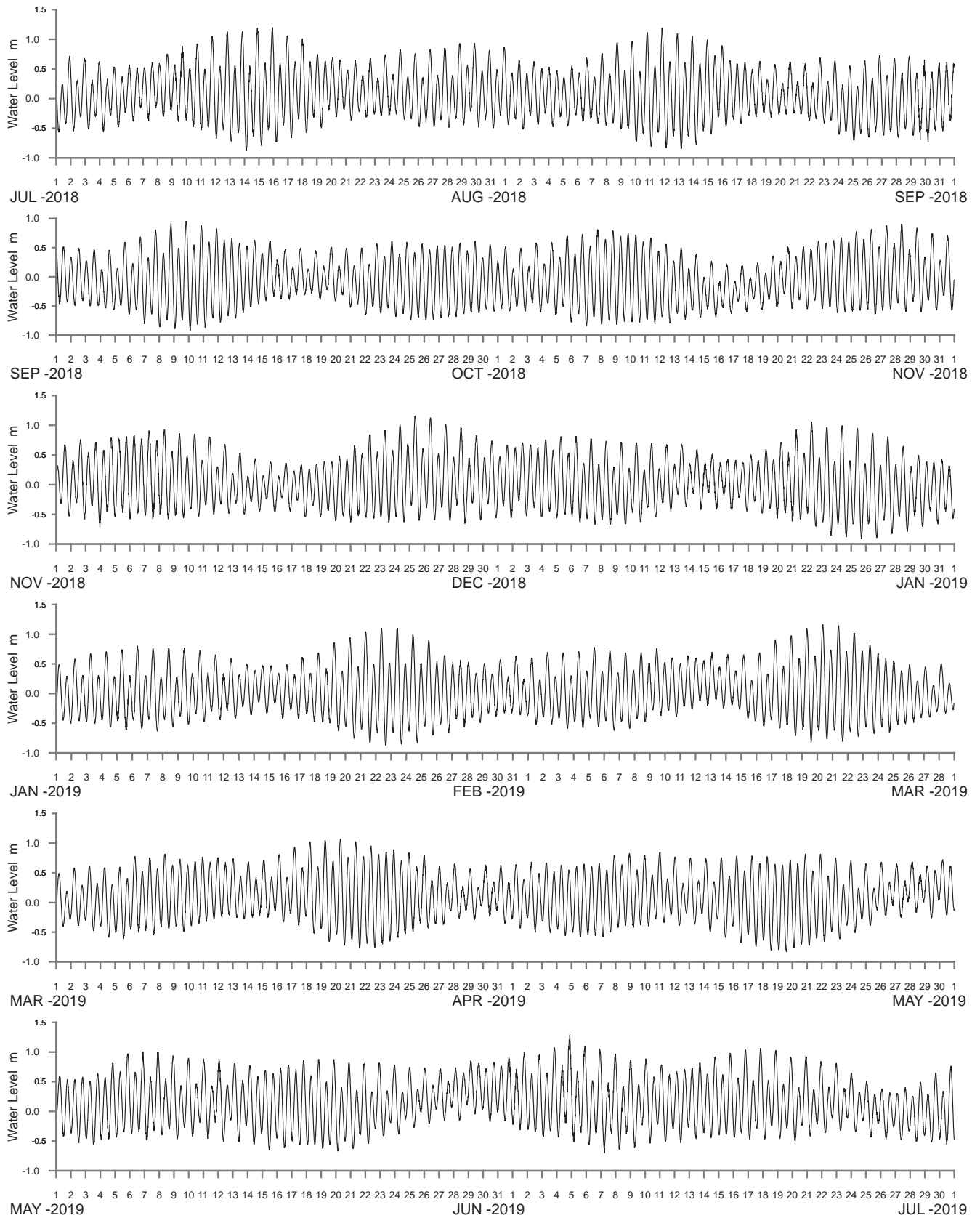


**BUNDEENA  
STATION LOCATION**

**Manly  
Hydraulics  
Laboratory**

Report MHL2693  
Figure  
A27

DRAWING 2693-A27.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



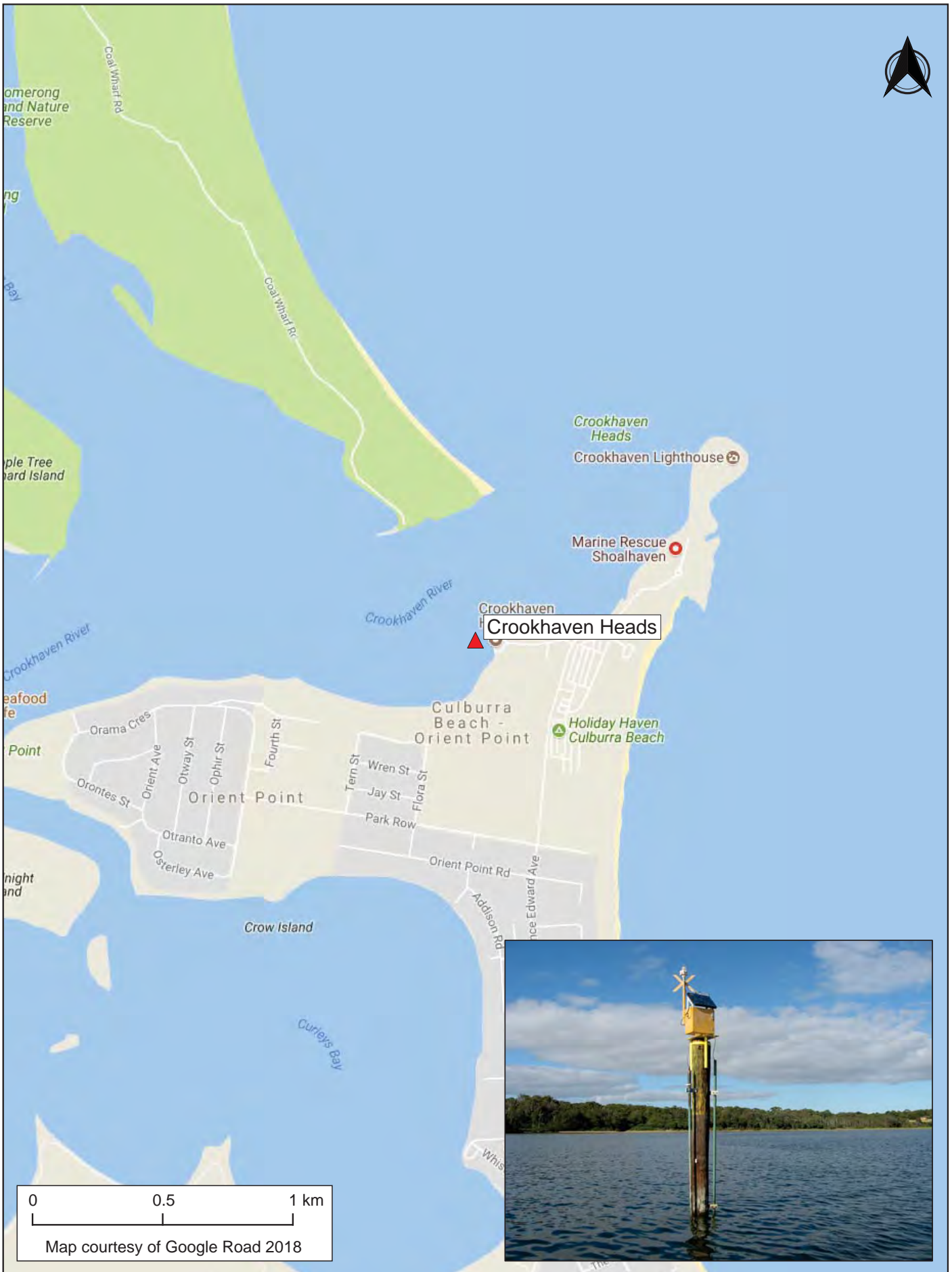
BUNDEENA DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A28

DRAWING 2693-A28.cdr



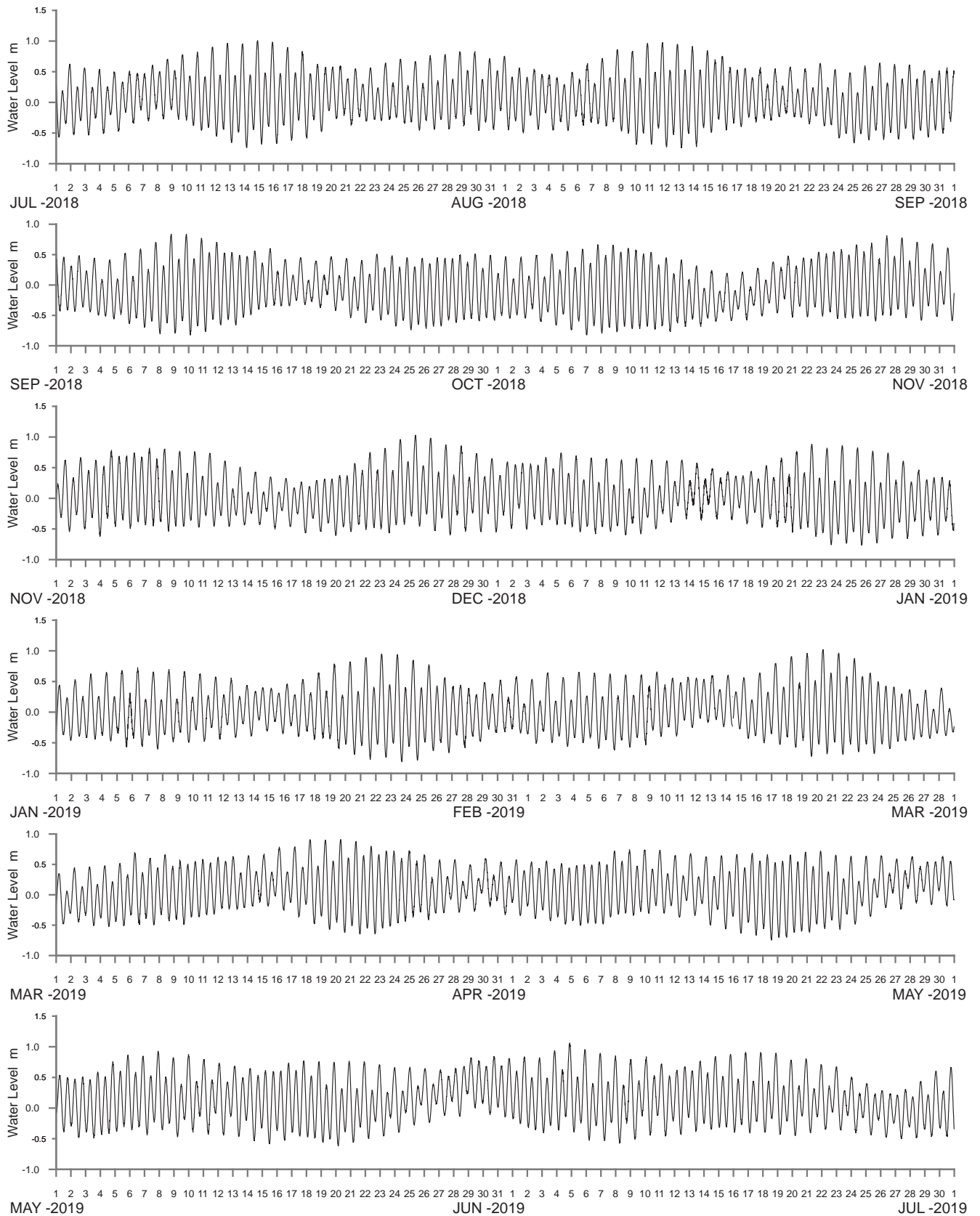
### CROOKHAVEN HEADS STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A29

DRAWING 2693-A29.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



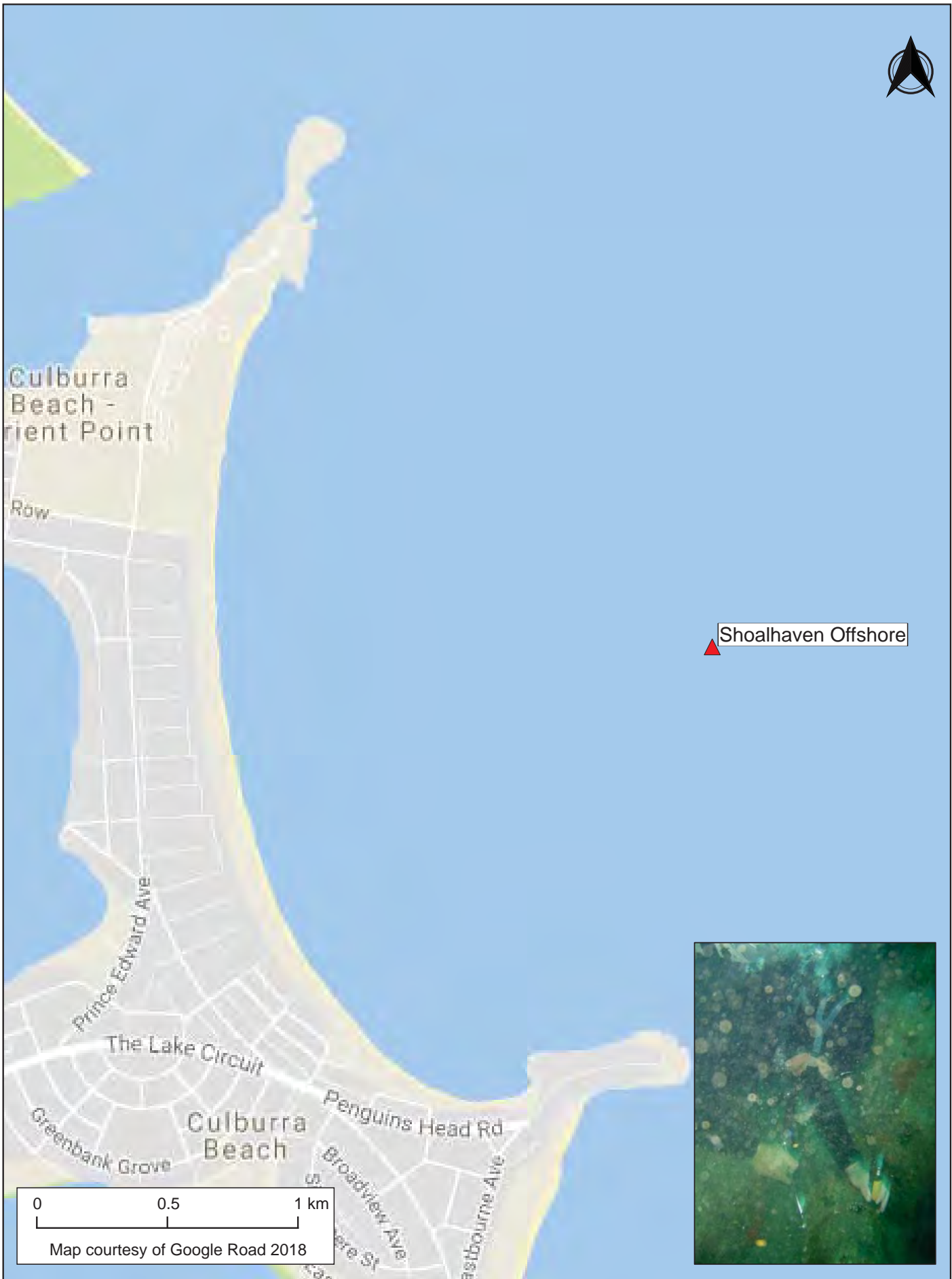
CROOKHAVEN HEADS DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A30

