



NSW OCEAN AND RIVER ENTRANCE TIDAL LEVELS ANNUAL SUMMARY 2014–2015

Report MHL2384
November 2015



East Coast Low Storm 21 April 2015



15 August 2015

prepared for
Office of Environment and Heritage



Office of
Environment
& Heritage

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NSW Ocean and River Entrance Tidal Levels Annual Summary 2014–2015

Report MHL2384
November 2015

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Cover photograph: East Coast Low Storm 21 April 2015 – showing waves and elevated water levels in Collaroy Basin, Sydney (Photo courtesy R Jacobs).

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Foreword

Manly Hydraulics Laboratory (MHL) is a team within NSW Water Solutions 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). NSW Water Solutions is a business unit within NSW Public Works, a division of the Department of Finance, Services and Innovation.

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 2014 to 30 June 2015, and catalogues all ocean and river entrance tidal data collected in NSW by MHL.

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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Annual Summary 2014–2015
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<http://www.mhl.nsw.gov.au> under the 'Publications' menu.

Acknowledgement is made of the following contributions to the delivery of the program:

- field management by Phil Clark, John Vaubell and Ben Cox
- technical expertise, direction and analysis by Ben Modra
- data review and management by Sarah-Kate Dakin and Michael Galloway.

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 2014–2015
- [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

FOREWORD	I
SUMMARY	III
1. TIDAL NETWORK MEASUREMENT PROGRAM	1
2. HOW TO USE THIS REPORT	3
2.1 Using and Accessing the Data	3
2.2 Station Location Terminology	3
2.3 Datums	4
2.4 Tidal Planes	5
3. SIGNIFICANT EVENTS 2014–2015	6
3.1 Tidal Anomalies	6
3.2 Tsunami Events	7
3.3 King Tide Events	8
3.4 East Coast Low Events	8
3.5 Coastal Trapped Wave Events	8
4. PROGRAM DEVELOPMENTS 2014-2015	11
4.1 Classification of Sites	11
4.2 Program Improvements/Changes	12
4.3 Program Plans 2015–2016	15
5. REFERENCES	16
APPENDICES	
A Annual Data Site Summaries	
B Current Sites Data	
C Historical Tide Data	
D Sample Outputs	
E Glossary of Terms	
F Publications of Interest	
TABLES	
2.1 Summary of Adjustment to AHD	4
3.1 Tsunami Events July 2014 to June 2015	7
4.1 Ocean and River Entrance Tide Site Classification	11
4.2 Ocean and River Entrance Tide HAT and LAT Values	13
4.3 MHL Tidal Logging and Sensing System Status June 2015	14
B1 Current Sites Digital Data	B1
C1 Historical Tide Data	C1

FIGURES

- 1.1 Ocean Tide Gauge Network
- 1.2 Radar Sensor
- 1.3 Electromagnetic Wave Staff and Backup Pressure Sensor
- 1.4 Typical Solid State Floatwell
- 1.5 Submersible Pressure Sensor
- 2.1 Tidal Range for Grouped Offshore and Nearshore Gauges 1990-2003
- 3.1 NSW Tidal Predictions – Extract from ‘NSW Tide Charts 2016’
- 3.2 Tidal Anomalies Plot 2014-2015
- 3.3 Tidal Anomalies July 2014 to February 2015
- 3.4 Tidal Anomalies March to June 2015
- 3.5 Tidal Anomalies 2014-2015 Tweed Entrance South to Port Macquarie
- 3.6 Tidal Anomalies 2014-2015 Crowdy Head to Bundeena
- 3.7 Tidal Anomalies 2014-2015 Crookhaven Heads to Eden
- 3.8 Tidal Anomalies 2014-2015 Norfolk Island and Lord Howe Island
- 3.9 Tidal Anomalies 2014-2015 Offshore Tide Gauges
- 3.10 Indonesian Tsunami November 2014
- 3.11 Sydney King Tide January 2014 Data and Photos
- 3.12 East Coast Low Water Level April 2015 Data and Photos
- 3.13 East Coast Low Wave Height April 2015 Data and Photos
- 3.14 Synoptic Maps 1–12 May 2015
- 3.15 Coastal Trapped Wave May 2015 Data
- 3.16 Hovmöller Plot of Residual Water Levels May 2015
- 3.17 Coastal Trapped Wave May 2015 Lake Levels
- 3.18 Coastal Trapped Wave May 2015 Photos
- A1 Tweed Heads Station Location
- A2 Tweed Heads Data Summary 2014–2015
- A3 Tweed Entrance South Data Summary 2014–2015
- A4 Tweed Offshore Tide Gauge Location
- A5 Tweed Offshore Data Summary 2014–2015
- A6 Brunswick Heads Station Location
- A7 Brunswick Heads Data Summary 2014–2015
- A8 Ballina Breakwall Station Location
- A9 Ballina Breakwall Data Summary 2014–2015
- A10 Yamba Station Location
- A11 Yamba Data Summary 2014–2015
- A12 Coffs Harbour Station Location
- A13 Coffs Harbour Data Summary 2014–2015
- A14 Port Macquarie Station Location
- A15 Port Macquarie Data Summary 2014–2015
- A16 Port Macquarie Offshore Tide Gauge Location
- A17 Port Macquarie Offshore Data Summary 2014–2015

- A18 Crowdy Head Station Location
- A19 Crowdy Head Data Summary 2014–2015
- A20 Forster Station Location
- A21 Forster Data Summary 2014–2015
- A22 Shoal Bay Station Location
- A23 Shoal Bay Data Summary 2014–2015
- A24 Patonga Station Location
- A25 Patonga Data Summary 2014–2015
- A26 Sydney Station Location
- A27 Sydney Data Summary 2014–2015
- A28 Port Hacking Station Location
- A29 Port Hacking Data Summary 2014–2015
- A30 Bundeena Station Location
- A31 Bundeena Data Summary 2014–2015
- A32 Crookhaven Heads Station Location
- A33 Crookhaven Heads Data Summary 2014–2015
- A34 Shoalhaven Offshore Tide Gauge Location
- A35 Shoalhaven Offshore Data Summary 2014–2015
- A36 Jervis Bay Station Location
- A37 Jervis Bay Data Summary 2014–2015
- A38 Ulladulla Station Location
- A39 Ulladulla Data Summary 2014–2015
- A40 Princess Jetty Station Location
- A41 Princess Jetty Data Summary 2014–2015
- A42 Batemans Bay Offshore Tide Gauge Location
- A43 Batemans Bay Offshore Data Summary 2014–2015
- A44 Bermagui Station Location
- A45 Bermagui Data Summary 2014–2015
- A46 Eden Station Location
- A47 Eden Boat Harbour Data Summary 2014–2015
- A48 Norfolk Island Station Location
- A49 Norfolk Island Data Summary 2014–2015
- A50 Lord Howe Island Station Location
- A51 Lord Howe Island Data Summary 2014–2015

- D1 1-minute and 15-minute Sample Data Plots
- D2 15-minute Sample Data File
- D3 366-day Tidal Analysis Tidal Planes
- D4 Tidal Level Ranking
- D5 Sample Tidal Prediction Data Plot

1. Tidal Network Measurement Program

This report presents the thirtieth 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 each located on Norfolk Island and Lord Howe Island ([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](#).
- Electromagnetic Wave Staff (EWS): the water level is sampled continuously by the EWS. The data is downloaded every 24 to 48 hours directly from the data logger via an IP link through a modem to the data server or transmitted via radio link to a shore-based receiving station where it can be transferred via a separate modem connection to 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 1.3](#).
- 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](#).

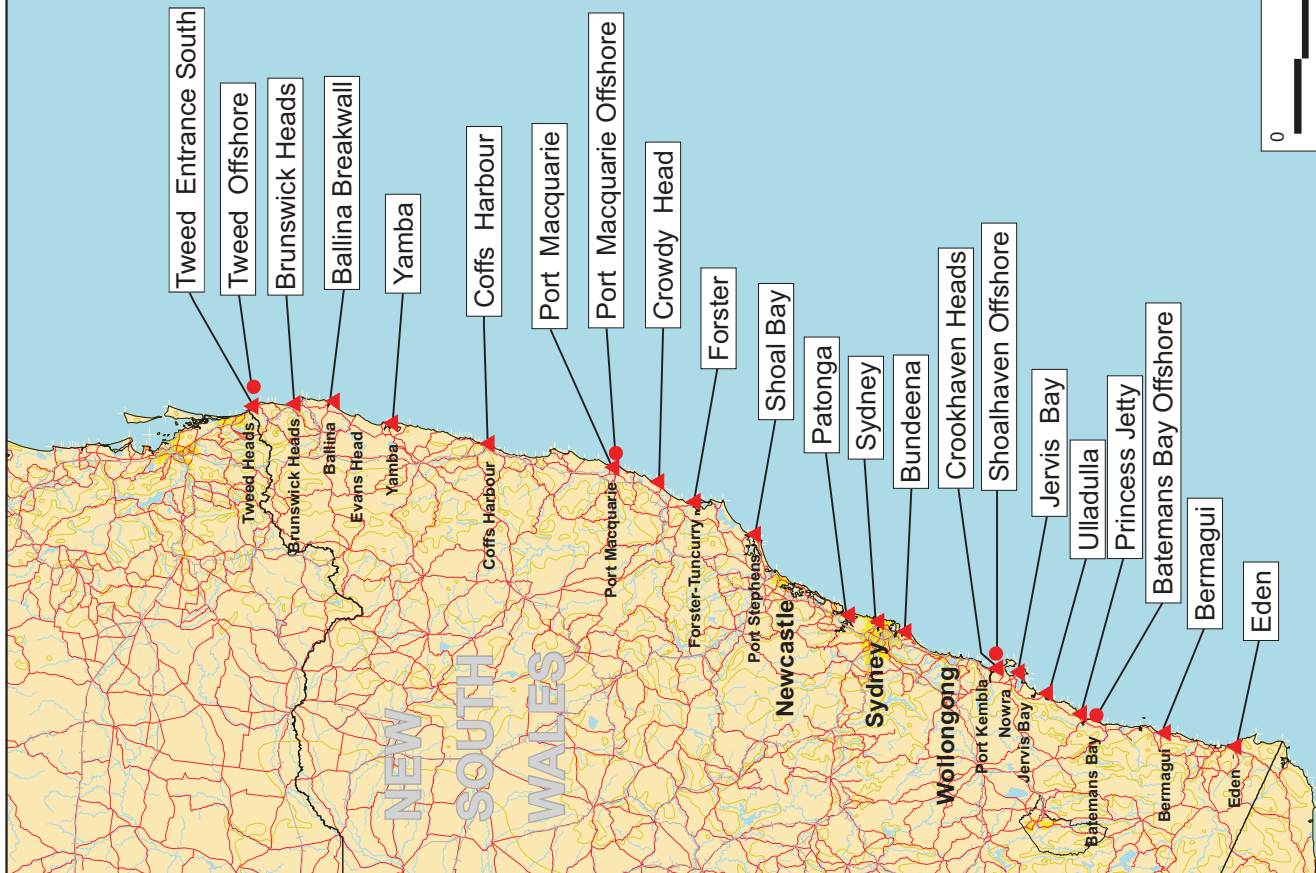
Tidal data is transferred to MHL's data server and is then immediately available to external users to view. A backup copy is also transferred to the NSW Data Collection Warehouse. The 15-minute tide data is available on-line in tables or as plots. One-minute data is also available on request (see Appendix 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 Data Collection Warehouse.

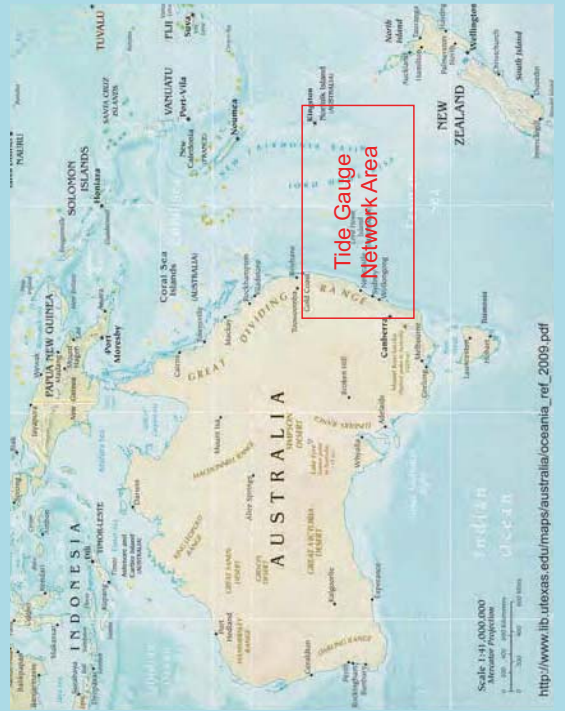
The station locations and data summaries for 2014–2015 are presented in [Appendix A](#).

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.



Norfolk Is.

Lord Howe Is.



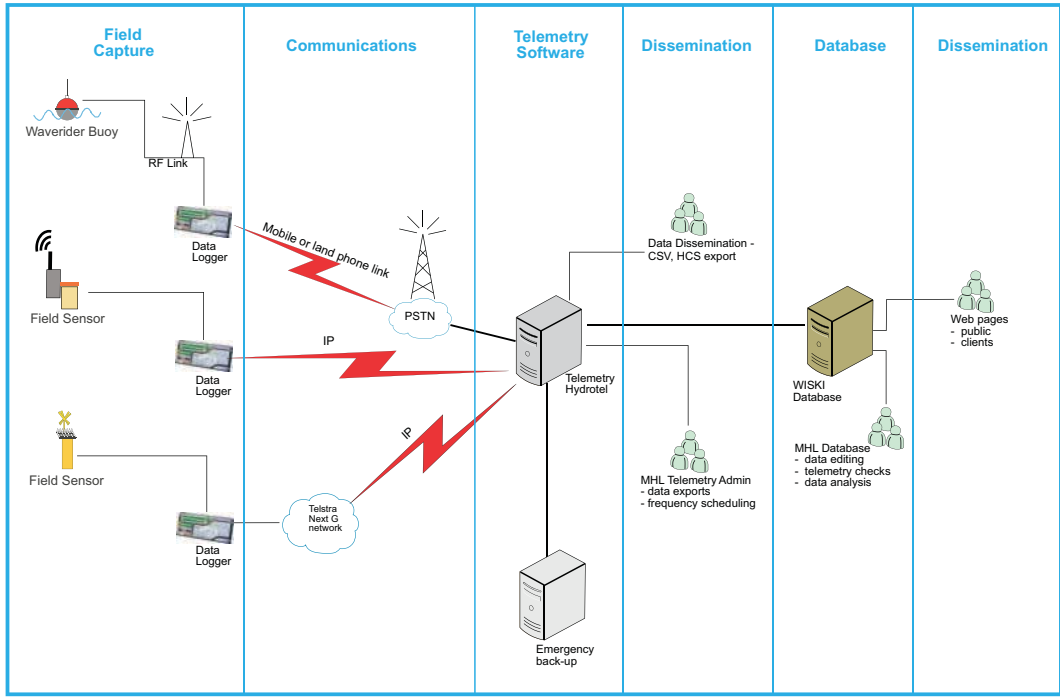
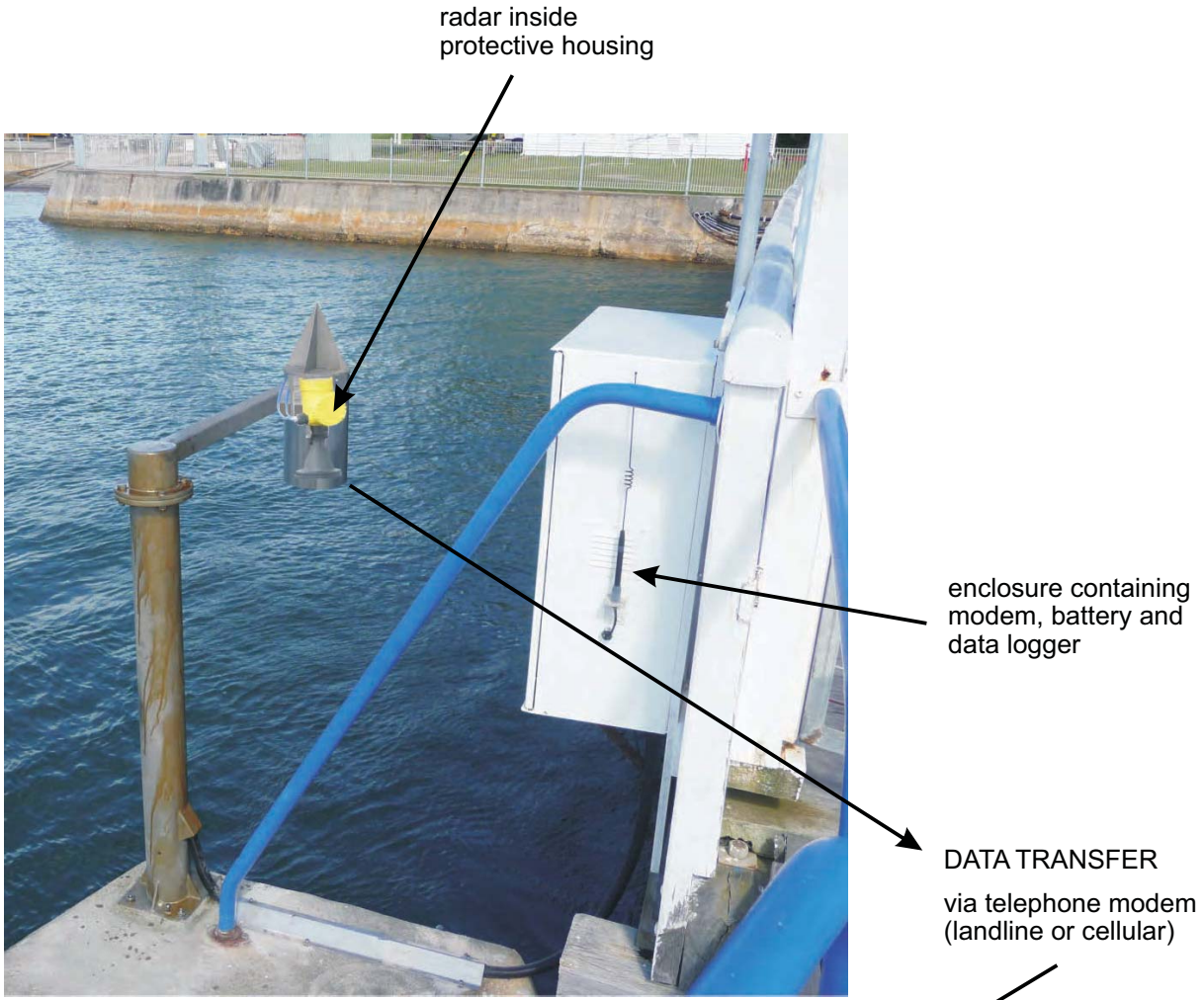
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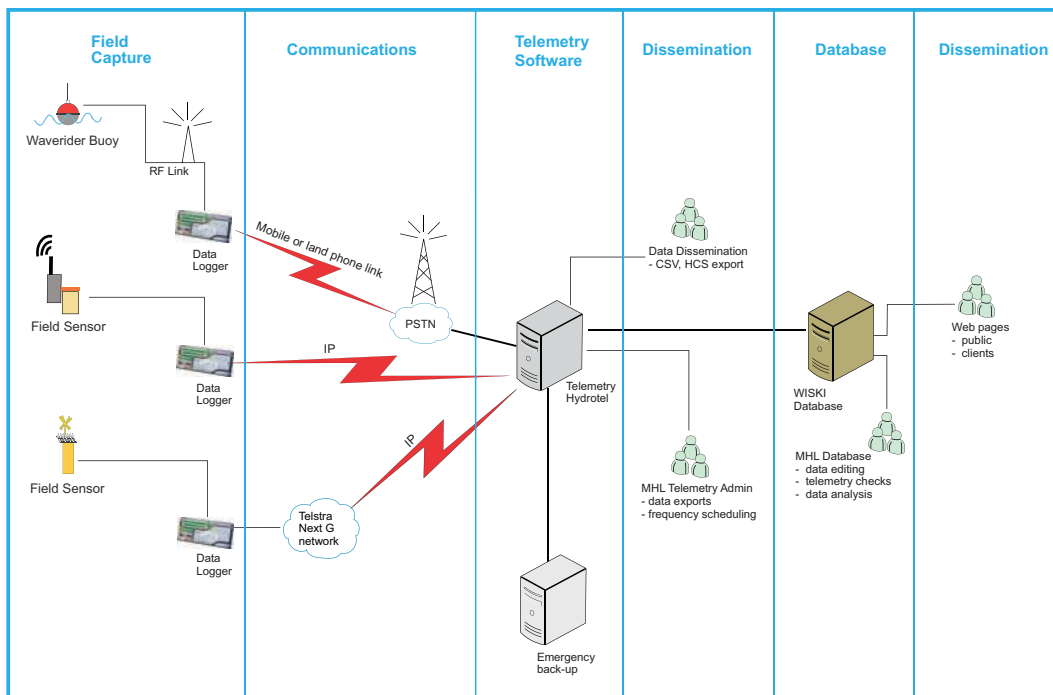
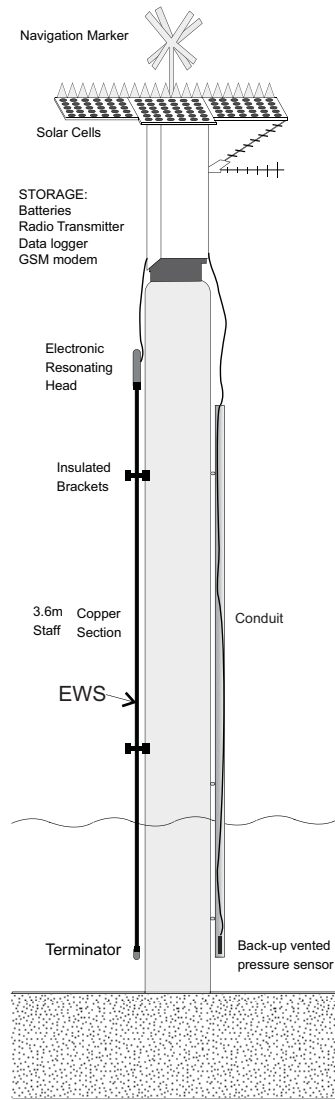
OCEAN TIDE GAUGE NETWORK

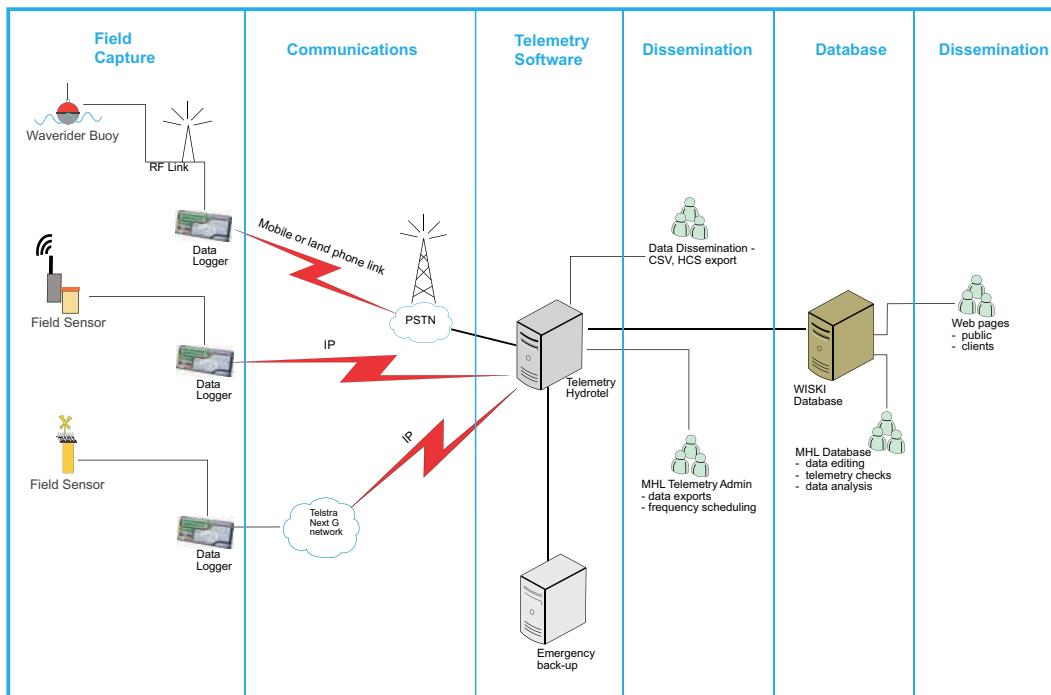
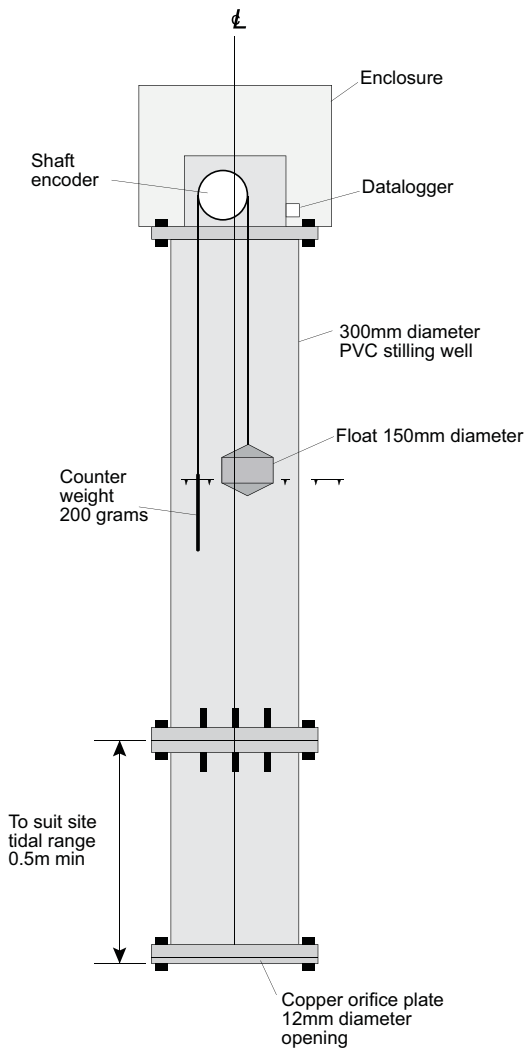
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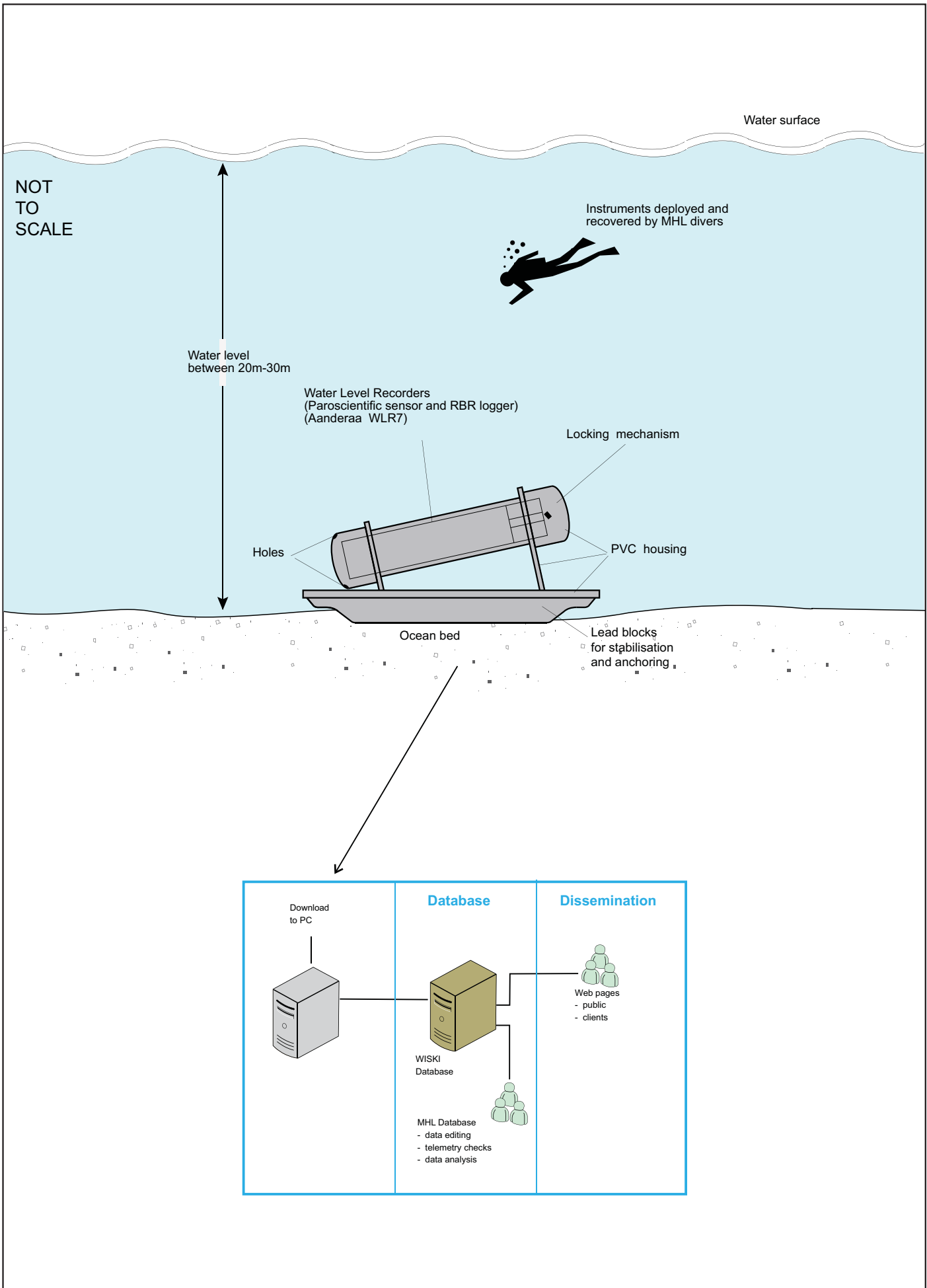
Figure
1.1

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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 2014 to 30 June 2015. 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 2014–2015. 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 the fastest possible access to 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 site context (Site Name, Table B1) has been used throughout the report to avoid any terminology confusion. The only exception is where references to other work are made in which case the terminology 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 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. Poor survey information is available for Norfolk Island and Lord Howe Island. Ongoing survey works are anticipated to improve offset definitions to AHD in the future.

Table 2.1 Summary of Adjustment to AHD

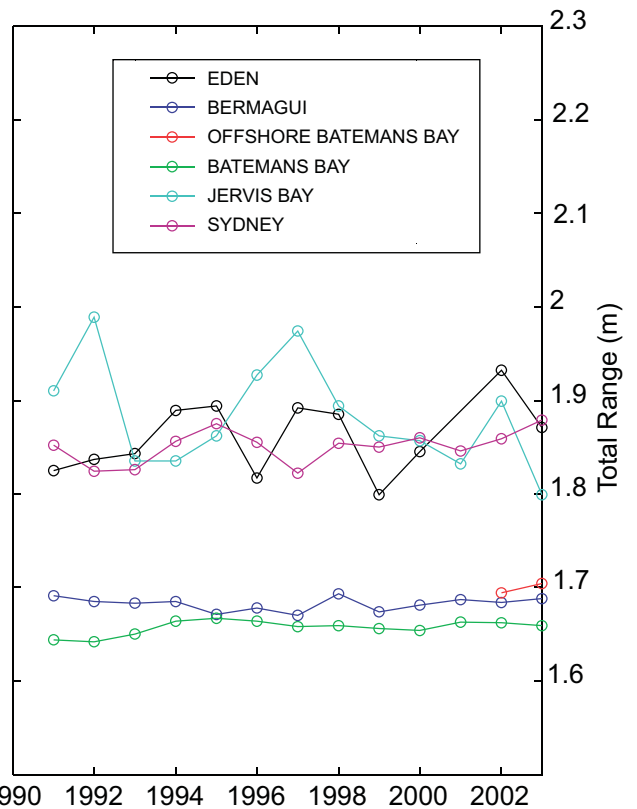
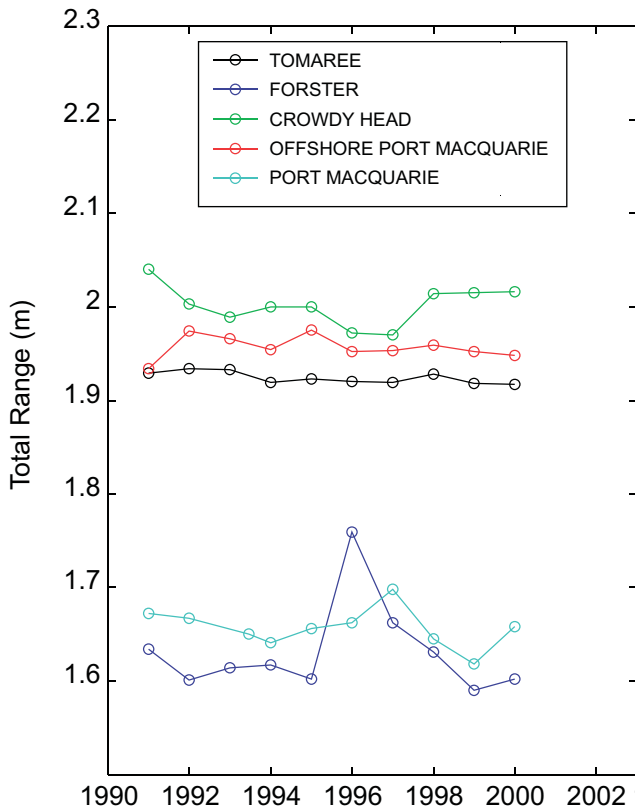
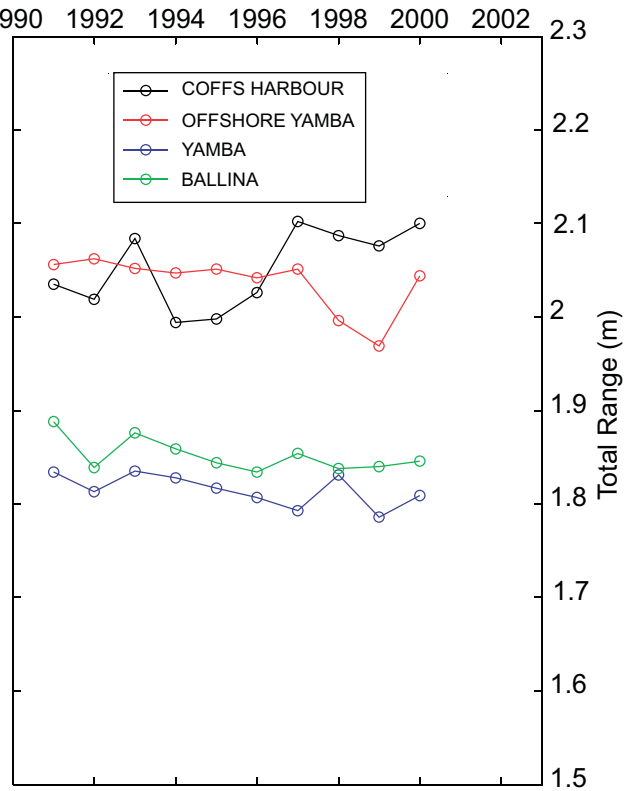
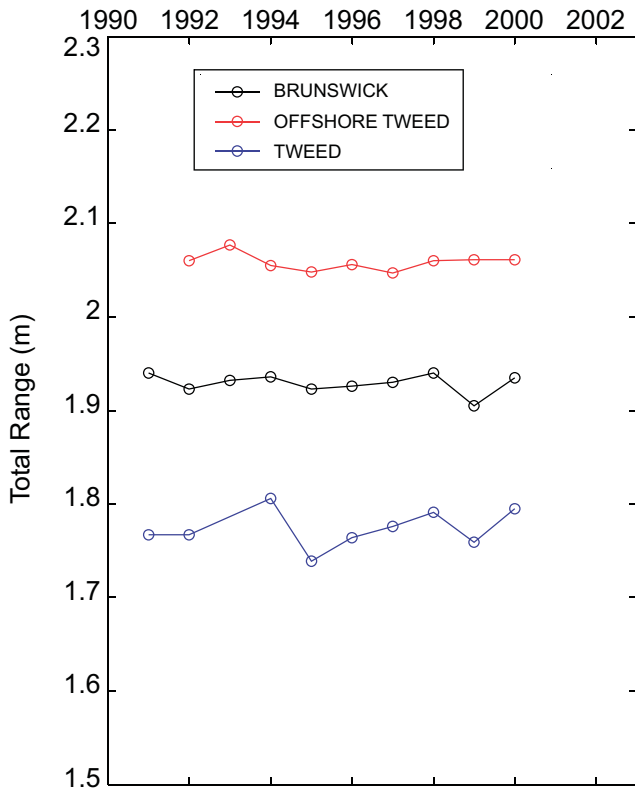
Station	Station Datum (SD)	Adjustment (SD – Adjustment = AHD)
Tweed Entrance South	Tweed River Hydro Datum	0.893
Tweed Offshore	Mean Sea Level	N/A
Brunswick Heads	Brunswick River Flood Mitigation Datum	0.046
Ballina Breakwall	Low Water Ordinary Spring Tide	0.860
Yamba	Iluka Port Datum	0.895
Coffs Harbour	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	N/A
Norfolk Island	Lowest Astronomical Tide	N/A

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. It was also concluded that nearshore sites located at the entrance of large bays/ports or as open ocean sites displayed ranges higher than the closest offshore site, inferring a tidal gradient increasing from offshore to the coast. Further, 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.

