Manly Hydraulics Laboratory

NSW OCEAN AND RIVER ENTRANCE TIDAL LEVELS ANNUAL SUMMARY
2016–2017

Report MHL2574
December 2017

Prepared for:

Office of Environment and Heritage

Cover Photograph: Princess Jetty ocean tide gauge, Princess Jetty, Batemans Bay, 6 July 2017
Photo courtesy Phil Clark

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Foreword

Manly Hydraulics Laboratory (MHL) is a business group within the Department of Finance, Services and Innovation which operates and maintains a number of ocean and river entrance tidal recording stations along the NSW coast under contract with the Office of Environment and Heritage (OEH).

The NSW ocean tide database has been developed by MHL to support a number of OEH 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 annual summary presents ocean and river entrance tidal data captured by the automatic tide level recording stations along the coastline of New South Wales (NSW) over the period 1 July 2016 to 30 June 2017, and catalogues all ocean and river entrance tidal data collected in NSW by MHL for OEH.

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.

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Summary

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 2016–2017
- 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
- Appendix F, a list of other publications which may be of interest.

Contents

FIGURES

1. Tidal network measurement program

This report presents the thirty-first 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, electromagnetic tide pole, solid state floatwell, vented pressure sensor and submersed water level pressure recorder. Each system functions as follows:

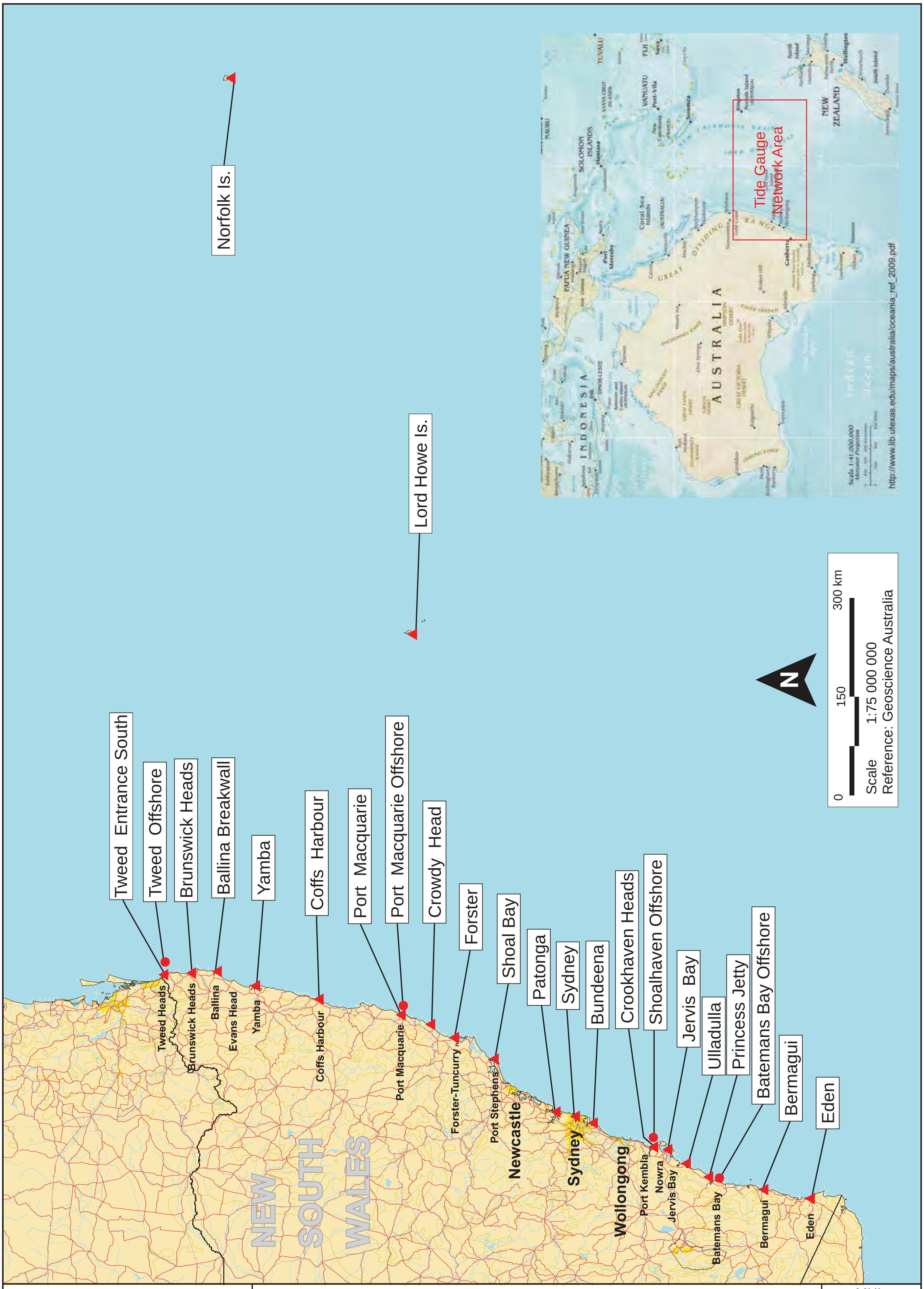
- Radar sensors: the water level is detected by radio detection and ranging technology. The data recorded is then transferred via an Internet Protocol (IP) link through a modem between the data logger and the data server. As the data is a direct measurement of the water surface, it requires no correction 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.
- Solid state floatwell: the level is sensed by a float connected to a shaft encoder. The data recorded is then transferred via an 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 1.4.
- 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 1.5.

Tidal data is transferred to MHL's data server and is then available to external users to view. A backup copy is also transferred to the NSW Government Data Centre. 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).

The data is stored in a database and subjected to a quality assurance process which involves several control steps to ensure data quality is maintained. Computer programs are used to further format and analyse data. The database is backed up daily and data archived to magnetic tape as a security measure at regular intervals at the NSW Government Data Centre.

The station locations and data summaries for 2016–2017 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.



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OCEAN TIDE GAUGE NETWORK

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Figure 1.1

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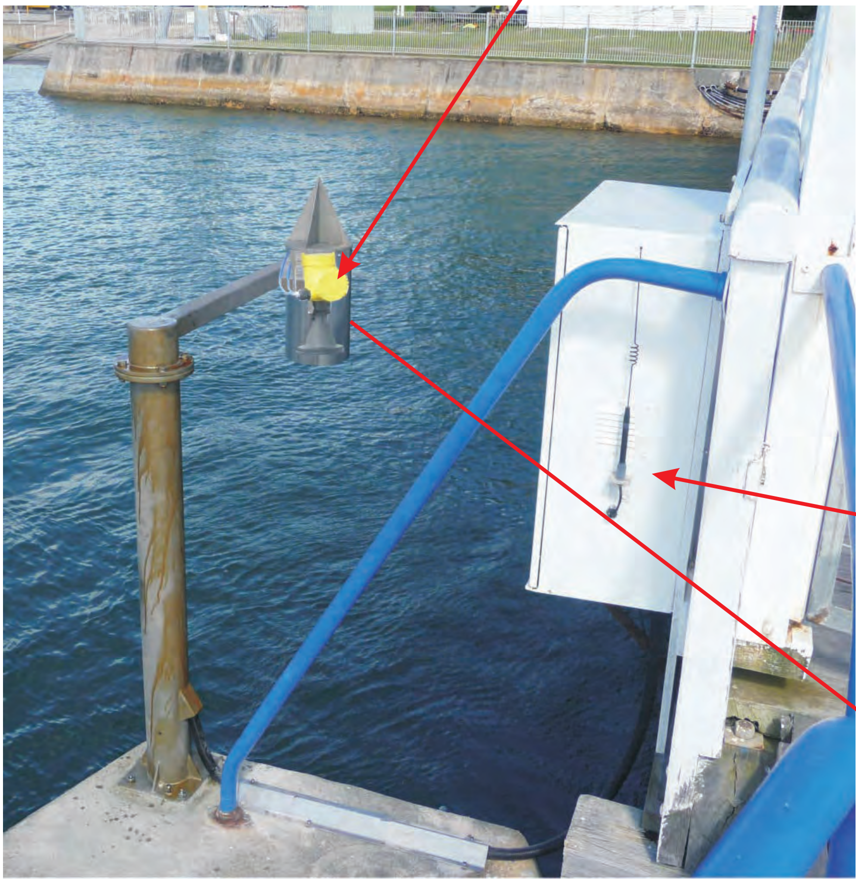
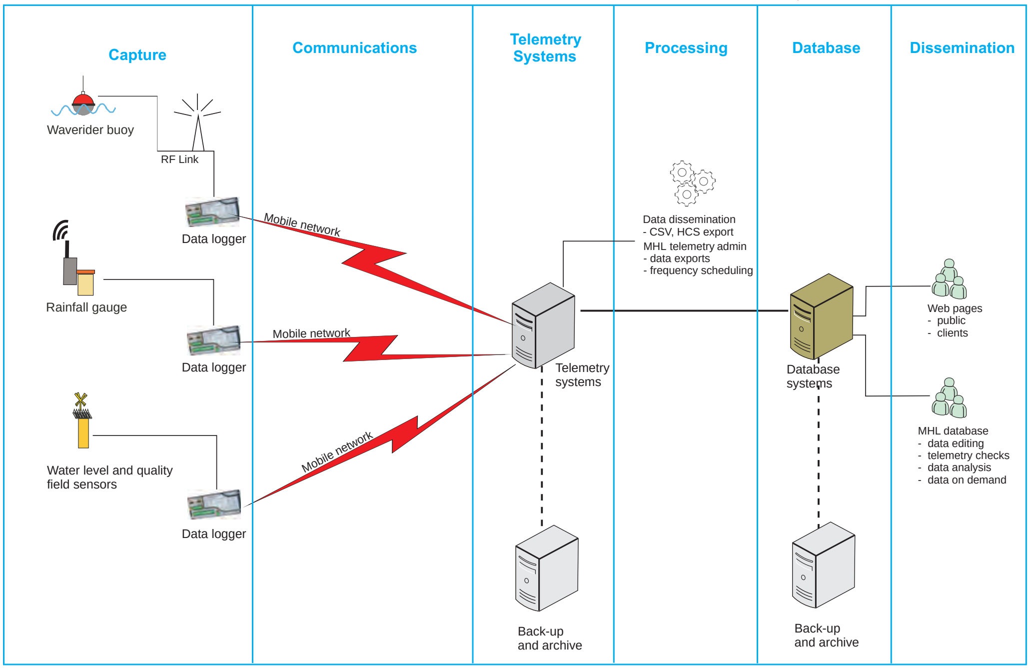
Radar inside
protective housing



Enclosure containing
modem, battery and
data logger

DATA TRANSFER
via telephone modem
(landline or cellular)



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RADAR SENSOR

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Figure 1.2

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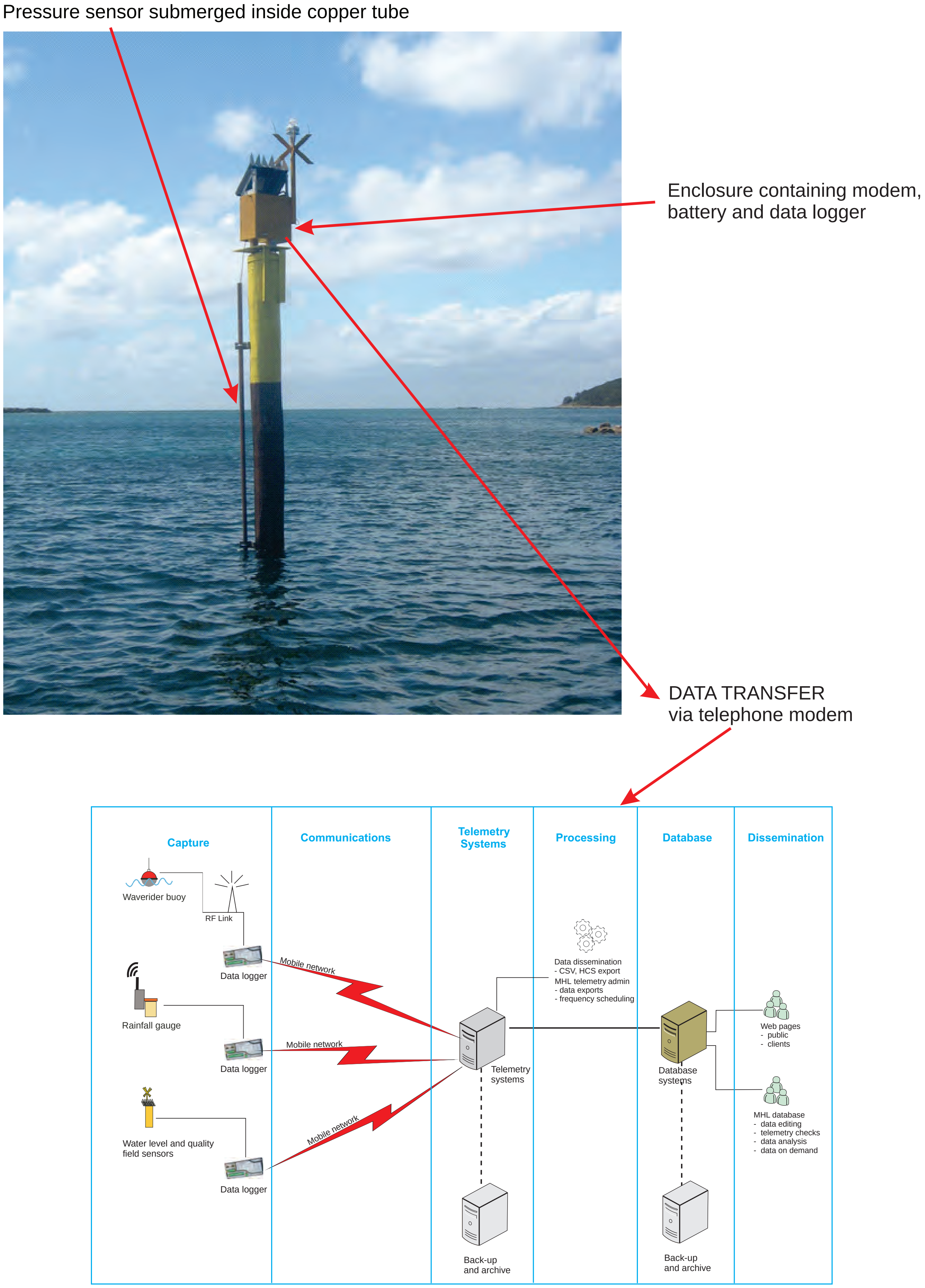

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ELECTROMAGNETIC WAVE STAFF
AND BACK-UP PRESSURE SENSOR

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Figure 1.3

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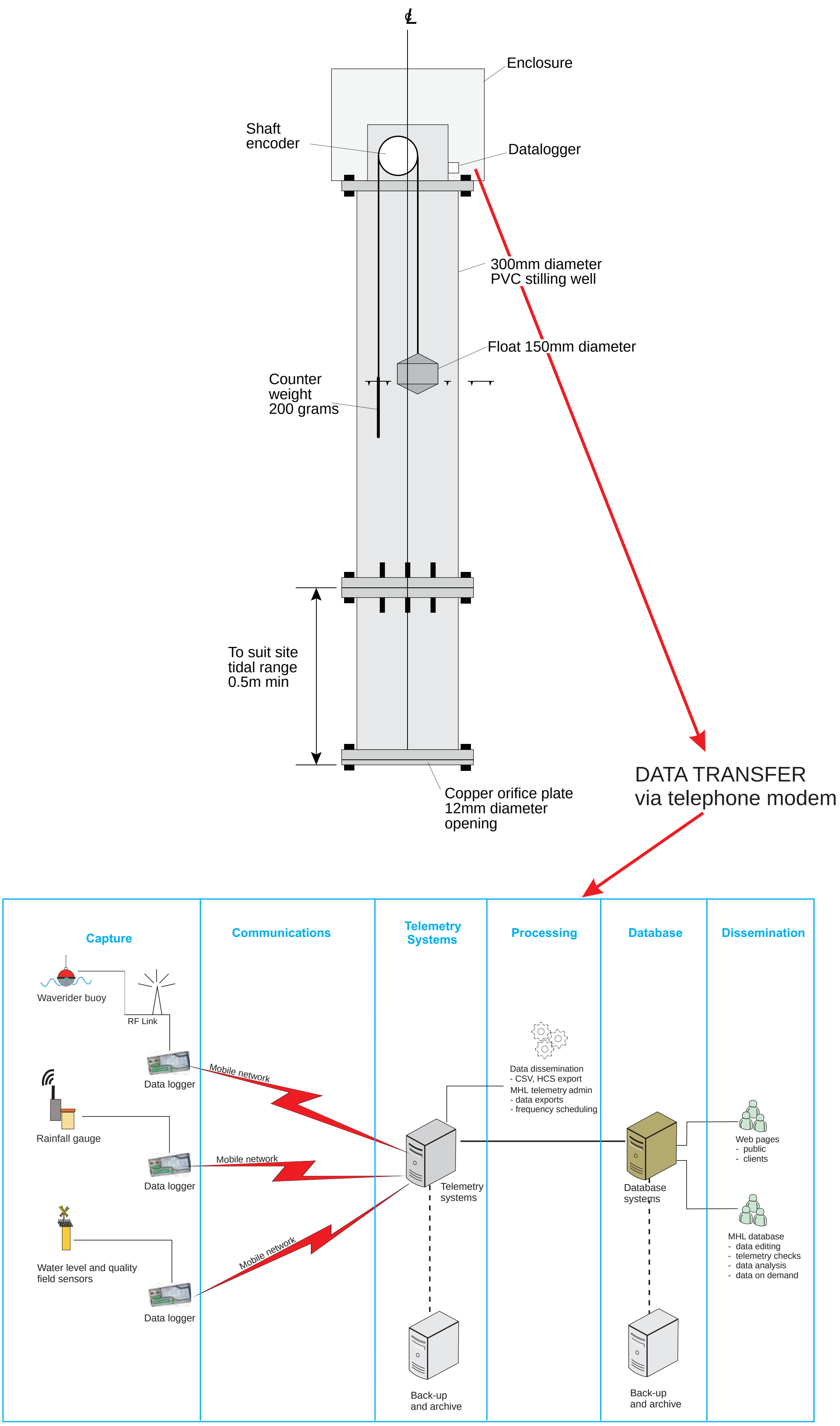

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TYPICAL SOLID STATE FLOATWELL

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Figure 1.4

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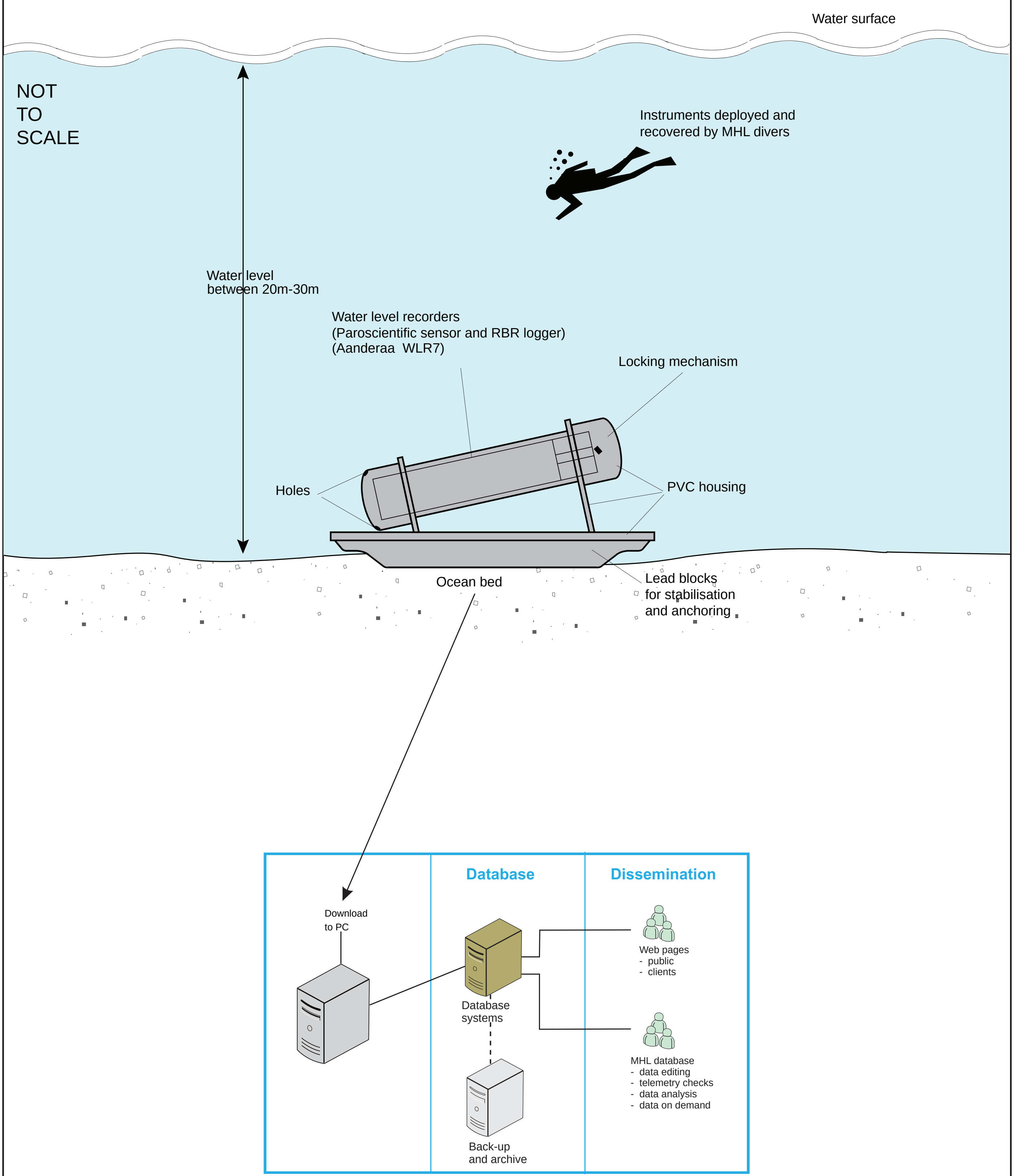

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SUBMERSIBLE PRESSURE SENSOR

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Figure 1.5

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2. How to use this report

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 2016 to 30 June 2017. 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 2016–2017. 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 Appendix D, including tidal predictions. This data consists of tide levels and can be reviewed in graphical or numerical format.

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, 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 datum level to the local Australian Height Datum (AHD) is shown in Table 2.1. These adjustments were calculated circa 1990 for MHL by the then NSW Public Works' Survey Branch using tidal harmonic analysis over a tidal epoch. These values 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 to AHD

Station	Station datum (SD)	Adjustment (SD – adjustment = AHD)
Tweed Entrance South	Tweed River Hydro Datum	0.893
Tweed Offshore	Mean Sea Level	N/A
Brunswick Heads	Brunswick River Flood Mitigation Datum	0.046
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

2.4 Tidal planes

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).

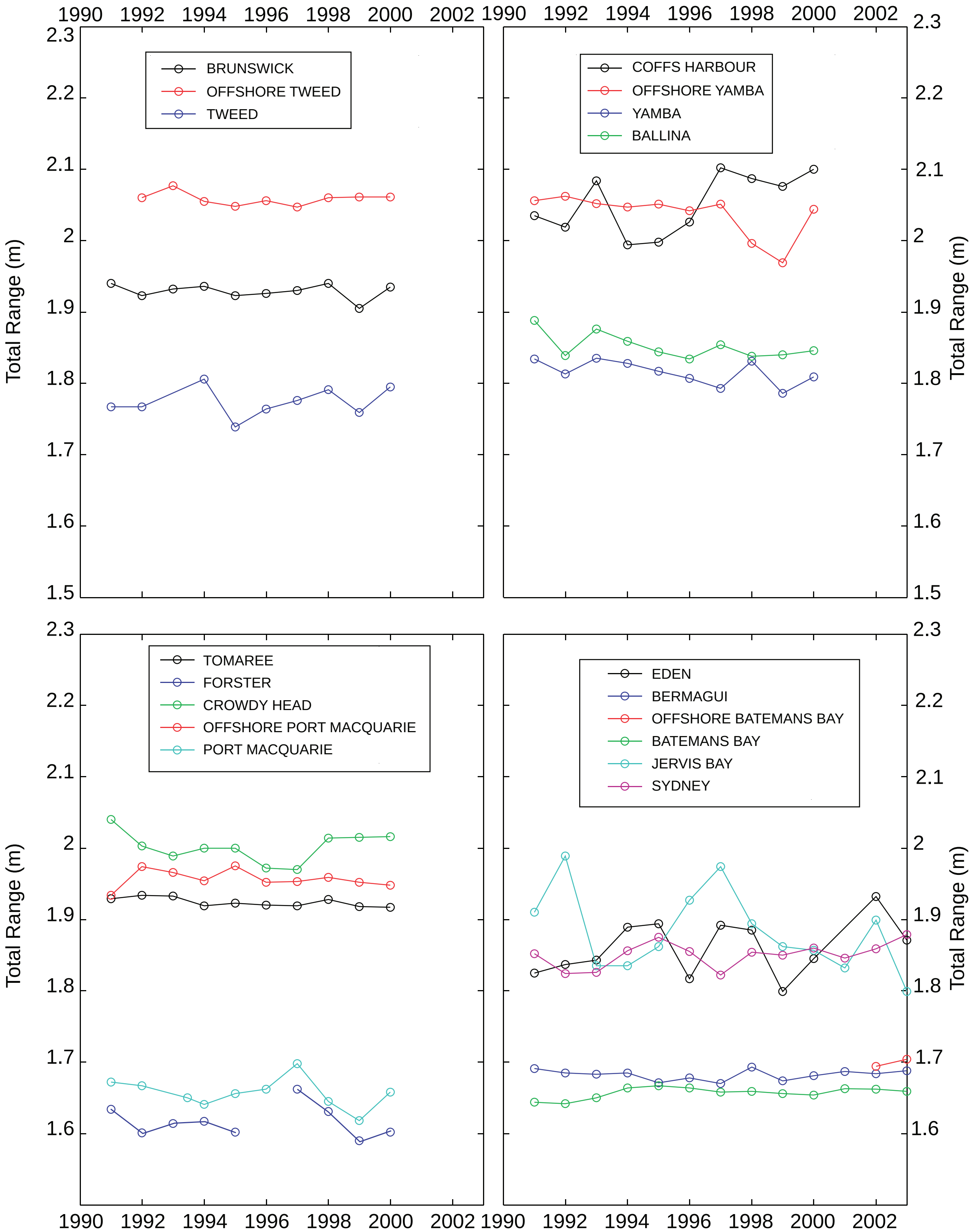
It is important to recognise such tidal plane and constituent variations when applying data from these ocean tide sites. Variations between sites may significantly influence investigation outcomes. For example, the difference between the sites when used as the boundary conditions for numerical hydrodynamic 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	LAT	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

* AHD offsets given in Table 2.1



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

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TIDAL RANGE FOR GROUPED OFFSHORE AND NEARSHORE GAUGES 1990–2003

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Figure 2.1

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3. Significant events 2016–2017

Data recovery rates across the NSW ocean tide network in 2016–2017 were greater than 90%, however, down from previous years due to the residual effects of the June 2016 East Coast Low event. The data recovery statistics are shown in Table 3.1.

Table 3.1 Data recovery July 2016 to June 2017

Data stream	Data recovery (%)	Comments
15-minute ocean tide data	96.3	Bundeena – damaged during June 2016 storm. Jervis Bay – logger problem and damaged in June 2016 storm. Ulladulla – issue with battery charging when mains power was lost. Patonga – radar glitches removed from data set, 1-minute set affected. Coffs Harbour – radar glitches removed from 1-minute data set, no 1-minute backup. Forster – power issue with battery and access issues.
1-minute ocean tide data	90.6	
5-minute offshore data	97.3	Shoalhaven – loss of data due to communication failure between the logger and sensor. Batemans Bay – loss of data due to battery failure 24 November 2016.

The 2018 NSW Tide Prediction Charts are available via download from the MHL public web page. The charts will be available free of charge via the MHL website. 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 and coastally trapped waves, and the influence of the East Australian Current (EAC). The NSW Ocean Water Levels report (MHL 2011) investigated anomalies recorded on the NSW coast and considered their occurrence and forcing mechanisms. 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.

Tidal anomalies in this report are calculated as the difference between the recorded data and the long-term epoch forecasts discussed in Section 2.4. Generally, tidal anomalies are caused by a range of oceanographic and meteorological and bathymetric effects, however, for ocean tide gauges located in river entrances hydrological anomalies such as floods can also occur. Further, tsunamis can cause waves that show up on the ocean tide gauges as tidal anomalies.