DRAWING 2693-A30.cdr



Shoalhaven Offshore



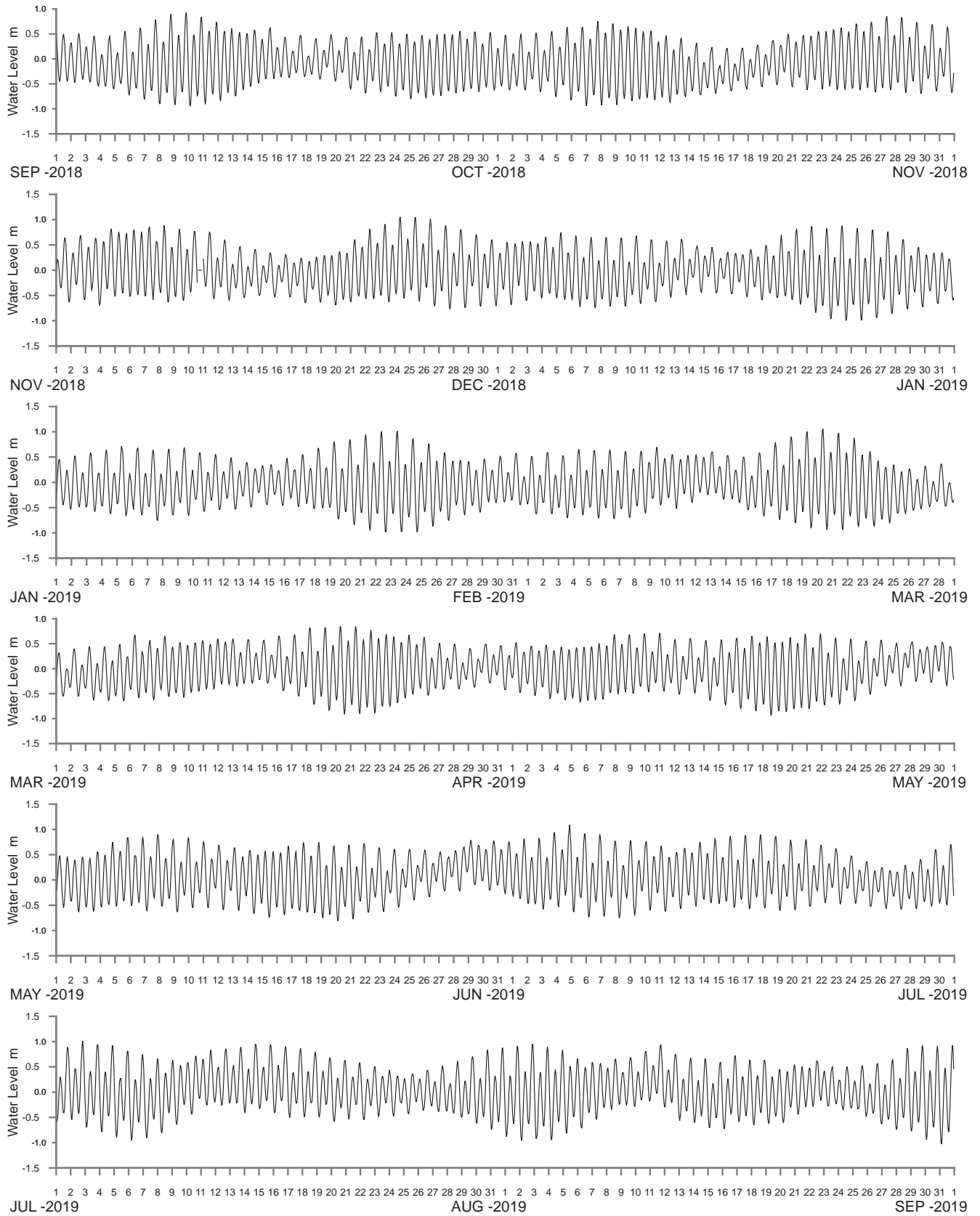
### SHOALHAVEN OFFSHORE STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A31

DRAWING 2693-A31.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS



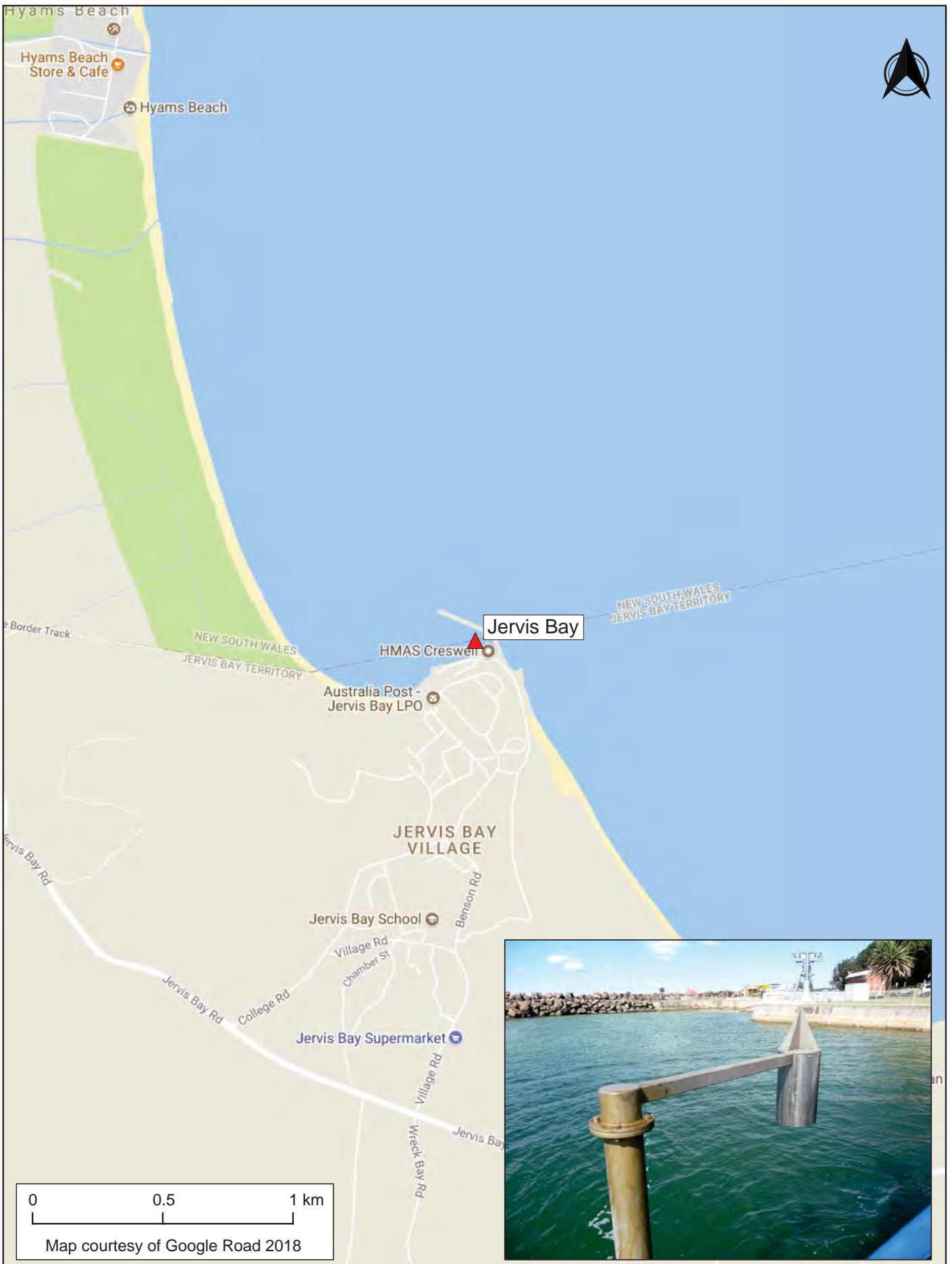
SHOALHAVEN OFFSHORE DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A32

DRAWING 2693-A32.cdr



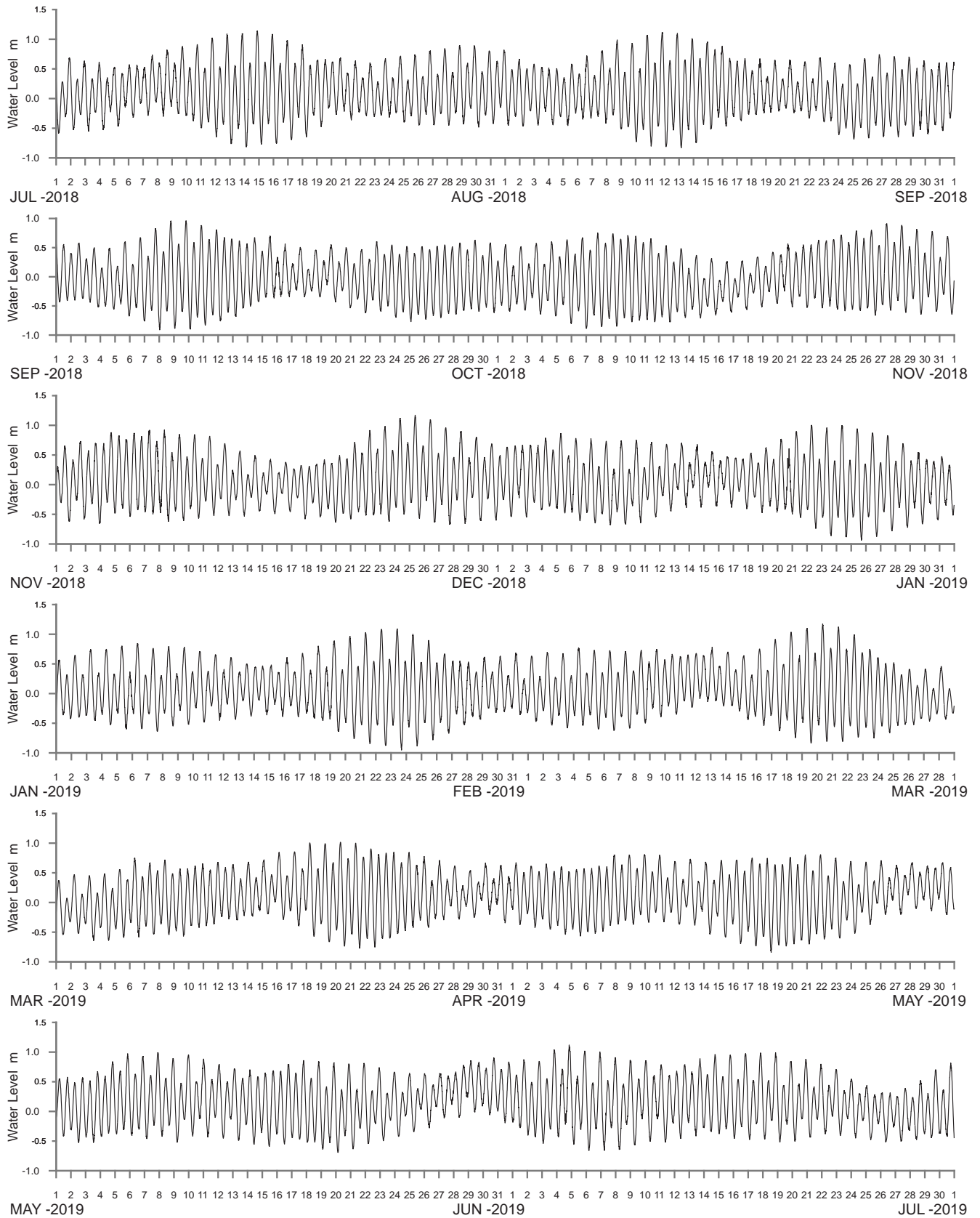
JERVIS BAY  
STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A33

DRAWING 2693-A33.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



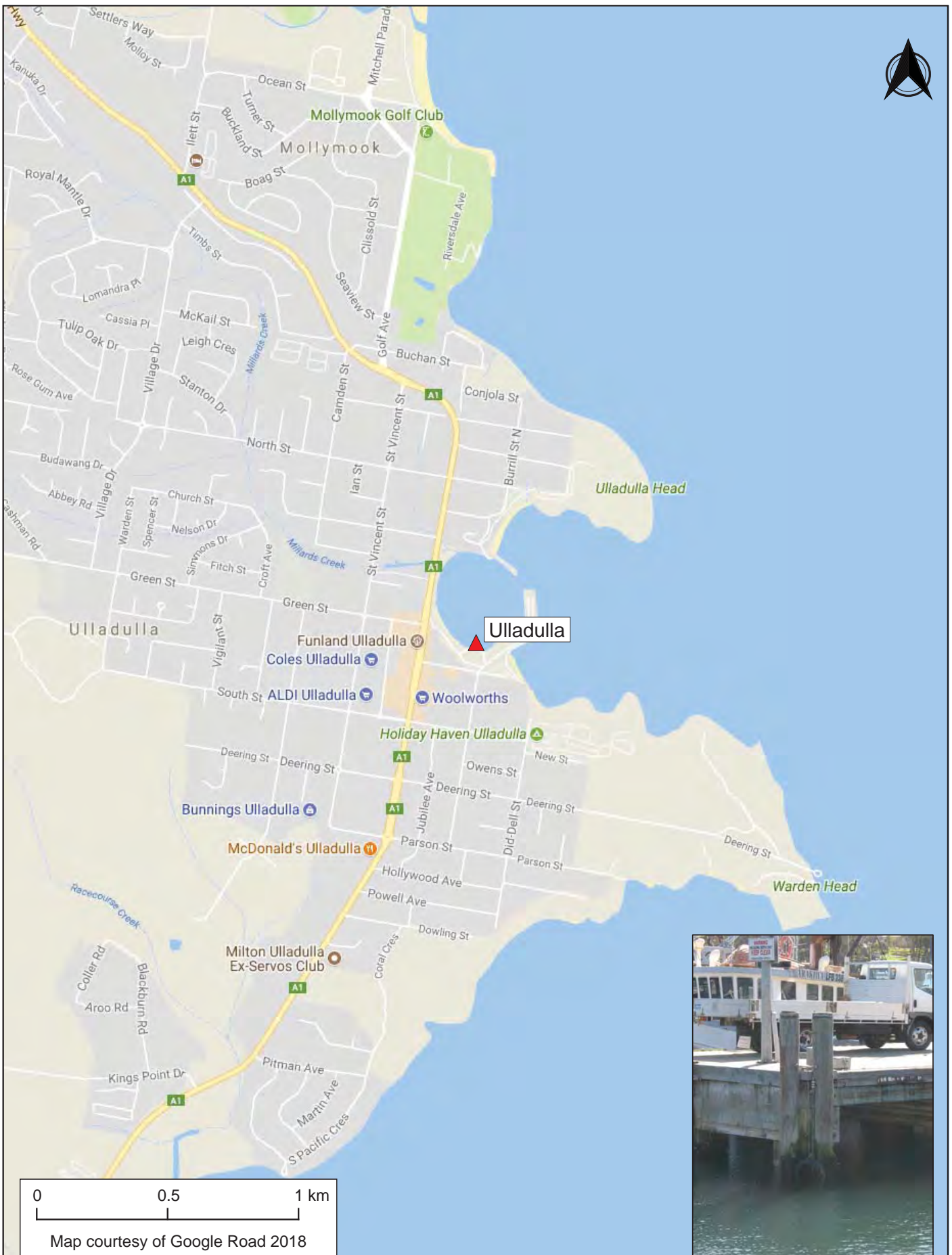
JERVIS BAY DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A34