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.



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 = $2(M_2 + S_2 + 1.2K_1 + 1.2O_1)$

Source: MHL 2005



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**TIDAL RANGE FOR GROUPED OFFSHORE
 AND NEARSHORE GAUGES
 1990-2003**

MHL
 Report 2384

Figure
 2.1

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3. Significant Events 2014–2015

Data recovery rates across the NSW Ocean Tide Network in 2014–2015 were very high; the data recovery on the 15-minute records was 100%. The data recovery for the four offshore tide sites was 91.1%. Some 35.6% of data for this financial year was lost at the Port Macquarie Offshore site as there was a battery failure part way through the deployment.

In 2016, MHL will make NSW Tide Prediction Charts available via download from the internet. The charts will be available free of charge via the MHL website. The charts remain the most complete authoritative charts for coastal NSW ([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 from an analysis of the tide levels recorded at gauges at each of the secondary locations.

A conference paper about the Ocean Tide Network and data was presented to the 17th Australian Hydrographers Association Conference in Sydney in October 2014 (Couriel, Modra and Jacobs 2014). The paper, titled *NSW Sea Level Trends – The Ups and Downs*, presented the NSW Ocean Tide measuring network and discussed forcing mechanisms, anomalies, understanding sea level trends, a review of NSW sea level trends and the importance of metadata and sustaining continuous quality records. Elements of this paper were included in the Environment Protection Authority's State of the Environment Report 2014–2015.

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 4.2](#). Generally, tidal anomalies are caused by a range of oceanographic and meteorological 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 shown 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 appear to be driven by East Coast Lows or large high pressure systems. In addition, there was a very clear coastal trapped wave recorded in May 2015 that is discussed in more detail in Section 3.2 below. [Figures 3.5–3.8](#) show the tidal anomalies recorded during the reporting period. [Figure 3.9](#) shows the anomalies for the four offshore tide stations.

The Bureau of Meteorology (BoM) recorded only one cyclone in North Queensland during the 2014–2015 reporting period:

- 18–20 February 2015, Cyclone Marcia Category 5 – Tropical Cyclone Marcia formed from a tropical low and reached Category 5 on Friday 20 February. Wind gusts at Middle Percy Island reached 208 km/h as the cyclone passed to the east. Marcia made landfall north of Yeppoon and the township received significant damage. A storm surge of 2m was recorded at Port Alma, and heavy rain and flooding also occurred extending south as far as the Sunshine Coast. Evidence of the impact of this cyclone can be seen at the Tweed Entrance South, Brunswick Heads and Ballina Breakwall NSW Ocean Tide stations, with anomalies of between 0.3 m and 0.5 m recorded. The anomalies caused by the cyclone can be seen on [Figure 3.2](#) but are not documented further in [Figures 3.3](#) and [3.4](#) as they only occur at three stations.

3.2 Tsunami Events

Table 3.1 lists the tsunami events in the Pacific Region for the period of time corresponding to the 2014–2015 data in this report.

Table 3.1 Tsunami Events July 2014 to June 2015

Date	Cause		Location	Observable on NSW Tide Recordings
	Earthquake Magnitude (M _w)	Other Causes		
11/7/2014	6.5	-	Sanriku, Japan	No
9/10/2014	7.1	-	Easter Island region, Chile	No
15/11/2014	7.1	-	N Moluccas Islands, Indonesia	Slight
16/2/2015	6.7	-	Honshu, Japan	No
19/2/2015	6.4	-	Vanuatu Islands	No
29/3/2015	7.5	-	Papua New Guinea	No
2/5/2015	5.7	-	South of Honshu Island, Japan	No
5/5/2015	7.5	-	Papua New Guinea	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 2014 to June 2015. The Bureau of Meteorology collects specific tsunami data for issuing warnings, and the data can be requested from BoM for further use.

Only a slight impact can be seen in the NSW water level traces for the November 2014 Indonesian earthquake event. The 1-minute residual data trace shows the slight effect of the earthquake on the water level. Traces from indicative sites are shown in [Figure 3.10](#).

3.3 King Tide Events

King tides occurred on 12 July 2014 and 20 January 2015. The July king tide produced a water level in Sydney of 2.10 m ZFD (1.18 m AHD), whilst the January king tide reached 2.05 m ZFD (1.13 m AHD). [Figure 3.11](#) shows the Sydney water level data along with some photographs of the January event. However, these two king tides were not the highest tides of the recording period – the highest occurred during an East Coast Low storm described in the next section.

3.4 East Coast Low Events

The highest water level for the reporting period at Sydney was recorded during an East Coast Low storm on 21 April 2015 of 2.14 m ZFD. The storm from 20 to 22 April produced some significant wave statistics also – the second highest significant wave height (Hs) in Sydney (8.1 m vs. 8.4 m in 1997), the longest period with Hs over 6 m (30 hours vs. 24 hours in 1997), and the largest single wave ever recorded in NSW (14.9 m). A synoptic chart for the storm can be seen in [Figure 3.4](#) (Event 7) and the water level and wave data for Sydney together with some photos are shown in [Figures 3.12](#) and [3.13](#). Further details of this storm and its impact on the NSW Hunter and Central Coast regions can be found in MHL (2015a).

3.5 Coastal Trapped Wave Events

A significant coastal trapped wave (CTW) impacted on the coast of NSW in May 2015.

3.5.1 Background

CTWs typically have phase speed of around 2–4 m/s; a period of around 10 days; a Sea Surface Height (SSH) amplitude of around 5–10 cm; and a wavelength of around 2500 km (Freeland et al. 1986). Maiwa et al. (2010) found CTWs to have an annual pattern, with amplitudes distinctly larger in winter than in summer and a range of propagation speeds as: 4.5 m/s 'or faster' on the western and southern coasts, and 2.1–3.6 m/s on the east coast, with a typical period of 1 to 2 weeks. They found that reinforcement of the CTWs by the wind forcing in the southern part of the eastern coast is necessary to obtain larger amplitudes of CTWs on the eastern coast.

Woodham et al. (2013) compared tide gauge data with SSH data from BoM Bluelink data and found close agreement. Applying SSH data from the Bluelink forecasting system Woodham et al. (2013) concluded that CTWs propagate as continuous features between the south-west and north-east Australian coast from one end of this expanse of coastline to the other. They found the CTW amplitudes, phase speed and periods were consistent with previous studies, and that CTWs travelled faster and had greater wavelengths where the continental shelf is wider and that their amplitude is greater along the south coast than on the east coast.

The role of wind forcing in Bass Strait was investigated and Woodham et al. (2013) concluded whilst there are some examples where anomalies were caused by wind forcing 'the majority of SSH variations at CTW frequencies propagate as continuous features between the south-west and north-west corners of the Australian Coast'.

3.5.2 May 2015 Coastal Trapped Wave Event

In early May 2015 a number of cold fronts impacted along the southern coast of Australia from Western Australia along the southern coast of South Australia and Victoria. Synoptic maps shown in [Figure 3.14](#) from the BoM from 1 to 12 May 2015 show cold fronts and high winds initially in south-west Australia and following in Bass Strait.

These maps are consistent with the findings of Maiwa et al. (2010) and Woodham et al. (2013) where the CTW may have originated in the south-west and propagated to Bass Strait where it was reinforced by the wind and continued up the NSW east coast.

The CTW was clearly evident in the ocean tide station records. The effect of the wave on the water level can be observed by viewing the residual (predicted – recorded) tidal data plot. The residual water level plots for Tweed Entrance South, Coffs Harbour, Crowdy Head, Shoal Bay, Sydney, Jervis Bay, Princess Jetty and Eden between 3 May and 20 May 2015 are shown in [Figure 3.15](#). The CTW can be seen propagating from south to north. The lines on the figure indicate the residual water level due to the coastal trapped wave progressing northward along the coast. The maximum amplitude of the residual is around 0.5 m but varies along the coast. Using the guidelines on the graph as a rough estimate the CTW lasted about 12.5 days and had an average speed of approximately 2 m/s. This is consistent with the findings of other researchers as summarised above.

A Hovmöller plot of the residual water levels is shown in [Figure 3.16](#). The plot shows a northerly movement of the water level residual along the coast between Eden and Tweed Entrance South. The trend line on the plot indicates the phase speed of 2 m/s calculated from [Figure 3.15](#).

While absolute water levels on the open coast during this event were not particularly high (peak water level of 1.09 m AHD on the Sydney gauge), water levels within some coastal lake systems became significantly elevated compared with normal tides. In Lake Macquarie even low tide levels were higher than normal high tide levels, with some foreshore and local street inundation. MHL (2013) found that at Lake Macquarie 'for longer anomaly events there is very little attenuation of the anomaly. Shorter duration anomaly peaks do not fully propagate past the lake entrance, with some attenuation observed.' This becomes significant

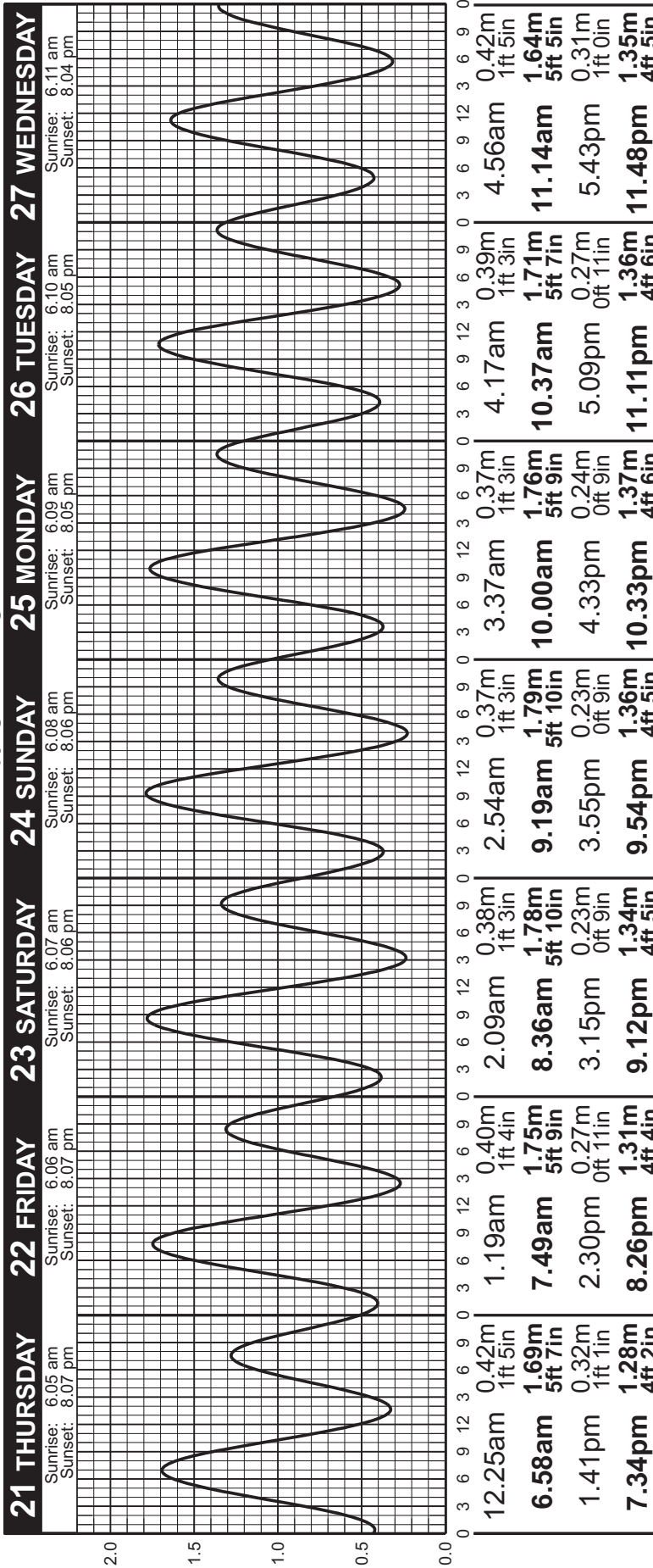
as diurnal and semi-diurnal tidal constituents in these systems are reduced compared with the ocean resulting in a very much reduced tide range. Collins et al. (2012) observed that for large water bodies (such as Lake Macquarie) near the ocean entrance, anomalies of a few days have a pumping effect on the lake level.

[Figure 3.17](#) shows the response of water levels within some of the NSW coastal lakes and lagoons to the CTW. This pumping up effect is shown by the general trend line on the plot indicating that the CTW appears to be acting like a fortnightly tidal curve as it moves along the coast over a longer period than short-lived storm events. Photos of the impact of the increased water levels are shown in [Figure 3.18](#) at Lake Macquarie and Manly Lagoon.

January 21-27, 2016

Daylight Saving Time
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○ Full Moon Jan 24



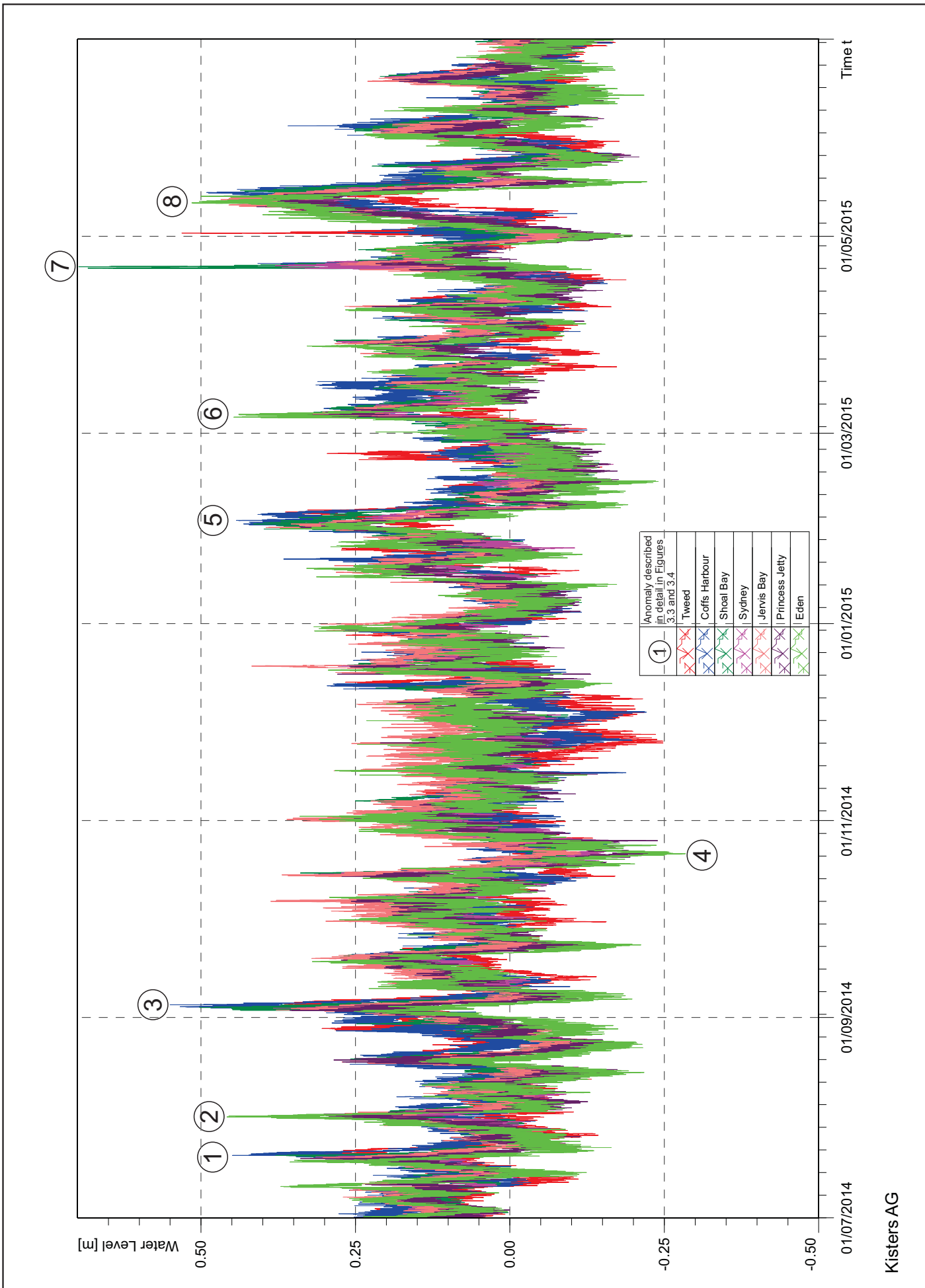
Public Works
Manly Hydraulics Laboratory

NSW TIDAL PREDICTIONS EXTRACT FROM 'NSW TIDE CHARTS 2016'

MHL
Report 2384

Figure
3.1

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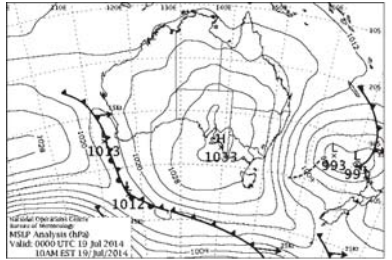
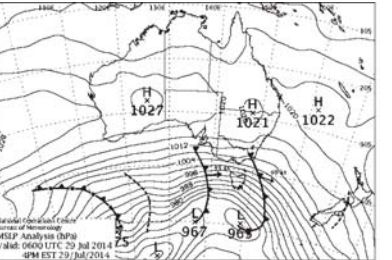
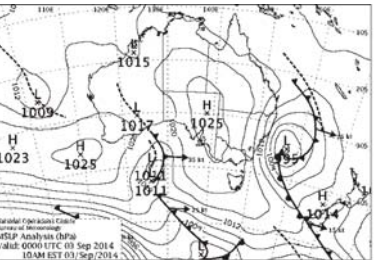
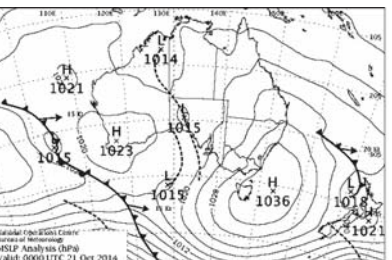
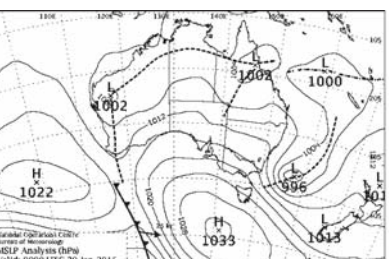
Public Works
Manly Hydraulics Laboratory

NSW TIDAL ANOMALIES PLOT 2014–2015

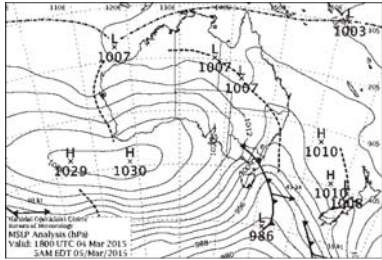
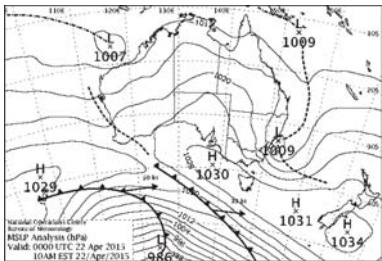
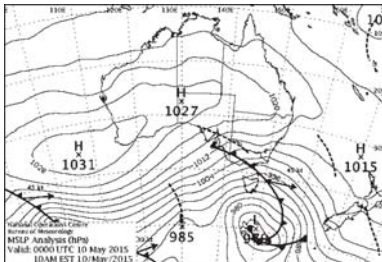
MHL
Report 2384

Figure
3.2

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Event Number (see Figure 3.2)	Event Period	BoM Weather Map*	Peak	Sites where Anomaly > +/- 0.2m
1	18–21 July 2014	 <p>Low Pressure in the Tasman Sea</p>	Site Coffs Harbour Date 20/7/14 Time 0730 Peak Value 0.45	Tweed Entrance South, Brunswick Heads, Ballina Breakwater, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
2	31 July–2 Aug 2014	 <p>Several cold fronts passing Bass Strait possible Coastal Trapped Wave</p>	Site Eden Date 1/8/14 Time 0500 Peak Value 0.46	Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
3	1–7 Sept 2014	 <p>East Coast Low in Tasman Sea</p>	Site Coffs Harbour Date 4/9/14 Time 2315 Peak Value 0.55	Tweed Entrance South, Brunswick Heads, Ballina Breakwater, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
4	20–22 Oct 2014	 <p>Large high pressure off south coast</p>	Site Ulladulla Date 22/10/2014 Time 0030 Peak Value -0.36	Bundeena, Crookhaven Heads, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
5	26 Jan–6 Feb 2015	 <p>East Coast Low off south coast</p>	Site Ulladulla Date 30/1/2015 Time 0530 Peak Value 0.49	Tweed Entrance South, Brunswick Heads, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden

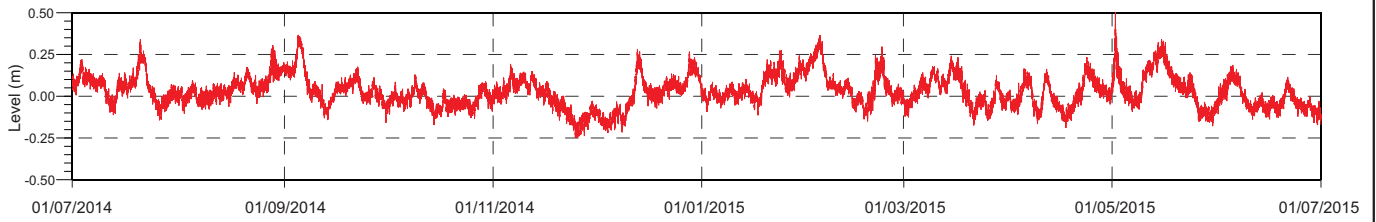


Event Number (see Figure 3.2)	Event Period	BoM Weather Map*	Peak	Sites where Anomaly > +/- 0.2m
6	5–10 Mar 2015	 <p data-bbox="448 797 831 853">Cold front passing through Bass Strait forming Coastal Trapped Wave</p>	Site Ulladulla Date 7/3/2015 Time 0915 Peak Value 0.48	Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
7	20–23 April 2015	 <p data-bbox="448 1140 831 1196">East Coast Low off central NSW coast</p>	Site Shoal Bay Date 21/4/2014 Time 1330 Peak Value 0.70	Tweed Entrance South, Ballina Breakwall, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladulla, Princess Jetty
8	5–20 May 2015	 <p data-bbox="448 1476 831 1590">Series of cold fronts passing through Bass Strait causing a Coastal Trapped Wave</p>	Site Ulladulla Date 12/5/2015 Time 1400 Peak Value 0.55	Tweed Entrance South, Brunswick Heads, Ballina Breakwall, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden

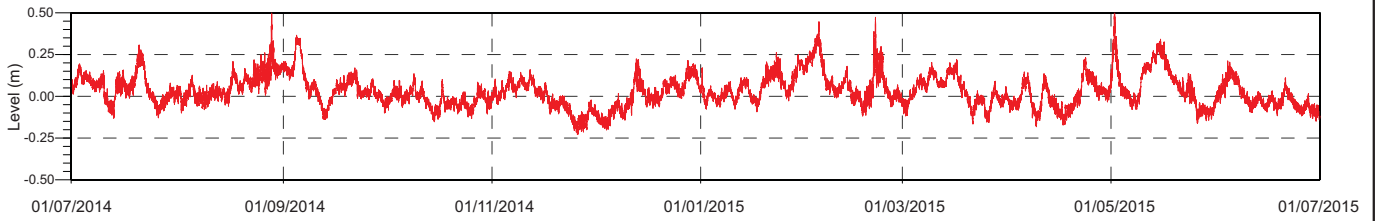
*Weather map images courtesy BoM © Commonwealth of Australia, Bureau of Meteorology



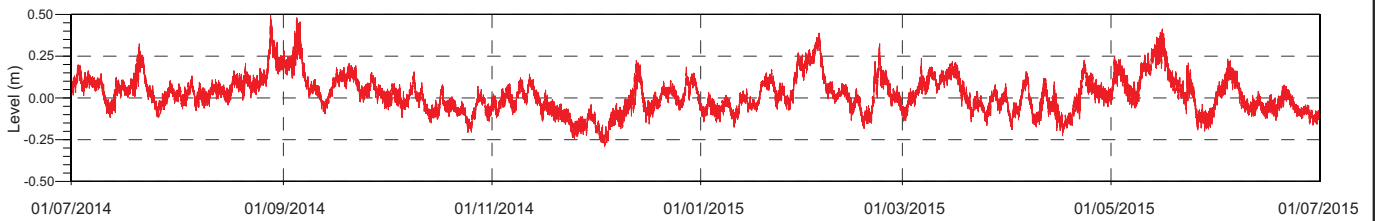
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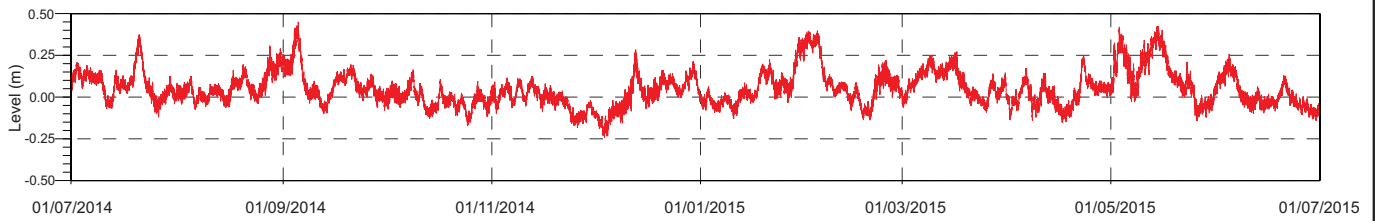
Brunswick Heads



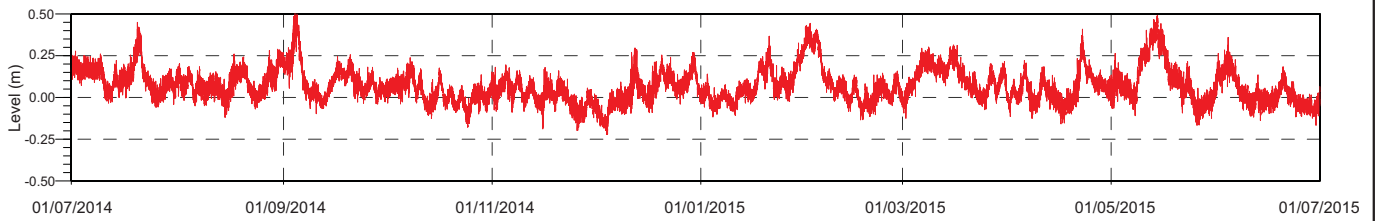
Ballina Breakwall



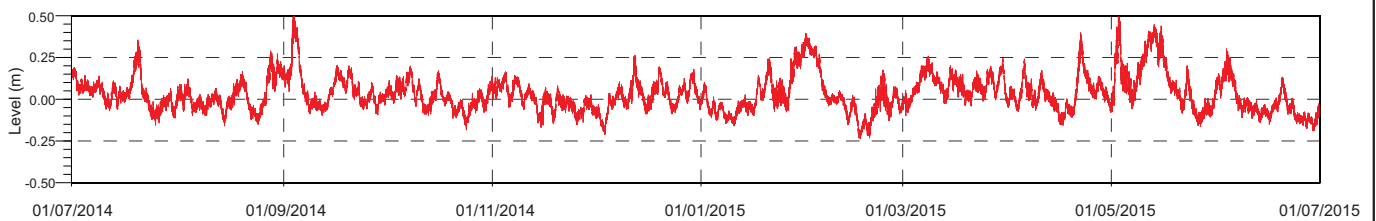
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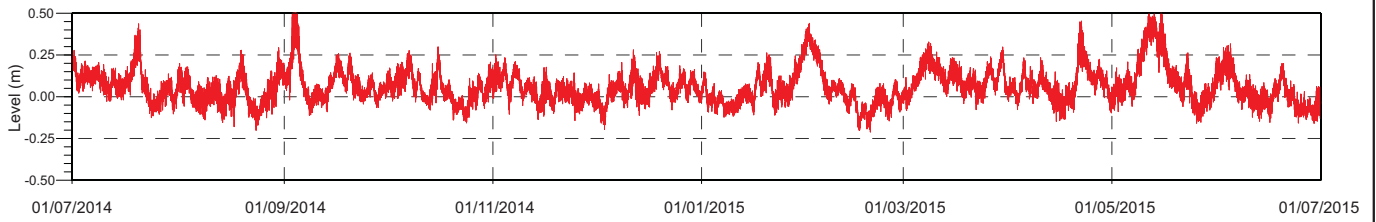
Coffs Harbour



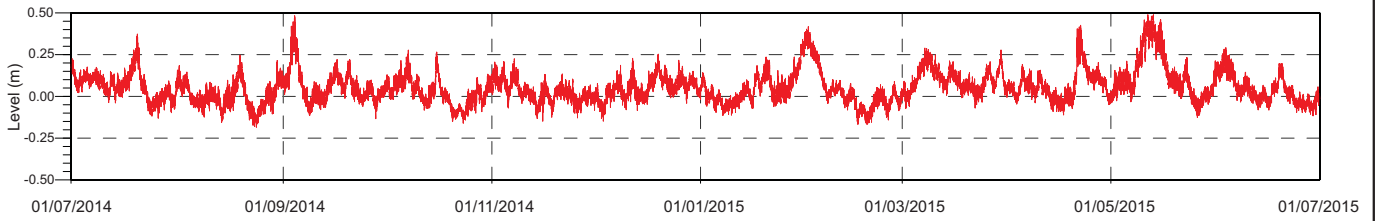
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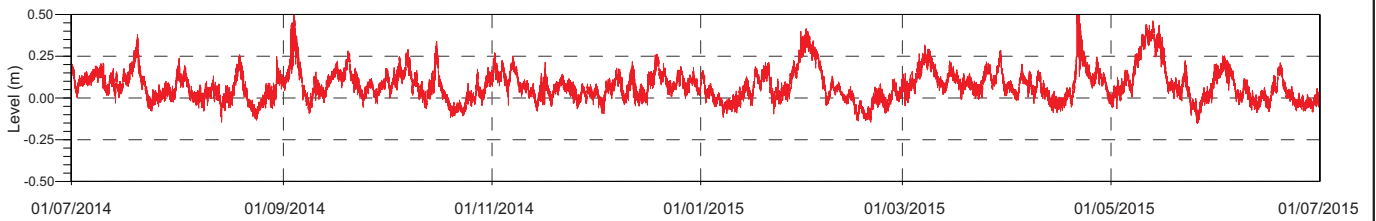
Crowdy Head



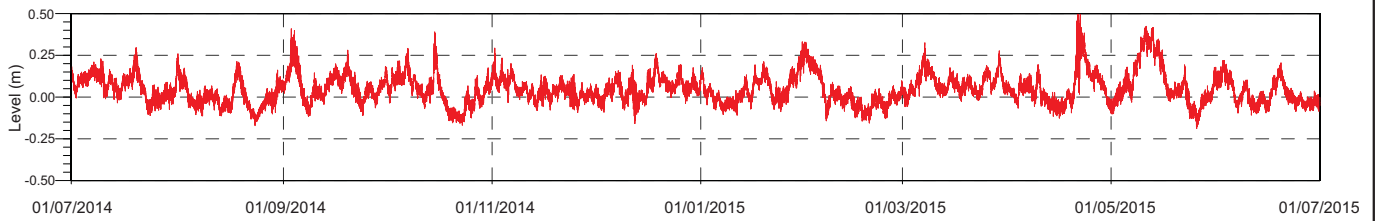
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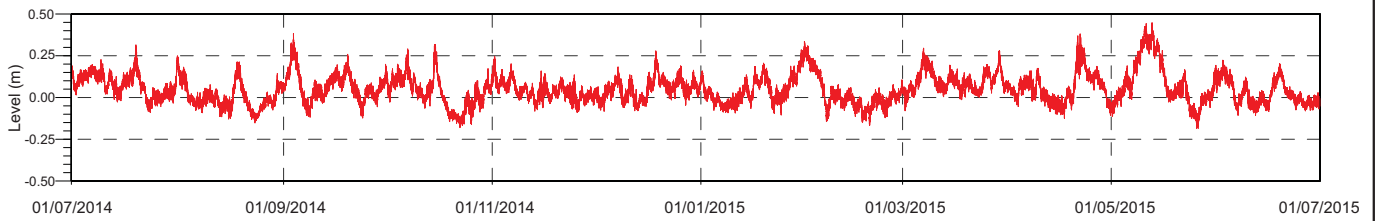
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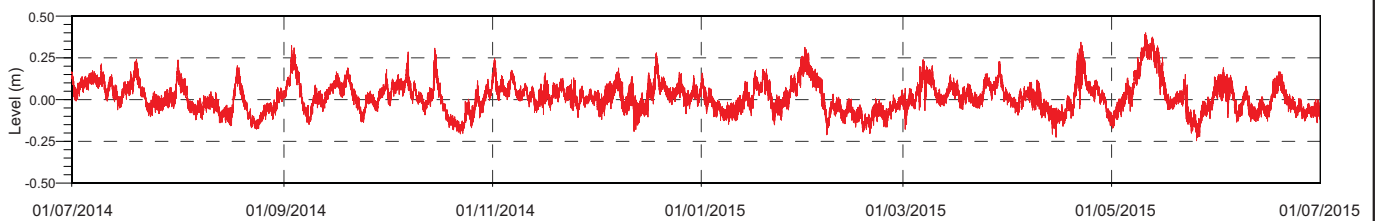
Patonga