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 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. In addition, a coastal trapped wave was recorded between 5 November and 9 November 2016. 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 one cyclone in North Queensland during the 2016–2017 reporting period:

- 23 to 30 March 2017, Severe Tropical Cyclone Debbie – Category 4 – developed over the Coral Sea near Papua New Guinea. The system rapidly intensified to a category 4 as it moved towards the coast off north Queensland with wind gusts of 263 km/h before crossing near Airlie Beach on 28 March. A storm surge of 2.5 m was recorded at Laguna Quays, roughly 1 m above HAT but lower than forecast. Ex-Tropical Cyclone Debbie moved into South East Queensland and brought the heavy rainfall and flooding experienced further north. These effects were felt in NSW, with large scale flooding on the Tweed, Brunswick and Richmond rivers. Subsequent anomalies of over 0.3 m were experienced on ocean tide gauges as far down as Yamba, as shown and discussed in Figure 3.3 and Figure 3.4. The life cycle of Severe Tropical Cyclone Debbie resulted in a total economic cost of $A2.4 billion and claimed 14 lives.

3.2 Tsunami events

Table 3.2 lists the tsunami events in the Pacific Region for the period of time corresponding to the 2016–2017 data in this report.

Table 3.2 Tsunami events July 2016 to June 2017

Date	Earthquake magnitude (M_W)	Location	Observable on NSW tide recordings
12/8/2016	7.2	New Caledonia	No
01/9/2016	7.1	New Zealand - Gisborne	No
13/11/2016	7.8	New Zealand - off east coast of South Island	No
21/11/2016	6.9	Japan	No
9/12/2016	7.8	Solomon Islands	No
17/12/2016	7.9	Papua New Guinea	No
25/12/2016	7.6	Chile	No
01/3/2017	6.9	Fiji	No
22/1/2017	7.9	Papua New Guinea	No
28/4/2017	6.9	Philippines	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 2016 to June 2017. 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 4 July 2016, 15 December 2016 and 24 June 2017. The July king tide produced a water level in Sydney of 2.14 m Zero Fort Denison Datum (ZFD) (1.22 m AHD), whilst the December king tide reached 2.01 m ZFD (1.09 m AHD). The highest tide of the year occurred the day after the predicted king high in June 2017, recording a water level of 2.26 m ZFD (1.34 m AHD was recorded at the Sydney gauge). Forecasted king tides can register lower recorded tides than anomaly events under similar conditions. Figure 3.10 shows a photo of Sydney Harbour at Little Manly Beach during the predicted king tide on 15 December. The photo of Queenscliff, Manly Beach in Figure 3.10 is taken during an actual recorded higher tide than that of the predicted king tide at 2.17 m ZFD which occurred during the next summer spring tide cycle, highlighting the anomaly conditions on that day.

3.4 Ex-Tropical cyclone flooding event

Severe Tropical Cyclone Debbie documented in Figure 3.11 eventually settled off the coast of south east Queensland as ex-Tropical Cyclone Debbie shown in the synoptic maps in Figure 3.4. The low speed at which the storm moved offshore brought with it heavy rain into the NSW Northern Rivers systems. For example, the Main Arm rainfall gauge on the Brunswick River system registered 425.5 mm on 31 March 2017 in conjunction with high wave climate as the Byron Bay wave buoy registered a significant wave height (Hsig) of 5.89 m on the same date.

The type of anomalies as shown in Figure 3.11 are due to the inflow flooding conditions created by high rainfall systems and can be greatly affected by the position of the gauge. In 2013, OEH commissioned MHL to conduct a scoping study to find more suitable ocean tide recording sites on the north coast (MHL 2013). It found that the north coast is devoid of a true onshore port or bay site north of Coffs Harbour which are currently part of the ocean tide program and the study could not find a location to satisfy all project criteria.

3.5 Meteotsunami events

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.

Meteotsunamis are irregular water level oscillations with a meteorological rather than seismic origin. They have been measured in a wide range of maximum wave heights, but are not catastrophic to the extent of seismic tsunamis. Their temporal and spatial occurrence is higher than seismic tsunamis, because their generating forces are more common. High energy meteotsunami events, however, are uncommon due the rareness of the combination of resonant effects necessary to cause such events. However, they have had significant impact (including loss of life) on coasts, harbours and inland waterways around the world.

The processes involved in creation and amplification of a meteotsunami are a rapid change in barometric pressure, movement of the pressure system at the same speed as the wave celerity (known as Proudman or Greenspan resonance) and the influence of the shape and depth of the shelf and local morphology close to the shoreline.

Meteotsunamis have had significant impact in some parts of the world (maximum wave heights recorded up to 5 m), including Western Australia. Pattiaratchi et al. (2015) documents meteotsunamis and their impacts in south-western Australia and notes a single occurrence in NSW. It would appear that due to the easterly movement of weather systems, in most cases away from the NSW coast, a Proudman resonance is not as likely in NSW. This means that in most cases the potential for formation of a meteotsunami impacting the NSW coast is lessened compared to some other parts of the world, and resultant meteotsunamis are either small or not reinforced sufficiently to amplify and impact on the coast. A low awareness of such waves in NSW and their small impact has to date meant they have remained undefined.

On 5 February 2017 a small meteorological effect (that possibly does not fit the meteotsunami definition due to difficulty in determining wave propagation along the coast) was detected on the mid north coast. Figure 3.12 highlights level oscillations in both ocean and estuarine gauges due to a sharp barometric shift. Initial analysis of the Bulahdelah and Bombah Point gauges would look like a random sensor spike amplified by the low tidal range; the overplot and timing of the spikes would suggest they are true observations. Overplotting the closest barometric gauge along with some greater resolution data available from the Lake Macquarie catchment, the meteorological effect on the area of coast is highly visible.

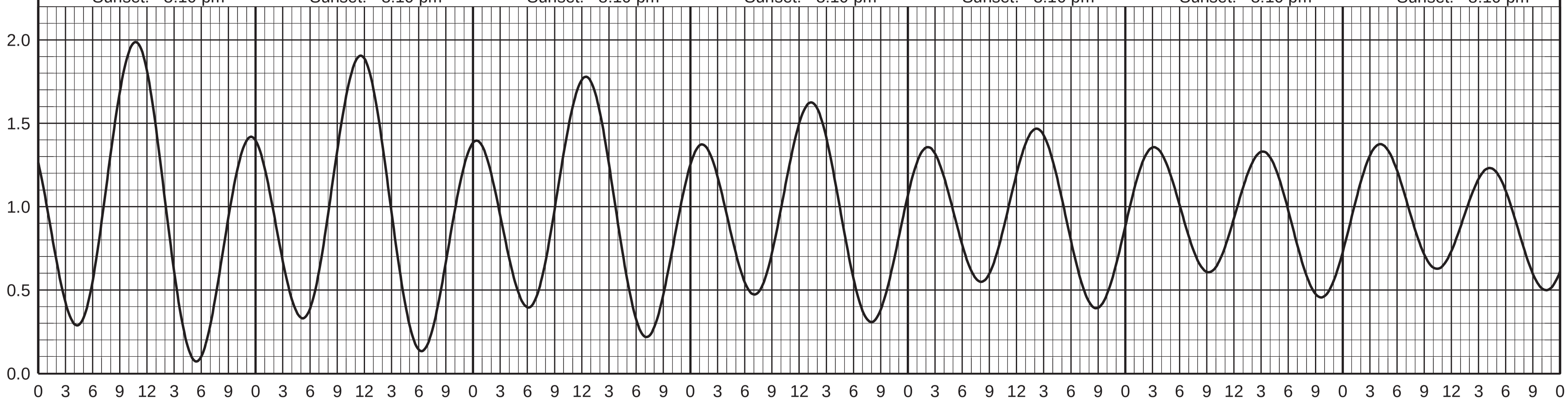
The closest ocean tide gauges of Forster and Shoal Bay in Figure 3.12 also show the effects of this small scale meteotsunami. Upgrade of loggers to high resolution 1-minute logging enables these meteotsunami and other coastal events to be identified and correlated with more accuracy. The continued rollout of the same logging resolution in surrounding river catchments such as the Cockle Railway Station gauge in the Lake Macquarie catchment used in Figure 3.12 will help support the ocean tide program's endeavour to identify meteotsunamis.

January 4–10, 2018

Daylight Saving Time

3rd Quarter Jan 9

4 THURSDAY	5 FRIDAY	6 SATURDAY	7 SUNDAY	8 MONDAY	9 TUESDAY	10 WEDNESDAY
Sunrise: 5:50 am Sunset: 8:10 pm	Sunrise: 5:51 am Sunset: 8:10 pm	Sunrise: 5:51 am Sunset: 8:10 pm	Sunrise: 5:52 am Sunset: 8:10 pm	Sunrise: 5:53 am Sunset: 8:10 pm	Sunrise: 5:54 am Sunset: 8:10 pm	Sunrise: 5:55 am Sunset: 8:10 pm



4 Thursday		5 Friday		6 Saturday		7 Sunday		8 Monday		9 Tuesday		10 Wednesday	
4:18am	0.29m 0ft 11in	5:11am	0.33m 1ft 1in	**12:22am**	**1.40m 4ft 7in**	**1:16am**	**1.37m 4ft 6in**	**2:13am**	**1.36m 4ft 6in**	**3:09am**	**1.36m 4ft 5in**	**4:09am**	**1.38m 4ft 6in**
10:45am	**1.99m 6ft 6in**	**11:35am**	**1.91m 6ft 3in**	6:07am	0.40m 1ft 4in	7:03am	0.47m 1ft 7in	8:05am	0.55m 1ft 10in	9:13am	0.60m 2ft 0in	10:24am	0.63m 2ft 1in
5:28pm	0.07m 0ft 3in	6:18pm	0.13m 0ft 5in	**12:28pm**	**1.78m 5ft 10in**	**1:18pm**	**1.63m 5ft 4in**	**2:13pm**	**1.47m 4ft 10in**	**3:11pm**	**1.33m 4ft 4in**	**4:13pm**	**1.23m 4ft 1in**
11:30pm	**1.42m 4ft 8in**			7:09pm	0.22m 0ft 9in	7:58pm	0.31m 1ft 0in	8:46pm	0.39m 1ft 3in	9:37pm	0.46m 1ft 6in	10:28pm	0.50m 1ft 8in

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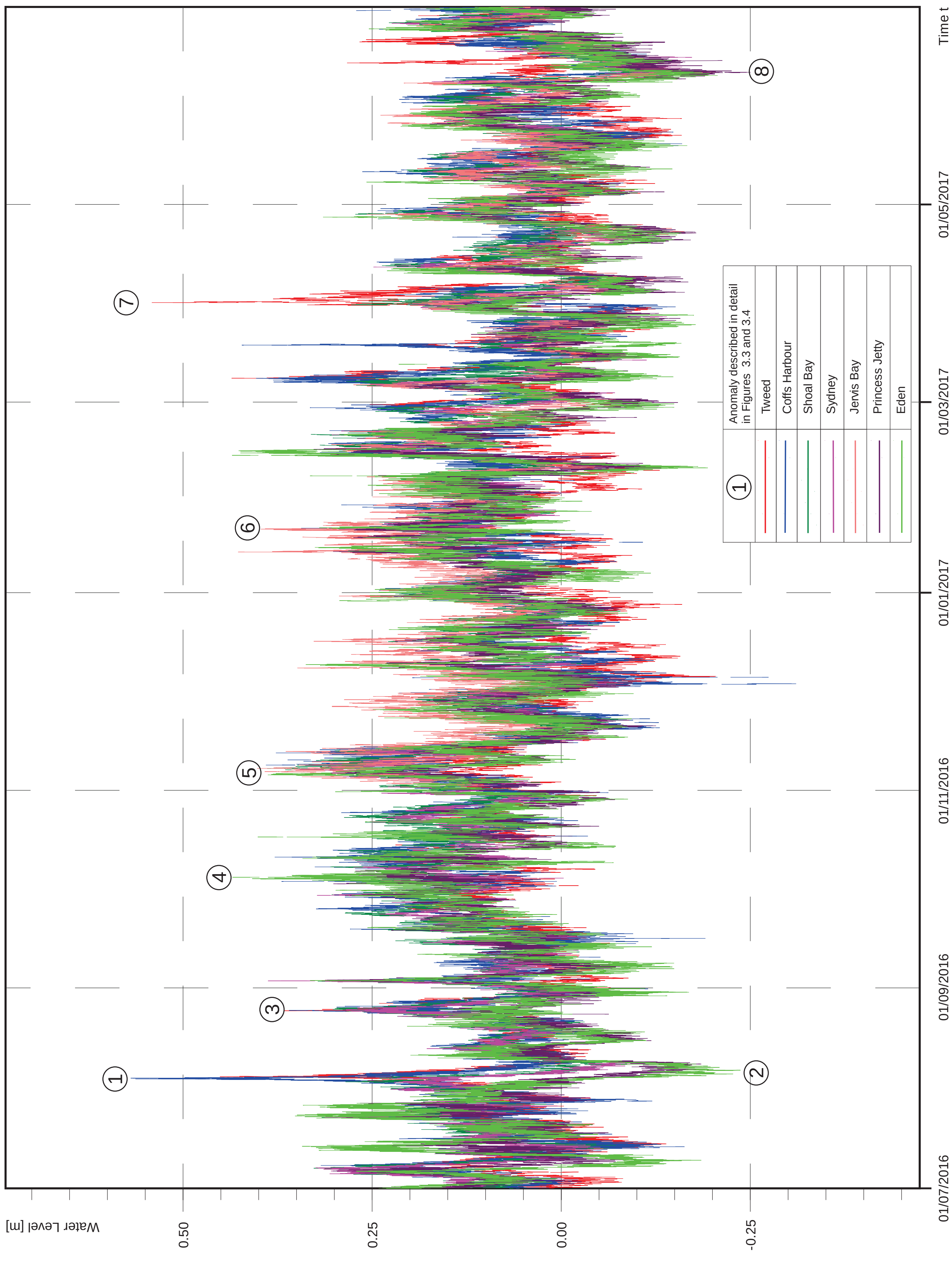
NSW TIDAL PREDICTIONS
EXTRACT FROM 'NSW TIDE CHARTS 2018'

MHL Report 2574

Figure 3.1

DRAWING 2574-03-01.cdr



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NSW TIDAL ANOMALIES PLOT 2016–2017

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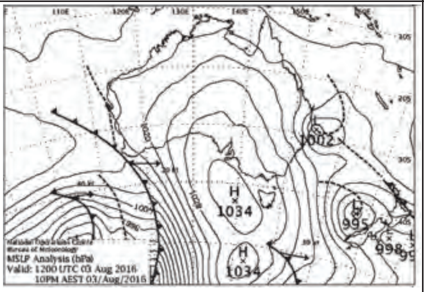
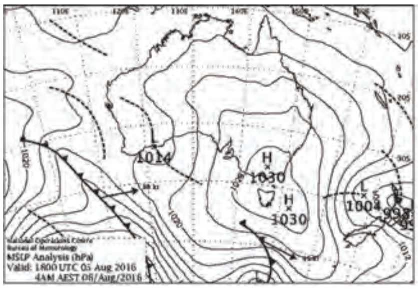
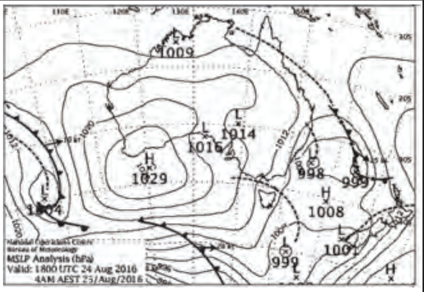
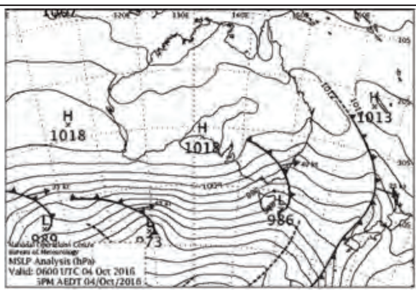
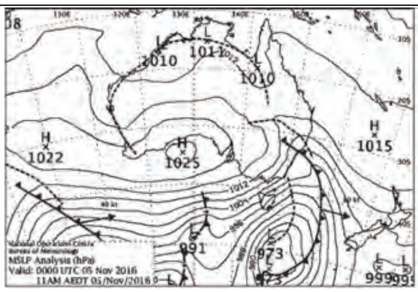
Figure 3.2

DRAWING 2574-03-02.cdr

Event Number (see Figure 3.2)	Event Period	BoM Weather Map*	Peak Anomaly	Sites where Anomaly > +/- 0.2m
1	3–6 August 2016	 East Coast Low	Site: Yamba Date: 4/8/2016 Time: 0100 Peak Value: 0.71 (flood affected)	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay
2	5–8 August 2016	 Large high pressure system	Site: Eden Date: 6/8/2016 Time: 1145 Peak Value: -0.24	Ulladulla, Princess Jetty, Eden
3	24–26 Aug 2016	 East Coast Low	Site: Brunswick Heads Date: 24/8/2016 Time: 1830 Peak Value: 0.39 (flood affected)	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Crookhaven Heads
4	3–6 October 2016	 East Coast Low	Site: Eden Date: 5/10/2016 Time: 1630 Peak Value: 0.43	Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven, Jervis Bay, Ulladulla, Bermagui, Eden
5	5–9 Nov 2016	 Coastal trapped wave	Site: Crowdy Head Date: 7/11/2016 Time: 2015 Peak Value: 0.40	Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven, Jervis Bay, Ulladulla, Bermagui, Eden

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TIDAL ANOMALIES
JULY 2016–NOVEMBER 2016

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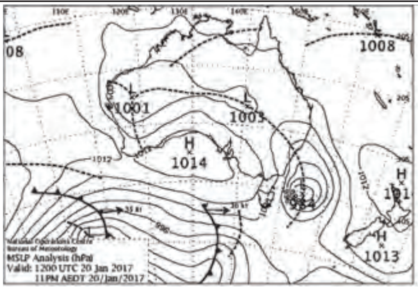
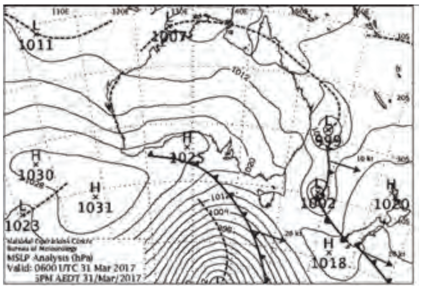
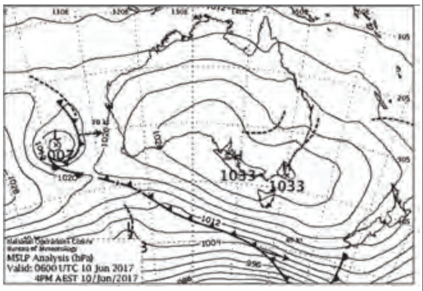
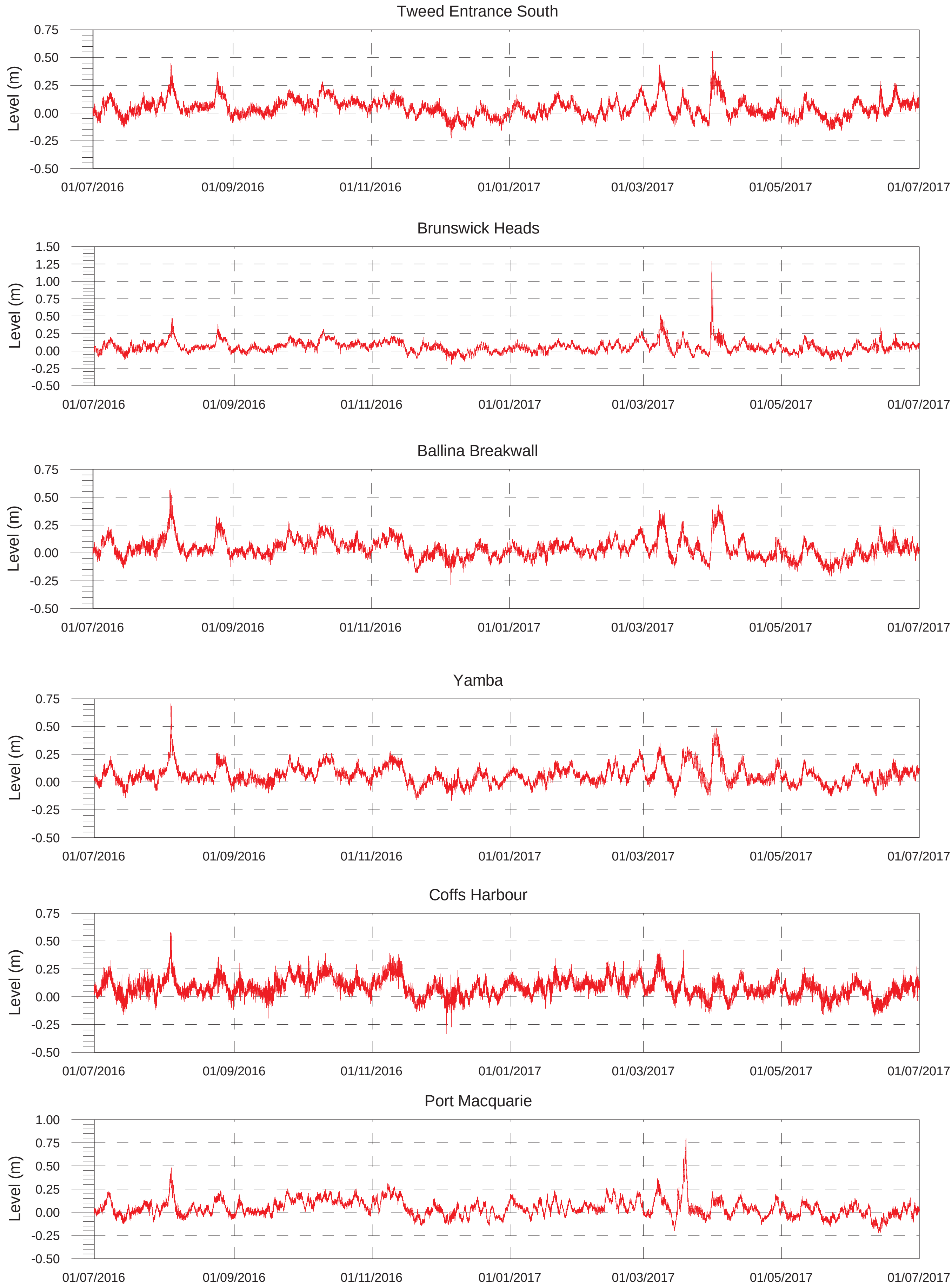
Figure 3.3

DRAWING 2574-03-03.cdr

Event Number (see Figure 3.2)	Event Period	BoM Weather Map*	Peak Anomaly	Sites where Anomaly > +/- 0.2m
6	20–22 Jan 2017	 Intense low off coast	Site: Jervis Bay Date: 20/1/2016 Time: 1830 Peak Value: 0.40	Coffs Harbour, Port Macquarie, Crowdy Head, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
7	30 March–6 April 2016	 Ex-Tropical Cyclone Debbie	Site: Tweed Date: 31/3/2017 Time: 1700 Peak Value: 0.56 (flood affected)	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie
8	9–11 June 2017	 Large slow moving high pressure system	Site: Ulladulla Date: 10/6/2017 Time: 1645 Peak Value: -0.30	Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden

* Weather map images courtesy BoM © Commonwealth of Australia, Bureau of Meteorology



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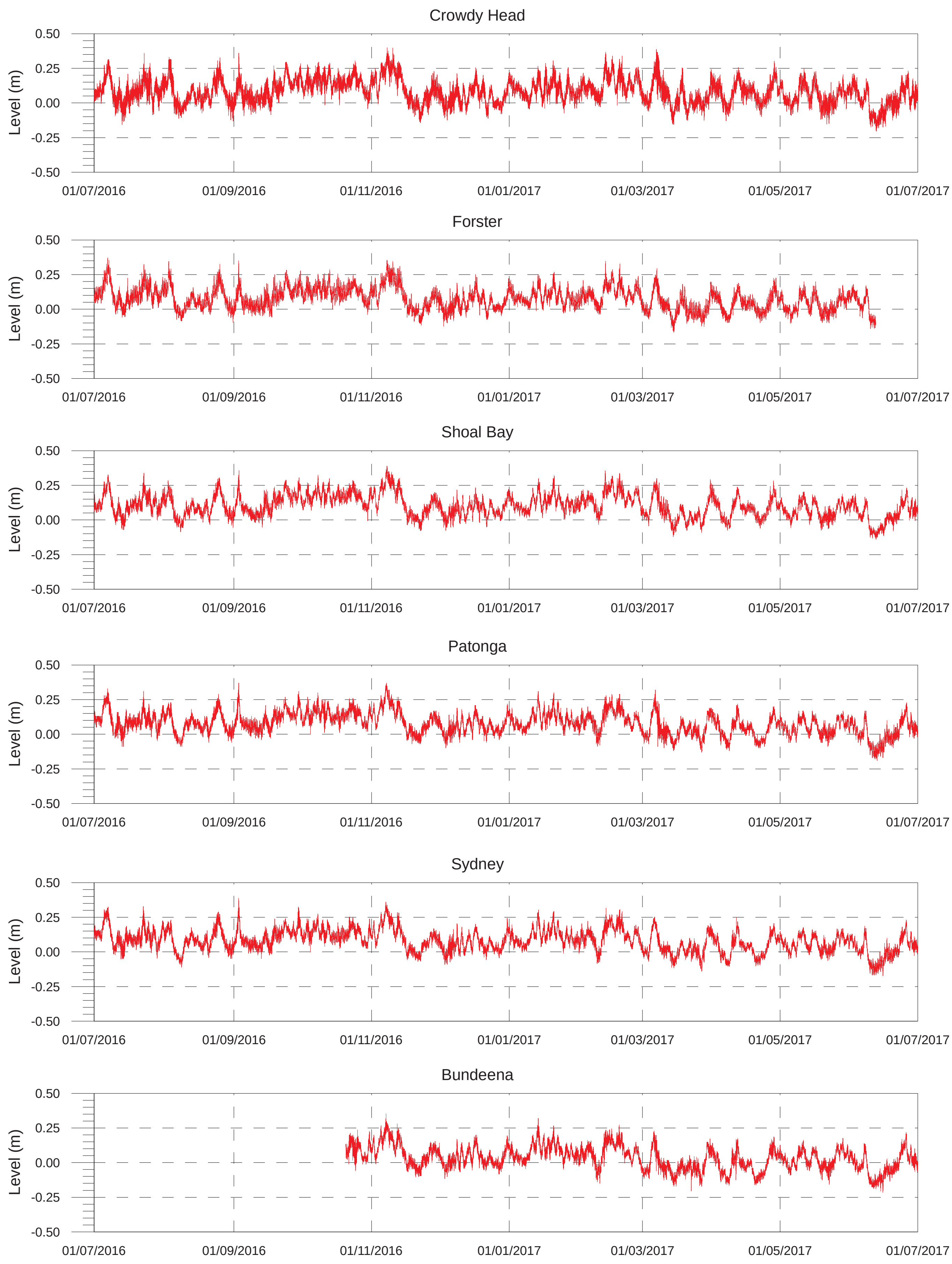
TIDAL ANOMALIES 2016–2017
TWEED ENTRANCE SOUTH TO PORT MACQUARIE

MHL Report 2574

Figure 3.5

DRAWING 2574-03-05.cdr



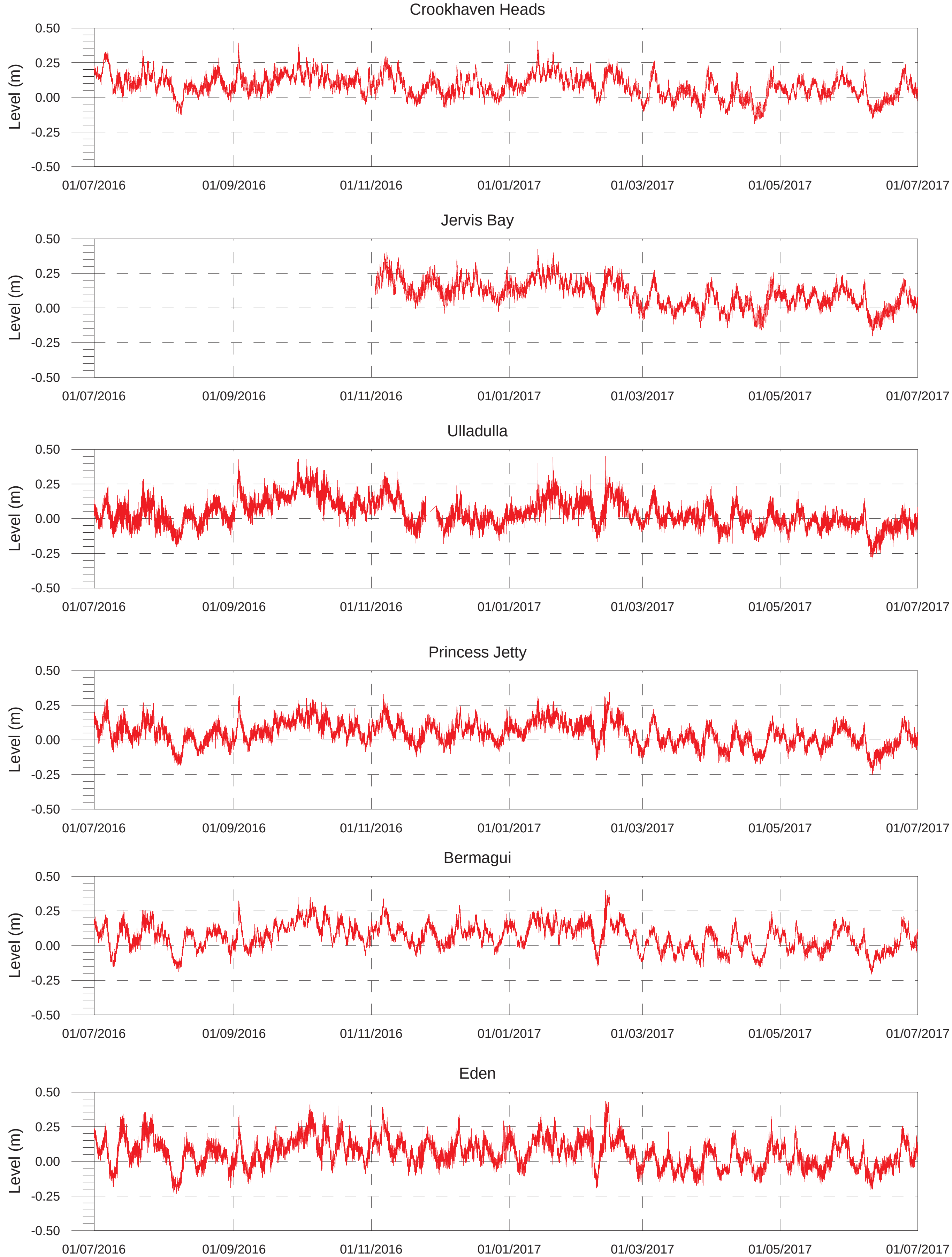
TIDAL ANOMALIES 2016–2017
CROWDY HEAD TO BUNDEENA