DRAWING 2693-A34.cdr

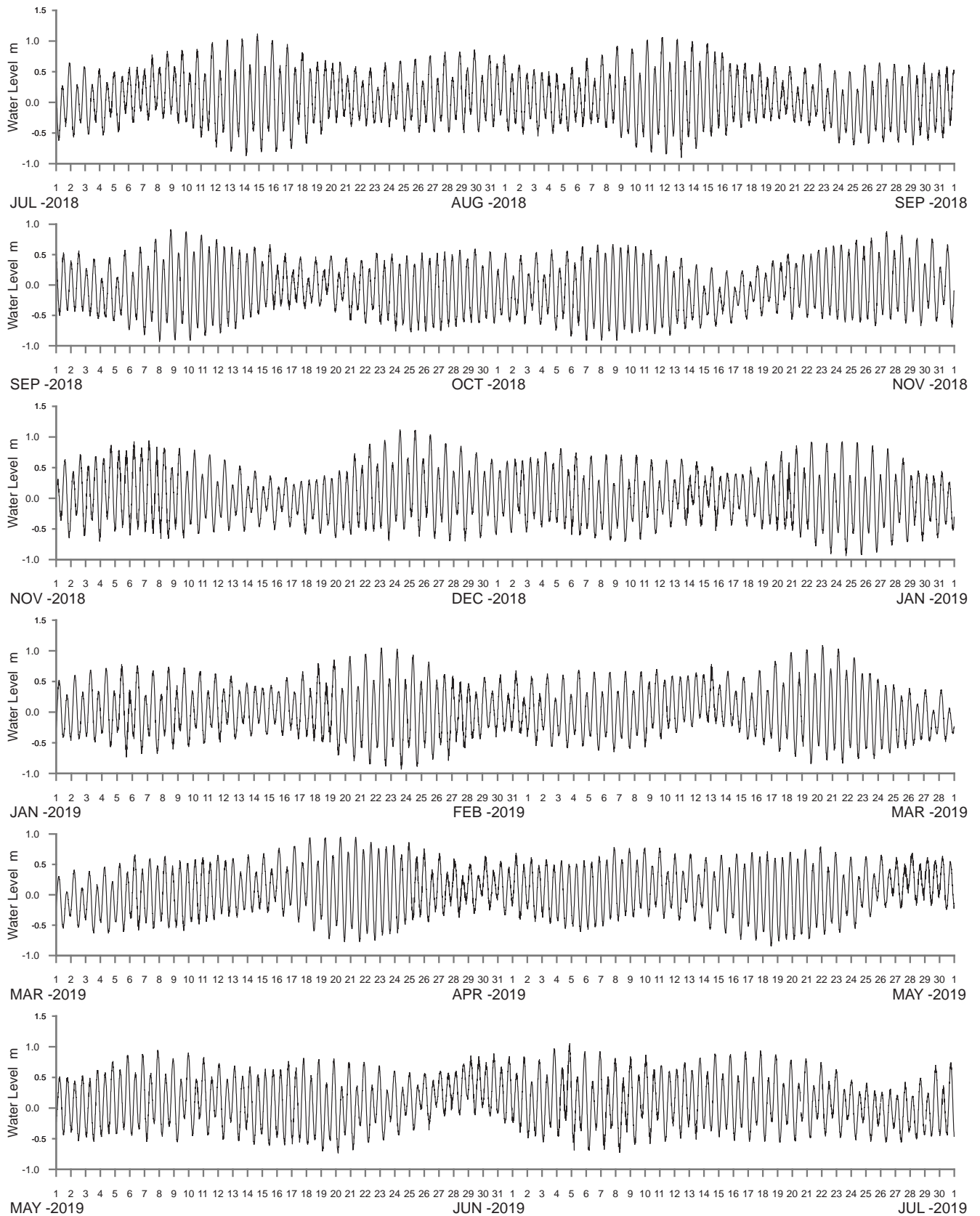


### ULLADULLA STATION LOCATION

**Manly  
Hydraulics  
Laboratory**

Report MHL2693  
Figure  
A35

DRAWING 2693-A35.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



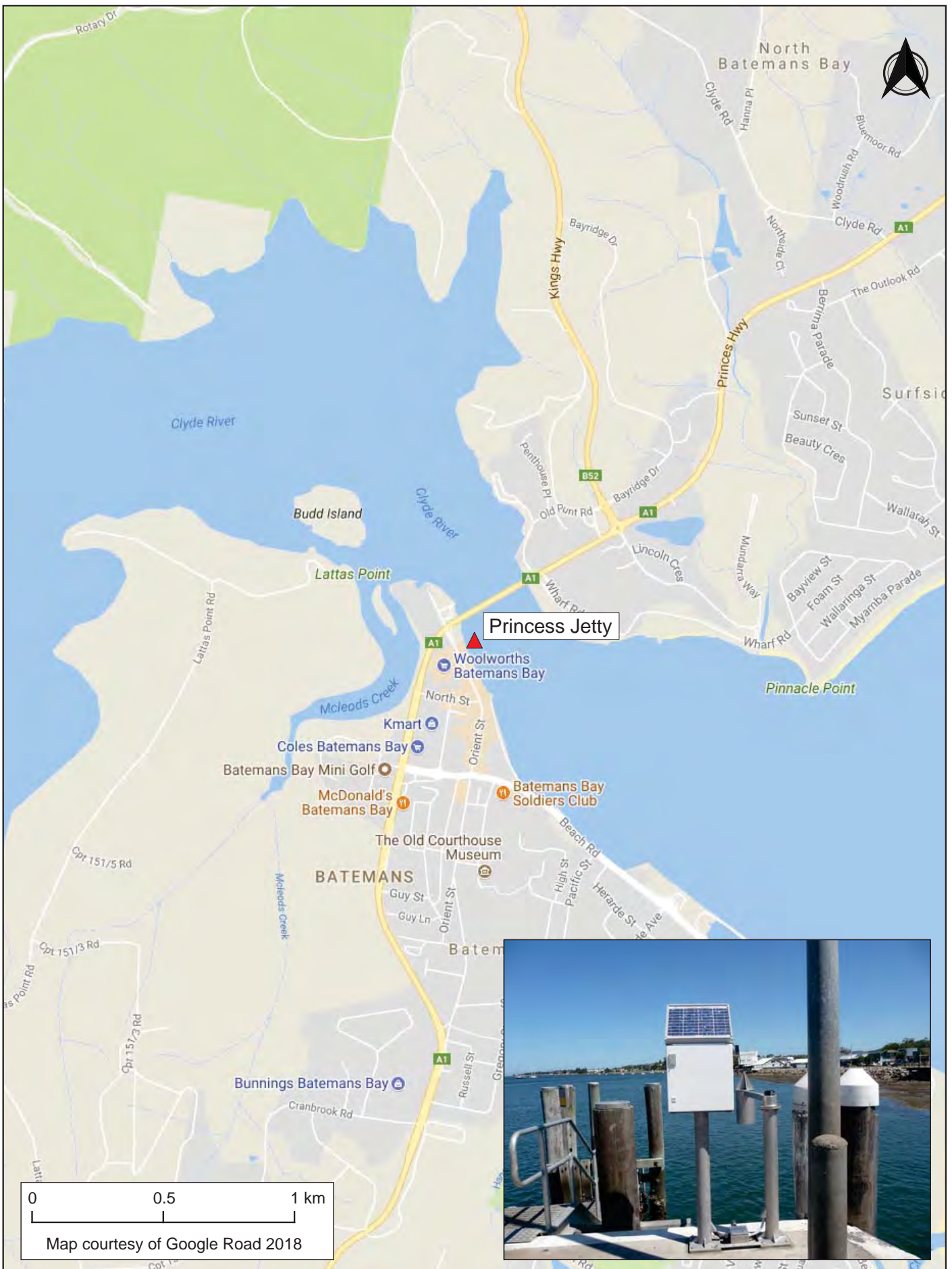
ULLADULLA DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A36

DRAWING 2693-A36.cdr

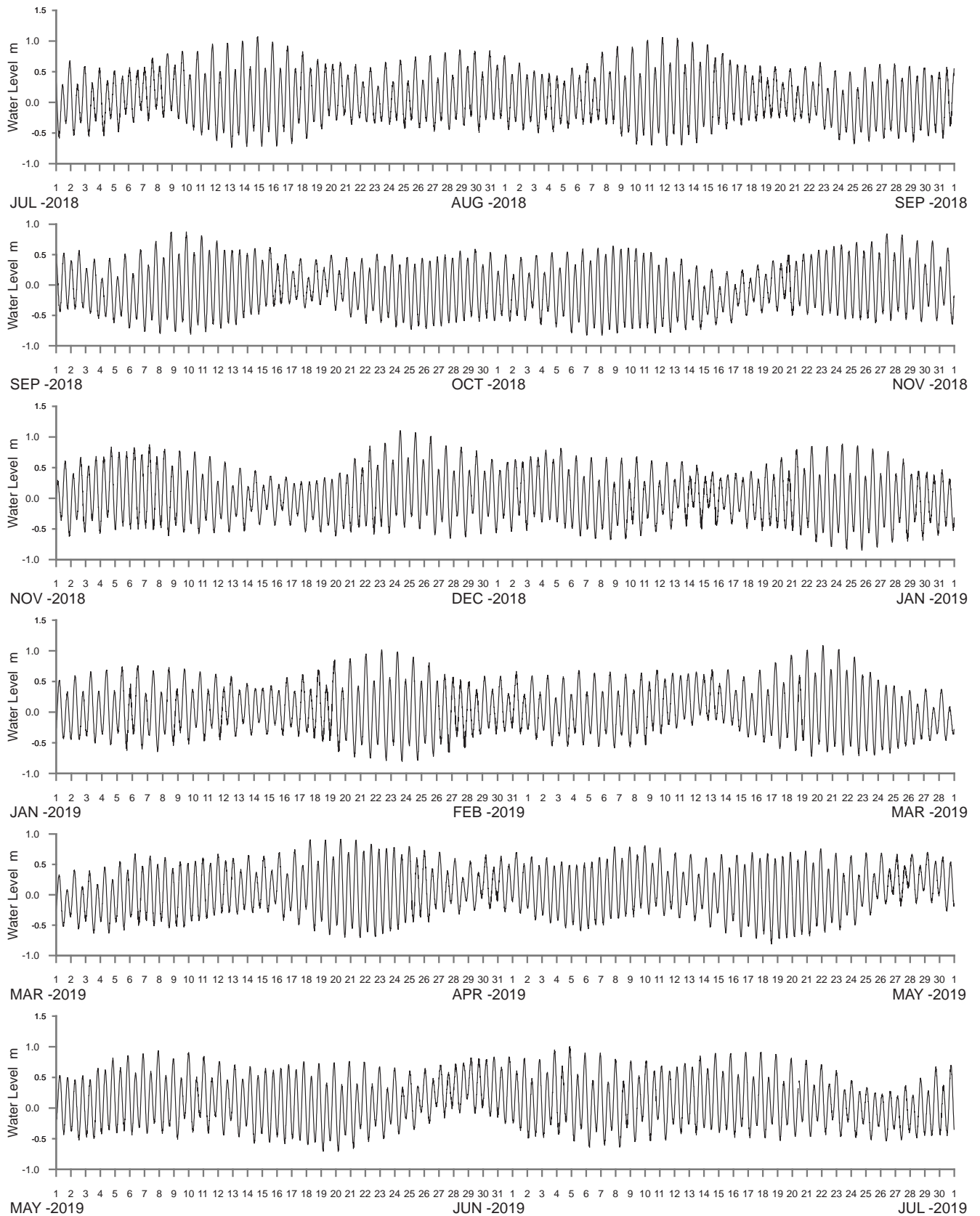


0 0.5 1 km  
 Map courtesy of Google Road 2018



**PRINCESS JETTY  
 STATION LOCATION**

**Manly  
 Hydraulics  
 Laboratory**  
 Report MHL2693  
 Figure  
 A37  
 DRAWING 2693-A37.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