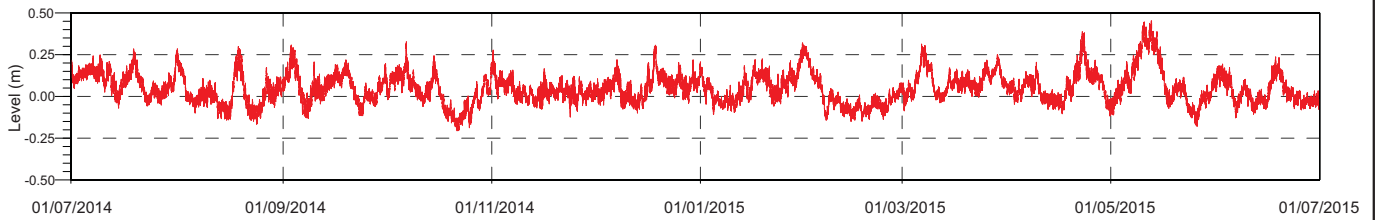
Sydney



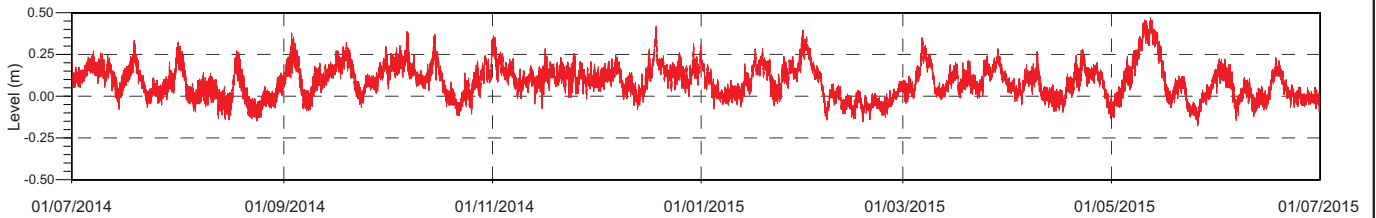
Port Hacking and Bundeena sites



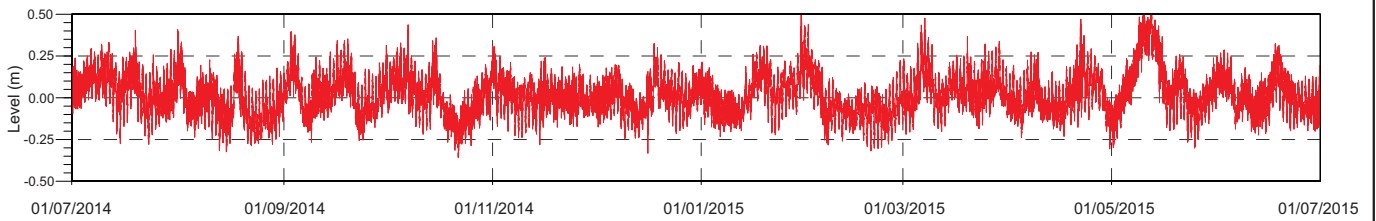
Crookhaven Heads



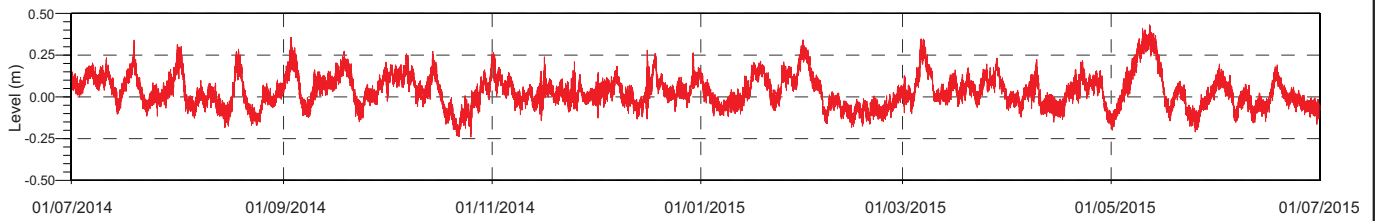
Jervis Bay



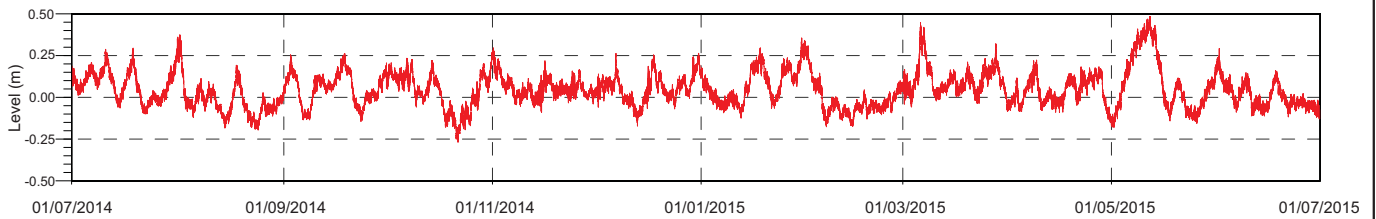
Ulladulla



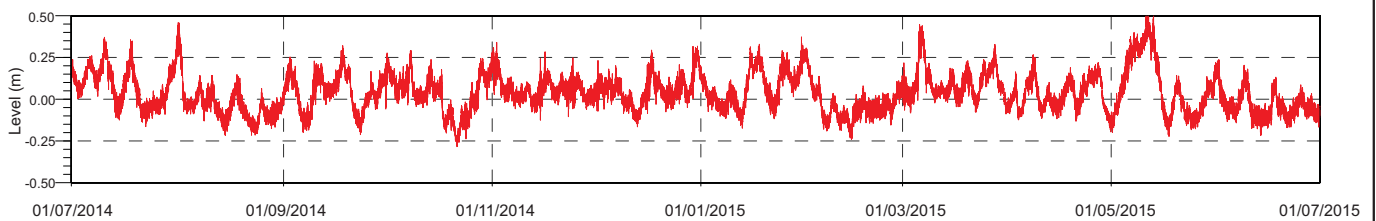
Princess Jetty



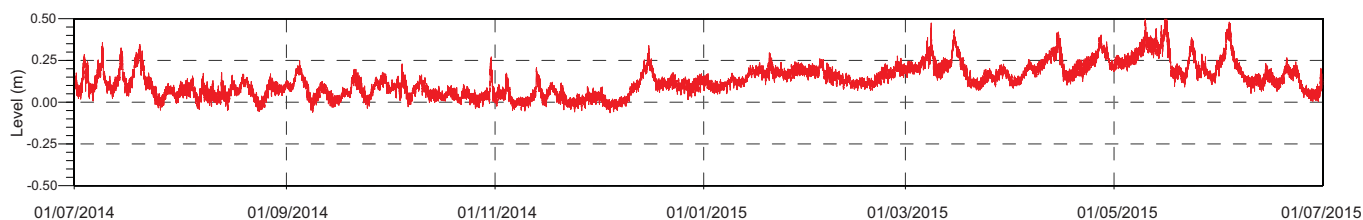
Bermagui



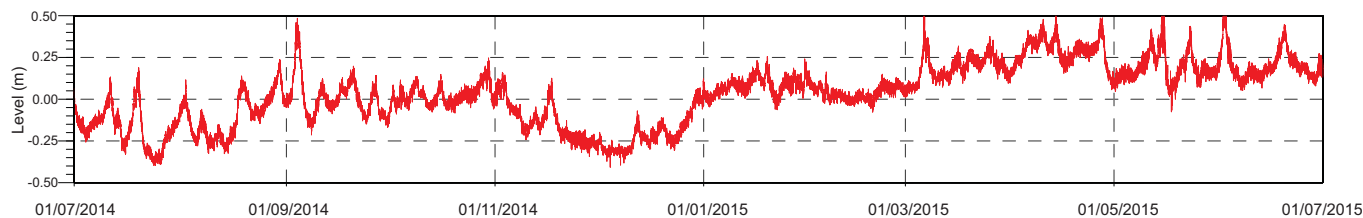
Eden



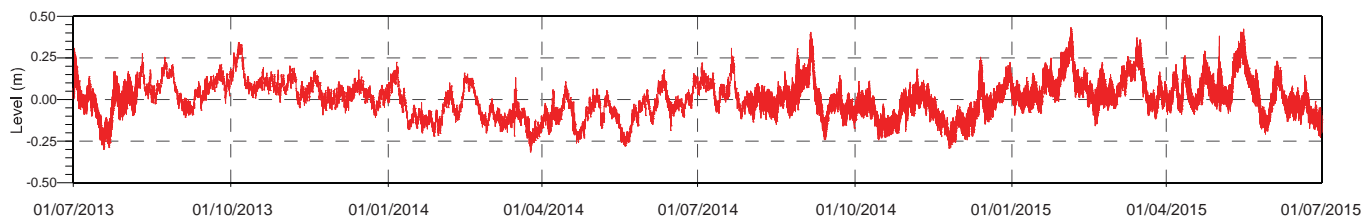
Norfolk Island



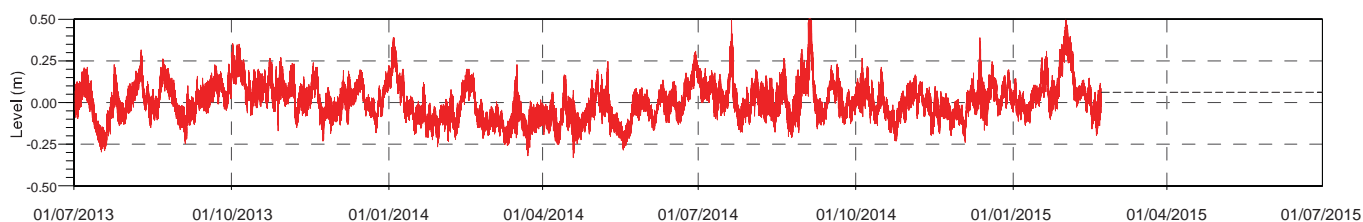
Lord Howe Island



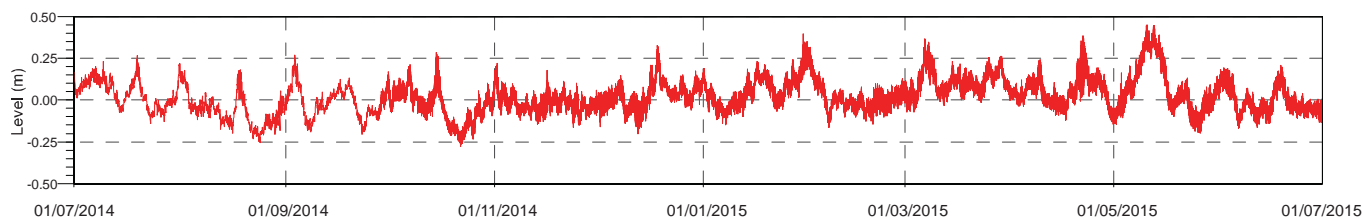
Tweed Offshore



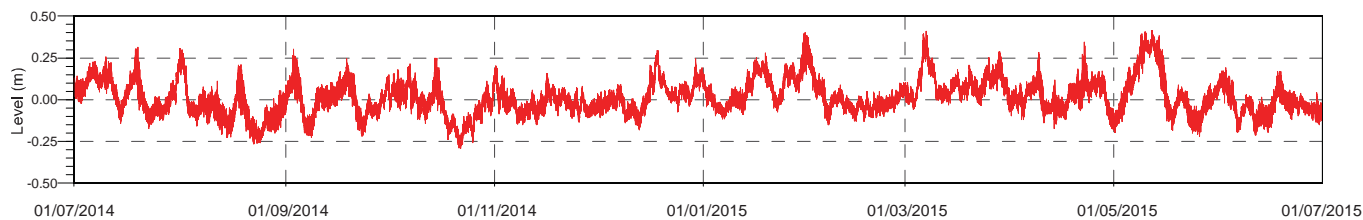
Port Macquarie Offshore



Shoalhaven Offshore

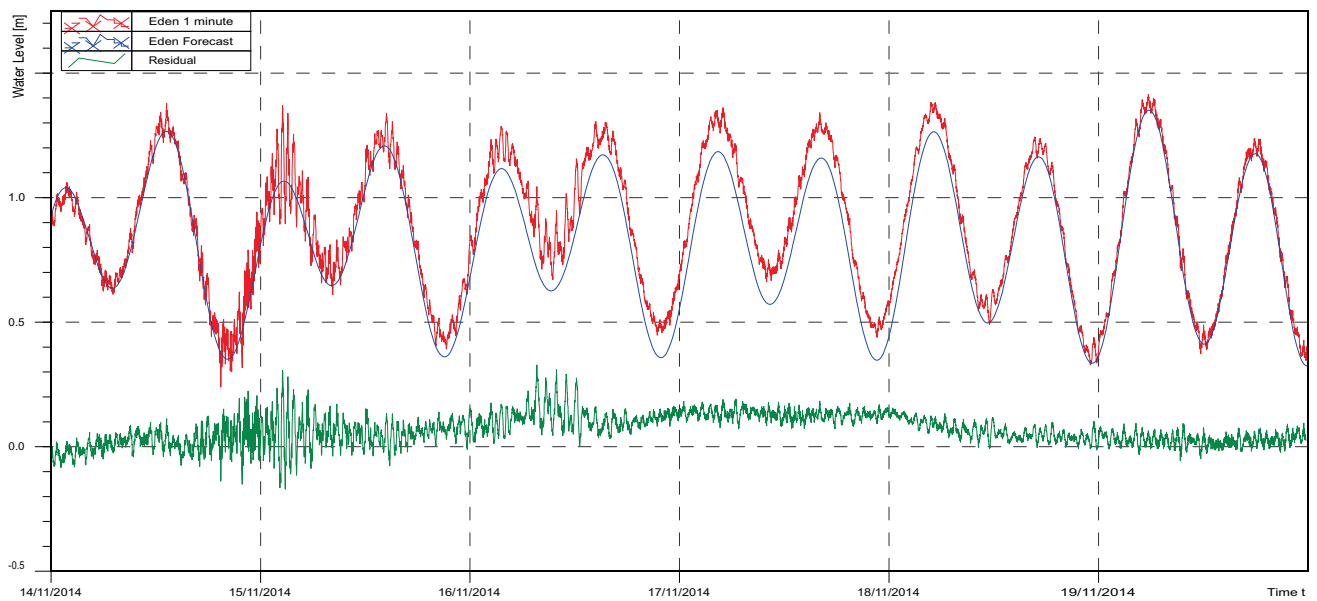
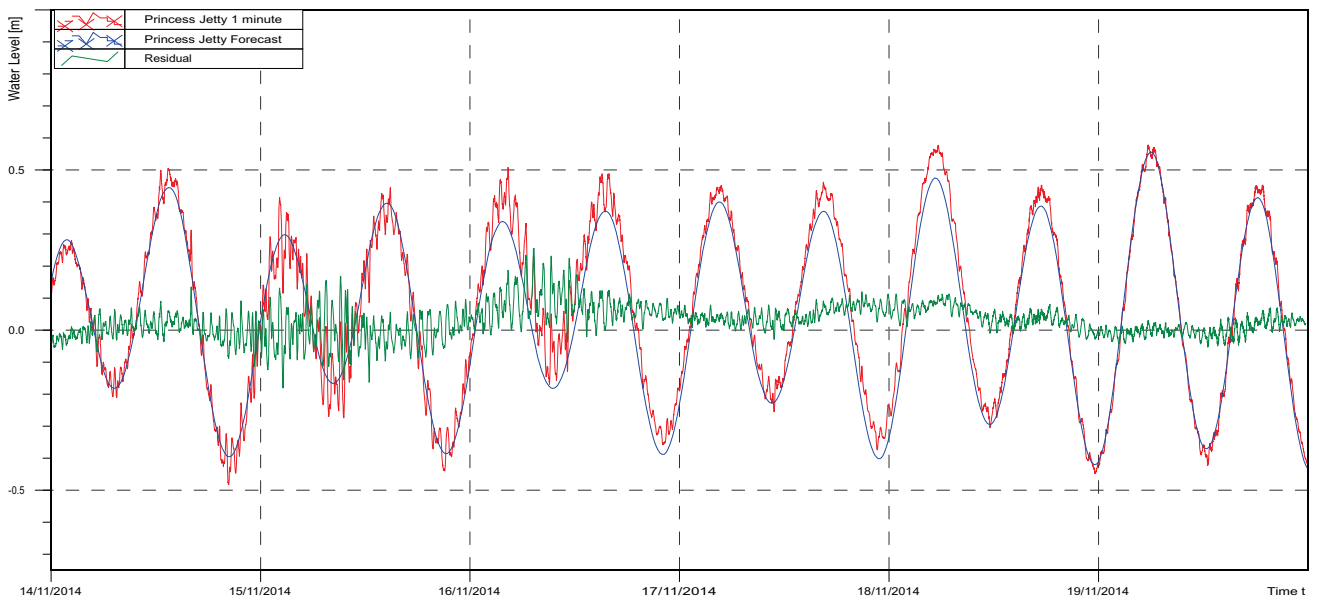
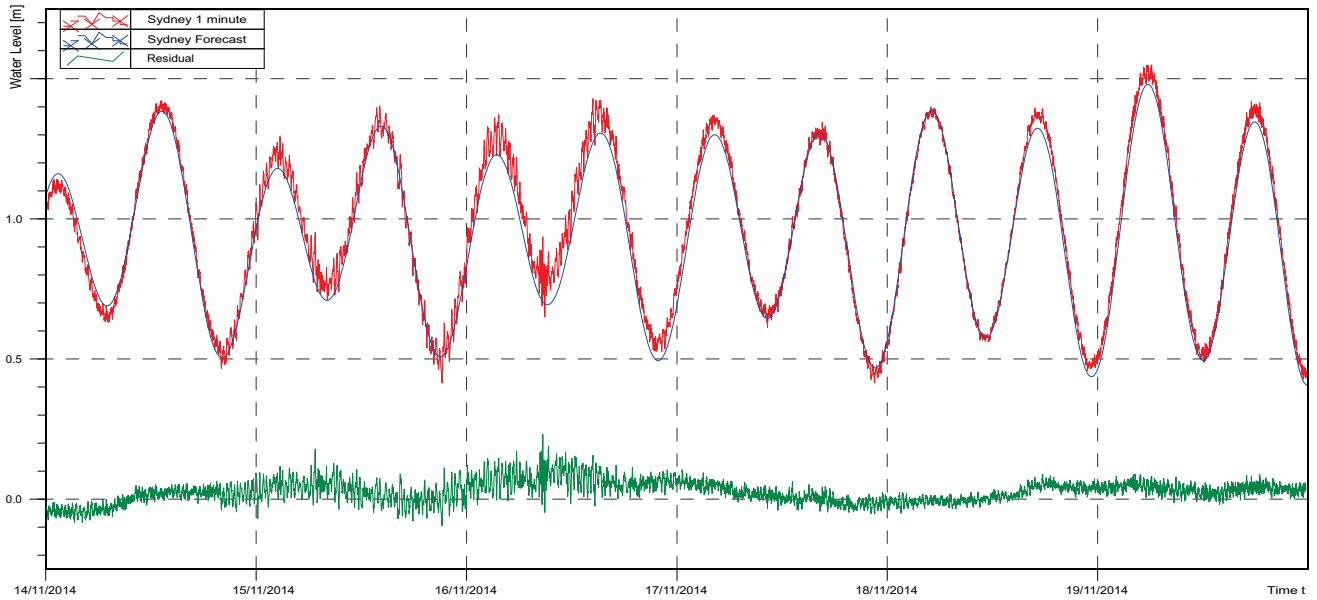


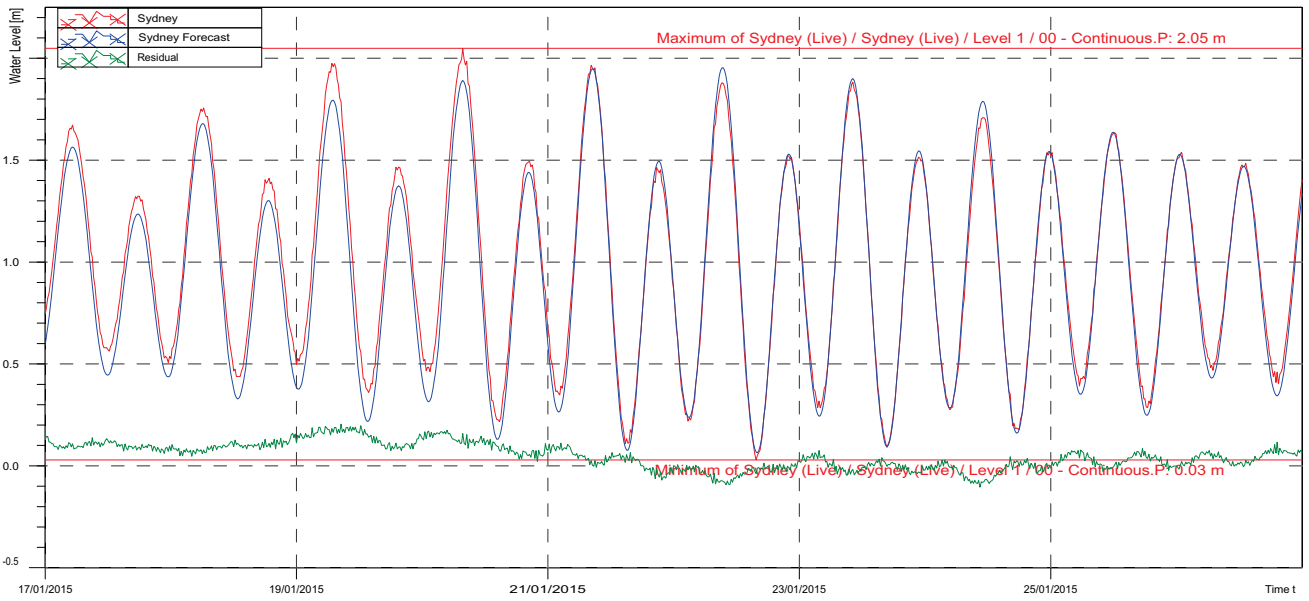
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----- DATA LOSS





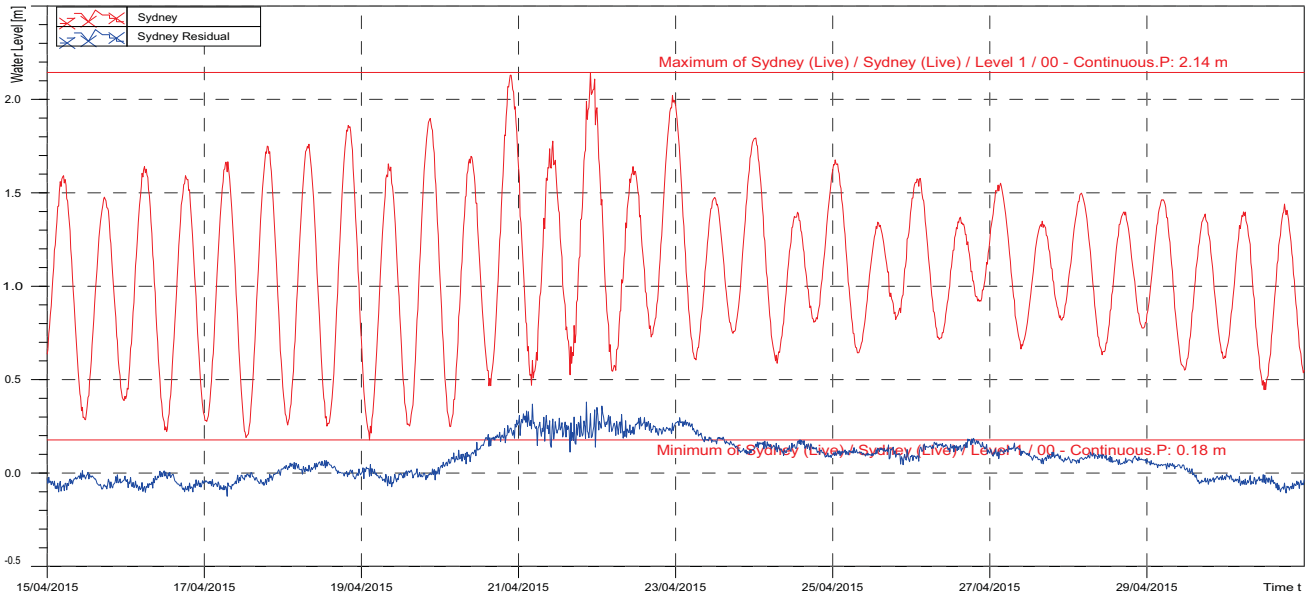


Fairlight Pool
Photo: R Jacobs



The Spit
Photo: R Jacobs





Dee Why Foreshore
Photo: E Couriel



Dee Why Pool
Photo: S Yeates

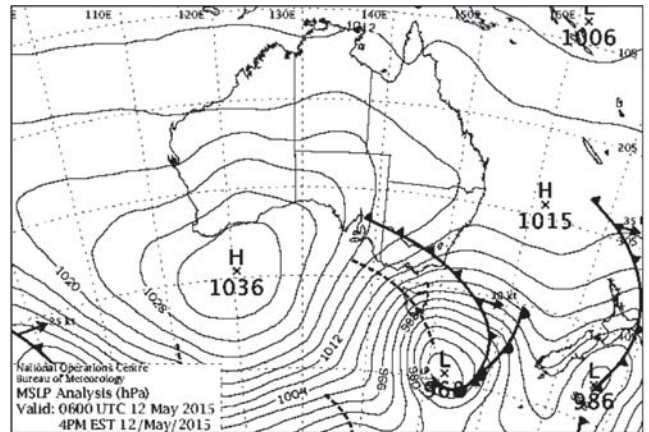
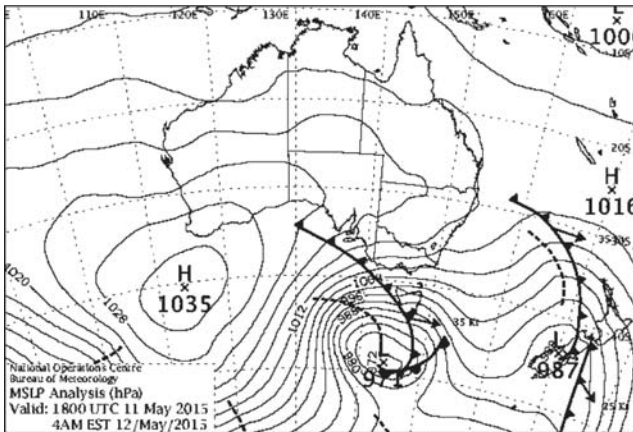
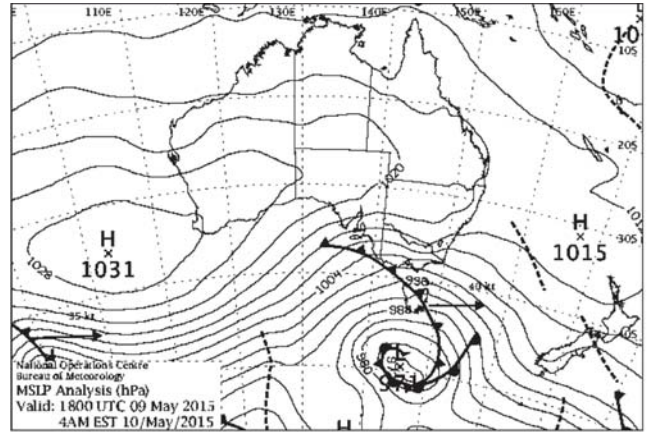
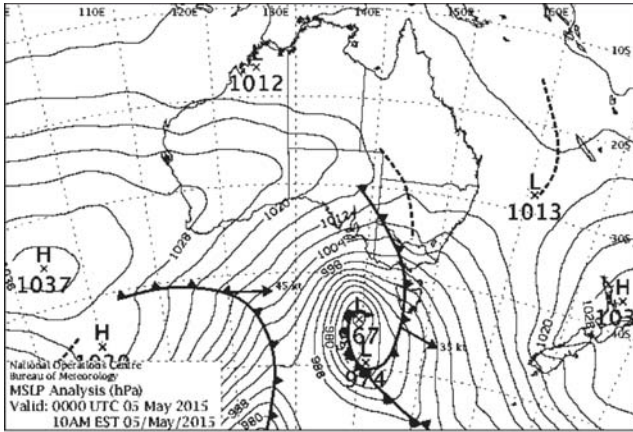
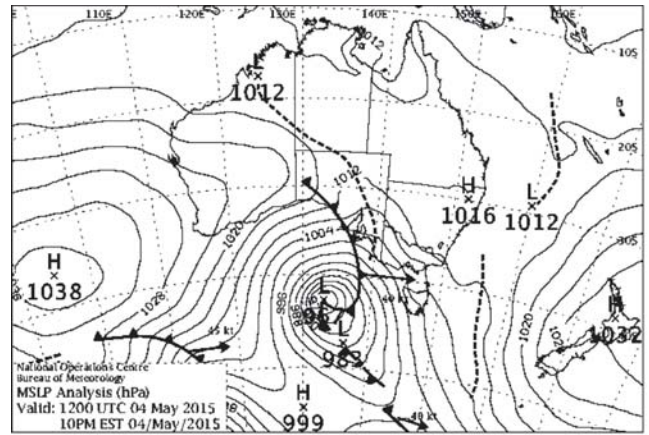
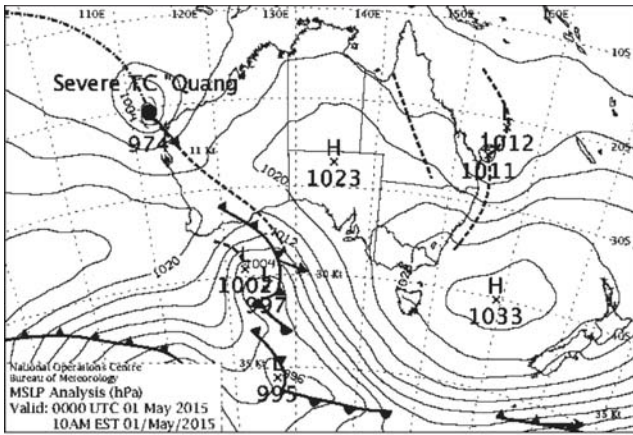


Collaroy Basin
Photo: R Jacobs



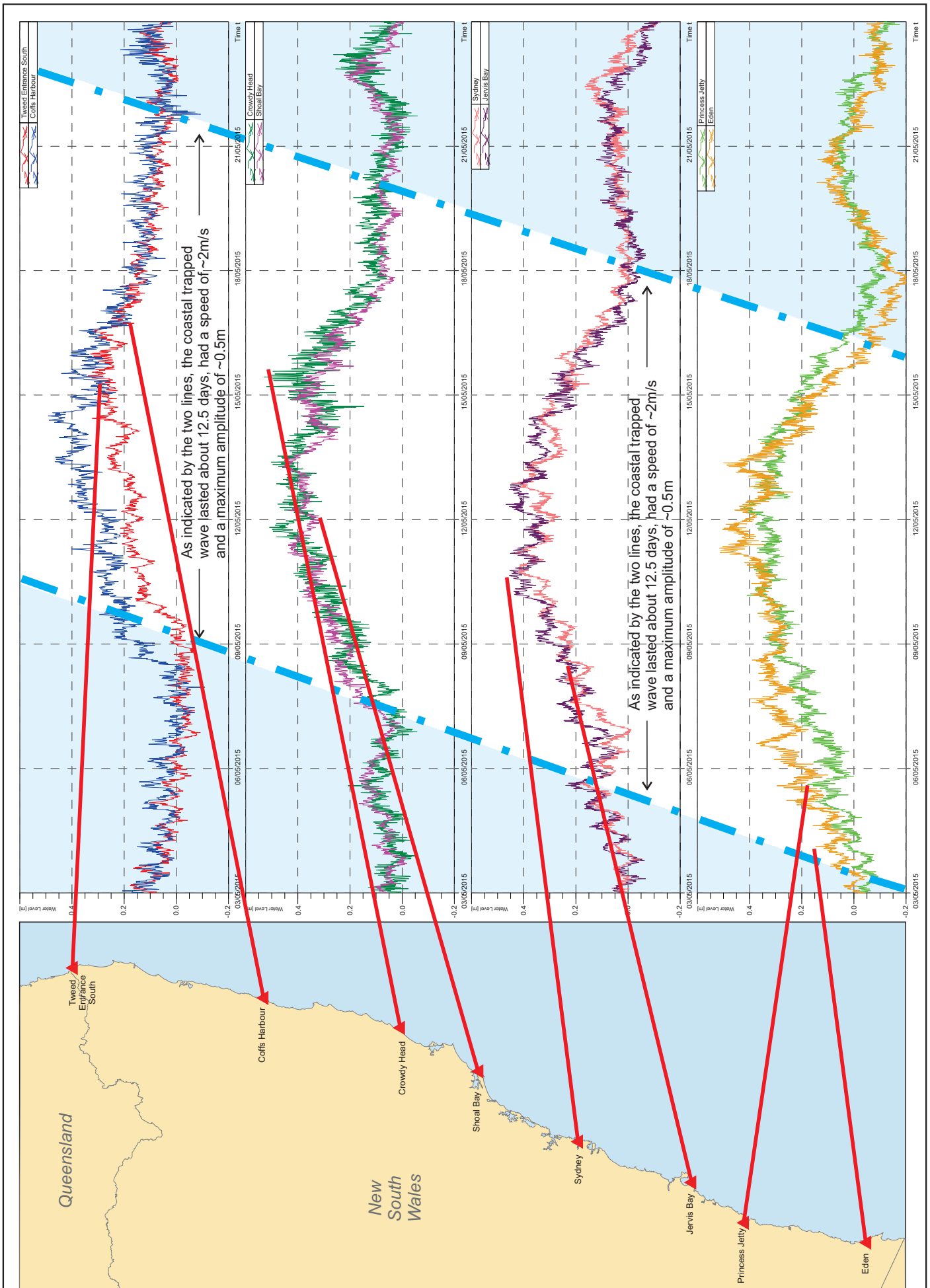
Dee Why Pool
Photo: S Yeates

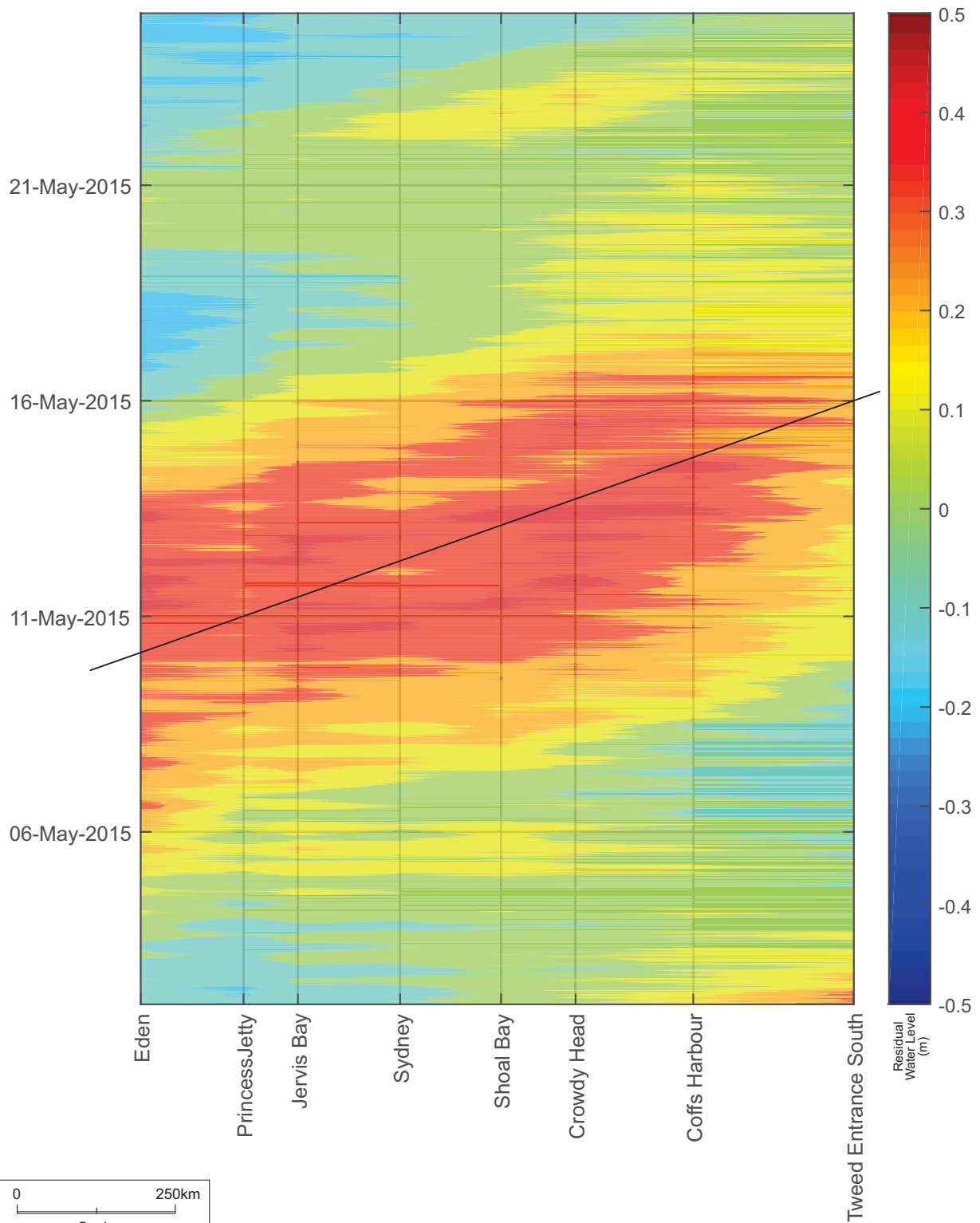


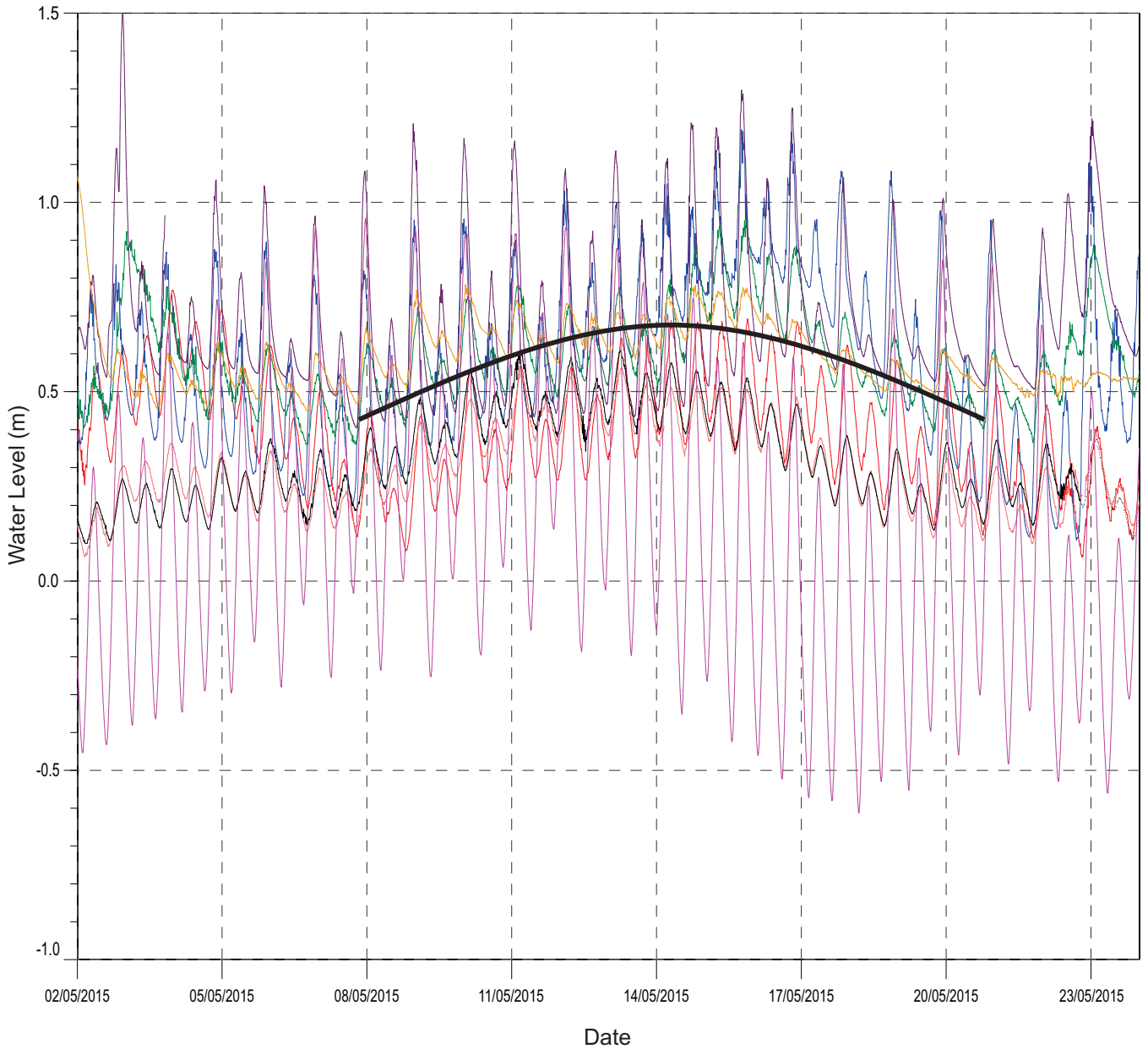


Weather Map images courtesy BoM © Commonwealth of Australia, Bureau of Meteorology