Manly Hydraulics Laboratory

MHL Report 2574

Figure 3.6

DRAWING 2574-03-06.cdr



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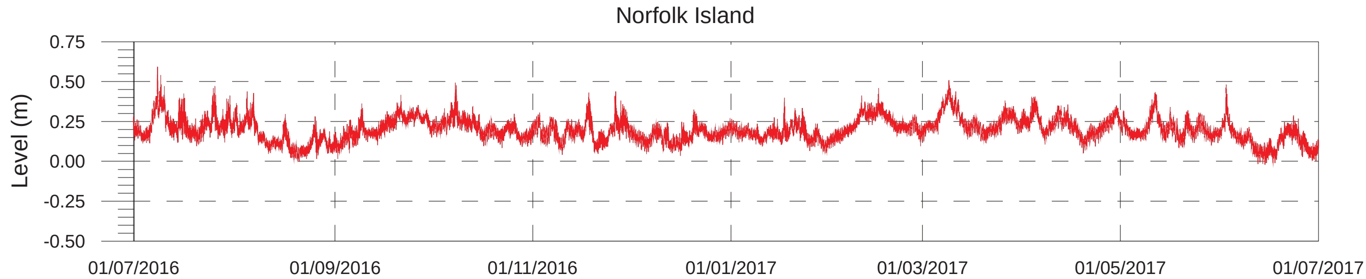
Manly Hydraulics Laboratory

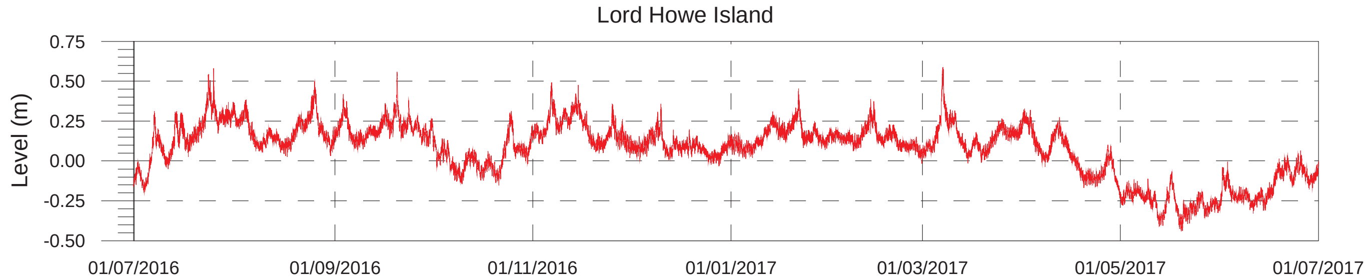
TIDAL ANOMALIES 2016–2017
CROOKHAVEN HEADS TO EDEN

MHL Report 2574

Figure 3.7

DRAWING 2574-03-07.cdr





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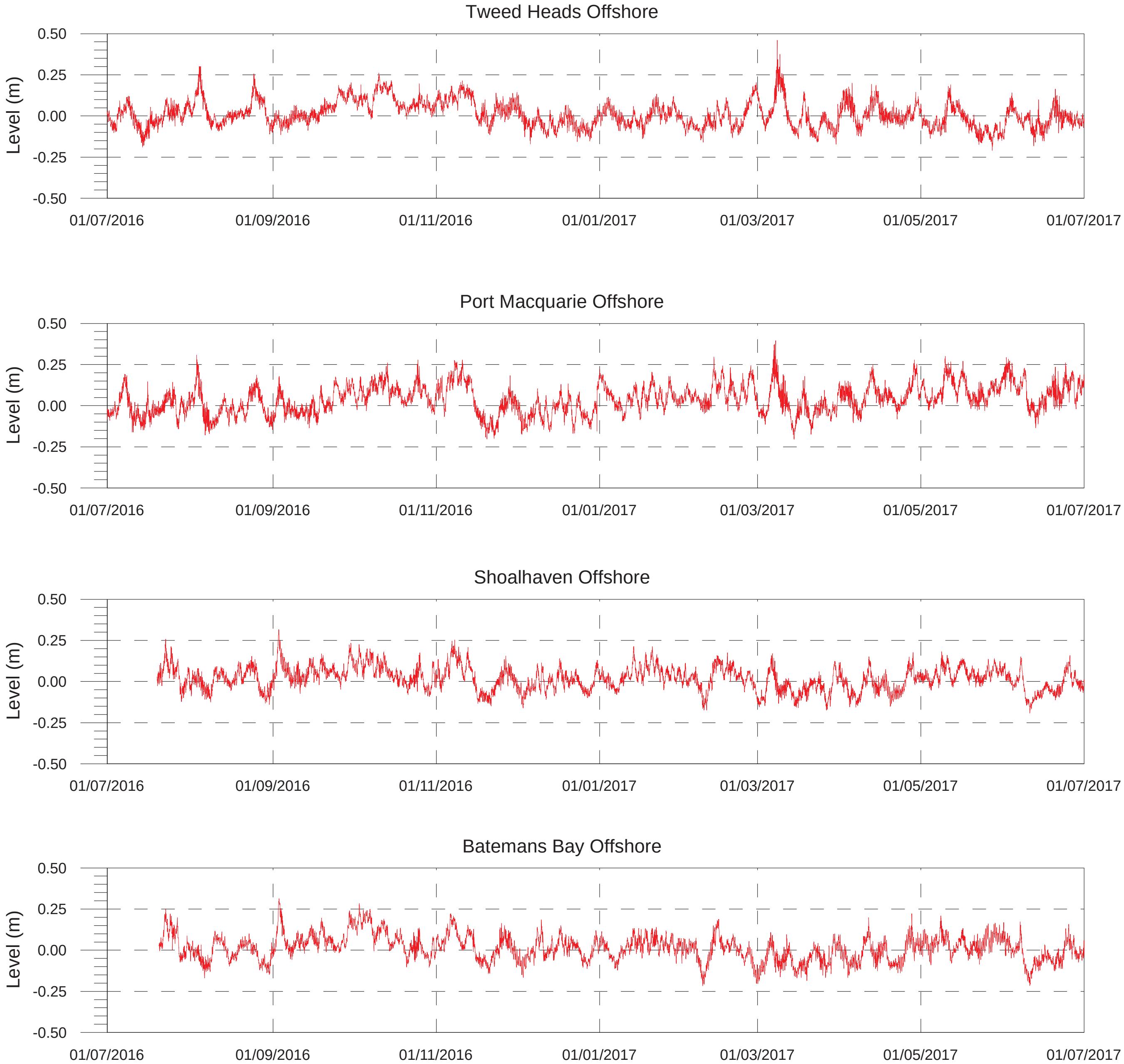
TIDAL ANOMALIES 2016–2017
NORFOLK ISLAND AND LORD HOWE ISLAND

MHL Report 2574

Figure 3.8

DRAWING 2574-03-08.cdr



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TIDAL ANOMALIES 2016–2017
OFFSHORE TIDE GAUGES

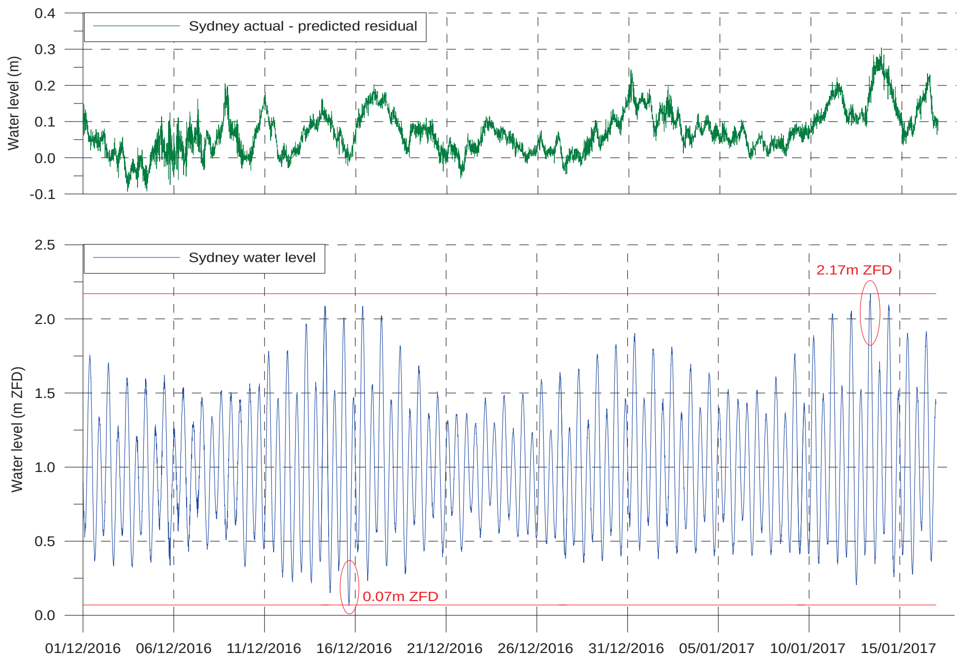
MHL Report 2574

Figure 3.9

DRAWING 2574-03-09.cdr

Little Manly Beach, Manly, 15 December 2016
(Photo: R Jacobs)

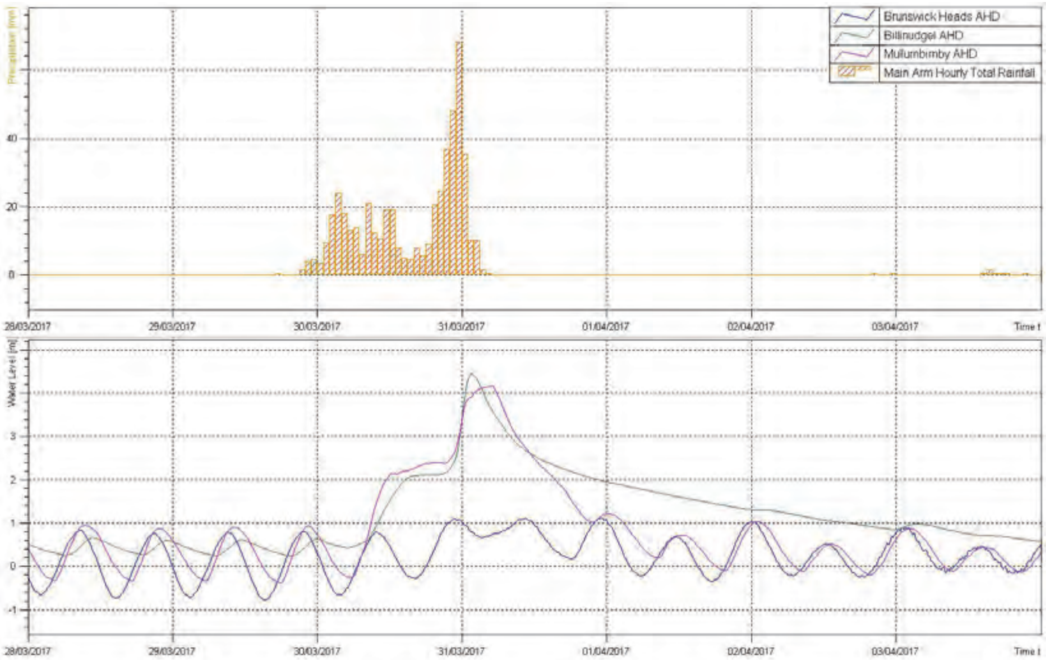
Queenscliff Beach, Manly, 13 January 2017



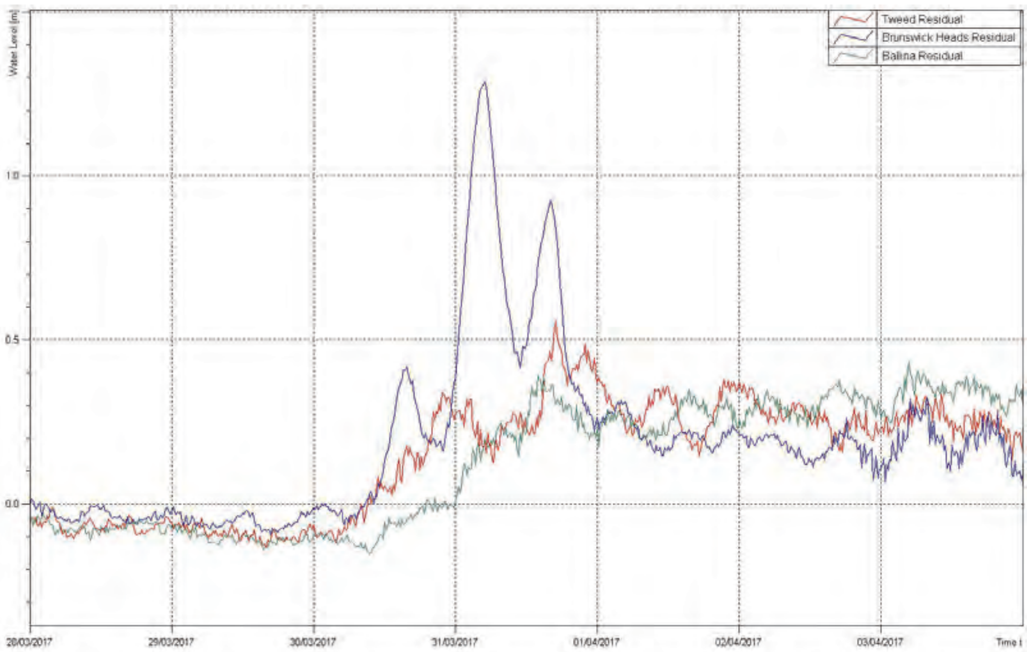
Sydney ocean tide gauge recorded high and low for the summer peak spring tides

NSW GOVERNMENT Manly Hydraulics Laboratory	SYDNEY KING AND ANOMALY HIGH TIDES	MHL Report 2574 Figure 3.10 DRAWING 2574-03-10.cdr

Brunswick River at Mullumbimby,
31 March 2017
(Photo: ABC)



AHD water levels on the Brunswick River during the event



North coast ocean tide gauge residuals during the event

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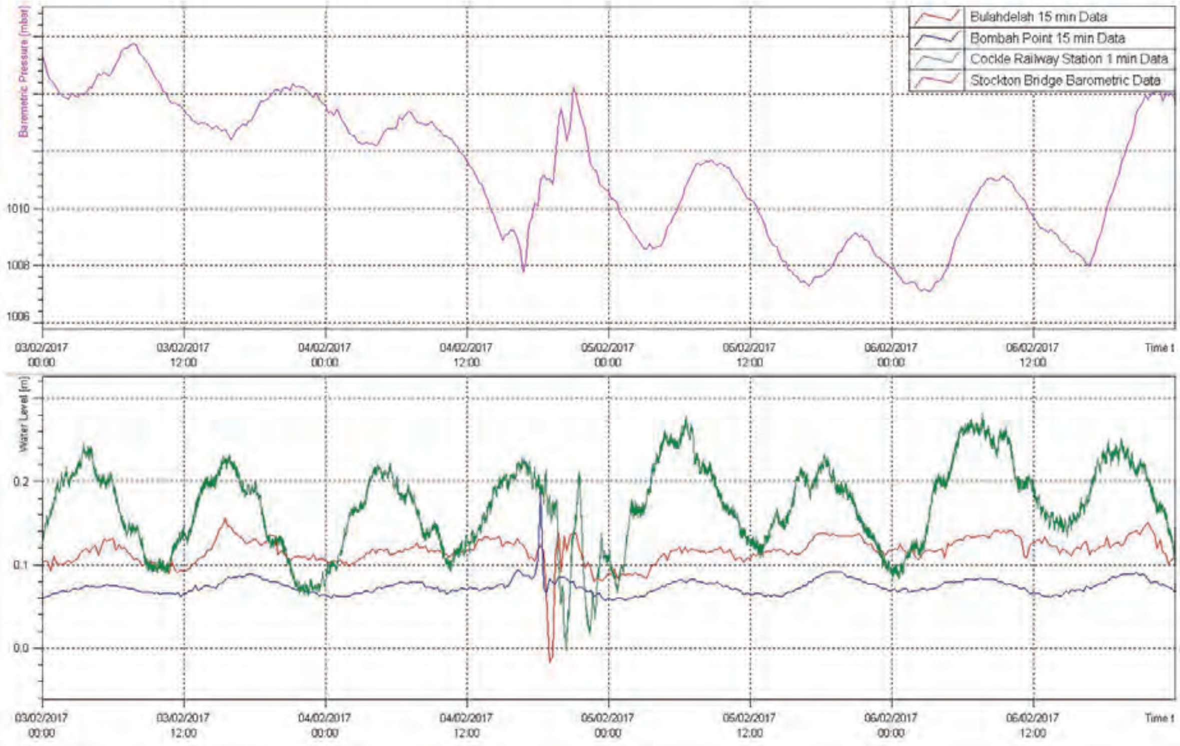
EX-TROPICAL CYCLONE DEBBIE ANOMALIES

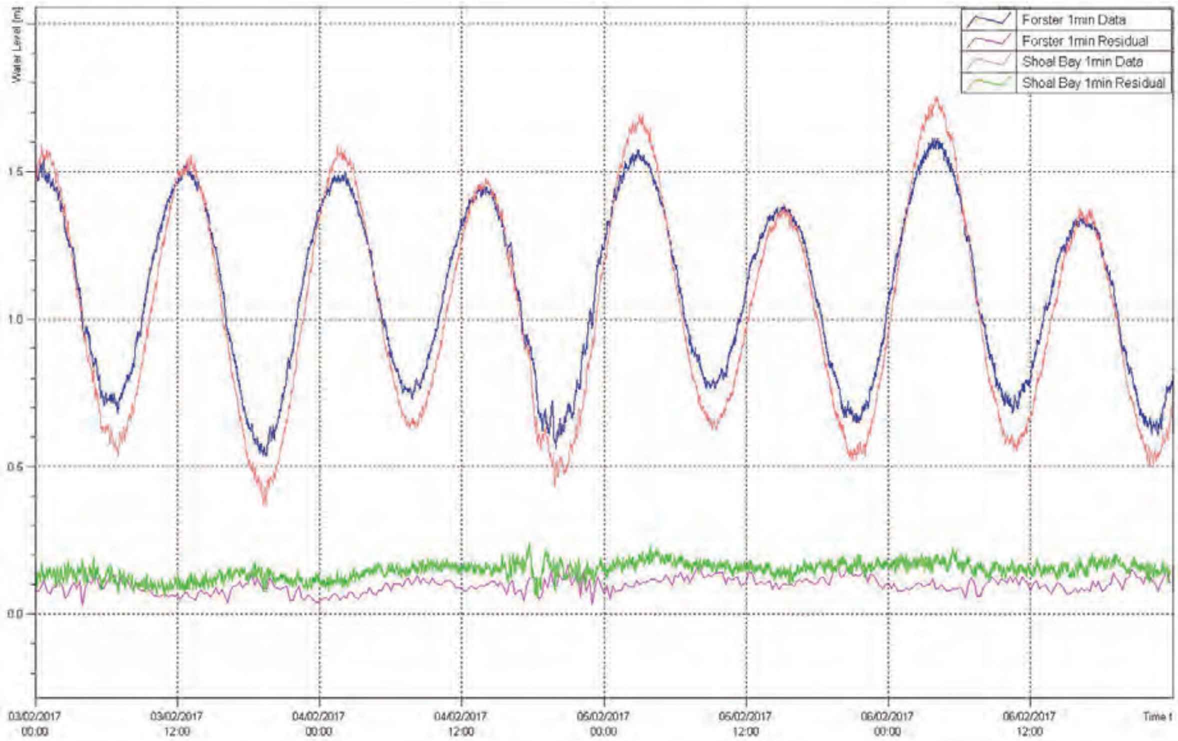
MHL Report 2574

Figure 3.11

DRAWING 2574-03-11.cdr



Potential meteotsunami effect on surrounding river system gauges



Potential meteotsunami effect on surrounding ocean tide gauges

NSW GOVERNMENT Manly Hydraulics Laboratory	POTENTIAL METEOTSUNAMI EVENT MID NORTH COAST	MHL Report 2574 Figure 3.12 DRAWING 2574-03-12.cdr

4. Program developments 2016–2017

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 of the data 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 provide good representation of ocean water levels but 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
Sydney	Onshore Bay or Port	OB

Station	Classification	Classification code
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 2016–2017. Major changes are summarised below.

- Stations damaged in the June 2016 ECL have been rectified and resumed logging. The initial period of the 2016–2017 financial year data period was lost for Bundeena and Jervis Bay before being repaired in October and November respectively.
- The Sydney backup site, Forster and Shoal Bay have now joined Eden in upgraded IP networks. This improved communications network provides faster data transfer between the logger and MHL's website after each point is logged.
- Upgraded status check procedures and technology have improved sensor confidence levels through the introduction of a hand-held laser level to minimise human error.
- Ballina, Shoal Bay and Jervis Bay sensor conduits were refastened due to wear.

Table 4.2 shows the status of the sites as of June 2017.

Table 4.2 MHL Tidal logging and sensing system status 1/7/2016–30/6/2017

Station	Latitude	Longitude	Site classif-ication[1]	Primary loggers[2]	Secondary loggers[2]	Primary sensors	Secondary sensors	Station Sampling	Station Logging
Tweed Entrance South	-28.1706	153.5512	OR	CR1000	-	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	CR800	-	Vented pressure	Vented pressure		
Ballina Breakwall	-28.8754	153.5844	OR	CR800	-	Vented pressure	Vented pressure		
Yamba	-29.4290	153.3621	OR	CR800	-	Radar	Vented pressure		
Coffs Harbour	-30.3029	153.1461	OB	CR800	-	Radar	Vented pressure		
Port Macquarie	-31.4268	152.9111	OR	CR1000	-	Radar	Vented pressure		
Crowdy Head	-31.8387	152.7500	OB	CR800	-	Radar	Vented pressure		
Forster	-32.1740	152.5082	OR	CR800	-	Vented pressure	Vented pressure		
Shoal Bay	-32.7197	152.1757	OB	CR1000	-	Radar	Vented pressure		
Patonga	-33.5510	151.2746	OB	CR1000	-	Radar	Vented pressure		
Sydney	-33.8255	151.2585	OB	CR800	-	Radar	n/a		
Sydney Backup	-33.8263	151.2572	OB	CR800	-	Vented pressure	Vented pressure		
Bundeena	-34.0827	151.1509	OB	CR800		Radar	n/a		
Crookhaven Heads	-34.9053	150.7594	OR	CR800	-	Vented pressure	Vented pressure		
Jervis Bay	-35.1220	150.7074	OB	CR800	-	Radar	Vented pressure		
Ulladulla	-35.3577	150.4765	OB	CR800	-	Vented pressure	Vented pressure		
Princess Jetty	-35.7038	150.1778	OR	CR1000	-	Radar	Vented pressure		
Bermagui	-36.4263	150.0715	OR	CR800	-	Vented pressure	Vented pressure		
Eden	-37.0712	149.9083	OB	CR1000n	-	Radar	Vented pressure		
Lord Howe Island	-31.5236	159.0581	OO	CR1000	-	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				

[1] Classification: OR = Onshore River entrance, OB = Onshore Bay or Port, OO = Onshore Open Ocean, O = Offshore Open Ocean
[2] Loggers: CR800/1000 = Campbell Scientific Loggers (Townsville Australia), RBR Virtuoso = RBR Ltd (Kanata, Canada), WLR7 = Aanderaa Data Instruments (Bergen, Norway)

4.3 Program plans 2017–2018

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 2017–2018 program upgrades include:

- continued rollout of upgraded IP network communications to enable faster data transfer
- an offshore tide metadata and site location report
- investigation of radar installations at Bermagui, Ulladulla, Crookhaven and Forster.

5. References

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.