PRINCESS JETTY DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

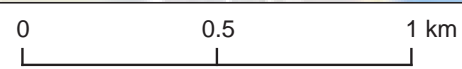
Report MHL2693

Figure  
A38

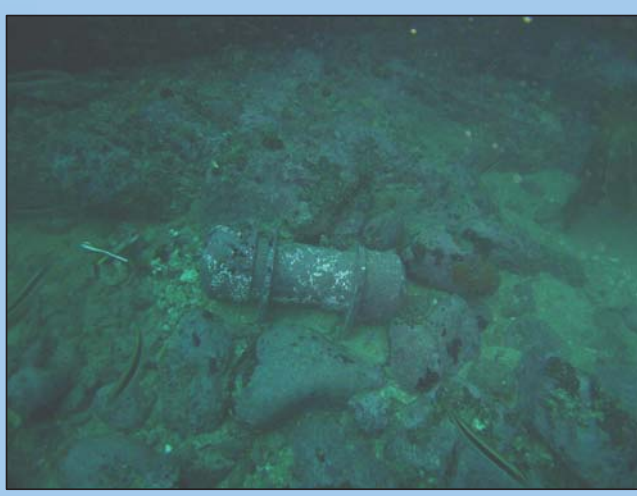
DRAWING 2693-A38.cdr



Batemans Bay Offshore



Map courtesy of Google Road 2018



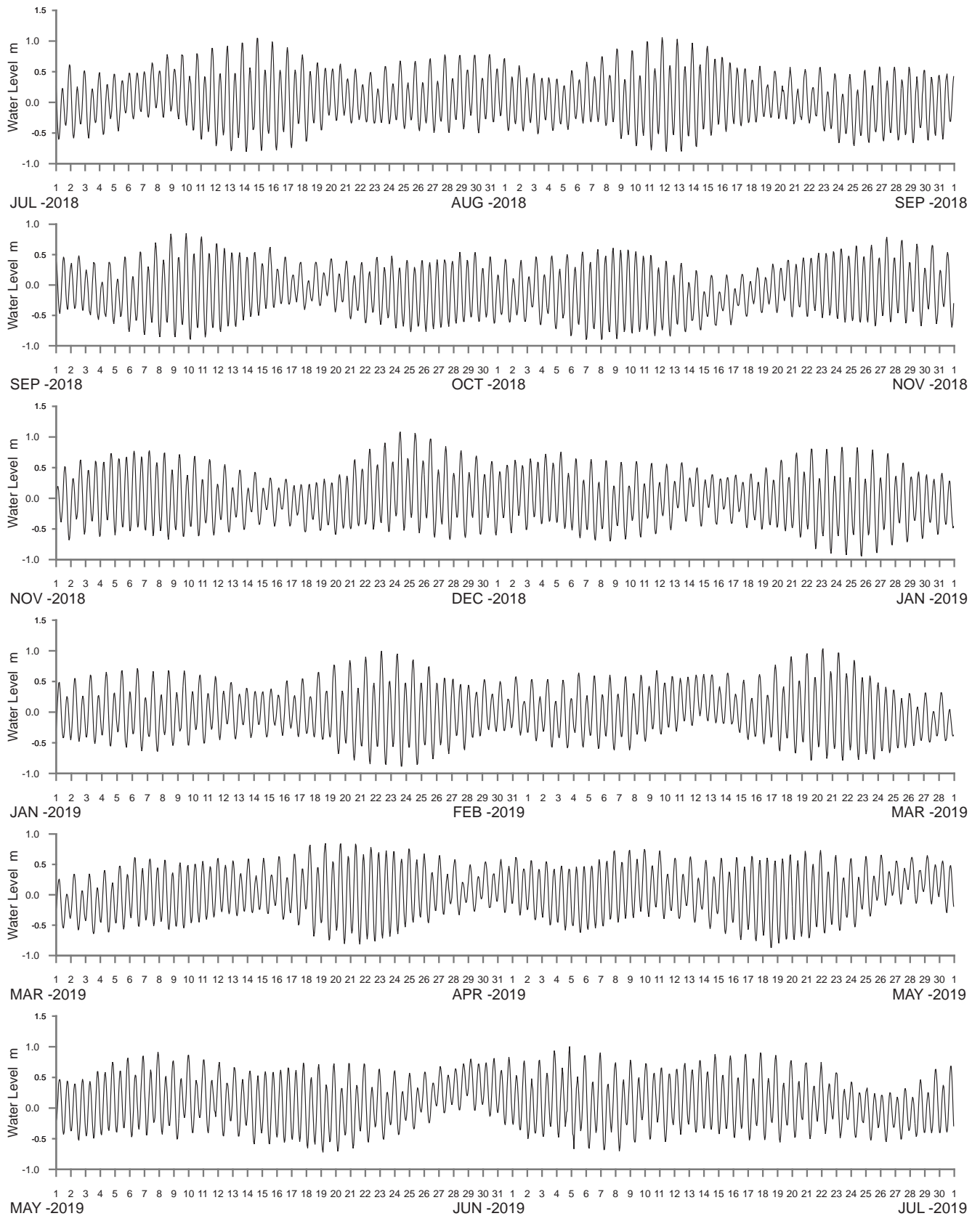
### BATEMANS BAY OFFSHORE STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A39

DRAWING 2693-A39.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS



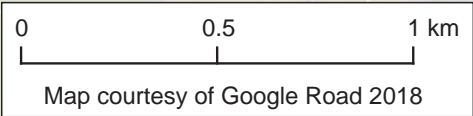
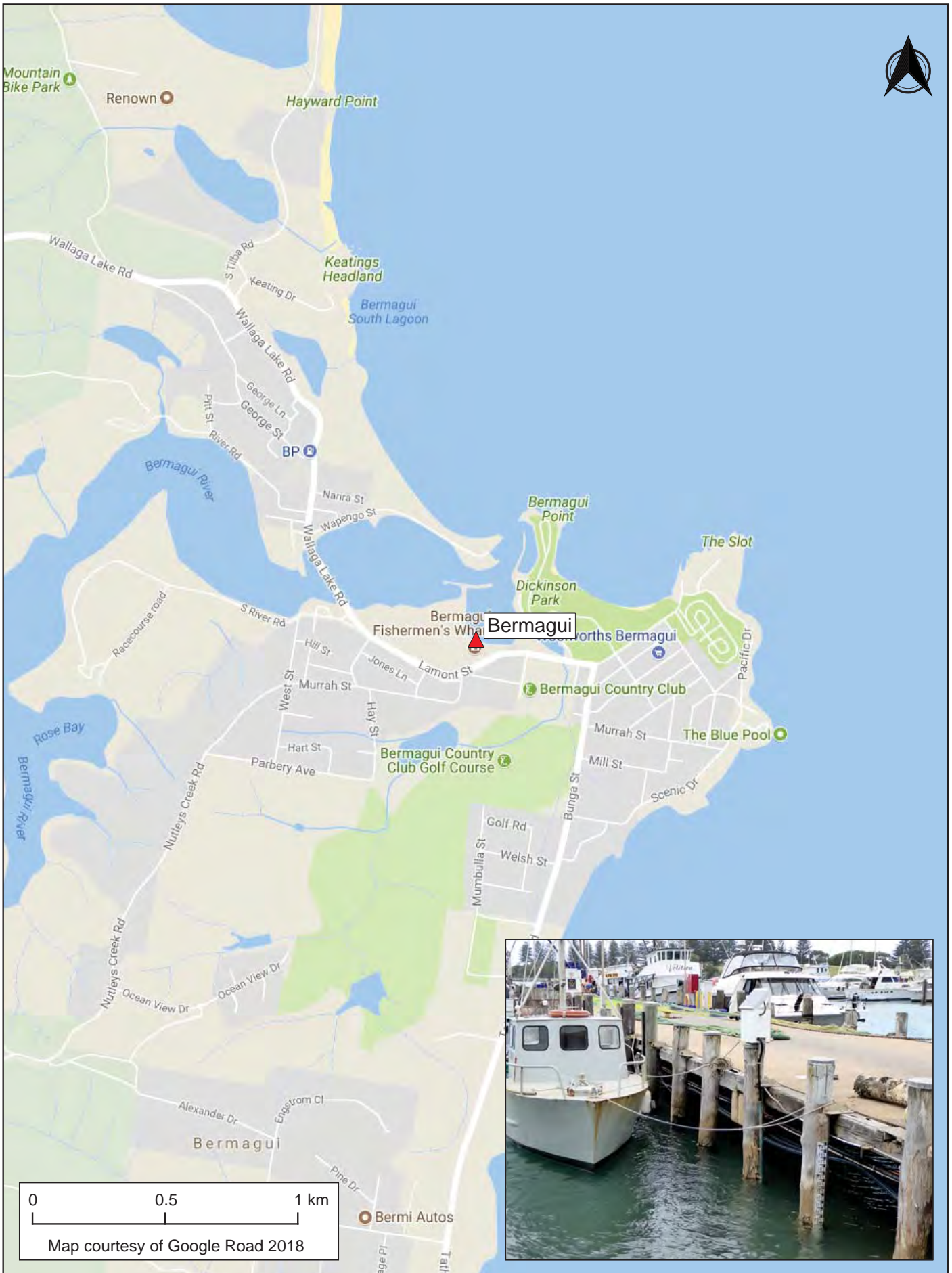
BATEMANS BAY OFFSHORE DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A40

DRAWING 2693-A40.cdr



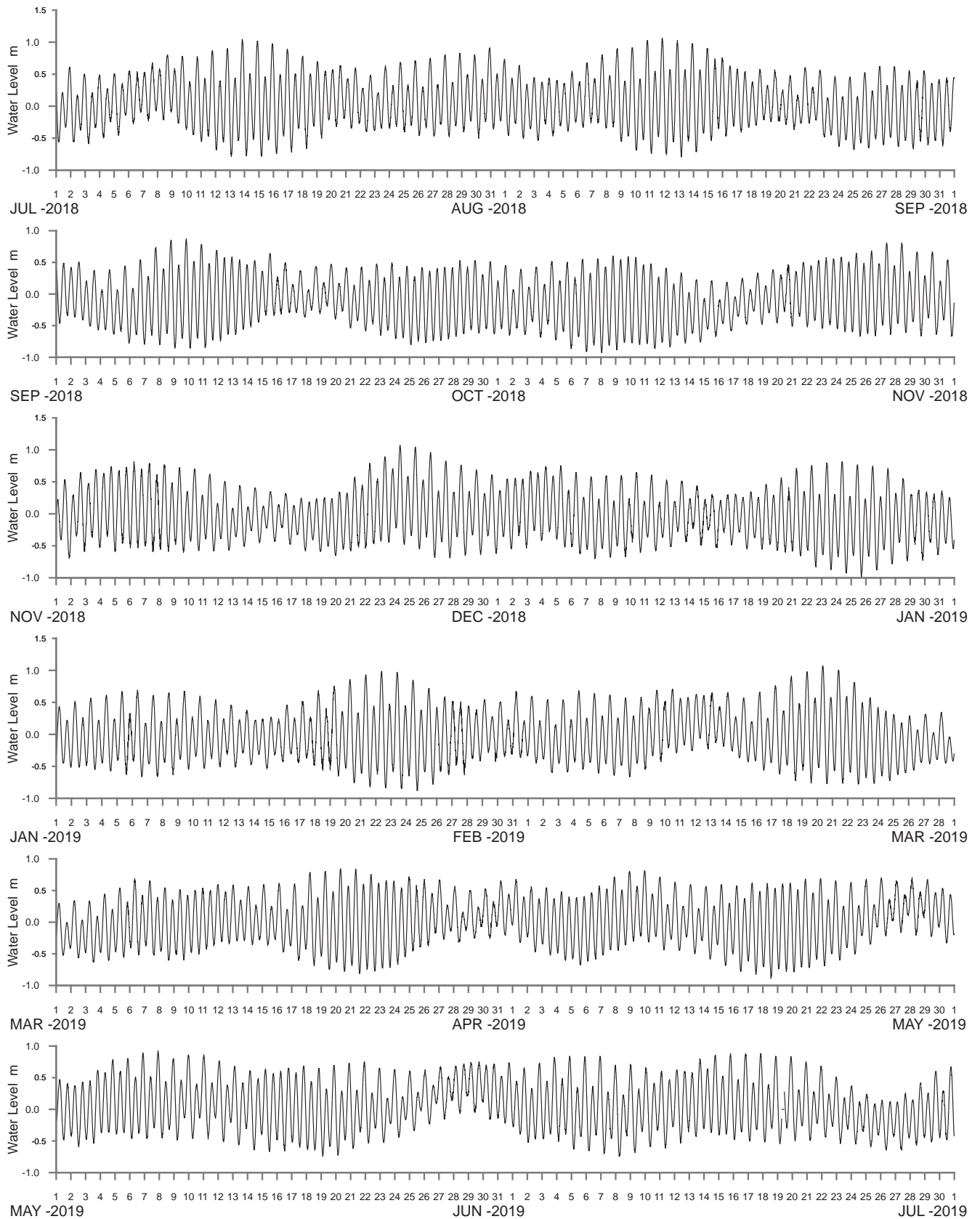
### BERMAGUI STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A41

DRAWING 2693-A41.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



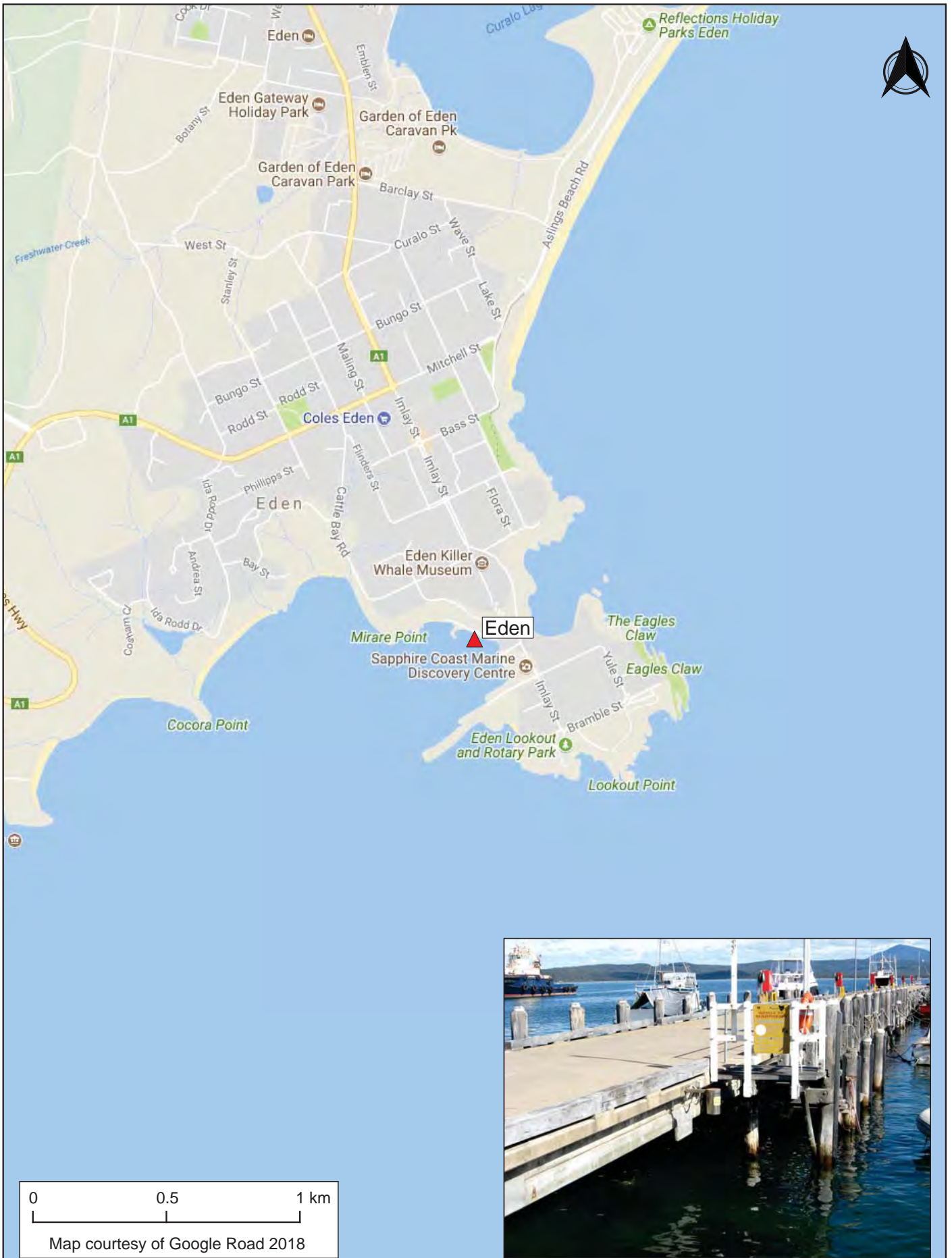
BERMAGUI DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A42