	Lake Wooloweyah
	Lake Cathie
	Lake Macquarie at Belmont
	Narrabeen Lagoon
	Manly Lagoon at Queenscliff
	Lake Illawarra at Koonawarra Bay
	Lake Tabourie
	Pambula Lake
	General Trend Line

Data from these lake and lagoon sites are not contained in this report but are presented in MHL 2015b





Lake Macquarie
Photo: D Hanslow



Lake Macquarie
Photo: D Hanslow



Manly Lagoon
Photo: R Jacobs

4. Program Developments 2014-2015

4.1 Classification of Sites

An increasing interest in sea level rise, tsunami and storm surge data has led to the adoption of a classification of each of the sites 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 – sites 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.
- 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 sites 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

Station	Classification	Classification Code
Forster	Onshore River Entrance	OR
Shoal Bay	Onshore Bay or Port	OB
Patonga	Onshore Bay or Port	OB
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 2014–2015. The following summarises the major changes:

- Tweed Entrance South, Port Macquarie, Lord Howe Island, Shoal Bay, Patonga, Princess Jetty and Eden sites primary sensor upgraded to record at 1-second intervals to onsite data storage card (see example data in [Figure D1](#)).
- Port Hacking (13/2/2015) and Tweed Heads (22/4/2015) sites were decommissioned and replaced with sites nearby at Bundeena (1/12/2014) and Tweed Entrance South (20/5/2014) respectively. Both sites were upgraded with radar sensors and provide shore-based sites with improved safety.
- For the first time a forecast was produced for each ocean tide site for the full data range of historical data and predicted to 2020. From these forecasts the Highest Astronomical Tide (HAT) and Lowest Astronomical Tide (LAT) were determined for the 1995 to 2014 epoch.
- A long-term forecast has been produced 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 HAT, LAT and MSL were calculated to local low water datums as well as to AHD and are shown in [Table 4.2](#).
- Monthly average data was submitted to the Permanent Service for Mean Sea Level (PSMSL) for publication on their website.

Table 4.2 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	0.93	-0.73	0.93	-0.73	1.66	0.04	0.04
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](#)

- A new Continuously Operating Reference Station (CORS) was installed at Eden by NSW Land and Property Information. The station became operational on 9/12/2014. This new CORS complements an existing network of similar stations in the southern coastal region of NSW which stream real-time GNSS observations and make possible efficient and consistent precise positioning capabilities across NSW (<http://corsnet.nsw.gov.au/>). The CORS station, as with all stations in the network, is continuously monitored for movement, horizontal or vertical. This monitoring and associated periodic levelling of the nearby tide gauge and its benchmarks will allow long-term assessment of ocean levels in the Eden area, while also taking into account any false trends or biases introduced by local land movement.

[Table 4.3](#) shows the status of the sites as of June 2015.

Table 4.3 MHL Tidal Logging and Sensing System Status 1/7/2014–30/6/2015

Station	Site Classification ¹	Primary Loggers ²	Secondary Loggers ²	Primary Sensors	Secondary Sensors	Station	
						Sampling	Logging
Tweed Heads ³	OR	CR800	-	Vented Pressure	Vented Pressure	120 samples averaged 1 minute either side of the quarter hour and	15 minutes on the quarter hour
Tweed Entrance South	OR	CR1000	-	Radar	Vented Pressure		
Brunswick Heads	OR	CR800	-	Vented Pressure	Vented Pressure		
Ballina Breakwall	OR	CR800	-	Vented Pressure	Vented Pressure		
Yamba	OR	CR800	-	Radar	Vented Pressure		1 minute on the minute
Coffs Harbour	OB	CR800	-	Radar	Vented Pressure		
Port Macquarie	OR	CR1000	-	Radar	Vented Pressure		
Crowdy Head	OB	CR800	-	Radar	Vented Pressure	60 samples averaged 30 seconds either side of each minute	
Forster	OR	CR800	-	Vented Pressure	Vented Pressure		
Shoal Bay	OB	CR1000	-	Radar	n/a		
Patonga	OB	CR1000	-	Radar	Vented Pressure		
Sydney	OB	CR800	-	Radar	n/a		
Sydney Backup	OB	CR800	-	Vented Pressure	Vented Pressure		
Port Hacking ⁴	OB	CR800	MetOcean	Electromagnetic	Vented Pressure		7 sites logging at 1 second to onsite data
Bundeena	OB	CR800	-	Radar	Vented Pressure		storage card
Crookhaven Heads	OR	CR800	-	Vented Pressure	Vented Pressure		(Tweed Ent South, Port Macquarie, Lord Howe Shoal
Jervis Bay	OB	CR800	-	Radar	Vented Pressure		Bay, Patonga, Sydney, Princess Jetty and Eden)
Ulladulla	OB	CR800	-	Vented Pressure	Vented Pressure		
Princess Jetty	OR	CR1000	-	Radar	Vented Pressure		
Bermagui	OR	CR800	-	Vented Pressure	Vented Pressure		
Eden	OB	CR1000n	-	Radar	Vented Pressure		
Norfolk Island	OO	CR800	-	Floatwell	Vented Pressure		
Lord Howe Island	OO	CR1000	-	Radar	Vented Pressure		
Tweed Offshore	O	RBR Virtuoso	WLR7	Submersible	Aanderaa Submersible Pressure (only at 2 of the 4 sites per deployment year)		RBR 5 minutes
Port Macquarie Offshore	O	RBR Virtuoso	WLR7	Paroscientific Pressure Sensor and RBR Logger		Integrated over 40 seconds	Aanderaa 60 minutes
Shoalhaven Offshore	O	RBR Virtuoso	WLR7				
Batemans Bay Offshore	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), MetOcean = PC logging via MHL Waverider buoy software.

³ Site decommissioned 22 April 2015

⁴ Site decommissioned 13 February 2015

4.3 Program Plans 2015–2016

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 2015–2016 program upgrades include:

- high frequency logging (1 second) upgrades at Jervis Bay and Eden
- upgrade communications to enable networked IP data transfers rather than telemetry at selected sites, commencing at Eden to provide Eden Pilot with access to the latest 5 minutes of data
- decommission the Norfolk Island gauge, due to its location being duplicated by the BoM tsunami gauge.

5. References

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Appendix A
Annual Data Site Summaries



Tweed Heads



Tweed Entrance South



0 1km
 Scale 1:25 000
 Map courtesy of
 Department of Lands 2006



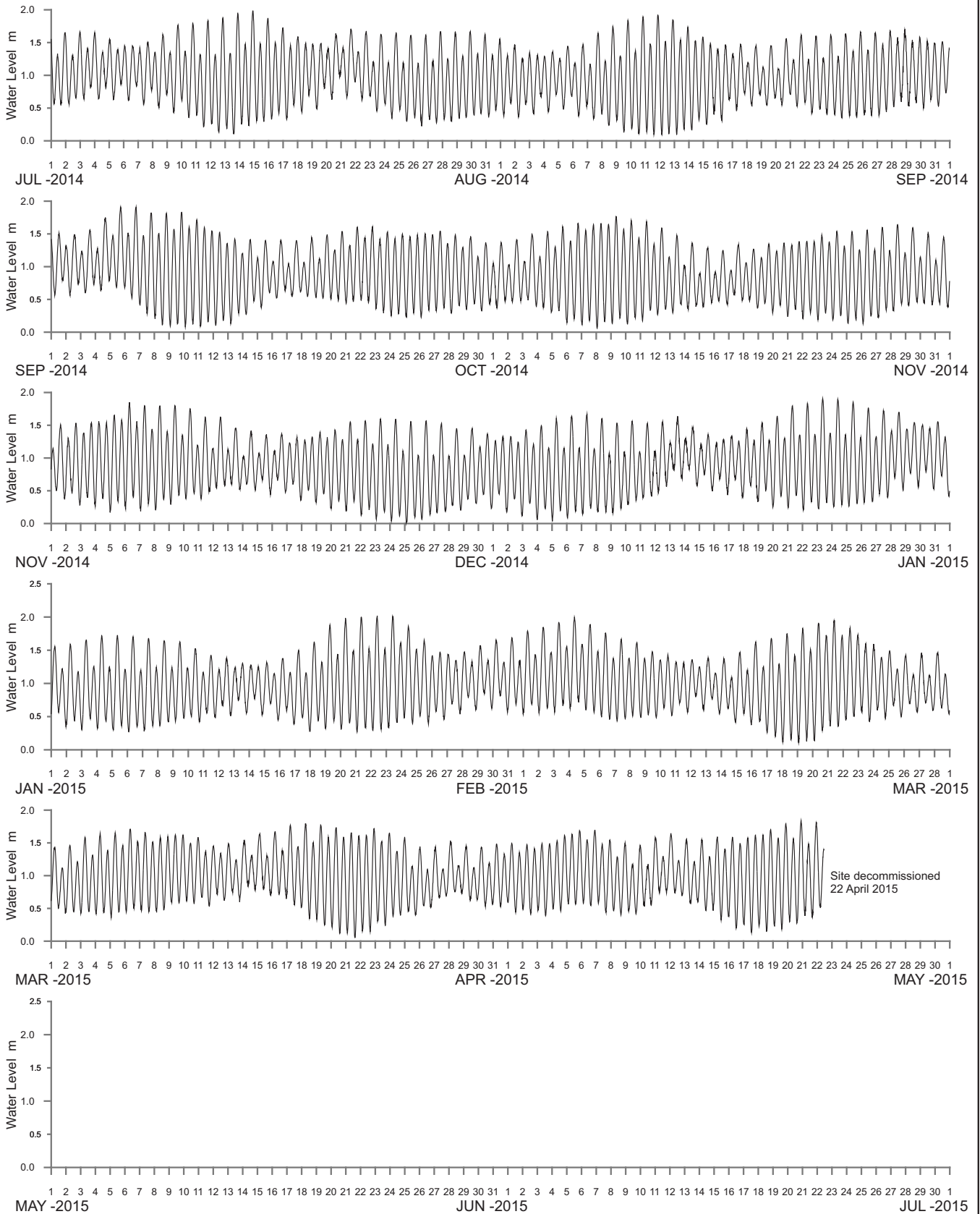
Public Works
 Manly Hydraulics Laboratory

**TWEED HEADS
 STATION LOCATION**

MHL
 Report 2384

Figure
 A1

DRAWING 2384-A1.cdr



WATER LEVEL REFERENCED TO TWEED RIVER HYDRO DATUM

----- DATA LOSS



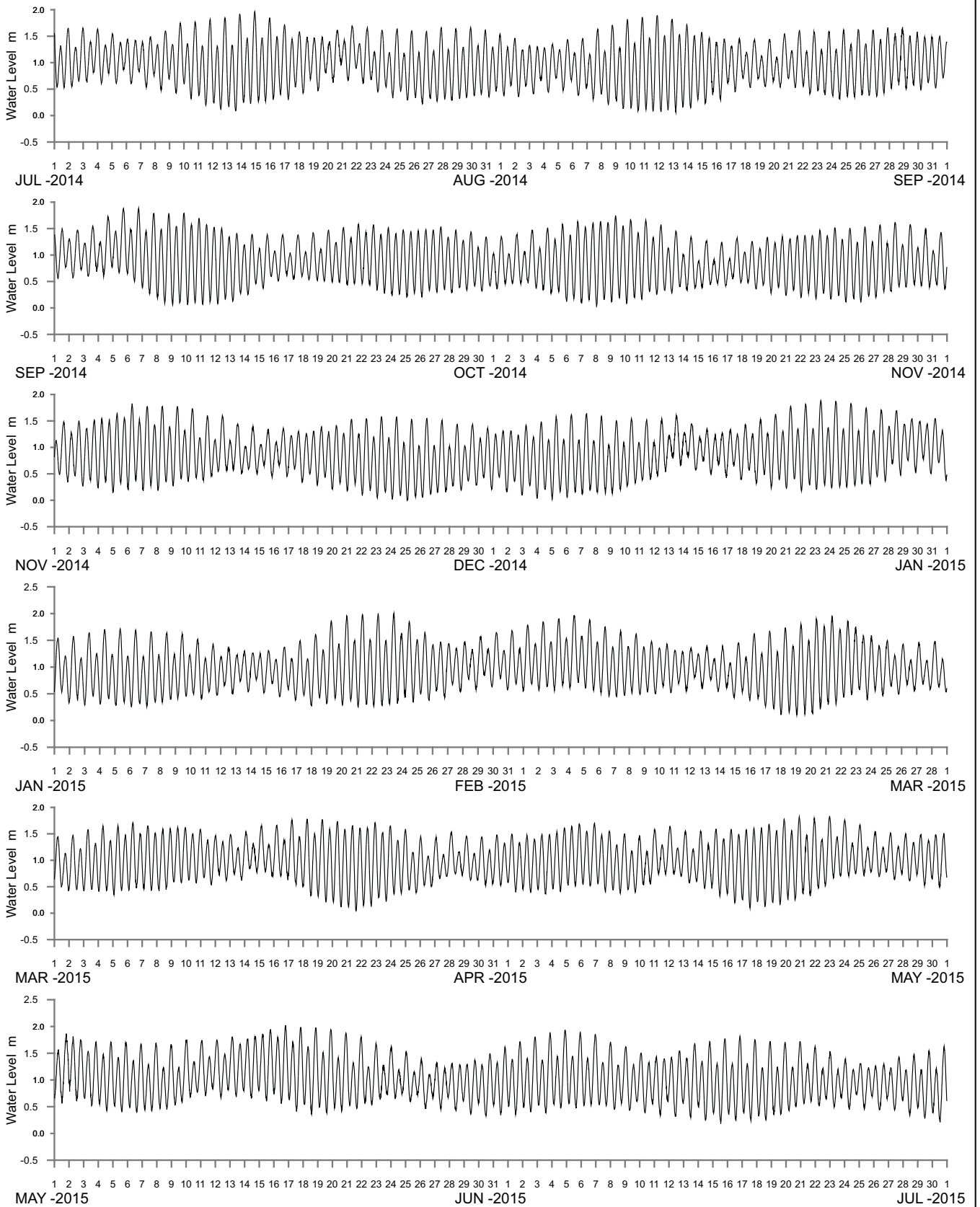
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TWEED HEADS DATA SUMMARY
2014–2015

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Figure
A2

DRAWING 2384-A1.cdr



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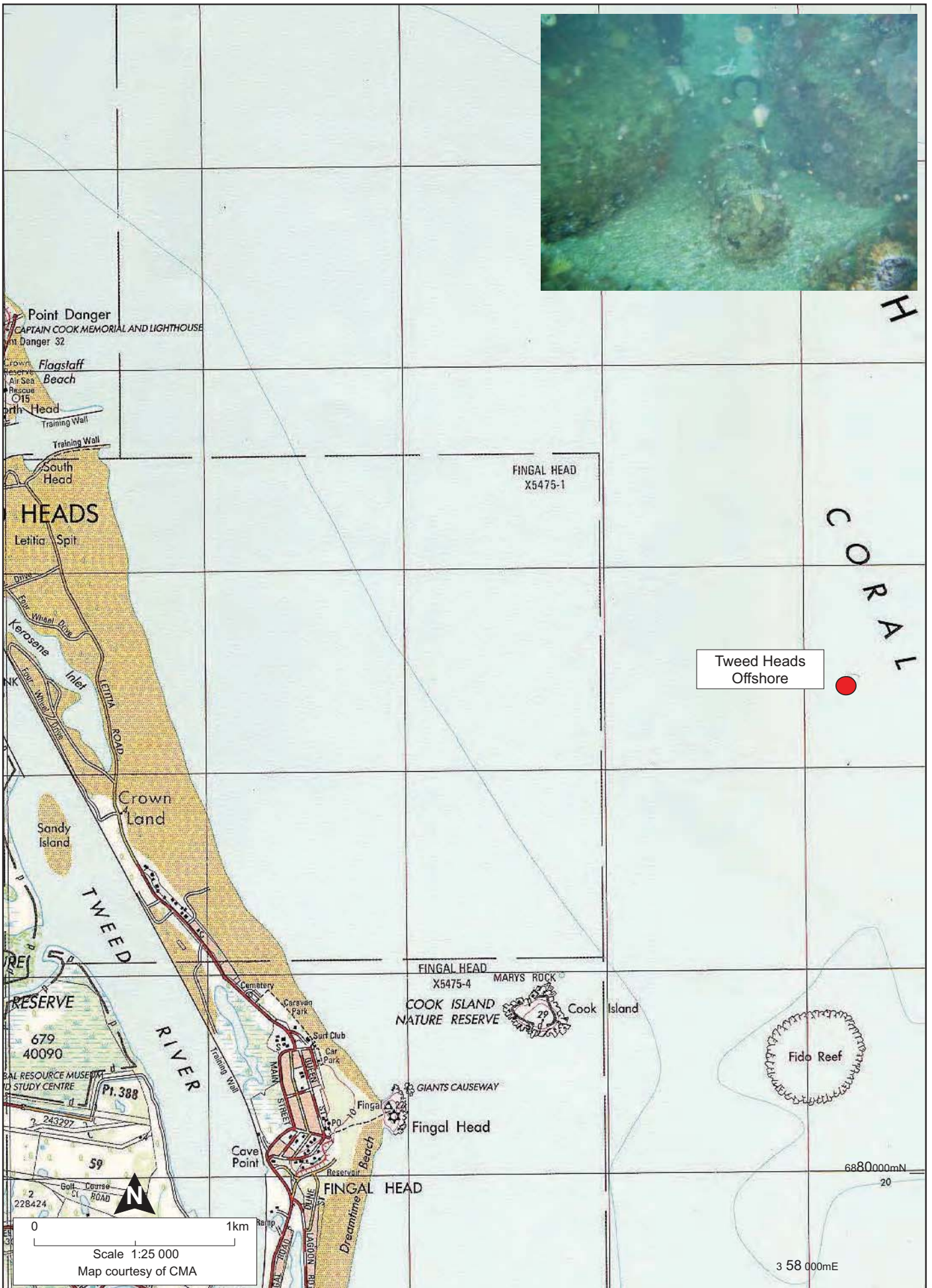
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TWEED ENTRANCE SOUTH DATA SUMMARY
2014–2015

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Figure
A3

DRAWING 2384-A1.cdr



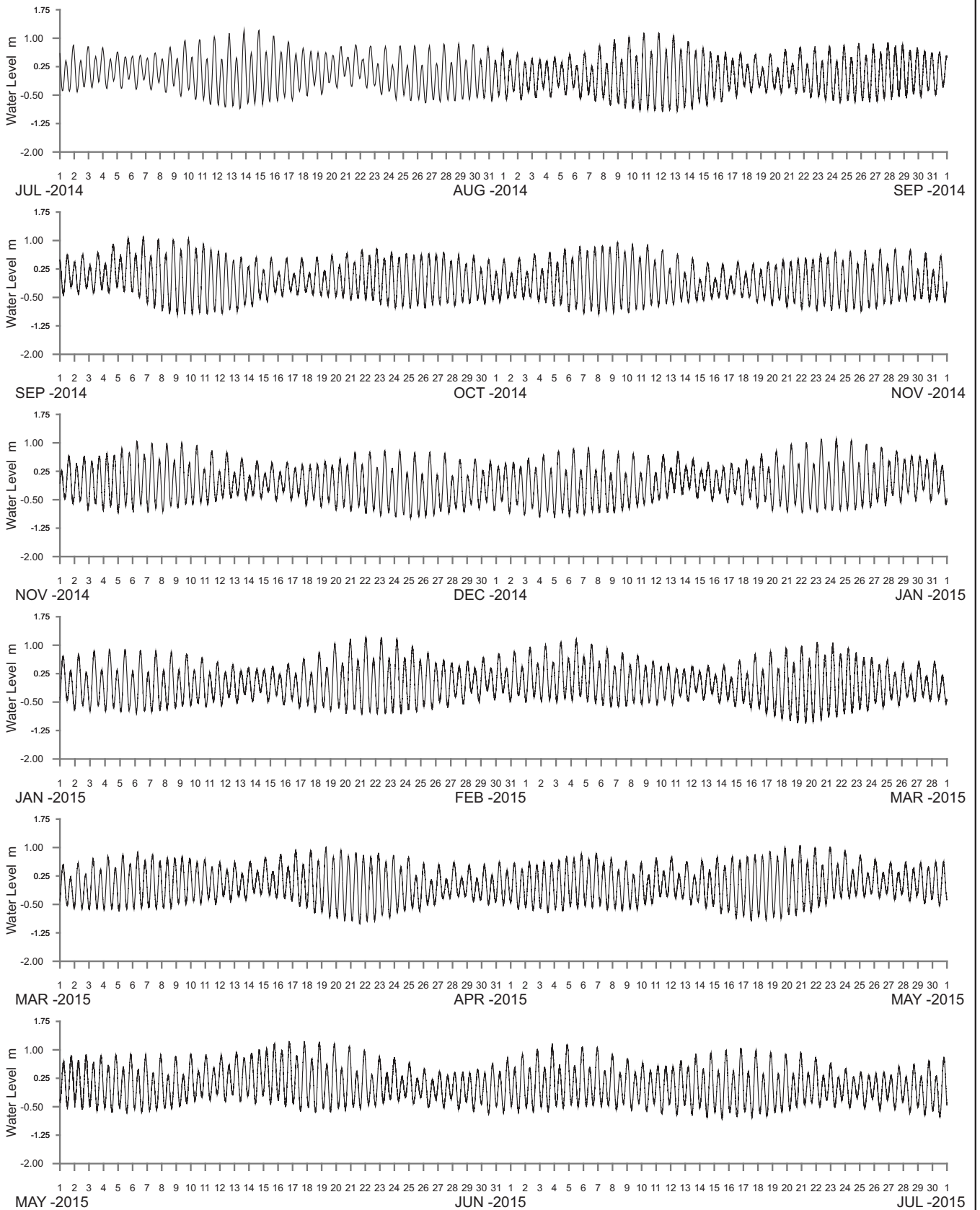
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**TWEED HEADS OFFSHORE
TIDE GAUGE LOCATION**

MHL
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Figure
A4

DRAWING 2384-A4.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS



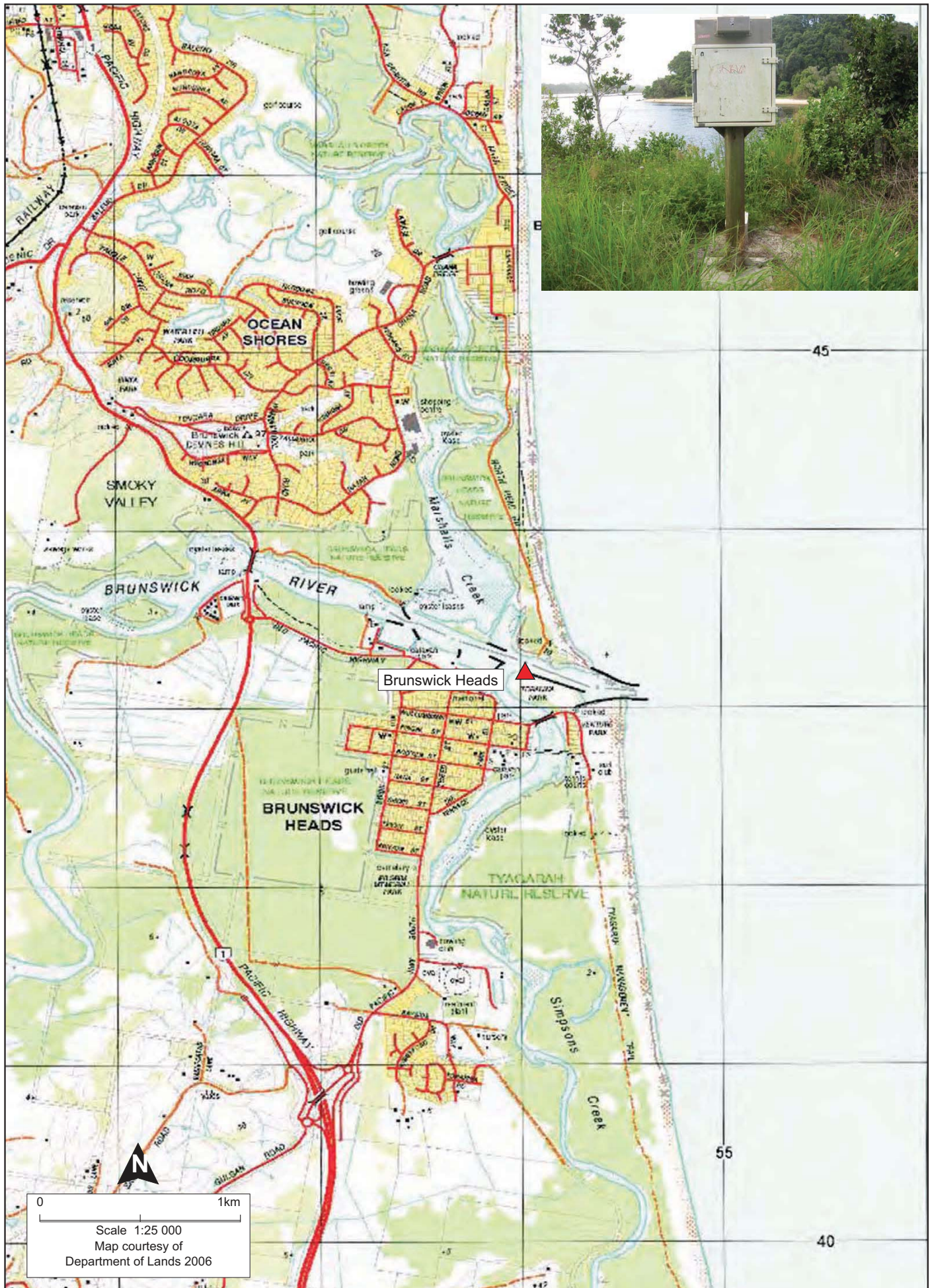
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Manly Hydraulics Laboratory

TWEED HEADS OFFSHORE DATA SUMMARY
2014–2015

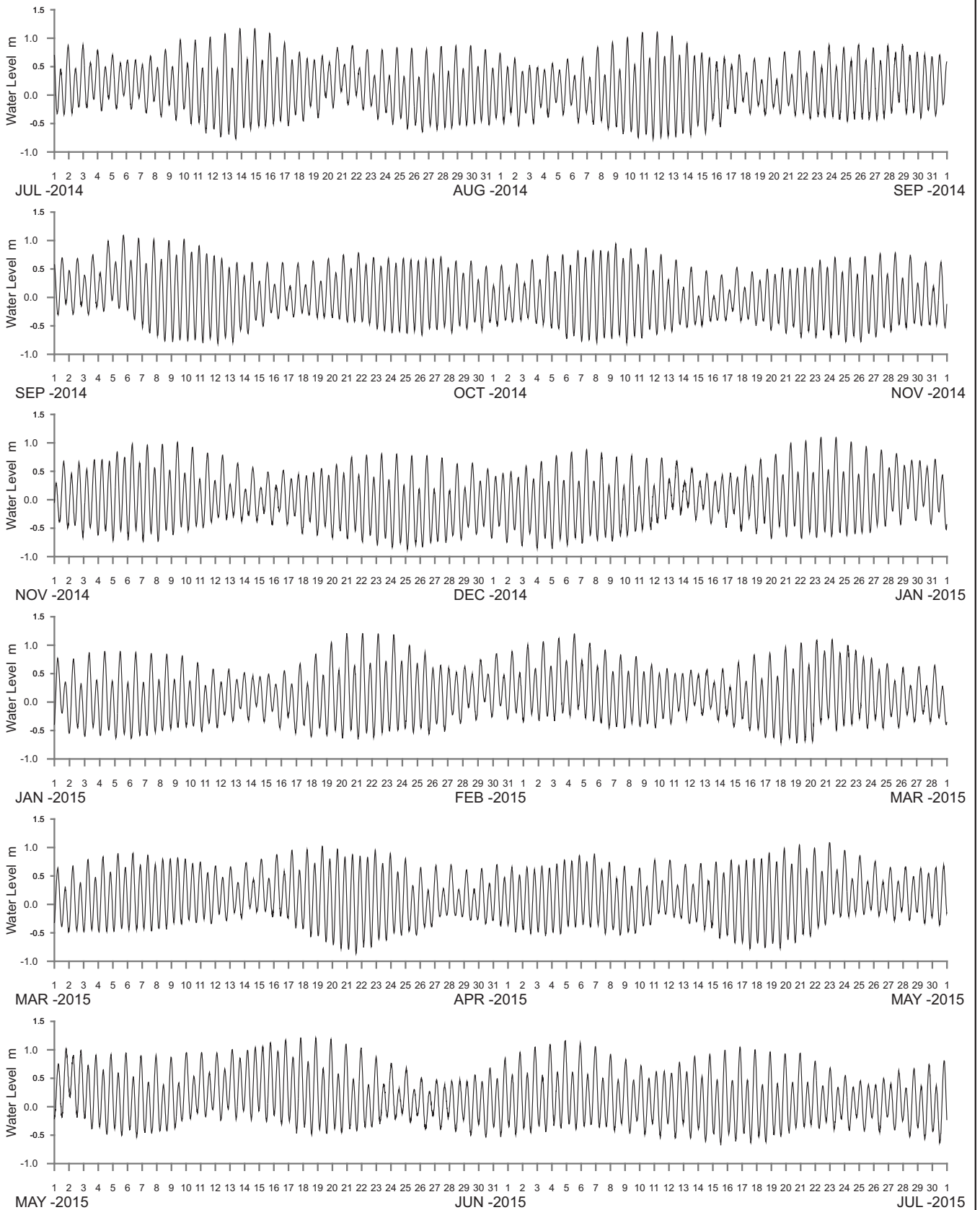
MHL
Report 2384

Figure
A5

DRAWING 2384-A5.cdr



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 Scale 1:25 000
 Map courtesy of
 Department of Lands 2006



WATER LEVEL REFERENCED TO BRUNSWICK RIVER FLOOD MITIGATION DATUM

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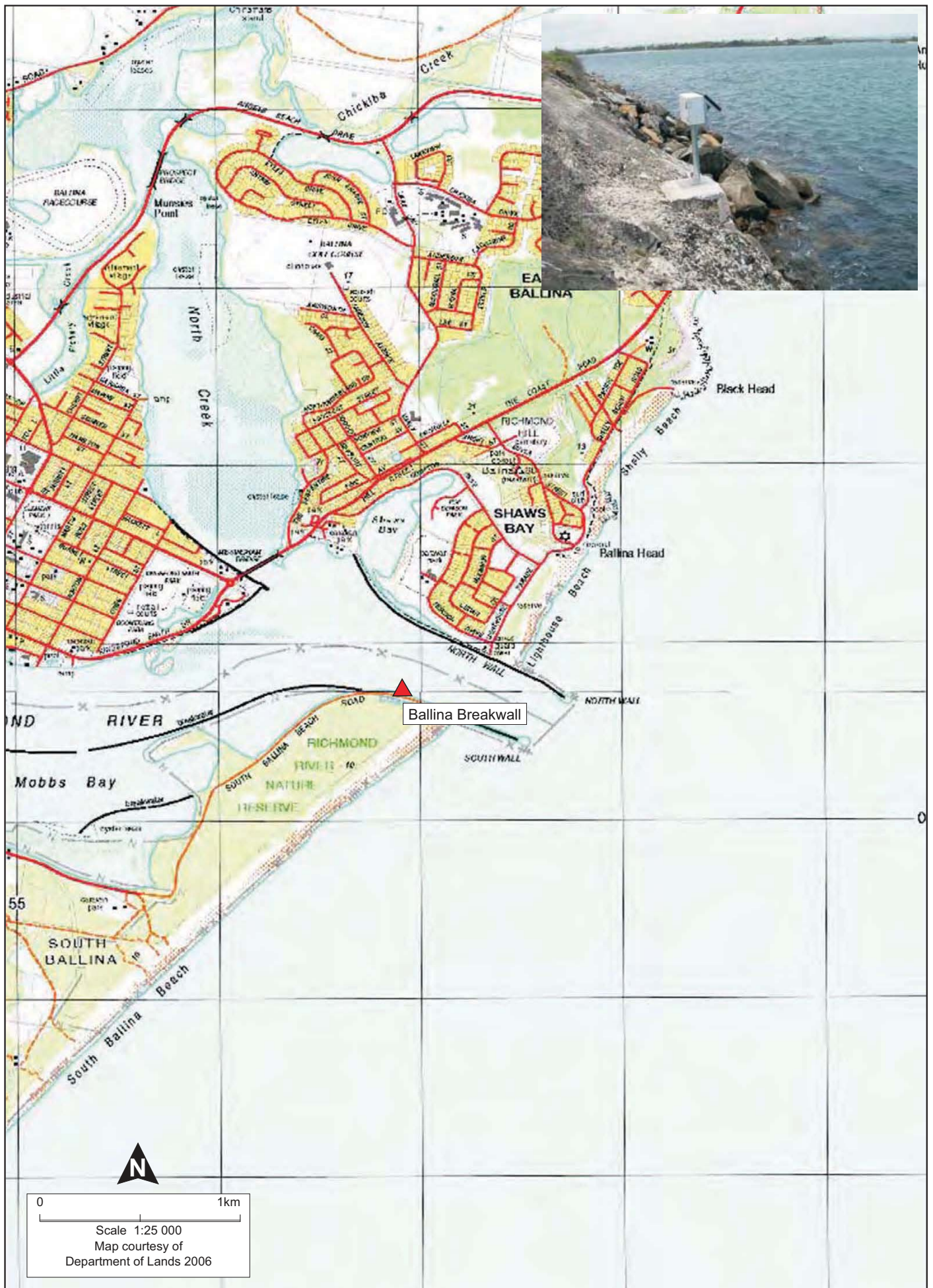
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BRUNSWICK HEADS DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A7