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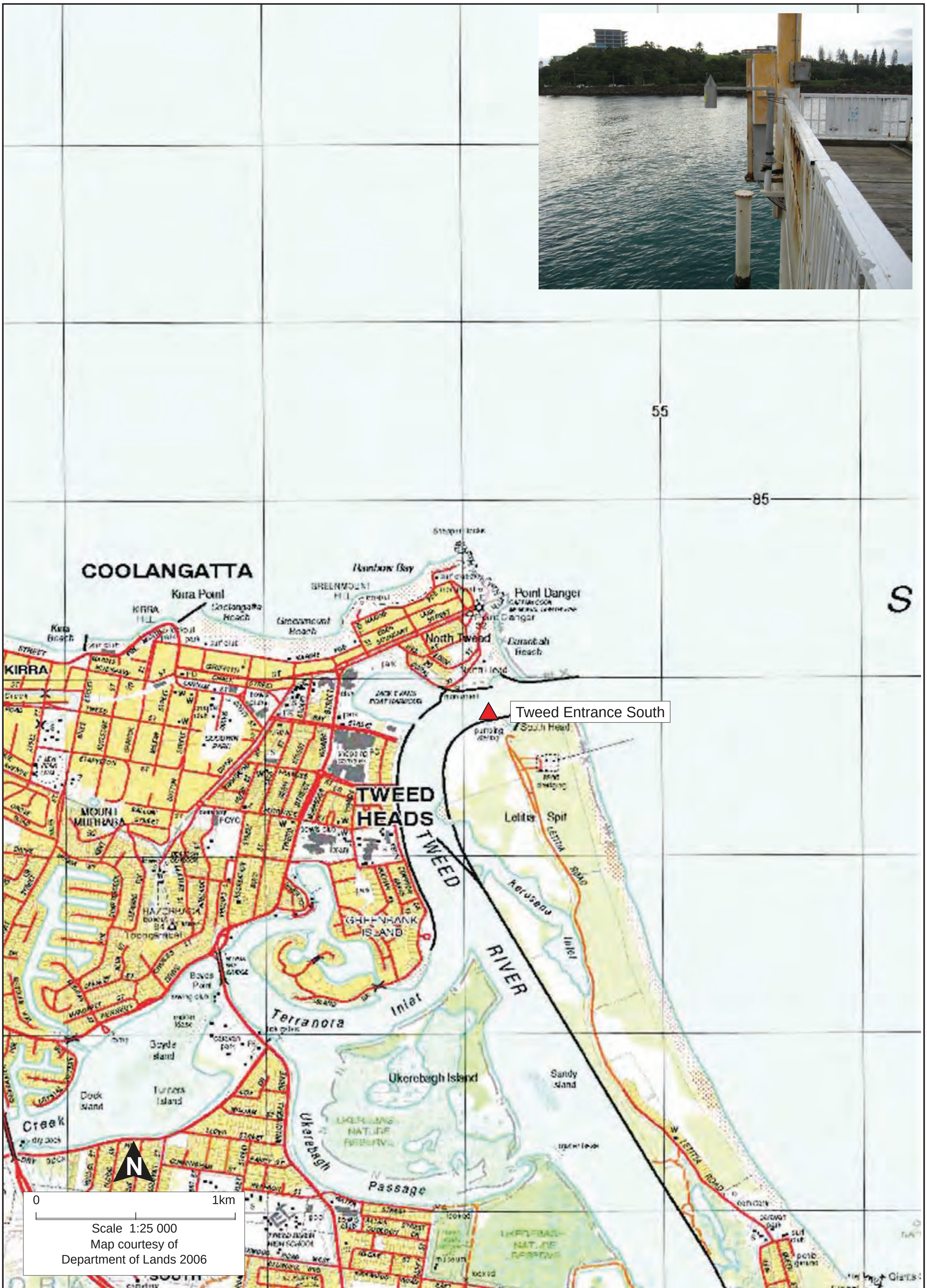
Appendix A Annual data site summaries



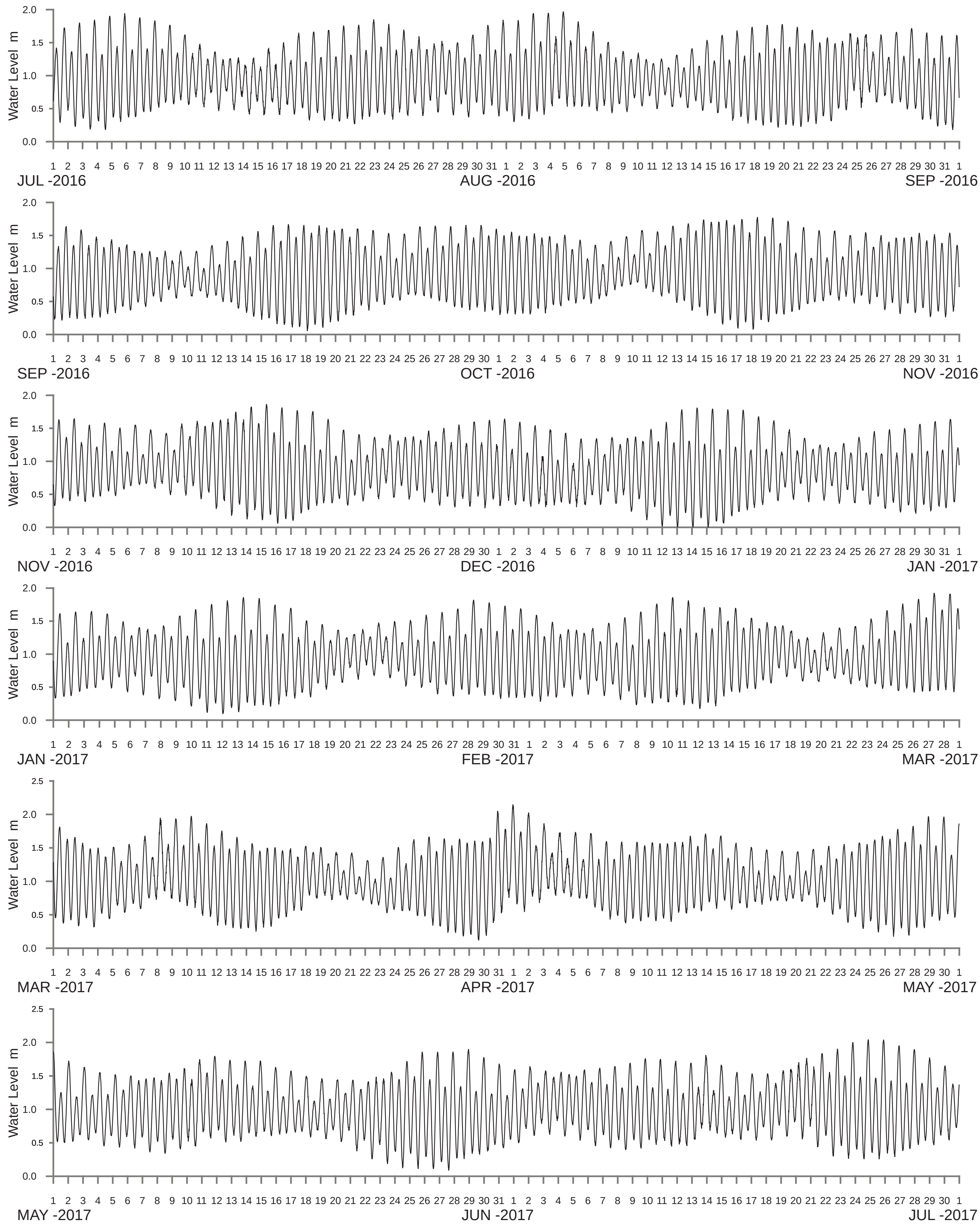
Manly Hydraulics Laboratory

TWEED ENTRANCE SOUTH
STATION LOCATION

MHL Report 2574

Figure A1

DRAWING 2573-A1.cdr



WATER LEVEL REFERENCED TO TWEED RIVER HYDRO DATUM

- - - - - - - - - - - - DATA LOSS

NSW GOVERNMENT
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TWEED ENTRANCE SOUTH DATA SUMMARY
2016–2017

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Figure A2

DRAWING 2573-A1.cdr

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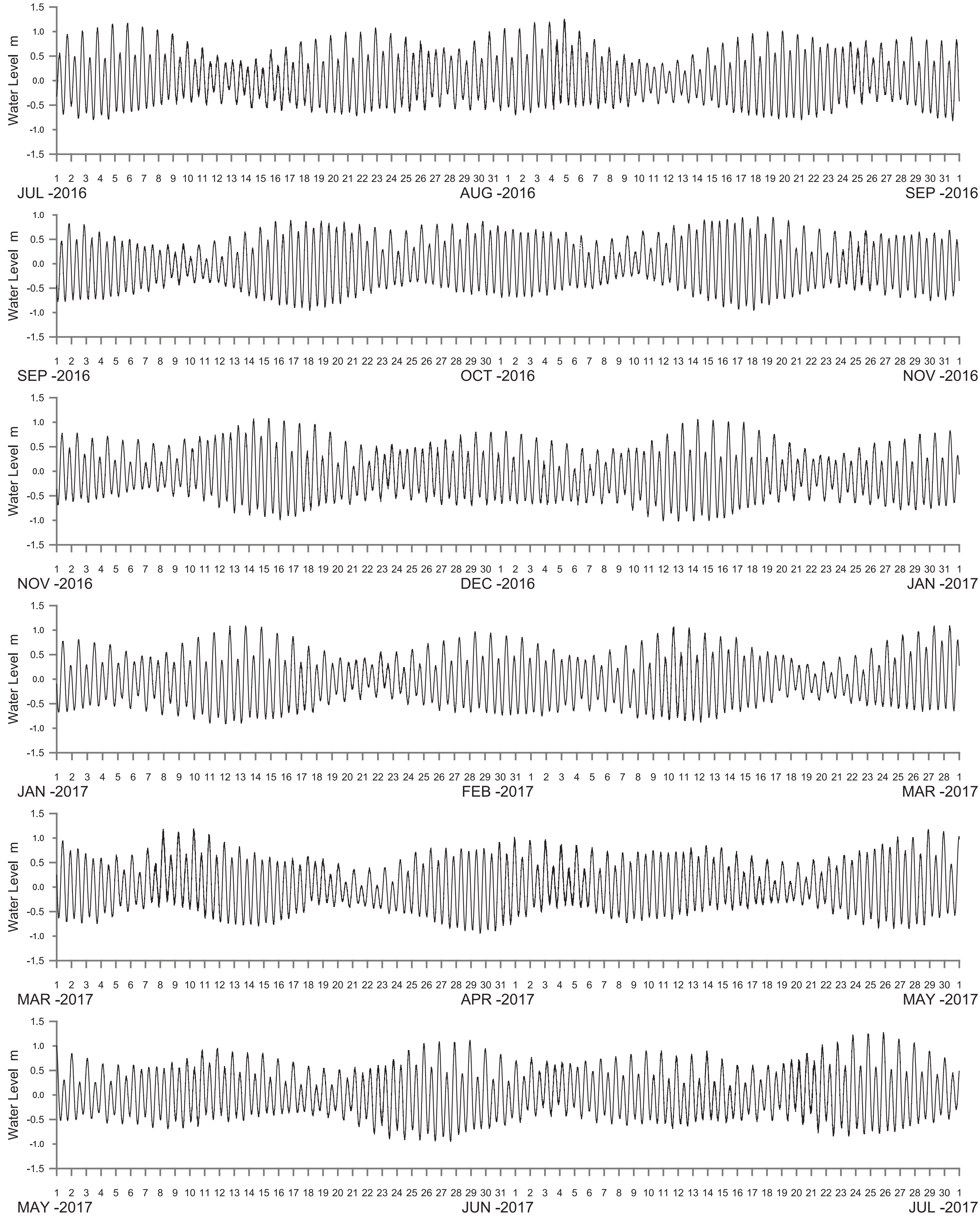
TWEED HEADS OFFSHORE TIDE GAUGE LOCATION

MHL Report 2574

Figure A3

DRAWING 2574-A3.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

------------ DATA LOSS

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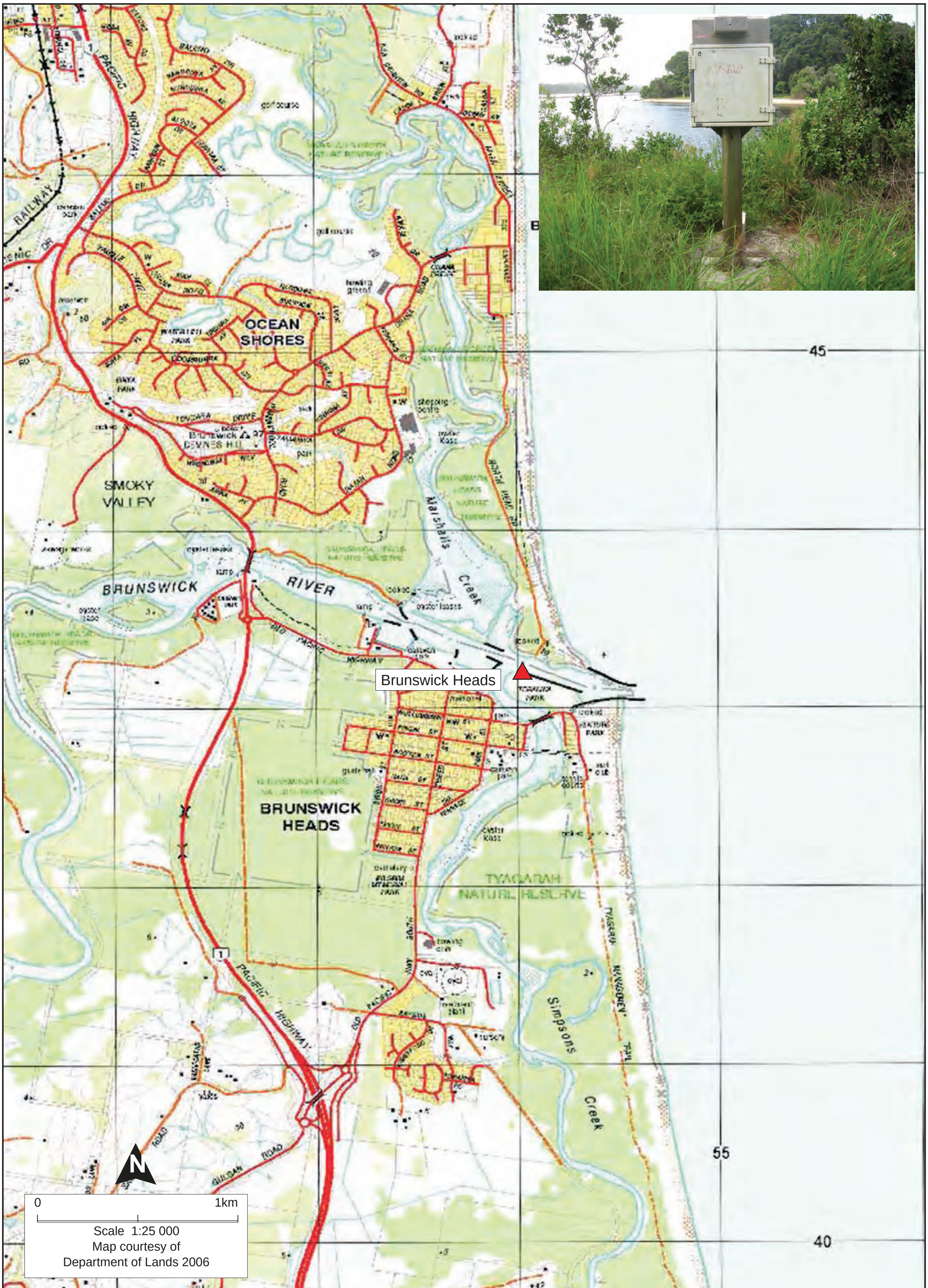
TWEED HEADS OFFSHORE DATA SUMMARY
2016–2017

MHL Report 2574

Figure A4

DRAWING 2574-A3.cdr



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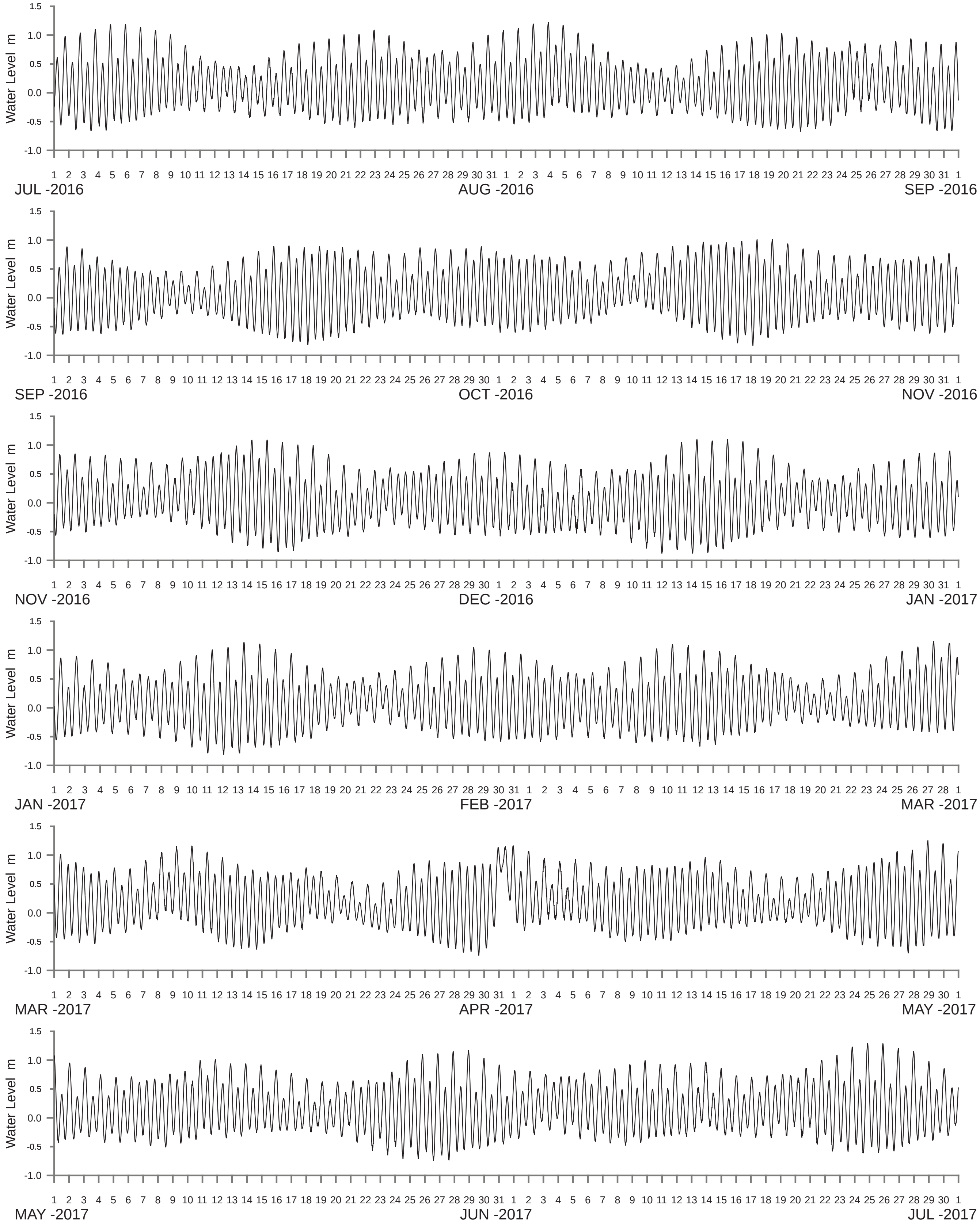
NSW GOVERNMENT

BRUNSWICK HEADS
STATION LOCATION

MHL Report 2574

Figure A5

DRAWING 2574-A5.cdr



WATER LEVEL REFERENCED TO BRUNSWICK RIVER FLOOD MITIGATION DATUM

------------ DATA LOSS

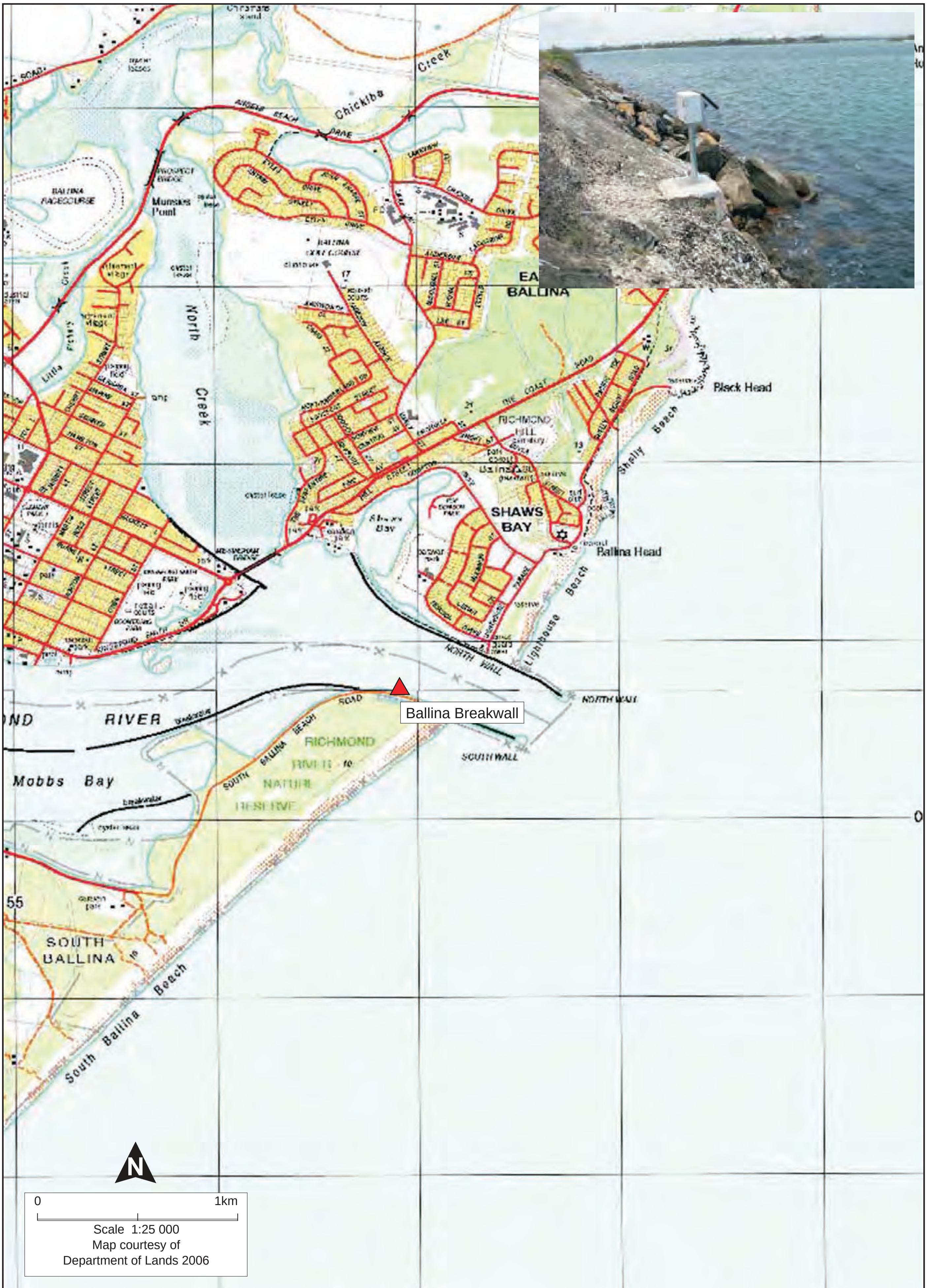
NSW GOVERNMENT | Manly Hydraulics Laboratory

BRUNSWICK HEADS DATA SUMMARY
2016–2017

MHL Report 2574

Figure A6

DRAWING 2574-A5.cdr



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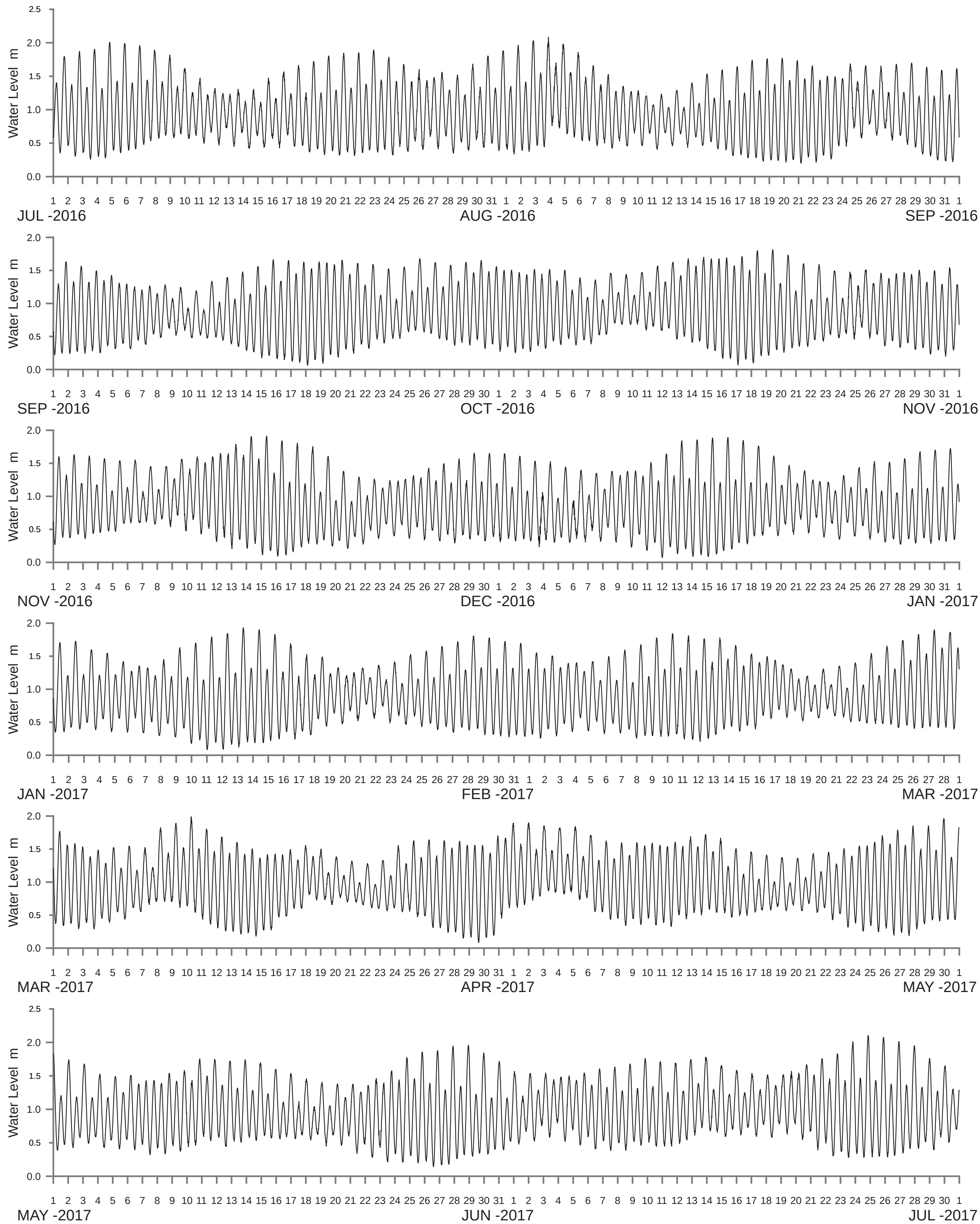
BALLINA BREAKWALL
STATION LOCATION

MHL Report 2574

Figure A7

DRAWING 2574-A7.cdr



WATER LEVEL REFERENCED TO RICHMOND RIVER VALLEY DATUM

- - - - - - - - - - - - DATA LOSS

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BALLINA BREAKWALL DATA SUMMARY
2016–2017

MHL Report 2574

Figure A8

DRAWING 2574-A7.cdr

NSW GOVERNMENT

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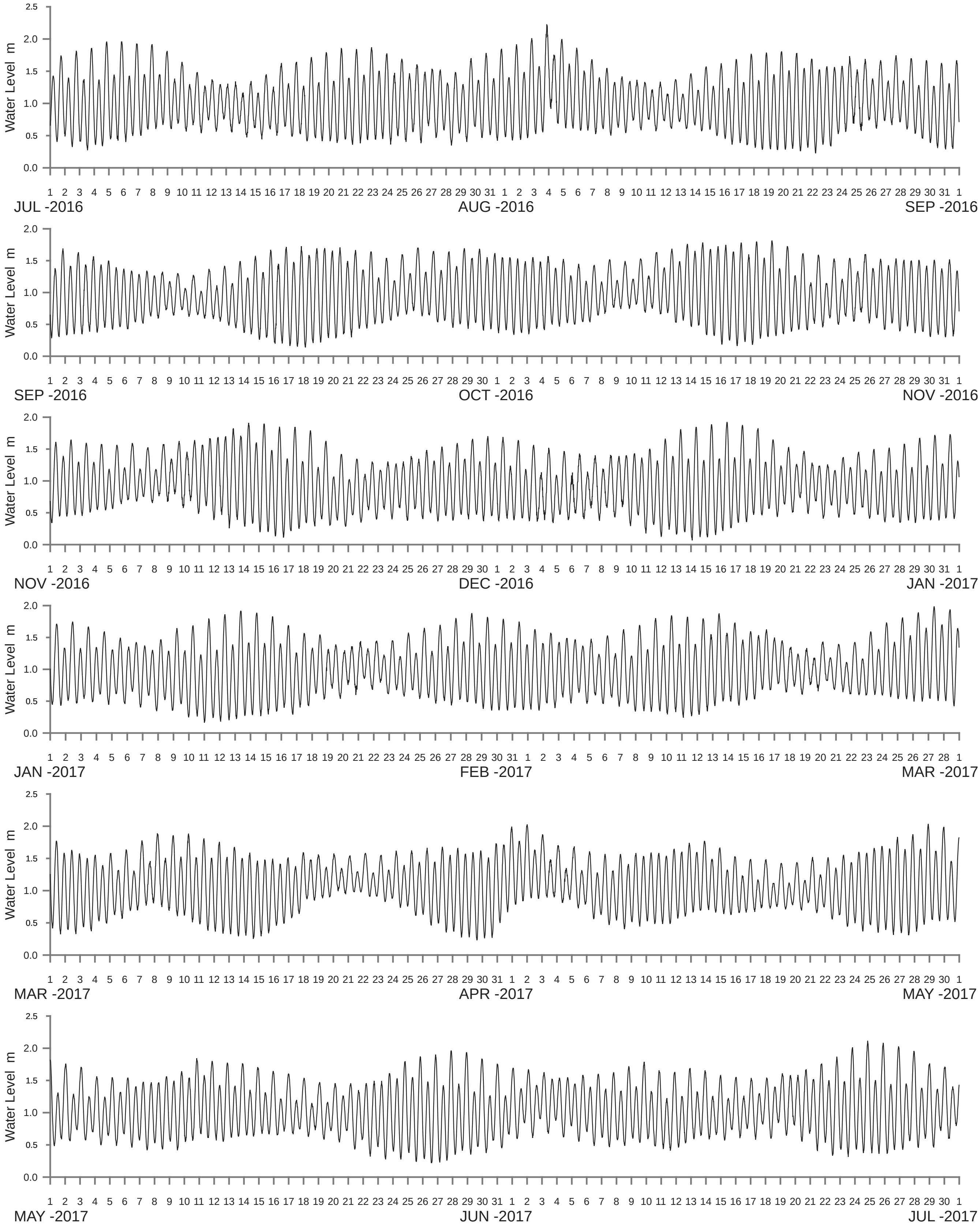
YAMBA
STATION LOCATION