DRAWING 2693-A42.cdr

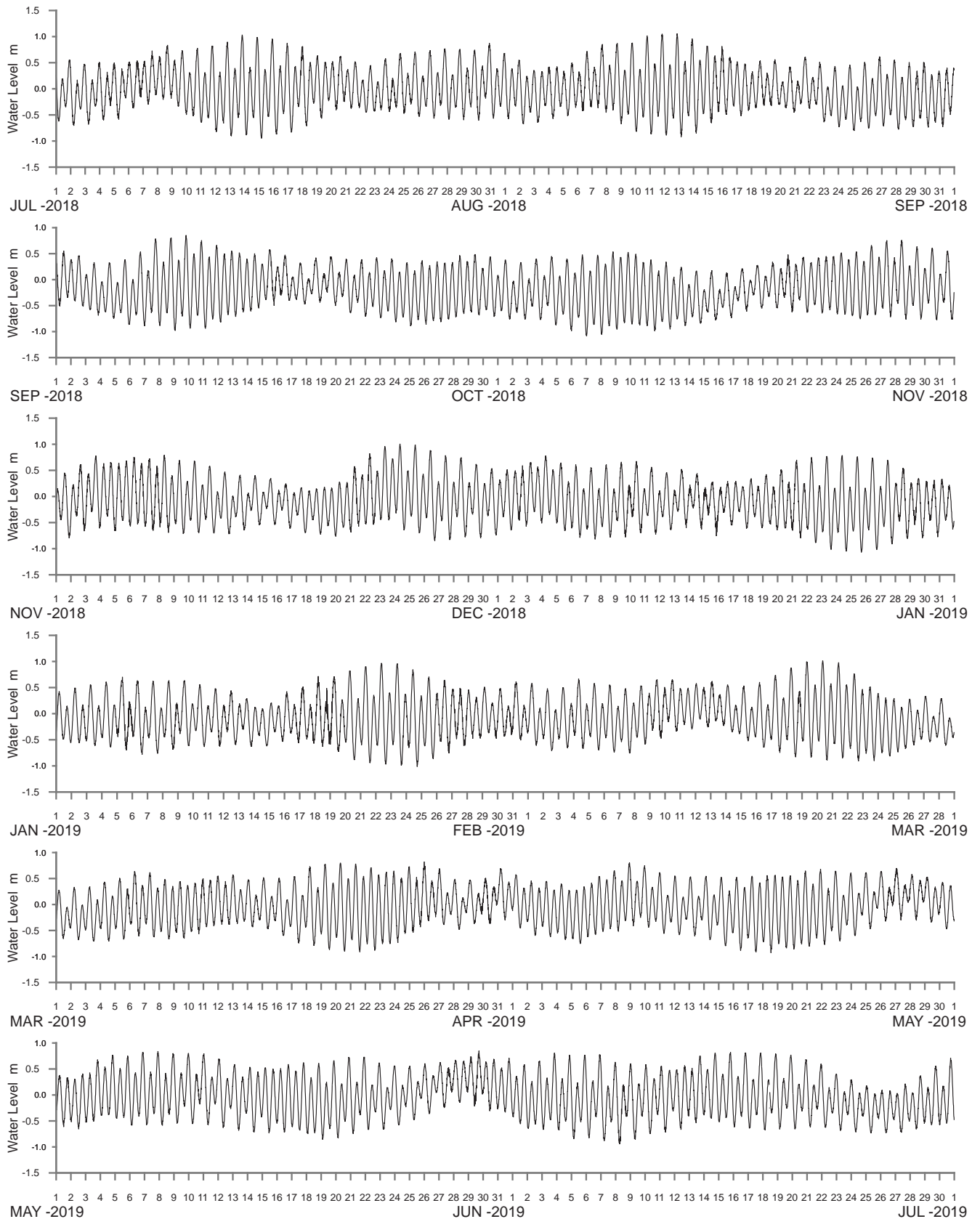


**EDEN  
STATION LOCATION**

**Manly  
Hydraulics  
Laboratory**

Report MHL2693  
Figure  
A43

DRAWING 2693-A43.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



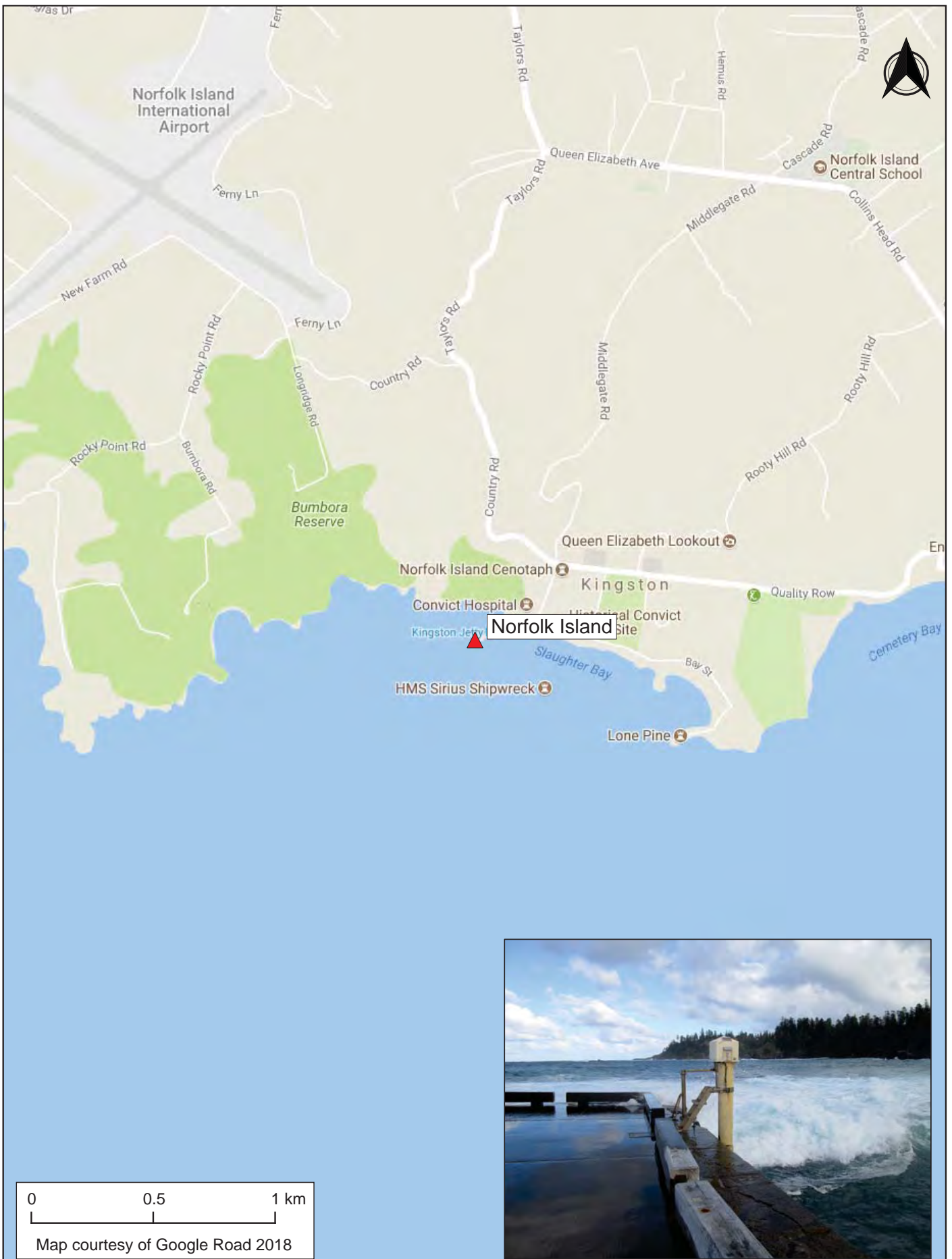
EDEN BOAT HARBOUR DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A44