DRAWING 2384-A7.cdr



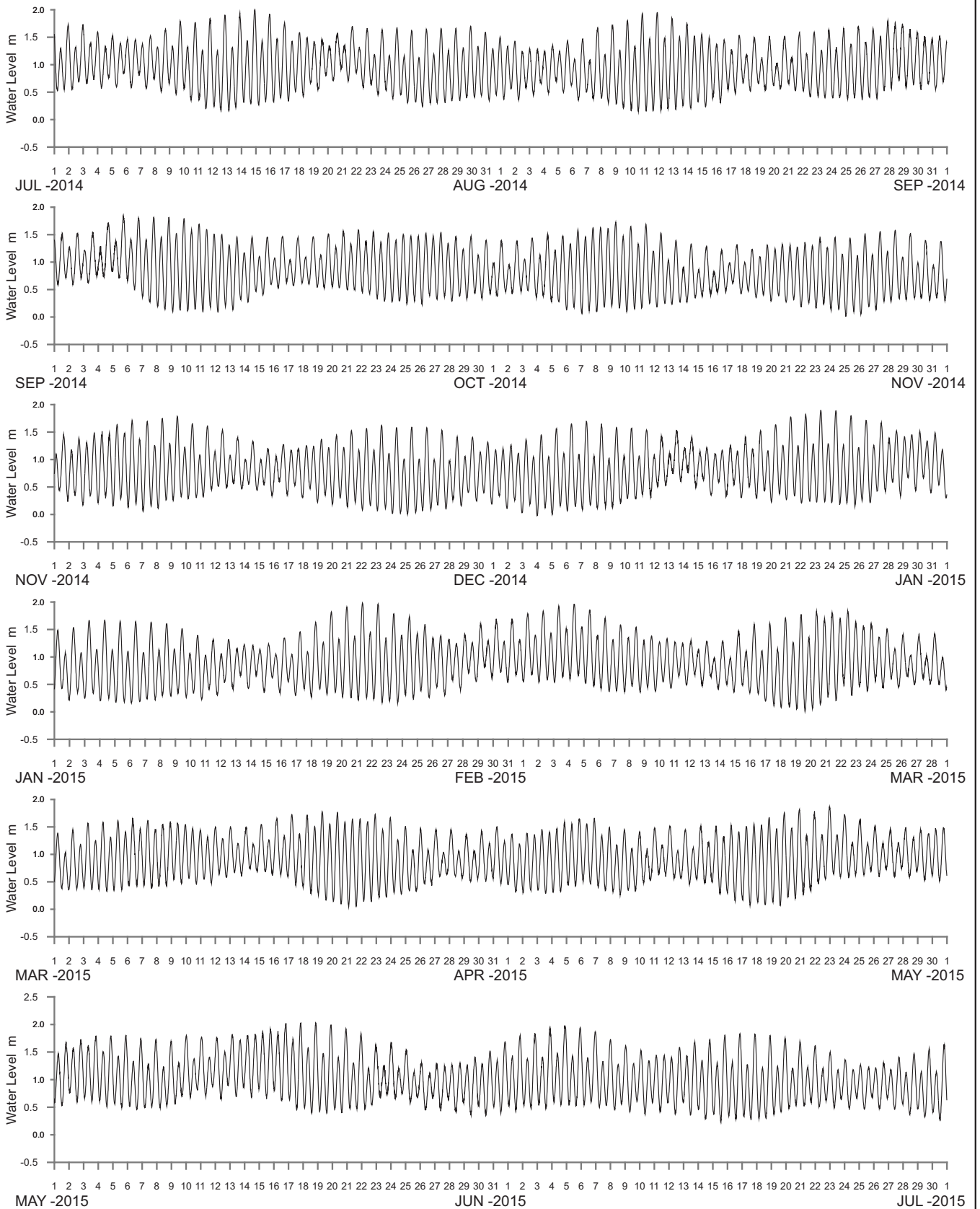
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BALLINA BREAKWALL STATION LOCATION

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Figure
A8

DRAWING 2384-A8.cdr



WATER LEVEL REFERENCED TO RICHMOND RIVER VALLEY DATUM

----- DATA LOSS



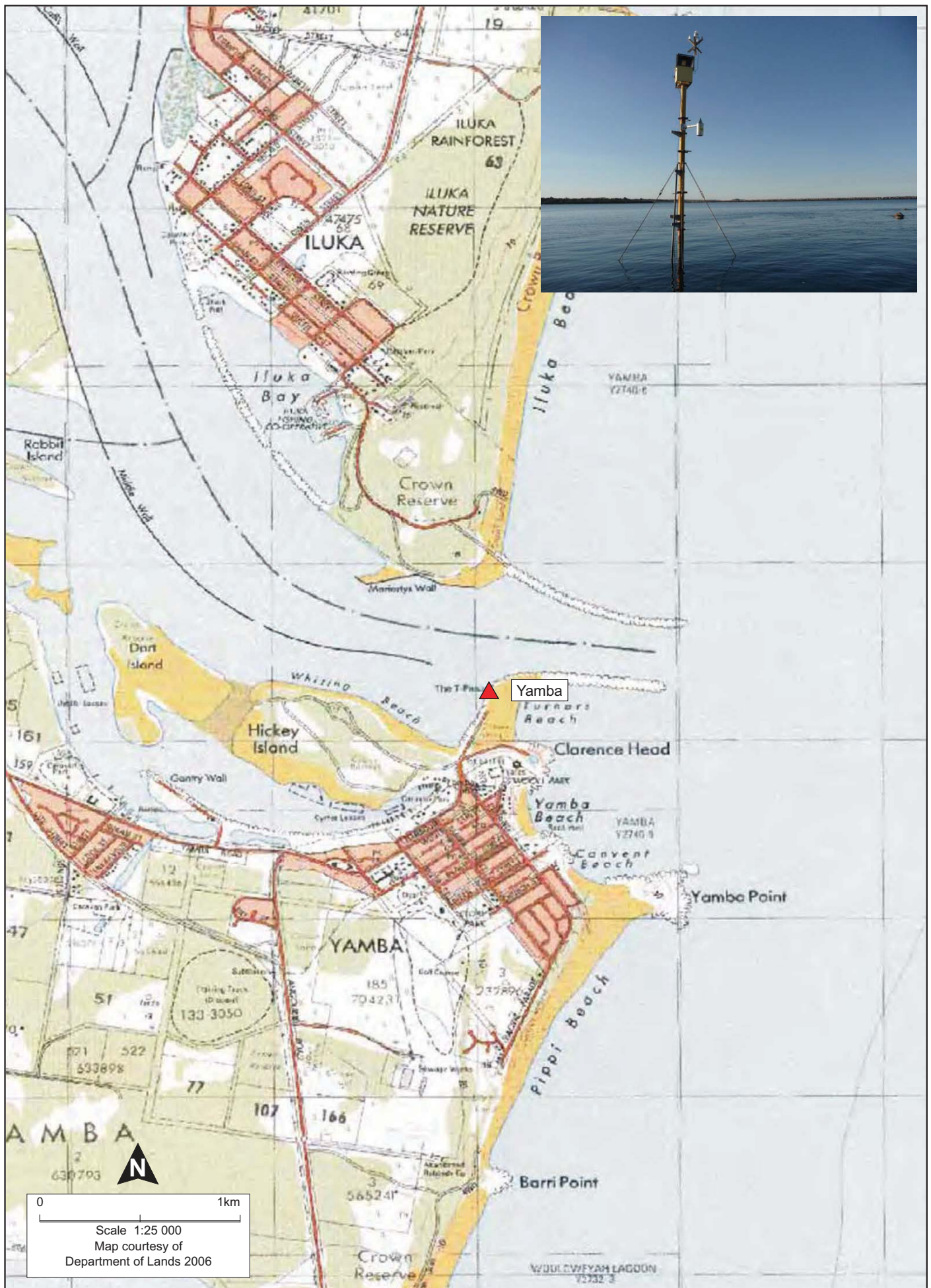
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Manly Hydraulics Laboratory

BALLINA BREAKWALL DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A9

DRAWING 2384-A8.cdr



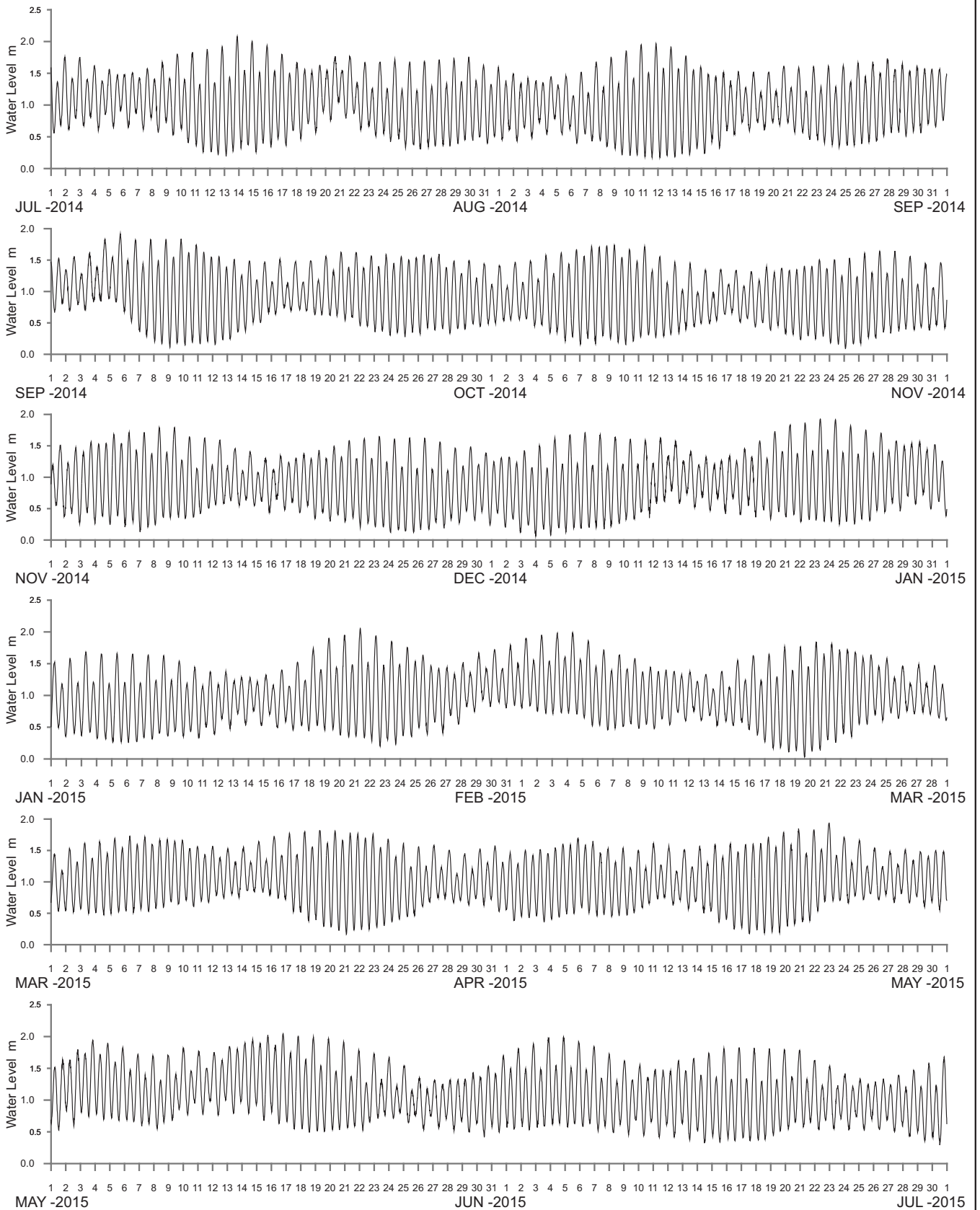
Public Works
Manly Hydraulics Laboratory

YAMBA STATION LOCATION

MHL
Report 2384

Figure
A10

DRAWING 2384-A10.cdr



WATER LEVEL REFERENCED TO ILUKA PORT DATUM

----- DATA LOSS



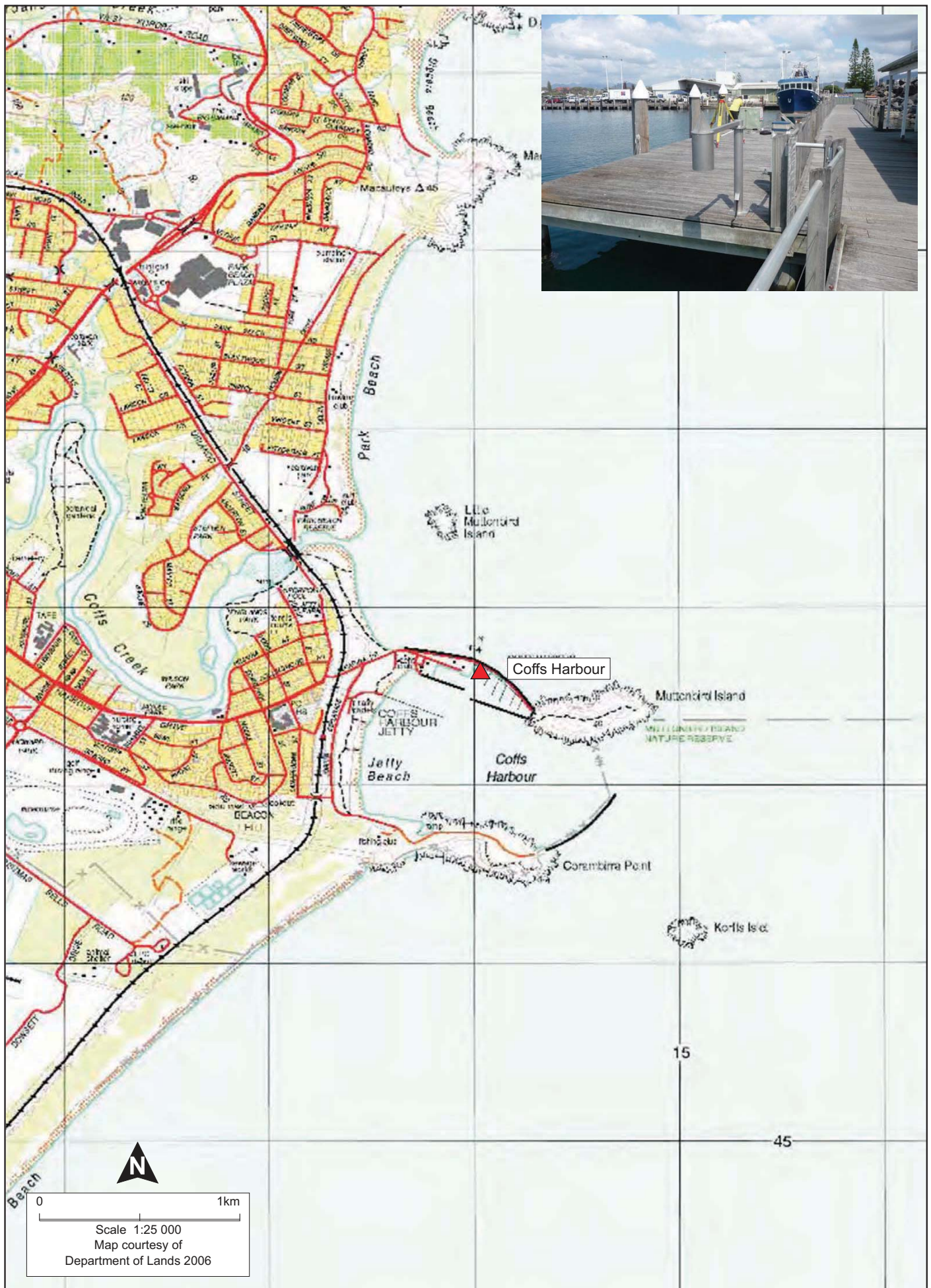
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YAMBA DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A11

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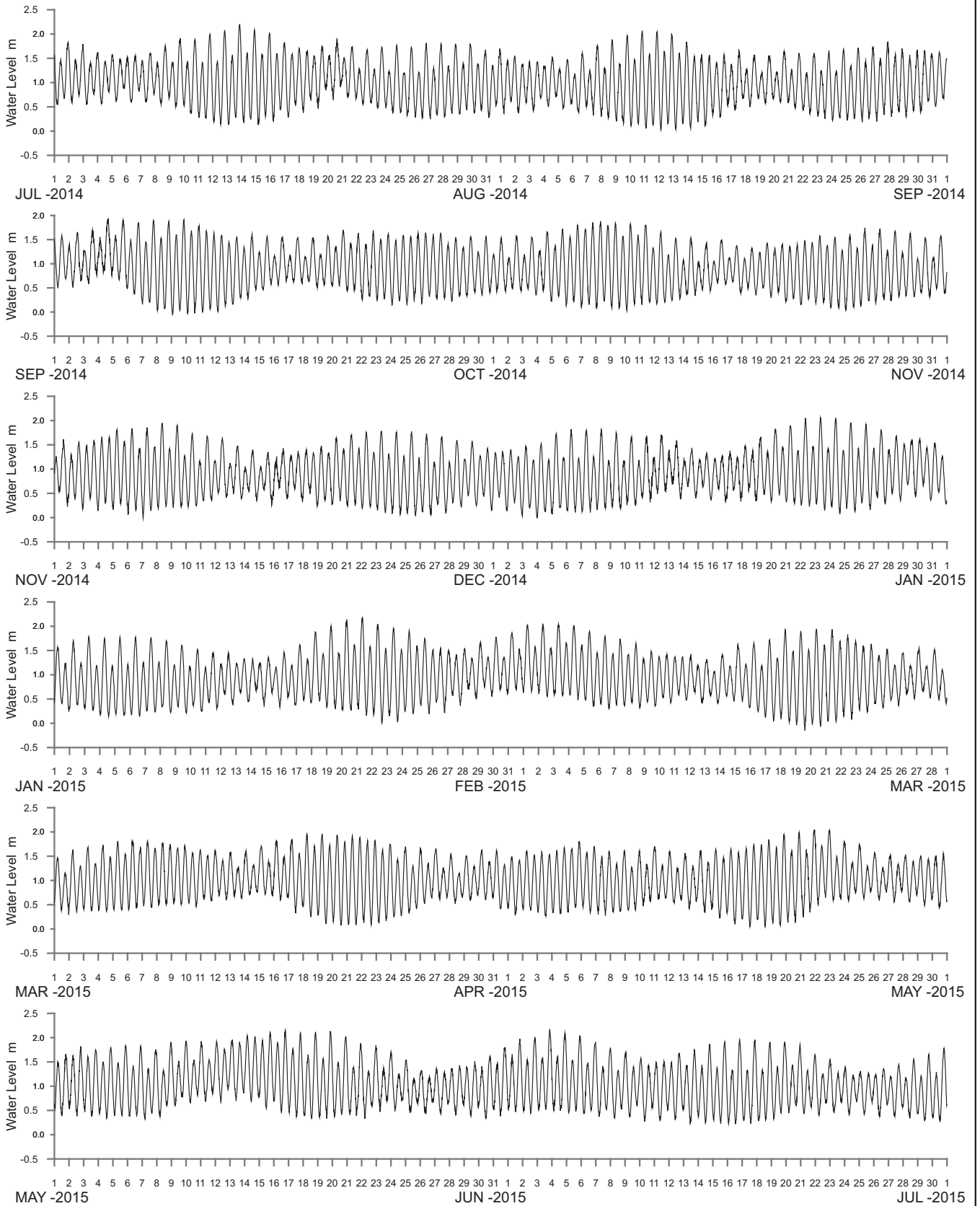
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COFFS HARBOUR STATION LOCATION

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Report 2384

Figure
A12

DRAWING 2384-A12.cdr



WATER LEVEL REFERENCED TO COFFS PORT DATUM

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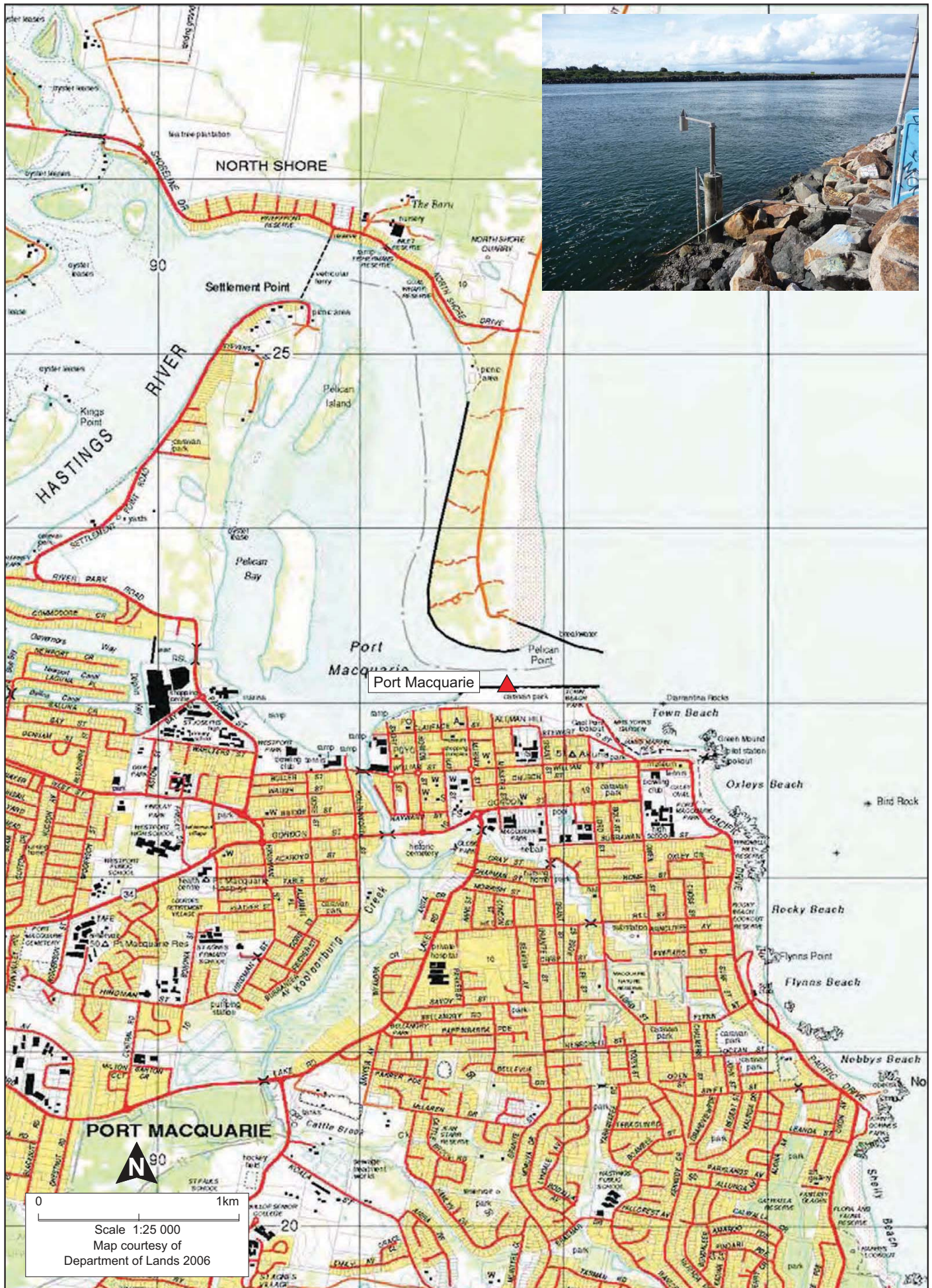
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COFFS HARBOUR DATA SUMMARY
2014–2015

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Report 2384

Figure
A13

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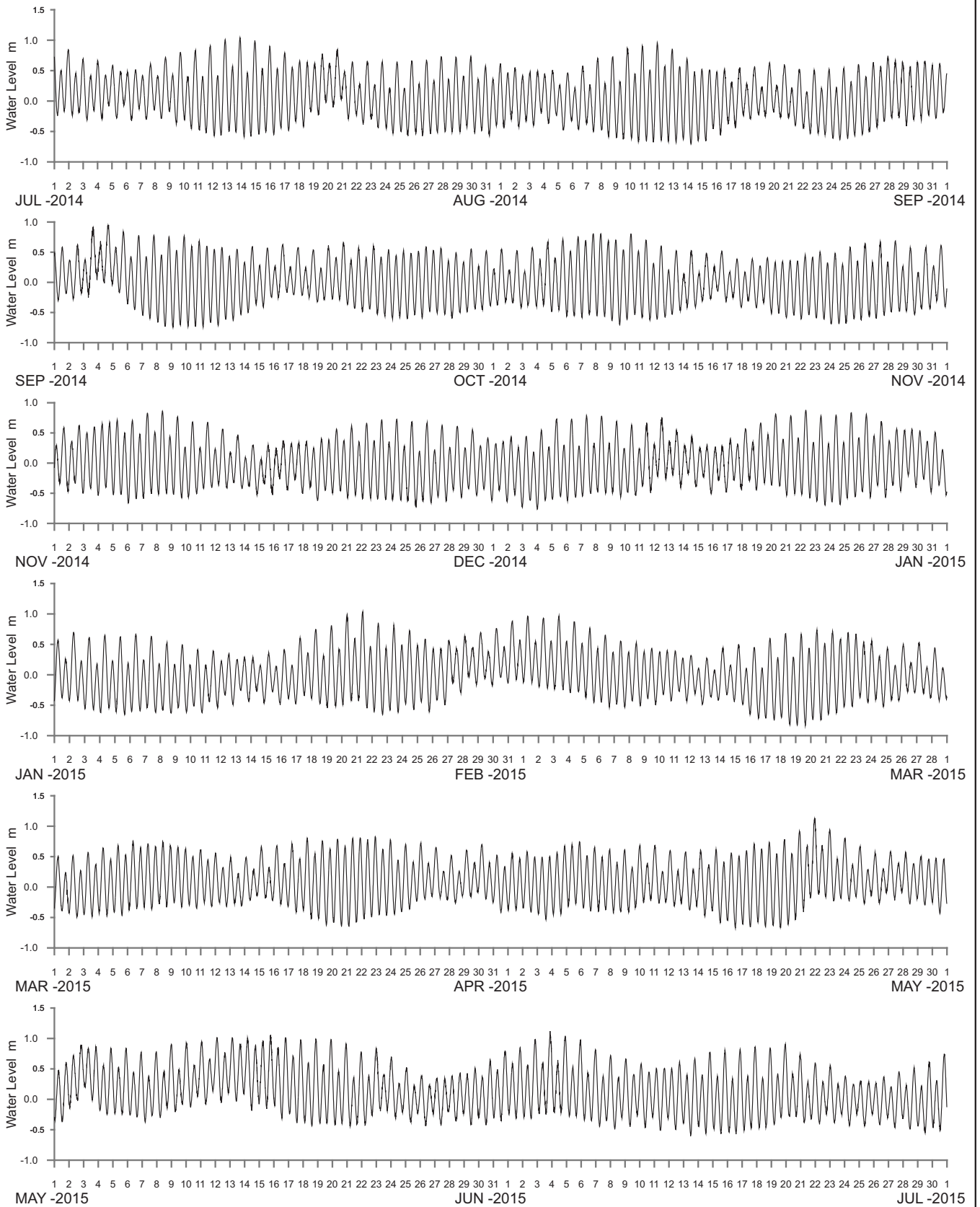
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**PORT MACQUARIE
STATION LOCATION**

MHL
Report 2384

Figure
A14

DRAWING 2384-A14.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



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Manly Hydraulics Laboratory

PORT MACQUARIE DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A15

DRAWING 2384-A14.cdr



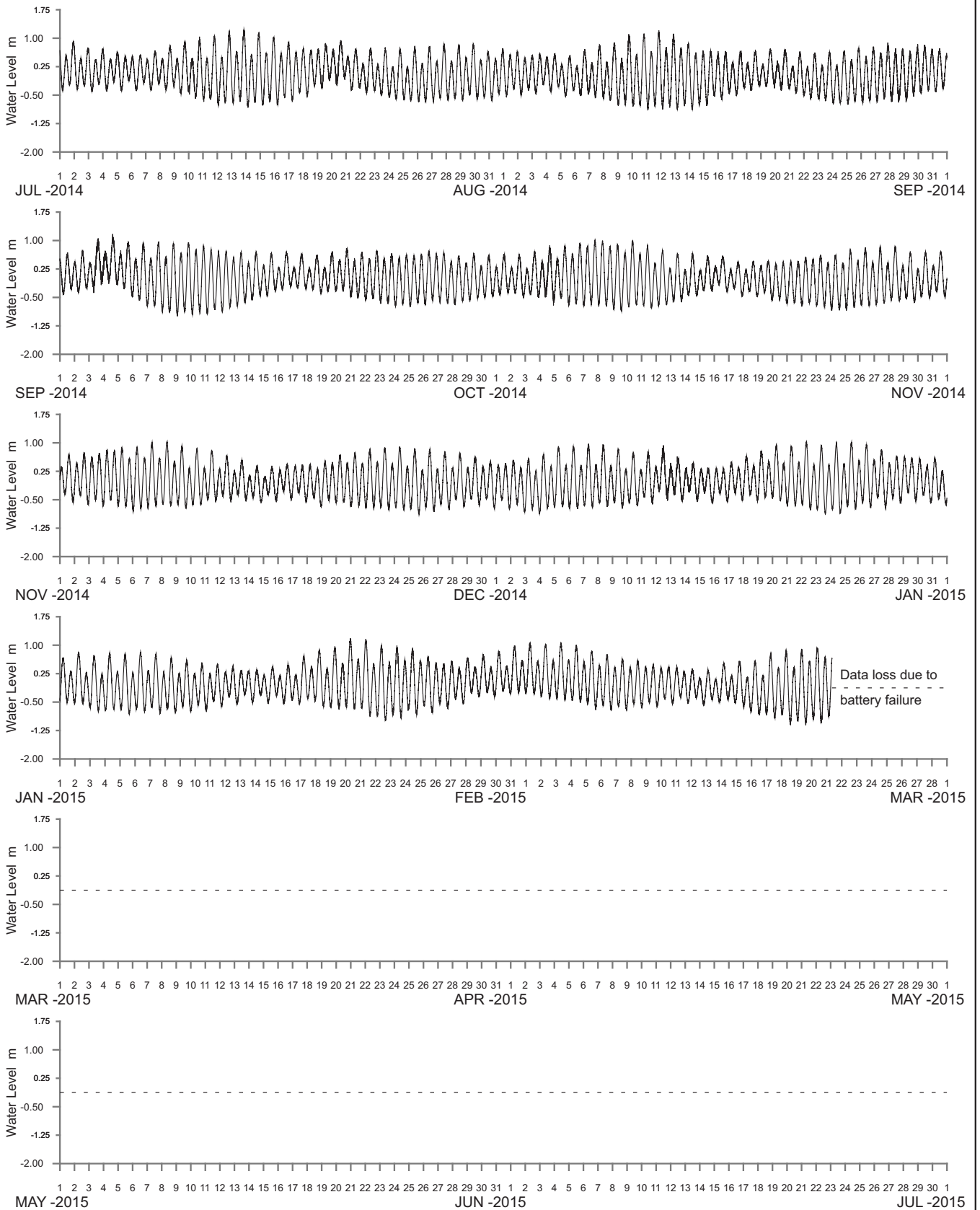
Public Works
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**PORT MACQUARIE OFFSHORE
TIDE GAUGE LOCATION**

MHL
Report 2384

Figure
A16

DRAWING 2384-A16.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS



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PORT MACQUARIE OFFSHORE DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A17

DRAWING 2384-A14.cdr



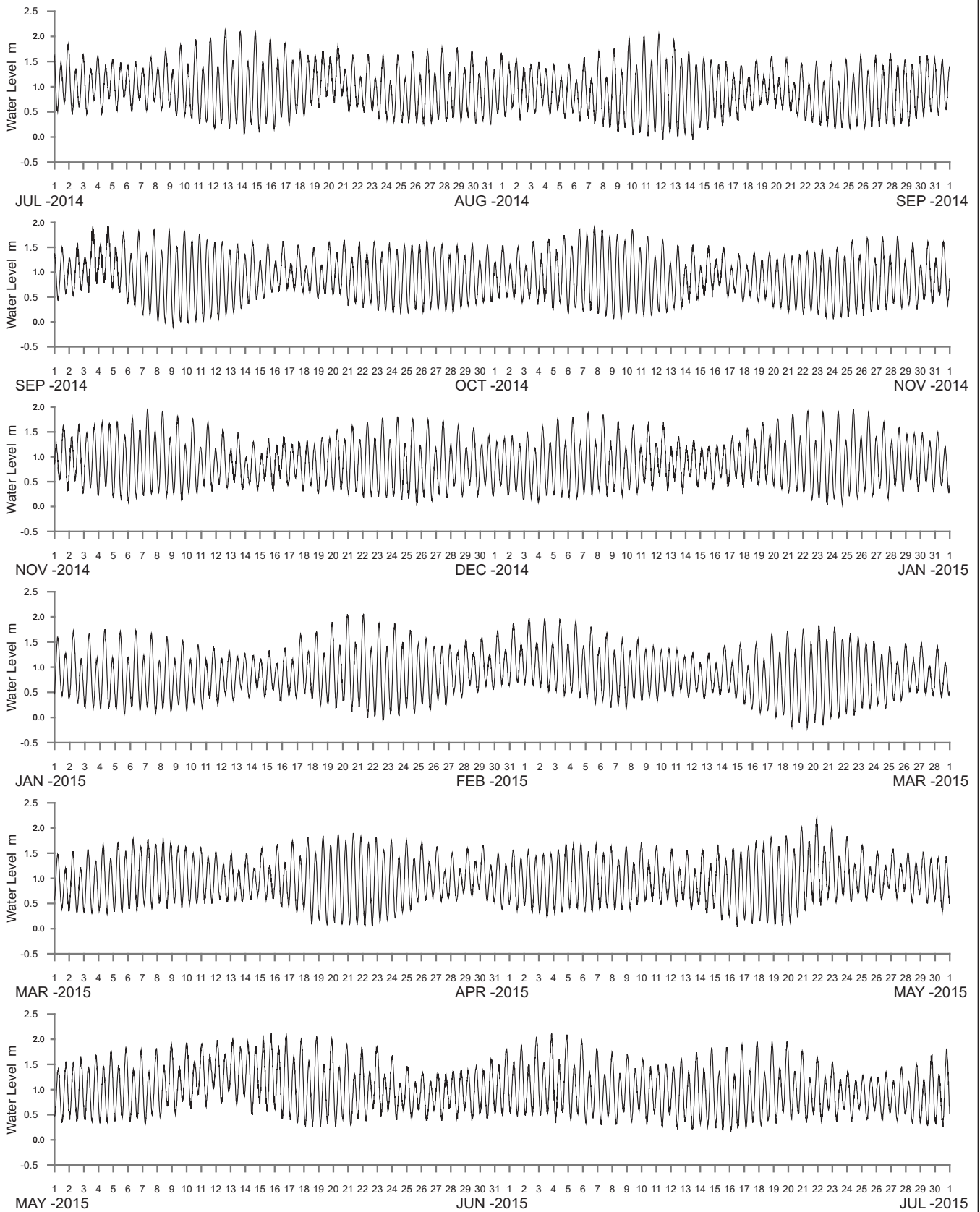
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Manly Hydraulics Laboratory