MHL Report 2574

Figure A9

DRAWING 2574-A9.cdr



WATER LEVEL REFERENCED TO ILUKA PORT DATUM

- - - - - - - - - - - - DATA LOSS

Manly Hydraulics Laboratory

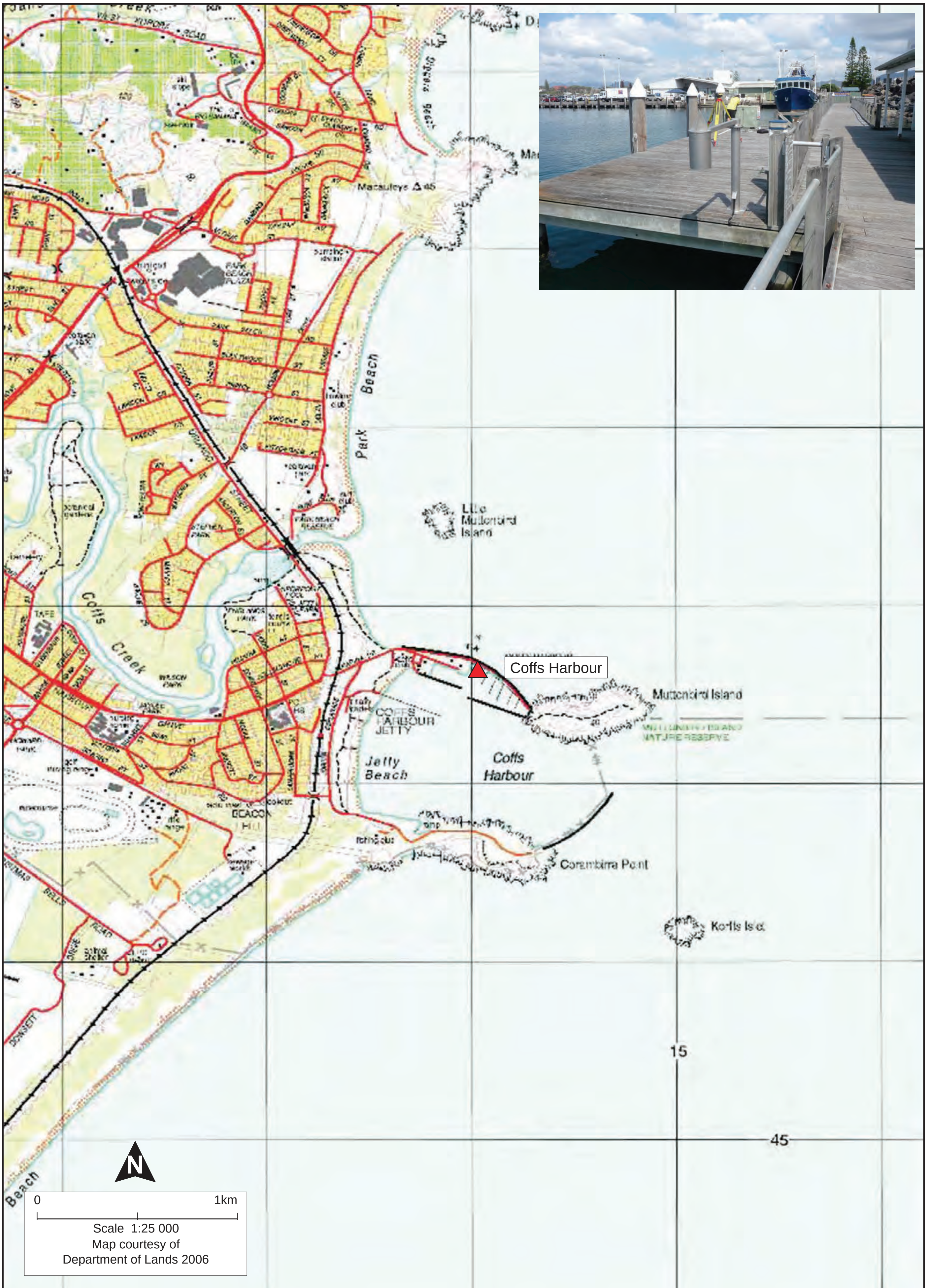
NSW GOVERNMENT

YAMBA DATA SUMMARY
2016–2017

MHL Report 2574

Figure A10

DRAWING 2574-A9.cdr



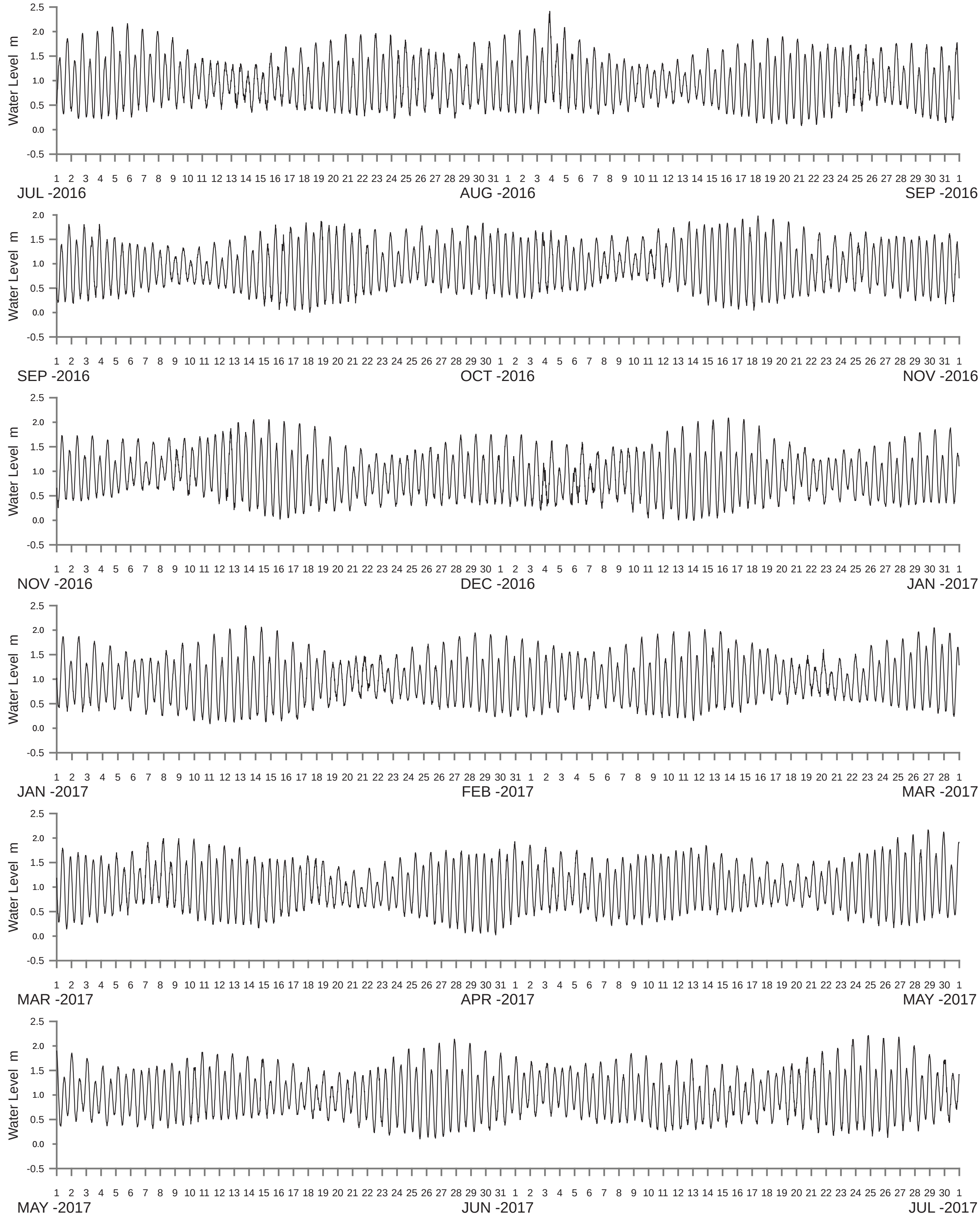
Manly Hydraulics Laboratory

COFFS HARBOUR
STATION LOCATION

MHL Report 2574

Figure A11

DRAWING 2574-A11.cdr



WATER LEVEL REFERENCED TO COFFS PORT DATUM

------------ DATA LOSS

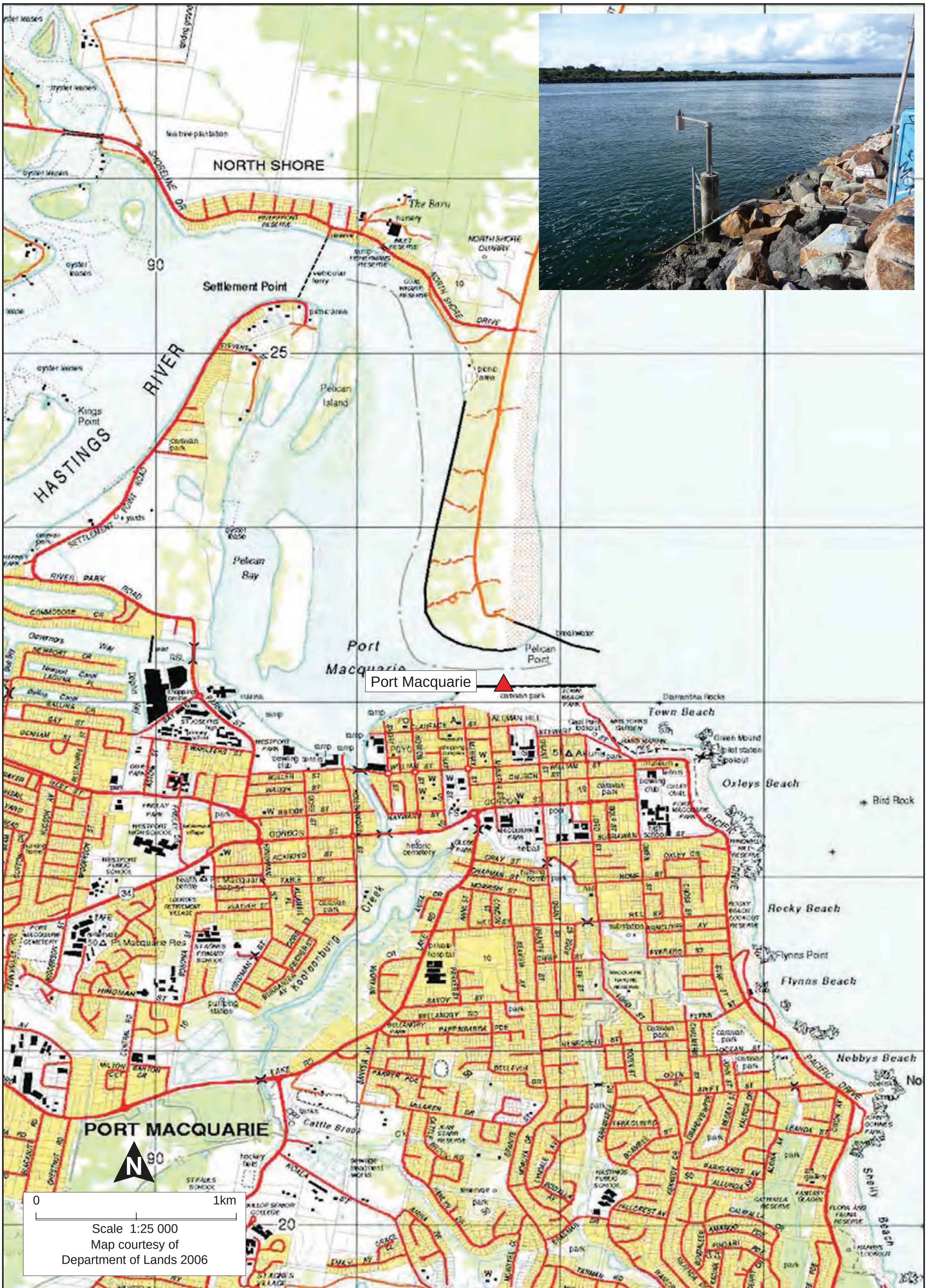
Manly Hydraulics Laboratory

COFFS HARBOUR DATA SUMMARY
2016–2017

MHL Report 2574

Figure A12

DRAWING 2574-A11.cdr



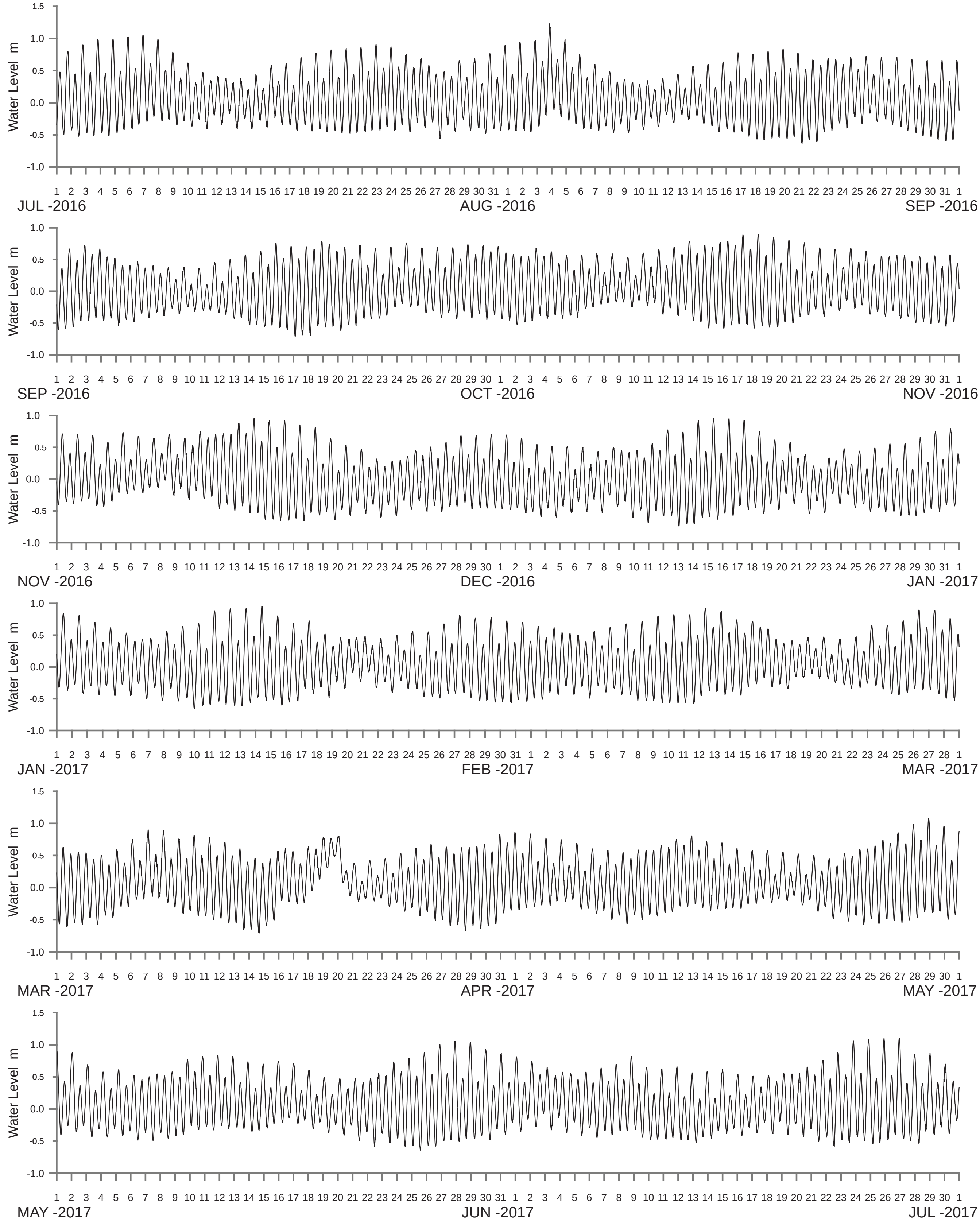
NSW GOVERNMENT | Manly Hydraulics Laboratory