DRAWING 2693-A44.cdr



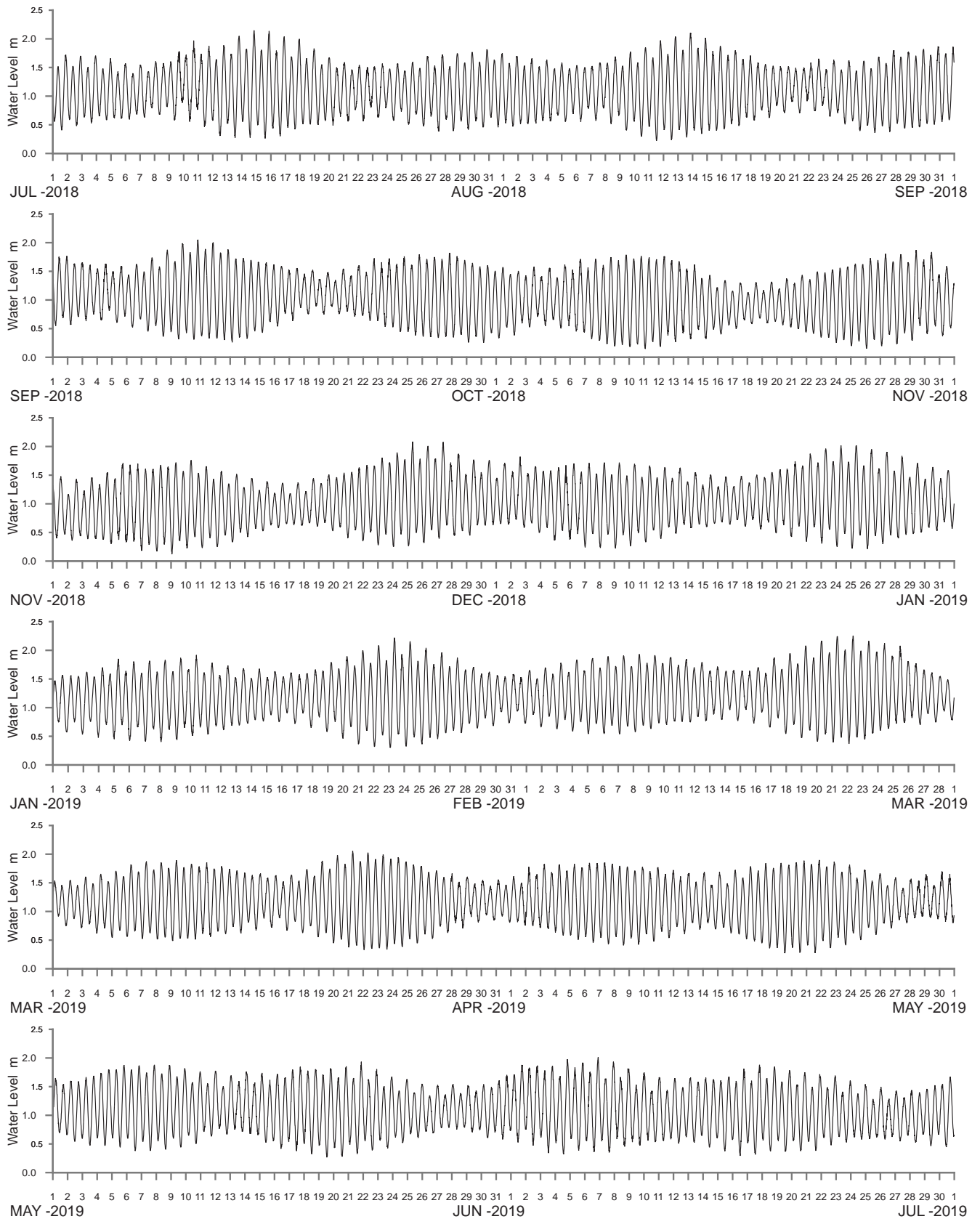
NORFOLK ISLAND  
STATION LOCATION

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A45

DRAWING 2693-A45.cdr



WATER LEVEL REFERENCED TO LOWEST ASTRONOMICAL TIDE

----- DATA LOSS

Data provided courtesy of Bureau of Meteorology's National Tidal Unit



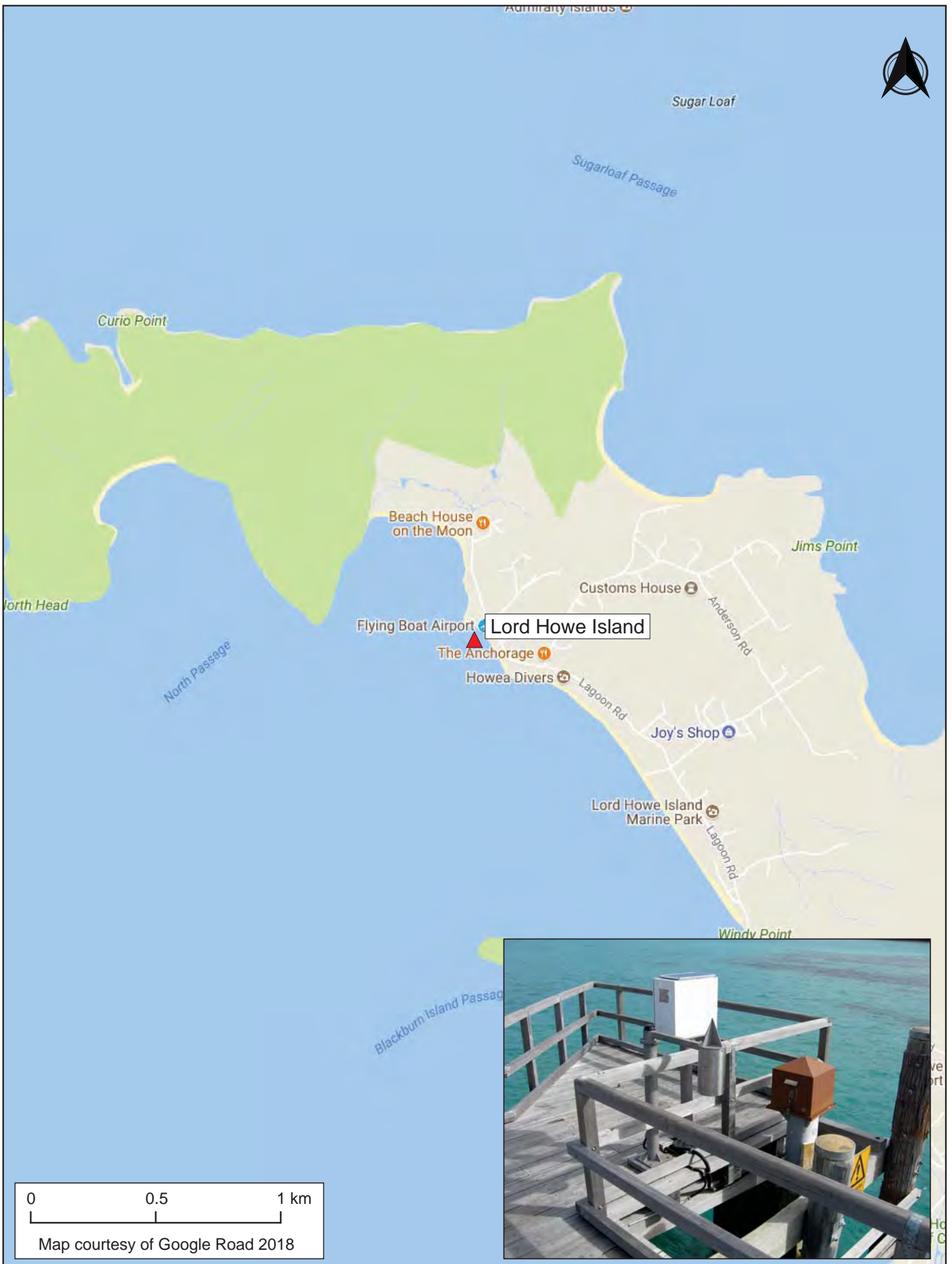
NORFOLK ISLAND DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

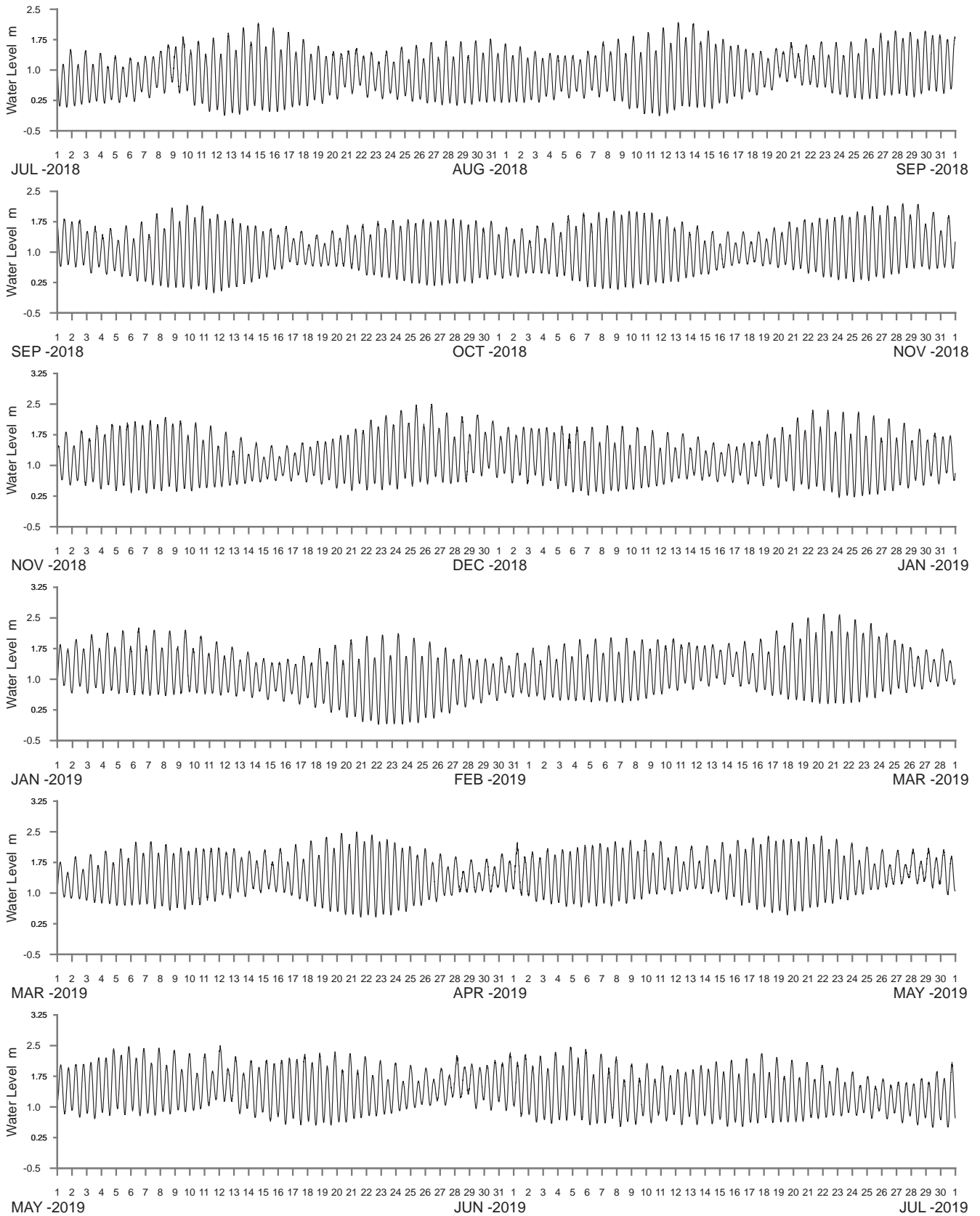
Figure  
A46

DRAWING 2693-A46.cdr



LORD HOWE ISLAND  
STATION LOCATION

Manly  
Hydraulics  
Laboratory  
Report MHL2693  
Figure  
A47  
DRAWING 2693-A47.cdr



WATER LEVEL REFERENCED TO LORD HOWE ISLAND DATUM

----- DATA LOSS



LORD HOWE ISLAND DATA SUMMARY  
2018–2019

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
A48

DRAWING 2693-A48.cdr

## Appendix B Current station data

**Table B1 Current station digital data**

NSW coastal region	Catchment, river or port	Station name	Location	Period of data
North	Tweed River	Tweed Entrance South	South Breakwater	May 2014–ongoing
North	Tasman Sea	Tweed Offshore <sup>1</sup>	Offshore	Dec 1982–ongoing
North	Brunswick River	Brunswick Heads	South Breakwater	Mar 1986–ongoing
North	Richmond River	Ballina Breakwall	South Breakwater	Dec 2008–ongoing
North	Clarence River	Yamba	South Breakwater	Jul 1986–ongoing
North	Coffs Harbour	Coffs Harbour <sup>1</sup>	Inner Harbour Pumpout Jetty	Aug 1996–ongoing
Mid North	Hastings River	Port Macquarie	South Breakwater	Mar 1986–ongoing
Mid North	Tasman Sea	Port Macquarie Offshore <sup>1</sup>	Offshore	Dec 1984–ongoing
Mid North	Crowdy Head Harbour	Crowdy Head <sup>1</sup>	Fishermans Wharf	Jul 1986–ongoing
Mid North	Wallis Lake	Forster	North Breakwater	Jul 1986–ongoing
Central	Port Stephens	Shoal Bay	Public Wharf	Apr 2014–ongoing
Central	Hawkesbury River	Patonga	Public Wharf	Jun 1992–ongoing
Central	Sydney Port Jackson	Sydney	HMAS Penguin Wharf	Sep 1987–ongoing
Central	Sydney Port Jackson	Sydney Backup	HMAS Penguin Wharf	Aug 2010 - ongoing
Central	Port Hacking	Bundeena	Public Wharf	Dec 2014-ongoing
Central	Crookhaven River	Crookhaven Heads	Upstream of Entrance	Mar 1992–ongoing
Central	Tasman Sea	Shoalhaven Offshore	Offshore	Sep 2005–ongoing
Central	Jervis Bay	Jervis Bay	HMAS Creswell	Sep 1989–ongoing
South	Ulladulla Harbour	Ulladulla	Wharf in Harbour	Dec 2007–ongoing
South	Clyde River	Princess Jetty	Public Wharf	Dec 1985–ongoing
South	Tasman Sea	Batemans Bay Offshore	Snapper Island	Sep 2000–ongoing
South	Bermagui River	Bermagui	Inner Harbour	Mar 1987–ongoing
South	Twofold Bay	Eden	Working Jetty	Sep 1986–ongoing
North Tasman Sea	Tasman Sea	Lord Howe Island	Main Wharf	Aug 1994–ongoing

<sup>1</sup> Station has changed location during data period

## Appendix C Historical tide data

**Table C1 Historical tide data**

Station Name	Location	Period of record	Location
Tweed Regional	North Breakwater	Feb 1987–Apr 2015	On line
Tweed Regional	Breakwater 201470	1978–1980	On line
Richmond River	Breakwater 202471	1889–1912	HiLos on line
Richmond River	Ballina	1959–1963	Microfiche MHL
Ballina 202470	Half Tide Breakwater	Apr 1986–May 2011	On line
Clarence River	Yamba	1900–1924	HiLos on line
Yamba Offshore	Yamba 204450	Jun 1987–Sep 2009	On line
Clarence River	Iluka 204437	1956–1961	On line
Clarence River	Breakwater	1957–1958	HiLos State Archives
Coffs Harbour	Main harbour	1966–68 and 1969–72	Microfiche MHL
Coffs Harbour	Main harbour	1972–1973	Microfiche MHL
Coffs Harbour	Main harbour	1951–52, 1961–64	HiLos State Archives
Coffs Harbour	Outer harbour 205470	1951–1996	On line
Coffs Harbour	Outer harbour	1953–56, 1957–60	Microfiche MHL
Coffs Harbour	Water Police Jetty Inner Harbour 205470	1990–1996	On line
Macleay River	Entrance 206477	1901–1913	HiLos on line
Crowdy Head	CSIRO 208470	1985–1986	On line
Tomaree	Hospital Jetty 209471	Oct 1985–Apr 2014	On line
Tomaree	Hospital Jetty	1967–1969	HiLos State Archives
Newcastle	Boat harbour 210461	1899–1921	HiLos on line
Newcastle	Breakwater	1946–1961	HiLos State Archives
Port Hacking	Hungry Point	Nov 1987–Feb2015	On line
Port Jackson	Fort Denison 60370	1914–2008	On line
Port Kembla	Harbour	1957–1965	Microfiche State Archives
Port Kembla	Harbour 214480	1987–1992	On line
Jervis Bay	HMAS Creswell 216471	1914–1919	HiLos on line
Jervis Bay	Huskisson 216472	1987–1993	On line
Batemans Bay Offshore	Snapper Island 216451	1986–1990	On line
Batemans Bay Offshore	Offshore 216452	1987–1988	On line (MHL556)
Moruya River	Moruya Heads 217403	1951–1952	HiLos State Archives
Moruya River	Entrance	1951–52, 1987–88	On line
Eden	Snug Cove 220470	1978–1990	On line
Eden	Snug Cove	1954–1956	Microfiche State Archives
Norfolk Island	Kingston Jetty	1994-2015	On line

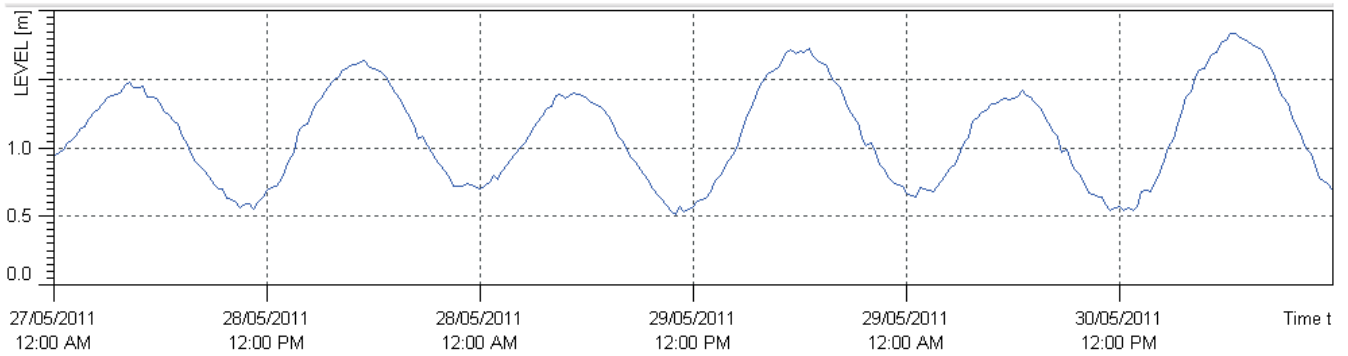
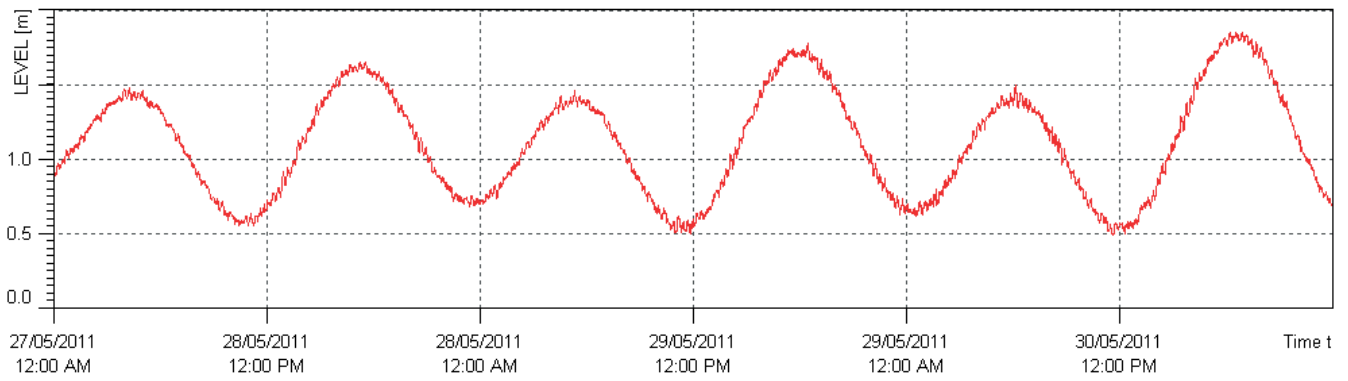
Fort Denison data courtesy of Sydney Ports Corporation and BoM National Tidal Unit.