**CROWDY HEAD
STATION LOCATION**

MHL
Report 2384

Figure
A18

DRAWING 2384-A18.cdr



WATER LEVEL REFERENCED TO CROWDY HEAD DATUM

----- DATA LOSS



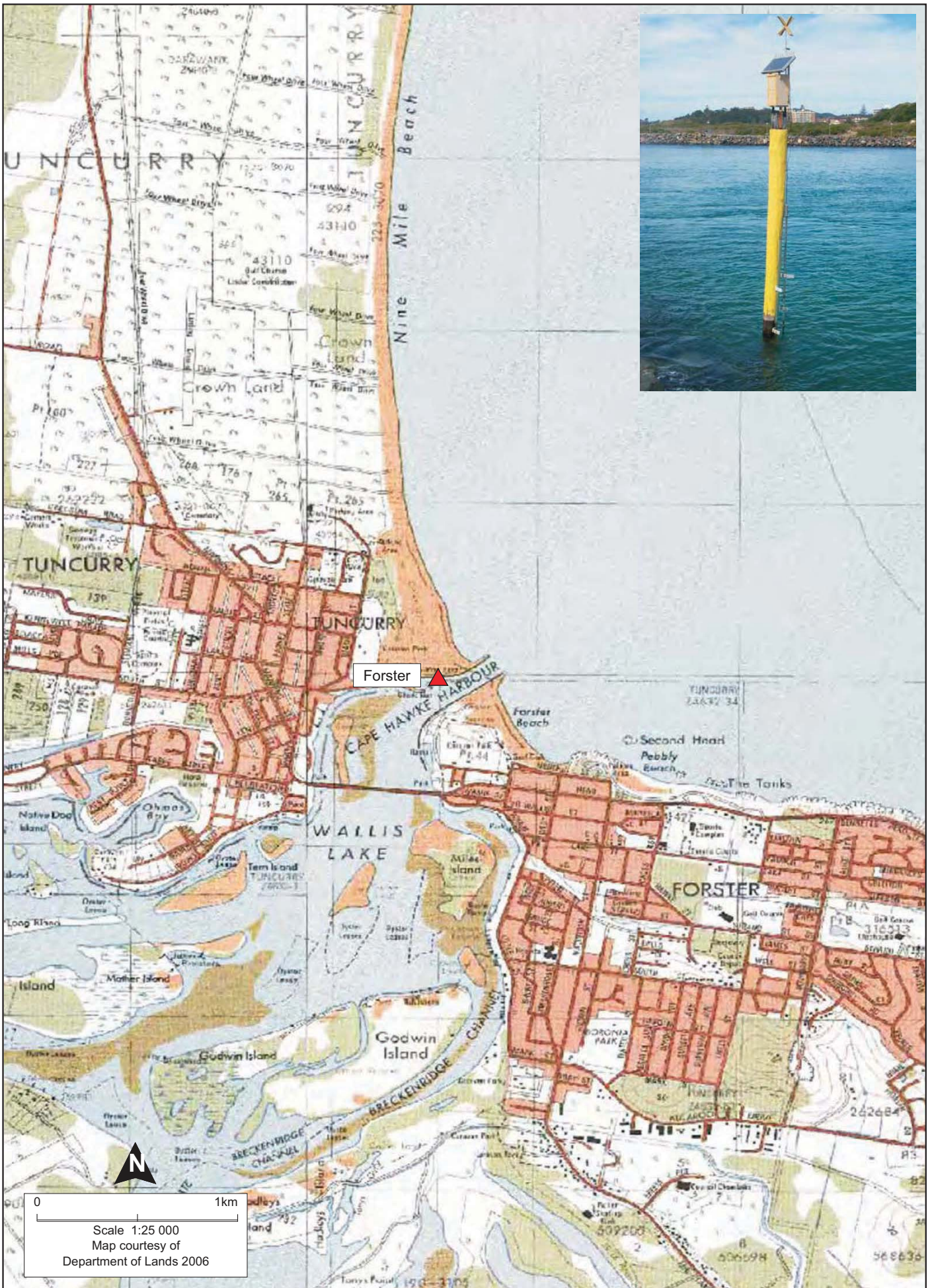
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CROWDY HEAD DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A19

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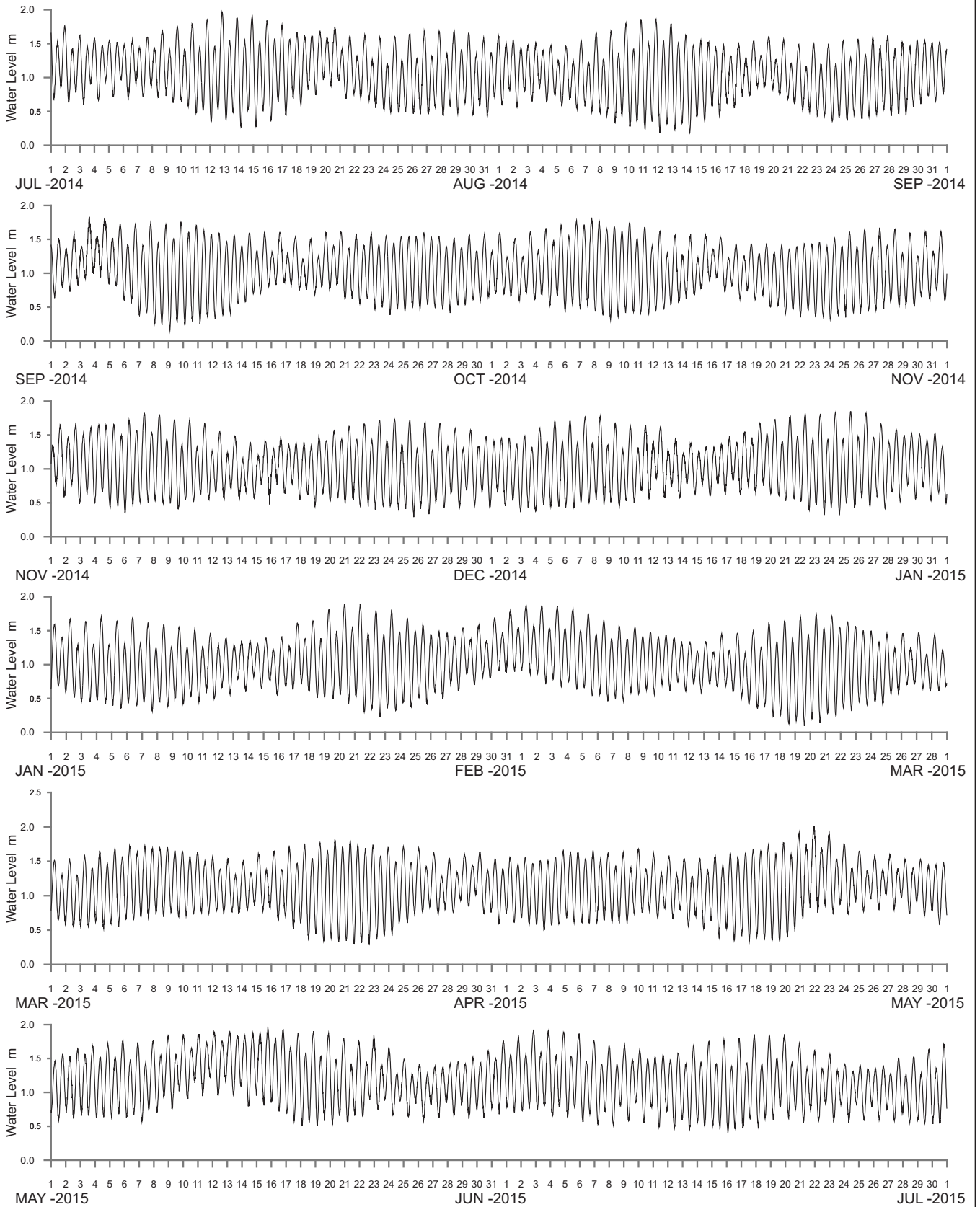
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Manly Hydraulics Laboratory

**FORSTER
STATION LOCATION**

MHL
Report 2384

Figure
A20

DRAWING 2384-A20.cdr



WATER LEVEL REFERENCED TO FORSTER HYDRO DATUM

----- DATA LOSS



Public Works
Manly Hydraulics Laboratory

FORSTER DATA SUMMARY
2014–2015

MHL
Report 2384
Figure
A21

DRAWING 2384-A20.cdr



Shoal Bay



0 1km
 Scale 1:25 000
 Map courtesy of
 Department of Lands 2006



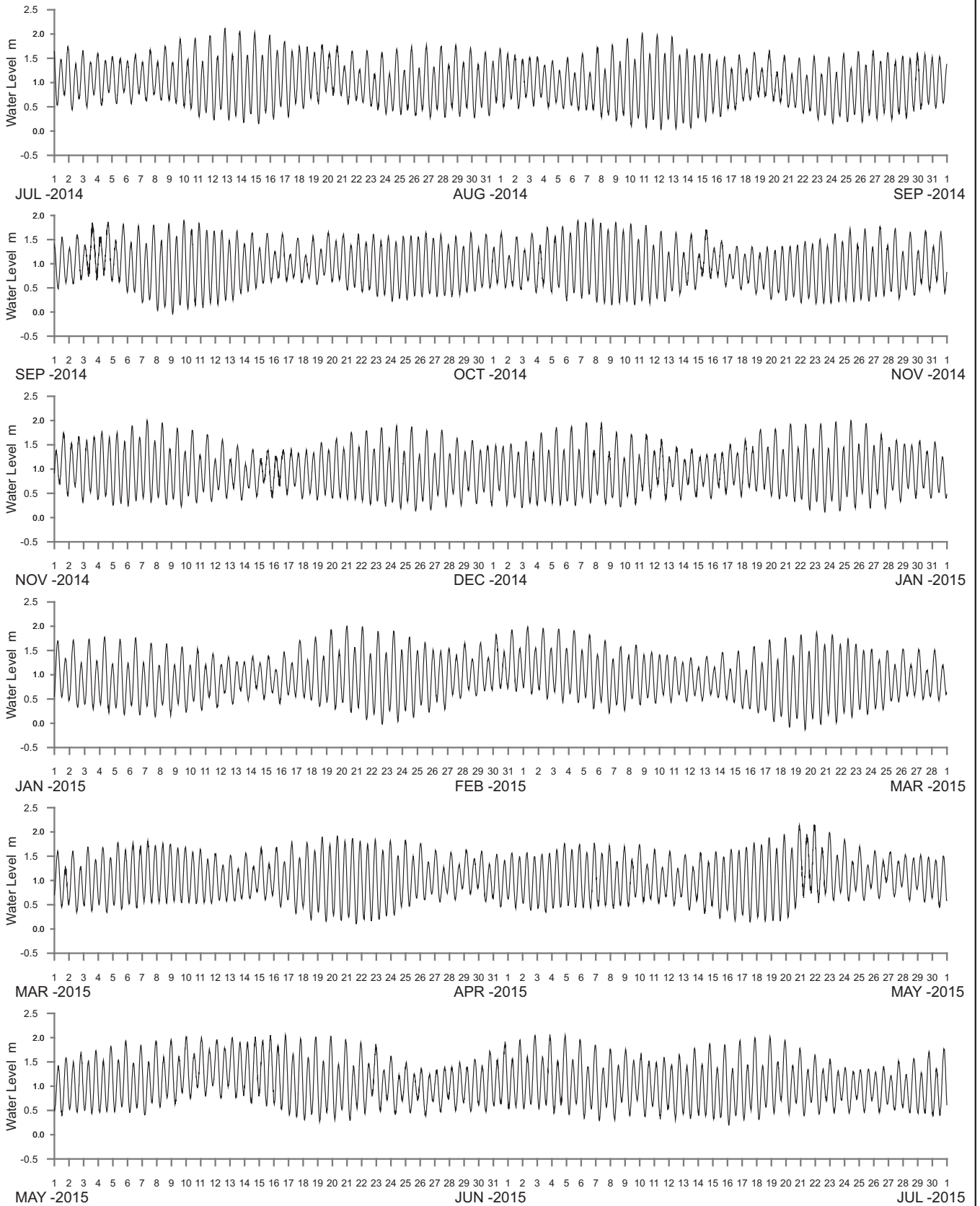
Public Works
 Manly Hydraulics Laboratory

**SHOAL BAY
 STATION LOCATION**

MHL
 Report 2384

Figure
 A22

DRAWING 2384-A22.cdr



WATER LEVEL REFERENCED TO PORT STEPHENS HYDRO DATUM

----- DATA LOSS



Public Works
Manly Hydraulics Laboratory

SHOAL BAY DATA SUMMARY
2014–2015

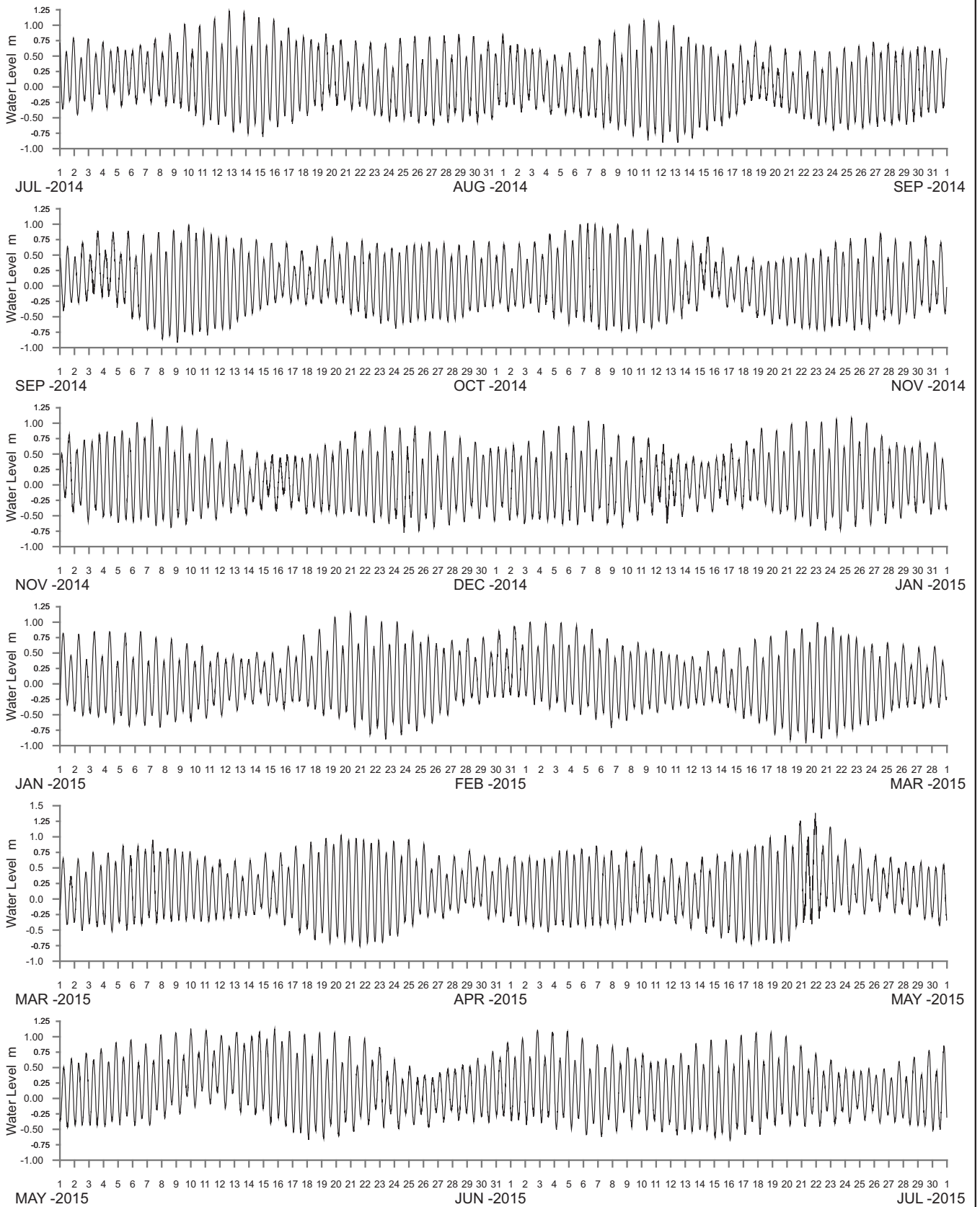
MHL
Report 2384

Figure
A23

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 Scale 1:25 000
 Map courtesy of
 Department of Lands 2006



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



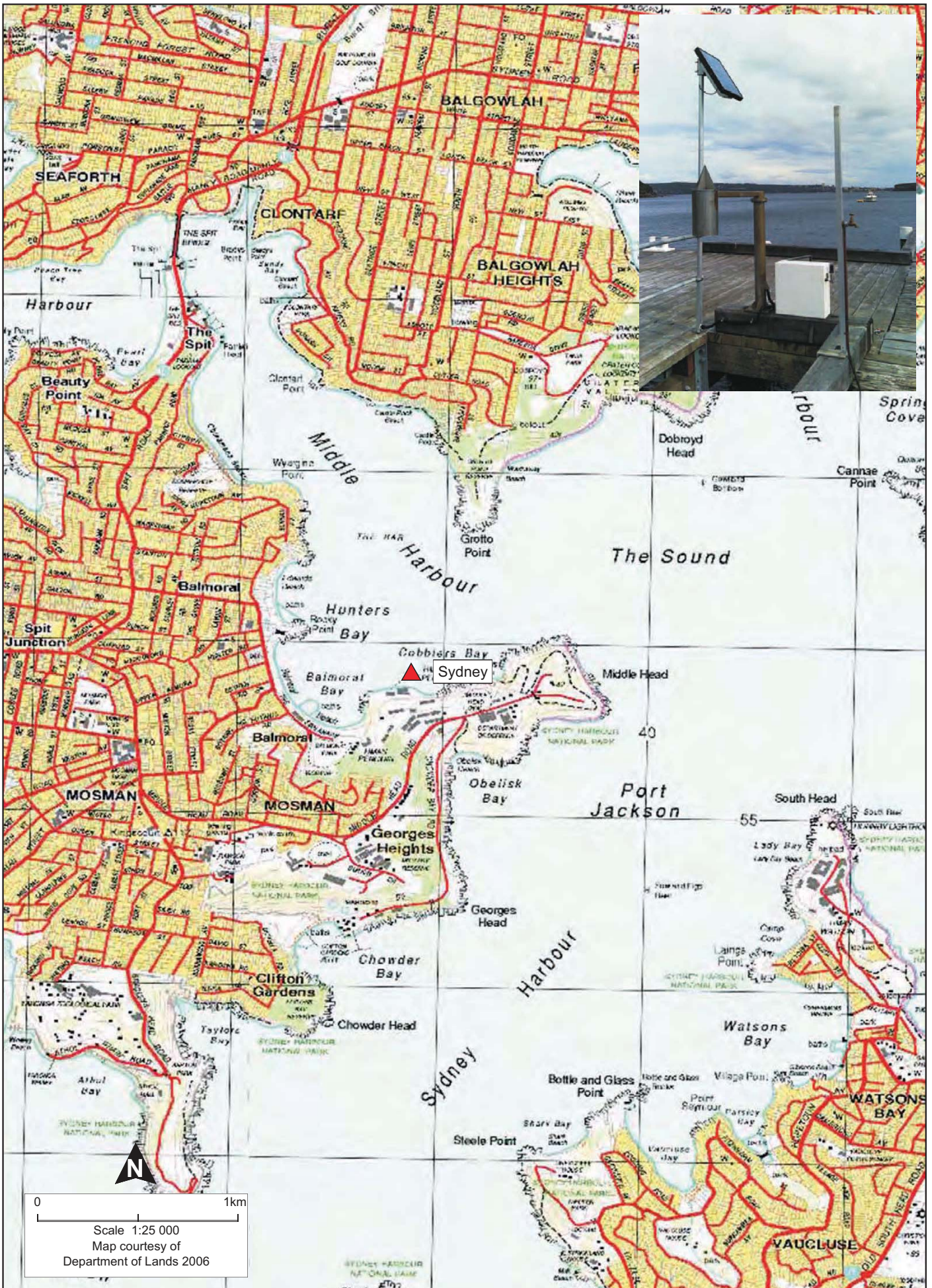
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Manly Hydraulics Laboratory

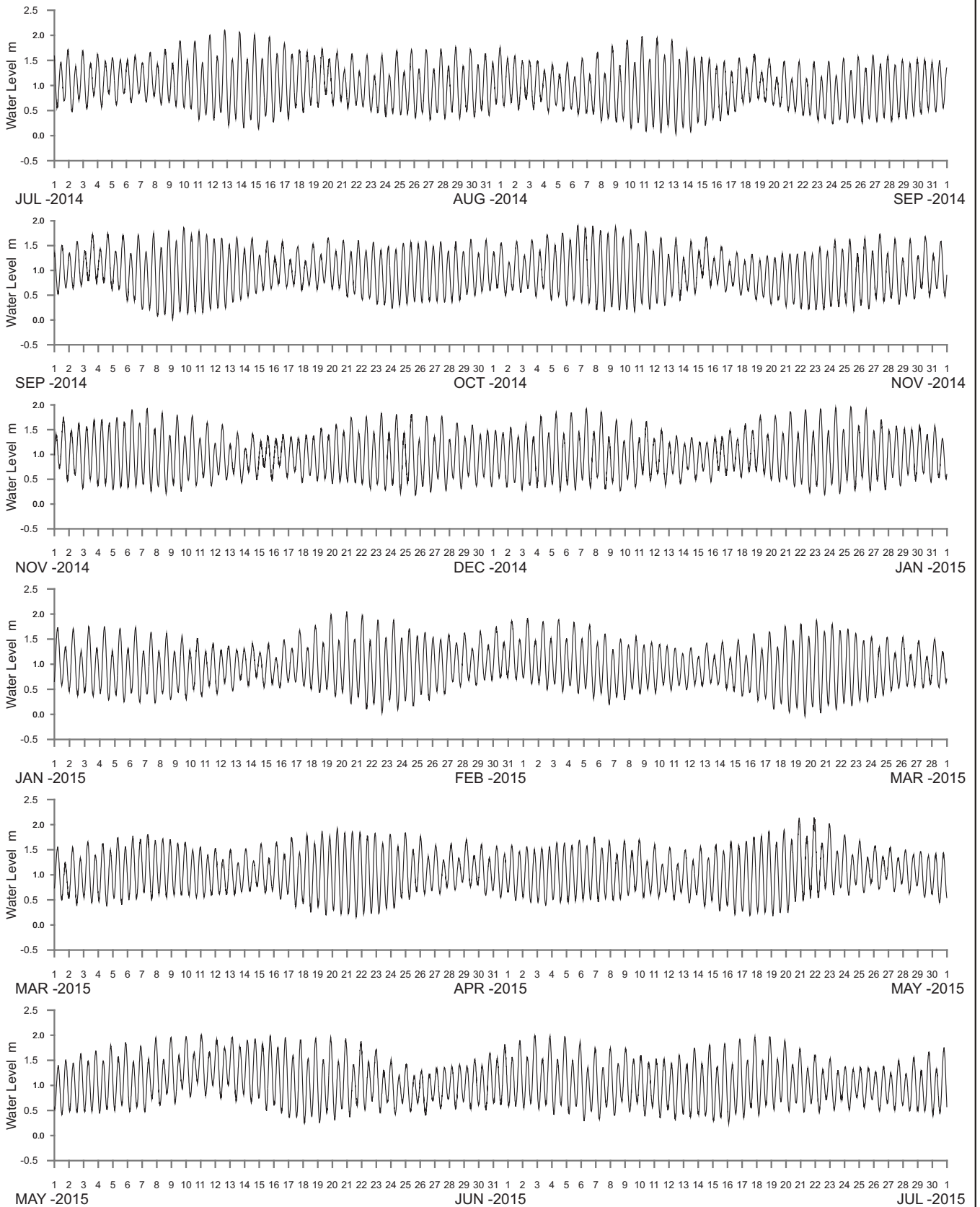
PATONGA DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A25

DRAWING 2384-A24.cdr





WATER LEVEL REFERENCED TO ZERO FORT DENISON

----- DATA LOSS



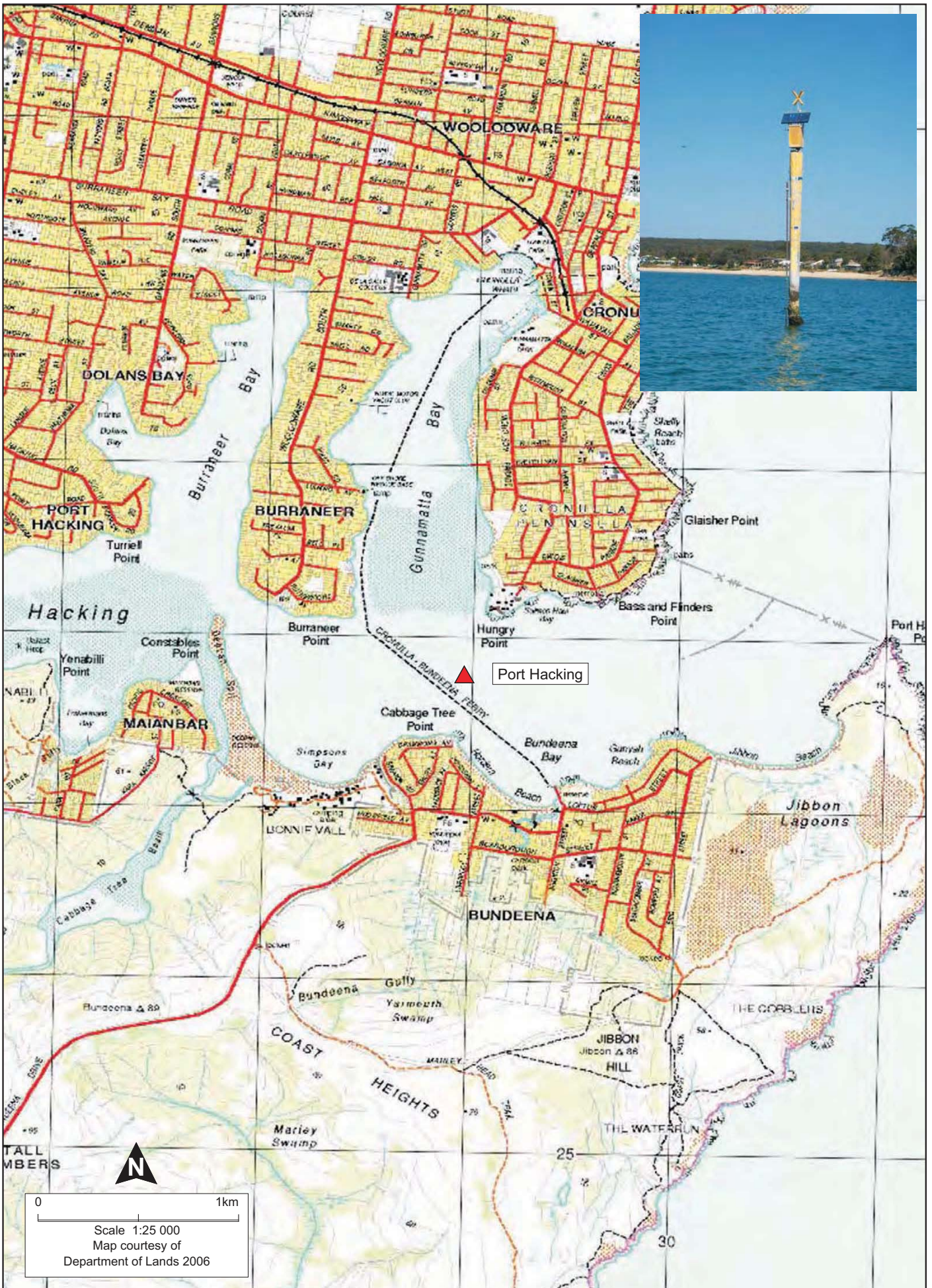
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Manly Hydraulics Laboratory

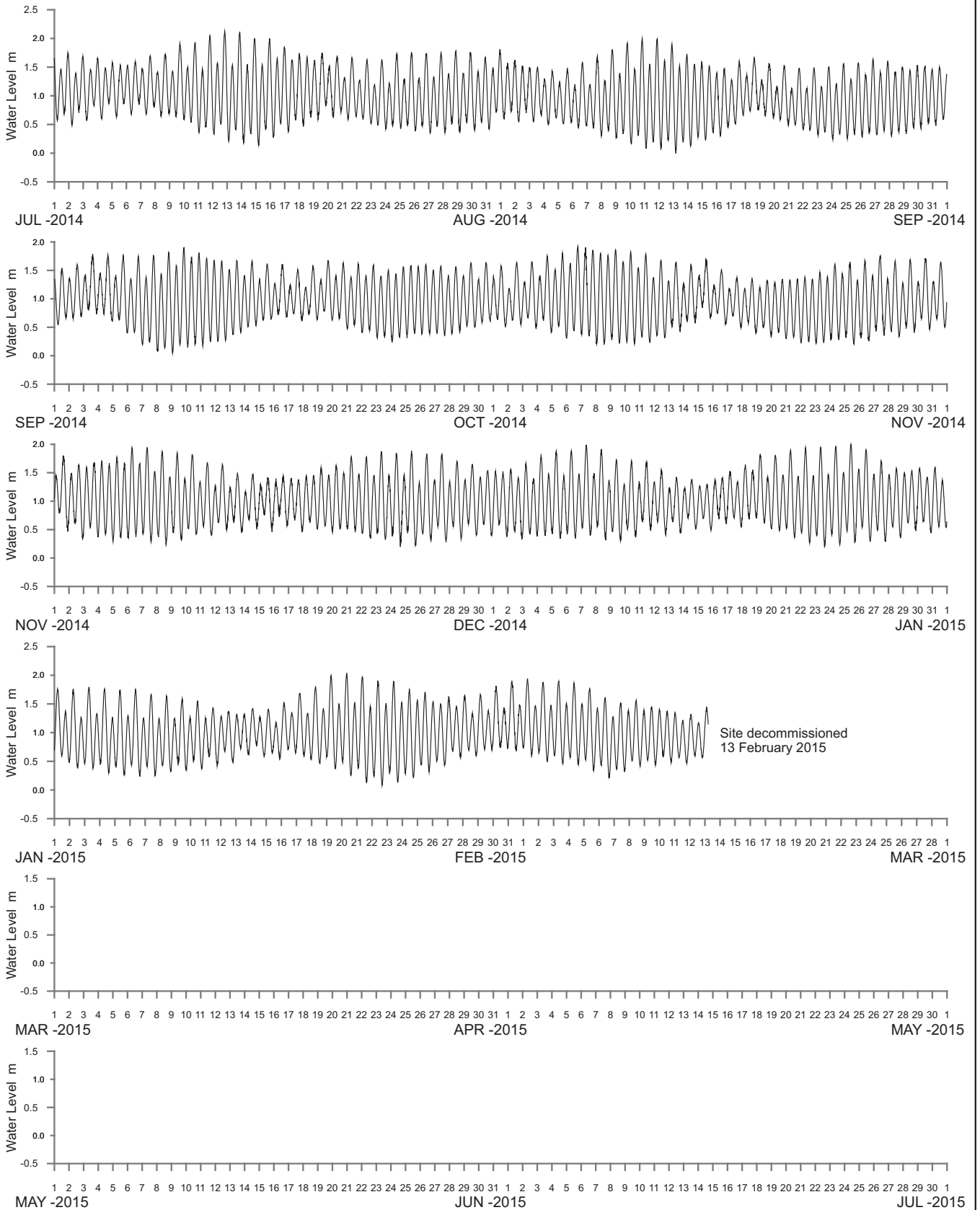
SYDNEY DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A27

DRAWING 2384-A26.cdr





WATER LEVEL REFERENCED TO ZERO FORT DENISON

----- DATA LOSS



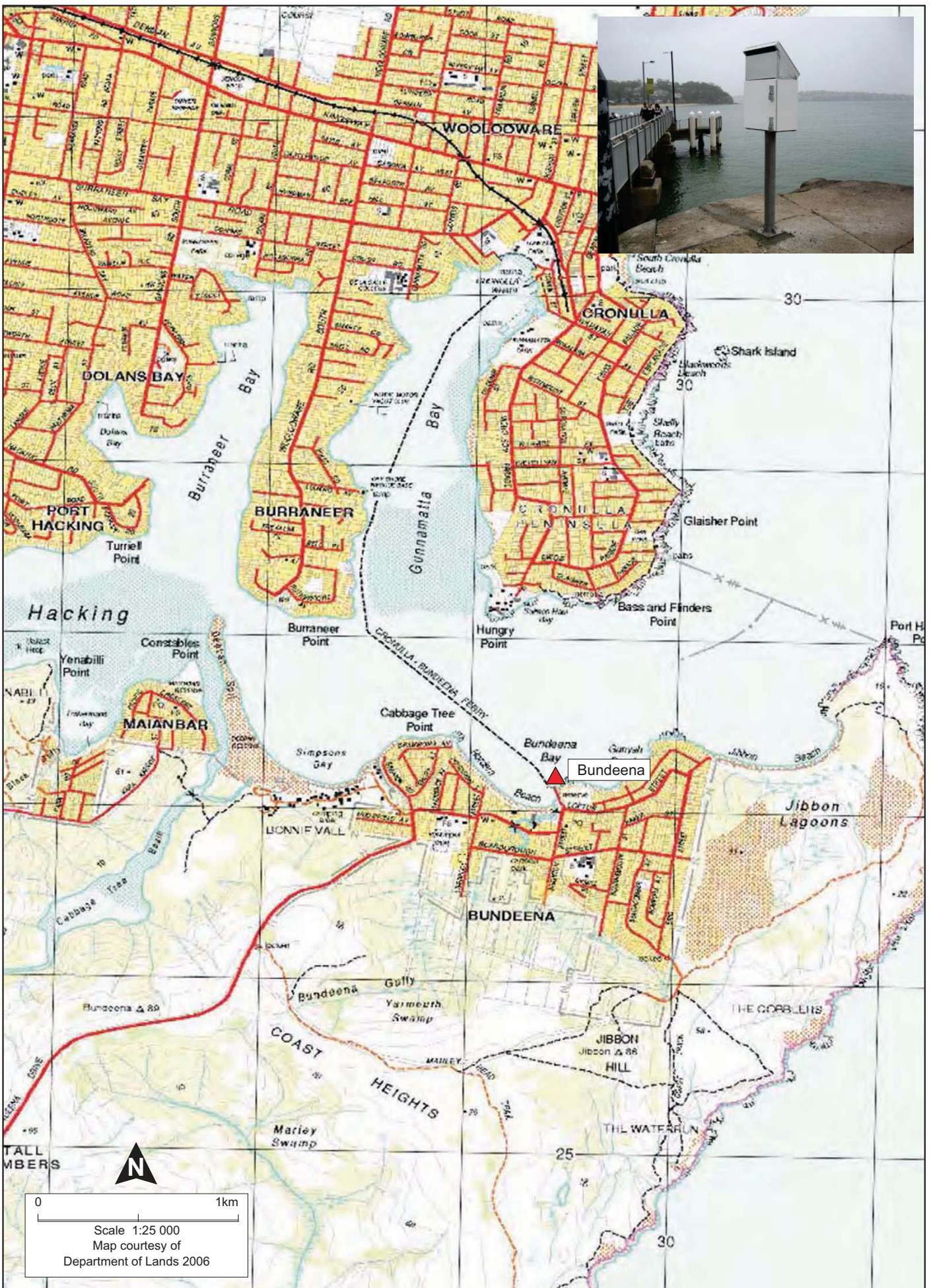
Public Works
Manly Hydraulics Laboratory