PORT MACQUARIE
STATION LOCATION

MHL Report 2574

Figure A13

DRAWING 2574-A13.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

------------ DATA LOSS

NSW GOVERNMENT | Manly Hydraulics Laboratory

PORT MACQUARIE DATA SUMMARY
2016–2017

MHL Report 2574

Figure A14

DRAWING 2574-A13.cdr

PORT MACQUARIE OFFSHORE
TIDE GAUGE LOCATION

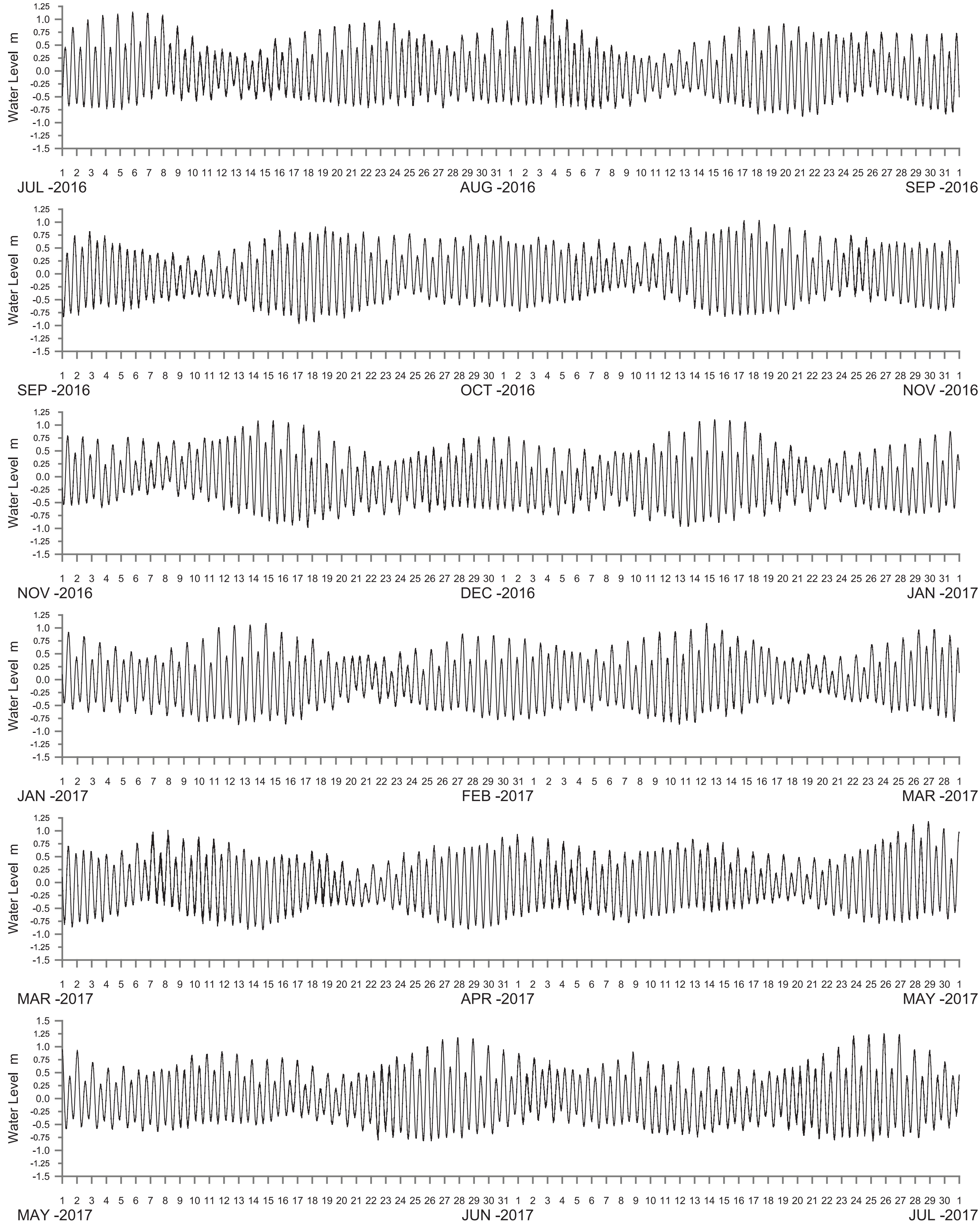
Manly Hydraulics Laboratory

NSW GOVERNMENT

MHL Report 2574

Figure A15

DRAWING 2574-A15.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

------------ DATA LOSS

Manly Hydraulics Laboratory

NSW GOVERNMENT

PORT MACQUARIE OFFSHORE DATA SUMMARY
2016–2017

MHL Report 2574

Figure A16

DRAWING 2574-A15.cdr

Manly Hydraulics Laboratory

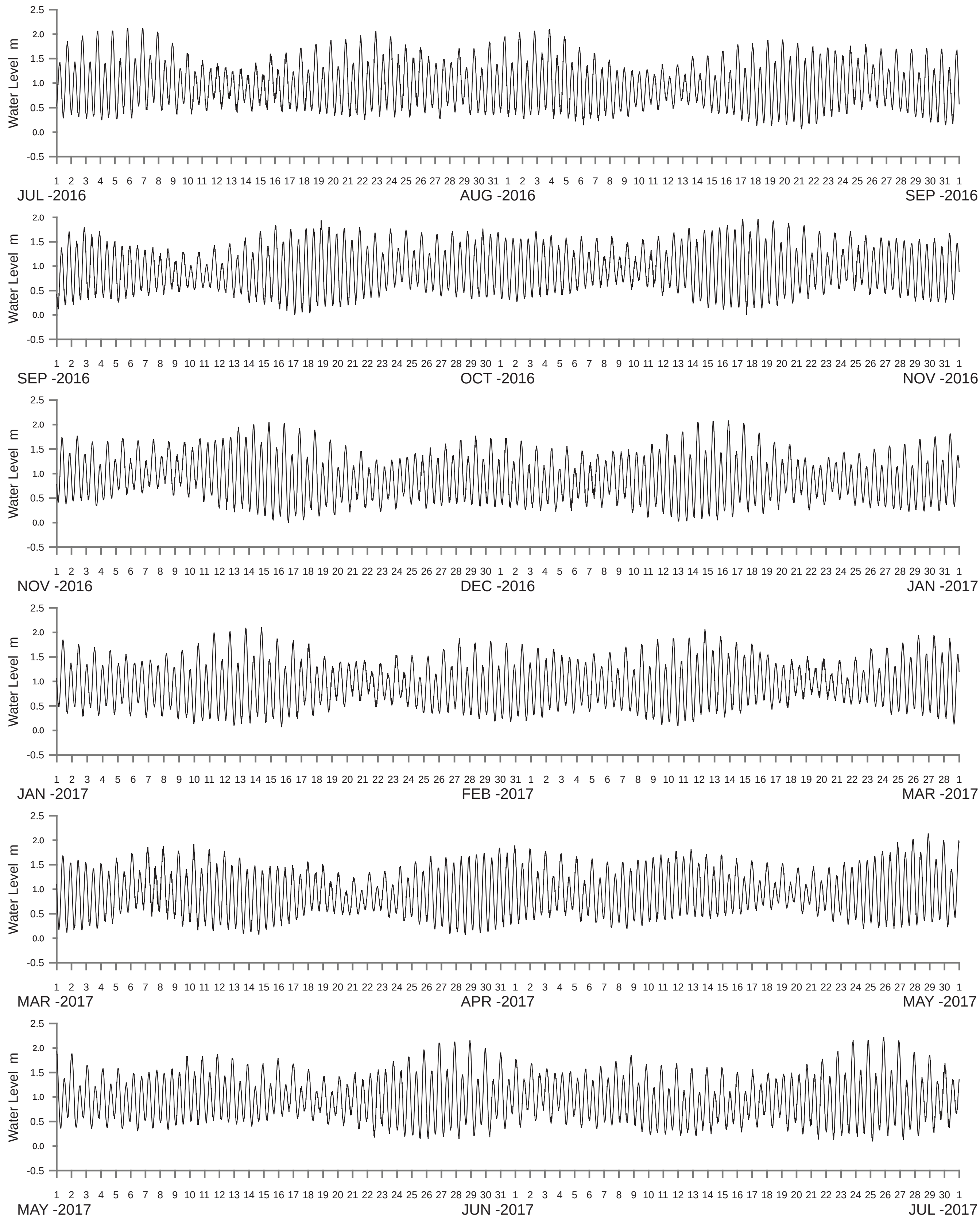
NSW GOVERNMENT

CROWDY HEAD
STATION LOCATION

MHL Report 2574

Figure A17

DRAWING 2574-A17.cdr



WATER LEVEL REFERENCED TO CROWDY HEAD DATUM

- - - - - - - - - - - - DATA LOSS

NSW GOVERNMENT | Manly Hydraulics Laboratory

CROWDY HEAD DATA SUMMARY
2016–2017

MHL Report 2574

Figure A18

DRAWING 2574-A17.cdr

NSW GOVERNMENT

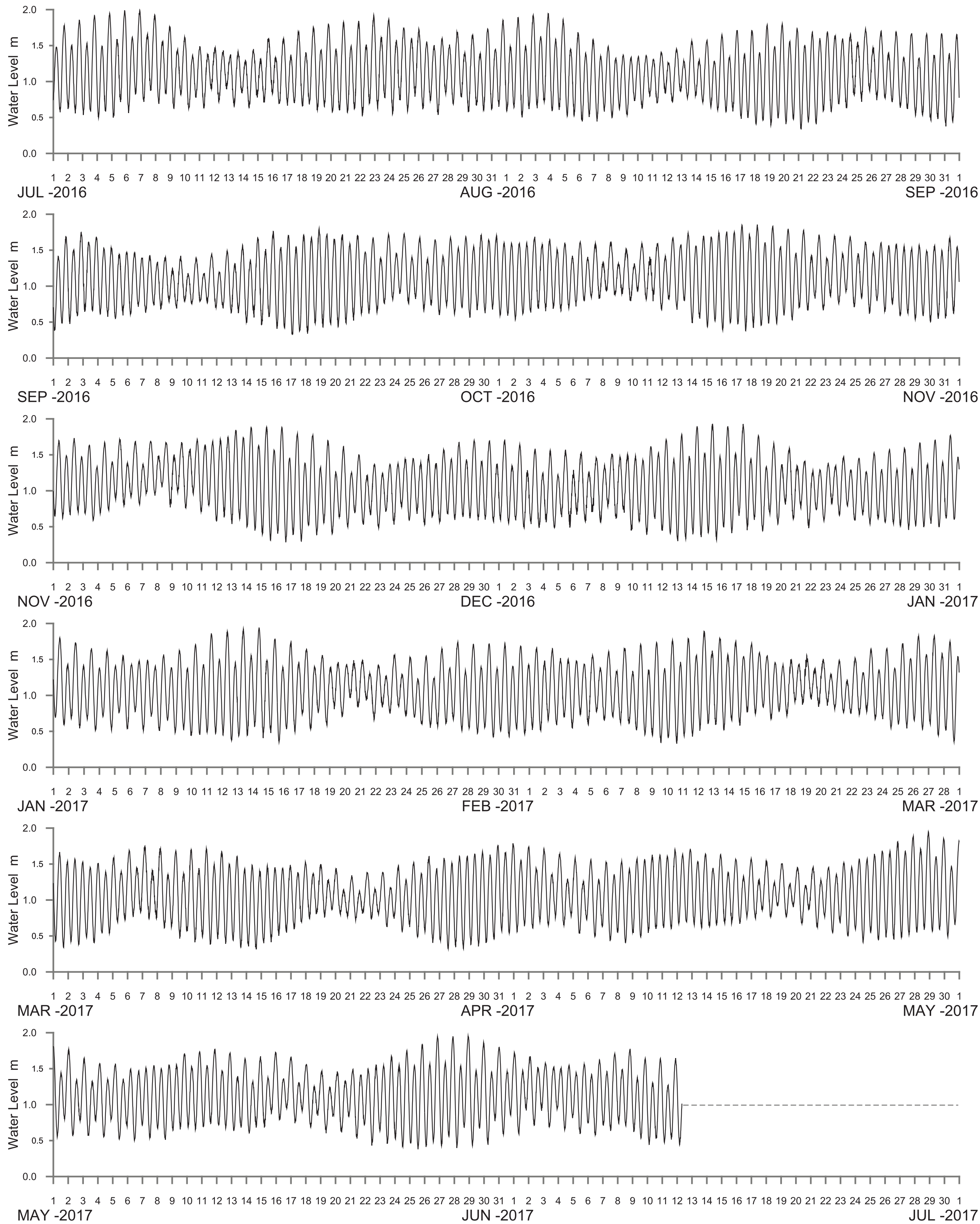
Manly Hydraulics Laboratory

FORSTER
STATION LOCATION

MHL Report 2574

Figure A19

DRAWING 2574-A19.cdr



WATER LEVEL REFERENCED TO FORSTER HYDRO DATUM

------------ DATA LOSS

Manly Hydraulics Laboratory

NSW GOVERNMENT

FORSTER DATA SUMMARY
2016–2017

MHL Report 2574

Figure A20

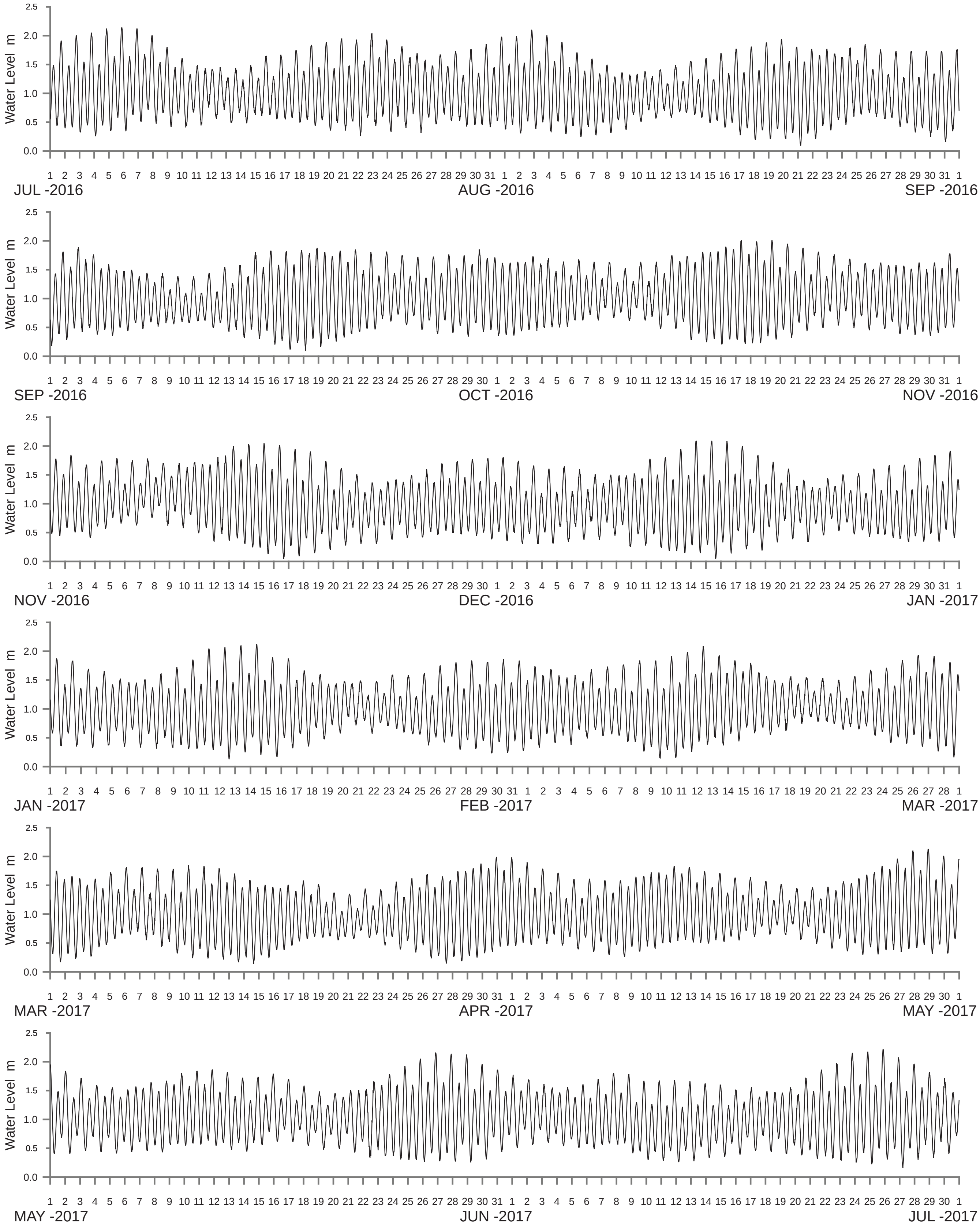
DRAWING 2574-A19.cdr

SHOAL BAY
STATION LOCATION

MHL
Report 2574

Figure
A21

DRAWING 2574-A21.cdr



WATER LEVEL REFERENCED TO PORT STEPHENS HYDRO DATUM

- - - - - - - - - - - - DATA LOSS

NSW GOVERNMENT | Manly Hydraulics Laboratory

SHOAL BAY DATA SUMMARY
2016–2017

MHL Report 2574

Figure A22

DRAWING 2574-A21.cdr

Manly Hydraulics Laboratory

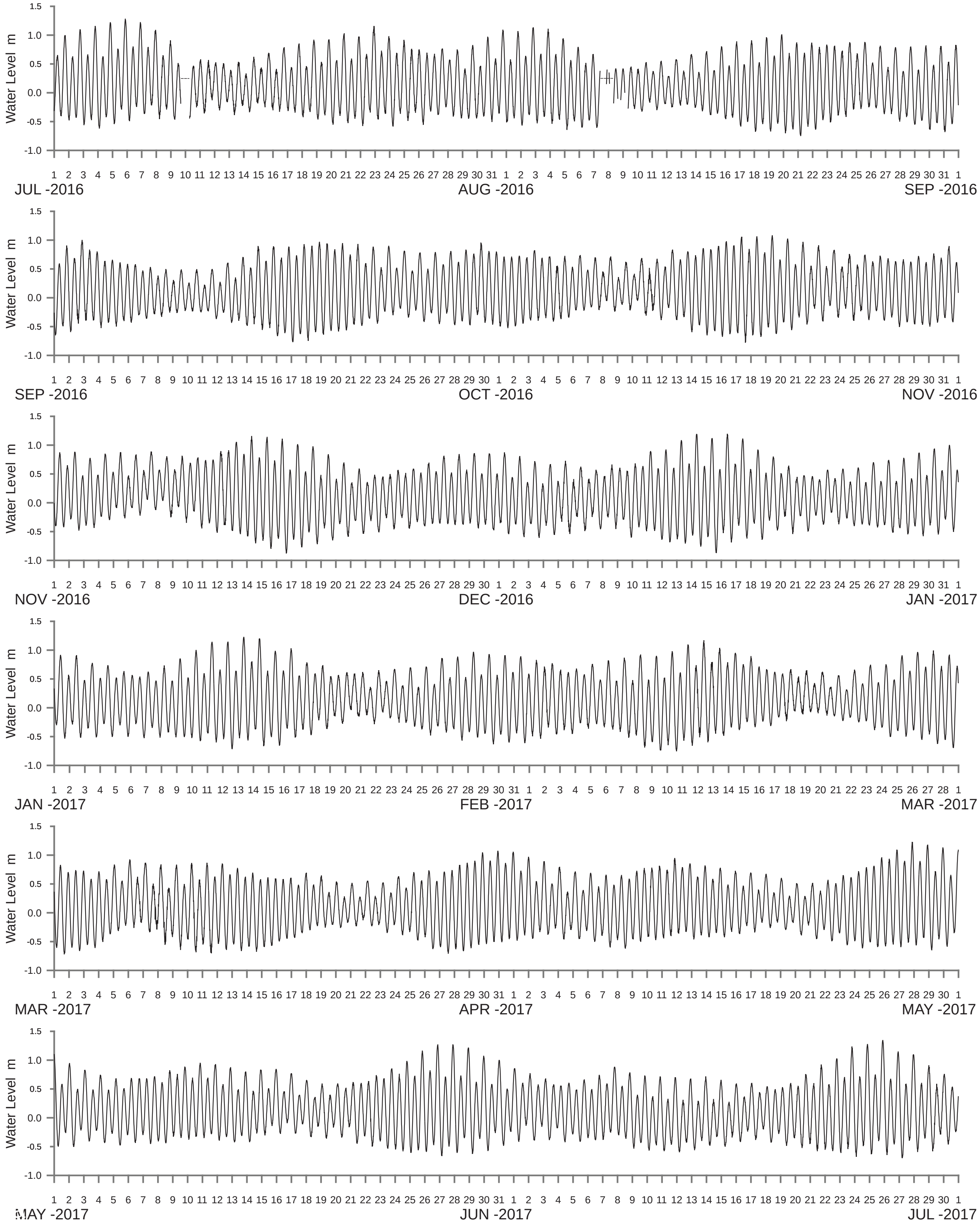
NSW GOVERNMENT

PATONGA STATION LOCATION

MHL Report 2574

Figure A23

DRAWING 2574-A23.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

------------ DATA LOSS

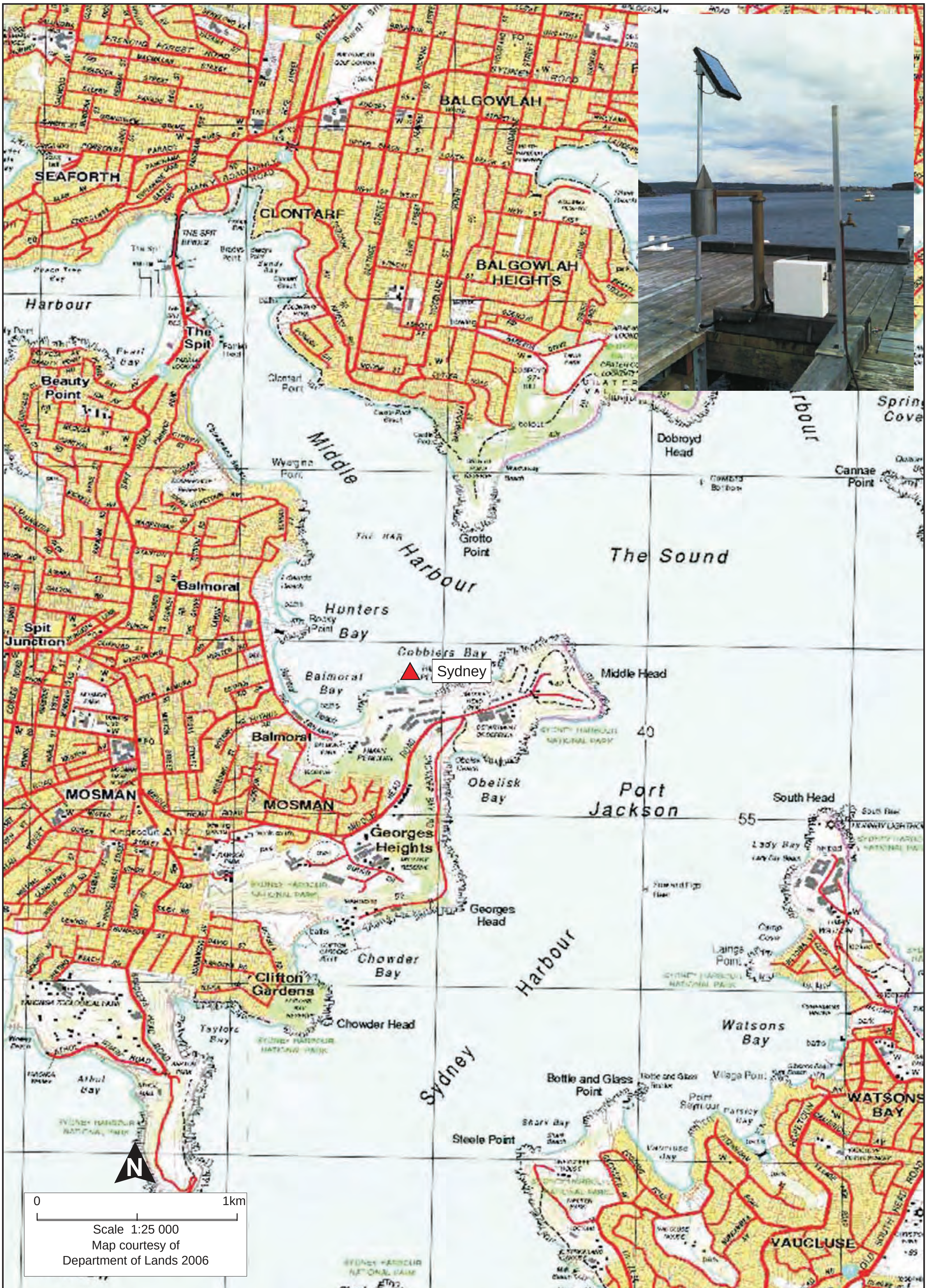
NSW GOVERNMENT | Manly Hydraulics Laboratory

PATONGA DATA SUMMARY
2016–2017

MHL Report 2574

Figure A24

DRAWING 2574-A23.cdr



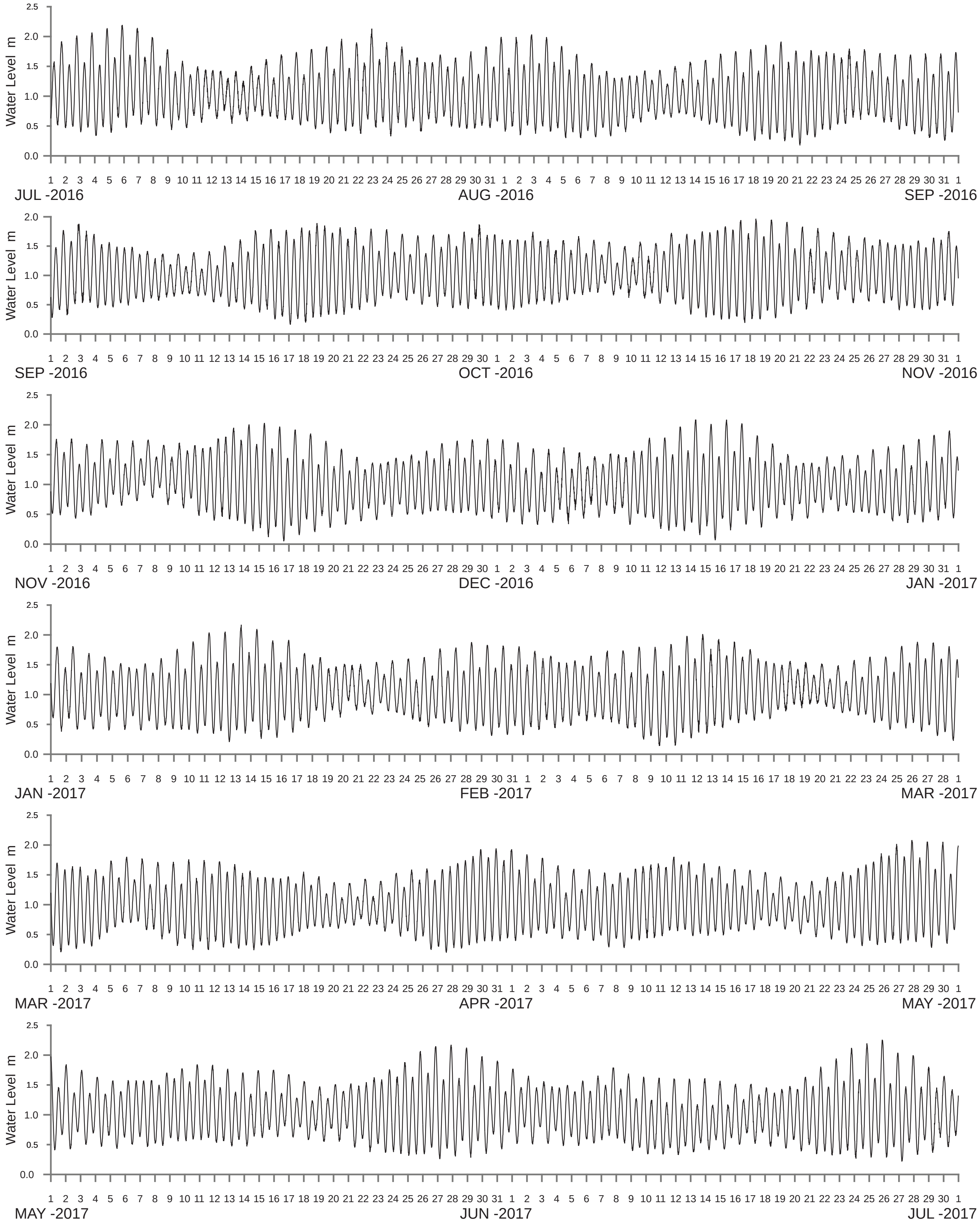
Manly Hydraulics Laboratory

SYDNEY
STATION LOCATION

MHL Report 2574

Figure A25

DRAWING 2574-A25.cdr



WATER LEVEL REFERENCED TO ZERO FORT DENISON

------------ DATA LOSS

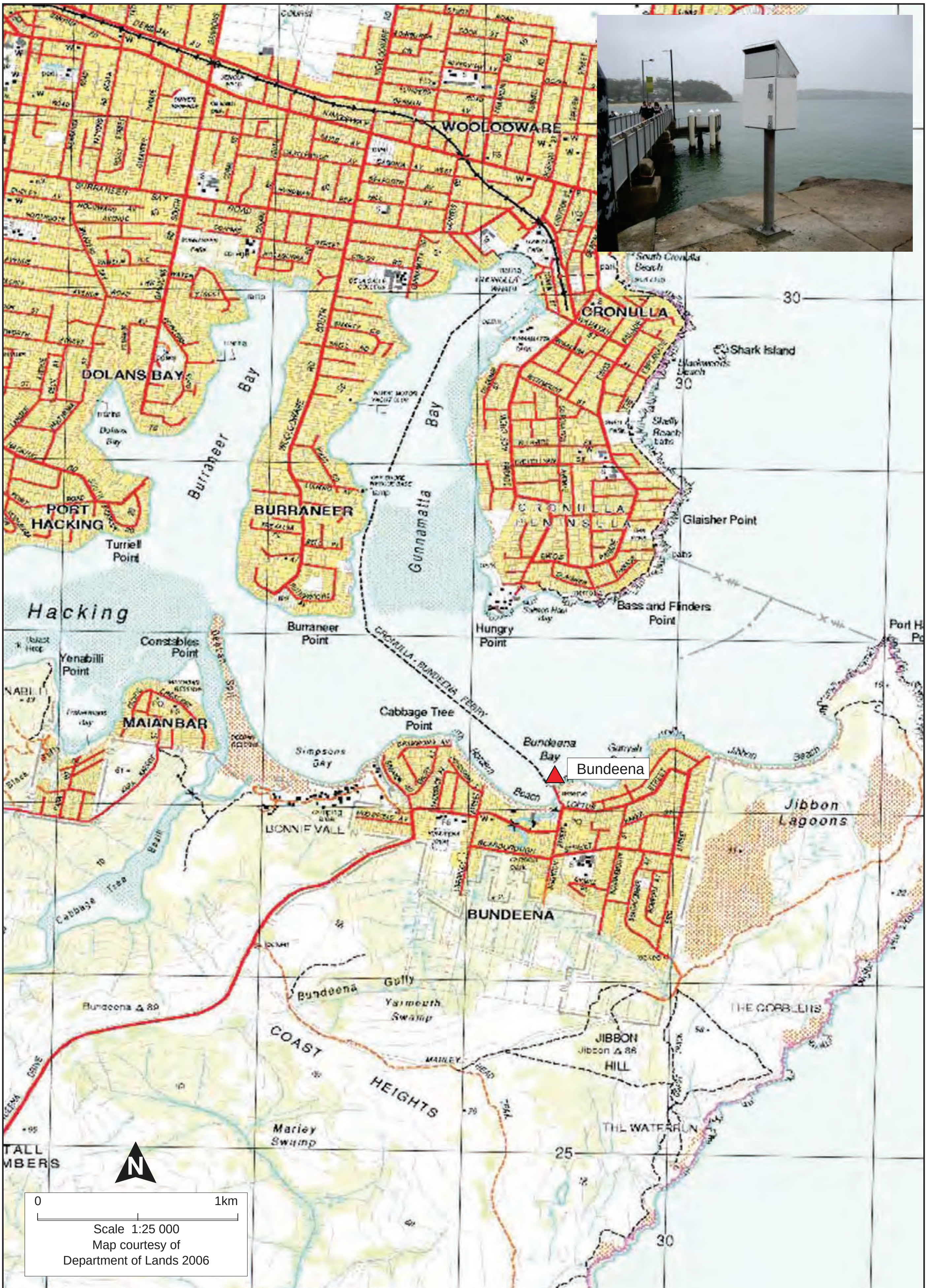
NSW GOVERNMENT | Manly Hydraulics Laboratory