Data for Norfolk Island since 2015 provided by Bureau of Meteorology's National Tidal Unit (NTU).

# Appendix D Sample outputs

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Coffs Harbour 1-minute data



Coffs Harbour 15-minute data



1-MINUTE AND 15-MINUTE SAMPLE DATA PLOTS

Manly  
Hydraulics  
Laboratory

Report MHL2693

Figure  
D1

DRAWING 2693-Appendix D.cdr

Station Name, Sydney (Live),,  
 Station Number,213470,,  
 Long,+151:15:30.72,,  
 Lat,-33:49:31.56,,  
 Datum,Zero Fort Denison,,  
 ,,  
 ,,Level 1,  
 ,,---,  
 Date,Time,Value [m],State of value  
 1/05/2014,0:00:00,1.267,55 (Fair)  
 1/05/2014,0:15:00,1.163,55 (Fair)  
 1/05/2014,0:30:00,1.112,55 (Fair)  
 1/05/2014,0:45:00,1.006,55 (Fair)  
 1/05/2014,1:00:00,0.912,55 (Fair)  
 1/05/2014,1:15:00,0.858,55 (Fair)  
 1/05/2014,1:30:00,0.784,55 (Fair)  
 1/05/2014,1:45:00,0.704,55 (Fair)  
 1/05/2014,2:00:00,0.662,55 (Fair)  
 1/05/2014,2:15:00,0.596,55 (Fair)  
 1/05/2014,2:30:00,0.537,55 (Fair)  
 1/05/2014,2:45:00,0.507,55 (Fair)  
 1/05/2014,3:00:00,0.486,55 (Fair)  
 1/05/2014,3:15:00,0.447,55 (Fair)  
 1/05/2014,3:30:00,0.445,55 (Fair)  
 1/05/2014,3:45:00,0.453,55 (Fair)  
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 1/05/2014,4:30:00,0.489,55 (Fair)  
 1/05/2014,4:45:00,0.527,55 (Fair)  
 1/05/2014,5:00:00,0.574,55 (Fair)  
 1/05/2014,5:15:00,0.609,55 (Fair)  
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 1/05/2014,5:45:00,0.731,55 (Fair)  
 1/05/2014,6:00:00,0.791,55 (Fair)  
 1/05/2014,6:15:00,0.868,55 (Fair)  
 1/05/2014,6:30:00,0.914,55 (Fair)  
 1/05/2014,6:45:00,1.004,55 (Fair)  
 1/05/2014,7:00:00,1.067,55 (Fair)  
 1/05/2014,7:15:00,1.132,55 (Fair)  
 1/05/2014,7:30:00,1.195,55 (Fair)  
 1/05/2014,7:45:00,1.243,55 (Fair)  
 1/05/2014,8:00:00,1.304,55 (Fair)  
 1/05/2014,8:15:00,1.366,55 (Fair)  
 1/05/2014,8:30:00,1.374,55 (Fair)  
 1/05/2014,8:45:00,1.42,55 (Fair)  
 1/05/2014,9:00:00,1.443,55 (Fair)



15-MINUTE SAMPLE DATA FILE

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Report MHL2693

Figure  
D2



MANLY HYDRAULICS LABORATORY

STATION NAME : Sydney (Live)  
 RECORDER TYPE : MHL Station  
 A.W.R.C. No. : 213470  
 DATA START : 29.06.2013  
 DATA FINISH : 30.06.2014  
 DATA TOTAL : 1 years 2 days  
 DATABASE TIME INTERVAL (second): 0  
 THRESHOLD LEVEL (m) : 1.900  
 DATUM : Zero Fort Denison  
 DATE OF ISSUE : 09:00 22.10.2014  
 ANALYSIS PERFORMED BY : RJ  
 COMMENTS : Sydney (Live) Level 1 00 - Continuous.P  
 event ranking for period 29.06.2013 to  
 30.06.2014

RANK	PEAK (m)	DATE	TIME	START	DURATION (hr)	MAX RISE (m/hr)
1	1.976	21.07.2013	18:45	21.07.2013	1.3	0.100
2	1.980	22.07.2013	20:15	22.07.2013	1.5	0.140
3	2.065	23.07.2013	20:30	23.07.2013	2.3	0.300
4	2.048	24.07.2013	21:45	24.07.2013	2.0	0.308
5	1.951	19.08.2013	19:00	19.08.2013	0.5	0.120
6	1.957	20.08.2013	19:30	20.08.2013	1.3	0.136
7	1.994	21.08.2013	20:15	21.08.2013	1.5	0.184
8	1.910	07.10.2013	09:45	07.10.2013	0.3	0.020
9	1.951	05.11.2013	09:00	05.11.2013	1.0	0.104
10	1.937	04.12.2013	09:00	04.12.2013	0.5	0.100
11	2.028	05.12.2013	10:00	05.12.2013	1.8	0.360
12	1.988	31.12.2013	06:30	31.12.2013	1.0	0.272
13	2.003	01.01.2014	07:45	01.01.2014	1.8	0.248
14	2.187	02.01.2014	08:30	02.01.2014	3.0	0.392
15	2.182	03.01.2014	09:15	03.01.2014	3.0	0.496
16	2.165	04.01.2014	10:00	04.01.2014	3.0	0.404
17	1.939	31.01.2014	08:15	31.01.2014	0.8	0.112
18	1.913	01.05.2014	22:00	01.05.2014	0.3	0.044
19	1.930	02.05.2014	22:30	02.05.2014	0.5	0.088
20	1.931	12.06.2014	19:30	12.06.2014	0.8	0.104
21	2.046	13.06.2014	20:15	13.06.2014	2.3	0.296
22	2.170	14.06.2014	20:45	14.06.2014	3.3	0.372
23	2.232	15.06.2014	21:45	15.06.2014	3.3	0.360
24	2.084	16.06.2014	23:15	16.06.2014	2.8	0.352
25	1.981	27.06.2014	20:30	27.06.2014	1.8	0.132
26	2.065	28.06.2014	21:00	28.06.2014	2.5	0.376
27	1.956	29.06.2014	21:45	29.06.2014	1.8	0.108

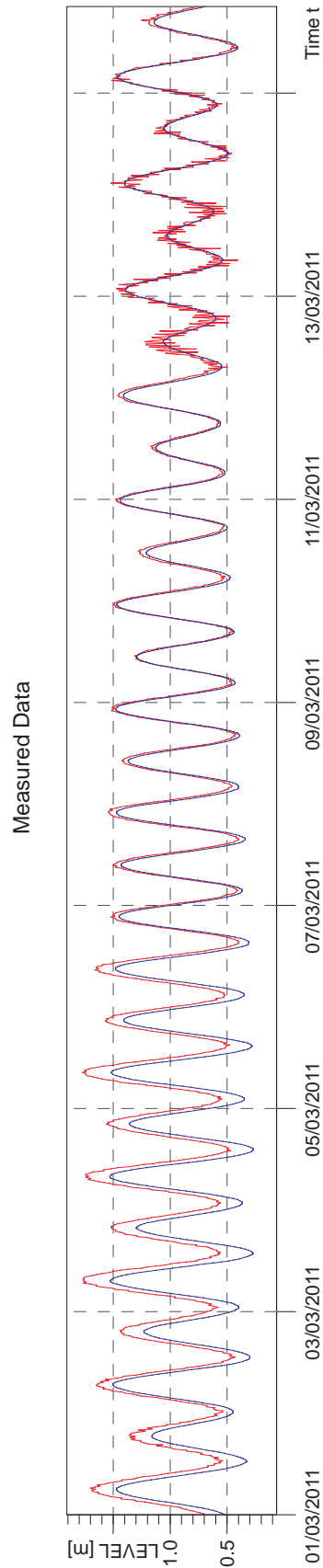
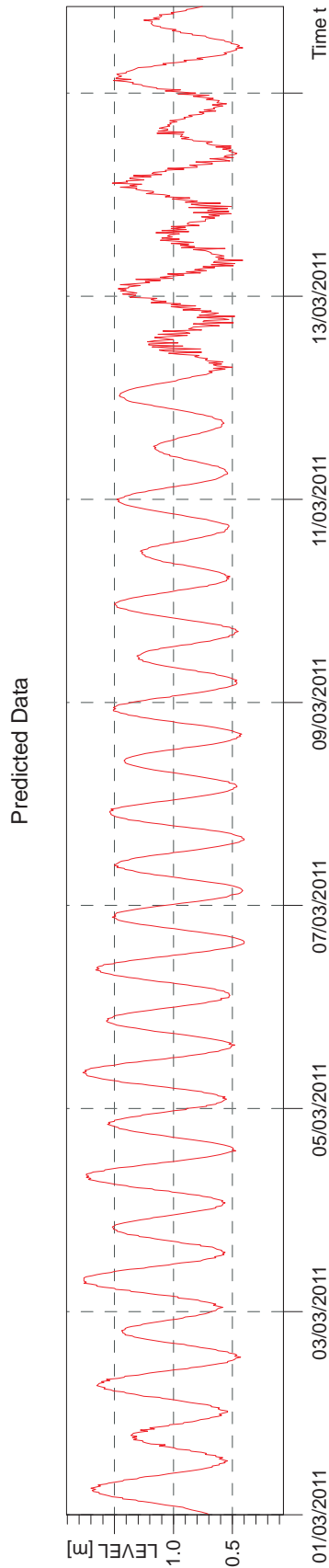
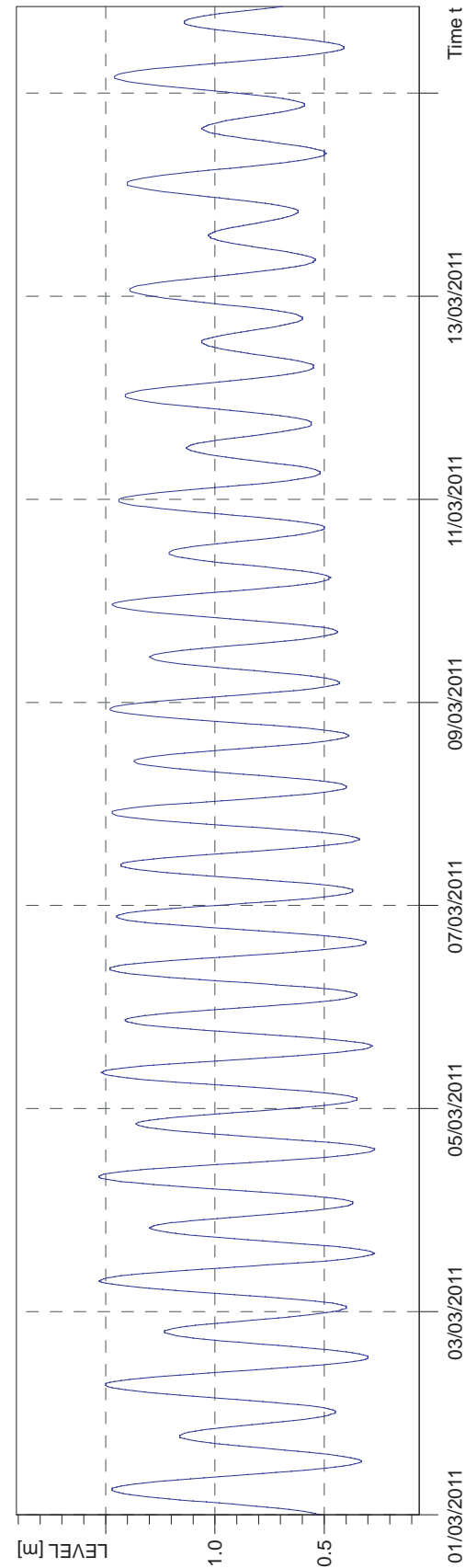


TIDAL LEVEL RANKING

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Figure  
D4



SAMPLE TIDAL PREDICTION DATA PLOT

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Laboratory

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Figure  
D5

## Appendix E Glossary of terms

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Amplitude (H)	One half of the difference in height between consecutive high water and low water, hence half the tide range.
Australian Height Datum (AHD)	Is a geodetic datum for altitude measurement in Australia. According to Geoscience Australia, in 1971 the mean sea level for 1966-1968 was assigned a value of zero on the Australian Height Datum for 30 tide gauges around the coast of the Australian continent. The resulting datum surface has been termed the Australian Height Datum (AHD) and was adopted by the National Mapping Council as the datum to which all vertical control for mapping is to be referred.
Automatic tide gauge	An instrument that automatically registers the rise and fall of the tide. In some instruments, the registration is accomplished by recording the heights at regular time intervals in digital format.
Benchmark (BM)	A fixed physical object or mark used as reference for a vertical datum. A tidal benchmark is one near a tide station to which the tide staff and tidal datums are referred. A primary benchmark is the principal (or only) mark of a group of tidal benchmarks to which the tide staff and tidal datums are referred.
Chart datum	Chart datum taken to correspond to a low-water elevation, and its depression below mean sea level is represented by the symbol Z.
Coastal boundary	The mean high water line (MHWL) or mean higher high water line (MHHWL) when tidal lines are used as the coastal boundary. Also, lines used as boundaries inland of and measured from (or points thereon) the MHWL or MHHWL.
Constituent	One of the harmonic elements in a mathematical expression for the tide-producing force and in corresponding formulas for the tide or tidal current. Each constituent represents a periodic change or variation in the relative positions of the earth, moon and sun. A single constituent is usually written in the form $y = A \cos (at + \acute{a})$ , in which $y$ is a function of time as expressed by the symbol $t$ and is reckoned from a specific origin. The coefficient $A$ is called the amplitude of the constituent and is a measure of its relative importance. The angle $(at + \acute{a})$ changes uniformly and its value at any time is called the phase of the constituent. The speed of the constituent is the rate of change in its phase and is represented by the symbol $a$ in the formula. The quantity $a$ is the phase of the constituent at the initial instant from which the time is reckoned. The period of the constituent is the time required for the phase to change through $360^\circ$ and is the cycle of the astronomical condition represented by the constituent.
Digital Recorder (or logger)	An electronic recorder system which stores the information in accessible form, for example, on tape or solid state memory.