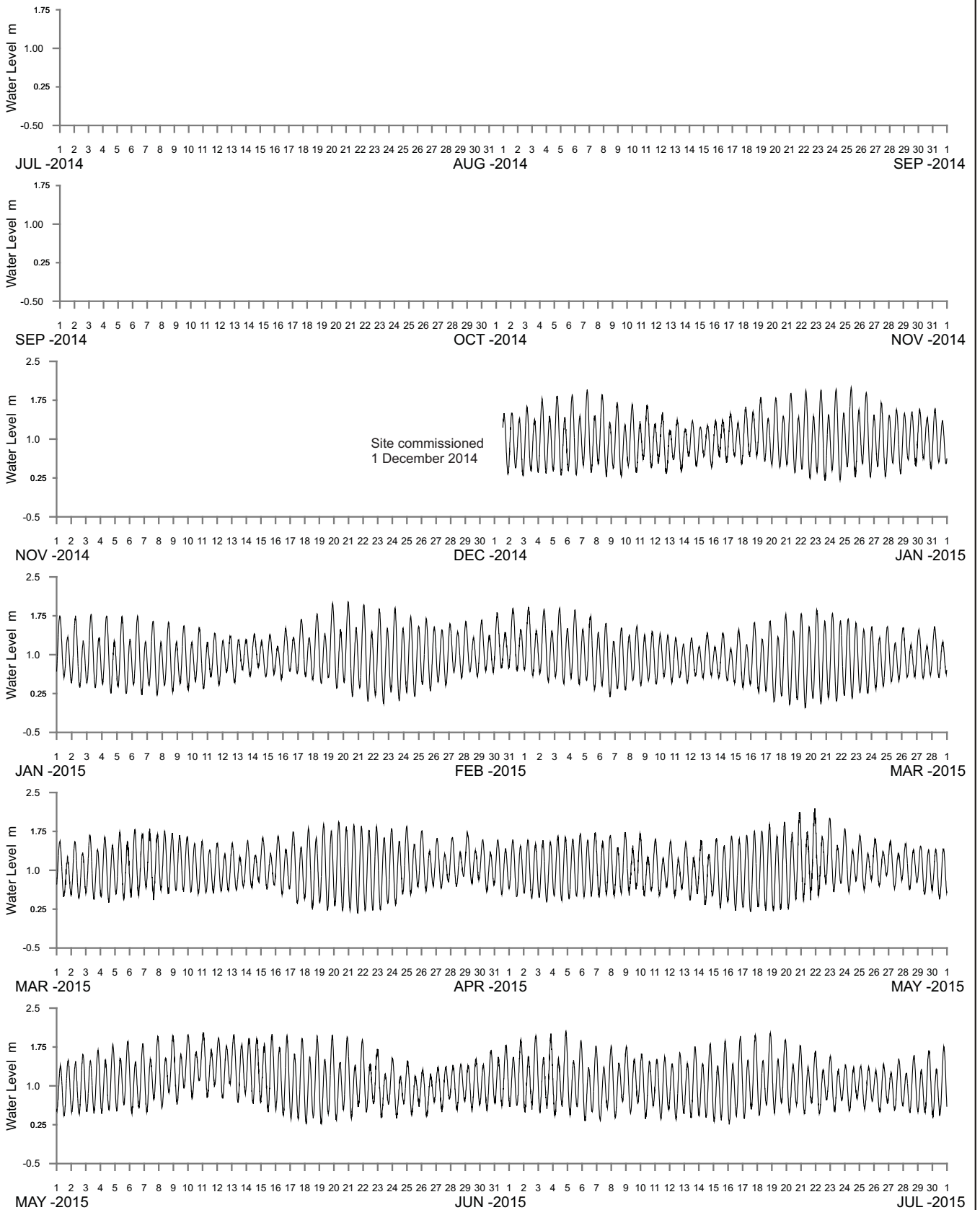
PORT HACKING DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A29

DRAWING 2384-A28.cdr





WATER LEVEL REFERENCED TO ZERO FORT DENISON

----- DATA LOSS



Public Works
Manly Hydraulics Laboratory

BUNDEENA DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A31

DRAWING 2384-A30.cdr



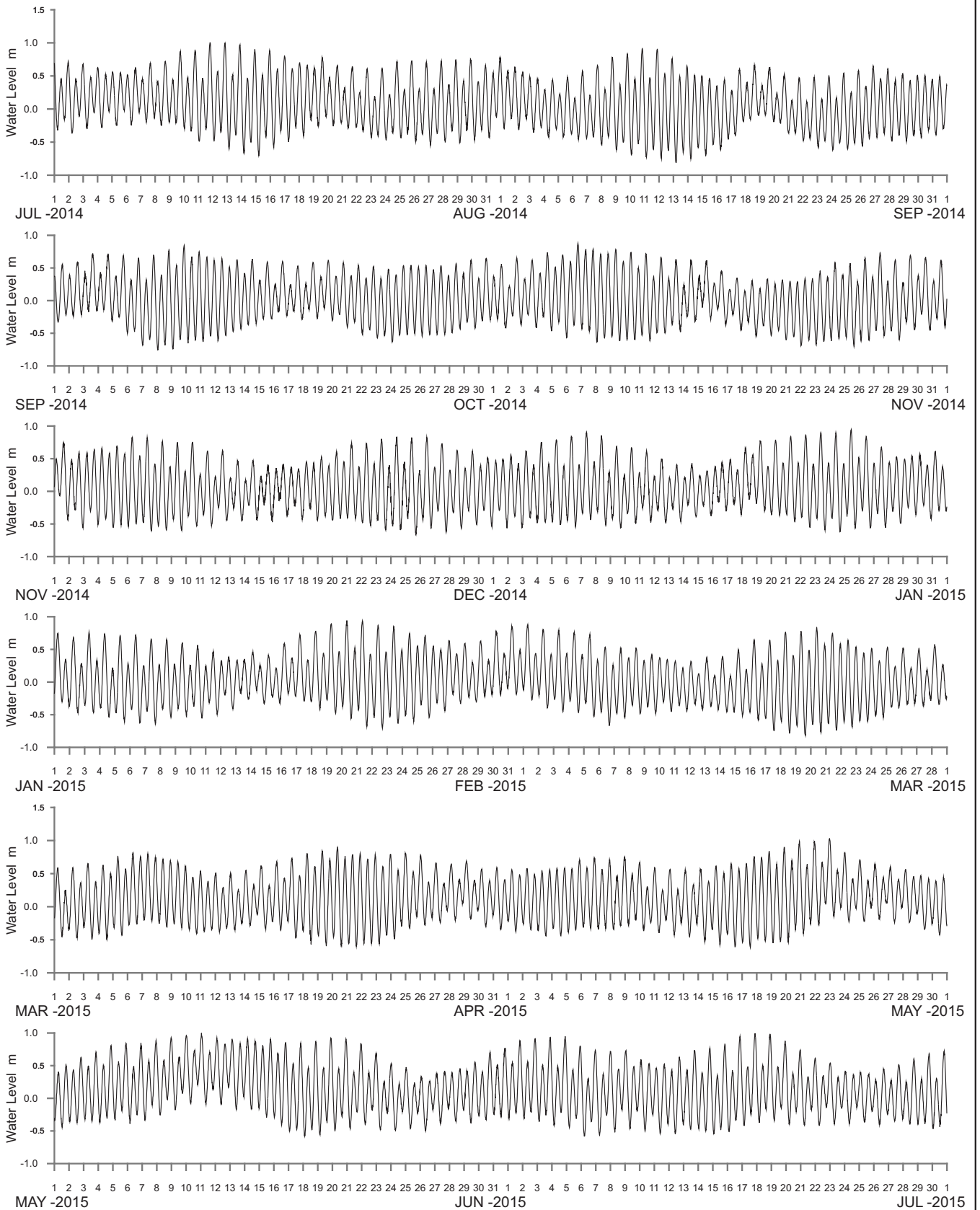
Public Works
Manly Hydraulics Laboratory

**CROOKHAVEN HEADS
STATION LOCATION**

MHL
Report 2384

Figure
A32

DRAWING 2384-A32.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



Public Works
Manly Hydraulics Laboratory

CROOKHAVEN HEADS DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A33

DRAWING 2384-A32.cdr



Shoalhaven Offshore



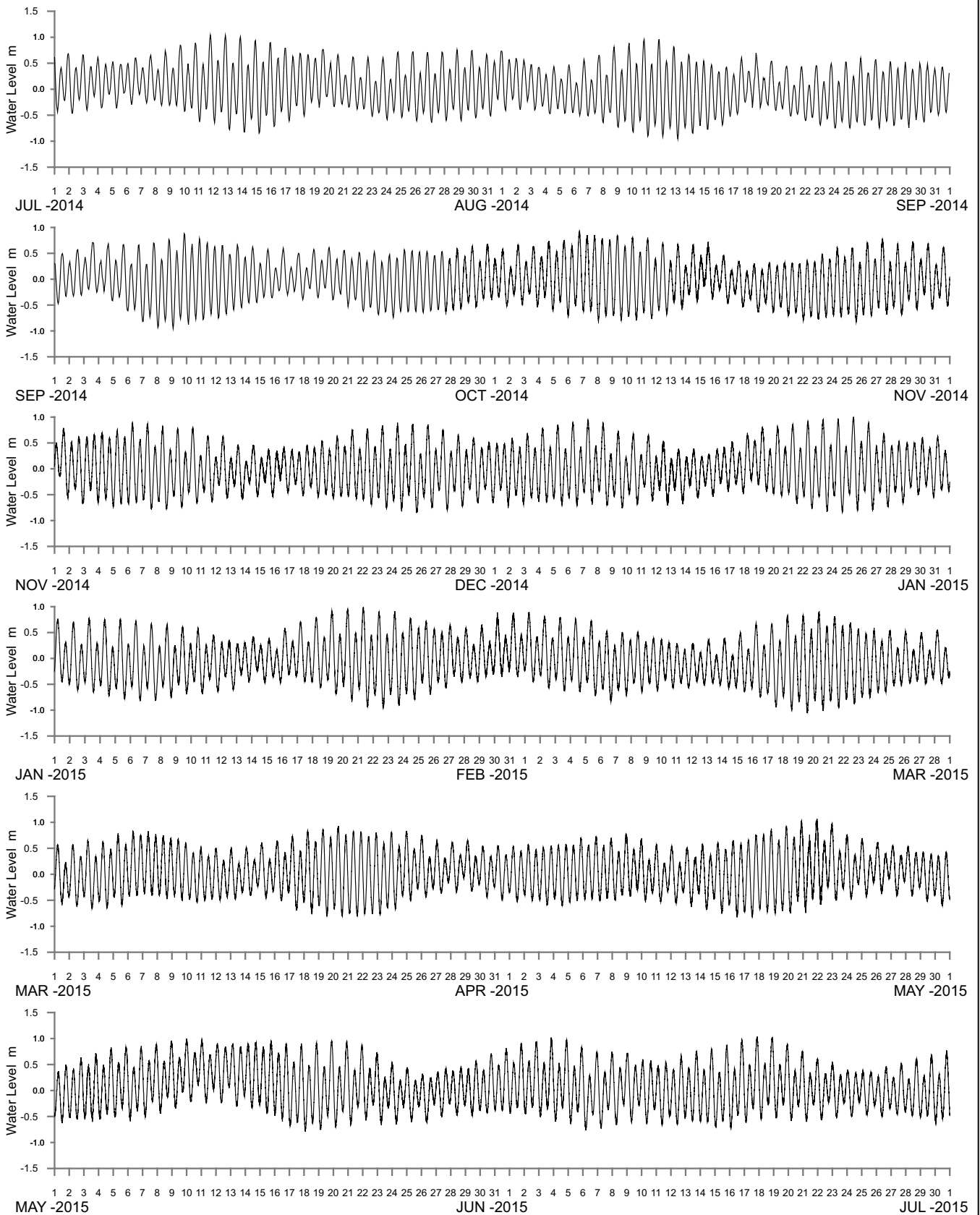
Public Works
Manly Hydraulics Laboratory

**SHOALHAVEN OFFSHORE
TIDE GAUGE LOCATION**

MHL
Report 2384

Figure
A34

DRAWING 2384-A34.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS



Public Works
Manly Hydraulics Laboratory

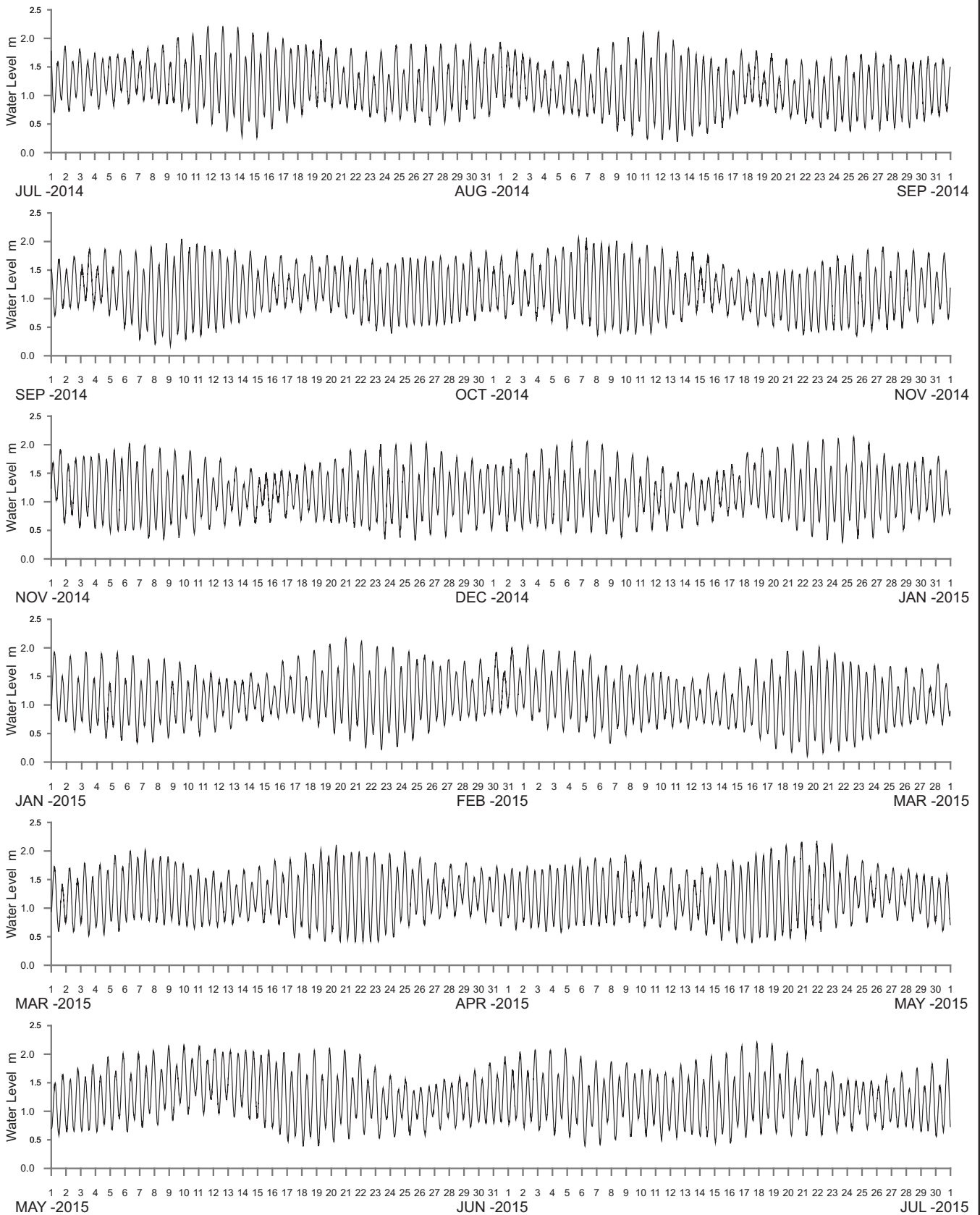
SHOALHAVEN OFFSHORE DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A35

DRAWING 2384-A34.cdr





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

----- DATA LOSS



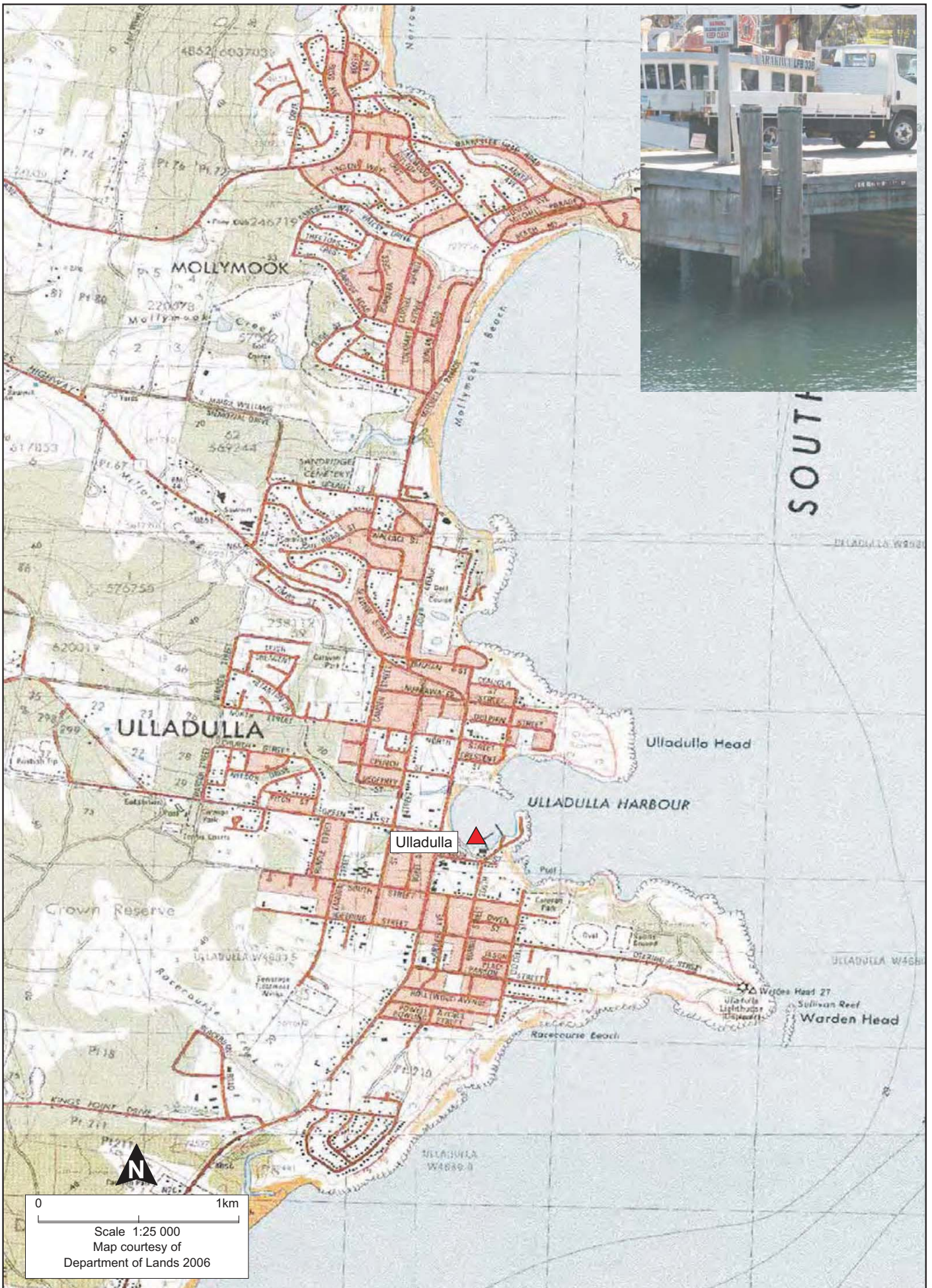
Public Works
Manly Hydraulics Laboratory

JERVIS BAY DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A37

DRAWING 2384-A36.cdr



0 1km
 Scale 1:25 000
 Map courtesy of
 Department of Lands 2006



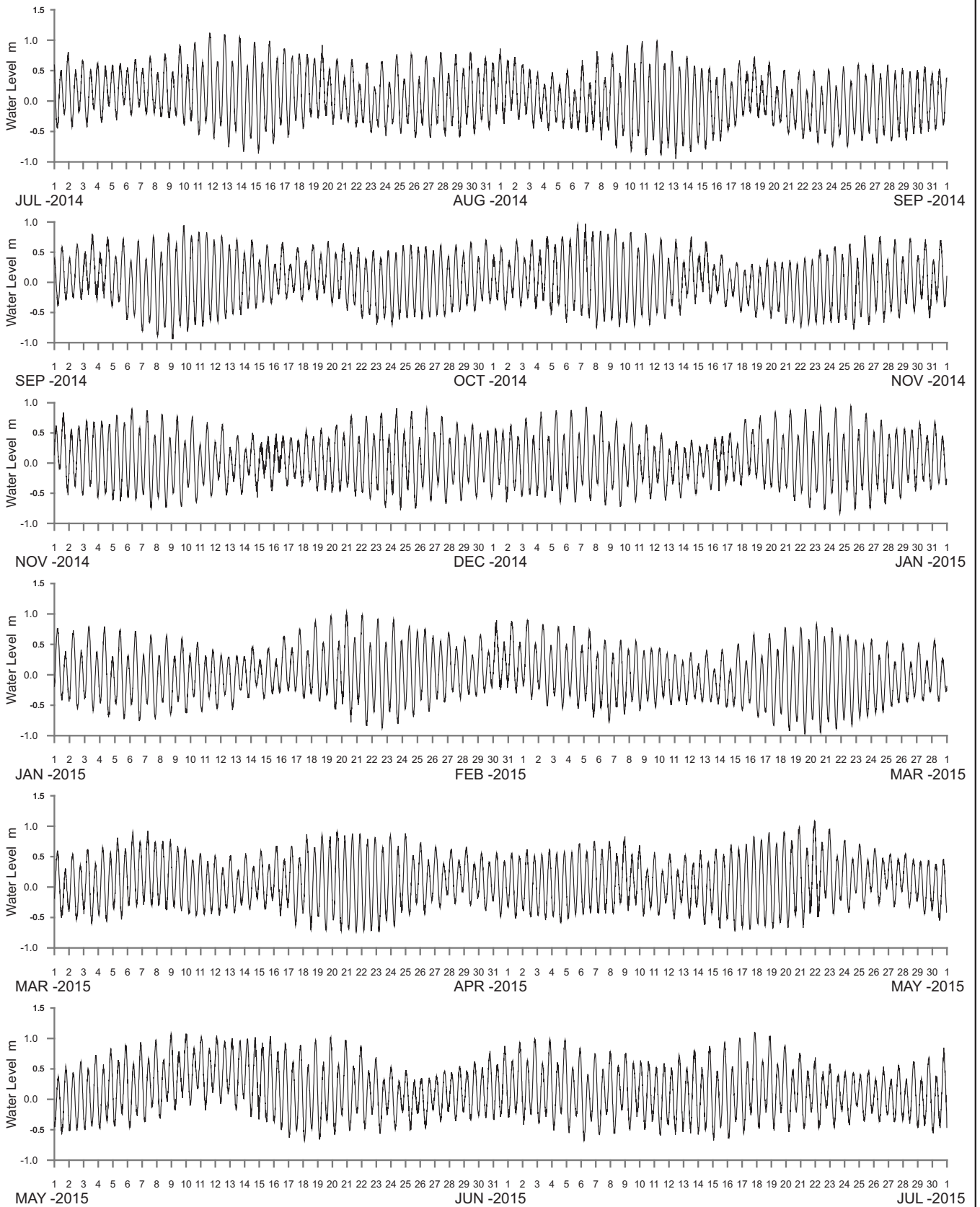
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ULLADULLA STATION LOCATION

MHL
 Report 2384

Figure
 A38

DRAWING 2384-A38.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



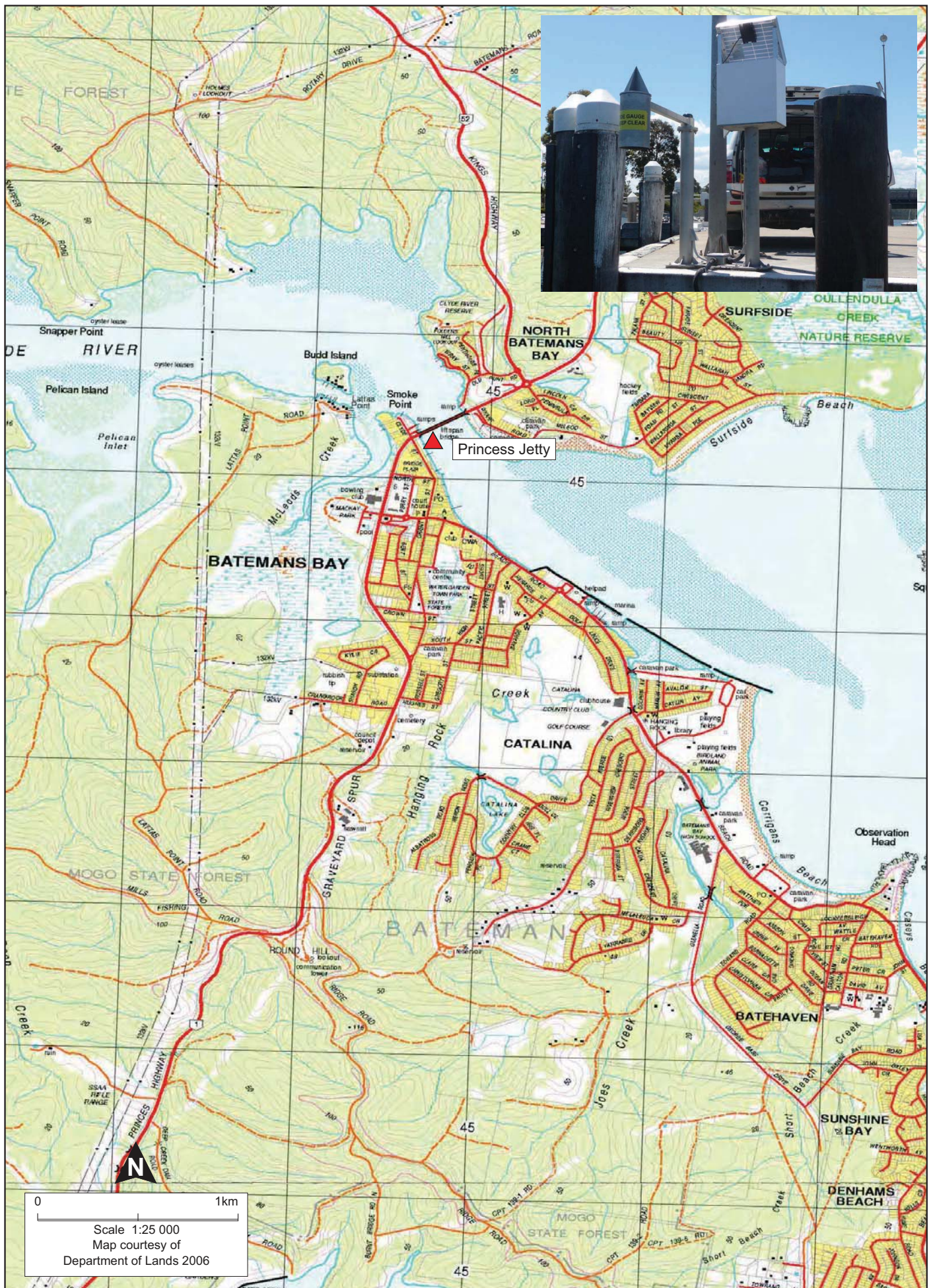
Public Works
Manly Hydraulics Laboratory

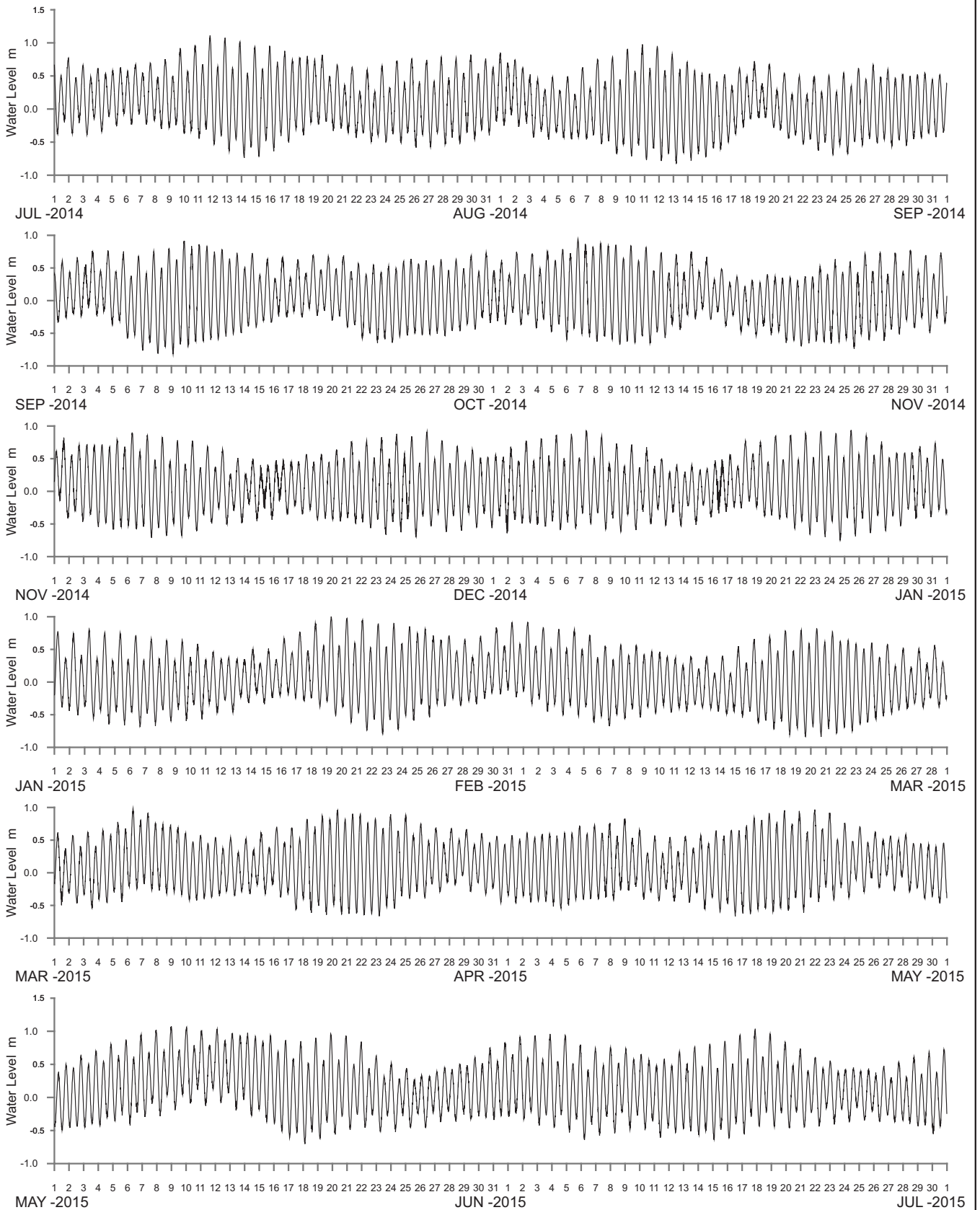
ULLADULLA DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A39

DRAWING 2384-A38.cdr





WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



Public Works
Manly Hydraulics Laboratory

PRINCESS JETTY DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A41

DRAWING 2384-A40.cdr



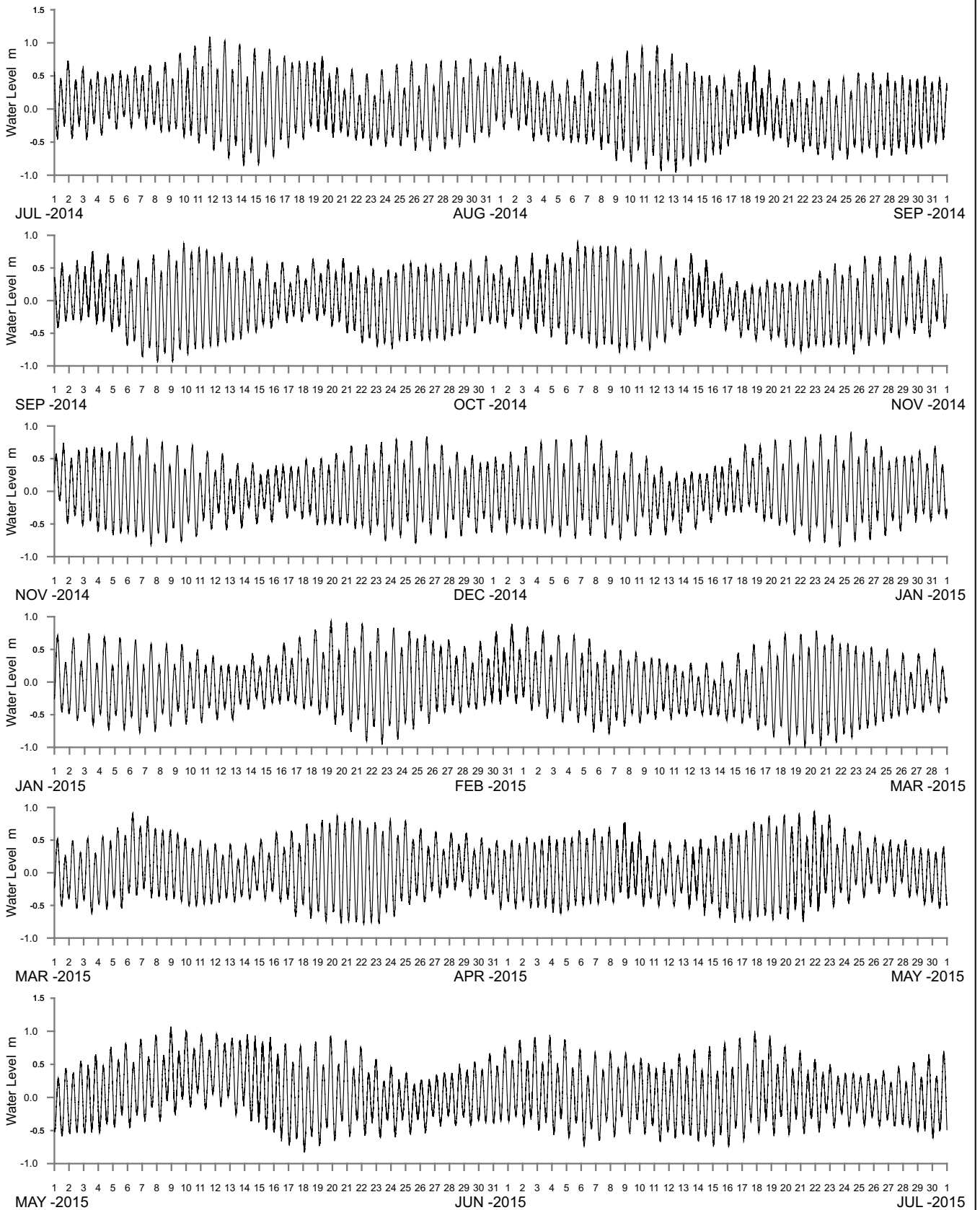
Public Works
Manly Hydraulics Laboratory