SYDNEY DATA SUMMARY
2016–2017

MHL Report 2574

Figure A26

DRAWING 2574-A25.cdr

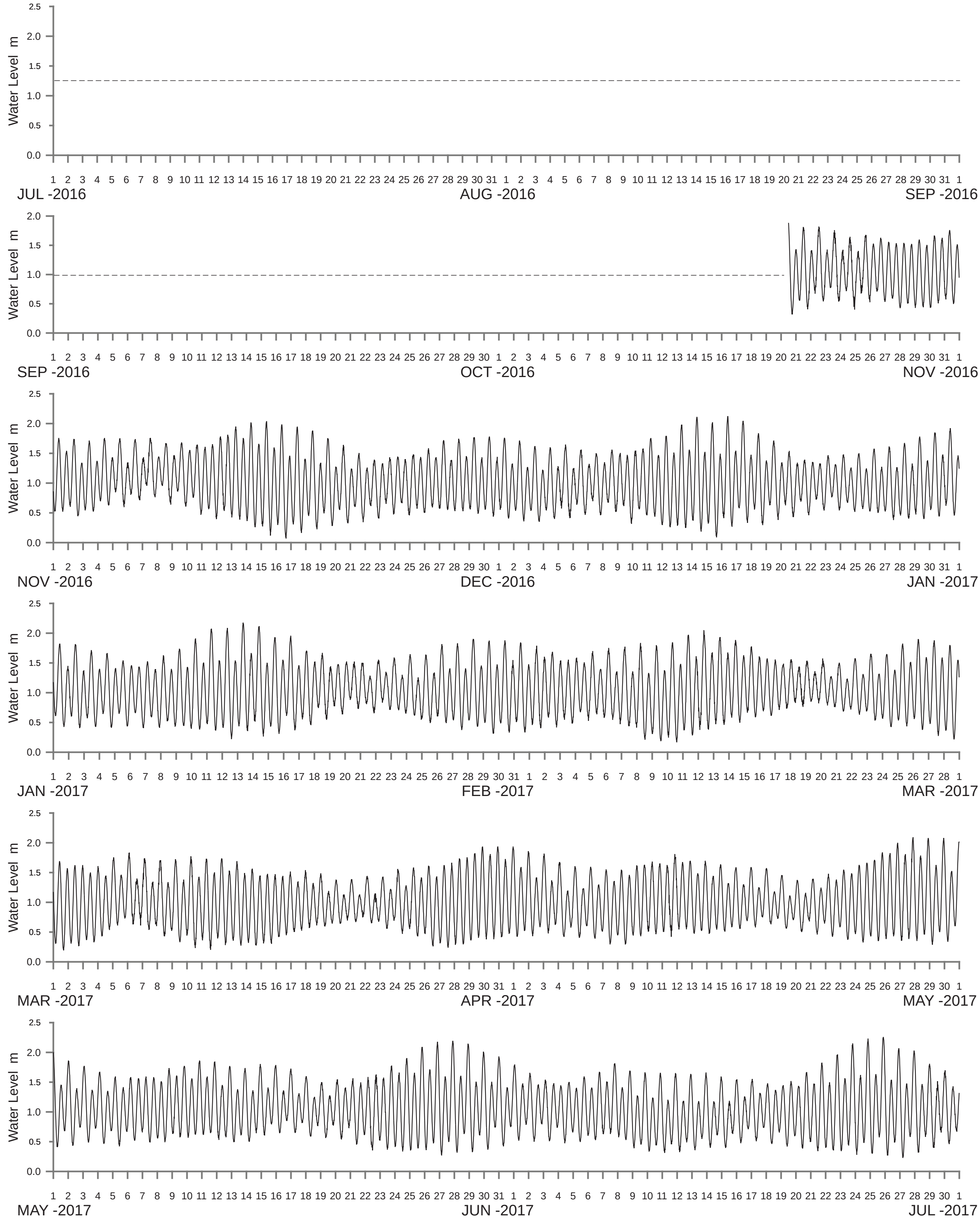


BUNDEENA
STATION LOCATION

MHL
Report 2574

Figure
A27

DRAWING 2574-A27.cdr



WATER LEVEL REFERENCED TO ZERO FORT DENISON

- - - - - - - - - - - - DATA LOSS

Manly Hydraulics Laboratory

BUNDEENA DATA SUMMARY
2016–2017

MHL Report 2574

Figure A28

DRAWING 2574-A27.cdr

Manly Hydraulics Laboratory

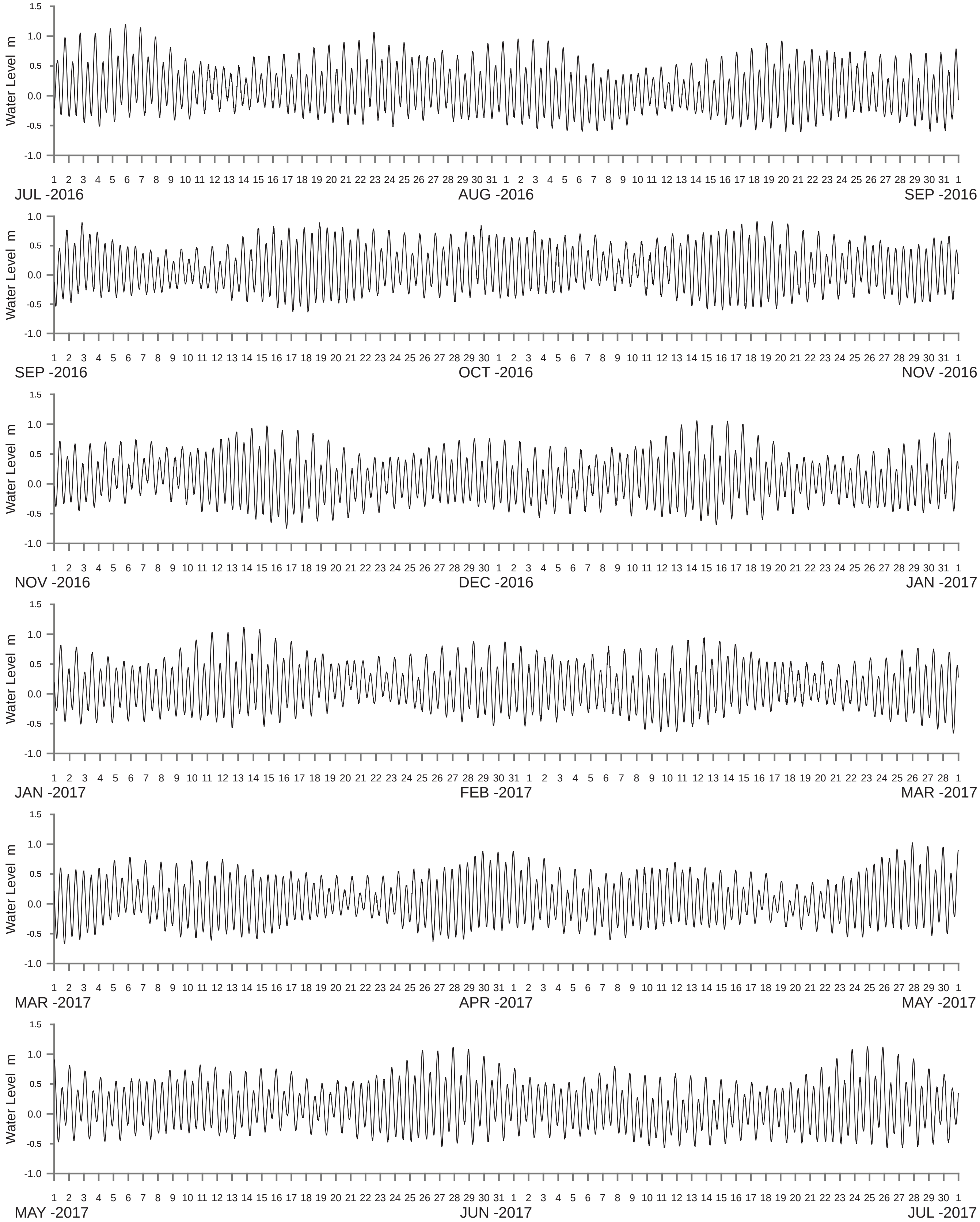
NSW GOVERNMENT

CROOKHAVEN HEADS
STATION LOCATION

MHL Report 2574

Figure A29

DRAWING 2574-A29.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

------------ DATA LOSS

Manly Hydraulics Laboratory

NSW GOVERNMENT

CROOKHAVEN HEADS DATA SUMMARY
2016–2017

MHL Report 2574

Figure A30

DRAWING 2574-A29.cdr

NSW GOVERNMENT

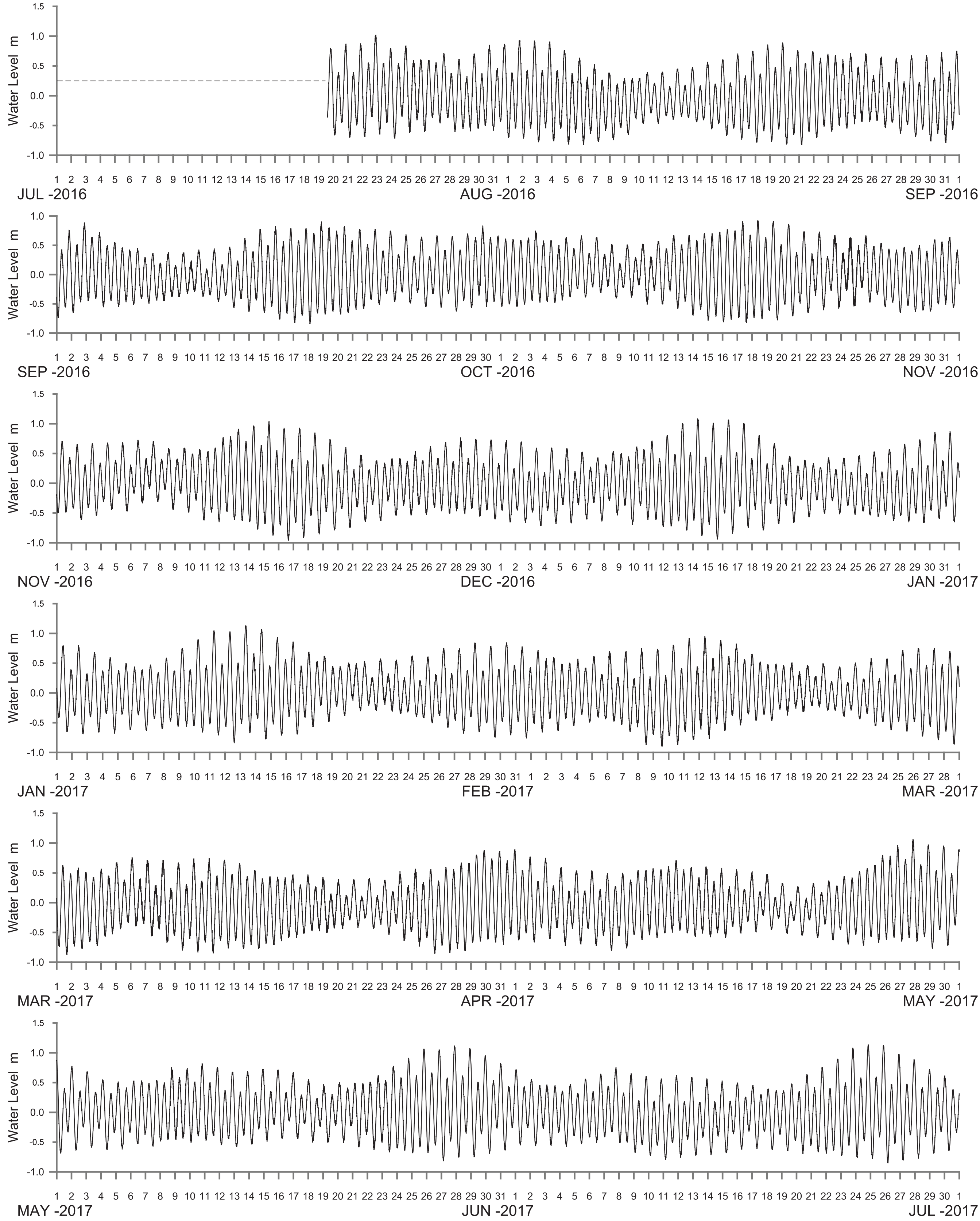
Manly Hydraulics Laboratory

SHOALHAVEN OFFSHORE
TIDE GAUGE LOCATION

MHL Report 2574

Figure A31

DRAWING 2574-A31.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

------------ DATA LOSS

Manly Hydraulics Laboratory

NSW GOVERNMENT

SHOALHAVEN OFFSHORE DATA SUMMARY
2016–2017

MHL Report 2574

Figure A32

DRAWING 2574-A31.cdr

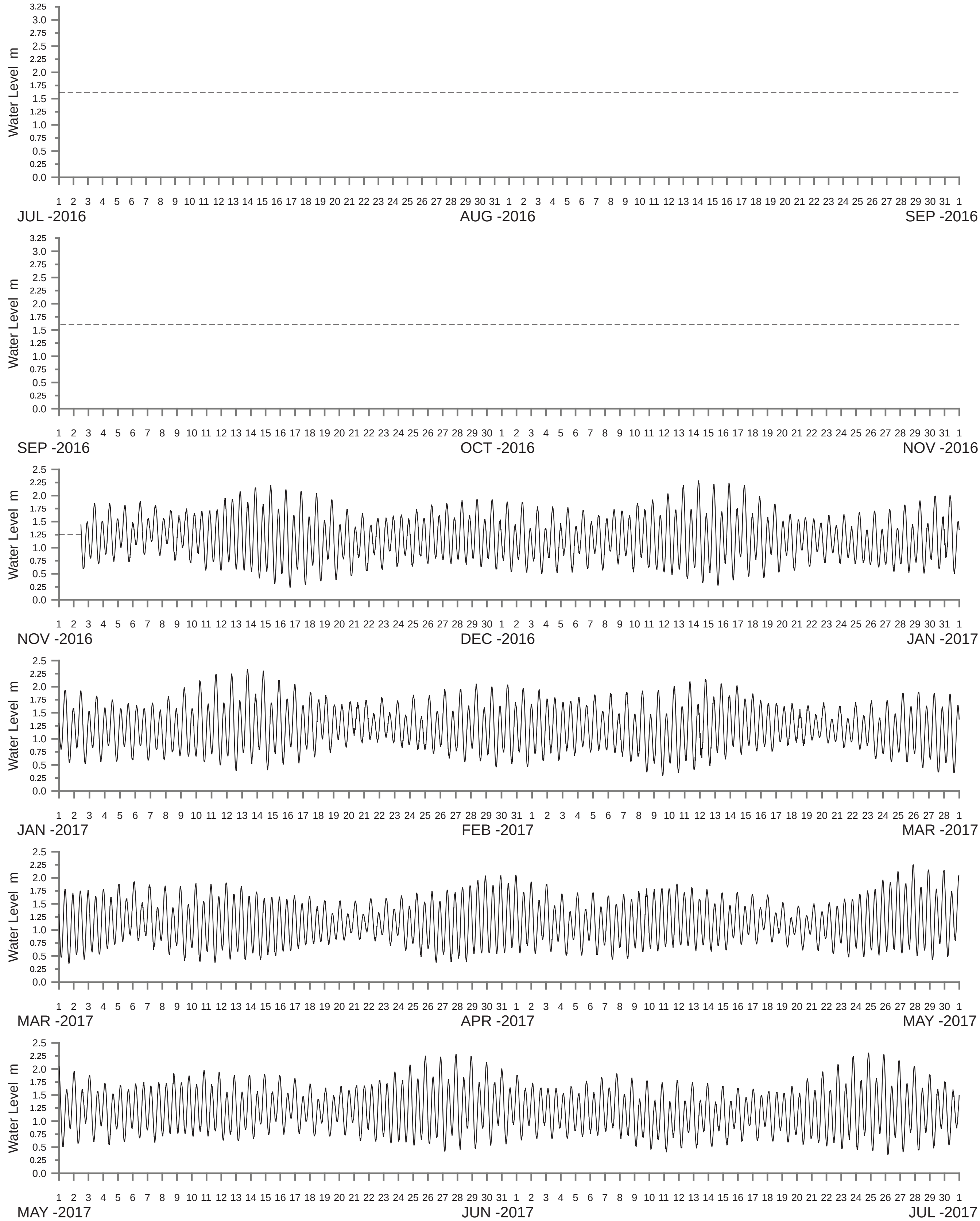
Manly Hydraulics Laboratory

JERVIS BAY
STATION LOCATION

MHL
Report 2574

Figure
A33

DRAWING 2574-A33.cdr



WATER LEVEL REFERENCED TO CHART DATUM (JERVIS BAY PORT DATUM)

- - - - - - - - - - - - DATA LOSS

NSW GOVERNMENT | Manly Hydraulics Laboratory

JERVIS BAY DATA SUMMARY
2016–2017

MHL Report 2574

Figure A34

DRAWING 2574-A33.cdr

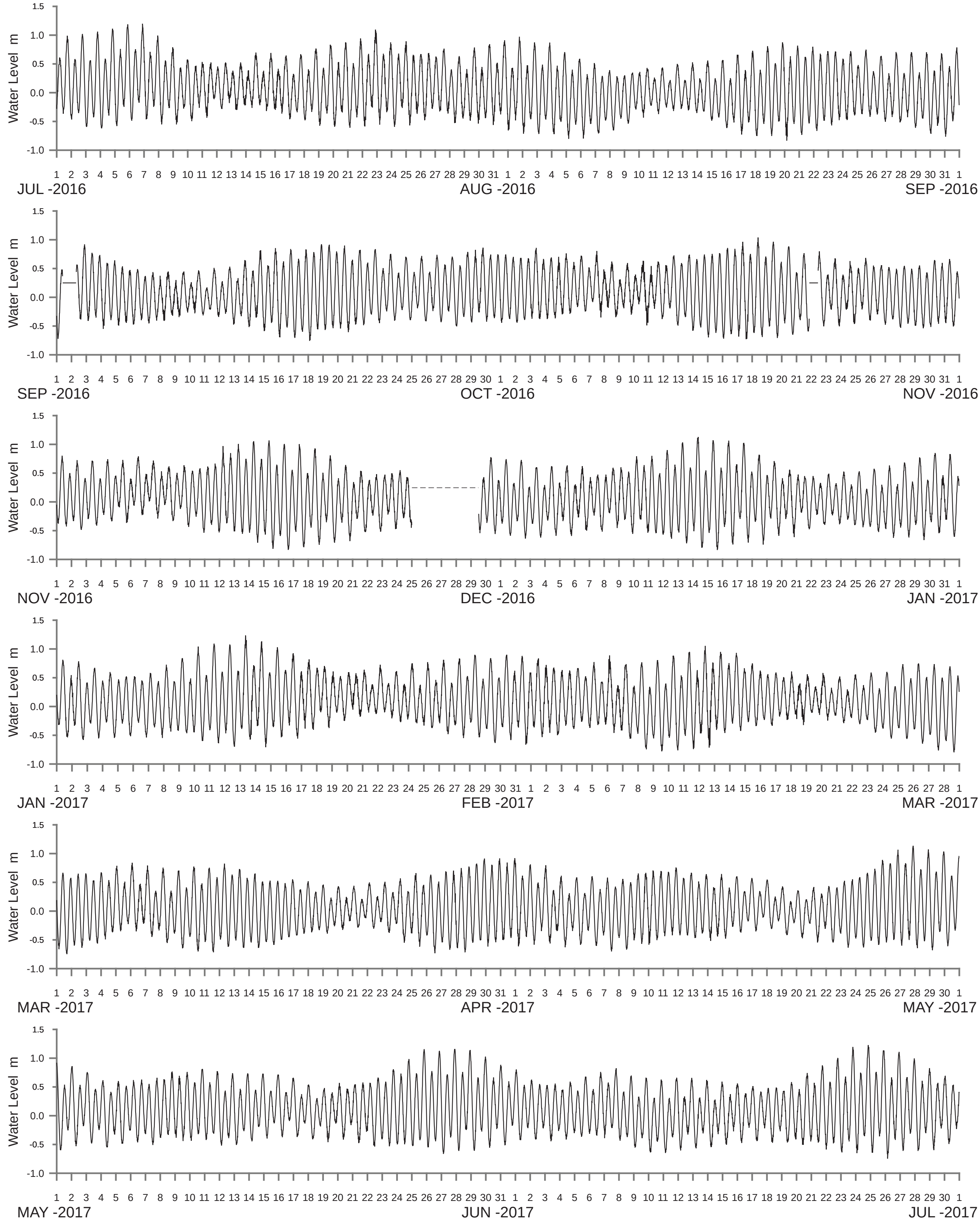
Manly Hydraulics Laboratory

ULLADULLA
STATION LOCATION

MHL Report 2574

Figure A35

DRAWING 2574-A35.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

------------ DATA LOSS

Manly Hydraulics Laboratory

NSW GOVERNMENT

ULLADULLA DATA SUMMARY
2016–2017

MHL Report 2574

Figure A36

DRAWING 2574-A35.cdr

Manly Hydraulics Laboratory

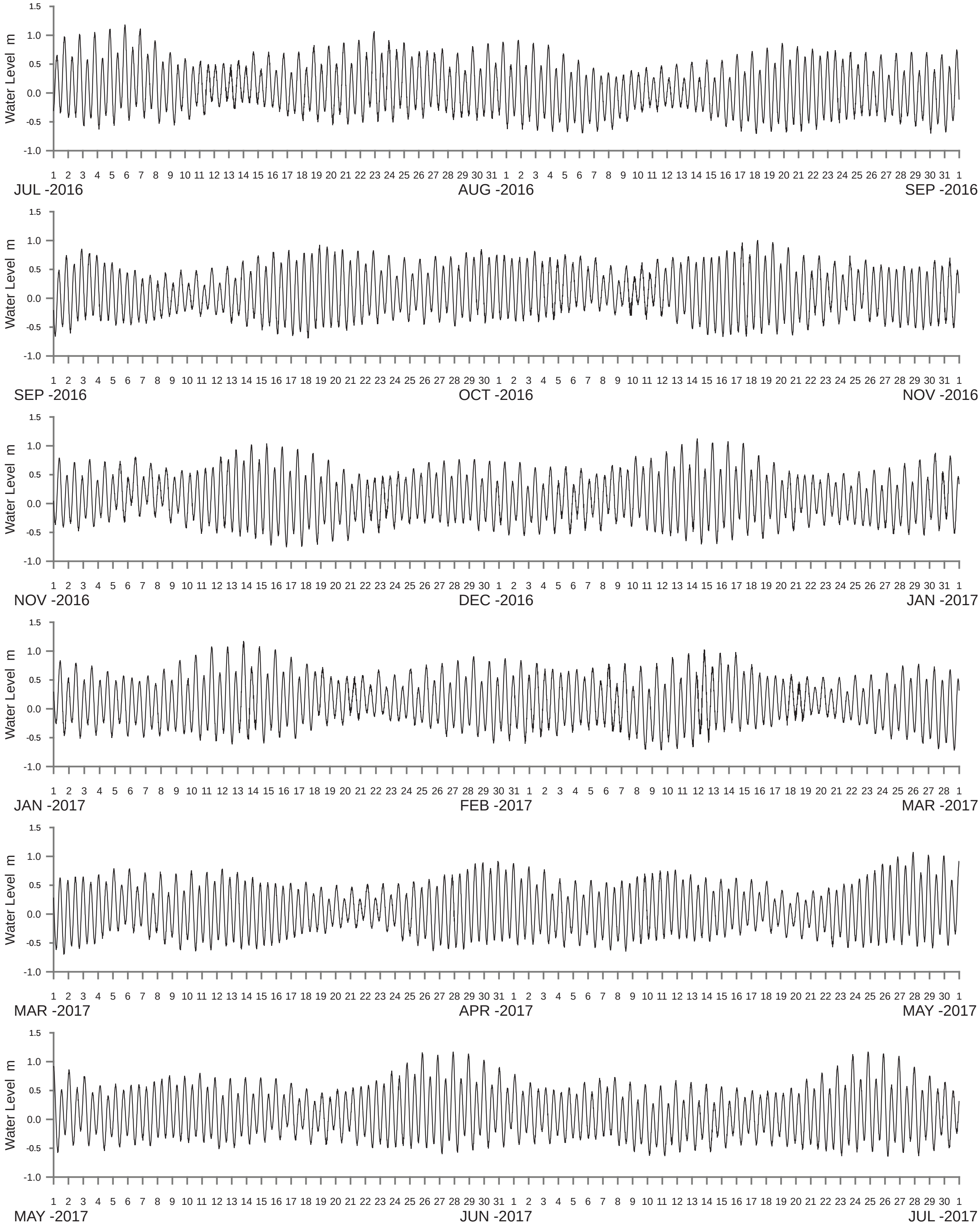
NSW GOVERNMENT

PRINCESS JETTY
STATION LOCATION

MHL
Report 2574

Figure
A37

DRAWING 2574-A37.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

- - - - - - - - - - - - DATA LOSS

NSW GOVERNMENT — Manly Hydraulics Laboratory	PRINCESS JETTY DATA SUMMARY 2016–2017	MHL Report 2574 Figure A38 DRAWING 2574-A37.cdr

NSW GOVERNMENT

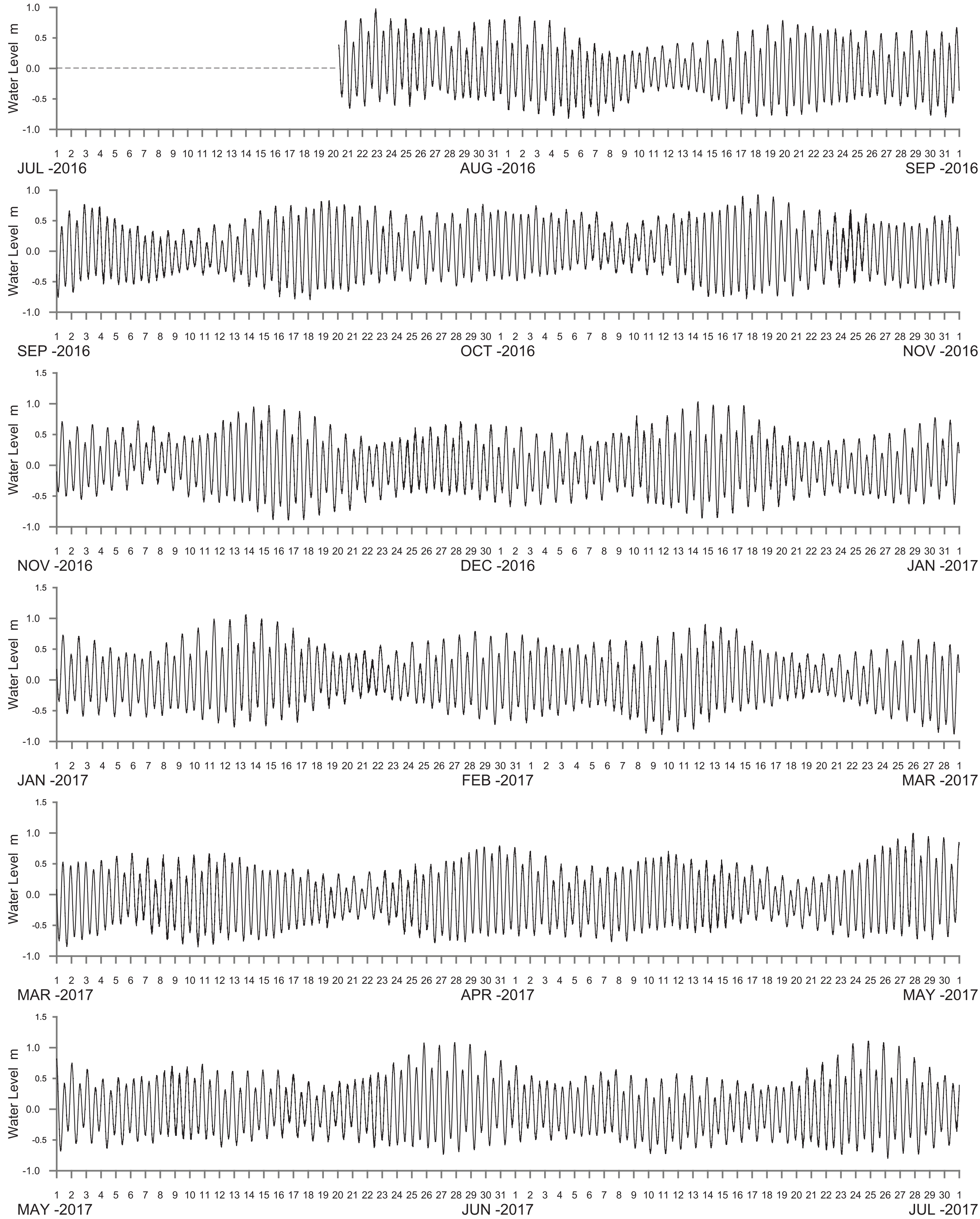
Manly Hydraulics Laboratory

BATEMANS BAY OFFSHORE
TIDE GAUGE LOCATION

MHL Report 2574

Figure A39

DRAWING 2574-A39.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

- - - - - - - - - - - - DATA LOSS

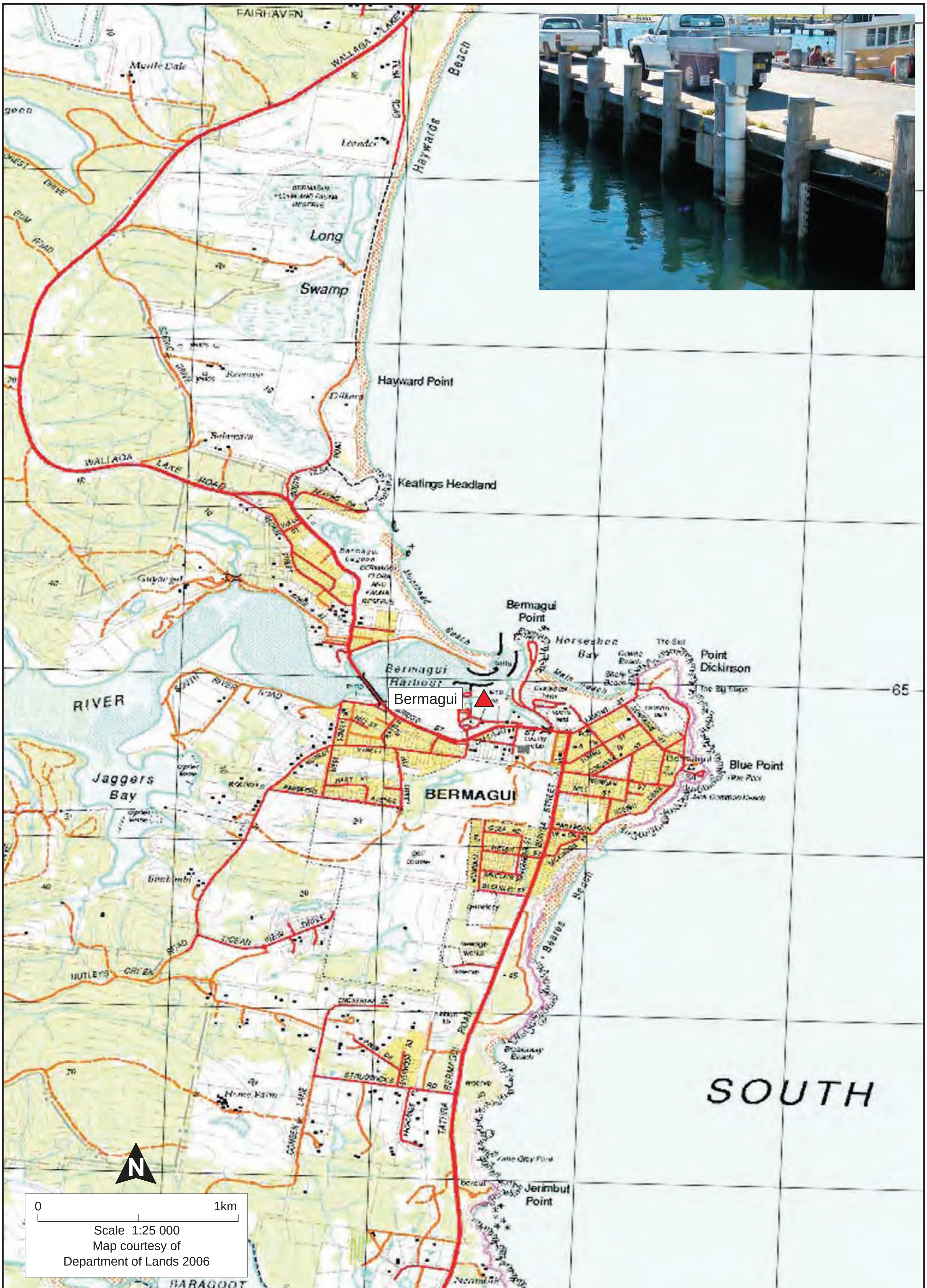
NSW GOVERNMENT
Manly Hydraulics Laboratory

BATEMANS BAY OFFSHORE DATA SUMMARY
2016–2017

MHL Report 2574

Figure A40

DRAWING 2574-A39.cdr



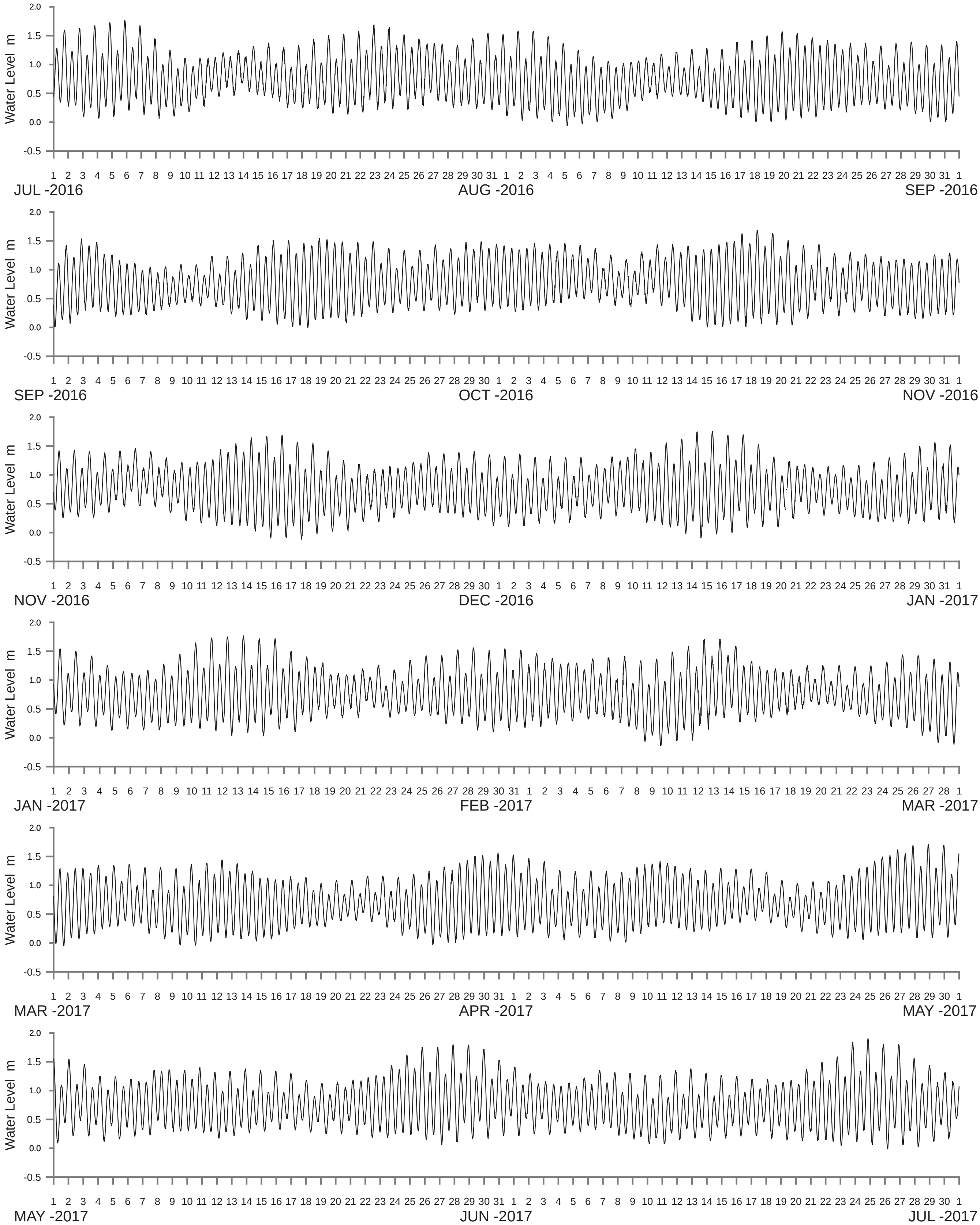
NSW GOVERNMENT
Manly Hydraulics Laboratory