Digitise	To translate analog information into digital form i.e. a series of numeric data readable by, and stored within, a digital computer.
Diurnal	Having a period or cycle of approximately one tidal day. Thus, the tide is said to be diurnal when only one high water and one low water occur during a tidal day, and the tidal current is said to be diurnal when there is a single flood and a single ebb period of a reversing current in the tidal day. A rotary current is diurnal if it changes its direction through all points of the compass once each tidal day. A diurnal constituent is one which has a single period in the constituent day. The symbol for such a constituent is the subscript 1.
East Coast Low (ECL)	East Coast Lows (ECL) are intense low-pressure systems which occur on average several times each year off the eastern coast of Australia, in particular southern Queensland, NSW and eastern Victoria. Although they can occur at any time of the year, they are more common during autumn and winter with a maximum frequency in June. East Coast Lows will often intensify rapidly overnight making them one of the more dangerous weather systems to affect the NSW coast. East Coast Lows are also observed off the coast of Africa and America and are sometimes known as east coast cyclones.
Encoder	A device that translates tidal movement into computer readable data.
Ellipsoid	An idealised model representing the mean sea level of the earth and is used as a computational reference for global position fixing
Estuary	An embayment of the coast in which fresh river water entering at its head mixes with the relatively saline ocean water. When tidal action is the dominant mixing agent it is usually termed a tidal estuary. Also, the lower reaches and mouth of a river emptying directly into the sea where tidal mixing takes place. The latter is sometimes called a river estuary.
Extreme high water	The highest elevation reached by the sea as recorded by a tide gauge during a given period.
Extreme low water	The lowest elevation reached by the sea as recorded by a tide gauge during a given period.
Floatwell	A stilling well in which the float of a float-actuated gauge operates. Also known as a stilling well.
Gas purged pressure gauge	A type of analog tide gauge in which gas, usually nitrogen, is emitted from a submerged tube at a constant rate. Fluctuations in hydrostatic pressure due to changes in tidal height modify the emission rate for recording.
Harmonic analysis	Process of measuring or calculating the relative amplitudes and frequencies of all the significant harmonic components present in a given wave form.

Harmonic prediction	Method of predicting tides by combining the harmonic constituents into a single tidal curve. The work is usually performed by electronic digital computer.
Head	The difference in water level at either end of a strait, channel, inlet, etc.
High water (HW)	The maximum height reached by a rising tide. The high water is due to the periodic tidal forces and the effects of meteorological, hydrologic, and/or oceanographic conditions. For tidal datum computational purposes, the maximum height is not considered a high water unless it contains a tidal high water.
High water mark	A line or mark left upon tide flats, beach, or alongshore objects indicating the elevation of the intrusion of high water. The mark may be a line of oil or scum on alongshore objects, or a more or less continuous deposit of fine shell or debris on the foreshore or berm. This mark is physical evidence of the general height reached by wave runup at recent high waters. It should not be confused with the mean high water line or mean higher high water line.
Higher high water (HHW)	The highest of the high waters (or single high water) of any specified tidal day due to the declination $A_1$ effects of the moon and sun.
Higher low water (HLW)	The highest of the low waters of any specified tidal day due to the declination $A_1$ effects of the moon and sun.
Highest Astronomical Tide (HAT)	The highest level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions; this level may not be reached every year. HAT is not the extreme level which can be reached as storm surges may cause considerably higher levels to occur.
Hydrographic datum	A datum used for referencing depths of water and the heights of predicted tides or water level observations. Same as chart datum. See datum.
Indian spring low water	A datum originated by Professor G. H. Darwin when investigating the tides of India. It is an elevation depressed below mean sea level by an amount equal to the sum of the amplitudes of the harmonic constituents $M_2$ , $S_2$ , $K_1$ , and $O_1$ .
Inverse barometer effect	The inverse response of sea level to changes in atmospheric pressure. A static reduction of 1.005 mb in atmospheric pressure will cause a stationary rise of 1 cm in sea level.
$K_1$	Lunisolar diurnal constituent. This constituent, with $O_1$ , expresses the effect of the moon's declination. They account for diurnal inequality and, at extremes, diurnal tides. With $P_1$ , it expresses the effect of the sun's declination. Speed = $T + h = 15.041,068,6^\circ$ per solar hour.

King Tide	A non-scientific term used to describe especially high tide events occurring twice a year around early January and early July. They occur when the earth, sun and moon are in alignment and when the sun is closest and furthest from the earth (perihelion and aphelion respectively).
Lambda	Smaller lunar evectional constituent. This constituent, with $V_2$ , $U_2$ , and $(S_2)$ , modulates the amplitude and frequency of $M_2$ for the effects of variation in solar attraction of the moon. This attraction results in a slight pear-shaped lunar ellipse and a difference in lunar orbital speed between motion toward and away from the sun. Although $(S_2)$ has the same speed as $S_2$ , its amplitude is extremely small. Speed = $2T - s + p = 29.455,625,3^\circ$ per solar hour.
Low water (LW)	The minimum height reached by a falling tide. The low water is due to the periodic tidal forces and the effects of meteorological, hydrologic, and/or oceanographic conditions. For tidal datum computational purposes, the minimum height is not considered a low water unless it contains a tidal low water.
Lower high water (LHW)	The lowest of the high waters of any specified tidal day due to the declination $A_1$ effects of the moon and sun.
Lower low water (LLW)	The lowest of the low waters (or single low water) of any specified tidal day due to the declination $A_1$ effects of the moon and sun.
Lowest Astronomical Tide (LAT)	The lowest level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions; this level will not be reached every year. LAT is not the extreme level which can be reached as storm surges may cause considerably lower levels to occur.
Lunar tide	That part of the tide on the earth due solely to the moon as distinguished from that part due to the sun.
$M_2$	Principal lunar semi-diurnal constituent. This constituent represents the rotation of the Earth with respect to the Moon. Speed = $2T - 2s + 2h = 28.984,104,2^\circ$ per solar hour.
Mean high water (MHW)	A tidal datum. The average of all the high water heights observed over the National Tidal Datum Epoch. For stations with shorter series, simultaneous observational comparisons are made with a control tide station in order to derive the equivalent datum.
Mean low water springs (MLWS)	A tidal datum. Frequently abbreviated spring low water. The arithmetic mean of the low water heights occurring at the time of spring tides observed over the National Tidal Datum Epoch. It is usually derived by taking an elevation depressed below the half-tide level by an amount equal to one-half the spring range of tide, necessary corrections being applied to reduce the result to a mean value.

Mean Sea Level (MSL)	The arithmetic mean of the water level heights at the tidal station observed over a period of time (preferably 19 years).
Modem	A device allowing a computer to be accessed over a telephone line.
Neap tides	Tides of decreased range or tidal currents of decreased speed occurring semi-monthly as the result of the moon being in quadrature. The neap range ( $N_p$ ) of the tide is the average range occurring at the time of neap tides and is most conveniently computed from the harmonic constants. It is smaller than the mean range where the type of tide is either semi-diurnal or mixed and is of no practical significance where the type of tide is predominantly diurnal. The average height of the high waters of the neap tide is called neap high water or high water neaps (MHWN) and the average height of the corresponding low waters is called neap low water or low water neaps (MLWN).
$O_1$	Lunar diurnal constituent. See $K_1$ . Speed = $T - 2s + h = 13.943,035,6^\circ$ per solar hour.
Phase	<ol style="list-style-type: none"> <li>1. Any recurring aspect of a periodic phenomenon, such as new moon, high water, flood strength, etc.</li> <li>2. A particular instant of a periodic function expressed in angular measure and reckoned from the time of its maximum value, the entire period of the function being taken as <math>360^\circ</math>. The maximum and minimum of a harmonic constituent have phase values of <math>0^\circ</math> and <math>180^\circ</math>, respectively.</li> </ol>
Pressure Sensor	A pressure transducer sensing device for water level measurement. A relative transducer is vented to the atmosphere and pressure readings are made relative to atmospheric pressure. An absolute transducer measures the pressure at its location. The readings are then corrected for barometric pressure taken at the surface.
Range of tide	The difference in height between consecutive high and low waters. The mean range is the difference in height between mean high water and mean low water. The great diurnal range or diurnal range is the difference in height between mean higher high water and mean lower low water. For other ranges see spring, neap, perigean, apogean, and tropic tides; and tropic ranges.
Relative mean sea level change	A local change in mean sea level relative to a network of benchmarks established in the most stable and permanent material available (bedrock, if possible) on the land adjacent to the tide station location. A change in relative mean sea level may be composed of both an absolute mean sea level change component and a vertical land movement change component, together.
$S_2$	Principal solar semi-diurnal constituent. This constituent represents the rotation of the Earth with respect to the Sun. Speed = $2T = 30.000,000,0^\circ$ per solar hour.

Seiche	A stationary wave usually caused by strong winds and/or changes in barometric pressure. It is found in lakes, semi-enclosed bodies of water, and in areas of the open ocean. The period of a seiche in an enclosed rectangular body of water is usually represented by the formula: $Period (T) = 2L / \text{square root } (gd)$ in which L is the length, d the average depth of the body of water, and g the acceleration of gravity.
Semi-diurnal	Having a period or cycle of approximately one-half of a tidal day. The predominant type of tide throughout the world is semi-diurnal, with two high waters and two low waters each tidal day. The tidal current is said to be semi-diurnal when there are two flood and two ebb periods each day. A semi-diurnal constituent has two maxima and two minima each constituent day, and its symbol is the subscript 2.
Shallow water constituent	A short-period harmonic term introduced into the formula of tidal (or tidal current) constituents to take account of the change in the form of a tide wave resulting from shallow water conditions. Shallow water constituents include the overtides and compound tides.
Slack water (slack)	The state of a tidal current when its speed is near zero, especially the moment when a reversing current changes direction and its speed is zero. The term also is applied to the entire period of low speed near the time of turning of the current when it is too weak to be of any practical importance in navigation. The relation of the time of slack water to the tidal phases varies in different localities. For a perfect standing tidal wave, slack water occurs at the time of high and of low water, while for a perfect progressive tidal wave, slack occurs midway between high and low water.
Solar tide	<ol style="list-style-type: none"> <li>1. The part of the tide that is due to the tide-producing force of the sun.</li> <li>2. The observed tide in areas where the solar tide is dominant. This condition provides for phase repetition at about the same time each solar day.</li> </ol>
Solid State	An electronic device composed of components with no moving parts – in this instance, using the electronic properties of solids, as in transistors, semi-conductors and integrated circuits.
Spring high water	Same as mean high water springs (MHWS). See spring tides.
Spring low water	Same as mean low water springs (MLWS). See spring tides.
Spring tides	Tides of increased range or tidal currents of increased speed occurring semi-monthly as the result of the moon being new or full. The spring range (Sg) of tide is the average range occurring at the time of spring tides and is most conveniently computed from the harmonic constants. It is larger than the mean range where the type of tide is either semi-diurnal or mixed, and is of no practical significance where the type of tide is predominantly diurnal. The average height of the high waters of the spring tides is called spring high water or mean high water springs (MHWS) and the

average height of the corresponding low waters is called spring low water or mean low water springs (MLWS).

Storm surge	The local change in the elevation of the ocean along a shore due to a storm. The storm surge is measured by subtracting the astronomic tidal elevation from the total elevation. It typically has a duration of a few hours. Since wind generated waves ride on top of the storm surge (and are not included in the definition), the total instantaneous elevation may greatly exceed the predicted storm surge plus astronomic tide. It is potentially catastrophic, especially on low-lying coasts with gently sloping offshore topography.
Telemeter	Transmit data to a distant receiving station via a telephone line or by telegraphic means.
Tidal characteristics	Principally, those features relating to the time, range, and type of tide.
Tidal constants	Tidal relations that remain practically constant for any particular locality. Tidal constants are classified as harmonic and non-harmonic. The harmonic constants consist of the amplitudes and epochs of the harmonic constituents, and the non-harmonic constants include the ranges and intervals derived directly from the high and low water observations.
Tidal current	A horizontal movement of the water caused by gravitational interactions between the sun, moon and earth. The horizontal component of the particulate motion of a tidal wave. Part of the same general movement of the sea that is manifested in the vertical rise and fall called tide.
Tidal Plane	A level of water (often defined by tidal constituents) from which water depths and heights of tides are referenced.
Tide	The periodic rise and fall of the water resulting from gravitational interactions between sun, moon and earth. The vertical component of the particulate motion of a tidal wave. Although the accompanying horizontal movement of the water is part of the same phenomenon, it is preferable to designate this motion as tidal current.
Tide curve	A graphic representation of the rise and fall of the tide in which time is usually represented by the abscissa and height by the ordinate. For a semi-diurnal tide with little diurnal inequality, the graphic representation approximates a cosine curve.
Tide (water level) gauge	An instrument for measuring the rise and fall of the tide (water level).
Tide Tables	Tables which give daily predictions of the times and heights of high and low waters. These predictions are usually supplemented by tidal differences and constants through which predictions can be obtained for numerous other locations.

Tsunami	A shallow water progressive wave, potentially catastrophic, caused by an underwater earthquake or volcano.
Universal time (UTC)	Same as Greenwich mean time (GMT).
Z <sub>0</sub>	Symbol recommended by the International Hydrographic Organisation to represent the elevation of mean sea level above chart datum

# Appendix F Publications of interest

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## Data Reports

MHL Annual Ocean Tide Levels Summaries available from 1986-87 to 2017-18

MHL Report Nos. 515 (86-87), 544 (87-88), 563 (88-89), 585 (89-90), 602 (90-91), 628 (91-92), 658 (92-93), 697 (93-94), 732 (94-95), 777 (95-96), 876 (96-97), 947 (97-98), 1013 (98-99), 1069 (99-00), 1129 (00-01), 1205 (01-02), 1277 (02-03), 1347 (03-04), 1423 (04-05), 1512 (05-06), 1764 (06-07), 1848 (07-08), 1933 (08-09), 2010 (09-10), 2089 (10-11), 2158 (11-12), 2219 (12-13), 2292 (13-14), 2384 (14-15), 2475 (15-16), 2574 (16-17), 2618 (17-18).

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Manly Hydraulics Laboratory 2010, *Tidal Data Compilation 2010*, MHL Report 1988, June 2010.

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## Mean Sea Level

Couriel, E, B Modra and R Jacobs 2014, *NSW Sea Level Trends – The Ups and Downs*, 17<sup>th</sup> Australian Hydrographers Association Conference, Sydney, Australia, October 2014.

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National Mapping Council, Permanent Committee on Tides and Mean Sea Level (PCTMSL), *Tide Gauge Survey Information*.

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