**BATEMANS BAY OFFSHORE
TIDE GAUGE LOCATION**

MHL
Report 2384

Figure
A42

DRAWING 2384-A42.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS



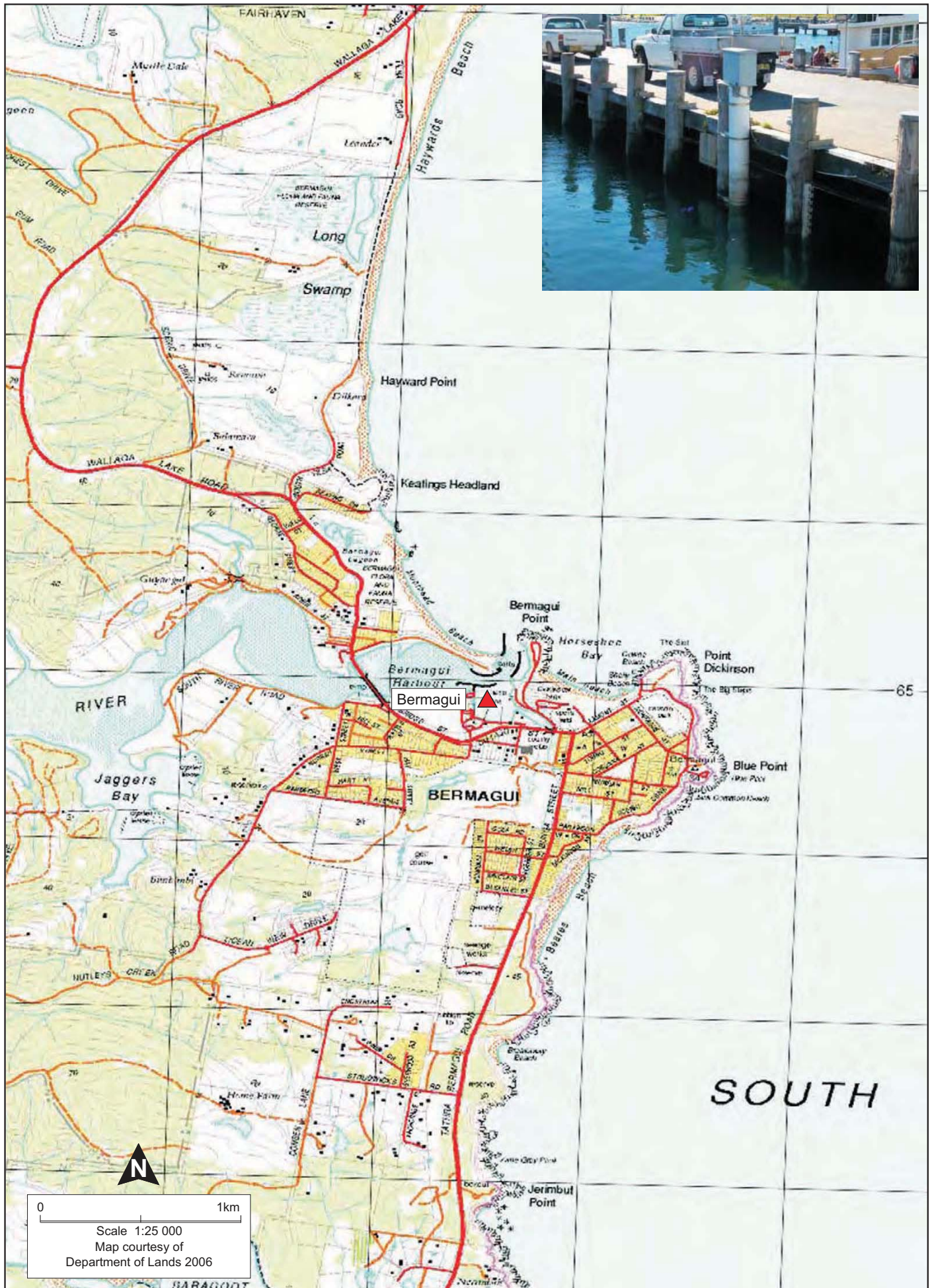
Public Works
Manly Hydraulics Laboratory

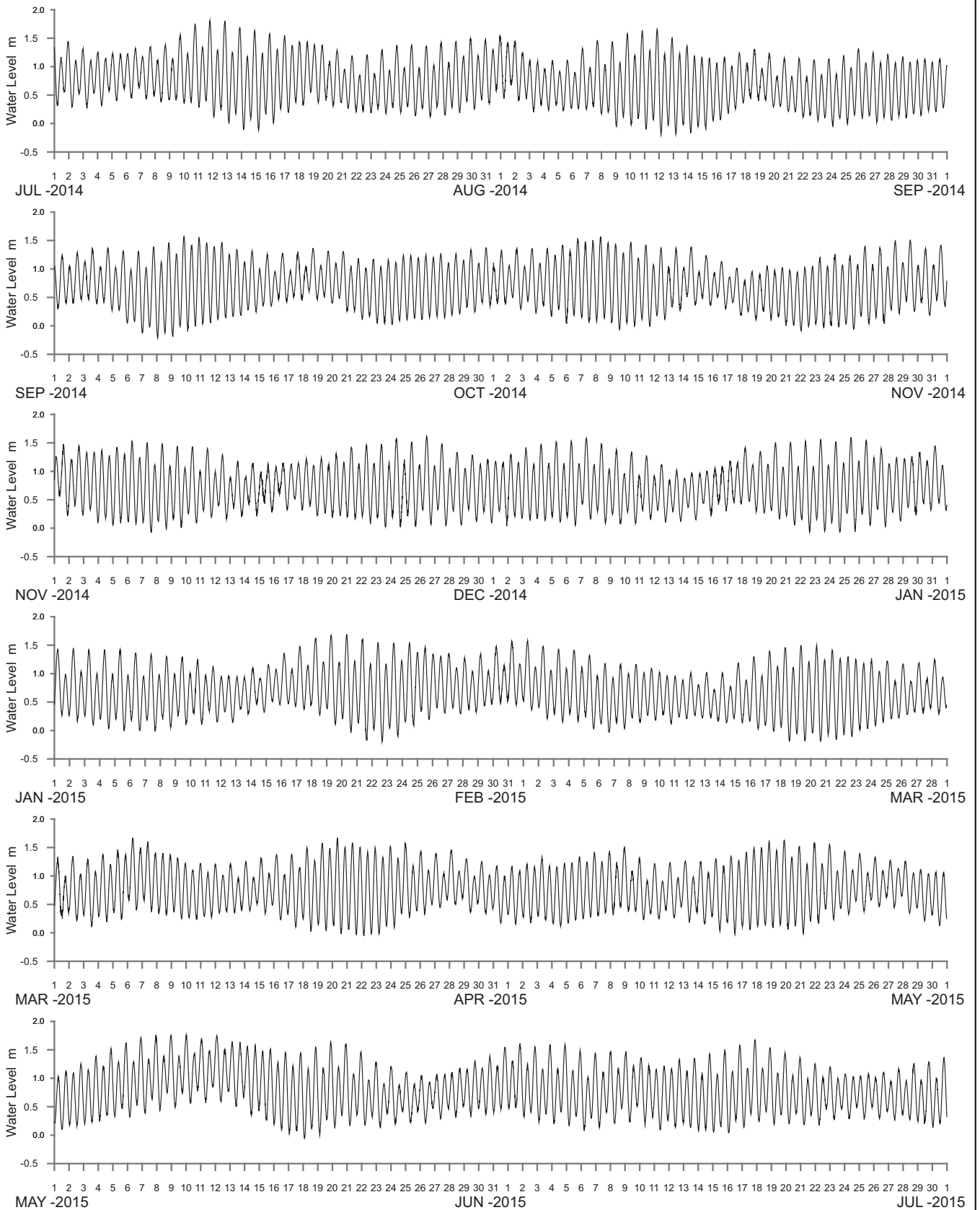
BATEMANS BAY OFFSHORE DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A43

DRAWING 2384-A42.cdr





WATER LEVEL REFERENCED TO BERMAGUI LOCAL HYDRO DATUM

----- DATA LOSS



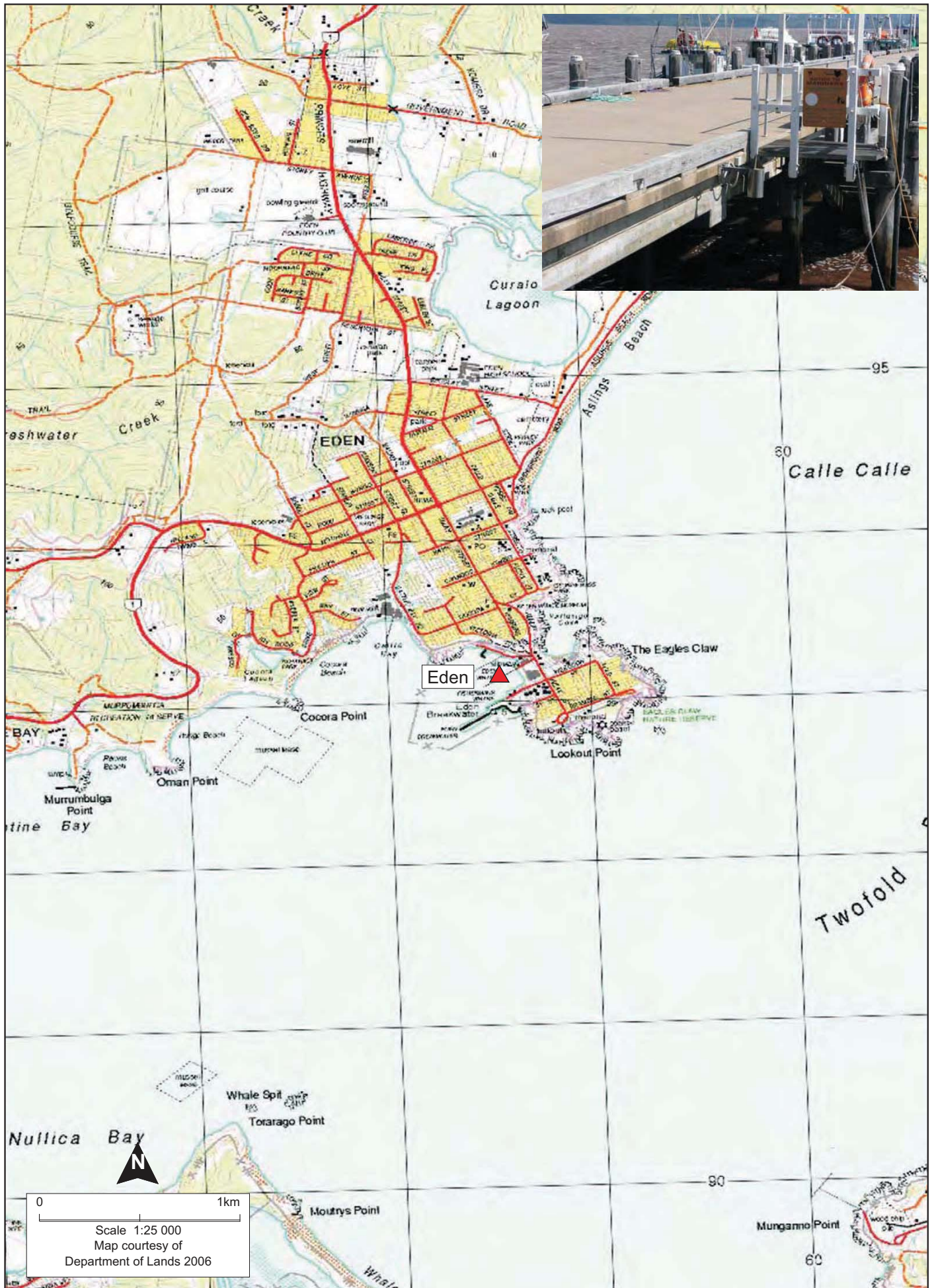
Public Works
Manly Hydraulics Laboratory

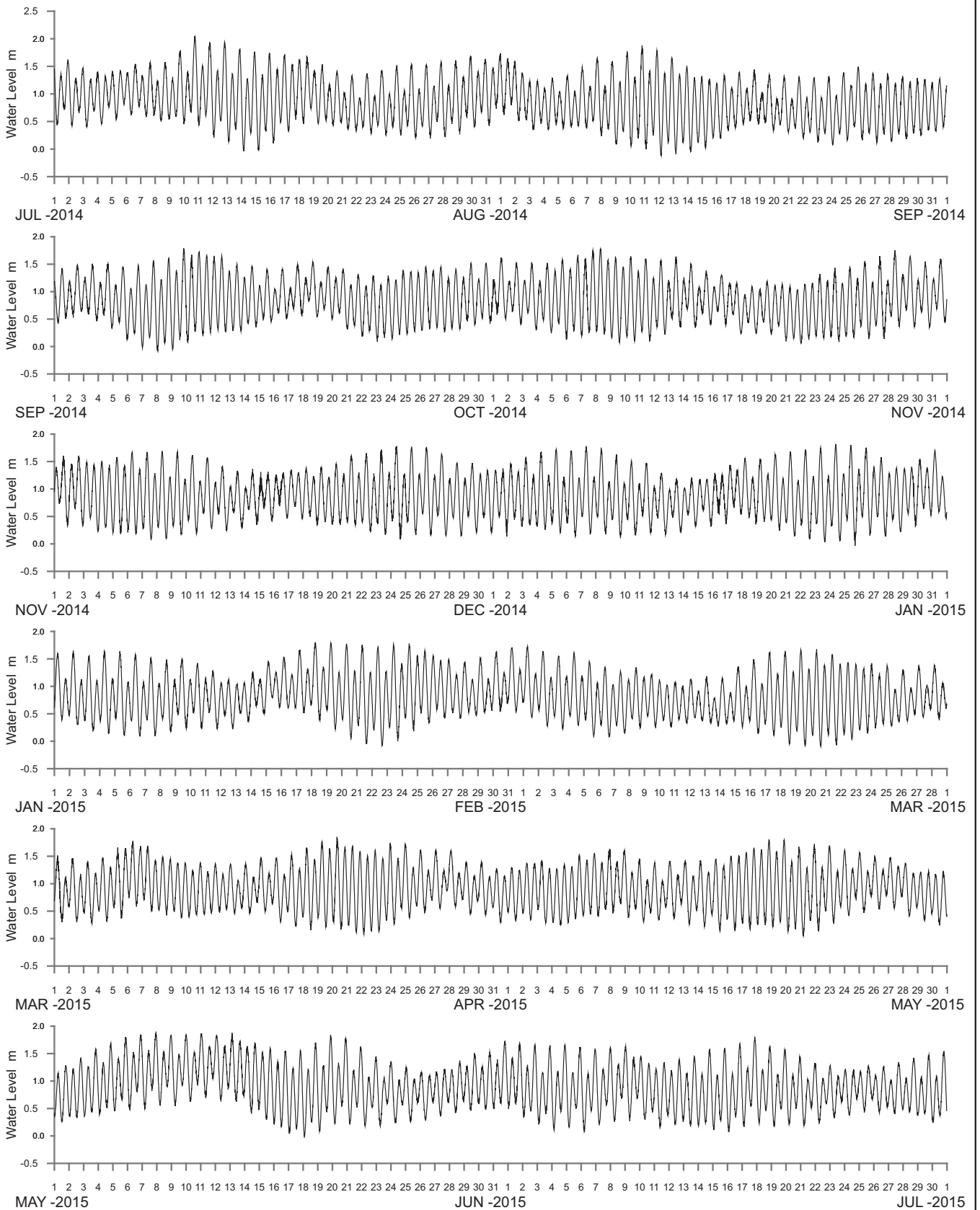
BERMAGUI DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A45

DRAWING 2384-A44.cdr





WATER LEVEL REFERENCED TO TWOFOLD BAY HYDRO DATUM

----- DATA LOSS



Public Works
Manly Hydraulics Laboratory

EDEN DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A47

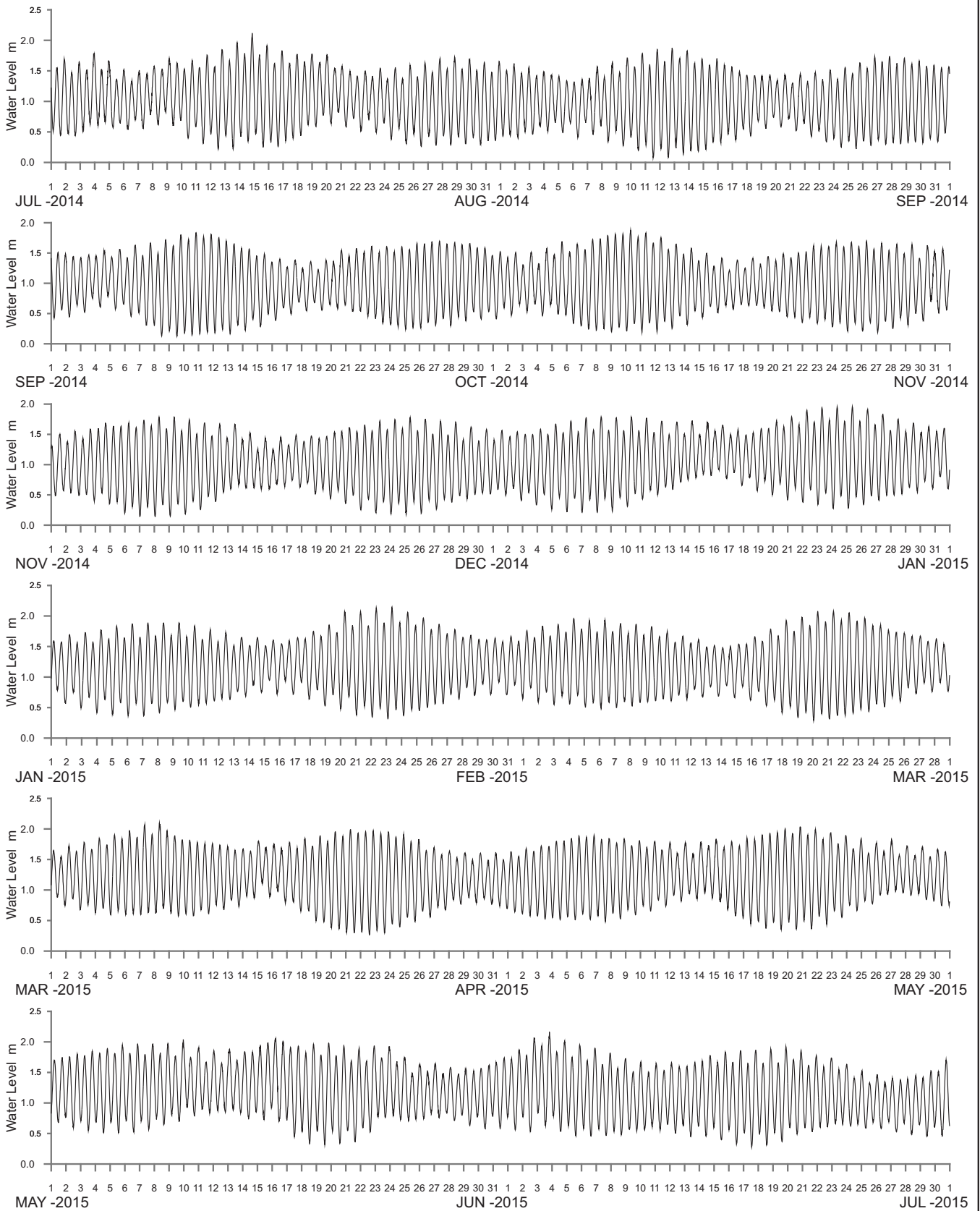
DRAWING 2384-A46.cdr



Public Works
Manly Hydraulics Laboratory

**NORFOLK ISLAND
STATION LOCATION**

MHL
Report 2384
**Figure
A48**
DRAWING 2384-A48.cdr



WATER LEVEL REFERENCED TO LOWEST ASTRONOMICAL TIDE

----- DATA LOSS



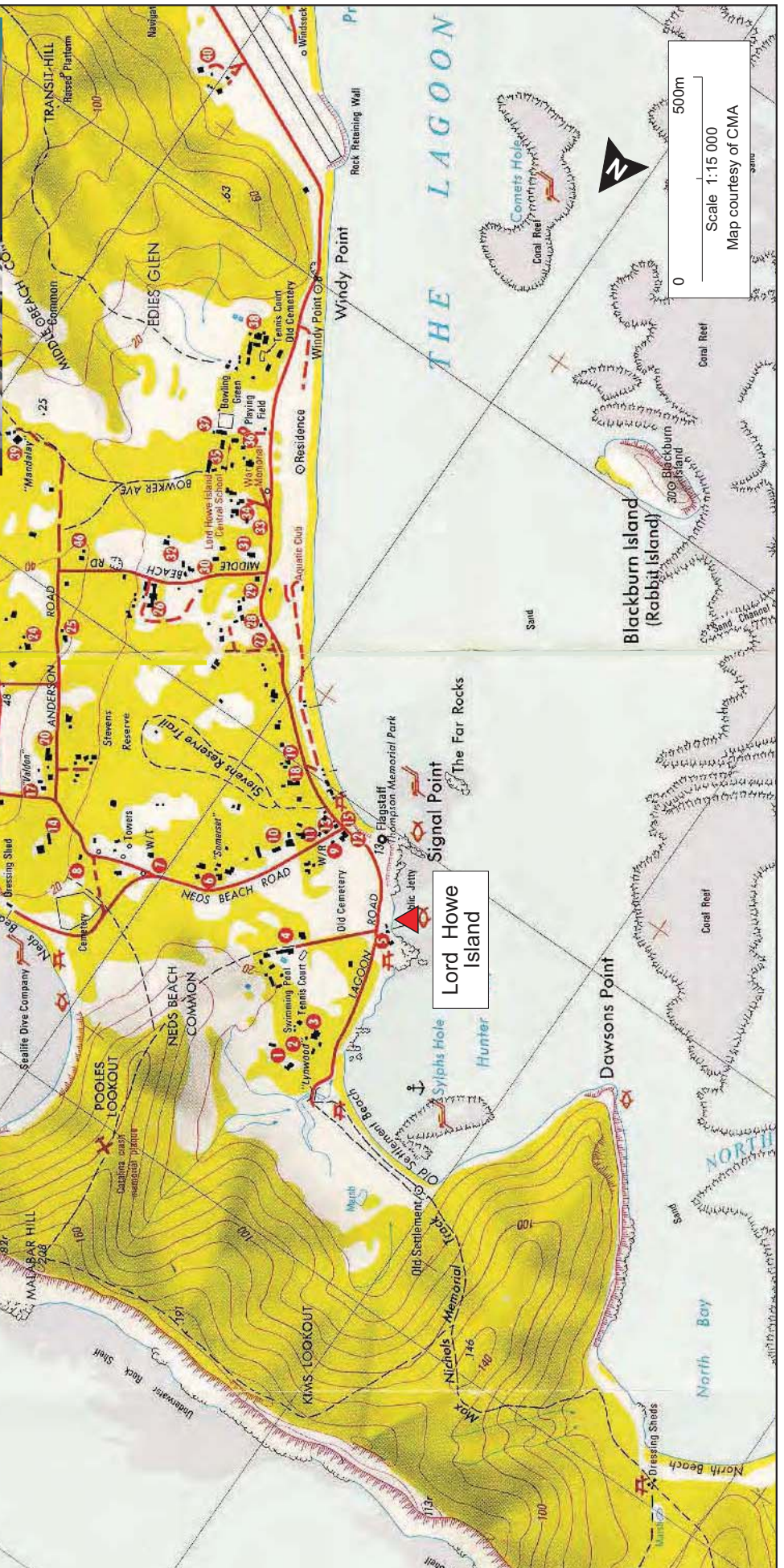
Public Works
Manly Hydraulics Laboratory

NORFOLK ISLAND DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A49

DRAWING 2384-A48.cdr



Lord Howe Island

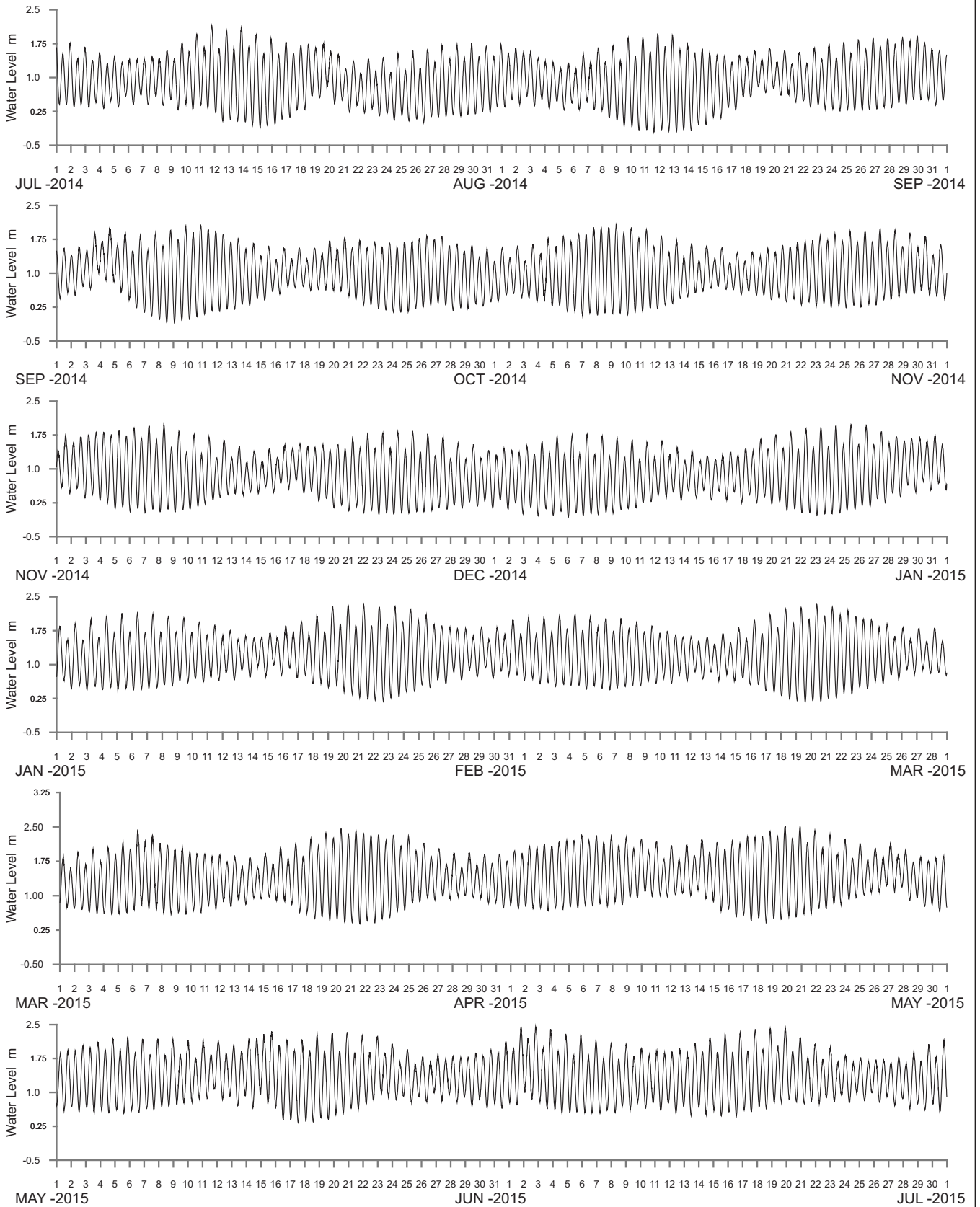


Public Works
Manly Hydraulics Laboratory

LORD HOWE ISLAND
STATION LOCATION

MHL
Report 2384
Figure
A50

DRAWING 2384-A50.cdr



WATER LEVEL REFERENCED TO LORD HOWE ISLAND TIDAL DATUM

----- DATA LOSS



Public Works
Manly Hydraulics Laboratory

LORD HOWE ISLAND DATA SUMMARY
2014–2015

MHL
Report 2384

Figure
A51

DRAWING 2384-A50.cdr

Appendix B
Current Sites Data

Table B1 Current Sites Digital Data

NSW Coastal Region	Catchment, River or Port	Site 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
North Tasman Sea	Tasman Sea	Norfolk Island	Kingston Jetty	Sep 1994–ongoing

¹ Site has changed location during data period

Appendix C
Historical Tide Data

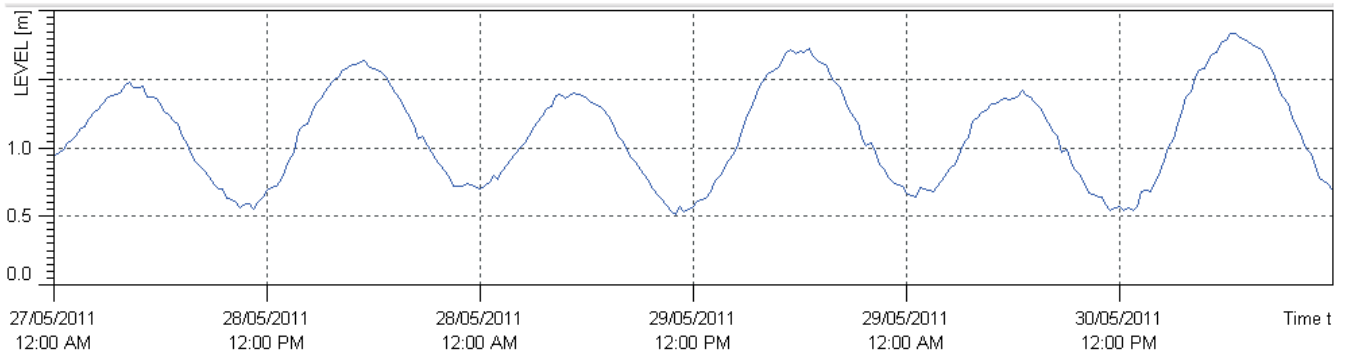
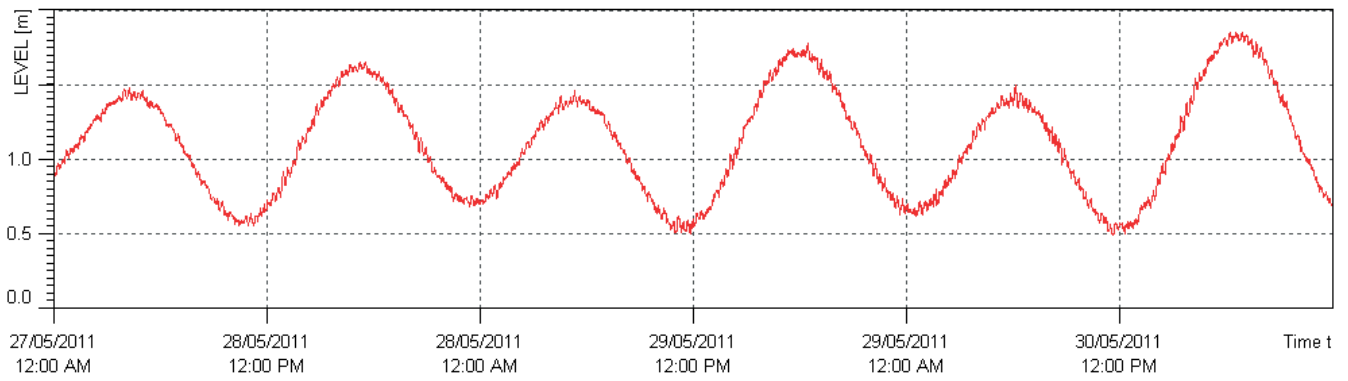
Table C1 Historical Tide Data

Site 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 Books MHL
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 Book MHL
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 Books MHL
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 Books MHL
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

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

Appendix D
Sample Outputs

Coffs Harbour 1-minute data



Coffs Harbour 15-minute data



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)
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 1/05/2014,7:30:00,1.195,55 (Fair)
 1/05/2014,7:45:00,1.243,55 (Fair)
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 1/05/2014,8:15:00,1.366,55 (Fair)
 1/05/2014,8:30:00,1.374,55 (Fair)
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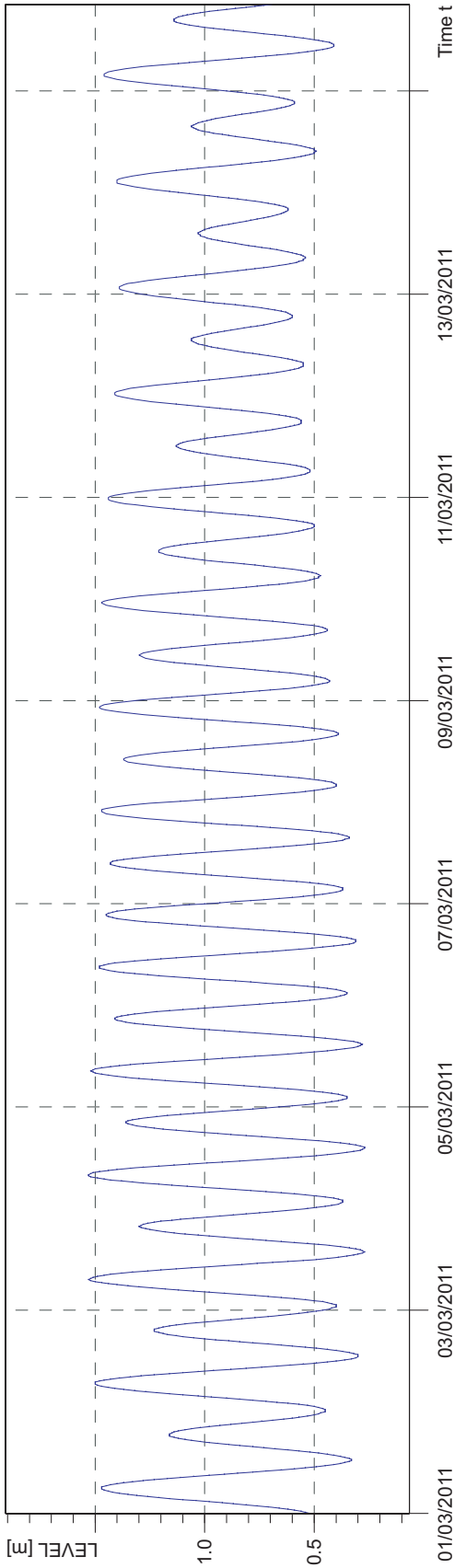


NSW PUBLIC WORKS, MANLY HYDRAULICS LABORATORY

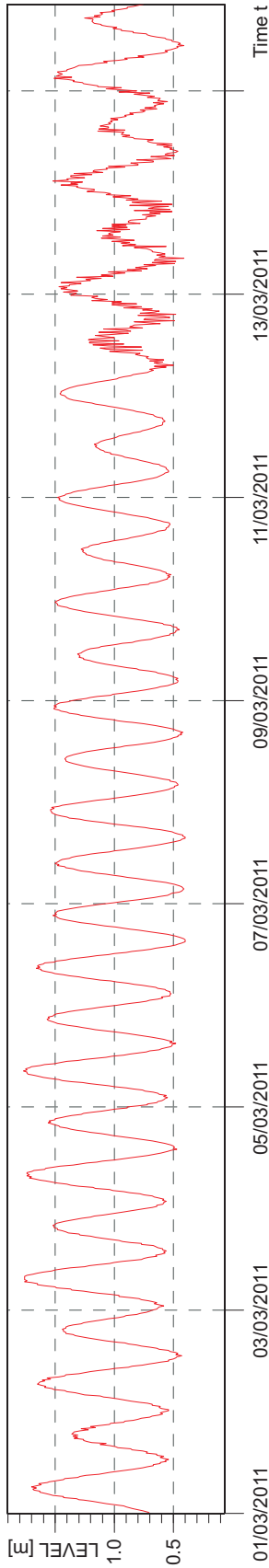
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 RECORDER TYPE : MHL Station
 A.W.R.C. No. : 213470
 DATA START : 29.06.2013
 DATA FINISH : 30.06.2014
 DATA TOTAL : 1 years 2 days
 DATABASE TIME INTERVAL (second): 0
 THRESHOLD LEVEL (m) : 1.900
 DATUM : Zero Fort Denison
 DATE OF ISSUE : 09:00 22.10.2014
 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

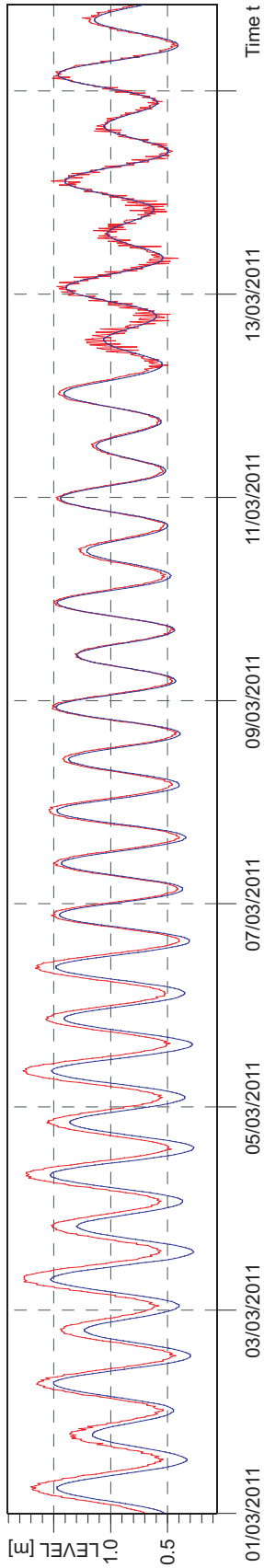




Predicted Data



Measured Data



Overplot of Measured and Predicted Data



Appendix E
Glossary of Terms

Glossary of Terms

Amplitude (H)	One-half the range of a constituent tide. By analogy, it may be applied also to the maximum speed of a constituent current.
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° 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 will 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.
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 (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 = $T - 2s + h = 13.943,035,6^\circ$ per solar hour.
Phase	<ol style="list-style-type: none"> 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 = $2T = 30.000,000,0^\circ$ 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"> 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

Publications of Interest

Data Reports

MHL Annual Ocean Tide Levels Summaries available from 1986-87 to 2012-13

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).

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Anomalies and Storm Surge Analysis

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