BERMAGUI
STATION LOCATION

MHL Report 2574

Figure A41

DRAWING 2574-A41.cdr



WATER LEVEL REFERENCED TO BERMAGUI LOCAL HYDRO DATUM

- - - - - - - - - - - - DATA LOSS

NSW GOVERNMENT | Manly Hydraulics Laboratory

BERMAGUI DATA SUMMARY
2016–2017

MHL Report 2574

Figure A42

DRAWING 2574-A41.cdr

Manly Hydraulics Laboratory

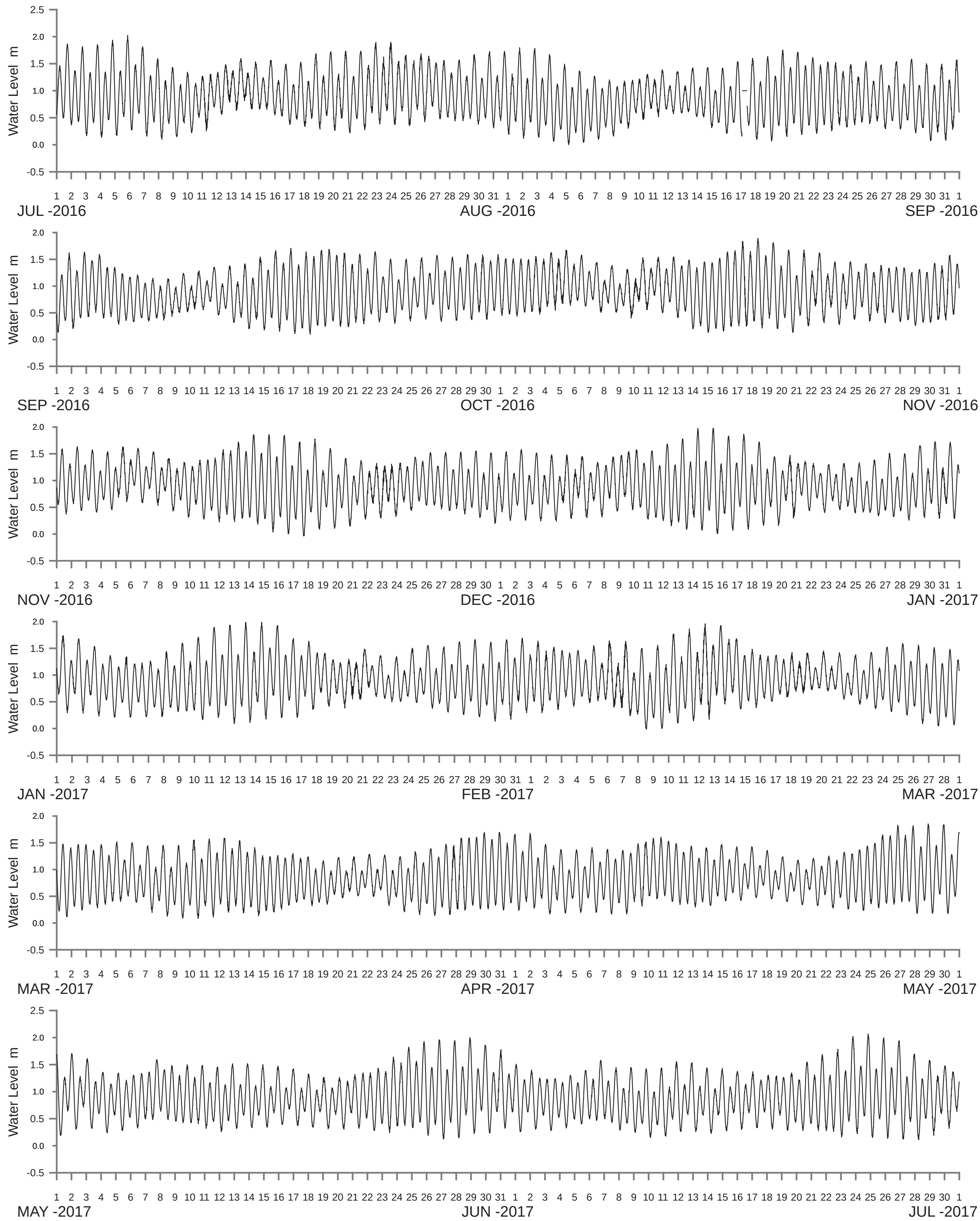
NSW GOVERNMENT

EDEN
STATION LOCATION

MHL Report 2574

Figure A43

DRAWING 2574-A43.cdr



WATER LEVEL REFERENCED TO TWOFOLD BAY HYDRO DATUM

------------ DATA LOSS

NSW GOVERNMENT | Manly Hydraulics Laboratory

EDEN BOAT HARBOUR DATA SUMMARY
2016–2017

MHL Report 2574

Figure A44

DRAWING 2574-A43.cdr

Manly Hydraulics Laboratory

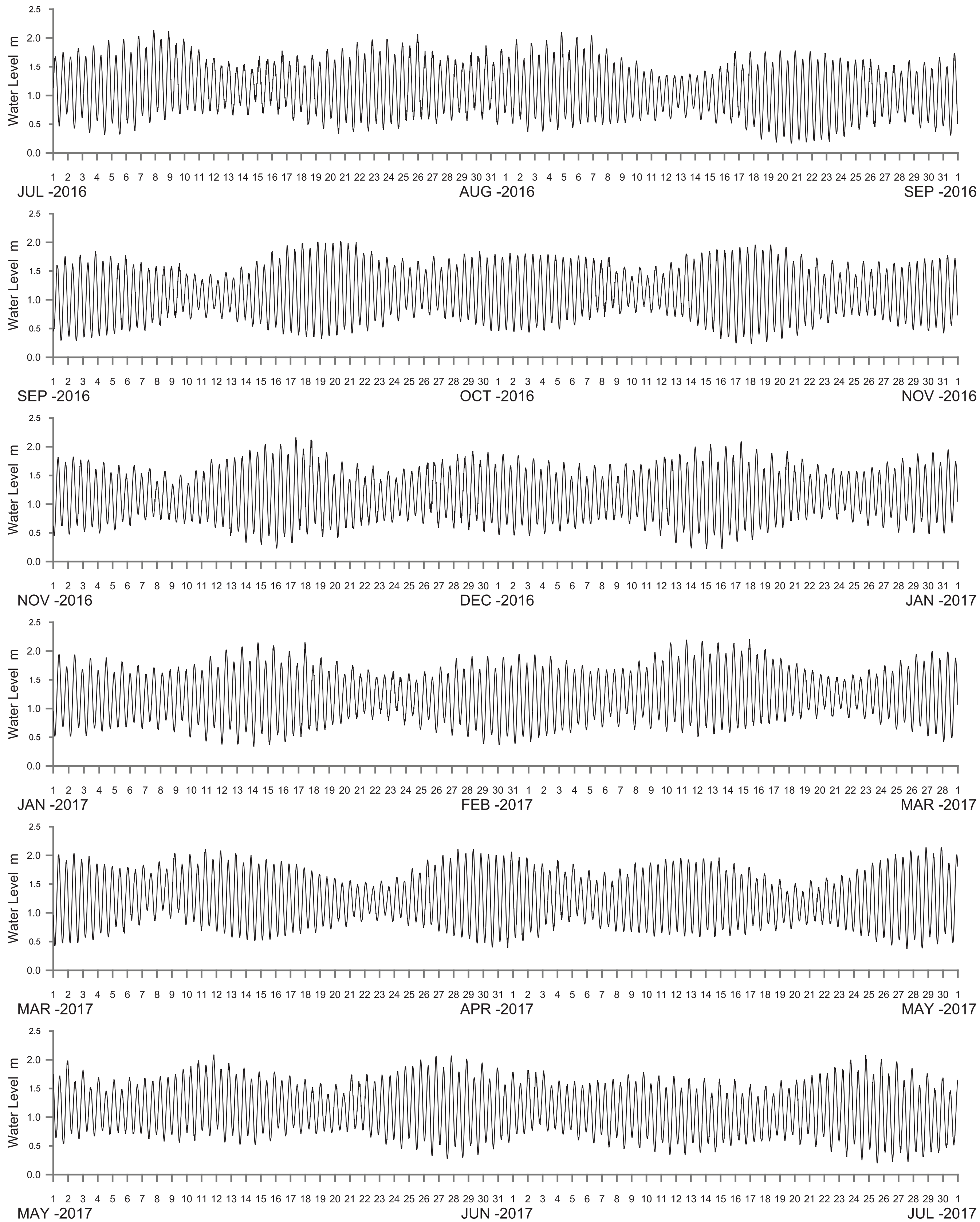
NSW GOVERNMENT

NORFOLK ISLAND
STATION LOCATION

MHL Report 2574

Figure A45

DRAWING 2574-A45.cdr



WATER LEVEL REFERENCED TO LOWEST ASTRONOMICAL TIDE

------------ DATA LOSS

Data provided courtesy of BoM National Tidal Unit

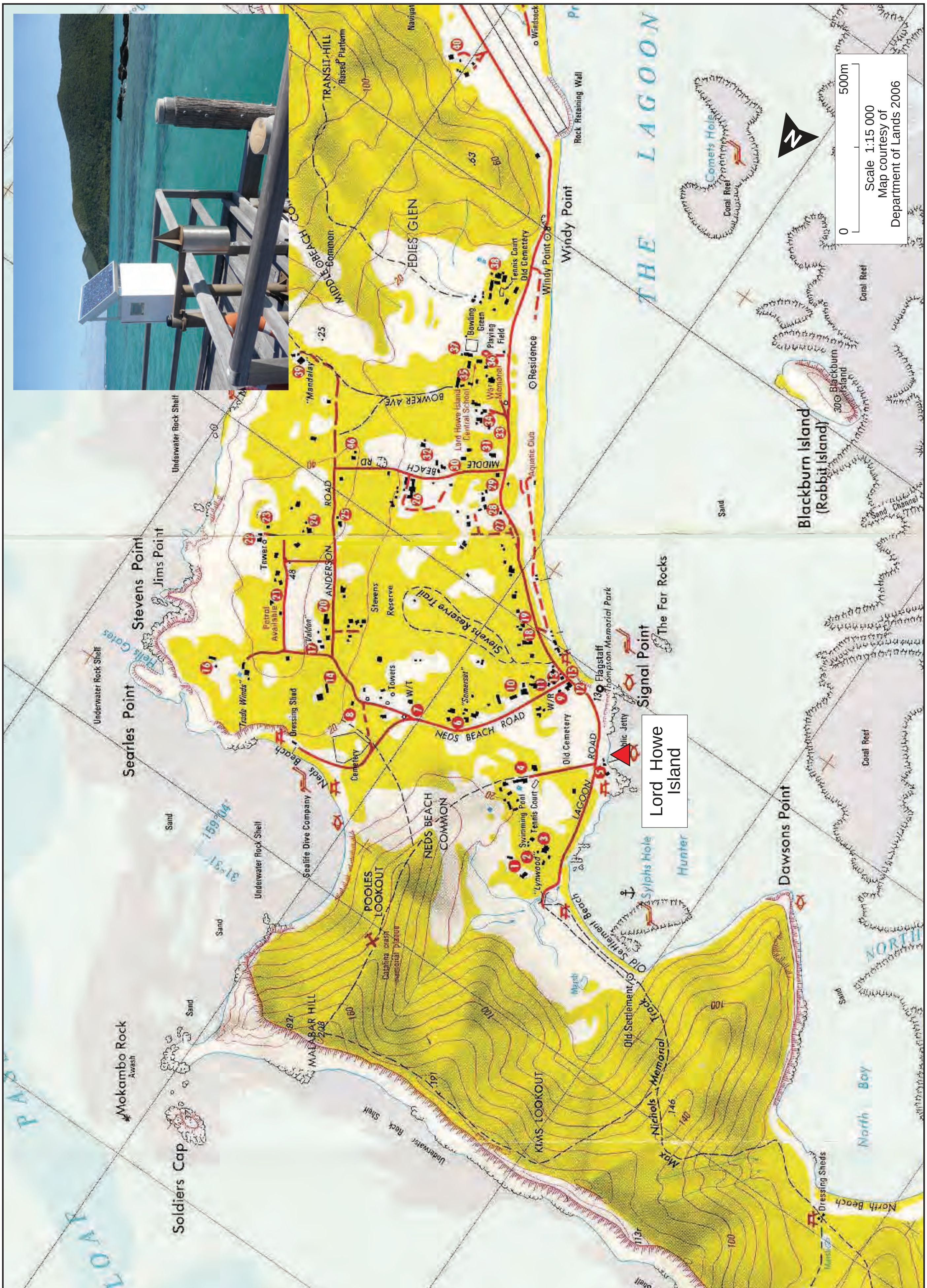
NSW GOVERNMENT | Manly Hydraulics Laboratory

NORFOLK ISLAND DATA SUMMARY
2016–2017

MHL Report 2574

Figure A46

DRAWING 2574-A45.cdr



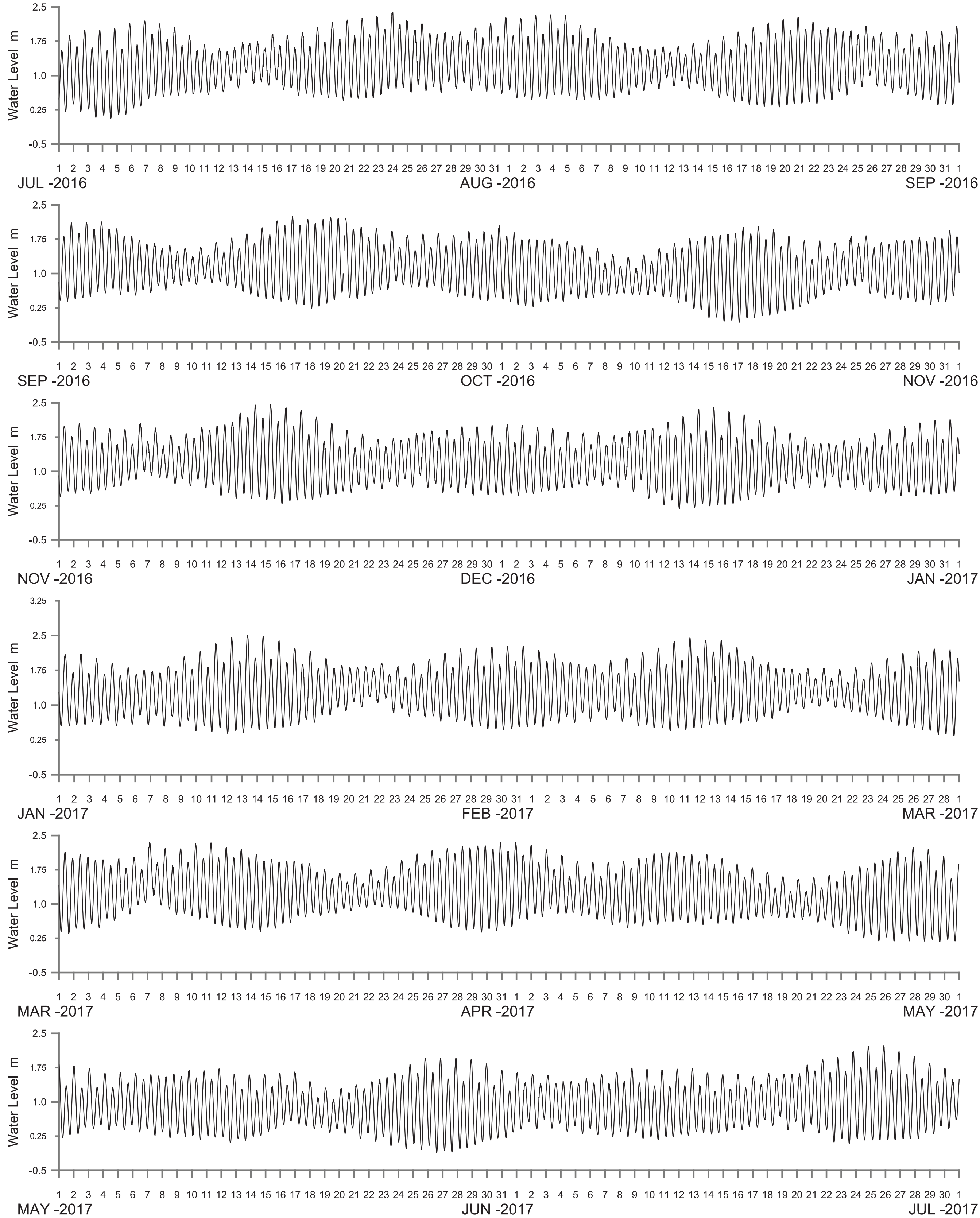
LORD HOWE ISLAND
STATION LOCATION

NSW GOVERNMENT Manly Hydraulics Laboratory

MHL Report 2574

Figure A47

DRAWING 2574-A47.cdr



WATER LEVEL REFERENCED TO LORD HOWE ISLAND TIDAL DATUM

------------ DATA LOSS

Manly Hydraulics Laboratory

NSW GOVERNMENT

LORD HOWE ISLAND DATA SUMMARY
2016–2017

MHL Report 2574

Figure A48

DRAWING 2574-A47.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[1]	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[1]	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[1]	Offshore	Dec 1984–ongoing
Mid North	Crowdy Head Harbour	Crowdy Head[1]	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	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

[1] Station has changed location during data period

Appendix C Historical tide data

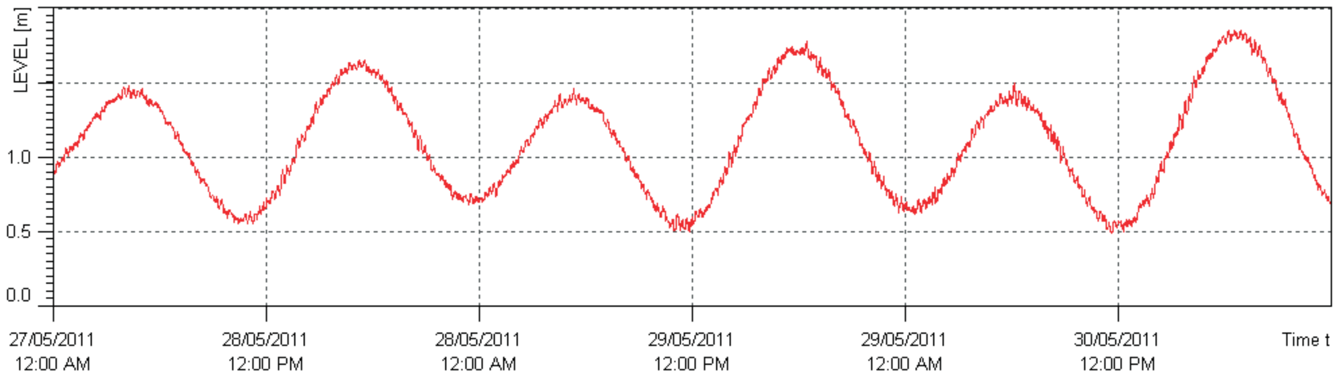
Table C1 Historical tide data

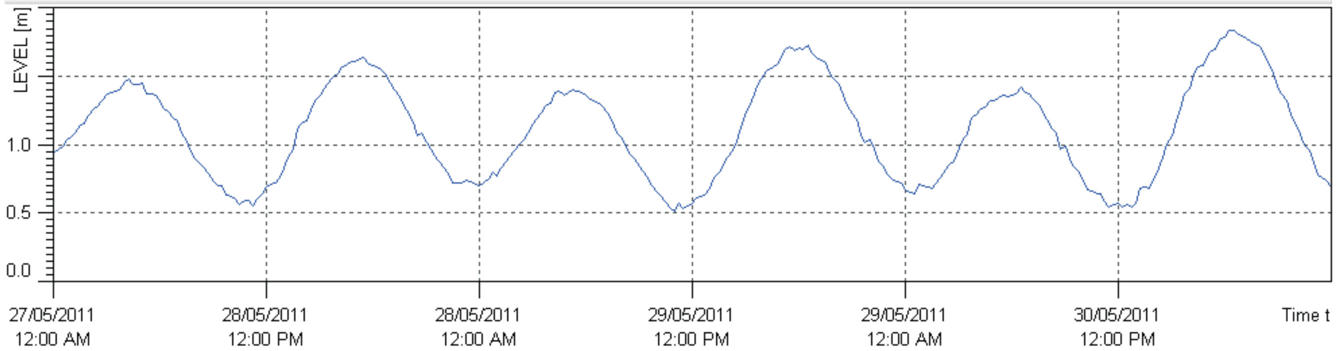
Station Name	Location	Period of record	Location
Tweed Regional	North Breakwater	Feb 1987–Apr 2015	On line
Tweed Regional	Breakwater 201470	1978–1980	On line
Richmond River	Breakwater 202471	1889–1912	HiLos on line
Richmond River	Ballina	1959–1963	Microfiche MHL
Ballina 202470	Half Tide Breakwater	Apr 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.
Norfolk Island data since 2015 courtesy of BoM National Tide Unit

Appendix D Sample outputs

Coffs Harbour 1-minute data





Coffs Harbour 15-minute data

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1-MINUTE AND 15-MINUTE SAMPLE DATA PLOTS

MHL Report 2574

Figure D1

DRAWING 2574-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)
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1/05/2014,5:30:00,0.676,55 (Fair)
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1/05/2014,7:45:00,1.243,55 (Fair)
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1/05/2014,8:15:00,1.366,55 (Fair)
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1/05/2014,8:45:00,1.42,55 (Fair)
1/05/2014,9:00:00,1.443,55 (Fair)
```

NSW GOVERNMENT | Manly Hydraulics Laboratory

15-MINUTE SAMPLE DATA FILE

MHL Report 2574

Figure D2

DRAWING 2574-D.cdr

ANALYSIS OF TIDAL OBSERVATIONS

TIME OF ANALYSIS	:	2014-10-22 08:49
ANALYSIS PERFORMED BY	:	Executed by RJ using Eden (Live) / Level 1 / 00 - Continuous.P
STATION LOCATION	:	Tasman Sea at Eden Boat Harbour
STATION NAME	:	Eden (Live)
STATION LATITUDE	:	-37 DEG 4 MIN SOUTH
STATION LONGITUDE	:	149 DEG 54 MIN EAST
DATUM	:	TBHD
ANALYSIS PERIOD START TIME	:	0000:29/06/2013
ANALYSIS PERIOD FINISH TIME	:	0000:30/06/2014
MID POINT TIME	:	0000:29/12/2013
PERIOD OF ANALYSIS	:	366 DAYS 00 HRS
LOCAL TIME ZONE NAME	:	EASTERN STANDARD TIME
LOCAL TIME FACTOR	:	GMT +10:00 HRS
TIME MERIDIAN	:	-10.08 HRS

TIDAL PLANES IN METRES ABOVE ZERO OF LOCAL GAUGE VALUES

High High Water (Solstices Springs)	H.H.W.(S.S.)	:	1.832
Mean High Water Springs	M.H.W.S.	:	1.436
Mean High Water	M.H.W.	:	1.336
Mean High Water Neaps	M.H.W.N.	:	1.236
Mean Sea Level	M.S.L.	:	0.883
Mean Low Water Neaps	M.L.W.N.	:	0.531
Mean Low Water	M.L.W.	:	0.431
Mean Low water Springs	M.L.W.S.	:	0.331
Indian Spring Low Water	I.S.L.W.	:	0.048

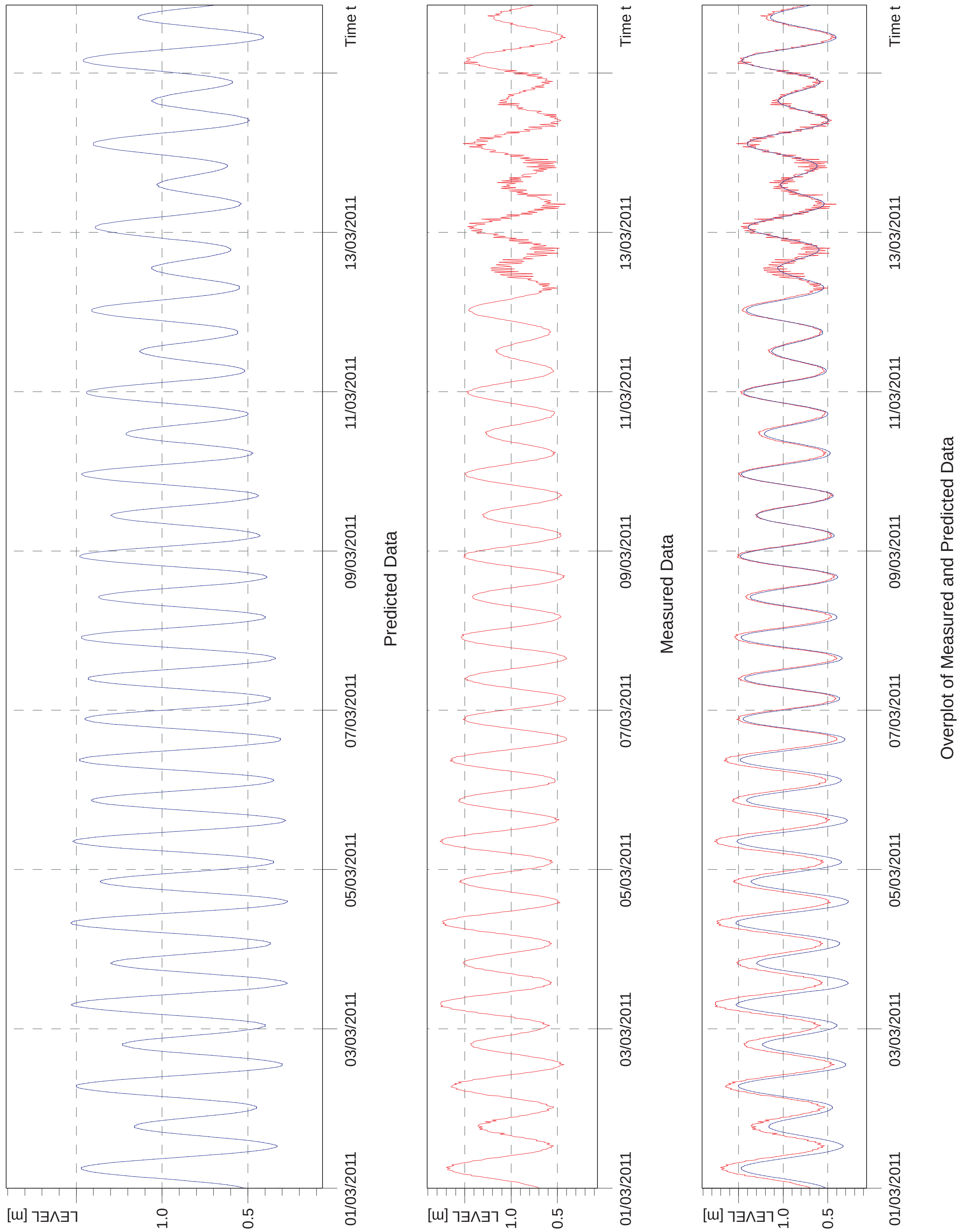
TIDAL RANGES IN METRES

Mean Spring Range	(M.H.W.S. - M.L.W.S.)	:	1.106
Mean Neap Range	(M.H.W.N. - M.L.W.N.)	:	0.705
Mean Range	(M.H.W. - M.L.W.)	:	0.906
Range	(H.H.W.(S.S.) - I.S.L.W.)	:	1.784

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



NSW GOVERNMENT

Manly Hydraulics Laboratory

SAMPLE TIDAL PREDICTION DATA PLOT

MHL Report 2574

Figure D5

DRAWING 2574-D.cdr

Appendix E Glossary of terms

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 + á), 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 + á) 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° 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_l 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_l 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° 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° 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_l 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_l 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° 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 (Np) 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° per solar hour.
Phase	1. Any recurring aspect of a periodic phenomenon, such as new moon, high water, flood strength, etc. 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 360°. The maximum and minimum of a harmonic constituent have phase values of 0° and 180°, respectively.
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° 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 / 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	1. The part of the tide that is due to the tide-producing force of the sun. 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.
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 and mean low water springs
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_0	Symbol recommended by the International Hydrographic Organisation to represent the elevation of mean sea level above chart datum

Appendix F Publications of interest

Data Reports

MHL Annual Ocean Tide Levels Summaries available from 1986-87 to 2015-16
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).

Manly Hydraulics Laboratory 1989, *Comparison of Tide Levels Between Fort Denison and Middle Harbour, Sydney Harbour,* Report No. MHL558.

Manly Hydraulics Laboratory 1998, *Tweed Heads, Yamba and Port Macquarie Offshore Tide Gauges 1982-1997,* MHL Report 722, May 1998.

Manly Hydraulics Laboratory 1990, *Batemans Bay Oceanographic and Meteorological Data 1986-1989,* Report No. MHL556.

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

Ocean Tide Program Reports

Manly Hydraulics Laboratory 1987, *Ocean Tide Measurement Program Progress Report,* Report No. MHL471.

Manly Hydraulics Laboratory 1987, *Tide Gauge System: Yamba - Clarence River,* Report No. MHL496.

Manly Hydraulics Laboratory 1990, *NSW Ocean Tide Network Jervis Bay HMAS Creswell Tide Gauge System,* Report No. MHL580.

Manly Hydraulics Laboratory 2005, *Review of Automatic Water Level Recorder Network,* MHL Report 1419, October 2005.

Manly Hydraulics Laboratory 2005, Tide Gauge Histories Metadata for National and NSW Tide Gauges, MHL Report 2179, November 2012.

Manly Hydraulics Laboratory 2013, *North Coast Ocean Tide Scoping Study,* MHL Report 2072, September2013

Harmonic Analysis and Tidal Planes

Manly Hydraulics Laboratory 1994, *The Harmonic Analysis of NSW Tide Gauge Network, Volumes 1 and 2,* Report No. MHL604.

Department of Public Works and Services 2003, *DLWC NSW Tidal Planes Data Compilation 2001 – Volume 1 Tidal Plane Analyses*, Manly Hydraulics Laboratory, Report No. 1098.

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Manly Hydraulics Laboratory 2012, *OEH NSW Tidal Planes Analysis: 1990-2010 Harmonic Analysis*, MHL Report 2053, October 2012.

Manly Hydraulics Laboratory 2012, *MHL Tidal Methodology Review,* MHL Report 2156, August 2012.

Manly Hydraulics Laboratory 2014, *OEH NSW Water Level Frequency Distribution Analysis*, MHL Report 2100, March 2014.

Mean Sea Level

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

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NSW Committee on Tides and Mean Sea Level 1990, The Role of the NSW Committee on Tides and Mean Sea Level.

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

Anomalies and Storm Surge Analysis

Manly Hydraulics Laboratory 1991, *Storm Surges Monitored Along the NSW Coast March-April 1990,* Report No. MHL591.

Manly Hydraulics Laboratory 2008 *South Coast NSW Tide-Storm Surge Analysis,* MHL Report 1618, December 2008.

Manly Hydraulics Laboratory 2011, *NSW Ocean Water Levels,* MHL Report 1881, March 2011.

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